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The Long Reach Macro Model - a case study

Presented by

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Introduction

This paper sets out the work that was carried out by DHV Burrow Crocker Consulting for the macro model of the Long Reach catchment on behalf of the Drainage Area Planning Section of Thames Water Utilities. The work was carried out between March 1991 and June 1992.

The Long Reach Catchment

The catchment for the Long Reach Sewage Treatment Works is located in northern Kent and the south-eastern suburbs of London within the Thames Water Utilities area. The catchment covers a total area of nearly 54,000 ha, includes all of Dartford, Sevenoaks, Bromley, most of Bexley and part of Croydon. The population is about 840,000 with several major industrial areas. The catchment has wide variations in development types and ranges from dense urban areas to wide expanses of rural countryside. The Average Annual Rainfall ranges from 550mm to 800mm. The catchment represents possibly the largest geographical area that has been modelled by a single model. The location of the catchment is shown in Figure 1:-

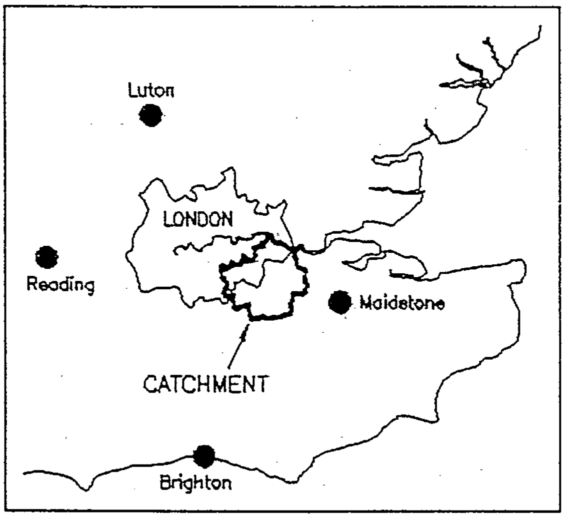

Fig 1 Catchment Location

The catchment is served by a (nominally) totally separate sewer system and has a network of Trunk Sewers which range in size from a single 300 mm dia pipe to twin 1800 mm dia pipes. The total length of Trunk Sewers is 152km with several lengths twinned or triplicated. The overall length of foul sewers in the catchment is in excess of 1,200km. There are numerous chambers (Connexion Chambers) on the Trunk Sewers where penstocks or weirs can be adjusted to distribute or divert flows between different sewers. The system is primarily gravitational with only the extreme western part of the catchment and low lying land bordering the River Thames served by pumping stations. The average daily flow into Long Reach STW is 140,000 m^3/day and the catchment has a time of concentration of approximately 6 hours with peak dry weather flows into the STW of 2,370 l/s occurring at 14.00 hrs.

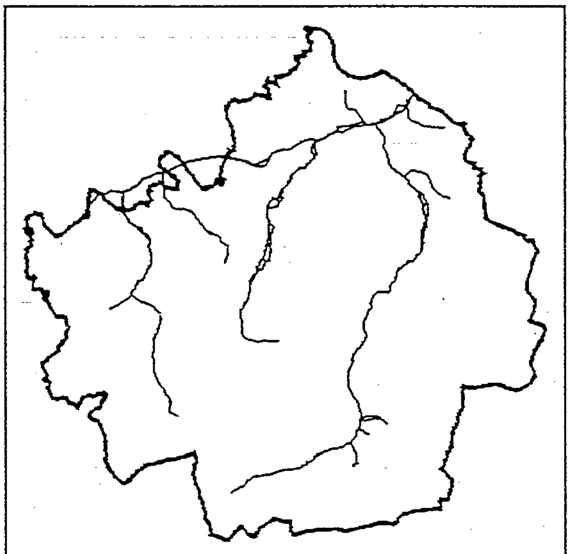

Fig 2 Layout of Trunk Sewers

The backbone of the sewer system is the West Kent A & B main Trunk Sewers which drain eastwards to the Long Reach Sewage Treatment Works and which intercept and collect flows from sewers (frequently duplicated or triplicated) which flow northwards along valleys (the Darenth Valley Sewers, the Cray Valley Sewers, the Chislehurst Sewer, the Ravensbourne Sewers). The Croydon area on the western side of the catchment is served by the South Norwood Sewer. The general arrangement of the sewer system is shown in Figure 2:-

The catchment can easily be divided into 7 sub-catchments, by the ridge lines between the valleys of the rivers Darenth, Chislehurst and Cray, the western (Croydon) area and the West Kent A & B sub-catchments. These sub-catchments are shown in Figure 3:-

Fig 3 Sub Catchments

Model Objectives

The Long Reach Macro Model was required to meet the following objectives:-

i) To study the complex factors affecting the operation of the Trunk (foul) Sewer system and to simulate the effects of operational changes to the system on a catchment wide basis.

ii) To provide information on incoming flows and water / surcharge levels at the boundaries of future more detailed models which may be constructed to evaluate the hydraulic performance of specific areas in greater detail.

iii) To evaluate the global effects of new development.

iv) To assess the hydraulic performance of the stormwater overflows.

Model Building and Simplification

The KeyWallingford program which links between AutoCAD and WALLRUS was used to store all of the original data, to generate the SSD files and to prepare all of the report drawings. The sewer data from nearly 1500 No 1:1250 scale sewer plans was digitised into KeyWallingford. It was found however that the size and complexity of the model meant that the speed of the program was a constraint on the revising, modifying and updating of the SSD files. As a result of this revisions etc to the SSD files were made using the data editor in WALLRUS.

In order to model the system which comprises a series of relatively large diameter Trunk Sewers often duplicated or triplicated with numerous relatively small side branches it was necessary to follow a very strict procedure for merging, pruning and equivalencing.

The model included all of the Trunk Sewers and the majority of the Connexion Chambers. The Connexion Chambers are frequently complex structures and their inclusion in the model to simulate the correct hydraulic conditions (especially with variable settings to weirs, penstocks etc) was frequently very difficult. An example of a Connexion Chamber is shown in Figure 4 and a schematic representation of how it was modelled is shown in Figure 5.

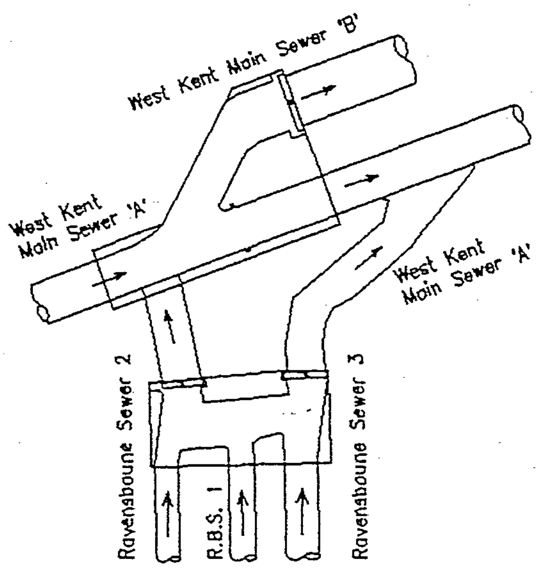

Fig 4 Connexion Chamber Ref No 38/71-001

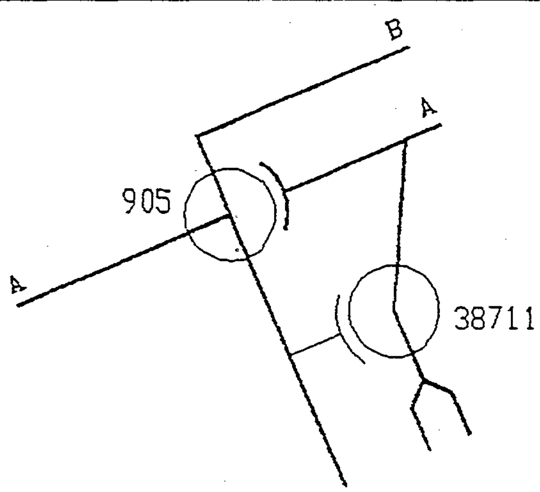

Fig 5 Modelling of Ancillary Ref No 38711

There are over 120 ancillaries in the catchment and in order to keep track of them and to ease their reference in the model the ancillaries were referenced by means of the 1 km Ordnance Survey Grid square and then by a unique reference number within that square. For example Ancillary 38/65-001 is the first ancillary within the grid square TQ3865. The reference numbers were then simplified to 5 digits for use in the model (eg 38651). These reference numbers cannot be entered using the WALLRUS editor and were entered externally.

The final model contained a total of 1,924 nodes, 58 on-line tanks (including all stormwater overflows) and 12 pumping stations.

The sequencing of the records in the model was extremely complex due to the Connexion Chambers with 2 outgoing Trunk Sewers and the need for the continuation flow from a tank having to appear in the SSD file before the overflow pipe. This resulted in the frequent use of junction records. An example of the complexity is shown in Figure 6.

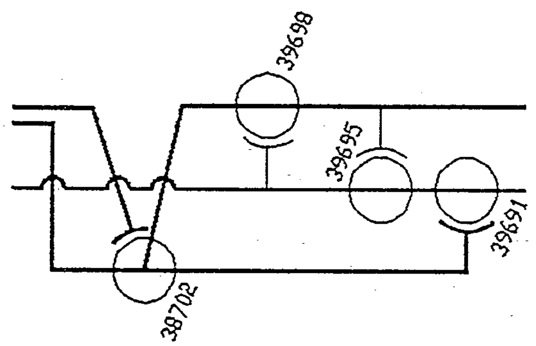

Fig 6 Example of Model Complexities

The numbering of pipes along branches was generally in increments of by 3 and alternate branch numbers were used. This will allow subsequent additions to the model to fit into the existing numbering.

Flumes

At several locations in the catchment there are round bottomed flumes which were previously used for measurement purposes (to charge the individual Borough Councils) but 4 of them controlled the continuation flow at stormwater overflows. Flumes can be modelled using WALLRUS by means of a head-discharge relationship but it is important to note that WALLRUS works on the difference in depth of flow across the flume not absolute depths. The head-discharge characteristics were derived from a purpose built program and the depth-flow characteristics of the downstream pipe were then deducted (using a spreadsheet program) to derive the head-discharge relationship for modelling. An example is shown in Figure 7.

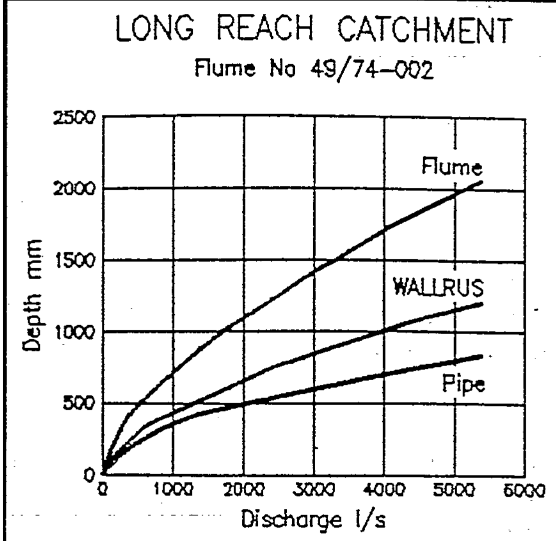

Fig 7 Head-Discharge Characteristics for Flume Ref No 49/74-002

Surveys

Over 700 manholes and 70 sewer ancillaries were surveyed as part of the study. Most surveys of the Connexion Chambers were undertaken at night during periods of low flow (typical diurnal variation ranged from 0.15 to 1.8 dwf).

A short term flow survey was undertaken in 2 phases. The first phase comprised 54 flow monitors most of which were utilised for determination of impermeable areas. The second phase comprised 53 flow monitors with 32 of these utilised for verification and the remainder for the determination of impermeable areas.

Dry Weather Flows & Dry Weather Verification

Though the system exhibits a significant storm response the sewer system for the catchment is nominally totally separate, apart from a few known small combined areas. In view of this it was necessary to consider the dry weather flows in detail to ensure that the model simulated the dry weather conditions correctly prior to attempting any storm verification.

The dry weather flows were determined and input to the model on a pipe by pipe basis. The flows were derived by determining the drainage area for each pipe and categorising the type of development into one of 5 density categories which were distinguishable on 1:10,000 scale mapping. The number of houses in each drainage area were then derived and 1 dwf flows were then calculated.

The diurnal variation in dry weather flows was derived from the observed dwfs' at various upstream locations throughout the catchment. The flow monitors used were selected to avoid masking of the variation by the time of concentration and any attenuation in the system. The monitor readings at two minutes intervals were averaged to give values at ten minute intervals and average daily dwfs' calculated. The ten minute averages were then divided by the average dwf figure to obtain the dimensionless variation about 1 dwf. These hydrographs were then plotted and compared and then either discounted or averaged to obtain a representative diurnal variation hydrograph for that particular part of the catchment.

The original intention was to produce a single .DWF file for the whole of the catchment but in deriving the diurnal variation hydrographs for the different sub-catchments a considerable variation was revealed. The use of a single .DWF file (averaged on a weighted basis) resulted in poor dry weather flow verification. As a result of this an alternative approach using the Land Use Index facility in WALLRUS was adopted. This index is included in WALLRUS to define dry weather inflow areas.

Diurnal variation hydrographs were derived for each of 9 sub-catchments. For each of the 9 sub-catchments a Land Use Index (1 to 9) was allocated and the corresponding number inserted in the pipe data (card 18) in the SSD file. The .DWF file had 9 columns of data with each column being the diurnal variation (dimensionless) hydrograph for the areas. The sub-catchment areas allocated the different Land Use Indices are shown in Figure 8.

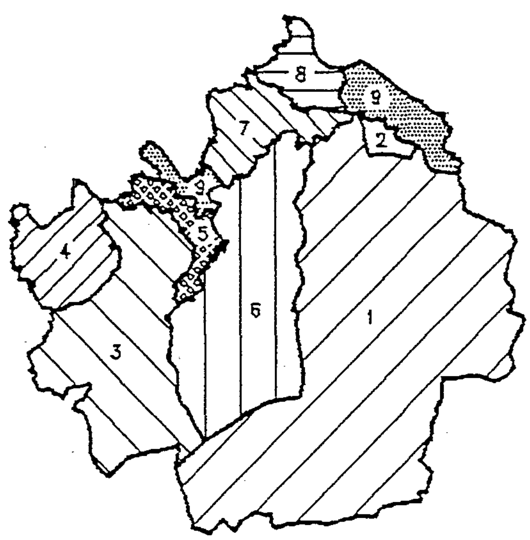

Fig 8 Land Use Indices

The overall volumes balances in the model were initially very poor due to the very large sub-catchments, differences in water consumption and the inevitable errors resulting from the sampling techniques used to derive the dry weather flows. The 9 diurnal variation hydrographs were therefore also used to adjust the volume balance by means of factoring the values in the .DWF file to correspond with the observed dwf flows at the most downstream monitor in each sub-catchment.

With the benefit of the improved representation of the diurnal variation it was then possible to identify and eliminate the modelling and connectivity errors in the model on the dry weather flows before the storm verification was carried out.

A typical comparison for the dry weather verification is shown in Figure 9. The simulation time used to achieve satisfactory verification was the 24 hour typical day plus an 8 hour stabilisation period at the beginning which was required because of the very long time of concentration. The first 8 hours results were stripped off the results file prior to plotting.

The modelling of the dry weather flows was difficult and time consuming. The on-line tanks especially where high surcharged flows occurred had a tendency to generate enormous inflows. The model was found to be very sensitive to the choice of overflow coefficients and downstream pipe gradients. Pipe junctions at overflows resulted in severe instabilities.

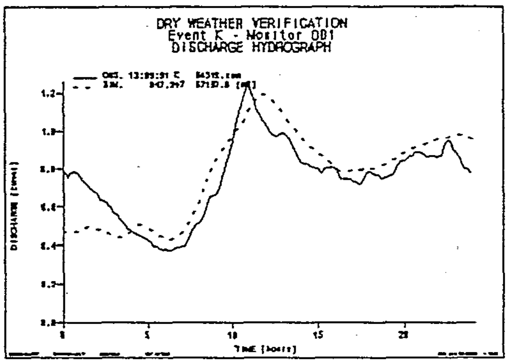

Fig 9 Typical Dry Weather Verification

Determination of Impermeable Areas

For the majority of the catchment it was considered that attempts at determining the impermeable areas by means of surveys would be very expensive and unlikely to produce satisfactory results since most of the areas would be mis-connections to the (totally separate) foul sewers.

Conventional impermeable area surveys were however carried out for the small areas of the catchment that were known to be served by combined sewer systems.

The impermeable areas for most of the catchment were derived from flow survey data by means of a specially written AutoCAD computer program. The program worked by reading rainfall data files and the flow monitor data for storm days and for dry days. The typical dry weather flow hydrograph was deducted from a storm hydrograph to give a storm response hydrograph. With the data shown in graphical format on the screen it was possible to see easily if there were major data errors or a very poor match between the dry weather flows in the non storm sections of the hydrographs. The time to peak between peak rainfall and peak storm response was then determined by picking the two peaks. A period of rainfall was then selected and the corresponding period on the storm response hydrograph was automatically selected and offset from the rainfall by the time to peak. The 'effective' contributing area was then calculated by the program by dividing the storm response by the rainfall. An example of a typical plot is shown in Figure 10.

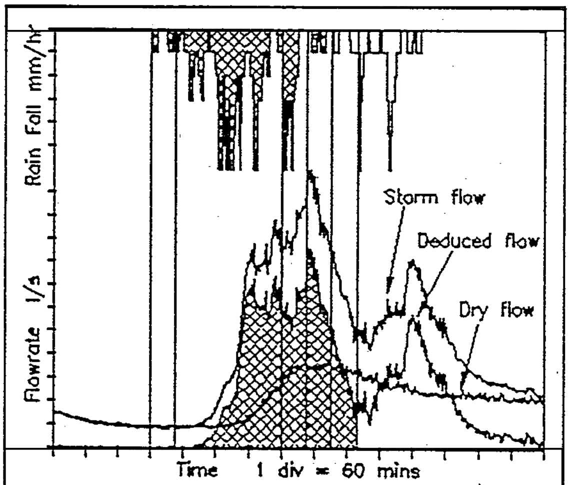

Fig 10 Typical Impermeable Area Determination

The 'effective' contributing area was then converted to contributing area using the Percentage Runoff derived using the Wallingford procedure. The percentage runoff is given by the equation:-

$$PR = 0.829\ PIMP + 0.078\ UCWI + 25\ SOIL - 20.7$$

For the determination of the impermeable areas a total of 67 flow monitors were used and for each it was necessary to make a number of assessments:-

PIMP was initially derived from a subjective judgement of the characteristics of the individual sub catchments. This was based on information obtained from the Local Authorities and was generally:-

-for known areas which were on a combined basis a PIMP of 50% was initially used.

-for areas known to be served by soakaways or separate surface water sewers an initial PIMP of 90% was used.

-for areas known to be partially separate an initial PIMP of 70% was used.

After the initial calculations had been carried out the PIMP was re-adjusted on the basis of the effective area per house. For effective areas per house less than 15 m^2 a PIMP of 95% was used on the basis that these areas were nearly totally separate. For effective areas up to the low 30's a PIMP of 90% was used and for most other values a PIMP of 70% was used except for known combined areas where a PIMP of 50% was still used. The value of PIMP that was used to determine the effective areas was also used as the percentage fast response in the SSD file.

For SOIL the values shown on the Wallingford Procedure Maps were used. Parts of the catchment have soil types 4,3 and 2 but the majority has soil type 1 with a SOIL value of 0.15.

The UCWI values for each sub-catchment were derived from the design values contained in the Wallingford Procedure Manual base on Standard Average Annual Rainfall.

The contributing area to each pipe was derived by apportioning the total contributing area upstream of the flow monitor as a fraction of the number of houses within the pipe contributing area and the total number of houses in the sub-catchment.

For the remainder of the system where a flow monitor had not been installed downstream and where impermeable area surveys had not been carried out an area was estimated. The estimate was derived on the basis of the number of houses in that particular drainage area with an area per house derived from adjacent similar areas whose areas had been determined from flow monitor results.

Storm Verification

Once the Dry Weather Verification had been completed the verification for storm events commenced. Five storm events were used for the verification since the size of the catchment meant that none of the storm events that occurred during the flow survey were adequate for verification across the whole of the catchment. Two of the storms were very good in the northern half of the catchment, another 2 for the southern half and the fifth storm event was reasonable across the whole catchment.

The storms used for verification had maximum rainfall intensities of up to 60 mm/hr with total rainfall depths of up to 19.4mm. Storm responses ranging from 15 in the upper catchments to 3 in the main trunk sewers were observed.

The storm verification comprised the running of the model for the appropriate duration plus an 8 hour initialisation period that was found to be necessary due to the very long time of concentration. The model as run for each of the 5 events F, G, H, I & J. However because of the size of the model and the number of ancillaries it was not possible to run the model with all the required gauge points and therefore the model had to be run twice for each event with half the required gauge points selected for each run. The average run time for a concurrent dual run for each event was in the order of 8 hours.

An example of a storm verification comparative plot is shown in Figure 11.

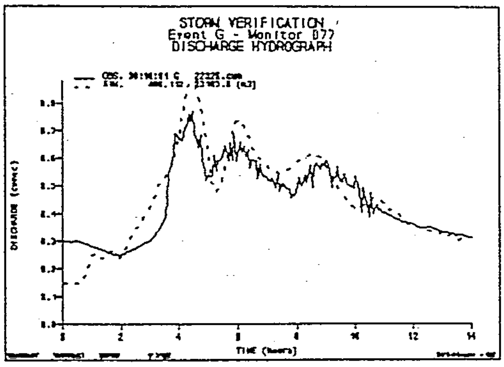

Fig 11 Typical Storm Verification

The storm verification also considered verification against historical flooding in the catchment. Following the running of the model for the verification storms it was run for 1 in 2 year and 1 in 5 year 60 minute events. The simulated flooding from these events showed a good correlation with the areas of known flooding.

Final Reports

A comprehensive Model Building Report and a Model Verification Report were prepared for the Long Reach Macro Model. These reports comprise a total of 16 volumes and were written to provide future users of the model within Thames Water with all the necessary details to update and run the model.

Acknowledgements

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RCA/DCB
October 1992

1.2 Long Reach Catchment Macro Model R.Allit and D.Beale (DHV Burrow Crocker)

Question

Rob Andoh Hydro Research

What hardware was the model run on ?

Answer

SUN IPC SPARC station but even then the runs took several hours often over a whole weekend. The output files were so large with the 58 tanks that verification runs had to be done twice to get output files at all flow monitor points.

Question

Gareth Catterson

As the flow monitors were used to calibrate the model what equipment was used.

Answer

There were two sets of monitors, one set for the verification, the other set for calculating contributing areas. The latter monitors were not used for the verification work. Standard flow monitoring equipment was used for evaluating contributing areas. These were not placed in the trunk sewers but in the branch sewers (300,450 and 600 diameter) as they were used to establish the response from these areas. The verification only monitors were in the larger trunk sewers.

Question

John Blanksby Wilde Allison

As the monitors were used for calibration and there were so many overflows how were the monitors placed with respect to the overflows in the catchment ?

Answer

The monitors were placed strategically round the catchment they were not just placed up and downstream of each overflow.