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CHELLASTON DRAINAGE AREA STUDY-CASE STUDY

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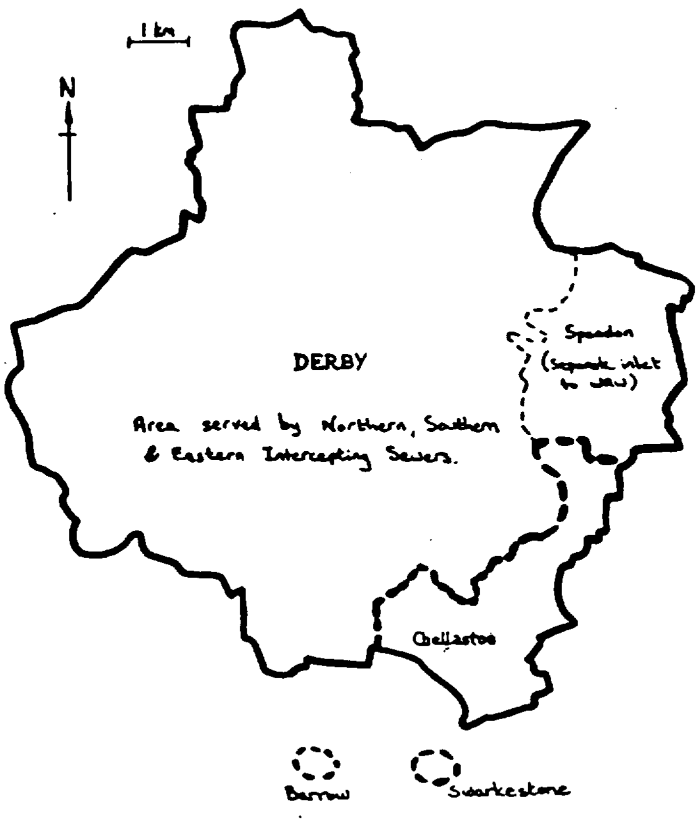
1 Synopsis

1.1 The paper describes a drainage area study involving a long flat outfall sewer of large diameter with downstream control. The study presented a number of unusual features. A plan of work to encompass these features including dry weather performance and septicity was devised. As the study proceeded and the true nature of the systems mode of operation was revealed it became apparent that a verified model of the complete system could not be produced. A revised specification was then agreed with the client and a detailed quantitative study report was submitted.

2 Introduction

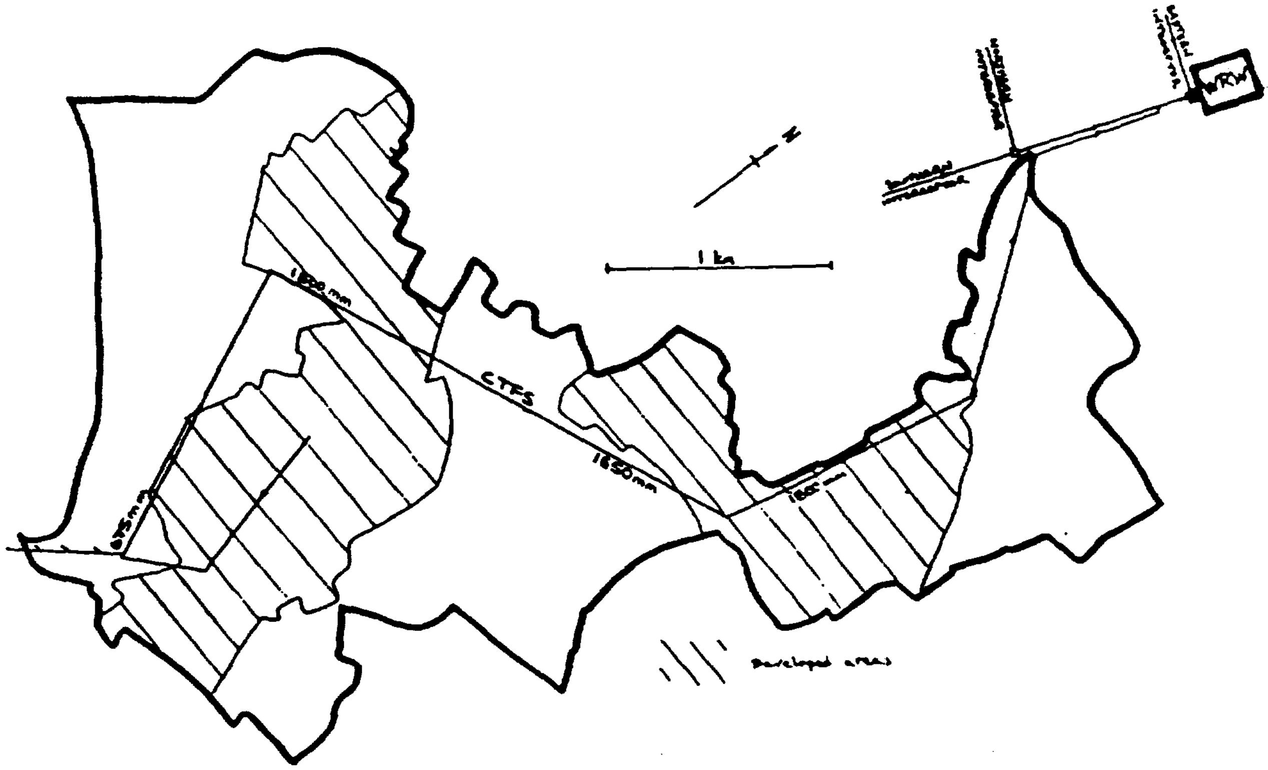
2.1 Scott Wilson Kirkpatrick were briefed in February 1989 by the Director of Technical Services of Derby City Council acting as agents for Severn-Trent Water. Chellaston is a suburb on the southern edge of Derby. The DAS was part of the STW's programme which aims to cover all major population centres.



2.2 The study area extends to 730 ha, with a population of 13,000 hd. It occupies generally low-lying and flat land between the rivers Trent and Dervent. Ground levels vary from 41 m in the NE to 58 m in the SW, but most of this difference occurs in the upstream section of the area. Prior to the 1970s this higher area had been served by a local Water Reclamation Works. After completion of the 7.5 km Chellaston Trunk Foul Sewer (CTFS) the works was abandoned and flows were taken to treatment at Derby WRW. The CTFS also permitted development of the intervening land, though to date this has taken place only in the NE of the area.

2.3 The older areas of Chellaston are drained on a combined or partially separate system. The newer development has been provided with separate systems. Consequently much of the impermeable areas generating a rainfall response in the CTFS are in the older south western part of the study area, at the upstream end of the trunk sewer.

2.4 The CTFS was constructed in sizes ranging from 675 mm to 1800 mm diameter. For much of its 7.5 km length it has a gradient slacker than 1/3000. Flow velocities are therefore unsatisfactory, especially in dry weather. This leads to sedimentation and septicity, a problem which is aggravated by septic pumped discharges from the outlying villages of Barrow and Swarkestone.



3 Objectives and Approach

3.1 The objectives of the study were to obtain a detailed quantitative understanding of the hydraulic and structural performance of the severage systems. The associated topics of pollution and water reclamation were also to be considered.

3.2 To enable a plan of work to be formulated to achieve these objectives the known deficiencies of the system were studied. Records showed a limited amount of flooding occuring on a regular basis in some of the older areas. Structural collapses were very few in number. The most widespread cause of concern was odours emanating from the severage. This was believed to be a dry weather problem. In addition to the poor gradients already mentioned it was believed that flows were held back in storm conditions by the operation of the inlet works at Derby WRW.

The CTFS shares an inlet to the works with the Northern and Southern Interceptors which together serve 75% of Derby. These two interceptors combine at the Alvaston overflow, but the CTFS does not pass through this overflow, joining instead some 600 m downstream. The operation of the overflow is controlled by the rate of pumping from the inlet works and penstocks on the approach pipes.

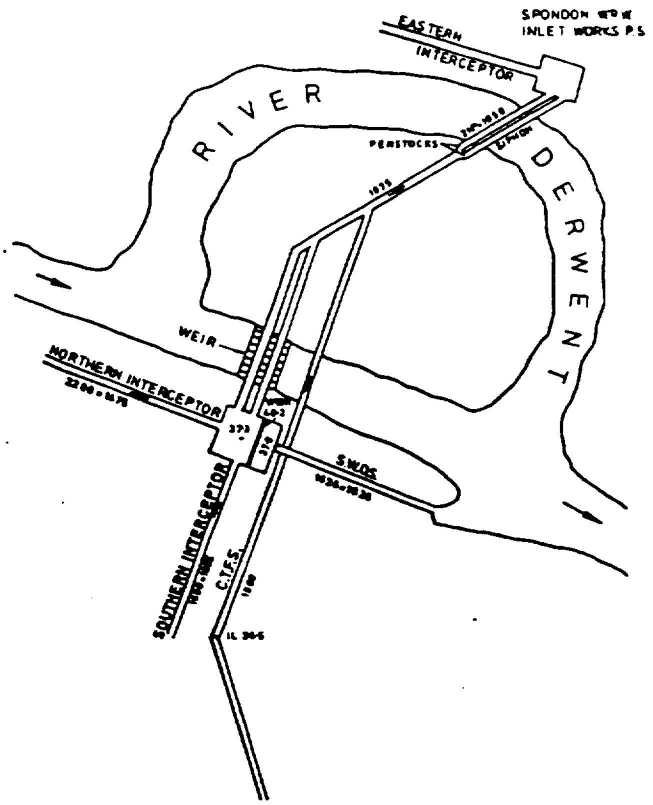


FIGURE 2

ARRANGEMENT OF TRUNK SEWERS

3.3 In addition to the usual flow survey and man-entry/CCTV surveys it was therefore proposed that to yield the necessary quantitative results the following would be required.

(a) Control gauging at the WRW to permit outfall conditions to be imposed on the model. Two gauges were installed in close proximity as a check on each other.

(b) Sampling and analysis of dry weather flow samples.

(c) Gauging to permit retention times at the outlying pumping stations to be evaluated.

3.4 It was known that the CTFS was only serving a fraction of its intended ultimate catchment and in the light rainfall events typically used for verification it was expected that free surface flow would prevail in the long 1500 mm to 1800 mm section. The slack gradient and downstream influence suggested that backwater effects would be substantial, and that WaSSP might not be the appropriate modelling package. WALLRUS was proposed as an alternative with a number of advantages in this particular case, namely:

(a) Free surface backwater modelling.

(b) Spatially varying rainfall modelling.

(c) Silt depth modelling.

(d) Pipe by pipe PR calculations.

3.5 Work commenced with identification of the networks to be modelled, contracts were then let for the following surveys:

(a) 7 km CCTV plus 6 x 100 m man-entry survey including flow sampling and analysis.

(b) 400 manholes locational survey and transfer of 33 nr 500 m x 500 m sewer record maps to Report 25 format.

(c) 10 depth/velocity and 2 depth only flow monitors and 4 rainfall gauges.

4 Modelling and Analysis

4.1 The modelling of the catchment was carried out in accordance with the recommendations given in the paper "Runoff equations and catchment data" presented at the WaPUG Spring Meetings 1989 and subsequently issued as User Note No 21. One foul sewer model and five separate surface water models were prepared.

4.2 The CTFS with its very flat gradient was modelled with flags set for backwater calculations. Wallingford Software recommended that for backwater calculations on WALLRUS the modelled pipe lengths should be no longer than 100 metres and the calculation timestep should be 5 seconds. The 100 metre restriction entailed artifically dividing some lengths of the CTFS, which in places has lengths of up to 250 metres between manholes. This was contrary to the more normal practice of simplifying hydraulic models by joining together adjacent pipe runs which have similar dimensions, gradients and characteristics. The resulting foul model contained 142 pipes, of which 68 represented the 5.4 km length of CTFS that was 1500 mm diameter or larger.

4.3 The initial intention was to represent the downstream influences of the Northern and Southern Interceptor Sewers on the CTFS by inputting a level hydrograph at the outfall of the model, on the assumption that the system behaved as though it had a tide-locked outfall. The flow monitors closest to the downstream end of the CTFS were used to provide the depth hydrographs for the verification events. These monitors revealed that in each of the 3 selected verification events the lower end of the CTFS became surcharged to a level between 0.4 and 1.0 metres above the pipe soffit. In the model simulations the sewage levels at all points upstream of the outfall rose and fell to match those imposed at the outfall. When the level at the outfall rose above pipe soffit level the indicated levels upstream remained constant at this level until the outfall level subsided again. Whilst the level at the outfall was rising the volume indicated by the model as stored within the CTFS increased by 9600 m^3 in 20 minutes, ie 8 m^3/s, compared with only 1100 m^3 total runoff from the Chellaston catchment. Except during the "emptying" phase the indicated flows in the CTFS remained low or zero. The behaviour of the model was clearly unrealistic.

4.4. Examination of the records from the flow monitors installed at various points along the CTFS provided the first real evidence that reverse flows do actually occur in the CTFS. Comparison of the depth hydrographs from the flow monitors showed that the levels rise in response to rainfall first at the bottom end of the CTFS and then progressively up through the whole of the CTFS, in some cases even causing surcharging in the contributing branches. Because the flow monitors record magnitude of flow velocity irrespective of direction the flow hydrographs show a characteristic double peaked shape. The first peak represents the reverse flow as the system fills up. The flow rate drops to zero and then rises again with the second peak representing the positive flow as the system gradually empties.

4.5 The CTFS itself exhibits some rainfall response from the older parts of Chellaston village which drain into the head of the CTFS. The Northern and Southern Interceptor Sewers serve a much greater impermeable area than the CTFS, and have a much quicker rainfall response time since they are laid to better gradients and have substantial impermeable areas close to their downstream ends. Thus very significant flows can arrive at their confluence with the CTFS well before the CTFS shows any response from rainfall on its own catchment. Under these circumstances, and when the flow exceeds the uptake at the WRW, a proportion of the Northern and Southern Interceptor flows will turn and flow in the reverse direction into the CTFS. This was observed at the confluence manhole and about 1.5 km upstream during the course of the study.

4.6 A number of attempts were made to simulate this situation on WALLRUS, with the system represented in a variety of different ways. Early contact with Wallingford Software suggested the use of an input hydrograph on a dummy leg to induce reverse flow in the model. These attempts were not successful, and it was eventually concluded that it was not possible to accurately represent the long flat CTFS with its downstream influences and variable flow direction. After running their own trials Wallingford Software confirmed that the current version 1.2 of WALLRUS was unable to calculate negative hydraulic gradients under free surface conditions and was therefore unable to represent the situation that we were trying to reproduce.

4.7 Because it had now proved impossible to represent the downstream influences on the CTFS and would therefore also be impossible to simulate realistically the effects of the required design storm events on the foul sewer system it was agreed at a meeting with our client Derby City Council and Severn Trent Water that we would carry out a conventional verification of the major branches contributing to the CTFS and would then simulate the effects of design storms assuming the hypothetical situations where:

(1) the CTFS had a free outfall

and (2) the CTFS had a sealed outfall and no external influences, ie a closed flap valve.

In fact there was effectively no difference between these two situations since even the 3120 m^3 total runoff generated by a 10 year 60 minute storm is small compared with the 12400 m^3 total storage available within the CTFS.

4.8 The poor flow regime within the CTFS has resulted in the deposition of silt and consequent problems. By plotting the depths of silt recorded at the flow monitor locations and those lengths of CTFS that were surveyed by man-entry onto a long-section of the CTFS it was possible to obtain a profile for the silt retained within the CTFS. The silt depths varied from 180 mm at the downstream end of the CTFS to 750 mm at the top of the 1500 mm diameter section. This silt profile strongly suggests that solids are carried upstream in the CTFS by the advancing flood from the Northern and Southern Interceptor Sewers and are then settled at its upstream end during the quiescent period before the system gradually empties again. The maximum reverse flow velocity recorded during the flow survey was approximately 0.45 m/s, and the peak velocity recorded during the emptying cycle was only 0.3 m/s so sedimentation will occur during the emptying cycle also.

4.9 The great depth of silt caused some problems during the man-entry structural survey of the CTFS, as it proved physically impossible to wade through it in some locations.

4.10 The excessive silting is likely to be the cause of the many odour reports that have been received from various locations near the CTFS, and also for the highly toxic atmospheres that were encountered during the manhole, man-entry and flow surveys that were carried out as part of this study.

4.11 Samples of sewage were taken from five separate locations along the CTFS, and analysed at the Nottingham laboratories of the National Rivers Authority. No significant trends were observed for variation of the measured properties along the CTFS, and most were within the normal ranges for crude sewage. Measured sulphide content, however, at an average value of 4.8 mg H_2S/l, was approximately 5 times normal levels, and confirmed the existence of septic conditions within the CTFS. The septic conditions are believed to be partly the result of excessive sedimentation within the CTFS and partly the result of septic discharges from the pumping main from Barrow and Swarkestone into the head of the CTFS. The retention times in the pumping main under dry weather flow conditions were estimated using the information obtained from the depth monitors installed in the pumping station wet wells as 29 hours from Barrow and 34 hours from Swarkestone. Sulphide attack has been observed in the manhole where the pumping main joins the CTFS.

5 Concluding Remarks

5.1 Chellaston DAS has been an interesting study in which the effects of an adjacent sewerage system on the flow regime in the Chellaston Trunk Foul Sewer have proved impossible to model satisfactorily. Despite this the information available has been used so as best to fulfill the original objective of providing a quantitative understanding of the performance of the sewerage system in the Chellaston drainage area.

6 Acknowledgements

6.1 The authors would like to thank the Director of Technical Services, Derby City Council for permission to present this paper.

CHELLASTON DRAINAGE AREA STUDY - R LONG, C RAMLER - SCOTT WILSON KIRKPATRICK

R Ashley - Dundee Institute of Technology

1) In view of the reverse flow problems experienced at the junction with the Southern Interceptor sewer, were the monitors installed the "wrong way round" in order to pick this up?

2) Were samples of sediment taken?

Ans: 1) The flow survey contractor used the Golden River Water Rat monitor which measures velocity and depth only. No indication is given as to the direction of the flow.

2) No. Samples were taken of the flow only.

S Ball - Fylde B C

How were the extensive silting problems overcome when installing the flow monitor?

Ans: There was a max. depth of silt of 200mm at the flow monitor locations. This was overcome adequately by simply offsetting the monitor.

B Sharman - North West Water Ltd

It was mentioned that the effects of design storms were simulated using both a free outfall and a closed flap valve. Was the possibility of using a level hydrograph, which would take up some of the available storage, looked at?

Ans: No. The model as it stands is not available for the application of design events until the other catchments have been modelled and accurate hydrographs can be obtained.

P Collier - Fife Regional Council

Have the problems of septicity and odour been resolved?

Ans: The study has only just been completed. The methods of solving the problems will be looked at in future work.

D Page - Flow Technics Ltd

How did you measure reverse flow? What type of monitor was used?

Ans: We did not set out to measure. The flow-monitors indicated that flow was reversing. Golden River "water-rats" were used.

D Beale - Howard Humphries

Reverse flow can only be measured with an accuracy +/- 50% at best. Were velocity profiles in the large diameter sewer produced by taking velocity measurements at numerous points? The variation in velocity can be very important.

Ans: The contractor used a hand-held meter and presumably only measured velocity in the vicinity of the monitor to check its accuracy.

R Kellagher (HRL)

On the graph (of flow-rate versus time) there appeared to be more "negative" volume than positive? You said that the sewer was filled up from the bottom yet there appeared to be more sediment at the top.

Ans: We feel this is attributable to inaccuracies in the flow measurement. The large catchment at the top is the source of the sediment and when the discharge enters the sewer, flow has stopped due to downstream conditions and consequently the sediment is deposited.

Nigel Simmonds - Consultant

Do you know the basis of the original design?

Ans: It was designed as a gravity sewer sized for flows from existing and future development.

A delegate

How successful was the verification?

Ans: In the laterals, fine. We found that the trunk sewer was very sensitive to downstream conditions and consequently verification could not be considered an accurate exercise.