MOSQITO 1

MODELLING OF STORMWATER QUALITY INCLUDING TANKS AND OVERFLOWS

DESIGN SPECIFICATION

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ABSTRACT

This report details the design specification of MOSQITO, the sewer flow quality model being developed at Hydraulics Research Limited.

The requirement specification for MOSQITO was produced by the Water Research Centre as part of the UK River Basin Management Programme, and development is funded by the Department of the Environment.

Model theory is described in two sections, dealing with above-ground and below-ground processes. Subroutines which simulate these processes are detailed in Appendix A.

Calibration of the above ground, separate system, foul flow, transport and combined system models is then described, followed by a section on model use which includes the major operational steps and details of assumptions made in development which affect model use. An overview of the implementation of MOSQITO within the Wallingford Storm Sewer Package is also provided.

CONTENTS

1 INTRODUCTION

The overflow of storm sewage from combined sewerage systems has been identified as one of the major causes of pollution of streams and rivers in the UK[1]. The removal of all of these overflows would however require large scale reconstruction of sewerage systems at considerable expense.

There is also growing concern about the discharge of storm water from separate sewerage systems directly into streams and rivers, because of its probable polluting effect[2]. Similarly the elimination of all of these discharges would be prohibitively expensive.

The need for economical upgrading of sewerage systems has already been faced for reducing flooding problems[3,4]. It was found that economic solutions could be devised by the use of accurate hydraulic simulation models which could be used to investigate the problems and assess the effect of proposed solutions.

It was realised that modelling storm water quality as well as quantity would help to resolve pollution problems.

A modelling procedure is therefore required which consists of four elements[5] (Fig. 1.1):

1 appropriate rainfall inputs

2 a sewer flow quality model

3 a river impact model

4 a river classification scheme

This documents describes the first version of the sewer flow quality model.

1.1 Requirements

A statement of need and a requirement specification were provided by WRc for the sewer flow quality model. These are given in Appendix C.

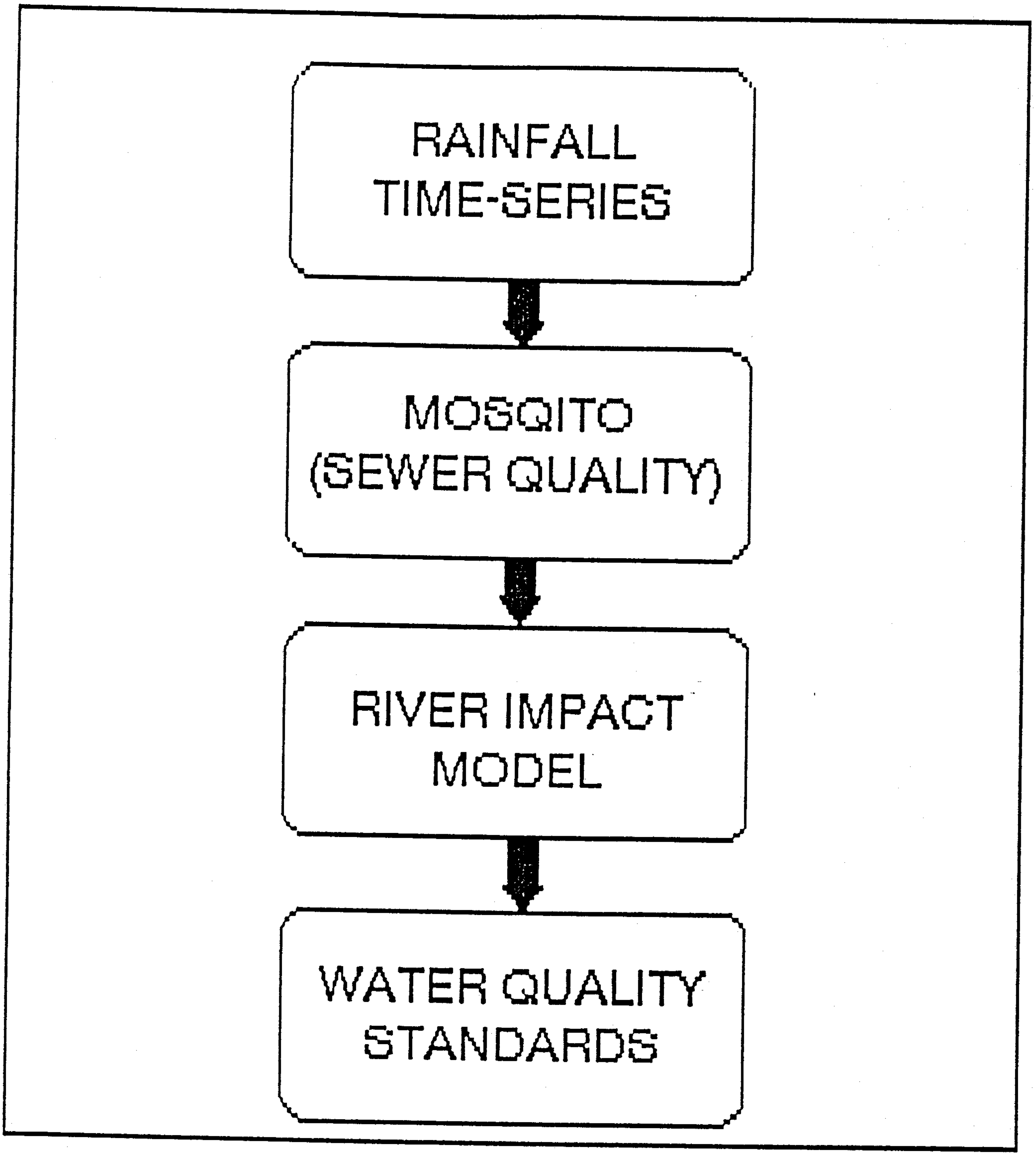

Fig 1.1 Methodology for analysing influence of SSO discharges on receiving waters

The main requirements of the model are that it is to:-

Be capable of simulating short term discharges of pollutants. A model which would provide only the total event loading would not be satisfactory due to the significance of the first foul flush.

Be an extension of the widely used WASSP program.

Use a probabilistic time series rainfall analysis rather than design events, and to provide some means of analyzing the probabilities of a particular pollutant event.

Model the following determinands:

Oxygen demand (BOD or COD)
Ammonia
Suspended solids
Hydrogen sulphide
Dissolved oxygen
Sediments

Model the build up and generation of pollutants on catchment surfaces and in sewers during the inter-storm dry weather flow periods.

Model the washoff of surface sediments during a rainfall event.

Model the effect of gully pots on surface washoff quality.

Include the foul inflows with their cyclical variation during the day.

Model the transport of pollutants through the sewer system including the deposition and erosion of sediments, the build up of slime and the generation of pollutants within the sewer.

These requirements are not met in full by the first version of the model. In particular the modelling of the deposition of sediments in sewers, and their build up during dry weather flow periods is limited. There are at present no statistical routines built into the model to carry out an analysis of the results.

1.2 Model components

The first version of the model is based on the WALLRUS hydraulic model[6], which is the latest implementation of the Wallingford Procedure. This model is made up of several component models each of which describes a separate part of the runoff process. The MOSQITO additions to this model also consist of a series of component models.

The component models for the hydraulics are:

(Synthetic rainfall)
Percentage runoff
Overland runoff
Dry weather inflow
Pipe and channel flow

The component models for the quality model are:

Surface washoff of pollutants
Foul inflow quality
Sediment build-up
Sewer sediment transport
Pollutant transport

The component models for quality are described in detail in Chapters 2 and 3, but some of the important features are given here.

The model for surface washoff of pollutants is based on a theoretical model, but has been calibrated against data from only a few catchments. It is uncertain how different from these other catchments may be.

In the first version of the model, the foul inflow model is provided outside of the main program, and creates a file of inflow quality data.

The model for sediment build-up within sewers considers the formation of a layer of mobile organic sediments during dry weather flow conditions. Consolidated sediments, or those which are generally immobile during low flows cannot be predicted by the model. The depth of these sediments is required input data, and the same depth is assumed to be present at the start of each storm.

There are very few data on the pollutants associated with sewer sediments, and on how much of this pollution is released into the flow. Values derived from a few catchments are included in the model, but if good data are available from the catchment being studied these may give better results.

Within the sediment transport model, sediments are classified either as bed load or suspended load. This distinction is made as they are likely to behave very differently at overflows.

The pollutant transport model includes consideration of advection and dispersion of the pollutants in suspension and in solution in the flow.

1.3 Methodology

The methodology for using the water quality model is best described by comparison with water quantity models (WASSP or WALLRUS) which are already familiar to most UK drainage engineers. Water quality models will always require that a water quantity model is constructed first, and usually the hydraulic inadequacies of the catchment will be determined first.

Hydraulic studies of an existing sewerage system using WASSP generally follow four stages:

Construction	Collect data for the model and construct a model using the best available data.
Proving	Analyse the model for large storms to demonstrate that it is stable and giving realistic results.
Verification	Analyse the model for all storms for which there are records of flooding, discharges, levels etc to identify errors. Where errors are found check the data collected when constructing the model to identify the errors.

Use Analyse the model for the required standard conditions to define the performance of the system.

Introduce proposed capital or operational works into the model and observe their results.

The same four stages are required for a water quality model.

Before trying to verify a water quality model it is essential that the hydraulic model has already been verified and shown to be not significantly incorrect. However for economy it may be necessary to collect the verification data for both models at the same time.

There is still considerable uncertainty over what data are required to obtain reliable results from the quality model, and over how verification should be carried out. This will only be clarified by use of the model and the build up of experience.

2 MODEL THEORY I - THE ABOVE GROUND MODEL

The above-ground model represents the generation and removal of sediments and pollutants from both catchment surfaces and gully-pots. Particular sub-models within MOSQITO are related to

1. Surface accumulation and solids-pollutant relationships
2. Removal by surface runoff
3. Behaviour of gully-pots
4. Representation of sewered sub-areas

2.1 Surface accumulation and solid-pollutant relationships

Studies of sediment and pollutant behaviour in the U.K. suggest that accumulation of material on catchment surfaces during dry-weather periods has little effect on the amount washed off during wet-weather conditions. As a result, MOSQITO does not directly consider the build-up of sediments or pollutants upon catchment surfaces. Put another way, it is assumed that the amount washed off is unaffected by its availability. However, there is a facility to limit the amount washed off during a particular event, by defining the quantity of material on the catchment surface if there is local knowledge to define such values.

Pollutants can be defined to be associated with suspended solids and/or to be in the dissolved state. The relationship between pollutants and solids is described by the use of the solid-phase concentration (potency factor). In this approach the concentration, or mass, of pollutant i is related to that of solid k by a fixed ratio, r_{ik}, that is

$$C_i = \sum_{k=1}^{n} r_{ik} C_k \qquad (2.1)$$

where

C_i = concentration of pollutant i on catchment surface

C_k = concentration of sediment k on catchment surface

r_{ik} = solid phase concentration (potency factor) between pollutant i and solid k

n = number of solid fractions on catchment surface.

These factors are input by the model user; however, a range of default values is to be defined for use in the U.K.

The amount of soluble pollutants derived from the surface sediments is also defined in terms of a concentration by mass, although the subsequent behaviour of these dissolved pollutants within the drainage system is treated separately from that of their solid-associated counterparts.

As stated above, in the first version of MOSQITO, no attempt is made to represent any dry-weather processes which may operate to change either the mass of accumulated sediments and pollutants or the relationships between pollutants and sediments. Instead, a 'standard surface sediment' is defined which is invariant through time. This standard sediment is characterised by means of 4 major sets of values:

1. Sediment composition (grading curve or median particle size, d_{50})

2. Specific gravity for each fraction or for the whole mass

3. Settling velocity for each fraction or for the whole mass

4. Pollutant associations, that is, solid-phase concentrations and dissolved-phase concentrations, for each fraction or for the whole mass.

Default parameter sets are to be provided with the model, and these will normally be used. (see Chapter 5).

2.2 Removal by surface washoff

Removal of material from the catchment surface is represented within MOSQITO by separate models for the removal of suspended solids and soluble pollutants. These two models operate on each surface type defined within a subcatchment. WALLRUS-SIM allows a total of 21 surface types to be defined from which 3 can be selected by the user to define the hydrological response of each subcatchment. The parameters particular to the sediment and washoff aspects of the model are predefined by the model for each surface type, although, as in WALLRUS-SIM it is possible for the user to override these values. The two models incorporated within MOSQITO are described below; further details can be found within Moys and Payne[8].

(a) Removal of suspended solids

The removal of suspended solids from catchment surfaces is represented by a modified form of the model first developed by Price and Mance[9]. This model was derived by consideration of mass conservation of suspended solids on a hypothetical 'catchment element' or 'conceptual strip' (Fig. 2.1). If M_s is the instantaneous mass of suspended solids per unit area, then the rate of change of M_s with respect to time can be given by

$$\frac{dM_s}{dt} = \text{erosion by raindrop impact } (E_i)$$

$$+ \text{ erosion by overland flow } (E_f)$$

$$+ \text{ input from rainfall } (I_r)$$

$$- \text{ deposition from overland flow } (D_f)$$

$$- \text{ removal from conceptual strip } (R_s) \qquad (2.2)$$

Each of the terms on the right-hand-side (R.H.S.) of Eq. 2.2 is represented by a separate rate equation (Fig. 2.2). However, within MOSQITO input of suspended solids from rainwater is assumed to be negligible and thus only four terms are modelled on the R.H.S. of Eq. 2.2. The original model was developed to represent the removal of total suspended solids; the new model has the capability to

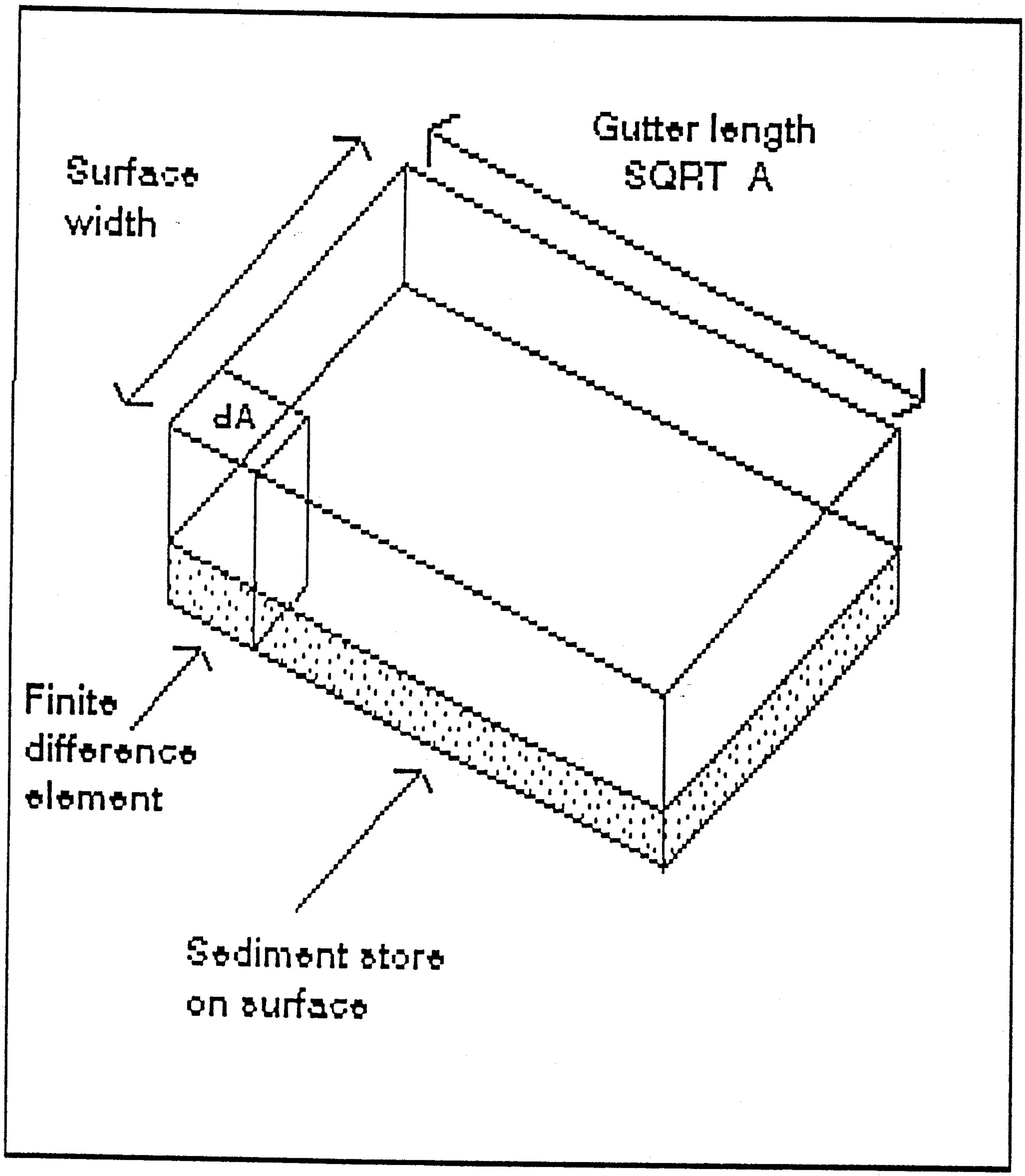

Fig 2.1 A hypothetical catchment element

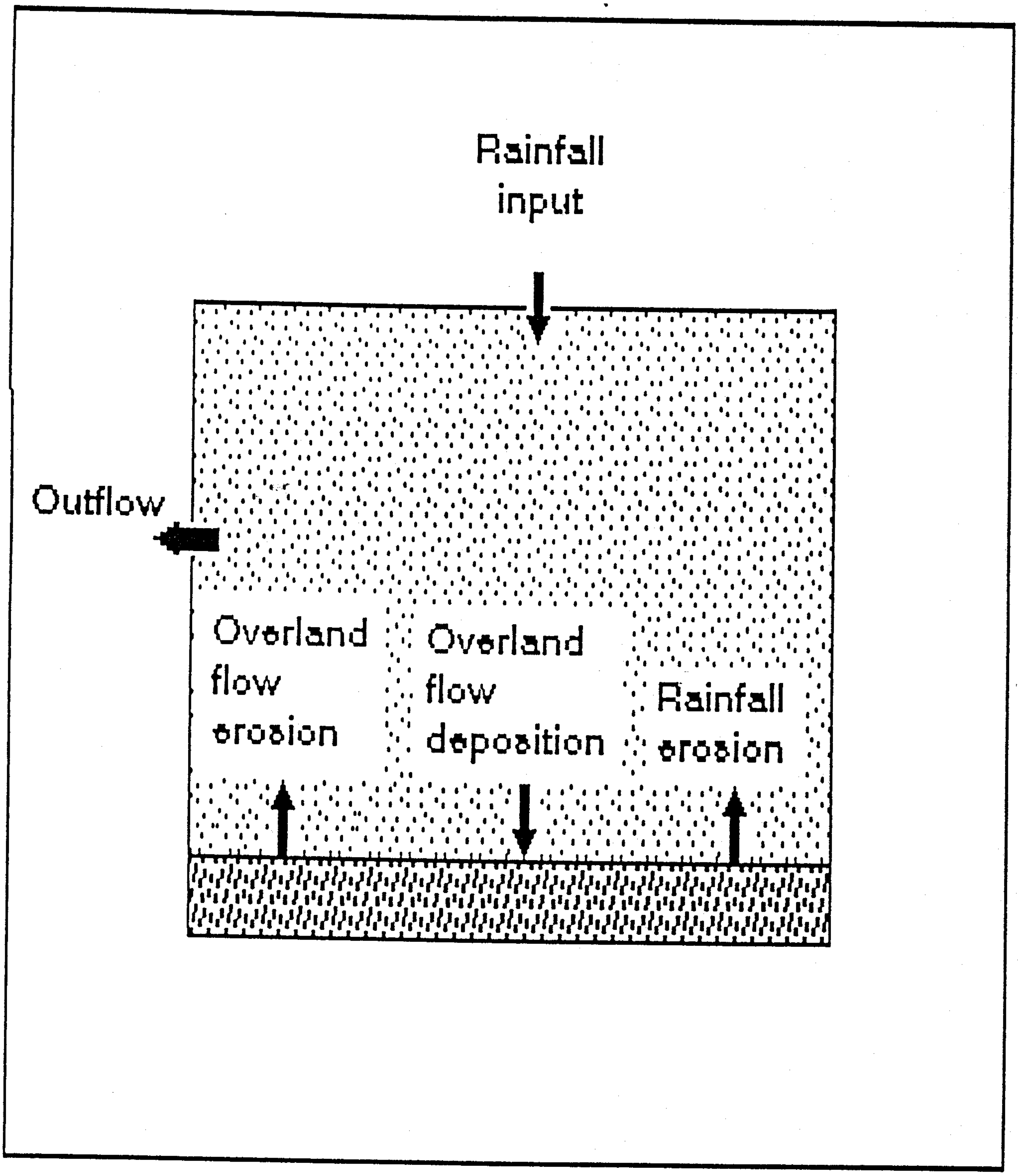

Fig 2.2 Overview of Price and Mance model

consider particular size fractions within a surface load grading curve. However, in the first version it will be generally more appropriate to represent suspended solids removal in terms of one fraction only with a d_{35} representative of the surface material.

Specific terms on the R.H.S. of Eq. 2.2 are described below.

1. Erosion by raindrop impact

$$E_i = a_i \, i^{\alpha} \qquad (2.3)$$

where

a_i = constant for each surface type

$\alpha = 1.5$

2. Erosion by overland flow

$$E_f = a_e \, (\tau - \tau_{ce}) \qquad (2.4)$$

where

a_e = constant for each surface type

τ_{ce} = critical shear stress for removal of sediment fraction obtained by interpolation of Shield's curve.

3. Deposition from overland flow

$$D_f = a_d \, (\tau_{cd} - \tau) \qquad (2.5)$$

where a_d = constant for each surface type
τ_{cd} = critical shear stress for deposition defined by

$$\tau_{cd} = a_f \, \tau_{ce}$$

a_f = ratio between deposition and erosion τ

4. Removal from conceptual strip

$$R_s = \frac{M_s q}{kq + h} \qquad (2.6)$$

where q = discharge per unit area over strip
k = linear reservoir storage coefficient
h = depression storage

Thus the differential equation used for representing suspended solids removal from catchment surfaces is

$$\frac{dM_s}{dt} = a_i i^\alpha + a_e(\tau-\tau_{ce}) - a_d(\tau_{cd}-\tau) - \frac{M_s q}{kq + h} \qquad (2.7)$$

This equation is solved numerically at each time step using finite difference approximations for each of the differential terms, that is

$$M_{t+\Delta t} = M_t + \Delta t \text{ (R.H.S. of Eq. 4.7)} \qquad (2.8)$$

Removal from each strip at each time-step is then calculated by means of Eq. 2.6. Three points with respect to the solution of this model require further clarification.

First, it is possible to define an upper limit or threshold to the amount of sediment removed during a single rain event. The cumulative amount of material removed at each time step is compared against this value, if it exceeds this value then no more erosion is allowed to take place.

Second, the boundary shear stress, τ, acting on the sediment surface is calculated by

$$\tau = \frac{p_w f U^2}{8} \qquad (2.9)$$

where p_w = density of water
f = Darcy-Weisbach friction factor due to grain resistance
U = flow velocity.

Values of f are obtained by assuming laminar overland flow conditions over rough surfaces[10]; these are defined for each surface type.

Third, critical shear stresses for erosion and deposition are obtained by interpolation of Shield's curve[11] which has been extended at the finer end of its range by Mantz[12].

(b) Removal of soluble pollutants

The removal of soluble pollutants is simulated within MOSQITO by a similar model to that used for suspended solids. If M_d is the instantaneous mass of a soluble pollutant per unit area, then the mass rate of removal can be given by

$$\frac{dM_d}{dt} = \text{input from bed } (E_b)$$

$$+ \text{ input from rainfall } (I_r)$$

$$- \text{ removal from conceptual strip } (R_d) \qquad (2.10)$$

Specific terms on the R.H.S. of the above equations are:

1. Input from bed

$$E_b = C_b \sum_{i=1}^{n} M_i \qquad (2.11)$$

where C_b = concentration of soluble pollutant on surface related to total mass of material on surface (kg/kg);
M_i = mass of material of each fraction removed from surface

2. Input from rainfall

$$I_r = k_i \; C_r \; i \qquad (2.12)$$

where k_i = constant transforming rainfall in mm/hr to $1/m^2/hr$;
C_r = concentration of pollutant in rainfall (mg/l)

3. Removal from conceptual strip

$$R_d = \frac{M_d \, q}{Kq + h} \qquad (2.13)$$

as before.

Hence, the differential equation used to represent dissolved pollutant removal from catchment surfaces is:

$$\frac{dM_d}{dt} = C_b \sum_{i=1}^{n} M_i + k_i \; C_i \; i - \frac{M_d \, q}{kq + h} \qquad (2.14)$$

Again, this model is solved over finite time steps using

$$M_{t+\Delta t} = M_t + \Delta t \text{ (R.H.S. of Eq.2.14)} \qquad (2.15)$$

2.3 Behaviour of gully pots

Gully-pots are sites where pollutants build up during dry-weather conditions. This is particularly true of dissolved pollutants such as NH_4-N within the gully-pot liquor. A form of constantly-stirred tank reactor (CSTR) model is used to represent the influence of gully-pots on the discharge of dissolved pollutants from the above-ground model, that is

$$\langle V_g \rangle \frac{dC}{dt} = \text{mass flow into pot } (M_i)$$

$$- \text{ mass flow out of pot } (M_o)$$

$$- \text{ change in volume of water in pot } (V_c) \qquad (2.16)$$

Individual terms on the R.H.S. of Eq. 2.16 are given below

1. Mass flow rate into pot

$$M_i = \sum_{j=1}^{3} M_j \qquad (2.17)$$

where

M_j = mass flow from surface j of subcatchment contributing to gully-pot.

2. Mass flow out of pot

$$M_o = \langle C_l \, Q_o \rangle \qquad (2.18)$$

C_l = concentration of pollutant within gully liquor

Q_o = discharge from gully-pot

3. Change in volume of water

$$V_c = \langle C_l \rangle \frac{dV_g}{dt} \qquad (2.19)$$

V_g = volume of water in gully-pot

The inclusion of gully-pots in MOSQITO presents some major problems. First, unlike WASSP-SIM, gully-density is not included in the data entry for each pipe/subcatchment record in the new format SSD-file for WALLRUS-SIM. Secondly, individual subcatchments contributing to individual gullies are rarely modelled. As a consequence, a standard gully density is associated with each subcatchment surface. This is multiplied by subcatchment area and gully-liquor volume per pot to give the total volume of storage used in Eq. 2.16. During an event it is assumed this volume does not change (that is, $dV_g/dt = 0$). To initialise the model the concentration of the pollutant in the gully-pot at the start of storm event must be supplied as input data.

2.4 Sewered sub-areas

Experience in the use of WASSP-SIM has shown that it is generally not necessary to include all the subcatchments and pipes within the real system in the model representation of that system in order to model successfully its hydraulic behaviour. However, in removing pipes and manholes from the model of the system, possible storage sites for accumulated sediments will also be removed. Furthermore, the model will not represent the transport processes within these pipes, which will tend to both delay and attenuate the predicted pollutograph. To take account of these effects a CSTR model, similar to the gully-pot model described previously, can be used. In this case sediments in the tank should be included, together with the material in the liquid phase. A separate model for the incorporation of these effects is not included within MOSQITO. Instead, extra terms and storage are added to the gully-pot model to represent the pollutant behaviour of a sewered sub-area.

The complete CSTR model, therefore, is given by

$$\langle V_g \rangle \frac{dC}{dt} = \text{mass flow into storage } (M_i)$$

$$- \text{ mass flow out of storage } (M_o)$$

$$\pm \text{ transfer to bed } (T)$$

$$- \text{ change in volume of water stored } (V_c)$$

with the new term, T, representing transfer to and from the bed of suspended solids and dissolved material. This term is derived from calibration against the full model.

3 MODEL THEORY II - THE BELOW-GROUND MODEL

Within the below-ground model, contaminants originating from surface runoff and foul-water flow are mixed and transported through the drainage system. Also, contaminants will be derived from sewer sediments which have accumulated as a result of deposition from both dry-and wet-weather flows. In the first version of the model the presence and nature of these deposits are defined by the user as part of the input data; in the second version a continuous simulation approach will be adopted in order to model the characteristics of these deposits, although it will still be necessary to define the initial conditions of the system.

3.1 Foul-water simulation

The model does not simulate the generation of foul-water flow within urban drainage systems. Instead, the user must provide input files containing this information for the catchment under study. Two types of file can be used to describe foul-water flows:

1. A dry-weather flow pollutant file;
2. An input pollutograph file.

The first of these files is analogous to the dry-weather flow file used by the WALLRUS package. Within this file the user defines the concentration of each pollutant and its time-varying behaviour (see Chapter 7 for further information of the format and data requirements). Dry-weather flow can be defined globally or locally. In the case of local definition, the user can define up to 9 dry-weather flow types which have uniform dry-weather flow characteristics. The user defines which pipe belongs to which dry-weather flow type within the SSD file. There will also be the facility to define this information by means of a 'foul-flow generator', similar to the rainfall generator currently within the WALLRUS package.

The foul-flow generator is based on statistical analysis of foul-flow data collected from a number of sites throughout the U.K.[13]. Independent variables used are land use, population density, time-of-day and day-of-week. First, the model defines a standard foul-flow for each pollutant for three land-use classes:-

1. industrial;
2. commercial;
3. residential.

For flow this is defined in terms of litres/head/day and for each pollutant parameter in terms of mg/litre. The user must then define the population density of the subcatchment and the percentage area occupied by each land-use class to produce a weighted flow for each foul-flow type in terms of either l/ha/day or mg/l. The time-of-day and the day-of-week parameters are then used to derive a series of multipliers which are applied over the duration of the simulation run.

The input pollutograph file will allow the user to define pollutant input at specific nodes within the drainage system (analogous to the input hydrograph file used by the simulation program within WALLRUS). This can represent specific discharges of foul-water from industry or could represent inputs from a part of the drainage system which has been modelled separately from the rest of the drainage system.

Both of these files must be accompanied by their flow counterparts for operating the WALLRUS-SIM program.

3.2 Behaviour in nodes

Nodes within an urban drainage system are considered to be of two types

1. Manhole or ordinary nodes;

2. Ancillary nodes.

At each node, irrespective of its type, a constantly stirred tank reactor (CSTR) model is applied (Fig. 3.1), that is

$$\frac{dM}{dt} = \langle \text{Mass In} \rangle - \langle \text{Mass Out} \rangle \pm \langle \text{Source} \rangle \qquad (3.1)$$

where $\langle\ \rangle$ denotes time-averaged variables.

The term on the L.H.S.can be expanded as

$$\frac{dM}{dt} = \langle V \rangle \frac{dC}{dt} + \langle C \rangle \frac{dV}{dt} \qquad (3.2)$$

Finite differences are used to replace the differential terms of these two equations and the system is solved to find the new concentration of each pollutant at each node and at each time step. A number of points are worthy of note in relation to these calculations.

1. During free-surface flow conditions, volumes within ordinary nodes do not affect the calculations; the above formulation is then equivalent to a simple mixing model.

2. Only when flow becomes surcharged at a manhole or flooding occurs at an open-channel node are the concentrations affected by a change in the volume of water stored.

3. The source terms (deposition and erosion) are not implemented within the first version of the model.

4. All outflows from a node have the same concentration.

5. Initial pollutant concentrations within nodes are set to those of the dry-weather flow into each node.

6. Only dissolved and suspended load passes out over overflows at tank nodes; bed-load is passed down the continuation pipe. Bed-load and suspended load are defined using Ackers-White mobility number (see section 3.3.c.1)

3.3 Behaviour in links

The behaviour of sediments and pollutants in links (pipes and open channels) within an urban drainage system can be represented by a one-dimensional continuity equation for the flow coupled with a sediment bed continuity equation (Fig. 3.1) (assuming no motion of the bed itself), that is

$$\frac{\delta(AC)}{\delta t} + \frac{\delta(AUC)}{\delta x} - \frac{\delta}{\delta x}\left(AF_x \frac{\delta C}{\delta x} \right) \pm S = 0 \quad (3.3)$$

$$\frac{dM}{dt} = \pm S \quad (3.4)$$

The continuity equation for sediment/pollutant flow can be simplified by assuming that flow continuity is satisfied at all points, that is

$$\frac{\delta A}{\delta t} + \frac{\delta Q}{\delta x} = 0 \quad (3.5)$$

so that Eq. 3.3 reduces to

$$A\frac{\delta C}{\delta t} + AU\frac{\delta C}{\delta x} - \frac{\delta}{\delta x}\left(AF_x \frac{\delta C}{\delta x} \right) \pm S = 0 \quad (3.6)$$

This latter equation is solved numerically by MOSQITO to represent transport through links. A fractional-step[14,15] method is used to solve this equation over two steps, that is

$$\frac{\delta C}{\delta t} = p \sum_{i=1}^{p} L_i\,[C]$$

where

p = number of fractional steps = 2

$$L_1[C] = -U\frac{\delta C}{\delta x}$$

and

$$L_2[C] = \frac{1}{A}\frac{\delta}{\delta x}\left(AF_x \frac{\delta C}{\delta x}\right) \pm KC \pm S$$

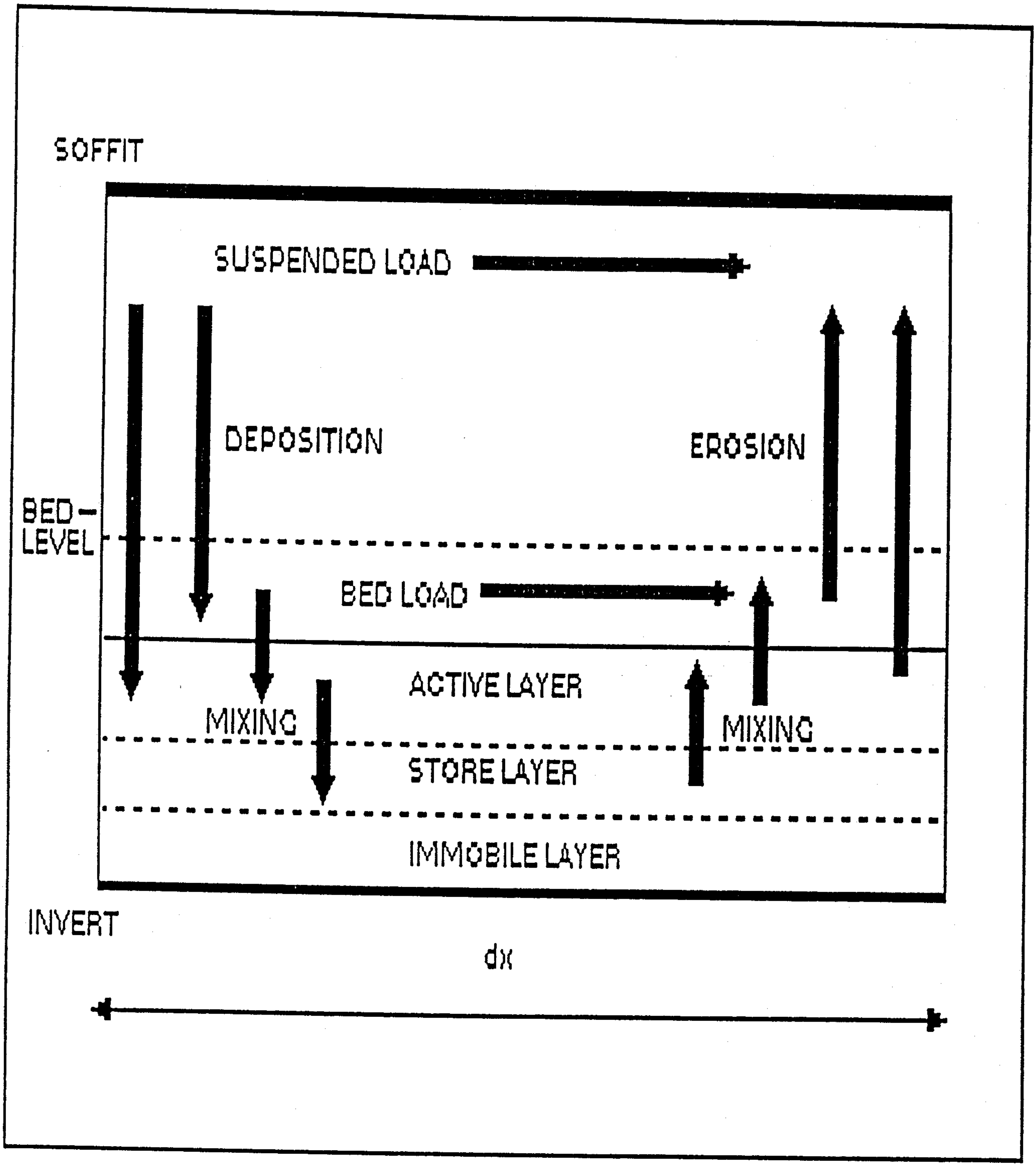

Fig 3.1 Processes represented within link submodel

The advection equation is solved from time step n to n+▲t/2 and the combined dispersion/source-sink equation is solved from n+▲t/2 to n+1 using the advection solution as the initial conditions (Fig. 3.2). Solution of the above system of equations can then can be considered under five headings

(a) calculation of hydraulic parameters;

(b) solution of advection term;

(c) solution of dispersion and source/sink terms;

(d) definition of source/sink terms;

(e) definition of dispersion term.

(a) Calculation of hydraulic parameters

Flow at each computational point within each link is computed by WALLRUS-SIM using one of three methods:

1. Muskingum-Cunge Storage Routing[16];

2. Free-Surface Backwater Routing - PAB Scheme[17];

3. Surcharge Routing[18].

It is possible using normal depth considerations to calculate the depth of flow at each point, and thence, the flow cross-sectional area, flow velocity and hydraulic radius (all required by various sub-models within MOSQITO). However, direct use of such methods with the Muskingum-Cunge routing technique leads to continuity imbalances of Eq.3.5. This is because the Muskingum-Cunge method does not exactly preserve flow continuity. In order to correct this imbalance, different techniques are used to calculate the necessary hydraulic parameters, dependent on the condition of the flow within a computational box (Fig. 3.3).

At the start of a simulation when base-flow conditions are operative, the hydraulic parameters are initialised using normal-depth calculations. Thereafter, if the flow is classified as steady, then parameters calculated at a previous time-step are transferred directly to the current

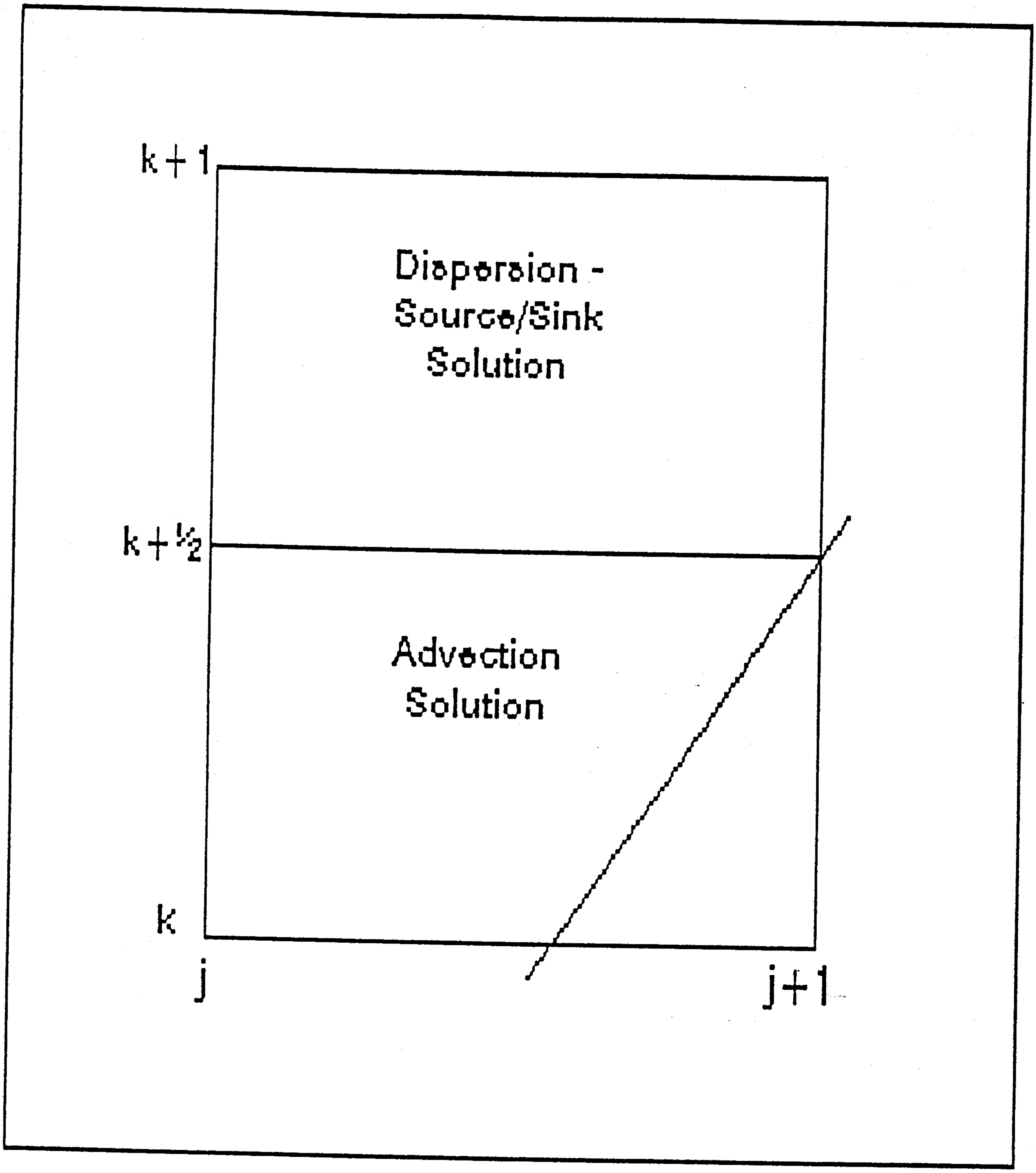

Fig 3.2 Computational grid for fractional step method

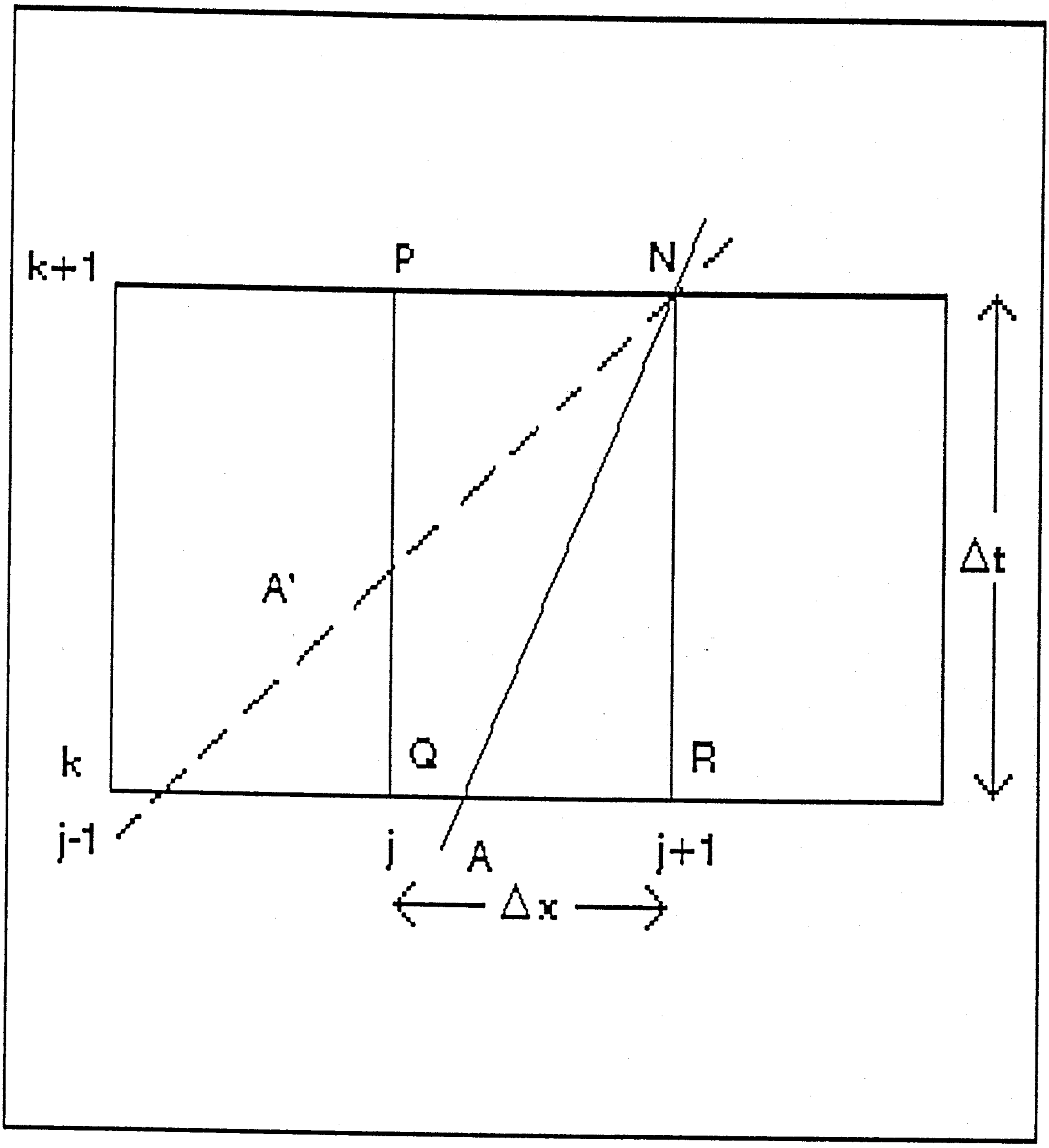

Fig 3.3 Computational grid for Holly-Preissman method

time-step.
If the flow is classified as unsteady, then the method used is dependent on whether the link is surcharged or not. If the link is surcharged then the hydraulic parameters are simply calculated by use of the flow and the pipe-full geometry. If the link is not surcharged then the program calculates the flow cross-sectional areas at the new time-step by the solution of Eq.3.5 and knowledge of previous hydraulic parameters and current flow conditions. This equation is solved by use of a four point finite-difference method with the upstream boundary condition defined by means of a forward difference approximation. The calculation proceeds as follows.

First, the upstream boundary condition, that is $A_{j,k+1}$ is calculated by

$$A_{j,k+1} = A_{j,k} + \Delta t \ (Q_{j,k} - Q_{j+1,k})/\Delta x \qquad (3.7)$$

Then, using an implicit scheme, $A_{j+1,k+1}$ is calculated by

$$\frac{\delta Q}{\delta x} \approx \Theta \frac{(Q_{j+1,k+1} - Q_{j,k+1})}{\Delta x} + (1-\Theta) \frac{(Q_{j+1,k} - Q_{j,k})}{\Delta x} \qquad (3.8)$$

and

$$A_{j+1,k+1} = A_{j+1,k} + A_{j,k} - A_{j,k+1} - \frac{2\Delta t}{\Delta x}\frac{\delta Q}{\delta x} \qquad (3.9)$$

with

$\Theta = .5$

Flow depth is then calculated by the use of a look-up table between depth and area. Mean flow velocity and wetted perimeter can then be calculated; subroutines within WALLRUS-SIM are used to do this.

(b) Solution of the advection term

A common feature of numerical techniques used to solve the advective portion of the transport equation is the production of numerical diffusion by the finite difference scheme[19,20]. A variety of techniques have been proposed to either reduce this 'parasitic diffusion'[21,22] or use this term to account for the actual dispersion within the system[23]. A comparative study of a number of solution techniques[24] indicated that the scheme suggested by Holly and Preissman[21] and developed within the CONDOR program[25] was suitable for adoption within MOSQITO for two major reasons:

1. The method was the most accurate at representing advection and dispersion processes when compared with analytical solutions under steady-state conditions.

2. The method was stable at all spatial and temporal time-steps and therefore could be interfaced easily with any of the flow solution technique used within WALLRUS-SIM.

The Holly-Preissman method is based on a 'method of characteristics' in which the advective transport equation

$$\frac{\delta C}{\delta t} + U_x \frac{\delta C}{\delta x} = 0 \qquad (3.10)$$

is replaced by two ordinary differential equations (ODE's)

$$\frac{dC}{dt} = 0 \qquad (3.11)$$

and

$$\frac{dx}{dt} = u(x,t) \qquad (3.12)$$

The first equation states that the change in concentration of any material within a particular parcel of water with respect to time is zero, while the second equation defines the path along which each parcel of water travels.

Solution of these two ODE's is carried out on a grid(x,t) (Fig.3.4) defined by the flow model, WALLRUS-SIM. The time-step over which calculations take place may be highly variable ranging typically from 15 to 60 seconds when a pipe is in free-surface flow to less than 5 seconds when the pipe is surcharged; the spatial step of the grid remains constant irrespective of the nature of the flow.

During each time step three operations are performed at each computational point:

1. Calculate the position of the 'foot' of the characteristic (Point A), by integration of Eq. 3.12

2. Interpolate concentration at neighbouring points to derive concentration at Point A

3. Integrate Eq. 3.11 along the characteristic

These steps are detailed below and are based on the outline provided by Sauvegat[20] and Moys[24].

Having established the velocities at each point as described above, the position of the foot of the characteristic can be obtained by use of the following iterative procedure

$$U_{A(}^{0)} = U_{j+1,k+1} \qquad (3.13)$$

$$x_A = x_{i+1} -(U_A^{(k-1)} + U_{j+1,k+1}) \blacktriangle t/2 \qquad (3.14)$$

$$U_A^{(k)} = [(x_A^{(k)} - x_i)U_{j+1,k} + (x_i - x_A^{(k)})U_{j,k}]/\blacktriangle x \qquad (3.15)$$

This procedure is repeated k times until the difference in the Courant Number calculated between two iteration steps is negligible (defined as 1.0×10^{-6}). The position of point A is then defined in terms of a parameter α, where

$$\alpha = (xj_{+1} - x_A) /\blacktriangle x \qquad (3.16)$$

If $\alpha \leq 1$ then the foot of the characteristic curve is positioned along segment QR on Fig.3.3. If $\alpha > 1$ then another positional parameter β is defined where

$$\beta = (t_{k+1} - t_A) /\blacktriangle t \qquad (3.17)$$

and the foot of the characteristic is positioned along segment PQ.

The second step involves the calculation of the concentration at point A. Conventional interpolation procedures often use 3 or more known values adjacent to point A. However, such techniques can introduce numerical oscillations into the solution. The interpolation method proposed by Holly and Preissman uses only values at points Q and R if $\alpha \leq 1$, or Q

and P if $\alpha > 1$.
The method uses both the concentration and the derivative of the concentration with respect to space at each of the two points to form a third order polynomial of the form

$$Y(\alpha) = A\,\alpha^3 + B\,\alpha^2 + D\,\alpha + E \qquad (3.18)$$

The four coefficients A,B,D and E are evaluated such that the following conditions are satisfied:

$$Y(1) = C_{j,k}$$

$$Y(0) = C_{j+1,k}$$

$$\frac{dY(1)}{dx} = \frac{\delta C_{j,k}}{\delta x} = CX_{j,k}$$

$$\frac{dY(0)}{dx} = \frac{\delta C_{j+1,k}}{\delta x} = CX_{j+1,k}$$

Having evaluated A, B, D and E these may be substituted back into Eq. 3.18 to obtain

$$Y(\alpha) = C_A = a_1\,C_{j,k} + a_2\,C_{j+1,k} + a_3\,CX_{j,k} + a_4\,CX_{j+1,k} \qquad (3.19)$$

where

$$a1 = \alpha^2\,(3 - 2\alpha)$$

$$a_2 = 1 - a_1$$

$$a_3 = \alpha^2\,(1 - \alpha)\,\Delta x$$

$$a_4 = -\alpha\,(1 - \alpha)^2\,\Delta x$$

The above scheme is used when $\alpha \leq 1$. If $\alpha > 1$ then point A will be situated along segment PQ of the computational grid (Fig. 3.3). In this case

$$Y(\alpha) = C_A = a_1'C_{j,k} + a_2'C_{j,k+1} + a_3'CX_{j,k} + a_4'CX_{j,k+1} \qquad (3.20)$$

where

$$a_1' = \beta^2\,(3 - 2\beta)$$

$$a_2' = 1 - b_1$$

$a3' = (-1/U_{j,k})\ \beta^2\ (1-\ \beta)\ \Delta t$

$a_4' = (-1/U_{j,k+1})\ -\beta\ (1\ -\ \beta)^2\ \Delta t$

The concentration derivative must also be advected along with the concentration. This is achieved using a similar scheme as for the concentration, that is, calculation of CX at the foot of the characteristic by interpolation and integration along the characteristic. However, the change of the concentration derivative along the characteristic is not zero as in the case of the concentration, but is given by

$$\frac{d(CX)}{dt} = -\ CX\ \frac{dU}{dx} \qquad (3.21)$$

The interpolating function for CX when $\alpha < 1$ takes the following form

$$\dot{Y}(\alpha) = CX_A = b_1\ C_{j,k} + b_2\ C_{j+1,k} + b_3\ CX_{j,k} + b_4\ C_{j+1,k} \qquad (3.22)$$

where

$b_1 = \alpha\ (\alpha\ -\ 1)/\Delta x$

$b_2 = -\ b_1$

$b_3 = \alpha\ (\alpha\ -\ 1)\ (3\alpha\ -\ 2)$

$b_4 = (\alpha\ -\ 1)\ (3\alpha\ -\ 1)$

If $\alpha > 1$ then

$$\dot{Y}(\beta) = CX_A = \frac{1}{U_A}\ [b_1'C_{j,k} + b_2'C_{j,k+1} + b_3'CX_{j,k} + b_4'CX_{j,k+1}] \qquad (3.23)$$

where

$b_1' = \beta\ (\beta\ -\ 1)/\Delta t$

$b_2' = -\ b_1$

$b3 = (-1/U_{j,k})\ \beta\ (\beta\ -1)\ (3\beta\ -\ 2)$

$b4 = (-1/U_{j,k+1})\ (\beta\ -\ 1)\ (3\beta\ -\ 1)$

Finally, Eq. 3.21 is integrated using the trapezium method, such that

$$CX_{j+1,k+1} = CX_A \left[1 - \frac{\Delta t}{2} \left.\frac{dU}{dx}\right|_A \right] / \left[1 + \frac{\Delta t}{2} \left.\frac{dU}{dx}\right|_N \right] \quad (3.24)$$

If $\alpha > 1$ then it is necessary to estimate upstream boundary conditions of the concentration and its spatial derivative. The concentration term is evaluated at each node as explained previously in Section 3.2. The derivative of the concentration is estimated by assuming that

$$\frac{\delta C}{\delta x} \approx \frac{-1}{U} \frac{\delta C}{\delta t}$$

and

$$\frac{\delta C}{\delta t} \approx \frac{dC}{dt}$$

at the node. If U equals zero then $\delta C/\delta x$ is set to zero.

The above scheme is used for both forward and reversed flow conditions encountered within a link. In the case of reversed flow, which only occurs within WALLRUS-SIM when a link is surcharged, the ordering of the computations is reversed.

(c) Solution of the dispersion and source/sink terms.

The second step in the fractional scheme used for solving Eq.3.6 is the dispersion/source-sink equation, that is

$$A \frac{\delta C}{\delta t} = \frac{\delta}{\delta x} \left(AF_x \frac{\delta C}{\delta x}\right) \pm S \quad (3.25)$$

But from before

$$\frac{\delta C}{\delta x} = CX \quad (3.26)$$

which leads to

$$A \frac{\delta C}{\delta t} = \frac{\delta (AF_x CX)}{\delta x} \pm S \quad (3.27)$$

Using a 4-point Preissman Scheme it is possible to substitute for the terms in Eq. 3.26 and Eq.3.27 by

$$A \approx \frac{\Theta}{2} (A_{j+1,k+1} + A_{j,k+1}) + \frac{1-\Theta}{2} (A_{j+1,k} + A_{j,k})$$

with similar representations of CX and S, and

$$\frac{\delta C}{\delta t} = [C_{j+1,k+1} - C_{j+1,k} + C_{j,k+1} - C_{j,k}] / 2 \Delta t$$

$$\frac{\delta C}{\delta x} \approx \Theta (C_{j+1,k+1} - C_{j,k+1})/\Delta x + (1-\Theta) (C^{j}_{+1,k} - C_{j,k})/\Delta x$$

with a similar representation of $\frac{\delta(AF_x CX)}{\delta x}$

The resulting system of equations is then solved to find $C_{j+1,k+1}$ and $CX_{j+1,k+1}$ using a double-sweep algorithm. Two boundary conditions are required. First, for the concentration term, an upstream boundary condition is used. Second, for the concentration derivatives a downstream boundary condition is used. Although, an upstream boundary condition could be used in this latter instance, the resulting solution suffers from numerical oscillations. The downstream boundary condition is obtained by advection of the derivative term over the last computational step; it is assumed that the dispersion and source/sink effects have a negligible effect on this boundary condition.

(d) Definition of the source/sink terms.

The way in which the model defines the source and sink terms varies according to whether the parameter is a sediment or a pollutant. Pollutants can be either associated with sediments or dissolved.

1. Sediment terms

The source term for sediments consists of erosion, E, from a sediment bed, while the sink term consists of deposition, D, from the flow into a sediment bed, that is

$$S = E - D$$

where

$$E = \Gamma_E\ A\ (T_p - C)$$

and

$$D = \Gamma_D\ A\ (C - T_p)$$

where

Γ_E = 1 if erosion
Γ_E = 0 if no erosion
Γ_D = 1 if deposition
Γ_D = 0 if no deposition.
T_i = sediment transport rate (mg/l)

The term T_i is defined by means of a sediment transport formulae. However, interfacing a conventional sediment transport formulae (e.g. Ackers-White[26]) within this scheme leads to a number of difficulties:

a. Conventional formulae usually relate to narrowly graded sediments whereas sediments in sewers are widely graded.

b. Sediment transport formulae have been developed from steady-state experiments within laboratory flumes whereas conditions during storm-events in sewers are unsteady. However, the time over which the sediment reaches its steady-state conditions is generally small compared to the time over which flows are changing, thus the system can be viewed as 'quasi-steady'.

c. Most sediment transport formulae have been developed for alluvial rivers with an unlimited supply of material available for erosion whereas in sewers there is generally a limited supply from the sewer bed.

d. The fine suspended load (sediments within the silt/clay ranges) is generally ignored by non-cohesive sediment transport formulae.

Models developed for application within rivers use the sediment bed grading curve to adjust the rates of transport defined by formulae for monogranular deposits. For example, Ackers and White[27] advise that if the sediment is narrowly graded (defined as $d_{84}/d_{16} < 5$) then the total transport of bed material could be related to d_{35}. If the material exhibits a wider grading, then the approach recommended by Einstein[28,29] could be used, in which each fraction is considered separately to calculate a potential transport rate. This is then adjusted by the amount of that material within the sediment bed. However, within sewers there may not be a sediment bed present with which to define a sediment grading curve. Therefore MOSQITO uses the grading curve of the material in the flow to derive the total transport capacity of the flow. A particular problem with this approach is how to cope with material which is in the bed and capable of being eroded, but is not present in the flow. The procedure outlined below allows these fractions to be eroded by a 'residual transport capacity'.

The transport rate at the point (j+1,k+1) is calculated for each fraction using the Ackers-White sediment transport formulae for bed material load; fine-suspended material is calculated separately. For the material in the Ackers-White range the total load that can be transported is calculated by summation of the transport capacities for each fraction adjusted by the grading curve within the flow, that is

$$T = \sum_{i=1}^{n} p_i \, T_i \qquad (3.28)$$

where

p_i = fraction of material in flow grading curve

For each fraction in transport the individual transport capacities are compared with the amount in transport to define a depositing or an eroding state. If $C_i > T_i$ then deposition occurs ($\Gamma_D = 1$; $\Gamma_E = 0$); if $C_i < T_i$ then erosion occurs if that material is available on the sediment bed ($\Gamma_D = 0$; $\Gamma_E = 1$); if material is not available then neither erosion nor deposition occurs ($\Gamma_D = 0$; $\Gamma_E = 0$).

During the above calculations a record is kept of the difference between the transport capacity and the amount in transport. The difference is defined as the residual transport capacity. If a material in the bed is able to be eroded (defined by Ackers-White), but is not present in the flow, then this material is eroded to fill the residual transport capacity.

The transport rate, T_i, for bed material load is defined by means of the Ackers-White sediment transport formula which has been adapted for use in sewers by Ackers[30,31]. Ackers[30] has put forward the case for using this equation rather than equations derived specifically for sewers as follows:

> 'This equation has a sound theoretical basis and has been confirmed for a wide range of conditions. It may therefore be more reliable when scaled to field conditions than other equations based on small scale laboratory research that may be subject to scale effects.'

In this approach sediment transport is related to two parameters, a mobility number and a dimensionless grain-size (or particle-size Reynold's number). T_i is given as a concentration (ppm) by

$$T_i = G_{gr} \frac{s\ d\ U^n}{y\ U_*^n} \qquad (3.29)$$

where

$$G_{gr} = C\ (F_{gr}/A_{gr} - 1)^m \qquad (3.30)$$

The mobility number is defined to be

$$F_{gr} = \frac{U_*^n}{\sqrt{(gd(s-1))}} \quad \frac{U^{(1-n)}}{(\sqrt{(32\ \ln(12R/d))})^{(1-n)}} \qquad (3.31)$$

and the parameters n, A_{gr}, m and C are functions of dimensionless grain size, D_{gr}, defined by

$$D_{gr} = d\ (g\ (s - 1)\ /\ v^2)^n \qquad (3.27)$$

n = 1/3

v = kinematic viscosity

For coarse sediments, when $D_{gr} > 60$, then

$n = 0.0$

$A_{gr} = 0.170$

$m = 1.5$

$C = 0.025$

and for transitional sizes, when $60 \geq D_{gr} \geq 1$, then

$$n = 1.0 - 0.56 \log_{10} D_{gr}$$

$$A_{gr} = \frac{0.23}{\sqrt{D_{gr}}}$$

$$m = \frac{9.66}{D_{gr}} + 1.34$$

$$\ln C = 2.86 \ln D_{gr} - (\ln D_{gr})^2 - 3.53$$

where A_{gr} is an initial motion condition.

In adapting this equation for use in sewers, flow depth, y, is interpreted as an equivalent depth defined by the flow area divided by an effective width for sediment transport, w_e. Ackers[31], in applying this approach to laboratory data, indicated that w_e varied with the amount of sediment on the pipe invert; but that at the limit of deposition when no sediment bed was present w_e was approximately 10 times the particle diameter. In the present model it is assumed that the effective width is at least 10 times the maximum particle diameter, otherwise it is equal to the width of the sediment bed, B_s, that is

$$w_e = \text{MAX} \left(10 \text{ MAX } (d_i), B_s \right) \qquad (3.33)$$

where

MAX = maximum value of

Sediments with $D_{gr} < 1$ are considered to be a wash-load and are not affected directly by the Ackers-White model.

Instead, these sediments are deposited at a rate controlled by their settling velocity, v_s, and uplifted at a rate controlled by a 'diffusion-like' relationship. Hence,

$$E = \Gamma_E \, A \, k_d \, C_b$$

and

$$D = \Gamma_D \, A \, v_s$$

Sediments in this class do not enter into the 'total load approach' defined above. However, in order to be compatible with the above approach, elements of the Ackers-White theory are utilised to control the values of Γ_D and Γ_E. In order to ensure that the very fine sediments are not deposited when there is transport of coarser deposits the criteria for deposition ($\Gamma_D = 1$ and $\Gamma_E = 0$) are set only when the mobility number, F'_{gr}, of the fraction with the same specific gravity as the fine fraction and a dimensionless grain size equal to unity is less than the initial motion condition. This is equivalent to

$$F'_{gr} < .37$$

Settling velocity v_s for these sediments is defined in terms of Stoke's Law with a factor accounting for hindered settling[32].

If $F'_{gr} > .37$ then $\Gamma_D = 0$ and $\Gamma_E = 1$. The coefficient k_d can vary between 0 and 1 with 1 leading to instantaneous removal from the sediment bed. In the first version of the model a value of 1 is assumed in order to represent the initial flush of these sediment types.

Continuity within the sediment bed is then maintained by a simple balance where

$$\frac{dM}{dt} = D - E \qquad (3.34)$$

where

M = mass of sediment per unit area within the available layer.

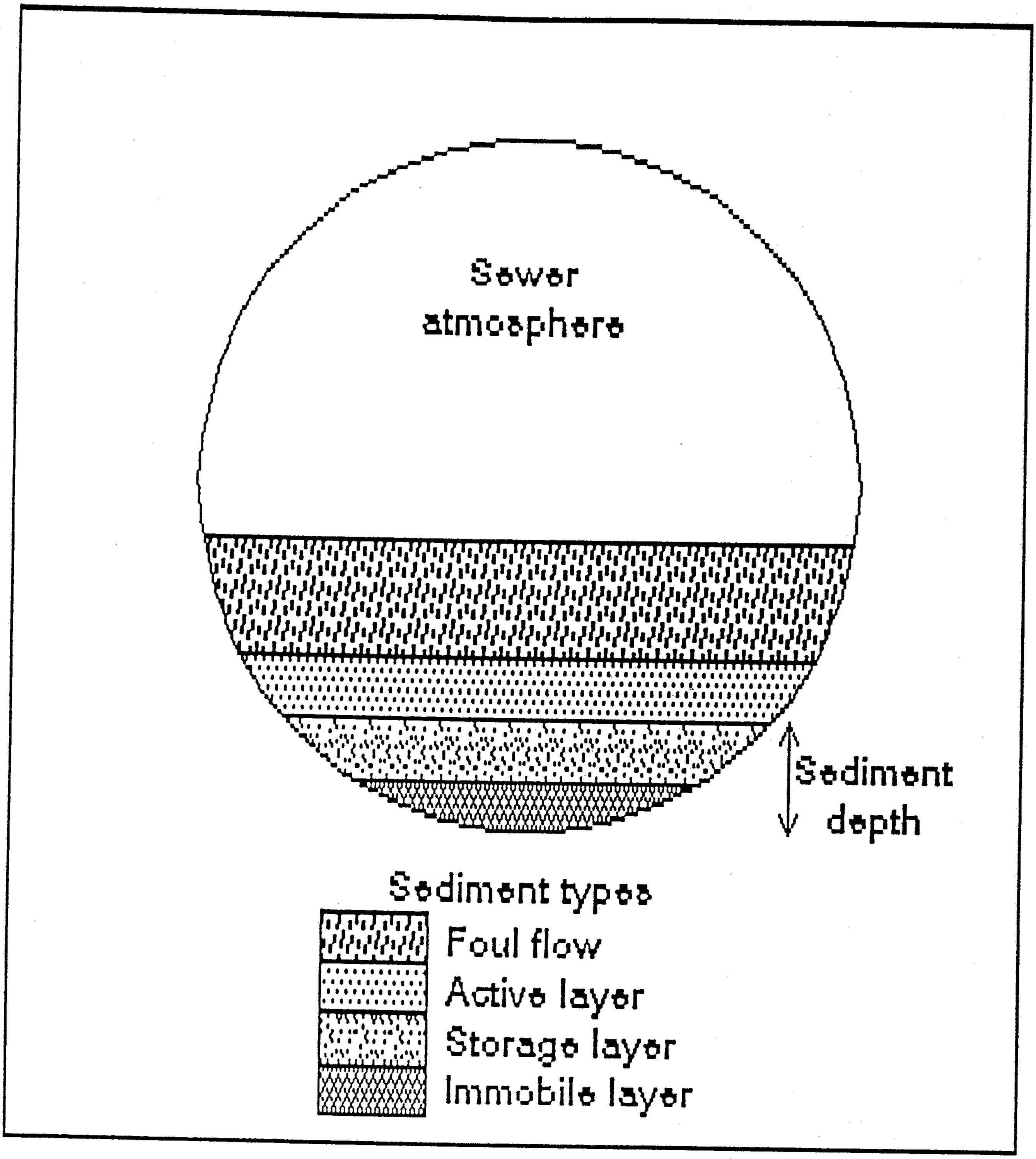

Fig 3.4 Location of sediment types in a sewer

The model considers that sediment deposits within a link are sub-divided into three discrete types:

1. An active layer on the pipe invert in which sediment is stored in an unconsolidated state

2. A storage layer on the pipe invert in which sediment is stored in a consolidated form exhibiting a cohesive shear strength

3. An immobile layer on the pipe invert which cannot be moved by the flow.

These three sediment types form separate layers of a sediment bed on the pipe invert (Fig 3.4). Sediment is transferred to and from the flow by means of deposition and erosion of the active layer. If the active layer is totally exhausted of sediment then a portion of the storage layer can pass into the active layer if the shear-strength of this layer is exceeded by the flow shear stress. In this fashion the cohesive behaviour of sewer sediments may be crudely represented. The shear strength, τ_b, of the storage layer is defined by the user as part of the input data characterising the nature of sediment deposits in the sewer. Shear stress, τ_o, is given by

$$\tau_o = g' \; S \; R \qquad (3.35)$$

where

g' = unit weight of water = g density of water

S = slope of link

A number of remaining points need to be clarified

1. The amount of material passing from the storage layer to the active layer is uncertain but can be taken approximately as the roughness of the sediment bed.

2. Passage of material from the active layer to the storage layer, that is, consolidation of the active layer, is not yet represented by the model. All deposited material remains within the active layer and is equally available for entrainment by the flow.

3. Sediment armouring is not directly modelled although it is crudely represented by constraining the uplift of the storage layer to take place only when the coarsest material from the active layer has been removed.

4. The initial conditions of each of these stores is defined by the user in terms of 'standard sediment types' (see 3 below).

2. Pollutant terms.

Pollutants in the below-ground model are treated as being either attached to sediments or are in the dissolved form. In the first version of MOSQITO all pollutants are treated as conservative; that is, pollutants do not degrade, develop or interact with other determinands during the time-scale of a single event.

Pollutant linkage to sediments is described by use of potency factors as in the above ground model; therefore, their behaviour is governed by the sediments they are attached to. Pollutants in the dissolved state in the bed are represented in terms of a concentration per unit volume of interstitial water. These are removed from the active layer by a diffusion process,

$$S = -k_d \ (C_b - C_f) \qquad (3.36)$$

where

C_b = concentration of dissolved pollutant in active layer

C_f = concentration of dissolved pollutant in flow

k_d = diffusion coefficient.

Dissolved pollutants are not allowed to diffuse back to the active layer, so

S = MAX(0.0,S)

3. Standard sewer sediment.

Sediments in the storage and immobile layers are defined in terms of a 'standard sewer sediment' characterised in terms of physical and chemical parameters:

i) bulk density;

ii) sediment composition (grading curve or d_{35});

iii) settling velocity for each fraction or for whole mass;

iv) specific gravity for each fraction or whole mass;

v) pollutant associations (solid-phase and dissolved-phase concentrations);

vi) ratio of depth of storage layer to total sediment depth (defined as the sum of the storage and immobile layers).

The model calculates the total mass of sediment in the storage layer based on the depth of this layer within the pipe and its bulk density.

(e) Definition of dispersion term

The dispersion process has not been considered in urban water quality models previously. To accurately predict a pollutograph it is essential to have some knowledge of this term. Two approaches could be used:

i) derive cross-sectional velocity variations and use approach of Taylor[33] to derive average longitudinal dispersion coefficients; these could then be related to average hydraulic parameters such as mean flow velocity, hydraulic radius, flow depth and shear velocity

ii) empirically derive dispersion coefficients from field observations

However, in the first version of MOSQITO an empirical relationship derived from river data is used[34] where

$$F_x = \frac{\beta\ Q^2}{U_* \ R^3} \qquad (3.37)$$

$\beta \approx 0.18\ (\sqrt{g}RS/U)^{1.5}$

4 MODEL CALIBRATION

The previous two chapters have described in detail the specifications of the individual sub-models forming MOSQITO. Although many of these models are physically-based, it is evident that there are a large number of parameters which require calibration. This could be left to the model user to perform individually on each catchment under investigation. This approach, however, has a number of disadvantages:

1. The cost of collecting sufficient data to adequately calibrate each sub-model on individual catchments is prohibitive.

2. Calibration of individual sub-models using observed data reflecting total system response is will not give reliable parameter estimates.

An important feature of the models constituting the Wallingford Procedure is the degree to which individual sub-models have been pre-calibrated for use in the U.K. For example, the hydrological model, commonly referred to as the Wallingford Model[35], was calibrated using data collected from a variety of experimental catchments specifically set up for this purpose. This feature has been of undoubted benefit in the successful application of the procedure to tackle urban drainage problems in the U.K.

It would therefore seem logical to attempt to pre-calibrate the sub-models incorporated within MOSQITO using data collected from experimental catchments in the U.K. A major problem with much of the available data that is to be used, is that the purpose of the data collection exercise was other than one of model development. Further, these 'field experiments' were not sufficiently coordinated to ensure continuity of experimental procedures and analytical methods.

Table 4.1 indicates data available for calibrating MOSQITO up to August 1988 indicating determinands measured pertinent to MOSQITO I, number of storm events and location of sampling point. A qualitative expression of data quality is also provided based on a review of the data collection methods[36].

The following sections provide details of the model calibration and verification exercises that are to be completed prior to model release in Spring, 1989. This exercise can be divided into five major sub-headings:

1. Calibration of above ground model

2. Validation of separate system model

3. Calibration of foul-flow model

4. Calibration of in-sewer transport model

5. Validation of combined system model

4.1 Calibration of above-ground model

The above-ground model, as detailed in Chapter 2, consists of three sub-models: a catchment washoff model; a gully-pot model; and a sewered sub-area model. The latter is calibrated against the behaviour of the full model - it is in fact 'a model of a model'.

In order to calibrate the washoff model data are required not only of the washoff of material from a variety of catchment surfaces (road, roof and pervious) but also of the various inputs of sediments and pollutants onto the catchment surfaces and of the hydrological response of each of the surfaces. Data available for these purposes comes from three catchments:

i) Clifton Grove, Nottingham: data of surface washoff from three road surfaces contributing to individual gully-pots.

ii) University sites, Goteborg: data of surface washoff from a road site, a parking lot and a roof surface.

iii) Oxhey subcatchment, London: data of surface washoff from one road surface.

TABLE 4.1 SUMMARY OF DATA AVAILABLE FOR CALIBRATION

Site Name	Type[1]	Determinands	Sampling Point	No.[2] events
Shephall	S	TSS, NH_4-N	Outfall	79
Chelmsley Wood	S	TSS, NH_4-N, COD, BOD	Outfall	41
Clifton Grove	S	TSS, NH_4-N, BOD	Outfall	20
Oxhey (whole)	S	TSS	Outfall	?
Oxhey (part)	S	TSS	Pipe d/s of gully	?
Sweden: roof	S	TSS	downpipe	4
car park	S	TSS	gully inflow	10
street	S	TSS	gully inflow	16
Tame Close	S	TSS, NH_4-N, COD, BOD	gully inflow and outflow	14
Churnet Close	S	TSS, NH_4-N, COD, BOD	gully inflow and outflow	5
Twyford Gdns	S	TSS, NH_4-N, COD, BOD	gully inflow and outflow	11
Higham Ferrers	C	TSS, NH_4-N, COD, BOD	overflow chamber	11
Great Harwood	C	TSS, NH_4-N, COD	overflow chamber	12

[1] C = combined, S = separate
[2] Total events monitored. Data incomplete for some events, especially Shephall and Chelmsley Wood.

The parameters of the sediment and washoff sub-models are to be calibrated by embedding these models within an optimization scheme. This also allows parameter sensitivity to be assessed. Objective functions used in the optimization scheme describe the 'goodness-of-fit' of the model over the duration of the storm-event(s), rather than an ability to represent event parameters, such as total load, over a number of events.

To calibrate the gully-pot model information is required of both inflow and outflow of material together with the conditions in the gully-pot prior to the storm-event. Data for this purpose are only available from the Clifton Grove subcatchments. A major purpose of this exercise will be to test the sensitivity of model response to the removal of the gully-pot model.

4.2 Validation of separate system model

The calibration of the sub-models constituting the above-ground portion of MOSQITO can be assessed by use of data from a number of storm-water systems in the U.K., that is

i) Clifton Grove, Nottingham

ii) Shephall, Stevenage

iii) Chelmsley Wood, Birmingham

iv) Oxhey, London

The primary validation measure will be the accuracy of simulated total load, having removed baseflow quality from the observed data. Tests on the distribution of load during an event will be used to assess the sensitivity of the model to the nature of the dispersion term within the transport model. It will be assumed that there are no sites of appreciable sediment deposition within these systems which may alter the total load discharged from these catchments during a storm event. Minor parameter adjustment will be allowed, but major parameter optimisations will not be conducted using these data.

4.3 Calibration of foul-flow model

The foul-flow model described previously is a statistical model based on observations of foul-flow behaviour from a number of sites within the U.K. Model parameters have been derived using regression analysis. Sites from which data have been collected can be sub-divided into two classes:

i) Sewage Treatment Plant (STP) influent quality during dry-weather flow conditions

ii) Catchment studies with associated measurements of base-flow conditions.

A major problem with the information from both these sources is that the foul-flow might be significantly altered in its passage through the drainage system to the point of measurement as a result of deposition or re-entrainment of sediment and associated pollutants. This model is being calibrated separately from the rest of the model; details of this work can be found in a separate report (Henderson, 1988).

4.4 Calibration of transport model

A number of parameters within the sediment and pollutant transport sub-model require calibration; these are listed below together with details of the data to be used where these are available.

i) Effective width, w_e, in Ackers-White equation: calibrated using data from laboratory pipes at HRL[37,31,38].

ii) Dispersion coefficient in advection-dispersion equation: no data yet available, although dilution gauging data has been sought.

iii) Volume occupied by active layer of sediment bed: no data for calibration.

iv) Cohesive shear strength of storage layer: no data.

At present few data are available to attempt to test and/or calibrate the various sub-models constituting this particular aspect of the model. However, this deficiency is being addressed by a number of studies organised under the aegis of the River Basin Management Programme.

4.5 Validation of combined system model

Data sets from two catchments have been supplied by the Water Research Centre to attempt to validate the behaviour of the combined systems model, these are:

i) Higham Ferrers

ii) Great Harwood.

The data supplied describes sewer quality and flow during both dry-weather and wet-weather periods and rainfall information. No details with regard to sediments and pollutants on either catchment surfaces or within the drainage system are available. As a result, these latter details must be inferred from the separate system studies.

However, further studies are being conducted on two other combined sewer catchments (Clayton-le-Moors and Preston) in which sediments from catchment surfaces and within the sewer system are being collected together with water and pollutant flow measurements. These data sources should enable the behaviour of the complete combined sewer model to be validated and its sensitivity to different input data to be assessed.

5 MODEL USE

The procedure for using the model is not yet completely defined, and many aspects will only be determined after several studies have been carried out. This chapter outlines the major steps involved in the use of the model, and the assumptions made in the development of the model which affect its use.

5.1 Outline procedure

The water quality model is intended to be attached to a hydraulic simulation model. In the first version of the model this is WALLRUS, the latest implementation of the Wallingford Procedure. The water quality model is more difficult to use than the quantity model, and requires more data. The results of the quality model will be much more uncertain than those of the quantity model.

The procedure for using the models is therefore to identify and resolve as many problems as possible when using only the hydraulic model before considering water quality. The hydraulic model must therefore be constructed and verified before looking at water quality. It is particularly important that the discharges at overflows and outfalls to the river system are being correctly predicted, as these will have an important effect on the water quality model.

The methodology for using a hydraulic model for water quantity is described below.

Construction

1 Construct a model using the best available data on the physical characteristics of the sewerage system and catchment and the average dry weather flow.

Proving

2 Analyse the model for long return period synthetic storms to check its stability and its response to extreme conditions.

Verification

3 Analyse the model for any significant historical flooding events, and for synthetic storms of return periods of typically 5 to 10 years for comparison with flooding reports.

4 Try to identify the causes of any poor predictions of these flooding events.

5 Measure rainfall and flow in the system for a few weeks, and compare the model predictions with the measured data.

6 Try to identify the causes of disagreement and re-collect the data of the physical characteristics where necessary.

Use

7 Analyse the model for synthetic storms of a range of durations and return periods to identify inadequate performance of the system.

8 Introduce possible improvements to the system and re-analyse for a range of conditions to see the results.

The procedure for the water quality model is generally similar.

Construction

1 Construct a model using the best available data on the extent and characteristics of sediment deposits in the sewers.

2 Use the standard foul inflow model, and with standard surface washoff and sewer sediment characteristics.

Proving

2 There is no additional stability requirement for the model, and analysing any event will demonstrate that the model is stable.

Verification

3 Analyse the model for any significant historical events which have caused serious pollution incidents. This will require the rainfall data, and also details of the antecedent dry period.

4 Analyse the model for synthetic storms of 1 year return periods for comparison with typical pollutant incidents. The antecedent conditions for these should be the standard summer catchment wetness index, and a standard summer number of dry days.

5 Try to identify the causes of any poor predictions of these first events. The most likely cause is errors in the depth of sediment in the system.

6 Measure rainfall, flow and pollutants in the system for a few weeks, and compare the model predictions with the measured data.

7 Try to identify the causes of disagreement and re-collect the data of the physical characteristics where necessary.

Use

8 Use the WRc interim procedure to identify the most significant storms from the available rainfall time-series. Typically up to 12 storms would be used. Analyse the model for these storms to identify inadequate performance of the system.

9 There are two types of result required from the analysis. The first is the total pollutant load per year. To determine this plot the pollutant loads against the rank of the storm on Gumbel paper. Extrapolate the line back to the point of no pollutant discharge. The area under the curve is the expected annual discharge.

The second type of result is the peak discharge concentration over a range of durations of discharge. This requires the outfall pollutographs to be examined for all of the analysed storms. The peak value of concentration for each duration can be assumed to be approximately a one in one year pollution event.

10 Introduce possible improvements to the system and re-analyse for the time series events to see the results.

5.2 Data requirements

An important consideration in the use of a model is the data which are required for it. These can be considered in several different classes.

> Static data which describe the physical characteristics of the system. These are not changed from event to event, but will be changed by capital works.
>
> Event data which are different for each event. This includes initial conditions and time varying data.
>
> Verification data which are not used to construct the model, but are used to give confidence that its predictions are correct.

For hydraulic models, the static data include hydraulically significant sediment deposits.

Dry weather flow data are normally taken as static. On catchments with significant infiltration it may be considered to vary from event to event. For long duration storms the daily variation of dry weather flow may be included. This is however a form of static data, as the same relationship is used for each event.

For water quality models more data which are required, and it is not always clear which data class each item falls into. The description below refers to the use of the first version of MOSQITO.

The static data will include not only sediments which are hydraulically significant, but also sediments which require a significant discharge to move them, and which are significant for pollutants. The depth of these sediments will be assumed to be present at the start of each event, unless the user provides new data.

The event data will include the pollutants on the catchment surface, and the mobile organic layer of sediment in the sewers. This will be calculated automatically by the program based on the number of antecedent dry days.

The pollutant strengths of the sewer sediments will be assigned standard values, although if there are found to be serious errors in the model prediction, this is the most likely source.

The erosion resistance of sewer sediments will also be assigned standard values.

The verification data will consist of several different types.

Surface sediment data. These would not normally be used as input data to the model, but will give a guide to the likely errors introduced by using the standard values.

Dry weather flow pollutant data. These would not normally be used as input data to the model, but will give a guide to the likely errors introduced by using the standard values.

Sewer sediment strength data. These will only be used as input data if there has been sufficient data collected to reliably show that the standard values are not suitable.

Sewer sediment depths after storms. The erosion of sediment during storms can be used as verification data to give confidence in the standard values of erosion resistance of the sediments.

Suspended solids, and pollutants in the flow will be used as an overall measure of confidence in the model.

6 SOFTWARE IMPLEMENTATION

Chapters 2 and 3 have described the major theoretical aspects of the sewer flow quality model. This chapter provides an overview of the implementation of the various sub-models within the updated Wallingford Storm Sewer Package, known as WALLRUS.

6.1 Subroutine organisation

The subroutines constituting MOSQITO are organised into 5 major blocks of code performing specific functions:

i) MOSQ1.FOR: Data entry and initialisation

ii) MOSQ2.FOR: Inflow of sediments and pollutants (above-ground model and foul-flow model)

iii) MOSQ3.FOR: Transport through drainage system

iv) MOSQ4.FOR: Utility routines called from routines in different blocks

v) MOSQ5.FOR: Reporting.

Calls are made to the HR Library Routines[39] to interface with the screen, open and close files, and provide help and error messages. Full details of the subroutines within each block are included in Appendix A.

6.2 Linkage to flow model

The sub-models constituting MOSQITO are incorporated directly within the Simulation Method in WALLRUS. A disadvantage with adding the MOSQITO code onto the WALLRUS-SIM code is the increase in core-storage and computational time spent in operating the model. This restricts the availability of the package as described below.

6.3 Hardware requirements

The program is specifically aimed at the micro-computer and workstation environments, although the model will also be available for use on mainframe computers. However, the program will not operate on micro-computers using MS-DOS due to restrictions imposed by this operating system on the amount of available memory and on the number of files that can be accessed at any one time. Instead the model is designed to run within UNIX (or UNIX-like) operating systems. Examples of recommended configurations are:

i) XENIX O.S. on Intel 80286/80386 machines with a maths co-processor (80287/80387);

ii) UNIX System V O.S. on Apollo/Sun workstations.

6.4 Data entry

Data included in input files for operating MOSQITO will be entered using the Data Entry program provided with WALLRUS. This will require additions to be made to the WALLFORM.SYS and WALLHELP.SYS files. On entry, data will be checked to ensure that values fall within predefined ranges. No pre-processing of these data is required before using MOSQITO, although the routines in MOSQ1.FOR will check the data before carrying out a simulation run.

Program control data will be entered from the screen during operation of MOSQITO. Two types of information will be entered:

i) file-names

ii) reporting control

Results will be reported in two formats:

i) summary results including sediment and pollutant balances over the duration of the event;

ii) pollutographs at selected gauge points and all outfalls and ancillaries within the drainage system.

6.5 Error and help messages

The WALLERR.SYS and WALLHELP.SYS files are to be appended with relevant information to trap any errors that may occur in the operation of the model and to aid in its use.

7 USER GUIDE

This chapter describes how MOSQITO is to be used in conjunction with the WALLRUS package. Reference to the WALLRUS User's Manual[6] is made where appropriate.

This guide is divided into 5 sections:

1. Data Capture and Edit

2. Foul Flow Generator

3. Simulation

4. Graphical Presentations

5. Data Files and Formats

7.1 Data Capture and Edit

The Data Capture and Edit program (see WALLRUS User's Guide Chapter 7) is used to create and edit three files for use with MOSQITO:

1. Sediment and pollutant calibration file (given a **.CAL** extension)

2. A dry-weather flow quality file (given a **.DWP** extension)

3. Quality inflows at specific nodes given a **.PIN.XXX** extension, where XXX is the extension name for the pollutant/sediment input at a node. One file is required per determinand.

Records used in each file are described in Section 7.5

Specific extensions are used to identify files for each sediment/pollutant (Table 7.1).

TABLE 7.1 Sediment and Pollutant File Extensions

Determinand	Extension
Suspended Solid 1	TS1
Suspended Solid 2	TS2
Suspended Solid n	TSn
Biochemical Oxygen Demand	BOD
Chemical Oxygen Demand	COD
Ammoniacal Nitrogen	NH4
Hydrogen Sulphide	H2S

7.2 Foul-flow Generator

(a) Function

The foul-flow generator is used to produce an input foul flow file of both water and sediments/pollutants for use with the simulation procedure. This can be used as an alternative to observed foul-flow information.

(b) Operation

When selected from the main menu the program **FOUL** prompts the user for the following information:

1. Filename to be created: the user types a filename followed by **{CONT}**. If the file exists the program will ask it the old file is to be overwritten. Conventionally, the filename should have the same fore-name as the rainfall file being used in the simulation and an extension of **.DWF**

2. Number of foul sub-areas in catchment: this allows the user to define spatially varying foul flows within the model. It takes a value from 1 to 9.

3. Time-of-day: the user inputs the start time of the simulation in GMT e.g. 12.45

4. Day-of-week: start day of the simulation in text, e.g. monday

5. Time-step: time-step of dry-weather flow variation in minutes. Typical values are 15 to 60. If a value of 0 is input the model assumes that no temporal variation of pollutant concentration is required.

6. Duration of simulation: if a time step other than 0 is input the program requires an approximate duration of the event to be simulated. This should be set to longer than the simulation time of the simulation run.

Then for each foul sub-area

7. Population density: the user inputs population density in units of head/ha

8. Land use: land use is defined in terms of three classes, residential, commercial and industrial. The user enters in the percentage of each in the sub-area.

The user then has the option to use default flows (l/head/day) and concentrations (mg/l) provided in the model or enter values particular to the catchment. Having entered, or accepted, average daily values, the user is then prompted to accept, or change, the values of the parameters defining the time-series (regression) models of foul-water flows.

7.3 Simulation

MOSQITO is operated as part of WALLRUS (see Section 11 of the WALLRUS User's Guide for information on operating this program). To implement MOSQITO within WALLRUS the user types **Y** in reply to the prompt 'Pollution to be considered ?' on the Program Control Data screen.

Model Options

The next screen asks the user which of the two pollutant prediction approaches incorporate within WALLRUS is to be used. The first approach is the MOSQITO model; the second is based on the WRc Interim Procedure[4]. The user has the option to select either approach, or both during a model run. When the pollutant simulation options have been selected press **{CONT}** to continue.

MOSQITO filenames

If MOSQITO is selected the program asks for the name of the input files. These are:

Pollutant definition file
Results files
Dry-weather pollutant file (optional)
Foul inflow file (optional)

The results file name is defaulted to that used for the flow simulation except that different extensions are used for the pollutant summary file (**.QUA**) and the pollutograph files (e.g. **.BOD**). However, this name can be overridden. If the optional files are not selected then the model assumes a zero concentration for the equivalent water flows if these are input in WALLRUS. When all the files have been selected press **{CONT}** to continue.

Interim Procedure

The program then reverts back to the model option screen. If the Interim Procedure is selected then the program proceeds through a number of screens to define the model parameters (see WALLRUS Manual Chapter 11 for details of the data entry). When all the data has been entered the program again reverts back to the model options screen.

When all models have been selected press **{CONT}** to continue. The program then prompts for the gauges to be set up (again see WALLRUS manual).

Results

At the end of the run the results can be printed from the main menu by pressing **{PRINT}** and giving a results filename with a **QUA** extension. The pollutograph results can be listed or plotted by pressing **{LIST}** or **{GRAPH}** and giving the results filename.

7.4 Graphical Presentations

A utility program for plotting the results of an analysis for comparison with another analysis or with observed conditions in the catchment is included in WALLRUS (see Section 12.3 of the WALLRUS manual). Pollutographs are plotted by entering **T** for true at the **Plot pollutants** prompt on the control data screen.

7.5 Data Files and Formats

Input data for MOSQITO are entered as records organised within three data files as described below (Fig. 7.1)

File 1 Sediment and Pollutant Parameter File

This file contains parameters defining the operation of the pollutant washoff and pollutant transport sub-models as well as general program control data for the model. This file should have the same forename as the SSD file used with the WALLRUS package, but with a **.CAL** extension.

The file will always start with:

Record 34 Title for parameter file
Record 35 Program control data
Record 36 Washoff model parameters *
Record 37 Transport model parameters *

and will always end with

Record 33 Terminator record

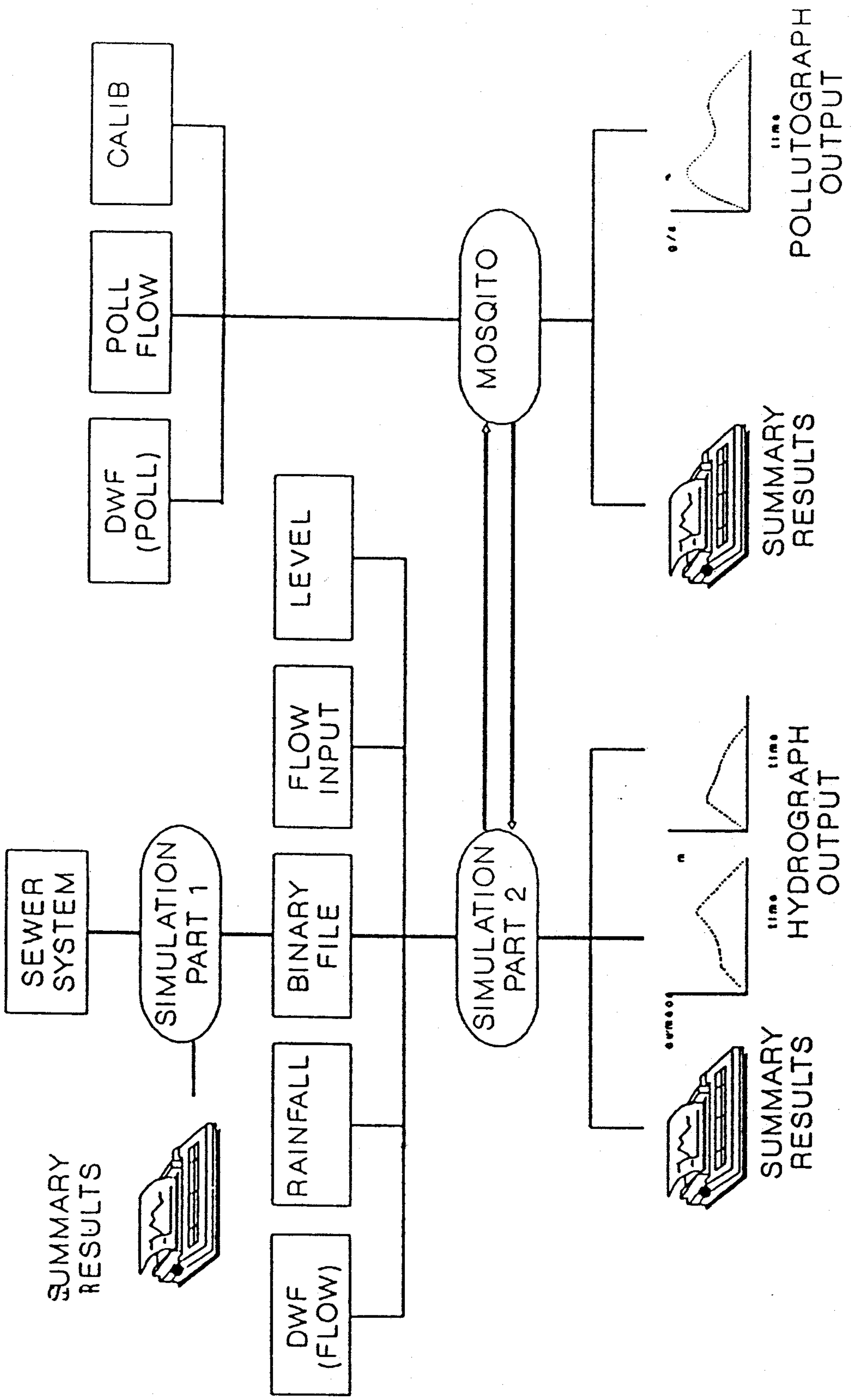

Fig 7.1 Program Structure

Between these records there will be a series of records representing the behaviour of individual sediment or pollutant types that the model simulates.

Sediment records are input before pollutant records. 3 records are required for each sediment type, as shown below:

Record 38 Sediment name
Record 39 Sediment washoff parameters
(Record 40 Sediment transport parameters)

Pollutant records are input after sediment records. 5 records are required for each pollutant type as shown below:

Record 38 Pollutant name
Record 39 Pollutant washoff parameters
Record 41 Pollutant potency parameters for surface
Record 41 Pollutant potency parameters for active bed
Record 41 Pollutant potency parameters for storage bed

Following these are a set of records describing the characteristics of the sediment mixtures found on the catchment surfaces and within pipes and ancillaries. The content of each record type varies dependent on location. 3 records are used to define sediment types:

Record 42 Location name
Record 43 General sediment parameters
Record 44 Content of each determinand per sediment type

One point is noteworthy:

> Records marked with a * will not be generally input by the user; these records are only available for calibration purposes.

Record 34 Title

Item No.	Description of item	Column	Format
1	Title	1-80	Text

Record 35 Program Control Data

Item No	Description of data	Column	Format
1	Number of determinands simulated	1-5	Integer
2	Number of sediments simulated	6-10	Integer
3	Number of pollutants simulated	11-15	Integer
4	Number of sediments with associated pollutants	16-20	Integer
5	Number of sub-areas within catchment (for foul-flow model)	21-25	Integer
6	Number of surface types defined in hydraulic model	26-30	Integer

Record 36 Washoff Model Parameters

Item No	Description of input	Column	Format
1	Coefficient for rainfall erosion term	1-8	Decimal (3)
2	Coefficient for overland flow erosion term	9-16	Decimal (3)
3	Coefficient for overland flow deposition term	17-24	Decimal (3)
4	Power for rainfall erosion term (set to 1.5)	25-32	Decimal (3)
5	Power for overland flow erosion (set to 1.0)	33-40	Decimal (3)
6	Power for overland flow deposition (set to 1.0)	41-48	Decimal (3)
7	Ratio of critical deposition to critical erosion shear stress	49-54	Decimal (3)

Record 37 Transport Model Parameters

Item No	Description of data	Column	Format
1	Global dispersion coefficient	1-8	Decimal (3)
2	Coefficient of uplift velocity term (non Ackers-White erosion)	9-16	Decimal (3)
3	Effective width	17-24	Decimal (3)
4	Depth of storage layer that moves into the active layer	25-32	Decimal (3)

Record 38 Sediment/Pollutant Name

Item No	Description of data	Column	Format
1	Name of sediment/pollutant (chosen from table of names)	1-3	Text

Record 39 Sediment/Pollutant Washoff Parameters

Item No	Description of data	Column	Format
1	Sediment size (mm) - not required for pollutants	1-8	Decimal (3)
2	Relative density (specific gravity) - not required for polls.	9-16	Decimal (3)
3	Concentration of sediment or pollutant in rain-water (mg/l)	17-24	Decimal (3)
4	Concentration of sediment or pollutant in gully-pot liquor (mg/l)	25-32	Decimal (3)

Record 40 Sediment Transport Parameters

This record is not implemented

Record 41 Pollutant Potency Parameters

Item No	Description of data	Column	Format
1-10	Potency of pollutant related to sediment mass. 1 item required for each sediment simulated. Expressed in 100 x kg/kg of each sediment.	1-8	Decimal (3)

Record 42 Location/Sediment Store Name

Item No	Description of data	Column	Format
1	Location name (for reference only)	1-10	Text
2	No. of sediment types	11-15	Integer

Record 43 General Sediment Parameters

Item No	Description of data	Column	Format
1	Mass of available sediment. For surface and tank sediments enter in units of kg/m^2. For pipe sediments enter in units of kg/m.	1-8	Decimal (3)
2	Bulk density of sediment (kg/m^3)	9-16	Decimal (3)
3	Length parameter For surface sediments this is the proportion of the catchment from which sediments are available for removal. For pipe sediments this is the proportion of the sediment depth entered in the SSD	17-24	Decimal (3)
4	Porosity of sediment (fraction)	25-32	Decimal (3)
5	Shear strength of sediment (N/m^2)	33-40	Decimal (3)

Record 44 Sediment/Pollutant Content

Item No	Description of data	Column	Format
1-10	Content of each pollutant/sediment within bulk sediment expressed as percentage by weight (100 x kg/kg)	1-8	Decimal (3)

File 2 Dry weather pollutant data file

The dry weather or base inflow of pollutants at any node is made up of two components; a global and a local dry weather flow. The global dry weather flow is defined as a concentration (mg/l) and is applied uniformly across the catchment. Local dry weather flow is applied over uniform sub-areas (no more than 9 per catchment). The sub-area index is entered within the SSD file on each pipe record and controls the dry-weather flow ascribed to each pipe.

Both the global and local dry weather concentrations can be either a constant value or a time varying value. The time variation is given by multiplying the concentration by a dimensionless pollutograph. Several different 'unit pollutographs' can be defined in this file.

The dry weather flow data file will contain the following records:

Record 46 Dry weather flow title
Record 47 Global dry weather flow parameters
Record 48 Global dry weather concentrations (one record per pollutant)
Record 49 Global dry weather potency factors (one record per pollutant)
Record 50 Local dry weather flow parameters (one record for each unit pollutograph and for each pollutant)
Record 51 Local dry weather flow potency factors (one record for each unit pollutograph and for each pollutant)
Record 52 Dimensionless hydrograph values (one record for each timestep at which the pollutographs are given)

The local parameter records must be given in the order in which they have been numbered.

The dimensionless pollutograph values must be given at a constant timestep, and a record must be given for every timestep even if that record is blank.

If the file is to contain data for more than one event, each event is terminated with a record 33 (Terminator for data) and the next event starts with a record 13.

Record 46 Dry weather pollutant flow title

Item No	Description of data	Column	Format
1	Dry weather pollutant flow title	1-80	Text

Record 47 Global dry-weather flow parameters

Item No	Description of data	Column	Format
1	Number of event (reference only)	1-5	Text
2	Start-time of foul flow	7-20	Text
3	Dry-weather flow time step (s)	21-25	Integer
4	Number of dry-weather flow unit pollutographs	26-30	Integer

Record 48 Global dry-weather concentrations

Item No	Description of data	Column	Format
1	Pollutant name (see Table 7.1)	1-3	Text
2	Pollutant concentration (mg/l)	41-50	Decimal (3)
3	Index of dry-weather flow unit pollutograph	51-55	Integer

Record 49 Global dry-weather potency factors

Item No	Description of data	Column	Format
1-10	Potency factor of pollutants related to solids	1-8	Decimal (3)

Record 50 Local dry-weather concentrations

Item No	Description of data	Column	Format
1	Pollutant name (see Table 7.1)	1-3	Text
2	Pollutant concentration (mg/l)	41-50	Decimal (3)
3	Index of dry-weather flow unit pollutograph	51-55	Integer

Record 51 Local dry-weather potency

Item No	Description of data	Column	Format
1-10	Potency factors of pollutants related to solids	1-8	Decimal

Record 52 Local dry-weather flow pollutograph

Item No	Description of data	Column	Format
1-9	Dry-weather flow multipliers (one per unit pollutograph)	1-8	Decimal (3)

File 3 Pollutograph data input file

One file is required per pollutant input at a node. Records used in this file are:

Record 53 Pollutograph title
Record 54 Pollutograph global parameters
Record 55 Pollutograph local parameters
Record 56 Pollutograph data
Record 33 Terminator for data

If the file is to contain data for more than one event the next event starts with a Record 29 after the terminator of this event.

Record 53 Pollutograph title

Item No	Description of data	Column	Format
1	File contents flag 3 sediment graph 4 pollutant graph	1	Integer
2	Descriptive title	2-80	Text

Record 54 Pollutograph global parameters

Item No	Description of data	Column	Format
1	Event reference number[a] (for reference only)	1-5	Integer
2	Start time of pollutograph	7-20	Text
3	Pollutograph time-step (s)	21-25	Integer
4	Number of hydrographs	26-30	Integer
5-10	Potency factors [b]	41-48	Decimal (3)

Notes

a) The event reference number should be the same as for the rainfall data for the same event. If data for more than one event is given in the file each event must have a different reference number.

b) Potency factors are only required for pollutant parameters; they are not required for sediments.

Record 55 Pollutograph local parameters

Item No	Description of data	Column	Format
1	Pipe number at which the pollutograph is to be applied.	1-10	Decimal
2	Node number at which the pollutograph is to be applied (optional)	11-18	Integer
3	Reserved for future use	21-27	
4	Local potency factors[a]	51-58	Decimal (3)

Notes

a) Potency factors applied to each pollutograph at each node (if left blank for a pollutant then the global potencies are assumed). Not required for sediment graphs

Record 56 Pollutograph data

Item No	Description of data	Column	Format
1-10	Mass flow (g/s) for all pollutographs. One record is used for each time-step.	1-80 each value occupies 8 columns.	Decimal

8 REFERENCES

1 **Clifforde, I T et al.** Urban pollution of rivers - the UK water industry research programme. Proc. Int. Conf. on Water Quality Modelling in the Inland Natural Environment, BHRA. 1986.

2 **Ellis, J B.** The nature and sources of urban sediments and their relation to water quality : a case study from NW London. In Man's Impact on the Hydrological Cycle in the UK (Ed Hollis G E), Geo. Abstracts, Norwich. 1979.

3 **Department of the Environment/National Water Council.** Design and Analysis of Urban Drainage Systems - The Wallingford Procedure. NWC, London. 1981.

4 **Water Authorities Association/Water Research Centre.** Sewerage Rehabilitation Manual. Second Edition, WRc. 1986.

5 **Clifforde, I T and Price, R K.** Quality Modelling in Urban Storm Sewers. 1985.

6 **Hydraulics Research Limited.** Design and Analysis of Urban Storm Drainage - The Wallingford Procedure. Volume 7 - Wallrus User's Guide. HRL. 1987.

7 **Mance, G.** The Quality of Urban Storm Discharges - A Review. WRc report ER 192-M. 1981.

8 **Moys, G D and Payne, J A.** The MOSQITO Surface Washoff Model. HRL report. 1988.

9 **Price, R K and Mance, G.** A Suspended solids model for stormwater runoff. In Urban Storm Drainage (Ed Helliwell, P), Pentech Press. 1978.

10 **Woolhiser, D A.** Simulation of unsteady overland flow. In Unsteady Flow in Open Channels (Ed Mahmood, K and Yevjevich, V), Water Resources Publications. 1975.

11 **Graf, W H.** Hydraulics of Sediment Transport. McGraw-Hill. 1971.

12 **Mantz, P A.** Incipient transport of fine grains and flakes by fluids - extended Shields Diagram. J. Hydraul. Div. (ASCE), 103 (HY6). 1977.

13 **Henderson, R J.** Prediction of foul flow quality in sewers. WRc report. 1988.

14 **Yanenko, N N.** The method of fractional steps. Springer-Verlag. 1971.

15 **Sobey, R J.** Fractional Step Algorithm for Estuarine Mass Transport. Int. J. Numerical Methods in Fluids, 3, 567-581. 1983.

16 **Price, R K.** Flood Routing. In Developments in Hydraulic Engineering - 3 (Ed Novak P), Elsevier Applied Science. 1985.

17 **Todini, E and Bossi, A.** PAB (Parabolic and Backwater), an unconditionally stable flood routing scheme particularly suited for real-time forecasting and control. Istituto di Costruzione Idrauliche, University of Bologna, Italy. 1985.

18 **Bettess, R.** A surcharging model for storm sewer systems. In Urban Storm Drainage (Ed Helliwell P), Pentech Press. 1978.

19 **Abbott, M B.** Computational Hydraulics - A short Pathology. J. Hydraul. Res. IAHR, 14 (4). 1976.

20 **Sauvegat, P.** Dispersion in rivers and coastal waters -2. In Developments in Hydraulic Engineering - 3 (Ed Novak P), Elsevier Applied Science. 1985.

21 **Holly F M and Preismann A.** Accurate Calculation of Transport in two dimensions. J. Hydraul. Div. (ASCE), 108 (HY11). 1977.

22 **Leonard, B P.** A stable and accurate convective modelling procedure based on quadratic upstream interpolation. Computer methods in applied mechanics and engineering, 19, 59-98. 1979.

23 **Koussis, A D et al.** Pollution Routing in Streams. J. Hydraul. Eng., 109 (12). 1983.

24 **Moys, G D.** Pollutant Routing in Urban Drainage Systems - A Comparison of Numerical Approaches. HRL report. 1988.

25 **Belleudy, P and Sauvegat, P.** A new system for modelling pollutant transport in river and canal networks. Int. Assoc. Hydraul. Research, Melbourne. 1985.

26 **Ackers, P and White, W R.** Sediment Transport: New Approach and Analysis. J. Hydraul. Div. (ASCE), 99 (HY11). 1973.

27 **Ackers, P and White, W R.** Bed Material Transport: A Theory for Total Load and its Verification. Int. Symp. on River Sedimentation, Beijing, China. 1980.

28 **Einstein, H A.** Bed load transportation in Mountain Creek. US Department of Agriculture, Washington, DC. 1944.

29 **Day, T J.** A study of the transport of graded sediments, Hydraulics Research Station, report INT 190, Wallingford. 1979.

30 **Ackers, P.** Urban Drainage: The Effects of Sediment on Performance and Design Criteria. In Urban Storm Drainage (Ed Helliwell P), Pentech Press. 1978.

31 **Ackers, P.** Sediment transport in sewers and the design implications. Int. Conf. on Planning, Construction, Maintenance and Operation of Sewer Systems, BHRA, 215-230. 1984.

32 **Happel, J and Brenner, H.** Low Reynolds Number Hydrodynamics. Prentice-Hall, Englewood Cliffs. 1965.

33 **Taylor, G I.** Dispersion of soluble matter in solvent flowing slowly through a tube. Proc. Roy. Soc. A., 219, 186-203. 1953.

34 **Liu, H.** Predicting dispersion coefficient of streams. J. Environ. Eng. Div. (ASCE), 103. 1977.

35 **Kidd, C H R and Lowing, M J.** The Wallingford urban subcatchment model. Institute of Hydrology report No. 60. 1979.

36 **Payne, J A.** Water Quality Data for MOSQITO. HRL report. 1988.

37 **May, R W P.** Sediment transport in sewers. HRL report IT 222. 1982.

38 **Hare, G R.** Sediment movement in sewers. HRL report SR 179. 1988.

39 **Hydraulics Research Limited.** HRL Library Routines. HRL report. 1988.

9 NOTATION

a_i, a_e, a_d	parameters of Price-Mance model
A	flow cross-sectional area
C	concentration
d	particle diameter
d_{xx}	particle diameter of xx-percentile
D_{gr}	dimensionless grain size (Ackers-White)
f	Darcy-Weisbach friction factor
F_x	longitudinal dispersion coefficient
F_{gr}	particle mobility number (Ackers-White)
G_{gr}	sediment transport rate
h	depression storage
i	rainfall intensity
k_d	diffusion coefficient
m	mass per unit area
M	mass
q	discharge per unit area
Q	discharge
r	solid phase concentration (potency)
s	specific gravity
S	slope
t	time
U	velocity
U_*	shear velocity

V	volume
w_e	effective width (Ackers-White)
α, β	position points of characteristic (Holly-Preissman)
Γ_D, Γ_E	parameters of sediment transport model

SUBROUTINE

SPECIFICATIONS

The subroutines forming the MOSQITO amendment to the WALLRUS-SIM model are organised into 5 major blocks of code:

1. MOSQ1.FOR - data entry and initialisation;
2. MOSQ2.FOR - generation of pollutants in catchment;
3. MOSQ3.FOR - transport of pollutants through drainage system;
4. MOSQ4.FOR - utility routines;
5. MOSQ5.FOR - reporting

Subroutines within each block are described below:

A.1 MOSQ1.FOR

This block of code performs three major functions:

1. Read in file-names
2. Set-up model parameters
3. Initialise arrays

Twelve subprograms are included within this block.

A.1.1 **Name:** **MOSQST**

Function: Input data files for use with MOSQITO

Method: Uses HR library routines and top-level subroutine of data input for MOSQITO.

Arguments:

npipes number of pipes in model

Calls: OPENLS, PUTEXT, **INPARS**, FNOPEN, GETSCR, **LODDWP**, **LODNOD**, **INIDWP**

A.1.2 **Name:** **LODDWP**

Function: Load dry weather pollutant file and parameters

Arguments:

iud	stream number of file
idwft	time of start of dry weather flow
npipes	number of pipes in model

Calls: EXIT

A.1.3 **Name:** **INIDWP**

Function: Initialise dry weather pollutant flows if no file provided

Arguments:

npipes	number of pipes in model
idwft	time of start of dry weather flow

Calls: none

A.1.4 **Name:** **LODNOD**

Function: Load input pollutograph files

Arguments:

iup stream number of file

Calls: EXIT

A.1.5 **Name:** **INPARS**

Function: Read in parameters from .CAL file

Arguments:

j	pollutant number
id	pollutant index
ig	pollutant group
i	stream number of .CAL file
iqua	stream number of summary results

Calls: EXIT, GETERR, DATERR

A.1.6 **Name:** **MOSQV1**

Function: Block data for MOSQITO

Arguments:
none

Calls: none

A.1.7 **Name:** **WRTMON**

Function: Write out headers for pollutant gauge files

Arguments:

istrm	stream number of file
ig	pollutant group

Calls: none

A.1.8 **Name:** **MOSQIT**

Function: Initialise arrays in MOSQITO

Arguments:

npipes number of pipes in hydraulic model

Calls: ANCCHK, NDEPIN, **VELPOL**, **SETHYD**, **INIBED**, WRTERR, **POLTKO**, **POLPPO**

A.1.9 **Name:** **INIBED**

Function: Initialise sediment bed in links

Arguments:

i	link number

Calls: none

A.1.10 **Name:** **POLTKO**

Function: Initialise tanks in MOSQITO

Arguments:

nsa	number of ancillary
nax	number of tank
i	link/node number
ipase	number of sub-area.

Calls: none

A.1.11 **Name:** **POLPPO**

Function: Initialise ponds in MOSQITO

Arguments:

nsa	number of ancillary
i	link/node number
ipase	number of sub-area

Calls: none

A.1.12 **Name:** **SETHYD**

Function: Set-up look-up tables for MOSQITO

Arguments:

i	link/node number

Calls: none

.2 MOSQ2.FOR

This block of code performs three functions:

1. Calculate dry-weather flow input at each node
2. Calculate input pollutograph values at each node
3. Calculate washoff of pollutants from catchment surfaces and influence of gully-pots/sewered sub-area.

A.2.1 **Name:** **DWFINP**

Function: Controls input from dry weather flow files

Arguments:
idel

Calls: **READWF**

A.2.2 **Name:** **READWF**

Function: Reads in unit pollutograph values from file

Arguments:

iu
n
ndets
idwft
idel

Calls: none

A.2.3 **Name:** DWFCAL

Function: Calculates dry-weather flow at new time-step

Arguments:
ipp

Calls: DWFPUT

A.2.4 **Name:** **DWFPUT**

Function: Calculates dry-weather flow at new time-step

Method: Uses unit dry-weather flow pollutographs as multipliers of average daily dry-weather flows.

Arguments:

i
d
n
j
totar

Calls: none

A.2.5 **Name:** **AMXPOL**

Function: Mixes pollutants derived from foul water flows, input pollutographs and catchment surfaces.

Method: Uses mixing model approach

Arguments:

ipp
runnod
qint

Calls: **GULPOT**

A.2.6 **Name:** **GULPOT**

Function: Calculates influence of gully-pots and sewered sub-areas on pollutants entering drainage system.

Method: Uses CSTR approach.

Arguments:

ipp
runnod
qint

Calls: none

A.2.7 **Name:** **STWASH**

Function: Initialises surface washoff arrays at new time step

Arguments:

n

Calls: none

A.2.8 **Name:** **WASHOF**

Function: Controls operation of washoff model, gully-poy model and mixes washoff from different catchment surfaces.

Method: Uses mixing model approach.

Arguments:

qstar
rnt
j
sk
i
gslop
is
rstep

Calls: **WASH1, GULPOT**

A.2.9 **Name:** **WASH1**

Function: Calculates washoff of sediments and pollutants from individual catchment surfaces.

Method: Uses derivative of model devloped by Price and Mance. The ODE is solved by the use of finite-differences to obtain the mass of each parameter held in suspension per m^2 of the catchment surface. This is then multiplied by discharge to obtain the mass flow per m^2. Various functions and subroutines calculate the influence of individual processes and a record is kept of the total mass removed if mass availability is a limiting factor.

Arguments:

qstar
rnt
j
sk
i
gslop
is
rstep

Calls: **CRTAU, SEDCHK, RERO, EROS, DEPO, RAININ**

A.2.10 **Name:** **SEDCHK**

Function: Checks availability of sediment/pollutant for removal by surface washoff.

Arguments:

erode
adts
ams

Calls: none

A.2.11 **Name:** **RERO**

Function: Calculates erosion of suspended solids from rainfall.

Method: Uses power-law on rainfall intensity.

Arguments:

rnt
nf

Calls: none

A.2.12 **Name:** **EROS**

Function: Calculate erosion of suspended solids by overland flow

Method: Uses excess shear stress multiplied by a calibration factor.

Arguments:

nf
tau
tauc

Calls: none

A.2.13 **Name:** **DEPO**

Function: Calculate deposition of suspended solids from overland flow.

Method: Uses deficit shear stress multiplied by a calibration factor.

Arguments:

nf
tau
tauc

Calls: none

A.2.14 **Name:** **RAININ**

Function: Calculates input of dissolved pollutants from rainfall

Method: Uses constant concentration multiplied by rainfall depth during time step.

Arguments:

rnt
nf

Calls: none

A.2.15 **Name:** **CRTAU**

Function: Calculates critical shear stress for erosion of sediments by overland flow.

Method: Uses hydraulic parameters calculated from overland flow. Interpolates Shields' Curve to obtain critical shear stress for erosion.

Arguments:

hrad
s
spg
visc
crd

Calls: none

.2.16 **Name:** **POLLUT**

Function: Reads in input pollutographs for selected nodes

Arguments:

n

Calls: none

A.3 MOSQ3.FOR

This block of code implements the below-ground model. Subroutines in this block perform a number of functions to

1. simulate pollutant behaviour at manholes and ancillaries;

2. simulate pollutant behaviour within pipes and open-channels.

A.3.1 **Name:** **SURPOL**

Function: Control calculation of below-ground model during surcharge conditions.

Method: WALLRUS defines a surcharged group of nodes and links. These are scanned to order the pollutant flow calculations. Flow computations are carried out only when the upstream node (defined in terms of current flow direction rather than flow direction under free-surface conditions) concentrations have been calculated.

Arguments:

nips
it
itmax
dt

Calls: **POLPIP**

A.3.2 **Name:** **POLPIP**

Function: Top-level subroutine controlling simulation of pollutant behaviour within a node-link system.

Method: Pollutant balance at upstream node is calculated using a CSTR formulation. Upstream is defined in terms of flow direction rather than slope of link. Pollutants are then routed through link using a fractional step method. Separate calculations are performed to take into account advection, dispersion and source/sink influences on transport through a link.

Arguments:

ij
i
dts
schg

Calls: **SETPOL, BALNOD, UPBNDY, AVVELY, SETADP, SETDIS, SEDPOL, ADVECT, RSTPOL**

A.3.3 **Name:** RSTPOL

Function: Resets data arrays for pollutant transport within links at end of current time-step.

Arguments:

i
revers
nb
njxi

Calls: none

A.3.4 **Name:** **AVVELY**

Function: Averages hydraulic parameters for pollutant computations.

Arguments:

n2
n
ua1
ua2
uav
ca1
ca2
cav
du1
du2
fda
hra

Calls: none

A.3.5 **Name:** **SETPOL**

Function: Puts pollutant variables into temporary work-arrays and computes hydraulic parameters necessary for pollutant flow computations at new time-step

Arguments:

i
nb
njxi
ns
ne
nstp
revers
schg

Calls: **HYDCAL, VELPOL**

A.3.6 **Name:** **BALNOD**

Function: Calculates concentration of pollutants within a manhole or an ancillary node.

Method: Uses a CSTR model.

Arguments:

i
revers
schg

Calls: ANCCHK, **SETTK1, SETPP1, CONNOD**

.3.7 **Name:** **SETTK1**

Function: Sets up parameters of CSTR model for tanks.

Arguments:

i
vnode
qsum1
nsa
nax
revers

Calls: none

A.3.8 **Name:** SETPP1

Function: Sets up parameters of CSTR model for ponds.

Arguments:

i
vnode
qsum1
nsa
revers

Calls: none

A.3.9 **Name:** CONNOD

Function: Calculate concentration in node

Method: Uses CSTR model

Arguments:

i
ia
nsa
nax
vnode
qsum1
off
anc
schg

Calls: none

A.3.10 **Name:** **UPBNDY**

Function: Defines upstream boundary conditions for a link

Arguments:

i
k
n
revers
p1
dp1

Calls: none

A.3.11 **Name:** **SETADP**

Function: Define parameters for Holly-Preissman method of characteristics.

Method: Integrates velocity variation over computational box to define points α and β of advection method. Then defined coefficients dependent on these parameters.

Arguments:

n
nj
alp
ua
a1
a2
a3
a4
b4
b3
b2
b1
xa1
ta2
n2

Calls: none

A.3.12 **Name:** TRIDAG

Function: Solves tridiagonal system of linear equations

Method: Forward and back-substitution.

Arguments:

l
b
c
d
e

Calls: none

A.3.13 **Name:** **SETDIS**

Function: Sets up coefficients for dispersion solution

Arguments:

n
nj
alp
ua
ua1
ua2
cs1
cs2
ca
fx
c1
c2
c3
c4
xa
ta
implt

Calls: none

A.3.14 **Name:** **SEDPOL**

Function: Set up parameters for source/sink terms and calculate concentrations affected by dispersion and source/sink terms

Method: Calls variety of subroutines to set up parameters. Uses 4 point Preissman scheme for solution of equations.

Arguments:

i
nj
n
fda
csav
ua
hra
bs
depos
revers

Calls: **NCTRAN, COTRAN, PARCAL, DISCAL, PARBED, DISBED, TRIDAG**

A.3.15 **Name:** **PARCAL**

Function: Calculate influence of sediments on pollutants in flow

Calls: none

A.3.16 **Name: DISCAL, PARBED, DISBED**

NOT IMPLEMENTED IN MOSQITO I

A.3.17 **Name:** **NCTRAN**

Function: Calculates transport rate for solids >63 μm

Method: Ackers-White sediment transport formulae

Calls: none

A.3.18 **Name:** **COTRAN**

Function: Calculates transport rate for solids <63μm

Calls: none

.3.19 **Name:** **ADVECT**

Function: Calculates advection portion of transport equation

Method: Uses Holly-Preissman method of charactersitics.

Calls: none

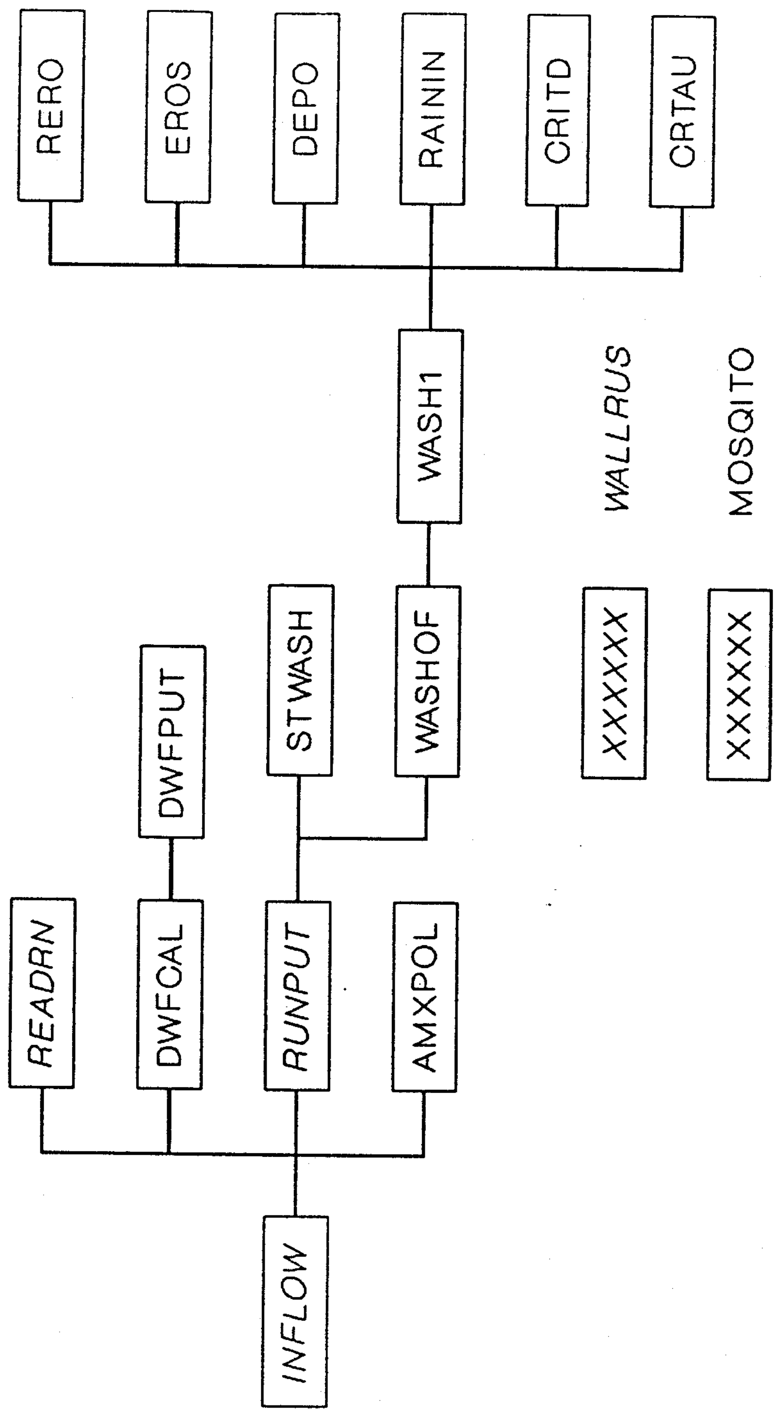

Fig A.1 Structure of sediment and pollutant washoff
submodel within MOSQITO

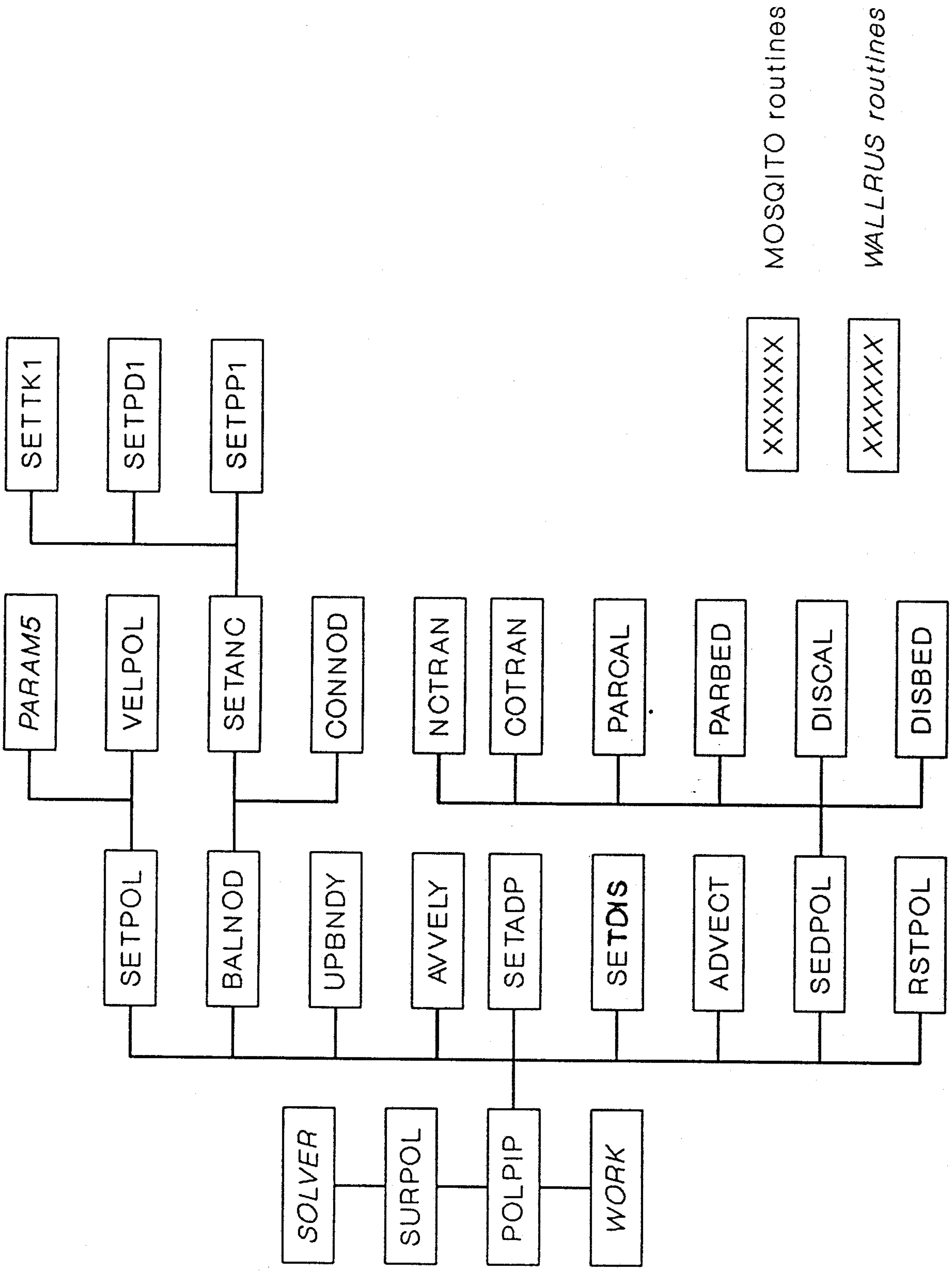

Fig A.2 Structure of sediment and pollutant routing submodel within MOSQITO

GLOSSARY

Air entrainment
The process by which bubbles or pockets of air are caught within the fluid and transported with the flow.

Ancillary structure
A structure within a sewerage system which is not a sewer. Ancillary structures include overflows, storage tanks and ponds, pumping stations, outfalls, sluice gates and flap valves.

Antecedent conditions
The wetness of a catchment before a rainfall event. There are two conditions, one representing the saturation of the ground as a whole, and one representing the wetness of the ground surface.

Areal reduction factor
A factor applied to synthetic point rainfall depths or intensities to give values applicable to an area.

Attenuation
The reduction in peak discharge of a flood wave as it passes down a sewerage system due to friction and gravity effects.

Back drop manhole
A manhole at which a vertical drop in the longitudinal profile of the sewer occurs.

Backfall
A sewer with a gradient in the opposite direction to the direction of flow.

Backwater effects
The effect of water flows or depths on hydraulic conditions upstream; backwater effects can only occur in subcritical flow.

Benching
The shaped floor of a manhole incorporating channels to direct the flow.

Branch
A number of sewers in series which form a part of a sewerage system.

Catchment

An area served by a single drainage system.

Catchment wetness index (CWI)

An index of the wetness of a rural catchment at the start of a rainstorm. It is used in the UK Flood Studies Reports runoff equations.

Combined sewerage system

A sewerage system in which both foul sewage and storm water are carried in the same pipes. (Compare separate system and partially separate system.)

Conceptual

A description of a process in equivalent or notional terms, which do not represent the physical forces involved. (Compare deterministic.)

Cost-benefit analysis

A method of economic analysis in which all identifiable costs and benefits are evaluated (if possible) to show whether expenditure is worth while.

Critical flow

Flow with a Froude number approximately equal to unity where there is a transition between subcritical and supercritical flow.

Culvert

A covered channel or pipeline.

Default value

A preset or standard value which is used for a data field if no other value is given.

Dendritic system

A sewerage system which can be represented by a tree-like diagram, i.e. one where branches converge as the system is traversed towards one outfall.

Depression storage

The initial loss of rainfall in forming puddles on the ground surface before runoff starts.

Depth duration frequency relationship
A table or graph showing the way in which rainfall depth at a particular location is related to the storm duration and the frequency of occurrence (or return period).

Detention tanks
Tanks constructed in a sewerage system to store temporarily a volume of water during peak flows. (See off-line tanks and on-line tanks.)

Deterministic
The representation of a process by the physical laws of cause and effect, such that the means by which the effect is caused is represented as well as the effect itself. (Compare conceptual.)

Discharge coefficient
A numerical value determined experimentally, in an equation relating discharge to the upstream head and the physical characteristics of a weir, orifice etc. Values are published for many standard situations.

Field
One item of data within a record or on a computer screen. Fields can be names (character fields), numbers or logical (true or false).

File
A collection of data in computer form which is handled and used as one block of data.

Filter
A smoothing procedure to convert point rainfall profiles to areal rainfall profiles by reducing the extreme high and low values.

Finite difference equations
Equations describing continuous functions in terms of values at discrete points.

Free surface flow
Flow where there is a free water surface at atmospheric pressure. (Compare with surcharged flow.)

Free surface backwater effects
Free surface backwater effects occurring under free surface flow.

Froude number

The ratio of flow velocity to the speed of a wave in shallow water V $\sqrt{(B / g A_f)}$, the flow is described as subcritical if this ratio is less than unity and supercritical if it is greater than unity.

Function keys

The block of keys on a computer keyboard which have no fixed function. They are generally labelled F1 to F10. The function of these keys is defined by a program while it is running.

Gradually varying flow

Flow conditions in which the discharge and depth vary gradually with distance along the sewer.

Ground condition

An index used in the resource cost model to describe the sub-surface conditions encountered during excavations.

Gully

A structure to permit the entry of surface runoff into the sewer system. It is usually fitted with a grating and a grit trap.

Head discharge curve

A graph or table of values which relates the discharge through a structure (e.g. an orifice or a pump) to the hydraulic gradient across it.

Hydraulic gradient

In free surface flow, the gradient of the water surface. In surcharged flow the gradient joining points to which the water would rise in pressure tappings.

Hydraulic radius

The ratio of cross sectional area of flow to wetted perimeter of a sewer.

Hydrograph

A series of values in numerical or graphical form of the flow rate, depth or level varying with time.

Hyetograph

A series of values of rainfall intensity varying with time. Sometimes called a rainfall profile.

Impermeable, impervious
A surface type which resists the infiltration of water although some does occur.

Infiltration (b) to sewers
The entry of groundwater into sewers by seepage through the ground.

Infiltration (a) to the ground
The loss of rainfall into the ground so that it does not form runoff.

Inflow
The total flow into a sewerage system including surface runoff foul flows and other inflows.

Inlet
An entry point for flow into a sewerage system, either a gully or a drain connection.

Inlet hydrograph
A hydrograph defined at a point in a sewerage system to represent flows other than local runoff or foul flows. This could be flows from a natural watercourse, another catchment or an industrial plant.

Intangible costs/benefits
Description of costs or benefits to be considered in an economic evaluation but to which monetary values cannot be put. (Compare with tangible.)

Intensity / duration / frequency relationship
A table or graph showing the way in which rainfall intensity at a particular location is related to the storm duration and the frequency of occurrence (or return period).

Interception
The process by which rainfall may be prevented from reaching the ground for example by landing on vegetation.

Invert level
The level of the lowest point of the internal bore of a pipe or of an open channel. (Compare with soffit.)

Inverted syphon

A pressurised pipeline carrying sewage or stormwater beneath an obstacle such as a river or a road.

Level pool storage

The estimation of the storage in a pipe or channel due to a high water level at the downstream end by assuming that the water surface is horizontal at this level.

Linear

A description of the relationship between two or more variables which vary in proportion to one another. (Compare with non-linear.)

Looped system

A sewerage system which is not dendritic and in which flow can change direction in some of the sewers depending on flow conditions.

Method

One of the main design or analysis programs of the Wallingford Procedure such as the Simulation Method.

Model

1) A representation of a sewerage system as data to be analyzed by a Method.

2) A representation of a physical process (such as runoff) by computer calculations. A Method is therefore made up of a series of models.

Muskingum-Cunge routing method

A method of routing flows in channels and pipes without considering backwater effects.

Non-linear

A description of the relationship between two or more variables which has the form of a power law rather than a strict proportion. (Compare with linear.)

Normal depth

The water depth for a given discharge in normal flow conditions, i.e. with the hydraulic gradient equal to the gradient of the pipe or channel.

Off-line tanks
Detention tanks which are off the normal path of the flow but which come into operation at large flows.

On-line tanks
Detention tanks which form part of the normal flow path of the sewerage system.

Orifice
A constriction in a pipeline to control the rate of flow.

Overflow chamber
A chamber incorporating some form of storm overflow.

Overland flow
Flow over the ground surface from where rainfall lands to its entry into the sewerage system.

Package
A suite of computer programs which operate together to carry out a range of functions.

Partially separate system
A sewerage system in which part of the storm runoff is carried with the foul sewage in a combined system, and part is carried in a separate system.

Peakedness
A measure of the sharpness of a rainfall profile, that is the ratio of the maximum to the mean rainfall intensity. Percentile peakedness is the profile which has the specified percentage of storms of a given return period with peakedness less than or equal to it.

Percentage runoff
The percentage of the rainfall volume falling on an area which enters the stormwater drainage system.

Percentile
The percentage of occurrences within a stated range. (See peakedness for its application to rainfall profiles.)

Performance cost analysis
A method of economic analysis in which the costs of achieving a given result are calculated in order to find the cheapest method of achieving that result.

Permeable, pervious
A type of ground surface through which water can infiltrate although some surface runoff may still occur.

Program
A computer method of carrying out some function.

Pumping station
A structure in a sewerage system to pump water when drainage cannot be achieved by gravity.

Rainfall intensity
The rate of rainfall expressed generally in mm/hr.

Rainfall profile
A series of values of rainfall intensity varying with time. Also called a hyetograph.

Rational method
A simple method in well established use throughout the world, for calculating the peak discharge in a drainage system.

Recession
The part of a flood event or hydrograph where the flow is reducing after the peak.

Record
One line of data in a file or on a computer screen. This will generally all refer to one physical structure or event.

Regression analysis
A statistical technique by which a dependent variable is expressed in terms of one or more independent variables.

Return period
The average period between occurrences of an event greater than or equal to a given value.

Rising main
The discharge pipe from a pumping station which operates under pressure.

Self cleansing velocity
A velocity of flow in a sewer which is sufficient to prevent the deposition of sediment.

Separate system
A sewerage system in which foul sewage and storm water are carried in separate pipes. (Compare with combined and partially separate systems.)

Sewer
A pipe, culvert or open channel (generally man made) for conveying foul sewage, storm water, or a mixture of both. It generally refers to a length of this which has a constant gradient, cross section and other physical characteristics along its length.

Sewerage
The collection of sewers and other structures which make up a complete conveyance system.

Sewerage system
A network of sewers to convey foul sewerage or stormwater or both.

Side weir
A weir constructed in the side of a pipe or overflow chamber to permit the spill off high flows out of the system.

Simulation
The representation of specific conditions in a sewerage system using a computer model.

Site condition
An index used in the cost model to describe the ground surface which has to be excavated to construct a sewer.

Soakaway
A pit, usually filled with large stone into which surface water is drained to allow it to infiltrate into the ground.

Soffit level
The level of the highest point on the internal bore of a pipe or culvert.

Soil moisture deficit (SMD)
A measure of soil wetness, calculated by the Meteorological office in the UK to indicate the capacity of the soil to absorb rainfall.

Standing wave
A wave formed on a water surface which does not progress with the flow. It is usually associated with the occurrence of critical flow conditions.

Stilling pond
A type of overflow chamber incorporating a stilling pond, intended to ensure that polluting material is retained within the pipe system.

Storage tanks
Tanks constructed in a sewerage system to store temporarily a volume of water during peak flows. Also called Detention tanks. (See off-line tanks and on-line tanks.)

Storm profile
A series of values of rainfall intensity varying with time. Also called a hyetograph.

Storm sewage
Storm runoff mixed with foul sewage in a combined system. (Compare with surface water.)

Storm water overflow
A structure built in a combined sewerage system to spill to a watercourse or a relief system the excess flows which cannot be carried along the sewer.

Sub-catchment
The area draining to one sewer.

Subcritical flow
Flow conditions in which the Froude number is less than unity.

Supercritical flow
Flow conditions in which the Froude number exceeds unity. Surface waves cannot propagate upstream in supercritical flow.

Surcharge
The occurrence in a pipe or culvert of flow conditions in which the hydraulic gradient is higher than the soffit level so that there is no free water surface. (Compare with free surface flow.)

Surcharge flow
For pipe or closed conduit drainage systems the occurrence of flows which cause a sewer to become full so that it is flowing under pressure.

Surface runoff
Flow over the ground surface from where rainfall lands to its entry into the sewerage system.

Surface water
Storm runoff not contaminated with foul sewage. (Compare with storm sewage.)

Suspended solids
Particulate matter carried in suspension by flow.

Synthetic rainfall
Rainfall depths or intensities derived from rainfall statistics and not representing an individual real rainstorm. Also known as Design rainfall.

Tangible
Description of costs or benefits to be considered in an economic evaluation to which monetary values can be put. (Compare with intangible.)

Time area diagram
A diagram showing the increase in area from which flow reaches the sewer system with time for a given catchment.

Time of concentration
The time taken for flow to reach the point under consideration from all parts of the catchment. It is equal to the time of entry plus the time of flow.

Time of entry
The time taken for surface runoff to reach the entry to the sewerage system from any part of the sub-catchment.

Time of flow

The time taken for flow to reach the point under consideration from the head of the sewerage system.

Turbulent flow

Flow conditions in which frictional resistance to flow depends mainly on the roughness of the sewer and only slightly on the viscosity of the water.

Urban catchment wetness index (UCWI)

An index of the wetness of the catchment at the start of a rainstorm. It is used in the UK runoff equations.

Utility

A short program to carry out some minor task to assist with the use of a Method.

Vortex overflow

A type of storm overflow which makes use of the spiralling flow in a vortex to retain polluting material within the sewerage system.

Vortex control

A form of orifice control which uses a vortex to control the flow through the control.

Wallingford Procedure

A set of methods for the design and analysis of urban drainage systems, and the computer packages which implement them. This manual forms a part of the Wallingford Procedure.

Water table

The surface within soil or rock strata at which ground water saturation occurs.

Wet well

The entry chamber in a pumping station from which water is pumped to a higher level.

APPENDIX.

REQUIREMENT SPECIFICATION FOR SEWER FLOW QUALITY SIMULATION MODEL

Discharges from sewer systems have been identified as a major source of river pollution (Ref 1). In severe cases the effect of these discharges may be identified by routine chemical monitoring and result in the river being given an appropriately low quality designation; e.g. Class 3 or 4 of the NWC River Classification System (Ref 2). More frequently the intermittent nature of these discharges is such that routine chemical monitoring does not detect the full impact. In these circumstances the chemical data may indicate an acceptable river quality (e.g. NWC Class 2) but the ecology, which is restricted as a result of the intermittent discharges, will prevent the desired use (e.g. a coarse fishery) being fully established.

Biological damage caused by short term oxygen depletion or the transient presence of acutely toxic substances is therefore a key issue in controlling intermittent pollution. Hence biological assessment should be the criterion by which the effects of sewerage discharges are evaluated. The link between biological effects and transient chemical concentrations is being made through short term toxicity testing with fish and other aquatic organisms. An initial attempt at establishing short term river quality standards (Ref 4) has shown that very short term changes in concentration can have deleterious effects on biological populations. It follows from this that both the total load of pollutants passed to the river during a discharge event and the short duration peak concentrations within the event need to be understood and controlled to limit the damaging effects.

The present and future requirement for river quality management will be to maintain an acceptable balance between sewerage costs and river pollution (Ref 5). This will call for objective planning for discharges from both combined and surface water sewer systems. Past practice has tended to assume that surface water runoff is "clean" and hence can be discharged anywhere without harm. Research into the nature and effect of such discharges has demonstrated that this is not the case (Ref 6). On combined sewer systems, past practice for the setting of overflows has been largely concerned with the control of flows within the sewer system to levels which avoid flooding. Little consideration has been given to the consequences of spilling storm sewage to a river. Future procedures must seek to limit both types of discharge to quantities and locations such that the assimilative capacity of the receiving water, compatible with the desired use, will not be exceeded.

In the foreseeable future, the majority of sewerage capital schemes in the UK will be directed towards the rehabilitation of existing combined sewerage systems. In accordance with the basic tenets of the Sewerage Rehabilitation Manual (Ref 7), the favoured solutions will often incorporate detention tanks. Where such tanks are provided to control pollution, it is important that the requisite polluting load is retained concomitant with the minimum storage volume to optimise construction costs. This is another major reason why it is necessary to have an understanding of the temporal variations of spill quality within a storm event.

From the foregoing, it can be concluded that a sewer flow and quality simulation model is required to aid in the design and rehabilitation of sewerage systems. The model will be used in conjunction with river impact models to provide an objective methodology for the control of sewerage discharges to allow desired receiving water uses to be attained. The WASSP-SIM hydraulic analysis model is already in common use to define the quantitative response of sewer systems. A complementary quality modelling capability is required to produce discharge (pollutographs) to complete the methodology.

Previous attempts at producing sewer flow and quality models (for example SWMM and SAMBA) have aimed to produce an assessment of total pollution load discharged per event. This approach is appropriate under circumstances where:

(i) the total pollution loading is important over long time periods, i.e. chronic pollution and eutrophication;

(ii) delayed oxygen depletion in the vicinity of the overflow after the event is more important than the immediate impact during the event;

(iii) acute pollution from the discharge of toxic substances is not considered to be important;

(iv) first foul flush effects are not significant.

It is recognised that there are difficulties in adopting a requirement to produce discharge pollutographs by a simulation model. However, only this approach will satisfy the two objectives for pollution control which have been described. In the UK the occurrence of the first foul flush effect has been widely reported (Ref 8). This effect must be modelled to:

1. achieve short term river quality criteria in relation to oxygen depletion and acutely toxic substances, such as ammonia and hydrogen sulphide, and hence allow desired uses to be established;

2. optimise design of engineering structures for pollution control.

REFERENCES

1. Shuttleworth, A J, 1986. "State of rivers and sewers in Britain: is there a problem"? The Public Health Engineer, Vol 14, No 3, 49-51.

2. National Water Council, 1977. "River Water Quality - the next stage". National Water Council, London.

3. North West Water Authority, 1983. "Outline strategy for achieving long term surface water quality objectives: Consultation paper". North West Water Authority, Warrington.

4. Bowden, A V and Solbe, J F de L G, 1986. "Effects of intermittent pollution on rivers - derivation of water quality standards: Progress Report". Water Research Centre, ER 1227-M (DRAFT).

5. Tyson, J M, 1986. "Setting Hydraulic and Water Quality Objectives". Developments in Storm Sewerage Management, Conference, March 1986. Sheffield City Polytechnic.

6. Mance, G, 1981. "The Quality of Urban Storm Discharges - A Review". Water Research Centre, ER 192-M.

7. WRc/WAA, 1984. "Sewerage Rehabilitation Manual". Water Research Centre.

8. Thornton, R C and Saul, A J, 1986. "Some quality characteristics of combined sewer flows". The Public Health Engineer, Vol 14, No 3. 35-39.

DESIGN SPECIFICATION FOR ESQS (EMISSIVE SEWER QUALITY SIMULATION) MODEL THE SEWAGE FLOW AND QUALITY SIMULATION VERSION OF WASSP

ABSTRACT

The proposed model (ESQS) will be required to model the processes leading to the production of first foul flush effects within sewerage systems and to produce results which show these effects in terms of short term variations in SSO discharge pollution concentration and load.

The design specification outlines the major processes and parameters to be modelled, both on the urban surface and within the sewerage system.

1. Purpose

The proposed model (ESQS version of WASSP) is to be capable of simulating the build-up and wash off of specified pollutants in an urbanised catchment or sub-catchment. These pollutants will then be routed through a combined or storm water sewer system. The model should simulate both the total pollutant load passing through the sewer system and the short term variations in pollutant concentrations during a storm event.

The role of the model is to produce storm period discharge pollutographs. These are required to evaluate the short term impact of sewage discharges on receiving water courses. Ultimately these pollutographs will provide input to a receiving river quality model. This larger scale model will permit the evaluation of the overflow performance and its impact on downstream river quality in terms of transient, acute effects and long term chronic effects on river quality and ecology.

While the model is primarily concerned with sewer behaviour during storm periods, the inter-storm dry weather flow periods are recognised as being of great significance in terms of duration and frequency. The model must also be capable of simulating the accumulation and generation of pollutants in a sewer during baseflow conditions. Therefore the simulation of the behaviour of the foul sewage flow during dry weather is essential.

A time series rainfall/dry weather period simulation methodology linked to probabilistic criteria for pollutant generation and removal is more appropriate than a fully deterministic design event criteria approach. The output from the stochastic/deterministic process modelling would also be expressed in probabilistic terms for the long and short term assessment of overflow performance.

2. Determinands

The short term impacts, on the environment, from sewer discharges are due to oxygen depletion in the receiving water and the discharge of toxic substances. In the longer term, many other determinands may be significant, but it is possible to relate these to the behaviour of suspended solids. The generation of Hydrogen Sulphide in sewers is also considered to be important.

ESQS should therefore be able to model:

Oxygen demanding load - (BOD and or COD)

Ammonia (NH_4 - N)

Suspended Solids - organic and inorganic fractions

Hydrogen Sulphide

Dissolved Oxygen - transport and re-aeration within the sewer

Sediments - large size bedload fraction i.e. affecting hydraulic performance of the sewer system.

Other determinands of less immediate interest, which may be appropriate for long term or overseas applications include:

- Heavy Metals
- Bacteria
- Phosphates
- Nitrates
- Specific pollutants of industrial origin

3. Model processes and mechanisms

The model must simulate the following basic processes:

(a) The build-up of pollutants on catchment surfaces:

Pollutants will build up from atmospheric dry deposition on all contributing surfaces within the catchment. Dry weather loading rates may be assumed to be uniform over a catchment and may represent a linear build up of a substantial portion of the total pollutant load of many determinands, notably ammonia and nitrates but also fine particulates, chlorides and heavy metals. Roof areas contribute significant pollution, particularly to surface water systems. Roads and other paved areas provide the majority of pollutants in urban storm runoff and in particular the organic solids component with an associated oxygen demand. The rate of build up of pollutants on road surfaces is a function both of time and traffic loading.

(b) The wash-off of accumulated surface pollutants during rainfall events:

Wash out of aerial pollutants (wet deposition) is rapid and complete and therefore relatively independent of the nature of the rainfall event. The rate of surface wash-off is a function of the quantity of accumulated pollutants; the intensity of rainfall and the physical hydraulic characteristics of the catchment.

Runoff from permeable surfaces may also provide a significant contribution of suspended solids and other pollutants. Soil leachate may contribute to pollutants in infiltration.

(c) Gulley Pot Performance

Gulley pots are believed to influence the quality of sewer flows in two ways:

(i) they may add to the polluting load in terms of ammonia, BOD and organic solids by degradation of the stored water, and

(ii) they may modify the characteristics of the wash off of a particular storm, since the gulley pot liquor will tend to be washed into the sewer system in advance of the new storm's run off from road areas.

The volume of water retained in gulley-pots is significant, typically equating to = mm of rainfall over the contributing catchment.

Temperature and dry weather period duration will be important factors in assessing the generation and storage of pollutants within gulley-pots.

(d) Foul sewage in combined sewers

The daily variations in the quantity and quality of domestic foul sewage are well understood. Cycles of daily and seasonal loads can be established for a catchment incorporating periodic industrial discharges.

For longer term events and assessing annual pollutant loads, a variability factor will be required to compensate for the random time of day at which rainfall events occur.

The settling out of a proportion of the foul sewage flow at various locations within pipe networks during dry weather flow will need to be simulated.

(e) Sedimentation in sewers

Two effects are suspected to be significant with regard to pollutant generation within this aspect:

(i) High density inorgnic particulates tend to deposit in slow flowing sewer lengths during recession limbs of major storm events and minor rainfall inputs. The presence of these deposits encourages the deposition of organic solids during base flow periods. Organic solids will also tend to accumulate at other types of physical obstruction or imperfection. Low density organic solids will be rapidly resuspended and flushed out by storm flows adding to the suspended solids and oxygen demand loads. Hydrogen sulphides is generated within anaerobic sediments. This may be released when the sediments are disturbed by storm flows.

(ii) Sewage slimes tend to build up on pipe surfaces over the range of diurnal flow variations. These slimes will tend to slough-off during turbulent storm flow conditions adding a further suspended solid and oxygen demand load to the storm flow. Hydrogen sulphide is generated within these slimes.

The accumulation of inorganic sediments within sewers, while not exerting a major pollutant load may seriously influence the hydraulic performance of the system. The model should therefore be able to predict where sedimentation may take place within a system.

(f) Transport of pollutants through the sewer system:

The in-sewer behaviour of pollutants can be sub-divided into:

1. the hydraulic performance criteria - e.g. the movement of a flood wave through the system,

2. the deposition and re-entrainment of sediments and the release of oxygen demanding and toxic pollutants,

3. the generation of pollutant loads associated with the accumulation of organic sediments and the growth of slimes.

For simplicity, sedimentation must be reduced to a relationship whereby the rate of deposition in a sewer length is proportional to the suspended sediment load carried in the flow and inversely proportional to the average daily velocity of flow during dry periods. The build-up must be considered to be uniform with time. The generation of oxygen demanding and toxic pollutants can then be related to volume and or mass of sediment or interstitial water and time since deposition.

4. Calibration and verification

The model should be capable of calibration and verification on the basis of flow survey and sewer inspection procedures employed in drainage area planning studies. Additional quality data requirements should be restricted to dry weather flow sampling where appropriate.