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Groundwater Recharge in Urban Areas

National Groundwater and Contaminated Land Centre

November 2002

Environment Agency

EA - Midlands

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Groundwater Recharge in Urban Areas

National Groundwater & Contaminated Land Centre

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Statement of Use
This report is aimed at Regional hydrogeologists involved in CAMS, Water Framework Directive characterisation, groundwater licence determination and groundwater modelling projects. The report provides guidance on using urban drainage models to estimate groundwater recharge in urban areas.

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EXECUTIVE SUMMARY

Estimation of recharge and runoff is an important part of water resource management and a fundamental component of all regional groundwater models. At present, the estimation of recharge in urban areas is subject to considerable uncertainty. In most water resources studies, estimates of a percentage of impermeable area are used along with modified soil moisture deficit calculations to estimate the amount of potential recharge which is able to percolate to the water table. These estimates are not validated against measured runoff data because such data are not generally available.

Extensive modelling of urban drainage networks has been carried out for many UK towns and cities to aid sewerage design and construction using specialised software. These projects could provide a useful, and currently untapped, source of information, which could help improve the estimates of groundwater recharge in urban areas.

The objectives of this study were to critically review the approach followed in urban drainage modelling studies and to determine whether output from such work could be used in water resource studies, both historically and by considering indicative results from current urban drainage projects.

From the critical review, it is apparent that there is potentially valuable overlap between urban drainage models and groundwater models. In particular, modern urban drainage models use observed and interpolated land use data to estimate the proportions of catchments that are permeable, impermeable or drain to soakaway. This geographically referenced data is processed, with actual or synthetic rainfall series, to predict flows to sewer. These steps are similar to those carried out by groundwater modellers. However, the calibration of urban drainage models tends to focus on short term rainfall events (minutes to hours) whereas groundwater models look at longer timescales of days to years. Moreover, where data are sparse, urban drainage modellers will tend to adopt assumptions that maximise the flow to sewer in order to ensure that systems incorporate a safety factor in design.

Case studies were carried out on drainage models from seven differing catchments in the UK. Because of confidentiality restrictions, these catchments are not named but their characteristics are summarised. Interrogation of the data used, and generated, in these case studies has been used to indicate the typical percentage areas defined as pervious and contributing to the sewer system (56% - 65%), impermeable and contributing to the sewer system (26% - 37%) and contributing to soakaway (1–16%).

The case studies also highlighted some dangers in transferring model output from drainage models to groundwater models if this is done without careful consideration. In particular, the focus on short term events means that the proportion of rainfall contributing to runoff is assumed to be high. In particular, pervious grassy areas are assumed by urban drainage modellers to contribute runoff to sewer if they are within ten metres of a road or other drained area. Commonly, if no catchment data are available, the entire permeable area may be considered to drain 100% to sewer. Models based on this assumption predict flows in sewers very well for short term rainfall events but may not accurately reflect the longer term processes that lead to recharge.

GLOSSARY

AMP	Asset Management Plan
ATO	Area Take Off
BOD	Biological Oxygen Demand
CAD	Computer Aided Design
CAMS	Catchment Abstraction Management Strategy
CCTV	Closed Circuit Television
CSO	Combined Sewer Overflow
DAP/S	Drainage Area Plan / Study
DoE	Department of the Environment
DWF	Dry Weather Flow
FEH	Flood Estimation Handbook
FSR	Flood Studies Report (published 1975)
GIS	Geographical Information Systems
IAS	Impermeable Area Survey
ICE	Institute of Civil Engineers
IoH	Institute of Hydrology
OFWAT	Office of Water Services
OS	Ordnance Survey
LAs	Local Authorities
Met. Office	Meteorological Office
NRA	National Rivers Authority
RTC	Real Time Control
SAAR	Standard Average Annual Rainfall
SRM	Sewerage Rehabilitation Manual (published 1977)
STW	Sewage Treatment Works
TSR	Time Series Rainfall
SUDS	Sustainable Urban Drainage Systems
UPM	Urban Pollution Management
WaPUG	Wastewater Planners User Group (previously the Wallingford Procedure User Group)
WRc	Water Research Centre
WWF	Wet Weather Flow

1 INTRODUCTION

Estimation of recharge and runoff is an important part of water resource management and a fundamental component of all regional groundwater models. Many different methodologies have been developed to estimate recharge in rural areas, but by comparison, relatively little attention has been paid to recharge in urban areas. Generally, estimates of the percentage of impermeable area are used along with modified soil moisture deficit calculations to estimate the amount of potential recharge which is able to percolate to the water table. These estimates are rarely, if ever, validated against urban runoff data, as the only data widely available is from sewerage treatment works.

Extensive modelling of urban drainage networks has been carried out for many UK towns and cities to aid sewerage planning using programs such as WaSSP (Wallingford Storm Sewer Package), WALLRUS and the modern HydroWorks and InfoWorks, the latter of which includes Geographical Information Systems (GIS) capabilities. These time variant models are validated against rainfall events, with data loggers being installed in key sewers to provide data on the actual flows in the sewer.

The methods for estimating near-surface inputs and outputs for groundwater models in urban areas are not very rigorous at present. Groundwater models are increasingly being used as tools for strategic water resource planning. In addition, Catchment Abstraction Management Strategies (CAMS) rely on resource balances that would benefit from an improved understanding of catchment based anthropogenic processes.

The influence of the urban drainage system can be very important due to the interception of groundwater and/or the leakage of drainage and effluent water. Both these processes can occur within the same area dependent on the season, type and operational performance of the sewerage system and the relative levels of the groundwater and pipe-work.

One potential means of improving the understanding of these processes that has been identified is to transfer and adapt the information generated from urban drainage modelling work as undertaken by the water companies.

The objectives of this study were to critically examine the approach followed in urban drainage modelling studies to determine whether output from such work could be used in water resource studies, both historically and by considering indicative results from current urban drainage projects.

This report presents the results of an initial review of this subject area and is structured as follows:

Section 2: Sets out a conceptual model of urban recharge processes.

Section 3: Provides a review of the development of urban drainage models.

Section 4: Provides an overview of the data used by urban drainage models.

Section 5: Describes details of the data used, and output from, urban drainage models, with reference to case studies.

Section 6: Discusses the potential applications of information from drainage area models to groundwater models and to CAMS and groundwater quality studies.

Section 7: Summarises the conclusions of the study.

Section 8: Makes recommendations for future work.

2 CONCEPTUAL MODEL OF URBAN RECHARGE

Figure 2.1 illustrates the urban processes which have been considered in this study. These processes may be of relevance to the estimation of recharge and runoff in urban areas or may affect other aspects of groundwater modelling, such as the development of anthropogenic components of water balances. However, not all of these processes are considered explicitly in drainage models. This study aims to identify not only the most important processes, but also those which can be most readily quantified using information gathered for drainage modelling or by interrogating the drainage models themselves.

In terms of the inputs to groundwater models, those processes illustrated in Figure 2.1 as above the 'water table' would normally be considered outside of a groundwater model itself as part of the near-surface water balance that provides a boundary condition to the saturated zone flow model. Only the inflow to sewers which are below the water table would need to be considered within the groundwater model itself; all other processes would be considered as part of the 'pre-processing' of input data to the model.

Some of the processes illustrated are currently considered explicitly in groundwater modelling studies, such as mains leakage, recharge in grassed areas and sometimes the influence of soakaways and septic tanks. However, a 'lumped' approach to all other processes is usually adopted whereby the approximate split between water which becomes recharge and water which becomes runoff is estimated as a crude percentage. This percentage is not usually spatially distributed in groundwater models and is never time variant.

This study was carried out by developing the 'conceptual model' shown in Figure 2.1 from the perspective of the groundwater modeller and presenting this to drainage modellers as a 'wish list'. The brief of the drainage modellers was then to consider which of these processes are measured, modelled or otherwise determined routinely as part of their work and how data may be extracted from drainage modelling studies and applied to groundwater models.

In order to provide groundwater modellers with the necessary background on drainage models and the data on which they are based, a history of the development of drainage models and an explanation of the modelling process are given in the following sections.

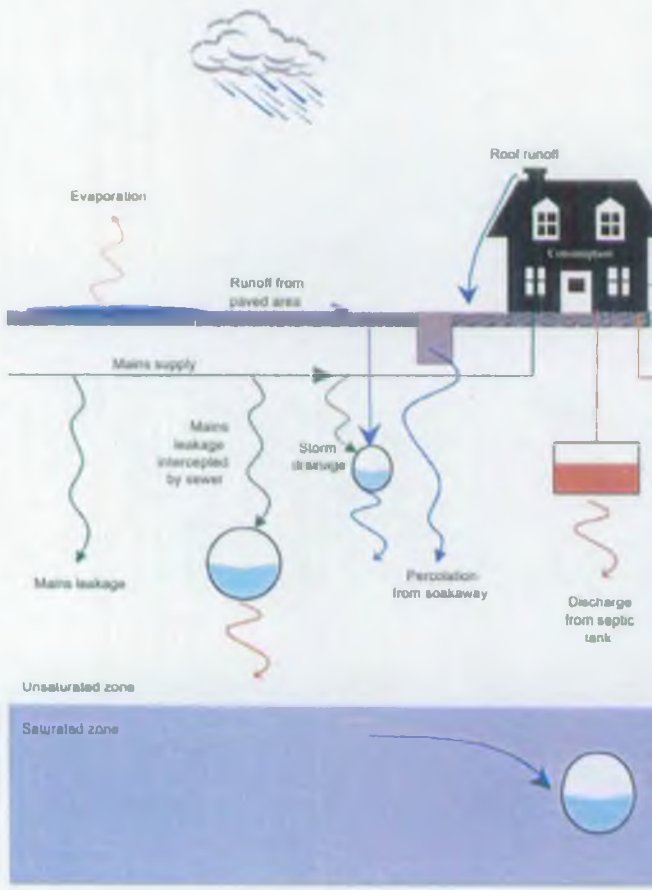
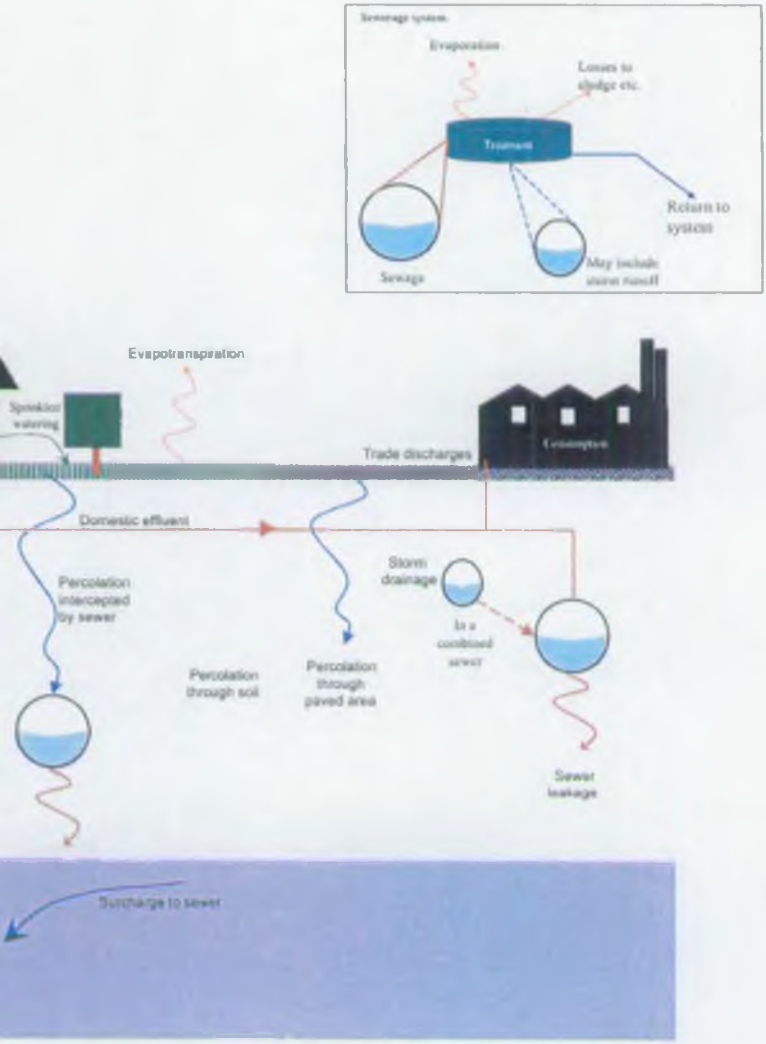


Figure 2.1 Conceptual drawing of urban processes


Sewerage system
Evaporation
Losses to sludge etc.
Treatment
Return to system
Sewage
May include storm runoff
Evapotranspiration
Sprinkler watering
Trade discharges
Consumption
Domestic effluent
Percolation intercepted by sewer
Storm drainage
In a combined sewer
Percolation through soil
Percolation through paved area
Sewer leakage
Surcharge to sewer

3 HISTORY OF URBAN DRAINAGE MODELS

3.1 Early developments

Since the Second World War rebuilding and modernisation of the UK infrastructure has taken place at an ever increasing rate. During the 1950's and 60's the strategy associated with surface water drainage of the highways was reviewed as large expanses of impermeable areas generated greater volumes of rainfall-runoff which had to be catered for. These developments provided the driver for improved design and led to the development of the first urban drainage models. The first major development was the Transport Road and Research Laboratory (TRRL) method (TRRL, 1962), the first internationally recognised computer based program for the design of storm drainage systems, published in 1962.

In 1975 a research programme funded by the Department of the Environment (DoE) was established at the Hydraulics Research Station, the Institute of Hydrology (IoH) and the Meteorological Office (Met. Office). The programme was monitored by a working party on the Hydraulic Design of Storm Sewers. The research led to the publication of the Flood Studies Report (FSR, 1975), comprising of five volumes and making use of meteorological and hydrological data from across the country. The FSR, which has been subsequently updated, is still in use today.

By the late 1970s it was becoming evident that rehabilitation of sewerage systems and improving the hydraulic performance of the existing systems was a key issue for drainage engineers. In response, the Water Research Centre (WRc) was commissioned to produce the Sewerage Rehabilitation Manual (SRM) 1977/78 (WRc, 1993) to predominantly address structural issues in the system. The new procedure was called the "Wallingford Procedure" after the location of the two organisations involved (IoH and Hydraulics Research Station). The procedure was designed to be run from a computer system and comprised of four main parts; the rational design method. hydrograph design method, optimising method and simulation method. Trials of this package began in 1980.

3.2 The Wallingford Procedure and the first water quality models

Following on from the developments in the late 1970s, the Wallingford Procedure report (in five volumes) was published in 1981 by the National Water Council. This package was released for use on mainframes and given the acronym WaSSP. This system gained rapid acceptance and forms the basis of modern models in use today.

In 1982 the Hydraulic Research Station was privatised and became the Hydraulics Research Limited (HRL). In 1984 due to problems with access to mainframe systems, HRL decided to produce a micro-computer version of WaSSP, Micro-WaSSP. Around the same time a PC based version of the rational method, MicroRAT, was released.

Since the first release of WaSSP, a Wallingford Procedure User Group had been in existence, which has since become the Wastewater Planning User Group (WaPUG). This group continues to act as a focus for users of urban drainage models.

As outlined in the SRM, water authorities were adopting the approach of Drainage Area Plans or Studies (DAP/S) which involved the generation of models of existing sewerage networks. These models were verified by means of flow monitoring exercises using information from rain gauges. An international version of WaSSP, WaSSPOS, was developed with funding from the DoE in 1983. This was to be the fore runner of WALLRUS.

With the confidence of drainage engineers growing in the use of hydraulic models, and more complex systems being simulated, the limitations in the use of programs such as WaSSP (and subsequently WALLRUS) was soon realised (Osborne, 1996a, 1996b, Orman, 1996, Walker and Sanderson, 1996). For example, only primarily dendritic systems (i.e. not looped) could be modelled. The solution to this came in the form of SPIDA (Osborne, 1990) released in 1985.

In 1986, the next stage of development of the Wallingford Software (the marketing name established by HRL) came in the form of water quality modelling (Foundation for Water Resources, 1994, ICE, 1997). Due to the perceived environmental problems associated with combined sewer overflows (CSOs), and tighter regulation, the need arose to predict not only hydraulic performance of the sewerage system, but also the water quality characteristics. The programme with this added facility was called MOSQITO. WALLRUS was released in 1989, SPIDA in 1992 and MOSQITO in 1993.

3.3 Modern models and GIS functionality

In 1994, Wallingford software introduced HydroWorks PM and HydroWorks MIS, both of which were fully Windows™ compatible. HydroWorks allows the modeller to view the model in plan and long section and updated the database in plan view. It enabled DWF (Dry Weather Flow) to be modelled in an improved manner and, as with SPIDA, did not rely on a dendritic pipe numbering system.

With models generated to assess the performance of storm overflows and pollution content of receiving watercourses, the limitation of the Wallingford Procedure to derive rainfall events of a minimum of one year return period was soon realised. Time Series Rainfall (TSR) (Henderson, 1988, Garside, 1990), as an approach to the analysis of tank sewers and storm overflows was developed; the WRc produced a package called STORMPAC which was able to produce TSRs for locations across England and Wales given minimal input data and is still in use today. These time series profiles allow models to simulate a range of storms that are similar in characteristics to those found in reality.

In 1998, InfoWorks was released by Wallingford software. This uses the same hydraulic and water quality simulation engine as HydroWorks. However, the main improvement to InfoWorks was the inclusion of GIS functionality (predominantly the commercially available MapInfo software). This allows the sewers to be viewed in a range of plan, long-section and 3D views. It also allows Ordnance Survey (OS) background maps and other 'key location' indicators to be viewed at the same time as the sewer network, providing additional information.

In recent years, a number of automated routines have been developed allowing the time consuming model building tasks to be completed relatively simply. These have been adapted from GIS network analysis or are new developments and include pruning and merging facilities, automated area take off, population counts based on address point data and several data inference tools. The ability of InfoWorks to import sewer databases of over 50,000 nodes has meant that the need to simplify models to represent key areas of the system is no longer a priority. Models are now frequently constructed that include all the nodes of the public sewerage system.

With the increase in available computing power and the ability of HydroWorks and InfoWorks to process increasingly large amounts of data , the construction of detailed 'macromodels', that integrate systems models of numerous drainage areas, is more common. These macromodels allows catchment wide interactions to be assessed at a scale more compatible with those considered in groundwater models. In addition, the models now include packages that simplify the calculation of dry weather flow, using population, catchment area and per capita flow and storm water runoff, using several UK and international runoff models and rainfall generators.

In the UK the HydroWorks and InfoWorks suite are currently the industry standard for urban drainage models. Internationally the Danish Hydraulic Institute (DHI) has developed MOUSE (Modelling of Urban Sewers) which is used extensively in Europe. The US has traditionally used a freeware programme "SWMM" but in recent years has been adopting both the Wallingford Software suite and MOUSE.

3.4 Applications of urban drainage models

Urban drainage models such as HydroWorks and InfoWorks, which are the most promising in terms of links to groundwater modelling in urban areas, are only part of a larger suite of models used in drainage planning and design.

The use of urban drainage models of sewerage networks may be crudely grouped into two categories, hydraulic modelling (Orman, 1996b, Allit and Beale, 1992, Bright, 1990, Dring, 1996) and water quality modelling (Allen and Crabtree, 1994), although, generally with programs such as HydroWorks and InfoWorks the two are often combined. A WaPUG Code of Practice provides guidance for modellers in constructing robust, fit for purpose hydraulic models. WaPUG identify four main groups of models currently being used.

- Type I - Skeletal Planning Model.
- Type II - Drainage Area Planning Model.
- Type III - Detailed Design Model.
- Type IV - Model for Sewer Quality Modelling.

The above are not intended to be clearly defined groups, but the classification provides an indication of the various levels at which models are applied. For example, models such as InfoWorks, may be used for Type II and Type III models and may provide boundary condition data for Type IV models. Additional information on broader categories of models, and the process of producing Drainage Area Plans, is included in Appendix A.

4 SET UP AND CALIBRATION OF URBAN DRAINAGE MODELS

Data required to set up drainage models falls into the following broad categories:

- **Asset data** Manhole/pipework data: manhole cover levels, sewer pipe invert levels, pipe sizes, manhole connection configurations including ancillaries and distances between manholes etc.

Operational data: frequency of cleansing, flooding incidences, overflow discharges, surcharging or pumping station failures, structural condition data, infiltration/exfiltration cracks, collapses etc.

- **Catchment data** Land use data: this covers sewer use i.e. foul/surface/combined, area draining to respective manholes (possibly derived from an impermeability survey), soil types etc.

Demographic information: population figures, commercial premises, water consumption rates, discharge consent licences (i.e. waste other than domestic) etc.

- **Hydrodynamic data** Event data such as rainfall and flow survey results are generally required as a minimum. Other information would relate to the monitoring of the performance of overflows and pumping stations.

4.1 Asset data

The sewer record data needed to build a model is as follows:

- Up-to-date OS plans (generally of a 1:1250 or 1:2500 scale);
- System layout related to a suitable plan;
- Pipe Sizes;
- Ground levels;
- Pipe invert levels;
- Pipe roughness;
- Parameters relating to ancillary structures;
- Chamber and shaft dimensions.

In general most of the data will be available from existing records. These may be available in paper or computer database form such as GeoThesis or SUS25. Much of this data is now supplied digitally in a water company specific asset database. This data is stored in formats which can be directly imported into InfoWorks. Errors may be present in the data and it is good practice to check datums as a minimum and preferably perform other spot checks on the data set before undertaking any model calibration.

4.2 Catchment data

4.2.1 Impermeability area surveys (IAS)

IAS are a common starting point for building up catchment data for drainage models. These surveys may be undertaken by survey companies and it is important that they are fully briefed on the requirements of the survey. It is often necessary to make interpretations on site conditions e.g. a paved driveway may not have a storm connection but under prolonged rainfall may generate runoff that can flow to an adjacent property with a storm drain or even to a road gully that has been wrongly connected to a foul sewer. It is detail such as this that can significantly help in the calibration of a hydraulic model.

A number of methods of data collection are available. The method selected will depend on the data collection level and type of system as well as the modelling approach adopted (i.e. the level of simplification). To illustrate the types of information and level of detail that may be collected, an example of a generic IAS data collection specification is provided in Annex B.

It is important to note that an IAS collects only information on impervious areas, not on pervious areas, and does not necessarily cover the whole of an urban catchment: frequently only 60% - 80% of the area is covered. It is common practice where the whole catchment has not been covered by the IAS to scale-up the data on a pro-rata basis.

Depending on the objectives of the model, impermeability surveys may not always be justifiable and in these instances the experience of the modeller is used in setting the percentage of the contributing area. This may be done by taking the results from a flow survey and removing the diurnal domestic profile, commercial and base infiltration flows from the storm hydrograph such that only the storm runoff response is left. Then from the inspection of the volume of rainfall falling, antecedent conditions and catchment area upstream of the flow monitor, it is possible to estimate the percentage contributing area for particular events. Catchment data generated through this process of expert judgement, estimation and calibration would not be based on direct observation, or even the extrapolation of observed data, and it would be important to note this if the data were to be used as an input to a component of a groundwater model.

4.2.2 Direct measurement from plans

The use of large scale sewerage record plans together with experience and local knowledge of flooding and the operational history of the catchment may be used to contribute to the definition of catchment characteristics for drainage models. Aerial photographs may further help to determine boundaries or changes in land use. This may help to provide information on possible recharge availability based on figures such as those in Table 5.1 and 5.2 which would be based on similar catchment areas.

4.2.3 Sewer flow surveys

As indicated above, detailed characterisation of catchments is not always justified. In such circumstances, flow surveys may be used as a means to estimate the characteristics of contributing areas. If this information is intended to be used right from the outset then this should form a criteria in establishing the location of the flow monitors. With OS maps of say 1:10 000 scale it is possible to identify developments of varying density and house types. These may be isolated and monitored independently from other areas to help typify the runoff from various subcatchments.

Calculation of the contributing areas should if possible be performed for at least three different events, e.g. short high intensity, long low intensity and typical intermittent (i.e. time series type) rainfall patterns. This is necessary to help develop characteristics of antecedent and depression storage for the catchment.

4.3 Hydrological and hydrodynamic data

Rainfall data: types of rainfall (Henderson, 1988, Gooch, 1996, Garside, 1990) data typically included in urban recharge models include:

i. The Wallingford Procedure synthetic design storms; when used in the computer based Urban Drainage models they range from 1 up to 100 year summer and winter rainfall storms.
ii. Extreme Event Time Series; WRc have developed STORMPAC to enable storms of shorter duration and time series rainfall profiles to be derived for locations in England & Wales.
iii. Annual Rainfall Time Series; This can also be derived from the WRc STORMPAC program and is used to check the performance of storm overflows.
iv. Historical rainfall records (long term)

These generated, or measured, datasets are used within the model, in combination with the catchment characteristic / contributing area data to generate the runoff component of the flow to sewer.

Winter rainfall acceptance potential: The Wallingford Procedure runoff model and the new UK run-off model requires the winter rainfall acceptance potential value. This can be obtained from the Wallingford Procedure. However, in some cases, due to local variations, the large scale maps in the Wallingford Procedure contain insufficient detail and information is checked by reference to large scale geological survey information or local knowledge.

Dry weather flows: Data from a number of sources may be used to estimate dry weather flows. Information may be derived from the following sources:

- global population figures, register of electors held by LA's;
- house counts;
- water usage statistics;
- flow surveys;

• trade effluent licences and measurements (of water usage or discharge);
• design parameters;
• post codes – GIS databases of population relating to post codes is now available as seed points.

Seasonal and diurnal (as well as weekdays to weekends) variations in dry weather flow may be significant. Where diurnal variation of dry weather flow is being measured, this should be taken at points near the head of the system.

Environmental conditions vary over the urban area. Rainfall, temperature and wind are all altered significantly over the urban environment in comparison to the nearest rural area. In comparison to annual means, urban areas can contribute to a 1°C increase in temperatures, a 20-30% decrease in wind speeds, and changes in rainfall and cloud cover of +10% or more (Landesberg, 1970).

Flooding and surcharge data: These should be obtainable from a flooding database for the catchment. These may need to be supplemented with questionnaires and possibly a site visit because sometimes people do not report incidences of flooding to local authorities for a number of reasons.

Operational records: These also offer a good source of information relating to surcharge or hydraulic performance, as surcharge levels are often evident in manholes by the flotsam or rags left on step irons which can be levelled.

4.4 Other data

Pipe condition data: These data are typically obtained from CCTV surveys, but it is worth checking the source, as this information may have been determined from back calculating information from short term flow surveys. The information is normally retained on databases such as SUS25, STC25 or GeoThesis. In the absence of roughness data it may be possible to derive suitable values from the Sewerage Rehabilitation Manual (SRM) (WRc, 1993).

Sediment depth: This information will be obtained from CCTV surveys or as a result of operational values derived from volumes of silt removed as part of operational programmes. The advantage of CCTV is that the sediment material can be identified i.e. fly ash or aggregate – they will give different roughness characteristics.

Ground levels: Ground levels adjacent to the sewer can be input to the model. The sewer modelling packages will interpolate/extrapolate these values if they are not detailed in the sewerage network. With programs such as HydroWorks and InfoWorks this is an important feature as they are able to model overland flow and thus flow between adjacent manholes; foul to foul, surface water to surface water or foul to surface water.

4.5 Calibration of urban drainage models

Following the construction of a hydraulic sewerage model, it is calibrated by comparing model predictions of flow and depth to observed data. Generally, flow surveys are carried out for a period of 6 weeks, where flow monitors are located at strategic points within the sewerage system. Rainfall is measured for input into the model.

Calibration is generally carried out as two stages. Firstly, Dry Weather Flow (DWF) calibration is carried out, whereby 'dry' days are simulated with the model. Discrepancies in the observed and modelled DWF are usually a result of incorrect representation of the catchment population, infiltration or trade flows. DWF verification is also very useful for confirming the modelled sewer connectivity. Sewers that are modelled as being connected to the wrong manhole / part of the sewerage system will generally be discovered during DWF verification. This is highlighted by flow imbalances in different parts of the modelled system.

Following DWF verification, the model is run with the observed rainfall and a comparison of the observed and predicted storm flows is carried out. Wet Weather Flow WWF (or "Storm") calibration will generally highlight areas where the impermeable and permeable contribution is modelled incorrectly, or the choice of runoff model is inappropriate. WWF calibration will also indicate whether the model is operating correctly at key sewerage ancillaries such as pumping stations and more importantly, CSOs. It is also important during WWF calibration that the depths of flow are checked as these need to be accurately represented by the model to allow flooding locations to be represented.

In all cases, should a change be required to the model based on the observations made from the flow survey, then additional site investigation should be carried out to confirm that these changes are physically justifiable. For example, this may mean confirming the presence of additional contributing area, populations, infiltration or trade discharges.

Calibration can be considered complete when the observed and predicted flows and depths are within pre-determined tolerances. Generally, those outlined in the WaPUG Code of Practice are followed. All the catchment models used in the analysis as part of this study have been calibrated against available flow survey data.

5 GROUNDWATER RECHARGE CASE STUDY

At the outset it is important to point out that urban drainage / sewerage models are generally used as planning tools for the design and modification of sewerage systems. The focus is commonly on extreme events to ensure that the systems are designed appropriately, the approach, if in doubt, is for assumptions to maximise the flow to sewer to ensure that the systems are not under-designed. These issues affect the potential value of information to groundwater modellers, as is illustrated by reference to the case studies.

A further point to note is that urban drainage / sewerage models are usually confidential property of sewerage companies. Use of the data for other purposes may not be allowed, or as a minimum, the companies may require that the data is not identified as coming from a particular catchment. These restrictions mean that negotiations may be required and protocols put in place before data can be used by groundwater modellers for specific studies.

Given confidentiality restrictions, it has not been possible in the time scales for this study to compare the outputs from urban drainage models with data generated during the development of a groundwater model. The approach has therefore been to interrogate calibrated hydraulic drainage models from a number of catchments throughout the UK to attempt to establish the types of data that may be of value to groundwater modellers.

5.1 Methodology used in case study

5.1.1 Overview of tasks

To investigate the hydrological characteristics of urban catchments the following tasks have been completed:

- seven representative catchments have been selected;
- determination of contributing area characteristics of each catchment;
- determination of runoff and flow contributions of each catchment.

Each task is described in more detail below. The results are summarised in section 5.2.

5.1.2 Catchment selection

In selecting urban catchments for this case study an attempt has been made to include a wide variety of town types in terms of size, age and setting so that broad differences in runoff and recharge characteristics between the different urban types can be identified.

The catchments selected had been modelled using InfoWorks, and included an impermeable area survey and were subject to a DWF verification as a minimum. The use of InfoWorks was an important criterion as it facilitated the proposed analysis and ensured that the flow components were in a form that could be segregated.

Seven UK catchments were selected for analysis from the portfolio available to the project team. They are given generic references to give some anonymity to the data presented. It is recognised that due to the variable nature of all catchments throughout the UK (in terms of topography, geology, climate and sewerage system development), this number of catchments is too few to provide data representative of all UK urban catchments. However, it does allow the analysis to be demonstrated and a range of indicative results determined.

For each catchment a calibrated hydraulic model in InfoWorks was available, containing information relating to DWF and surface water runoff characteristics. In each case, some degree of IAS was also available. Table 5.1 summarises the catchment characteristics of the study examples.

Table 5.1 Catchment characteristics

Catchment	Connected population	Urban area (ha)	Geology	System type	Other comments
A	35,900	1,500	Oxford Clay	Separate	Predominantly recent developments (last 50 years)
B	28,800	750	Kimmeridge Clay	Partially Separate	Old Town, situated in river flood plain
C	18,000	450	Coal Measures	Combined	Old Town, coastal catchment
D	8,400	200	Jurassic Limestones & Lias Clay	Predominantly separate	Market Town
E	2,100	50	Coal Measures	Combined	Rural
F	1,900	50	Permian Sandstones & Basalt	Combined	Rural
G	600	20	Coal Measures	Combined	Rural

5.1.3 Determination of contributing area characteristics

General approach

The extent of the area contributing to a sewer is typically determined by desk study and the characteristics of this area are determined by a combination of desk and field studies, which usually include an Impermeable Area Survey (IAS) by a specialist contractor. IASs collect only data for impermeable surfaces (defined as roofs and paved areas) but the results can be extrapolated to pervious areas. In the case studies presented here, the results of the IASs have been used to determine the relative contributions of:

- roof area to foul or surface water sewer;
- paved area to foul or surface water sewer;
- pervious area to foul or surface water sewer;
- roof area to soakaway;
- paved area to soakaway;
- pervious area to soakaway.

Determining contributing areas from IAS results

An IAS collects only information on impervious areas, not on pervious areas, and does not necessarily cover the whole of an urban catchment: frequently only 60% - 80% of the area is covered.

The 'Area Take Off' facility in InfoWorks has been used to calculate the relative contributions to the sewerage system and soakaways from different surfaces for each sample catchment as a whole, based on the IAS data. The contributions have also been calculated for residential and industrial areas within the sample catchments.

In general where the whole catchment has not been covered by the IAS the data are scaled on a pro-rata basis.

In the case of Catchment A, the IAS covered less than 30% of the catchment. A much lower percentage of the IAS was focused on industrial areas than was present in reality, therefore rather than applying this sample throughout the entire catchment, a simple land use definition analysis was carried out and the sample IAS results applied based on land use type. This prevented an unrealistically low industrial area being assigned to Catchment A in the total catchment analysis.

For this analysis, the area takeoff results have not been modified using the 10 metre rule for pervious areas (although this may have been applied in the use of the IAS data in developing the calibrated model).

InfoWorks calculates the contributing areas as follows:

1) calculate the impermeable areas contributing to foul sewers, storm sewers and soakaway systems, based on IAS results and scaled as appropriate;

2) subtract this area from the total catchment area and allocate the remaining area as pervious area;

3) divide the pervious area into area contributing to the foul system, area contributing to the storm system and area contributing to the soakaway system, based on the relative magnitude of the impermeable areas contributing to foul and storm sewers and soakaways i.e. *the split between sewer and soakaway contributions is*

assumed to be in the same proportions for the pervious area as for the impervious area.

Contribution of runoff from pervious areas

Whilst the runoff contributions of the impervious land use types (roof and paved areas) are relatively simple to determine, the contribution of the pervious area is much more complex.

In urban catchments significant amounts of rain fall onto pervious surfaces, such as grass verges, gardens or parks. This rainfall may contribute to the groundwater system through percolation or to the sewerage system as runoff. The relative magnitude of each is difficult to quantify as it is a function not only of the pervious surface characteristics (e.g. soil type) but also of the antecedent conditions. For example, if a pervious surface is relatively saturated, due to an earlier rainfall event, then it is likely to produce a much greater runoff contribution to the sewerage system than if the soil is dry. At the other extreme, 'baked' pervious surfaces in summer may produce a high runoff contribution to the sewerage system that is similar to impervious runoff response.

A second important factor determining the runoff contribution to the sewerage system from pervious surfaces is the distance of the pervious surface from the sewerage system or, more importantly, the distance from a paved area which connects to the sewerage system (by way of road gullies and drains). Rain falling on pervious surfaces a long way from any paved area, and thus from the sewerage system, is likely to infiltrate deep into the ground, rather than be conveyed as surface runoff to the sewerage system. However rainfall to a pervious surface close to a paved area is more likely to contribute runoff directly to the sewerage system.

For this reason, and because of limitations of early modelling software, urban drainage engineers have traditionally used the '10m rule' to determine pervious area contribution to hydraulic sewer models. The 10m rule is a rule of thumb which assumes that rainfall to pervious areas will only contribute runoff to the sewerage system if the pervious area is within 10m of some contributing paved area. However, many recent studies have shown that runoff from pervious surfaces does provide a significant contribution to sewer flows, even when the pervious area is a long way from the sewerage system. This, and the need to develop "conservative" models that maximise the flow to sewer, has meant that recent studies tend to ignore the 10m rule, and assume that 100% of pervious areas contribute runoff to the sewerage system, provided there is some paved area to convey the runoff to the sewer.

Hydraulic modelling software includes runoff packages, such as the New UK Runoff model, which translates rainfall data into storm flows entering the sewer. The runoff package can account for the differences in runoff behaviour between pervious and impermeable surfaces.

The runoff models used in hydraulic modelling software are empirically calibrated to account for evapotranspiration, percolation to ground and storage on pervious surfaces and impervious surfaces (such as depression storage in puddles). Parameters relating to these processes are adjusted in the model calibration until a fit with flow data is found. Evapotranspiration is generally considered to be unimportant for the 'within event' representation of rainfall losses: for example, the InfoWorks help file gives the example of only a 4% evaporative loss for rainfall falling on hot asphalt.

In the absence of field data for any of these parameters, these loss processes are commonly disregarded initially in urban drainage models, and this is the case for the case studies presented here. In other words, *it has been assumed that there is no evaporation, no surface storage and no percolation from either impervious or pervious surfaces within the catchment areas of the sewerage system.* As a result, the data presented here relating to runoff to sewer and percolation to ground via soakaway are likely to be an overestimate as these initial losses have not been included. By contrast percolation to ground in pervious areas contributing to sewer is likely to be underestimated.

5.1.4 Determination of runoff and dry weather flow contributions

Runoff contribution

For this analysis the Standard Average Annual Rainfall (SAAR) for each catchment has been obtained from the Wallingford Procedure. This annual rainfall depth has been multiplied by each of the contributing areas, determined as described above, to give the annual contributing runoff to storm and foul sewers from pervious and impervious areas and the annual flow to soakaways from pervious and impervious areas for each catchment. Flow data area expressed in $l/s/km^2$.

It should be noted that it has been assumed that all of the rain falling upon a surface is available for runoff directly to the sewerage system, or percolation ground via soakaway. In reality there are a number of initial and continuing losses that reduce the amount of net rainfall. These include depression storage, initial wetting and evapotranspiration. As a result, the data presented is likely to overestimate the total flows to the sewerage system being considered.

Dry weather flow (DWF)

In order to determine the proportion of sewer flow that can be assigned to DWF for each catchment, the calibrated models were analysed to determine the relative amounts of domestic, industrial (trade effluent) and infiltration flow.

The domestic flow element was determined by taking the population from the model and the water consumption rate from the calibrated model wastewater generator file. It is important to note that this file is used to obtain the water consumption rate, rather than a simple assumption, as each catchment has its own water consumption rate. Part of the model calibration process is to find a balance between modelled population and modelled water consumption rate so as to allow model predictions to match observed flows.

The water consumption rate used in sewer modelling is equivalent to a sewage production rate. It is typically an average figure that includes an allowance for flows that are not modelled in other ways, such as commercial flows or an element of infiltration. The figure should not be directly compared with water consumption figures used for water distribution main analysis or water demand analysis.

Trade effluent is determined from water company data on discharge permits and it should be noted that any unlicensed inputs will not be included.

Infiltration flows are determined by calibration of the sewer model against flow data from night time surveys when the only contribution to dry weather flow is likely to be from infiltration of groundwater to the sewer.

5.2 Case study results

5.2.1 Catchment parameters

The catchment parameters from the calibrated models and IAS data are presented in Table 5.2. The data include:

1) catchment area – shown for the total urban area and for areas of residential and industrial land use within the urban catchment. These figures generally refer to the exact area of the town included in the sewer model. However in the case of Catchment A (and possibly Catchment F) the area included in the model is significantly smaller the total urban area, the difference representing pervious areas of the town which are thought not to interact with the drainage system at all.
2) soil type – descriptions for each soil types are given in Table 5.3. These are similar to the WRAP classification, a simplified pre-cursor to the HOST system of soil types used to derive soil runoff properties. In urban areas NATMAP (Mackney et al 1983) defines soil properties as 'unmapped'. As such urban drainage models are a useful additional source of soil data in urban areas;
3) total trade flow – based on water company data for consented discharges to sewer;
4) water consumption rate – based initially on water company figure of 165 litres per head per day, refined as part of the model calibration procedure. This figure is used with the population data to determine volume of domestic sewage;
5) infiltration to sewer – calibrated against detailed night time flow surveys;
6) total pervious area to sewer – pervious area contributing to either foul or surface water sewer. Figures given as area in hectares and as percentage of catchment area;
7) total impermeable area to sewer – impermeable area contributing to either foul or surface water sewer. Figures given as area in hectares and as percentage of catchment area;
8) total area to soakaway – pervious and impermeable areas draining to soakaway and thus available to percolate directly to the soil water and groundwater stores. Figures given as area in hectares and as percentage of catchment area.

Note that the areas to sewer plus the area to soakaway add up to the total catchment area (i.e. (1) = (6) + (7) + (8)) i.e. there is assumed to be no part of the urban area where rainfall is not intercepted by sewer or soakaway.

The charts in Figure 5.1 illustrate the figures in Table 5.2 and show for each catchment:

- the breakdown of the catchment area in terms of land use, and
- the proportion of each of these areas that has pervious surface contributing to sewers, impermeable surface contributing to sewers and pervious or impermeable surface draining to soakaway.

Table 5.2 Catchment parameters

Catchment	Land use	Model catchment area (ha)	Soil type	Total trade flow (m^3/s)	Total population	Water Consumption Rate (l/hd/d)	Infiltration (m^3/s)	Total pervious area to sewer		Total impermeable area to sewer		Total area to soakaway	
								ha	*% of total catchment*	ha	*% of total catchment*	ha	*% of total catchment*
A	Residential	107	3	0	4,571	150	0.009	74.9	*70 %*	20.7	*19 %*	10.9	*10 %*
	Industry	10	4	0.00099	115	150	0	5.6	*56 %*	4.3	*43 %*	0.0	*0*
	All catchment	1,021	3&4	0.00943	35,912	150	0.0195	665.8	*65 %*	271.5	*27 %*	83.4	*8 %*
B	Residential	78	2	0	5,685	145	0	53.3	*68 %*	21.2	*27 %*	3.3	*4 %*
	Industry	10	2	0.00748	151	145	0	4.4	*44 %*	2.0	*20 %*	3.5	*35 %*
	All catchment	735	2	0.01994	28,789	145	0	447.3	*61 %*	215.4	*29 %*	70.3	*10 %*
C	Residential	159	1&4	0	9,367	165	0.0055	99.0	*62 %*	59.8	*38 %*	0.7	*0*
	Industrial	37	1&4	0.00046	985	165	0.00125	24.3	*66 %*	13.0	*35 %*	0.1	*0*
	All catchment	439	1&4	0.00249	17,986	165	0.01325	270.3	*62 %*	163.0	*37 %*	7.4	*2 %*
D	Commercial	14	4	0.00005	715	155	0	6.2	*44 %*	6.3	*45 %*	1.2	*9 %*
	Residential	79	4	0	3,189	155	0.0038	47.1	*60 %*	15.9	*20 %*	15.7	*20 %*
	All catchment	208	4	0.00013	8,387	155	0.0048	117.4	*56 %*	53.2	*26 %*	34.2	*16 %*
E	Residential	24	4	0	1,031	165	0.002	13.6	*57 %*	7.5	*31 %*	2.4	*10 %*
	Industry	0	0	0	0	0	0	0	*0*	0	*0*	0	*0*
	All catchment	46	4	0	2,102	165	0.002	27.7	*60 %*	14.1	*31 %*	3.8	*8 %*
F	Residential	11	4	0.00208	534	165	0	6.3	*57 %*	4.2	*38 %*	0.3	*3 %*
	Industry	0	0	0	0	0	0	0	*0*	0	*0*	0	*0*
	All catchment	40	4	0.00208	1,869	165	0.0015	25.4	*64 %*	14.0	*35 %*	0.5	*1%*
G	Residential	17	4	0.002	636	165	0	10.7	*63 %*	5.9	*35 %*	0.4	*2 %*
	Industry	0	0	0	0	0	0	0	*0*	0	*0*	0	*0*
	All catchment	17	4	0.002	636	165	0	10.7	*63 %*	5.9	*35 %*	0.4	*2 %*

Table 5.3 Soil type descriptions

Description of soils:	
Soil type 1:	*a) Well drained permeable or sandy soils, over highly permeable limestone, chalk, sandstone or related drifts.* *b) Earthy peat soils drained by dykes and pumps.* *c) Less permeable loamy over clayey soils on plateaux adjacent to very permeable soils in valleys.*
Soil type 2:	*a) Very permeable soils with shallow ground water.* *b) Permeable soils over rock or fragipan, commonly on slopes in western Britain associated with smaller areas of less permeable wet soils.* *c) Moderately permeable soils, some with slowly permeable subsoils.*
Soil type 3	*a) Relatively impermeable soils in boulder and sedimentary clays, and in alluvium especially in eastern England.* *b) Permeable soils with shallow ground water in low lying areas.* *c) Mixed areas of permeable and impermeable soils in approximately equal proportions.*
Soil type 4	*a) Clayey, or loamy over clayey soils with an impermeable layer at shallow depth.*
Soil type 5	*Soils of wet uplands:* *i) with peaty or humose surface horizons and impermeable layers at shallow depth,* *ii) deep raw peat associated with gentle upland slopes or basin sites.* *iii) bare rock cliffs and screes,* *iv) shallow permeable rocky soils on steep slopes.*

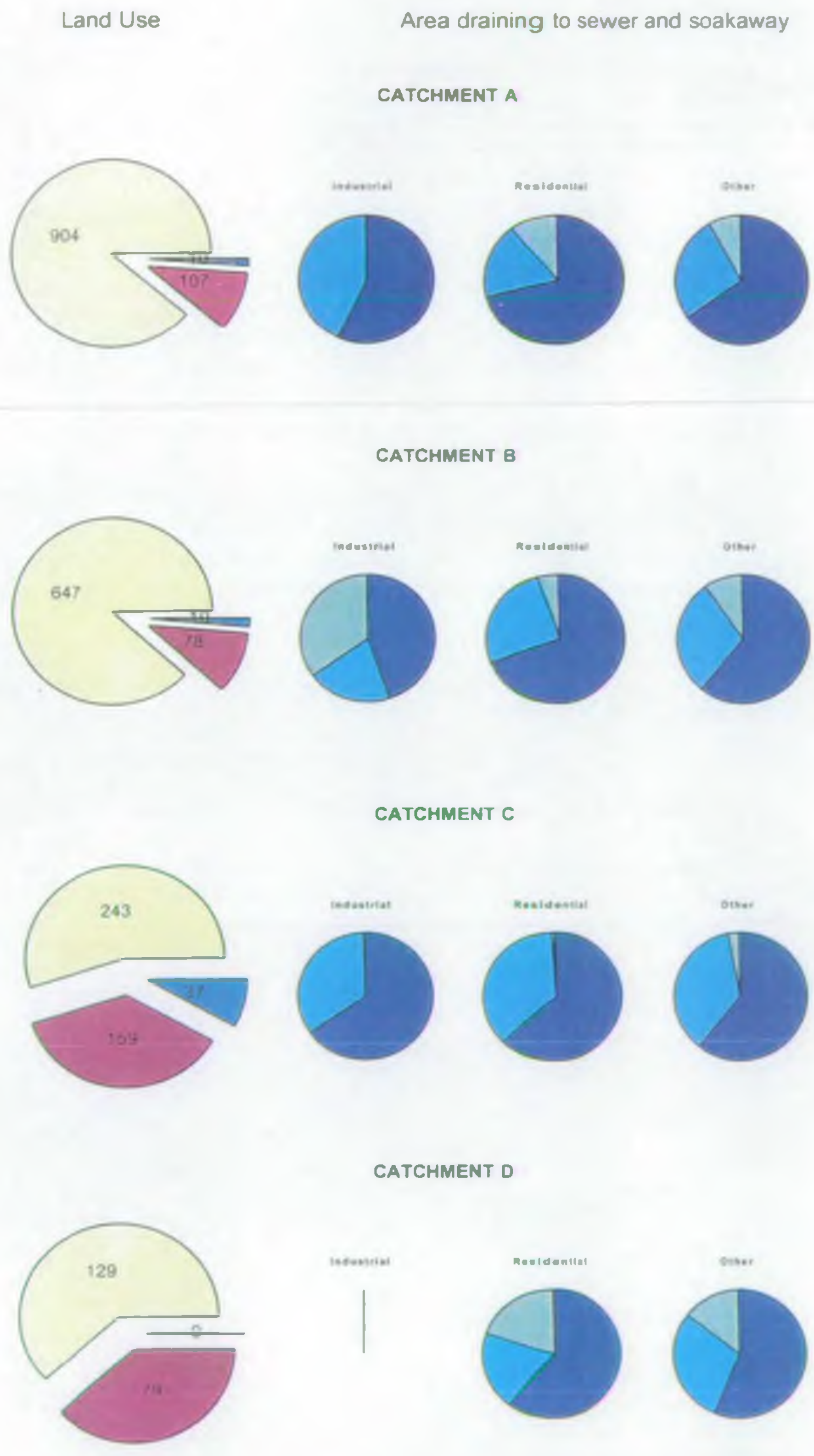


Figure 5.1 Analysis of catchment areas in terms of land use and proportion draining to sewer and soakaway

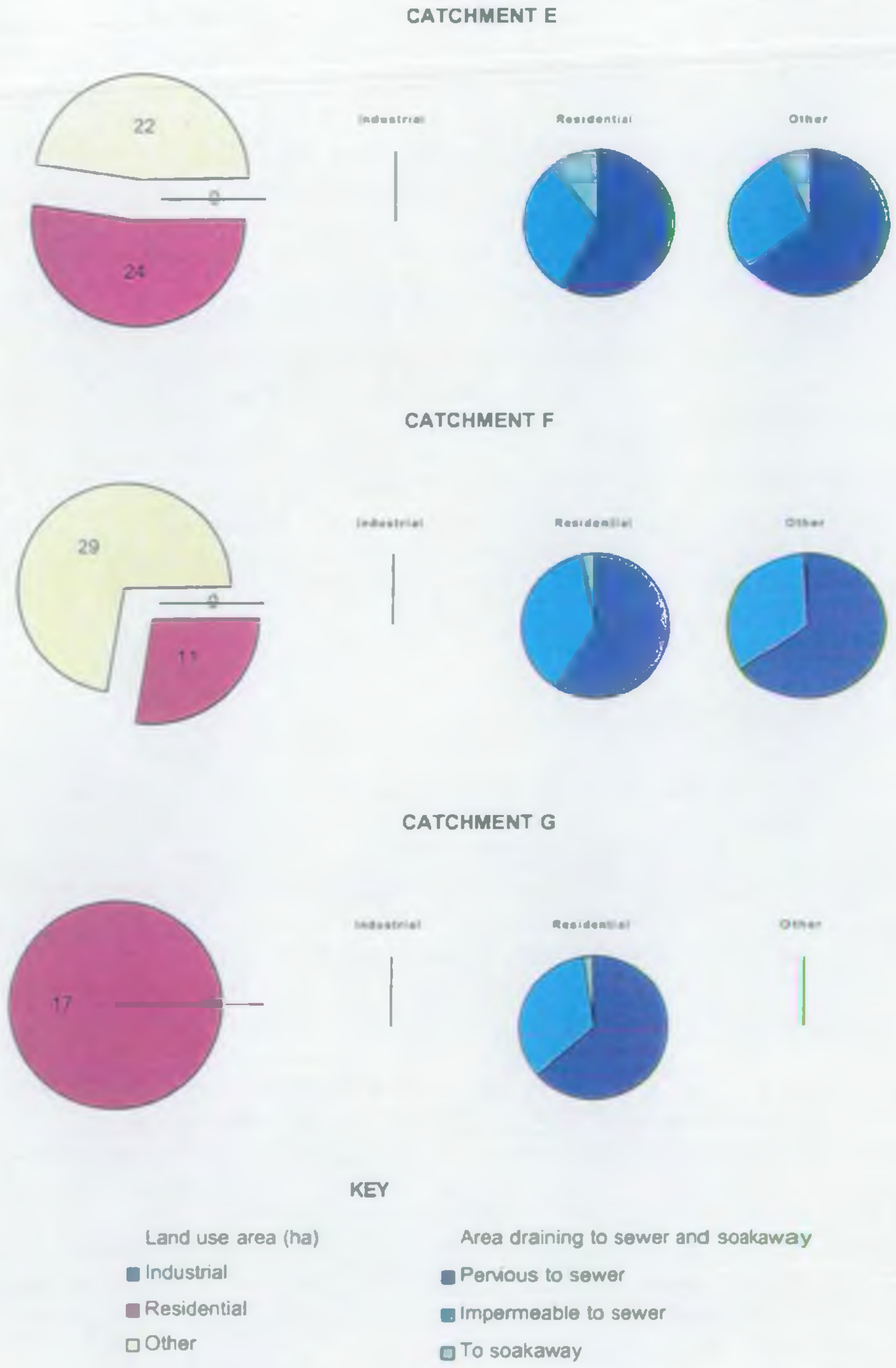


Figure 5.1 Analysis of catchment areas in terms of land use and proportion draining to sewer and soakaway (cont...).

Taking the whole urban catchment, the percentage of the catchment area defined as pervious and contributing to the sewerage systems ranges from 56% - 65%, and the percentage of the catchment defined as impermeable and contributing to the sewerage system ranges from 26% - 37%. Only a small volume (1 – 16%) drains to soakaway.

The pie charts illustrate that whilst the pervious area contributing to sewer is relatively constant, there is generally a trade off between impermeable area draining to sewer and area draining to soakaway: the catchments with a high percentage impermeability are observed to have a low proportion of the area draining to soakaway. The factors affecting the degree of soakaway in a catchment are varied, but are functions of the soil type and geology, size of catchment as well as the planning policies of the water companies and local councils as the catchments develop. There is therefore not a clear relationship between town type (in terms of size, age and setting) and percentage of urban area draining to soakaway.

There is little apparent relationship between land use and runoff surface characteristics. For example, in Catchment A there is a larger proportion of soakaway use in residential areas than in industrial areas, whereas in Catchment B the opposite is true. The distribution within Catchment C is relatively similar between residential and industrial areas.

5.2.2 Flow contribution

Table 5.4 compares the flow rates to sewer and soakaway for each of the catchments calculated from the figures given in Table 5.2. The runoff contributions to sewer and soakaway are calculated by multiplying the contributing area (Table 5.2) by the Standard Average Annual Rainfall (SAAR) depth. The trade and infiltration flows are the rates given in Table 5.2, and the domestic sewage flow is taken from the catchment population and water consumption rate (Table 5.2).

All flows are divided by the catchment area to give comparable rates in $l/s/km^2$.

The total flow in the sewerage system is the sum of the pervious and impermeable contributions to sewer, trade flow, infiltration and domestic sewage. For catchments with separate storm and foul systems this is the total volume in both the storm and foul sewers.

The flow contributions are illustrated in Figure 5.2 and discussed in turn below. In all areas, except the industrial zone of Catchment B, flows to sewer are dominated by the runoff component, rather than DWF, on an annual basis.

Table 5.4 Flow contributions

Catchment	Land use	Model Catchment Area (ha)	SAAR (mm)	Pervious contribution to sewer (l/s/km^2)	Impermeable contribution to sewer (l/s/km^2)	Flow to soakaway (l/s/km^2)	Trade flow input		Infiltration Input		Domestic sewage input		Total sewer flow (l/s/km^2)	*DWF % of total sewer flow*
							(l/s/km^2)	*% of DWF*	(l/s/km^2)	*% of DWF*	(l/s/km^2)	*% of DWF*		
A	Residential	107	650	14.49	4.01	2.12	0.00	*0*	8.45	*53%*	7.45	*47%*	34.4	*46%*
	Industry	10	650	11.64	8.98	0.00	10.05	*83%*	0.00	*0%*	2.03	*17%*	32.7	*37%*
	All catchment	1,021	650	13.44	5.48	1.68	0.92	*10%*	1.91	*21%*	6.11	*68%*	27.86	*32%*
B	Residential	78	600	13.05	5.18	0.80	0.00	*0%*	0.00	*0%*	12.27	*100%*	30.5	*40%*
	Industry	10	600	8.50	3.78	6.75	75.15	*97%*	0.00	*0%*	2.55	*3%*	89.98	*86%*
	All catchment	735	600	11.58	5.58	1.82	2.71	*29%*	0.00	*0%*	6.57	*71%*	26.44	*35%*
C	Residential	159	1000	19.67	11.90	0.14	0.00	*0%*	3.45	*24%*	11.22	*76%*	46.24	*32%*
	Industry	37	1000	20.61	11.03	0.07	1.23	*13%*	3.34	*35%*	5.02	*52%*	41.23	*23%*
	All catchment	439	1000	19.54	11.78	0.54	0.57	*5%*	3.02	*26%*	7.83	*69%*	42.74	*27%*
D	Commercial	14	650	9.41	9.45	1.75	0.37	*4%*	0.00	*0%*	9.37	*96%*	28.6	*34%*
	Residential	79	650	12.34	4.16	4.11	0.00	*0%*	4.83	*40%*	7.27	*60%*	28.6	*42%*
	All catchment	208	650	11.66	5.28	3.40	0.06	*1%*	2.31	*24%*	7.25	*75%*	26.56	*36%*
E	Residential	24	1000	18.24	10.08	3.26	0.00	*0%*	8.43	*50%*	8.30	*50%*	45.05	*37%*
	Industry	0	0	0	0	0	0		0		0		0	
	All catchment	46	1000	19.27	9.80	2.66	0.00	*0%*	4.39	*33%*	8.81	*67%*	42.27	*31%*
F	Residential	11	1000	18.64	12.31	0.76	19.45	*67%*	0.00	*0%*	9.53	*33%*	59.93	*48%*
	Industry	0	0	0	0	0	0		0		0		0	
	All catchment	40	1000	20.16	11.17	0.42	5.22	*29%*	3.76	*21%*	8.95	*50%*	49.26	*36%*
G	Residential	17	1000	19.91	11.05	0.75	11.72	*62%*	0.00	*0%*	7.12	*38%*	49.8	*38%*
	Industry	0	0	0	0	0	0		0		0		0	
	All catchment	17	1000	19.91	11.05	0.75	11.72	*62%*	0.00	*0%*	7.12	*38%*	49.8	*38%*

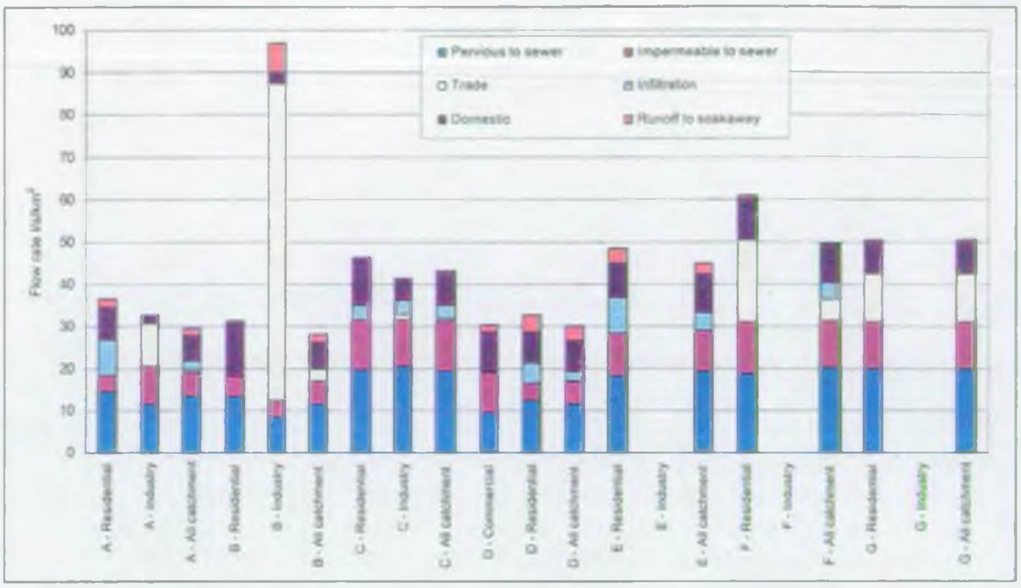


Figure 5.2 Annual average rate of flow to sewer and soakaway per km^2

DWF contribution to sewer

DWF comprises trade effluent, infiltration to sewer and domestic sewage.

The amount of trade flow varies significantly between catchments; it is a function of the type of industry found within a catchment and the density of the industry. Considering the total catchments, trade effluent ranges from 0 to 12 l/s/km^2.

However, it should be noted that the calculated trade input for catchments F and G is distorted by a single large industry in each of these small catchments, which takes the proportion of trade flow to between 30% and 60% of the total DWF. In the larger catchments, trade flow does not exceed 3 l/s/km^2. In the industrial section of Catchment B the trade discharge per square kilometre is very high at 75 l/s/km^2, more than the total flow rate to sewer in any of the other catchments. However, as this occurs over a relatively small area, the average trade flow for the whole catchment is low.

Infiltration inputs generally range from 0 to 4.5 l/s/km^2, and equate to up to 35% of the total DWF in the study catchments. These figures are typical of the UK as a whole, although in some catchments, where the sewerage system is below the level of the water table, infiltration to sewer may account for up to 80 % of DWF. There can also be specific issues in relation to how infiltration enters the sewer with regard to the pipe construction and bedding.

Leakage from the sewerage system (exfiltration) is not simulated by urban drainage models and has not been considered in this study.

Domestic sewage is generally the dominant contribution to DWF when considering the catchments as a whole. In the larger catchments the proportion of domestic sewage is highest in the residential areas.

Pervious contribution to sewer

As indicated above, the areas contributing runoff to sewer are predominantly pervious, therefore the annual volume of storm flow to sewers is mainly derived from pervious areas. However, on shorter time scales, such as individual storm events, flows from impermeable areas may be more important as they tend to arrive at the sewer with less delay and attenuation than flows from pervious areas.

There is a degree of uncertainty in quantifying the pervious area contribution to sewer: the figures in Table 5.4 indicate significant amounts of pervious runoff but these should be viewed as a maximum potential pervious contribution to the sewerage system. In reality, a proportion of the rainfall falling on these pervious surfaces will be lost to evaporation and to soil water and groundwater stores through percolation processes. These processes are not taken into account in these case studies, as is commonly the case in the initial set up of urban drainage models where specific data are not readily available.

The contribution to sewer for a given pervious surface may vary with season. For example, in winter when soils are saturated, all of the rainfall to a pervious surface may contribute to the sewerage system as runoff (although this may be considerably delayed), whereas in summer the same pervious surface may produce no runoff and instead rainfall may be lost through evapotranspiration and percolation to the soil and groundwater stores. This is an area of research that many urban drainage studies are focusing upon; whilst the variation in response from pervious runoff surfaces has frequently been observed, the modelling tools do not allow them to be accurately represented. As a result, sewer models are frequently calibrated empirically to attempt to replicate this variation in runoff from pervious surfaces.

In summary, the results presented represent the maximum sewer flow but this is likely to mean that the amount of percolation available as groundwater recharge would be under estimated if these data were used as an input to a groundwater model

Impermeable contribution to sewer

The figures in Table 5.4 indicate that the runoff contribution from impermeable surfaces represents 17% to 28 % of the total flow in sewers on an annual basis. Runoff from impermeable surfaces will be less affected by initial losses and percolation (although these do occur to some degree) than runoff from pervious surfaces and the contributing volumes are therefore more easily assessed.

5.2.3 Short term contributions to sewer flows

The data presented above consider only long term averages of the flow components over a year. The relative contributions on shorter timescales can be very different and are more important in many aspects of sewer design.

In order to demonstrate the breakdown of sewer flow over shorter time periods the hydraulic sewer models for catchments C and D have been run with a range of input storm events, and a downstream point in the catchment identified for analysis. Data have been extracted allowing the sewer flows to be separated into the relative proportions of DWF and storm response.

Figures 5.3, 5.4 and 5.5 show the response of Catchment C. Here the sewerage system is predominantly combined and therefore there is a significant input of storm runoff to the modelled sewer flow.

Figures 5.6, 5.7 and 5.8 show the response of Catchment D. In this catchment there are separate foul and storm sewers but only the foul sewers are represented in the model. Much of the impermeable area contributes runoff to the storm system, which is not modelled, therefore the storm runoff component of the modelled flow is very small.

The infiltration and diurnally varying domestic sewage elements are clearly visible in the sewer flows for catchments C and D but the trade flow elements are minor. Short term fluctuations in the domestic flow for Catchment D probably result from pump operation.

Figures 5.3 to 5.8 show the flowrates for the model in twenty four hours, recorded in minutes. The flows shown are cumulative; the meaning of the summary legends is explained below:

Infiltration

DWF: Infiltration + population flow

Trade: Infiltration + population + trade flow

Event code: Infiltration + population + trade + event flow (i.e. storm runoff).

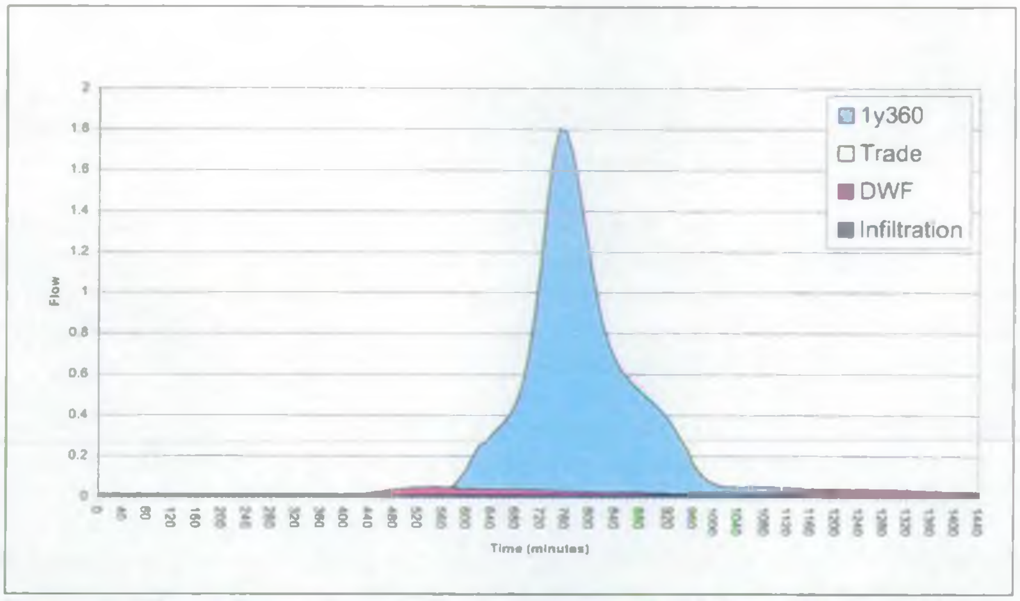


Figure 5.3 Breakdown of sewer flow – Catchment C 1 year 60 minute event

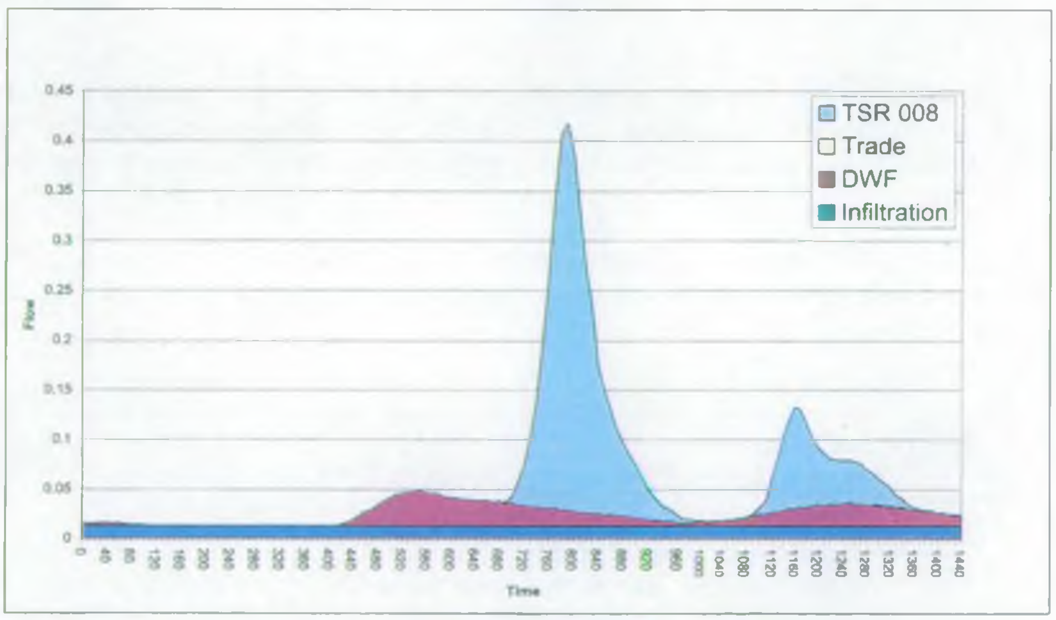


Figure 5.4 Breakdown of sewer flow – Catchment C TSR event 1

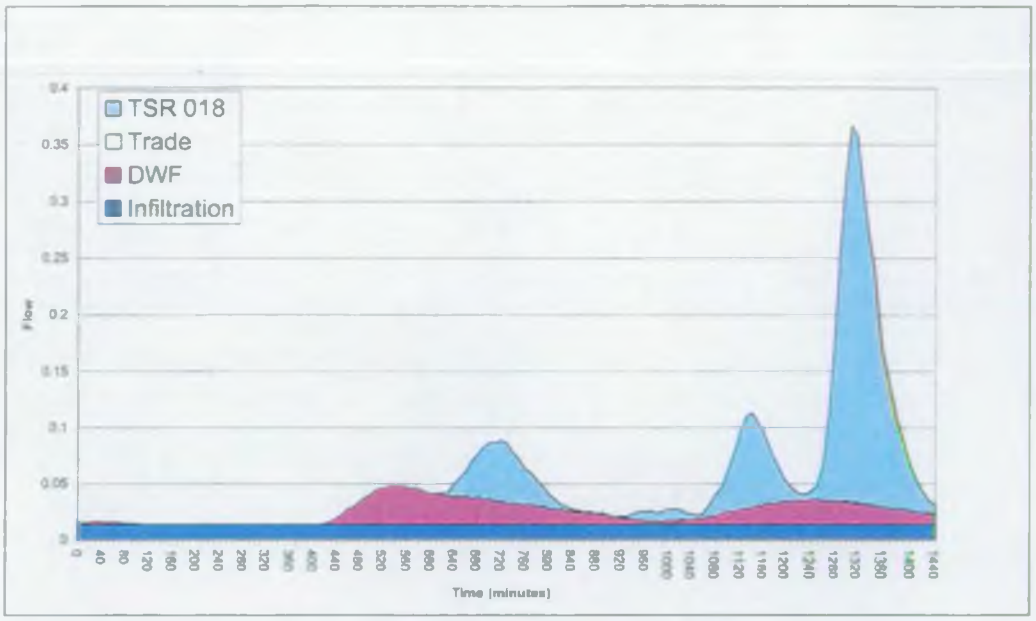


Figure 5.5 Breakdown of sewer flow – Catchment C TSR event 2

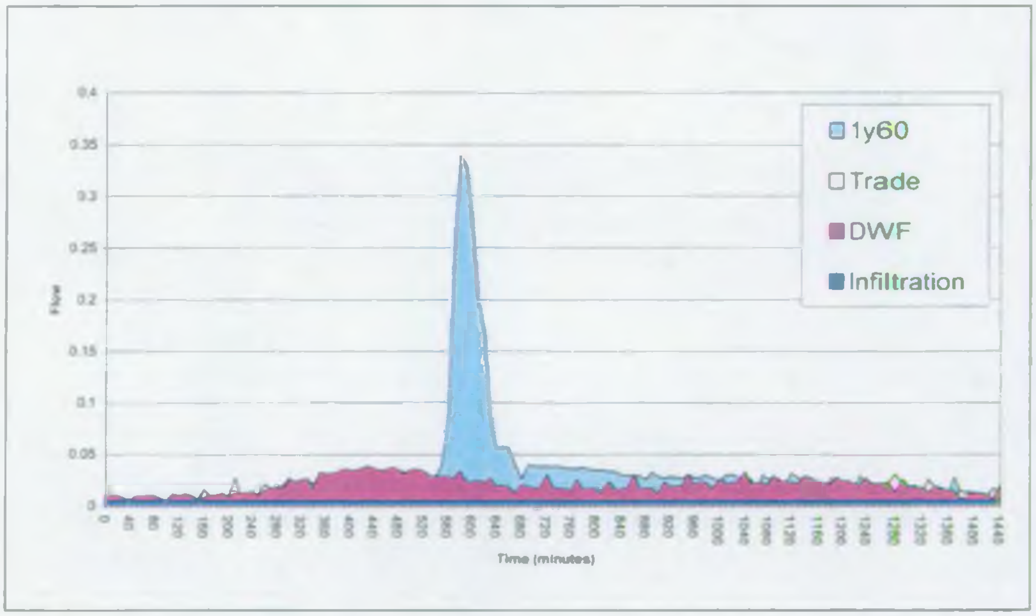


Figure 5.6 Breakdown of sewer flow – Catchment D 1year 60minute event

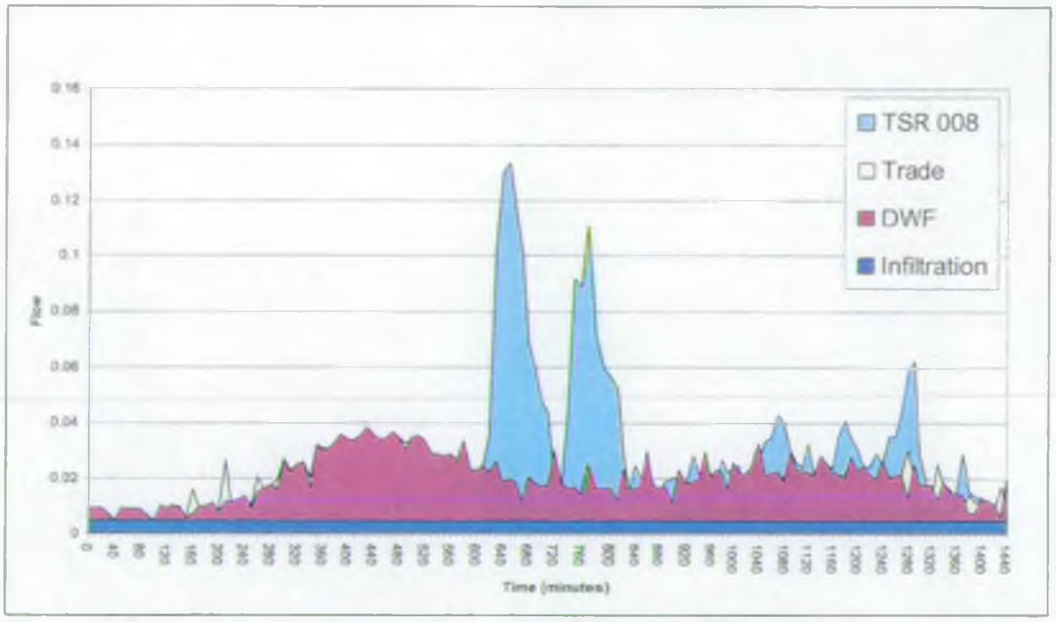


Figure 5.7 Breakdown of sewer flow - Catchment D TSR event

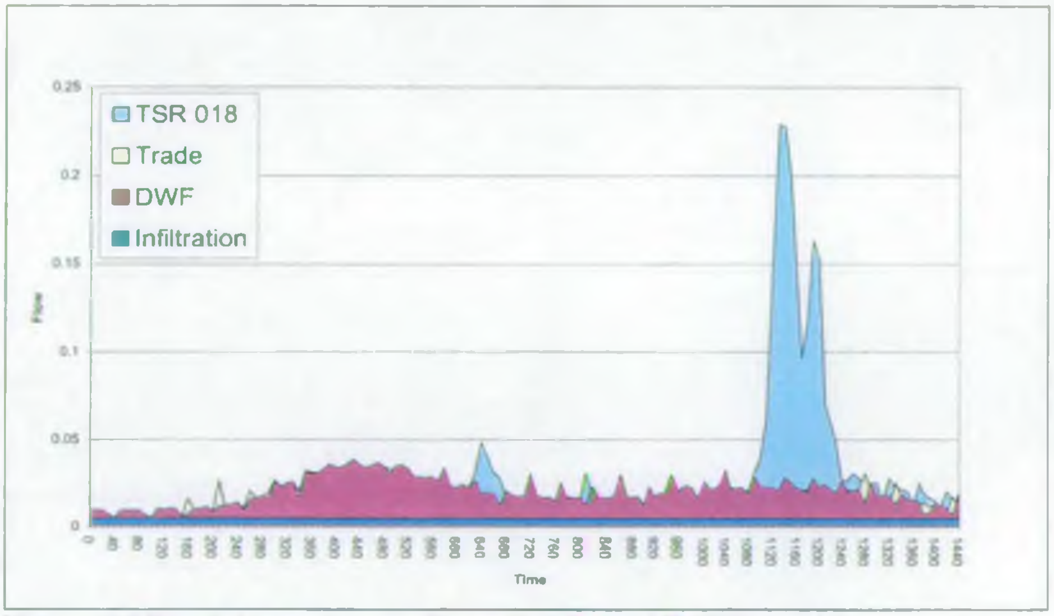


Figure 5.8 Breakdown of sewer flow - Catchment D TSR event 2

5.2.4 Flow contribution to soakaway

Table 5.4 includes data on the volume of rainfall runoff that passes to soakaway. The annual rainfall volume passing direct to soakaway (and hence to groundwater) is between 0% and 16% of the total available runoff from urban catchments. No allowance is made for evaporative losses.

With the assumptions made in this analysis, the flow to soakaway represents the only contribution to groundwater recharge in urban areas. However, it is re-iterated that this figure may increase should a proportion of the runoff from pervious areas contributing to the sewerage system percolate into the ground before reaching the sewer.

5.2.5 Calibration of the hydraulic models

The models for the study catchments have been calibrated against measured flows. If the initial match to observed data for a particular area is poor, further detailed field investigations may be carried out and parameters relating to less measurable factors, such as loss from pervious areas, may be adjusted. Typically a model will be calibrated against three different scenarios.

Examples of the calibration process for Catchment C are represented in graphical format in Figures 5.9, 5.10 and 5.11. Figure 5.9 shows the DWF at the downstream end of the catchment; Figure 5.10 shows the DWF immediately downstream of an industrial input (the 9am – 5pm trade profile is clearly distinguishable); Figure 5.11 shows the storm profile at the downstream end of the catchment.

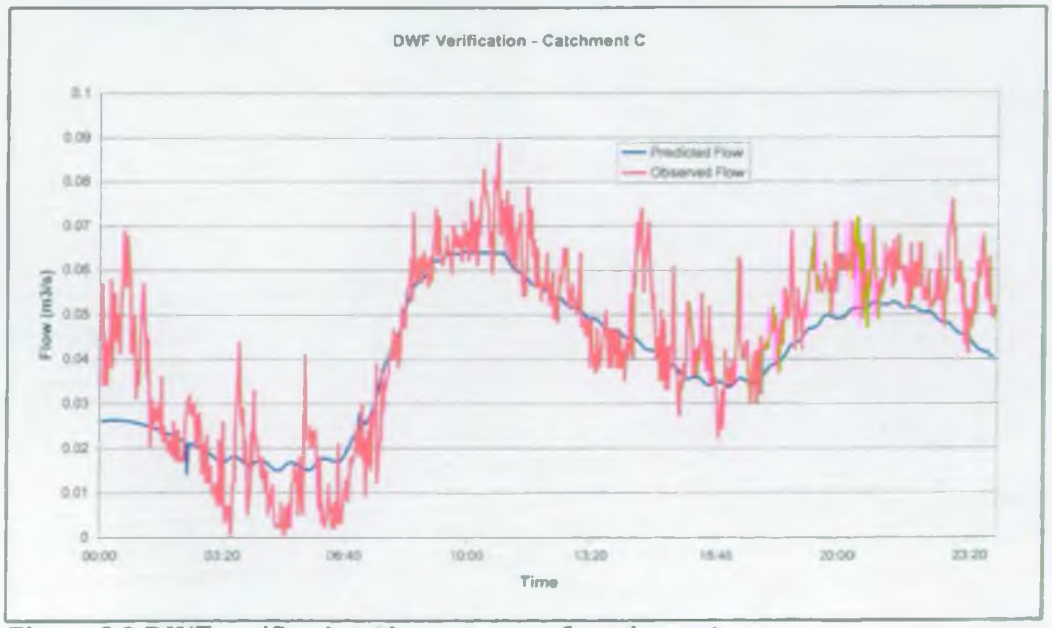


Figure 5.9 DWF verification (downstream of catchment)

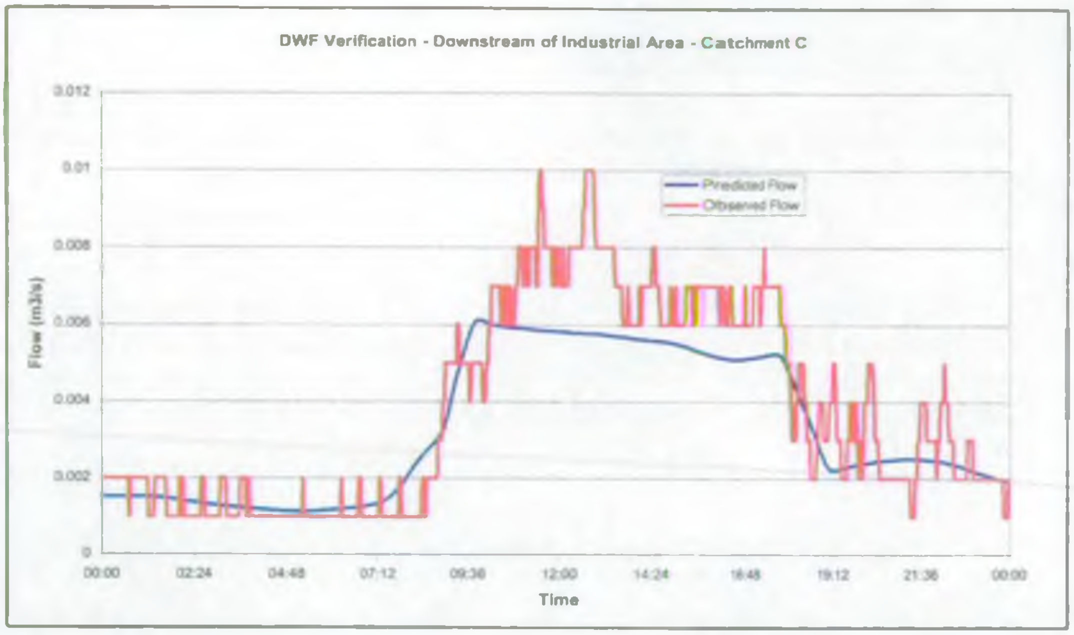


Figure 5.10 DWF verification (downstream of industrial area)

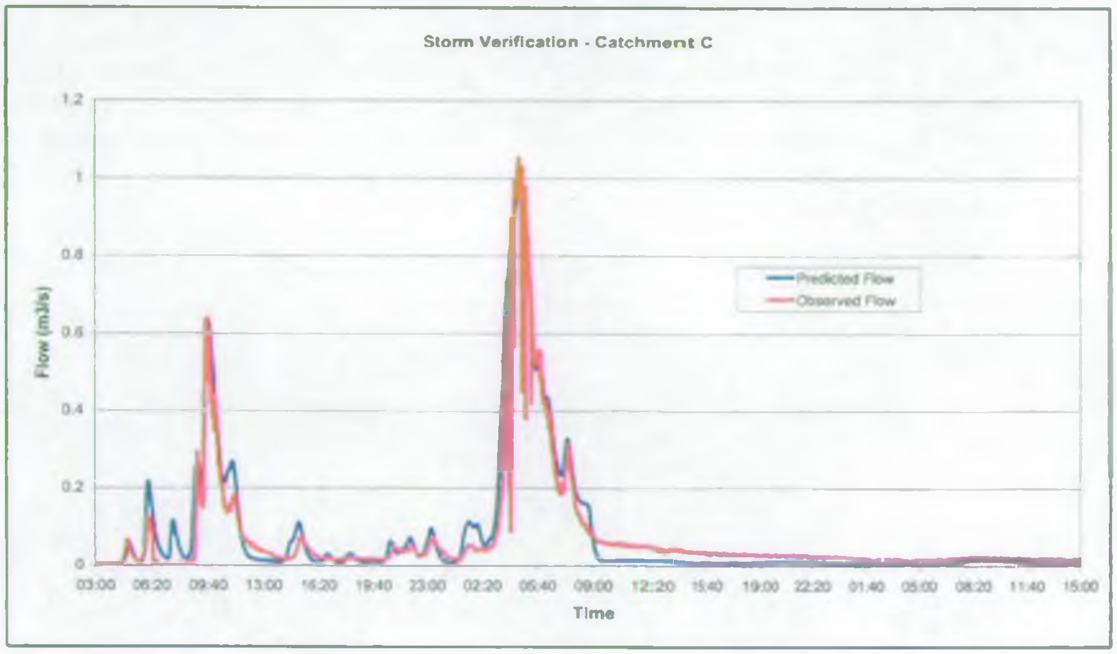


Figure 5.11 Storm Verification (downstream of catchment)

6 DISCUSSION OF POTENTIAL APPLICATIONS

6.1 Applications to groundwater modelling

6.1.1 Potential applications to urban recharge estimation

The primary aim of this study was to establish how groundwater recharge estimates may be refined by using sewer models or the data collected for sewer modelling.

The current practice in water resource modelling is to assume that a certain proportion of designated 'urban area' is made up of impermeable surfaces which produce 100% runoff through surface water drains or combined sewers. The remaining area is regarded as permeable and is treated in the same way as the rural parts of the catchment. This usually means that a Penman-type soil moisture balance is applied to determine recharge. The approach is of course a simplification: in practice the split between instantaneous runoff and recharge is not this absolute.

The main difficulties with the current approach are:

- defining the percentage cover of impermeable surfaces;
- estimating the proportion of the impermeable surface which discharges to soakaway.

In the absence of specific data the 'percentage impermeable surface' value tends to be used as a calibration parameter to produce approximately the right proportion of baseflow to runoff in simulated river flows.

Typically the split between the area producing runoff and area producing recharge is taken to be around 50:50. Any output from sewer models which helps to refine this split would be valuable.

Based on the review of urban drainage / sewer models and the results of the case studies, it is suggested that the most valuable information is likely to come from use of the IAS and its extrapolation over urban catchments that give:

- a percentage of urban area draining to soakaway, typically 10%;
- a percentage of the remaining area which is impermeable, typically 30%;
- a percentage of the remaining area which is pervious, typically 60%.

From this information alone, applying the simplified approach described above, it might be assumed that 10% of rainfall to an urban area bypasses the soil moisture balance and is available to groundwater and a further 60% is potentially available, subject to evaporative and soil moisture loss i.e. 70% of the urban area allows recharge to groundwater.

However, if the sewer model interpretation is taken into account, the 60% of the urban area which is pervious and does not drain to soakaway is not available for groundwater recharge but instead goes entirely to sewer. In this case only the 10% of the urban area which drains to soakaway contributes any groundwater recharge.

The key question is the fate of the rainfall to pervious urban areas. As discussed in the previous section this is complex and is a function of a number of factors including antecedent conditions, sewer layout and distance from a paved area. The relative proportions of rainfall (a) lost to evapotranspiration and soil moisture deficit, (b) percolating to groundwater and (c) intercepted by sewers, will vary over small distances and with time.

Within sewer models a runoff package translates the incoming rainfall profile into a profile of storm inflow to sewer. This is a function not only of the initial losses but also of catchment topography, drainage patterns, rainfall intensity etc. A simplified approach would be to subtract initial losses and then multiply the rainfall by a runoff coefficient, typically 0.7-0.95 for impervious surfaces, 0.1-0.4 for pervious surfaces.

However, data required to quantify the initial losses from rainfall to pervious areas and the subsequent translation of the remaining rainfall into an input flow to sewer are very often not available. Sewer models are therefore frequently calibrated by varying the amount of pervious area contributing runoff and the proportion of that runoff reaching the sewer, until a match with the observed storm flows is found. Often loss factors in the runoff package are left at default values and the contributing pervious area is used as the main calibration parameter. In other words, contributing pervious area and runoff coefficients are assigned values as a mechanism for generating correct sewer flows, without necessarily being based on physical characteristics. In addition the parameters used for a particular calibrated event may not be applicable on an annual basis. It would therefore be inappropriate to extract runoff data from calibrated sewer models for use in recharge estimation.

It is interesting that in the absence of any site specific data sewer modellers tend to assume that all rainfall to a pervious area becomes runoff, whereas groundwater modellers assume that it is all available to recharge (subject to losses as in any rural area). This is in part because sewer modellers are most interested in peak flows and ensuring sufficient capacity in the system. For design purposes they need to consider a worst case scenario and the flow data presented here represent maximum flows to sewer. Similarly they do not allow for any evaporative loss from impermeable areas.

However the assumption is also based on observation. Many grassed urban areas are close to sewer networks and the potential for interception is high. Traditionally it had been assumed that any pervious area within 10m of a paved area drains to sewer: this probably accounts for most urban pervious areas. This rule has now largely been abandoned because it has been observed that even more distant pervious areas contribute runoff to sewer.

The volume modelled as infiltration to sewer could also provide a useful refinement to groundwater recharge estimates. The infiltration component comprises mains leakage, groundwater or drainage from the soil store that is being intercepted by sewer but would otherwise be considered to contribute to recharge. Urban recharge estimates should therefore be reduced by this amount to account for these processes. However the infiltration component must then be included in dry weather flow discharge from sewage treatment works if a model water balance is to be maintained.

Three approaches are suggested for using sewer models to refine urban recharge estimates:

1. If reliable drainage models exist for an area within a groundwater model, and access to the data can be negotiated, information on the amount of pervious and impermeable urban areas should be extracted and used to refine recharge estimates. The origin and reliability of this data must be checked and where possible initial survey data should be used rather than taking areas directly from the calibrated model. The time required by an expert user to extract the data is not great and the benefits in terms of increased confidence in the values of runoff and recharge in urban areas are considerable. The volume of infiltration to the sewer network, which would result in a reduction in recharge rates, should also be extracted from the model.

   It should be noted that most water company sewer models are commissioned for areas where there is a combined sewerage system. Areas with separate foul and storm systems are less likely to be modelled and the models would only include the storm system in exceptional cases. However if these areas have been modelled, raw survey data would include information on catchments of both storm and foul sewers.

2. If reliable drainage models do not exist or are not available due to confidentiality restrictions, then it may be worth commissioning a sample of IAS within the catchment. This would allow estimates of permeable and impermeable areas and areas discharging to soakaway to be based on real values for the particular catchment rather than an arbitrary split.

3. If no drainage models exist and insufficient resources are available to commission new IAS, the information provided in Tables 5.2 and 5.4 of this report may allow estimates to be drawn up based on the characteristics of the urban areas summarised in Table 5.1. Again this is a refinement on the existing practice of assigning a rather arbitrary split.

In any of these cases, once the amounts of pervious and impermeable areas have been established, a judgement must be made as to how much of the pervious area contributes to groundwater.

6.1.2 Limitations on the use of sewer models to estimate urban recharge

Sewer models are developed to aid water company operation of drainage systems and to tackle particular problems such as foul flooding. A degree of caution must therefore be used in applying the results to a completely different problem, namely groundwater recharge estimation. There are a number of limitations in the use of sewer models and the data presented here in quantifying groundwater recharge in urban areas. These include:

- Time intervals in groundwater models are typically measured in days or longer, whereas sewer models are designed to investigate short term events. Sewer models are typically calibrated against only six weeks of flow survey data. There is a great deal of seasonal variability with regard to flows in urban catchments, in particular infiltration to sewers and runoff from pervious areas. Therefore the extrapolation of the data to produce annual totals and the application of the annual data to any particular time during the year may not be valid.
- The level of detail included in a sewer model is not necessarily appropriate to groundwater modelling: groundwater modellers tend to be interested in quantifying the amount of runoff and potential water available for recharge over broad areas, whereas drainage modellers are interested in contributions from particular paved or roofed areas
- IAS are only carried out on a proportion of the catchment on a sample basis, and the results extrapolated to cover the entire catchment. Also, the surveys record data only for impermeable areas: pervious areas are assumed to have the same distribution between sewer and soakaway as the impermeable areas. These assumptions may introduce errors.
- The contribution of runoff to the sewerage system from pervious surfaces is almost impossible to quantify. In this study, all of the rainfall to pervious surfaces has been assumed to contribute to the sewers (unless it drains to soakaway). In reality, a series of initial losses act to reduce this contribution, including evapotranspiration, depression storage and percolation. It is therefore likely that the estimated contribution to the sewers from pervious areas is overestimated and the figures should be treated with a degree of caution. Further research is required to determine the relative sewer/groundwater contributions of pervious surfaces in urban catchments, and how this may vary on a seasonal basis.
- Similarly, evapotranspiration, depression storage and percolation may reduce contribution to sewer from impermeable surfaces, although the effect will be minor in comparison to pervious surfaces.
- Surface water sewers are not included in sewer models; the data presented here are derived from the IAS results. Model calibration provides a check that areas contributing to foul sewer are reasonable – no such check is possible for the surface water sewer data.
- The analysis is based on only seven catchments throughout the UK and, due to the highly variable nature of urban drainage catchments, this cannot be considered a representative sample on which to derive data for application across the UK.

Limitations on the application of sewer models to groundwater modelling need to be seen in the context of other uncertainties/exclusions regarding anthropogenic components of the near-surface water balance in urban areas:

- **Leakage from water mains**. The infiltration to the sewerage system included in the drainage models may include a proportion of clean water originating from water mains leakage. However, this is not directly allocated to water mains leakage within the model, and attempts are rarely made to quantitatively differentiate between the different sources of infiltrative inputs to the sewerage system. Sewer models hold no data on the total amount of flow lost to the soil water and groundwater stores from water mains.

- **Discharges from septic tanks.** Septic tanks are not included in most hydraulic sewer models as they do not add flow to the overall sewerage system: the discharges are typically to soakaways or infiltration trenches. As a result, no data on septic tank discharge to groundwater can be extracted from sewer models.
- **Leakage from the sewerage system** (exfiltration). This can be present in a small number of catchments, although the quantities tend to be small compared to the overall peak and daily flows. Very rarely does exfiltration remove large enough quantities of flow to be included in an urban drainage model and as a result, it has not been investigated as part of this study. There are also practical difficulties in measuring the quantities.

6.1.3 The use of sewer models to estimate sewage treatment works discharge

Discharges from sewage treatment works are included in groundwater models as inputs of flow to surface water, or more rarely groundwater. Accurate estimates are therefore important for simulating the catchment system correctly. They are also useful on a smaller scale to assess components of the anthropogenic water balance.

Problems are often encountered in trying to quantify sewage treatment works discharges: records of flow rates are not submitted to the Agency and limits on consents do not necessarily reflect actual flow. An estimate of the volume of runoff derived flow from STWs, CSOs and storm drains can be made separately as part of the recharge calculation, but it is difficult to estimate the dry weather flow component.

Sewer models can be used to simulate flows into sewage treatment works and therefore to estimate discharges from sewage treatment works. Losses at the sewage treatment works through evaporation and leakage may need to be taken into account but are generally small. The model can be used to separate the flow components and evaluate the dry weather flows from sewage treatment works.

6.1.4 Potential future uses

It is possible that in the future, there may be significantly more opportunity to draw upon urban drainage models than is described here.

- Full time series hydrographs of runoff from urban areas generated from sewer models could be added to baseflow hydrographs to simulate total river flows.
- Surface water drains may be considered in drainage models as well as foul and combined sewers.
- Consideration may also be given to infiltration groundwater into sewers below the water table. In this situation, urban drainage models may be required to interact with groundwater models to simulate this condition.

The most important lesson to be drawn from this study by groundwater modellers, however, is that considerable quantities of data exist outside of that which is most familiar. By making use of data from other sources, significantly improved estimates of urban recharge and runoff may be made with very little additional cost.

How drainage models and impermeable surface surveys may be used to quantify urban runoff and recharge process

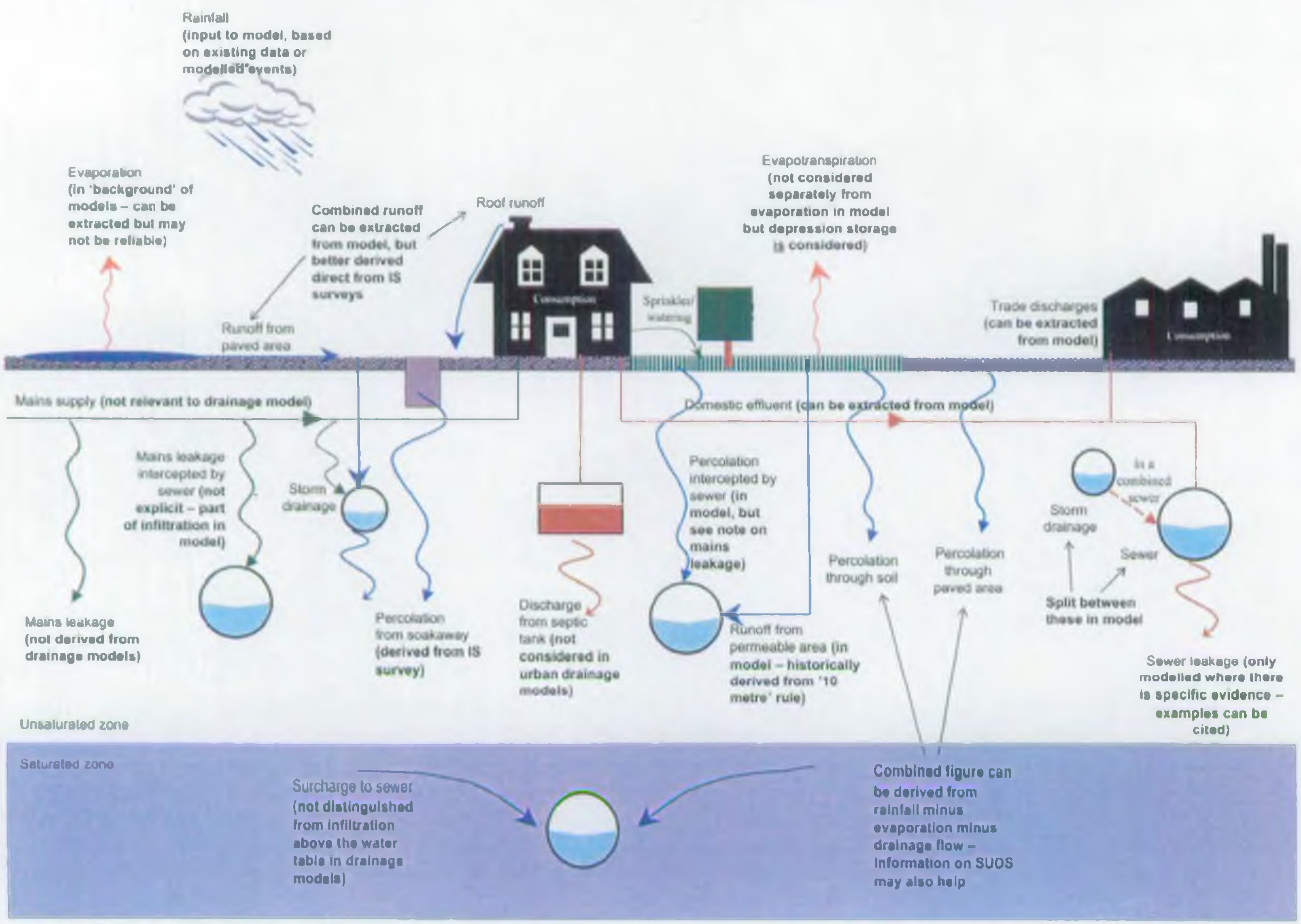


Figure 6.1 Potential data sources for quantifying urban runoff and recharge processes

6.2 Application to CAMS

CAMS are currently being developed by the Environment Agency to make more information on water resources allocation publicly available and to allow the balance between the needs of abstractors and the needs of the aquatic environment to be determined in consultation with local interested parties. The process involves the calculation of available resources within a catchment and considers how this availability may vary spatially and temporally.

Estimation of recharge is a key component of the water resource assessment process as given in the RAM Framework. One of the 'tests' which determines the availability of water for abstraction is a comparison against recharge, and therefore any improvements to the accuracy and rigour with which recharge calculations are made may ultimately be of considerable benefit to the CAMS process.

However, the potential benefits of an improved understanding of urban recharge processes go beyond simply improving the rigour with which the first test of the availability of groundwater resources is applied. A fundamental aspect of the assessment of resources is the estimation of the anthropogenic effects on rivers flows at current levels of abstraction and discharge. Historically, data on effluent discharge to rivers has been patchy or non-existent and the estimation of this aspect of the anthropogenic water balance has consequently been very approximate. Drainage models can potentially significantly improve on current estimates of effluent discharges and should also result in a much greater understanding of the fate of water abstracted, including consumption at a household level. Quantification of the different components of DWFs, including infiltration, may improve understanding of how much of the water abstracted for public supply is returned at STWs.

Flow naturalisation is an important step of the RAM methodology that, following incorporation of an environmental weighting factor, leads to the definition of hands off flows. Understanding the uncertainties in naturalised flows is therefore important. In the current methodology, flow naturalisation is carried out based on discharge licence data for STWs. Flow predictions from sewer models could, following an allowance for losses across works, be averaged and used to assess the uncertainties in discharge volumes, at least for major works, in resource assessment areas. This may help constrain one of the major variables in the naturalised flow profile for the river.

6.3 Water quality applications

The emphasis of this project has been on the application of drainage models to water resources assessments such as regional water resources models.

Quantification of urban recharge is also vitally important in the assessment of groundwater vulnerability in urban areas. Groundwater vulnerability and recharge are very closely related in that they both concern the flow of water from the ground to the water table. Where urban areas are situated on major or minor aquifers, the influence of impermeable areas is relevant to groundwater vulnerability in the same way as it is to the estimation of recharge.

Groundwater models constructed to investigate the potential of groundwater contamination tend to cover much smaller areas than water resource models and are often based on urban areas. A more detailed approach is therefore taken to assigning recharge properties to specific areas. Current practice would typically assign areas as permeable or impermeable, possibly with subdivisions for different types of impermeable surface. A percentage of the effective rainfall available for recharge is then assigned to each of the different surface types. For permeable areas this would typically be 80-90%, whereas for an impermeable surface 10% may be used.

The percentage rainfall assumed to infiltrate impermeable and permeable surfaces may be adjusted on a site specific basis to account for particular condition or properties of the surface, for example the presence of significant cracks in concrete.

This approach, which assumes there is some potential for recharge even through impermeable surface, takes the opposite view to sewer models because of the different drivers for the modelling exercise: a worst case scenario for sewer models assumes very little recharge; a worst case scenario for groundwater vulnerability models assumes the largest feasible volume of recharge.

However data collected for sewer models could be valuable:

- If calibration of a sewer model has demonstrated that a high proportion of the urban catchment contributes runoff to the sewers, the recharge to groundwater and therefore the vulnerability to contamination may be less than otherwise assumed;
- Information from the IAS may be used to assign surface type and distribute recharge parameters;
- The identification of specific areas of drainage to soakaways as part of IAS may help to identify areas where groundwater is particularly vulnerable.

7 CONCLUSIONS

The evaluation and investigation into urban drainage modelling has shown that a significant amount of information can be obtained that can further the estimation of groundwater recharge and run off and thereby improve water resource management.

One of the most promising types of information that would be of use for groundwater modellers is IAS. These are commonly carried out for sewer models and provide valuable information on the distribution of surfaces within specific areas of urban catchments. Although the IAS commonly only cover 60% to 80% of urban catchments, facilities within InfoWorks software, can be used to extrapolate and interpolate these data to cover entire catchments to estimate the areas which are pervious or impermeable and which drain to sewer or drain to soakaway. Use of this detail, on a catchment-specific basis, would allow a much greater confidence in urban recharge calculations.

This study has, however, highlighted some dangers in transferring catchment understanding from drainage models to groundwater models if this is done without careful consideration. In particular, because drainage models will tend, on a precautionary basis, to over-estimate flows to sewer, the net result is that the water available for recharge may often be underestimated. In particular, pervious grassy areas are assumed by urban drainage modellers to contribute runoff to sewer if they are within ten metres of a road or other drained area. Commonly, if no catchment data are available, the entire permeable area may be considered to drain 100% to sewer as an initial assumption. Models based on this assumption may predict flows in sewers very well, at least for short term rainfall events.

The runoff component of flow in sewer models is calibrated by varying the amount of pervious area contributing to the flow and parameters relating to initial losses, such as evaporation, until modelled flows match observed flows. In practice the loss factors tend to be fixed and most of the refinement is carried out by adjusting the areas included in the model: the final areas included may not reflect reality. Moreover parameters used for a particular calibrated event may not be appropriate on an annual basis. It is therefore recommended that the raw catchment characteristic data is referred to for use in recharge estimates, rather than extracting runoff components of flow from calibrated sewer models.

The issue of time scales is important. Although urban drainage models can be used to estimate long term average flows, their calibration generally focuses on short term rainfall events. Transposition of model output from the short time scales (minutes and hours) of drainage models to the long term (days to years) commonly needed in groundwater models, without care, is likely to lead to inaccuracies and a misrepresentation of the longer term processes that lead to groundwater recharge.

Bearing the above caveat in mind, calibrated sewer flow models could, following an allowance for losses at sewage works, be used to improve estimates of discharges from STWs. This would be valuable as an input to groundwater models that include this data in stream flow calculations. These data would also be useful for flow naturalisation that is a common simulation carried out in groundwater models and is an important aspect of CAMS. Averaged data from sewer models could be used as a sensitivity case and compared with the naturalisation output based on discharge licences to get a feel for one of the main uncertainties in the estimation of naturalised flow.

With the expanding use of GIS in diverse disciplines of water management, there is increasing potential for crossover of information. Investigations into urban recharge estimation for groundwater; interest from drainage modellers and the implementation of more complete UPM studies, which may soon incorporate river and catchment modelling, could lead to fully integrated water management plans.

8 RECOMMENDATIONS

The two main recommendations for further work are described below.

Comparison with area covered by groundwater model
It would be interesting to carry out the analysis that was used on the sample catchments in this study on an area included in an existing groundwater resource model. Subject to any confidentiality restriction, a refined estimate of recharge could be made based on impermeable area surveys and sewer model data for particular urban areas within the model, and the impact on the groundwater model output investigated.

Analysis of further sample catchments
The tables of data included here cover only seven towns, each with different characteristics. With the extreme diversity of urban areas in the UK, this selection is not necessarily representative. It would be useful to extend the analysis to a large number of catchments to provide a source of base data for future models, so that for any town under consideration, a proxy can be found with similar characteristics. It would also be useful to analyse data from a number of apparently similar towns to identify trends and differences.

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APPENDIX A: THE HIERARCHY OF URBAN DRAINAGE MODELS

It is important to remember that urban drainage models such as HydroWorks and InfoWorks are only part of a larger suite of models used in drainage planning and design. A WaPUG Code of Practice provides guidance for modellers in constructing robust, fit for purpose hydraulic models

WaPUG identify four main groups of models currently being used:

- Type I - Skeletal planning model.
- Type II - Drainage area planning model.
- Type III - Detailed design model.
- Type IV - Model for sewer quality modelling.

The above are not intended to be clearly defined groups, as in some cases the requirements of models dictate that the finished model could satisfy the criteria of more than one of the groups listed above.

The engineer, when considering the application of a model, must be certain of what the objectives are such that the correct type of model (Thompson, 1993) (see below) is produced for the intended use. Often the objectives will be influenced by budgets or time constraints. However, since the introduction of InfoWorks and greater data handling capabilities, many DAP models constructed today are similar in type and resolution to the detailed design models.

Type I - Skeletal planning model

This type of model is sometimes referred to as a Planning model. The specific objectives may cover all or some of the following:

- To ascertain the performance of the system at an outfall or to provide a network to which a more detailed subcatchment model is to be added.
- To simulate the correct tailwaters in a trunk sewer such that first and second order sewers (interceptor sewers) are pruned or simplified in the remainder of the system.
- To provide a generalised overview of the effects of development of an area within the catchment on either the Sewage Treatment Works (STW) or a trunk sewer.
- As an operational objective such that a quick understanding of the system is required to observe the flow regime evident in the catchment.
- To aid in the design of a STW (e.g. the sizing of storm tanks) or as an estimation of likely overflows during rainfall events with respect to quality and quantity.
- As a strategic planning tool

These models are typified by the extent of simplification applied to the sewerage system network. The various water undertakers dictate a range of levels of simplification guidelines but generally the number of nodes per 1000 population may be as little as 2 to 6.

Due to the level of simplification applied to these models they are not suitable as planning study models looking into localities of flooding in any detail, as they may identify the rough locality of flooding but with little accuracy.

Type II - Drainage area planning model

These models will have a significant advantage over Type I models when identifying areas susceptible to flooding. The number of nodes per 1000 people would traditionally be in the region of 6 to 20 although the resolution has increased in the last few years with computational improvements and developments in software. The model may be of a specific drainage area of a discrete sub-catchment. The objectives of such a model are likely to be:

- The identification of sewers in the sub-catchment which are prone to flooding, surcharging, reverse flows, act as throttles, susceptible to operational problems (sediment) or possibly the operation of ancillaries.
- To identify the lengths of sewer in need of upsizing or other types of remedial work.
- To analyse the operation of storm water overflows for frequencies of operation or at which storm return period operation may be anticipated.
- To assess the impact of developments on the local sewerage system.

A Type II model will incorporate all ancillaries, manholes known to surcharge/flood and sewer lengths with known operational problems. In essence only lengths of sewer with no governing effect on the performance of the system are likely to be removed.

Type III - Detailed design model

This is the type of model that may be used in conjunction with the Type I model, whereby a detailed area model of a catchment is added to an overall simplified model such that the head and tail waters of the detailed model may be simulated as accurately as possible. The use of detailed models for entire catchments would be prohibitive on resources and cost, though the use of InfoWorks has meant that there has been an increase in the level of detail that can be represented. The aim of this type of model is to identify in detail all the aspects of the sewerage system under appraisal including hydraulic and water quality characteristics.

The number of nodes per population figure in this incidence would be inappropriate as all known nodes and ancillaries would be included in the model irrespective of their effect on the performance of the overall system.

Type IV - Model for sewer quality modelling

Where a sewer quality model is to be produced, a verified hydraulic model is the first stage in this process. This model could be a combination of a Type I, II or III model with the additions described below, but it is unlikely to be a Type I model alone.

The accuracy required for such a model is generally in excess of that required, for instance, for a drainage area planning model. A verified drainage area planning model may be a suitable starting point for the construction of a model for use in sewer quality modelling.

The principal features of such a model are that it should not only accurately simulate storm flows but it should also accurately simulate the dry weather flows. It is important that the model is able to simulate the hydraulic conditions correctly both in pipelines and ancillaries for the sewer quality model to simulate sediment deposition rates and sediment transport.

The model should have the dry weather flow inputs in a form which allows different water quality parameters to be applied to different inflows, for example, major trade effluents should be input as inflow hydrographs.

Drainage Area Plans (DAPs)

The UK Water Utility companies are currently running a programme of generating hydraulic models based on STW catchments that at present do not have specific objectives other than the desire to have the sewer network modelled; these models are being produced as part of a DAP Exercise. Models such as these are intended to be used in the future for assessing the impact of possible developments on the STWs/sewerage system within the catchment, along with any operational performance criteria (overflow frequency, lengths prone to sedimentation etc.).

The use of DAPs has been found to be more cost effective and afford greater confidence in the end use of the models compared to the use of previously developed models for objectives other than their original purposes. The reason for this is due to one or more of the following:

- Varying degree of details in the model due to simplification. This often comes about when detailed planning models are extended to cover additional areas to satisfy new requirements of the model. A problem which used to occur, with packages such as WALLRUS where the modeller was limited to 400 nodes, is that the remaining part of the catchment would be oversimplified to ensure that maximum number of nodes was not exceeded, though such problems are now less common.
- Misconceptions about the original model may be passed on to the overall model, i.e. percentage values for contributing areas may have been exaggerated due to poor interpretation of the antecedent conditions. This results in the overall model exhibiting greater/lesser storm response volumes than in reality.
- Errors inherent in the original model, which for reasons of the original model's objectives are not considered in detail, may have ramifications for the new intended use of the model. This may come about in the incidence of water quality modelling. The original model may have been developed to analyse capacity problems in the system and as such overflows may have been omitted owing to a desire to eliminate them from the system. If this was not correctly documented then receiving water courses may be perceived to be less of a water quality problem than in reality.

One possible hydrological application of this data is for stream naturalisation estimation. Stream naturalisation in the context of catchment modelling is turning off all the abstractions and discharges to groundwater and surface and seeing how the system would behave without these manmade influences.

Usually abstractions are well documented, because abstractors have to report what they take each month but discharges are much more of an unknown, often because the quality of the water is of more importance than the volume and there is not the same reporting system available.

Currently, the only way to estimate what the discharges are, is from maximum daily volumes or allowable dry weather flows given in the discharge consent. Generally, all DAPS will have a reference to the STW and what it would generally discharge, though this would only be a consented treated flow rate. Other than that, DAPs do not really go into more detail at the STW but may provide more information than is currently available.

APPENDIX B: METHODOLOGY FOR IMPERMEABLE AREA STUDIES

Domestic, public buildings and factories

All rain water down pipes must be tested and several methods of testing may be used:

i. Firstly a visual check will immediately identify any rain water down pipes entering bathroom hoppers or kitchen gullies, notice also if any paved drives or patios drain to low lying kitchen gullies.
ii. If the Rain Water Down pipes discharge to an open gulley either of the following tests can be applied.
    a. Dye test: this is the most positive and involves a small amount of dye being washed down the gulley with water and checking to see if this dye can be seen flowing through the foul manhole.
    b. Drop test: while watching the level of water in the gulley, have the assistant lift the cover of the foul manhole slightly and drop. If the gulley is connected to the manhole the level of water will show signs of movement.
iii. If the rain water pipes enter the ground with no gulley the following tests should be applied.
    a. Dye test: if a bungalow it can be possible to pour water and dye into the gutter and check for a flow of dye in the foul manhole.
    b. Acoustic test: while listening close to the open foul manhole have the assistant gently tap the Rain Water Down pipe, if connected it should be possible to hear the sound in the open manhole. An electronic listening device can also be used when the result is unclear.
iv. Patio and drives draining to open gullies should be tested with either the dye test or drop tests as above.

Highway road gullies

- Dye testing: with the appropriate foul or surface water manhole open, place dye in an upstream road gulley and flush through with water using the hydrant standpipe. If connected, dye will be seen in the relevant manhole.
  Different coloured dyes must be used to avoid confusion when carrying out several tests in one area.
- Acoustic testing: with the road gulley open and the rodding eye removed, strike the foul manhole cover with a hammer or similar tool, it should be possible to hear the sound through the gulley
  This procedure can be reversed i.e. open foul manhole and strike the gulley rodding eye, it should be possible to hear the sound through the manhole.
  An electronic listening device can be used if the results are unclear.
  The procedures above apply to playgrounds, car parks and other paved areas draining through similar gullies.

Additional information

All road gullies to be shown on field sheets with tested ones highlighted.
All tested houses to be clearly marked on field sheets
Arrows showing direction of flow in manholes.
Arrows showing drives contributing to roads.
Notes of surcharging in manholes.

Any relevant information from householders/locals regarding problems with sewers.

Results

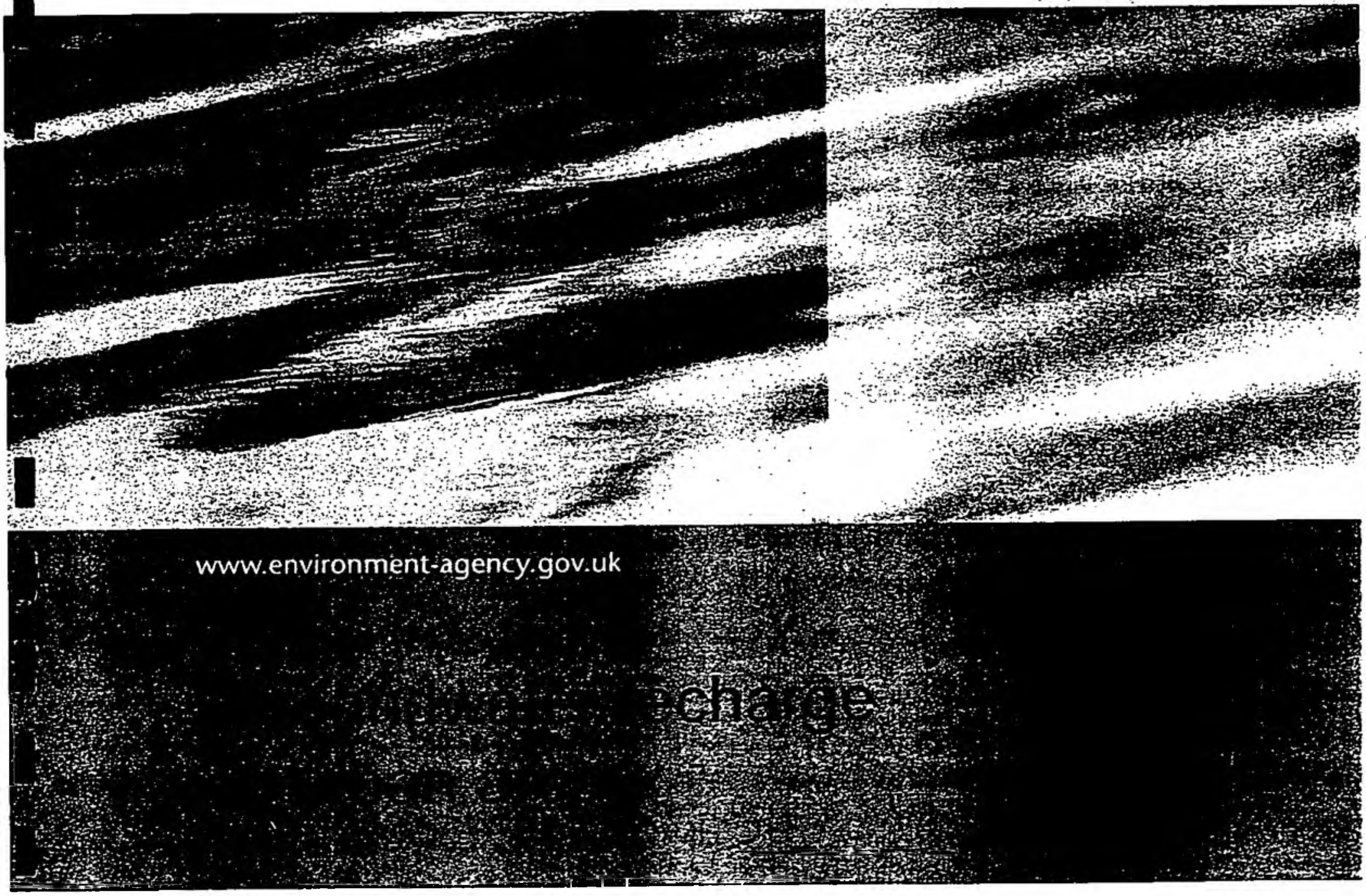
When houses are physically tested these results must be used on site to interpolate drainage types for adjacent dwellings. Important factors to note will be: age, design, type of guttering, signs of modifications.

All houses and paved areas are colour coded on field sheets to ensure accurate interpretation by office staff.

Neat plans will be prepared after which they must be checked by site staff to ensure that they have been accurately understood.

Colour coding is then transferred to GIS via the Ordnance Survey Landline data

NC/01/59



National Groundwater and Contaminated Land Centre
September 2002

30 front & 30 back

enclosed

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