Hydraulics Research
Wallingford

MODELLING OF STORMWATER QUALITY
INCLUDING TANKS AND OVERFLOWS
(MOSQITO) - DESIGN SPECIFICATION

by

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This report describes work carried out under contract No PECD 7/7/053 in the development of a sewer quality sub-model for the Wallingford Storm Sewer package, funded by the Department of the Environment from April 1985 to March 1988.

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The DoE nominated officer is Dr R P Thorogood. This report is published with the permission of the Department of the Environment, but any opinions expressed are not necessarily those of the Department.

ABSTRACT

This report details the design specification of the sewer quality model
under development at Hydraulics Research Limited and funded by the
Department of the Environment. Following a summary of the requirement
specification, two particular elements of the model design are discussed.
First, an appropriate methodology for simulating pollutant discharges from
urban sewered systems is introduced. This together with details of various
aspects of software design is discussed as part of the "non-procedural"
aspects of the design. Second, particular sub-models and algorithms for
simulating the behaviour of pollutants and sediments within an urban
drainage system are detailed. Definition of the elements to be included
within the final model form a major part of the "procedural" aspects of the
design. Finally, a provisional timetable of the various milestones in the
development of the model is also outlined.

CONTENTS

Abbreviations

USWQM	Urban Storm Water Quality Model
COD	Chemical Oxygen Demand
BOD	Biological Oxygen Demand
SS	Suspended Solids
CSO	Combined Sewer Overflow
SSO	Stormwater Sewer Overflow

Models

SWWM3	StormWater Management Model III (US EPA)
QQS	Quality Quantity Simulation (Dorsch Consult)
DR3M-QUAL	United States Geological Survey
SAMBA	Danish quality model
STORM	Storage, Treatment Overflow Runoff Model (US Army Corps)
WASSP-SIM	The Wallingford Procedure - Simulation Programme

1   INTRODUCTION

Storm overflows have been identified as one of the major causes of poor receiving water quality within the United Kingdom (Clifforde et al., 1986, Crabtree, 1986). Economic constraints, however, dictate that a large number of these overflows will have to remain in operation for the foreseeable future (Ministry of Housing and Local Government, 1970; Scottish Development Department, 1977; Clifforde et al., 1986). Therefore, to limit pollutant discharges from overflows, structural amendments will need to be made to urban drainage systems usually in the form of increased storage. The efficient design of such rehabilitation measures, in order to both limit the receiving water impact as well as the flooding hazard, requires a collection of analytical tools. Presently available tools for considering storm overflow settings and sewer rehabilitation are unable to fulfil this task; see for example the 'Ministry of Health Requirements', 'Formula A', and WASSP-SIM Hence a rational procedure is required for the design of sewerage rehabilitation structures (Clifforde et al., 1986). This procedure has been defined to consist of four major elements:

   (i)   appropriate rainfall inputs to sewer flow
         simulation models,

   (ii) a sewer flow quality model;

   (iii) a river impact model;

   (iv) a comprehensive river classification
         scheme.

This document details the development of the sewer-flow quality model and its incorporation, together with an existing sewer flow quantity model

(WASSP-SIM, National Water Concil, 1981), into a
software package for the analysis of the pollutant
behaviour of urban stormwater drainage systems.

The design of software can be viewed in general as a
'top-down' process (Spriet and Vansteenkiste, 1982),
in which the design requirements, design
specifications and the final implementable program are
all derived from an initial definition of the problem
to be tackled (Figure 1). It is the customer, in this
instance the UK Water Industry represented by the
Water Research Centre (WRc), who by examination of the
problem provides a detailed design requirement. This
should consist of two major parts: the 'functional
requirements' describing what the software must be
able to do; the 'attributes' of the software
constraining how it should operate. Chapter 2
provides a short summary of the requirement
specification (Appendix B contains the requirements
specified by WRc).

Chapter 3, then, develops the non-procedural design
detailing the methodological principles upon which the
model itself is founded and the major components of
the model. These elements together with the
properties of the software identified from the
attributes, comprise the 'static' design specification
of the software which remains invariant during
software development.

The 'dynamic' design specification comprises the
actual procedures, and algorithms, which are
incorporated into the software. By testing each
component individually, if possible, or by testing the
overall behaviour of the model, the non-procedural
design can be transformed into the 'procedural' design
and, then, eventually into a preliminary version of
the required software. This, itself, must undergo

considerable verification tests to eradicate malfunctions and errors. Chapter 4 details the procedural design phase of this strategy, Appendix A provides an overview of the major functional subroutines within the model and their procedural relationship.

The final chapter, Chapter 5, provides an outline of the development schedule of the program as well as the data requirements necessary for model development. These latter requirements are specified to take into account not only existing data-collection programmes but, also, to recommend either modifications to these programmes or the initiation of new efforts.

2 REQUIREMENT SPECIFICATION FOR THE SEWER QUALITY MODEL

The requirement specification of the sewer quality model has been defined by WRc. These are described within two documents (see Appendix B): one describing the reasons for developing a sewer quality model and the other providing a short functional specification of the model. Distillation of the elements within these documents provide the following requirement specification.

1. Determinands

    Determinands to be simulated are:

    (a) Suspended solids (SS);

    (b) Dissolved oxygen (DO);

    (c) Biological oxygen demand (BOD) or chemical oxygen demand (COD);

(d)   Ammoniacal nitrogen (NH_4-N);

(e)   Hydrogen sulphide (H_2S);

(f)   Sediments - large sediment fractions.

2.   Complexity of simulation.

Time-varying pollutant levels are required; that
is, the model must be capable of simulating
pollutographs. This stipulation dictates that
the model must be able to represent the
time-varying behaviour of contaminant interaction
and transport both upon catchment surfaces and
within the sewer system, itself.

3.   Verification

The model when used must be capable of producing
accurate simulations of both total event loadings
and within-event loadings of the various
contaminants without the need for parameter
calibration. Model verification will consist of
the measurement of dry-weather flows and,
possibly, sampling of a limited number of
pollutant levels as part of an extended
flow-survey study. It is conceivable, however,
that this exercise may involve the comparison of
pollutants/determinands against related
variables; for example, suspended solids can be
calibrated by the measuring turbidity levels
within the runoff. It must be stated at this   .
juncture that this level of calibration is
apposite to that currently recommended in the use
of comparable modelling procedures and may place
a limit on overall model accuracy.

3 THE NON-PROCEDURAL DESIGN SPECIFICATION

The development of a new model for predicting urban sewer water quality is only justified when current models are unable to fulfil the defined modelling purposes adequately. Even if it can be shown that present models are, indeed, inadequate it is important to note that any new model consists of no more than addendums to previously constructed models, or the collection together of previously validated component models. The selection of which models and algorithms to incorporate within the overall model can be divided into two steps within the general modelling process (Figure 3.1). First, a general class of models is selected based on the interaction of theory and practice (largely 'a priori' knowledge). Then having decided on the general methodology to be employed, and employing direct knowledge of the system in question, those subclasses, components and algorithms offering parsimonious solutions to the particular problem (Box and Jenkins, 1970) are identified. Within this document the former step has been designated as the non-procedural design incorporating the static design specifications which will remain largely invariant during the course of model development. The latter step, embodied within the procedural design (Chapter 4), incorporates much of the iterative aspects of the design specification in which competing models and algorithms are selected upon the basis of both 'a priori' validation and 'a posteriori' verification. This chapter considers the selection of a model type given the prescribed requirements specified in the previous chapter (and Appendix B) and the limit of current knowledge of the interactive processes between water, sediment and pollutants within urban catchments and sewerage systems.

3.1 Selection of a model type

In order to select a general class of model for urban
runoff pollutant simulation it is necessary to possess
a rudimentary classification of model types.
Urban runoff models may be distinguished upon a
multiple of grounds; foremost amongst these for this
discussion are the degree of stochasticity treated by
the model, the level of application to which the model
is suited (sometimes synonymous with model
complexity), and the degree of simplification of the
simulation period (that is continuous or event-based
modelling). These elements, although highly
interrelated, are nevertheless considered separately
below.

(a) Stochastic/Deterministic

A general model of catchment behaviour may be
portrayed thus:

$$y \text{ (output(s))} = f(\text{input(s), catchment char22, ...)} + \text{errors}$$

The functional relation, $f(x1, x2, ...)$ is commonly
regarded as the 'function of the determinist' while
the error term is the 'function of the statistician'
(Clarke, 1973). Typical urban runoff models (SWWM3,
WASSP-SIM, ILLUDAS, QQS) are all deterministic models,
in that no allowance is made for probabilistic or
stochastic influences upon model parameters. However,
as a model can not be a perfect representation of
reality, then some error will always have to be
entertained in the output from a runoff simulation.
In the situation where the quantity of urban runoff is
being simulated, say for the design of a new pipe
system or the analysis of old systems to assess their
flooding attributes, magnitudes of errors between

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observed and simulated results will not be too large
(e.g. no more than 10%). However, in the simulation
of water quality, by the use of deterministic models,
errors are likely to be much greater. Without
extensive calibration typical USWQMs have been
described as of little use in the prediction of
absolute contaminant magnitudes (Huber, 1986). This
is a feature of the influence of imperfect knowledge
of the behaviour of pollutants within the urban
hydrological system, and the influence of seemingly
random process operations. Furthermore, the
calibration of models such as SWWM3 to a variety of
catchments has illustrated the need for specific data
with which to define the parameters of the model as
well as to select the functional relationships used
within the model (Jewell and Adrian, 1981; Huber,
1986). Calibration procedures within this modelling
exercise have been restricted to dry weather flow
sampling with possibly a small number of samples
obtained during wet weather; this is a much more
restricted calibration period than that required by
the use of SWWM3 and other similar USWQM.

(b) Level of application

It is generally recognised that urban runoff models
operate at three levels (McPherson, 1975):

  (i)   planning level;

 (ii)   design/analysis level;

(iii)   operational level.

The urban runoff quality model will by definition have
to operate at the second of these levels thus
requiring commensurably more detailed computation than
a model that operated at the planning level. Hence, a

model similar to SWWM3 (or its ilk) is needed for
analysis purposes; models such as STORM and SAMBA
(simple planning type models) would not satisfy the
design requirements of this exercise. However, the
latter group of models are useful in conjunction with
more detailed analysis models, especially in
highlighting particular events from a long rainfall
time-series, which it would be too time-consuming to
run through an analysis-type model.

(c)   Event/Continuous Simulation

A continuous record of precipitation over a period
such as one year or ten years consists of periods of
wet and dry-weather; in event-based modelling the
model simulates only the processes operative during
the course of an event, whereas in continuous
simulation the model will operate during both dry and
wet-weather periods. In the simulation of flooding in
urban catchments, the difference between these two
modelling procedures has become enhanced by the nature
of the rainfall input. Hence, with event-based
simulation of future flooding potential in urban
catchments it is common to use a statistical
representation of the rainfall record (the well-known
intensity duration frequency curve and associated
design storms); in continuous simulation the rainfall
record is directly input into the model. The
assumption in the former approach is that:

        urban runoff frequency = rainfall frequency

This equivalence is sometimes 'forced' to take into
account the probabilistic nature of antecedent
conditions and their resultant influence upon rainfall
excess determination; but is nevertheless the
overriding doctrine in conventional urban runoff
simulation. Within continuous simulation no such

assumption is made; however, considerably more effort
is expended in obtaining an estimate of flooding
behaviour suitable for design purposes. Furthermore,
it has never been proved that the above assumption is
significantly incorrect for the prediction of flood
levels.

However, for the prediction of the polluting effect of
SSO discharges upon receiving streams **it is clear
that the use of traditional event-based modelling
incorporating design-storms is inappropriate.**
Primary amongst the reasons for this assertion are:

1. Although data sources are limited and as of
    yet there is no long time series of
    rainfall, runoff and urban water-quality,
    evidence does suggest that the
    magnitude-frequency relationships of urban
    pollutant discharge bears little
    relationship to the magnitude frequency
    relationships of rainfall or runoff (Huber,
    1986). Added to this is the recognition
    that the magnitude-frequency relations of
    individual pollutants will be different
    (Geiger, 1986); that is, different storms
    will produce the critical event for
    different pollutants. This reflects the
    varying influence of antecedent periods upon
    the behaviour of each pollutant.

2. The magnitude-frequency relationships of
    receiving water behaviour will not in
    general be related to those of the incident
    rainfall employed within urban runoff
    simulation. It is true that the pollutional
    response of small rivers will be dominated
    by the behaviour of the discharging outfall;
    for larger rivers behaviour will be a

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combined effect of river and catchment response.

3. Pollution events occurring within some receiving waters may be occurring a number of times per year; this is not commensurate with the return period of design storms used for flooding prediction.

4. Although the primary focus of this procedure is to aid the amelioration of short term effects upon receiving waters, longer-term effects arising from SSO discharges may become an important consideration in future scenarios; it would appear appropriate that the capability must exist to simulate the influence of pollutants that are accumulative within the receiving water.

These considerations indicate that the sewer quality model must explicitly consider the influence of the antecedent period. This effect can be considered either by the use of a continuous simulation model or the use of an event model with simple antecedent indices. Unfortunately, the definition of appropriate antecedent indices with significant explanatory power to describe the build-up of pollutants within an urban drainage system would appear difficult to achieve; the use of a continuous simulation model in this case would seem warranted. However, to simulate a long-term series of rainfall events will undoubtedly be prohibitive in terms of computational costs. A procedure for reducing these costs has been advocated elsewhere (Harremoes et al., 1984); the technique consists essentially of running a long rainfall time-series through either a simpler model (a planning model) or through a simplified representation of the sewer system itself, identifying those events/periods

of rainfall that lead to potential design problems,
and, then, run these events/periods of rainfall
through a more complex model with appropriately
defined antecedent conditions to produce results
amenable for the re-design of a system. Figure 3.2
compares this approach with the more traditional
design storm methodology.

3.2 The non-

procedural design

The following paragraphs provide a detailed
specification of the non-procedural aspects of the
sewer quality model divided into the functional
specifications and the attributes of the software.

(a) Functional Specifications

It is apparent from the foregoing discussion that the
sewer quality model will have a number of
properties:

1. The ability to simulate both the stochastic
   and deterministic behaviour of all the
   pollutants considered in the design
   specification.

2. The ability to operate in a continuous
   fashion in order to simulate pollutant
   discharges derived from urban sewer systems
   over a wide variety of time periods.

3. The ability to simulate pollutant behaviour
   within an urban catchment from a planning
   aspect in order to identify critical
   pollution events generated by the rainfall
   time-series, and from a more precise design
   aspect to aid in the assessment of various
   sewer rehabilitation structures.

Appendix B provides greater detail of some of the functional specifications of the sewer quality model. In concept the model will operate on two levels: a screening-level, where the complex geometry of the sewer system is dramatically simplified, analogous to the 'sewered sub-area' model currently incorporated within WASSP-SIM, a design-level, which operates over a period encompassing a 'pollution event', as defined in the description below. In both instances it is envisaged that a form of error analysis will be employed to characterise uncertainties in pollutant simulation; a first-order error error analysis will be employed for these purposes. Use of these procedures within 'design mode' will enable the engineer to assign probabilistic risks to his/her rehabilitation scheme.

As intimated above, the definition of a critical pollution event will not be achieved by the use of the sewer quality model alone. Sewer rehabiltitation for controlling pollutant discharges will be assessed in terms of critical pollutant events within the receiving water. Not only will these events not be related to rainfall event frequency, but individual rainfall events may not be necessarily associated with individual pollution events. Temporal response within the receiving water may be such that a number of individual rainfall events may cause, by accumulative effects over a short period, pollutant events within the receiving water. This dictates that the planning model of the sewer quality model will have to be run to provide input to the river impact model. Identified pollution events will be assessed in terms of a short-term receiving water criteria. Critical events are then used to assess the relative performance of different rehabilitation measures again in terms of receiving water impacts.

(b) Attributes of the software

The need to ensure ready access by drainage engineers
to the software dictates that the primary hardware
environment in which the software should be employed
is the micro-computer or workstation as opposed to the
mainframe environment. Although, the computing power
of the former has increased dramatically over the
years, and will no doubt continue to do so, it is
still envisaged that computer run-time, and hence
computing costs, will be a major constraint. This is
again a reason for dividing the modelling procedure
into a first-level screening approach and a
second-level design approach. However, the use of
micro-computer systems does enable a greater deal of
flexibility in the use of graphics and interactive
input-output procedures. These aspects are
particularly important in order to ease the use of the
model as a number of concepts contained within the
model will, in general, be new to the engineer.
Specific details of the software specification are
detailed below:

(i)   Hardware requirements

The program will be specifically aimed at the
micro-computer and workstation environment. Specific
machines upon which its use will be recommended are
the Intel 80286 range of micro-computers with a maths
co-processor (IBM-PC/AT and compatibles; Apricot
XEN's) operating within DOS; workstations including
the Apollo Domain series, Micro-VAX II, and Sun
workstations operating either as DOS-workalikes or
within a UNIX-based system. In each case a hard-disk
storage of at least 10Mbytes will be required together
with a printer and a mouse (optional). There is a
strong possibility that as machines based on the Intel
80386 processor become more widely used, these

machines will be preferable to machines with the 80286 processor.

(ii)   Display layouts and report layouts

Displays will in general follow the format associated with current software (e.g. WASSP) and future released software (e.g. WALLRUS and SPIDA). Specific displays relevant to the water quality software will involve the input of various factors associated with each pollutant simulated by the model. This will be achieved by the use of a spread-sheet type approach; associated with each element of the spread-sheet will be a help-screen containing the default values and a range of likely values for the parameters to be entered.

Results will be placed into a file in a similar format to depth and discharge data as produced currently by WASSP; it will also be possible to plot out data for comparison with observed pollutant data and to analyse computed results in terms of critical events likely to cause damage to the receiving water ecosystem.

(iii) Error handling

In general, errors in data-input should be trapped before passage to the major part of the software utilising a check program similar to that currently used by WASSP. Other errors, such as using too large a time-step for simulation and unreasonable input parameter values, will be accounted for by the use of specific ranges for these parameters above or below which data will not be allowed to be input. Help-screens associated with each parameter value will give guidance as to the likely range of values.

4   THE PROCEDURAL
      DESIGN
      SPECIFICATION

4.1 Introduction

It has been identified that a mixed deterministic-
stochastic approach to modelling stormwater quality
runoff from urban catchments is appropriate.
Furthermore, for practical purposes it will be
desirable to operate the model in both a long-term and
a short-term mode. This chapter details the
individual components to be included within the final
model to fulfil both the design requirements of the UK
Water Industry (Chapter 2 and Appendix B) and to
follow the general methodology introduced in Chapter
3.

In order to characterise the response of a variety of
sewer systems adequately, an urban water quality
model must be formed from a set of component models.
Within urban catchments two major component models can
be recognised, one representing the accumulation,
generation and transport of pollutants upon catchment
surfaces, the other representing the behaviour of
pollutants within the sewer system. Within the sewer
system pollutants are obtained from both the
foul-water flow (in the case of combined sewer
systems) and from the sediments deposited within the
pipe-network, which takes place during both
dry-weather periods and during falling stages of a
stormwater hydrograph. The basic principle in
simulating outflow discharges from a combined sewer
system consists of the amalgamation of these flows by
the use of a simple mixing model applied at various
nodes within the sewer network (Figure 4.1). The
background and specification of the two systems
defined above are described here and in Appendix A.

The model as indicated in Chapter 3 will operate on a continuous basis over a period incorporating a collection of individual events. However, it is important to define appropriate initial conditions to operate the model. Furthermore, in running an extended period of rainfall events, it is necessary to simplify either the modelling procedure or the system characteristics to ensure economic model application. These aspects of the water quality model are discussed in later sections of this chapter together with a definition of the treatment of uncertainty in model output predictions associated with both model uncertainties and input-data uncertainties.

4.2 The Surface Sub-System

(a) Background

Contaminant generation upon catchment surfaces within typical USWQM, for example, SWWM3 and STORM, is simulated by the use of 'buildup' and 'washoff' functions. The former account for the accumulation of pollutants by a variety of processes in terms of a single empirical formulation relating buildup, M (mg), to the antecedent dry-weather period, adwp (days), such as:

$$M = r.adwp$$

where r = the buildup rate in mg per day.

Washoff functions are used to represent the removal of pollutants from catchment surfaces (strictly only artificial surfaces) in terms of the amount of material remaining on the surface:

$$dM/dt = - K \; f(r) \; M \; AV(r)$$

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where M = mass of contaminants on surface,

t = time,

K = coefficient,

r = runoff rate,

AV(r) = availability factor, usually a
function of r.

Models employing the above approach have been
criticised on a number of grounds. First, pollutant
accumulation rates cannot be assumed to be linear;
Sartor and Boyd (1972) indicated that for impervious
surfaces sediment accumulation is highly non-linear.
This observation has been incorporated within USWQMs
by the use of linear build-up with a threshold; a
non-linear build-up functions, or the use of a
continuous mass balance of pollutant accumulation.
SWWM3 allows the user to employ one of four build-up
function, the selection of which one to use in a
particular circumstance is seen as part of the
calibration process. Other models use an exponential
build-up model (e.g. DR3M, QUAL-ILLUDAS) or other
complex non-linear functions (e.g. QQS). A possible
alternative to the use of build-up formulations is the
use of a continuous balance of contaminant and
sediment accumulation upon catchment surfaces (James
and Boregowda, 1986). In this latter approach,
elements constituting the overall accumulation process
are quantified by individual, calibrated
relationships, thus allowing the potential for
flexibility in simulation without the necessity for
extensive data collection to re-calibrate the sediment
build-up formulae.

Secondly, the use of washoff formulations has also
received heavy criticism (Sonnen, 1981). Although
such a representation of the sediment transport
processes upon urban catchment surfaces is based upon
actual experimental research (Sartor and Boyd, 1972),

the selection of the parameters of the model have
tended to become little more than a curve-fitting
exercise. Comparison of SWWM3 and STORM, which
effectively use identical buildup and washoff
formulations, indicate that each model will produce
different results from the other based upon the
standard or default parameters specified for model
application. Alternative approaches to the use of
washoff formulations are the use of linear regression
relationships (between either total runoff and total
load or instantaneous discharges and instantaneous
loads), and the use of sediment transport based
approaches. However, it is evident that in the use of
the former, unless the parameters of the model have
been regionalised, extensive calibration will again be
required in model application.

Finally, the manner by which contaminants are
associated with the 'dirt and dust' (sediment) which
is simulated by the buildup equations requires
examination. In general, simple ratios are used,
known as 'potency factors', to relate the total amount
of sediment to the pollutant load transported
(strictly in the suspended phase). However, for
individual pollutants this simple approach is
complicated by the use of various factors for
accommodating loads in phases other than the suspended
phase, such as the dissolved state. Sonnen (1981)
regards the use of potency factors as an undue
simplification, with equilibrium isotherms (e.g. the
Freundlich Isotherm) suggested as an alternative.
However, the use of these latter approaches requires
knowledge of pH, ionic concentrations and temperature
which would be difficult to provide either by
simulation or data collection within this context.

The problem with the use of these modelling techniques
has been summarised by Jewell and Adrian (1981). In

application of numerous buildup and washoff equations,
it was found that no one set of relationships were
better than any other, put another way, all were
equally bad! A methodology was recommended consisting
of:

  (i)   acquire water quality data,
 (ii)   analyse the data with scatterplots and
        correlation analysis;
(iii)   perform a multiple regression analysis;
 (iv)   select the most representative model on
        the basis of correlation indices;
  (v)   apply the model.

Huber (1986) emphasises the need for data to calibrate
current USWQMs (i.e. DR3M-QUAL, FHWA, HSPF, QQS,
STORM, SWWM3):

"Without exception, these models are capable of
accurate simulation of hydrographs and pollutographs,
given accurate data for calibration. By the same
token, none of the models can be assumed to accurately
predict absolute magnitudes of concentrations and
loads without such data, although they may be very
useful for comparative studies and estimation of
relative effects. Caveat emptor!".

Other aspects of the surface runoff system to be
considered are the contribution of contaminants from
the rainwater itself, and the variety of sink/source
effects that may operate with respect to contaminants
within gully-pots. Studies of the removal mechanisms
of atmospheric contaminants via rainwater
('scavenging') appear to suggest a supply-limited
effect (Goettle, 1978); however, within the UK
insufficient data exists to adequately quantify a
model of this process. Hence, this effect will not be
explicitly tackled within the final model but will be

subsumed within the sediment source pertinent to catchment surfaces. The behaviour of gully-pots in trapping sediments (one of their major purposes) also appears to be an unnecessary complication; furthermore, studies indicate that this behaviour can not be related to any factors descriptive of either the prevailing flow conditions or the antecedent conditions (Lager et al., 1977; Pratt et al., 1986), although laboratory studies indicate that the exponential model used within SWWM3 might be correct under ideal conditions where the gully-pot is cleaned regularly (Pratt and Adams, 1981).

Nevertheless, the problems arising in the use of conventional USWQMs would suggest that a different approach may be suitable for the UK. Experimental studies of polluted runoff discharged from urban catchments within the UK, recently summarised by Mance (1981), suggest that such discharges are largely independent of antecedent dry weather period; such a conclusion has been emphasised by Ellis and Harrop (1986). Arising from this conclusion is the indication that runoff load within surface runoff is transport-limited, as opposed to supply-limited, suggesting that for modelling purposes the store of sediments/pollutants available for entrainment by surface runoff is effectively unlimited. Such an approach has been recently suggested for BOD/COD removal from catchment surfaces (Servat, 1986).

A further aspect involved in the simulation of this system, related to the problems of calibration discussed by Jewell and Adrian (1981) and Huber (1986), is that of error in simulation. The wide variability of runoff loadings reported by Mance (1981), together with the lack of association with catchment and event characteristics, suggests that an estimate produced by deterministic modelling is likely

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to be markedly different from that actually observed.
This can be accommodated by the use of an error term,
derived from a probabilistic description of residual
errors between observed and simulated values. A
log-normal distribution has been typically used in
such contexts, such as the approach used by Pratt et
al. (1986). This term is then added to that estimated
by the use of the deterministic washoff model.

The washoff model, itself, will be based primarily on
sediment transport concepts, thus allowing hopefully
the use of a rational procedure for parameter
estimation. However, it must also be remembered that
as the first goal of the model outlined herein is to
simulate the behaviour of combined sewer systems, then
the overall contaminant behaviour will probably not be
markedly sensitive to the simulation of surface
pollution generation and transport.

(b) Specification of the Surface Sub-System
     (Appendix A, Module: CATSED)

Contaminants available for entrainment and transport
by surface runoff will be simulated within a
continuous mass balance framework (Figure 4.2).
However, the use of a detailed mass-balance in which
terms such as dry weather deposition, traffic inputs,
aeolian redistribution, etc., are quantified (James
and Borregowda, 1986), would appear both unwarranted
and, given the paucity of information within the UK,
difficult to establish on a regional basis.
Therefore, elements within the surface sub-system will
consist of surface accumulation and contaminant
relationships, removal by surface runoff, and
interaction of the contaminated runoff with gully-pots
(Figure 4.2).

(i)   Surface accumulation and contaminant
       relationships.

The supply of sediment available for entrainment by
surface runoff is assumed to be unlimited. Sediments
within this store are divided within a particle size
distribution. Contaminants are then associated, by
the use of 'potency factors', with sediment masses
within each fraction; this takes account of the
reported relationship between sediment size fractions
and contaminant load (Sartor and Boyd, 1972; Ellis,
1979; Yamada, 1981). Dissolved oxygen values are
simulated assuming saturation level for specific
temperature and dissolved solids levels.

(ii)   Surface washoff

Removal by surface runoff will use a simplified
consideration of sediment transport upon catchment
surfaces (Price and Mance, 1978). Figure 4.3
illustrates the principles of this approach. Sediment
transport within shallow surface runoff is effected by
two major processes: firstly, by erosion via the
influence of raindrop impact; and secondly, by
entrainment and deposition controlled by the shear
stress of the overland runoff.

Originally, the Price-Mance model was applied to a
conceptual strip representing the subcatchment area.
However, distribution of sediment upon road surfaces
would indicate that the near-gutter region represents
a site of preferred sediment accumulation (Sartor and
Boyd, 1972; Ellis, 1977). This would indicate, for
road surfaces at least, that contaminants are largely
supplied from this zone; hence a conceptual strip

occupying only a fraction of the area of the
subcatchment road surface, length represented by
gutter length, and a slope represented by the
longitudinal gutter slope (approximated by
subcatchment slope) would be the area upon which these
equations are applied - a 'catchment segment'(Fig
4.4).

Sediment and pollutants resulting from pervious
surfaces within the catchment can either be treated
separately or treated as a supply to the conceptual
strip. In the former approach a variant of the
sediment transport approach or the Universal Soil Loss
Equation may be used. However, the quantity of runoff
from these sources will be much smaller than that from
the impervious surfaces; furthermore, runoff from
pervious areas will normally occur later during the
hydrograph. It would, therefore, appear appropriate
that sediment from these sources act as a supply to
the conceptual strip, these may be treated as a
lateral inflow over the length of this conceptual
strip, associated with a uniform lateral inflow of
runoff from pervious surfaces. Hence, excess supply
at the end of the hydrograph will tend to be deposited
within the conceptual strip available for erosion
during the next storm period. However, given that
sediment accumulation is modelled using a limitless
store, this effect will not need to be incorporated
within the modelling procedure.

(iii) Gully-pots

Gully-pots will have three major influences pertinent
to water quality modelling:

1.   Degradation of trapped organic matter into
      BOD/COD, consumption of BOD/COD during
      dry-weather periods leading to anoxic conditions

within the stored gully-pot liquor;
denitrification of nitrates into ammoniacal
nitrogen;

2. Retention of large particulate matter transported
    by surface runoff;

3. Resuspension of basal sediments held within the
    gully-pot via surface runoff.

The former effect can be conveniently simulated by the
use of a system of first order rate equations as
indicated in Appendix A. Simulation of the trapping
and release effects of gully-pots in terms of
particulate matter are less straightforward. When the
gully-pots are operating efficiently (which requires
that they should be cleaned regularly) they will trap
sediments, until full. However, the cleaning of gully
pots is generally infrequent, hence for modelling
purposes the pot can be assumed co be full of
sediment. Thus gully-pot output of particulates will
be assumed to be the same as the input from surface
runoff.

4.3 Sub-surface
     sub-system

(a) Background

Within this subsystem contaminants originating from
surface runoff or from the dry-weather flow become
mixed. Also, contaminants will be derived from
material which is deposited from both dry- and
wet-weather flows. Again, it would appear that the
use of a continuous mass balance is the best approach
to simulate the various sources of sub-surface
contaminant material. This section will detail the
method of dealing with foul-water flows and the
sediment, and associated contaminant material
deposited within sewers.

Foul-water flows (dry-weather flow) contribute
contaminants in two ways to the sewer flow during
storm periods: firstly, by the mixing of foul-water
occurring during the course of the rainfall event;
and secondly, by the deposition of sediment during
dry-weather periods, which are subsequently eroded
during the storm event. In order to account for both
of these effects the time-varying behaviour of the
foul-water must be described within the model. This
may be achieved by the direct input of foul-water as
an input hydrograph and pollutograph, or by
time-series modelling of the variations in foul-water
flow. USWQMs such as SWWM3, STORM and QQS allow the
user to input constant concentration values for the
foul-water flow, which are then subject to hourly and
daily correction factors; HSPF allows the user to
input directly a time-series of foul-water flows;
SWWM3 and STORM also can estimate foul-flows on the
basis of regression on population parameters.

Foul-water flows also contribute pollutants by
deposition during dry-weather periods. These
pollutants are subsequently entrained by wet-weather
flows. Field investigations carried out at
Northampton, Brighouse and Bradford (Ministry of
Housing and Local Government, 1970) illustrate that
apart from ammoniacal nitrogen, much of the
contaminant load contained within storm sewage arises
from the scouring of deposits deposited during
dry-weather flow periods. However, it is also
apparent from these studies that such effects are
highly dependent upon the nature of the drainage
system under consideration. Recent studies of storm
sewage discharge from combined sewer systems indicate
that there is some correlation between contaminant
discharges associated with particulate matter and the
antecedent dry weather period (Saul and Thornton,
1986), which in part supports the above observation.

Actual sediments deposited within sewers appear have been classified into five major types (Water Research Centre, 1986):

Type A - largely inorganic coarse particulate matter;

Type B - similar to above but concreted;

Type C - organic, highly mobile fine particulate load;

Type D - cohesive sediments and slimes adsorbed to sewer walls.

Type E - tank sediments

The distribution of the first four sediment types within a pipe can be hypothesised to occur as shown in Figure 4.5. These sediment types originate either from the surface flow (largely Types A and B) or from the foul flow (Types C and D). In the case of the former, deposition will occur at the tail-end of the hydrograph; the growth of the latter sediment types takes place during dry-weather periods, although a limit to this growth will be imposed by the shear-stress of the dry-weather flow. This characterisation of sediment types, together with the characterisation of sediment upon catchment surfaces in terms of a crude particle- size-distribution, suggests that a conceptual sediment-transport model for in-sewer transport could be useful in the simulation of contaminant discharges; such a model has been previously developed by Sonnen (1977) and provides a basis for the development of a comparable model for use within this procedure.

(b)   Specification of the Sub-surface Sub-system
      (Appendix A, Module: SEWCON)

(i)   Foul-water simulation

Foul-water flows within the drainage system will be
dealt with in two ways:

1.   As a prescribed input hydrograph and
       associated input pollutographs applied at
       various node-points within the system;

2.   As synthetic hydrographs generated from
       known trends and periodicities of the
       foul-water component.

In the latter approach seasonal and diurnal
periodicities are represented by sine waves with
amplitudes derived from the difference between the
minimum and maximum values of the foul-water flows;
residuals will be represented by a simple
probabilistic distribution (e.g. normal distribution).
Trade effluent flows, where important can be
represented as specific inputs at known points within
the drainage system or as perturbations imposed upon
the general trend of the foul water.

(ii)   Sediments in sewers.

The accumulation of sediment loads within a specific
pipe must be related to the hydrodynamic properties of
the pipe. However, it is also apparent that random
influences will have a great impact due to both random
processes, per se, and due to a lack of knowledge of
the system and sediment characteristics.
Nevertheless, simulation of the accumulation of these
sediment types will follow the broad outline described
below and illustrated in Figure 4.6.

Type A and B sediments comprise largely inorganic
sediment originating from surface runoff, which are
deposited within the sewer system during the
falling-limb of the hydrograph. Erosion and
deposition of this material will be controlled by the
difference between the shear-stress exerted by the
flow and the critical shear stresses pertaining to
these conditions. They therefore form a major
source/sink term within the contaminant routing
equations desribed in the next section. Type A
sediments are then slowly transformed into Type B
sediments during dry-weather periods by
calcification/concretion processes; the process may be
represented as a linear function of the dry weather
period, such as

$$d(Mb)/dt = kc.Ma$$

where Ma = mass of Type A sediments within pipe,
      Mb = mass of Type B sediments within pipe,
      kc = rate coefficient describing concretion
      process.

Type B sediments will be considered as permanently
fixed to the pipe invert. Type A sediments, however,
will be allowed to move, although this will occur only
during relatively rare events when high shear stresses
are generated capable of eroding these sediments. The
total depths of Type A and B sediments will be used to
reset the hydraulic radius of pipe-sections prior to
the simulation of any event; the hydraulic radius,
however, will remain invariant during the course of
the event.

Type C sediments originate from the foul-water flow,
but again their erosion and deposition can be
simulated in terms of a critical shear stress. Type D
sediments accumulate as a result of bacterial growth
during dry-weather periods which consume organic
material within the foul-water flow and transform this

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into toxic compounds such as hydrogen sulphide under anoxic conditions.

(iii) Transport sub-system

Transport of suspended sediments and associated contaminants will be simulated by the use of a one-dimensional equation considering advection and incorporating a nominal diffusion term, used to reduce numerical dispersion introduced by solution of the advection-wave equation alone, that is

$$\frac{\partial c_i}{\partial t} + \frac{u . \partial c_i}{\partial x} - \frac{e . \partial^2 c_i}{\partial x^2} = \pm si$$

where c_i = concentration of contaminant i,

x = longitudinal dimension,

t = time,

u = discharge velocity along dimension x,

$+-s_i$ = summation of source and sink terms for contaminant i.

e = longitudinal dispersion coefficient.

This equation may be solved for each pipe, or collection of pipes, constituting a 'pipe segment' (Figure 4.6) using an appropriate finite difference grid. The major difference in the simulation of the transport of each contaminant will be the definition of the source and sink terms of this equation. Figures 4.7 to 4.10 illustrate the interactions considered for each determinand. Before solving this equation it is necessary to determine the concentration of the input runoff. This is achieved using a simple mixing model.

Unlike conventional USWQMs, this procedure does not assume that all contaminants are conserved in their passage through the drainage system. The following sections detail the interactions pertinent to each

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determinand quoted within the design requirement, and how the transformations fit in with the sediment transport based approach adopted within this model. The definition of this system must be compatible with the sedimentological classification described above. Hence, sediment and associated contaminant loads will be transported as a wash-load, a suspended load and a bed-load following the broad outlines of a sewer scour and deposition model described by Sonnen (1977). Type A sediments, dependent upon flow conditions, primarily flow shear stress, will either be transported as a suspended load or as a bed load; Type B sediments will not be available for transport; Type C sediments appear to be highly mobile and thus transported as a form of wash-load eroded and deposited only at very low critical shear-stresses; similarly with Type D sediments, although the shear stress at which entrainment occurs will be different from that of Type C sediments.

Once entrained within the flow these sediment types will undergo a different fate. The behaviour of Types C and D sediments will be constrained so that within the time-scale of a runoff event these sediments will not be capable of settling out of the flow; Type A sediment will be subject to deposition dependent upon flow conditions. Particulate loads already within the storm-water derived from surface runoff will be treated in a similar fashion; particulate matter within the small fractions constituting much of the pollutant load are considered to be analagous with Type C sediments and, therefore, will be simulated in a similar fashion; larger fractions, constituting the major source of inorganic sediments, within the sewer system, will be subject to the same fate as Type A sediments.

A further aspect to be modelled within this system is the performance of ancillaries in relation to sewer quality. In the case of types C and D sediments, constituting a wash-load, ancillaries will do little to alter the constituent material transported within the storm runoff; however, for type A sediments it is clear that detention tanks will allow the settling out of suspended material; the highly mobile cohesive fractions will also undergo deposition in these sites. These deposits will constitute the Type E deposits quoted as occurring in tanks (WRc, 1986)

(a) Dissolved Oxygen

Figure 4.7 illustrates the simulation of dissolved oxygen within a pipe segment. Surface water with a DO level formed by the combination of saturated oxygen within rain-water and low DO levels within gully-pots, is mixed with both foul-water flow from the subcatchment and upstream flow; the resultant DO level input into a pipe segment is given by:

$$Cp = \frac{Cs.Qs + Ci.Qi + Cf.Qf}{Qp}$$

where Cp = DO level within upstream pipe flow,

Cs = DO level within surface water flow,

Ci = DO level within upstream flow

Cf = DO level within foul water flow,

Qp = discharge into upstream end of pipe

= Qs + Qi + Qf

Qs = surface water discharge,

Qi = upstream discharge,

Qf = foul water discharge.

Within the pipe segment, DO levels are affected by the consumption of BOD/COD and reaeration processes. The

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former can be represented by a first-order rate
equation:

$$d(Cp)/dt = -k.BOD$$

The problem, however, with the use of such an equation
is the specification of the rate coefficient. It is
highly likely that this value will be quite small
compared to typical values quoted within natural
rivers. However, BOD values are comparatively large
enabling significant decreases in the DO level of
sewer flow to occur. Counteracting this process
within the sewer is the effect of reaeration as a
natural part of the flow process and reaeration
occurring as a result of passage over weirs and
hydraulic jumps. A limiting influence on this process
is the oxygen level within the sewer atmosphere.
Parkhurst and Pomeroy (1972) provide data suggesting
that oxygen levels within this environment are not
significantly different from those in the outer
atmosphere. They also provide an equation
representing the reaeration process within sewer flow
(see Appendix A).

Reaeration over weirs can be simulated using equations
developed by Gameson et al (1958). However, it is
debateable whether these formulae are applicable to
the sewer environment given the markedly different
hydrodynamic conditions within a sewer.

(b) BOD/COD simulation

BOD/COD is hypothesised as occurring within the
suspended phase associated with small fraction
material from catchment surfaces and Type C sediments,
although a small fraction will occur within the
dissolved phase and will thus be simulated as a
washload similar to DO (Fig 4.8). BOD concentration

within the inflow discharge to a pipe segment is
obtained using a mixing model. BOD levels decrease as
a result of BOD consumption of both suspended and
dissolved BOD, and by sedimentation of particulate
matter; increases occur by the entrainment of the
latter during passage through the pipe segment.

(c) NH_4-N simulation.

NH_4-N is treated as a non-conservative pollutant
(Figure 4.9) associated with dissolved solids. As a
consequence it will be simulated for each pipe segment
by the use of a simple mixing model approach plus
simple first-order degradation during passage through
a pipe.

(d) H_2S simulation

H S again is simulated as a non-conservative pollutant
(Fig 4.10), and involves the use of a simple mixing
model and first-order degradation. The entrainment of
these contaminants will be associated with the
entrainment of sediment type D. However, the
simulation of the amount of H_2S contained within these
sediments is at present difficult to define. Current
equations for the generation of H_2S within sewers are
largely empirical and refer, anyway, to atmospheric H
S (hence, these equations could be used within this
model to predict the occurrence of conditions suitable
to sewer corrosion).

4.4 Model
     Initialisation

The prescription of initial conditions for a model run
when using the WASSP model is achieved using simple
input variables such as the Urban Catchment Wetness
Index (UCWI) and a dry weather flow value. In the use
of the model outlined above, it will be particularly

difficult, if not impossible, to define an analogous
index to describe the prior catchment conditions for
pollution generation. Hence, as stated within Chapter
3, the model will run continuously over a predefined
period of simulation to establish appropriate initial
conditions for each particular rainfall event.
However, the problem remains of defining the initial
conditions prior to the continuous simulation run.

On the catchment surface, it is assumed (section 4.2)
that sediment supply is unimportant in defining runoff
pollutant loads, although this still does remain to be
proved for catchments within the U.K.. However,
within gully-pots the stored liquor will degrade over
a dry period from an initial constituent level similar
to that within surface runoff. There is an obvious
problem in defining the level of accumulated
pollutants prior to a model run. For this reason a
single model run should incorporate at least one
event, inconsequential in terms of its effect upon the
receiving water, prior to the event or set of events
of major interest. This will enable the surface
sub-system to be initialised.

Two aspects of the below-surface sub-system require
initialisation. Firstly, the foul-water flow; this is
accomplished utilising the model described in ouline
in section 4.3. Secondly, defining the depths of
sediment and associated pollution accumulations within
pipe sections, ancillaries and various 'dead-zones'
(sites of preferential deposition within the sewer
system). Limited research suggests that of the
sediment types within sewers (see classification
within section 4.3), types C and D are relatively
impermanent and accumulate between events from an
initially low level. This would suggest that
initialisation of these sediment types can be achieved
by the use of the 'prior minor-event' methodology

introduced above. However, in the case of sediment
types A, B and E accumulation will reflect the prior
history of a multiple succession of events.

Type B deposits will be assumed to be permanent during
any particular model run. Depths of these sediments
can be based upon a measurement exercise. This could
involve, for example, the classification of
pipe-lengths upon the basis of shear-stress/shear
velocity using a WASSP model; selection of a number of
accessible pipe-lengths within each classification
category; and the visual identification of sediments
within manholes and near manhole pipe-lengths.

The initialisation of Type A deposits is however more
problematic. These sediments are capable of motion
but will accumulate over a time-period encompassing a
number of runoff events. Hence, the depth of Type A
deposits during a particular monitoring exercise will
reflect the history of events prior to this period,
which will not be generally indicative of depths prior
to the events of interest in simulation unless it is
assumed that the depth of these sediments oscillates
around some mean value. Nevertheless, occasional
monitoring of these sediments during the flow survey
stage of a rehabilitaion scheme will aid in the
verification of the model for a particular
application. Two alternative hypotheses may be put
forward for initialising these sediment types within a
model run.

First, it is assumed that sewer sediments buildup to
an equilibrium level; this level is obviously
dependent upon the hydraulic characteristics of the
pipe. Simple surveys as described above will also aid
in the definition of this level. Initialisation then
simply consists of starting the simulation run with
these values associated with particular pipe-classes.

Second, within a time-series of rainfall events input into the model there will be a small number of larger events which remove virtually all mobile sediments. This may be described as the n-year event. If it is assumed that such an event occurs before a simulation run, then the system can be assumed to be bereft of sediment types A, C and D. The continuous simulation run would then operate over a period of n-years extent utilising a simplified model of the catchment's behaviour.

Accumulation within tanks (Type E sediments) and dead-zones will again reflect the prior sequence of events. In these circumstances it is less easy to visualise the occurrence of a critical flushing event. It may be more appropriate, therefore, to consider that these sediments build-up over a period to an equilibrium level. This level could be determined by using the maximum level observed over the period of a short-term flow survey within relatively accessible regions within the sewer system.

However, these are only hypotheses at present and require testing during the course of model development and as part of the research projects under the aegis of the River Basin Management programme (Clifforde et al., 1986)

4.5 Model simplification

In order to generate a long time-series of pollutant discharges from an urban drainage system, the model will be capable of simulation using a simplified geometric representation of the system. For this purpose a complementary hydrological model is being developed (an updated version of the 'Sewered Sub-Area' model currently within WASSP) to simulate flow discharge from such areas; pollutant discharge is

simulated similarly in each case whether the system is simplified or not.

However, in the use of a simplified system associated with a long continuous time-series run, spatial steps and time-steps will be generally larger than those required to ensure stability of the explicit finite difference techniques used for solution of the pollutant transport equations. Two alternative solution techniques are available for overcoming this problem. Firstly, instead of using an Eulerion approach in solution, a Lagrangian approach can be employed (known as a 'plug-flow' approach within chemical engineering) as is used in such models as QQS; or, secondly, the advection-diffusion wave equation can be integrated if it is assumed over the duration of the solutional time-step that certain coefficients remain constant (Medina et al., 1981). Of the two approaches, the latter would appear the most useful as it is similar in concept to the finite-difference technique in application. The accuracy of this scheme will need to be assessed.

Yet it must be noted that neither of these approaches are as accurate as the finite-difference solution, which itself is not a perfect solution of the pollutant transport processes. Consequently, it is useful to consider the potential model errors that may arise in order to provide a confidence level to output predictions.

4.6 Representation of
     model prediction
     uncertainty

Uncertainty associated with an output prediction is a general problem associated with the use of all forms of simulation model. These uncertainties may arise from a number of causes generally classified into

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model uncertainties and input-data uncertainties (Burges and Lettanmaier, 1975). Methods of representing uncertianty within simulation models have been developed based on the recasting of deterministic differential equations into their stochastic counterparts. The solution of these equations involve the use of Monte-Carlo Analysis or direct solution by numerical procedures. Both of these techniques have disadvantages for use with this particular modelling exercise: whereas the former approach is too uneconomic in terms of computational expense for routine operation, the latter, solution of stochastic differential equations by numerical techniques, appears intractable for the complex system representing the behaviour of urban drainage systems.

An alternative technique, therefore, is the use of First Order Error Analysis. Although this approach is relatively stsraightforward to implement and use it does suffere from a number of quite serious drawbacks (Gardner and O'Neill, 1983). Nevertheless, the procedure will be used within the model to allow the user to allocate confidence limits to predictions made by the model.

4.7 Input data associated with model use

Input data associated with model use can be divided into two major types: first, time-varying input data, such as dry-weather flow quantity and quality; secondly, input parameters associated with specific subcatchments, surfaces, pipe elements or sewer ancillaries, which control the behaviour of particular sub-models within the overall model. This latter type of data will, in general, be time-invariant.

(a) Time-varying input data

As indicated above the major form of time-varying
input data, other than those already used by WASSP,
within the model will be the variation of dry-weather
flow quality. The structure of the input data records
will broadly mirror those already utilised within such
models as WASSP and SPIDA. It will also be possible,
similar to WASSP, to utilise input hydrographs and
pollutographs in order to facilitate the modelling of
exceptionally large and complex drainage systems,
although this practice will be advised against for
water quality simulation.

This input data may be used in two ways within the
overrall modelling procedure. Either as a direct
input of dry-weather flow or alternatively it can be
used to calibrate a model of dry weather flow
variation. This model, as described previously, will
utilise 'end-of'pipe' foul-water flow values together
with the distribution of land-uses within the
catchment in order to derive inputs of dry-weather
flow at specific node-points within the drainage
system.

Finally with regard to rainfall data, it must be
re-emphasised that design storms will not be used with
this procedure. A rainfall time-series following the
outline of the series defined by WRc will be the
primary source of input rainfall data for prediction
purposes; for verfication of model behaviour on
individual catchments observed hyetographs will be
required, as is the case with the use of WASSP.

(b) Time-invariant input data.

Specific input parameters will be associated with each
of the program modules described in sections 4.2 and

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4.3. Although a full description of the parameters
necessary as input for utilising the model is not yet
possible, it is possible to list certain values
following the format of the modules defined above.

(i) Surface module

The major set of input parameters for use within the
surface module consist of the potency factors for
different sediment fractions. Default values will be
supplied within nthe program, but hte user will have
the option to override these values in order to aid
verification of a particular application model. Other
input parameters, defining the behaviour of the
surface module may become necessary to define the
particle size distribution and the mass of material
available for removal by surface runoff.

(ii) Below-surface module

Parameter inputs for this module may be divided into
those used within the foul-flow simulation model and
those used within the in-sewer flow model.

In the use of the foul-flow model input parameters
will be required to describe catchment population and
land-use, and potency factors associated with
foul-flow sediments. These latter values and the
variations in dry-weather flow values will generally,
however, be obtained by the use of input dry-weather
flow data.

In the use of the in-sewer flow model parameters will
be required to describe the amount of sediments
present within the sewer before a simulation run, as
described in section 4.4. Other input parameters will
be the potency factors for these sediments,

the degradation rates of certain pollutants within a sewer, and certain parameters associated with the use of sediment transport equations.

4.8 Conclusion

Much of what has been stated above is no more than conjectural. Many of the process elements described above and stated within Appendix A will inevitably be subject to considerable change and redevelopment during the course of model development: this, however, is as it should be!

The next chapter details some of the data requirements necessary in the formulation of this model and the schedule of model production.

5 PROGRAM DEVELOPMENT SCHEDULE

Initial program development will consist of the construction of a suspended solids model for separately-sewered surface water systems (Figure 5.1). This is logical, as data are available from a variety of catchment sites within the UK to validate this model separately from validation of the combined sewer model. Hence, it is necessary as a first step to obtain as much of the data available within the UK for the separately sewered catchments in order to develop a satisfactory model. Particular elements of the surface system model that will need consideration are:

(i)   Calibration of 'potency factors' associated with each sediment fraction;

(ii) Resolution of the availability limited/runoff limited question with respect to surface runoff loadings;

(iii)   Examination of factors such as land-use in
        affecting runoff loadings;

(iv)   Calibration of dry-weather gully-pot
        process models, that is, deoxygenation,
        denitrification and organic matter
        degradation rates.

It is recommended, therefore, that as part of the
general data collection programme, WRc coordinate the
collection of an enhanced surface water quality
data-base. This should incorporate not only a variety
of urban subcatchments but also a variety of different
surface types, in order to characterise a range of
values for the parameters in the Price and Mance
(1978) model.

The development of the complete model - the combined
sewer model - offers many more problems, especially
with regard to the availability of data. The current
WRc data-base, plus similar data derived from other
sites, allows the developed model to be verified only
in terms of an 'input-output' verification. Many
uncertainties exist as to the nature of the processes,
the type and behaviour of the sediments within the
sewer, the contaminant interactions that may or may
not take place within a sewer, et cetera. Current
research in these areas will not be producing
meaningful results until near the end of model
development, thus suggesting that it is logical to
delay development of the combined sewer model at least
until the surface system model has been verified.
Particular data-needs would appear to be:-

(i)   Extension of the WRc data-base to include
        flatter or possibly larger catchments than
        are currently being monitored;

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(ii)   Basic research on the generation of
        hydrogen sulphide within sewage slimes
        (also, on the growth of these slimes);

(iii)   Characterisation of sediments in sewers,
        not only in terms of their behaviour in
        laboratory conditions, but also in terms
        of their field-based behaviour. An 'ideal
        investigation' would consist of the
        monitoring of sediment within sewers at
        representative sites within a catchment
        also monitored for sewer quality outflow.

(iv)   Measurement of the dissolved oxygen within
        sewer outflow.

Although, it is appreciated that some of these data
are easier to obtain than others, with some being no
more than 'pipe-dreams', it must also be recognised
that expenditure at this stage must reap dividends in
the application of the planned modelling procedure.

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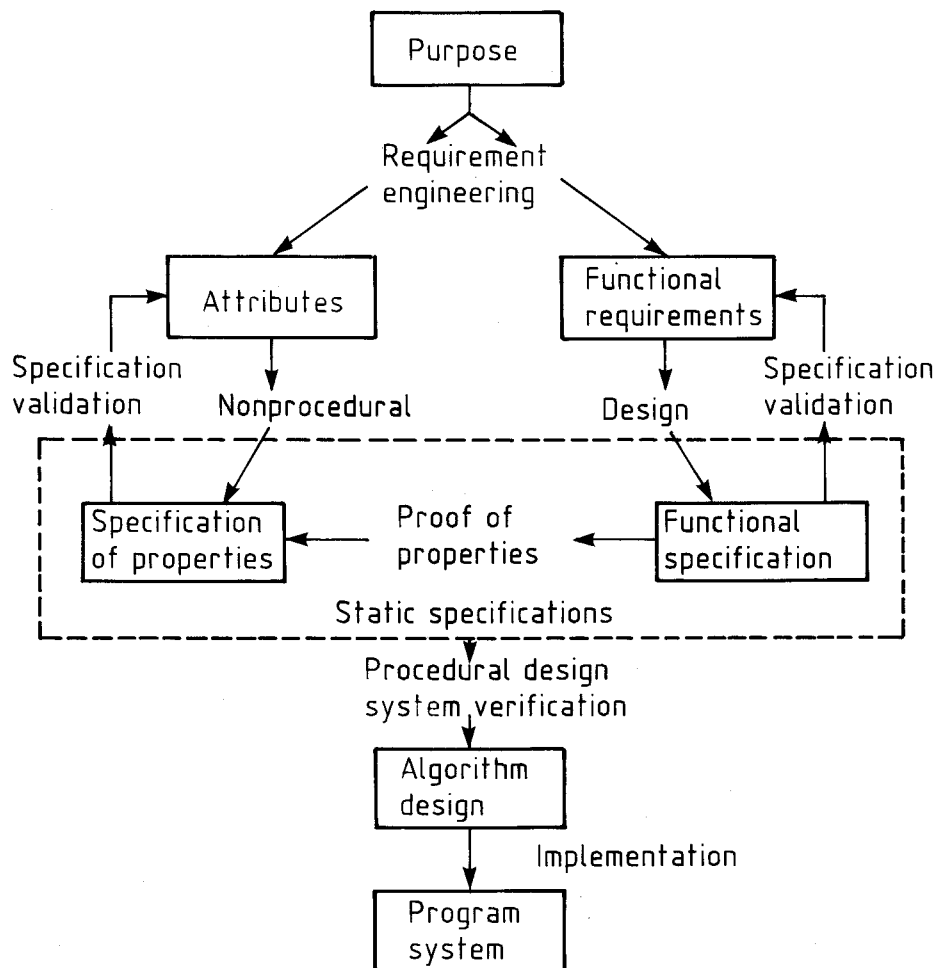
Figures

Fig 1   Hierarchical software design methodology
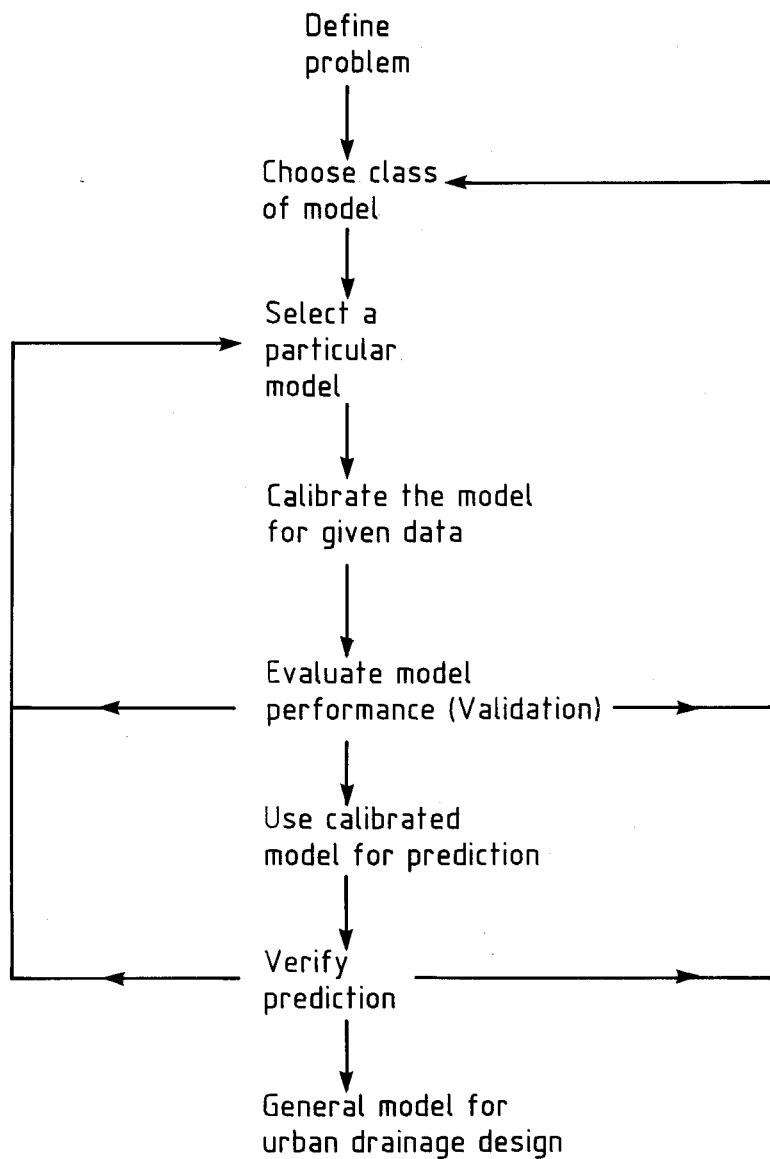   (from Spriet & Vansteenkiste, 1982)

Define
problem

↓

Choose class
of model

↓

Select a
particular
model

↓

Calibrate the model
for given data

↓

Evaluate model
performance (Validation)

↓

Use calibrated
model for prediction

↓

Verify
prediction

↓

General model for
urban drainage design

Fig 3.1   The modelling process (adapted from Box & Jenkins 1970)
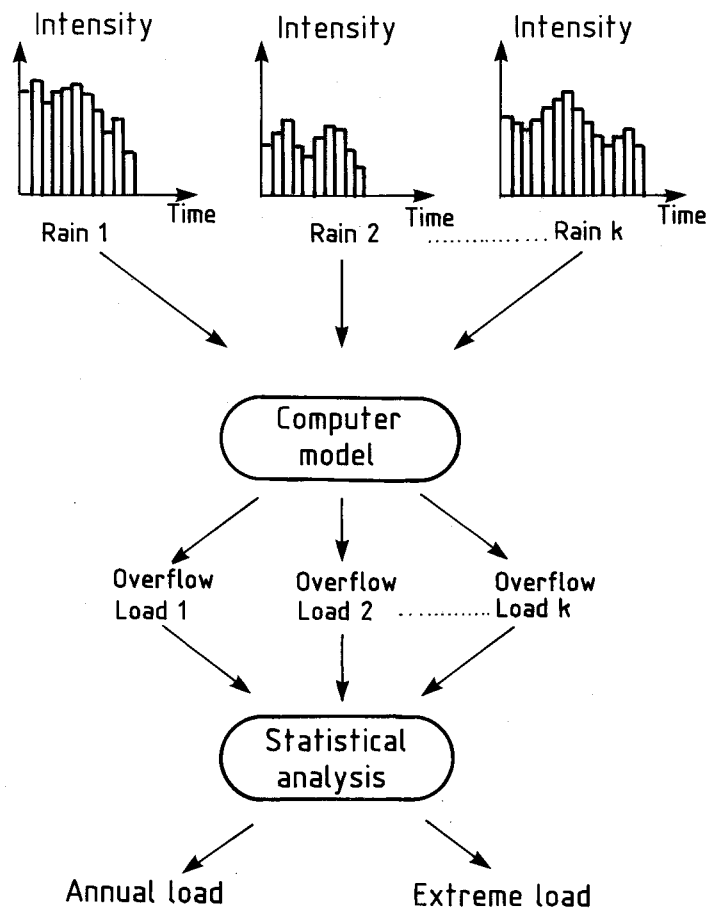
Fig 3.2   Principles of the historical rain-series approach
(from Harremces et al 1984)

Q_s, C_s

Q_i, C_i →

Mixing element

$$C_m = \frac{Q_s\,C_s + Q_i\,C_i + Q_f\,C_f}{Q_m}$$

Q_f, C_f →

$$Q_m = Q_s + Q_i + Q_f$$
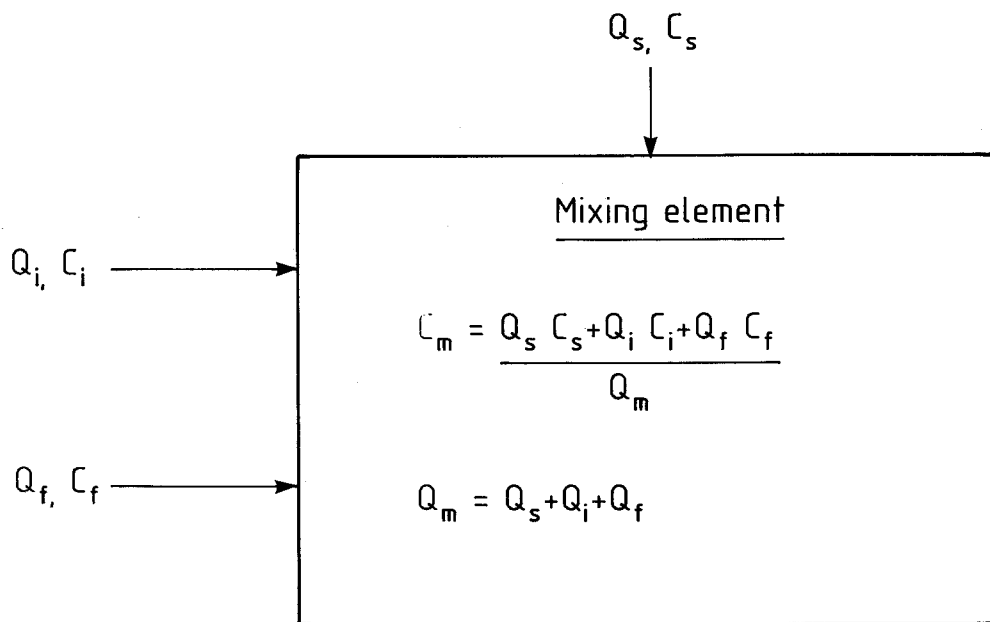
Subscript s = stormwater
i = upstream inflow
f = foul-water
Q = discharge, C = contaminant concentration
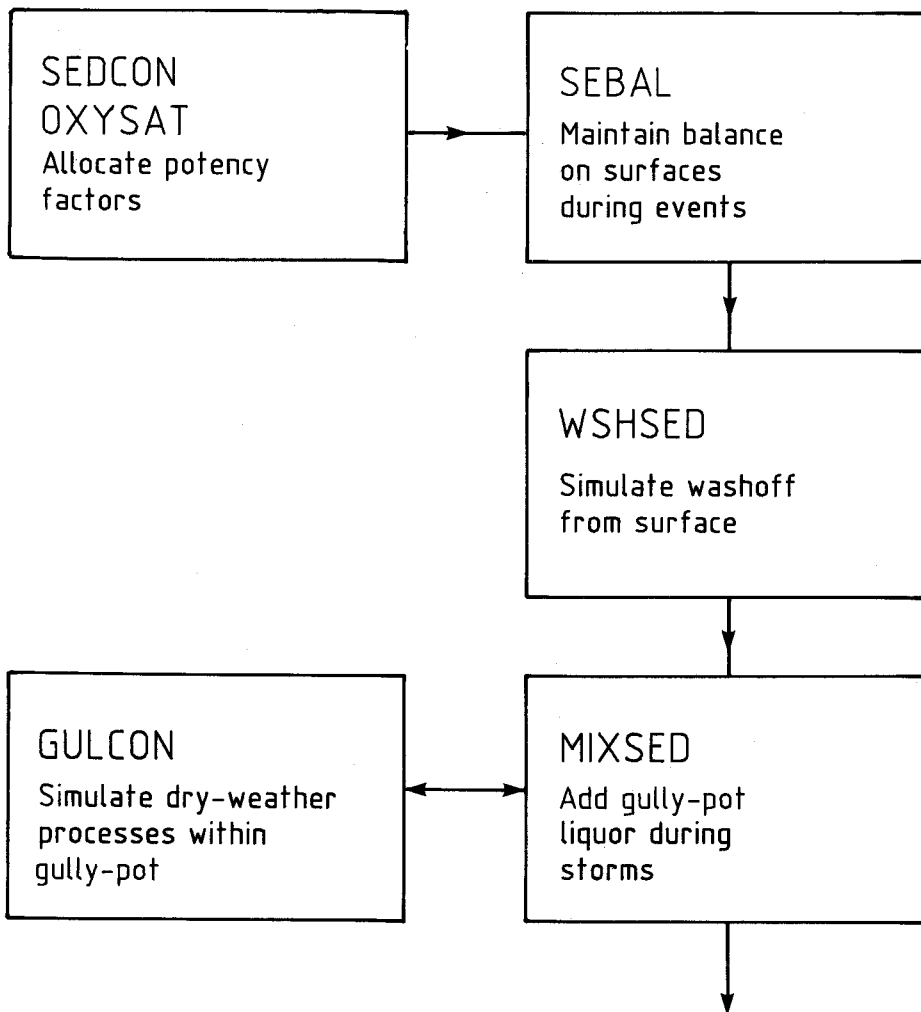
Fig 4.1   Mixing element applied at network nodes
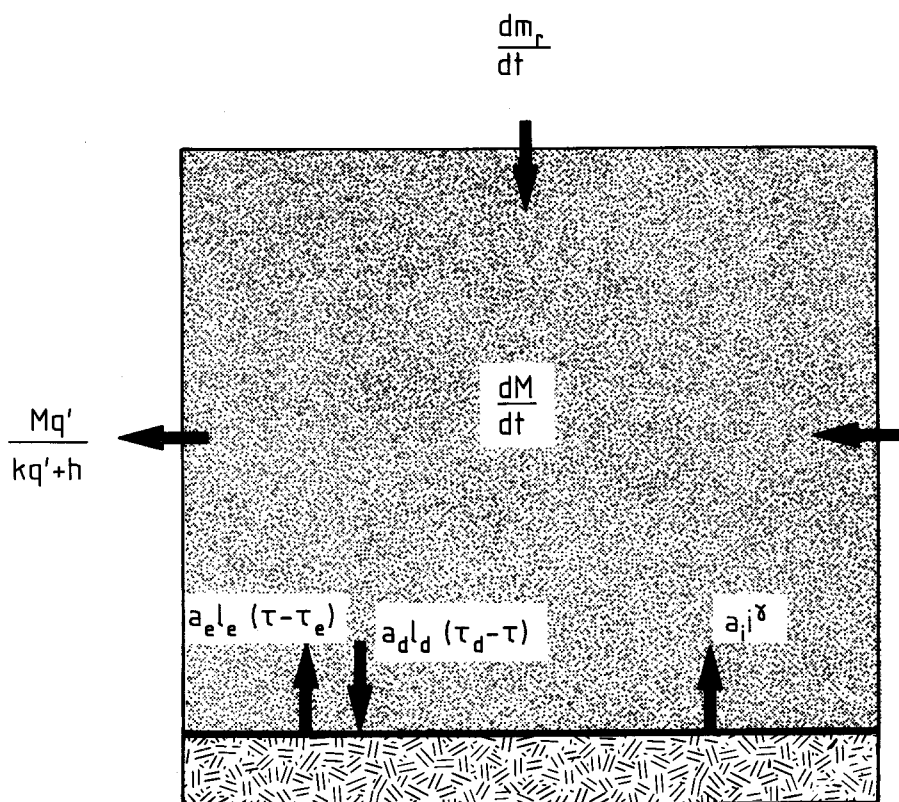
Fig 4.2   Surface-system contaminant model

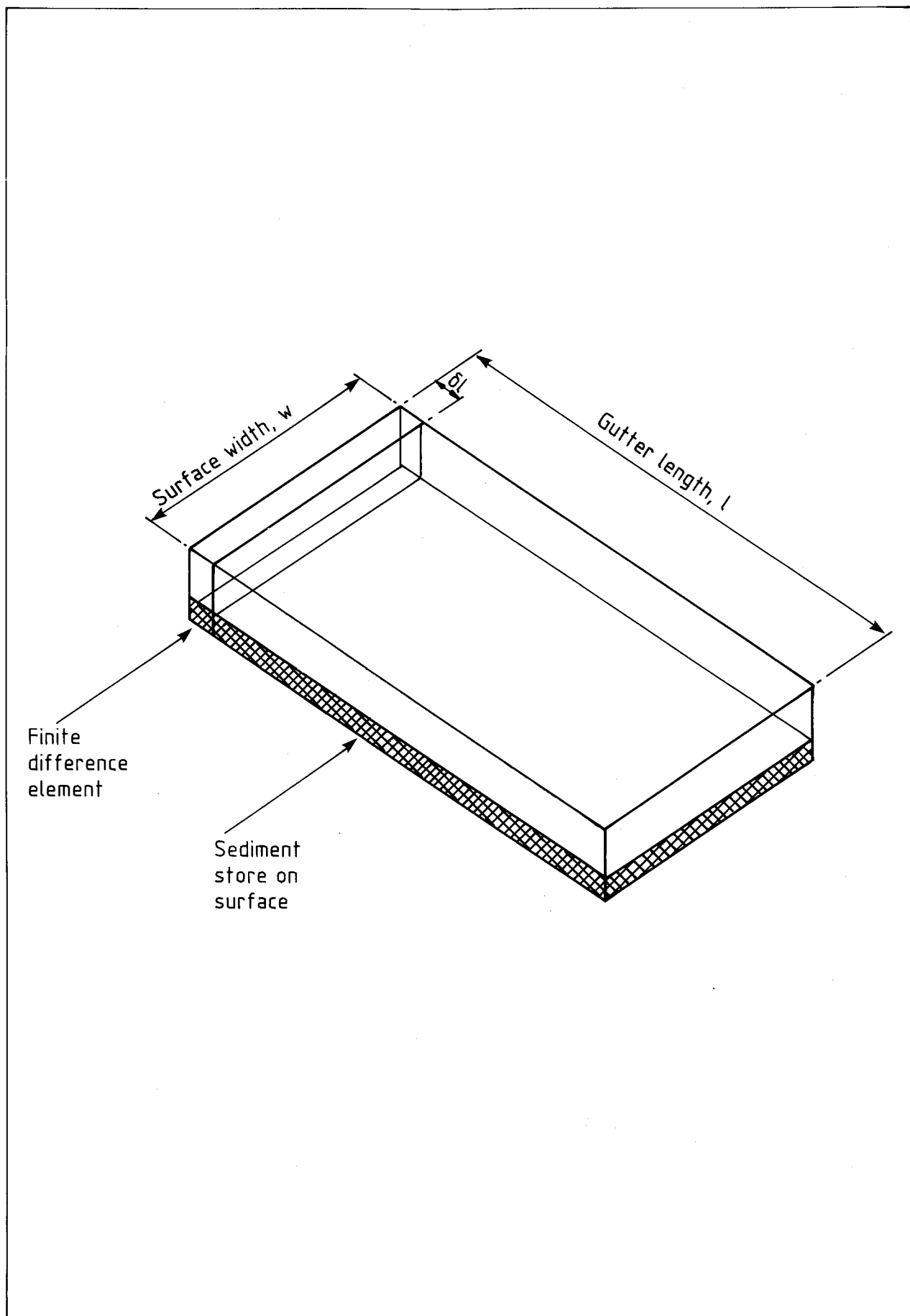Fig 4.3   Overview of Price and Mance model

Fig 4.4   A hypothetical catchment element

Sewer
atmosphere
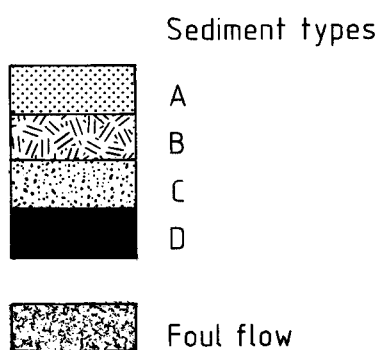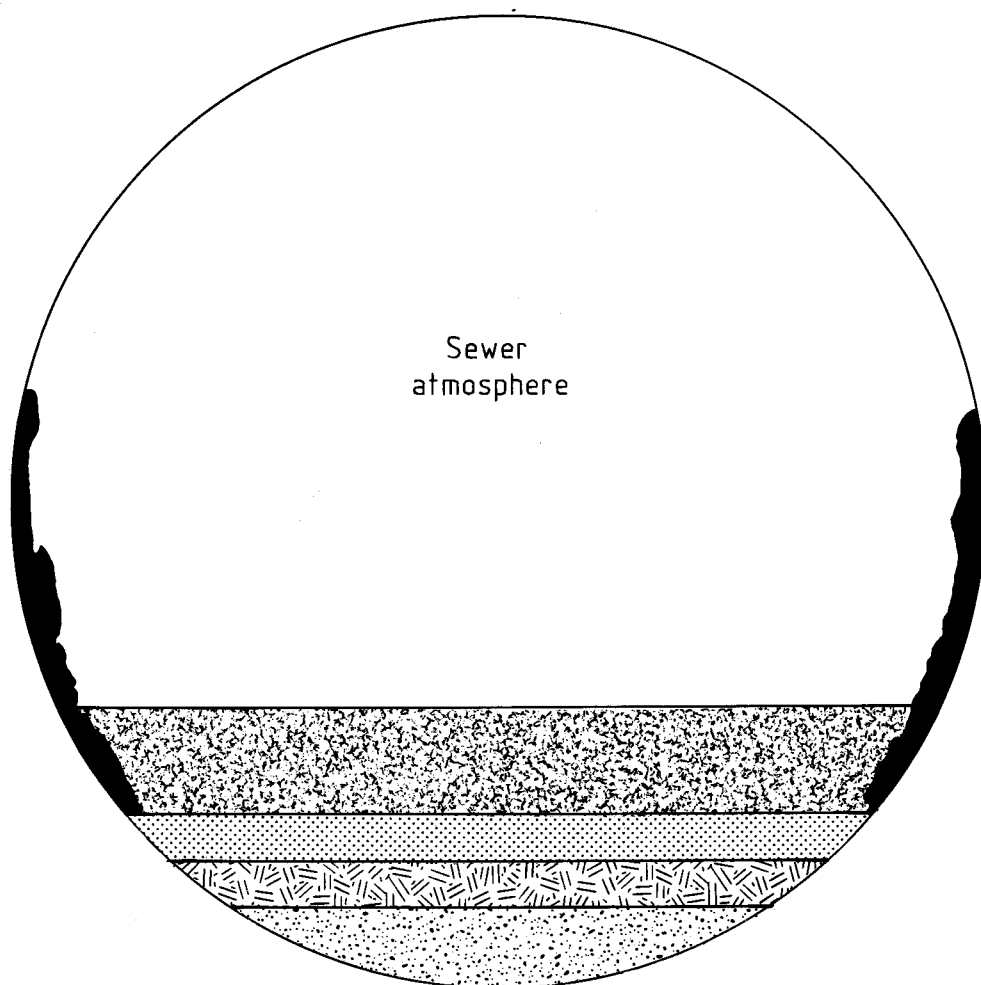
Sediment types

A
B
C
D

Foul flow
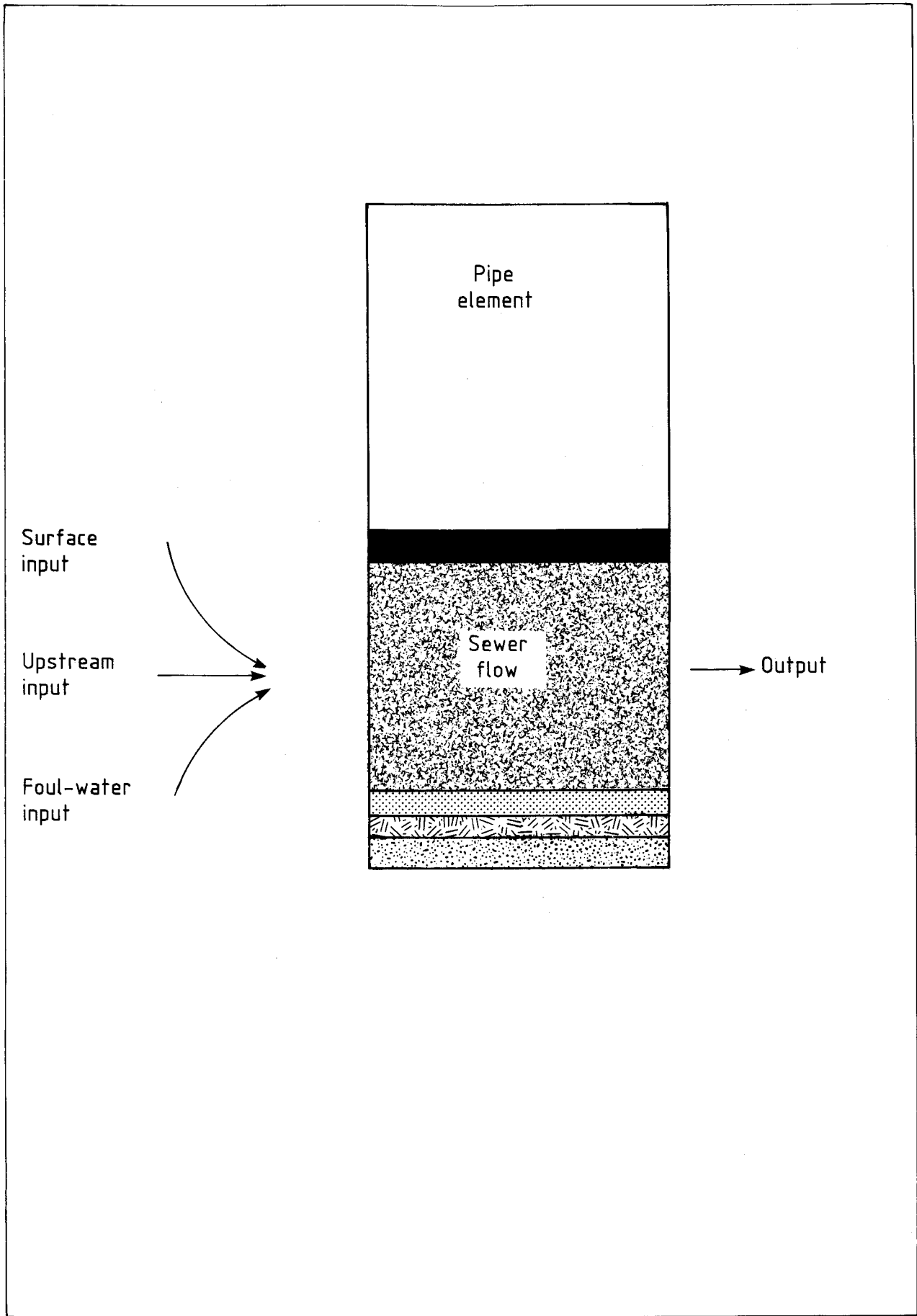
Fig 4.5   Location of sediment types

Fig 4.6   Basic 'pipe element' (Key as in Fig 4.5)

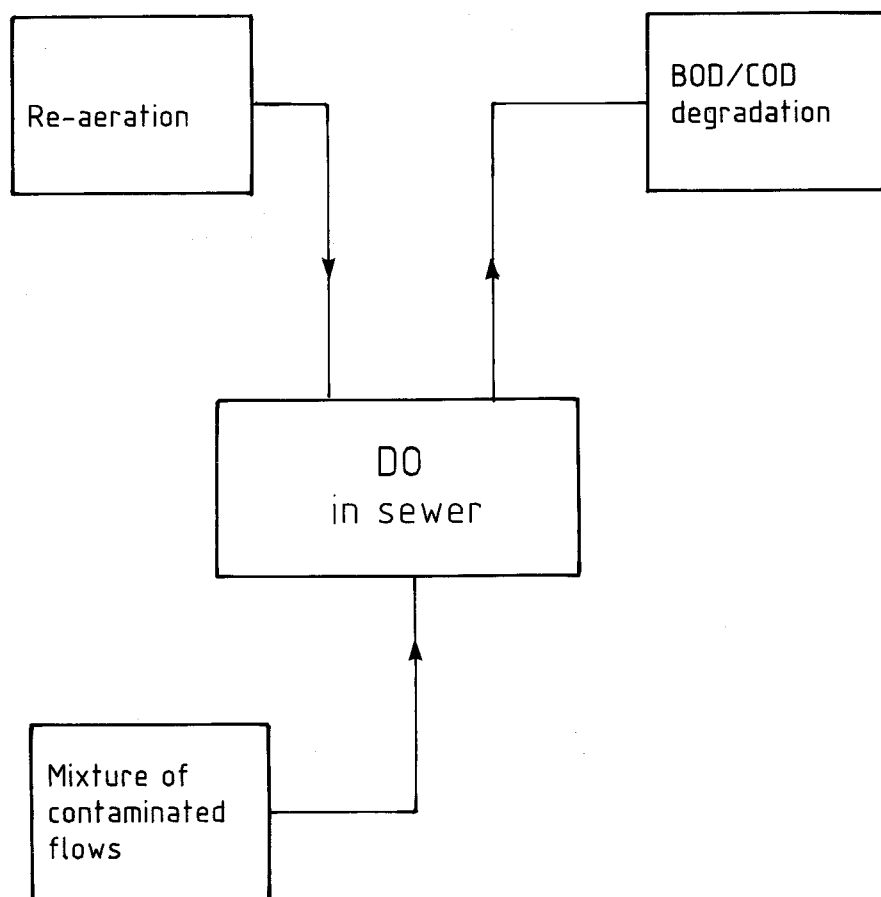Fig 4.7   Simulation of DO in sewer
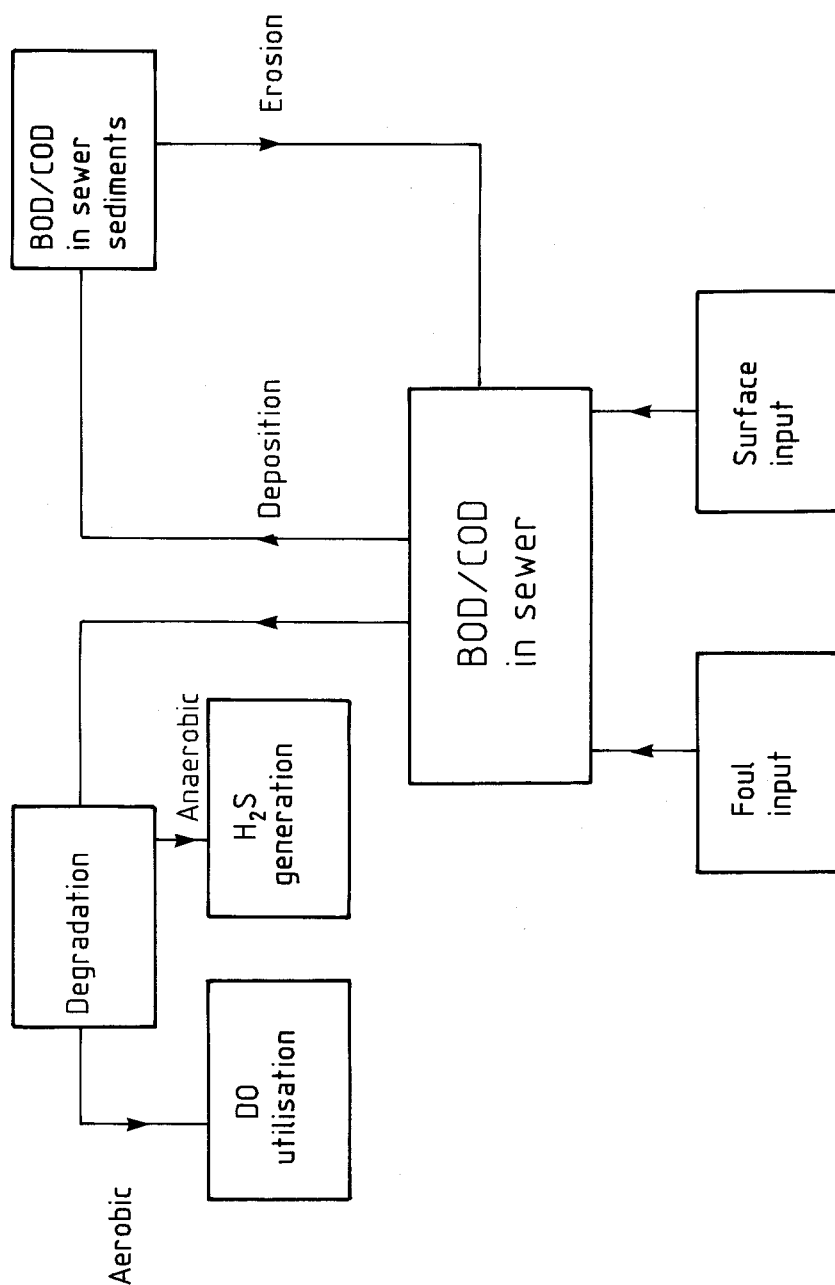
Fig 4.8   Simulation of BOD/COD in sewer
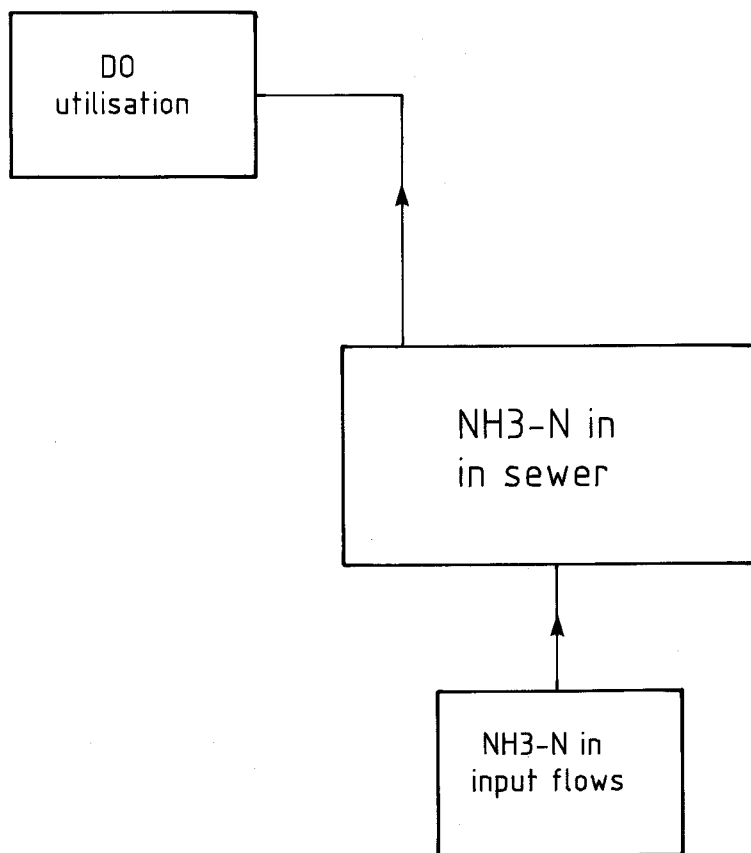
Fig 4.9   Simulation of NH3-N in sewer

Fig 4.10   Simulation of H2S in sewer

Time-period

Development
stage

1986   1987   1988
      A W S A W S A W S S

Design spec.

Separate system model

Combined system model

Quality assurance

Release for testing
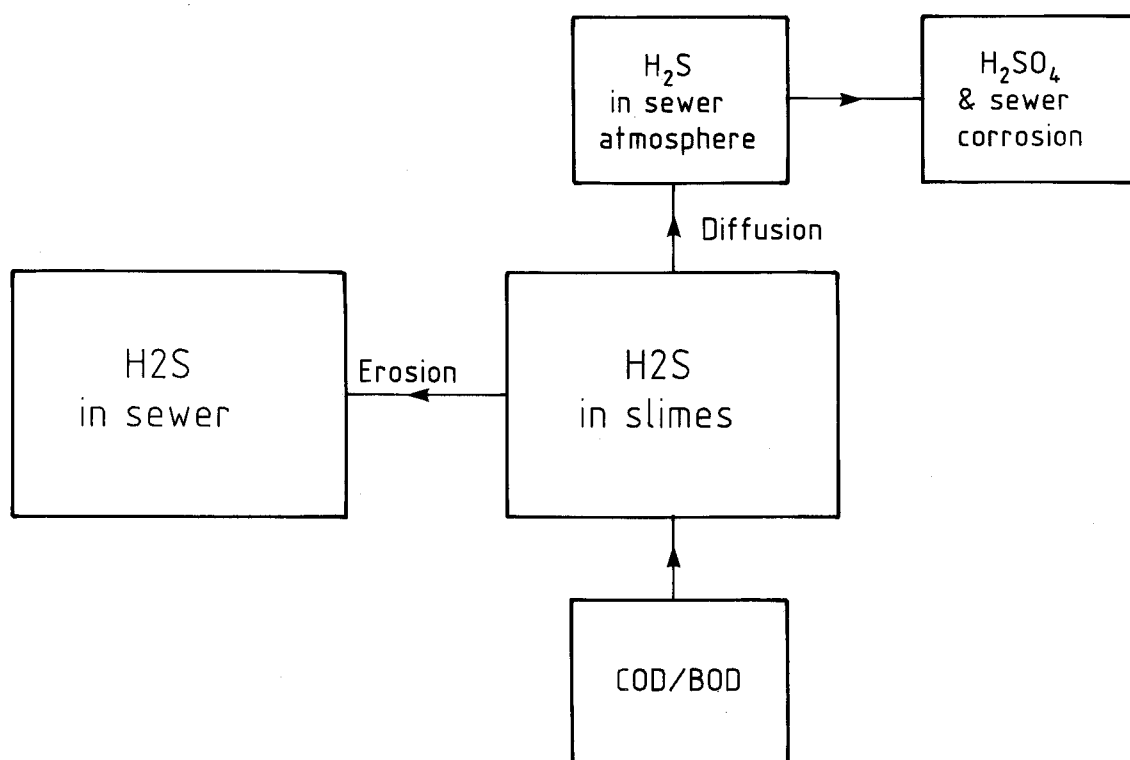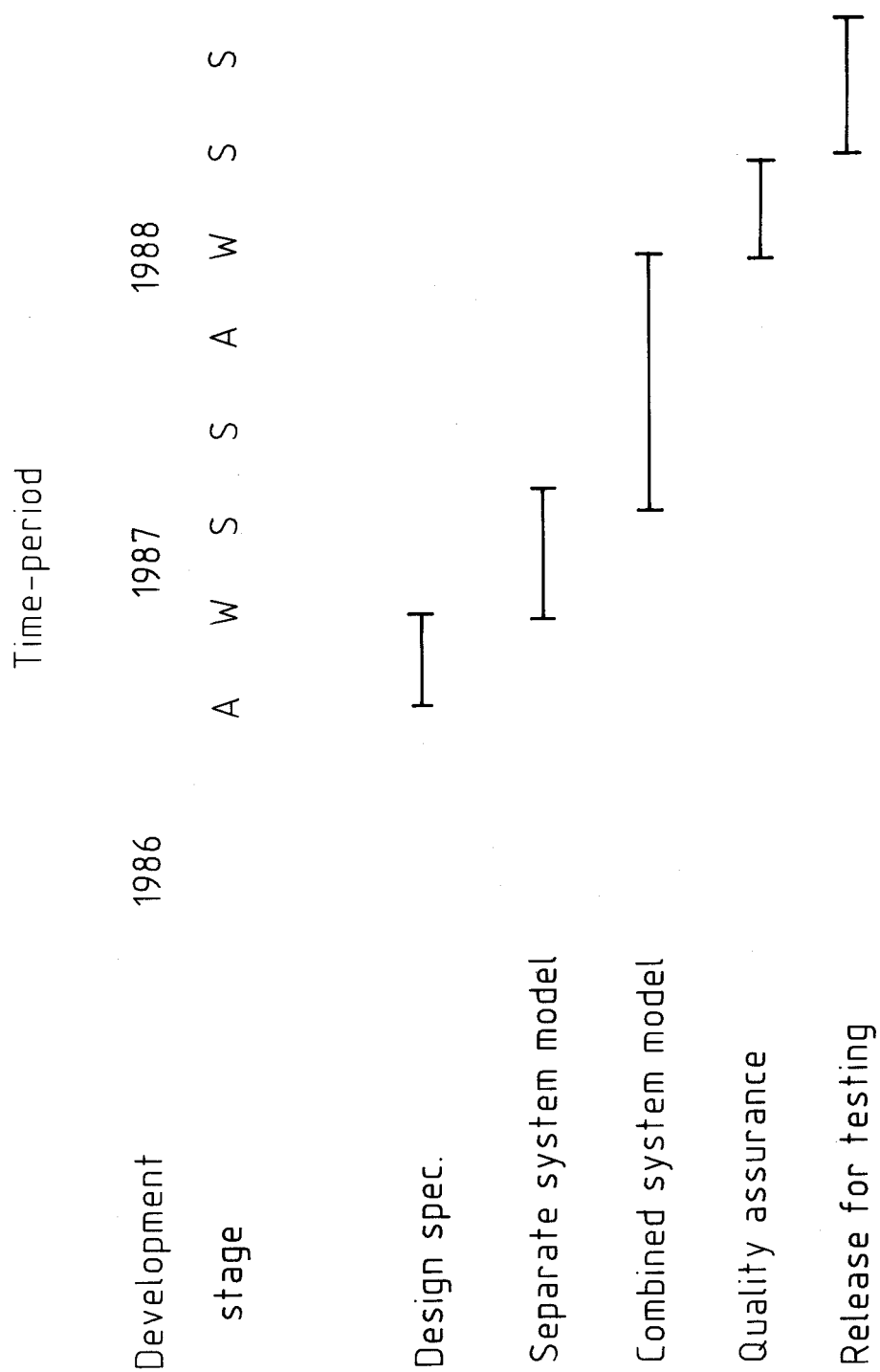
Fig 5.1   Overview of development strategy

APPENDIX A

Module: CATCON

Purpose

To simulate the time-varying behaviour of contaminant
discharges from urban catchment surfaces and
gully-pots, and to simulate the continuous dry-weather
processes pertinent to contaminant generation within
such a system.

Method

Contaminants are specified either as input, or
internally, to be associated with particular sediment
size classes. The distribution of sediment sizes
themselves can also be specified externally. This is
handled by input-output routines and SEDCON. The
dissolved oxygen concentration within surface water is
obtained by use of OXYSAT; dissolved oxygen within
gully-pots are obtained by use of GULCON; mixture of
gully-pot liquor and runoff concentrations to obtain
surface system outflow is obtained by use of MIXCON.

Flows generated by the use of INFLOW within the
WASSP-SIM module are used together with WSHSED and
TAUCAL to derive the amount of sediment, and, thence,
the amount of contaminants washed off a catchment
surface. ERRCON is then applied to each contaminant
in order to simulate likely errors associated with
simulation. ADVECT can then be used to simulate the
routing of contaminants. The above collection of
subroutines when added to WASSP-SIM form a
surface-water system contaminant model.

Subroutine: WSHSED

Purpose

Removal of solid material from catchment surfaces.

Method

Sediment removal from different surface types within a subcatchment is simulated by use of the Price and Mance (1978) sediment transport model. The rate of change of suspended sediment within overland runoff, dM/dt, is given by

$$\frac{dM}{dt} = a_i i^g + a_e l_e (\tau - \tau_e) - a_d l_d (\tau - \tau_d) - \frac{dm}{dt} - \frac{Mq'}{kq'+h}$$

where i   = rainfall intensity (mm/hr),

τ = flow shear stress,

τ_e, τ_d = critical shear stress for erosion and deposition,

l_e = 0 when $\tau \leqslant \tau_{cr}$ = 1 when, $\tau \geqslant \tau_{cr}$

l_d = 0 when $\tau \geqslant \tau_{cr}$ = 1 when, $\tau \leqslant \tau_{cr}$

dm/dt   = input of particulate solids by rain,

q'   = surface runoff,

h   = depression storage depth,

K   = storage constant of linear reservoir,

a_i, a_e, a_e, g = constants.

This equation is first solved in integral form to obtain the mass M; this is then used to evaluate the discharge of sediment mass. This equation is applied to either a conceptual strip representing the lumped behaviour of all surfaces within the subcatchment, or individually to different surface types within the subcatchment. In the latter case, surfaces are represented as conceptual strips; in the case of road surfaces, this strip has the dimensions of gutter length and a fraction of the road width to reflect the unequal distribution of sediment accumulation upon road surfaces.

Subroutine: MIXSED

Purpose

To calculate resultant sediment concentration upon mixing of two or more input flows.

Method

Uses simple mixing model approach, that is,

$$CS_j = \sum_{k=1}^{n} \frac{CS_{j,k} \; Q_k}{\sum_{r=1}^{n} Q_k}$$

where CS_j = sediment concentration within outflow from mixing element,

$CS_{j,k}$ = sediment concentration within influent flow k,

Q_k = discharge of flow k,

i = fraction size class.

This model is applied whenever flows of different concentrations become mixed. The mixing is assumed to occur instantaneously and occurs within a hypothetical 'mixing segment'.

Subroutine: SEDCON

Purpose

Associates contaminants with a particular sediment size class.

Method

The particle size distribution upon catchment surfaces is divided in to n fractions. Within each fraction, contaminants are associated by the use of 'potency factors'. For example, for contaminant j within sediment size class i, the relationship between contaminant mass, MC , and sediment mass, M, is given by

$$MC_{i,j} = k_{i,j} MS_i$$

where $k_{i,j}$ = potency factor for contaminant j and fraction i.

The total sediment mass upon each catchment surface is assumed to be limitless. The particle size distribution is divided into four major classes synonymous with solids transported in the following phases:

1. Dissolved/soluble phase (less than 43 microns);
2. Cohesive suspended phase;
3. Non-cohesive suspended phase;
4. Non-cohesive bed-load.

Total contaminant load is then given by

$$MC_j = \sum_{i=1}^{n} MC_{i,j} = \sum_{i=1}^{n} k_{i,j} MS_i$$

Subroutine: OXYSAT

Purpose

To simulate the DO saturation level contained within surface runoff water at a certain temperature.

Method

DO saturation levels vary as a function of atmospheric pressure, temperature and chlorinity. Sensitivity to pressure, however, is very small thus DO saturation levels are given by

$$
\begin{aligned}
\ln C_{do,s} = &-139.34411 + (1.575701 \times 10^5/T) \\
&-(6.642308 \times 10^7/T^2) + (1.2438 \times 10^{10}/T^3) \\
&-(8.621949 \times 10^{11}/T^4) \\
&-Chl[(3.1929 \times 10^{-2}) - (1.9428 \times 10/T) \\
&+(3.8673 \times 10^3/T^2)]
\end{aligned}
$$

where $C_{do,s}$ = saturation level of DO,

T = temperature, kelvin,

Chl = chlorinity, parts per thousand.

Chlorinity is defined in terms of salinity which can itself be defined in terms of specific conductance. It is well known that a relationship exists between this latter variable and dissolved solids. Hence, it is possible to define the saturation content in terms of absolute concentrations given a knowledge of temperature and a simulated dissolved solids content.

Subroutine: GULCON

Purpose

To simulate the degradation of the water (liquor)
stored within gully-pots during dry-weather flow
periods.

Method

Gully-pot storage is assumed to be fully occupied
following the cessation of a wet-weather period. This
water will contain BOD/COD
which utilises the DO within the stored water
following a first-order reaction,

$$d(CC_{do})/dt = -k\ CC_{BOD}$$

where CC_{do} = DO level within gully pot liquor,
CC_{bod} = BOD within gully-pot liquor,
k = rate coefficient of the DO-BOD
degradation process.

Similar rate-equations are used to describe the
degradation of organic matter to BOD/COD and the
denitrification of nitrates into ammoniacal nitrogen.
In all cases rate-coefficients can be adjusted for
temperature dependency.

Subroutine: SUMCON

Purpose

Summate contaminants occurring within each size class
to derive total contaminant concentration.

Method

Addition of contaminants occurring within each
fraction class, that is,

$$C_j = \sum_{i=1}^{n} CC_{i,j}$$

where C_j = contaminant, j, concentration within
flow,

CC_{ij} = contaminant, i, concentration associated
with sediment concentration, j.

Module: SEWCON

Purpose

To simulate the accumulation and transport of
contaminants within the sub-surface drainage system,
assuming contaminants behave in a non-conservative
manner. This module operates continuously so as to
calculate the sediment/contaminants available for
entrainment during wet-weather/increased flow
periods.

Method

The basic element within this module is the concept of
a 'pipe segment'. Contaminant inputs to a pipe
segment consist of inputs derived from CATCON, FOULIN
and from upstream application of SEWCON. These
inflows are combined by use of MIXSED to provide
input concentrations to a pipe segment. Within the
pipe-segment suspended sediments are transported by
use of ADVECT; sources and sinks of sediment and
contaminants are described by DOXBOD, SEDBAL, DOXAIR,
and TAUCAL, and in association with routines
within WASSP-SIM.

However, elements must also be included to describe
the behaviour of sewer ancillaries, especially storage
tanks and overflows, in relation to contaminant
discharges. These will be included in updates of this
draft proposal. However, to derive contaminants
associated with overflow discharge SUMCON is used to
summate the contaminant load associated with each
phase of transport/sediment fraction.

Subroutine: ADVECT

Purpose

Simulate the transport of sediment within the
dissolved and suspended phase.

Method

Uses a one-dimensional advection-diffusion equation
assuming negligible dispersive effects (apart from
contaminant exchange with dead-zones),

$$\partial(CS_j)/\partial t + u.\partial(CS_j)/\partial x - e.\partial^2(CS_j)/x^2 = +-\sum_{j=1}^{n} MS$$

where CS_j = sediment concentration of fraction j,

t = time,

x = longitudinal dimension,

u = stream velocity in direction x,

MS_j = concentration of sediment in fraction j
(sink/source).

e = longitudinal dispersion coefficient.

Subroutine: H2SGEN

Purpose

To simulate the growth of sewage slimes (Type D
sediments) and generation of hydrogen sulphide within
sediments and released to sewer atmosphere.

Method

Sewage slimes following an event are assumed to grow
during periods when flow shear-stress is less than a
critical shear stress; a limit to growth is also
applied by a critical shear stress (Perkins and
Gardiner, 1982).

The definition of the mass of hydrogen sulphide
generated and stored within slimes is at present
difficult to achieve by simulation, largely because no
equation has yet been developed. Equations available
for the simulation of hydrogen sulphide within sewers
are only pertinent to the simulation of gaseous
hydrogen sulphide. Such equations can be incorporated
within the model to provide an assessment of those
sewer lengths likely to suffer from corrosion
problems.

Subroutine: FOULIN

Purpose

To simulate the input of foul-water into a sewer
segment from a specific contributing catchment area.

Method

The input of foul-water to a specific 'pipe segment'
may be treated as an input hydrograph and associated
pollutographs, or simulated in terms of factors
describing the diurnal and seasonal trends in
foul-water flow and constituents. In the latter case
the mean level of foul-water flow may be either input
itself or simulated on the basis of demographic
factors.

(i)   Simulation of mean concentration
        and mean flow

Mean concentration of foul-water flow can be simulated
in terms of both land-use and demographic factors,
such as:

$$< CC > = b_0 + b_1 \text{ (land-use factors)} + b_2 \text{ (population)}$$

where b_0, b_1 and b_2 are parameters obtained by
regression analysis.

Similarly, mean foul-water flow may be related to
these parameterisations of these variables, that is,

$$< Q_f > = a_0 + a_1 \text{ (land-use factors)} + a_2 \text{ (population)}$$

where $< Q_f > =$ foul-water flow,

        $a_0, a_1, a_2 =$ constants derived by regression
        analysis.

(ii)   Simulation of deviations about the mean
        concentration

The concentration of contaminants within the
foul-water can be assumed to be either constant, with
variations in contaminant loadings accounted for by
the variation of the foul-water flow, or variable
dependent upon the time-of-day and the day-number of
the year.   For example, the variation in foul water
discharge could be described by

$$\frac{Qf}{< Qf >} = c0 + c1(time\text{-}of\text{-}day) + c2(day\text{-}of\text{-}year)$$

where Qf = foul-water discharge at a specific hour on
a specific day.

Subroutine: SEDBAL

Purpose

To simulate the transfer to and from sewer discharge
of sediments during its passage through a pipe
segment.

Method

The method will vary dependent upon the transport
phase by which the sediments are carried within the
flow, and the cohesive/non-cohesive nature of the
sediments.

For the non-cohesive load, a variant of the
Ackers-White model can be used (Ackers, 1984)

For the cohesive load, processes are less well
researched. Possible methods include equations for
deposition developed by Krone (1962) and scour
developed by Partheniades (1962).

The results of sediment transport studies within pipes
conducted by HRL and Newcastle University should
provide the necessary information to select a
particular suite of sediment transport routines within
this procedure.

Subroutine: DOXBOD

Purpose

To simulate the consumption of dissolved oxygen by
BOD/COD during transport through a pipe-segment.

Method

Assumes validity of first-order kinetics for the
consumption of dissolved oxygen by BOD/COD, i.e.

$$d \; (CC_{do})/dt \;\; = -k \; .CC_{BOD}$$

where CC_{do} = concentration of dissolved oxygen in
sewage flow,

CC_{BOD} = concentration of BOD/COD in sewage
flow,

k = rate coefficient.

There is an obvious lack of knowledge concerning the
magnitude of the rate coefficient in pipe-flow. USWQM
in general do not simulate dissolved oxygen, hence,
this process is ignored, as the consumption of BOD is
marginal compared to the absolute magnitude of BOD
within the sewage; however, it may not be marginal
compared to the dissolved oxygen level and the rate of
reaeration within the sewer length.

Subroutine: DOXAIR

Purpose

To simulate the reaeration of sewage during its
passage through a pipe-segment.

Method

For reaeration during free-surface flow through a
pipe-segment a formula developed by Parkhurst and
Pomeroy (1972) can be used.

For reaeration due to passage over weirs equations
developed by Gameson et al. (1958) may be used,
although their applicability to highly contaminated
sewer flow must be questioned.

Subroutine: ERRCON

Purpose

Assign an error term to a specific deterministic
simulation of a contaminant concentration or
accumulation.

Method

Error terms are drawn from a probabilistic
distribution on the basis of random-number generation.
A First-Order Error Analysis is then performed to
provide a sample estimate of the mean and variance of
the simulated output.

Subroutine: ERRORS

Purpose

Define distribution of error terms associated with the
three elements of the mixing-model.

Method

Errors associated with the specification of inflows
into the mixing-model applied at each node are
described by a probabilistic model. This subroutine
specifies the form of these distributions for a
particular catchment.

Subroutine: TAUCAL

Purpose

Calculate bed/wall shear stress of fluid flow in both catchment and pipe segments.

Method

In surface flow (IFLAG=1) shear stress can be calculated by
(Price and Mance, 1978)

$$tau = \frac{k\ q'}{(Kq' + h)}$$

where variables are as in WSHSED.

In pipe flow (IFLAG=0) by

$$tau = S.gamma.R$$

where S = slope of energy gradient,
gamma = unit weight of water,
R = hydraulic radius of flow.

APPENDIX B

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.

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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.

(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.

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.