THE DESIGN OF REPLACEMENT SEWERS TO ALLEVIATE FLOODING IN MONTROSE

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1. INTRODUCTION

An increase in the number and frequency of complaints from residents in Montrose concerning sewage flooding of the basements of properties in the Mid Links and John Street areas of the town prompted the Water Services Department of Tayside Regional Council to initiate an investigation into the causes of the problem with a view to determining appropriate relief measures. Messrs Peter Fraenkel, Leslie & Reid (PFL&R), consulting engineers, of Edinburgh, in conjunction with the Department of Civil Engineering, Surveying and Building of Dundee Institute of Technology (DIT) were appointed to formulate the optimum design solution to the flooding problem. PFL&R were responsible for the conceptual and detailed design of the engineering solutions and DIT for the creation of a verified computer model of the existing sewerage system and for the detailed hydraulic analysis of the flooding problem and the testing of the proposed remedial schemes.

A sewer simulation model of the system has been set up and verified using version 1.0 of the WALLRUS software.

2. THE DESIGN PROCESS

Design is concerned with the synthesis of solutions to problems and involves both creativity and the application of established techniques to assess the validity of conceptual solutions. Simulation, which is concerned with the representation of real or proposed systems, is such a technique. Clearly simulation alone will not produce solutions to problems but it can be effectively employed as a design tool at all stages of the design process. French (1985) (reference 1), has proposed a model of the design process, shown in Figure 1, which can be used to describe the development of the optimal solution to the problem of sewage flooding at Montrose.

2.1 The Need

Figure 2 shows the central part of the catchment involved in the study and the areas susceptible to sewage flooding. The flooding has been generally confined to old residential and commercial basement properties in two areas of particular concern in the vicinity of John Street and Mid Links. Inspection of the properties revealed that flooding has been a regular feature as the threshold of each doorway at the front and back of the basement entrances has a raised step, with a 'ramp' running down into the property. Slots at either side of the doorway suggest that in the past, stop-logs have been inserted to restrain the inflow of water.

In the period since 1975 there have been six reported flooding incidents in these basements, five of which coincided with high tide conditions. Flooding has occurred via ingress from backflowing domestic drains and from direct surface runoff through walls and doorways. It is believed that the basements have flooded since the properties were built, and that the increasing number of reports are as a consequence of comparatively recent conversion of a number of basements to residential use, rather than because of any increase in the susceptibility of the area to flood.

2.2 Analysis and Statement of the Problem - WALLRUS Model

Description of the System

The town of Montrose is built on a promontory of land surrounded on three sides by water. The land connection is to the north and a bridge connects the town to the south. The sea is to the east, and there is a large tidal basin to the west. Inevitably the town is very flat and is ideal bicycling terrain, being very similar to Dutch topography. The sewerage system is split into two independent parts, with a western, recently renovated section, and the eastern section described in this paper. Both systems discharge sewage into the fast flowing river South Esk, which flows from the tidal basin into the sea. The western sewerage gravitates to a pumping station below tide level and solids are there macerated.

The eastern sewers are approximately 100 years old and gravitate to a river outfall which has no outlet control. There are some 18km of primary sewers in this part of the town, with a main length of 1.6km which falls about 7m with an average gradient of about 1 in 250. Parts of the sewer system have even shallower gradients and the topography is such that there is virtually no surface slope for some of the drainage surfaces contributing to the sewers. The maximum sewer size is a 930mm x 650mm brick egg-shape. This system drains some 120ha and has an average percentage impermeability of 47%. The area is almost entirely residential and has an extensive linear 'park' area which runs virtually the whole length of the main sewer run.

Under high spring tide conditions the encroaching tide rises up the sewers as far as about the middle of the system. The quantification of the 'backwater' effect of storm flows encountering this rising tide and the consequent estimation of the extent of tidal influence beyond the point to which the 2.65m (AOD) tide reaches, were clearly important considerations when analysing the system. This, together with the slack gradients and the extensive and rapid (following cleaning) deposition of sediments within the system, meant that WASSP modelling was of doubtful value, and the use of the, (at the time) new, WALLRUS simulation model essential.

WALLRUS Model Development

A limited programme of sewer flow measurement was initiated in parallel with the WALLRUS, version 1.0, model development. The erroneous estimation of flow in egg-shaped sewers of up to 20%, acknowledged by HRL for WALLRUS 1.0, was not deemed significant for the initial modelling work. The objective of this was to produce a model which would be good enough to identify the causes of the flooding, and which would suggest probable optimum remedial measures. Detailed design would follow when more flow data were collected to prove the model, and when a more robust version of WALLRUS became available.

One flow logger only was installed at manhole 761, a point in the system where tidal levels were estimated to 'mask' the flow for only some 34% of the time. This estimate took into account the exaggerated effect of tidal influence, as the tide actually rises to above the invert level at this manhole for only some 12% of the time. Nine storm events were recorded by the logger at this manhole, but only one of these was free from tidal influence and did not suffer from the velocity transducer being covered with sediment. Two other events were selected for model verification, one in which the storm flow was affected by a neap tide and the other affected by a spring tide. For these, verification was based on level rather than flow hydrograph fits, as no velocities could be measured. The details of these events are given in Table 1 where the first 3 events were used for the initial verification.

TABLE 1

VERIFICATION EVENTS

Date	Logger Site	Rain Vol (mm)	Rain Dur (h)	Tide	Area (ha)	PR (%)
6. 9.88	761	7.0	1.3	Neap	-	-
23. 9.88	761	7.6	1.3	Low	58	9.0
25.10.88	761	13.8	5.5	Spring	-	-
12. 3.89	891	6.2	3.0	Low	33.3	9.4
27. 3.89	842	5.2	4.0	Mid	-	-

The event of 23/9/88 suggested that the runoff from the catchment was very low, with a rain volume to sewer flow ratio of only 9.0%. In order to simulate this low volume using WALLRUS 1.0, the RUNOFF.PRM file was modified so that the minimum allowable runoff from the impermeable areas could be as low as 5%, rather than the default value of 20% and the maximum runoff was constrained from 100% to 32%. The modelled fit for this event is shown in Figure 3, together with the model result using the as-supplied default RUNOFF.PRM file. As WALLRUS 1.0 would only accept an antecedent rainfall depth of 1 mm in the PCD file, the only possible antecedent specification was using UCWI. Because of this, and the initial storage problems known to exist in the model, the noticeable mismatch at the start of modelled events was not considered significant for this initial verification. A painstaking process of trial and error was used to ensure that the level hydrograph gave as reasonable a fit as possible, and this was achieved with a downstream sediment deposit depth of 150mm in the main sewers. The influence of sediment deposits on the system were found to be substantial with regard to the level hydrograph, and relatively small depths of sediment deposits in the Mid-Links area upstream of the logger site were shown to have a major influence on the propensity of the system in this area to surcharge even at low tides and under rainfall of one year return period. Figure 4 illustrates some of the model predicted effects of sediment within the system.

The recorded tidally affected events for 6/9/88 and 25/10/88 were used to test the initially verified model. Unfortunately no other events were recorded in which the logger site was not influenced by the tides and so no further volume checks could be made on the low PR found for the 23/9/88 event. The results of the modelled tidally affected events are shown in Figure 5. The level fits are remarkably good for both events, although there is a time phase difference between the modelled and observed levels. This is possibly due to the in-built WALLRUS model assumption that all tidal outfalls have flap-valves. The time differences could be attributed to the model time lag in equalisation of tide with in-sewer water levels. The results of the tidally influenced runs showed that the effects of in-sewer sediments on water levels were much attenuated under high tide conditions, and that as suspected, the primary cause of basement flooding was due to an inpropitious combination of high tide and storm flows.

There are limitations in using level hydrograph data alone to confirm model verification, and so a further flow monitoring programme was instituted with loggers situated at three sites simultaneously. Tides, ragging and logger corrosion, however resulted in no recording of events simultaneously at all three sites. Two usable events, one of which was tidally influenced, were recorded in March of this year and are shown in Table 1. These are now being used with WALLRUS 1.2 to further tune the model and to confirm the proposed design solution. The event of 12/3/89 in which both flow and level were recorded had a similar rainfall volume to the earlier verification event of 23/9/88, and with a PR of 9.4%, also confirms the originally observed low PR value of only 9%.

3. CONCEPTUAL DESIGN AND SELECTION OF SCHEMES

PFL&R were responsible for formulating possible engineering solutions to the problem and, at the conceptual stage, initially proposed four design options as follows:

Option 1 - an off-line detention tank in the Mid Links area;
Option 2 - an off-line detention tank in the vicinity of the sports centre;
Option 3 - a tank sewer near the sports centre;
Option 4 - a new sewer and outfall from manhole 761;

Simulation models based on the previously verified model of the existing catchment were set up to evaluate the alternative conceptual designs.

The design criteria were:

(i) there should be no surcharging of the sewers in John Street or Mid Links during any storm with a two year return period;

(ii) only limited surcharging should occur in these sewers for any storm with a ten year return period.

Simulation of these options revealed that none of the options proposed would satisfy the design criteria. Two revised options and a new one were formulated:

Options 1A and 3A - Similar to options 1 and 3 but with overpumping of flows during high tides;

Option 5 - Construction of a larger diameter trunk sewer from Wellington Street to Garrison road where a pumping station would overpump flows during high tides.

Simulation modelling of the revised options for storms of two year and ten year return periods indicated that each of them could satisfy the design criteria, subject to some further refinement and verification of the initial simulation model and the simulation models for the options. Subsequent cost estimates for the three proposals showed that option 5 had the lowest capital cost.

4. EMBODIMENT OF SCHEMES AND DETAILED DESIGN

Following further consideration of the three final options described in Section 3 above, and taking into account the known poor condition of certain sections of the existing main sewer, it was decided that only Option 5 would be considered for detailed design.
The initial simulation model for option 5 was refined by including more detailed design information and a series of simulation runs were instituted to determine optimum pipe sizes. This was done on an iterative basis with pipe sizes being judiciously altered between runs until the optimum pipe size for each section of the proposed sewer could be deduced. Hydraulic bottlenecks in the system were identified by examining output files for surcharging in pipes which should have had spare capacity. In a number of instances the enlargement of pipes causing bottlenecks enabled reductions to be made in pipe sizes in sections upstream of the bottlenecks. Initially all pipes in the main sewer were assumed to be 1000mm diameter and following the iterative simulation these were revised as follows:

MH 1.18 - 1.12	1200 mm dia
MH 1.12 - 1.10	1000 mm dia
MH 1.10 - 1.05	900 mm dia
MH 1.05 - 1.03	750 mm dia
MH 1.03 - 1.00	600 mm dia.

The iterative simulation also identified that the reconstruction should be extended to include:

(i) the addition of an extra length of 600mm diameter sewer above manhole 1.00;
(ii) the replacement of the sewer across Mid-Links by a 525mm diameter sewer extending up to the bottom of John Street;
(iii) the replacement of the existing John Street sewer by a 300mm diameter sewer;
(iv) The construction of a 750mm diameter sewer in parallel to the existing sewer in ralway place.

The possibilities of phasing the construction of the works were also considered. An examination of the results of the previous simulation runs revealed that although phasing of the works would not permit an immediate solution to the problem of flooding to be instituted, the risk of flooding could be most effectively reduced by adopting the five phase approach shown in figure 2.

5. CONCLUSIONS

A verified model of the eastern sewer catchment in Montrose has been set up using WALLRUS version 1.0 and this has been used to identify the causes of flooding problems in this very flat, tidally-affected catchment.

The model was developed using a modified RUNOFF.PRM file to constrain the percentage runoff from the impervious surfaces to match that observed from rainfall and flow monitoring. Notwithstanding the known problems with version 1.0, the WALLRUS model appeared to give results consistent with observation under free-flow and tidally-affected conditions. The model showed how significant both backwater and sedimentation effects are for this sewer system.

Following the comparison of a number of alternatives using the WALLRUS model, an optimum design solution has been developed, which entails the construction of a replacement trunk sewer and a tidal pumping station. Further model and design refinement is now underway after a second period of flow logging and the issue of version 1.2 of WALLRUS by HRL.

REFERENCE

Cross, N. Engineering design methods. Wiley 1989.

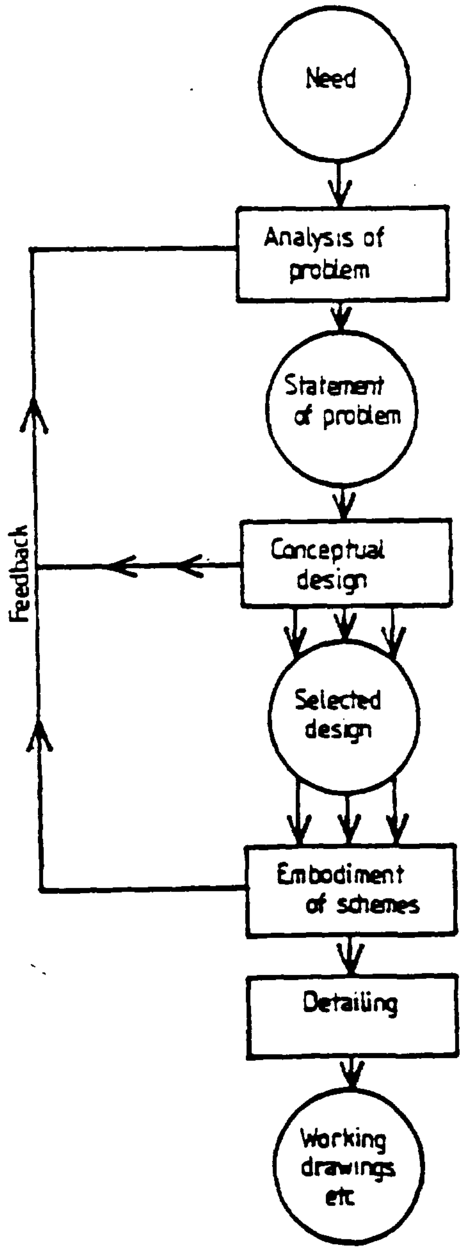
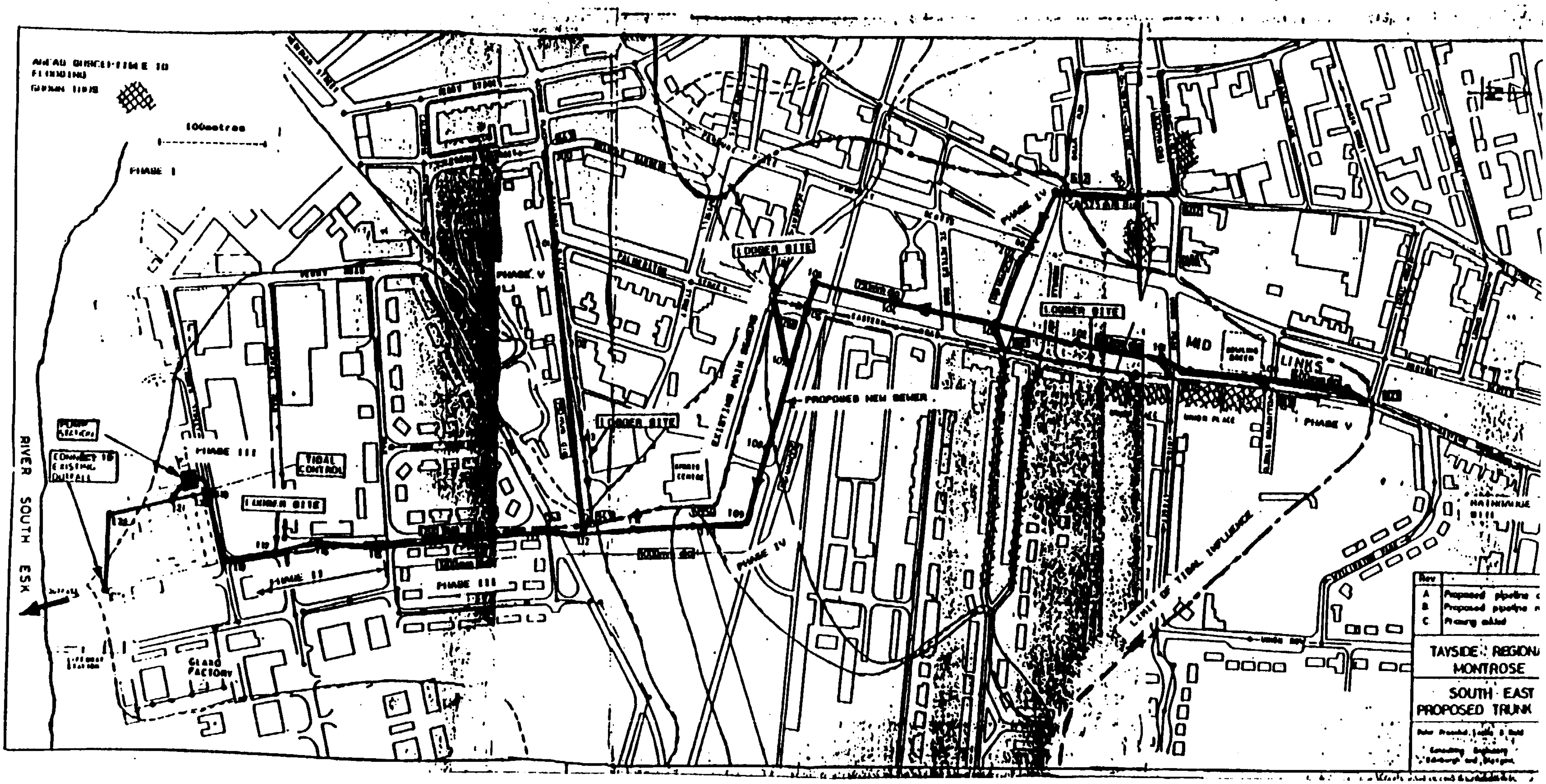
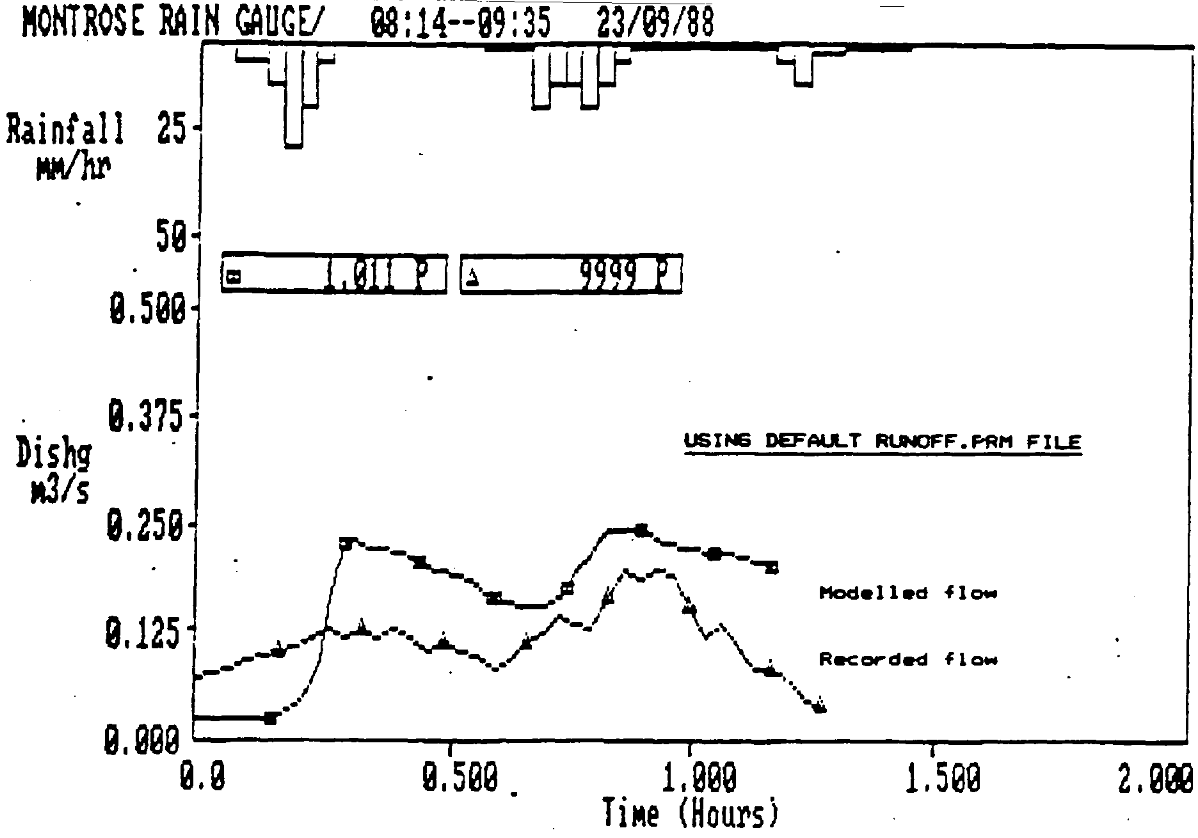


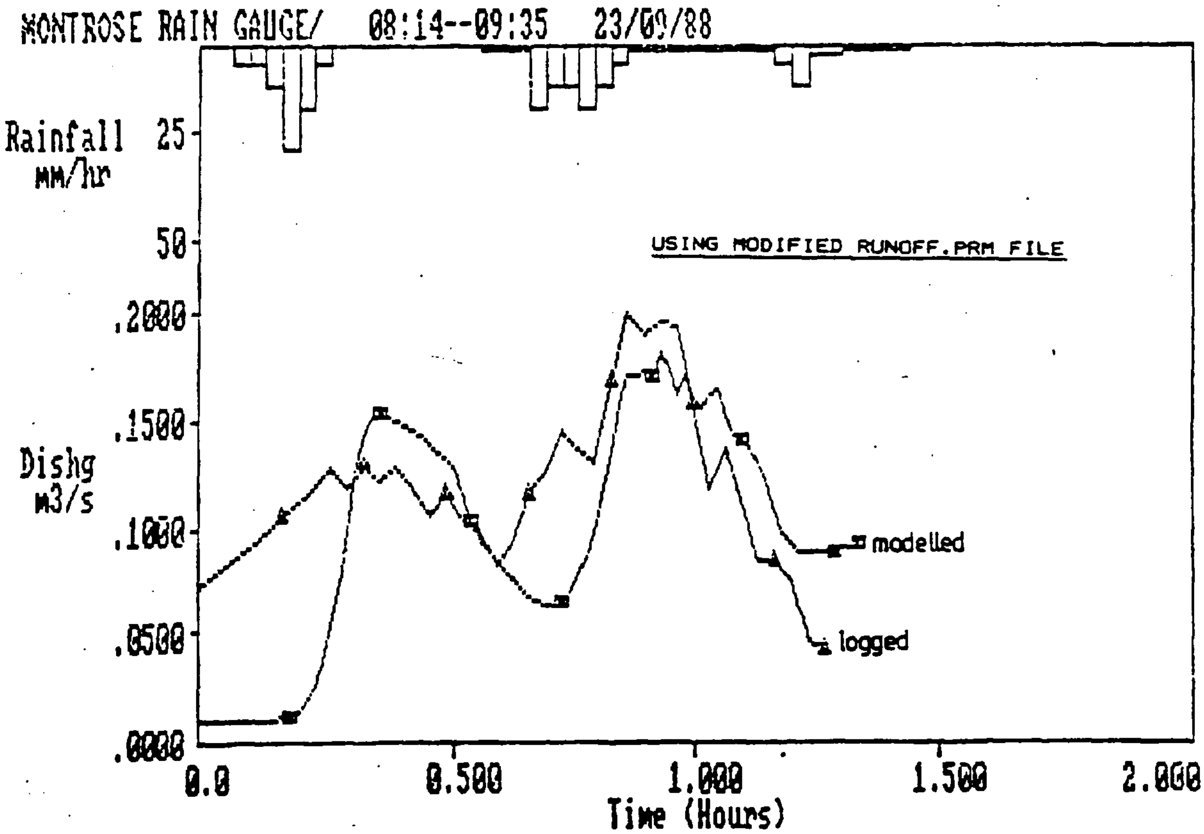
Figure 1. French's model of the design process.



PROPOSED NEW SEWER AND PART CATCHMENT DETAILS

FIGURE 2

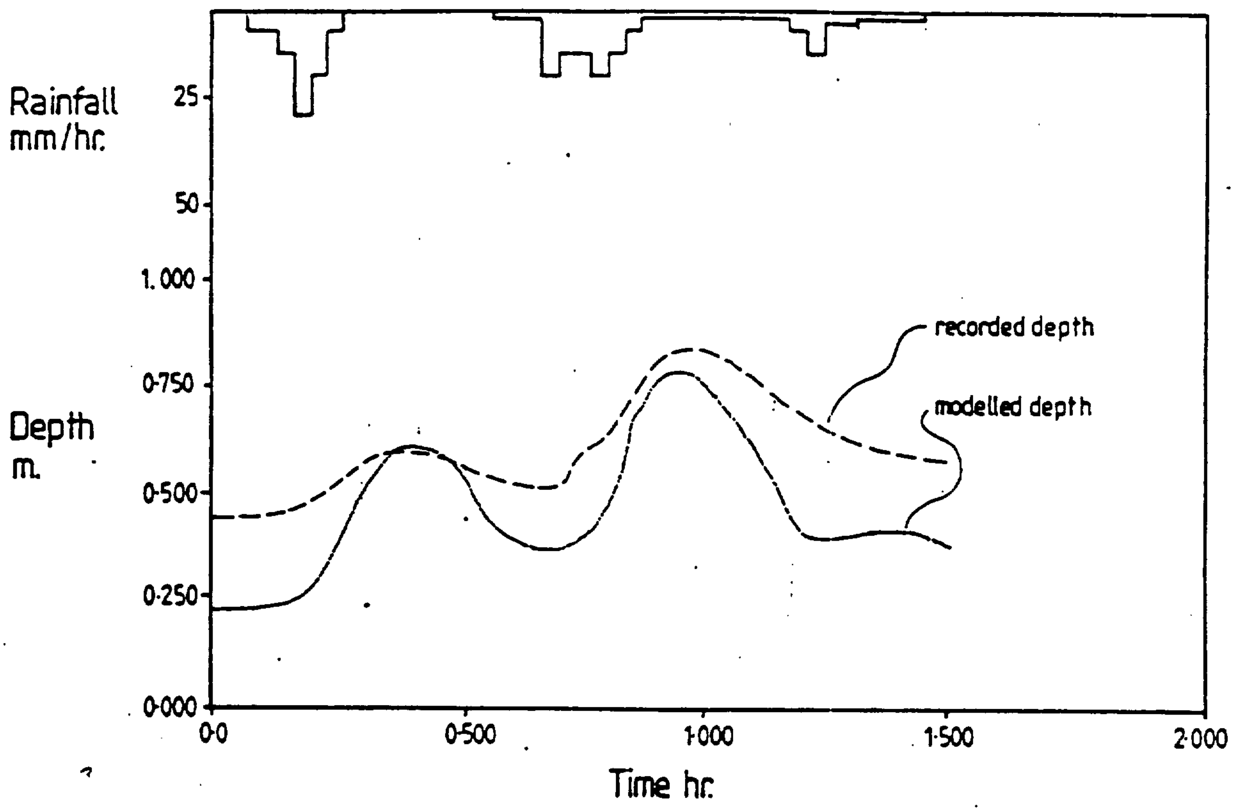




VERIFICATION EVENT 23/9/88 RECORDED/MODELLED FLOW AT GAUGE MANHOLE

VERIFICATION - FREE OUTLET EVENT

FIGURE 3(a)



VERIFICATION EVENT 23/9/88 RECORDED/MODELLED DEPTH AT GAUGE MANHOLE

FIGURE 3(b)

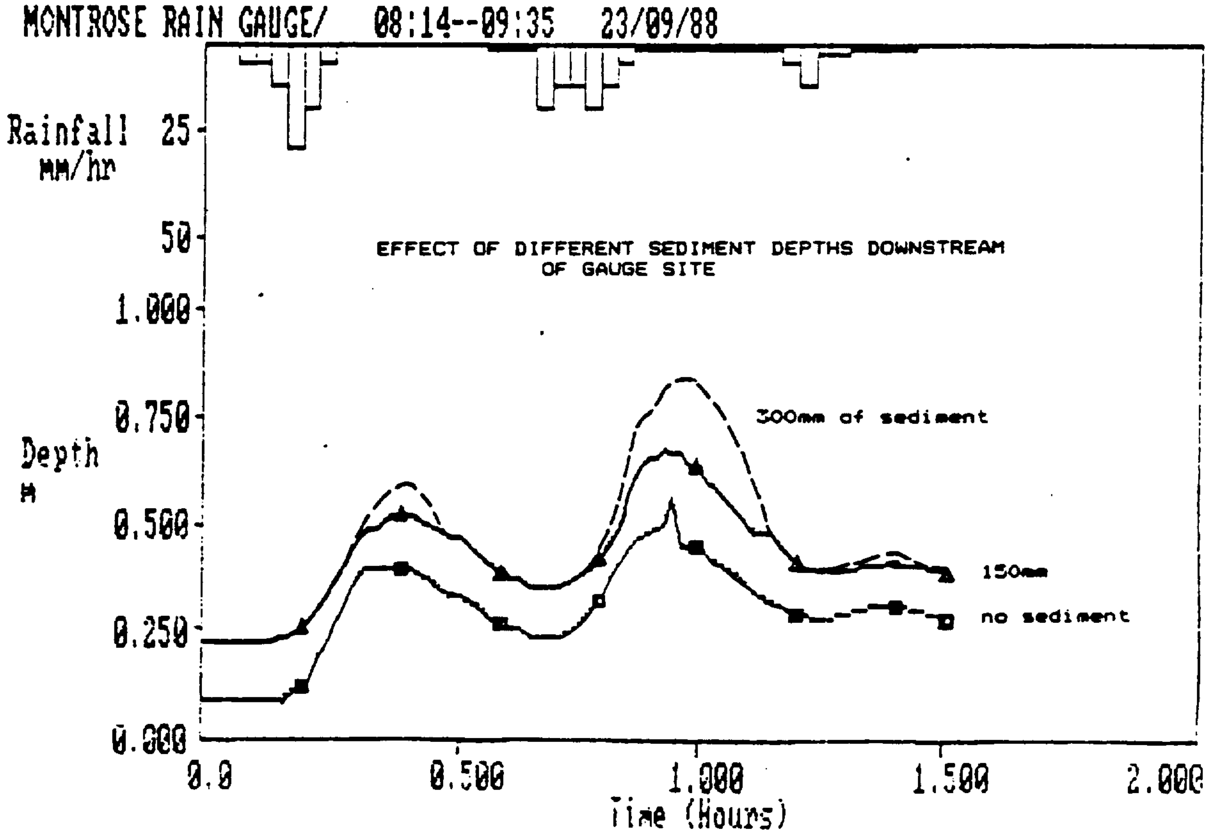


FIGURE 4

3.2 **The Montrose Eastern Catchment - R Ashley - Dundee Institute of Technology**

In the presentation of the paper a few points were clarified.

The basements which were prone to flooding acted as off line storage tanks.

The tide levels measured during the study were found to be consistently 300 mm higher than those obtained from Admiralty Charts.

The estimated cost of the scheme was £3m to remedy a problem where the most severe flooding affected only 10 properties. Was this justified?

Tom Silkstone - Bournemouth B.C.

If the basements act as storage tanks how is this modelled?

Ans: As off line tanks with a very small connection to represent the drains connecting them to the sewer. Some of the properties had none return valves so that they did not flood from the sewer, but they still suffered from flooding due to the inability to drain the rainfall on the property.

Richard Marshall - Sheffield C.C.

Would small pumping schemes have offered a cheaper solution to the property flooding problems?

Ans: They may have done, but there were also problems of road flooding in the catchment which they would not have solved.

Phil Nightingale - Ellesmere Port & Nelson B.C.

The scheme was designed for 1 in 2 year protection. Is this adequate?

Ans: In practice the protection provided to the properties would be greater than the 1 in 2 year design target.

David Gordon - Strathclyde R.C.

Was WASSP tried before using WALLRUS?

Ans: No. It was realised from the start that the limitations of WASSP would be significant, particularly in the handling of the runoff equation.

Don Prebble - Shepway D.C.

Was adjusting the PRM file in effect just force fitting the model?

Ans: Yes, probably. I am surprised that nobody else has yet commented on that.

Martin Osborne - Hydraulics Research

Yes, it is force fitting, and like all force fitting is dangerous. For example the same results could have been achieved for the verification storms by increasing the depression storage, and leaving the percentage runoff at the standard value. This would then give completely different answers for the design storms.

Ans: That is true, but we had difficulty in adjusting the value of depression storage with the earlier version of WALLRUS.

Nick Orman - WRc

I am also concerned about the force fiting of the model. The values used in the PRM file are outside the range of values experienced before. What physical justification was there for this catchment being so different?

Ans: The large amounts of permeable areas could be the cause of the problem. However I do not believe that the PR equation necessarily applies to all catchments and I would generally calibrate models.