WaPUG AUTUMN MEETING, BOURNEMOUTH

MOSQITO I - a parasitic urban water quality model

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ABSTRACT

MOSQITO I is the first version of a suite of water quality models to be linked to the flow simulation models within the Wallingford Procedure. This version is linked directly with the flow simulation model incorporated within the WALLRUS-SIM package and is designed for use primarily in the UK; although use overseas is not precluded.

The model simulates the time-varying discharge of suspended solids, oxygen demand, ammoniacal nitrogen and hydrogen sulphide during a storm event or over a series of storm events. The model is comprised of four major sub-models representing washoff from catchment surfaces, the inflow of foul water, the behaviour of pollutants within manholes and ancillaries within the drainage system, and the behaviour of pollutants within pipes and channels in the drainage system.

The model is being calibrated for use in the UK in a similar manner to other models within the Wallingford Procedure (such as the various hydrological models) using data sets from a variety of experimental catchments within the UK. Results of some of this calibration work are presented within the paper together with illustrations of the model's performance on experimental catchments within the UK. An indication is also given of the manner in which the model may be used to upgrade sewer systems in order to improve receiving water quality.

INTRODUCTION

Intermittent discharges of storm sewage from combined sewer systems have been identified as one of the major causes of poor water quality in UK rivers (Clifforde et al, 1986). Discharges from surface water systems can also have a polluting effect, particularly where cross-connections to the foul system exist.

Elimination of these discharges is impractical, but their effects can be minimised. To do this requires a simulation model which is capable of modelling water quality in sewers, to assess rehabilitation options. This model, MOSQITO, is part of an analytical methodology which has four elements:

(1) rainfall time series inputs to sewer flow simulation models

(2) a sewer flow quality simulation model

(3) a river impact model

(4) a river classification scheme appropriate to intermittent pollution events.

MOSQITO is being developed in two stages. The initial version is due to be released in April 1989 and meets the basic requirement described below. An enhanced version is currently under development and includes additional pollutants as well as the more sophisticated processes in the requirement.

Model Requirements

The main requirement of MOSQITO is that it will simulate the time-varying behaviour of pollutants on catchment surfaces and in sewer systems, and produce discharge pollutographs which can be used as input to a river water quality model for impact assessment. The design of cost-effective solutions to storm overflow pollution problems, particularly if storage is involved, calls for a knowledge of the temporal distribution of pollutant loads during an event.

MOSQITO will operate as an extension of the flow simulation model in the WALLRUS package and will utilise a probabilistic time series rainfall analysis rather than design events. This continuous simulation approach allows for the modelling of sediment build up during dry weather.

The following determinands will be modelled:

Biochemical/Chemical Oxygen Demand
Ammonia
Suspended Solids
Hydrogen Sulphide
Dissolved Oxygen
Sediments

Within this basic requirement, specific processes will be represented. These include the build up and generation of pollutants on catchment surfaces and in sewers during dry weather; the washoff of pollutants from catchment surfaces; the effects of gully pots on runoff quality; and the transport of pollutants and sediment through sewer systems.

Most of these processes are modelled in MOSQITO I. Those which will not be fully implemented in MOSQITO I are the deposition of sediments in sewers and their build up during dry weather.

THE MODEL

MOSQITO consists of four sub-models which represent washoff from catchment surfaces (the above-ground model), foul water inflow, pollutant behaviour in pipes and channels, and pollutant behaviour in ancillary structures within drainage systems (the below-ground model). These sub-models are linked to the flow simulation model incorporated in the WALLRUS package. Full details of MOSQITO are given in the Design Specification (Moys et al, 1988) and WALLRUS is described in the User's Guide (HRL, 1987).

In MOSQITO I the foul inflow model is a separate program which creates a file of inflow quality data which is then read by the main program. The foul flow generation program is based on statistical analysis of data collected in the UK (Henderson, 1988) and is analogous to the rainfall generator in the WALLRUS package.

The remaining sub-models are described below.

The above-ground model

The above-ground model represents the accumulation of sediments and pollutants on catchment surfaces and their removal by surface runoff. The effects of gully pots are not modelled explicitly but have been taken into account during calibration.

Surface accumulation and solid-pollutant relationships

Studies of sediment and pollutant behaviour in the UK suggest that the amount of material washed off catchment surfaces by rainfall is independent of the length of the antecedent dry period. MOSQITO therefore assumes that the amount of material available for washoff is unlimited, although it is possible to impose limits if required.

Pollutants are associated with sediments by the use of potency factors. These relate soluble and insoluble pollutant fractions to the amount of sediment on the catchment surface. Soluble and insoluble fractions are subsequently treated separately in the below-ground model.

A standard surface sediment will be defined for use in MOSQITO I, characterised by particle size, specific gravity, settling velocity and pollutant potency factors.

Removal of material by surface washoff

The removal of solids from catchment surfaces is represented by a modified form of the model proposed by Price and Mance (1978). This is based on the principle of mass conservation of suspended solids on a hypothetical catchment element, or conceptual strip (Fig. 1). The rate of change of M_s, the mass of solids per unit area, is given by

$$\frac{dM_s}{dt} = E_i + E_f + I_r - D_f - R_s$$

where E_i = erosion by raindrop impact
E_f = erosion by overland flow
I_r = input from rainfall
D_f = deposition from overland flow
R_s = removal from conceptual strip

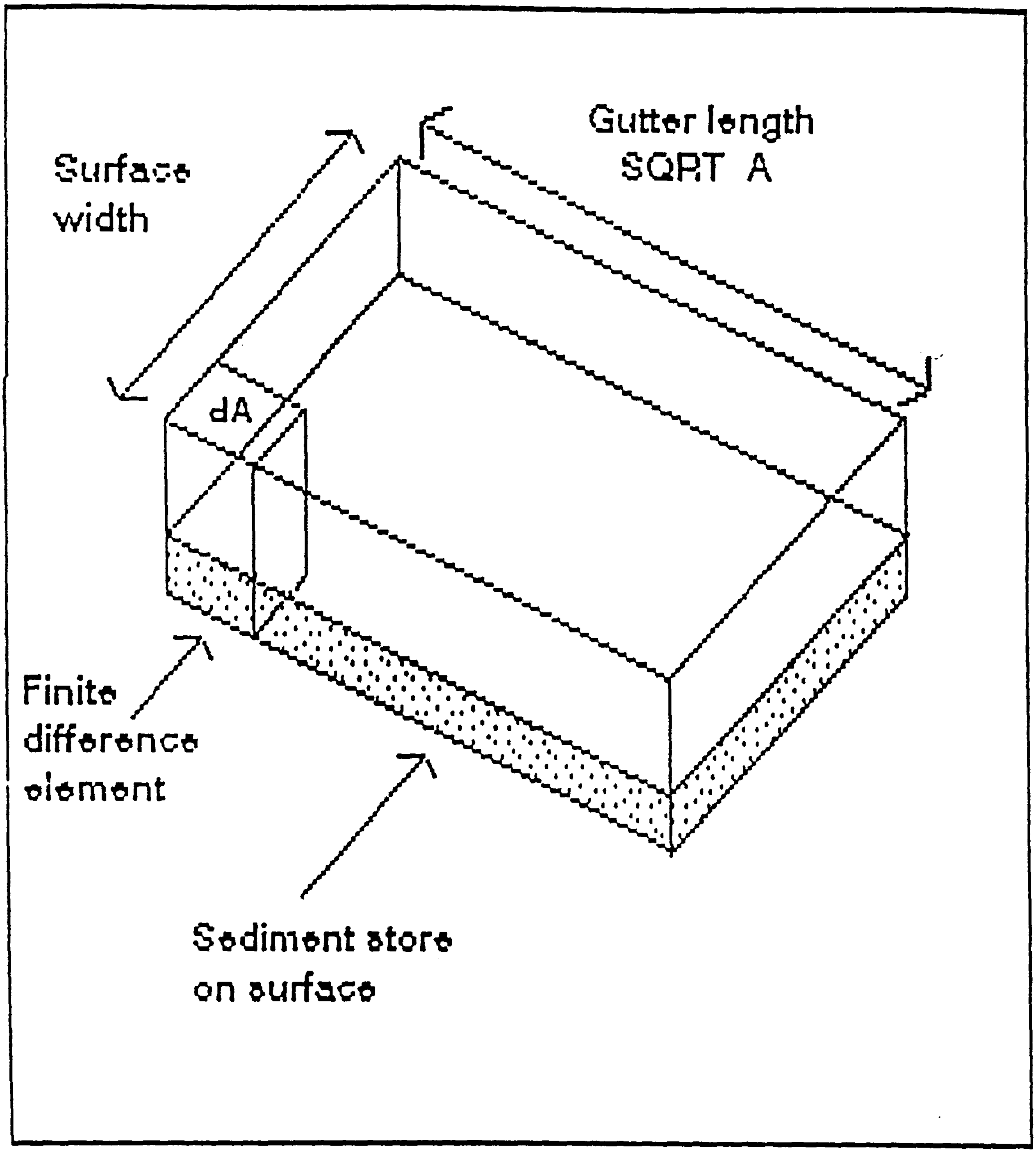

FIGURE 1 A HYPOTHETICAL CATCHMENT ELEMENT

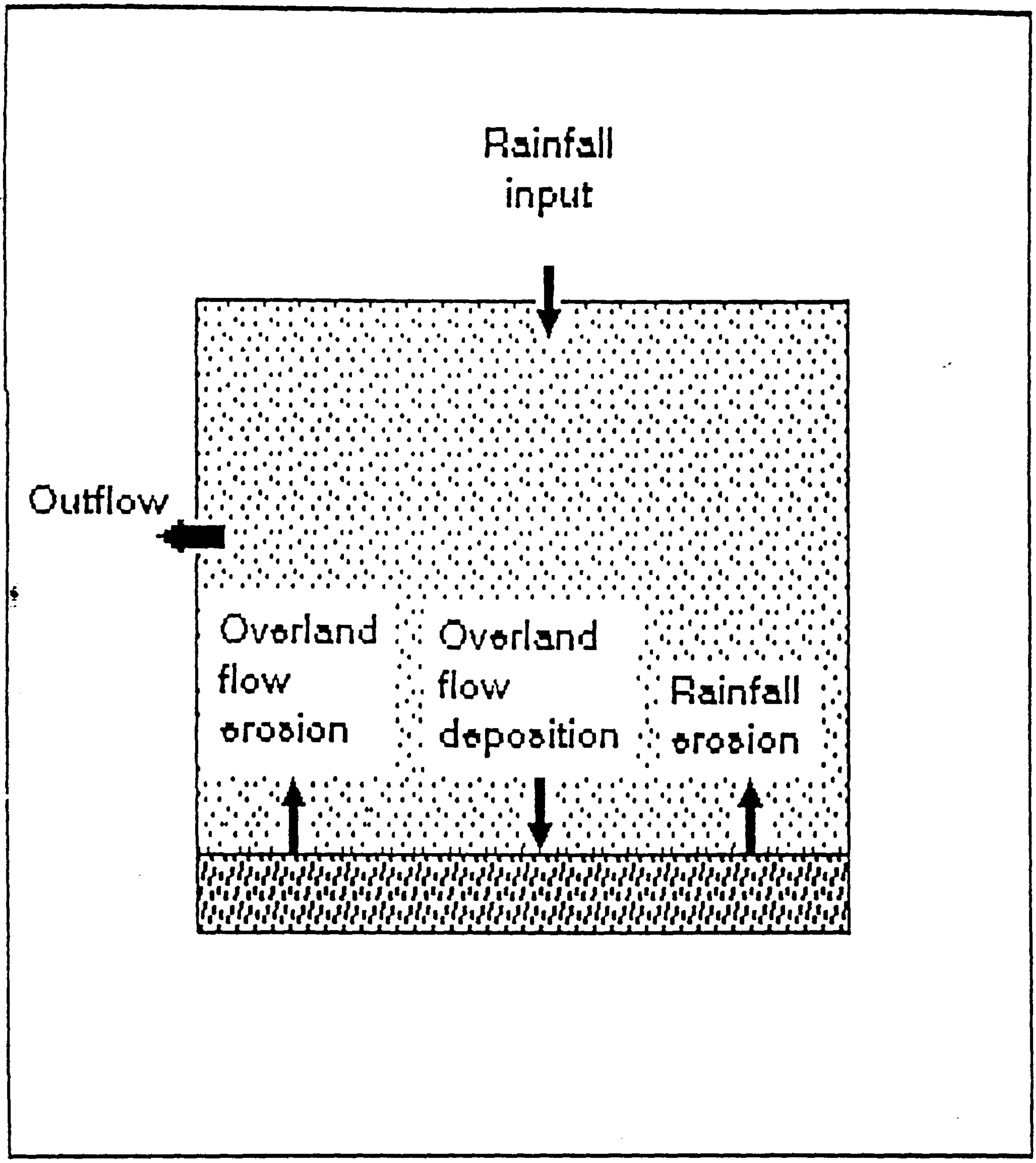

FIGURE 2 OVERVIEW OF PRICE AND MANCE MODEL

In MOSQITO the input of solids from rainfall is assumed to be negligible and the I_r term is omitted from the calculations. The processes are illustrated in Fig. 2.

Soluble pollutants are treated in a similar manner. The rate of change of M_d, the mass of a soluble pollutant per unit area, is given by

$$\frac{dM_d}{dt} = E_b + I_r - R_s$$

where E_b = input from bed and I_r and R_s are defined above.

The equations for suspended solids and soluble pollutant removal are solved numerically at each time-step using finite difference approximations for each differential term. Removal from each conceptual strip at each time-step is then calculated.

The below-ground model

In the below-ground model, the pollutants and sediments derived from the catchment surface are mixed with those from the foul flow and transported through the drainage system. Additional pollutants and sediments are derived from re-entrainment of sediments previously deposited in the system. In MOSQITO I the quantity of deposited sediment and its polluting strength is defined by the user in the input data.

Pollutant behaviour in manholes and ancillary structures

Nodes in an urban drainage system are of two types: manhole (ordinary) nodes, and ancillary nodes which represent tanks, overflows and other structures.

MOSQITO applies a constantly stirred tank reactor (CSTR) model at each node, irrespective of its type. The change in mass of material is given by

$$\frac{dM}{dt} = \langle \text{mass in} \rangle - \langle \text{mass out} \rangle \pm \langle \text{source} \rangle$$

where < > denotes time-averaged variables.

The source terms (erosion and deposition) are not implemented in MOSQITO I. During free-surface flow the CSTR is equivalent to a simple mixing model.

This equation is solved to give the concentration of each pollutant at each node and at each time-step.

Pollutant behaviour in links

The behaviour of sediments and pollutants in links (pipes and open channels) in an urban drainage system is represented by a one-dimensional continuity equation for the flow coupled with a sediment bed continuity equation. The modelled processes are illustrated in Fig. 3.

Sediment deposits are modelled as three types:

(1) an immobile layer on the pipe invert which cannot be moved

(2) a storage layer on the pipe invert in which sediment is consolidated and exhibits a cohesive shear strength

(3) an active layer on the pipe invert in which sediment is unconsolidated.

Sediment is transferred to the flow by erosion of the active layer and from the flow by deposition to the active layer. Portions of the storage layer are allowed to pass into the active layer if the flow shear stress is sufficient, thus crudely representing the cohesive behaviour of sewer sediments.

A standard sewer sediment will be defined in a similar manner to the standard surface sediment, characterised by physical and chemical parameters.

CALIBRATION AND VALIDATION

Although most of the sub-models in MOSQITO are physically-based, there are a large number of parameters which require calibration.

Other models in the Wallingford Procedure have been pre-calibrated for use in the UK, and this has been of undoubted benefit to users both financially and in terms of reliability of parameter estimates.

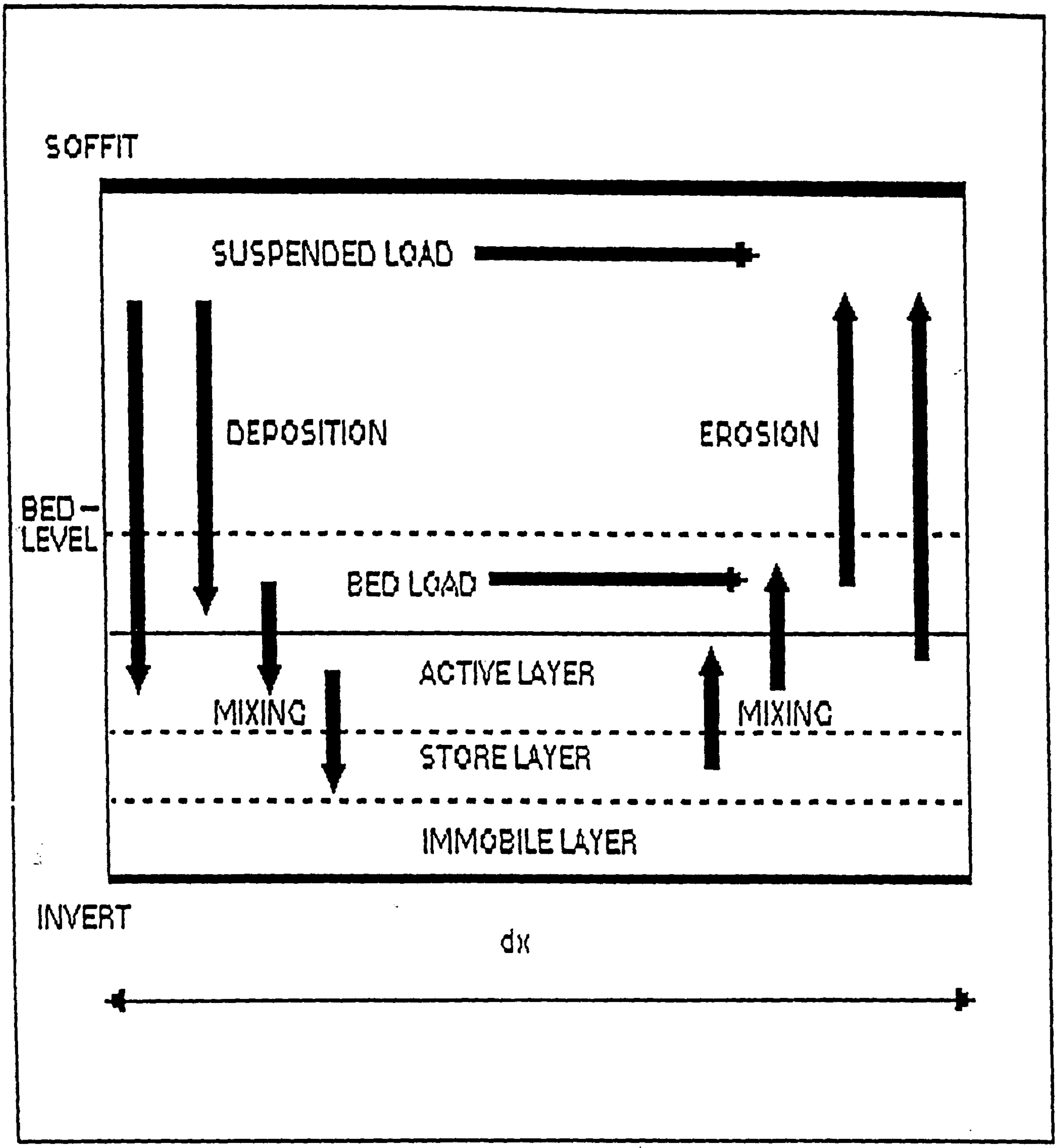

FIGURE 3 PROCESSES IN THE LINK SUBMODEL

Pre-calibration of the sub-models in MOSQITO is being attempted using data collected from experimental catchments in the UK. A major problem with much of the available data is that the purpose of data collection was not model development, and the early experimental work was not sufficiently coordinated to ensure continuity of procedures.

The calibration and validation exercises that are to be completed before MOSQITO I is released are as follows:

(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

The above ground model is currently being calibrated, and validation of the separate system model has been started. The foul flow and transport models have not yet been calibrated.

Calibration of above ground model

To calibrate the surface washoff model, the subroutines have been embedded in an optimisation procedure which operates on parameters of the sediment and pollutant washoff model. This operates by searching for the parameter values which result in the closest fit of observed and simulated data sets.

Calibration has been carried out in two stages:

(1) Estimation of sediment washoff parameter values

(2) Estimation of pollutant parameter values

Three surface washoff parameters have been considered and their values estimated by comparison of simulated and observed TSS levels. This exercise has shown that the most important factor in the removal of material by surface washoff is erosion by rainfall impact. Erosion and deposition from overland flow had negligible effect on the amount of material washed off the catchments studied.

The pollutant parameters (potency factors) have been estimated from statistical analysis of the data.

The parameter estimates are currently being used in validation of the separate system model, and the simulated total pollutant loads are being compared with observed values.

MODEL USE

The procedure for using MOSQITO is not yet fully defined. As MOSQITO is linked to WALLRUS, the hydraulic model must be constructed and verified before water quality is considered. The water quality model is more difficult to use than the hydraulic model, and requires more data.

It is important to identify and resolve as many problems as possible when using the hydraulic model before water quality is considered. In particular, discharges at overflows and outfalls must be correctly predicted, as these are important in MOSQITO.

The outline procedure for using MOSQITO will be similar to the procedure for using WASSP and WALLRUS, and the major steps involved will be model construction, model verification and model use.

Data requirements

The data required for model use generally fall into three categories:

(1) Static data which describe the physical characteristics of the system

(2) Event data which are different for each event

(3) Verification data which are used to give confidence that the model predictions are correct.

In MOSQITO I the static data will include not only sediments which are hydraulically significant, but also potential polluting sediments which require a significant discharge to move them. The depth of sediment 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 active layer of sediment in the sewers. This will be calculated by MOSQITO.

DISCUSSION NOTES

Technical Session 1

Paper 1.3 Discussion

J.Skinner ; Stoke-on-Trent City Council

The new methods all sound very tricky ! Are you confident ?

J.Payne ; H.R.Ltd.

We are confident that the model to be released in April will be ok, but admittedly a bit crude.

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J.Skinner

Are the Water Authorities promoting its development?

J.Payne ; H.R.Ltd.

Yes, W.A's are involved and are steering the research.

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D.Sutciffe ; Flowtechnics Ltd.

How accurate do you expect model verification to be ? There are already errors in the hydraulic side, let alone this.

J.Payne

Unknown yet. Agreed it won't be easy.

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D.Beale ; Howard Humphries

What data will need to be collected ?

J.Payne ; H.R.Ltd. C.Jefferies ; Dundee college of Technology

For the first version, probably only sediment depths. Default values are likely to be used for the "quality" of the sediment. In the future, data will probably be required regarding particle size, distribution, pH and COD.

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K.McGregor ; Hydro Scan Ltd.

How do you propose to measure the depth of sediment ? Sediment is transient, it may prove impossible to define a depth.

J.Payne

We don't know yet. Various methods are being investigated. I agree with you regarding the difficulties. We still have to establish how sensitive the method will be to depth.

cont'd

D.Wright ; Applied Research

Please don't release the software too early, there are enough problems with WASSP.

J.Payne & M.Osborne ; H.R.Ltd.

Some Water Authorities are demanding it by April. We are confident the major problems will be sorted by then.

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D.Beale ; Howard Humphries

Do you intend to model sediment quality only, and water quality later ? For example, the removal of silt during storm, and then its gradual return ?

M.Osborne

I'm not clear what you mean. We can model moving sediment but once it has settled we don't know how it is moved again.

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A.R.Eadon ; Severn Trent Water

What are we aiming at in terms of SSO discharge ?

J.Payne

We intend to produce river impact model, and results from MOSQITO will be fed into it. (ie. MOSQITO on its own is of little use.)

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A.R.Eadon

Will a river impact model be released with MOSQITO ?

J.Payne

Yes, called FLEAS.

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D.Wall ; Wessex Water

Who is paying for the research ?

M.Osborne

Water Authority subscriptions, D.O.E., University Research. There is a Steering Committee chaired by D.Fiddes of W.R.c and there are representatives from Severn Trent, North West Water, Yorkshire, W.R.c. Universities and D.O.E.