Monitoring of storm sewer overflows

LONSDALE, K.G.

Monitoring of Storm Sewer Overflows

K. G. Lonsdale

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ABSTRACT

The poor quality of many receiving waters has been attributed to the frequent operation of combined sewer overflows (C.S.O.s). As the existing need for overflow structures is unlikely to change in the foreseeable future it is imperative that these deleterious effects are minimised. The present study investigates the pollution performance of three common overflow structure designs (the stilling pond, the double high side weir and the double low side weir) and aims to institute a novel pollution monitoring methodology for combined sewer overflows. Four sites in the central Sheffield area were monitored for periods from 9 to 13 months (two high-side weirs, one low-side weir and a stilling pond). Each overflow was monitored with continuous flow measurement equipment and bottle samplers to obtain samples of sewage from the storm and dry weather flows. The bottle samples were analysed for suspended solids (SS), ash, BOD, COD, pH, conductivity and ammonia. Mesh bags and frames were also installed to trap the gross solids (solids with a median size>6mm) from the inflow and the spill flow.

The stilling pond and the high side weirs were found to perform well hydraulically, limiting the flow to treatment to a steady maximum. The low side weir performed unsatisfactorily, hydraulically, as the flow to treatment rose as the incoming flow increased and, for some storm conditions, a hydraulic jump formed towards the downstream end of the chamber.

The first foul flush was regularly observed at the stilling pond and low side weir sites. Peak concentrations for SS were found to be 600 times greater than the dry weather flow for the same time of day. The first foul flush was rarely observed at the other sites. For the majority of storms at each site the spill concentrations were of a similar magnitude to the inflow sample concentrations. However for a large minority of SS, BOD and COD samples, the concentrations of the spill samples were significantly less than the inflow samples. t-Tests suggested that at the stilling pond and high side weir sites there is a significant reduction in the spill sample concentrations for the water quality (bottle) samples.

Although the load of material spilled during an overflow event was found to be small in comparison to the inflow load, large amounts of material were spilled to the watercourse during storm events at each of the sites investigated. The storm load entering the CSO was found to be considerably influenced by peak intensity of the storm at the stilling pond site and antecedent dry weather period at one of the high side weir sites. At the other sites a number of hydrological factors were found to be influential e.g. duration. It is thought that time of year may also be important factor as this influences the type of rainfall (its duration and intensity).

The types of gross solid collected at each site were similar with leaf material and sanitary towels consistently being the major items in terms of total mass. The efficiency of the stilling pond and one of the high side weirs in retaining gross solids in the flow to treatment appeared to be explained by the flow split although for 5 of 14 storms at the stilling pond and 3 of 7 at the high side weir a treatment effect was observed. The treatment factors at the low side weir were noticeably less than those for the other three sites with all being less than unity (average 0.5). This suggests that the low side weir preferentially discharges gross solid material over the weir. The treatment factors at the other high side weir were low due to inadequate sampling of the spill flow.

CHAPTER 1 INTRODUCTION

In this chapter a brief account of the history of sewage treatment and the sewerage system is given. This is followed by a discussion on the origins of the combined sewer overflow, their function in the sewerage system, the problems that they cause and means of control .

1.1 The Development of Present Day Sewerage Systems

Sewers were originally constructed for the sole purpose of carrying rain water away from built-up areas and arable land or orchards to prevent damage due to flooding. The first legislation relating to this was 'The Bill of Sewers' during the reign of Henry VIII in 1531 (Barty-King, 1992). These sewers were not designed to take solid material. Up to the beginning of the Nineteenth century the main role of sewers was still to prevent flooding and not to carry away dirty water and foul wastes.

Faecal material was primarily dealt with by privy-midden systems and cesspools. There were a number of different designs although the basic structure consisted of a central midden pit with privies (a plank seat with a hole in a small hut) to either side. The excreta would run down the sloping side of the floor into the pit. The pits were periodically dug out by scavengers who dried out the material and sold it as a fertiliser (Stanbridge, 1976). Ashes, and later industrial wastes such as mill dust, were added to the pits in an attempt to absorb the faecal material and render it inoffensive. The pits could be made more permanent by lining them with bricks or stone. The linings allowed some leakage so that the pits would not have to be emptied so often. However, such leakage could result in the contamination of nearby sources of drinking water.

The principal precipitating factor which lead to the gradual acceptance of a water-carriage system was the Industrial Revolution and the concomitant increase in the urban population. In the first national census of 1801 the population of the country was 10 million with three million living in towns and cities. By 1851 the population was 20 million and 10 million of these lived in urban areas where there was an enormous demand for labour from the new industries (Wylie, 1959). Many of these people were living in appalling conditions in densely populated areas of the town. These conditions are vividly described in Edwin Chadwick's "Report on the Sanitary Condition of the Labouring Population of Great Britain" published in 1842, which had been written following a tour of the country in his capacity as the head of the Royal Commission on the Health of Large Towns and Populous Districts in England and Wales.

The privy-midden systems were not suitable for high densities of population. The need to prevent the build up human waste in such areas was becoming apparent. The stagnation of the material in cesspools and pits, built close to and sometimes under houses, inevitably lead to noxious fumes. More seriously, a link between outbreaks of diseases such as typhoid and cholera and water contaminated with human wastes had recently been detected. Some means of removing these wastes from the urban areas was urgently required.

Chadwick, proposed an arterial system of town drainage. He argued that the road sewers which were then being used to take the overflow from cesspools and middens had not been designed to carry solid material and as a result they were prone to blocking or dumping the material where the gradients were not sufficiently steep. In conjunction with the potter, Sir Henry Doulton, Chadwick developed vitrified fire-clay pipes which could carry a much greater volume of flow. Also at this time, the engineer John Roe designed the egg-shaped sewer which concentrated the base, dry weather flow in the narrow channel at the bottom so that even when flows were low there would be sufficient force to carry the solid wastes (White, 1970).

Many saw the water-carriage system as unnecessarily wasteful of water, which was not always readily available. In the mid-Nineteenth century water was only piped to homes that could afford it. The slum areas were dependent on water carriers and standpipes that were only operational for one or two hours per day three days a week (Barty-King, 1992). The organisation of the water companies that were then supplying the water would have to be radically altered to allow for the new system. Many of the smaller companies were afraid that they would go out of business. Other objections included the pollution of the water courses that would receive the foul flow and the loss of faecal material as a fertiliser.

Such objections delayed rather than halted the reformers' campaign to sewer towns. Large-scale building of sewers outside London began in the 1860's and the Sanitary Act of 1866 gave the Government the power to take action against any local authority who had received a complaint about the lack of sufficient sewers or the maintenance of existing ones. In Sheffield, the conversion process began in the late 1880's. The Sheffield Corporation Act of 1890 enabled the Council to compel the conversion of insanitary middens to water closets. In 1893 there were 32,362 privy middens. By 1914 there were 7,450. Complete conversion to the water carriage system in Sheffield is thought to have occurred in the late 1920's (Shaw, 1993)..

When the new sewers were built the water closets were connected directly to them. The basis for the arrangement of the sewage pipes was laid down by the Chief Engineering Inspector to the General Board of Health, Robert Rawlinson. He recommended that sewers should be laid with straight pipes between manholes, manholes at each change of direction and lamp shafts at intervening points (Barty-King, 1992). These recommendations were adopted and are still being used today. The original sewers had been laid along the principal streets to avoid interference with public property (White, 1970). As the water became more polluted interceptor sewers were constructed parallel to the water courses and the sewage was discharged downstream of the town with some attempt at treatment.

The continued growth of towns meant that the sewerage systems often had to be enlarged and extended to cope with the increases in flow and the expansion of the urbanised area. Many towns and cities still have the remnants of piecemeal attempts to relieve overloaded sewers. The excess could often only be relieved by the construction of combined sewer overflows. The early overflows were often simply holes in the wall of the sewer and often where the principal branches of the sewers connected with the interceptor sewer or where newer sewers connected with older ones (Mercer, 1967).

Three distinct phases in the development of British sewerage systems have been identified (Green, 1981):

1. The Nineteenth Century programme of construction brought about by the awareness that waterborne diseases were causing epidemics. These still make up a large part of older city centre systems.

2. First World War: Foul and surface water was separated into a two pipe system (the "separate system"). This coincided with the development of urban estates on the outskirts of cities and large towns.

3. Second World War: Another dramatic rise in the new sewer construction associated with the development of "new" towns. The separate system was again used.

Although the separate system has been in use for over 50 years many of the sewers constructed using it are in the upper reaches of older, combined systems. Green (1981) estimates that only 10% of the present day systems are completely separate. The advantages of this system are that all the foul is taken to treatment and there is no need for storm overflows as all the rain water is discharged directly to a watercourse. The disadvantage is that the runoff from streets and houses is often highly polluting (Payne, 1989; Cordery,1976; Ellis, 1988). Also, the Scottish Development Department Report in 1977 concluded that a few wrong connections of the foul and surface water pipes would negate any potential benefits of the system.

1.2 The Legislation Relating to Storm Overflows and their Pollution of the Receiving Water.

In 1868 the second Royal Commission on River Pollution recognised the great effect that rainfall had on sewage treatment and on river pollution (Stanbridge, 1970). The Commission recommended that "unavoidable" overflow of storm water to rivers should be permitted but emphasised that it was of utmost importance to keep this to a minimum. The Rivers Pollution Prevention Act 1876, stated that it was an offence to discharge sewage to a river and sewage treatment on land then became the usual method.

In 1898 the Royal (Iddesleigh) Commission on Sewage Disposal was set up and an early report recommended that there should be "no discharge to a stream until the flow has reached 6 times the dry weather flow (DWF). No precise definition of what was meant by the "dry weather flow" was given but it was, at least, an attempt to calculate a setting for overflows.

The Fifth Report of this Commission, published in 1908, recommended that:

"Storm overflows on branch sewers should be used sparingly, and should usually be set so as not to come into operation until the flow in the branch sewer is several times the maximum normal dry weather flow in the sewer. No general rule can be laid down as to the increase in the flow which should occur in the branch sewers before sewage is allowed to pass away by the overflow untreated"

It was also recommended that in setting the overflow for storm sewage the general principle should be "to prevent such an amount of unpurified sewage from passing over the overflow as would cause nuisance".

Recommendations about the size of storm tanks at treatment works were also given in this report. It was recommended that storm sewage over 3DWF should be screened and diverted into storm tanks were some settlement would occur. These tanks would have a capacity of 6 hours DWF. No direct discharge to the river was to be made until these tanks were full and then only discharge of the effluent (after sedimentation).

In 1919 the Ministry of Health took over responsibility for sewerage and sewage disposal from the Local Government Boards in London and Edinburgh. The "Ministry of Health Requirements", based on the findings of the Royal Commission on Sewage Disposal Reports, were devised and became the standards for sewer overflow design for many years. The main requirement relating to sewer overflows was that they should be designed so that discharge should not take place until a flow equal to 6 times the DWF was being passed to treatment.

The setting of an overflow is its fundamental design criterion. It influences both the frequency of spill and the volume spilled to the receiving watercourse. Problems arose because there was no clear definition of "dry weather flow". The population in many urban areas continued to increase as did the per capita consumption of water. This meant that the base flow in many sewerage systems set to spill at 6DWF were now spilling prematurely. To investigate the problems brought about by storm discharges the "Technical Committee on Storm Overflows and the Disposal of Storm Sewage" was appointed in 1955.

Their Final Report was published in 1970. Of the 10,000 to 12,000 overflows in England and Wales they estimated that 37% were operating unsatisfactorily. The Report confirmed the view that the custom of setting the overflow as a multiple of DWF was unacceptable. It recommended the use of formulae for calculating the setting of storm overflows on sewers. It was recommended that the setting would be better expressed as a sum of two variables, the DWF and the surface water to be retained in the sewer before overflow commences.

The setting of the overflow was expressed as:

$$\text{Setting } (Q) = DWF + 1360P + 2E \quad \text{litres/day}$$

where: DWF is in litres/day
P is the population
E is the volume of industrial effluents discharged in 24 hours (litres/day)

The DWF is defined as the average daily rate of dry weather flow in dry weather and it includes infiltration water and industrial effluents.

This was the standard formula or "Formula A" which was to be applied to all new overflows except where the receiving water was unusually large (where the setting could be increased) or small (where the setting should be decreased). In many cases, the Formula A setting was very similar to the 6DWF setting.

The main objection to "Formula A" (which also applies to the fixed 6DWF setting) was that it addresses the problem only from the standpoint of sewer design and took no account of the capacity of the downstream system or the ability of the receiving water to assimilate pollutant material.

The Jeger Working Party was appointed in the late 1960's to investigate the reorganisation of sewage disposal. In their report in 1970 they proposed that water supply, sewage disposal and the recreational use of water should be combined. The 1973 Water Act reorganised the water industry into 9 English Water Authorities and one Welsh Authority. The areas of the authorities were based on river basin catchments. Some consisted of just one catchment e.g. Thames and others consisted of several catchments e.g. Yorkshire. They were the statutory authorities responsible for the provision of surface water drainage. They were responsible for the design, financing and maintenance of the drainage services and had a statutory duty to evaluate future needs and invest for the future.

Now that the river basins were under the control of one authority the collection and interpretation of river basin data became much easier. It was also possible to take stock of the condition of the sewerage systems. This process lead to the publication of the Sewer Rehabilitation Manual in 1983 and, in 1986, the River Basin Management Programme was initiated to provide "the necessary tools and methodology to allow objective and rational upgrading of deficient sewer systems" in the U.K. (Clifforde et al, 1986). It was recognised that research was urgently required to determine the extent and form of the contamination of the receiving water. It was also necessary to design new overflow structures, or improve the old designs, to minimise pollution discharges.

The Water Act of 1989 created the National Rivers Authority (N.R.A.) and transferred to it the pollution control function of the former Water Authorities. The Discharge Consents and Compliance Group was set up by the N.R.A. at its first meeting in 1989 to "review the way in which discharge consents for all discharges are set; the appropriate levels of compliance for different types of discharger and the way in which compliance with these consents is assessed and monitored". All discharges from C.S.O.s now require a consent from the N.R.A.. Applications for new consents require detailed information on the flows, contaminants, treatment measures and site plans. In an increasing number of cases environmental impact assessments could also be required (Morris, 1991; N.R.A., 1990).

1.3 Computer Simulations for the Design of Sewerage Systems

Computer models to simulate the chemical and biological effects of acute and chronic pollution resulting from combined sewer discharges are now being developed (Crabtree et al, 1988; Eadon & Williams, 1988; Beck et al, 1988; Payne et al, 1990; Wishart et al, 1990). These simulations, such as QUALSOC or CARP, can be used in place of traditional sewer system design methods when used in conjunction with existing hydraulic simulations. The new simulations are limited by uncertainties as to how overflows operate with respect to their hydraulic and pollution performance and the need for suitable data for verification.

1.4 Combined Sewer Overflows - Their Role and Performance

During heavy rain the volume of surface water entering the combined sewerage system is many times greater than that of dry weather flow (DWF). Storm treatment works have traditionally been designed to treat up to 3DWF during storm events and to divert a further 3DWF to specially built storm tanks with a joint capacity of 6 hours DWF. It is considered impracticable and uneconomic to build treatment works that are capable of treating the full storm discharge, or to provide sufficient storage at the works to retain the full volume of storm sewage for treatment at a slower rate. Very dilute sewage is also harder to treat using modern biological processes e.g. the activated sludge process.

It is also considered impracticable and uneconomic to build sewers capable of carrying the full storm discharge to the treatment works. Average storm flow volumes in the U.K. are between 40-150DWF (Lester, 1967). Any volume in excess of 6DWF must be allowed to escape from the sewerage system to prevent surcharging, backing up, overflowing and causing possible flooding. Combined sewer overflows are thus incorporated into the sewerage system to relieve this excess flow. The original theory was that the overflow will only discharge when the flow in the sewer is diluted by large volumes of storm water and the resulting mixture will thus not be polluting. Also, as the receiving water course would be swollen by the rain, the dry weather flow would be diluted still further. This analysis has proved to be too simplistic.

The Technical Committee on Storm Overflows and the Disposal of Storm Sewage Final Report (Ministry of Housing and Local Government, 1970) presented five general design recommendations that each overflow chamber should achieve.

1. The overflow should not come into operation until the prescribed flow is passed to treatment.

2. The flow to treatment should not increase significantly as the amount of overflowed storm sewage is increased.

3. The maximum amount of polluting material should be passed to treatment.

4. The design of the overflow should avoid any complication likely to lead to unreliable performance.

5. The chamber should be designed so as to minimise turbulence and the risk of blockage; it should be self-cleaning and require a minimum of attendance and maintenance

Other desirable features for a combined sewer overflow include :

i The overflow should be fully automatic.

ii Construction costs should be kept to a minimum.

iii The overflow should not take up much land (this is especially important in densely populated areas).

iv The chamber should be constructed from non-corrosive materials.

v The chamber should have a working life of over 30 years.

vi The setting of the overflow should be appropriate to the location.

vii The chamber should have proper ventilation and safe access.

1.5 COMBINED SEWER OVERFLOW DEVICES

The older designs simply gave hydraulic relief to avert the surcharging of sewers and minimise the risk of flooding. Such designs included:

- Leaping weir
- Hole in Manhole
- Low Side Weir

With these designs it was often not possible to achieve the proper hydraulic control required to satisfy at least the first two of the general design recommendations suggested by the Technical Committee on Storm Overflows and the Disposal of Sewage which were quoted in Section 1.4.

In order to ensure that the overflow operates to the desired setting the outlet should be throttled in some way (using an orifice plate, a penstock, or a throttle pipe). The overflow weir should also be set above the centreline of the incoming sewer. This should encourage a gentle controlled motion in the incoming flow and thus ensure a predictable first spill and the required regulation of the flow to treatment (Balmforth, 1986). Designs that achieve these criteria include:

- high sided weir
- stilling pond
- swirl/vortex chamber

It is also important to ensure that the velocity of the incoming flow is low (but not so low that it allows suspended material to sediment out in the sewer pipes). The greater the velocity of flow within the pipe the lower the efficiency of the chamber. The Scottish Development Department Final Report, 1977 suggested that the best performances occurred when the inlet pipe is long and straight and velocities are as small as possible.

The overall efficiency of a C.S.O. chamber is also dependent on the terminal velocity distribution of the particulate matter in the storm sewage passing through it. The Scottish Development Department Final Report stated that if the proportion of particles with low terminal velocities is high the proportion of material that is passed on to treatment will tend to the flow ratio. A brief description of the different designs follows.

1.5.1 Hole in Manhole

This is the simplest device (see Figure1.1). It consists of no more than a diversion pipe set in the wall of a manhole chamber at some distance above the invert of the main channel. Excess storm sewage is allowed to spill to the nearest watercourse if the level in the manhole rises above the bottom of the introduced pipe.

1.5.2 Leaping Weir

The leaping weir consists of a trough or sometimes just a large hole in the bottom of the sewer pipe (see Figure 1.2). In dry weather the sewage drops through the hole into a lower pipe which continues on to the treatment works. As the flow increases at the onset of storm flow some of the flow has enough momentum to 'leap' across the gap. This flow is discharged to the water course. In some designs the length of the gap was adjustable. One of the main problems with this design is that the gap often becomes bridged by materials in the flow so that the overflow spills in dry weather.

There is no control of the flow in either of these two designs. Also, no account was taken of the need to restrict polluting material. These types of overflow are often not able to provide sufficient relief. As the flow in the sewers increased, due to an increase in urbanisation and per capita consumption, other overflows had to be introduced near to the existing structures in order to supply the necessary relief for the system. These types of overflow are no longer constructed although a number of them in are still in operation.

1.5.3 Low Side Weir

In this design the sewage flows along a channel (which may be tapered) to the outlet of the overflow chamber (see Figure 1.3). The height of the weir crest is less than half the diameter of the inlet pipe. The weir can be either single or double sided. The early types of weir had low weirs crests and the downstream sewer was the same size as the upstream pipe. In later designs the height of the weir was increased and a throttle control downstream of the weir was incorporated. Scumboards or dip plates were fixed near to the weir(s) to restrain the floatable material in the flow from passing over the weir.

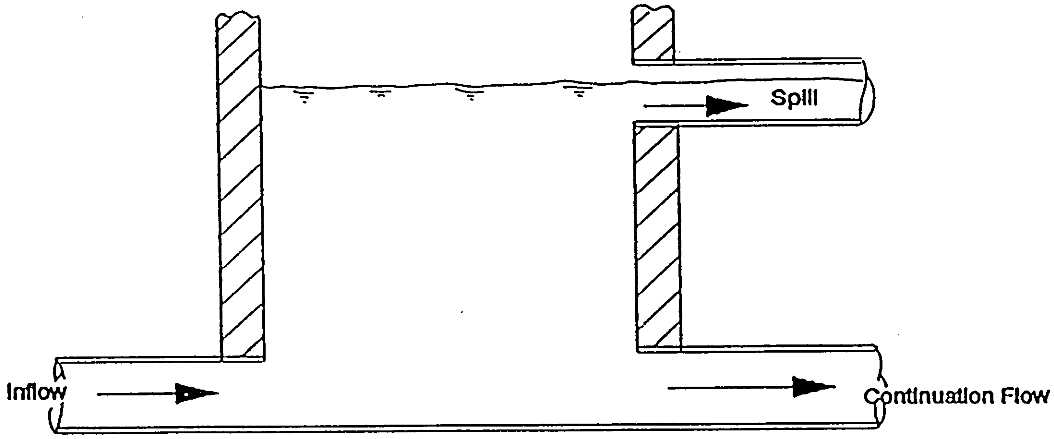


Figure 1.1 Hole in Manhole

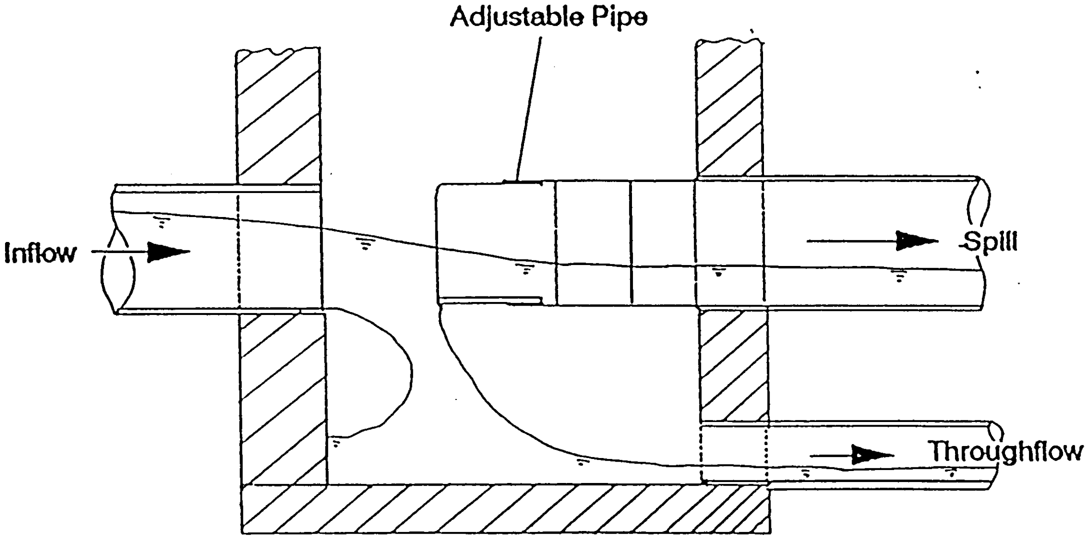
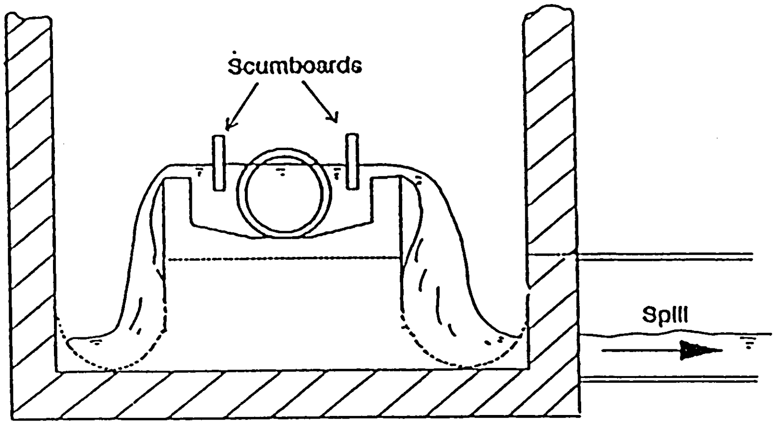


Figure 1.2 Leaping Weir



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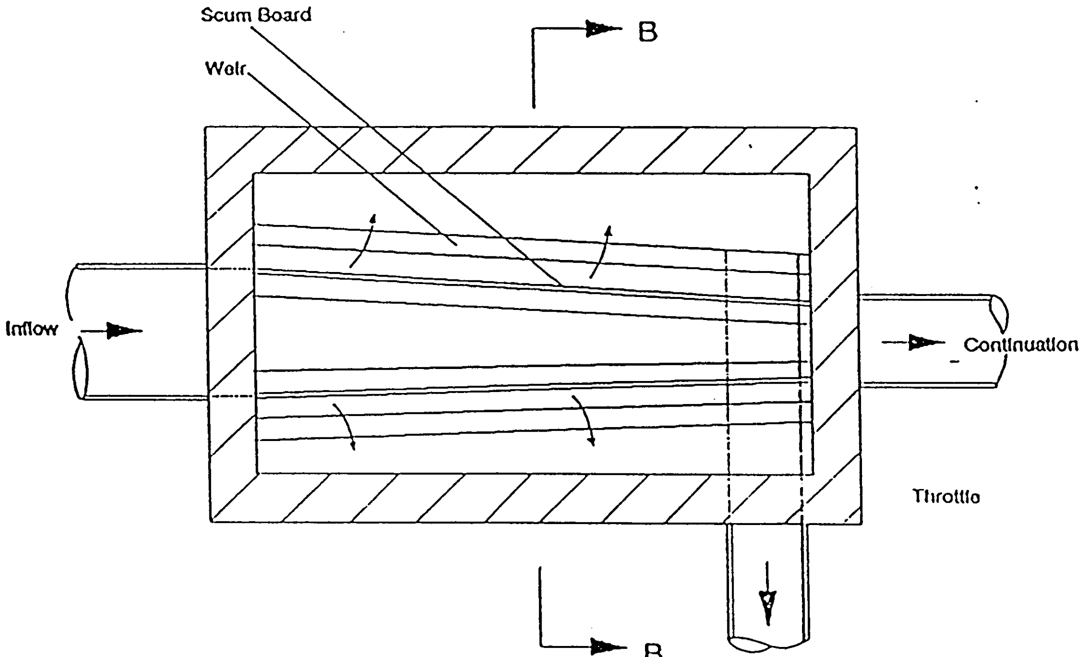


PLAN VIEW

Figure 1.3 Low Side Weir

Low side weirs tend to exhibit poor hydraulic control during storm events. A drawdown of the flow occurs as the flow increases above a certain level. This causes the level of the flow above the weir to diminish along the length of the weir. This encourages an increasing proportion of the flow to continue on to the treatment works. A secondary, longitudinal roller flow also occurs which is responsible for passing settleable solids over the weir. Such poor hydraulic control is undesirable as it is not possible to restrain the flow to a steady maximum.

The most important limiting factors affecting the proportion of flow that is spilled are the crest height and the setting of the downstream throttle (if present). The discharge will be increased if the crest is lowered or if the effect of throttling is increased. If the crest is lowered too much there is a risk of premature spilling. At low flows the inclusion of scumboards or dip plates seem to be detrimental. At higher flows the effect is rarely beneficial and often negligible. The operation of the low side weir has been shown by many to be unsatisfactory both in terms of the hydraulic performance and its ability to restrict suspended material from passing over the weir (Ackers et al, 1967; Min. Housing and Local Govt., 1970).

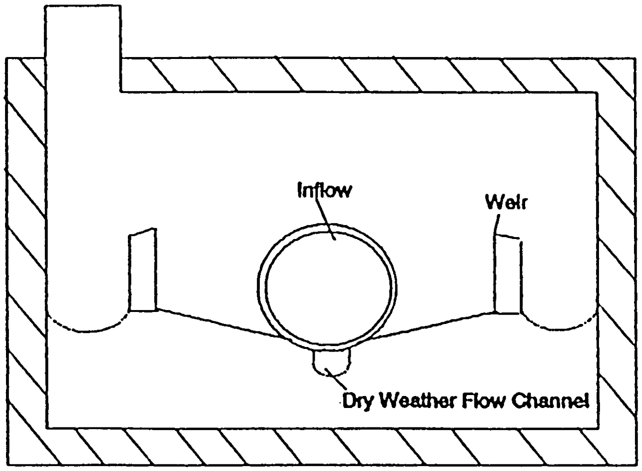
1.5.4 High Side Weir

This is a rectangular chamber with high, single or double crested weirs to the side of a central dry weather flow channel (see Figure 1.4). The weir crest is designed to be above the mid-point of the incoming sewer. There is a throttle on the throughflow pipe that ensures that flow in the chamber can be restricted to the required setting and that there will be a minimal increase in the flow to treatment after the first spill. There are a number of methods of calculating the optimal length of the weir for a given site for the design flow rate (De Marchi, 1934; Balmforth & Sarginson, 1978; Delo & Saul, 1985).

Delo and Saul (1985) outlined a series of design requirements for a high side weir to maximise the efficiency of the chamber with respect to its ability to separate and pass on the maximum polluting load to treatment. They investigated the solids separation performance of a laboratory scale model of a high side weir which could be easily modified to give various configurations. Each configuration was tested under steady flow conditions and plastic particles were used to represent the sewage particles. The main conclusions of their work were:

1. The chamber dimensions and entry conditions to the chamber should create a uniform flow zone in which the particulate matter is encouraged to separate. An oversized inlet pipe or a rectangular section stilling zone should be provided. The length of the stilling zone should be as long as is practically possible and not less than four times the diameter of the inlet pipe. Manholes and changes of direction of the sewer immediately upstream of the chamber should be avoided if at all possible.

2. Chamber efficiency is a function of head over the weir and consequently the weir length should be as long as possible. Double side weirs are thus preferable to single side weirs although they are more expensive.



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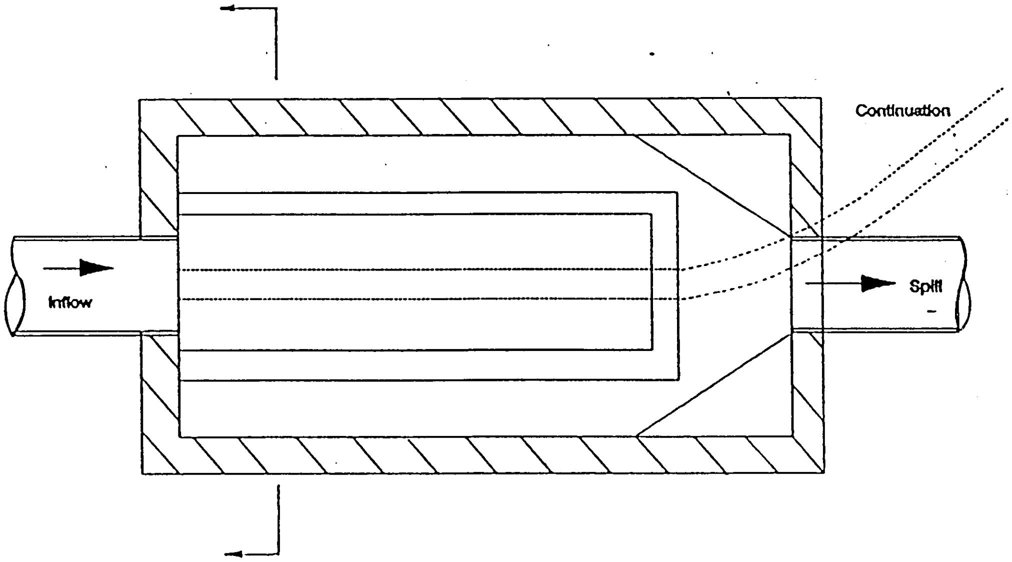


PLAN

Figure 1.4 High Side Weir

3. The weir height should be as high as possible and not less than 0.7D. Little improvement in performance is achieved with weir heights greater than 0.9D.

4. Scumboards should be incorporated into the overflow design to prevent the discharge of floating material over the weir.

5. A small retention volume should be provided downstream of the weirs primarily for the collection of floating particulate retained by the scumboards.

6. The inlet and the throttle pipe should be centrally located along the longitudinal axis of the chamber.

The high side weir has been shown to give good hydraulic control (Balmforth & Sarginson, 1978). The solids separating efficiencies are almost as good as those resulting from the stilling pond overflow for scale model tests. The high side weir was recommended by the Technical Committee on Storm Overflows and the Disposal of Storm Sewage (1970) as being an adequately efficient and cost-effective design. It is still considered to be a reliable design although now dynamic designs and stilling ponds are more popular for new overflow constructions.

1.5.4 Stilling Pond

The stilling pond was developed by Sharpe and Kirkbride in the late 1950's specifically to provide good separation and retention of gross solids (defined as material where the median size of the particle is greater than 6 millimeters (Green, 1991)). The stilling pond is a rectangular tank with an end weir (or sometimes a siphon). A scumboard is fitted parallel to the weir. A throttle is provided on the continuation pipe (see Fig. 1.5). The chamber is designed to provide a suitable flow pattern in the chamber to allow sufficient time for the separation of suspended material. Dense particles in the storm sewage sink and are entrained into the continuation flow. Floating material rises and is trapped in the chamber by a scumboard and reverse surface currents until the flow subsides and the depth of storm sewage in the chamber is reduced to that of the dry weather flow. The trapped material is then passed forward to treatment.

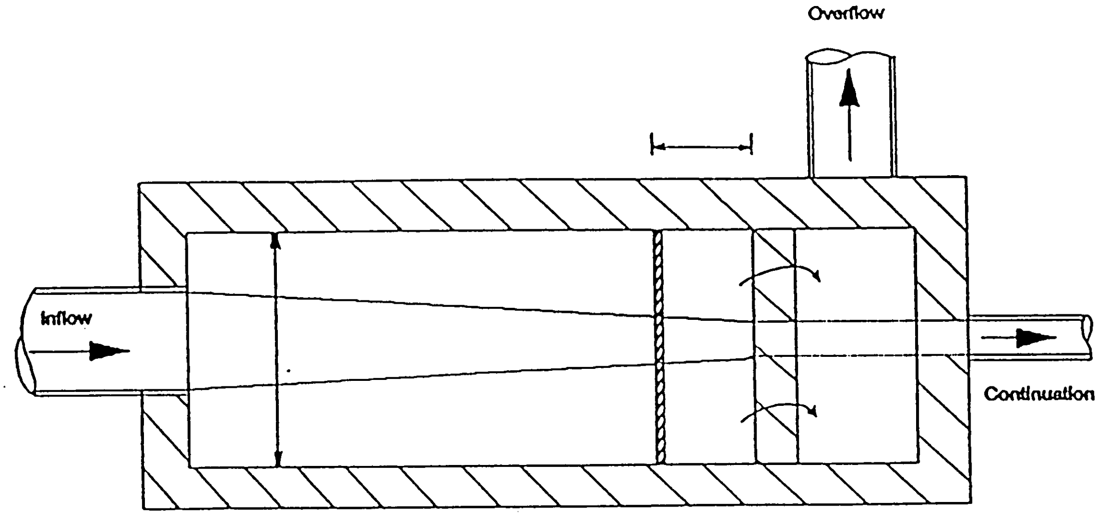
Sharpe and Kirkbride made five basic recommendations for the efficient operation of stilling ponds in their report in 1959.

1. The chamber must be of adequate length and the downstream velocities low enough to allow the floating bodies to reach the surface upstream of the scumboard.

2. A tranquil area or areas should exist within the chamber as far as possible from the scumboard where the separated floating bodies can congregate and be stored until the storm has subsided.

3. Surface flow conditions should naturally carry all floating bodies to the tranquil storage area.

4. The water velocities in the chamber should not be so high that they remove the floating bodies once they have reached the tranquil zone.



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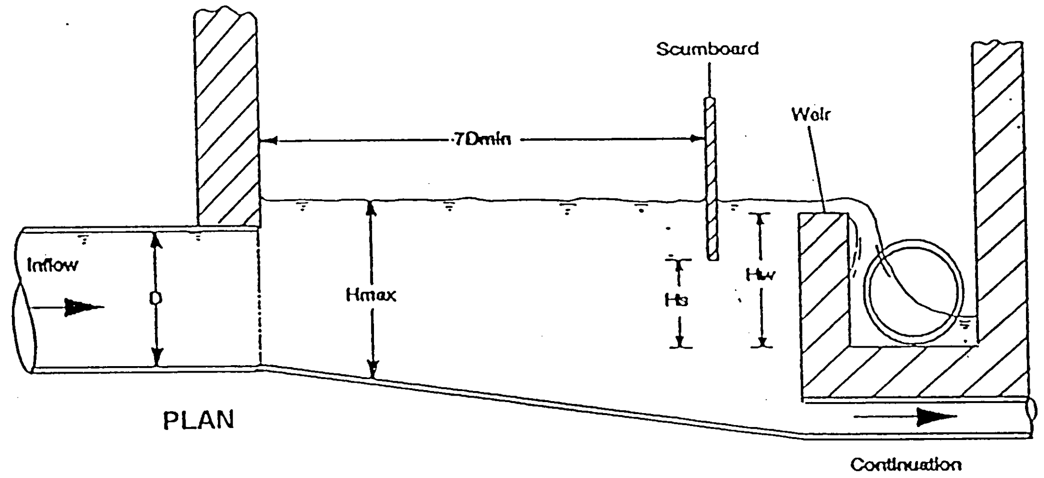


PLAN

$H_w = WD$	$D_{min} = KQ^{0.4}$	$H_{max} = CD_{min}$	$H_s = SD$
W	K	C	S
0.90	0.85	1.60	0.50
1.00	0.83	1.70	0.60
1.20	0.82	1.85	0.80

Figure 1.5 Stilling Pond

5. The inlet velocity and the downstream velocity should not be high enough to lift the heavy bodies up and over the weir.

The length of the chamber has a large influence on the performance of the chamber. Sharpe and Kirkbride recommended design dimensions for optimal performance in their paper in 1959. More recent work by Saul (1977) and Balmforth (1982) suggests that an extended stilling pond design is more effective in separating the suspended material in the flow. Saul (1986) comments that increasing the length of the chamber upto a maximum of 9D (D is the diameter of the inlet pipe) resulted in an improvement in efficiency over the whole range of particulate terminal velocities.

Increasing the width of the chamber above 2.5D did not appear to show any significant change in the gross solids separation characteristics of the chamber although increasing the width does increase the storage available and thus reduces the frequency of overflow operation.

The stilling pond has been widely used in new installations as it is relatively cheap to construct and gives a reliable performance. It was also recommended by the Technical Committee in 1970 in their Final Report. The separation of solids has been shown to be higher in the stilling pond than the high side weir for similarly sized chambers.

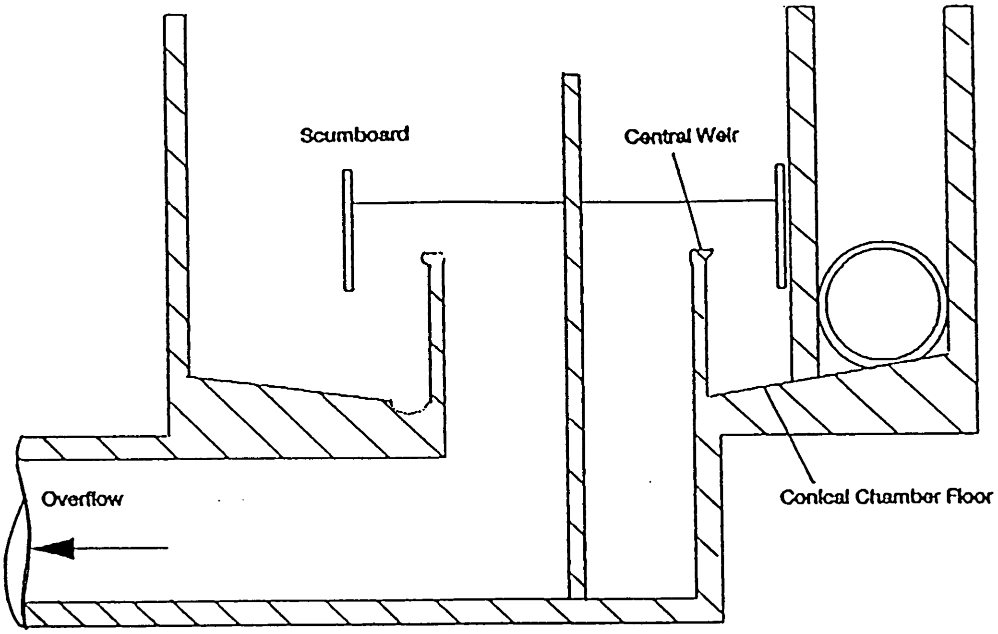
1.5.5 Vortex

The idea of using the vortex motion of storm sewage to separate suspended material and to act as a hydraulic control in a combined sewer overflow was first devised by Bernard Smisson in 1932 in Bristol (Smisson, 1967). In 1963 two such devices were constructed in Bristol. His son, Robert Smisson, has continued to promote the use of vortex separators under the name of "hydrodynamic separator". Several have now been tested and are currently being successfully used as C.S.O. devices.

In the Smisson design the vortex is formed in a cylindrical chamber with a central spill (see Figure 1.6). A complex flow pattern forms with a circular motion and the development of separate vortices around the wall and near to the central column. The separation of solids relies on the action of centrifugal forces. Denser particulates settle at the bottom and are drawn into the centre by secondary currents. Lighter particulates tend to rise to the surface in the middle of the chamber.

The vortex concept was taken up in the U.S.A. A "Swirl-Concentrator" design was developed by Field (Field, 1974). This had some success in U.S.A. although it was thought not to be a suitable design for British sewerage systems due to the greater ratio of storm to foul sewage in the storm sewage in this country.

In the early 1980's Balmforth and others at Sheffield City Polytechnic developed a vortex design with the weir on the circumference of a circular chamber (Wardle, 1976; Winder, 1976; Brown, 1977; Balmforth, Lea & Sarginson, 1984). This was known as a "vortex with peripheral spill" (see Figure 1.7). Using model tests Balmforth and Lea produced a design which induced a forced vortex in the incoming flow which was found to be more effective in separating suspended material than the free vortex created in earlier designs.



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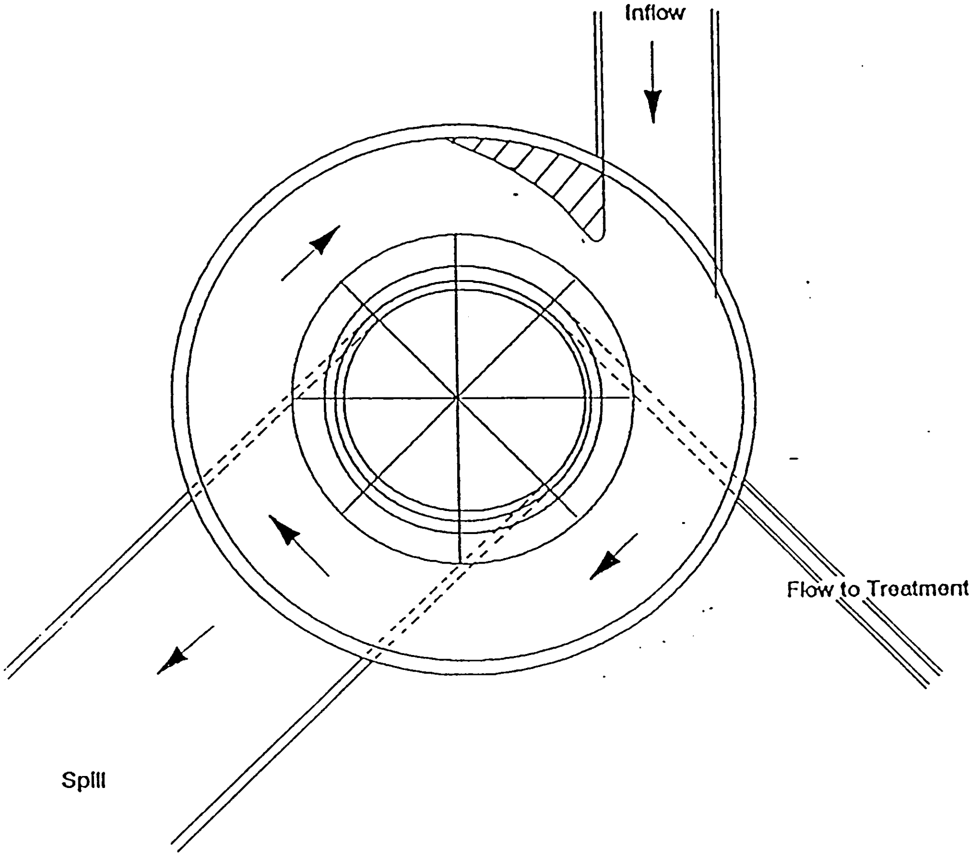

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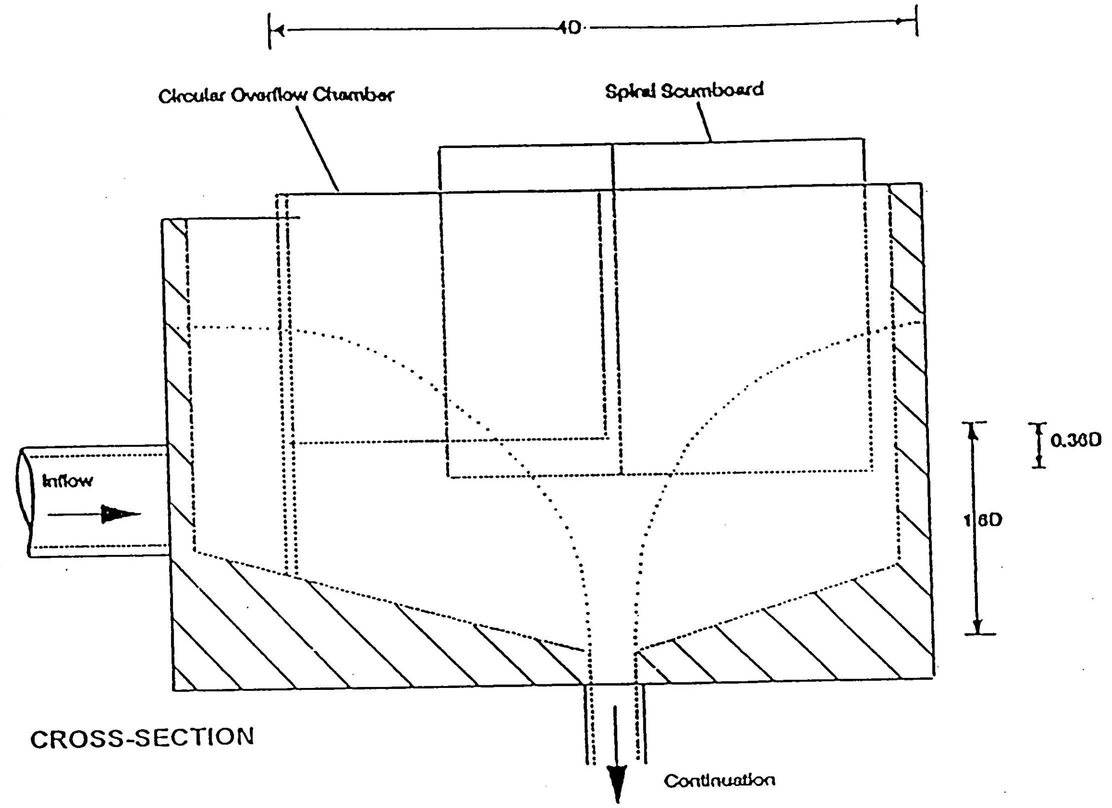
Figure 1.6 Vortex with Central Spill



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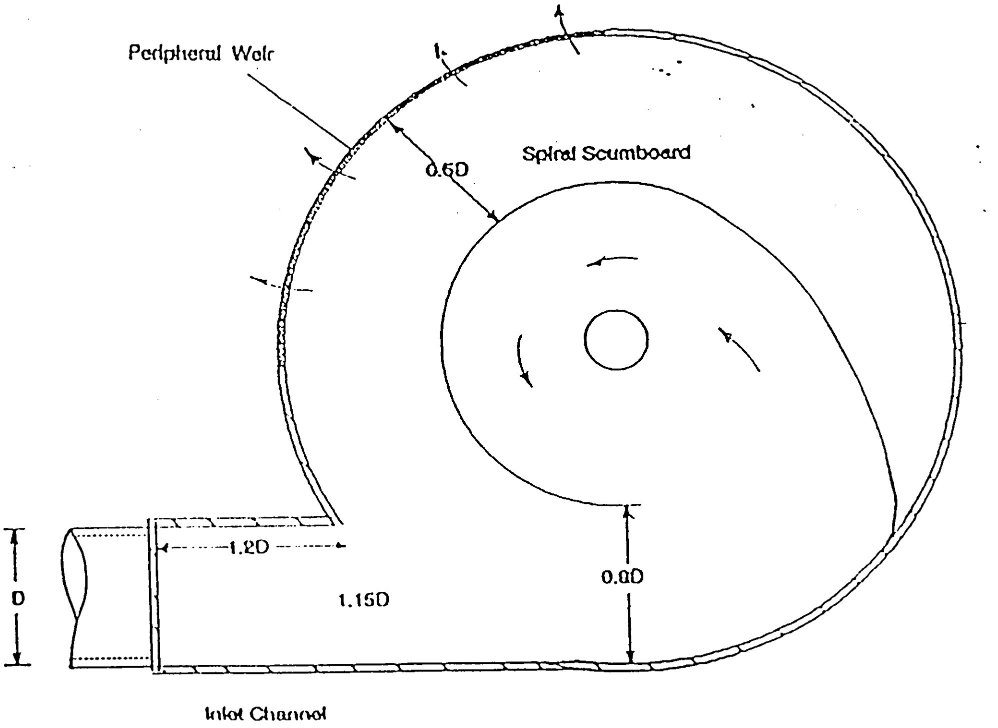

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Figure 1.7 Vortex with Peripheral Spill

The vortex concept has also been used in Germany. In 1984 Brombach designed a vortex separator with which he hoped to "fill the technical gap between storm overflows and storm overflow tanks" (Brombach, 1987). In model tests, using a 4m diameter structure and polystyrene granules to represent suspended material, only 6.3% of the outflowing water going to the treatment works, was found to contain 60% of the "polluting material" (the polystyrene granules). It was calculated that a conventional side weir overflow would have to be three to four times greater in volume to achieve the same efficiency.

The efficiency of the different designs in retaining gross solids has been investigated in a number of studies (Smisson, 1989; Lockley, Hedges & Martin, 1989, Cootes, 1990). Cootes in a three year study of a vortex with peripheral spill found that the structure performed well hydraulically. The continuation flow did not increase significantly after first spill. The chamber was found to concentrate gross solids (rags, tissues, sticks etc.) in the foul flow reducing the concentration of such objects in the flow by 20-40% compared with that in the inflow during storms with flows up to twice that required to spill. The estimated pollutant load retained in the foul flow was 60-95% of that entering the chamber.

The results of various studies using the hydrodynamic separator were summarised by Robert Smisson in 1991. Monitoring had demonstrated that 46-60% of the mass of suspended solids and 35-69% of the biochemical oxygen demand entering during a storm event is retained in the throughflow and passed forward to treatment. They also found that there was a 5-45% reduction in dissolved contaminants such a nitrates.

A comparison of the performance of a vortex with peripheral spill, a stilling pond, an expanded stilling pond and a high side weir, using plastic particulates to represent the gross polluting solids, was conducted by Balmforth using his own data and data from other studies (Balmforth, 1990). The three designs were found to operate equally well hydraulically. The vortex was found to give the best separating efficiency. However a drop in invert of 1.5D is required thus limiting the number of sites at which it can be installed. Balmforth concludes that there is no single best type of overflow and that the choice will largely depend on the topography of the construction site.

1.5.6 Storage Tank Overflows (S.T.O.)

Extra storage in the sewerage system can be provided by covered concrete tanks below ground or the inclusion of oversize pipes known as tank sewers.

The advantages of S.T.O.s are described by Saul and Murrell (Saul & Murrell, 1986):

- the alleviation of downstream flooding
- a delay in the onset of first spill
- a reduced frequency of overflow
- a reduced volume of combined sewage spilled
- a reduction in the pollutant load discharged to the watercourse

They can also be effective in retaining the 'first foul flush' (see Section 1.6.2) although some means of calculating the storage volume required to retain the first foul flush must be determined. Hedley and King investigated the provision of storage at overflows to protect watercourses against severe summer storms (Hedley & King, 1971). They found that for very intense storms most of the excess BOD (approximately 90%) is carried off in the time of concentration or just longer than this. They argue that for a design storm the peak runoff occurs, usually, when flow is being received from all parts of the drainage area including the most remote. It can be assumed that at this time after the start of the storm, all the sewers and impervious areas will have been flushed clean so that from that time on the foul sewage will simply be being diluted. Thus retention of the storm sewage longer than the time of the peak runoff is unnecessary.

Storm tanks can be "on-line" or "off-line". The two configurations are illustrated in Figures 1.8 and 1.9. A number of trials of storm tanks especially in the North West of England, have shown storm tanks to be an efficient and cost effective means of reducing the load of pollutant material entering the watercourse (Saul & Murrell, 1986). A study in Littleborough, near Rochdale, investigated the performance of a 1500m3 storage tank that had been installed to replace the eight existing C.S.O.s. A report of this study written 12 months after it was commissioned suggests that the upstream river quality had improved and the new overflow discharged less frequently than had been predicted (Davis & Parkinson, 1991).

1.6 The Problems Caused by Combined Sewer Overflows

In many urban areas there has been a significant increase in the water consumption per head of population since many of the C.S.O. settings were proposed. An increase in urbanisation is usually associated with an increase in the proportion of the impervious areas. This gives rise to flashier storm runoff, a reduced time of concentration and a larger volume of runoff reaching the sewerage system. These factors, along with higher dry weather flows, have considerably increased the volume of flow in the sewers since they were constructed. Many overflows spill before their design setting and some even in dry weather. The poor design of many of the original sewers has led to the deposition of silt in the pipes thus reducing the hydraulic capability of the system still further and leading to premature overflow (Water Research Centre, 1983).

Several reports in recent years have published data on the approximate number of unsatisfactorily operating combined sewer overflows. In 1970 Technical Committee on Storm Overflows and the Disposal of Storm Sewage published the results of their survey conducted among the then River Boards. The River Boards were asked for information on all the known overflows in their respective areas. From this it was estimated that there were 10,000-12,000 overflows in England and Wales and that 37% of these overflows were operating unsatisfactorily.

In 1974 the Scottish Development Department sent out a questionnaire to 234 Water Authorities in Scotland asking them to state the size, number and type of overflows in their area and to state whether they were operating satisfactorily or not. The results suggested that 20% (423 overflows) were operating unsatisfactorily.

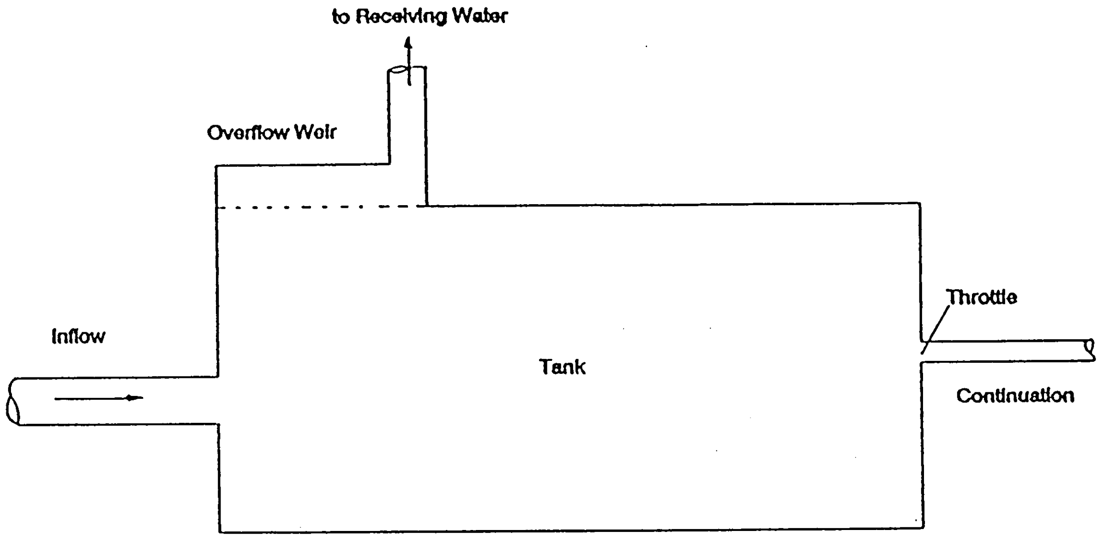


Figure 1.8 Storage Tank Overflow (on line)

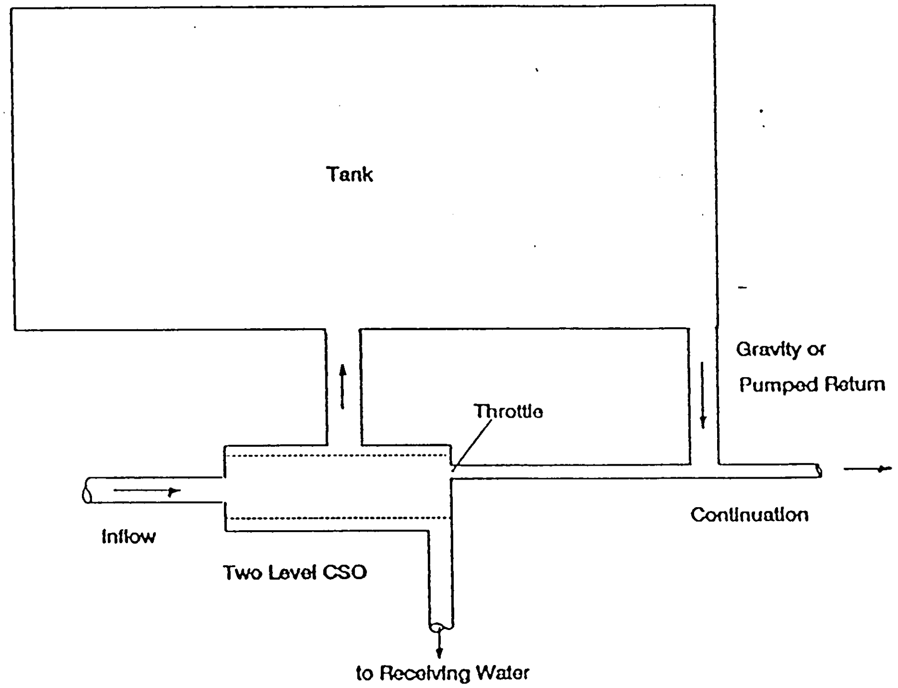


Figure 1.9 Storage Tank Overflow (off line)

During the privatisation of the Water Industry it was found that these earlier estimates of the number of storm overflows was rather low and that a figure of 21,000 was more realistic (O'Sullivan, 1990). Morris (1991), quotes a figure of 22,000 for the number of combined sewer overflow consents inherited by the National Rivers Authority. He also comments that several estimates of the problem have been made and that 25-30% of all combined sewer overflows are considered to be unsatisfactory i.e. 5,500-6,600 combined sewer overflows in England and Wales.

Shuttleworth (1986) in his review of the state of rivers and sewers in Britain encourages us to take such estimates with a pinch of salt. He quotes an example of the number of unsatisfactory C.S.O.s in Yorkshire. Having investigated three separate documents he noticed that although the total number of C.S.O.s were the same the number of unsatisfactory overflows varied considerably. This was put down to the absence of a precise definition of "unsatisfactory". Several definitions have been used in the past. A collation of the main reasons for describing a C.S.O. as unsatisfactory are as follows:

1. It causes or contributes to a change in the river classification (maybe in combination with a group of overflows) i.e. it has an adverse effect on the biotic environment surrounding the site.

2. There has been a history of complaints at the site e.g. reports of the stranding of objectionable solids in the vicinity of the overflow, odour problems.

3. The overflow operates in dry weather.

4. The overflow operates too frequently in wet weather.

5. The overflow does not spill a large enough volume to provide sufficient relief for the downstream sewerage system.

6. The overflow chamber is structurally unsound.

7. Access to the chamber is difficult or dangerous.

8. The overflow discharges into an amenity area where the public health risk is high.

Figures published in the most recent survey of "The Quality of Rivers, Canals and Estuaries in England and Wales" published by the National Rivers Authority in 1991, state that the water quality in the Yorkshire region has deteriorated since 1985 (5% of the classified river length has been downgraded). Most of the problems are said to be as a result of sewage discharges and sewage effluent. In the same year it was estimated that 21% of the poor quality of the River Aire (Yorkshire) could be attributable to prematurely operating or inadequate C.S.O.s (Morris, 1991). In 1989 there were over 250 serious reported pollution incidents caused by storm overflow discharges in England and Wales. Thus, although it may be hard to define the exact number of unsatisfactory overflows, it can be seen that the problem is quite a significant one.

In the late 1960's the gradual replacement of combined systems with separate systems was seen as a reasonable solution to this problem (Klein, 1966). It now seems that this view is unrealistic. The combined parts of the sewerage systems tend to be in the older, more built-up parts of towns and cities were large-scale disruption of major roads would be costly and inconvenient. The need for overflows within the drainage system is not likely to change in the foreseeable future.

1.6.1 The Setting

The setting of an overflow is its fundamental design criterion influencing both the frequency of spill and the volume spilled to the receiving watercourse. The following factors should be taken into account to ensure that the correct setting is chosen.

- the composition of the dry weather flow
- the capacity of the downstream sewer and treatment works
- the impact on the receiving water (from a physical and a biological viewpoint)
- the current and proposed river quality objectives

1.6.2 The Composition of the Dry Weather Sewage and Storm Sewage in Combined Sewer Systems

When sewage flow is mainly domestic dry weather flow it may be defined as "the average daily flow to treatment during seven consecutive days without rain (excluding a period which includes a public holiday or local holidays) during which rainfall is not above 0.25mm on any one day". With industrial sewage the definition is based on five working days (Aspinwall, 1981). In order to gain as representative a picture as possible one set of samples should be taken in the summer and one in the winter.

Dry weather sewage is a complex mixture of natural inorganic and organic materials with a small proportion of synthetic substances. The strength of dry weather sewage depends on such factors as the per capita water consumption, the amount of infiltration occurring in the catchment and the time of day. Peaks of urea and ammonia are discernible in the early morning and late at night, reflecting the habits of the population. The peak concentration of parameters such as BOD generally occur in the middle of the morning although this depends on the length of the sewers and the nature of the sewered area (Gray, 1989). It is generally found that the larger the catchment the smaller the diurnal concentration fluctuations.

The pollutant concentrations of combined storm sewage are inherently variable. Reasons for the recorded differences in combined storm sewage discharge concentrations have been given in a number of studies (Hogland, 1984; Ellis, 1988; Thornton & Saul, 1987; Lester, 1967; Field, 1974; Tucker & Mortimer, 1978; Lindholm, 1984; Lessard & Lavallee, 1984):

- characteristics of the rainfall (intensity, duration, total volume, time to first spill)
- the amount of pollutant that has accumulated in the sewer pipes and the overflow chamber (related to the age of the sewerage network, its state of repair etc.)
- the length of the antecedent dry weather period
- total volume of runoff
- scouring ability of the flow
- the dry weather sewage characteristics
- the possibility of solids deposition during storm events
- time of day
- land use
- proportion of the catchment that is impervious
- topography of the catchment

The "first foul flush" phenomenon can be defined as a peak of pollutant concentration in advance of the peak flow. This was known about at the beginning of this century. The Third Report of the Royal Commission of 1868, who were investigating the best means of preventing the pollution of rivers, notes that "chemical analysis shows that storm water, so far at least as its earlier portions are concerned, is more polluting that dry weather sewage, owing to old deposits in the sewers being swept to the outfall". Since this time the phenomenon has been recorded by numerous other workers (Harremoes, 1992; Thornton & Saul, 1987; Eckhoff et al, 1969; Tucker & Mortimer, 1978).

The occurrence and timing of such a flush of pollutants is highly variable. Work done by Geiger (1984) suggests that the first foul flush only occurs about 25% of the time. It is usually ascribed to the removal of materials accumulated in the sewerage system since the previous storm event. Thornton and Saul found that 50-60% of the pollutant load originated from the accumulation of material on the sewer pipe walls and from deposited sediments in the pipes. Eckhoff et al, (1969) identified three phases of pollutant concentration in sewerage systems in the U.S.

1. initial stage : the combined sewage strength is analogous to the dry weather flow
2. middle stage : the combined sewage pollutant concentrations increase above those of the dry weather flow (values of 125-200% are given)
3. final stage : the combined sewage strength diminishes to become dilute sewage (10-25% of the strength of the dry weather flow)

The initial phase is not often described in the U.K. Ellis reports that the initial flush, when it occurs, can be equivalent or greater than the dry weather flow but that it rapidly declines until a delayed pollutant wave is received, thought to be due to fresh material entering the drainage system from the roads and paved surfaces. This delayed wave can be up to three hours behind (Ellis, 1982; Ellis,1986). Harremoes (1984) reports that in

Danish experiments 60% (+/- 10%) of the mass was passed when only 50% of the water had passed over the weir. Canadian experiments found that the peak flow and the peak concentrations during 9 events were usually coincident (Lessard & Lavallee, 1984). This was thought to be because the catchment was quite steep and there were no deposition problems in the sewerage system. Many report that where the first foul flush occurs it approximates to the time of concentration of the sewerage system (Hedley & King, 1971; Ellis, 1979).

1.6.3 The Impact of Combined Storm Sewage on the Receiving Water

Combined sewer overflows discharge intermittently. It is estimated that some 35% of the total annual pollutant load discharged to receiving waters in the U.K. comes from C.S.O.s and storm water overflows which only operate 2-3% of the time (Ellis, 1986). Chemical analyses can only give a limited view of the effect of a storm sewage discharge on the receiving watercourse. Only the state of the water at a single point in time is recorded. Intermittent discharges may easily be missed by routine (weekly or even daily sampling). An effluent which changes the ecology of a river is said to be polluting. One that leaves the biota unaffected is seen as acceptable (Chandler, 1970). Thus, in one situation a watercourse with a recorded BOD of 5mg/l may be seen as extremely polluted in one situation e.g. where flow is sluggish but the same pollution level in another situation, e.g. a fast flowing stream, may be perfectly acceptable.

Any investigation into the effects of a combined sewer overflow discharge on the flora and fauna of the receiving watercourse is extremely complex. This is due to the diversity of the chemicals in the sewage and the complexities of the interactions between the hydrosphere, geosphere and biosphere (Lockwood, 1976). This makes it difficult, if not impossible, to analyse the different inputs separately.

LC50 tests are used to examine the tolerance of a given animal species to different concentrations of a pollutant under laboratory conditions (it is the concentration which causes the death of 50% of the sample). However, this method will not take account of the varying concentrations that would occur in the watercourse or different stages in the life cycle of the animal. It will also miss effects that may only be obvious at the population or ecosystem level (Lijklema et al, 1988). Biological sampling, by macroinvertebrate surveys or experiments with caged indicator species in the flow (Seager & Abrahams, 1989) can give an assessment of the quality of the watercourse over a much longer period of time and should be carried out in conjunction with a chemical survey in order to obtain a full assessment of the river water quality.

The impact of the discharge of combined storm sewage can be divided into two main effects:

1. an acute effect: an immediate toxic effect at the point of discharge
2. a chronic effect: due to the settlement of discharged solids which may exert an influence on the sediment/water boundary or be resuspended after being disturbed

The immediate effect is often an increase in the BOD and suspended solids concentration of the receiving watercourse. The concentration of dissolved oxygen is then reduced. Where there is exposure to high concentrations of BOD or where the exposure is for a prolonged duration then the dissolved oxygen may be reduced to such an extent that the biological condition of the river is disrupted, maybe irreversibly. It may also detract from the value of any abstracted water. Low oxygen concentrations are associated with fish kills, putrefaction and if prolonged the death of the entire flora and fauna of the watercourse (Mason, 1991; Klein, 1957). The immediate toxic effect will also include any inorganic materials or metal ions discharged. The severity of any effects will depend on the bioavailability of the material.

The chronic effects, due to the prolonged exposure to low concentrations of pollutants, are thought to be more significant for intermittent storm overflow discharges (Lijklema et al, 1988). It is estimated that 35% of the total potential oxygen demand from a spill event is exerted as a delayed chronic demand by the bed sediment and that only 4% is exerted in the water column during the spill event (Harremoes, 1992). The solids are considered to be the main vectors of pollution in storm water discharges. Chebbo and his colleagues report that 69% of the hydrocarbon compounds are adsorbed by particles that are >250um. Finer particles (<50um), adsorb 52-68% of the COD and BOD pollutant load. While solids that are between 50-250um gather 60% of the solid nitrogen pollution (Chebbo et al, 1990). The sediment downstream of an overflow may be 10-50 times more contaminated that the sediment upstream (Villeneuve & Lavallee, 1986).

The addition of enhanced concentrations of nutrients, specifically nitrogen and phosphorus, may result in the stimulation of plant growth, especially the growth of algal blooms and species such as *Spaerotilus natans*. (sewage fungus) which is often found in the vicinity of unsatisfactory storm overflows. It exudes a gelatinous substance which act as a filter to trap large amounts of fine particulate matter which will later be returned to the water (Ellis, 1982).

A study on the effects of combined sewer overflows on the ecology of the receiving waters in Switzerland concluded that an important direct effect on ecology was an increased flow velocity and a related erosion of the benthos and turnover of the sediment material (Gujer & Krejci, 1987). This erosion of the benthos contributed to the loss of the self-purification capacity of the receiving watercourses. This study also found that, except for fish, the fauna can tolerate fairly high concentrations of ammonia with acute effect, and also, low dissolved oxygen concentrations over short periods (hours) as the transport in these organisms is usually by slow diffusion rather than fast exchange at blood vessels.

Other problems include caused by storm overflows include:

- the release of unpleasant odours
- the washout of organisms
- an increase in the turbidity of the water (leading to a reduction in primary productivity)
- a reduction in the aesthetic value of the site
- a reduction in biodiversity (as only pollution tolerant species can survive)

1.7 Introduction to the Present Study

The need for overflows within the drainage system is not likely to change in the foreseeable future. Research is urgently required to determine the extent and form of the contamination of the receiving water and to investigate new designs of overflow or improvements to the old designs. Early investigations into the pollution performance of C.S.O.'s tended to be confined to model tests using plastic particulate to represent the sewage solids (e.g. Ackers et al, 1967; Frederick & Markland, 1967; Balmforth, 1978). Model tests are still used to test new designs of overflow (Smisson, 1989; Lockley et al, 1989). Such tests are useful as the make it possible to compare the performance of different types of overflow under similar conditions. There are, however, obvious limitations to this technique as the solids used are unlikely to be wholly representative of those found in field conditions.

There is still a dearth of information concerning how the common overflow structures actually operate with respect to dissolved, finely suspended and gross solids in the field (Shuttleworth, 1986). However, with the advent of more reliable monitoring and sampling equipment, flow and water quality surveys have become more feasible. It has been recognised that the major portion of the polluting material is held in the dissolved and finely suspended solids fraction (Ministry of Housing and Local Government, 1970; Jeffries, 1992). However, it is the presence of gross, aesthetically objectionable material that is most obvious and offensive to the public and which gives rise to the majority of the complaints received by the N.R.A.. This is apparent in the form of plastics, sanitary towels and condoms etc. strewn on the banks of the receiving watercourses. It has been recognised that research is needed in order to ascertain the gross solids removal efficiencies in the field for the various types of overflow device commonly in use (O'Sullivan, 1990).

The present study attempts to address this need. Certain overflow designs have been monitored and reported on elsewhere (Cootes, 1990 (vortex with peripheral spill); Smisson, 1989 (hydrodynamic separator); Jeffries, 1989 (hydrodynamic separator)). For this reason these types of overflow are not included in this study.

1.8 Aims of the Study

This study sets out to investigate the performance of three common combined sewer overflow designs (stilling pond, high-side weir and low-side weir) and more specifically:

1. to determine the hydraulic character of each overflow chamber investigated and thus the frequency and spill volume of storm sewage to the receiving watercourses.

2. to establish the pollution performance of each overflow chamber on the transport of pollutants during storm events, with particular reference to aesthetically objectionable material.

3. to institute a novel monitoring methodology to evaluate the hydraulic and pollution performance of common overflow designs.

4. to investigate the correlation between pollutants in storm sewage.

1.9 Selection of Sites and Sampling Stations

Potential study sites were identified in consultation with the Local Authority (Sheffield City Council, Department of Building Services). Safety is obviously a prime consideration. A site was not chosen if there was any history of poisonous gases in the chamber or local sewers or toxic discharges upstream. Many of the characteristics of a suitable chamber can be assessed from their maps and plans. However, many a potentially suitable site has had to be abandoned as a result of the preliminary site visit.

During this visit the suitability of the sites were assessed according to the following criteria:

1. Accessibility
* distance to Sheffield Hallam University
* position of the chamber access manholes with regard to road traffic, pedestrians etc.
* potential for leaving a trailer or cabinet to store non-intrinsically safe equipment

2. Safety
* proximity of the outfall to the watercourse and the potential for lifting upstream manhole during site visits for ventilation purposes
* build up of silt in the dry weather flow channel
* evidence of rats (carriers of Weil's disease)

3. Age and State of Repair of the Chamber

4. Vandalism of Equipment

5. Installation of Equipment
* installation of data loggers to accurately record flow data for the inflow, spill flow and/or continuation
* installation of frames for the collection of gross solids from the inflow and spill
* sufficient space to allow easy access to the equipment during the weekly maintenance and cleaning visits

Once the above criteria for a site were satisfied it was obviously important to obtain as much information about the catchment and local sewerage as possible to ensure that the overflow does spill regularly. Ideally, a thorough computer analysis should be undertaken before the start of the monitoring period. This would provide information about the frequency of operation of the overflow, whether the storm water backed up along the inflow pipe and thus the most suitable positions for the flow monitors and other equipment. Some of this information could also be picked up during a preliminary survey period at the site and observations taken during storm events.

1.10 Introduction to the Sites

Four sites were investigated; a stilling pond with 15mm mechanically raked bar screen (Chesterfield Road), a double-sided low-side weir with dip plates (Retford Road), and two double-sided high-side weirs without dip plates (Dobcroft Road and Leyburn Road). The monitoring periods for the four sites are shown in Table 1.1.

Table 1.1 Monitoring Periods For the Different Sites

Type of Overflow	Location	Monitoring Period	Duration (months)
Stilling Pond	Chesterfield Road	Sept. 1990 to July 1991	11
High-Side Weir	Dobcroft Road	Jan. 1991 to Jan. 1992	12
Low-Side Weir	Retford Road	Nov. 1991 to Dec. 1992	13
High-Side Weir	Leyburn Road	Oct. 1992 to Mar 1993	6

The duration of the monitoring at the high-side weir in Leyburn Road was restricted on two counts. Firstly there were delays in obtaining replacement intrinsically safe samplers, and secondly the sewer was found to be heavily silted. The desilting was not completed until mid-September. Plans of the four sites giving the chamber dimensions are given in Figures 1.10 to 1.13.

1.11 Catchment Characteristics

The four study sites were all within five miles radius of the city centre (see Figure 1.14). The catchments tended to be reasonably steep with areas ranging in size from 57.8 to 160 hectares. All the sites were predominantly residential and in each there was a high percentage (approx. 64%) of impervious area. Significant industrial activity was only found on one site (Retford Road). Maps of the catchment areas are given in Figures 1.15 to 1.18. The general site characteristics are given in Table 1.2.

Table 1.2 Land Use of the Catchments

Site	% Land Use				
	Residential	Highway	Open	Industrial	Commercial
Chesterfield Road	70.4	10.9	16.2	1.8	0.7
Dobcroft Road	61.2	10.4	28.4	-	-
Leyburn Road	70.0	9.8	20.0	-	0.3
Retford Road	68.7	12.9	11.9	6.1	0.4

1.11.1 Stilling Pond Site (Chesterfield Road).

The storm overflow chamber is situated in the car park of the Arnold Laver D.I.Y. Warehouse off Chesterfield Road. It is approximately 1.5 miles from the city centre (see Figure 1.14). The catchment is reasonably large (85.4 hectares) and predominantly residential. The "open" area includes allotments and city parks, the largest of which is Meersbrook Park. Although the catchment is very steep in some parts, as a whole, the fall is only 136m over its 2.4 km length (1 in 17.6).

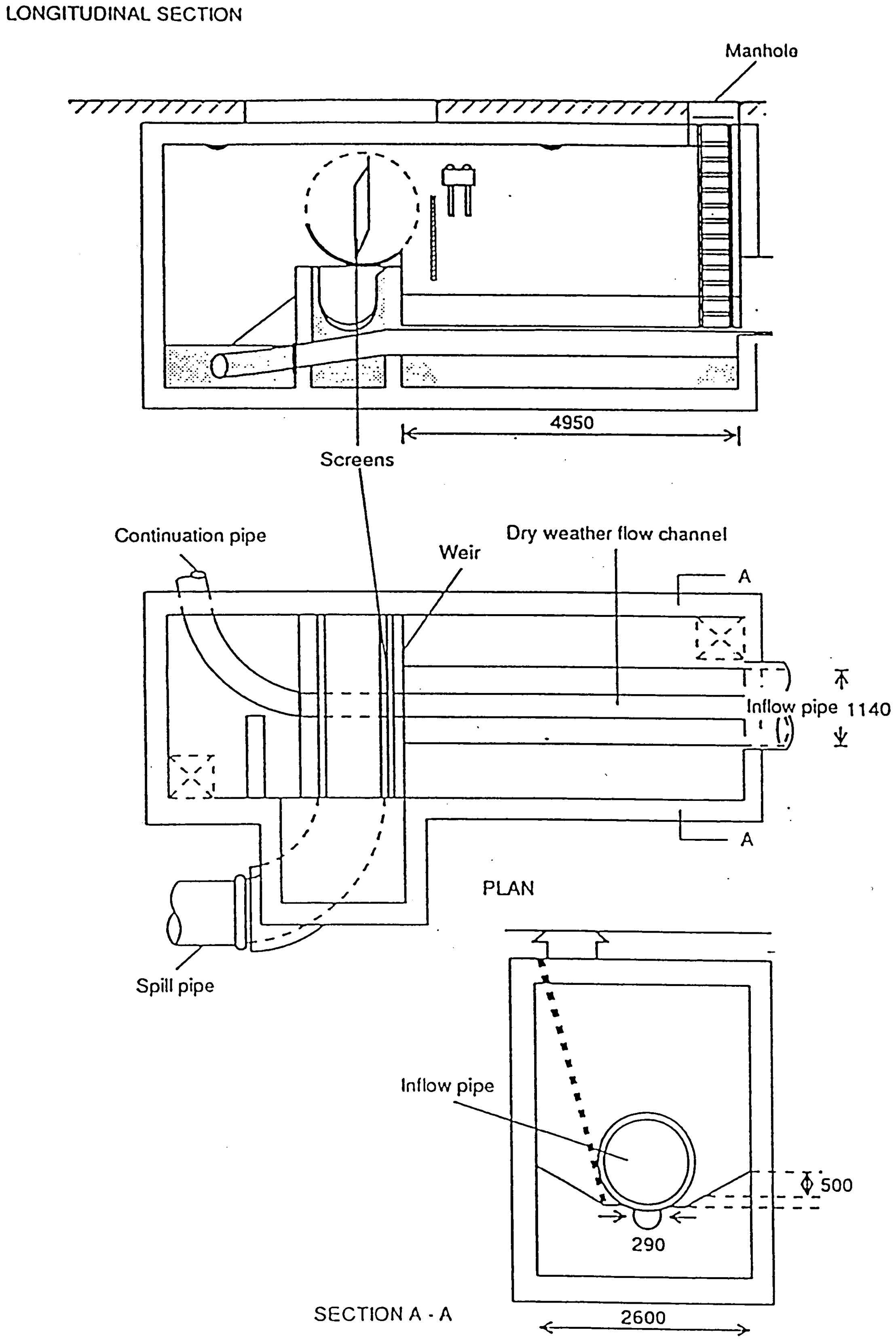


Figure 1.10 Plan and Cross-Section of the Stilling Pond Site (Chesterfield Road)

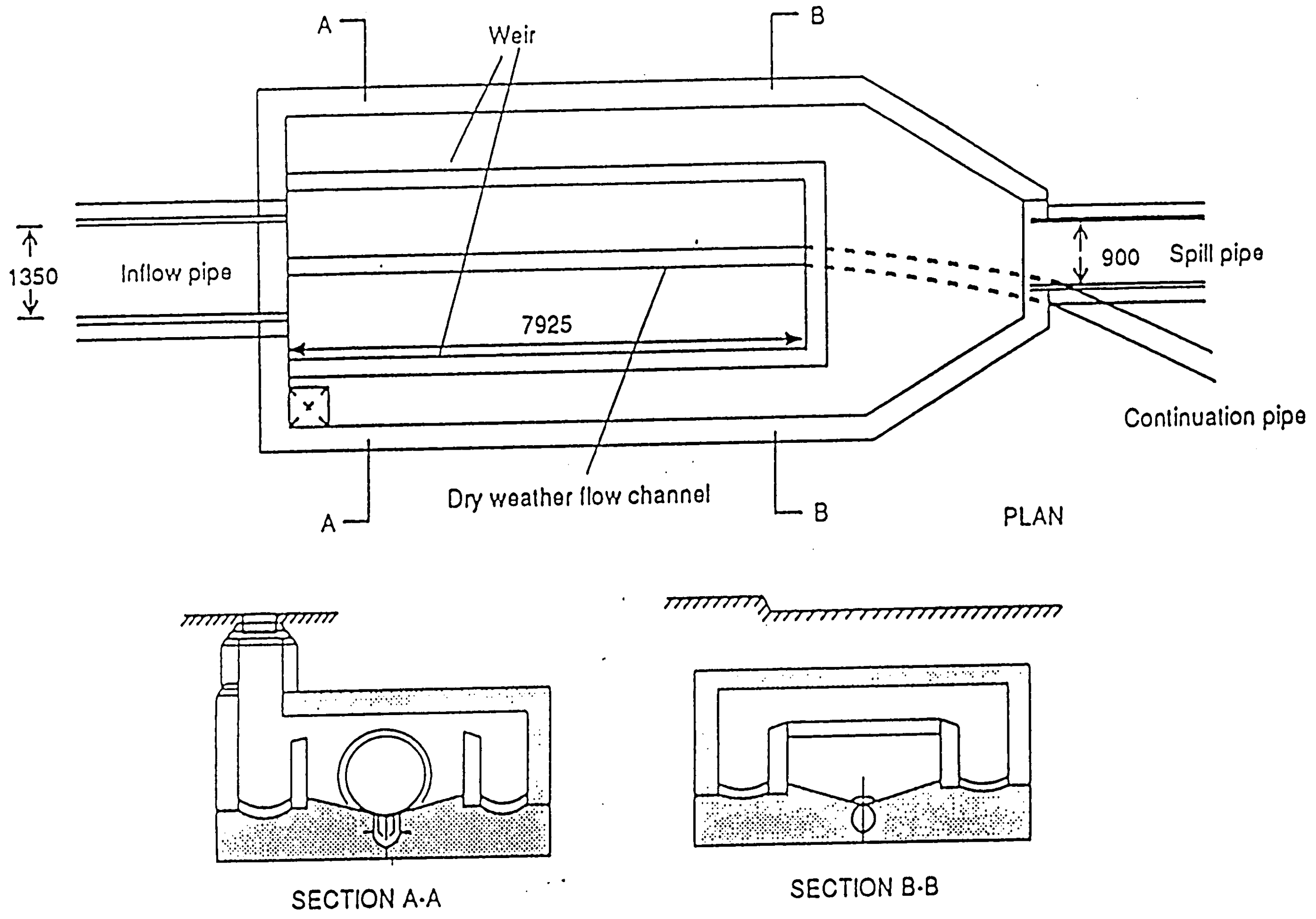


Figure 1.11 Plan and Cross-Section of the High Side Weir Site (Dobcroft Road)

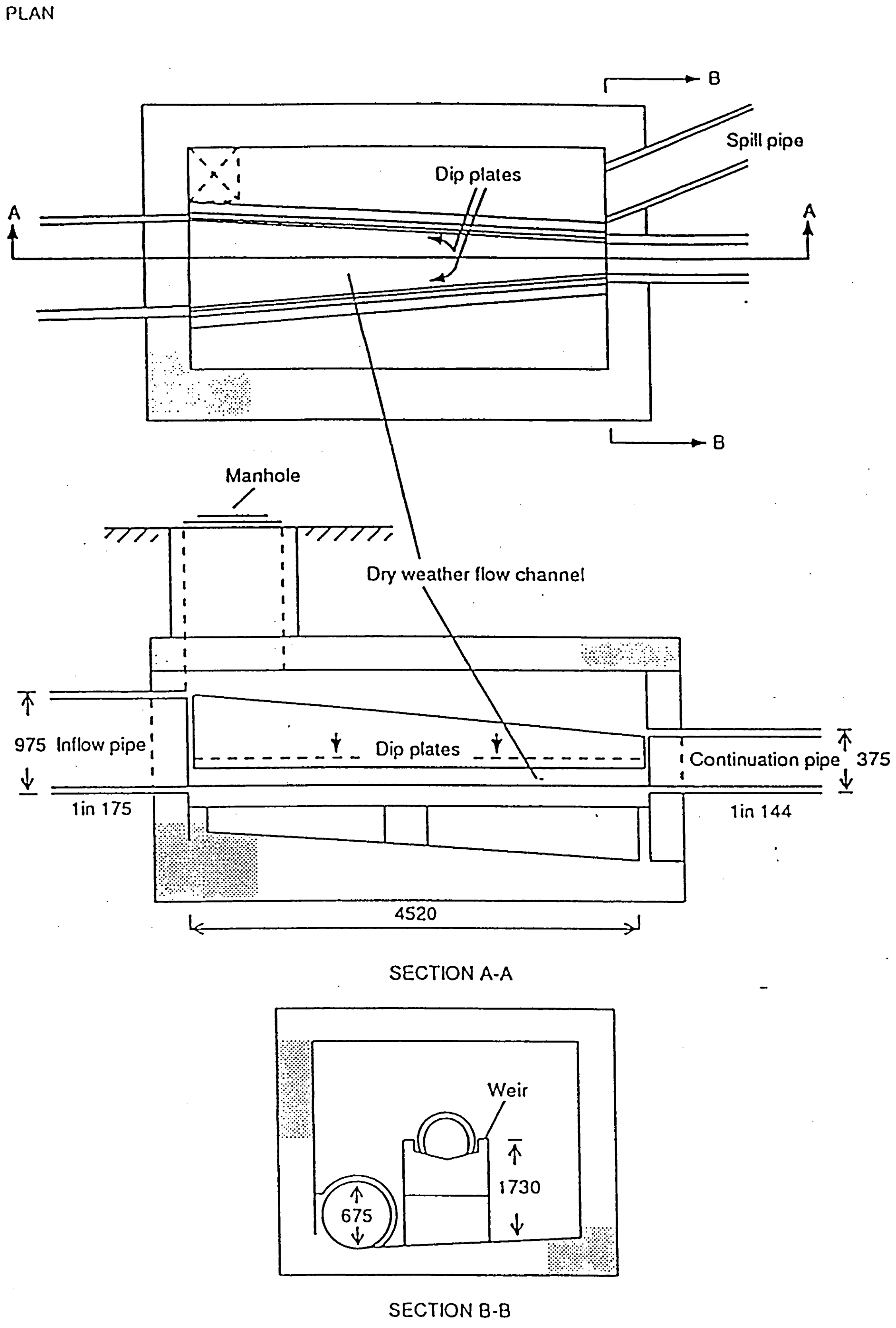


Figure 1.12 Plan and Cross-Section of the Low Side Weir Site (Retford Road)

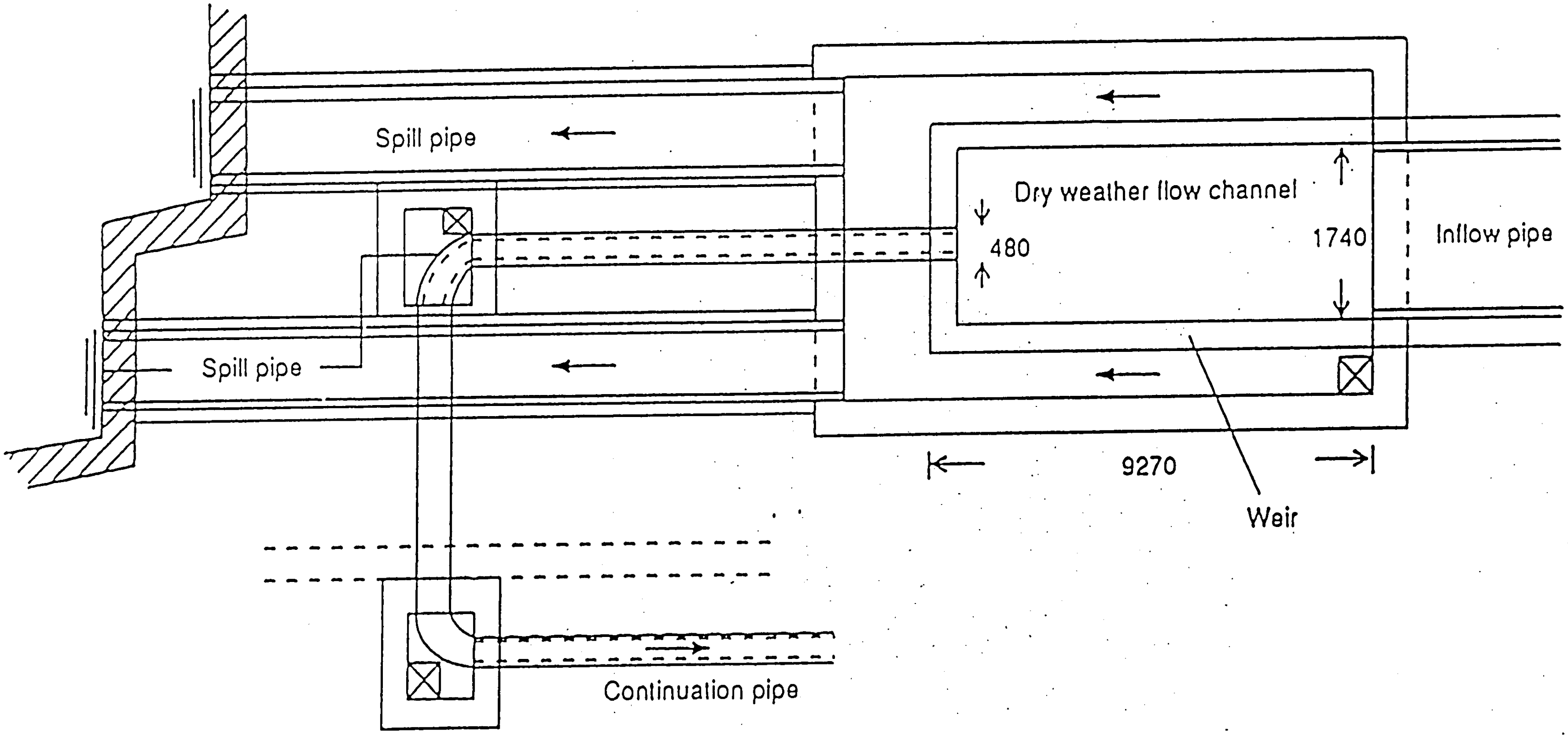


Figure 1.13 Plan of the High Side Weir Site (Leyburn Road)

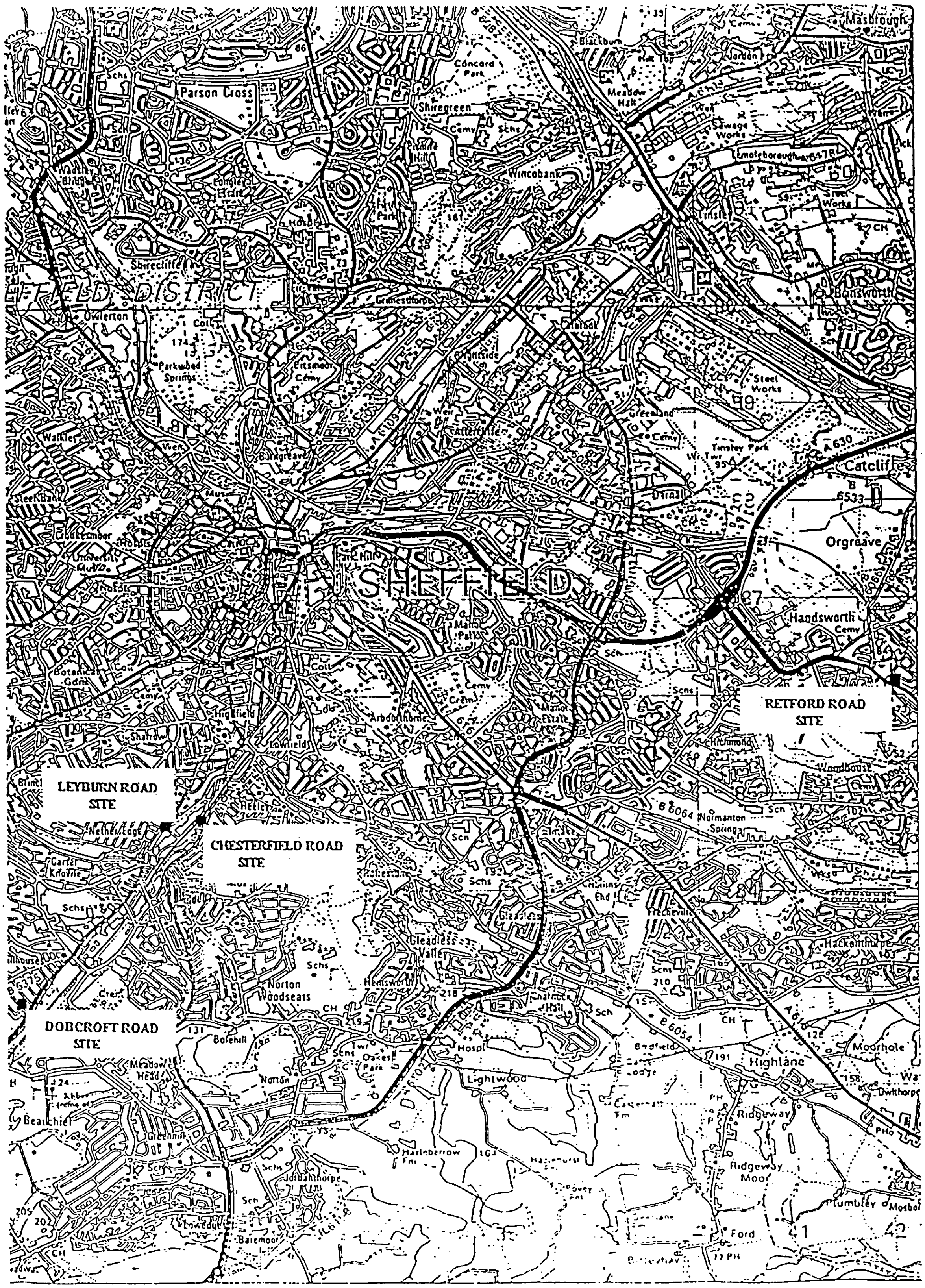


Figure 1.14 Map of Shefffield Showing the Position of the Surveyed Sites

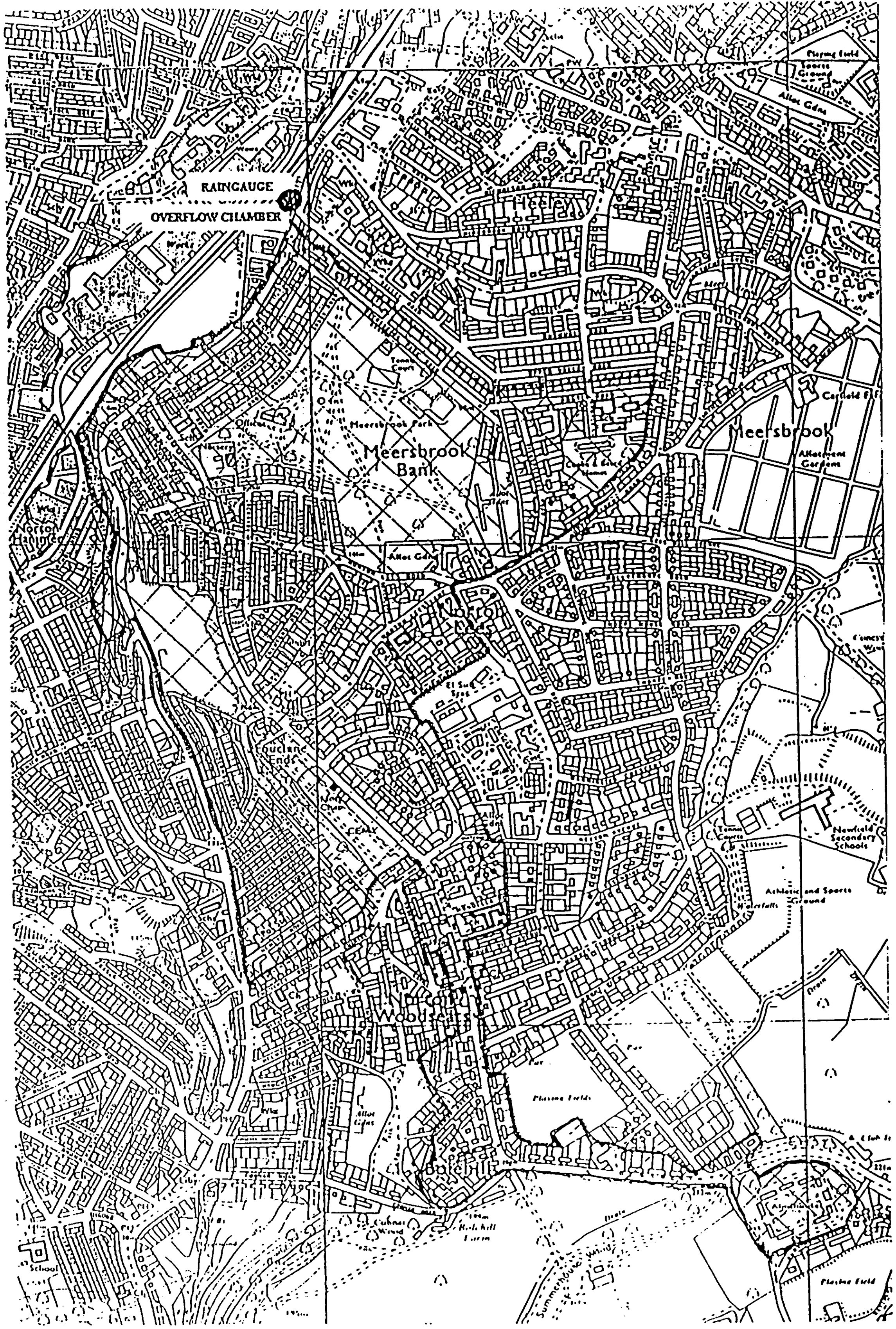


Figure 1.15 Map of the Chesterfield Road Catchment
(Scale: 1:12,000)

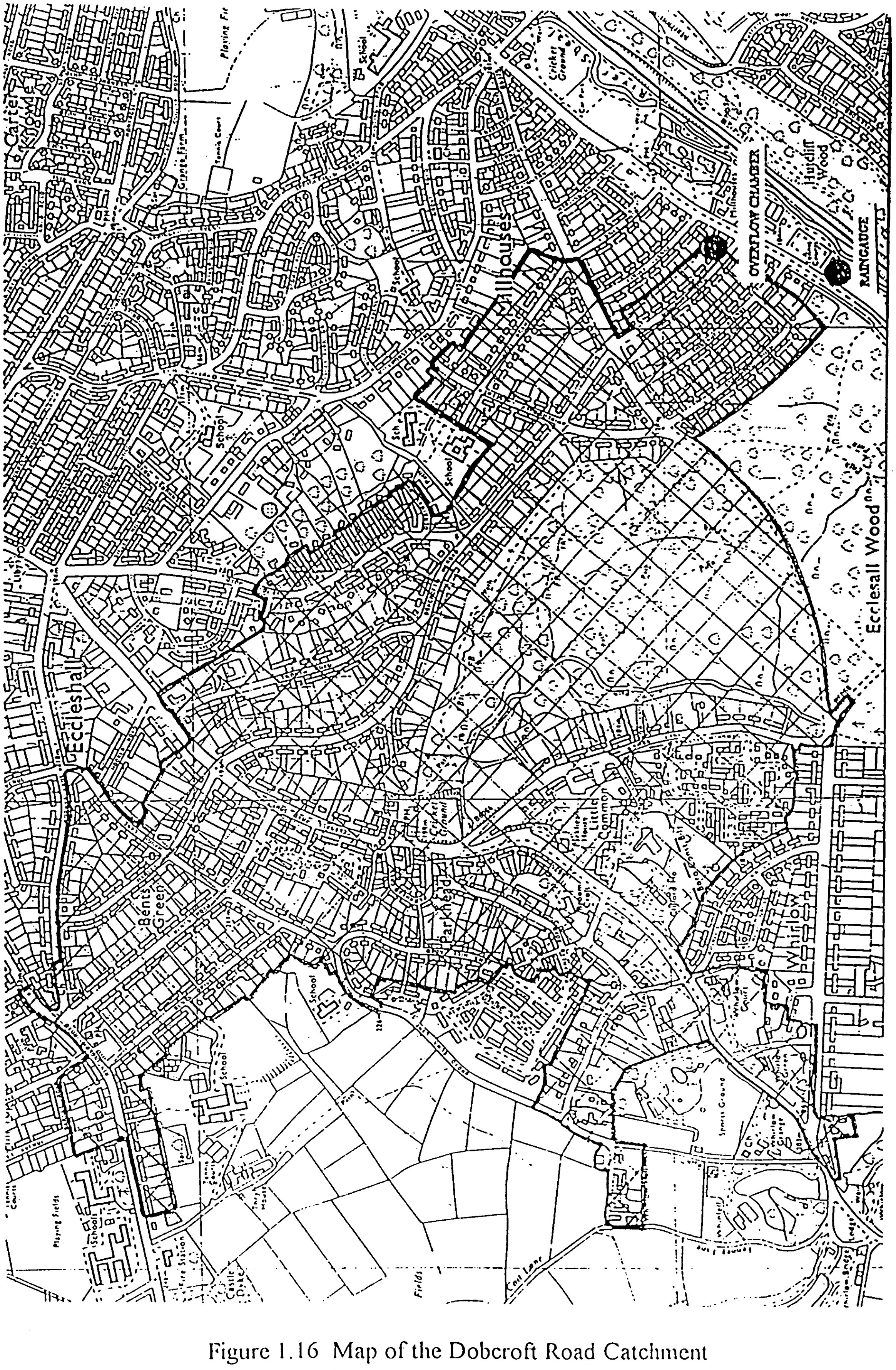


Figure 1.16 Map of the Dobcroft Road Catchment
(Scale: 1:12,000)

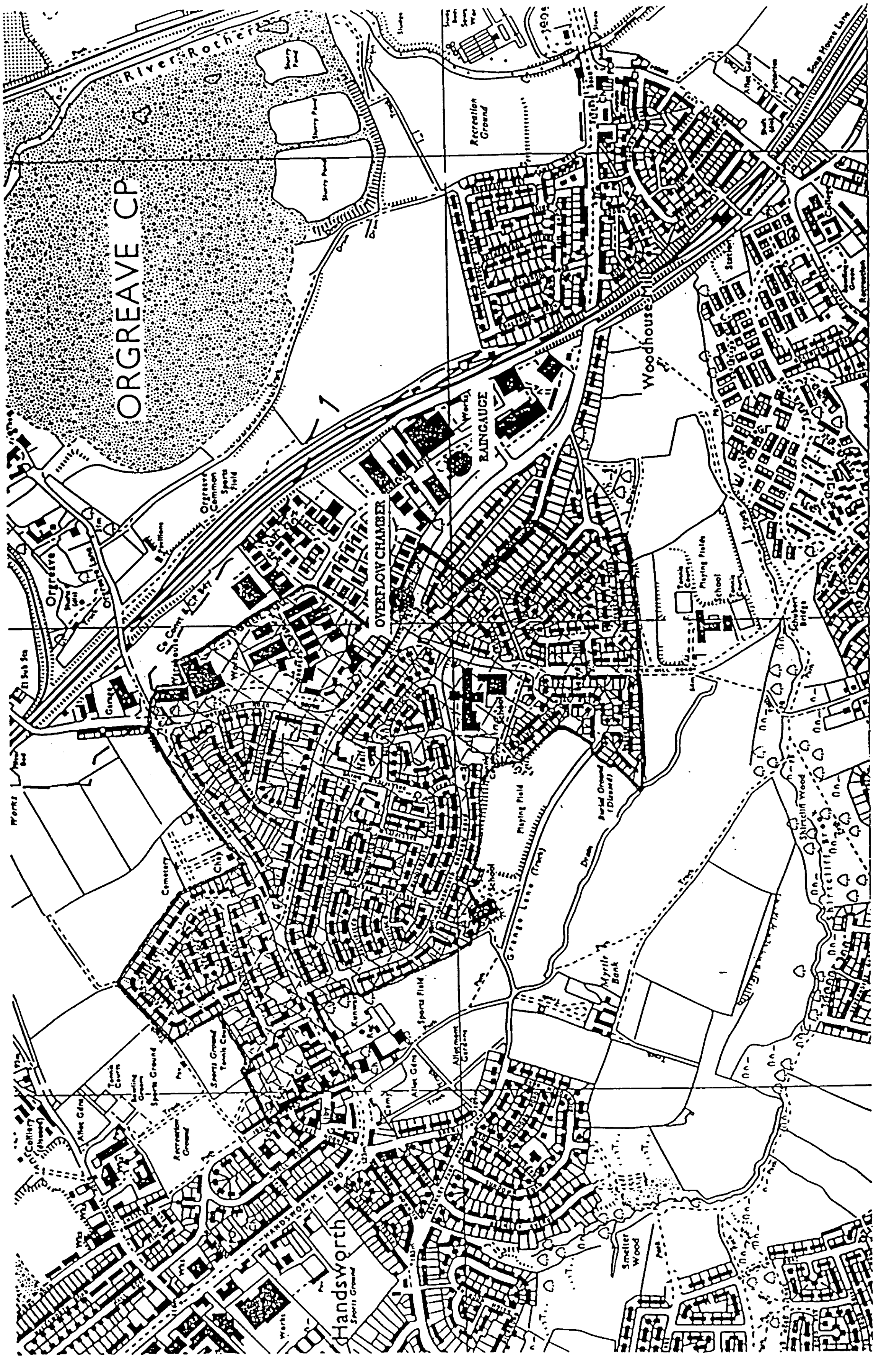


Figure 1.17 Map of the Retford Road Catchment
(Scale: 1:12,000)

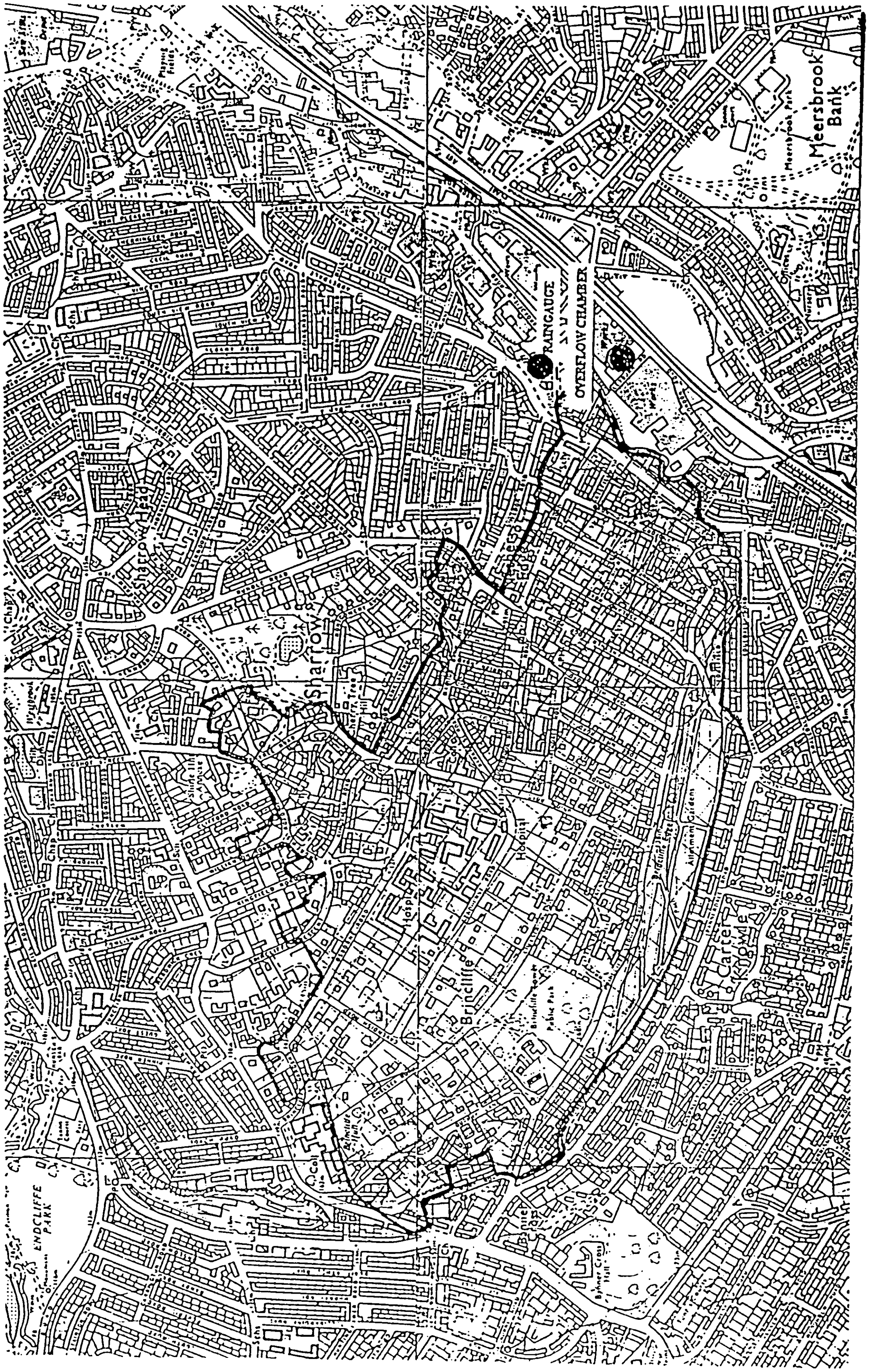


Figure 1.18 Map of the Leyburn Road Catchment
(Scale: 1:12,000)

1.11.2 High Side Weir Site (Dobcroft Road)

The overflow chamber is situated in Dobcroft Road near to its junction with Abbeydale Road South. The access manhole is in the grass verge on the side of the road. The site is approximately 3 miles Southwest of the city centre (see map of the catchments positions, Figure 1.14). The area of the catchment was estimated to be 160 hectares.

The Dobcroft Road catchment is the largest of all the sites investigated. Like the other sites it is also mainly residential. It is the only site that has no commercial or industrial activity within its drainage area. It also has the largest proportion of "open land" (28%). This open area is dominated by a park in the middle of the catchment, although there are also a reasonable number of smaller parks and allotments. The catchment has a fairly consistent slope, falling 135m over its 2.3km length (1 in 17).

1.11.3 Low Side Weir Site (Retford Road)

This chamber is situated at the side of Retford Road opposite its junction with Beaverhill Road, approximately 4 miles east from the city centre (see Figure 1.14).

The catchment area is estimated to be 58 hectares. This is the smallest catchment monitored. It has the largest proportion of area devoted to industrial activities (the Chesterfield Road site being the only other one with any industrial activity), although this only amounts to 6.1% of the area. It also has the smallest proportion of open ground. The proportion of land in residential use is very similar to the other sites. The slope of the catchment is 175m over its 1.05km length (1 in 6). This makes this the steepest overall of all the catchments monitored.

1.11.4 High Side Weir Site (Leyburn Road)

The chamber is situated at the far end of a cul-de-sac off the Abbeydale Road approximately 2 miles south of the city centre. The two outfall pipes discharge directly into the River Sheaf which runs at right angles to the end of the road. The catchment area was calculated to be 103.5 hectares (the second largest area). The proportion of land in the residential land use category is the largest. There is a small amount of area devoted to commercial enterprise in the catchment but there is no industrial activity. The open area is taken up by small areas of grass, fields or allotments at various parts of the catchment, rather than one large park as was the case at the other sites monitored.

It falls 75m over its 1800m length.

CHAPTER 2 LITERATURE REVIEW ON COMBINED SEWER OVERFLOW PERFORMANCE STUDIES

This chapter presents detailed accounts of the most directly relevant previous research. As monitoring of the pollution performance of combined sewer overflows is a reletively new area for research, much of the work described has been carried out recently. Particular attention has been given to the ways in which gross solids and the water samples have been collected and the methodologies for obtaining accurate hydraulic and pollution data for combined sewer overflows. The terminology used here and the opinions expressed are those of the particular author referenced.

2.1 Gross Solids Monitoring Methodology

2.1.1 A Method of Gross Solids Collection by Mutzner in Switzerland (Mutzner, 1987).

An experiment, conducted one summer by the author, was described. The aim of the study was to find out how long after an CSO event gross solids were still visible on the banks of the receiving watercourses and also, how far downstream from the overflow they were still present. The duration of the overflow event was recorded and gross polluting solids were collected from the banks of the streams as far downstream as they were found to occur.

The main results of the survey can be summarised as follows:

- Gross solids that were captured on bushes remain visible (and therefore offensive to the public) much longer than gross solids that were discharged on to the grassy banks where they soon became covered.

- The density of gross solids on the bank decreased continually with distance from the overflow.

- The larger the gross solids load discharged from the overflow the further downstream the gross solids were found.

- Gross solids were recovered at some considerable distance downstream from the overflow structure. A willow tree 800m from the overflow received the heaviest pollution.

- No relationship between the amount of pollution and the antecedent dry weather period (ADWP), time of day, overflow duration, overflow volume or maximum discharge (calculated from the rain records) was apparent.

Mutzner concluded that problems due to the visibility of gross solids on riverbanks was not likely to be solved by increasing the volume of stormwater that received full treatment. He recommended that new combined overflow structures should be designed which would be more effective at concentrating gross solids in the flow to be passed to treatment.

2.1.2 The Gross Solids Monitor (Cootes, 1990)

The gross solids monitor was developed at the Water Research Centre as a means of estimating the gross solids in the inflow and spill flow of an overflow chamber. The monitor records videos of samples of sewage flowing past a window. From these it is possible to count the number of large particles in the flow and thus get an estimate of the total number of large solids (greater than 3mm).

The monitor requires a large peristaltic pump to pull the sewage up from the chamber through a 100mm diameter hose. This sewage is then passed through a steel tube with transparent sections on both the top and the bottom. These sections are illuminated from below with near infra red illumination and viewed from above by a video camera sensitive to this radiation. Any objects in the flow appear as dark shadows on the video image. By counting the shadows it was possible to get an estimation of the quantities of the large objects in the flow.

In the study referred to a vortex overflow with peripheral spill was monitored using the gross solids monitor. It was found to operate quite reliably producing fairly clear video images. The shadows only became obscured when the sewage was very turbid. Automatic image analysis of the videos was attempted but had to be abandoned due to the difficulty that the monitor had in isolating valid particles and distinguishing them from the edges of bubbles. More advanced computer systems and improvements in the clarity of the image (better lighting and cameras) and bubble traps were suggested as ways of improving the system so that automatic analysis would be possible.

2.1.3 Work by Jeffries and The Wastewater Research Group at Dundee Institute of Technology (Jeffries & Dickson, 1990; Jeffries, 1992)

Much of Jeffries recent work has been on ways to estimate the performance combined sewer systems particularly with respect to the discharge of gross solids. In the earlier paper Jeffries described a method, similar to that used by Mutzner, of collecting the visible solids on the banks of the receiving watercourse immediately downstream of the overflow. He noted that this method was rather subjective and dependent on the time at which the survey was carried out. The site used in this study had the advantage that it was dry for significant periods between discharges, thus material could be collected from the stream bed and the lateral vegetation. A 20m stretch downstream of the overflow was surveyed.

This method was used to collect material from 21 events during the study period. The results indicated that the overflow (a hydrodynamic separator) performed well in the handling of these visible solids. The great majority of the material (all but two floating solids) was made up of plastic and paper strips which were found to be approximately neutrally buoyant. It was thought that such material would be difficult to separate without the use of fine screens. A positive correlation between the number of solids collected and the volume of sewage discharged was calculated.

The later paper described a project in which Jeffries compared three methods of collecting gross solids data.

1. Trash Traps

This was devised as a passive method of trapping visible solids. One or more screens were set horizontally just below the discharge from an overflow weir. The trap intercepted gross solids (faecal matter, sanitary towels, condoms etc.) and also much smaller particles (shredded paper, foodstuffs, fat particles etc.). Blinding was found to be an occasional problem, due to the mesh being covered by a layer of sodden tissue paper. When this occurred the results were ignored as flow was found to pass over the trap carrying gross solids with it.

2. The Gross Solids Sampler

The gross solid sampler was developed by the Water Research Centre having recognised that there was a dearth of information on the behaviour of gross solids at combined sewer overflows (Walsh, 1990). The prototype sampler was used in this study. The sampler had been built inside a standard ISO container. It consisted of a peristaltic pump with two 100mm diameter suction and delivery hoses. Sampling was initiated by an ultrasonic sensor, situated above the overflow, when the water level rises at the beginning of a storm. Both the inlet and the spill flow were sampled and the samples were discharged into "Copasac" mesh bags in two bins. ("Copasacs are woven polypropylene bags with variable mesh sizes. The size used here was 4-6mm.) Any gross solids collected were thus held in the mesh bags.

A single bulked sample was taken in each operating cycle. This bulked sample could consist of up to 20 samples although if the water level had dropped sufficiently before 20 samples had been taken then the sampler automatically shut off.

3. Visible Solids

A survey of the banks and bed of the receiving stream was undertaken after an overflow event (as described above). Visible Solids were described as "material which is identifiably sewage in origin and would be noticed by the casual observer walking on the riverbank". Jeffries stated that this material was in effect plastic and paper strips which had virtually neutral buoyancy. This material was similar to the material retained on screens in sewers.

A project was set up at two sites in the Fife Region of Eastern Scotland to compare the different methods. The gross solids from a hydrodynamic separator and a stilling pond were investigated. Flow rates and volumes of flow in the sewer were also determined.

No correlation was found to exist between the number of visible solids in the stream and the spill volume or peak flow rate. A correlation between the number of visible solids and the antecedent dry weather period (ADWP) was found. The ADWP was defined in this project as "the greatest time between periods of filling, although not necessarily causing overflow and spill".

Eighty-two percent of the visible solids on the trash traps were made up of plastic and paper strips. The remaining 18% comprised faecal matter, plastic sticks and condoms in equal proportions. Good correlations were obtained for the number of visible solids and the mass collected on the trash trap. Correlations between the mass of trash collected and the volume spilled were poor.

The hydrodynamic separator was found to give significantly better removal of visible solids than the stilling pond. This may be expected due to the difference in their relative size.

Relationships between the number of visible solids (VisNo) discharged and the mass of the total suspended solids (MTSS) discharged were calculated:

Stilling Pond $\text{VisNo} = 0.15 \times \text{MTSS} + 11$

Hydrodynamic Separator

$$\text{VisNo} = 0.75 \times \text{MTSS} + 55$$

The gross solids sampler was installed at the stilling pond site for six months during which time 22 storms were sampled. In 14 of these events no measurable weight of material was recorded on the overflow sacks. In most of the events a small amount of material (predominantly paper and plastic strips) was recovered. On visual examination the material was found to comprise 50% faecal material and 50% tampons and associated plastic material. Virtually no condoms or plastic sticks were recovered.

Event loads were calculated for gross solids (LGSS) and total suspended solids (LTSS). The following relationship was determined:

$$\text{LGSS} = 0.005 \times e^{2 \times \ln(\text{LTSS})}$$

This relationship was found to apply to both the inlet and the spill data. It is proposed that this relationship would be convenient for estimating the gross solids from a catchment.

2.1.4 Artificial Surcharge Tests (Lockley et al, 1989; Smisson, 1990)

In such tests permission is granted to pump water into the inflow pipe upstream of the overflow structure to artificially induce an overflow event. The obvious advantage of this is that the timing of the event can be controlled (i.e it happens between 9a.m. and 5p.m. on a weekday) and it is possible to witness the operation. In the examples quoted here this procedure was used to investigate the performance of hydrodynamic separators with respect to gross solids.

1. The James Bridge Site, near Birmingham. (Lockley et al, 1989).

During the surcharge test a large amount of floatable material was injected into the inlet. This material included 200 oranges and approximately 100 pieces of wood and plastic. Nets were placed across the overflow and an observer was stationed in the overflow chamber. Only two pieces of wood and one piece of plastic were observed in the overflow, no oranges were seen. The average flow rate during the test was 34l/s.

2. The Lochgelly Site, Fife. (Smisson, 1990).

This is a twin "Storm King" installation i.e there are two hydrodynamic separators at the site. Material was inserted into the middle of the flow by using a 2m long (50mm diameter) pipe at two locations at the site.

a. Location A : at the inlet to the system (upstream from both overflow devices)
b. Location B : at the inlet to the second overflow.

At location A, 100 condoms and 400 plastic sticks in a range of sizes were inserted. At location B, 50 condoms and 200 sticks were inserted. For the duration of the test a mesh covered both outlets to prevent any of the injected solids, or any sewage present in the dry weather flow , from being discharged.

None of the inserted tracer material was discharged via the overflow during the test. Also, no identifiable sewage solids greater than 3mm were collected by the mesh material.

2.1.5 Model Tests at Sheffield University (Ruff, 1992)

Experiments are currently being made to accurately compare the gross solid pollutant retention performance of four types of CSO using scale models with similar storage volumes. The four types being tested are the Stilling Pond (an extended and a Sharpe and Kirkbride design), the High Side Weir, the Vortex and the Hydrodynamic Separator. Particulate (untied condoms, pant liners, pant liner release tapes and cotton buds) were introduced manually into the system 6.5m upstream of the overflow chamber for various steady inflows.

For all the chambers tested to date (the high side weir and the two stilling ponds) the efficiency of the overflows in retaining the gross solids in the flow to treatment increased with a reduction in inflow. The retention performance of the extended stilling pond was far superior to the Sharpe and Kirkbride stilling pond at low and mid flow but the same at the high flow (120l/s). The Sharpe and Kirkbride stilling pond performed better than the single high side weir at all the flows tested. -The effect of changing the chamber configurations from the recommended dimensions was to significantly reduce the retention efficiency.

2.2 CSO Performance Studies

2.2.1 Field Studies on the Flow and Composition of Storm Sewage (Davidson and Gameson, 1967)

This was one of the earliest studies to investigate the pollution performance of combined sewer overflows. A five year study of three catchments, with double low side weir overflow structures, was undertaken with samples being collected between February 1960 and January 1964. Samples of storm sewage and dry weather flow were taken as well as continuous rainfall logging. Flow was recorded using stilling chambers and measuring flumes or from depth measurements after calibration by salt-velocity or salt dilution methods.

Samples were taken manually and automatically at each site. The automatic sampler was initiated by an increase in flow or depth at the beginning of the storm. Samples were taken every 5 minutes for the first hour, and then hourly until the end of the storm or until the 36 sample bottles were filled. The samples were usually examined for 5-Day biochemical oxygen demand (BOD), permanganate value, suspended solids and ammoniacal nitrogen. Many were also examined for chloride content and ash. Manual samples were taken in such a way to be representative of the flow as a whole. The resulting samples could then be compared with the automatic samples. It was found that there was no significant difference between the two sets for ammonia and chloride but, on average the manual samples contained 15% more suspended material.

The normal diurnal variation was discerned in the samples collected in a 24 hour period from the dry weather flow. Strong foul flush effects were recorded at two of the sites. The concentration of ammonia in the storm flow was thought to be primarily determined by the composition of the dry weather flow. Ammonia and the other parameters measured are thought to be greatly affected by local conditions, such as deposition within the sewerage system. The accumulation of material was found to be greater after a long dry period.

It was concluded that the low side weir was not efficient at either controlling the flow to treatment or reducing the amount spilled to the watercourse. The results of the sampling were inconsistent although a decrease in concentration of a given parameter with time was apparent for many of the storms.

2.2.2 Storm Overflow Performance Using Crude Sewage (Ackers et al, 1967)

The aims of this study can be summarised as follows:

a. to determine the difference in composition of the storm sewage discharged from an overflow and that passed to treatment

b. to compare the performance of different types of overflow

c. to examine the effectiveness of scumboards

d. to measure the changes in flow to treatment with increasing total flow in each structure.

Four full sized storm overflow structures were built and connected to a trunk sewer so that their performance with could be determined. The following designs were investigated:

1. low side weir
2. high side weir
3. stilling pond
4. central spill vortex

The flow to treatment and the spilled sewage passed through 0.25 inch (6.5mm) screens. Samples were taken from the screenings for both flows. The dry weight and the moisture content of these samples was recorded. Some of the material was observed to break up in the overflow or while being passed through the screens.

The low side weir was found to be hydraulically unsatisfactory. The weirs were used inefficiently with most of the spill taking place over the last metre. A hydraulic jump formed at the downstream end of the weir. The flow to treatment rose markedly with the incoming flow. Attempts to calculate the discharge using classical side weir theory failed to give satisfactory agreement with the observed values.

The flow in the high side weir was considerably more tranquil than that in the low side weir and spill took place over the whole weir. The discharge to treatment for the stilling pond was almost exactly the design value. The vortex was found to have better hydraulic control than the low side weir but not as good as the stilling pond.

The low side weir had little noticeable effect on the screened solids. The stilling pond had a tendency to discharge solids, particularly faeces, over the weir although paper was concentrated in the flow to treatment. The vortex was found to be generally ineffective with all the material in the flow. It was concluded that the high side weir with scumboards was the most effective design tested and the vortex the worst.

2.2.3 CSO Performance Studies (Saul & Thornton, 1989)

This project was set up to monitor the hydraulic performance and the temporal variation of pollutants in the inflow and the overflow at five CSOs in North West England. This paper describe how one of the sites, a storage overflow, was set up. Continuous flow readings were taken from the inflow , continuation and spill. Water samples were taken using automatic samplers from both the inflow and the spill. Samples were analysed for total suspended solids (TSS), chemical oxygen demand (COD), total dissolved solids (TDS), ammonia and sometimes biochemical oxygen demand (BOD). The water level in the chamber was recorded using an ultrasonic water level transducer and a swingmeter fastened to the roof of the chamber.

The overflow was monitored for one year during which time it overflowed 85 times. The hydraulic performance of about one third of these storms was calculated. The average delay between the time at which the storm first entered the chamber and the time to first spill, called here the "delay time" was approximately 60 minutes. The shortest recorded delay was 4 minutes and the longest 239 minutes. The delay time was found to be extremely significant in determining the retention time of pollutants in the system.

Full sample, flow and rainfall data was obtained from 16 storms. The average pollutant load efficiencies for the parameters measured were 86%, 88%, 90% and 92% for TSS, COD, TDS and ammonia respectively. The average flow retention efficiency of the 16 storms was 86%. From this it was concluded that the long term hydraulic performance of any overflow structure will necessarily control the long term pollutant load discharged to the receiving watercourse. Unfortunately, wide variations in the pollutant load discharged becomes apparent when individual storm events of different intensities and durations are investigated.

Four examples were considered.

1. A long duration storm where the rainfall was of low intensity at the start of the storm. This lead to a significant first flush in the concentration of each pollutant (>1000mg/l for COD and TSS). These values were some 4 times greater than the expected concentrations in the dry weather flow for that time of the day.This flush was caused by a highly mobile fraction of in-sewer sediment deposits which had accrued during the antecedent dry weather period. The onset of the overflow occurred 44 minutes after the storm first entered the chamber. Only 2.5% of the total storm flow was spilled.

   The overall pollutant load retention efficiencies were 97%, 98%, 98% and 98% for TSS, COD, TDS and ammonia respectively. The retention of flow within the system was 97.5%. Secondary pollutant concentration peaks were observed. These were due to the wash-off of pollutants from catchment surfaces. In this example these did not cause any detrimental effect on the watercourse quality as overflow only occurred when the pollutant concentrations were low.

2. A twin peaked storm with intense rainfall of short duration. Initial and secondary flushes in pollutant concentration and load were observed to occur with the peaks in flow. These flushes were found to be of high concentration due to the high intensity of the rain. The delay time for this storm was 63 minutes. Thus all the pollutant load from the first flush and the majority of the second flush was retained within the system. The resulting load retention efficiencies were 79%, 84%, 87% and 86% for TSS, COD, TDS and ammonia, respectively.

3. A storm with a high intensity start which was so prolonged that the delay time was only 9 minutes. A large proportion of the first flush was thus discharged to the watercourse. The load retention values were 67%, 70%, 83% and 79% for TSS, COD, TDS and ammonia, respectively. The flow retention was 75%.

   Despite the lower retention load efficiencies recorded for the third storm described the actual total load of polluting material spilt to the watercourse was, in fact, higher for the second storm due to higher concentrations of material in the latter storm. Thus it is important to consider the concentration of pollutants discharged and not the load retention efficiencies in isolation. This is illustrated in the following example.

4. In this storm the pollutant retention efficiencies were all over 80% but the total load of ammonia spilled during the event was 3.4Kg. This could have a severe effect on the biota in the receiving watercourse. The impact could, of course, have been much worse if the overflow had not performed as hydraulically efficiently as it did.

It is concluded that in assessing the performance on CSOs it is necessary to consider both the concentration and the load of the spilled pollutants. The separation performance of the chamber will also have a significant influence on the quality of the effluent discharged to the receiving watercourse.

2.2.4 CSO Monitoring Methodology (Saul & Marsh, 1990; Water Research Centre, 1992)

The first paper referred to describes the development of a methodology for short term monitoring of pollutants in sewers, overflows and tanks. This was undertaken in response to the need to identify procedures for the collection of data and to develop an appropriate strategy for model calibration and verification. It was hoped that the verification of sewer quality simulation models, such as MOSQITO, could be verified at the same time as sewer flow quantity models, such as WALLRUS.

The following equipment is used:

1. WRc Swingmeter: this measures the water level in the overflow chamber.

2. Detectronic Flow Survey Loggers: these are used to give continuous depth and velocity readings.

3. Sirco Samplers: to take automatic samples from the storm flow and the dry weather flow.

4. Raingauges: to obtain a continuous rainfall record.

5. A Golden River Retriever: to download data from the loggers.

The sampler operation was controlled using software routines written to the memory of the Golden River environmental computer. The sampler was triggered when the flow level attained a preprogrammed level. The optimum trigger level was considered to be that which was sufficiently large to avoid the operation of the storm flow sampler at peak dry weather flow yet sufficiently small to ensure the collection of samples during the early part of the storm. This level can be determined from examining the flow records from the site for a period of at least one week. The first 10 samples were programmed to be taken at 3 minute intervals. The next 10 were taken at 7 minute intervals and the final 4 were taken at 30 minute intervals. This gave a total monitoring period of 217 minutes.

An additional background sampler was operated in continuous mode to extract hourly samples. This contributed extra information about the pre and post storm pollutant concentrations. In the absence of any storm, the collected samples were retrieved and the bottles emptied and clean bottles replaced. Samples were analysed for TSS, volatile suspended solids (VSS), COD and ammonia.

The site was monitored for 11 weeks. During this time 9 sets of dry weather flow data and five sets of storm data were obtained. The dry weather flow samples demonstrated the expected diurnal variation. The storm samples indicated the presence of first and secondary flushes in the concentration and load of pollutants. From this it is concluded that the control and operation of the system is sufficiently sensitive to monitor the complete pattern in the temporal load of pollutants at times of dry weather and over the complete duration of a storm event.

It is concluded that the system described is able to provide good quality data which would be suitable for the verification of computer simulations. It would be possible to develop the control technology but this was not thought to be advantageous due to the increase in the required level of calibration and time taken to collect the necessary data. It is recommended that instrumentation should be robust, reliable, and relatively easy to handle, install and operate.

The second paper describes current techniques for the assessment of combined overflow performance. Several definitions are provided for terms in common use relating to CSO performance. Some of these are given below.

A. Classes of Pollutant.

- pollutants/sediments in solution
- finely suspended sediments with d = 0.5mm
- coarse sediments with d = 3.5mm
- gross solids with d > 6mm

Where d is the median size of the particle.

B. Overflow Efficiency

(i) The "total efficiency" is the overall performance of the overflow and storage associated with it. It can be expressed in terms of quantity and quality parameters as:

$$\text{Total Efficiency} = \frac{\text{Total Storm Load Retained}}{\text{Total Storm Inflow Load}}$$

This can also be expressed graphically (see Figure 2.1):

$$\text{Total Efficiency} = \frac{\sum_{t_0}^{t_1} q_c c_c}{\sum_{t_0}^{t_1} q_i c_i}$$

Where: t_0 = start of storm hydrograph
t_1 = end of storm hydrograph (or the time at which the flow returns to pre-storm conditions)
q_c = continuation flow
q_i = inflow
c_c = pollutant continuation flow concentration
c_i = pollutant inflow concentration

(ii) The Treatment Factor. This allows the quality performance of the overflow to be assessed and the results for different CSO systems and devices be compared where:

$$\text{Treatment Factor} = \frac{\text{Total Efficiency}}{\text{Flow Split}}$$

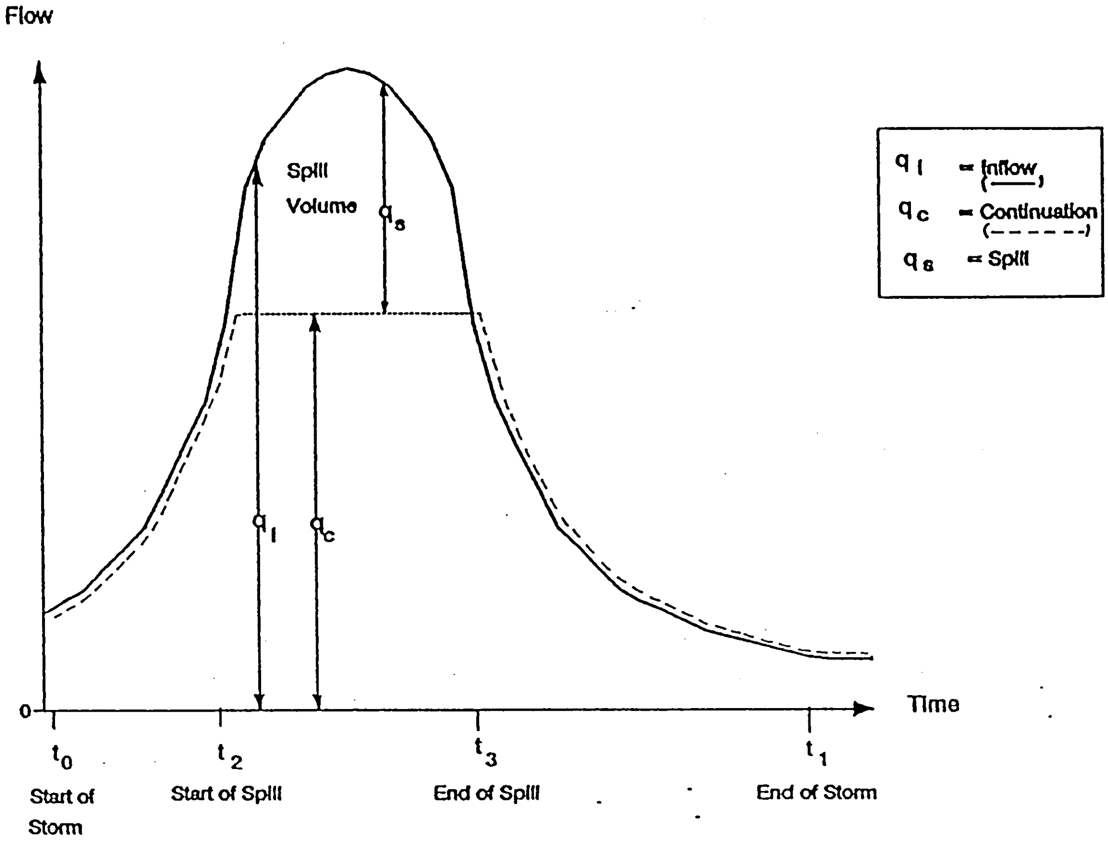


Figure 2.1 Hydrograph for Combined Sewer Overflow with No Storage

Where Flow Split is :

$$\text{Flow Split} = \frac{\text{Total Storm Volume Retained}}{\text{Total Storm Inflow Volume}}$$

(i) a treatment factor > 1 indicates some degree of treatment of the spilled flows have taken place

(ii) a treatment factor = 1, the pollutant load is discharged to the receiving watercourse according to the flow split i.e. no treatment is achieved.

(iii) a treatment factor < 1, here the opposite effect is occurring and the overflow is having an adverse effect by concentrating the pollutant load in the spilled flows.

The above definitions can be applied to the overall system or to an individual device for the total storm hydrograph or just the spill period.

2.2.5 A Description of Some of the Problems Encountered in CSO Performance Monitoring (Geiger, 1984, Geiger, 1986)

The earlier paper describes an intensive 4 year study of a combined sewer system in Munich-Harlaching, Germany. Continuous records of rainfall, runoff, temperature, turbidity and conductivity were taken. Dry and wet weather flows were sample for TSS, BOD, COD, total organic carbon (TOC), Kjeldahl-Nitrogen and phosphorus.

The methods used to monitor the storm sewage quantity and quality are limited by a number of factors. These are summarised below:

- the wide range of flows which can rapidly change from virtually zero to the peak rate;
- the change from free to surcharged flow conditions;
- the frequently varying flow boundary geometry caused by the deposition of solids and leading to flow nonuniformity;
- the contamination of metered media by solids, fibres and floating debris posing a physical threat to sensors or sampling intakes;
- the damp, corrosive sewer environment necessitating frequent and knowledgable maintenance of all installations;
- the necessity to determine the majority of the pollutional constituents via laboratory analysis;
- the laboratory sometimes being unable to handle the unpredictably varying amounts of samples.

The second paper referred to above discusses the use of field data in urban drainage planning. In this, some further problems of accurately characterising combined sewer flows are addressed.

These may be summarised as below:

- the possibility of backwater, or even flow reversal, in certain situations;
- the extremely wide range of pollutants that can be found;
- the possible spatial variation of these pollutants in a given cross-section;
- the presence of significant bed loads which may be highly polluted.

2.3 Comments on Previous CSO Performance Studies

As safety considerations make it impossible to enter a CSO to take samples during storm events, methods of gross solid collection are required which will sample all, or a representative portion of, the incoming and/or spilled flows. Various different methods have been described here; visual observations of gross solids deposited along the bank of a receiving stream; videos of gross solid material in the inflow and spill flow of a CSO during a storm event (the Gross Solids Monitor); passive trapping techniques; active pumping of storm sewage to obtain samples that are then sieved (the Gross Solids Sampler). Each method has advantages and disadvantages. Both the Gross Solids Sampler and the Gross Solids Monitor are large pieces of equipment which have power requirements that strictly limit the number of sites at which they can be used. The mesh of the passive "trash trap" can be easily blinded by toilet paper forcing water containing the gross solids to pass over the mesh and thus not be collected. The visible observations provide a useful estimate of what is being spilled but in order to determine the performance of different designs of overflow structure some means of estimating the load of gross solid material (or of "visible solids") must be found. Both Jeffries (1992) and Mutzner (1987) investigate the influence of external factors, such as ADWP, spill volume, time of day, on the loads of gross solids (or visible solids). It is important to obtain as clear an understanding as possible of the influence of such factors when designing or comparing different CSO structures.

To obtain truly comparative data on performance the CSO structures compared must be of equal size and have equal storage volumes. This is difficult to achieve in the field and so laboratory tests, such as those by Ruff (1992), at Sheffield University, must be undertaken. The main advantage of the laboratory situation is that the tests can be controlled and the data obtained are thus easier to interpret than those obtained in the field, where the number of "unknowns" are much greater. The disadvantage of laboratory simulations are that it is almost impossible to accurately represent the behaviour of sewage solids in the field.

The methodology for determining the performance of CSOs with respect to finely suspended and dissolved material has been investigated by a larger number of studies and is now reasonably well developed, although the problems of the collection of both hydraulic and water quality data, described by Geiger, still hold true. The importance of considering both the concentration and the load of pollutant material entering and spilling from a CSO was explained in the paper by Saul & Thornton, 1989. This paper also describes the influence of the size of the available storage on the load of material spilled to the receiving watercourse. From such studies it is apparent that the provision of adequate storage is one of the most important design requirements for CSO structures.

3. DATA COLLECTION METHODS

3.1 The Sewer Entry Team

When the project began the sewer entry team consisted of myself and three technicians from the then Polytechnic, all of whom had been trained in the use of breathing apparatus in confined spaces. This training consisted of a week long course which taught the use of breathing apparatus under working conditions and for escape, as well as correct maintenance procedures to ensure that the equipment is ready for use. Two of the team were also qualified in the correct use of road signs and cones to indicate an obstruction to traffic caused by people at work. All members of the team were enrolled on a course of injections to reduce the risk of catching diseases that could be found in the sewer environment. These were tetanus, typhoid, polio, hepatitis A and hepatitis B. Lung function tests were also taken. These tests can reveal problems with the respiratory system which might preclude the use of breathing apparatus.

Three was considered the minimum and four the optimum number of people for the safe entry of a sewage overflow chamber. Many of the tasks undertaken in a routine maintenance visit required two people to be below ground and one person the "top man", was required to remain above ground to pass equipment down and up, download data and help in the event of an accident. The team was later enlarged to five for although usually only four came out on the regular site visits, it was found necessary to have at least five trained people on site during the installation of equipment in a new site or during blocking tests.

3.2 The Sewer Entry Team Van

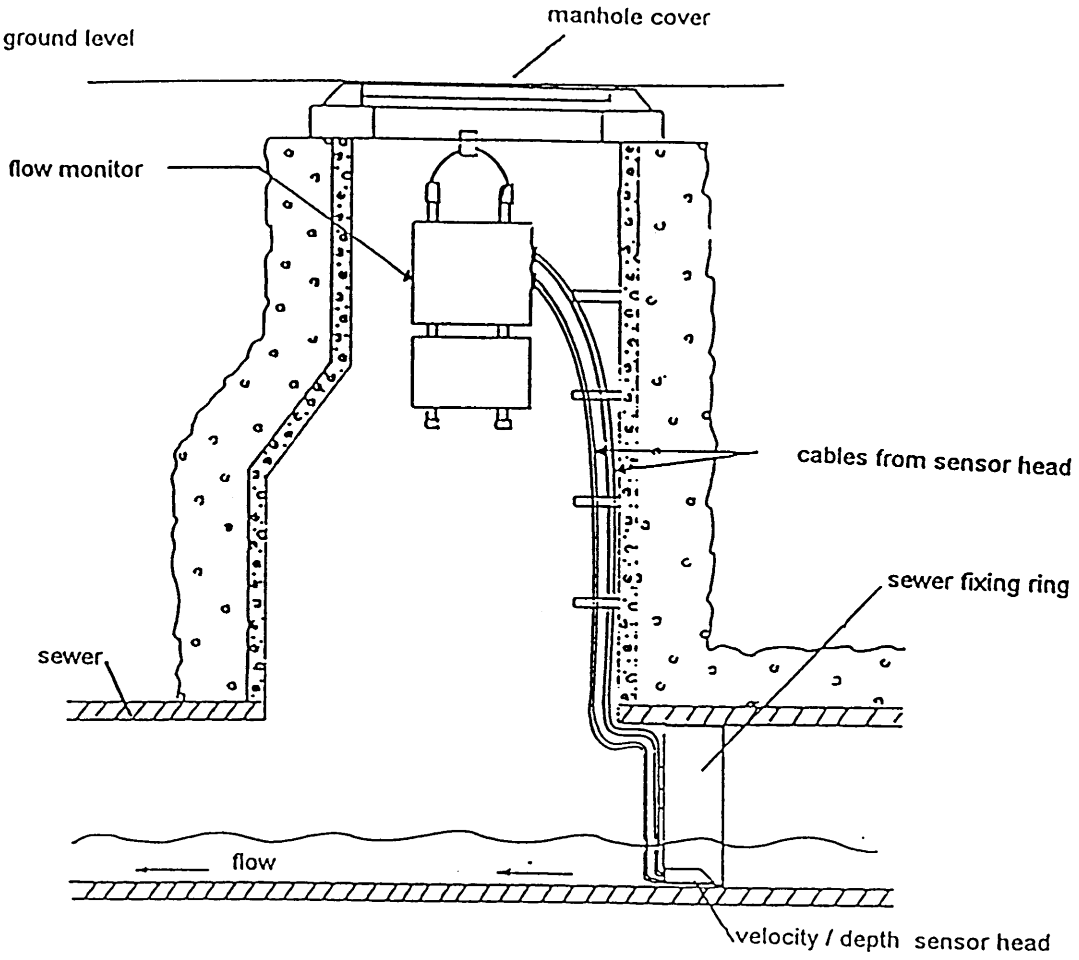
At the original site (Chesterfield Road) the large amount of equipment necessary for the weekly maintenance visits (e.g. road signs, cones, ventilation manhole covers, breathing apparatus, waterproof clothing and waders, tools and manhole lifting keys, winch and batteries) all had to be stored at the Polytechnic and loaded onto the School of Construction Landrover every week. This was both time consuming and inconvenient for the other users of the Landrover. After the first year of the project a Sherpa van was obtained ,for the sole use of the sewer entry team. This was fitted out to store all the necessary equipment and was able to charge up logger and sampler batteries. The van also had a sink with hot and cold water and enough space to carry five people. Such a vehicle is of immense benefit for a project such as this.

3.3 Monitoring Equipment

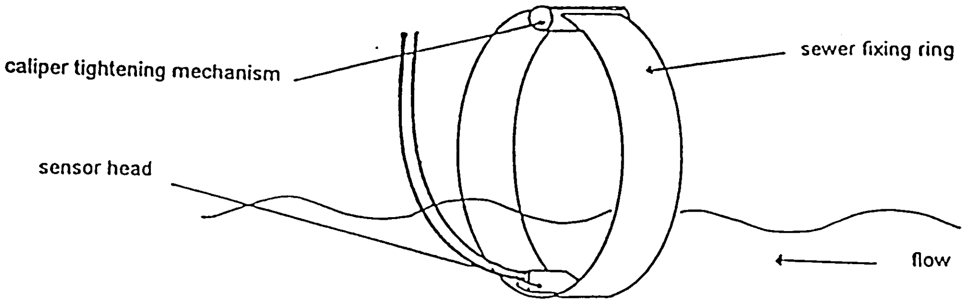
Diagrams of the flow and sampling equipment used and their installation in the overflow are given in Figures 3.1 to 3.3.

3.3.1 Flow Monitors

A diagram of a flow monitor, monitor head, sewer attachment ring and typical site set up is given in Figure 3.1. Detectronic Intrinsically Safe flow monitors were used in this study. These were supplemented by two Arx depth monitors during the latter part of the study to provide extra information on the depths in the chambers.



A. Typical Monitor Installation (after Wallingford Software)



B. Sewer Fixing Ring

Figure 3.1 Flow Monitor Installation

The Detectronic monitors consist of four main components (Detectronic, 1991):

- sensor
- processor
- data logger
- power supply

The depth of fluid over the sensor, recorded as a pressure head, was measured by a pressure transducer. This measured the strain experienced by a silicon diaphragm caused by the pressure difference between the fluid surrounding the sensor and atmospheric pressure introduced via a breather tube at the back of the sensor (Catterson, 1991). Pressure transducers are prone to drift over a period of time and this drift must be regularly detected and corrected. Depth checks were made during the weekly site maintenance visits. With the flow loggers used it was possible to obtain an immediate reading of the depth and velocity of the flow in the sewer. This was then compared with a measurement made at the same time using a hand-held, propeller type velocity meter. Several readings of the velocity were taken to ensure that a reading representative of the flow was used.

The fluid velocity was recorded by means of a Doppler meter. This records the velocity of "reflectors", air bubbles and particulate matter, transported in the flow. A continuous ultrasonic wave is emitted from a piezo-electric crystal and the reflected signal excites a separate crystal in the sensor head. The emitted and the received signals are then compared and the phase shift between them is related to a velocity using the Doppler principle (Catterson, 1991).

Guidelines for the installation of flow monitors in sewers are given in the Water Research Centre's "Guide to Sewer Flow Surveys" (Green and Drinkwater, 1985). Acceptable monitoring sites are limited by the depth of the effluent, the size of the sewer and the velocity of the flow. The recommended ranges to obtain accurate readings from the flow monitors used are as follows:

1. Effluent Depth : 10 to 1200 mm
2. Sewer Size : 225 to 1200 mm
3. Velocity : 0.2 to 2.0 m/s (the upper end of the range being dependent on the effluent depth and/or size of the sewer)

If the depth of effluent is too low or the sewer too small accurate measurement is not possible due to the disturbance caused by flow passing over the sensor. If the velocity is too high the sensor will create too much disturbance in the flow pattern and reduce its accuracy.

The Guide also recommends that flow monitors should be installed away from pipe junctions to avoid any interference caused by the combining flows and other positions where gross turbulence exists. Sites prone to silting should be avoided as far as possible but if monitoring at such a site is required accurate measurements of the silt depth, taken a regular intervals are essential.

In this study the sensor head was held in place at the bottom of the sewer by attaching it to either a steel strip (in pipes of 0.5m diameter or over) or an expanding steel fixing ring (in pipes less than 0.5m). These rings were curved to fit the sewer pipe and have an adjustable calliper mechanism. This was used to expand the ring so that it fitted tightly into the sewer pipe.

Data were collected from the Detectronic monitors using a Husky Hunter portable computer. The data were then transferred to an IBM personal computer provided by the Water Research Centre for the project. The depth and velocity data obtained from the survey loggers were processed using the Water Research Centres "Sewer Survey Analysis Software" (SSAS). The size and shape of the sewers from which the data were obtained was entered into the programme at the start of the survey. The programme then calculated the flows and depths from the raw depths and velocity readings. Specific storm events could then be defined and the data viewed graphically. Data from the raingauges were also transferred into this package so that graphs of the rainfall data could be compared with graphs of the flow data in the sewer overflow for the same time periods.

The Arx depth sensor measures depth using the principle of immersed ultrasonics. The instrument is purely digital and it needs no calibration (Arx Instruction Manual). Although ultrasonics have been used for some time to measure depths in the process industry its use in sewerage systems has previously been considered to be impractical as the many reflectors in the flow prevented a clear single reflector source (i.e. the surface of the liquid) from being identified (Catterson, 1991).

With the Arx monitor this problem is overcome by applying a probability technique to all the collected reflected signals saved in the instrument's memory in order to derive the liquid surface (the most probable reflection source). The Arx monitor head was installed by attaching it to a steel plate and then to the floor of the chamber, in the same way as the flow monitor heads. It has very low power requirements and the battery can thus last for up to a year of operation.

Before installation all the monitors were tested in the Hydraulics Laboratory to ensure that the depth and velocity reading were in accordance with the manufacturers specification. During the second year of the project a course was attended by three of the sewer entry team. This enabled us to calibrate the Detectronics equipment ourselves when drift occurred.

Data from the Arx were collected by an Olivetti portable computer. These were then transferred to an IBM personal computer. The data were analysed using a specific Arx depth monitor software package.

3.3.2 Water Quality (Bottle) Samples

Sirco samplers were used to obtain samples of sewage for the first three sites in this study. A diagram of a Sirco sampler is given in Figure 3.2. Samples were drawn from the sewage when the samplers were triggered by an external float switch mechanism. When triggered, air was pumped down the 10mm diameter sample tube for 60 seconds to flush it free of any obstructions. A sample of sewage was then sucked up into the Perspex cylinder on the top of the sampler unit until a predefined level was reached (equivalent to 400ml), On reaching this level the pump stopped and the sample was allowed to flow down through the distributor arm into one of the 24 bottles in the base unit.

Once this had been completed the arm moved round onto the next sample bottle and the procedure was repeated. The sampler was set to sample at five minute intervals. The total sampling time was thus 115 minutes. After each event the entire base unit was removed and a new one, with sterilised, empty bottles installed. The battery was replaced each week or after every 2 storms (whichever came first).

The free end of the sampler tubes were fixed so that they pointed away from the direction of the flow. This minimised the build up of debris that was found to rapidly build up on any projections into the flow of sewage. This process was known as "ragging up". A filter was attached to the end of the tube in order to reduce the risk of blockages occurring. Unfortunately, this seemed to encourage the build up of rags and it was eventually lost, presumably due to the weight of material built up on it between maintenance visits. Blockages were not found to be a problem so the end of sampler tube was left unfiltered.

The trigger mechanism used with the Sirco samplers were simple float switches. These consisted of a ballcock on one end of a 600mm arm. The other end of the arm was pivoted at a potentiometer. For the inflow this was fixed above the dry weather flow channel so that the sampler would be initiated at the point of spill. The spill float switch was set to sample when it was estimated that the spill flow depth was sufficient for a sample to be drawn up the sample tube. The samplers were positioned so as to minimise the height and distance that the sewage had to be pumped. The heights and distances at all the sites were well within the design specification of the samplers.

The Epic samplers used at the final site operated in essentially the same way as the Sirco samplers. Their use was necessitated because at this site all the equipment had to be stored in the overflow chamber. Intrinsically safe samplers thus had to be obtained.

Once obtained the samples were taken immediately to the Yorkshire Water laboratories where they were analysed for suspended solids, non volatile suspended solids (ash), biochemical oxygen demand (BOD), chemical oxygen demand (COD), pH, conductivity and ammonia. All these parameters are commonly used water quality determinands for studies of this nature. The results of this study would therefore be comparable with the results of other, similar studies. However, the NRA are recommending that a measure of turbidity be substituted for suspended solids and total organic carbon (TOC) for BOD. A more detailed discussion of this is given in Section 6.13.3.

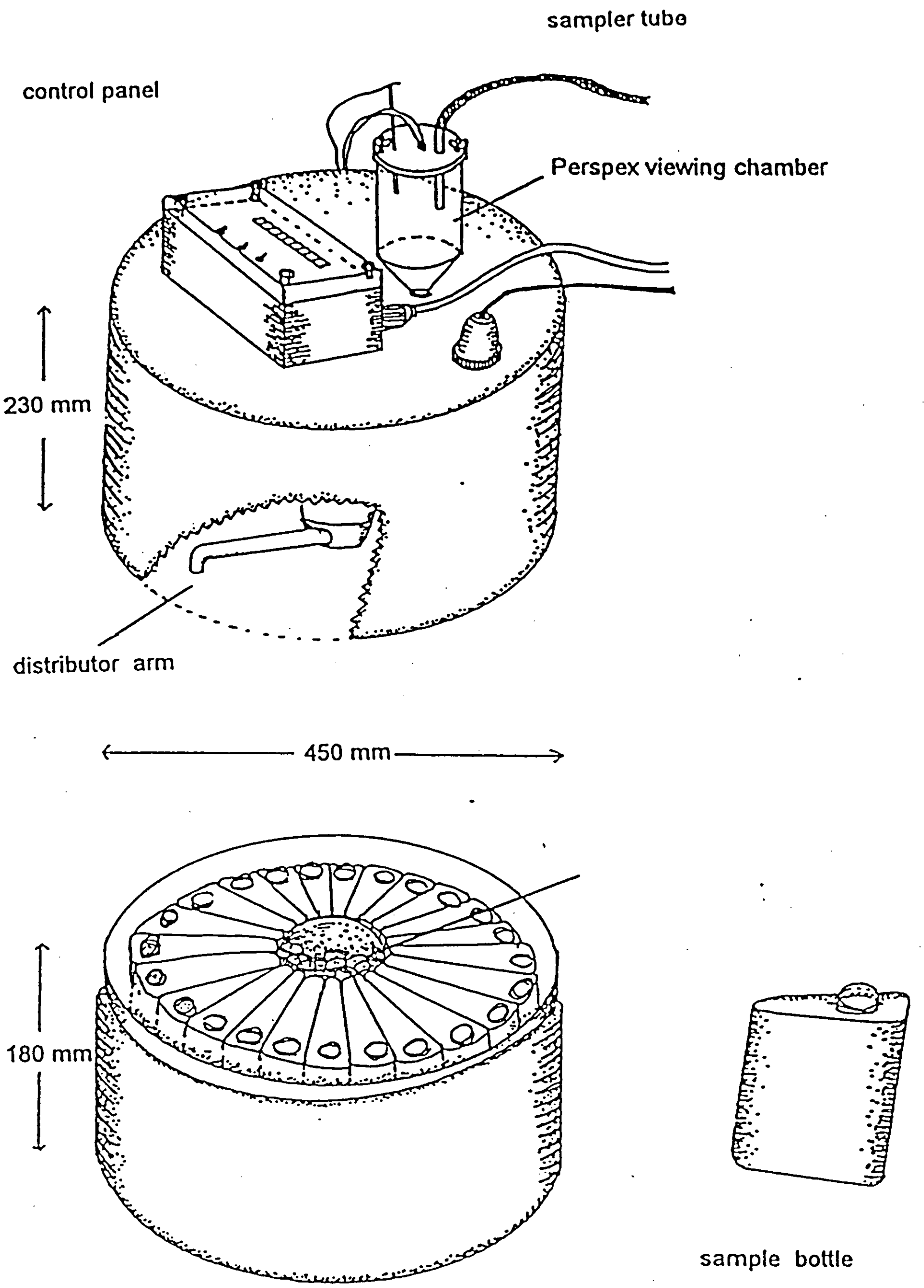


Figure 3.2 Sirco Bottle Sampler

When the results of the analysis were obtained from Yorkshire Water, the were typed into a spreadsheet package (Quattro Pro) on a personal computer. Flow data for the same time periods could then be added to this data which could then be manipulated to test for correlations between the parameters, to plot pollutographs and to give total loads for the sampling period.

3.3.3 Gross Solid Samples

Samples of gross solid materials were taken from both the inflow and spill using a passive sampling technique. Woven polypropylene mesh bags ("Copasacs") with an aperture of 4-6mm were used to collect samples from a portion of the incoming and overspilling flow during storm events. The approximate dimensions of the bags were 500mm wide and 900mm long. Originally, for the inflow samples at Chesterfield Road, two bags were cut open down one of the long edges and then "sewn" together using plastic cable ties to produce a bag with a mouth twice the area of the original bag. This was the attached to a metal "Dexion" frame that had been fixed across the inflow pipe at a height above dry weather flow so that it would only start to fill in storm conditions.

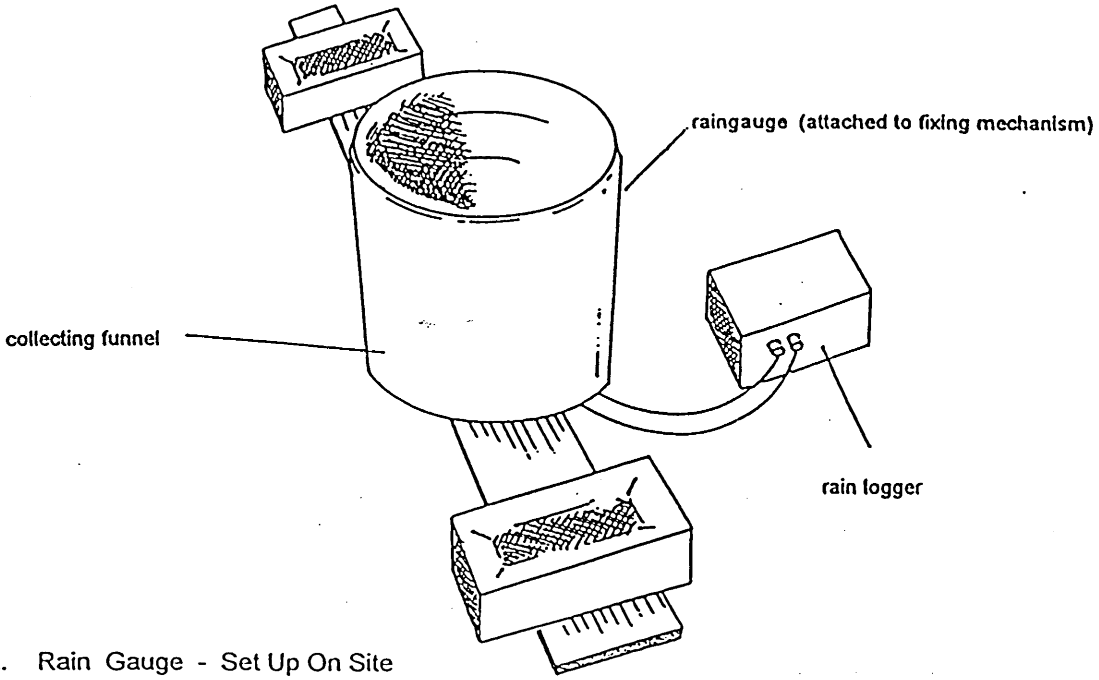
This method was later abandoned as the bags were found to rip apart along the weakened, sewn seam as soon as any sizeable volume passed through them. The bags were then attached to the frame side by side. This proved to be successful and was used at all of the four sites. In the siting of these bags it was assumed that the gross solids in the flow were well distributed throughout the flow profile. This assumption was thought to be reasonable due to the steepness of the catchments investigated and the corresponding turbulence of the flow which minimises the settlement of solid material which could result in biased sampling.

The siting of the mesh bags for the sampling of gross solids from the spill depended on the site being monitored. At the Chesterfield Road site it was possible, .by entering a manhole downstream, to place the mesh bags so that the whole of the spill was covered as there was a drop in level where the spill entered a culverted river. At the other three sites the spill bags were attached to the weir, usually in more than one position so that a more complete picture of the behaviour of the gross solids in the chamber could be obtained.

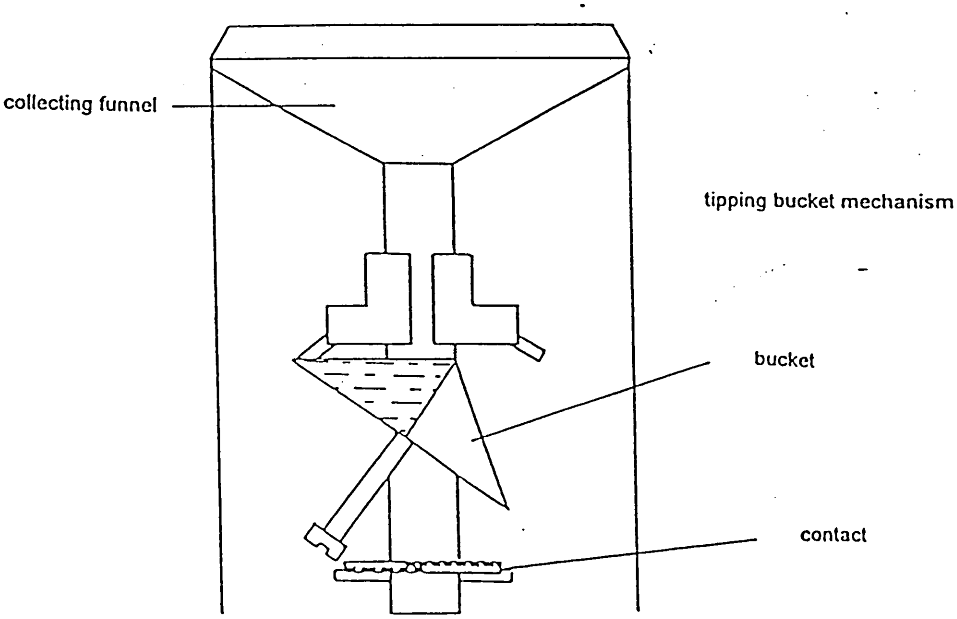
The material obtained was drained on site to remove any excess water then placed in a large plastic bag and returned to the laboratory. Here the material was separated into the following categories: faeces, sanitary towels, tampons, leaves and twigs, thick paper towels, plastic, miscellaneous material and material adhering to the mesh bag (mostly toilet tissue). A more detailed discussion of these categories is given in Section 6.7.

3.3.4 Raingauges

The rainfall was measured using tipping-bucket raingauges (see Figure 3.3). These were set to tip on the collection of 0.2mm of rain. The time of each tip was recorded in the data logger. Data were downloaded using the Husky Hunter portable computer. This was then transferred to an IBM personal computer using the same SSAS software as that used for the flow monitors.



A. Rain Gauge - Set Up On Site



B. Cross-Section of Tipping Bucket Rain Gauge (after Wallingford Software)

Figure 3.3 Raingauge

In order to obtain rain data representative of the rainfall of a particular catchment it was important to find sites, usually building with flat roofs, that were out of the way of any rain shadow effects produced by surrounding buildings. Care had also to be taken to ensure that the raingauge was out of the way of any strong winds as this can lead to under recording. The security of the site also had to be taken into account as the raingauges, necessarily, have to be fairly exposed.

3.4 Positioning of the Equipment

3.4.1 The Stilling Pond

At this site two flow monitors were used, one in the inflow and one in the continuation flow. The inflow monitor sensor head was positioned in the overflow chamber approximately 0.5m into the inflow pipe. The continuation flow monitor sensor head was positioned at the upstream end of the short continuation throttle pipe beneath the weir. An Arx depth recorder was installed, with its sensor in the middle of the main chamber, for just over half the monitoring period.

The inflow gross solid collection bag (Copasac) was attached to a rectangular metal frame and placed where the inflow pipe discharges into the overflow chamber at a height above dry weather flow. The spill bag was positioned in a downstream manhole where the spill flow discharged into a culverted stream. At this location the whole of the spill could be sampled.

As permission to leave a trailer on site had been granted by the Arnold Laver D.I.Y. warehouse, the water quality samplers could be kept in the trailer immediately above the chamber. The sampler pipes were run through a specially designed manhole cover into the chamber. The inflow sampler tube was fixed along the wall of the chamber and the end of the tube fixed above the dry weather flow channel in the middle of the chamber. The spill sampler tube was fixed in the spill channel approximately two metres beyond the screens.

3.4.2 The High Side Weir (Dobcroft Road)

Flow and depth readings were taken from the inflow and spill outlet pipe in the main chamber by the Detectronic flow monitors. An Arx depth recorder took readings from the middle of the main chamber.

A frame was installed above the dry weather flow level in the inflow pipe for the inflow gross solids collection bag. The spill bag was installed on another frame on the end weir at approximately 0.75m from the middle.

The samplers were stored in a specially designed, waterproof, secure metal cabinet that could be chained down to prevent theft. The inflow sampler tube was placed above the dry weather flow channel at the upstream end of the main chamber. The spill tube was positioned in the spill pipe approximately 1.5m from the entrance to the pipe at 50mm from the bottom of the pipe.

3.4.3 The Low Side Weir

Three flow monitors were used at this site so that the inflow, spill and continuation flow could be recorded. All were positioned in the main chamber. The inflow monitor sensor head was installed at approximately 0.5m upstream of the chamber. The spill monitor sensor head was installed at the entrance to the spill pipe. The continuation flow was positioned approximately 0.75m into the continuation pipe.

The inflow gross solids bag was installed above the dry weather flow channel, approximately at weir level, 0.5m down from the inflow pipe. Two spill bags were installed on one side of the weir (the side with the spill pipe). The first spill bag was positioned 0.75m downstream of the inflow pipe. The second was 2.25m downstream of the inflow pipe.

The samplers were stored in a metal cabinet identical to that used at the Dobcroft Road site. The inflow sample tube was positioned between the monitor sensor head and the inflow gross solids bag. The spill tube was positioned beneath and to one side of the weir, approximately 0.5m from the entrance to the spill channel.

3.4.4 The High Side Weir (Leyburn Road)

Three flow monitors were originally installed at this site. The inflow monitor was placed in a school yard approximately 150m upstream of the chamber. This was done to avoid backwater affecting the readings as far as possible. The monitor could not have been placed further up as at the next manhole upstream there was a bifurcation which would have affected the flow readings obtained. The continuation flow monitor was also positioned in a separate manhole, 40m from the main chamber. This site has two spill channels which spill directly into the River Sheaf at the bottom of Leyburn Road. As only a limited number of monitors were available it was decided that only one of the two should be monitored. However, when a second monitor became available from another project it was installed in the second spill pipe. An Arx depth recorder was installed in the main chamber part way through the monitoring period.

The inflow gross solids collection bag was installed across the inflow pipe, attached to a metal frame, in the normal way. Ten spill bags were positioned at regular intervals around the weir. It was hoped that this number would sample an adequate proportion of the flow spilled.

Sampler tubes were placed to sample above the dry weather flow in the middle of the chamber (for the inflow) and at the entrance to the spill pipe (for the spill).

3.5 Maintenance

Cleaning and equipment maintenance visits were made to each site on a weekly basis in order to check the correct operation of all the equipment. The monitor heads and sampler tube ends and fixings were freed of all debris and the monitor head sensors gently wiped.

Data stored in the flow loggers were downloaded and the batteries replaced. Instantaneous velocity and depth readings recorded by the loggers were then checked. The depth was measured upstream of the monitor head and as near to it as possible using a ruler. Velocity measurements were taken with a hand-held propeller-type velocity meter. This was placed in the dry weather flow channel immediately upstream of the monitor head and held at approximately the mid-depth of the dry weather flow. Readings were taken until three similar counts were obtained. These counts, in the form of revolutions per second, were later converted to velocities using the manufacturer's calibration.

The sampler unit batteries were replaced each week, even if the samplers had not been operational. Testing of the sampler units and the float switches was then undertaken. Both the inflow and the spill float switches were raised in turn to ensure that sampling during a storm would be initiated at the correct height and that the arm could move freely. The samplers were checked to ensure that they could pump up the required volume of sample, that the sample drawn up was correctly placed in the sample bottle and that the distribution arm was then free to move on to the next sample bottle.

Data were collected from the rain gauges on a monthly basis. An input test was undertaken to check that tips were being accurately recorded and the funnel was flushed with water to ensure that it emptied freely and was not impeded by grit or other debris.

4. DATA ANALYSIS METHODS

A. HYDRAULIC ANALYSIS

4.1 Measurement of the Chambers

Data and drawings of the chambers were obtained from the Local Authority. Unfortunately, some of the measurements were found to be inaccurate so the pipe, weir and chamber dimensions had to be measured on site. Also, at each of the side weir sites, a survey of the variation of the levels along the weir was undertaken, using an automatic surveyor's level and scale rule.

As detailed knowledge of the volumes in the pipes upstream of the overflow was required it was necessary to have information about their size and levels. Where possible, the cover levels of the relevant manholes were measured and the invert levels obtained from depth measurements. Where "on site" measurements were not possible e.g. due to heavy traffic, the Local Authority levels were used. This information was then used to define the limit of backing up of the storm sewage during an overflow event and to obtain the storage in the pipes.

At the stilling pond site, Chesterfield Road, the only position for the continuation flow monitor was in the 290mm diameter throttle pipe. It later became apparent that this monitor was not reading the velocity correctly. This is thought to be due to the formation of eddies at the entrance to the pipe reducing its effective area. As it was not possible to site the monitor downstream of the combined sewer overflow an alternative method was sought to measure the continuation flow. In addition, at the stilling pond site the velocity decreased below the inflow monitor sensor threshold as the stilling pond filled up. Monitoring at the upstream manhole was not possible. The alternative method chosen was the blocking test. This was used at the stilling pond and high-side weir sites.

4.2 Blocking Test

The continuation discharge characteristics of the stilling pond and the high side weir overflows were determined by performing a falling head test. During a period of dry weather, the continuation pipe was closed off allowing the dry weather flow to back up in the overflow chamber and upstream pipes. At the stilling pond site the blocking took place beyond the weir, at the end of a short continuation pipe. Here a wooden board, shaped to fully cover the pipe and covered with a foam material to reduce leakage, was held in place with a wooden stake jammed against the back wall of the chamber. The stake and the board were attached to ropes so that from above ground, the stake could be dislodged and the board displaced when the dry weather flow reached weir level.

At the high side weir sites a similar plugging device was used, attached to a metal pole. This was placed in the main chamber in front of the continuation flow pipe so that the backing up of the dry weather flow in the chamber forced the board against the end wall of the weir. When the dry weather flow level reached the top of the weir the board was lifted out and the ponded water released.

Depths in the chambers, after the release of the plug, were recorded at equal time intervals (15 seconds) until the depth returned to that of dry weather flow. These depths were taken from a metre rule in the main overflow chamber and also from the data loggers already installed at the site. These data loggers, which were usually set to read at 2 minute intervals, were reset for the period of the blocking test to read at 15 second (Detectronic) and 30 second (Arx) intervals in order to obtain as much information as possible.

The dry weather flow was recorded before and after the test and, where there was no backing up of water, during the filling and release stages. Where backing up occurred the dry weather flows could be estimated from the records of diurnal variation. Upstream volumes were calculated from survey drawings and site measurements.
The graph of the time-depth for the blocking test was obtained by calculating the discharge at each depth measurement. For a fall in depth, d_n to d_{n+1} the discharge was taken as:

$$\frac{(Q_n + Q_{n+1})}{2} \qquad \text{Equation 4.1}$$

Volume change was calculated as $S_{n+1} - S_n$ and hence the time is equal to:

$$\frac{(S_{n+1} - S_n)}{(Q_{dwf} - 0.5(Q_n + Q_{n+1}))} \qquad \text{Equation 4.2}$$

The first few measured points were ignored due to the initial instability of the flow when the plug was released. This method allows the continuation flow to be calculated from the sewage depth measurements in the overflow chamber.

4.3 Measurement of Depth and Discharge

4.3.1 Stilling Pond Site

The initial information concerning the hydraulic operation of this site came from scattergraphs composed of all the data measured at the Chesterfield Road site, both during dry weather and precipitation (see Appendix 1). This showed that there was a considerable scatter of values for both the inflow and continuation monitors. A variation in flows at a given depth is not unusual in sewers due to the pipe roughness, silt and backing up of storm sewage all of which alter the hydraulic gradient. However, many of the storms also had missing velocity readings, possibly due to the build-up of deposits and other debris over the monitor head.

A comparison of the inflow and continuation flow monitors show that there are significant differences in the magnitude of the flow. Preliminary theoretical estimates of the continuation discharge suggested that the continuation flow monitor was underestimating the flow. The scattergraph indicates that there is more than one head discharge relationship for the continuation flow.

When the inlet monitor is not affected by backing up the flow could be directly calibrated against the measured depth. In this range the continuation flow was assumed to be equal to the inflow. Small errors in the continuation discharge will occur in the transition between free flow and drowned flow over the monitor head because of the small increase in storage. At depths greater than this the values given by the continuation monitor were thought to be unreliable.

For the gross solids and dissolved and finely suspended solids investigation it was necessary to have full inflow and spill readings during storm events. The missing inflow data thus had to be interpolated from a calibration curve. This was made easier when it was shown that inflow depth measurements taken by the loggers agreed with the depths that were measured during the blocking tests and with the data obtained by the Arx monitor.

The continuity equation was used to determine the relationship between the continuation discharge and inlet depth i.e.

Discharge In - Discharge Out = Rate of Change in Storage

Thus to calculate the change in storage in the time step n to n+1 the following equation could be used:

$$(Qin_n + Qin_{n+1})\frac{dt}{2} - (Qout_n + Qout_{n+1})\frac{dt}{2} = S_{n+1} - S_n \qquad \text{Equation 4.3}$$

Where:

Qin is the inflow discharge
Qout is the outflow discharge
S is the volume stored

This is shown graphically in Figure 4.1 below:

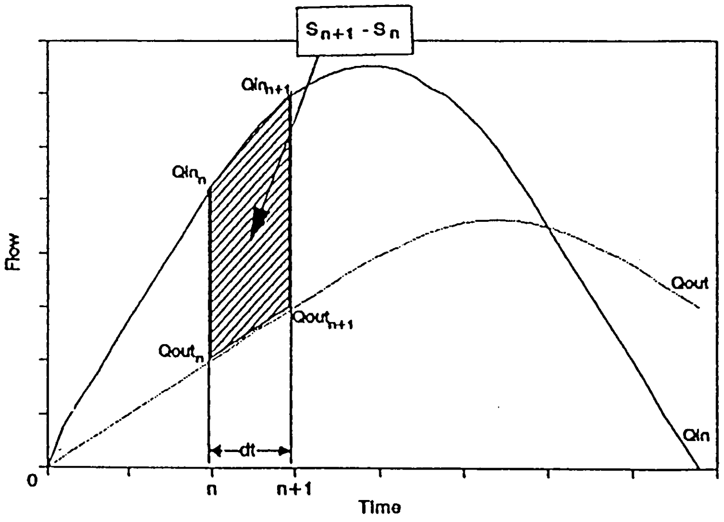


Figure 4.2 Graphical Representation of Equation 4.3

The continuation discharge could thus be determined using data from the inflow monitor for storms with sufficient recorded values.

$$Qout_{n+1} = Qin_n + Qin_{n+1} - Qout_n + (S_n - S_{n+1})\frac{2}{dt} \qquad \text{Equation 4.4}$$

Once this had been determined the missing inflow data could then be derived for the remaining storms:

$$Qin_{n+1} = Qout_n + Qout_{n+1} + (S_{n+1} - S_n)\frac{2}{dt} - Qin_n \qquad \text{Equation 4.5}$$

The outflow value, Q_{out}, will be the continuation flow, when the depth is below weir level, or continuation flow and weir flow when the depth is above weir level.

The continuation discharge is a function of the differential head loss across the pipe. To obtain this, upstream depths were calculated from the inflow pipe depths and the downstream depths determined by a calibration to the upstream value. This calibration, obtained from the blocking test results, was used because downstream depths were not measured during storm conditions. The same relationship was assumed to hold when depths were above weir crest.To calculate the discharge over the weir the following equation was used:

$$Q = Cd\,\frac{2}{3}\sqrt{2g}\,Bh^{1.5} \qquad \text{Equation 4.6}$$

Where:

B is the length of the weir
Cd is the discharge coefficient
H is the head above crest level

The discharge through a throttle pipe is determined by considering the total energy upstream and downstream. Figure 4.2 indicates the parameters of interest in this investigation.

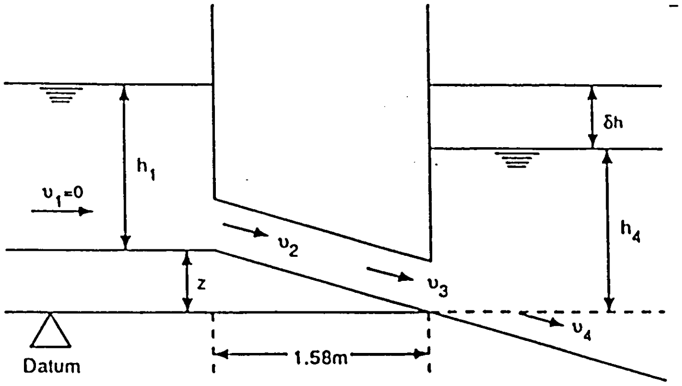


Figure 4.1 Throttle Pipe Hydraulics

From this the following equation could be derived:

$$h_1 + \frac{v_1^2}{2g} + z = h_4 + \frac{v_4^2}{2g} + \text{losses} \qquad \text{Equation 4.7}$$

In this system the losses are:
an entrance loss:

$$\frac{0.5v^2}{2g}$$

a friction head loss, h_f, (as given by the Darcy-Weisbach Equation):

$$\frac{\lambda l v^2}{2gd}$$

and an exit loss:

$$\frac{(v_3 - v_4)^2}{2g}$$

In the friction equation λ is a function of velocity and relative roughness. To avoid the need for successive approximation rough turbulent flow is assumed. The friction head loss can then be determined by the Manning equation (Ackers P., 1958):

From the Manning equation:

$$v = \frac{1}{n} R^{\frac{2}{3}} i^{\frac{1}{2}} \qquad \text{Equation4.8}$$

or,

$$v^2 = \frac{1}{n^2} R^{\frac{4}{3}} i$$

$$n = \text{Manning's Roughness Coefficient} = \frac{k_s^{\frac{1}{6}}}{83.3}$$

Thus, Equation 3.7 can be written out fully:

$$h_1 + z + \frac{v_1^2}{2g} - h_4 = \frac{v_4^2}{2g} + \frac{0.5v_3^2}{2g} + \frac{\lambda l v_3^2}{2gd} + \frac{(v_3 - v_4)^2}{2g} \qquad \text{Equation 4.9}$$

If it is assumed that v_4 (for which there are no measured values) is v_3 multiplied by some constant, C. i.e.

$$\text{Let } v_4 = Cv_3$$

Thus,

$$h_1 + z + \frac{v_1^2}{2g} - h_4 = \frac{C^2 v_3^2}{2g} + \frac{0.5v_3^2}{2g} + \frac{\lambda l}{d}\frac{v_3^2}{2g} + \frac{(v_3 - Cv_3)^2}{2g} \qquad \text{Equation 4.10}$$

Where,

$$H \text{ (head loss)} = h_1 + z + \frac{v_1^2}{2g} - h_4$$

This can be rearranged as below,

$$H=\frac{v_3^2}{2g}\left(C^2+0.5+\frac{2gn^2l}{R^{\frac{4}{3}}}+(1-C)^2\right) \qquad \text{Equation 4.11}$$

and again, in terms of v_3, to give:

$$v_3=\frac{\sqrt{2gh}}{\sqrt{C^2+0.5+\frac{2gn^2l}{R^{\frac{4}{3}}}+(1-C)^2}} \qquad \text{Equation 4.12}$$

To obtain the discharge, Q, both sides of this equation must be multiplied by A, as Q=Av. Here, A is the cross-sectional area of the pipe,

$$\delta h = h_1 + z_1 - h_4$$

The equation of an orifice is given as:

$$Q= Cd\ A\ \sqrt{2gH} \qquad \text{Equation 4.13}$$

This can be rearranged in terms of Cd, as below:

$$Cd=\frac{Q}{A\ \sqrt{2gh}}$$

This can then be substituted into Equation 4.12 to give:

$$Cd=\frac{1}{\sqrt{C^2+0.5+(1-C)^2+\frac{2gn^2l}{R^{\frac{4}{3}}}}} \qquad \text{Equation 4.14}$$

Values of C and k_S (used in calculating Manning's roughness coefficient) were derived by finding the best fit curve to the blocking test results (found by eye) and the weir coefficient estimated from five storms with an adequate number of recorded values. The assumptions made in this method are that there is rough turbulent flow and that $v_4 = Cv_3$. The discharge-depth calibration was then tested on all storms in addition to the ones used in the calibration, by comparing the input hydrographs from the calibration with the measured hydrographs, to ensure that the calibration accorded with the actual performance and to confirm that the appropriate values of the parameters had been chosen.

Gross Solid Load Calculations

Only a portion of the incoming flow was covered by the mesh bags used to collect the gross solids. The total solids load during a storm thus had to be estimated. This was done by assuming that the discharge through the Copasac mesh bags was proportional to the area of the opening exposed to the flow. This could be done for any level of storm sewage. These discharges could thus be estimated after the complete inflow discharges had been determined. It was possible to position the spill mesh bag to cover the whole of the spill flow so no adjustments had to be made to the values obtained from this. A discussion of the analysis of the gross solids obtained will be given in the next section.

4.3.2 High Side Weir (Dobcroft Road)

As the continuation pipe at Dobcroft Road was too small to permit the installation of a monitor and the downstream manhole was inaccessible, values obtained from the inflow and spill monitors were to be used to determine the continuation flows. In the inlet pipe, velocity measurement was satisfactory at low flow but at high flows, low velocities and ragging of the sensor prevented adequate measurement when the water levels backed up. The results of the blocking test thus had to be used to interpolate the missing values from the inflow pipe depths in a similar manner to that used for the stilling pond.

The scattergraph of the overflow monitor showed a consistent depth-discharge relationship (see Appendix 1). Also, the measured hydrographs of the overflow discharge were complete for most storms. These values could thus be used, in combination with the continuation flows and the rate of change of storage, to determine the inflow discharges when the water levels were above the weir crest. It is not possible to calibrate the spill flow monitors in situ as there is no flow in the spill channel except in storm conditions when it is not possible to enter the chamber safely. Calibration of the spill loggers was thus done in the hydraulics laboratory at the University, during maintenance of the loggers and when they were removed from the site at the end of the survey.

Gross Solids Load Calculations

The discharge through the mesh bags was determined by calculating the mean velocity of flow at each time step and multiplying by the area of the mouth of the mesh bag which is submerged.

Discharge through the overflow mesh bags was obtained by proportioning the flow over the weir to the lengths of the frame to which the mesh bag was attached. To do this the theoretical total discharge and discharge through the mesh bag were determined using a standard weir equation for the end weir and by solving the spatially varied flow over the side weir with the Runge-Kutta method (Balmforth, 1978). These proportions were calculated at different total discharge rates. A regression equation for the variation of discharge through the mesh bag with depth in the chamber was then derived.

4.3.3 Low Side Weir (Retford Road)

The three monitors at Retford Road produced a continuous record of depth and velocity, allowing the necessary hydrographs to be produced.

Gross Solids Load Calculations

As with the gross solids calculations for the high side weir, the discharge through the inflow mesh bags was determined by calculating the mean velocity of flow at each time step and multiplying by the area of the mouth of the mesh bag which was submerged. Discharge through the overflow mesh bags were obtained by proportioning the overflow over the weir to the lengths of the frame to which the mesh bags were attached.

4.3.4 High Side Weir (Leyburn Road)

The inflow monitor recorded satisfactorily at low flows but once depths in the chamber neared the weir level the monitor sensor started to be covered with backwater and this prevented adequate measurements of the flow depth and velocity. This became more significant as the depths in the chamber increased. A calibration was produced for the inflow using the scattergraph and the blocking test data. This is described in Section 5.5. Spill flow was recorded from one of the two spill pipes for the whole of the monitoring survey. As soon as another monitor was made available from another project it was installed in the second spill pipe.

The continuation flow monitor was placed in a manhole chamber 40m from the overflow chamber. Unfortunately much of the data recorded was useless. Most of the velocity data was lost due to the rapid build-up of silt and gravel in the bed of the channel. The chamber had been cleaned by Sheffield City Council Main Drainage Department prior to the installation of equipment but silt and gravel remained a problem at this site. Every storm event brought more into the chamber and the associated pipes.

This was the only chamber that could be used to measure the continuation flow. The two previous chambers were on 90° bends in the flow. The subsequent manhole was where the pipe joined the main sewer in the middle of one of Sheffield's busiest roads.

As the data recorded at this site were inadequate several months were spent trying to create a Wallrus model for the site. This proved to be problematic. The two pipes between the inflow monitor and the chamber were difficult to simulate accurately and the lack of continuation flow data made it difficult to verify. Eventually it was decided that a simpler method would be more appropriate in the time available.

A scattergraph of the inflow depths and flows was produced for all the storms with sample data (see Figure 5.48). From this it was apparent that the flow depth relationship was fairly consistent up to flows of 250-300l/s. Beyond this point backing up started to occur and data was lost. A calibration curve was produced from this, allowing for the depth and velocity checks made each week. This approximation was adequate although at depths higher than 270mm it is possible that the calibration was overestimating the flows.

As the inflow monitor was 150m upstream of the chamber it was necessary to calculate the flows at the entrance to the chamber so that the inflow through the gross solids bag, situated at the entrance to the chamber, could be calculated. This was done by calculating the change in volume in a given time step using the continuity equation i.e. Discharge In - Discharge Out = Rate of Change in Storage. The "level pool" assumption was made. This assumes that the water level is horizontal. This was considered to be reasonable in view of the large cross-sectional area of the pipes and the chamber compared to the pipe where monitoring occurs. Velocities of flow are therefore very low. First the incoming volume at the upstream monitor for a given time step was calculated. Then the change in the volume of the water stored in the pipes and manhole chambers upstream of the inflow monitor was calculated. The inflow into the chamber was given by subtracting the change in volume stored from the monitored inflow volume for the same time step and dividing the result by that time step (see equation 4.3).

Gross Solid Load Calculations

As at the Dobcroft Road, discharge through the overflow mesh bags was obtained by proportioning the flow over the weir to the lengths of the frame to which the mesh bag was attached.

B. SAMPLE ANALYSIS

4.4 Estimating Efficiency

4.4.1 Dissolved and Finely Suspended Solids

The relationship between the hydraulic data and the dissolved and finely suspended solids samples was investigated in a number of different ways. A number of basic questions to be addressed were identified:

a) is there any notable 'first foul flush' effect?

b) is there any correlation between the mass or load of a given parameter measured during a storm event and other factors such as the length of the antecedent dry weather period before the event, the duration of the storm, the peak or average intensity of the storm?

c) do the different parameters measured (suspended solids, ash, biochemical oxygen demand, chemical oxygen demand, ammonia, pH, conductivity) behave in the same way under the same conditions (either during dry weather or during a storm event)?

d) can the sources of the main pollutants be determined? i.e. is it possible to determine whether a pollutant is primarily of dry weather origin or whether it comes from other sources e.g. from road runoff.

Not all these questions could be fully answered due to the limited number of events recorded at any one site during the time scale of this project. The resulting small sample size made it difficult to determine the presence or absence of meaningful correlation. The project time scale would have to have been significantly longer to have thoroughly answer these questions.

Three graphical ways of examining the dissolved and finely suspended solids date were identified. Each can be used to present different aspects of the data.

4.4.1.1. Graphical Analysis

The following explanation is based on hypothetical examples and is intended to assist in the interpretation of the results given in Chapter 5 by isolating specific phenomena and discussing the implications of different possible outcomes.

a. Graphs of Concentration and Inflow against Time

This type of graph can be used to illustrate how the concentration of a given parameter changes during the period of the storm and in relation to an increase or decrease in the incoming flow. Such graphs are known as 'pollutographs' and they are often used in investigations of this nature as they clearly show the presence or absence of a 'first foul flush'. This is shown in Figure 4.3 for a hypothetical storm with samples. In this example the sample concentration peak appears in advance of the flow peak (it should be remembered that the concentration and the flow are measured on different scales on the primary and secondary Y-axes). The concentrations of the samples increase up to the third sample and then decrease. The differences in concentration between the successive samples after the peak concentration is, at first, quite large but later becomes less marked. The concentrations even out as the storm flow returns to the dry weather flow level. At this point the concentrations are below the level of the typical dry weather flow concentration for that time of the day.

If the first foul flush effect is ignored and it was supposed that all the pollutant material present in the sewer system was of dry weather origin and that the storm water contained none of the parameters measured then the resulting graph could be depicted as shown in example 1 in Figure 4.4. The additional storm water acts purely to dilute the dry weather sewage and consequently, the concentrations fall as the flow increases and a larger volume of water is present and then rise again as the flow decreases and the volume of water present returns to that of the dry weather flow. In this example the minimum concentration would be found when the flow was at its maximum value.

In example 2 on Figure 4.4 the concentration of the sample parameter measured increases and decreases with the flow of the storm water. This suggests that the storm water is bringing in an amount of that parameter in addition to that brought in by the dry weather sewage. Real examples tend to show a mixture of the two examples given here. The results of the storms measured in the current project will be given in Chapter 5.

b. Graphs of the Change in Incoming Load with Time

Another way of representing the same information is to produce a graph of load against time as shown in Figure 4.5 (Load is taken as the product of the mass coming in per unit of time). This type of graph shows at which part of the storm the maximum amount of material is entering. This could be useful when considering which part of the storm is potentially the most polluting and which portion of the storm volume should be prevented from discharging to the water course.

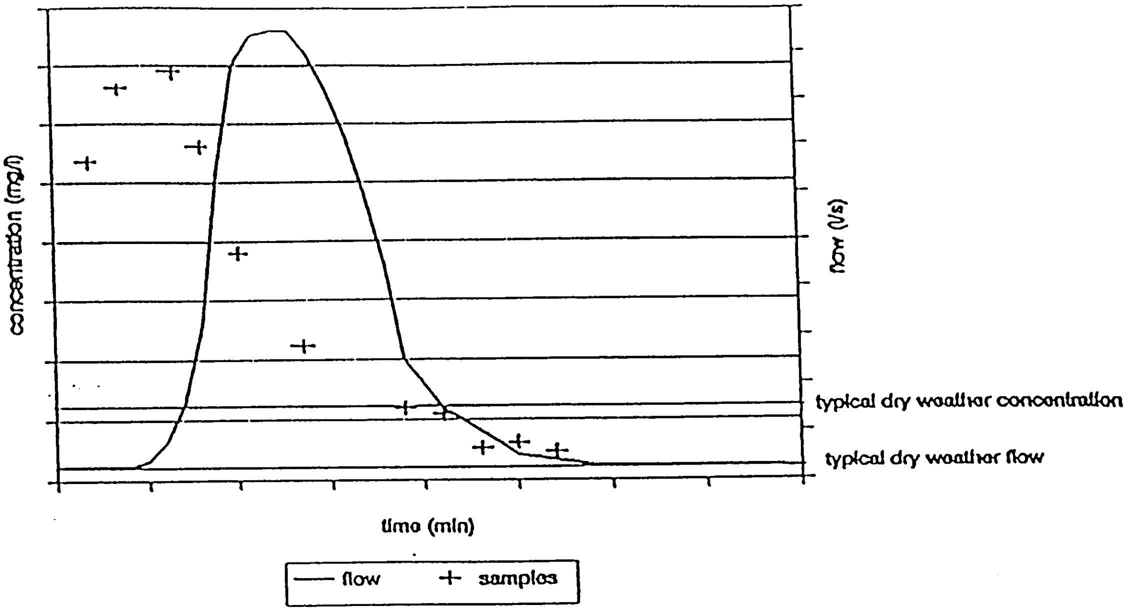


Figure 4.3 Theoretical Graph to Show First Foul Flush Effect

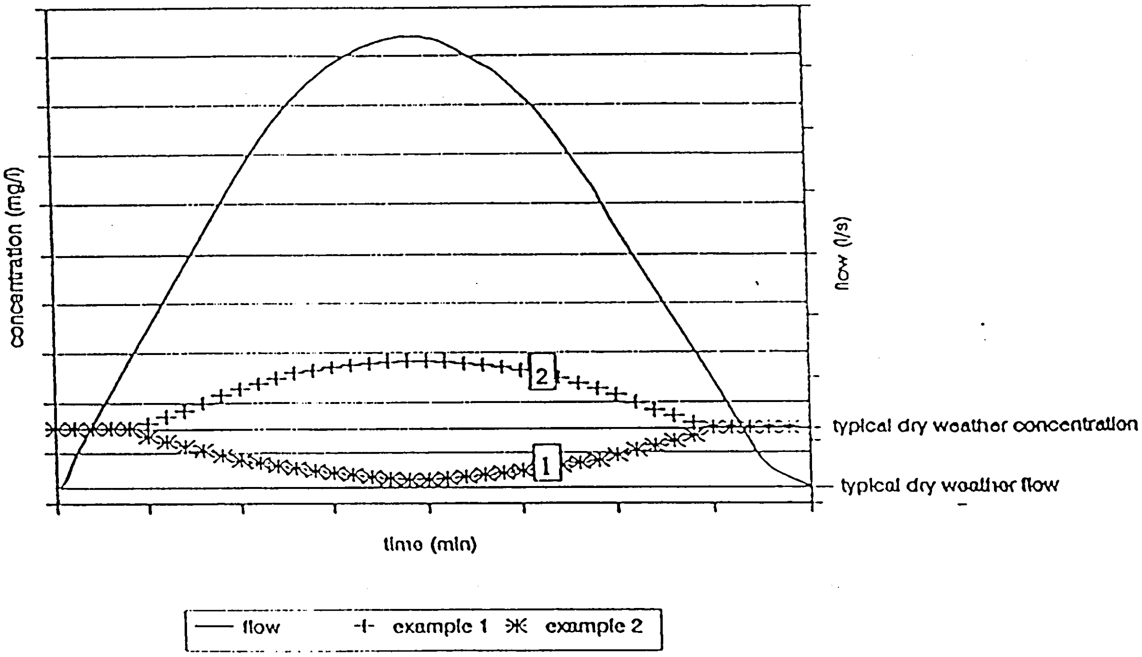


Figure 4.4 Theoretical Hydrograph Illustrating Possible Patterns for Sample Concentrations Plotted Against Time

In the graph shown in Figure 4.5 the 2 examples are developed from those given in the previous Figure 4.4. i.e. they were produced from the product of the flow and the concentrations of the examples given. Thus for example 1, in which the storm water acts purely to dilute the dry weather sewage and contains none of the parameters measured, the load entering would be as shown in example 1. Here the load remains in a relatively narrow range after an increase at the beginning of the storm. In example 2, however, there is a peak load which occurs at the same time as the peak flow. In a storm which exhibited a 'first foul flush' the maximum load would occur towards the earlier part of the storm i.e. before peak flow was reached.

c. Graphs of the Change in Mass with Time

If the incoming mass from the start time is plotted, a cumulative graph is produced (mass is the cumulative sum of load). This is shown on Figure 4.6 for the same examples as were used in the previous two figures. Here, the peak value is the total mass of the parameter entering the combined sewer overflow during the sampling period (the sampling period would normally be the period of the storm except where the length of the storm exceeded the maximum time allowed by the automatic samplers). From such a graph the total mass of a given parameter that has been brought in could be determined at any time during the sampling period. Thus if the load to a water course was to be reduced by a given % for a given parameter this type of graph could be used to determine what period of the storm or volume of storm water would have to be stored or otherwise prevented from entering the water course to achieve this reduction.

The graphs illustrated here are, of course, theoretical and ideal examples. When taking samples 'in the field', conditions are far from ideal and as a result samples are often lost or are otherwise unusable. This produces much more patchy data making it harder to determine what is actually happening. However, it was intended that a comparison of such data with these theoretical models would lead to an understanding of the processes affecting the movement of the various pollutants measured in the sewerage systems and combined sewer overflows.

4.4.1.2. The Relationship between the Inflow and the Spill Samples

Combined sewer overflows were originally designed to simply split the storm sewage in order to reduce the volume that went forward to treatment. The composition of the storm sewage that was discharged to the water course was thought to be the same as that which went forward to treatment. It was considered important only that the storm sewage was adequately diluted (often specified as six times the dry weather flow).

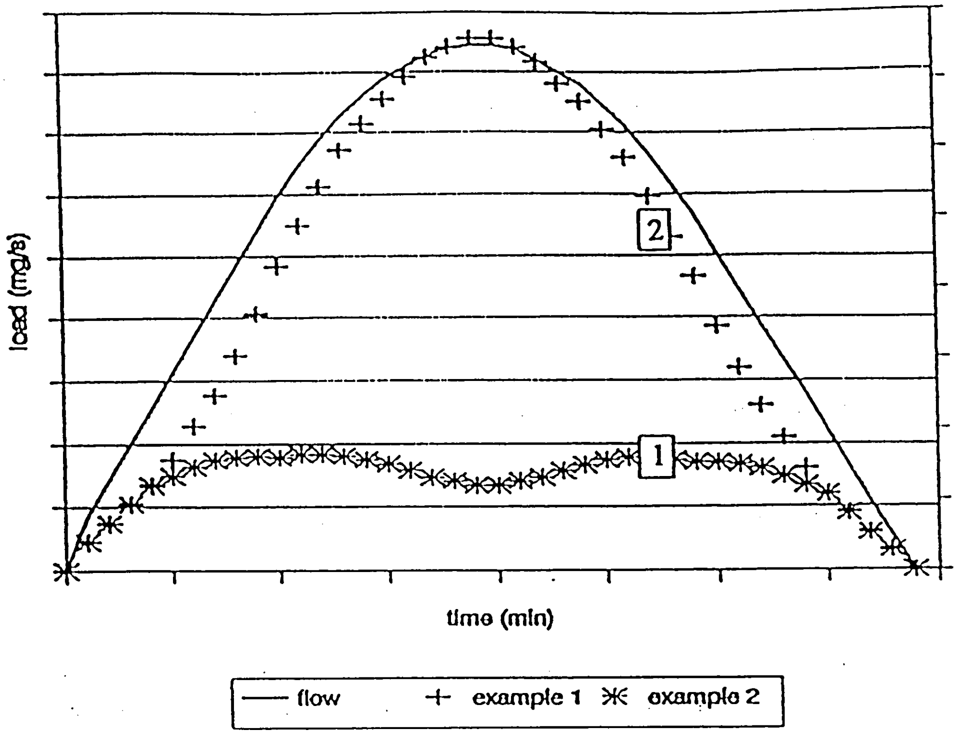


Figure 4.5 Theoretical Hydrograph Illustrating Possible Patterns for Sample Loads Plotted Against Time

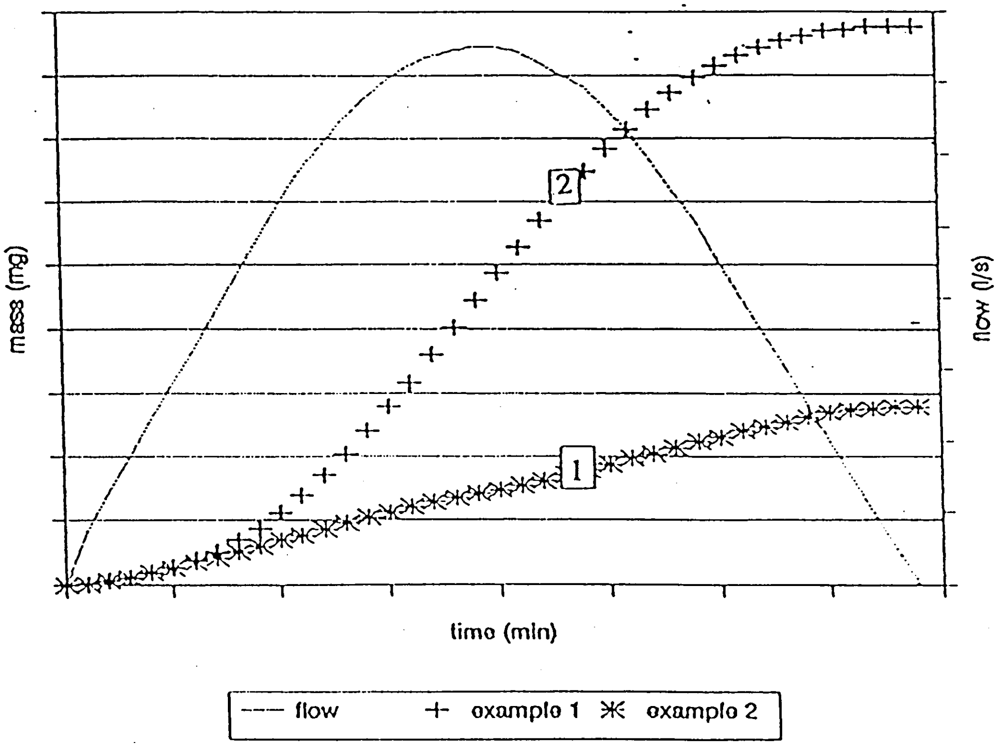


Figure 4.6 Theoretical Hydrograph Illustrating Possible Patterns of Cumulative Mass Plotted Against Time

As overflow design and the available technology became more sophisticated, the positioning of the weirs and the increase in the available storage volume of the new overflow designs led to claims that some were able to concentrate the major portion of the pollutant material in the flow that was going forward to treatment so that what was discharged to the water course was of a less damaging nature to this environment than that which was passed forward to treatment. One of the primary aims of this study is to determine whether the combined sewer overflows investigated do have any significant effect in treating the storm sewage passing through them or whether an apparent difference can simply be explained by the flow split.

This was initially investigated using unpaired t-test analysis to determine whether there was a significant difference in the means of the inflow sample parameters and the spill sample parameters for the same period of time (assuming that the lag time between the inflow and the spill samplers is less than the sampling period of five minutes) during a given storm. The F-test was used before the t-test to see whether the variances of the two populations were equal. A full description of these tests can be found in most statistics textbooks (e.g. Wardlaw, 1985; Clarke, 1980).

If the chamber design in some way enabled the majority of the polluting material to be transported forward to treatment the means of the concentrations for the parameters measured should be significantly less for the spill flow samples than for the inflow samples. If it was found that there was a negligible difference in the concentration means for the parameters measured then this would suggest that the design of the chamber had no beneficial effect in reducing the load of material that will be carried to the water course. It was likely that the parameters measured do not all act uniformly i.e. a beneficial effect might have been demonstrable for one parameter but not for another. The aim of this analysis was to determine whether the inflow samples and the spill samples were of the same composition for the parameters that were being measured and thus to determine whether apparent differences could simply be explained by the flow split.

Total loads for the inflow and spill samples were also calculated for all of the storms with adequate sample data. The dry weather flow contribution to the total load was estimated and subtracted from these totals in order to give a 'storm load' value i.e. a value which represents the load of material brought in during the storm and not including what was brought in the dry weather flow.

As the concentration of the parameters measured during the dry weather flow varied considerably during the day dry weather loads were calculated to allow for this. Hourly samples were taken during dry weather over one or more 24-hour periods. A concentration value for each parameter was then determined for each hour. As storm samples were taken at five minute intervals it was desirable to also estimate the dry weather flow concentrations in five minute intervals. This was done by dividing the difference between the hourly concentration values by twelve and sequentially adding the result to the earlier hour for each of the twelve five minute periods in the hour. This was repeated for each hour of the day.

Measurements of flow were taken every two minutes during the study period so flow values could be obtained for the periods of dry weather flow sampling. The dry weather loads could thus be obtained by simply multiplying the concentration estimated value for a given five minute period during the day by the flow at that point in the day. and then by five to give the load for the whole five minute period. (This was then multiplied by 60 to get load coming in one minute and then by 5 to obtain the load for the five minute sampling period.)

The estimated dry weather flow loads were then calculated for the same time of day and duration as a given storm. The results were then subtracted from the total load calculated for the storm to give the 'storm load'. An investigation into the contribution of the dry weather sewage to the total load was also made and the influence of various factors was examined i.e. the antecedent dry weather period (defined as the greatest time between periods of filling, although not necessarily causing spill, Jeffries, 1992), the duration of the storm, the depth of the rain, the volume of flow and the peak and the average rainfall intensities.

It might be supposed that the longer the antecedent dry weather period the smaller the contribution of the dry weather sewage will be. This was implied by experiments e.g. by Lindholm, 1984 and Malmqvist, 1982. Their work suggested that during dry weather deposits build up in sewer pipes and on the road, roofs and other structures, which are picked up and washed away by the impact of the rain on the roads and roofs and the storm wave in the sewer pipes. The longer the period of antecedent dry weather the longer there is for deposits to build up. Similar suppositions can be made for the other factors investigated e.g. a storm with a larger volume of inflow might be expected to produce a greater storm load than a storm with a smaller volume of inflow.

It can be seen from what has previously been written that the dry weather flow is thought to deposit some material during periods of dry weather. For the purposes of this report these deposits are considered to be of 'storm origin' as they are washed down only by the extra volume of flow that is present during storm conditions.

4.4.1.3. Correlation Between Sample Parameters

The sewage samples that were taken were analysed for seven water quality parameters: suspended solids, ash, biochemical oxygen demand (BOD), chemical oxygen demand (COD), pH, conductivity and ammonia. Some of these parameters can be analysed using relatively quick and simple techniques but others require more rigorous procedures, especially the BOD test which needs five days before results can be determined.

If significant and consistent correlation between one or more of these parameters were demonstrated then the number of tests that would routinely have to be performed could be reduced. This would be particularly advantageous if one of these strong correlations involved a parameter that was easy to measure with one that was difficult to measure. The samples would not then have to measured for the difficult test as the results could be implied from the other parameter.

This situation would seem very desirable as it could save a great deal of analysis time and money. However, the degree of correlation would have to be extremely high and consistent on a diurnal and seasonal basis and for all concentrations, for this to be realistic. For example, there might be a good correlation between BOD and suspended solids and this might lead to the suggestion that BOD values should no longer be measured but could be implied from the results of the suspended solids analysis. This should be done with great caution if the correlation is not extremely consistent and strong (an allowable error could be estimated for each of the parameters), as although this could be accurate in the majority of the cases in some the values could be extremely misleading. This could lead to serious consequences for a parameter such as BOD which is used to determine the amount of oxygen that would be required to degrade a given substance. If the BOD value was significantly underestimated a highly polluting material could be mistaken for a harmless one and discharged to a water course causing considerable damage to the biotic environment.

Relationships between the different parameter values were first investigated graphically. A graph of the concentrations of all the samples of one parameter was plotted against all the concentrations of the samples of a second parameter (e.g. suspended solid concentration would be on the y-axis and ash concentration along the x-axis). Any trend in the pattern of the points could then be clearly seen and, if present, suggested that there might be a significant correlation between the two sets of parameter concentrations. Examples of this are given in Chapter 5.

These relationships were further investigated using correlation and regression analysis. Correlation analysis was used to determine the degree of association between two parameter values. Regression analysis was used to describe the association of the two sets of parameter concentrations including the shape of the relationship i.e. whether it was linear or curved. A full description of these tests can be found in most statistics text books.

Multiple regression was also used as this is a regression with two or more predictors i.e. the sample concentrations of six of the parameters was regressed with the sample concentrations of the seventh parameter. From this, the dependence of the seventh parameter on the other six could be described in the form of an equation.

4.4.2 Gross Solids

Estimates of the efficiency of the different overflow chambers in terms of the ability of the overflow to retain gross solids in the flow to treatment were made using the overflow performance terms (Green, 1991).

$$\text{Total Efficiency} = \frac{\text{Total Storm Load Retained}}{\text{Total Storm Inflow Load}}$$

$$\text{Flow Split} = \frac{\text{Total StormVolume Retained}}{\text{Total Storm Inflow Volume}}$$

Total efficiency is defined as "the overall performance of the overflow and the storage associated with it". Once the total efficiency and the volume ratio for a storm have been calculated the "treatment factor" of the overflow for each storm can be derived where:

$$\text{Treatment Factor} = \frac{\text{Total Efficiency}}{\text{Flow Split}}$$

The treatment factor allows the quality performance of an overflow to be assessed and the results for different combined sewer overflow systems to be compared. If the resultant value is greater than 1.0 some sort of treatment effect on the spilled flow is thought to have taken place (e.g. a settling of solids so that the concentration in the spill flow is less than that in the inflow). If the value is equal to 1.0 no treatment occurs and the apparent difference in loads between the spill and the inflow is due, solely to the flow split occurring during the storm event. If the value is less than 1.0 the spill contains a larger load than would be predicted purely by the flow split i.e. the spill flow is more concentrated than the inflow for the particular parameter being investigated. In this case. the overflow is having an adverse effect by concentrating the pollutant load in the spill flow. The "load" referred to here was the mass of the gross solids or a particular category of gross solid that was estimated from the mass that was captured in the mesh bag

The efficiency, volume ratio and treatment effect values were determined for each of the sites for gross solids. The efficiencies and treatment factors were also calculated for specific categories of gross solid materials (e.g. sanitary towels, leaves etc.). The latter was undertaken to investigate whether the overflows (or screens, at the stilling pond site) were any more effective at preventing the passage of one type of material than another.

The antecedent dry weather period (A.D.W.P) was calculated for each of the storms being investigated. The average and peak intensity of each storm as well as the antecedent storm was also determined. The length of the A.D.W.P. is thought to affect the pollutional strength of the "first foul flush". Both A.D.W.P. and storm intensity affect the volume of runoff and infiltration occurring during a storm event. The delay time (defined as the average delay between the time at which the storm first entered the chamber and the time to first spill, Saul & Thornton, 1989) was also calculated for each storm.

An investigation into the composition of the gross solid material collected in the mesh bags was undertaken. The material captured during a storm event was sorted into eight different categories (faeces, sanitary towels & tampons, leaves and twigs, thick paper towels, miscellaneous plastic, miscellaneous absorbent material, miscellaneous non-absorbent material, material adhering to the mesh bag (mostly toilet tissue)). Comparisons of the proportions of the different gross solid categories at the different sites could thus be made to see whether a given site could be classified by the sewage type. A comparison between the range of values obtained during dry weather flow sampling and the range obtained during storm events was also made. The aim of this being to determine whether the highest concentrations occurred during dry weather or storm conditions.

5. RESULTS

A. HYDRAULIC ANALYSIS

5.1 Blocking Tests

The results of the blocking tests at Chesterfield Road, Dobcroft Road and Leyburn Road are given graphically in Figures 5.1 to 5.6.

5.1.1 Stilling Pond Site (Chesterfield Road)

Three attempts at the blocking test were undertaken at this site. The first was unsuccessful as the board used to cover the continuation pipe produced an inadequate seal. In the second blocking test the time interval between depth readings was too large and insufficient depth readings were obtained. The final test was successful. It took 59 minutes for the chamber to fill in both the second and the third blocking tests.

Figure 5.1 illustrates the time-depth relationship for the stilling pond. It can be seen that the measured values did not produce a smooth relationship between depth and time. This caused a significant variation in the gradient of the curve from which the rate of change of storage could be calculated. Even with curve smoothing the errors were significant. To avoid this problem the time for emptying for a theoretical depth-discharge relationship was calculated using Equation 4.2 where Qout is determined from Equation 4.13. The discharge coefficient was then adjusted until a fit to the depth-time curve was achieved.

For the curve illustrated in Figure 5.1 the ratio of velocities (C) was taken as 0.74. Rough turbulent flow was assumed and the value of k_s was taken as 1.5mm.

Figure 5.2 illustrates how the downstream depth varied as the upstream depth increased during the final blocking test. As a vortex was formed in this downstream chamber no values of depth were taken during storm events. It was thus very important to determine this relationship as accurately as possible during the blocking test. From Figure 5.2 it can be seen that the relationship fluctuates. Despite this, as there was no other information that could be used, a straight line through these values was used as an estimate of the relationship.

The assumed relationship was taken as:

$$H_{down} = 0.53H_{up} - 124$$

5.1.2 High Side Weir (Dobcroft Road)

Two blocking tests were undertaken during the survey at Dobcroft Road. Figures 5.3 and 5.4 illustrate the results of these tests on the 4 December 1991 and 26 February 1992 respectively. It took 195 and 125 minutes respectively to fill the overflow chamber to weir level. The same procedure of fitting a theoretical depth-discharge relationship was undertaken and these are also illustrated on the figures. Figure 5.5 illustrates the problem with direct calculation of discharge using the depth-time relationship derived from the blocking test.

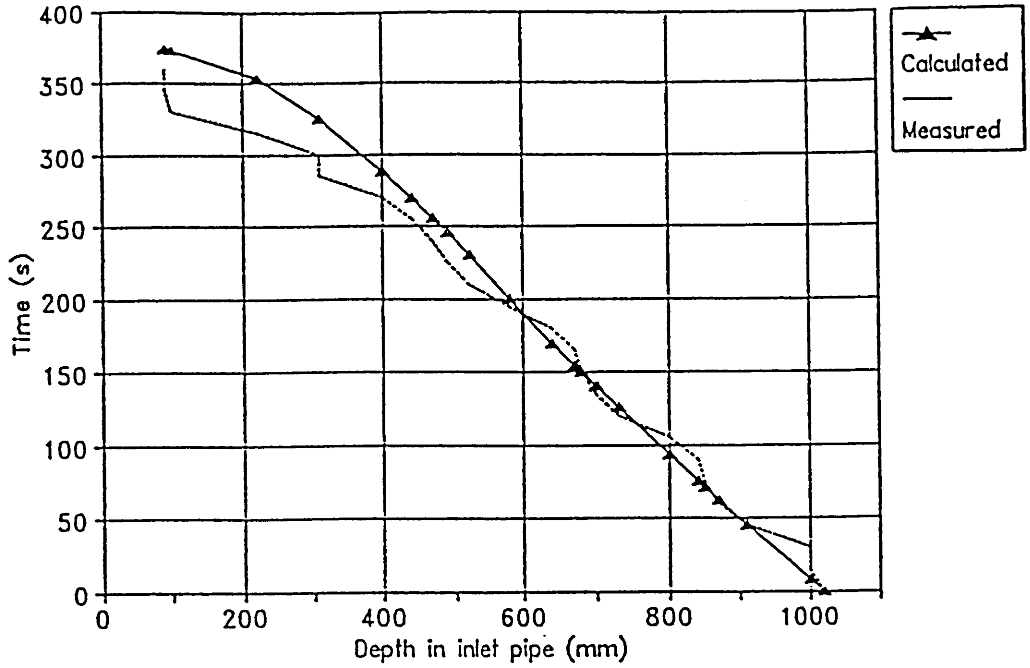


Figure 5.1 Depth/Time Graph for the Stilling Pond (Chesterfield Road) Blocking Test
k_s = 1.5 mm C= 0.74

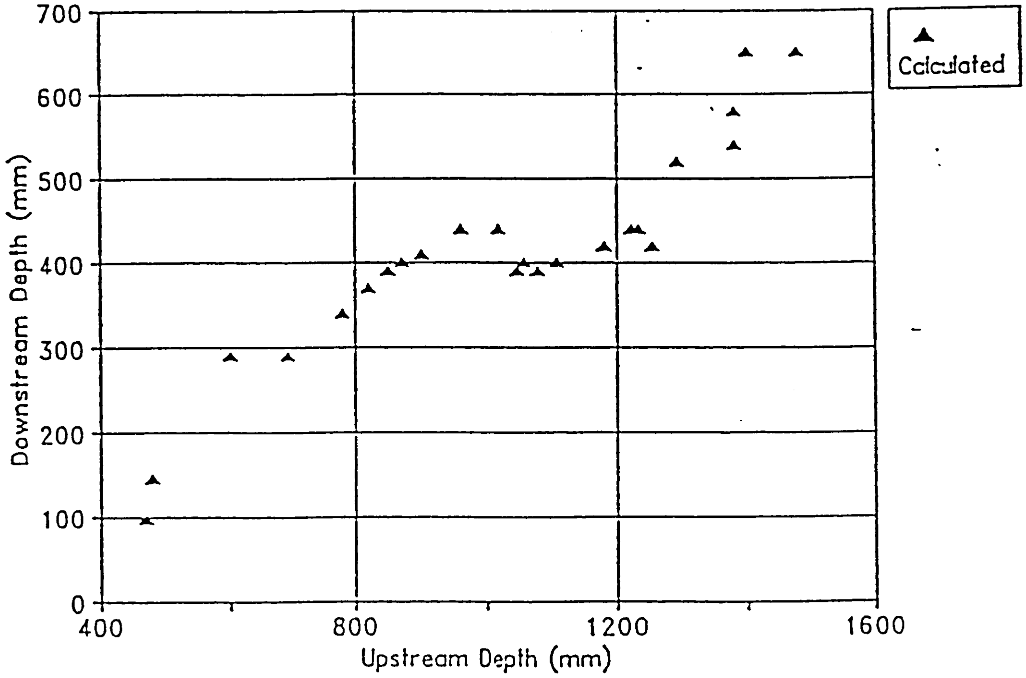


Figure 5.2 Relationship Between Depths Upstream and Downstream of the Overflow During the Stilling Pond Blocking Test

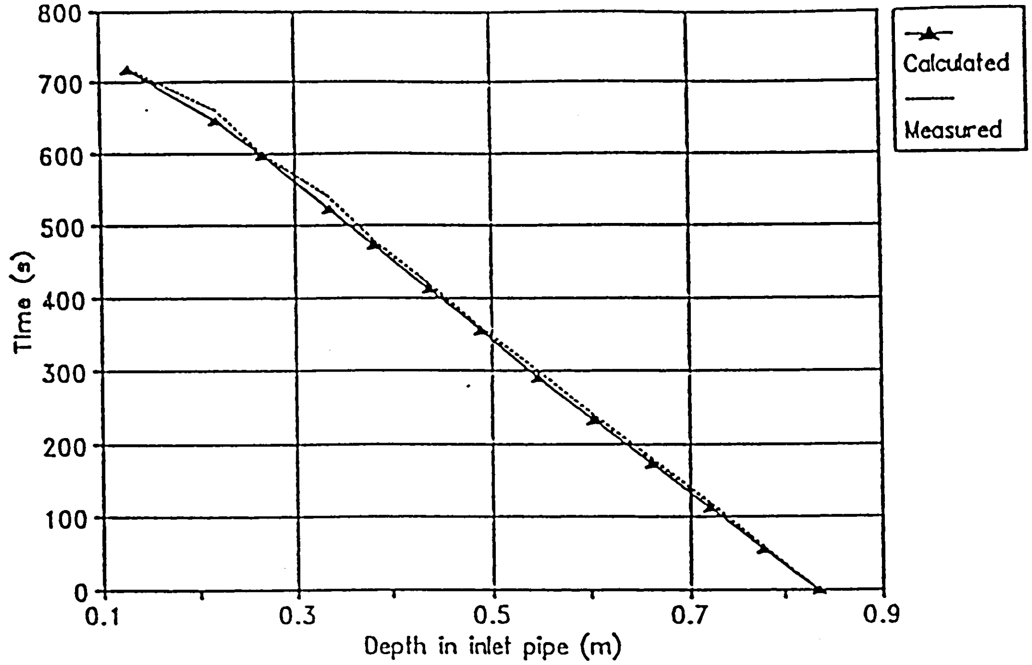


Figure 5.3 Depth /Time Graph for the High Side Weir (Dobcroft Road) Blocking Test on 4/12/91

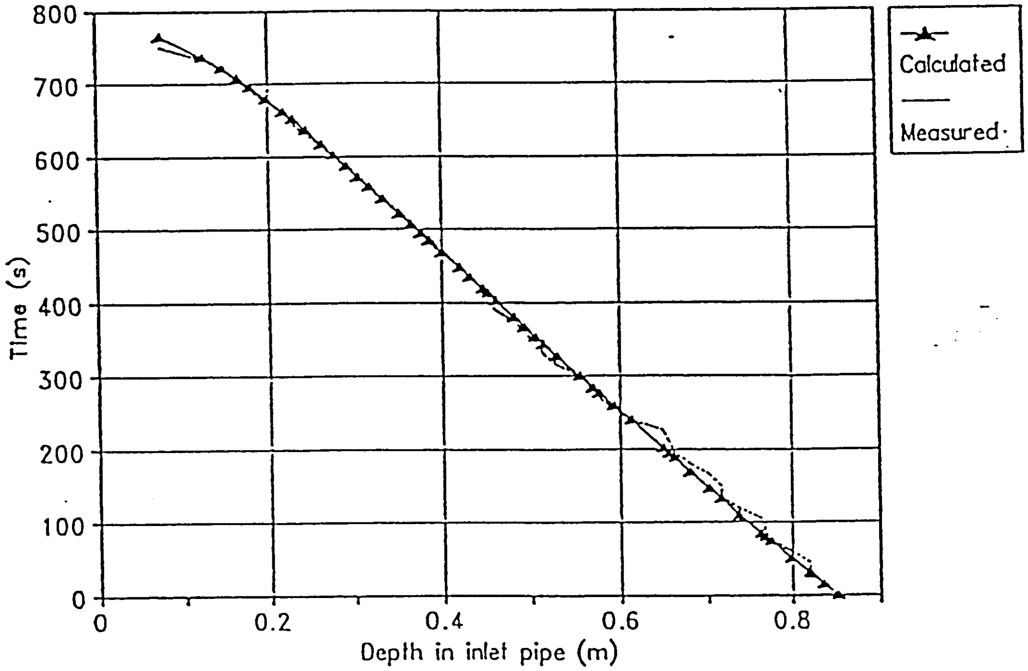


Figure 5.4 Depth / Time Graph for the High Side Weir (Dobcroft Road) Blocking Test on 26/2/92

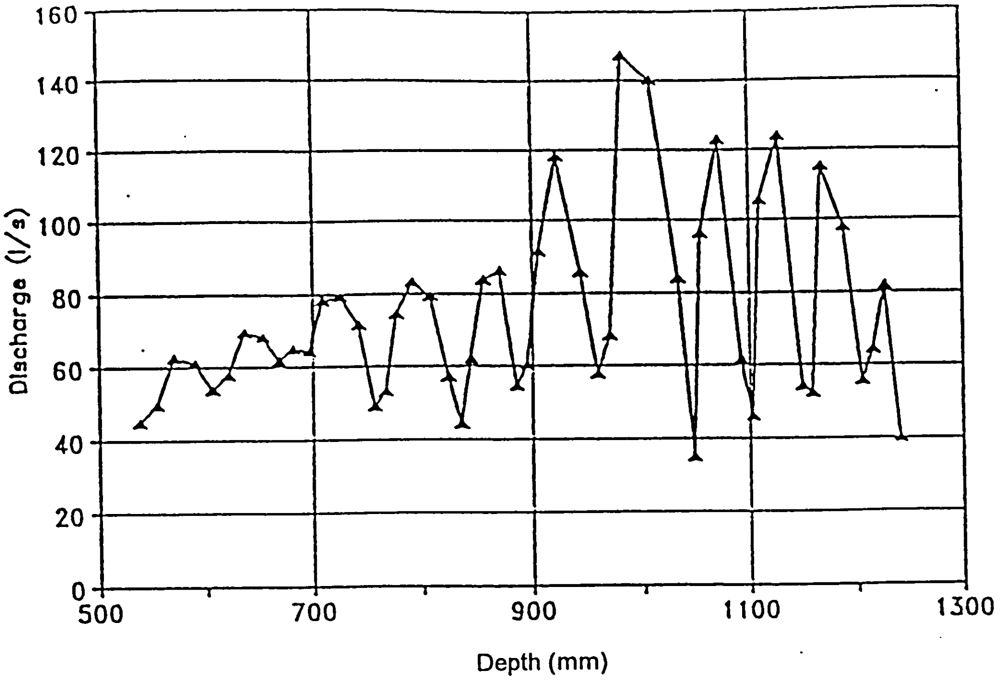


Figure 5.5 Calculation of the Discharge Using the Depth /Time from the Blocking Test at the High Side Weir Site (Dobcroft Road)

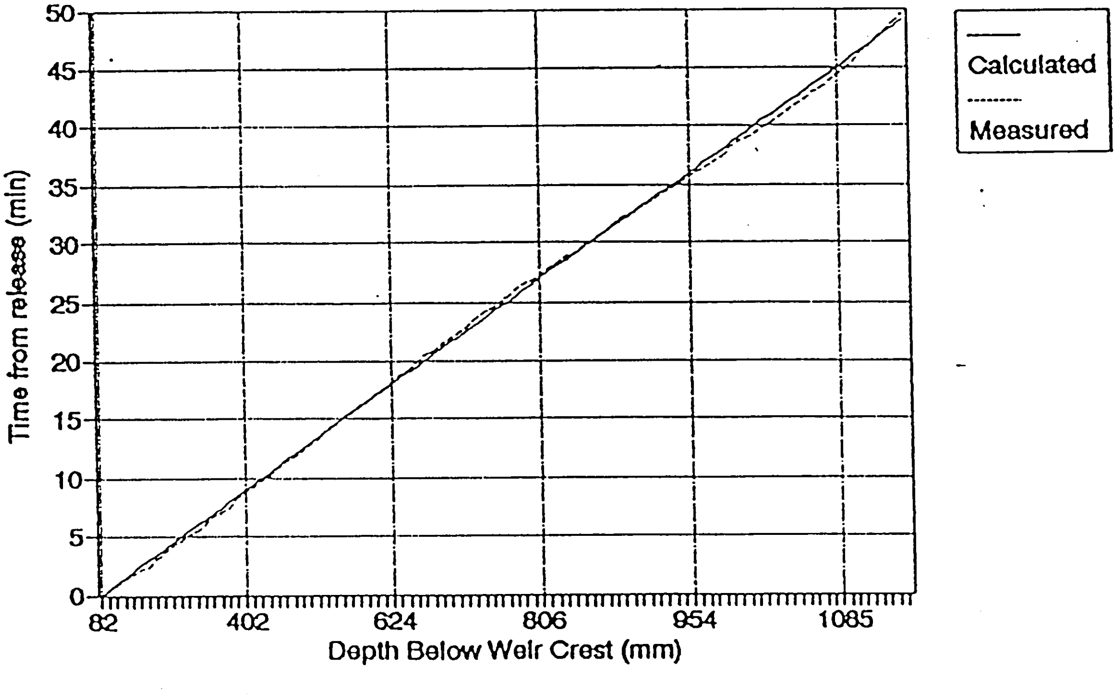


Figure 5.6 Depth/Time Graph for the High Side Weir (Leyburn Road) Blocking Test

5.1.3 High Side Weir (Leyburn Road)

Two blocking tests were undertaken at the Leyburn Road site (21 December 1992 and 23 March 1993). Both were successful and Figure 5.6 illustrates the results of the first test (the second test giving almost identical readings). It took just over one hour on each occasion to fill the chamber to the point of spill. The results of the tests were again used to fit a theoretical depth-discharge relationship (illustrated on the figures).

5.2 STILLING POND SITE (CHESTERFIELD ROAD)

5.2.1 Producing the Calibration

The hydrographs of two storms (27 February 1991 and 15 June 1991 respectively) showing the measured values of inflow and continuation flow are given in Figures 5.7 and 5.8. First spill occurs at approximately 249 l/s so it can be seen that for the measured values, even when there is no spill, Q_{in} does not equal Q_{out}. Some difference in the measured flows could be explained by storage in the overflow chamber but in this case the difference is greater than could be explained by storage indicating the need for an accurate calibration.

The depth-discharge relationship for the inflow pipe at discharges where there was no drowning of the sensor is illustrated in Figure 5.9. The discharge values for the continuation pipe are assumed to be equal to the inflow values up to this point. Figures 5.10 and 5.11 illustrate the relationship between the continuation pipe discharge and the inflow pipe depth for the rising and falling stages of the hydrographs respectively for the storms used in the calibration.

A graph illustrating the increase in storage for a given depth above the continuation invert is given in Figure 5.12. Using this information a calibration curve could be produced. The relationship between the continuation flow and the spill flow against inflow is illustrated in Figure 5.13. This indicates the inflow value at which first spill occurs (approximately 249 l/s at an inflow depth of 1460mm). The average dry weather flow for the Chesterfield Road site is approximately 10-12 l/s. The overflow thus appears to be set to spill at 21-25 x DWF. Some examples of how the calibration fits the measured data are given in Figures 5.14 to 5.18.

5.2.2 Comparison with Theoretical Discharge Equations

During dry weather flow and at the beginning of a storm the flow in the continuation pipe is free surface flow. A comparison of the critical (H_c) and normal depths (H_n) showed that the pipe has a steep slope (i.e. $H_c > H_n$). This is illustrated in Figure 5.19.

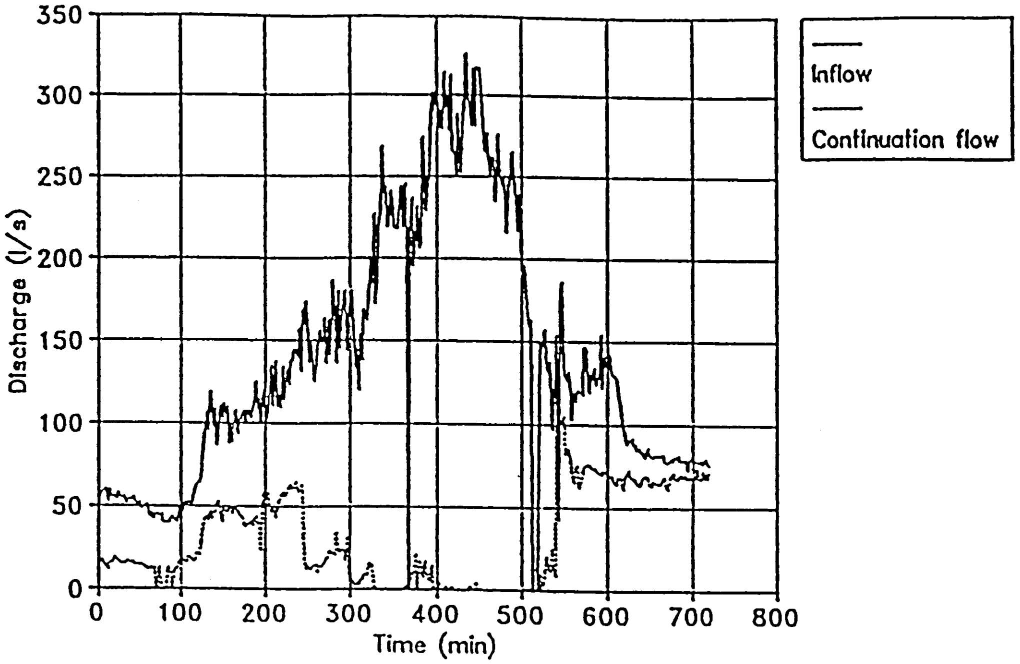


Figure 5.7 Measured Continuation and Inflow for Storm on 27/2/91 at the Stilling Pond Site

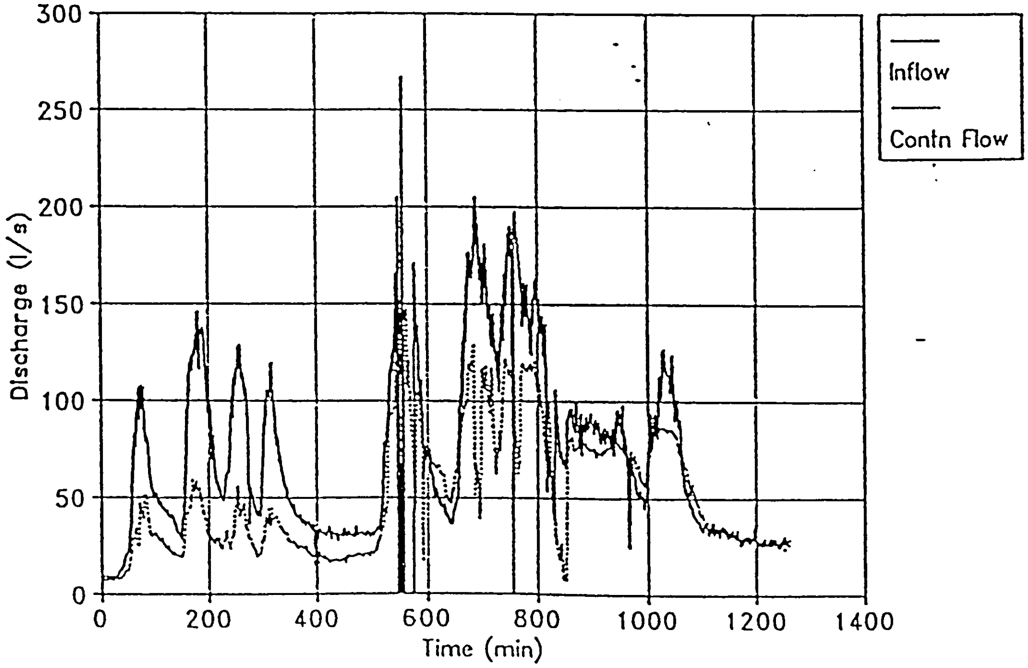


Figure 5.8 Measured Continuation and Inflow for Storm on 15/6/91 at the Stilling Pond Site

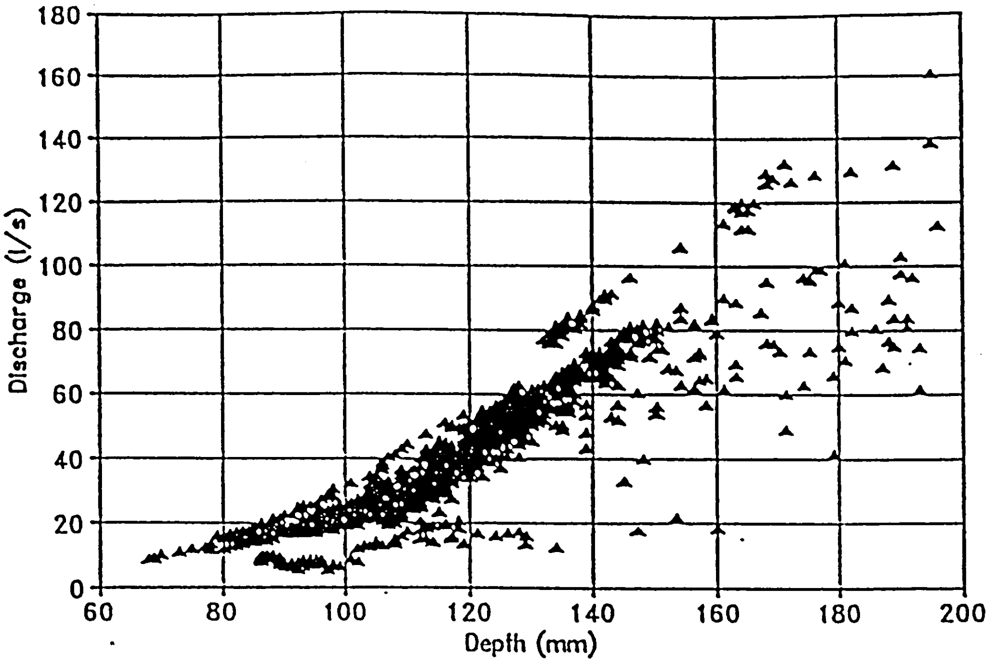


Figure 5.9 Depth-Discharge Relationship for the Inflow Pipe at Discharges with no Drowning of the Sensor (Stilling Pond Site)

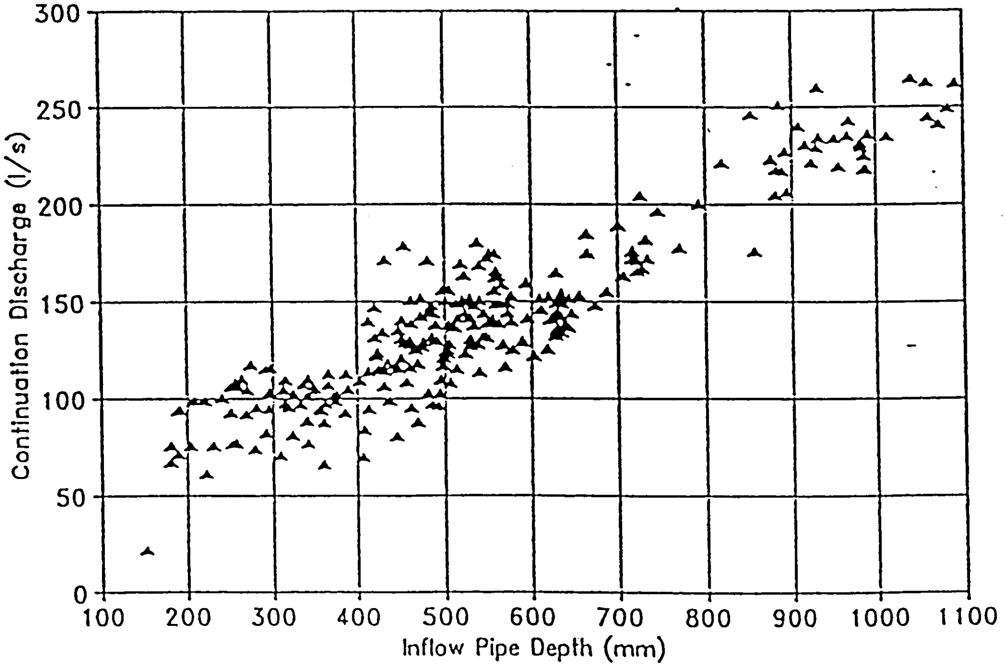


Figure 5.10 Inflow Pipe Depth Against Continuation Flow Discharge for the Rising Stage (Stilling Pond Site)

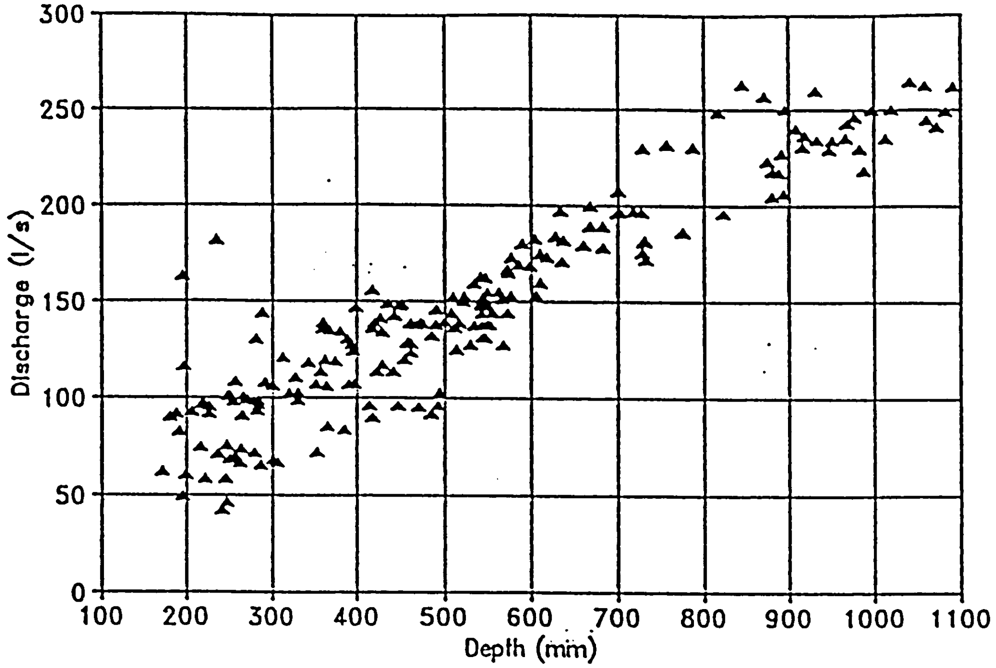


Figure 5.11 Inflow Pipe Depth Against Continuation Flow Discharge for the Falling Stage (Stilling Pond Site)

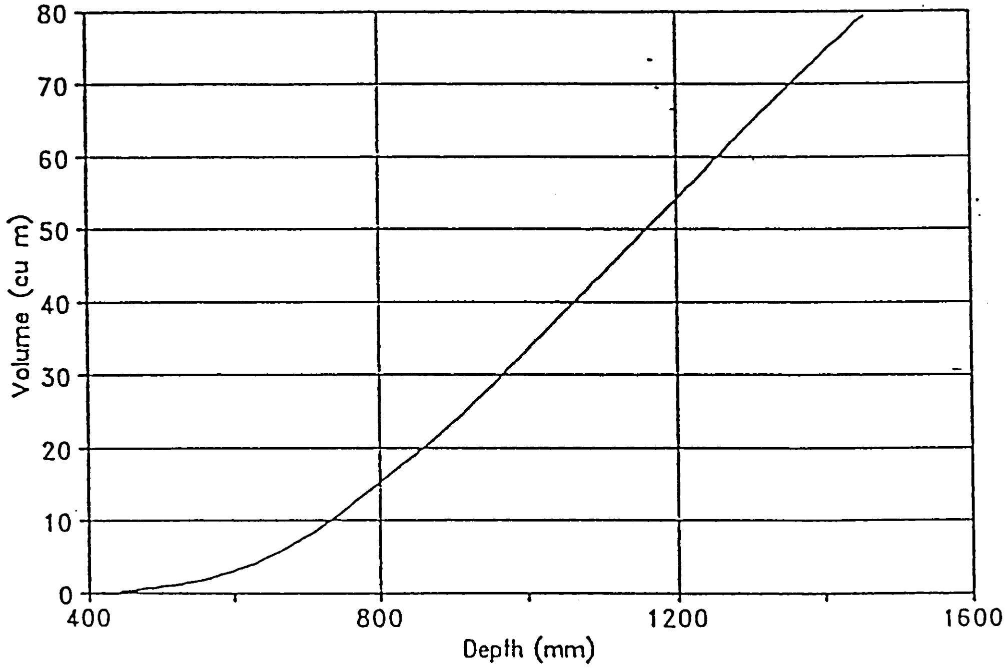


Figure 5.12 Stored Volumes Against Depth Above Continuation Invert at the Stilling Pond Site

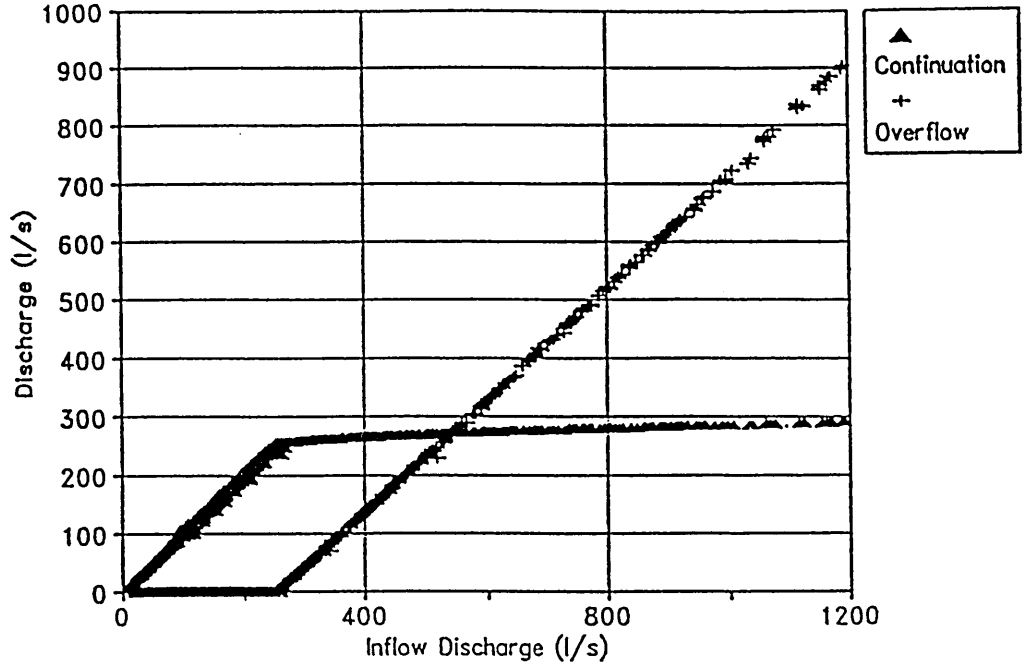


Figure 5.13 Continuation Flow and Overflow Discharge Against Inflow at the Stilling Pond Site

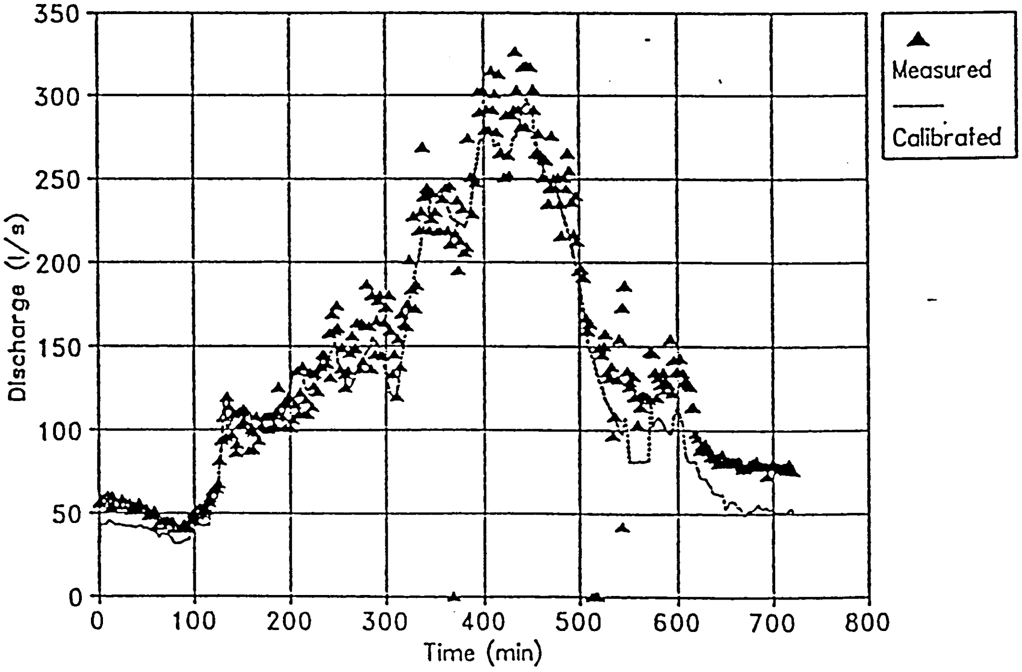


Figure 5.14 Comparison of the Measured and Calibrated Inflow for Storm on 27/2/91 at the Stilling Pond Site

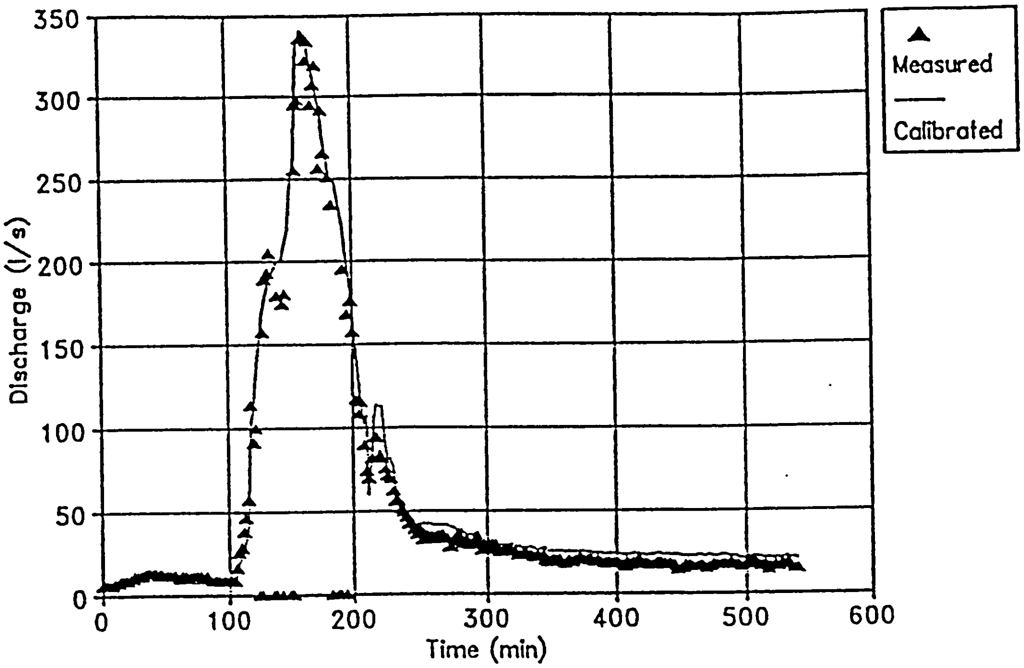


Figure 5.15 Comparison of the Measured and Calibrated Inflow for Storm on 25/6/91 at the Stilling Pond Site

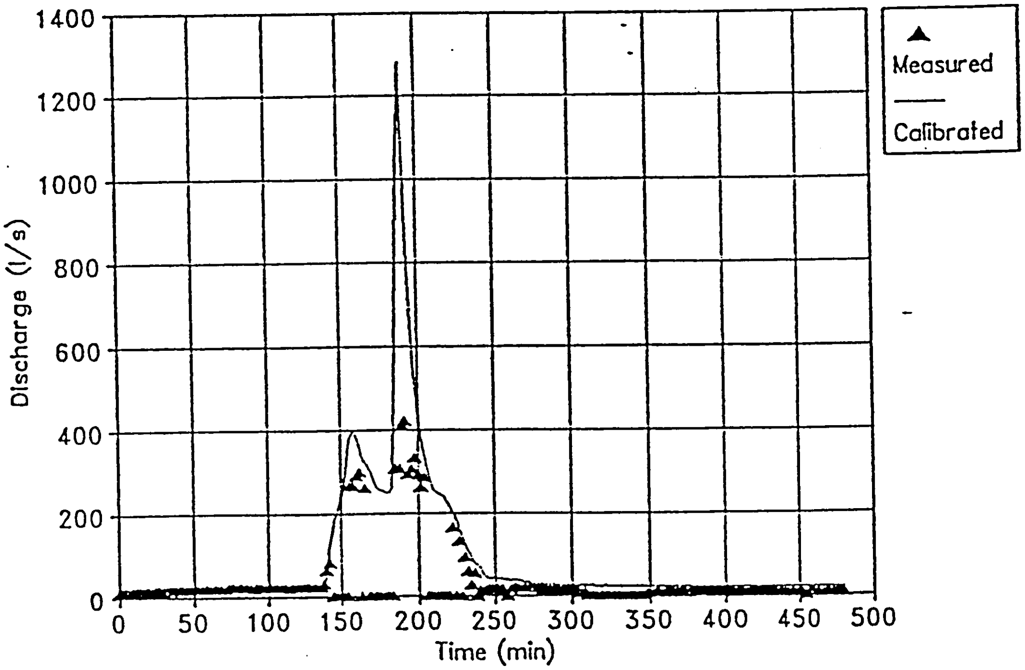


Figure 5.16 Comparison of the Measured and Calibrated Inflow for Storm on 13/6/91 at the Stilling Pond Site

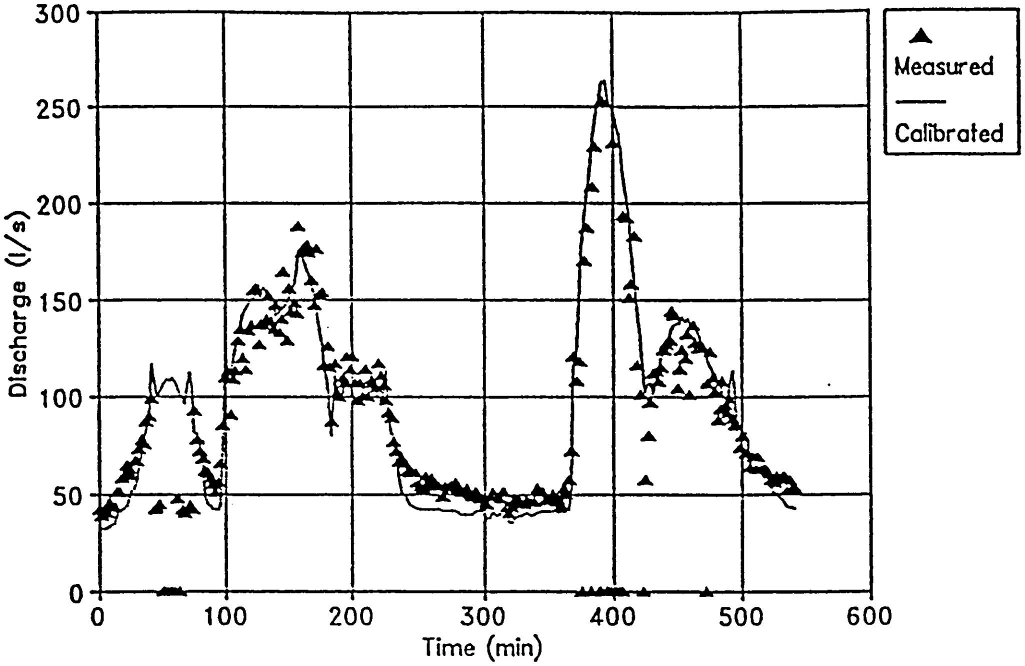


Figure 5.17 Comparison of the Measured and Calibrated Inflow for Storm on 20/3/91 at the Stilling Pond Site

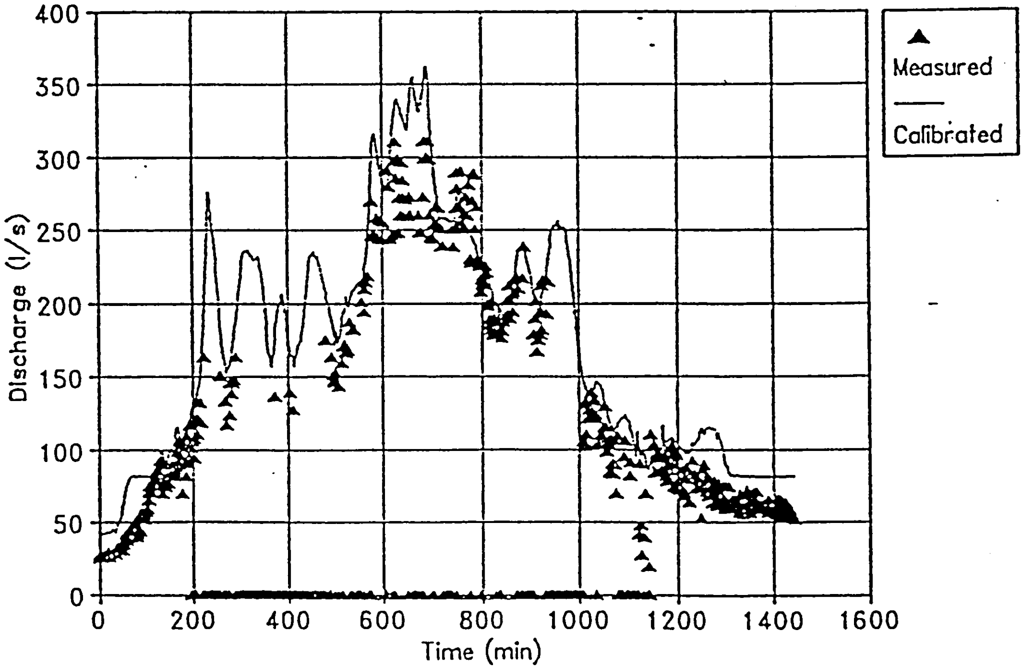


Figure 5.18 Comparison of the Measured and Calibrated Inflow for Storm on 24/9/91 at the Stilling Pond Site

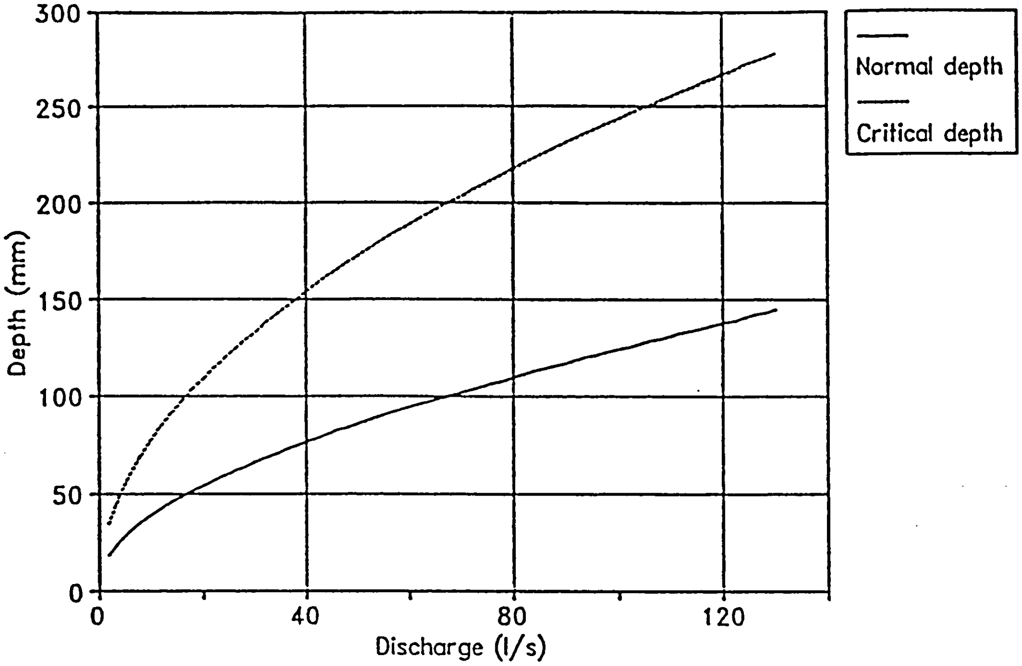


Figure 5.19 Normal and Critical Depths for the Continuation Pipe at the Stilling Pond Site

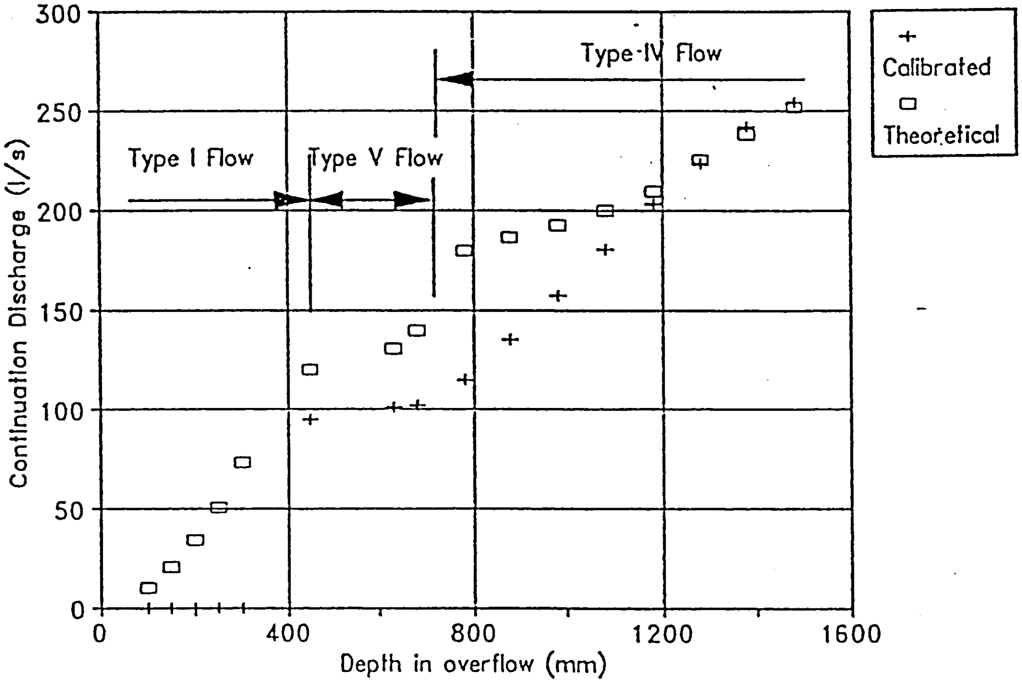


Figure 5.20 Depth-Discharge Graph For Calibrated and Theoretical Values Showing Flow Types

At the beginning of the storm the depth is unaffected by the transition from the dry weather flow channel in the chamber to the continuation pipe. As the level increases above half channel depth, however the transition becomes important causing subcritical flow in the chamber. Flow in the pipe is supercritical. Provided that the downstream depth remains below critical depth this will be Type I flow (Hager W.H., 1991). A description of the different flow types is given in Appendix 4.

At the point where the depth in the chamber backs up to the inflow monitor head the calculated discharge agrees with the measured value. As the depth increases beyond this point the flow will change to Type V flow provided that the upstream depth is below 1.5 times the pipe diameter, and the downstream depth remains below the critical depth. If the depth increases, the flow will change to Type IV flow with the continuation pipe running full. Type IV flow exists for all higher depths.

The different flow types described are given in Figure 5.20. This graph shows a comparison of the theoretical and calibrated depth-discharge curves. (The calibrated values are for the rising limb of the hydrograph). The apparent differences are mainly due to the differences between the assumed downstream depth (estimated from the values measured during the blocking test) and those occurring during storm conditions (which were not measured) when additional drowning of the downstream end of the pipe may occur.

The downstream depths could not be measured under storm conditions as there was no suitable position to install a flow monitor. It was thus very difficult to compare the recorded data with the theoretical equations. The best estimate of these values thus had to be used, determined from a linear relationship obtained from values measured during the blocking test.

As well as the downstream depth, the downstream velocities are also required. This cannot be easily calculated due to a vortex that was observed to form in the small chamber beyond the screens. Velocity values thus had to be determined from a "best fit" to the blocking test results.

5.3 HIGH SIDE WEIR (DOBCROFT ROAD)

5.3.1. Producing the Calibration

Depth and velocity check measurements for the inflow monitor were made during site visits. Figure 5.21 shows the depth offsets. It appears that the second value is excessively low and, although there is no clear explanation for such a value it is thought to be spurious. The calibrated velocities were unreliable due to the low depths of the dry weather flows when they were taken.

Although the site measured values showed an average of approximately 30mm difference at low depths, comparison of depth measurement with the Arx monitor installed in the main chamber, and with the scale read values obtained during the blocking tests indicated a much smaller difference at the higher depths. Low flow values were modified to take these measured values into account.

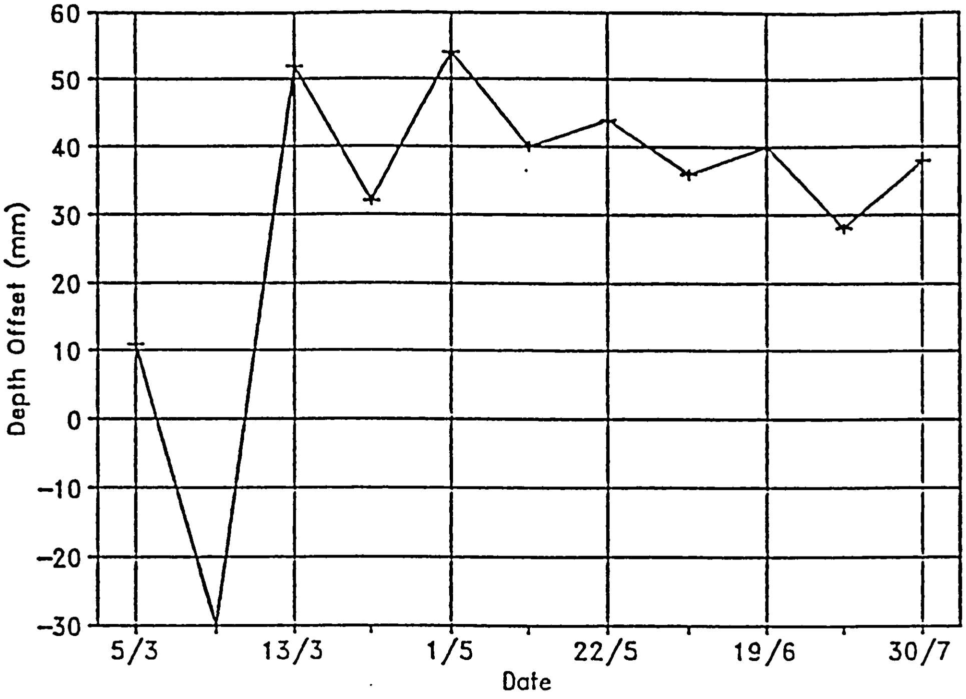


Figure 5.21 Depth Offset for the Inflow Monitor at the High Side Weir Site (Dobcroft Road).

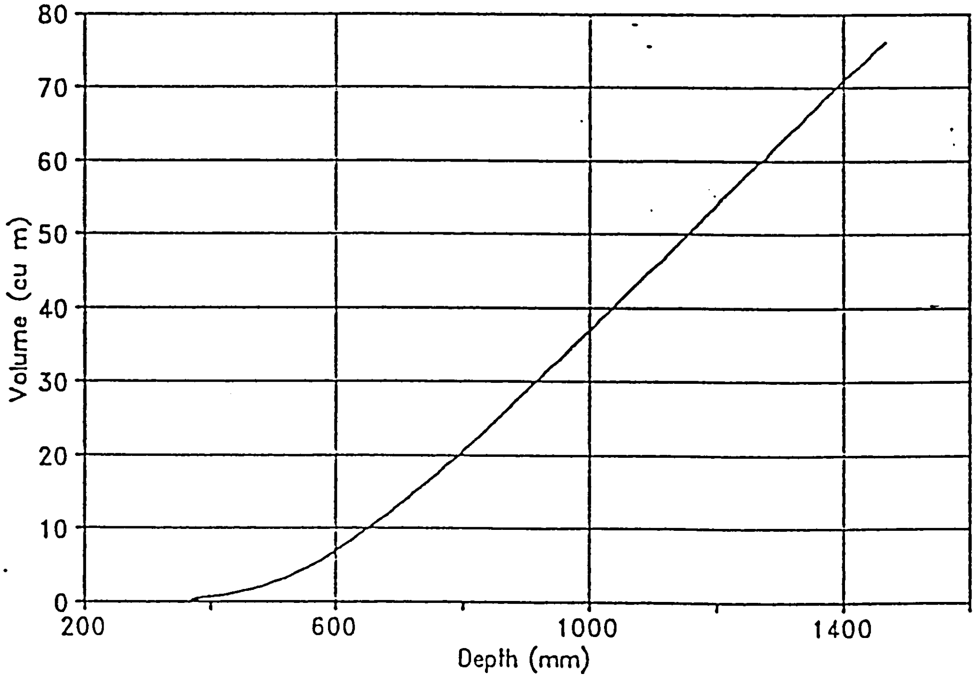


Figure 5.22 Stored Volumes Against Depth Above Continuation Invert at the High Side Weir Site (Dobcroft Road)

The stored volumes in the overflow chamber and upstream pipe in relation to the depth above the continuation invert are shown in Figure 5.22. Figure 5.23 illustrates the relationship between the overflow discharge and the inlet pipe depth, indicating the variation in inlet pipe depth at which spill occurs. From the blocking test this depth was found to be 1073mm for the lowest part of the weir and 1078mm for the end weir.

The relationship between continuation flow and spill flow against inflow is presented in Figure 5.24. From this the inflow discharge at which first spill occurs can be seen (approximately 113 l/s). The average dry weather flow for the Dobcroft Road site is approximately 15 l/s. Thus the overflow is set to spill at approximately 7.5 x DWF.

Measured values of inflow are very irregular at high flows and cannot be considered to be reliable. Figures 5.25 to 5.28 show a good fit between the calibrated and measured data whilst Figures 5.29 to 5.32 show fits which are poor at high discharge. Some discrepancies can be expected. The addition of measured weir flows does not give precise magnitudes due to storage in the overflow channel before flow reaches the monitor, which causes attenuation of discharge.

5.3.2. Comparison of Measured and Calculated Hydrographs

Figure 5.31 shows that the continuation pipe has a steep slope ($h_c > h_n$). As flow in the chamber is subcritical the discharge in the pipe is initially controlled by critical depth near the entrance (Type I flow). The pipe begins to run full at a discharge of about 64 l/s and the flow changes to Type IV. When the water levels reach the crest of the weir the continuation discharge is 113 l/s.

5.4 LOW SIDE WEIR SITE (RETFORD ROAD)

Examination of raw data showed that the sum of discharges for the continuation flow and overflow were generally lower than the inflow discharges for the corresponding times.

Examination of the depths and velocities measured during the site calibration of the instrumentation for the inflow and continuation flow are shown in Figures 5.34 to 5.37. These show that depths in the inflow were consistent but that the velocities were more irregular. This is largely due to the depths being below the values at which the monitor can be expected to be reliable. Depths for the continuation flow were much more variable. Site depths were used to calibrate the continuation flow hydrograph. The overflow monitor could not be calibrated *in situ* but calibration in the laboratory showed that the depth was underestimated by an average of 33.3mm. This was allowed for in determining the depth and discharge hydrographs.

Of the three monitors the continuation monitor was most likely to give inconsistent results. The monitor had to be positioned at the upstream end of the pipe. It was therefore affected by the disturbance to the velocity caused by the weir and by the upstream mesh bag. In some cases a hydraulic jump formed part way along the weir.

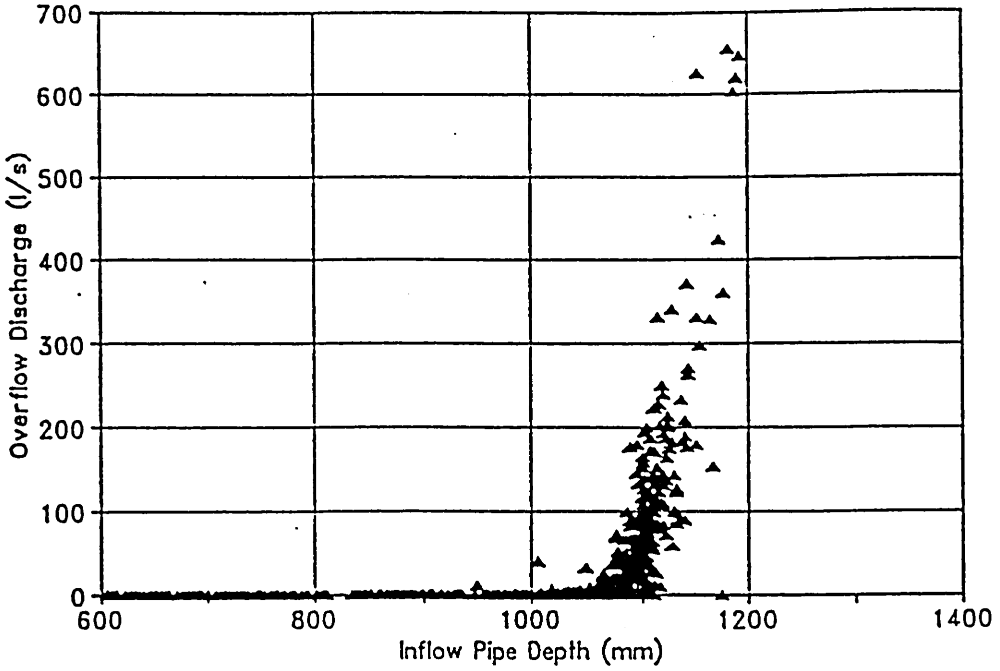


Figure 5.23 Overflow Discharge Against Inlet Pipe Depth at the High Side Weir Site (Dobcroft Road)

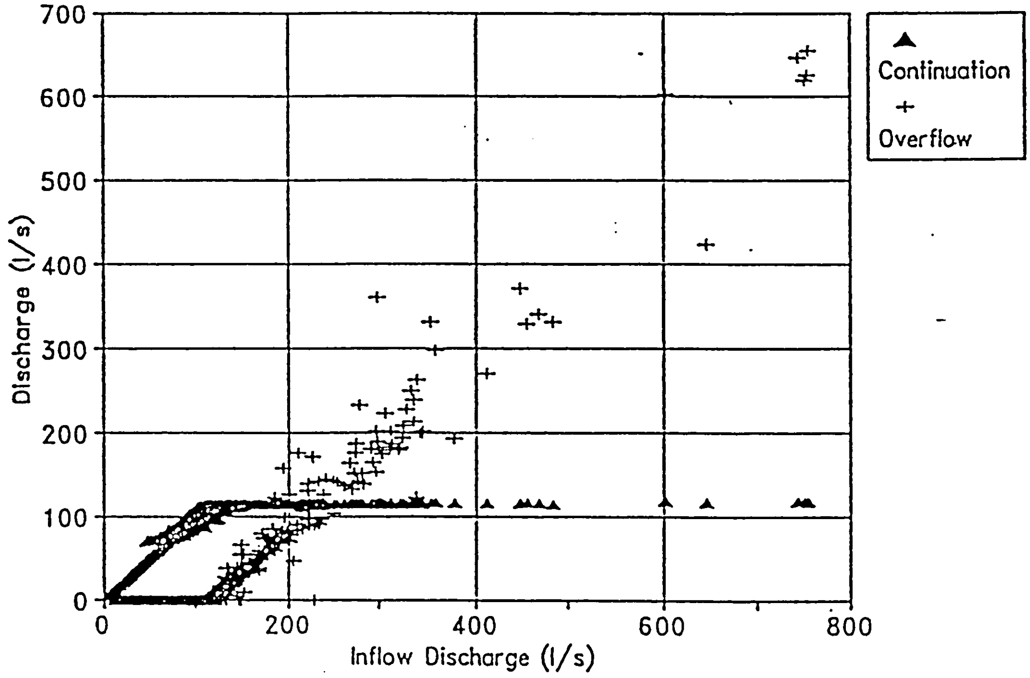


Figure 5.24 Continuation Flow and Overflow Discharge Against Inflow at the High Side Weir Site (Dobcroft Road)

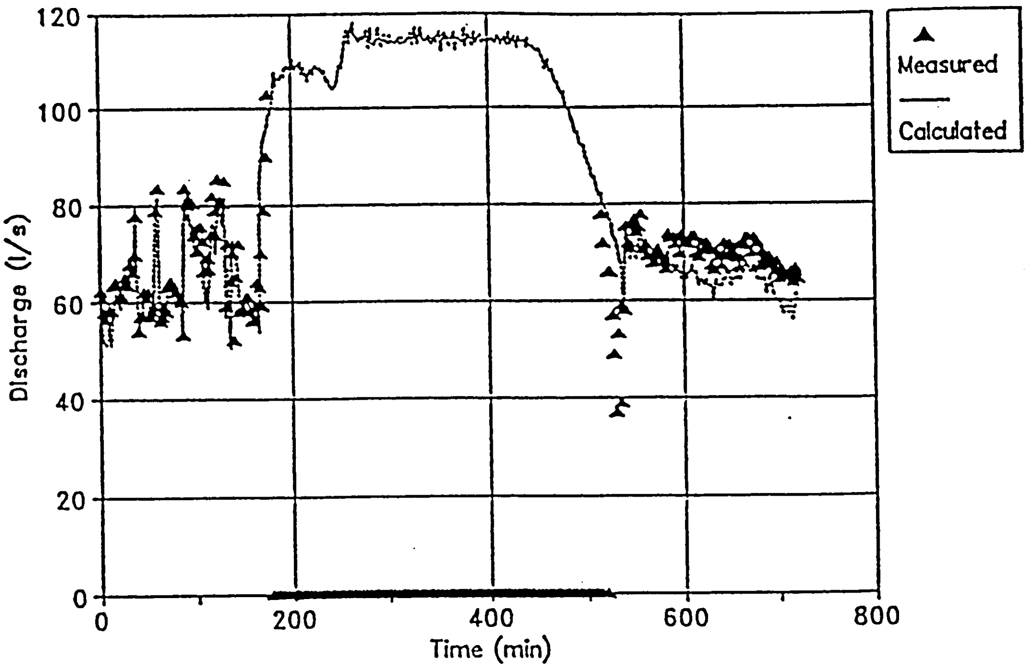


Figure 5.25 Comparison of the Measured and Calculated Discharges for the Storm on the 27/2/91 at the High Side Weir Site (Dobcroft Road)

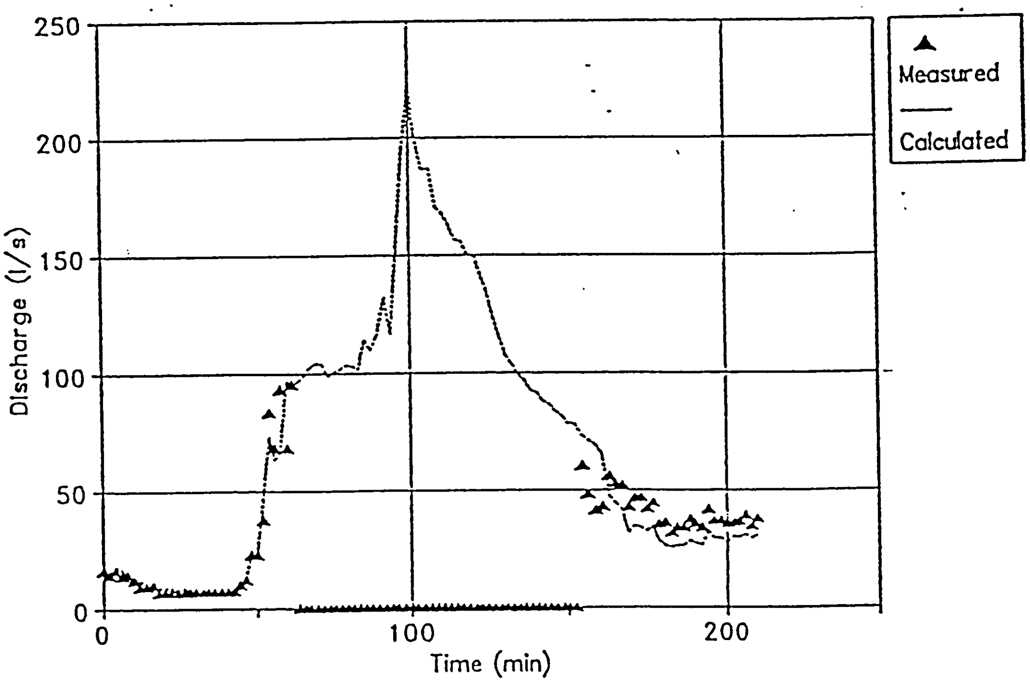


Figure 5.26 Comparison of the Measured and Calculated Discharges for the Storm on the 25/6/91at the High Side Weir Site (Dobcroft Road)

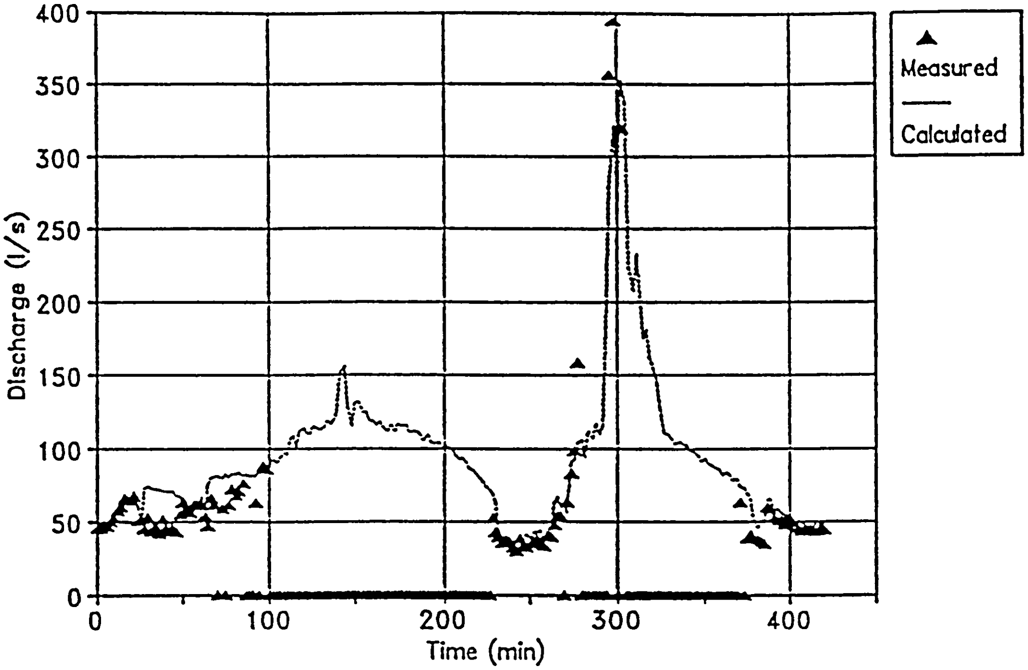


Figure 5.27 Comparison of the Measured and Calculated Discharges for the Storm on the 29/10/91at the High Side Weir Site (Dobcroft Road)

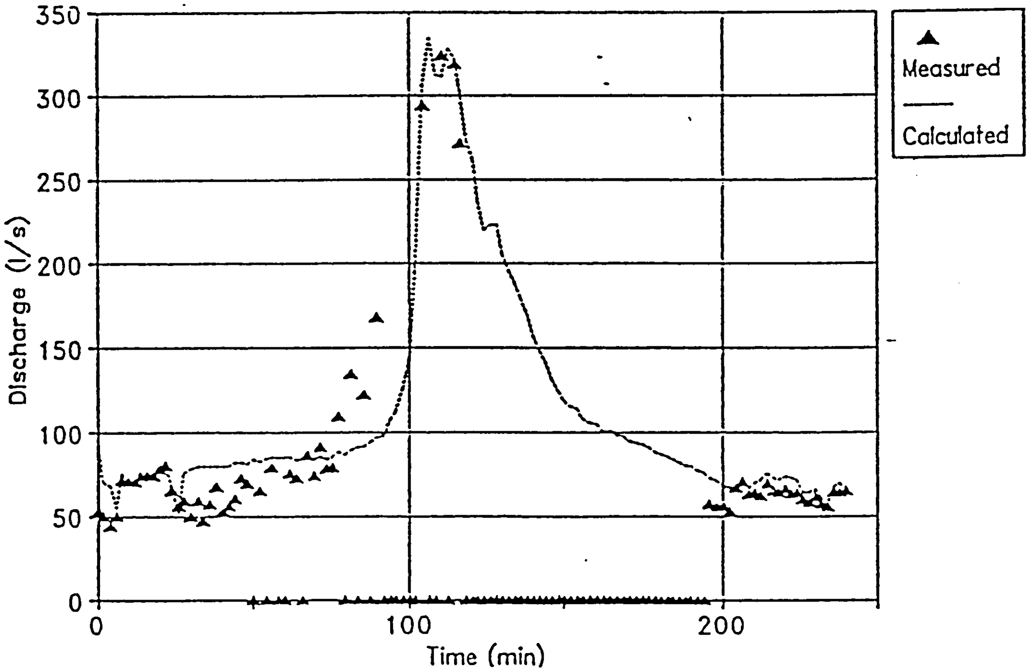


Figure 5.28 Comparison of the Measured and Calculated Discharges for the Storm on the 11/11/91at the High Side Weir Site (Dobcroft Road)

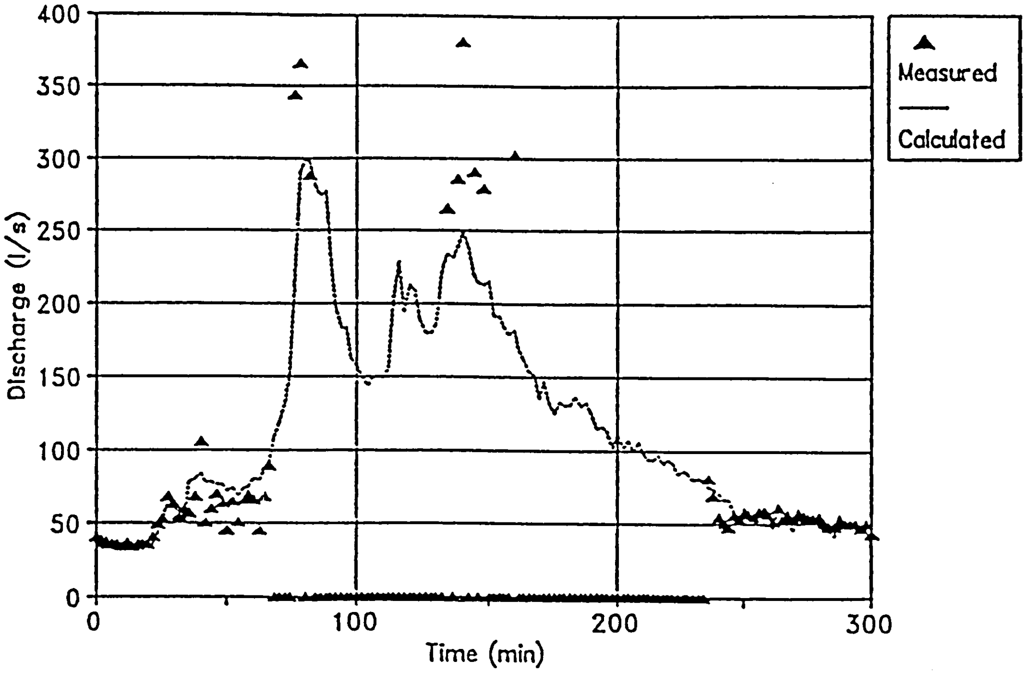


Figure 5.29 Comparison of the Measured and Calculated Discharges for the Storm on the 17/10/91at the High Side Weir Site (Dobcroft Road)

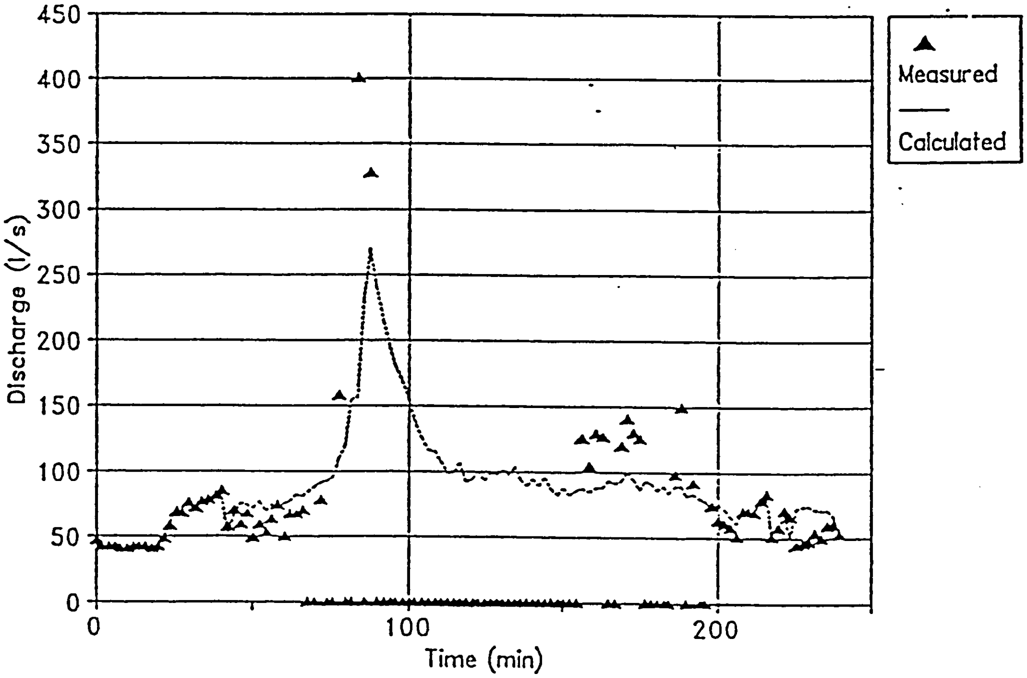


Figure 5.30 Comparison of the Measured and Calculated Discharges for the Storm on the 02/11/91at the High Side Weir Site (Dobcroft Road)

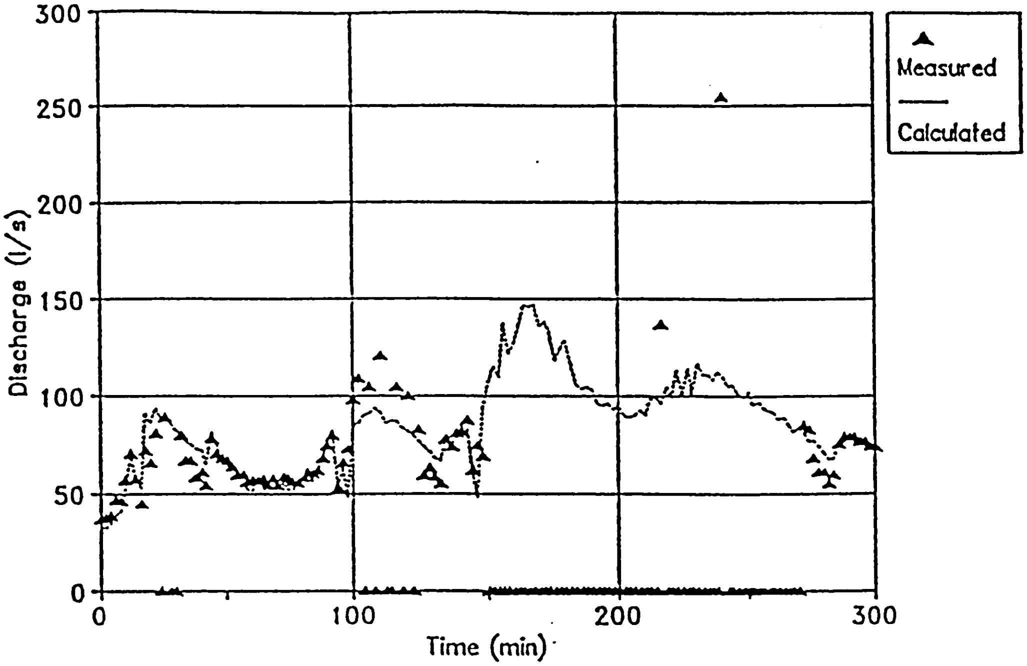


Figure 5.31 Comparison of the Measured and Calculated Discharges for the Storm on the 04/11/91at the High Side Weir Site (Dobcroft Road)

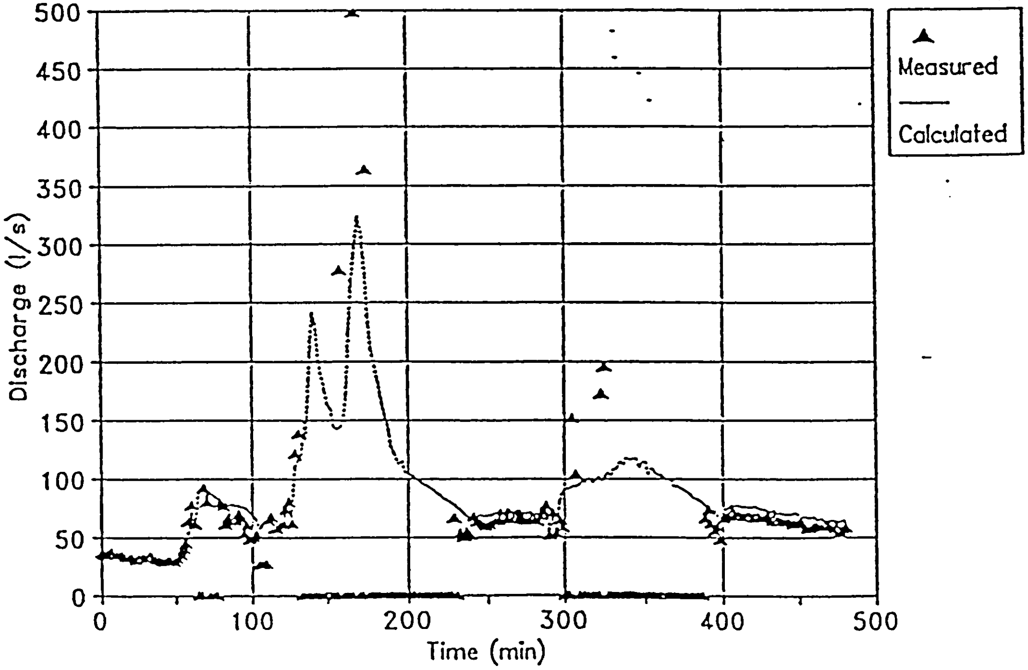


Figure 5.32 Comparison of the Measured and Calculated Discharges for the Storm on the 18/11/91at the High Side Weir Site (Dobcroft Road)

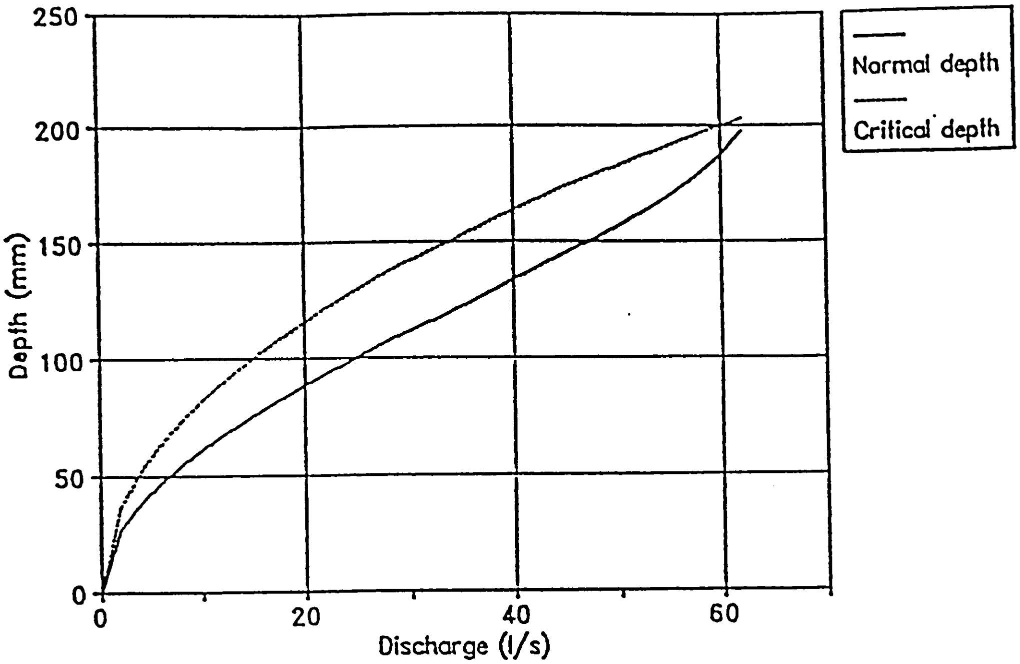


Figure 5.33 Graph Showing the Normal and Critical Depths for the Continuation at the High Side Weir Site (Dobcroft Road)

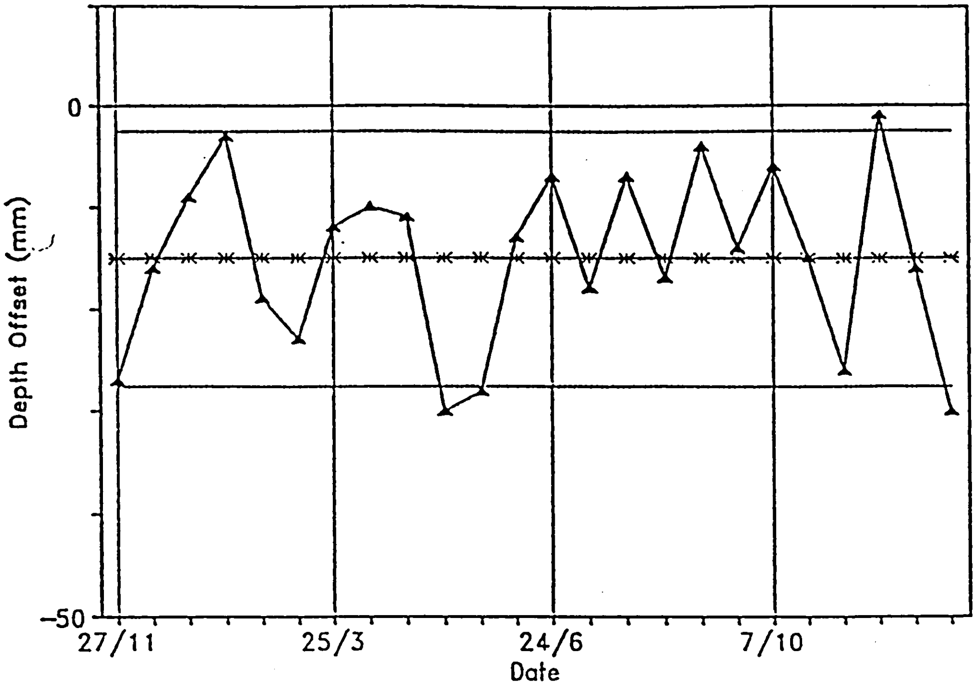


Figure 5.34 Depth Offsets for the Inflow Monitor at the Low Side Weir Site (Retford Road) Mean Value : 15.80mm

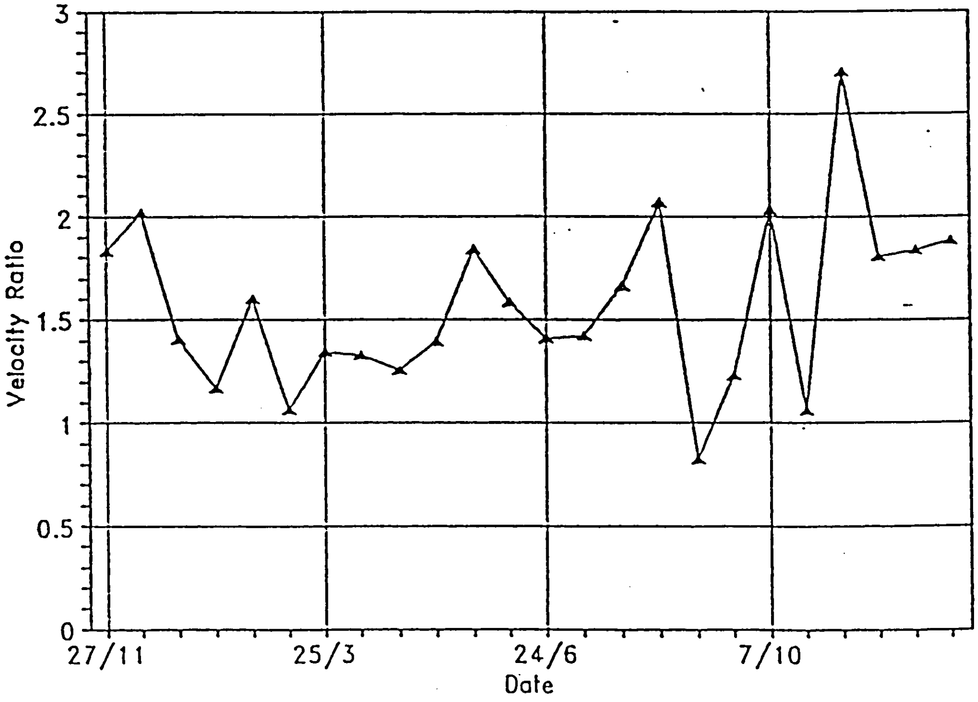


Figure 5.35 Logged Velocity / Measured Velocity for the Inflow Monitor at the Low Side Weir Site (Retford Road) Mean Value 1.574

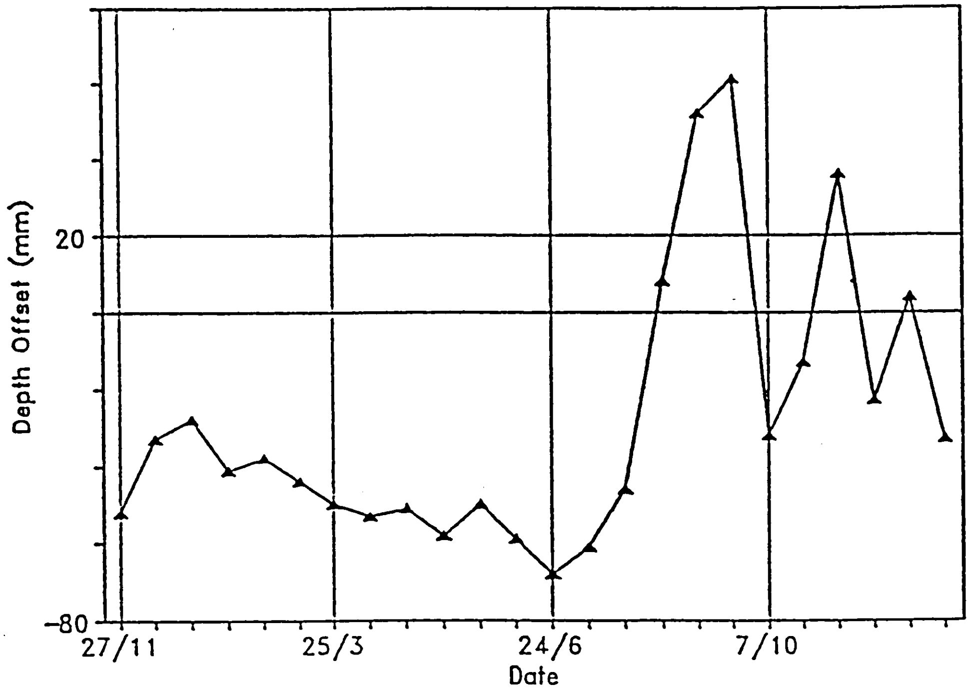


figure 5.36 Depth Offsets for the Continuation Monitor at the Low Side Weir Site (Retford Road)

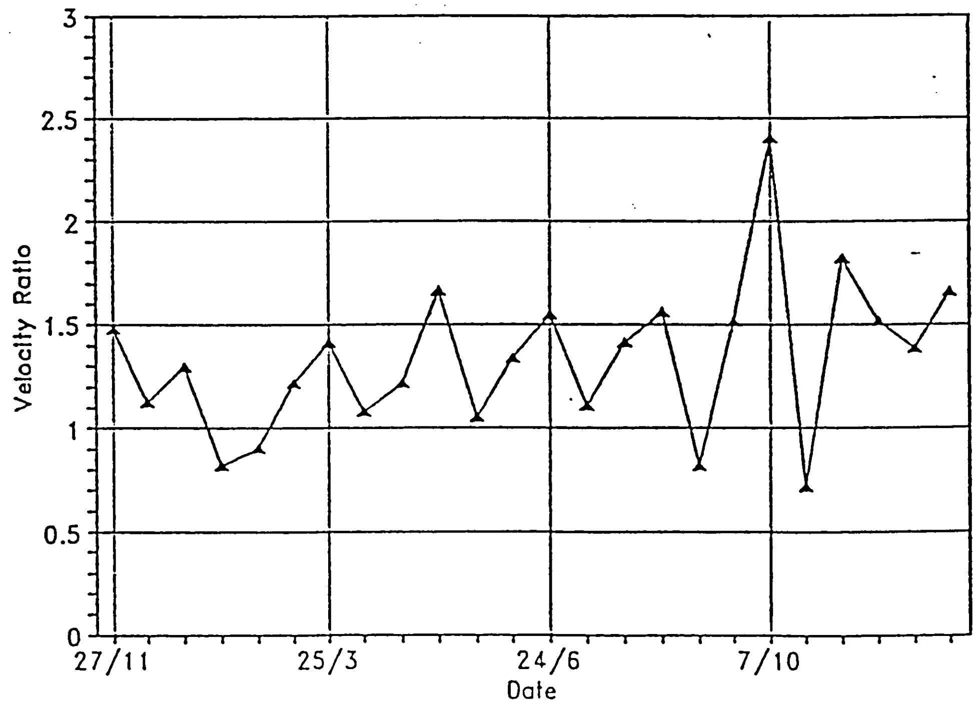


Figure 5.37 Logged Velocity / Measured Velocity for the Continuation Monitor at the Low Side Weir Site (Retford Road) Mean Value 1.336

In order to obtain a correct volume balance a multiplying factor (f_2) was applied to the continuation hydrograph in the form of:

$$Q_{\text{modified}} = Q \times f_2$$

For some storms modification of inflow and overflow was also required using a similar relationship. Inflow was matched to continuation flow when there was no spill, and spill flow adjusted for the peaks. Figures 5.38 to 5.41 show examples of the fits of the inflow and the sum of the continuation flow and the overflow discharge.

The multiplying factors and continuation depth adjustment used for the graphs in Figure 5.38 to 5.41 are as follows:

Storm Event	Factor 1	Factor 2	Factor 3	Continuation Depth Adjustment
19 November 1992 3p.m.	1.1	0.8	1.2	-30
20 July 1992	1	1	1	47
21 July 1992	1	1	1	47
26 August 1992	1	1	1.2	37

Table 5.1 Factors Used in Retford Road Flow Adjustments

Figures 5.42 to 5.45 show the depth-discharge relationships for the inflow, continuation flow and overflow for a number of storms. Figures 5.42 and 5.43 show the relationship between the continuation flow and the inflow (Figure 5.43 is an enlargement of Figure 5.42). Figures 5.44 and 5.45 show the relationship between the overflow discharge and the inflow discharge (Figure 5.45 is an enlargement of Figure 5.44). The flow at which first spill occurs is between 30 to 34 l/s. Average dry weather flow is approximately 11 l/s at this site. It thus appears that this overflow is set rather low (3 x DWF). This is supported by observations during site visits, of spills during dry weather.

5.5 HIGH SIDE WEIR (LEYBURN ROAD)

5.5.1 Producing the Calibration

Depth and velocity check measurements were taken during the weekly site visits. Figure 5.46 shows the depth offsets calculated from these measurements. It appears that there is a significant drift in the logged depth measurements over the six month monitoring period. The logged values were initially 20mm lower than the measured values but, by the end of the monitoring period, they were 40mm higher. The weekly checks were invariably done when the flow was low. Data obtained during the blocking test suggest that the drift is smaller at higher depths. Low flows were modified to allow for this drift.

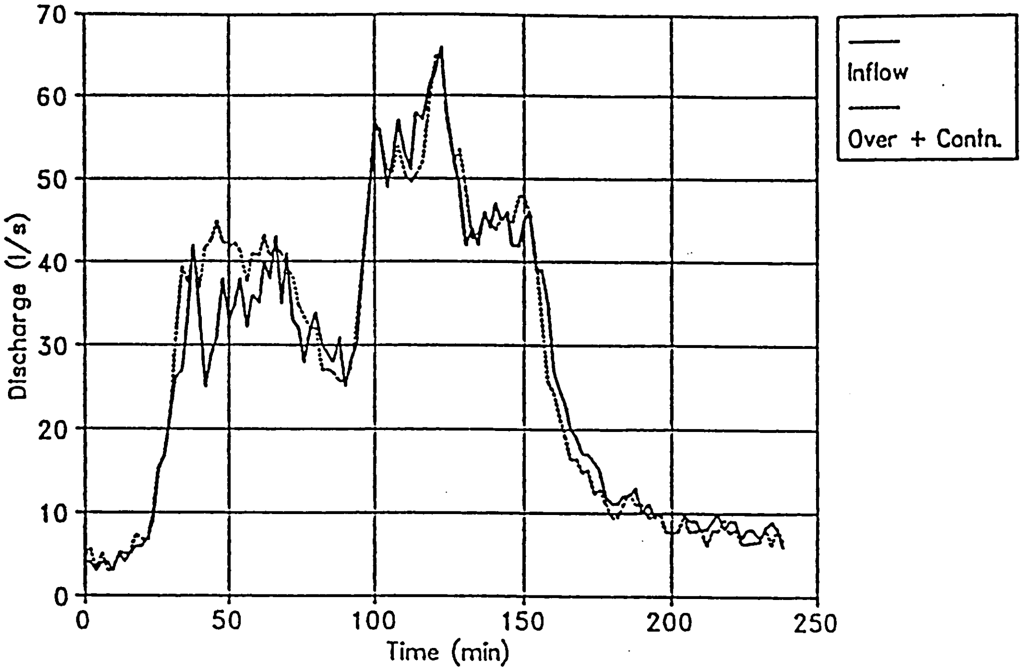


Figure 5.38 Example of the Fit Between Inflow and the Sum of Continuation Flow and Spill Flow for the Storm on the 26/6/92 at the Low Side Weir Site (Retford Road)

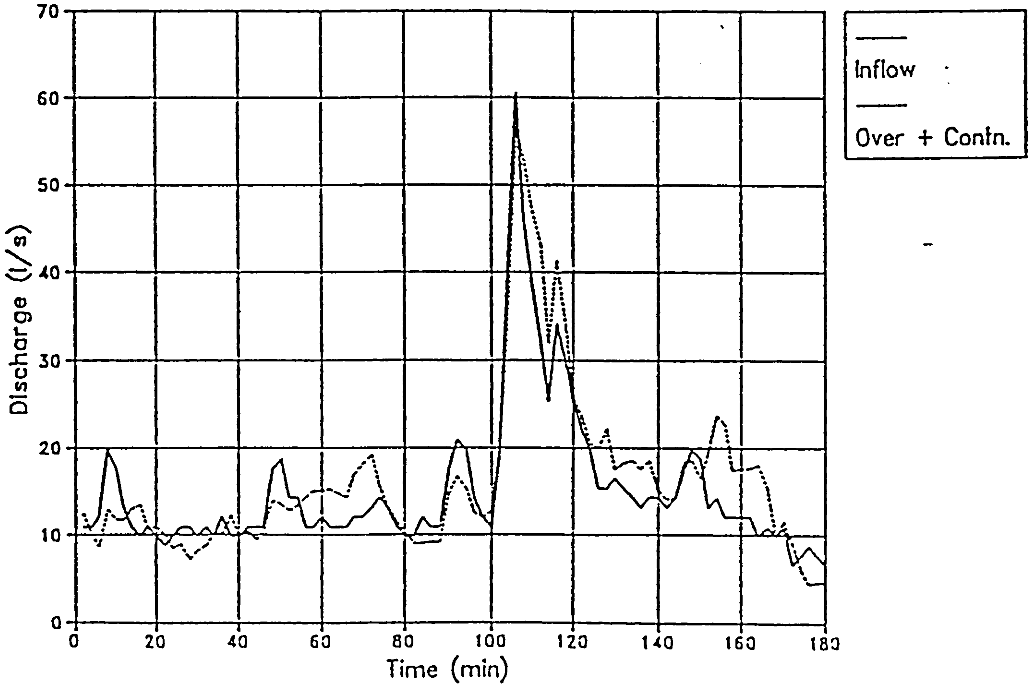


Figure 5.39 Example of the Fit Between Inflow and the Sum of Continuation Flow and Spill Flow for the Storm on the 19/11/92 at the Low Side Weir Site (Retford Road)

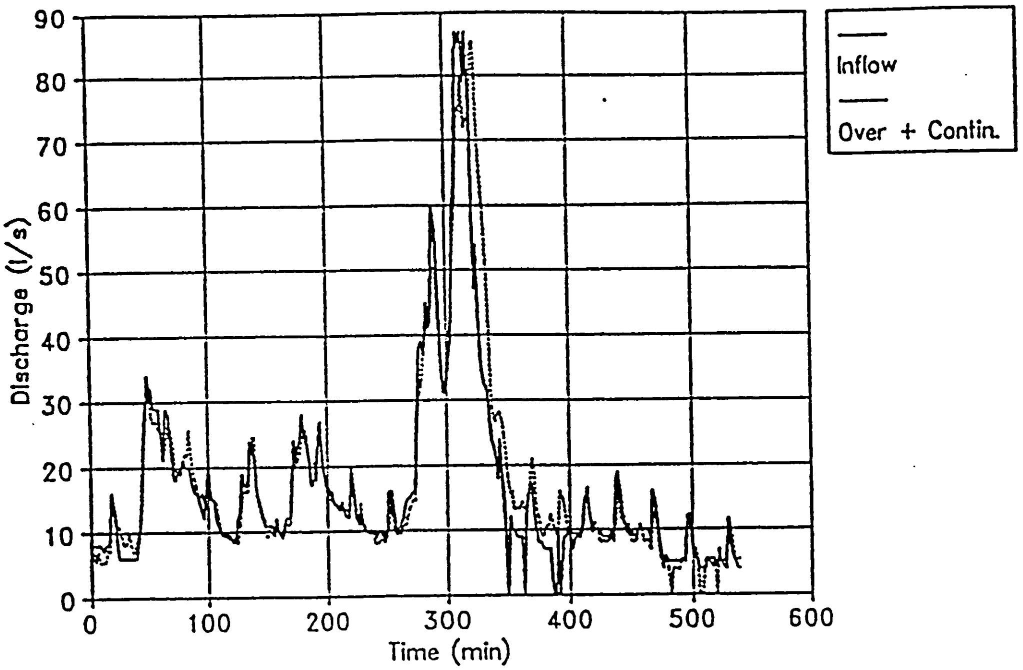


Figure 5.40 Example of the Fit Between Inflow and the Sum of Continuation Flow and Spill Flow for the Storm on the 20/7/92 at the Low Side Weir Site (Retford Road)

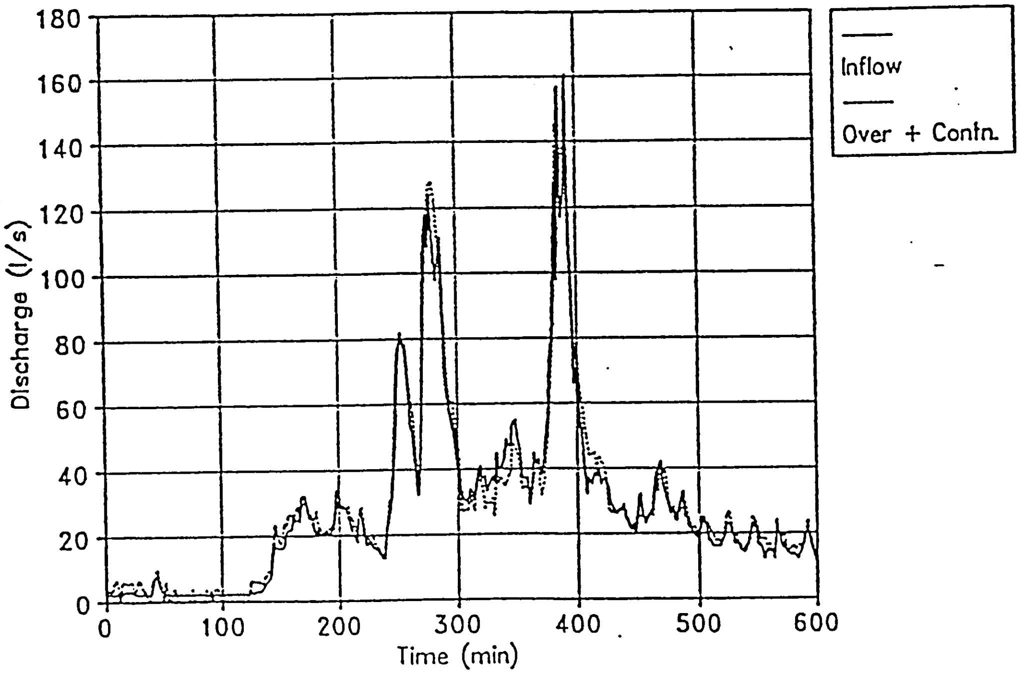


Figure 5.41 Example of the Fit Between Inflow and the Sum of Continuation Flow and Spill Flow for the Storm on the 21/7/92 at the Low Side Weir Site (Retford Road)

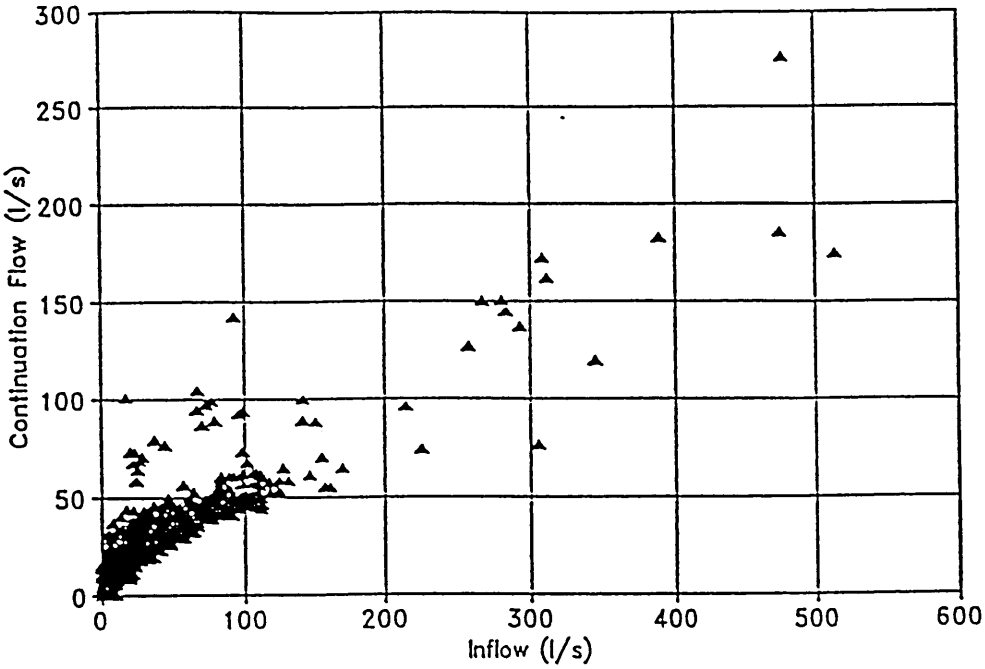


Figure 5.42 The Relationship Between Continuation Flow and Inflow for Eleven Storms at the Retford Road Site

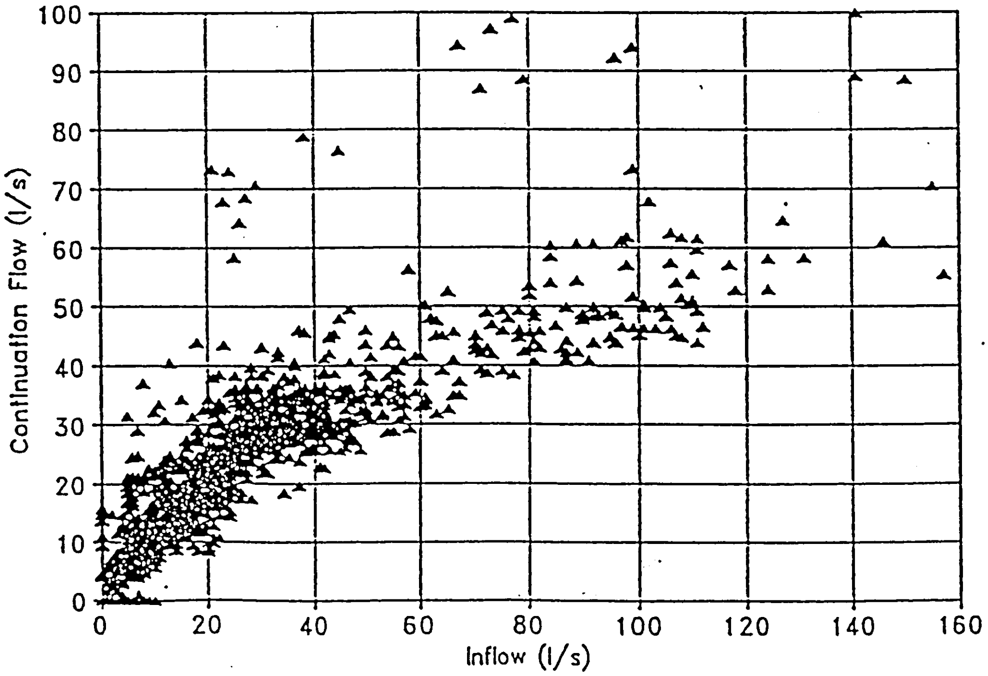


Figure 5.43 An Enlargement of Figure 5.42

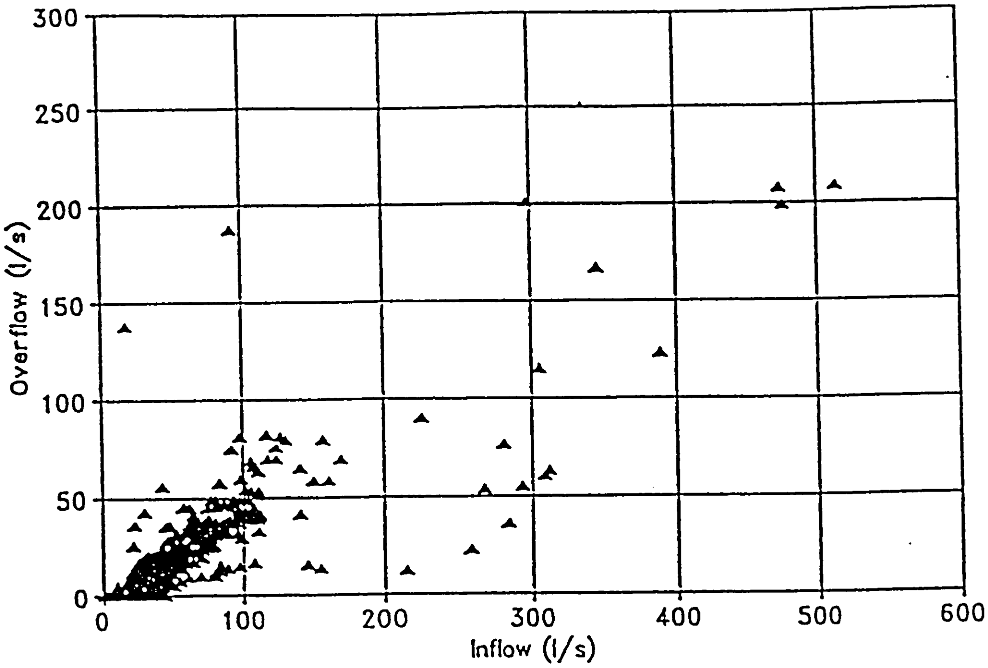


Figure 5.44 The Relationship Between Overflow Discharge and Inflow for Eleven Storms at the Retford Road Site

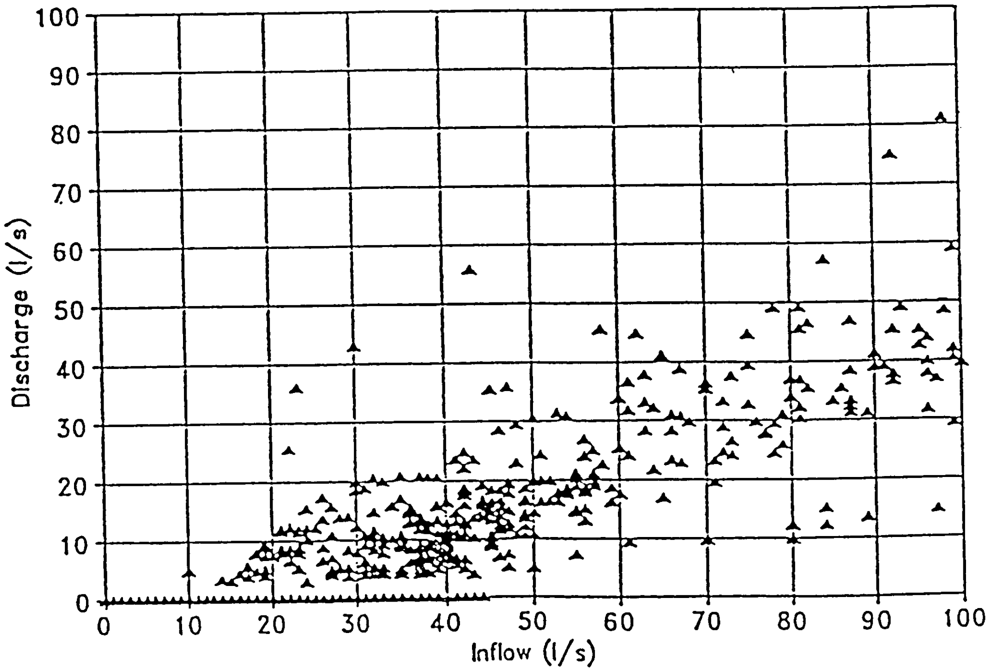


Figure 5.45 Enlargement of Figure 5.44

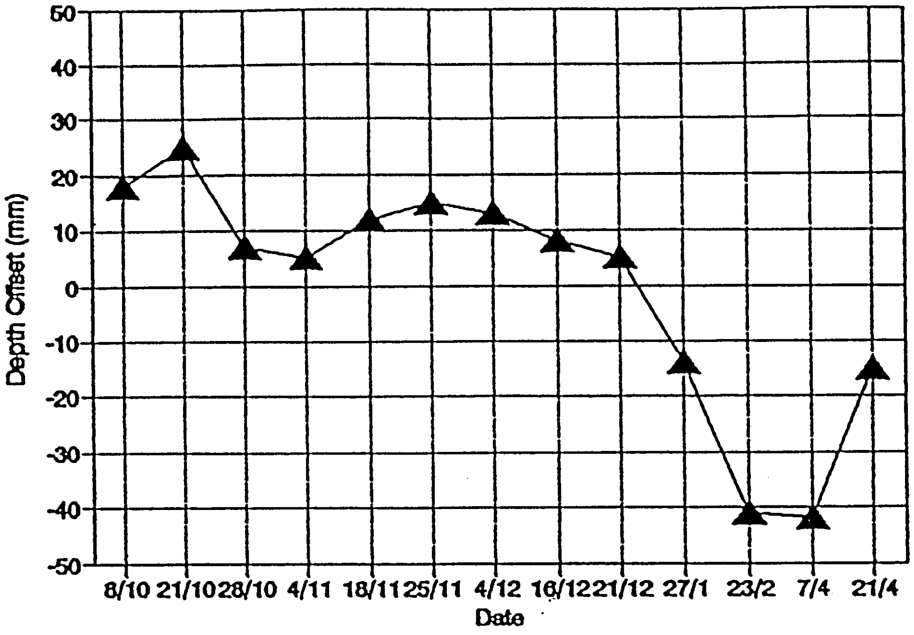


Figure 5.46 Depth Offset for the Inflow Monitor at the High Side Weir (Leyburn Road)

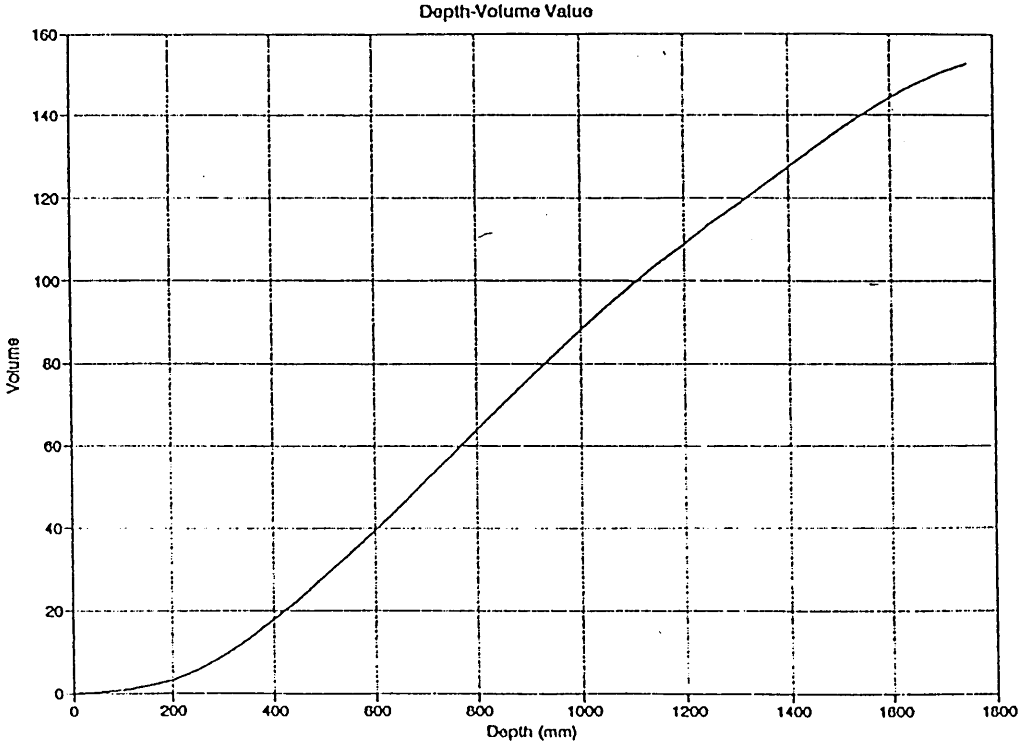


Figure 5.47 Stored Volumes Against Depth above Continuation Invert at the High Side Weir (Leyburn Road)

The stored volumes in the overflow chamber and upstream pipe in relation to the depth above the continuation invert are shown in Figure 5.47. The chamber depth at which spill occurs was found during the blocking test to be 1385mm at the lowest part of the weir (the furthest upstream section of the weir). At the highest part of the weir (the end weir) the depth was found to be 1508mm. Thus the total increase in the height of the weir from the upstream to the downstream end of the chamber is 128mm.

The relationship between the spill flow and the inflow into the chamber is shown in Figure 5.48. From this it appears that flow at which spill occurs is between 260l/s and 340l/s. The average dry weather flow was calculated to be 13l/s. Thus this overflow is set to spill at 20-26xDWF.

Measured values of inflow were found to be very unreliable at high flows. When the level in the chamber was 340mm below the weir level the inflow monitor started to be affected by the backing up of water and data were lost.

As there was a shortage of flow monitors only one of the spill pipes was monitored at the start of the survey period. It was intended that the second pipe would be monitored as soon as a logger became available. Unfortunately, the time available for the survey was limited and the second logger was not available until all the sampling events had taken place. The logger was installed on 9 December 1992 and 7 events were monitored hydraulically. This enabled data to be obtained for comparison of the two spill pipes. It might be assumed that a similar amount of flow passes down each pipe during a storm but, as the weirs are of not of equal height on both sides of the chamber, it is likely that one spill pipe receives more flow than the other. An example of a comparison of the two spills is given for the storm on 18 December 1992 (Figure 5.49). Note that this was the spill before the flows were adjusted in accordance with the flow calibrations.

A scattergraph was produced for the 7 events with both spills recorded. Spill monitors cannot easily be calibrated in situ but, at the end of the survey period they were tested for flow and depth in the hydraulics laboratory. With this information it was possible to estimate the average proportion of the total flow that was flowing down each of the pipes. It was found that slightly more flow (approximately 61%) was passed down the second pipe to be monitored. This is in accordance with the survey of the weir heights. As the distance from the inlet increases the weir on the right hand side of the chamber becomes lower than the weir on the left hand side. At the end weir a 10mm difference in weir height was measured.

A scattergraph of the inflow depths and flows was produced for all the storms with sample data. This is shown in Figure 5.50(i). A description of how the calibration was obtained is given in Chapter 4, section 4.3.4. Examples of how the calibration fits the measured data are given in Figures 5.50 (ii) and (iii).

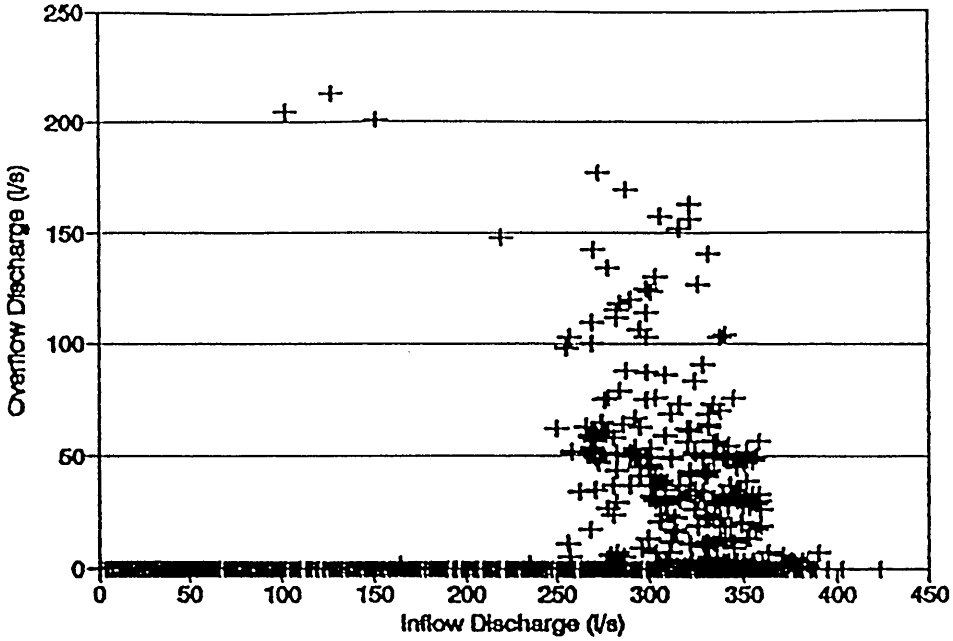


Figure 5.48 Relationship between Spill Flow and Inflow into the Chamber at the High Side Weir (Leyburn Road)

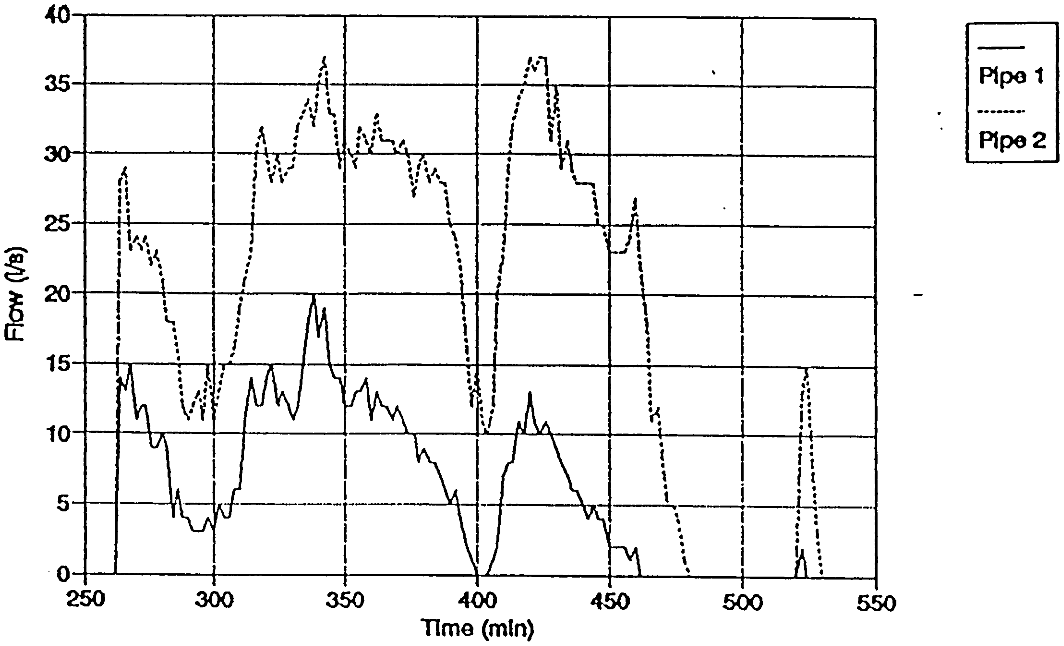


Figure 5.49 Comparison of Flows From the Two Spill Pipes at the High Side Weir (Leyburn Road) (before calibration)

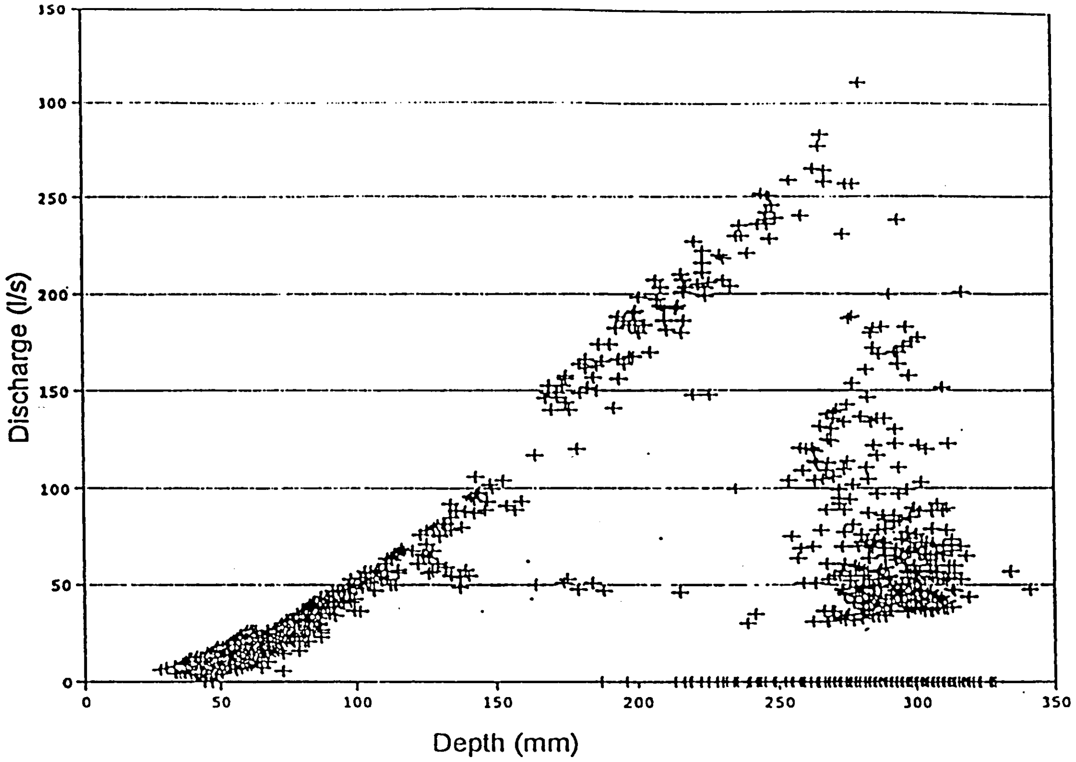


Figure 5.50 (i) Depth/Discharge Scattergraph for the Inflow Monitor for all Storms with Sample Data at the High Side Weir (Leyburn Road)

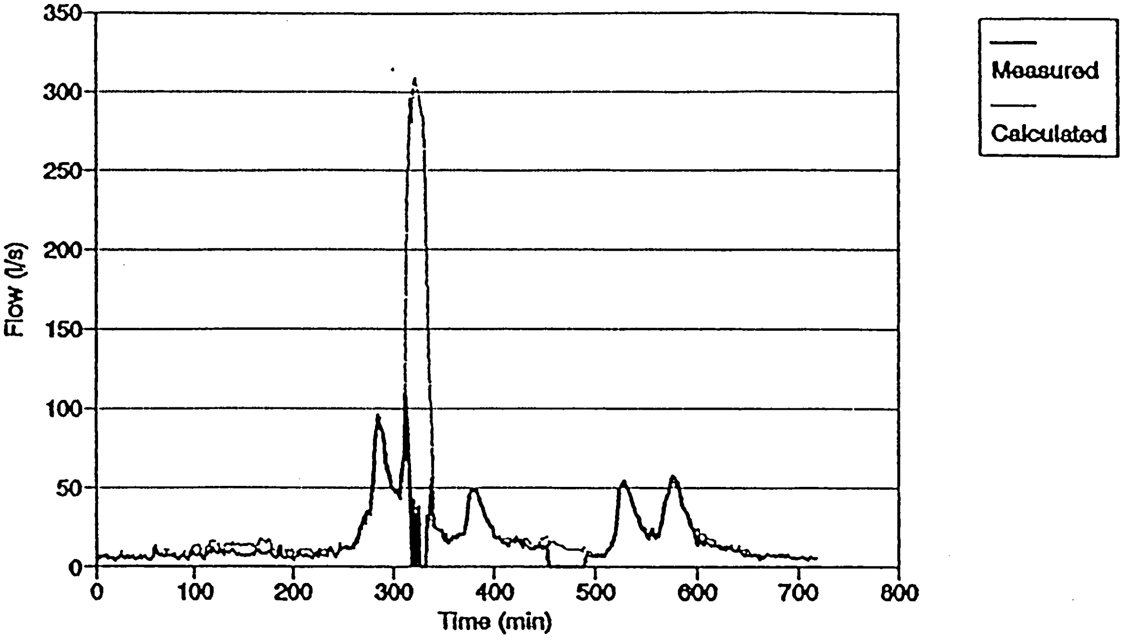


Figure 5.50 (ii) Comparison of the Measured and the Calibrated Data for the storm on 2/11/92 at the High Side Weir site (Leyburn Road)

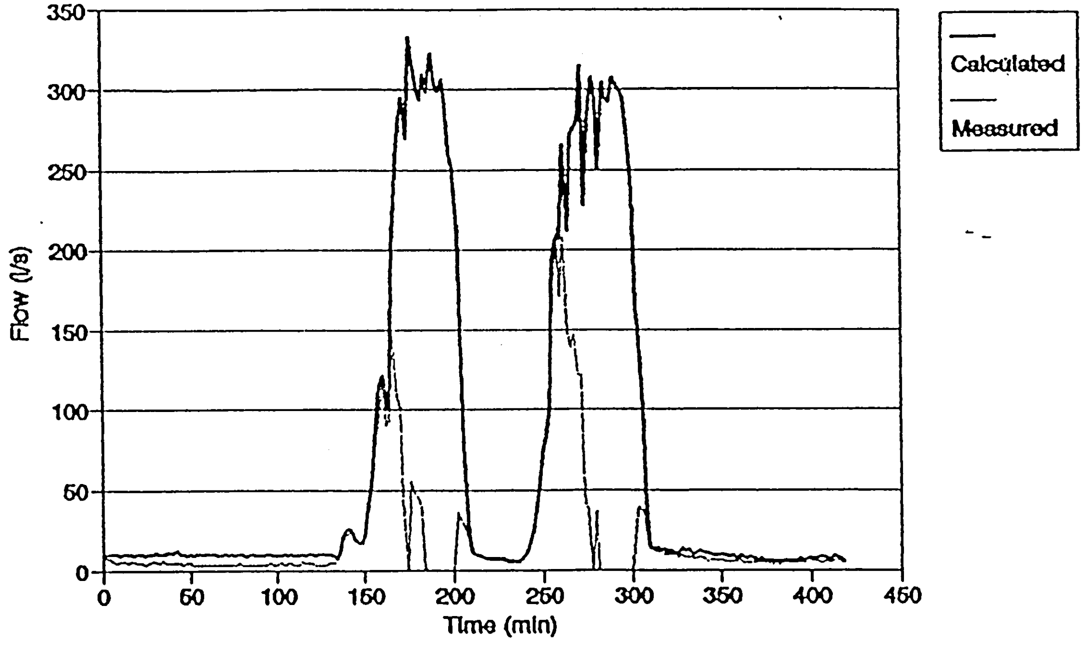


Figure 5.50 (iii) Comparison of the Measured and the Calibrated Data for the storm on 19/11/92 at the High Side Weir site (Leyburn Road)

5.6 DRY WEATHER FLOW PATTERNS

Figures 5.51 to 5.54 give the dry weather flow pattern for a typical day. Minimum flow values at all sites occur between 2a.m. and 6a.m. This is followed by a sharp increase in flow up to 8a.m. The dry weather flow patterns found during the day tend to vary much more according to the site. Peak flow at the Dobcroft and Retford Road sites (approximately 24 l/s and 25 l/s respectively) occur at around midday whilst at the Chesterfield Road site there is a trough in values at this time (approximately 9 l/s) between twin peaks which occur between 8a.m. to 10a.m. and 5p.m. to 7p.m. (both reaching approximately 14 l/s). At Leyburn Road the peak flow is between 7p.m. and 9p.m. when the flow reaches approximately 25 l/s. The range in flow values at Dobcroft Road, Retford Road and Leyburn Road are reasonably similar (between 4 l/s and 26 l/s) whilst at the Chesterfield Road site the range in values is from 3 l/s to 16 l/s.

B. SAMPLE ANALYSIS

5.7 MONITORING PERIODS

The monitoring periods for the four sites are given in the following table (Table 5.2). The number of storms from which finely suspended and dissolved samples were taken is given and the number of storms with both inflow and spill samples is indicted. The number of storms from which gross solid data was obtained is also given.

Site	Monitoring Period	Storms with Samples	Storms with Inflow and Spill Samples	Events with Gross Solid Samples
Stilling Pond (Chesterfield Road)	Sept. 1990 to July 1991	24	8	14
High Side Weir (Dobcroft Road)	Jan. 1991 to Jan. 1992	19	7	14
Low Side Weir (Retford Road)	Nov.1991 to Dec. 1992	18	12	17
High Side Weir (Leyburn Road)	Oct. 1992 to Dec. 1992	12	8	11

Table 5.2 Monitoring Periods and the Number of Storms Sampled

5.8 DAILY SAMPLE VALUE VARIATION DURING DRY WEATHER

The daily variation at each of the sites is given in Figures 5.55 to 5.58. All sites indicate a decline to minimum sample concentrations between 2a.m. to 6a.m. following an evening peak between 4p.m. to 8p.m. This is apparent for all the sample parameters investigated. At Leyburn Road, however, there is a peak between 10a.m. and 2p.m. for all the parameters except ammonia. This could be due to a rogue sample or one-off discharge that occurred during the day on which the dry weather flow samples were taken. After 4a.m. there is a rapid rise at all sites, for all the parameters, to reach a morning peak between 6a.m. and 8a.m. for all sites except Leyburn Road.

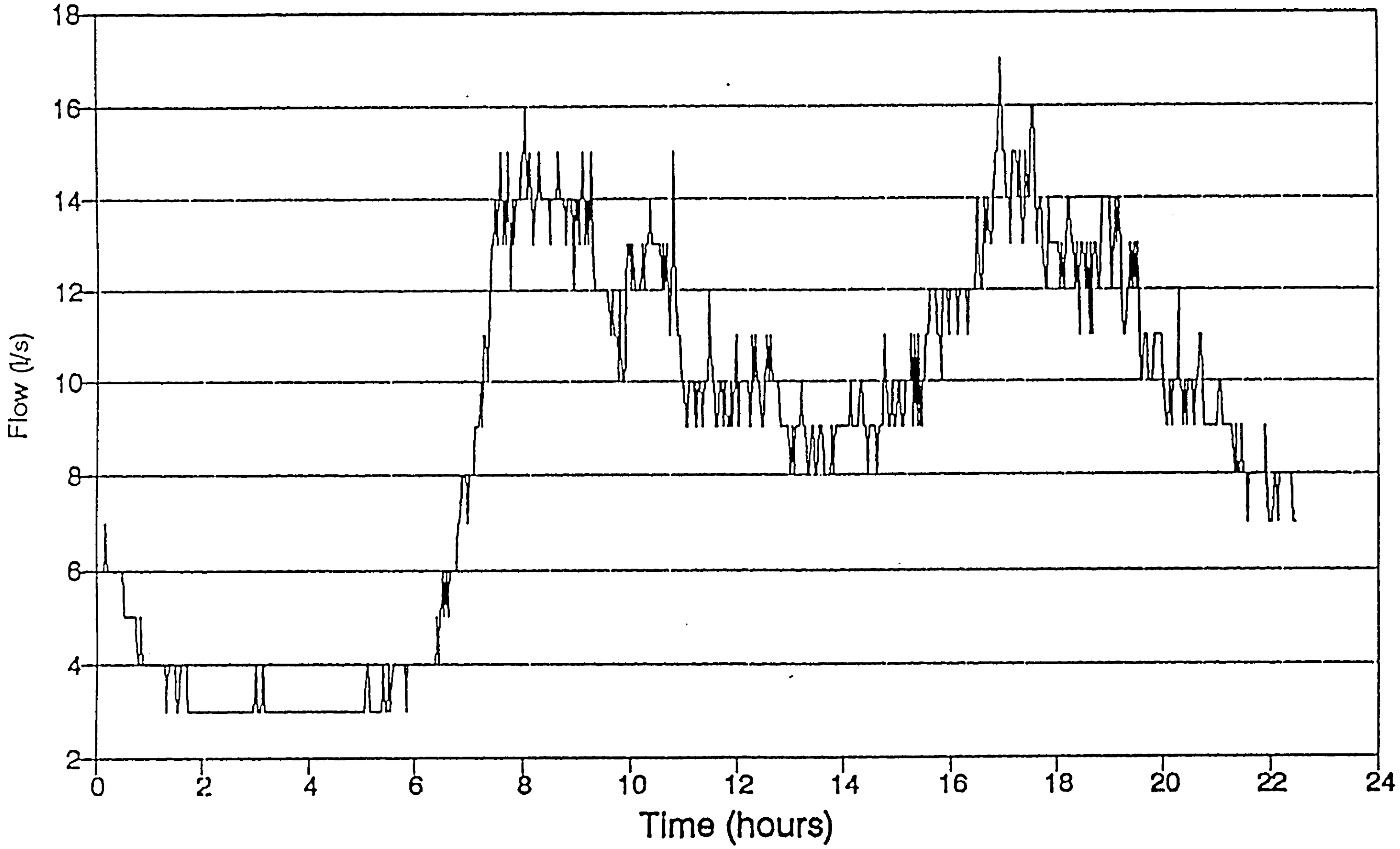


Figure 5.51 Dry Weather Flow at the Stilling Pond Site

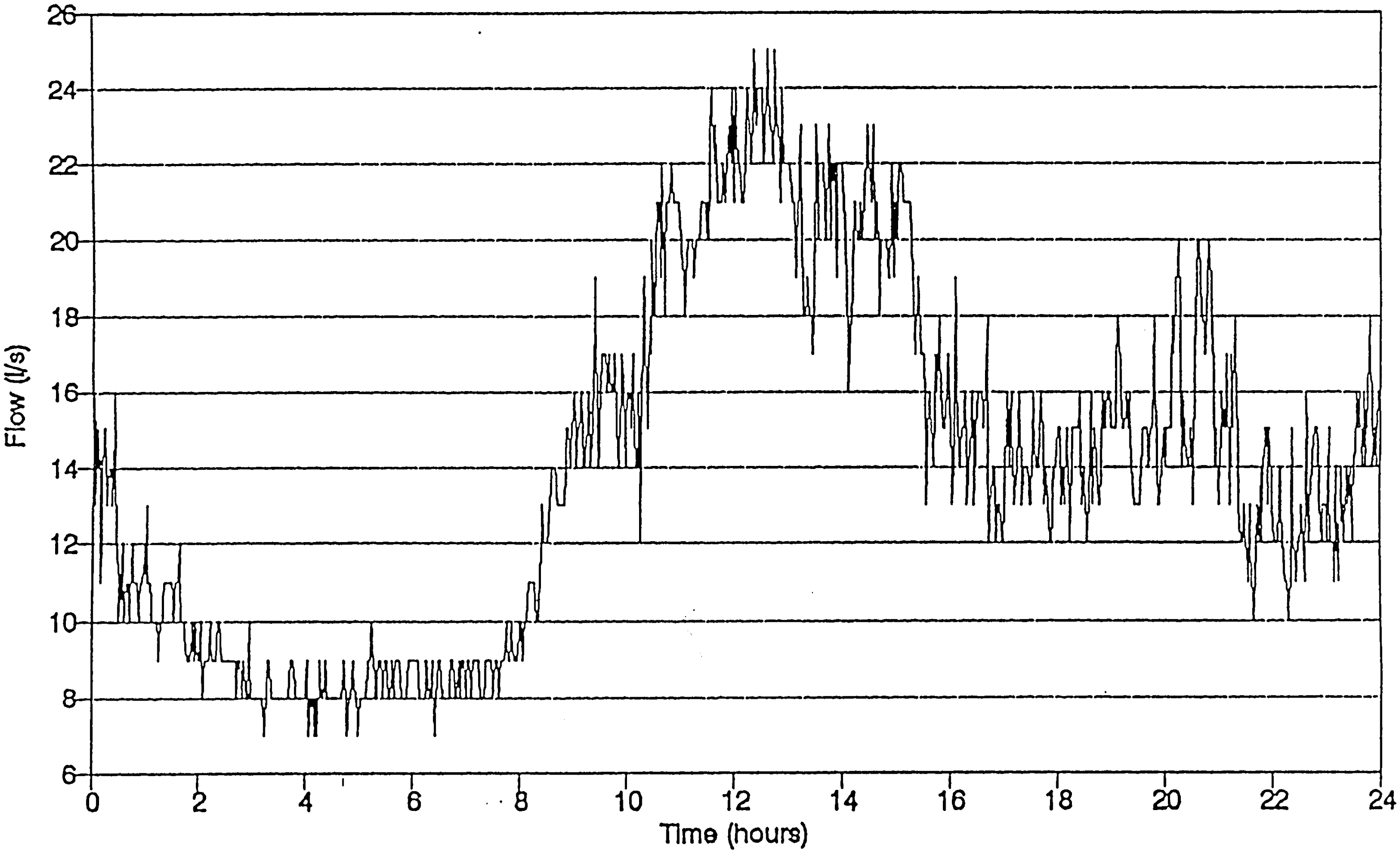


Figure 5.52 Dry Weather flow at the High Side Weir Site (Dobcroft Road)

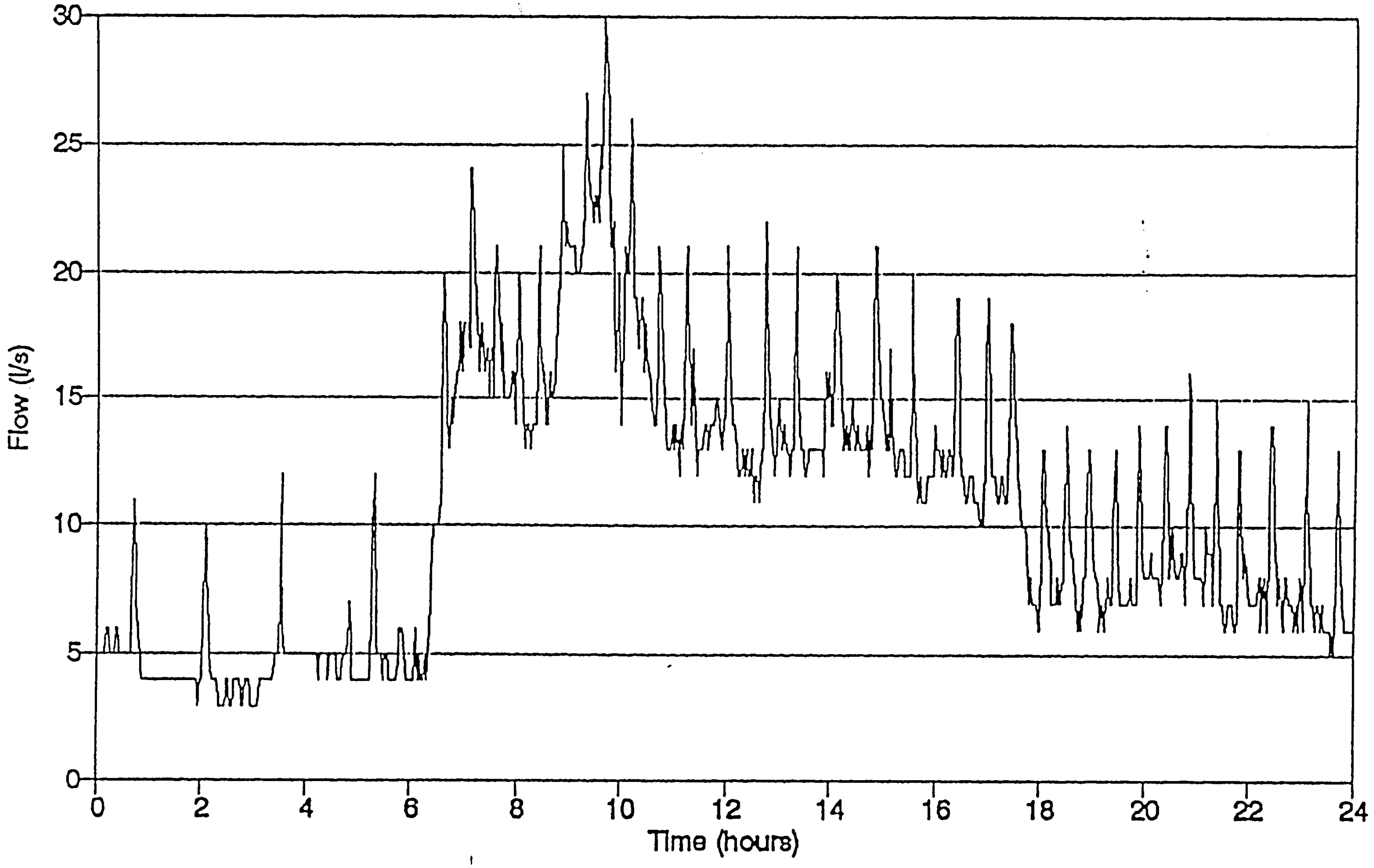


Figure 5.53 Dry Weather Flow at the Low Side Weir Site (Retford Road)

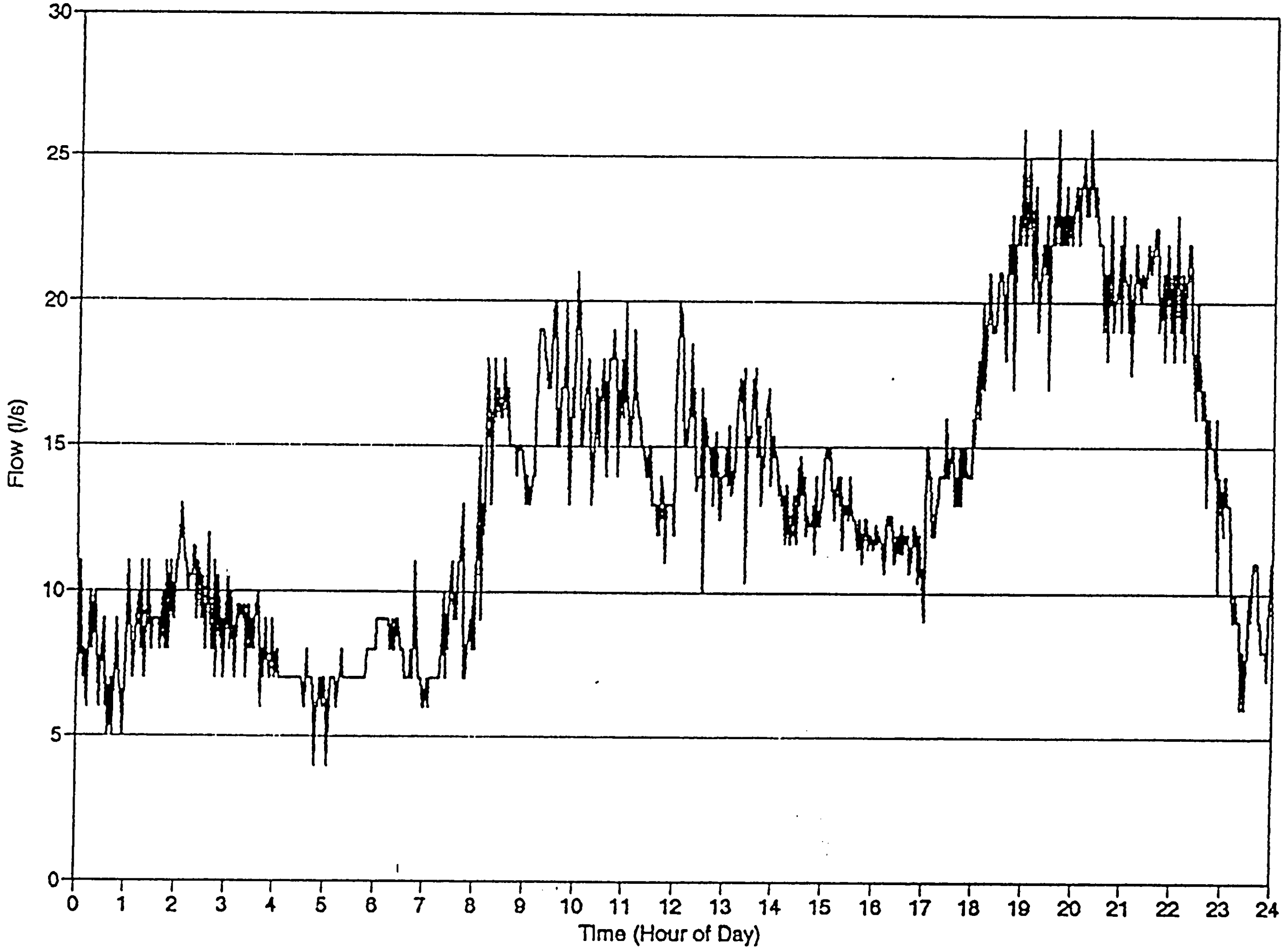


Figure 5.54 Dry Weather Flow at the High Side Weir (Leyburn Road)

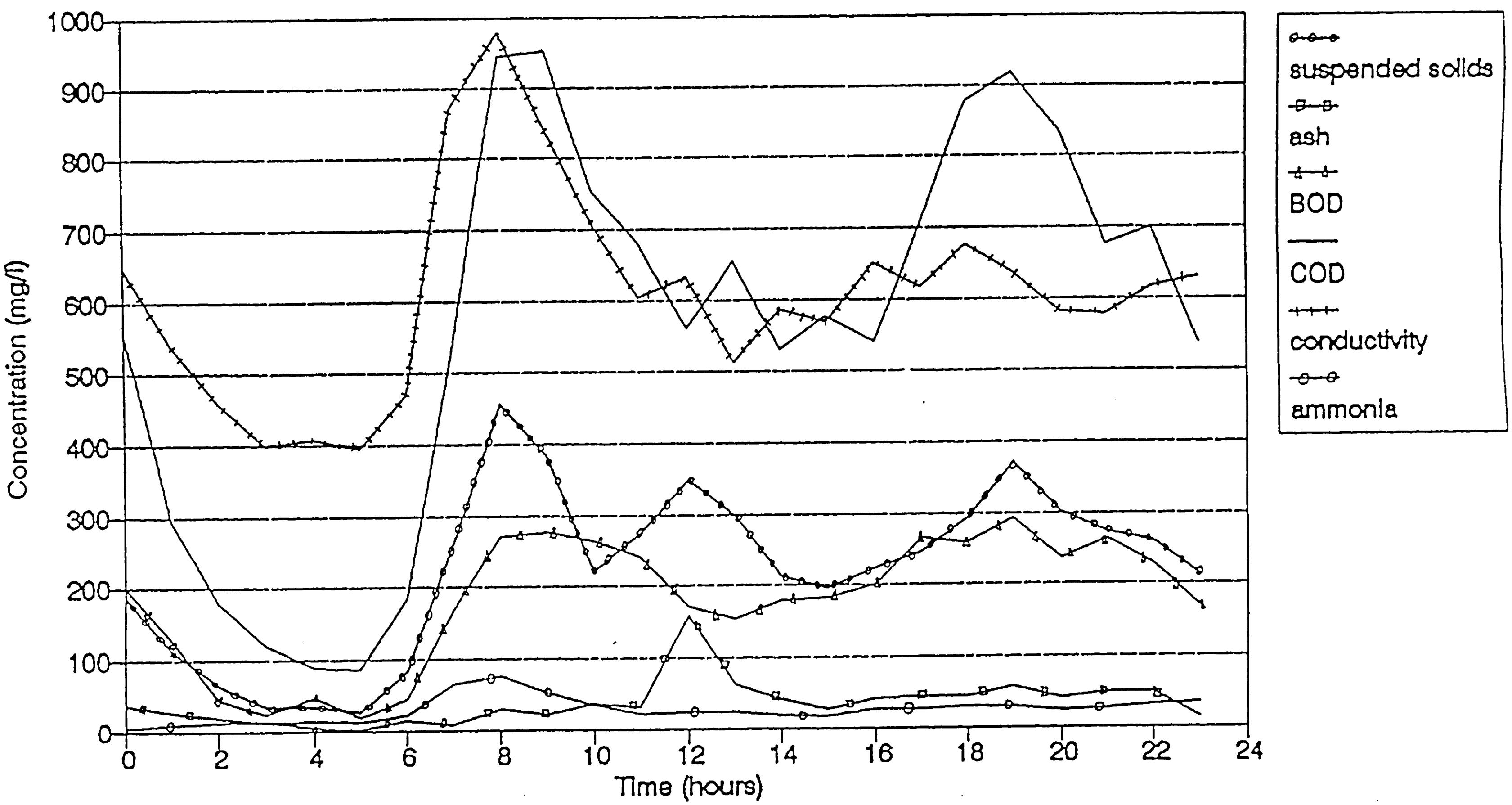


Figure 5.55 24-Hour Dry Weather Samples the Stilling Pond Site

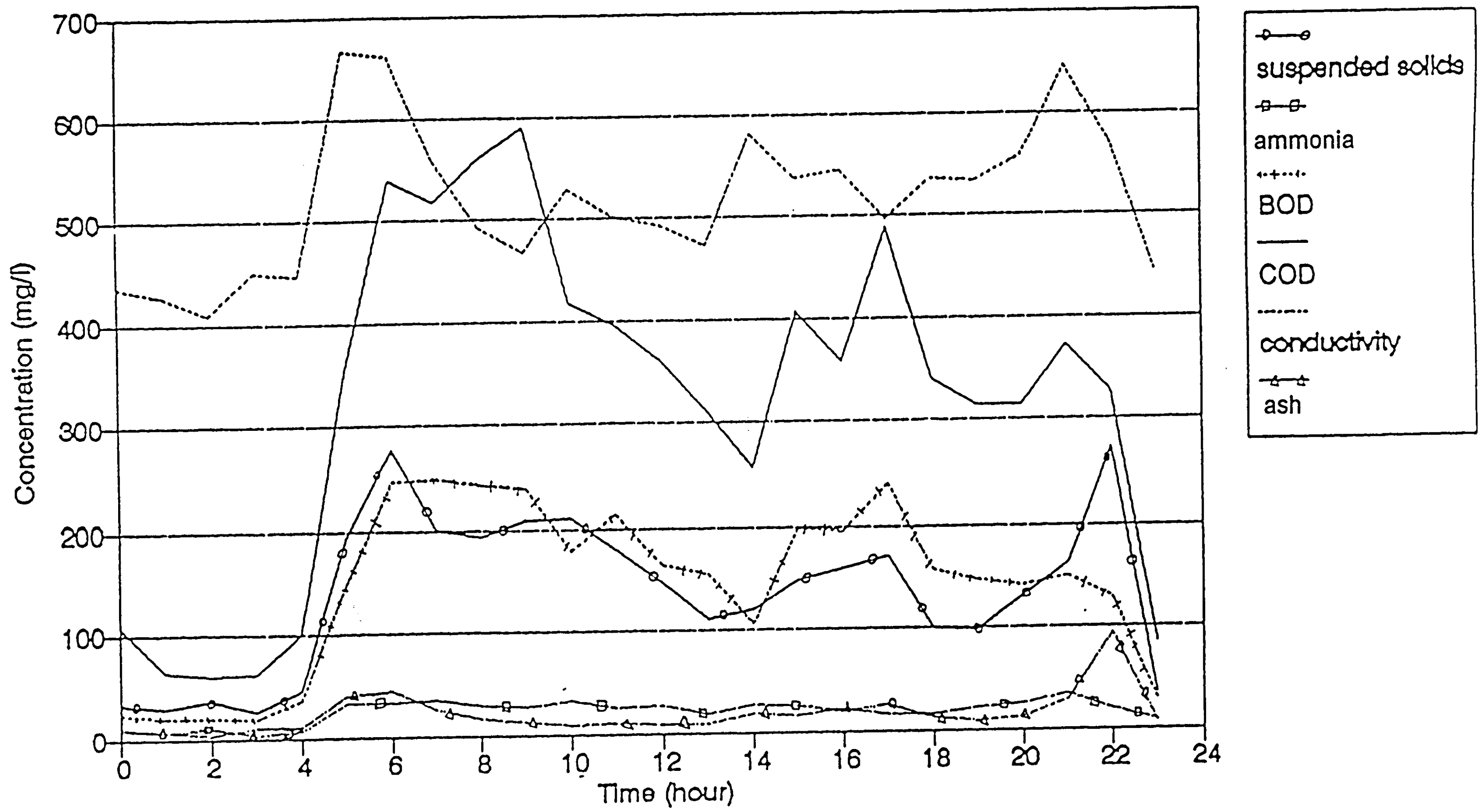


Figure 5.56 24-Hour Dry Weather Samples the High Side Weir Site (Dobcroft Road)

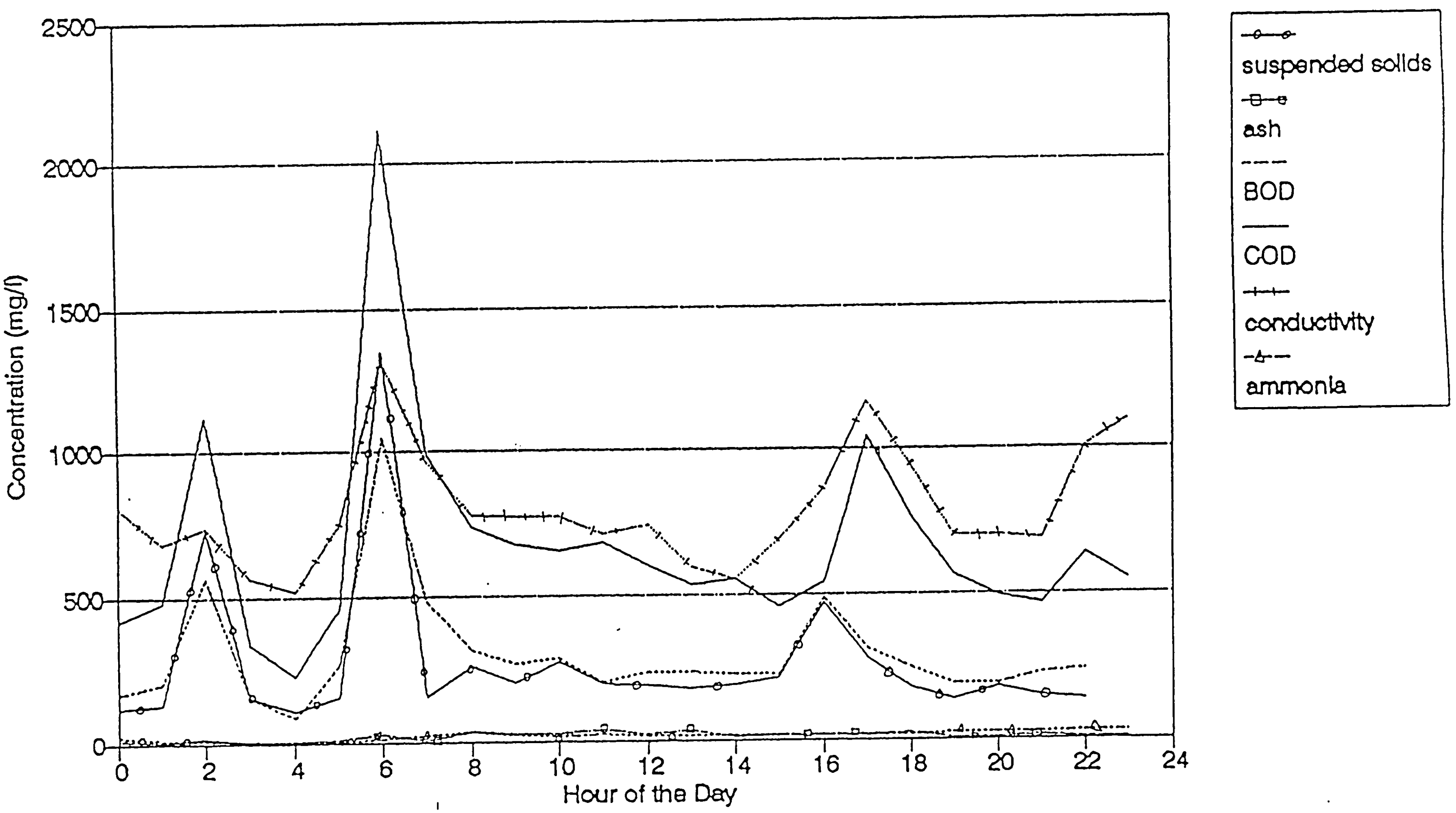


Figure 5.57 24-Hour Dry Weather Samples the Low Side Weir Site (Retford Road)

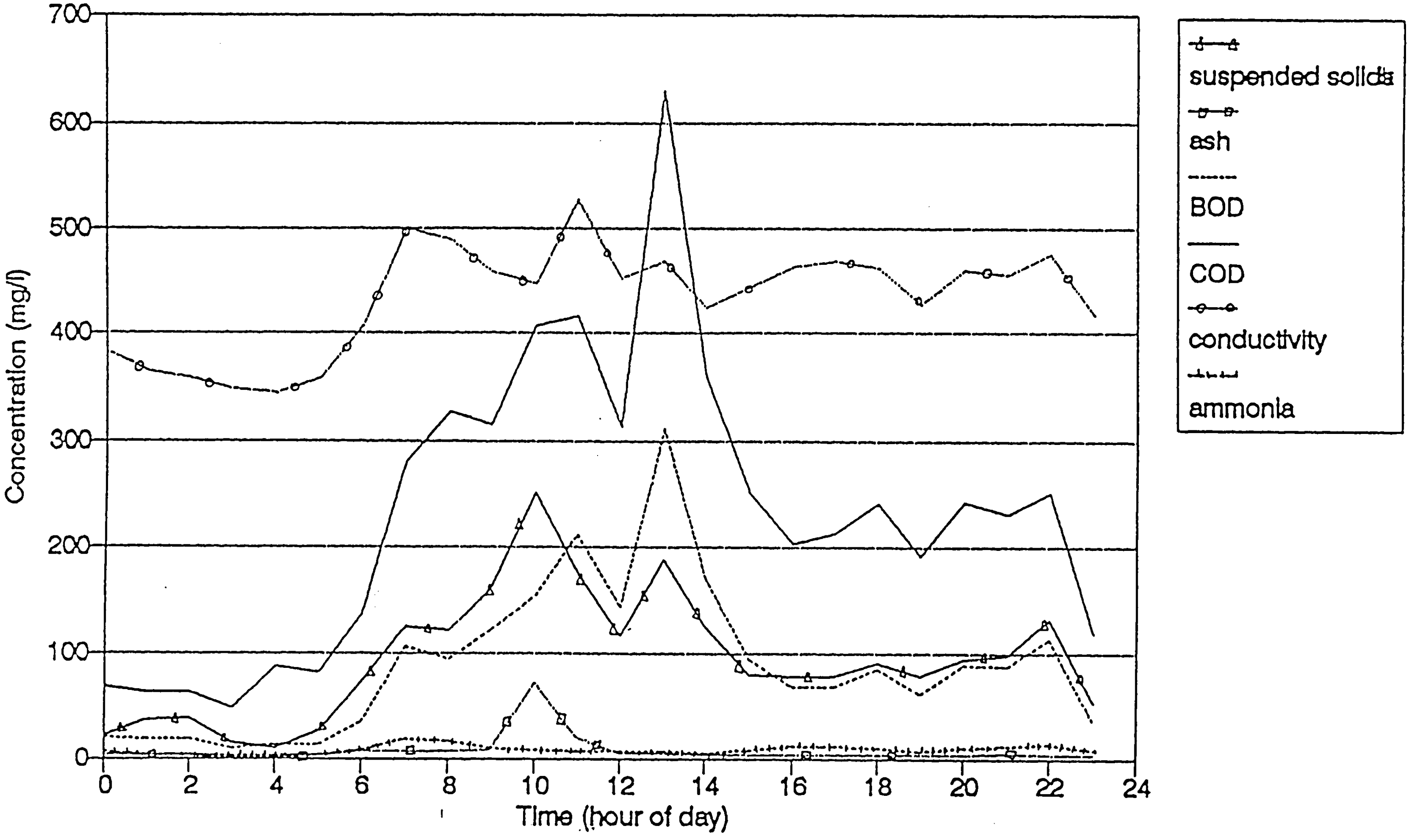


Figure 5.58 24-Hour Dry Weather Samples the High Side Weir Site (Leyburn Road)

The pattern for the rest of the day is more site dependent. At the Chesterfield Road site there are two pronounced daily peaks for all the parameters. The first peak is between 8a.m. and 12a.m. and the second between 6p.m. and 10p.m. with a trough in between showing a drop of over 50% in sample values for suspended solids, ash, BOD, COD and conductivity. A midday trough is also apparent at Retford Road for all sample parameters and at Dobcroft Road to a less pronounced extent for BOD and COD.

As these are predominately residential catchments these observations correspond with the normal diurnal pattern of people getting up between 6a.m.and 8a.m. and discharging waste water down showers, sinks and toilets. The midday peak observed at Leyburn Road may correspond to midday meals and breaks from work to use the toilet. The evening peaks can be explained by people returning from work, the preparation of meals and further use of the sinks and toilets.

In Table 5.3 the range of parameter values obtained during the 24-hour dry weather sampling is compared with the range obtained in storm events. The ratio of the peak values of the parameters (Dry Weather : Storm Event) is also given. From this it can be seen how much more concentrated the peak values of the storm samples can be.

5.9 ESTIMATING THE EFFICIENCY OF THE SYSTEMS

5.9.1 Water Quality (Bottle) Samples

These samples were used to obtain information on the finely suspended and dissolved fraction of material present in the combined sewer overflows. For each of the storms from which bottle samples were taken, graphs were produced to show the relationship between the inflow and the concentration variations for both the inflow and the spill samples. An example of this is given in Figures 5.59 to 5.65 for each of the measured parameters for the storm on 15th October 1990 at the Chesterfield Road site. Graphs of suspended solids, BOD, conductivity and ammonia for each of the storms with adequate sample data are given in Appendix 2. The change in the load of a parameter with time during a storm is given in Figures 5.66 to 5.70. The corresponding cumulative mass for the same storm and parameters is given in Figures 5.71 to 5.75.

The results of the t-tests are given in Tables 5.4 to 5.7. These indicate the significance of any difference between the means of the two sets of samples for the parameters measured. The significance of a result is shown as either 'n.s.' i.e. not significant, or as a percentage value. The smaller the percentage value the more significant the result is i.e. the greater the difference in the means for the number of samples investigated. The means of the inflow and spill are included for all the tests that gave a significant relationship.

Table 5.3 Comparison of Dry Weather Flow and Storm Sample

a. Dry Weather Flow : Range of Sample Concentrations

Site	Suspended Solids (mg/l)	Ash (mg/l)	BOD (mg/l)	COD (mg/l)	pH Value	Conductivity (uS/cm)	Ammonia (mg/l)
Retford Road	110-1350	2-38	161-1050	231-2120	6.3-7.3	519-1328	4.7-30.3
Dobcroft Road	24-276	2-94	18-247	60-591	6.8-7.4	409-666	6.0-42.9
Chesterfield Road	34-456	1-158	20-272	87-952	6.9-8.5	399-979	11.3-77.5
Leyburn Road	10-252	2-72	9-311	48-630	6.5-7.7	343-527	0.8-17.6

b. Storm Events:Range of Sample Values

Site	Suspended Solids (mg/l)	Ash (mg/l)	BOD (mg/l)	COD (mg/l)	pH Value	Conductivity (uS/cm)	Ammonia (mg/l)
Retford Road	8-3120	2-1684	13-3410	25-3480	5.2-12.5	91-4160	2-103
Dobcroft Road	28-8960	1-3264	16-736	60-1860	6.7-7.4	119-1360	0.9-19.5
Chesterfield Road	25-1448	2-363	20-654	82-2290	6.9-8.0	112-515	0.1-19.5
Leyburn Road	8-782	2-216	12-249	28-1801	6.5-7.2	120-473	0.01-4.63

c. Ratio of Peak Values (DWF : Storm Events)

Site	Suspended Solids	Ash	BOD	COD	pH	Conductivity	Ammonia
Retford Road	0.43:1	0.02:1	0.31:1	0.61:1	1:0.98	1:3.00	1:3.20
Dobcroft Road	0.03:1	0.03:1	0.34:1	0.32:1	1:1.00	1:2.00	1:0.45
Chesterfield Road	0.31:1	0.11:1	0.42:1	0.42:1	1:0.94	1:0.53	1:0.25
Leyburn Road	0.32:1	0.33:1	1.20:1	0.35:1	1:0.94	1:0.90	1:0.26

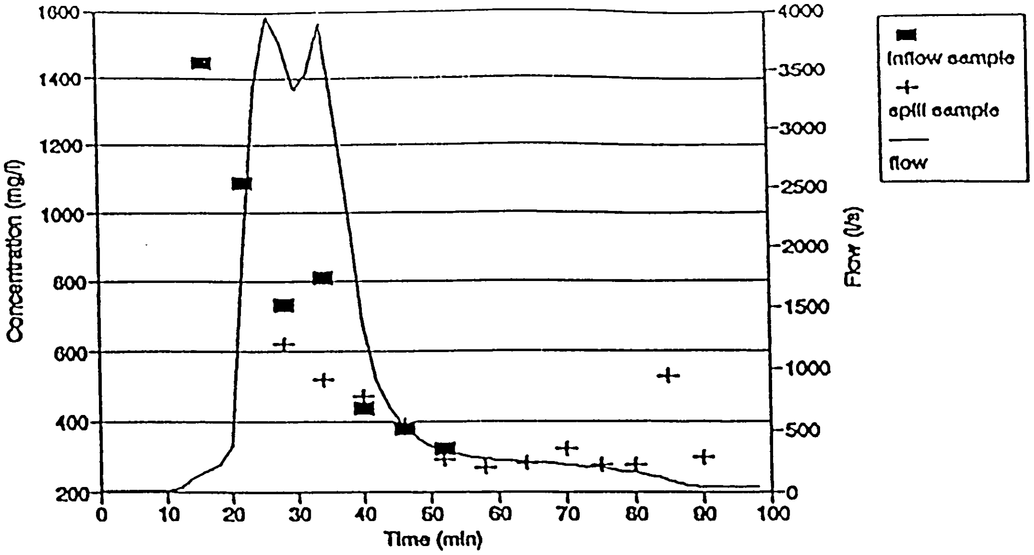


Figure 5.59 Suspended Solids Concentration (Inflow and Spill) and Inflow for the Storm on 15 October 1990 (Chesterfield Road)

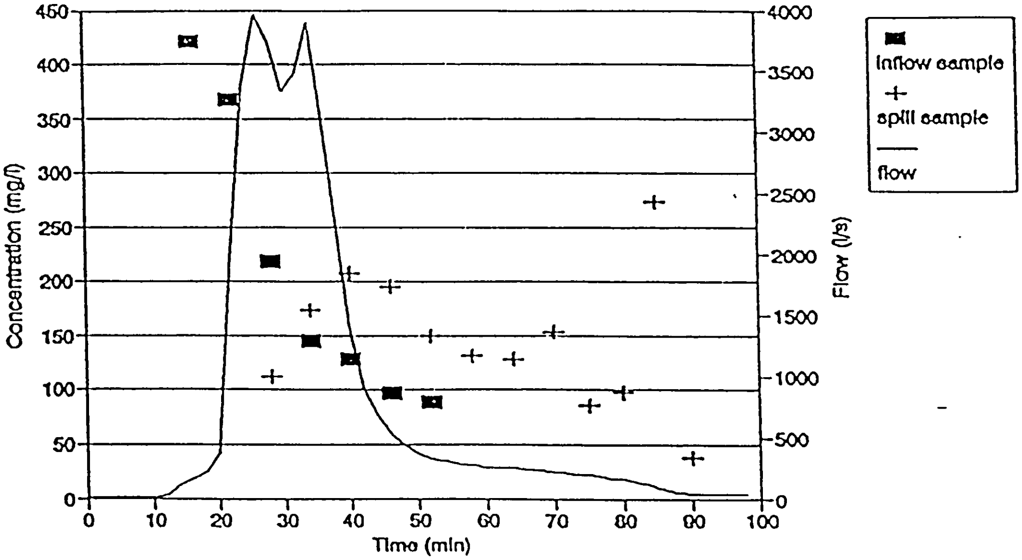


Figure 5.60 Ash Concentration (Inflow and Spill) and Inflow for the Storm on 15 October 1990 (Chesterfield Road)

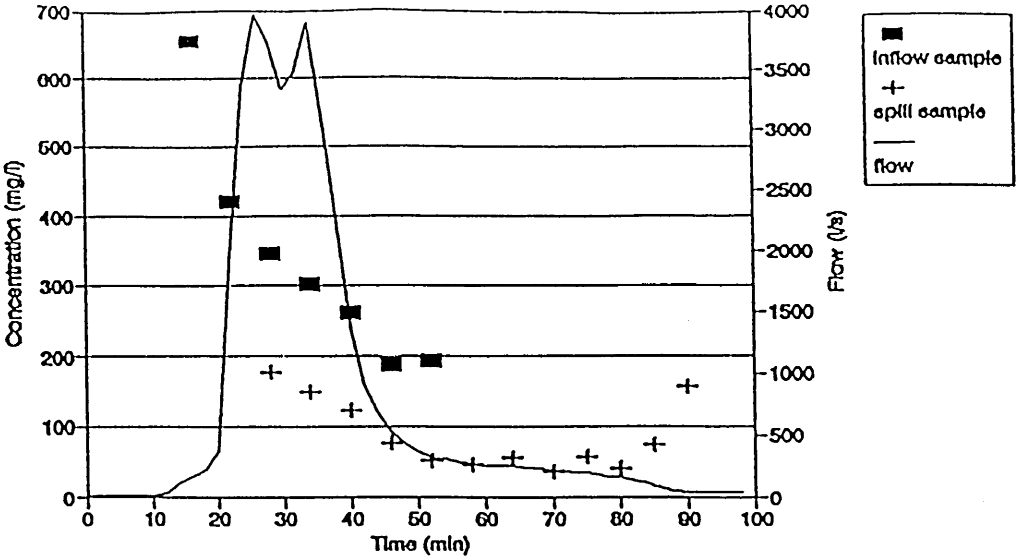


Figure 5.61 BOD Concentration (Inflow and Spill) and Inflow for the Storm on 15 October 1990 (Chesterfield Road)

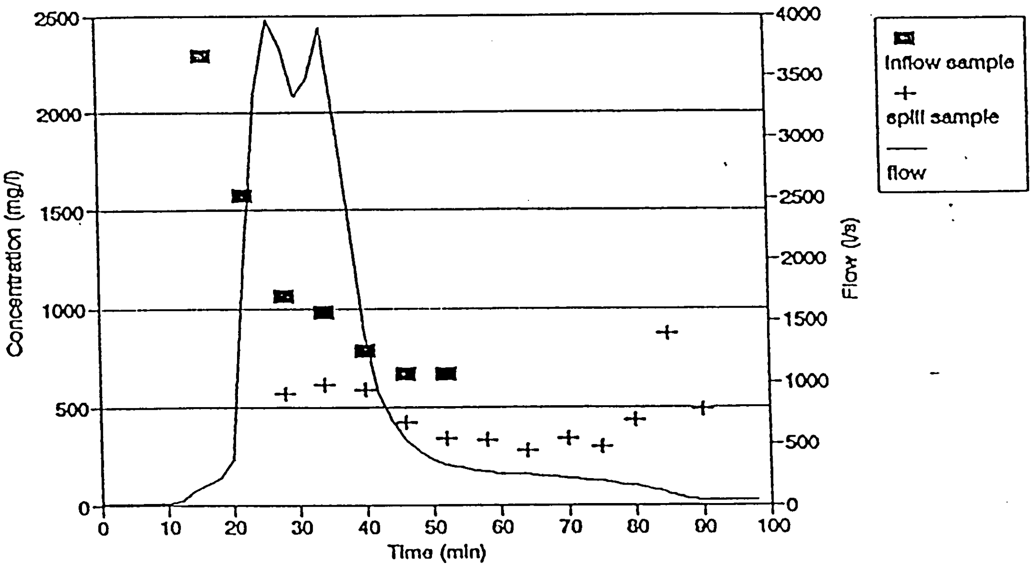


Figure 5.62 COD Concentration (Inflow and Spill) and Inflow for the Storm on 15 October 1990 (Chesterfield Road)

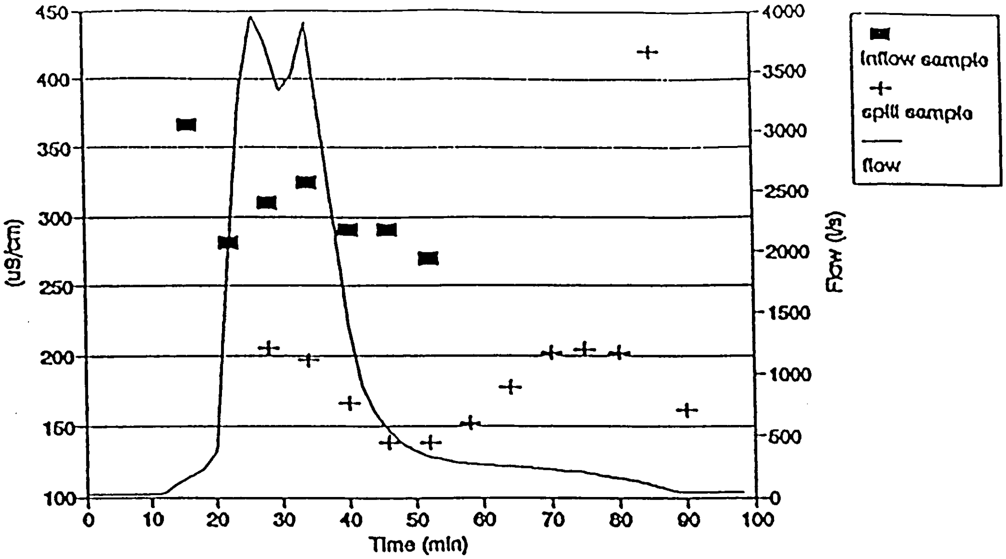


Figure 5.63 pH Value Variation (Inflow and Spill)and the Inflow for the Storm on 15 October 1990 (Chesterfield Road)

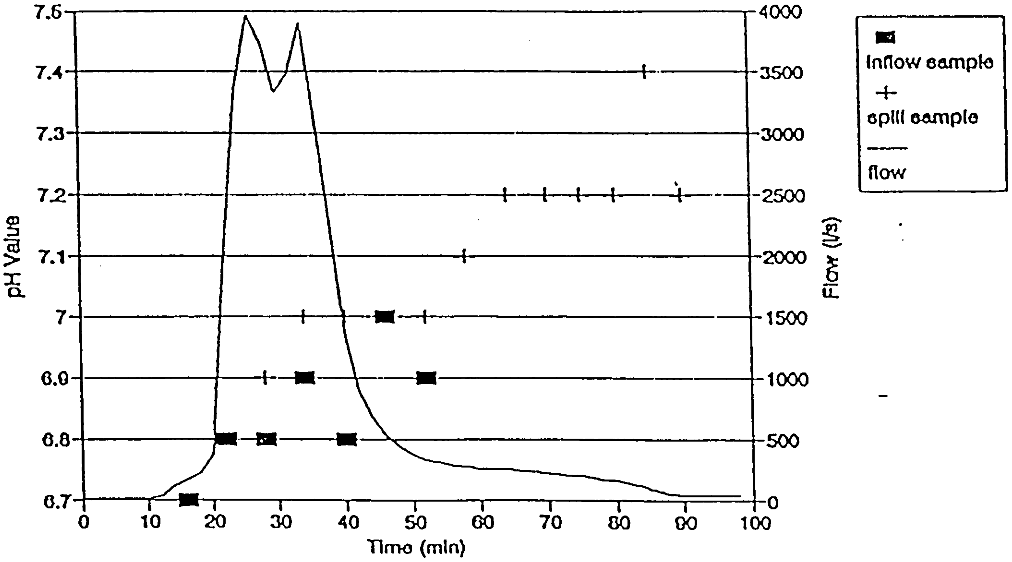


Figure 5.64 Conductivity Variation (Inflow and Spill) and the Inflow for the Storm on 15 October 1990 (Chesterfield Road)

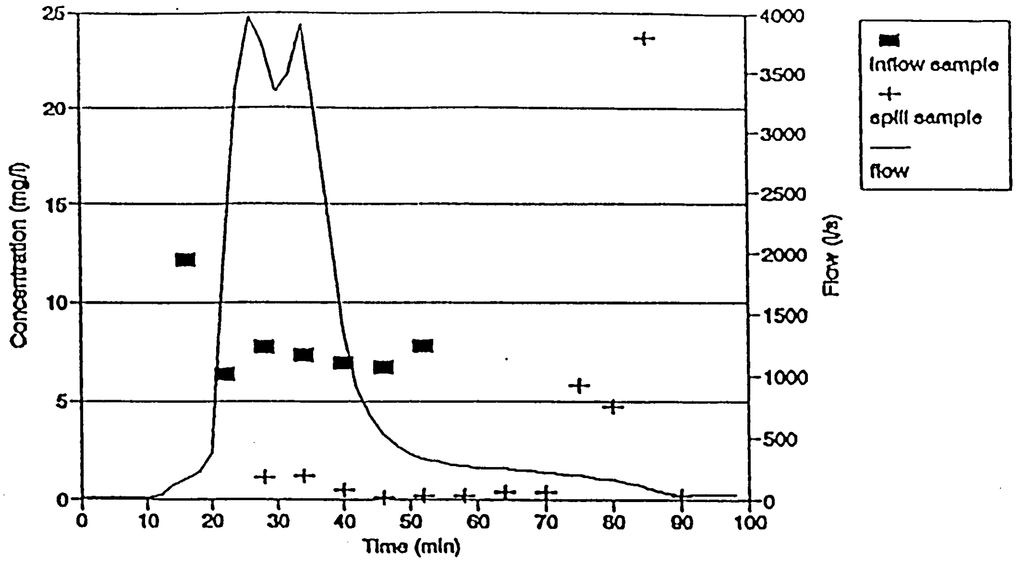


Figure 5.65 Ammonia Concentration (Inflow and Spill) and the Inflow for the Storm on 15 October 1990 (Chesterfield Road)

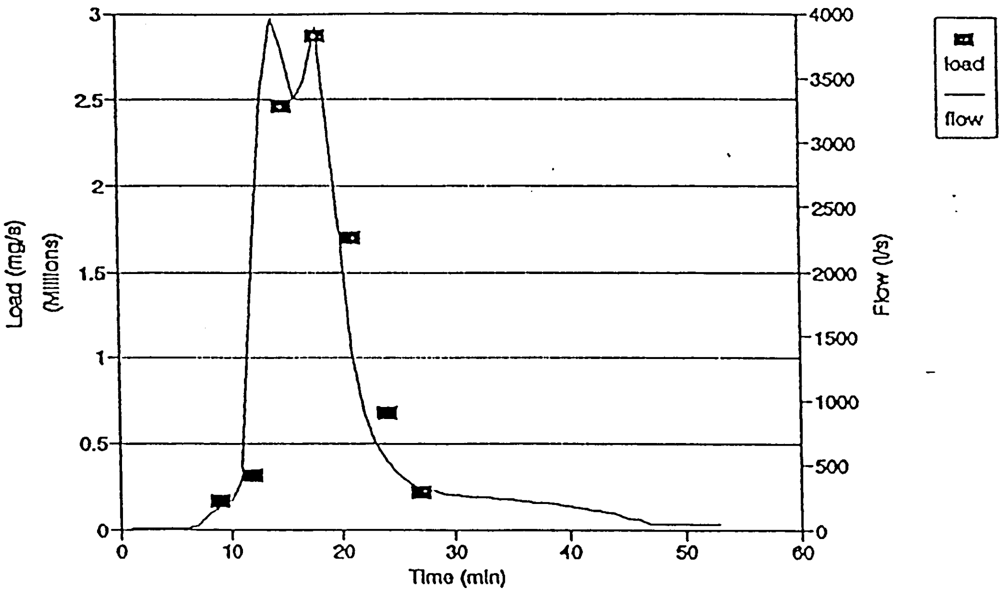


Figure 5.66 Load of Suspended Solids Entering the Stilling Pond Overflow Chamber on 15 October 1990

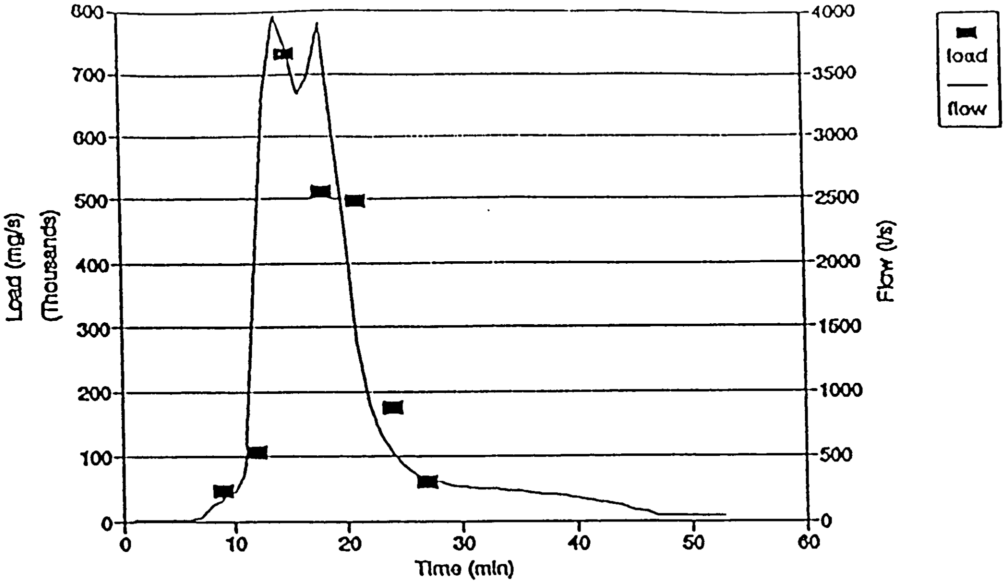


Figure 5.67 Load of Ash Entering the Stilling Pond Overflow Chamber on 15 October 1990

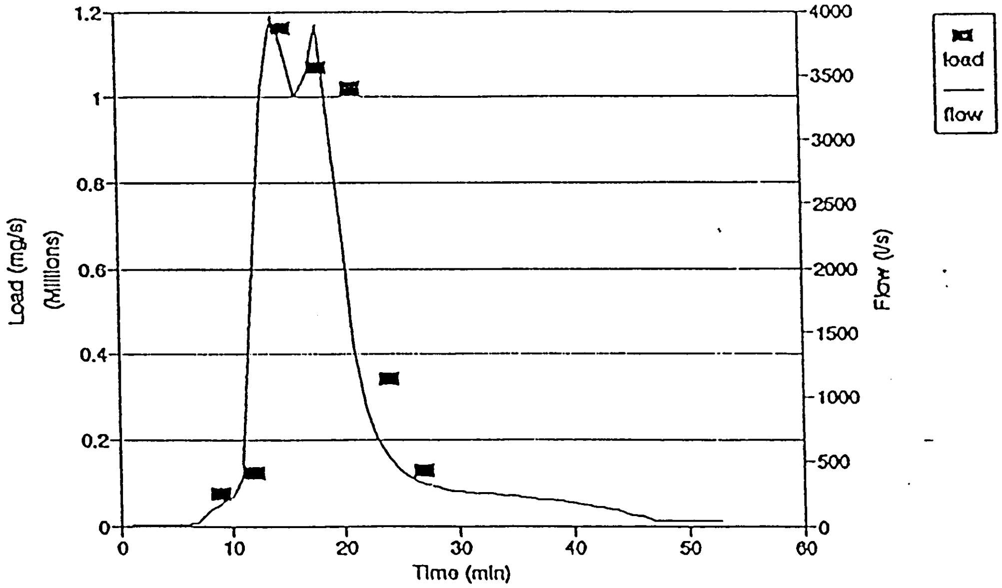


Figure 5.68 Load of BOD Entering the Stilling Pond Overflow Chamber on 15 October 1990

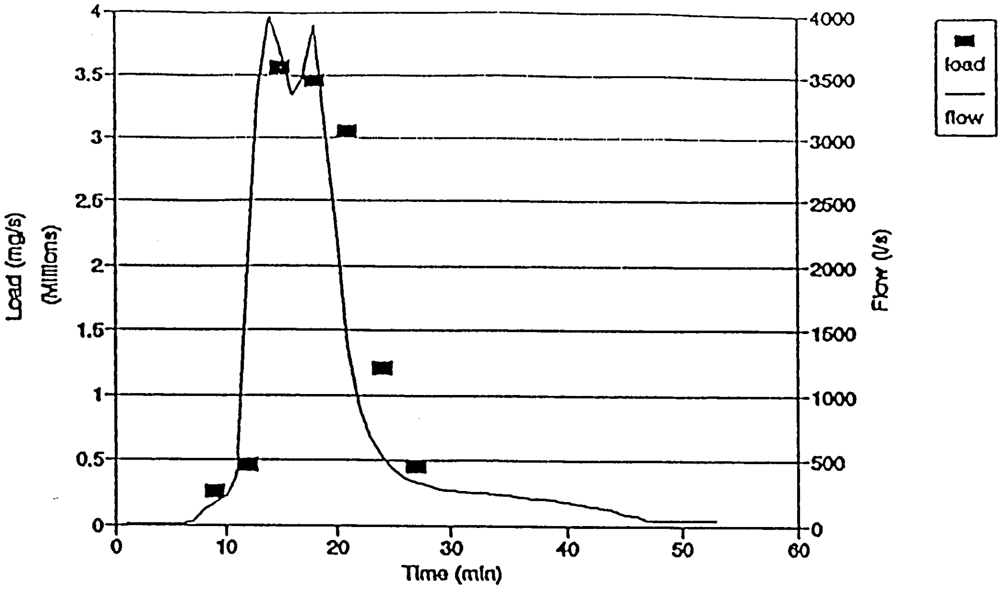


Figure 5.69 Load of COD Entering the Stilling Pond Overflow Chamber on 15 October 1990

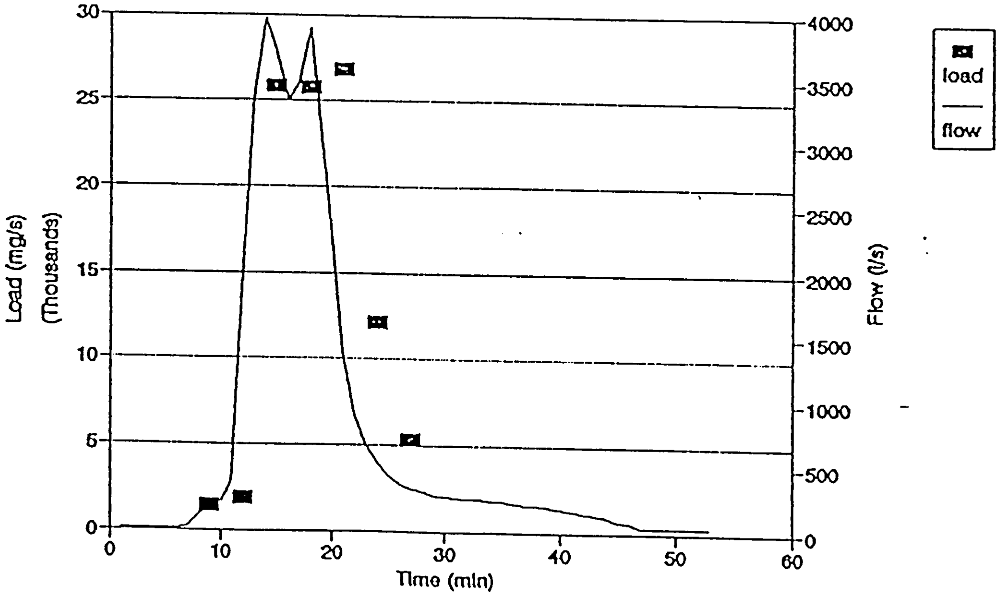


Figure 5.70 Load of Ammonia Entering the Stilling Pond Overflow Chamber on 15 October 1990

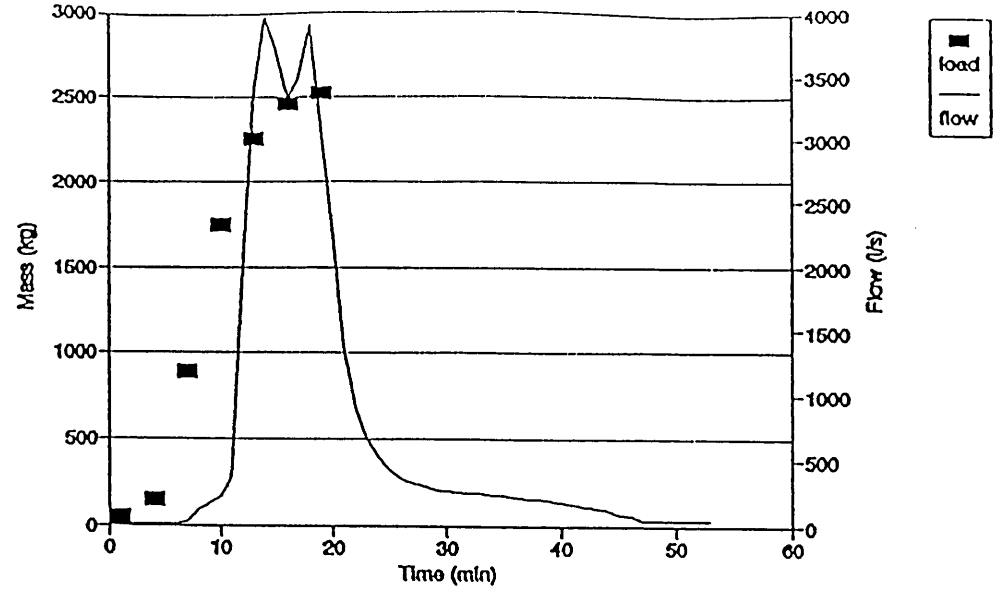


Figure 5.71 Cumulative Mass of Suspended Solids for the Storm on 15 October 1990 at Chesterfield Road

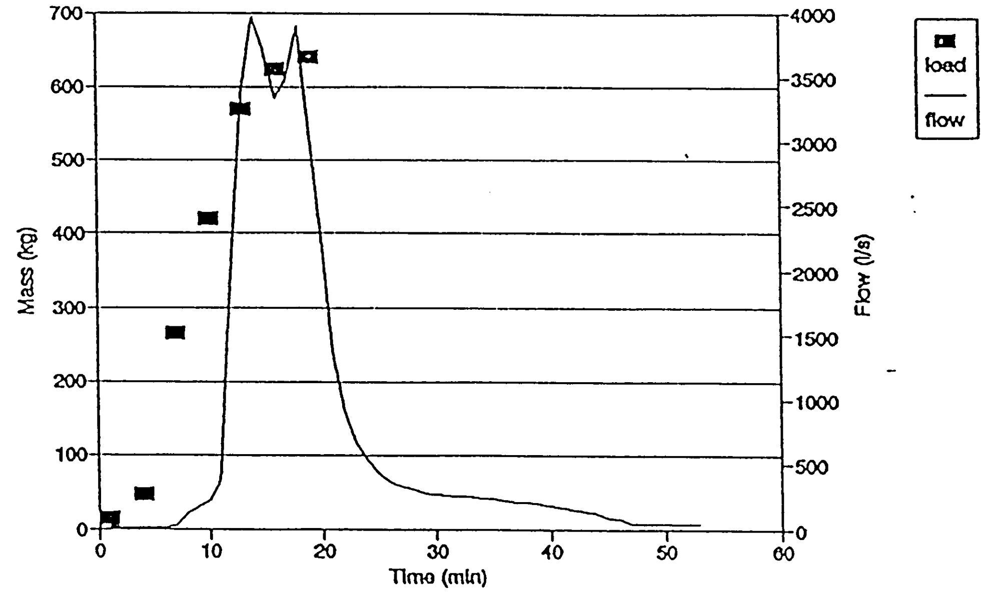


Figure 5.72 Cumulative Mass of Ash for the Storm on 15 October 1990 at Chesterfield Road

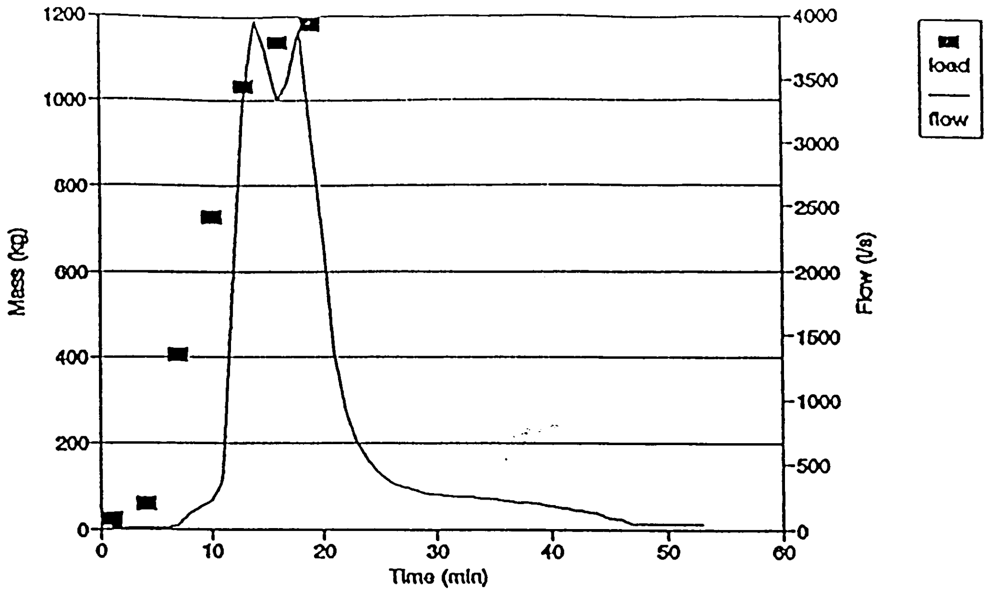


Figure 5.73 Cumulative Mass of BOD for the Storm on 15 October 1990 at Chesterfield Road

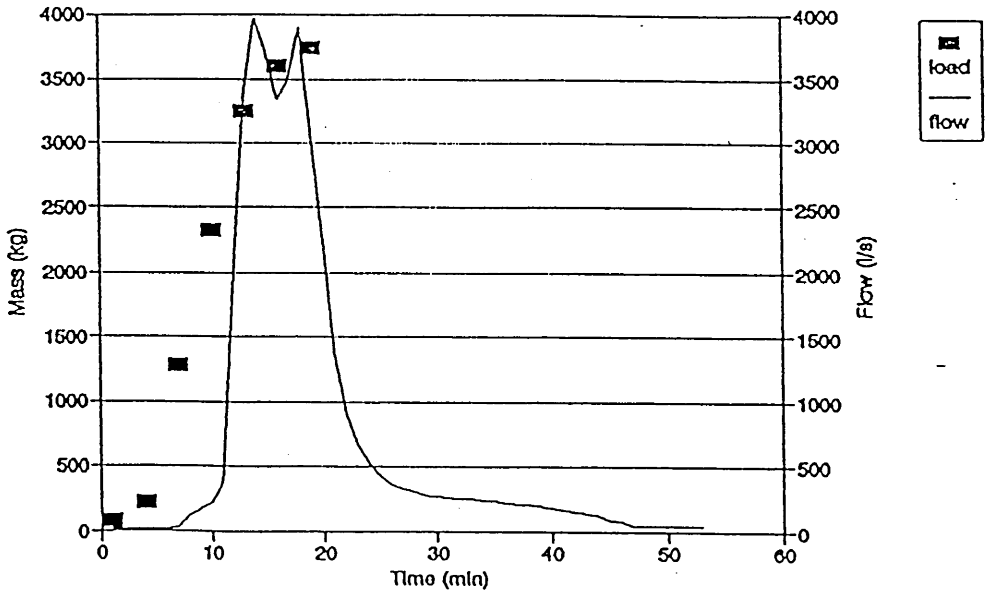


Figure 5.74 Cumulative Mass of COD for the Storm on 15 October 1990 at Chesterfield Road

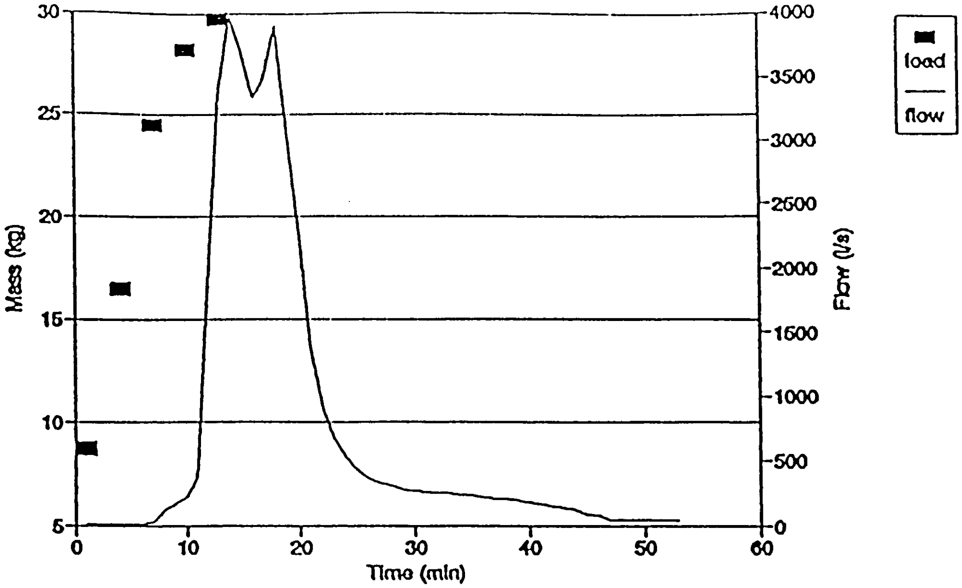


Figure 5.75 Cumulative Mass of Ammonia for the Storm on 15 October 1990 at Chesterfield Road

Table 5.4 t-Test Results for the Stilling Pond Site (Chesterfield Road) (n.s. = not significant)

Storm Event	Suspended Solids	Ash	BOD	COD	Conductivity	Ammonia
3 October 1990 No. Samples = 5	n.s.	n.s.	n.s.	n.s.	n. s.	inflow mean = 6.2 spill mean = 3.2 significance: 5%
15 October 1990 No. Samples = 5	n. s.	n.s.	inflow mean = 259 spill mean = 115 significance: 0.5%	inflow mean = 832 spill mean = 502 significance: 0.1%	n.s.	inflow mean = 7.3 spill mean = 0.6 significance: 0.1%
17 October 1990 No. Samples = 7	n.s.	n.s.	inflow mean = 52 spill mean = 43.1 significance: 0.5%	inflow mean = 131 spill mean = 123 significance: 5%	no spill value	inflow mean = 2.2 spill mean = 1.2 significance: 0.5%
8 March 1991 No. Samples = 12	inflow mean = 148 spill mean = 447 significance : 0.1%	inflow mean = 62.7 spill mean = 212.0 significance: 0.1%	inflow mean = 34.8 spill mean = 99.7 significance: 0.1%	inflow mean = 159.5 spill mean = 473.2 significance: 0.1%	inflow mean = 324 spill mean = 382 significance: 5%	n.s.
19 April 1991 No. Samples = 7	inflow mean = 523 spill mean = 189 significance : 0.1%.	inflow mean = 181 spill mean = 52 significance: 0.1%.	inflow mean = 231 spill mean = 123 significance: 5%	inflow mean = 735 spill mean = 249 significance: 1%	inflow mean = 354 spill mean = -283 significance: 2.5%	inflow mean = 11.3 spill mean = 4.9 significance: 2.5%
29 April 1991 No. Samples = 14	inflow mean = 245 spill mean = 120 significance : 0.1%.	inflow mean = 59 spill mean = 26 significance: 0.5%	inflow mean = 94 spill mean = 38 significance: 0.1%	inflow mean = 287 spill mean = 141 significance: 0.1%	inflow mean = 249 spill mean = 174 significance: 0.1%	inflow mean = 5.2 spill mean = 3.6 significance: 0.1%
13 June1990 No. Samples = 6	n.s.	inflow mean = 359 spill mean = 170 significance: 2.5%	inflow mean = 151 spill mean = 230 significance: 0.1%	inflow mean = 393 spill mean = 663 significance: 0.1%	n.s.	inflow mean = 3.8 spill mean = 4.9 significance: 5%
25 June 1990 No. Samples =7	n. s.	n.s.	n.s.	n. s.	n.s.	n.s.

Table 5.5 t-Test Results for the High Side Weir Site (Dobcroft Road) (n.s. = not significant)

Storm Event	Suspended Solids	Ash	BOD	COD	Conductivity	Ammonia
19 April 1991 No. Samples=6	inflow mean = 869 spill mean = 227 significance : 0.5%	inflow mean = 303 spill mean = 76 significance: 0.5%	inflow mean = 415 spill mean = 128 significance: 1.0%	inflow mean = 1199 spill mean = 292 significance: 1.0%	inflow mean = 355 spill mean = 313 significance: 1.0%	n.s.
25 June 1991 No. Samples=6	inflow mean = 185 spill mean = 94 significance : 0.1%	n.s.	inflow mean = 68 spill mean = 41 significance: 2.5%	n.s.	n.s.	n.s.
27 September 1991 No. Samples=8	n.s.	n.s.	n.s.	n.s.	inflow mean = 194 spill mean = 156 significance: 5.0%	n.s.
17 October 1991 a.m. No. Samples=6	n.s.	n.s.	n.s.	n.s.	inflow mean = 329 spill mean = 283 significance: 0.5%	n.s.
17 October 1991 p.m. No. Samples=8	inflow mean = 239 spill mean = 139 significance : 0.5%	inflow mean = 61 spill mean = 37 significance: 0.5%	inflow mean = 75 spill mean = 46 significance: 1.0%	inflow mean = 252 spill mean = 180 significance: 1.0%	inflow mean = 203 spill mean = 235 significance: 1.0%	n.s.
29 October 1991 No. Samples=13	inflow mean = 305 spill mean = 134 significance : 2.5%	n.s.	inflow mean = 67 spill mean = 41 significance: 0.5%	n.s.	inflow mean = 159 spill mean = 128 significance: 0.1%	inflow mean = 1.4 spill mean = 0.6 significance: 1.0%
18 November 1991 No. Samples=12	inflow mean = 227 spill mean = 128 significance : 0.5%	n.s.	inflow mean = 72 spill mean = 35 significance: 0.1%	inflow mean = 323 spill mean = 186 significance: 0.1%	n.s.	inflow mean = 3.2 spill mean = 1.8 significance: 0.5%

Table 5.6 t-Test Results for the Low Side Weir Site (Retford Road)

Storm Event	Suspended Solids	Ash	BOD	COD	Conductivity	Ammonia
12 March 1992 No. Samples = 13	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
29 March 1992 No. Samples = 15	n.s.	n.s.	n.s.	n.s.	inflow mean = 1010 spill mean = 262 significance: 2.5%	inflow mean = 13.8 spill mean = 4.0 significance: 0.5%
3 July 1992 No. Samples = 7	inflow mean = 139 spill mean = 274 significance : 0.5%	inflow mean = 43.6 spill mean = 92.7 significance: 0.1%	inflow mean = 964 spill mean = 211 significance: 0.5%	n.s.	inflow mean = 362 spill mean = 534 significance: 1.0%	inflow mean = 7.6 spill mean = 12.7 significance: 5.0%
21 July 1992 No. Samples = 7	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
23 July 1992 No. Samples = 8	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
27 August 1992 No. Samples = 19	inflow mean = 266 spill mean = 317 significance : 0.1%	inflow mean = 76 spill mean = 125 significance: 0.1%	n.s.	n.s.	n.s.	n.s.
21 September 1992 No. Samples = 12	inflow mean = 233 spill mean = 317 significance : 0.1%	n.s.	n.s.	n.s.	n.s.	n.s.
28 October1992 No. Samples = 23	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Continued on Next Page

Table 5.6 t-Test Results for the Low Side Weir Site (Retford Road) (Continued from Previous Page)

Storm Event	Suspended Solids	Ash	BOD	COD	Conductivity	Ammonia
11 November 1992 No. Samples = 21	inflow mean = 242 spill mean = 97 significance : 99.9%	n.s.	inflow mean = 264 spill mean = 39 significance: 99.9%	inflow mean = 615 spill mean = 206 significance: 99.9%	inflow mean = 746 spill mean = 161 significance:99.9%	inflow mean = 5.8 spill mean = 1.3 significance: 99.9%
19 November 1992 No. Samples = 4	inflow mean = 472 spill mean = 95 significance : 99.9%	inflow mean = 186 spill mean = 38 significance: 99.9%	inflow mean = 186 spill mean = 48 significance: 99%	inflow mean = 690 spill mean = 137 significance: 99.9%	n.s.	n.s.
24 November 1992 No.Samples = 20	inflow mean = 295 spill mean = 68 significance : 99.9%	inflow mean = 82 spill mean = 29 significance: 99.9%	inflow mean = 319 spill mean = 42 significance: 99.9%	inflow mean = 720 spill mean = 145 significance: 99.9%	inflow mean = 653 spill mean = 204 significance: 99.9%	inflow mean = 7.3 spill mean = 2.0 significance: 99.9%
30 November 1992 No. Samples = 11	n.s.	inflow mean = 132 spill mean = 184 significance: 99%	n.s.	n.s.	n.s.	n.s.

Table 5.7 t-Test Results for the High Side Weir (Leyburn Road) (n.s. = not significant)

Storm Event	Suspended Solids	Ash	BOD	COD	Conductivity	Ammonia
9 November 1992 No. Samples = 19	inflow mean =183 spill mean = 93 significance: 0.1%	inflow mean =56 spill mean = 31 significance: 5.0%	inflow mean =58 spill mean = 40 significance: 0.5%	inflow mean = 209 spill mean = 136 significance: 0.1%	n.s.	n.s.
11 November 1992 No. Samples = 17	inflow mean =61 spill mean = 41 significance : .1.0%	n.s.	n.s.	n.s.	n.s.	n.s.
11 November 1992 No. Samples = 17	inflow mean =228 spill mean = 187 significance : 0.1%	n.s.	inflow mean = 72 spill mean = 39 significance: 2.5%	n.s.	inflow mean = 258 spill mean = 213 significance: 0.5%	n.s.
12 November 1992 No. Samples = 24	n.s.	n.s.	inflow mean =43 spill mean = 34 significance: 2.5%	n.s.	inflow mean = 406 spill mean = 358 significance: 0.1%	n.s.
24 November 1992 No. Samples = 21	inflow mean =84 spill mean = 45 significance : 1.0%	n.s.	inflow mean =38 spill mean = 28 significance: 5.0%	n.s.	inflow mean = 184 spill mean = 161 significance: 2.5%	n.s.
30 November 1992 No. Samples = 16	n.s.	n.s.	no samples	n.s.	n.s.	n.s.
2 December 1992 No. Samples = 18	n.s.	n.s.	no samples	inflow mean = 205 spill mean = 164 significance: 2.5%	n.s.	n.s.
3 December 1992 No. Samples = 23	inflow mean =91 spill mean = 54 significance : .0.1%	inflow mean =13 spill mean = 7 significance: 0.1%	n.s.	inflow mean = 134 spill mean = 100 significance: 0.1%	n.s.	n.s.

Calculations to estimate the loads of the finely suspended and dissolved material for the sampling period were made and these are given in Tables 5.8 to 5.11.. These tables also show the percentage contribution of the loads of dry weather sewage origin to the total load. The percentage contribution of the dry weather flow volume to the inflow volume that was recorded during the sampling period is also given.

The dissolved and finely suspended solids loads comparisons for samples at similar time periods given in these tables do not represent the total inflow and spill loads for the whole of the storms as for storms lasting over 200 minutes only a proportion of the storms were sampled. The values given indicate the load coming in and the load contained in the spill flow for the periods where the inflow and spill flow samples coincide (assuming that the time lag between the inflow sampler and the spill sampler is less than the 5 minute sampling frequency). The inflow values are different to the inflow values for the same storms given in later parts of the table because the latter represent the load for the whole inflow sampling period and not just the period where the inflow and the spill samples coincide.

The calculated loads for each of the measured parameters in turn for each of the storms with adequate data given indicate the estimated dry weather sewage load for the same duration at the same time of the day. The 'storm load' is simply the result of subtracting the dry weather flow load from the total load. This allows for the changes in dry weather flow concentrations that occur during the day.

The antecedent dry weather period (ADWP), peakedness and intensity of the rainstorms producing the storms with samples is given in Tables 5.12 to 5.15. The peakedness and intensity of the antecedent storm is also given here. The delay time is also given on these tables. This value is similar to that described by Saul (see Chapter 2). It refers to the time between the first storm flow entering the overflow chamber and the first spill over the weir. It was hoped that relationships between these parameters (ADWP, storm intensity, delay time etc.) and the volume of flow or the load of pollutant material spilled to the watercourse could be determined for the chambers under investigation. The results of these investigations and an interpretation of the results described here are given in Chapter 6.

The possibility of any correlation between the measured parameters was first assessed by examining graphs of all the samples of one parameter against all the samples of a second parameter. Examples where a reasonably strong relationship exists (R^2 over 0.5) are given in Figures 5.76 to 5.83 for the inflow and the spill samples separately. Only the data for the Leyburn Road site is given in the main text. The data for the other sites is given in Appendix 3. Correlation analysis confirmed the existence of significant relationships. This investigation was performed for every storm with sample data. Where significant correlations were found to exist regression analysis was used to establish the form of the relationship.

Table 5.8 Load Information for Chesterfield Road

a. Percentage Contribution of Dry Weather Flow Loads to Total Loads

Date	Time of Day	Duration	Suspended Solids	Ash	BOD	COD	Ammonia	Flow
3 October 1990	05:06	306	0.15	0.05	0.33	0.29	1.84	0.57
15 October 1990	15:14	914	0.16	0.11	0.34	0.29	1.89	0.56
17 October 1990	20:22	1222	4.40	4.06	7.35	5.02	17.6	1.55
8 March 1991	17:22	1042	5.21	1.73	17.9	12.7	13.1	3.76
19 April 1991	08:06	486	6.97	1.36	11.0	12.8	61.9	9.75
29 April 1991	21:20	1280	4.87	2.64	10.4	10.7	31.7	5.26
13 June 1991	08:20	500	2.56	0.35	7.23	9.43	60.8	4.71
25 June 1991	05:26	326	0.87	0.37	1.21	1.7	11.2	1.89

b. Ratio of the % of the Total Flow to the % of the Total Parameter Load Provided by the Dry Weather Flow

Date	Time	Duration	Suspended Solids	Ash	BOD	COD	Ammonia
3 October 1990	05:06	306	0.26	0.09	0.58	0.51	3.23
15 October 1990	15:14	914	0.29	0.19	0.60	0.51	3.37
17 October 1990	20:22	1222	2.84	2.62	4.74	3.24	11.37
8 March 1991	17:22	1042	1.39	0.46	4.77	3.37	3.49
19 April 1991	08:06	486	0.71	0.14	1.13	1.31	6.34
29 April 1991	21:20	1280	0.93	0.50	1.98	2.04	6.03
13 June 1991	08:20	500	0.54	0.07	1.54	2.00	12.91
25 June 1991	05:26	326	0.46	0.20	0.64	0.90	5.93

c. Volumes of Flow

Date	Time	Total Inflow (l)	Storm Flow (l)	Dry Weather Flow for the Sampling Period (l)
3 October 1990	05:06	2566500	2551920	14580
15 October 1990	15:14	3602670	3582420	20250
17 October 1990	20:22	5396850	5313000	83850
8 March 1991	17:22	2116590	2036940	79650
19 April 1991	08:06	1034310	933510	100800
29 April 1991	21:20	1388070	1315020	73050
13 June 1991	08:20	739350	704550	34800
25 June 1991	05:26	1310700	1285950	24750

d. Dissolved and Finely Suspended Solids Load Comparisons for Similar Time Periods

Storm Event	No. Samples	Sampling Time (min)	Suspended Solids (kg)	Ash (kg)	BOD (kg)	COD (kg)	Ammonia (kg)
3 October 1990							
inlet samples	5	15	620.8	233.6	165.3	659.9	8.30
spill samples	5	15	31.9	10.2	8.9	31.8	0.20
15 October 1990							
inlet samples	5	15	534.4	131.3	251.4	803.1	6.80
spill samples	5	15	147.7	64.8	34.1	168.9	0.15
17 October 1990							
inlet samples	7	35	73.9	17.4	32.7	145.6	1.70
spill samples	7	35	17.4	3.9	14.8	26.7	0.30
8 March 1991							
inlet samples	22	110	446.4	208	109	496	9.30
spill samples	22	110	270.4	121	58.8	271.4	2.90
19 April 1991							
inlet samples	7	35	374.4	133.2	152.3	470.9	3.70
spill samples	7	35	3.5	1.0	2.3	4.7	0.09
29 April 1991							
inlet samples	14	70	197.5	48.3	77.8	233.7	4.50
spill samples	14	70	13.8	3.7	4.8	18.4	0.70
13 June 1991							
inlet samples	6	30	393.5	188.4	80.6	211.8	2.04
spill samples	6	30	142.1	41.3	57.6	152	1.10
25 June 1991							
inlet samples	7	35	43.5	5.1	14.9	57.2	2.94
spill samples	7	35	16.9	2.6	7.5	23.5	0.30

e. SUSPENDED SOLIDS

Date	Time	Total Load (Kg)	Storm Load (Kg)	DWF Load (Kg)	% of Total Provided by Dry Weather Sewage
3 October 1990	05:06	1201.1	1199.3	1.90	0.15
15 October 1990	15:14	2759.3	2754.9	4.40	0.16
17 October 1990	20:22	507.4	485.0	22.4	4.41
8 March 1991	17:22	505.3	479.0	26.3	5.20
19 April 1991	08:06	560.8	521.8	39.1	6.97
29 April 1991	21:20	359.4	341.9	17.5	4.87
13 June 1991	08:20	502.0	487.0	15.1	3.00
25 June 1991	05:26	355.8	332.8	2.9	0.87

f. ASH

Date	Time	Total Load (Kg)	Storm Load (Kg)	DWF Load (Kg)	% of Total Provided by Dry Weather Sewage
3 October 1990	05:06	338.2	338.0	0.2	0.05
15 October 1990	15:14	729.0	728.2	0.8	0.11
17 October 1990	20:22	97.6	93.6	4.0	4.06
8 March 1991	17:22	233.2	229.2	4.0	1.73
19 April 1991	08:06	197.0	194.3	2.7	1.36
29 April 1991	21:20	91.3	88.9	2.4	2.64
13 June 1991	08:20	277.0	276.1	0.9	0.35
25 June 1991	05:26	49.1	48.9	0.2	0.37

g. BIOCHEMICAL OXYGEN DEMAND (BOD)

Date	Time	Total Load (Kg)	Storm Load (Kg)	DWF Load (Kg)	% of Total Provided by Dry Weather Sewage
3 October 1990	05:06	337.9	336.8	1.1	0.33
15 October 1990	15:14	1180.4	1176.4	4.0	0.11
17 October 1990	20:22	275.1	254.8	20.3	7.35
8 March 1991	17:22	122.8	100.8	22.0	17.92
19 April 1991	08:06	248.1	220.7	27.4	11.04
29 April 1991	21:20	142.4	127.6	14.8	10.41
13 June 1991	08:20	131.7	122.2	9.5	7.23
25 June 1991	05:26	141.7	140.0	1.7	1.21

h. CHEMICAL OXYGEN DEMAND (COD)

Date	Time	Total Load (Kg)	Storm Load (Kg)	DWF Load (Kg)	% of Total Provided by Dry Weather Sewage
3 October 1990	05:06	1359.1	1355.2	3.9	0.29
15 October 1990	15:14	3880.4	3869.2	11.2	0.29
17 October 1990	20:22	1142.5	1085.1	57.4	5.02
8 March 1991	17:22	558.3	487.6	70.7	12.67
19 April 1991	08:06	723.4	631.0	92.4	12.77
29 April 1991	21:20	422.0	376.7	45.3	10.73
13 June 1991	08:20	349.5	316.6	32.9	9.43
25 June 1991	05:26	368.6	362.3	6.3	1.70

i. AMMONIA

Date	Time	Total Load	Storm Load	DWF Load	% of Total Provided by Dry Weather Sewage
		(Kg)	(Kg)	(Kg)	
3 October 1990	05:06	25.6	25.1	0.5	1.84
15 October 1990	15:14	26.2	25.7	0.5	1.90
17 October 1990	20:22	14.2	17.7	2.5	17.62
8 March 1991	17:22	17.5	15.2	2.3	13.13
19 April 1991	08:06	9.8	3.7	6.1	61.85
29 April 1991	21:20	7.8	5.3	2.5	31.70
13 June 1991	08:20	4.0	1.6	2.4	60.82
25 June 1991	05:26	6.7	5.9	0.7	11.21

Table 5.9 Load Information for Dobcroft Road

a. Percentage Contribution of Dry Weather Flow Loads to Total Loads

Date	Time of Day	Duration	Suspended Solids	Ash	BOD	COD	Ammonia	Flow
19 April 1991	08:22	196	3.4	1.3	8.8	7.25	9.9	8.6
25 June 1991	05:26	192	3.3	3.1	8.3	8.3	40.1	2.9
27 Sept. 1991	23:06	46	0.98	0.73	3.5	4.32	31.1	11.1
17 Oct. 1991 (1)	06:44	136	7.96	12.2	45.3	19.95	43.2	8.7
17 Oct. 1991 (2)	18:10	232	2.1	0.89	8.4	5.8	57.6	4.2
29 Oct. 1991	00:36	424	0.28	0.16	0.66	0.61	6.06	2.4
18 Nov. 1991	23:56	220	0.3	0.5	0.77	0.65	5.3	2.5

b. Ratio of the % of the Total Flow to the % of the Total Parameter Load Provided by the Dry Weather Flow

Date	Time of Day	Duration	Suspended Solids	Ash	BOD	COD	Ammonia
19 April 1991	08:22	196	0.4	0.15	1.02	0.84	1.15
25 June 1991	05:26	192	0.13	1.07	2.86	2.86	13.8
27 Sept. 1991	23:06	46	0.09	0.07	0.32	0.39	2.8
17 Oct. 1991 a.m.	06:44	136	0.9	1.4	5.2	2.29	4.97
17 Oct. 1991 p.m.	18:10	232	0.5	0.21	2.0	1.38	13.7
29 Oct. 1991	00:36	424	0.12	0.07	0.28	0.25	2.53
18 Nov. 1991	23:56	220	0.12	0.2	0.308	0.26	2.12

c. Volumes of Flow

Date	Time	Total Inflow (l)	Storm Flow (l)	Dry Weather Flow for the Sampling Period (l)
19 April 1991	08:22	587700	537450	50250
25 June 1991	05:26	712410	691710	20700
27 Sept. 1991	23:06	360870	320970	39900
17 Oct. 1991 a.m.	06:44	952200	869400	82800
17 Oct. 1991 p.m.	18:10	641640	614640	27000
29 Oct. 1991	00:36	681300	665150	16650
18 Nov. 1991	23:56	1003800	979050	24750

d. Dissolved and Finely Suspended Solids Load Comparisons for Similar Time Periods

Storm Event	No. Samples	Sampling Time (min)	Suspended Solids (Kg)	Ash (Kg)	BOD (Kg)	COD (Kg)	Ammonia (Kg)
27 Sept. 1991							
inlet samples	10	50	128.8	40.3	27.3	83.2	0.9
spill samples	10	50	35.8	9.9	9.7	38	0.4
17 Oct. 1991 a.m.							
inlet samples	8	40	51.6	7.9	12.9	80.3	1.5
spill samples	8	40	26.3	1.3	5.13	35.5	0.59
17 Oct. 1991 p.m.							
inlet samples	6	30	78.2	20	24.3	83.6	0.27
spill samples	6	30	18.3	5.0	6.8	25.5	0.5
29 Oct. 1991							
inlet samples	13	65	149.4	5.9.3	2.2	112.9	0.8
spill samples	13	65	4.8	0.9	1.5	5.9	0.04
18 Nov. 1991							
inlet samples	12	60	150.8	24.1	45.2	205.1	1.4
spill samples	12	60	36.8	9.4	9.8	52.3	0.52
19 April 1991							
inlet samples	3	15	94	34	35.5	103	1.0
spill samples	3	15	4.4	1.5	2.4	5.7	0.1
25 June 1991							
inflow samples	6	30	54.9	4.2	20.7	50.4	0.5
spill samples	6	30	11.2	2.8	5.0	17.2	0.3

e. SUSPENDED SOLIDS

Date	Time	Total Load (Kg)	Storm Load (Kg)	DWF Load (Kg)	% of Total Provided by Dry Weather Sewage
19 April 1991	08:22	301.7	291.4	10.3	3.40
25 June 1991	05:26	150.0	145.1	4.9	3.30
27 September 1991	23:06	134.5	101.9	1.3	0.98
17 October 1991 a.m.	06:44	206.6	190.1	16.5	7.96
17 October 1991 p.m.	18:10	126.2	123.5	2.7	2.10
29 October 1991	00:36	185.5	185.0	0.5	0.28
18 November 1991	23:56	222.9	222.14	0.76	0.30

f. ASH

Date	Time	Total Load (Kg)	Storm Load (Kg)	DWF Load (Kg)	% of Total Provided by Dry Weather Sewage
19 April 1991	08:22	106.0	104.6	1.4	1.30
25 June 1991	05:26	22.1	21.4	0.7	3.10
27 September 1991	23:06	42.3	42.0	0.3	0.73
17 October 1991 a.m.	06:44	19.7	17.3	2.4	12.20
17 October 1991 p.m.	18:10	29.2	28.9	0.3	0.89
29 October 1991	00:36	8.0	7.9	0.1	0.16
18 November 1991	23:56	37.7	37.5	0.2	0.50

g. BOD

Date	Time	Total Load (Kg)	Storm Load (Kg)	DWF Load (Kg)	% of Total Provided by Dry Weather Sewage
19 April 1991	08:22	132.5	120.9	11.6	8.80
25 June 1991	05:26	59.5	54.6	4.9	8.30
27 September 1991	23:06	29.1	28.1	1.0	3.50
17 October 1991 a.m.	06:44	44.0	24.1	19.9	45.30
17 October 1991 p.m.	18:10	48.7	44.6	4.1	8.40
29 October 1991	00:36	50.7	50.3	0.3	0.66
18 November 1991	23:56	66.6	66.1	0.5	0.77

h. COD

Date	Time	Total Load (Kg)	Storm Load (Kg)	DWF Load (Kg)	% of Total Provided by Dry Weather Sewage
19 April 1991	08:22	391.8	363.4	28.4	7.25
25 June 1991	05:26	129.4	118.7	10.7	8.30
27 September 1991	23:06	87.7	83.9	3.8	4.32
17 October 1991 a.m.	06:44	230.4	184.5	46.0	19.95
17 October 1991 p.m.	18:10	152.0	143.2	8.8	5.80
29 October 1991	00:36	175.9	174.8	1.1	0.61
18 November 1991	23:56	299.5	297.6	1.9	0.65

i. AMMONIA

Date	Time	Total Load (Kg)	Storm Load (Kg)	DWF Load (Kg)	% of Total Provided by Dry Weather Sewage
19 April 1991	08:22	6.18	5.57	0.61	9.9
25 June 1991	05:26	1.77	1.06	0.71	40.1
27 September 1991	23:06	0.98	0.68	0.31	31.1
17 October 1991 a.m.	06:44	3.31	1.88	1.43	43.2
17 October 1991 p.m.	18:10	0.91	0.39	0.52	57.6
29 October 1991	00:36	1.37	1.29	0.08	6.1
18 November 1991	23:56	2.91	2.76	0.15	5.3

Table 5.10 Load Information for Retford Road

a. Percentage Contribution of Dry Weather Flow Loads to Total Loads

Date	Time of Day	Duration	Suspended Solids	Ash	BOD	COD	Ammonia	Flow
12 March 1992	00:32	132	1.9	0.2	4.2	3.1	5.2	15.1
29 March 1992	19:36	110	4.7	0.7	9.9	8.8	16.2	9.3
3 July 1992	13:26	498	91.7	20.6	-	-	67.9	32.9
21 July 1992	04:06	282	8.8	1.16	14.5	9.9	3.0	8.4
23 July 1992	17:42	150	4.7	2.1	9.7	11.1	7.1	8.4
27 August 1992	07:04	38	26.7	10.0	49.7	75.3	-	32.8
21 September 1992	16:44	456	57.5	7.2	-	77.6	38.9	25.8
29 October 1992	11:56	202	8.5	2.7	30.1	18.8	-	12.0
11 November 1992	20:08	390	5.5	1.7	7.4	6.9	30.1	8.8
19 November 1992	03:53	140	2.4	0.3	5.3	4.1	9.2	7.3
24 November 1992	07:18	204	3.9	0.8	5.2	5.9	29.0	9.2
30 November 1992	12:32	174	5.6	0.5	-	7.2	5.3	8.3

b. Ratio of the % of the Total Flow to the % of the Total Parameter Load Provided by the Dry Weather Flow

Date	Time of Day	Duration	Suspended Solids	Ash	BOD	COD	Ammonia
12 March 1992	00:32	132	0.13	0.01	0.28	0.21	0.34
29 March 1992	19:36	110	0.50	0.08	1.06	0.95	1.74
3 July 1992	13:26	498	2.79	0.63	-	-	2.06
21 July 1992	04:06	282	1.05	0.14	1.73	1.18	0.36
23 July 1992	17:42	150	0.56	0.24	1.15	1.32	0.85
27 August 1992	07:04	38	0.81	0.30	1.52	2.30	-
21 September 1992	16:44	456	2.23	0.28	-	3.01	1.51
29 October 1992	11:56	202	0.71	0.23	2.51	1.57	-
11 November 1992	20:08	390	0.63	0.19	0.84	0.78	3.42
19 November 1992	03:53	140	0.33	0.03	0.73	0.56	1.26
24 November 1992	07:18	204	0.42	0.09	0.57	0.64	3.15
30 November 1992	12:32	174	0.67	0.06	-	0.87	0.64

c. Volumes of Flow

Date	Time	Total Inflow	Storm Flow	Dry Weather Flow for the Sampling Period
12 March 1992	00:32	117000	99300	17700
29 March 1992	19:36	542400	491850	50550
3 July 1992	13:26	83400	55950	27450
21 July 1992	04:06	380400	348600	31800
23 July 1992	17:42	451200	413250	37950
27 August 1992	07:04	294600	198000	96600
21 September 1992	16:44	182700	135600	47100
29 October 1992	11:56	775200	681900	93300
11 November 1992	20:08	609000	555450	53550
19 November 1992	03:53	199500	184950	14550
24 November 1992	07:18	457200	415200	42000
30 November 1992	12:32	308400	282750	25650

d. Dissolved and Finely Suspended Solids Load Comparisons for Similar Time Periods

Storm Event	No. Samples	Sampling Time (min)	Suspended Solids (Kg)	Ash (Kg)	BOD (Kg)	COD (Kg)	Ammonia (Kg)
12 March 1992							
inlet samples	8	40	51.6	7.9	12.9	80.3	1.5
spill samples	8	40	26.3	1.3	5.13	35.5	0.6
21 July 1992							
inlet samples	7	35	58.6	20.7	13.9	68.4	1.2
spill samples	7	35	29.4	10.9	6.7	36.9	0.6
23 July 1992							
inlet samples	4	20	5.2	1.1	3.7	8.4	0.1
spill samples	4	20	2.3	0.5	1.3	3.0	0.1
27 August 1992							
inlet samples	19	95	77.9	21.2	67.9	99.9	1.7
spill samples	19	95	32.1	13.8	15.4	31.3	0.6
21 September 1992							
inlet samples	10	50	37.5	8.2	15.8	50.9	1.0
spill samples	10	50	19.9	5.0	8.3	34.7	0.3
27 October 1992							
inlet samples	23	115	193.4	82.4	63.9	248.8	5.1
spill samples	23	115	63	29.4	22.2	99.0	1.8
11 November 1992							
inlet samples	21	105	150.8	21.8	162.1	390.1	3.9
spill samples	21	105	33.1	11.2	13.5	52.5	0.5
19 November 1992							
inflow samples	4	20	36.9	14	22	49.4	0.7
spill samples	4	20	5.2	2.2	2.6	7.4	0.4
24 November 1992							
inflow samples	19	95	131.5	34.7	155.3	339.8	3.1
spill samples	19	95	10.9	4.6	6.5	20.3	1.2

e. SUSPENDED SOLIDS

Date	Time	Total Load (Kg)	Storm Load (Kg)	DWF Load (Kg)	% of Total Provided by Dry Weather Sewage
12 March 1992	00:32	190.1	186.5	3.7	1.9
29 March 1992	19:36	182.6	174.1	7.5	4.6
3 July 1992	13:26	11.6	1.0	10.6	91.7
21 July 1992	04:06	144.9	132.1	12.8	8.8
23 July 1992	17:42	14.3	13.7	0.7	4.7
27 August 1992	07:04	77.9	57.1	20.8	26.7
21 September 1992	16:44	43.4	18.4	25.0	57.5
29 October 1992	11:56	208.5	190.8	17.7	8.8
11 November 1992	20:08	152.3	143.9	8.4	5.5
19 November 1992	03:53	75.7	73.9	1.8	2.4
24 November 1992	07:18	141.3	135.8	5.6	3.9
30 November 1992	12:32	184.3	173.9	10.4	5.6

f. ASH

Date	Time	Total Load (Kg)	Storm Load (Kg)	DWF Load (Kg)	% of Total Provided by Dry Weather Sewage
12 March 1992	00:32	68.0	67.9	0.1	0.2
29 March 1992	19:36	39.3	39.0	0.3	0.7
3 July 1992	13:26	0.5	2.7	0.7	20.6
21 July 1992	04:06	31.9	31.5	0.4	1.2
23 July 1992	17:42	2.9	2.8	0.1	2.1
27 August 1992	07:04	21.2	19.1	2.1	10.0
21 September 1992	16:44	9.6	8.9	0.7	7.2
29 October 1992	11:56	87.6	85.2	2.4	2.7
11 November 1992	20:08	21.8	21.5	0.4	1.7
19 November 1992	03:53	29.7	27.6	0.1	0.3
24 November 1992	07:18	38.4	38.1	0.3	0.8
30 November 1992	12:32	38.7	38.5	0.2	0.5

g. BOD

Date	Time	Total Load (Kg)	Storm Load (Kg)	DWF Load (Kg)	% of Total Provided by Dry Weather Sewage
12 March 1992	00:32	102.9	98.5	4.4	4.2
29 March 1992	19:36	107.1	96.5	10.6	9.9
3 July 1992	13:26	8.1	-	11.0	-
21 July 1992	04:06	85.8	73.4	12.4	14.5
23 July 1992	17:42	9.4	8.5	0.9	9.7
27 August 1992	07:04	67.9	34.2	33.7	49.7
21 September 1992	16:44	17.7	-	23.9	-
29 October 1992	11:56	73.5	51.4	22.1	30.1
11 November 1992	20:08	164.5	152.3	12.2	7.4
19 November 1992	03:53	39.4	37.3	2.1	5.3
24 November 1992	07:18	160.6	152.3	8.3	5.2
30 November 1992	12:32	-	-	8.6	-

h. COD

Date	Time	Total Load (Kg)	Storm Load (Kg)	DWF Load (Kg)	% of Total Provided by Dry Weather Sewage
12 March 1992	00:32	310.3	300.6	9.7	3.1
29 March 1992	19:36	277.4	252.9	24.5	8.8
3 July 1992	13:26	-	-	-	-
21 July 1992	04:06	244.0	220.0	24.1	9.9
23 July 1992	17:42	22.0	2.8	11.1	
27 August 1992	07:04	24.7	75.2	75.3	
21 September 1992	16:44	123.2	45.6	77.6	
29 October 1992	11:56	277.5	225.4	52.1	18.8
11 November 1992	20:08	395.3	368.0	27.3	6.9
19 November 1992	03:53	106.5	102.1	4.34	4.1
24 November 1992	07:18	356.0	335.0	21.0	5.9
30 November 1992	12:32	240.4	223.0	17.4	7.2

i. AMMONIA

Date	Time	Total Load (Kg)	Storm Load (Kg)	DWF Load (Kg)	% of Total Provided by Dry Weather Sewage
12 March 1992	00:32	4.21	4.00	0.21	5.2
29 March 1992	19:36	6.48	5.43	1.05	16.2
3 July 1992	13:26	0.62	0.20	0.42	67.9
21 July 1992	04:06	0.95	6.74	0.21	3.02
23 July 1992	17:42	1.00	0.92	0.08	7.14
27 August 1992	07:04	0.69	-	2.51	-
21 September 1992	16:44	0.88	0.54	0.34	38.9
29 October 1992	11:56	1.10	-	1.35	-
11 November 1992	20:08	3.96	2.77	1.19	30.1
19 November 1992	03:53	0.82	0.75	0.08	9.2
24 November 1992	07:18	3.39	2.42	0.97	29.0
30 November 1992	12:32	3.18	3.01	0.17	5.3

Table 5.11 Load Information for Leyburn Road

a. Percentage Contribution of Dry Weather Flow Loads to Total Loads

Date	Time of Day	Duration	Suspended Solids	Ash	BOD	COD	Ammonia	Flow
9 Nov. 1992	16:10	166	2.9	0.2	8.3	6.8	35.6	6.5
11 Nov. 1992	02:20	164	0.4	0.2	0.8	0.5	3.8	1.5
11 Nov. 1992	17:34	234	3.3	0.2	10.5	8.0	58.5	12.7
24 Nov. 1992	04:28	220	3.9	1.0	5.3	7.0	20.4	6.7
30 Nov. 1992	07:10	428	5.0	2.2	-	8.3	15.8	4.8
2 Dec. 1992	07:36	536	4.7	1.3	11.8	7.4	38.3	4.7
3 Dec. 1992	18:40	118	3.3	0.5	7.9	5.7	13.1	3.6

b. Ratio of the % of the Total Flow to the % of the Total Parameter Load Provided by the Dry Weather Flow

Date	Time of Day	Duration	Suspended Solids	Ash	BOD	COD	Ammonia
9 Nov. 1992	16:10	166	0.45	0.04	1.28	1.05	5.52
11 Nov. 1992	02:20	164	0.25	0.10	0.52	0.33	2.48
11 Nov. 1992	17:34	234	0.26	0.02	0.83	0.63	4.62
24 Nov. 1992	04:28	220	0.58	0.14	0.79	1.04	3.05
30 Nov. 1992	07:10	428	1.05	0.45		1.73	3.29
2 Dec. 1992	07:36	536	1.00	0.28	2.53	1.60	8.22
3 Dec. 1992	18:40	118	0.92	0.15	2.21	1.60	3.68

c. Volumes of Flow

Date	Time of Day	Total Inflow for the Sampling Period	Storm Flow for the Sampling Period	Dry Weather Flow for the Sampling Period
9 Nov. 1992	16:10	2340270	2189220	151050
11 Nov. 1992	02:20	2201490	2167740	33750
11 Nov. 1992	17:34	881910	770310	111600
24 Nov. 1992	04:28	1756440	1639140	117300
30 Nov. 1992	07:10	2252190	2143800	108390
2 Dec. 1992	07:36	2296500	2189550	106950
3 Dec. 1992	18:40	2083500	2009250	74250

d. Dissolved and Finely Suspended Solids Load Comparisons for Similar Time Periods

Storm Event	No. Samples	Sampling Time (min)	Suspended Solids (Kg)	Ash (Kg)	BOD (Kg)	COD (Kg)	Ammonia (Kg)
9 November 1992							
inlet samples	19	95	328.0	101.0	107.0	368.0	3.2
spill samples	19	95	22.0	8.0	8.0	30.4	0.4
11 November 1992 a.m.							
inlet samples	17	85	94.0	32.0	36.0	357.0	0.8
spill samples	17	85	19.8	7.0	9.0	102.0	0.2
11 November 1992 a.m.							
inlet samples	17	85	225.0	89.0	66.0	260.0	1.2
spill samples	17	85	31.0	11.0	7.0	36.0	0.4

continued on next page

Table 5.11 Dissolved and Finely Suspended Solids Loads Comparisons for Similar Time Periods (continued)

Storm Event	No. Samples	Sampling Time (min)	Suspended Solids (Kg)	Ash (Kg)	BOD (Kg)	COD (Kg)	Ammonia (Kg)
24 November 1992							
inlet samples	21	105	141.0	47.0	54.0	176.0	2.6
spill samples	21	105	26.0	12.0	7.6	30.5	2.1
30 November 1992							
inlet samples	16	80	288.0	106.0	-	311.0	3.8
spill samples	16	80	42.0	14.0	-	53.5	3.2
2 December 1992							
inlet samples	18	90	301.0	98.0	85.0	391.0	2.4
spill samples	18	90	65.5	24.0	18.0	79.4	0.6
3 December 1992							
inlet samples	21	105	184.0	28.0	68.0	264.0	4.2
spill samples	21	105	31.6	5.0	20.0	58.0	1.2

e. SUSPENDED SOLIDS

Date	Time	Total Load	Storm Load	DWF Load	% Total Provided by Dry Weather Sewage
9 November 1992	16:10	426.5	414.2	12.3	2.9
11 November 1992	02:20	129.6	129.1	0.5	0.4
11 November 1992	17:34	290.9	281.4	9.5	3.3
24 November 1992	04:28	154.0	148.0	6.0	3.9
30 November 1992	07:10	391.0	371.3	19.7	5.0
2 December 1992	07:36	351.8	335.4	16.5	4.7
3 December 1992	18:40	198.0	191.5	6.5	3.3

f. ASH

Date	Time	Total Load	Storm Load	DWF Load	% Total Provided by Dry Weather Sewage
9 November 1992	16:10	129.6	129.3	0.3	0.2
11 November 1992	02:20	44.0	43.9	0.1	0.2
11 November 1992	17:34	97.9	97.7	0.2	0.2
24 November 1992	04:28	49.2	48.7	0.5	1.0
30 November 1992	07:10	137.6	134.6	3.0	2.2
2 December 1992	07:36	111.1	109.6	1.5	1.4
3 December 1992	18:40	29.9	29.7	0.2	0.5

g. BOD

Date	Time	Total Load	Storm Load	DWF Load	% Total Provided by Dry Weather Sewage
9 November 1992	16:10	135.2	124.0	11.2	8.3
11 November 1992	02:20	45.2	44.8	0.4	0.9
11 November 1992	17:34	80.7	72.2	8.5	10.5
24 November 1992	04:28	60.5	57.3	3.2	5.3
30 November 1992	07:10				
2 December 1992	07:36	102.9	90.8	12.1	11.8
3 December 1992	18:40	73.7	67.9	5.8	7.9

h. COD

Date	Time	Total Load	Storm Load	DWF Load	% Total Provided by Dry Weather Sewage
9 November 1992	16:10	485.0	451.9	33.1	6.8
11 November 1992	02:20	468.0	465.6	2.4	0.5
11 November 1992	17:34	310.2	285.4	24.8	8.0
24 November 1992	04:28	195.9	182.2	13.7	7.0
30 November 1992	07:10	451.4	414.0	37.4	8.3
2 December 1992	07:36	470.3	435.3	35.0	7.4
3 December 1992	18:40	287.4	271.0	16.4	5.7

i. Ammonia

Date	Time	Total Load	Storm Load	DWF Load	% Total Provided by Dry Weather Sewage
9 November 1992	16:10	4.3	2.8	1.5	35.1
11 November 1992	02:20	1.04	1.00	0.04	4.0
11 November 1992	17:34	1.6	0.7	0.9	58.8
24 November 1992	04:28	1.0	2.4	0.6	19.7
30 November 1992	07:10	6.5	5.5	1.0	15.4
2 December 1992	07:36	3.2	2.0	1.2	37.5
3 December 1992	18:40	4.7	4.1	0.6	12.7

Table 5.12 Rainfall Data for Storms at the Stilling Pond Site (Chesterfield Road)

Storm Event	A.D.W.P. (hours)	Depth of Rain for Previous Storm (mm)	Duration of Previous Storm (min)	Depth of Rain (mm)	Storm Duration (min)	Average Intensity (mm/h)	Peak Intensity (mm/h)	Delay Time (min)
30 September 1990	116	2.6	96	6.8	484	0.8	6.0	14
3 October 1990	55	6.8	484	4.0	218	1.1	8.0	128
6 October 1990	11	3.2	184	2.2	144	0.9	6.0	36
15 October 1990	168	6.2	26	10.6	100	6.4	72.0	12
17 October 1990	51	10.6	100	40.4	886	2.7	30.0	18
18 November 1990								18
9 December 1990								128
18 January 1991	32	0.6	24	4.8	342	0.8	6.0	76
27 February 1991	104	6.4	646	9.0	484	1.1	3.0	274
8 March 1991	14	3.2	156	3.8	202	1.1	3.0	72
19 April 1991	8	3.0	172	3.2	152	1.3	6.0	146
29 April 1991	216	2.8	134	26.2	108	1.5	6.0	136
13 June 1991	115	2.2	68	3.6	124	1.6	3.0	118
25 June 1991	97	4.2	92	10.2	166	1.9	6.0	46
27 June 1991								16
6 July 1991				3.8	740	0.3	1.2	68
18 July 1991				2.4	644	0.2	1.2	26

Table 5.13 Rainfall Data for the High Side Weir Site (Dobcroft Road)

Storm Event	A.D.W.P. (hours)	Depth of Rain in Previous Storm (mm)	Duration of Previous Storm (min)	Depth of Rain (mm)	Storm Duration (min)	Average Intensity (mm/h)	Peak Intensity (mm/h)	Delay Time (min)
27 February 1991	22	0.2	10	3.4	266.0	0.8	3.0	132
7 March 1991	13	0.8	72	3.2	158.0	1.2	6.0	66
18 March 1991	56	8.2	330	4.8	160.0	2.7	12.0	68
19 March 1991	9	2.4	78	4.0	158.0	1.5	6.0	58
18 April 1991	235	3.2	122	3.6	166.0	1.2	12.0	16
19 April 1991	9	3.8	226	3.4	196.0	1.0	6.0	28
29 April 1991	177	0.4	20	26	1168.0	0.8	3.0	140
1 May 1991	25	26	1168	1.2	36.0	2.0	3.0	24
15 May 1991	200	4.8	336	3.9	112.0	2.1	24.0	36
13 June 1991	116	1.4	6	6.0	134.0	3.0	18.0	12
21 June 1991	31	2.4	108	0.4	24.0	1.0	1.2	32
25 June 1991	61	2.0	10	5.0	192.0	1.6		8
27 June 1991	39	1.8	64	6.2	84.0	4.4	36.0	40
6 July 1991	72	1.2	112	13.8	22.0	37.4	90.0	12
8 July 1991	26	0.4	20	1.8	3.6	3.0	6.0	38
11 July 1991	53	2.0	36	2.6	92.0	1.7	6.0	14
18 July 1991	22	1.6	118	6.2	178.0	2.1	6.0	22
27 September 1991	36	2.6	92	1.7	46.0			54
17 October 1991	48	1.8	84	41.0	1080.0	2.3	30.0	84
29 October 1991	106	2.2	64	1.8	424.0	1.3	24.0	106
31 October 1991	35	1.0	44	0.4	16.0	1.5	1.2	76
2 November 1991	25	1.4	68					50
4 November 1991	55	1.2	112					81
6 November 1991	47	0.8	56	3.2	96.0	3.3	6.0	52
8 November 1991	40	3.2	98					18
11 November 1991	31	0.8	36					76
12 November 1991	19	5.0	228					48
18 November 1991								76

Table 5.14 Rainfall Data for the Low Side Weir Site (Retford Road)

Storm Event	A.D.W.P. (hours)	Depth of Rain for Previous Storm (mm)	Duration of Previous Storm (min)	Depth of Rain (mm)	Storm Duration (min)	Average Intensity (mm/h)	Peak Intensity (mm/h)	Delay Time (min)
13 March 1992	78	1.2	92					26
18 March1992	133	8.2	336					22
22 March 1992	102							16
29 March 1992 a.m.	13	0.2	10	3.0	70	2.6	18.0	30
29 March 1992 p.m.	5	2.4	68	2.2	110	1.2	1.5	34
30 March 1992	15	2.0	88	4.1	436	0.6	6.0	6
31 March 1992	15	4.1	436	1.2	146	0.5	1.2	4
3 June 1992	17	7.2	118	7.2	44	3.0	36.0	18
4 June 1992	6.5	7.0	90	7.9	320	1.5	6.0	10
5 June 1992	8	10.8	696	1.4	74	1.1	6.0	34
1 July 1992	16	1.0	28	17.6	478	2.2	12.0	38
3 July 1992	37	17.4	470	16.8	498	2.0	12.0	26
4 July 1992	3	0.8	108	7.2	562	0.8	6.0	22
9 July 1992	42	0.2	10	2.2	92	1.4	3.0	6
11 July 1992	41	4.2	184	9.4	244	2.3	30.0	6
17 July1992	34	0.4	10	4.0	76	3.2	18.0	8
20 July 1992	27	0.2	10	5.1	172	1.78	6.0	22
21 July 1992	8	5.4	308	9.5	282	2.1	12.0	64
22 August 1992	154	2.8	340	1.6	144	0.7	1.2	16
26 August 1992	25	1.0	158	4.6	158	1.8	3.0	22
27 August 1992 6 a m.	11	4.6	160	1.2	38	1.9	6.0	24
27 August 1992 1 p.m.	2	4.2	344	10.2	118	5.2	18.0	18
27 August 1992 6 p.m.	2	9.4	148	1.0	44	1.4	6.0	8
30 August 1992 6 a.m.	6	0.4	70	5.2	228	1.4	6.0	10
30 August 1992 1 p.m.	3	5.2	230	5.2	154	2.0	36.0	14
30 August 1992 6 p.m.	2	5.6	262	0.2	10	1.2	1.2	10
12 September 1992	32	1.4	60	4.8	276	1.04	6.0	12
21 September 1992	26	1.0	146	10.7	456	1.4	18.0	32

Table 5.14 Continued

Storm Event	A.D.W.P. (hours)	Depth of Rain for Previous Storm (mm)	Duration of Previous Storm (min)	Depth of Rain (mm)	Storm Duration (min)	Average Intensity (mm/h)	Peak Intensity (mm/h)	Delay Time (min)
25 October 1992	13	2.6	104	9	472	1.1	6	14
27 October 1992	14	0.4	52	8.2	202	2.4	18	16
1 November 1992	100	1.4	42	0.8	26	1.9	6	10
2 November 1992	17	0.4	72	0.8	38	1.3	3	10
9 November 1992	87	0.8	94	8.8	336	1.6	12	20
11 November 1992 a.m.	30	6.8	288	12.2	390	1.9	6	18
11 November 1992 p.m.	7	10.8	392	5.0	382	0.8	6	22
16 November 1992	10	1.0	104	7.5	155	2.9	3	12
19 November 1992	3	0.4	52	2.3	140	1.0	12	44
21 November 1992	43	3.2	186	10.0	386	1.6	12	16
22 November 1992	19	10.0	386	0.5	40	0.8	1.2	18
24 November 1992	27	0.8	12	6.4	204	1.9	6	16

Table 5.15 Rainfall Data for the High Side Weir (Leyburn Road)

Storm Event	A.D.W.P. (hours)	Depth of Rain in Previous Storm (mm)	Duration of Previous Storm (min)	Depth of Rain (mm)	Storm Duration (min)	Average Intensity (mm/h)	Peak Intensity (mm/h)	Delay Time (min)
1 July 1992	19	0.8	50	8.9	240	2.2	12	40
3 July 1992	51	11.8	506	10.4	426	1.5	6	82
4 July 1992	4	1.4	166	11.8	390	1.8	6	118
20 July 1992	56	0.4	20	6.0			12	88
21 July 1992	19	7.4	378	7.4	276	1.6	6	156
21 September 1992	47	3.8	166	18.2	372	2.9	24	124
25 September 1992	45	1.4	168	13.0	406	1.9	12	68
2 October 1992	29	4.8	288	4.6	246	1.1	2	130
24 October 1992 a.m.	5	0.8	132	3.8	112	2.0	6	90
24 October 1992 p.m.	3.5	6.2	430	4.8	160	1.8	6	76
25 October 1992	22	4.8	206	6.6	190	2.1	6	126
27 October 1992	14	0.4	78	10.8	234	2.8	12	84
28 October 1992	29	8.4	192	14.0	436	1.9	6	28
2 November 1992	13	1.0	32	8.2	132	3.7	18	64
9 November 1992	146	0.6	60	3.6	166	1.3	6	92
11 November 1992 a.m.	30	7.8	254	4.4	164	1.6	6	58
11 November 1992 p.m.	6	11.8	436	9.1	234	2.3	12	96
19 November 1992	2	0.8	58	8.1	464	1.1	6	42
21 November 1992	54	5.8	144	9.3	282	2.0	18	24
22 November 1992	12	12.8	406	18.2	562	1.7	12	166
24 November 1992	50	3.8	366	5.0	220	1.4	12	24
30 November 1992	146	5.0	220	13.8	428	1.8	12	23
2 December 1992	11	3.2	166	9.0	536	1.9	12	61
3 December 1992	35	9.0	536	3.4	118	1.1	6	66

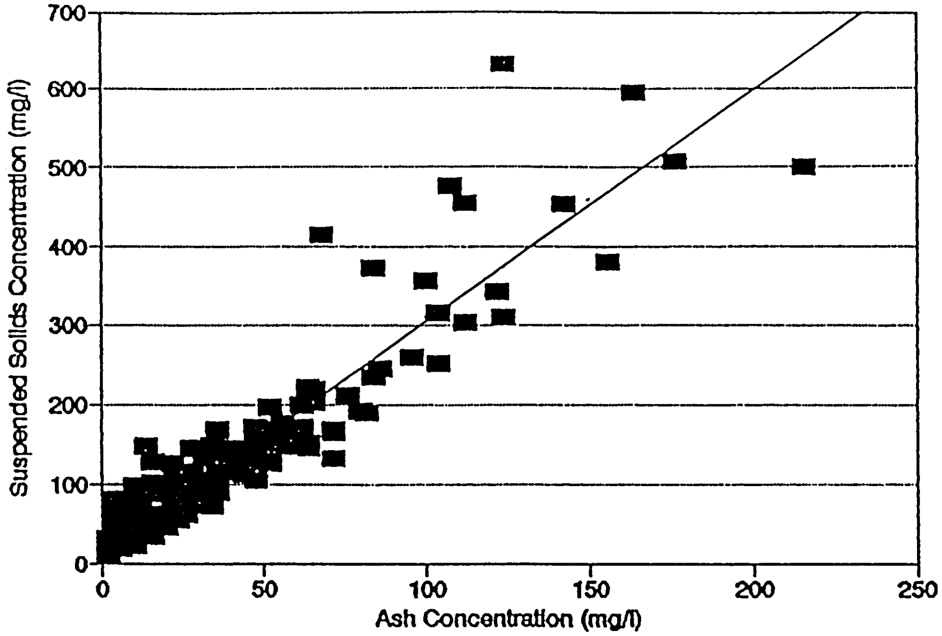


Figure 5.76 Graph of Suspended Solids Concentration Against Ash Concentration for Inflow Samples at the High Side Weir, Leyburn Road
Regression: SS = 24.1 + 2.8 Ash $R^2 = 0.84$

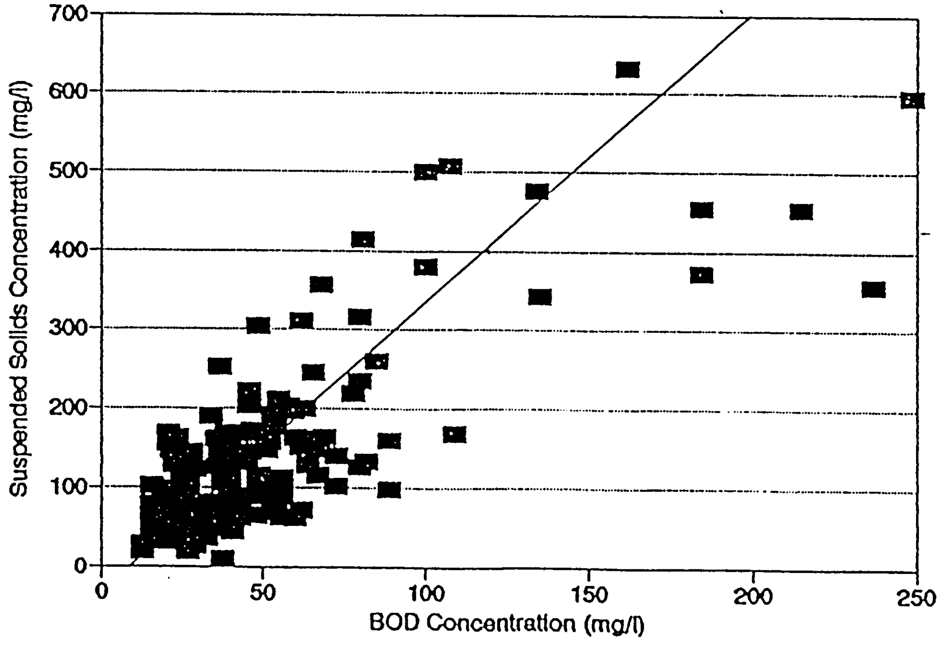


Figure 5.77 Graph of Suspended Solids Concentration Against BOD Concentration for Inflow Samples at the High Side Weir, Leyburn Road
Regression: BOD = 11.8 + 0.3 SS $R^2 = 0.65$

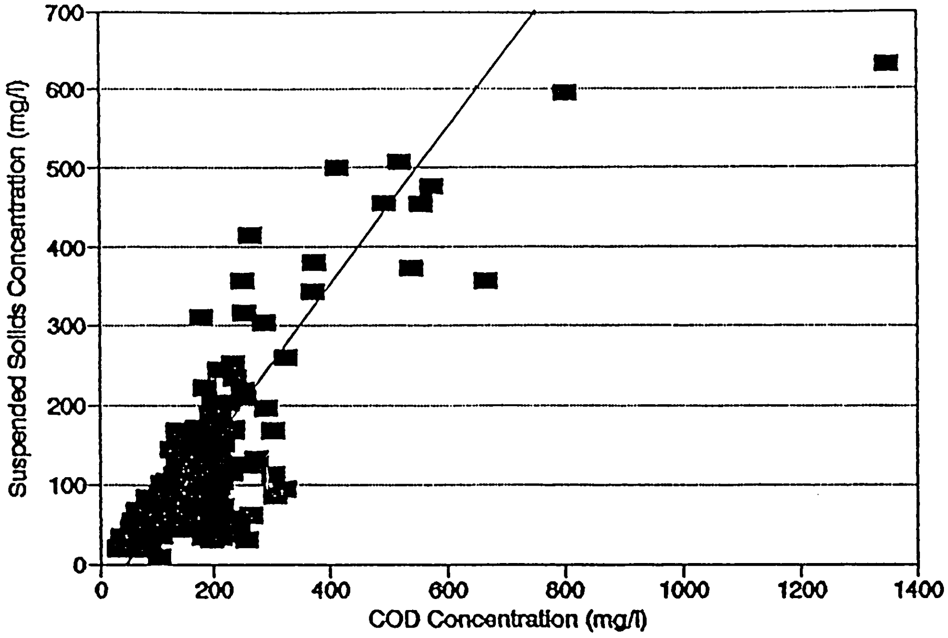


Figure 5.78 Graph of Suspended Solids Concentration Against COD Concentration for Inflow Samples at the High Side Weir, Leyburn Road
Regression: COD = 59.6 + 1.0 SS $R^2 = 0.65$

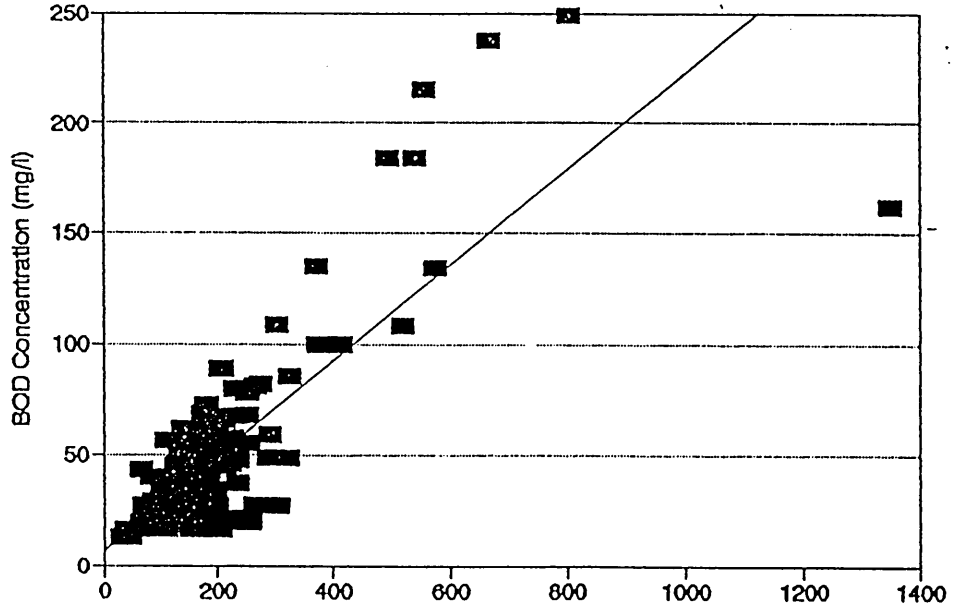


Figure 5.79 Graph of BOD Concentration Against COD Concentration for Inflow Samples at the High Side Weir, Leyburn Road
Regression: BOD = 8.0 + 0.2 COD $R^2 = 0.60$

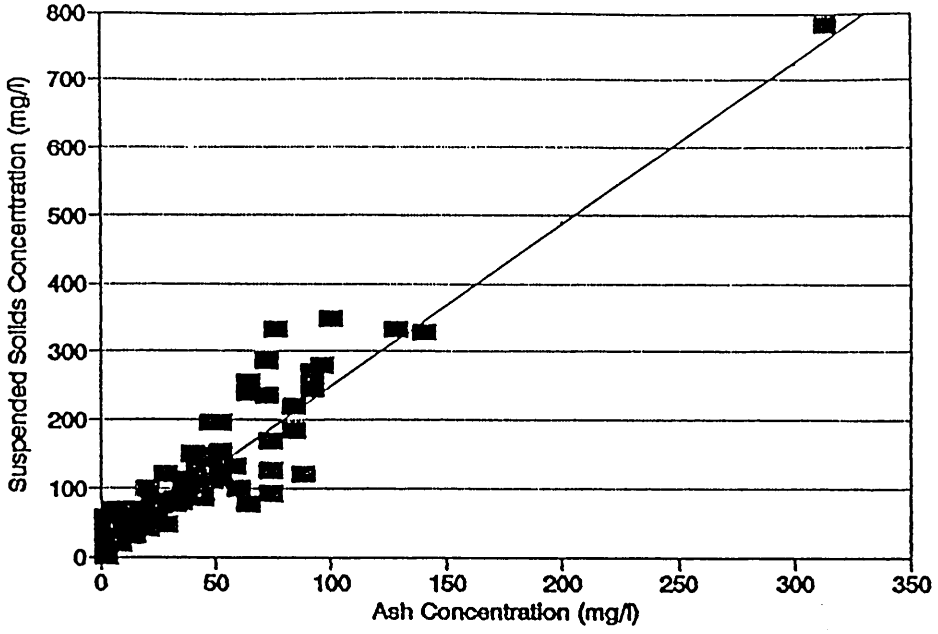


Figure 5.80 Graph of Suspended Solids Concentration Against Ash Concentration for Spill Samples at the High Side Weir, Leyburn Road
Regression: SS = 17.5 + 2.4 Ash $R^2 = 0.89$

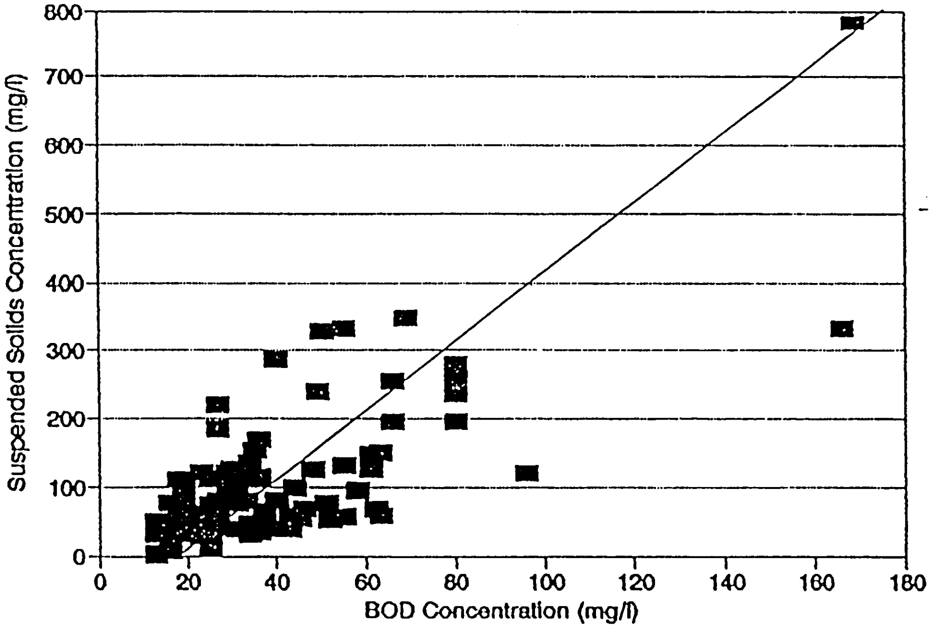


Figure 5.81 Graph of Suspended Solids Concentration Against BOD Concentration for Spill Samples at the High Side Weir, Leyburn Road
Regression: BOD = 16.7 + 0.2 SS $R^2 = 0.60$

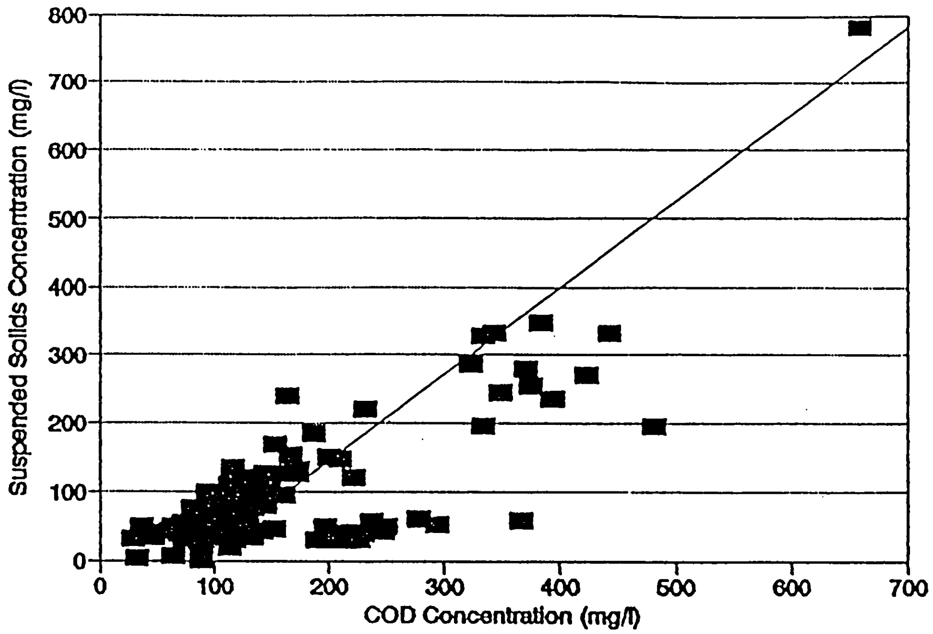


Figure 5.82 Graph of Suspended Solids Concentration Against COD Concentration for Spill Samples at the High Side Weir, Leyburn Road
Regression: COD = 89.3 + 0.8 SS $R^2 = 0.59$

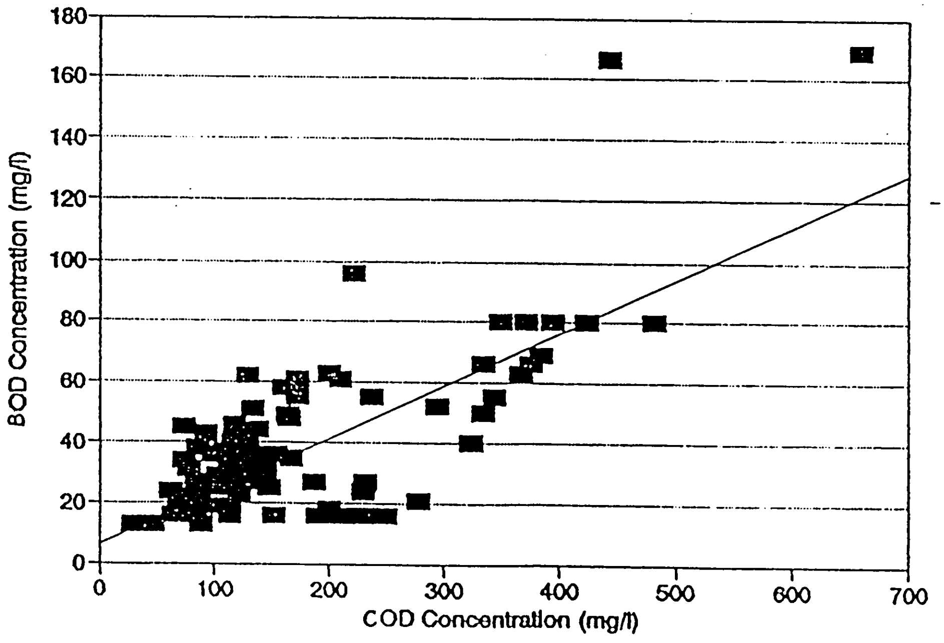


Figure 5.83 Graph of BOD Concentration Against COD Concentration for Spill Samples at the High Side Weir, Leyburn Road
Regression: BOD = 6.5 + 0.2 COD $R^2 = 0.53$

This was first investigated by linear regression analysis. The significant relationships are shown on the graphs referred to above. They represent only those relationships derived from a collation of all the results at this site for the inflow samples and the spill samples. It was then decided that the data should be analysed using multiple regression and the results of this are given in Table 5.16. This table indicates the value for a collation of all the samples for a given parameter at a given site. An example of the variation in the relationships between the measured parameters over all the storms in the monitoring period is given in Table 5.17. From this the consistency of the relationships can be determined.

5.9.2 Gross Solids

The results of the investigation into the composition of the gross solids material at the four sites is given in Table 5.18. At the low side weir site (Retford Road) gross solids were collected from two mesh bags on the weir. At the second high side weir site there were ten mesh bags attached at regular intervals along the weir. In Table 5.18 percentage values are given for each of the mesh bags individually and an average values for all the spill mesh bags are also given

For each of the storms from which gross solid samples had been taken the total inflow and total spill flow was calculated. This information, together with the estimated total mass of inflow and spill flow gross solids, is given in Tables 5.19 to 5.23, for the four overflow chambers and for the screens at the stilling pond site. Other relevant flow data, including the percentage flow to treatment or 'flow split', is given in Tables 5.24 to 5.27. As explained in Chapter 4, to investigate whether the overflow is having a treatment effect on the concentration of gross solids or other pollutant material, the total efficiency of the system must be divided by the flow split.

The calculated efficiencies and the corresponding treatment factors of the different overflows (and the screens at the stilling pond site) in retaining gross solid material is given in Tables 5.28 to 5.36. The efficiencies were calculated for total solids as well as for separate categories.

Table 5.16 Multiple Regression Equations for the Significant Relationships for All Samples at Each Site

a. Chesterfield Road

i. Inflow Samples

Regression Equation	R^2 value
SS = 555 + 1.3 Ash + 0.44 COD - 76.6 pH + 4.5 Ammonia	0.879
Ash = -385 + 0.46 SS - 0.1 COD +56.1 pH - 4.13 Ammonia	0.759
BOD = 472 + 0.247 cod - 67.6 pH + 0.01 Conductivity + 3.04 Ammonia	0.814
COD = 142 + 0.54 SS - 0.33 Ash + 1.70 BOD + 0.05 Conductivity	0.857

ii. Spill Samples

Regression Equation	R^2 value
SS = 4.78 + 1.25 Ash + 0.77 BOD + 0.304 COD - 64.3 pH	0.963
Ash = - 366 + 0.55 SS - 0.56 BOD + 49.0 pH	0.921
BOD = - 180 + 0.40 SS - 0.66 Ash + 25.9 pH	0.771
COD = 68 + 0.73 SS + 0.551 BOD + 10.3 Ammonia	0.897

b. Dobcroft Road

i. Inflow Samples

Regression Equation	R^2 value
SS = 102 + 2.53 Ash + 1.28 BOD - 0.25 COD - 11.9 Ammonia	0.952
Ash = 206 + 0.34 SS	0.950
BOD = 353 + 0.037 SS + 0.234 COD - 50.8 pH - 0.035 Conductivity + 5.38 Ammonia	0.862
COD = -415 - 0.08SS + 2.58 BOD + 0.24 Conductivity - 6.99 Ammonia	0.787

ii. Spill Samples

Regression Equation	R^2 value
SS = 23.8 + 1.35 Ash +0.376 BOD	0.987
Ash = -18.0 + 0.72 SS - 0.25 BOD - 0.19 COD	0.984
BOD = 183 + 0.14 SS - 0.17 Ash + 0.09 COD - 26.5 pH + 7.18 Ammonia	0.589
COD = - 190 + 1.28 SS - 1.56 Ash + 1.07 BOD - 7.45 Ammonia	0.757

3. Retford Road

i. Inflow Samples

Regression Equation	R^2 value
SS = 473 + 1.41 Ash - 0.22 BOD + 0.25 COD - 61.2 pH + 4.46 Ammonia	0.924
Ash = - 259 + 0.57 SS - 0.04 COD + 34 pH - 0.03 Conductivity - 2.76 Ammonia	0.903
BOD = - 2.2 - 0.23 SS - 0.54 COD - 0.41 Conductivity + 1.77 Ammonia	0.907
COD= -370+0.71SS -0.29Ash+1.49BOD+56.1pH+0.11Conductivity -3.25Ammonia	0.939
Conductivity = - 1120 - 1.68 Ash - 1.0 BOD + 1.01 COD + 187 pH + 6.61 Ammonia	0.514

ii. Spill Samples

Regression Equation	R^2 value
SS = 194 + 1.35 Ash + 0.219 COD - 26.6 pH + 5.56 Ammonia	0.978
Ash = 157 + 0.67 SS - 0.17 BOD - 0.08 COD + 21.6 pH - 4.70 Ammonia	0.968
BOD = - 273 - 0.16 Ash - 0.22 COD - 41.3 pH - 0.08 Conductivity + 3.47 Ammonia	0.857
COD= -533+0.84 SS - 0.65 Ash + 1.84 BOD + 82.5 pH - 7.65Ammonia	0.903
Conductivity = 107 + 0.09 SS - 0.06 COD - 0.09 pH + 27.2 Ammonia	0.656
Ammonia = -12.5+0.01SS -0.02Ash+0.01BOD - 0.003COD+1.77pH+0.01Conductivity	0.645

4. Leyburn Road

i. Inflow Samples

Regression Equation	R^2 value
SS = - 195 + 1.96 Ash + 0.499 BOD + 0.193 COD + 25.2 pH + 6.0 Ammonia	0.944
Ash = -54.2 + 0.36 SS - 0.04 COD - 5.25 Ammonia	0.907
BOD = 155 + 0.23 SS - 0.04 COD - 23.7 pH - 0.04 Conductivity + 6.87 Ammonia	0.777
COD = 1391+ 1.23 SS - 1.29 Ash + 0.57 BOD - 189 pH - 0.195 Ammonia	0.775
Ammonia = - 8.22 + 0.01 SS - 0.03.Ash + 0.01 BOD + 1.24 pH + 0.01 Conductivity	0.505

ii. Spill Samples

Regression Equation	R^2 value
SS = - 47 + 1.73 Ash + 0.752 BOD + 0.155 COD + 8.04 Ammonia	0.944
Ash = -100 + 0.41 SS - 0.22 BOD + 15.2 pH	0.912
BOD = 88.6 + 0.2 SS - 0.25 Ash + 0.9 COD + 0.04 Conductivity + 5.85 Ammonia	0.765
COD = 780 + 0.73 SS + 1.51 BOD - 96.2 pH - 46.8 Ammonia	0.758
Ammonia = 6.03 + 0.01 SS + 0.01 BOD - 0.01 COD - 0.80 pH + 0.01 Conductivity	0.595

Table 5.17 COLLATION OF MULTIPLE REGRESSION RESULTS

CHESTERFIELD ROAD INFLOW

a. SUSPENDED SOLIDS

Date	Ash	BOD	COD	pH	Conductivity	Ammonia	R^2
3 October 1990		0.1	0.1	0.1	0.1	0.1	0.99
15 October 1990							0.98
16 October 1990	5.0						0.89
17 October 1990	0.1						0.90
18 October 1990	5.0		2.0	1.0		0.1	0.84
10 December 1990	0.1						0.84
18 January 1991	5.0						0.85
4 March 1991		5.0					0.57
8 March 1991			2.0		1.0		0.92
19 March 1991	0.1						0.82
19 April 1991	0.1	10.0					0.98
29 April 1991	0.1		1.0			10.0	0.83
15 May 1991	0.1	10.0	1.0				0.98
19 June 1991	0.1	5.0	5.0				0.99.
21 June 1991	10.0		10.0				0.83
25 June 1991	10		2.0				0.91
27 June 1991	0.1						0.96
9 July 1991	10.0		1.0				0.94

Dry Weather Flow	0.1		0.1			10.0	0.98
Total Inflow	0.1		0.1	1.0		0.1	0.87

b.ASH

Date	Suspended Solids	BOD	COD	pH	Conductivity	Ammonia	R^2
3 October 1990							0.67
15 October 1990	-	-	-	-	-	-	-
16 October 1990	5.0					2.0	0.89
17 October 1990	0.1						0.84
18 October 1990	5.0			1.0			0.85
10 December 1990	0.1	1.0					0.90
18 January 1991	5.0				5.0	10.0	0.93
4 March 1991				10.0		5.0	0.34
8 March 1991							0.95
19 March 1991	0.1					10.0	0.82
19 April 1991	0.1	10.0					0.99
29 April 1991	0.1					5.0 -	0.73
15 May 1991	0.1	10.0	1.0				0.97
19 June 1991	0.1	5.0	5.0				0.98
21 June 1991	10.0		10.0				0.81
25 June 1991	10.0						0.81
27 June 1991	0.1						0.93
9 July 1991	10.0		10.0		5.0		0.95

Dry Weather Flow	0.1		1.0			5.0	0.86
Total Inflow	0.1		0.1	0.1		0.1	0.76

c. BOD

Date	Suspended Solids	Ash	COD	pH	Conductivity	Ammonia	R^2
3 October 1990	0.1	0.1	n.s.	10.0	2.0	0.1	0.99
15 October 1990	2.0	1.0	10.0	10.0	10.0		
16 October 1990			0.1			10.0	0.97
17 October 1990			10.0	5.0			0.78
18 October 1990			1.0				0.44
10 December 1990		1.0				5.0	0.82
18 January 1991			1.0				0.91
4 March 1991	5.0			5.0		5.0	0.70
8 March 1991							0.90
19 March 1991			5.0	10.0			0.45
19 April 1991	10.0	10.0	10.0				0.88
29 April 1991							0.48
15 May 1991	10.0		2.0		5.0		0.96
19 June 1991	1.0	1.0					0.95
21 June 1991							0.90
25 June 1991			1.0				0.96
27 June 1991			0.1		10.0		0.96
9 July 1991							0.90

Dry Weather Flow			1.0		10.0		0.93
Total Inflow			0.1	0.1	10.0	0.1	0.81

d. COD

Date	Suspended Solids	Ash	BOD	pH	Conductivity	Ammonia	R^2
3 October 1990	0.1		10.0	5.0	10.0	10.0	0.96
15 October 1990			10.0				
16 October 1990			0.1	1.0	10	0.1	0.98
17 October 1990			10.0				0.49
18 October 1990	2.0		1.0	1.0		2.0	0.76
10 December 1990					10.0		0.45
18 January 1991			1.0	5.0	5.0		0.97
4 March 1991							0.36
8 March 1991	2.0				5.0		0.97
19 March 1991			5.0	5.0	1.0		0.58
19 April 1991			10.0				0.90
29 April 1991	1.0						0.67
15 May 1991	1.0		2.0				0.98
19 June 1991	5.0	10.0					0.94
21 June 1991	10.0	5.0				–	0.93
25 June 1991	2.0		1.0				0.97
27 June 1991			0.1				0.97
9 July 1991	1.0	10			10.0		0.95

Dry Weather Flow	0.1	1.0	1.0	10.0			0.98
Total Inflow	0.1	0.1	0.1		2.0		0.86

e. pH

Date	Suspended Solids	Ash	BOD	COD	Conductivity	Ammonia	R^2
3 October 1990	0.1		0.1	5.0	0.1	0.1	0.98
15 October 1990	0.1		10.0		0.1		
16 October 1990				1.0	0.1	5.0	0.72
17 October 1990			5.0				0.72
18 October 1990	1.0	1.0		1.0	5.0	1.0	0.89
10 December 1990				5.0		1.0	0.11
18 January 1991						0.1	0.51
4 March 1991							0.94
8 March 1991			10.0	5.0	2.0		0.75
19 March 1991						1.0	0.47
19 April 1991							0.73
29 April 1991						0.1	0.17
15 May 1991							0.90
19 June 1991							0.71
21 June 1991					1.0	0.1	0.89
25 June 1991						0.1	0.96
27 June 1991							0.16
9 July 1991							0.88
Dry Weather Flow				10.0		10.0	0.90
Total Inflow	1.0	0.1	0.1		1.0	0.1	0.51

f. CONDUCTIVITY

Date	Suspended Solids	Ash	BOD	COD	pH	Ammonia	R^2
3 October 1990	0.1		2.0	10.0	0.1	0.1	0.99
15 October 1990	0.1		10.0		0.1	1.0	
16 October 1990				10.0	0.1		0.80
17 October 1990							0.19
18 October 1990					5.0		0.55
10 December 1990				10.0			0.35
18 January 1991		5.0		5.0			0.94
4 March 1991							0.35
8 March 1991	1.0			5.0		5.0	0.75
19 March 1991				1.0	1.0	0.1	0.77
19 April 1991						0.1	0.84
29 April 1991		10.0				0.1	0.90
15 May 1991			5.0				0.92
19 June 1991						0.1	0.95
21 June 1991						5.0	0.97
25 June 1991						0.1	0.90
27 June 1991			10.0			0.1	0.75
9 July 1991		5.0		10.0		1.0	0.98
Dry Weather Flow			10.0			1.0	0.96
Total Inflow			10.0	2.0	1.0		0.10

g. AMMONIA

Date	Suspended Solids	Ash	BOD	COD	pH	Conductivity	R^2
3 October 1990	0.1		0.1	10.0	0.1	0.1	0.99
15 October 1990							0.95
16 October 1990		2.0	10.0	0.1	5.0		0.80
17 October 1990							0.23
18 October 1990	0.1			2.0	1.0		0.90
10 December 1990			5.0				0.60
18 January 1991					1.0		0.58
4 March 1991		5.0	5.0		0.1		0.96
8 March 1991							0.76
19 March 1991		10.0				0.1	0.72
19 April 1991					1.0	0.1	0.84
29 April 1991		10.0	5.0			0.1	0.90
15 May 1991					0.1		0.92
19 June 1991						0.1	0.95
21 June 1991						5.0	0.97
25 June 1991					0.1	0.1	0.98
27 June 1991						0.1	0.67
9 July 1991						1.0	0.94

Dry Weather Flow	10.0	5.0			10.0	1.0	0.96
Total Inflow	0.1	0.1	0.1		0.1		0.52

Site	Faeces (%)	Sanitary Products (%)	Leaves & Twigs etc. (%)	Thick Paper Towels (%)	Miscellaneous Plastic (%)	Miscellaneous Absorbant Material (%)	Miscellaneous Non-Absorbant Material (%)	Material Adhering to Mesh Bag (%)
Chesterfield Road								
Inlet	2.1	29.6	2.7	7.4	1.4	8.1	11.2	46.1
Spill	trace	33.3	6.6	6.9	1.7	8.2	16.9	41.4
Dobcroft Road								
Inlet	2.3	27.0	12.3	8.0	1.2	1.7	6.8	48.2
Spill	12.1	14.1	41.3	5.9	2.1	5.0	44.0	33.8
Retford Road								
Inlet	6.0	28.7	12.4	6.4	1.6	16.7	5.9	29.9
Spill 1	8.9	31.6	12.6	9.2	2.1	10.9	5.0	27.3
Spill 2	8.1	33.5	10.9	11.8	2.0	11.0	6.5	26.2
Spill (averaged)	8.6	32.5	11.8	10.5	2.1	11.0	5.7	26.7
Leyburn Road								
Inlet	4.8	16.0	22.8	9.4	1.8	5.6	9.9	38.9
Spill 1	12.2	19.7	47.8	9.9	7.4			33.0
Spill 2	7.8	19.8	26.0	12.5	3.1	10.7	18.4	34.9
Spill 3	6.2	17.7	49.6	9.6	3.5	6.3	4.2	15.1
Spill 4	7.0	36.0	29.4	9.6	3.4	15.4	15.4	28.3
Spill 5	8.8	21.2	22.8	15.9	4.2	11.6	11.6	20.8
Spill 6	3.9	19.8	33.2	2.1	3.3	16.6	14.3	25.9
Spill 7	8.5	24.6	27.9	11.0	3.5	3.0	9.5	31.4
Spill 8	9.5	23.3	40.3	19.3	5.4			26.5
Spill 9	4.0	24.3	38.2	9.0	1.6	6.0	8.6	19.3
Spill 10	8.6	12.6	58.9	13.4	6.0	18.7		26.5
Spill (averaged)	7.6	21.9	37.4	11.2	4.2	11	11.7	26.2

Table 5.18 Percentage Values at the Four Sites for the Different Categories of Material Examined

Table 5.19 Gross Solids Data for the Stilling Pond Site (Chesterfield Road)

Events	Total Inflow Volume (l)	Estimated Total Mass of Gross Solids in Inflow (g)	Total Spill Flow Volume (l)	Estimated Total Mass of Gross Solids in Spill Flow (g)
30 September 1990	2129760	110654	35076	2936
15 October 1990	4535676	16500	3439200	4540
18 November 1990	300960	36844	16500	2031
10 December 1990	21709400	65666	106300	331
18 January 1991	2039047	50921	9450	241
27 February 1991	3433956	73872	80688	693
8 March 1991	4956700	37000	759200	779
19 April 1991	852744	54404	4524	300
29 April 1991	11532300	43888	513900	554
8 June 1991 13 June 1991 15 June 1991	3814900	45625	1902200	1254
19 June 1991 21 June 1991	1969664	63058	245292	1653
27 June 1991	3574100	115952	717400	1397
6 July 1991	403536	51515	3012	1237
19 July 1991	1689804	193571	672528	1255

Table 5.20 Gross Solids Data for the Screens at Chesterfield Road

Event	Flow (l/s)	Total Material Collected (g)
30 September 1990 3 October 1990 6 October 1990	914144	12663
15 October 1990 17 October 1990	18377800	17401
18 November 1990	16536	11618
9 December 1990	106300	8674
18 January 1991	11713	1740
27 February 1991	80688	3886
8 March 1991	55416	3713
19 April 1991	4524	no data
29 April 1991	512900	6946
13 June 1991 15 June 1991	622392	4348
19 June 1991 25 June 1991	245292	11004
27 June 1991	717400	3748
6 July 1991	14524	7586
18 July 1991	55800	22900

Table 5.21 Gross Solids Data for the High Side Weir Site (Dobcroft Road)

Event	Total Inflow (l)	Estimated Total Mass of Gross Solids in Inflow (g)	Total Spill Flow (l)	Estimated Total Mass of Gross Solids in Spill Flow (g)
27 February 1991	3298608	5722	989076	2182
18/19 April 1991	1237864	23432	60744	12314
29 April 1991 1 May 1991	7119566	36712	401527	10880
15 May 1991	449920	41030	72240	13111
13 June 1991	1128370	45585	488352	19861
21/25 June 1991	985266	19667	102036	11148
27 June 1991	1186716	146431	607512	136522
6/8 July 1991	1294538	55304	658836	41125
11/18 July 1991	1023870	34569	205210	29952
17 October 1991	934342	33934	204864	no spill data
29 October 1991	1515742	16048	299140	14758
31 October 1991 2 November 1991	5636196	35844	1365744	34952
6/12 November 1991	3549290	45742	868056	36716
5 January 1991	6587806	21276	948742	18739

Table 5.22 Gross Solids Data for the Low Side Weir Site (Retford Road)

Event	Total Inflow (l)	Estimated Total Mass of Gross Solids in Inflow (g)	Total Spill Flow (l)	Estimated Total Mass of Gross Solids in Spill Flow (g)
13 March 1992	277440	49090	35844	22352
22 March 1992	84456	24129	2755	18290
29 March 1992 30 March 1992	936168	65056	310376	30560
3 June 1992 5 June 1992	1334344	60850	170066	28808
1 July 1992	1266600	15476	365690	14414
4 July 1992	956520	19166	46251	14394
9 July 1992 11 July 1992	1372356	24574	287698	21047
17 July 1992 21 July 1992	1834800	18972	438435	15047
22 August 1992 26 August 1992	646320	70344	167026	26870
27 August 1992 30 August 1992	2129760	59638	703173	35130
12 September 1992	444972	35152	12807	20632
21 September 1992	1076880	15330	251571	15637
25 October 1992 27 October 1992	2286600	91724	209133	62135
1 November 1992 2 November 1992	258120	43457	18338	31389
9 November 1992 11 November 1992	2098448	43892	435403	32000
16 November 1992	120720	12433	33496	6197
19 November 1992 22 November 1992	626124	37037	85292	25088

Table 5.23 Gross Solids Data for the High Side Weir Site (Leyburn Road)

Event	Total Inflow Volume (l)	Estimated Total Mass of Gross Solids in Inflow (g)	Total Spill Flow Volume (l)	Estimated Total Mass of Gross Solids in Spill Flow (g)
21 September 1992	3529092	185750	376452	30173
25 September 1992 2 October 1992	5349744	141658	1324278	14104
24 October 1992 to 28 October 1992	4520352	92595	928040	13039
2 November 1992	349056	200779	19320	27196
9 November 1992	3527132	76507	653364	23271
11 November 1992 a.m. 11 November 1992 p.m.	10099688	272125	1321106	37101
19 November 1992 to24 November 1992	7017329	308262	1100426	28528

Table 5.24 Flow Data for the Storms From the Stilling Pond Site (Chesterfield Road)

Event	Total Inflow Volume (l)	Total Spill Flow Volume (l)	Total Continuation Flow (l) (Inflow - Spill)	% Flow to Treatment	% of Total Spilled
30 September 1990	2129760	35076	2094684	98.4	1.6
3 October 1990	2566500	219513	2346987	84.4	15.6
15 October 1990	4535676	3439200	1096476	63.0	37.0
17 October1990	30897000	15274900	15622100	50.6	49.4
18 November 1990	300960	16500	284460	94.5	5.5
10 December 1990	21709400	106300	21603100	99.5	0.5
18 January 1991	2039047	9450	2029597	99.5	0.5
27 February 1991	3433956	80688	3353268	97.7	2.3
8 March 1991	4596700	759200	3837500	83.5	6.5
19 April 1991	852744	4524	848220	99.5	0.5
29 April 1991	11532300	513900	1101840	95.5	4.5
13 June 1991	381490	1902200	1912700	50.1	49.9
25 June 1991	1969664	254292	1724372	87.5	12.5
27 June 1991	3574100	717400	2856700	79.9	20.1
6 July 1991	403536	3012	400524	99.3	0.7
18 July 1991	1689804	672528	1017276	60.0	40.0

Table 5.25 Flow Data for Storms From the High Side Weir Site (Dobcroft Road)

Event	Total Inflow Volume (l)	Total Spill Flow Volume (l)	Continuation Flow (l) (Inflow - Spill)	% Flow to Treatment	% of Total Spilled
27 February 1991	3298608	989076	2309026	70	30
18 April 1991	556690	60744	495946	89	11
19 April 1991	681174	33180	647994	95	5
29 April 1991	6762906	398760	6364146	94	6
1 May 1991	356660	2767	353893	99	1
15 May 1991	449920	72240	377680	84	16
13 June 1991	1128370	488352	640018	57	43
25 June 1991	697842	102036	595806	85	15
27 June 1991	1186716	607512	579204	48	51
6 July 1991	1134408	658836	475572	42	58
11 July 1991	401828	20520	381308	95	5
17 October1991	934342	204864	729132	78	22
29 October 1991	1515742	299140	1216602	80	20
31 October 1991	3149786	1205448	1944338	62	38
2 November 1991	860276	99804	760472	88	12
4 November 1991	1264608	27924	1236684	98	2
6 November 1991	1377042	329160	1047882	76	24
8 November 1991	288060	9168	278892	97	8
11 November 1991	1116636	332748	783888	70	30
12 November 1991	767552	196980	570572	74	26
5 January 1992	6587806	948742	5639064	86	14

Table 5.26 Flow Data for Storms From the Low Side Weir Site (Retford Road)

Event	Total Inflow Volume (l)	Total Spill Volume (l)	Total Continuation Flow Volume (l) (Inflow - Spill)	% Flow to Treatment	% of Total Spilled
13 March 1992	277440	35844	241596	87	13
18 March 1992	70176	5516	64660	92	8
22 March 1992	84456	2755	81701	97	3
29 March 1992 a.m.	259440	164682	94758	36	64
29 March 1992 p.m.	255240	33759	221481	87	13
30 March 1992	421488	111935	309553	73	27
3 June 1992	843000	156012	686988	81	19
1 July 1992	1266600	365690	900910	71	29
11 July 1992	1047600	234354	813246	75	25
17 July 1992	281640	129084	252556	90	10
20 July 1992	536520	68599	467921	87	13
21 July 1992	1016640	240661	775979	76	24
22 August 1992	261360	73036	188324	72	28
26 August 1992	384960	93989	290971	76	24
27 August 1992 6a.m.	223320	39348	183972	82	18
27 August 1992 1p.m.	1024920	375893	649027	63	37
27 August 1992 6p.m.	525840	192661	333179	63	37
30 August 1992 3 a.m.	249504	75206	174300	70	30
30 August 1992 12 p.m.	106176	20065	86111	81	19
12 September 1992	444972	12807	432165	97	3
21 September 1991	1076880	251571	825309	77	23
25 October 1992	1356840	332418	1024422	76	24
27 October 1992	929760	276715	653045	71	29
1 November 1992	123600	9443	114157	92	8
2 November 1992	134520	8895	125625	93	7
9 November 1992	970848	146218	824630	85	15
11 November 1992	2608800	566426	2042374	78	22
16 November 1992	120720	33496	87224	72	28
19 November 1992 a.m.	294960	74959	220001	75	25
19 November 1992 p.m.	164604	9663	154941	94	6
21 November 1992	1274040	405432	868608	68	32
22 November 1992	166560	669	165891	99	1

Table 5.27 Flow Data for the Storms From the High Side Weir Site (Leyburn Road)

Event	Total Inflow Volume (l)	Total Spill Flow Volume (l)	Total Continuation Flow (l) (Inflow - Spill))	% Flow to Treatment	% of Total Spilled
21 September 1992	3529092	376452	3152640	89	11
25 September 1992 2 October 1992	5349744	1324278	4025466	75	25
24 October 1992 to 28 October 1992	4520352	928040	3592312	80	20
2 November 1992	349056	19320	329736	95	5
9 November 1992	3527132	653364	2873768	81	19
11 November 1992 a.m. 11 November 1992 p.m.	10099688	1321106	8778582	87	13
19 November 1992 to 24 November 1992	7017329	1100426	5916903	84	16

Table 5.28 Efficiency in the Transport of Gross Solids at the Stilling Pond Site (Chesterfield Road)

Event	Total Solids (%)	Sanitary Towels (%)	Leaves Twigs etc. (%)	Thick Paper Towels (%)	Miscellaneous Plastic (%)	Miscellaneous Material (%)	Material Retained on the Mesh Bag (%)
30 September1990 3 October 1990 6 October 1990	86	64	90	79	84	86	97
15 October 1990 17 October 1990	89						96
18 November 1990						66	95
9 December 1990	76	64		62		94	8
18 January 1991	97	96	87	90	38	93	99
27 February 1991	91	92	63	54	71		97
8 March 1991	94	95		96	47		99
19 April 1991	98	98	89	98			98
29 April 1991	86	60	75	73		77	99
13 June 1991 15 June 1991	87	90	35	49	57	89	94
19 June 1991 25 June 1991	72	88	55	31	74		97
27 June 1991	92	89	71	67	32	74	97
6 July 1991	92	80	66	78	86		99
18 July 1991	73	78	2	88	66		96
Average Values	87.2	82.8	63.3	72.1	61.7	82.7	90.8

Table 5.29 Efficiency of the Screens at the Stilling Pond Site (Chesterfield Road)

Event	Total Solids (%)	Sanitary Towels (%)	Leaves Twigs etc (%).	Thick Paper Towels (%)	Miscellaneous Plastic (%)	Miscellaneous Material (%)
30 September 1990 3 October 1990 6 October 1990	81	89	77	99	97	78
15 October 1990 17 October 1990	79	99	97			92
18 November 1990	85	91	93	96		56
9 December 1990	96	96	97	97	98	95
18 January 1991	81	83	89	84	90	79
27 February 1991	85	88	98	87	96	96
8 March 1991	83	86	98	95	98	93
19 April 1991	64	75				
29 April 1991	93	96	97	98	97	96
13 June 1991 15 June 1991	78	74	91			
19 June 1991 25 June 1991	87	34	96	98	99	99
27 June 1991	73	78	97	85	97	91
6 July 1991	86	83	88	94	99	
18 July 1991	91	91	99	96	96	

Average Efficiencies	83.5	81.3	94.8	93.0	96.7	88.1

Table 5.30 Treatment Factors for the Stilling Pond Site (Chesterfield Road)

Event	Total Solids	Sanitary Towels	Leaves Twigs etc.	Thick Paper Towels	Miscellaneous Plastic	Miscellaneous Material	Material Retained on the Mesh Bag
30 September1990 3 October 1990 6 October 1990	0.87	0.65	0.91	0.80	0.85	0.87	0.99
15 October 1990 17 October 1990	1.00						1.08
18 November 1990						0.70	1.01
9 December 1990	0.76	0.64		0.62		0.94	0.08
18 January 1991	0.97	0.96		0.90	0.38	0.93	0.99
27 February 1991	0.93	0.94	0.87	0.55	0.73		0.99
8 March 1991	1.13	1.14	0.64	1.15	0.56		1.19
19 April 1991	0.98	0.98		0.99			0.98
29 April 1991	0.90	0.63	0.89	0.76			1.04
13 June 1991 15 June 1991	1.73	1.80	0.79	0.98	1.14	0.81	1.88
19 June 1991 25 June 1991	0.82	1.01	0.70	0.35	0.85	1.78	1.11
27 June 1991	1.15	1.11	0.63	0.84	0.40		1.21
6 July 1991	0.93	0.81	0.89	0.79	0.87	0.93	1.00
18 July 1991	1.22	1.30	0.66	1.47	1.1		1.60
Average Values	1.03	1.00	0.03	0.85	0.76	0.99	1.08

Table 5.31 Efficiency in the Transport of Gross Solids at the High Side Weir Site (Dobcroft Road)

Event	Total Solids (%)	Sanitary Towels (%)	Leaves Twigs etc. (%)	Paper Towels (%)	Miscellaneous Plastic (%)	Miscellaneous Material (%)	Material Retained on Mesh Bag (%)
27 February 1991	62		26	*	*	*	
18 April 1991 19 April 1991	47	33	*	*	*	*	56
29 April 1991 1 May 1991	70	63	*	*	*	*	75
15 May 1991	68	91	*	72	*	*	72
13 June 1991	56	51	*	*	*	*	76
21 June 1991 25 June 1991	43	76	*	*	*	*	40
27 June 1991	7	*	*	*	*	*	93
6 July 1991 8 July 1991	26	*	*	*	*	*	57
11 July 1991 18 July 1991			*	*	*	*	
17 October 1991	12	79	*	*	*	*	
29 October 1991	8	67	*	75	*	*	2
31 October 1991 2 November 1991	3	81	*	*	*	*	
6 November 1991 to 12 November 1991	25	68	*	65	*	*	
5 January 1991	12	78	*	*	*	*	35

Average Efficiency	33.8	68.7	26.0	70.7			56.2

* denotes negative result

Table 5.32 Treatment Factors for the High Side Weir Site (Dobcroft Road)

Event	Total Solids	Sanitary Towels	Leaves Twigs etc.	Paper Towels	Miscellaneous Plastic	Miscellaneous Material	Material Retained on Mesh Bag
27 February 1991	0.89		0.37				0.72
18 April 1991 19 April 1991	0.60	0.42					0.79
29 April 1991 1 May 1991	0.74	0.67					0.86
15 May 1991	0.81	1.08		0.86			1.33
13 June 1991	0.98	0.89					0.47
21 June 1991 25 June 1991	0.51	0.89					1.90
27 June 1991	0.14						1.36
6 July 1991 8 July 1991	0.62						
11 July 1991 18 July 1991							
17 October 1991	0.15	1.01					
29 October 1991	0.10	0.84		0.94			0.03
31 October 1991 2 November 1991	0.04	1.20					
6 November 1991 to 12 November 1991	0.30	0.82		0.78			0.42
5 January 1991							
Average Treatment	0.45	0.78	0.37	0.86			0.88

Table 5.33 Efficiency in the Transport of Gross Solids at the Low Side Weir Site (Retford Road) * denotes negative result

Event	Total Solids (%)	Sanitary Towels (%)	Leaves Twigs etc (%).	Paper Towels (%)	Miscellaneous Plastic (%)	Miscellaneous Material (%)	Material Retained on Mesh Bag (%)
13 March 1992	55	8	22	*	68	78	69
22 March 1992	24	*				31	88
29 March 1992 30 March 1992	53	*	29	*	73	94	53
3 June 1992 5 June 1992	47	46	*	37	82	98	19
1 July 1992	7	24	5	4		*	63
4 July 1992	25	33	*		*	53	46
9 July 1992 11 July 1992	14	23	*	8	35	*	54
17 July 1992 to 21 July 1992	21	50	*	23			29
22 August 1992 26 August 1992	62	75	47	65	34	*	66
27 August 1992 30 August 1992	41	29	*	63	58	82	*
12 September 1992	41	56	36	72	*	10	5
21 September 1992	*	*	21	*	*	55	*
25 October 1992 27 October 1992	32	32	32	*	*	40	32
1 November 1992 2 November 1992	28	43	31	3	10	64	*
9 November 1992 11 November 1992	27	38	39	28	*	35	*
16 November 1992	50	71	45	11	74	88	38
19 November 1992 22 November 1992	32	34	48	*	*		26

Average Efficiency	34.9	40.1	32.3	31.4	54.3	60.7	45.2

Table 5.34 Treatment Factors for the Low Side Weir Site (Retford Road)

Event	Total Solids	Sanitary Towels	Leaves Twigs etc	Paper Towels	Miscellaneous Plastic	Miscellaneous Material	Material Retained on Mesh Bag
13 March 1992	0.63	0.09	0.25		0.78	0.90	0.79
22 March 1992	0.25					0.32	0.91
29 March 1992 30 March 1992	0.79		0.43		1.09	1.41	0.79
3 June 1992 5 June 1992	0.58	0.57		0.46	1.01	1.21	0.24
1 July 1992	0.10	0.34	0.07	0.06			0.89
4 July 1992	0.32	0.42				0.67	0.58
9 July 1992 11 July 1992	0.29	0.31		0.11	0.47		0.72
17 July 1992 21 July 1992	0.26	0.61		0.28			0.36
22 August 1992 26 August 1992	0.84	1.01	0.63	0.88	0.46		0.89
27 August 1992 30 August 1992	0.61	0.43		0.94	0.87	1.22	
12 September 1992	0.42	0.58	0.37	0.74		1.03	0.05
21 September 1992			0.27			0.71	
25 October 1992 27 October 1992	0.44	0.44	0.44			0.55	0.44
1 November 1992 2 November 1992	0.30	0.46	0.33	0.03		0.69	
9 November 1992 11 November 1992	0.34	0.47	0.49	0.35	0.11	0.44	
16 November 1992	0.69	0.99	0.63	0.15		1.22	0.53
19 November 1992 22 November 1992	0.43	0.46	0.65		1.03		0.35

Average Efficiency	0.45	0.51	0.41	0.40	0.73	0.79	0.58

Table 5.35 Efficiency in the Transport of Gross Solids at the High Side Weir Site (Leyburn Road)

Event	Total Solids (%)	Sanitary Towels (%)	Leaves Twigs etc. (%)	Thick Paper Towels (%)	Miscellaneous Plastic (%)	Miscellaneous Material (%)	Material Retained on the Mesh Bag (%)
21 September1992	83.6	74.8	65.2	48.6	84.9	86.1	86.1
25 September 1992 2 October 1992	90.0	81.8	85.7		87.4	93.0	95.1
24 October 1992 to 28 October 1992	85.9	78.0	14.9	10.9	82.1	93.7	96.3
2 November 1992	86.5	87.7	91.7	84.4	77.6		75.9
9 November 1992	69.6	73.5	76.9	78.4			77.1
11 November 1992 a.m. 11 November 1992 p.m.	86.4	84.2	68.9	32.9	68.3	96.5	96.7
19 November 1992 to 24 November 1992	90.7	93.5	47.3	95.8	98.3		94.7

Average Efficiency	86.1	81.9	64.4	50.1	71.2	52.8	88.9

Table 5.36 Treatment Factors for the High Side Weir Site (Leyburn Road)

Event	Total Solids	Sanitary Towels	Leaves Twigs etc.	Thick Paper Towels	Miscellaneous Plastic	Miscellaneous Material	Material Retained on the Mesh Bag
21 September1992	0.93	0.84	0.73	0.54	0.95	0.96	0.96
25 September 1992 2 October 1992	1.20	1.09	1.14		1.16	1.24	1.27
24 October 1992 to 28 October 1992	1.08	0.98	0.19	0.14	1.03	1.18	1.21
2 November 1992	0.92	0.93	0.97	0.89	0.82		0.80
9 November 1992	0.86	0.90	0.94	0.96			0.95
11 November 1992 a.m. 11 November 1992 p.m.	0.99	0.97	0.79	0.38	0.79	1.11	1.11
19 November 1992 to 24 November 1992	1.08	1.11	0.56	1.14	1.17		1.12

Average Efficiency	1.01	0.97	0.76	0.68	0.99	1.12	1.06

PART ONE : HYDRAULIC ANALYSIS

6.1 COMPARISON OF RECOMMENDED AND ACTUAL CHAMBER DIMENSIONS

Previous research, referred to in the introduction, suggested various chamber dimensions for the optimum performance of different designs of storm sewer overflows. A comparison of these design dimensions with the dimensions of the chambers used in this project was made. Saul & Delo, 1981 suggested a number of relative dimensions for the high side weir. In Table 6.1 their suggested dimensions are compared with the actual dimensions of the high side weirs investigated (Dobcroft Road and Leyburn Road). Most of these dimensions are given in terms of a proportion of the inlet pipe dimension (D).

Dimension	Saul & Delo	Dobcroft Road	Leyburn Road
Weir Height	0.75-0.9D (not<0.6D)	0.81D	0.92D
Weir Length	"as long as possible"	5.8D	6.0D
Diameter of Throttle Control	not < 300mm	228	203

Table 6.1 Comparison of the Dimensions of Design and Surveyed High Side Weir Chambers

A long section of straight pipe, without manholes, before the chamber was also recommended to reduce the turbulence of the flow. This was present at both these sites. The dimensions of both the high side weir sites are reasonably close to the design optima for these criteria. However, a stilling zone in the upstream part of the chamber and a storage zone in the downstream stream part of the chamber, were also found to be critical to the performance of the high side weir chamber recommended by Saul & Delo. These were not present at either site.

A similar comparison can be done for the stilling pond site. Design dimensions were originally suggested by Sharpe and Kirkbride, 1959. An extended stilling pond was then developed and tested (Saul, 1977; Balmforth, 1982). The recommendations for this extended chamber are given below.

Dimension	Extended Stilling Pond	Chesterfield Road
Weir Height	1.2D (Saul, 1977)	0.97D
Length of Chamber	6-8D (Balmforth, 1982)	4.8D
Scumboards:		
a. distance from weir	0.5D (Balmforth, 1982)	0.5D
b. height	2D (Balmforth, 1982)	1.9D
Width of Chamber	2.5D (Saul, 1977)	2.5D

Table 6.2 Comparison of the Dimensions of the Design and Surveyed Stilling Pond Chamber

The recommended length of the chamber given in the table is the length at which no further improvement in the efficiency is achieved, over the whole range of particulate terminal velocities. Thus, the longer the chamber the more efficient it is up to this length. A compromise thus has to be made between efficiency, cost and the characteristics of a given site (area available, diameter of the inlet pipe etc.). The dimensions of the Chesterfield Road site, other than the length, therefore appear to be similar to those of the optimum design chamber.

6.2 BLOCKING TESTS

6.2.1 Problems with the Blocking Tests

At the high side weir site (Dobcroft Road) it was not possible to gain access to the manhole downstream of the continuation pipe as the cover was capped with road surfacing material. Thus an assumption was made that the level of water did not exceed the soffit level of the subsequent pipe downstream.

The inflow monitor at this site is drowned out as the level of water in the overflow chamber rises. The inflow used in the storage calculations was therefore estimated as a mean of values measured before blocking commenced and after the release of the water when levels in the tank no longer affected the monitor. Inflow volume during the time for the tank to fill could not be used to check the volume of water stored due to leakage of water past the plug used to block the flow.

A check on the sensitivity of the continuation pipe discharge coefficient to the inlet dry weather discharge during the blocking test is given in Table 6.3, below.

Percentage Change in Dry Weather Flow	Percentage Change in Discharge Coefficient
+25	+3.5
+50	+5.7
+100	+12
-25	-2.7
-50	-5.5
-100	-11

Sensitivity to changes in the assumed downstream depth is shown in Table 6.4, below.

Percentage Change in Downstream Depth	Percentage Change in Discharge Coefficient
+25	+7
+50	+15.5
+100	+39
-25	-3.9
-50	-8.6
-100	-17.3

From Table 6.4 it can be seen that large errors in discharge will occur when the downstream depth is higher than that assumed. This could occur in storm conditions but is unlikely to be important in dry weather flow conditions when the blocking tests were undertaken.

At the stilling pond site (Chesterfield Road) the chamber downstream of the continuation pipe was accessible so that depths could therefore be measured. However, there was considerable oscillation in the depths due to a formation of a vortex in the chamber. Mean values for each time step thus had to be estimated from a scale.

The downstream chamber at Leyburn Road was also accessible. Depths were measured on a scale rule in this chamber during both blocking tests. Again, an average value was used as there was considerable oscillation in the depths shortly after release of the plug due to the formation of a vortex in the chamber

6.2.2 Recommendations For A Successful Blocking Test.

1. Depths should be measured in both the overflow chamber and the manhole at the downstream end of the continuation pipe.

2. Measurements of the inflow should be conducted at a point upstream of the chamber which is not affected by the backing up of water when the level of water in the chamber is at the weir crest.

3. The plug used should create an exact seal so that an estimate of the volume stored can be obtained from the inflow discharge measurements.

4. A survey of the upstream pipes should be conducted so that the volume can be calculated from the geometry of the system.

5. The time steps chosen for the test should be small enough to ensure that the number of depth measurements is sufficient for the finite difference calculation.

6. The depth of any silt upstream should be determined.

7. The plug used should be designed so that it can be removed easily, quickly and safely.

8. Care must be taken to release the plug as soon as the level of sewage in the chamber reaches the weir crest so that pollution of the watercourse is avoided.

6.3 FLOW RECORDS

6.3.1 Stilling Pond Site (Chesterfield Road)

Problems with missing data were experienced at the Chesterfield Road site due to backwater conditions and "ragging up" of the sensor. The inflow monitor was not positioned at an adequate distance upstream to prevent backwater affecting the sensor head. Readings in the continuation flow were affected by turbulence and eddy formation in the pipe. The continuation monitor would have been better placed at the downstream end of the throttle pipe. This position had been rejected initially due to the difficulty of installing the monitor in this position. Had the hydraulic conditions been more fully understood, at this stage, more effort would have been made to install the monitor there

Although these problems were recognised early in the monitoring period there were no suitable alternative sites for the equipment. The manholes upstream followed the line of the busy Chesterfield Road (one of the main routes into Sheffield). Regular visits to download information would therefore have been both dangerous and inconvenient for us and the road users. An alternative method of calculating the flows thus had to be devised. Despite these complications, the fits obtained between the calibration and the independent measured results are generally good. It is thus likely that the values chosen for the parameters (i.e. k_s and C) are acceptable.

6.3.2 High Side Weir (Dobcroft Road)

Problems with the positioning of equipment were also experienced at this site. Again it was not possible to install the inflow monitor upstream at the previous manhole as there was a 2m height increase which would have disturbed the flow and affected the flow values whether the monitor had been placed before or after it.

As the measured data were patchy at the higher flows during storm events it is not easy to know how accurate an approximation the calibrated flows are to the measured values. An example of this is given by the storm on the 4 November 1991. Just two inflow values are recorded, the first 137 l/s at 216 minutes and the second, 225 l/s at 240 minutes. A value of 225 l/s would cause depths to rise in the overflow chamber and would also suggest that overflow should occur. Neither of these happen. For the whole period from 200 minutes to the end of the storm at 300 minutes the depths in the chamber were below weir level and no spill was recorded. However, a good was fit obtained for both the blocking tests between the theoretical depth-discharge relationship and the measured values.

A model of part of the weir was made and the coefficient of discharge for this was calculated from the laboratory test results. (The Cd value for a weir crest of similar dimensions (given in King & Brater, 1976), was found to give comparable results to this model.) The Cd values of the model were used to produce a graph of overflow discharge against inflow pipe depth. This graph is given in Figure 6.1. The coefficient of discharge calculated is also given plotted against depth (Figure 6.2). This theoretical analysis for the side and end weirs for a given depth, suggests that the actual weir discharge is greater than the values recorded by the

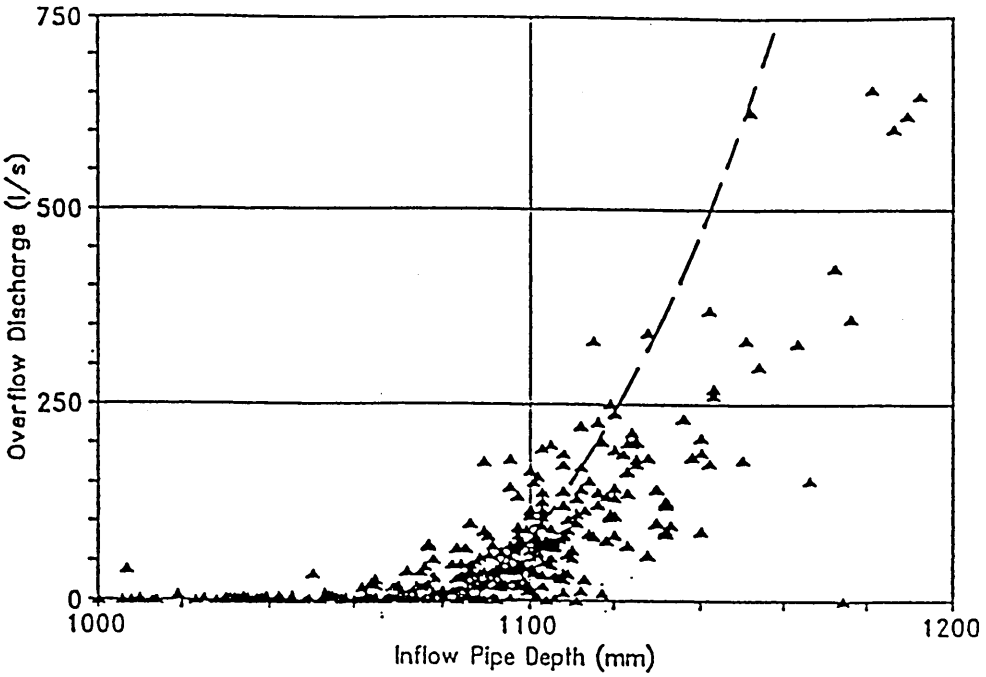


Figure 6.1 Overflow Discharge Against Inflow Pipe Depth for Values Calculated Using Cd Obtained From Weir Profile Test and for Logged Values at the Dobcroft Road High Side Weir

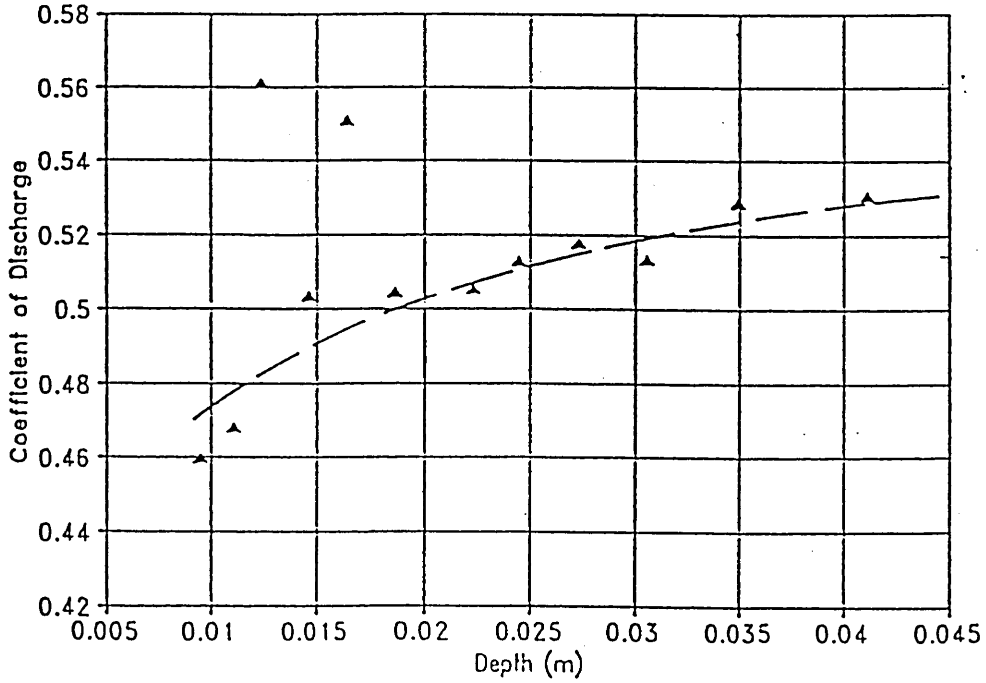


Figure 6.2 Test on Dobcroft Weir Profile in Laboratory Flume

overflow monitor i.e. the spill monitor is reading low and the flows over the weir are underestimated. This could be partly due to a storage effect in the two channels on either side of the side weir which would affect discharge values but not total volumes. This is not expected to have a very significant effect on the conclusions drawn of the spill loads discharged over the weir as the samplers tended to take samples from the early part of the storm and sampling had often been completed when the higher flows were reached.

6.3.2 Low Side Weir (Retford Road)

Although adjustments were necessary to produce hydrographs where the inflow was equal to the continuation plus weir flow we can be reasonably confident that the values used were reliable. As regular measurements of depth and velocity were taken during the monitoring period each storm could be adjusted to allow for a depth offset that had been recently recorded at the site.

Not all the storms seemed to behave in the same way. It can be seen from the scattergraphs (Appendix 1) that the bands are quite large. By splitting the large storms up from the smaller ones the amount of scatter is greatly reduced. For the lower flows the inlet depths are controlled by the continuation depth.

Calculation of the Froude Number for the inlet flow for the largest storms shows that the flow at the upstream monitor becomes supercritical at a discharge which just causes the downstream pipe to run full. As the downstream flow is subcritical a hydraulic jump forms partway along the weir. The formation and position of this jump was also influenced by the presence of the inflow gross solids collecting bag and also how full it was.

6.3.4 High Side Weir (Leyburn Road)

The calibration fitted the measured data well at the lower flows but, like the other high side weir site, data were patchy at flows greater than approximately 300l/s. A check to investigate the influence of a given error in the calibration at these flows was undertaken. An example of the storm on the 9 November 1992 is given in Table 6.5. The original calibrated total volume (A) used was 4078484 litres.

Error in Calibration (l/s)	New Volume (B) (l)	% Difference Between A and B
10	4023284	1.4
20	3968084	2.7
30	3912884	4.1
40	3857684	5.4
50	3802484	6.8

Thus, even if the calibration was 50l/s out at flows of 300l/s and above the percentage error over the whole storm would only be 6.8%. Considering that the flow monitors are only +/-10% accurate, this level of error would be acceptable.

PART TWO: SAMPLE ANALYSIS

6.5 DAILY SAMPLE VALUE VARIATION DURING DRY WEATHER

The range of dry weather flow sample values vary quite considerably between the different sites (see Table 5.3a and Figures 5.55 to 5.58 in Chapter 5). This information is summarised in Table 6.6.

Site	Average Concentration of Dry Weather Samples			
	Suspended Solids	BOD	COD	Ammonia
Chesterfield Road	225	177	554	29.5
Dobcroft Road	137	143	321	16.1
Retford Road	271	301	670	16.5
Leyburn Road	94	89	230	7.4

A brief survey of the literature gives the following dry weather flow sample parameter values: suspended solids (113-355), BOD (135-311), COD (433-755) and Ammonia (25-43) (Davidson & Gameson, 1967; Geiger, 1984; Aalderlink, 1989: Vanderborght et al, 1989). The values obtained at Chesterfield Road fit comfortably into these ranges. This is also true for the Retford Road site for suspended solids, BOD and COD and for Dobcroft Road for suspended solids and BOD. All the averages calculated for the Leyburn Road site are considerably lower than the other sites and the ranges given in the other studies. The ammonia values at all sites other than Chesterfield Road are less than those given in the literature.

For suspended solids, BOD, COD and conductivity the peak values at Retford Road are considerably greater than any of the other sites. The ranges in values and peak values for ash, pH and ammonia are reasonably similar. Dobcroft Road and Leyburn Road appear to have reasonably similar ranges and peak values for the sample parameters investigated. The peak values at the Chesterfield Road site tend to be higher for all parameters except ash and BOD.

Only one or two sets of dry weather flow samples were taken during the sampling periods as the emphasis was always on ensuring that sufficient storm samples were obtained. It now seems obvious that it is important to obtain an accurate picture of the sample variation during dry weather so that it can be compared with storm data taken at the same time of day. It would also be useful to take the dry weather samples at different times of the year to pick up any seasonal variations.

6.6 SAMPLE VALUES DURING STORM EVENTS

Table 5.3b indicates the range of sample values, from maximum to minimum, that have been recorded during storm events at each of the sites. Table 5.3c gives the ratio of peak dry weather flow values to the peak value recorded during a storm event. The aim of this is to indicate how each of the sample parameters investigated behaves under the different conditions.

From this analysis it can be noted that for certain parameters which are primarily of domestic sewage origin e.g. ammonia, the dilution effect that occurs during a storm event is important and the ammonia values thus tend to be lower during storms than in dry weather flow. For other parameters e.g. suspended solids, ash, BOD and COD the peak values are recorded during storm events. The ratios in Table 5.3c show that the peak values can be considerably greater during a storm event for these parameters. This corresponds with the concept of the "first foul flush" in which the early part of the storm is thought to carry an extra burden of pollutant material derived from the scouring of pipes by the influx of rain water and solids brought in off roads, gulley pots, roofs and other impervious or semi-impervious, surfaces by runoff. The first foul flush has been reported in a number of studies (Saul et al, 1989; Hedley & King, 1971) although they are not consistently present in overflow events. The magnitude of the load brought in during the first foul flush (where present) is thought to be related to the antecedent dry weather period (ADWP), the storm peak and average intensities, the time between the entry of storm sewage into the chamber and the first spill (the 'delay time' Saul and Thornton, 1989) and the duration of the storm.

An investigation into the occurrence of a first foul flush (defined as a peak in concentration greater than that of dry weather flow, assuming a dilution with a volume equal to the storm water volume) was undertaken at each of the sites. Elevated concentrations were found to occur at all the sites but, only at the stilling pond site and the low side weir site were these found to be commonly in advance of the flow peak. At the Chesterfield Road site concentration peaks of 640:1 (storm peak:DWF (for same time of day)) were recorded for suspended solids. The ratios for peak concentrations for the peaks of the other measured parameters are 50:1, 15:1, 20:1 and 3:1 for ash, BOD, COD and ammonia respectively. For the low side weir peak ratios are 9.5:1, 140:1, 33:1, 5:1, 8.5:1 and 2.5:1 for the same parameters. This advance peak flush of material tended to be short-lived (average 18 minutes at the Chesterfield Road site and 20 minutes at the Retford Road site). Concentrations commonly remained higher than the dry weather flow concentrations (for the same volume of storm water) for a much longer period, sometimes the whole sampling time (115 minutes).

Ideally, a much longer sampling period would have been used but, the samplers used initially could only sample at similar intervals. A compromise thus had to be made between the length of time a storm could be sampled and the number of samples that could be obtained from the initial, more concentrated section of the storm. Most water quality samplers can now be programmed to sample at different time intervals during different sections of the storm. Thus the sampling frequency at the beginning of the storm could be 5 minutes for the first 10 bottles, then 10 minutes for the next 8 bottles then 20 minutes for the remaining 6 bottles. This would give a total sampling time of 250 minutes.

The influence of ADWP, storm peak intensity, delay time and duration on the mass pollutant loading entering the overflow chamber during a storm are discussed in section 6.9.

6.7 WATER QUALITY (BOTTLE) SAMPLES

6.7.1. Graphs of the Parameter Concentrations and the Incoming Flow

It is often useful to obtain a visual impression of the results of an experiment. By plotting the results graphically patterns may become more readily obvious than they would be in a tabular form. This helped us to determine the direction of further investigations. The graphs that were included in the results section (Figures 5.59 to 5.65) are taken from only one of the eight storms from which adequate sample data was obtained at the Chesterfield Road site. It was considered preferable to concentrate on describing the analysis of one storm in detail and then to refer to the general findings of the other storms and other sites. The graphs of concentration variations with flow for the other site is given in Appendix 2.

The graphs shown thus refer to a storm that took place on 15th October 1990. The first seven graphs show the variation in the concentrations of the different measured parameters with the flow. It was noted in the introduction that the first foul flush effect is often obvious on graphs such as these. This phenomenon was found in the Chesterfield Road data, although it was more pronounced in certain storms. For the storm illustrated in the results a high initial concentration was recorded for the suspended solids, ash, BOD and COD. For all these parameters this concentration peak falls rapidly to a level close to or just above what would be the dry weather flow concentrations for that time of the day. This follows the pattern recorded by other workers for the first foul flush. However, the graphs produced by other workers e.g. Cootes, (1990), show the initial concentration peak coinciding more closely with the peak in the flow. From the pattern of the samples on the graph it appears that a first foul flush effect has been recorded.

The spill samples for the storm on the 15 October 1990 are generally of a lower concentration than the inflow samples for BOD, COD, conductivity and ammonia. Visual investigation of the graphs produced for the other storms at this site and for the other sites suggests that for the majority of storms the concentrations of each parameter are generally similar between the inlet and the spill. This is indicated on Table 6.7

	Chesterfield Road (%)	Dobcroft Road (%)	Retford Road (%)	Leyburn Road (%)
spill sample concentrations < inflow sample concentrations	32	43	15	29
spill & inflow sample concentrations are similar	68	57	70	71
spill sample concentrations > inflow sample concentrations	-	-	15	-

However, for a large minority of the storms at each site the spill concentrations appear to be lower than the inflow sample concentrations. This effect seems to be particularly common at Dobcroft Road. The difference in values was found to be most obvious for suspended solids, BOD and COD and to a lesser extent ash and ammonia. This could suggest that there is some form of 'treatment' i.e. the overflow design in some way concentrates certain material into the flow to treatment (the continuation flow) so that what is spilled to the river is of a less concentrated nature. It has always been thought unlikely that any treatment effect could be demonstrated for this class of sewage material i.e. finely suspended and dissolved material (Green, et al, 1991). However, the bore of the sampler tube is approximately 10mm, so it is conceivable that material that is capable of settling out in the stilling pond is being sampled.

Sewage materials are classed into 4 main categories: pollutants/sediments in solution, finely suspended sediments with a mean diameter of 0.5mm, coarse sediments with diameter of 3.5mm and gross solids with diameter of 6mm or greater. Thus it seems likely that these samplers can also sample the coarse material which would be separated by settlement far more readily. It should also be noted that the stilling pond has quite a high storage capacity compared to many of the conventional combined sewer overflow designs so, although it may be correct to say that no treatment effect occurs in combined overflows for the finely suspended and dissolved classes of material the extra storage provided in the stilling pond overflow may make some separation possible.

The extent of the visual differences between the inflow and the spill samples, apparent in these graphs is investigated further in the Section 6.7.2 using t-test analysis.

It is also interesting to note that the concentrations are often significantly higher than would be expected if the source of the materials was simply the dry weather flow. This was investigated theoretically in Chapter 3. There, graphical examples were given of the difference between a storm where the source of the incoming material was solely the dry weather sewage and one where material also came from other sources. This must also provide material beyond the period of the initial flush as the elevated concentrations can exist for the duration of the storm. The importance of the dry weather sewage as a source of material is investigated further by examining the contribution of the dry weather sewage to the total load brought in to the overflow during the sampling period of a storm. This is described more fully in Section 6.8.

6.7.2 Comparison of the Inflow and Spill Parameter Values

The t-test results (given in Tables 5.4 to 5.7) indicate that in quite a large number of storms there is a significant difference in the mean of the inflow and the mean of the spill for a given parameter. A summary of the results is given in Table 6.8.

Site	Number of t-Tests	Number of Significant t-Test Results	Number Indicating a Beneficial Treatment Effect
Chesterfield Road	40	24	21
Dobcroft Road	42	21	20
Retford Road	70	27	19
Leyburn Road	46	17	17

Table 6.8 Summary of the t-Test Results

The different sites will now be considered in turn.

6.7.2.1 Stilling Pond (Chesterfield Road)

At the stilling pond site the means of the inflow and spill of six parameters (suspended solids, ash, BOD, COD, conductivity and ammonia) were investigated from a total of 8 storms i.e. a total of 40 t-tests were undertaken. Of these, 24 gave significant results (51% of the total) i.e. there was a significant difference in the means for these parameters for these storms.

In 3 of the 24 (13%) tests that gave significant results the mean of the spill was greater than the mean of the inflow. Thus in 21 of the 40 tests the overflow appears to be having a significant beneficial or treatment effect on the concentrations of certain parameters. The concentration is greater in the inflow than it is in the spill flow. In 3 of the 40 tests (one each for BOD, COD and conductivity) the overflow appears to have a deleterious effect on the concentrations. In these cases the concentration in the spill flow is significantly greater in the spill flow than the inflow.

6.7.2.2 High Side Weir (Dobcroft Road)

In 21 tests out of a total of 42 a significant result was obtained for the high side weir site (Dobcroft Road) i.e. 50% of the tests produced a significant result. In only 1 of the 21 tests where a significant result was obtained was the mean spill concentration found to be greater than the mean inflow concentration. Thus in 45% of the tests the overflow appeared to be having a treatment effect.

6.7.2.3 Low Side Weir (Retford Road)

At this site 27 of the tests gave a significant result out of a total of 70 tests (39%). In 8 of the 27 tests where a significant result was obtained, the mean spill concentration was greater than the mean inflow concentration i.e. in 11% of all the tests the overflow was having a deleterious effect by apparently increasing the mean spill concentration. In 27% of the tests the overflow appeared to have a treatment effect on the concentrations spilled.

6.7.2.4 High Side Weir (Leyburn Road)

Of a total of 46 tests 17 were found to give significant results (37%). In none of the 17 tests where a significant result was obtained was the mean spill concentration found to be greater than the mean inflow concentration. The overflow thus appeared to be having a purely beneficial, treatment effect on the parameter concentrations.

6.7.2.5 Discussion of the t-Test Results

From these results it appears that the large majority of the tests where a significant result was obtained, for all the sites, produce a treatment effect, by reducing the mean concentration of the spill, for the given parameter. This supports the findings of the visual investigation of the pollutographs. The Retford Road low side weir, however, has the highest proportion of tests in which there is no significance in the difference between the two means. It also has the greatest proportion of tests in which the mean spill concentration is higher than the mean inflow concentration i.e. the overflow is having a deleterious effect (11% for the low side weir as opposed to 6% for the stilling pond, 2% for the Dobcroft Road high side weir and 0% for the Leyburn Road high side weir). This is not surprising, in fact it seems more surprising that the low side weir should have any significant effect, especially an apparent treatment effect, as it has no storage capacity.

From this analysis it appears that, although the Leyburn Road site was only monitored for a relatively short period, the high side weirs produce the most significant treatment effect. This is probably due to the large storage capacity available at these sites.

6.8 PARAMETER LOADS

6.8.1 Graphical Representation

Graphs of the change of load with time are given in Figures 5.66 to 5.70 in Chapter 5. For the 15th October 1990 (the storm taken as the example) the pattern of the loads tend to follow the variation in the flow very closely i.e. an increase in the flow leads to a concomitant increase in the load of the parameter entering the overflow per second. This suggests that the variations in the concentrations are small relative to the variations in the flow. The maximum load per second can therefore be safely predicted as being at around the time of the peak inflow. This is also found to occur for the majority of the other storms at this site and at the other sites. Table 6.9 shows the results of a visual investigation of all these graphs.

	Chesterfield Road (%)	Dobcroft Road (%)	Retford Road (%)	Leyburn Road (%)
load variation matches flow variation	65	50	50	57
reduction in load values in advance of flow	35	11	25	29
load has a separate peak to flow	-	20	22	11
no obvious relationship apparent	-	19	3	3

Thus, for a significant number of storms the load tails off in advance of the peak. This could be because the extra load brought in during the early part of the storm, due to the flushing of sewer deposits and the scouring of ground surfaces, has been exhausted and the later flow is simply dilute dry weather flow. For all sites, apart from Chesterfield Road, a number of examples of loads having a separate peak were observed. This was particularly common for ammonia , BOD and COD. This could be due to the presence of high concentrations at a point in the storm unrelated to the flow peak. It could also be influenced by the sampling time available. In a storm which has a slow build up of flow due to low intensity rainfall at the beginning of the storm which is then followed by an increase in rainfall intensity and a concomitant increase in flow into the chamber the sampling may be finished before the flow has reached peak values. The load peak will then appear distinct from the flow peak.

For a number of storms no obvious relationship between the flow variation and the load variation was apparent. This was particularly common at the Dobcroft Road high side weir. It was most often found to occur when the depth of storm sewage in the chamber had reached weir height in a relatively short space of time (i.e. a short delay time) and the incoming flow remained fairly constant for the sampling period.

One implication of these observations is that for the storms where the load variations closely follow the flow variations the 'first foul flush' with its high concentrations may not be such an important phenomenon as it occurs at the beginning of the storm when the flow is low, providing that the chamber is able to provide some storage. For these storms the concentration of a parameter is relatively unimportant in determining the load when compared to the inflow at the time. So, if the impact on the receiving river is being investigated, the load of material entering, rather than its concentration, should be seen as the important determinant.

This is an oversimplification, however, as it is also important to know the concentration of the storm water entering the receiving water. High concentrations of particular parameters e.g. BOD can have serious acute effects leading to dramatic reductions in the amount of available oxygen and subsequent death of fish and other biota. It is therefore important to establish both the concentration and the load of the material entering the receiving water courses in order to be able to fully understand its effect on this environment.

Figures 5.71 to 5.75 show the cumulative load of a given parameter from the start of sampling in that storm. They also show the point at which further samples contribute relatively little to the total mass. An S-shaped curve is produced. At the beginning the loads are low as the flow is generally low. The flows then increase to a maximum and then tail off again, usually rapidly, so that at the end of the sampling the extra samples contribute a relatively small mass to the total.

6.8.2 Tabulated Results

6.8.2.1 Dry Weather Flow : Storm Load Ratios

The maximum loads for the whole sampling periods were calculated for each parameter and the contribution of the dry weather flow to these loads was estimated. The results of this investigation is given in Table 5.8 to 5.11 (parts e to i). The proportion of the total load that was made up by the dry weather sewage is given in Part a of the Tables, for each parameter and each storm. The ratio of the percentage contribution of the dry weather flow volume to the total volume to the percentage contribution of the dry weather flow load to the total load for a given parameter is given in Part b of the Tables.

The aim of this is to establish the origin of a particular parameter. A value of 1.0 would indicate that the % of the total volume due to dry weather volume is equal to the % of the total load due to dry weather load. This would suggest that that parameter is only found in the dry weather flow. If the ratio gave a value greater than 1.0 then this would indicate that the % of the total volume made up by the dry weather volume is less than the % of the total load made up by dry weather flow. This would suggest that the dry weather flow is the main source of this material as less of it is found in the material brought in during the storm. A similar explanation can be given if the ratio calculated is less than 1.0. Here the % of the total volume made up by the dry weather volume is greater than the % of the total load made up by dry weather load. This suggests that the parameter load is greater than can be explained simply by the material contained in the dry weather flow. There must therefore be some other source of this material present during an overflow event.

From the above it should be possible to suggest the likely values of the ratio for the measured parameters for the largely domestic catchments in this study. As the suspended solids and ash material is likely to be of various origins (grit off the roads, scouring of sewer walls, small particles of faecal material etc.), a ratio of less than 1.0 would be expected. The BOD and COD parameters would also be expected to be found in both the storm and the dry weather flows but possibly more in the dry weather flow, especially for the BOD values. A prediction of a value less than 1.0 but higher than the suspended solid and ash values is made. Ammonia would be expected to be mostly derived from the domestic dry weather flow in these predominantly residential catchments. A ratio significantly greater than 1.0 is therefore predicted.

A summary of the average values obtained form this investigation is given in Table 6.10.

Site	Suspended Solids	Ash	BOD	COD	Ammonia
Chesterfield Road	0.93	0.53	2.00	1.70	6.60
Dobcroft Road	0.32	0.45	1.72	1.23	5.90
Retford Road	0.91	0.19	1.15	1.22	1.53
Leyburn Road	0.64	0.17	1.36	1.14	4.41

The predictions made thus hold fairly well for all parameters although the BOD and COD ratios are slightly greater than expected i.e. the parameter load is more dependent on the dry weather flow as a source than had been expected. Only the mean values for all the storms at one site were investigated here. The values for each storm taken separately vary quite significantly (see Tables 5.8 to 5.11). Only ammonia is consistently above a value of one. All the other sample parameters give ratios for individual storms with implications that are quite different to those that were made for the mean values. To get a more accurate impression of what is occurring a much larger number of storms would have to be investigated. The main point of interest of such an analysis is that the parameters do not all behave in the same manner and that the dry weather flow contributes a fairly small amount to the total load.

6.8.2.2 Loads from Inflow and Spill for the Same Time Periods

For storms lasting over two hours not all of the storm could be sampled due to the fixed sampling period. Comparisons between the total inflow load and the total spill load of a storm event were therefore not possible. Thus, only the loads for samples taken at the same time from the inflow and spill were considered here (see Part d. of the Load Tables). As total flow over the weir tends to be considerably less than the inflow for the same period of time the loads spilled are also considerably less than the inflow for every parameter measured. However, large loads of material are spilled and these go directly to the receiving watercourse. For example, on 13 June 1991 at the Chesterfield

Road site, 13.8 Kg of suspended solids were spilled. The amounts of ammonia released are much smaller due to the lower concentration of ammonia present in storm sewage. However, even relatively small amounts can have significant toxic effects. In 80 minutes at Leyburn Road 3.2 Kg of ammonia was spilled. This could have a significant deleterious effect on the receiving water (River Sheaf) which at that point is shallow and no more than 7m wide. The BODs can also be high. Discharge of material with high BODs can cause a serious reduction in the oxygen available for plant and animal respiration. The maximum loading recorded occurred at the Chesterfield Road site where 58.8 Kg was discharged in 110 minutes.

6.9 THE EFFECT OF VARIOUS FACTORS ON SAMPLE CONCENTRATION AND LOAD

Many other similar projects have reported that the concentrations or loads of combined sewage are influenced by such factors as the antecedent dry weather period (ADWP), the peak storm intensity, the duration of the storm and the depth of rain (Hedley & King, 1971; Saul & Thornton, 1989) an attempt was made to investigate this with data from the present study. As so few storms were fully sampled (12 at Retford Road, 8 at Chesterfield Road and 7 each at Dobcroft and Leyburn) the conclusions drawn are tentative.

Graphs were initially produced to investigate the influence of peak intensity, average intensity, depth of rainfall, ADWP and duration on the peak and average concentration of the storm for each sampled parameter. Few relationships were obvious from this analysis and none were found to be significant when a regression relationship was applied to the data.

It was then decided that the influence of the dry weather flow should be eliminated so that only the load of material that was brought in during the storm was being considered. Thus "storm loads" were calculated. These are recorded in Tables 5.8 to 5.11 parts e to i. As explained in Chapter 4 these loads are the total inflow loads minus the dry weather flow load for the same time period for that time of the day.

An investigation was then made to determine the following:

1. Was there any interrelationships between the factors? e.g. did the storms with higher peak intensities have shorter durations?

2. How did these factors influence the storm load of the parameters? Are there any obvious differences in the way in which the different parameters behave? Are there any obvious differences between the results for the different sites?

3. Does the length of the delay time influence the magnitude of the load discharged over the weir?

6.9.1. Interrelationships Between Factors

It seems logical that there should be some relationship between several of the factors being investigated. Storms that had a very high peak might be expected to have a short duration, storms with long duration might be expected to have a greater depth of rain.

A correlation matrix was produced for each site for ADWP, duration of the storm, peak storm intensity and the depth of rain. From this it was possible to determine which factors were influenced by which other factors.

For the majority of the factors no correlations existed. The relationship between peak intensity and duration was poor at all sites except Leyburn Road where longer durations were associated with higher peak intensities, although this was not highly significant. However, a good correlation between peak intensity and the ADWP existed at Dobcroft Road, where higher peak intensities were associated with a longer ADWP. The relationship between these two factors was also reasonable at the Chesterfield Road site and at Retford Road but at these latter sites a high peak intensity was associated with a shorter ADWP. From this it was concluded that the amount of data obtained was insufficient for such analysis.

6.9.2. The Influence of ADWP, Duration, Peak Intensity and Storm Depth on the Storm Load

The influence of these factors on the magnitude of the storm load of the parameters measured was determined by regression analysis. Where this was found to be significant a graph was produced so that the relationship could be determined visually. At the Chesterfield Road site the peak rainfall intensity was found to have a significant influence on the magnitude of the storm load for suspended solids, ash, BOD and COD (see Figures 6.3 to 6.6). A higher peak intensity was associated with a greater storm pollutant load. This seems logical, as if peak rainfall intensity increases, greater material removal from the ground surface would be expected. Higher peak intensities would also be associated with greater discharges and velocities and hence more material would be scoured from the sewer pipes. A high pollutant load would thus be predicted for a storm with high peak rainfall intensity.

A significant relationship between peak intensity and storm load was not apparent at any of the other sites. At Dobcroft Road and Retford Road no significant relationships were apparent for the factors investigated. This may be due to the paucity of the data obtained.

At the Leyburn Road site a significant relationship was demonstrated between the ADWP and suspended solids, ash and BOD storm loads (see Figures 6.7 to 6.9). This suggested that the longer the ADWP the larger the volumes of pollutant material of storm origin. This would be expected as the greater the time there is between storms, the longer there is for material to build up on the roads, roofs etc. and to be deposited in the sewer pipes from the dry weather flow.

As so few storms were sampled it is difficult to infer too much from these results. However, it is possible that differences in the catchment could be used to explain the results. At the Chesterfield Road site the catchment is steep immediately upstream of the overflow chamber, the sewer pipes were clean and there was no significant

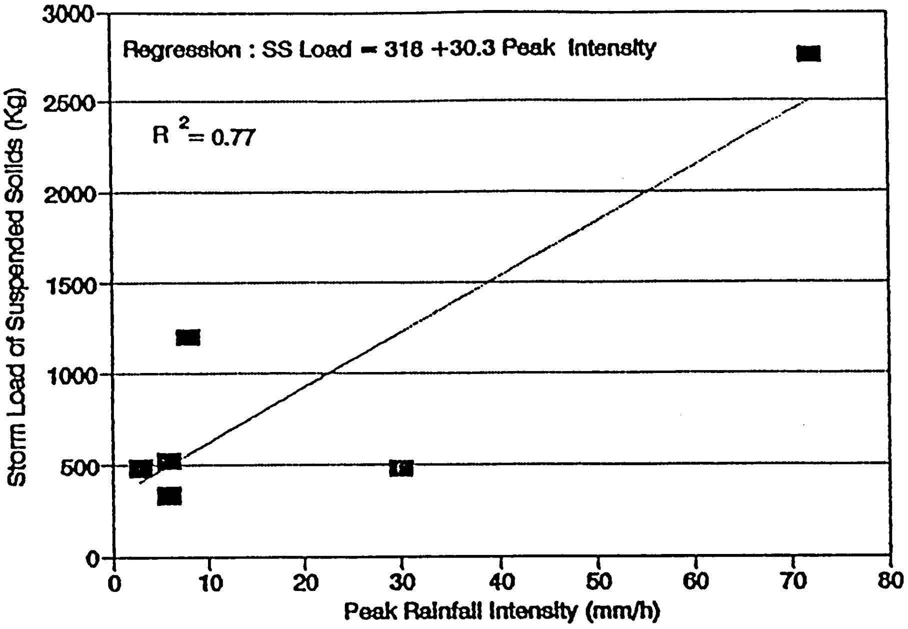


Figure 6.3 Relationship Between Storm Load of Suspended Solids and Peak Rainfall Intensity at the Chesterfield Road Site.

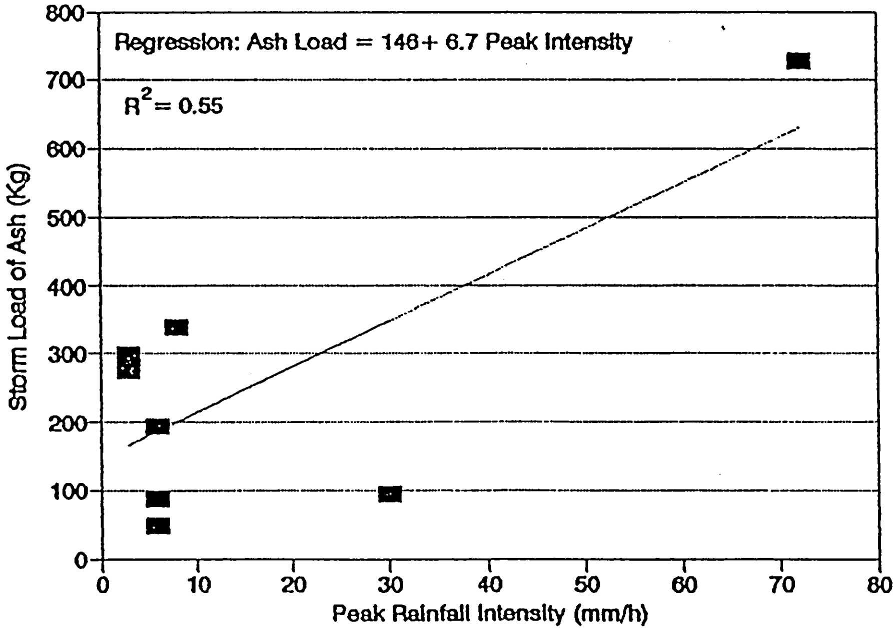


Figure 6.4 Relationship Between Storm Load of Ash and Peak Rainfall Intensity at the Chesterfield Road Site.

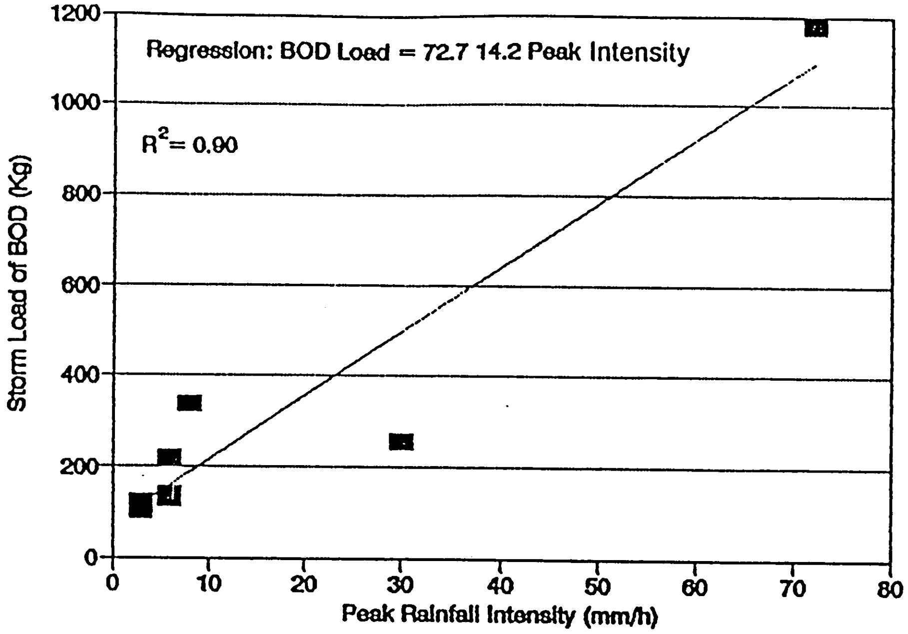


Figure 6.5 Relationship Between Storm Load of BOD and Peak Rainfall Intensity at the Chesterfield Road Site.

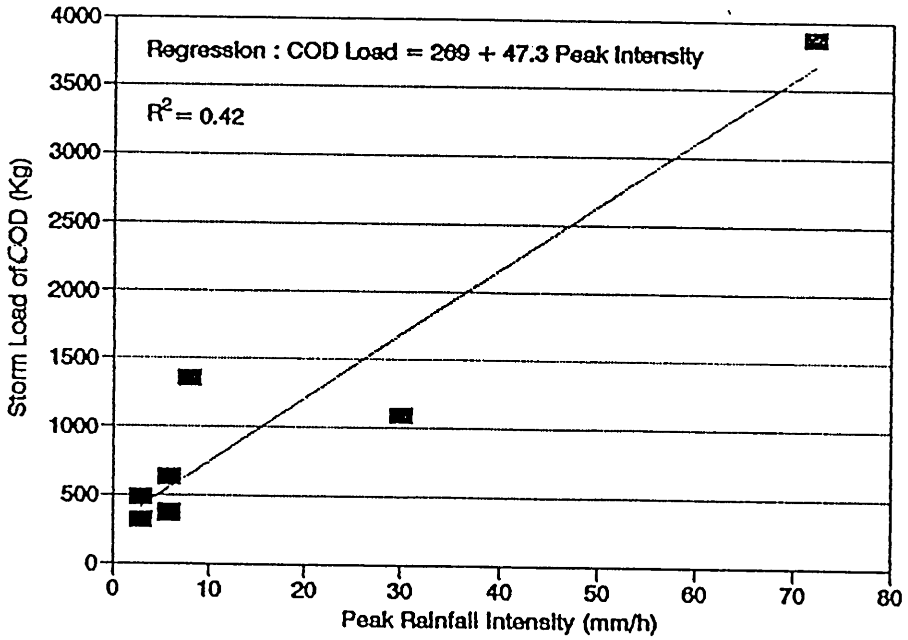


Figure 6.6 Relationship Between Storm Load of COD and Peak Rainfall Intensity at the Chesterfield Road Site.

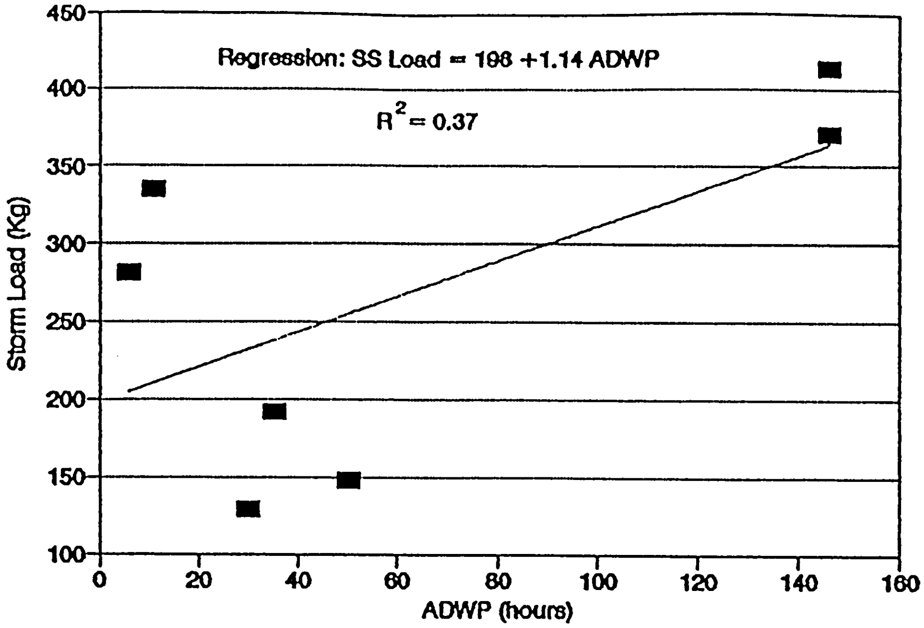


Figure 6.7 Relationship Between Storm Load of Suspended Solids and ADWP at the Leyburn Road Site.

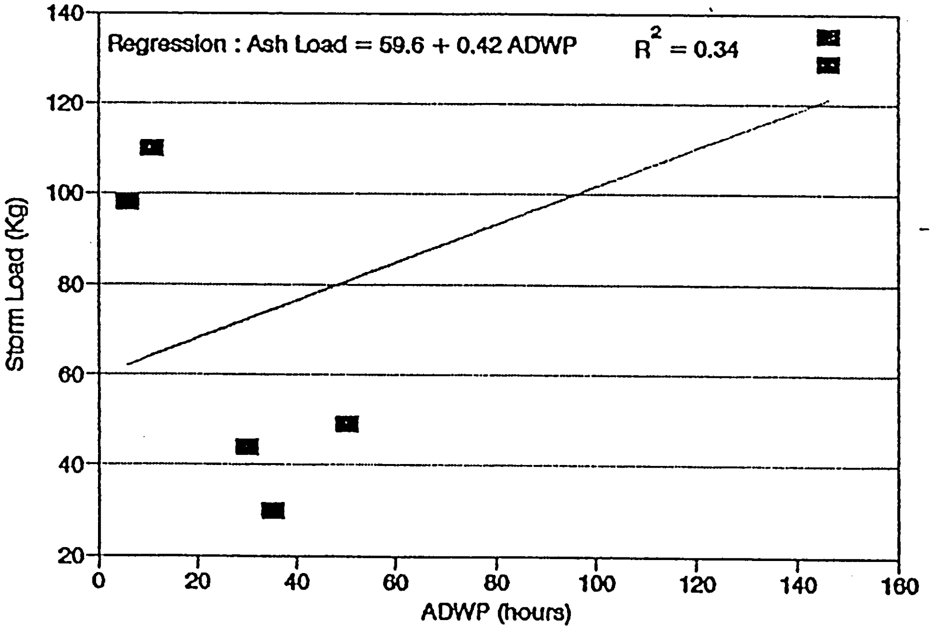


Figure 6.8 Relationship Between Storm Load of Ash and ADWP at the Leyburn Road Site.

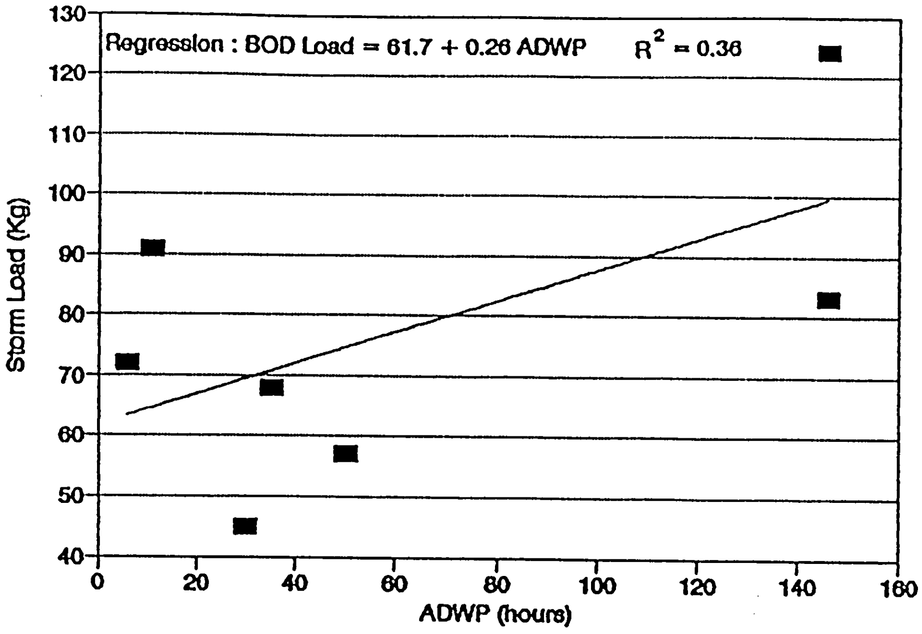


Figure 6.9 Relationship Between Storm Load of BOD and ADWP at the Leyburn Road Site.

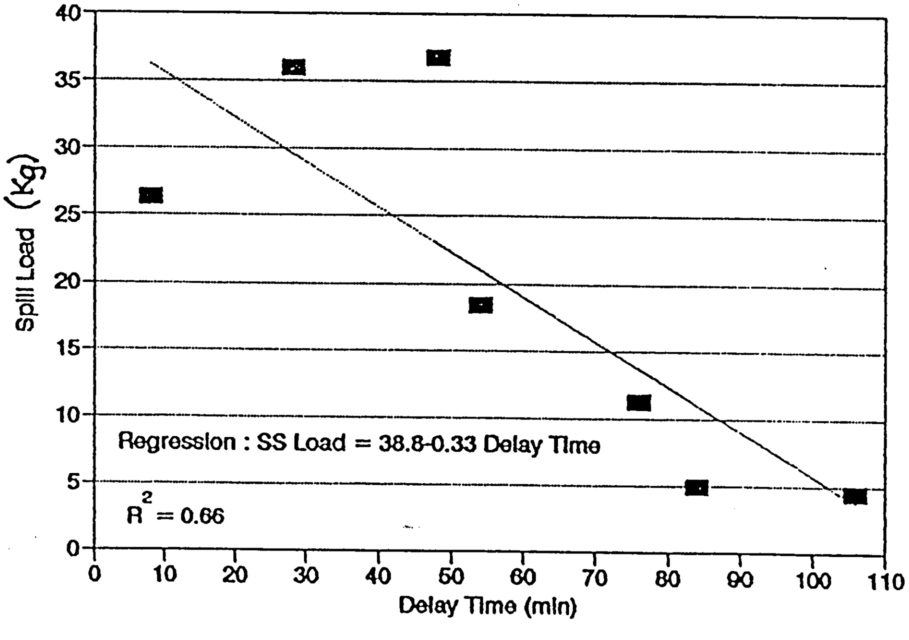


Figure 6.10 Relationship between the Spill Load of Suspended Solids and Delay Time at the Dobcroft Road Site

deposition of material in the overflow chamber. At the Leyburn Road site, deposition in the chamber and the pipes immediately upstream was a problem. The antecedent dry weather period might therefore be expected to be more influential at the Leyburn Road site rather than the Chesterfield Road site as it is prone to deposition whereas the Chesterfield Road site is generally clean.

This would suggest that the majority of the Leyburn Road site storm load is derived from material in the sewer and the majority of the Chesterfield Road storm load is derived from material brought in off the roads, roofs and other ground surfaces. However, the influence of the time of the year must also be considered. At the Leyburn Road site, all the sample data were obtained in November and December 1992. At that time of the year storms tend to be longer and less intense. The Chesterfield Road data were obtained from storms throughout the year and the peak rainfall intensities obtained are more variable.

6.9.3. The Influence of the Delay Time on the Load Spilled

The delay time is the time between the storm wave first entering the overflow chamber to the time of the first spill. As the concentration of pollutants in the early part of the storm is usually significantly greater than the later part of the storm, it would be expected that the loads of storms which had short delay times would be greater than those which had longer delay times. The shorter the delay time the less time there is for material to be sedimented out and, in storms where some storage exists, retained in the flow to treatment.

The influence of this factor on the load of material spilled was investigated graphically and by regression analysis. For all the sites except the Chesterfield Road, some significant relationships were demonstrated. These are shown in Figures 6.10 to 6.18. At Retford Road, significant relationships were recorded for all the parameter measured. At Dobcroft Road significant relationships were found for suspended solids, BOD, COD and ammonia. At the Leyburn Road site a significant relationship was only demonstrated for ammonia. In all these relationships longer delay times were associated with smaller loads of material being measured in the spill.

For all these investigations into the influence of various factors on the magnitude of storm loads more data needs to be obtained before any further conclusions can be drawn.

6.10 CORRELATIONS BETWEEN MEASURED PARAMETERS

6.10.1 Linear Regression

One of the aims of the project was to investigate the strength of the correlations between the dissolved and finely suspended solids sample parameters measured during storm events. Some of the parameters are difficult and time consuming to analyse so, if it was found that one such parameter showed a strong and consistent correlation with a parameter that was easier to analyse then this could be used to predict the value of the other.

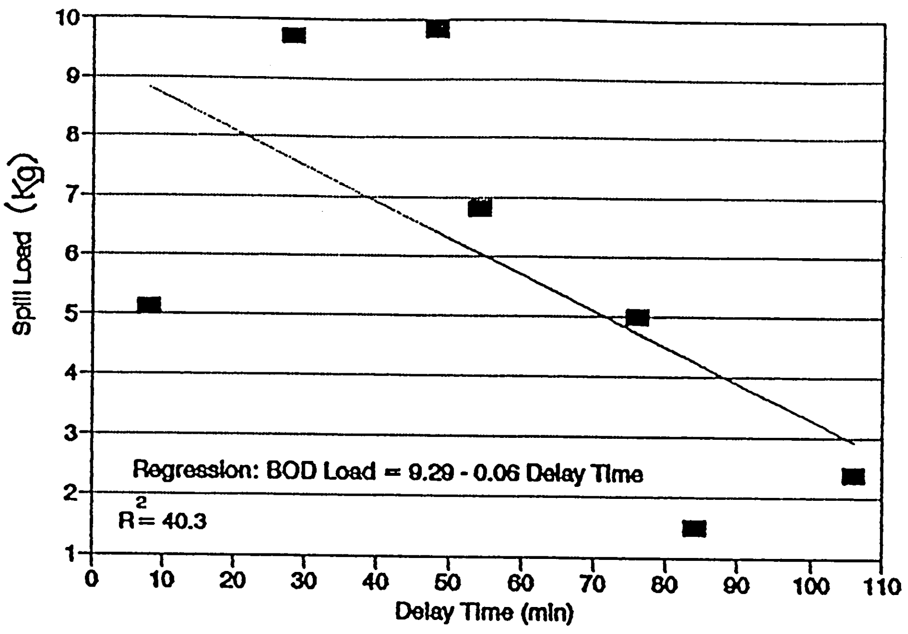


Figure 6.11 Relationship between the Spill Load of BOD and Delay Time at the Dobcroft Road Site

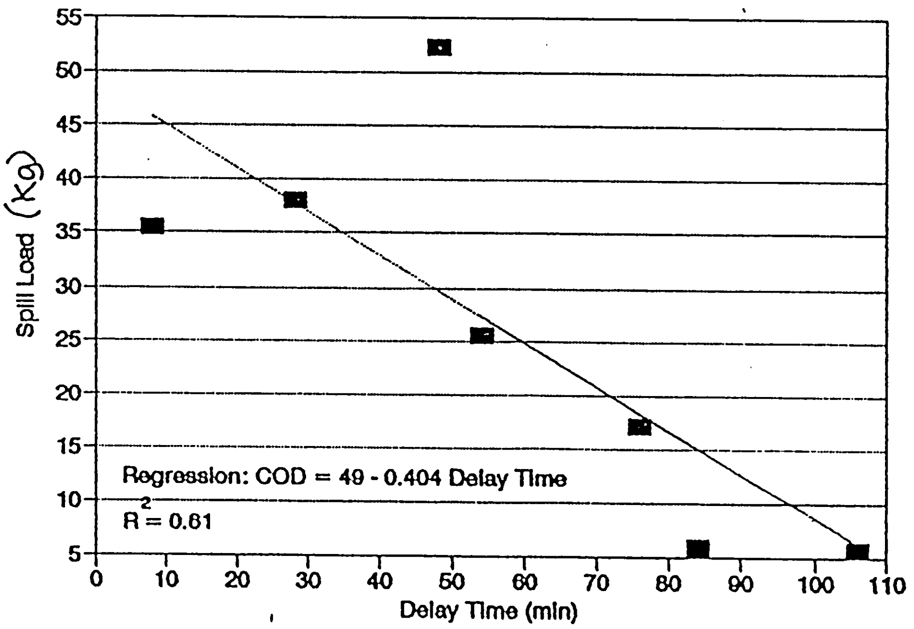


Figure 6.12 Relationship between the Spill Load of COD and Delay Time at the Dobcroft Road Site

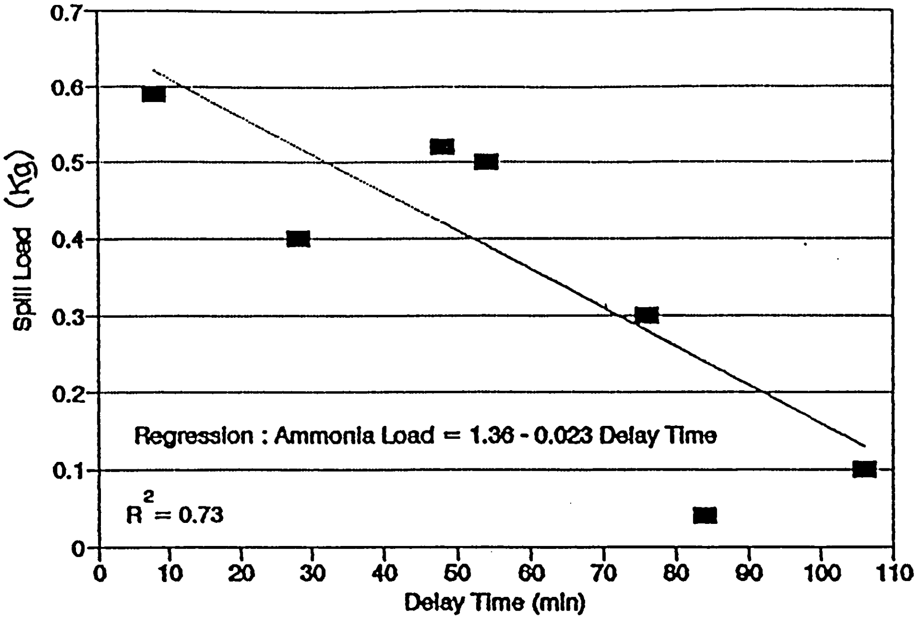


Figure 6.13 Relationship between the Spill Load of Ammonia and Delay Time at the Dobcroft Road Site

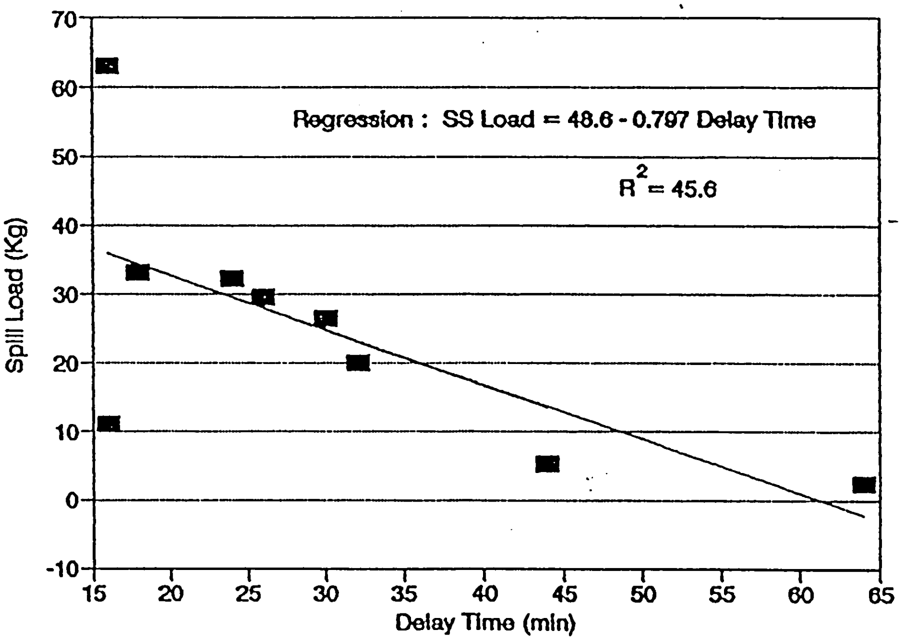


Figure 6.14 Relationship between the Spill Load of Suspended Solids and Delay Time at the Retford Road Site

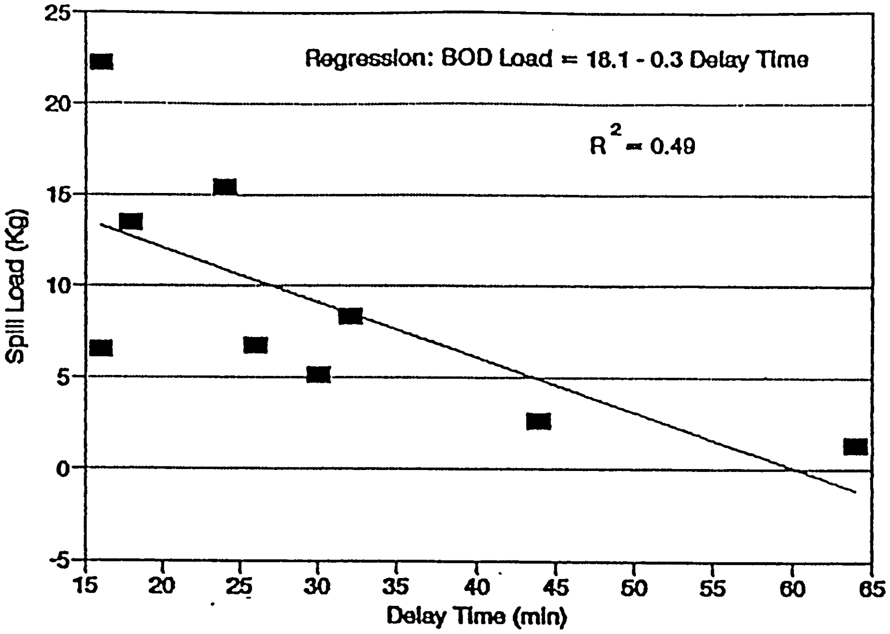


Figure 6.15 Relationship between the Spill Load of BOD and Delay Time at the Retford Road Site

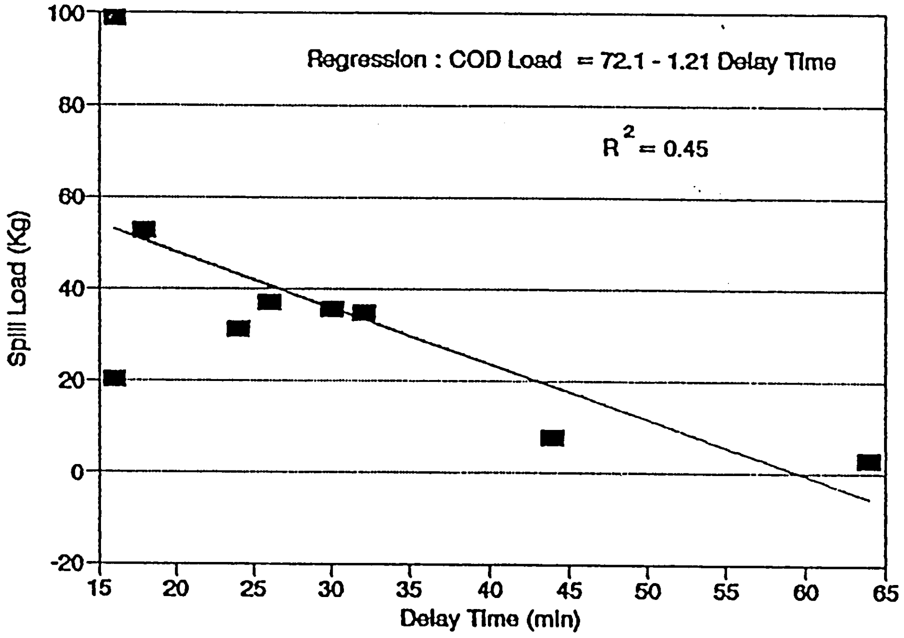


Figure 6.16 Relationship between the Spill Load of COD and Delay Time at the Retford Road Site

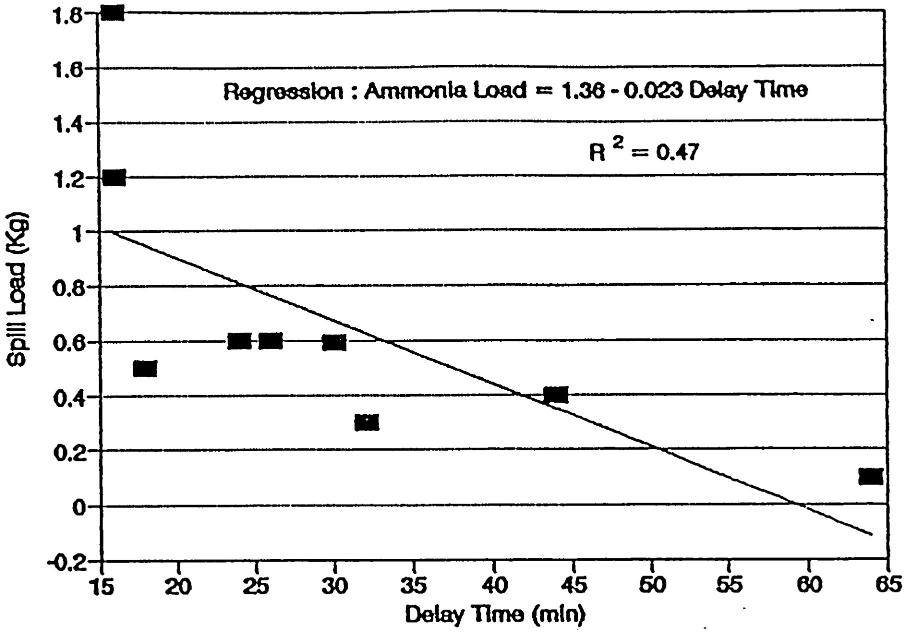


Figure 6.17 Relationship between the Spill Load of Ammonia and Delay Time at the Retford Road Site

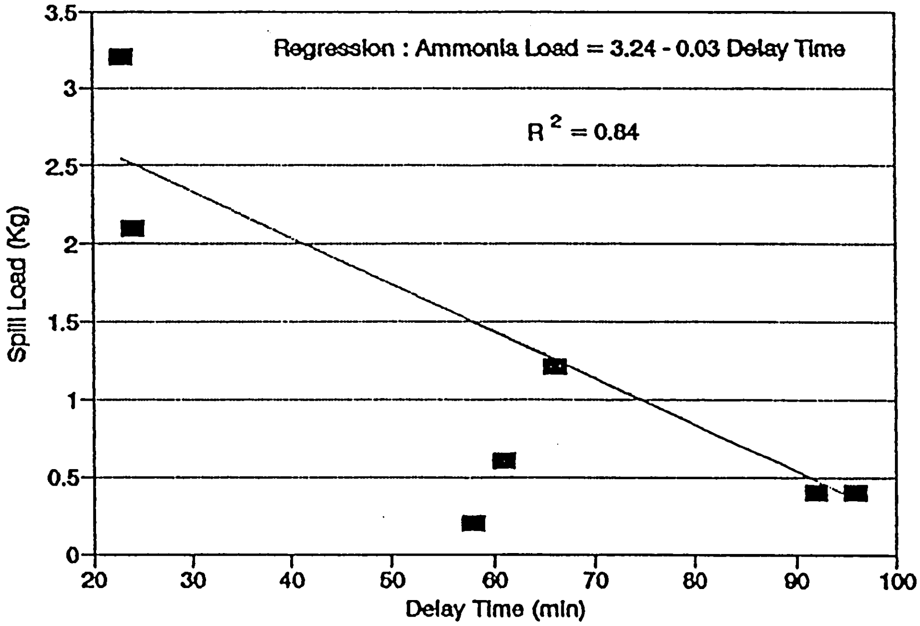


Figure 6.18 Relationship between the Spill Load of Ammonia and Delay Time at the Leyburn Road Site

This idea was investigated for all the samples of every storm obtained. Reasonably good correlation was found to occur for a number of parameters from both the inflow and the spill. The examples of the strongest relationships for the Leyburn Road site are illustrated in Figures 5.76 to 5.83. Examples from the other sites are given in Appendix 3. From these figures it can be seen that strong relationships exist at each site for both the inflow and the spill for suspended solids and ash and for BOD and COD. The relationship between suspended solids and BOD and between suspended solids and COD is also good at some sites but there is more variation from the regression line (i.e. a lower R^2 value). At the Retford Road site the relationship for these latter parameters is poor, possibly due to the presence of a meat factory upstream which discharged large quantities of fatty substances and blood at various times of day. The relationship between ash and suspended solids was consistently found to be strong although the relationship between ash and BOD or COD is far less strong than that for suspended solids. Conductivity and ammonia show no apparent correlation with any of the other four parameters measured (pH was not included in this investigation). A relationship between conductivity and ammonia could be detected from a visual inspection of the regression graphs but the R^2 values were significantly less than for the other parameters (usually between 0.30-0.40).

The relationship between suspended solids and ash was found to be very consistent between sites. Thus, a regression line taken from one site could be drawn onto a regression graph from another site and the two lines would be almost identical. This was also true, but to a lesser extent, for BOD and COD.

Although good correlations were found to occur for a number of parameters from both the inflow and the spill when all the storms were included in the regression, when individual storms were investigated the strength of the correlations, or the R^2 value of the regression were more variable. For some storms stronger relationships between a given pair of parameters existed but for other storms there was no significant relationship between the same two parameters. From this it could be concluded that although there were, on several occasions, strong correlations between the measured parameters these correlations were not consistent. This is not surprising when the nature of the liquid being sampled is considered.

Although certain generalisations could be made about the composition of storm water it must be remembered that these are generalisations. Storm water, even when the dry weather flow is largely of domestic origin, is subject to very large fluctuations, at different times of the day, from one day to the next and seasonally. It may also be affected by the duration and intensity of the rain and the antecedent dry weather period. Thus although a prediction of say, BOD from suspended solids, might provide an adequate estimate for a number of occasions on others it would be completely unrelated to the actual value of the assumed parameter giving misleading information for a potentially important parameter.

6.10.2 Multiple Regression (Linear Regression with More than One Independent Variable)

Multiple regression analysis was also used to try to elucidate the relationships between the different parameters. The results of this analysis support the conclusions of the linear regression analysis. Table 5.16 gave examples of the most highly significant relationships for all the data at the inflow and the spill at each site. The R^2 value is again used as an indicator of the strength of the regression relationship. Only the variables that make a significant contribution to determining the concentration of the dependent variable are included in these equations. The resulting equations give the concentration of one sample parameter as equal to a constant and various proportions of other parameters.

This investigation shows that although significant relationships can exist between two parameters the addition of other parameters to a regression equation can contribute to providing a more precise estimate of the dependent variable. Thus, a linear regression relationship might be calculated for the suspended solids and ash concentrations of a set of samples and the R^2 value calculated to be 0.81. With the extra contribution of COD and ammonia concentrations this value could be increased to 0.94. In practical terms, this could be useful in the prediction of a parameter e.g. BOD which is not being measured as it provides a more accurate estimate than simply using one parameter to make the prediction.

These relationships were taken from a collation of all the data from the inflow and spill for the whole survey period at each site. As for the linear regression relationships, when individual storm data are investigated the relationships are not so consistent and wide variations can exist. To illustrate this point Table 5.17 is included here. This shows the collation of multiple regression results at the Chesterfield Road site for the inflow samples. The influence of the each variable parameter on the dependent parameter is indicated by the number in the box, 0.1 being the highest significance and an empty box indicating that this variable parameter has no significant influence on the concentration of the dependent parameter. The R^2 value in the end column indicates how significant the whole regression equation is for that dependent parameter for the given storm. For example, on the 3 October 1990, the suspended solids concentration can be estimated from the regression equation the BOD, COD, pH, conductivity and ammonia concentrations. For other storms at this site, e.g. on the 19 March 1991, only ash concentration is found to a have a strong correlation with the suspended solids concentration.

As was concluded the regression results in the previous section, these relationships should only be used as a rough guide and they should not be used to replace the measurement of important parameters when poor estimation of a parameter value could have harmful effects.

6.11 THE COMPOSITION OF THE GROSS SOLIDS COLLECTED

The proportion of the total made up by different categories of gross solid material found at the inflow and spill was investigated for each of the sites. This information is given in Table 5.18 in Chapter 5. Some observations on the investigation follow.

6.11.1 Faecal Material

The values obtained for the amount of faecal material is bound to be an underestimate due to the nature of the material. Flow passing through the mesh bags will obviously force much of the faeces through and what remains, due to a drop in the flow or a blinding of the mesh, will cover whatever else is in the bag. Faecal material is broken down in the sewer and becomes dispersed in lumps or a thin slime over other materials. Only the hard, compact nodules remain intact. For this reason faeces was not included in the tables showing the efficiency or the treatment factors at a particular site for different categories (Tables 5.28 to 5.36). It was observed, however, that more of this material was retrieved at the low side weir, inflow and spill, than at the other sites. It was also found in some abundance on the screens at the stilling pond site but nowhere else at that site.

The results for the proportion of faeces at the various sites given in Table 5.18 must therefore be taken as an underestimate of the full proportion. This table indicates that at every site, apart from the stilling pond, the proportion of faecal material is greater for the spill than for the inflow. This may be due to the force of the water flowing through the particular bags, it perhaps being less through the spill bags than through the inflow bags.

6.11.2 Sanitary Towels and Tampons

Few tampons were found in the sorting of the material and, where present, they comprised less than 0.5% of the total mass of material. No useful conclusions could be made about their behaviour.

A reasonably consistent proportion of sanitary towels was found from the inflow for each of the sites (an average of 25.3% +/- 6%) although the proportion for the high side weir at Leyburn Road was somewhat smaller (16%). It must be noted however that the large majority of the sampling at this site took place from October to December. Seven of the eleven bags sorted were taken from events in autumn i.e. when there was a significantly larger proportion of leaf debris present than at any other time of the year. This has obviously affected the results for this site, making the organic/leaf debris category more significant than it would have been if samples had been taken over a whole year. All the other sites have samples from each of the seasons and it is hoped that the results portray a more accurate picture of reality.

The proportion of sanitary towels in the spill is more variable with the stilling pond site (Chesterfield Road) and the low side weir (Retford Road) providing similar proportions (33.3% and 32.5% respectively) and the high side weir at Dobcroft Road providing the lowest proportion (14.1%). It is only at Dobcroft Road that the proportion of the total contents taken up by sanitary towels actually decreases from inflow to spill. For each of the other sites there is a 3.5% to 6% increase from inflow to spill. A problem with sampling error becomes important at the high side weir site at Dobcroft Road. At this site only 2%-3% of the spill was being sampled and analysed. This is too small a proportion to provide useful results. If contents of a particular spill bag contained a higher than average proportion of one material when this was multiplied up to provide an estimate of the total mass of solids spilled in that event the amount for that material would obviously be an overestimate. This problem was overcome at the high side weir a Leyburn Road by installing 10 mesh bag frames along the weir. This sampling error will be discussed further in Section 6.12.1.3. The consistently large proportion of sanitary towels found in both the inflow and the spill mesh bags is of interest as the U.K. is the only country in the EU which permits the disposal of sanitary towels in the sewer system. From these results it appears that a ban on this method of disposal would be effective in significantly reducing the total discharge of gross suspended solids from combined sewer overflows.

6.11.3 Thick Paper Towels

Very similar proportions were found for all the sites at the inflow (range from 6.4% to 9.4%). Again there was more variation on the spill although the values were not notably different from the inflow values.

6.11.4 Miscellaneous Plastic Material

This is found in very similar proportions at each of the sites (average of 1.5% +/- 0.3%). A moderately larger proportion is found on the spill (average 2.5% +/- 1.1%). The buoyancy of many plastic materials may contribute to them being preferentially passed over the weir. For the great majority of the events investigated at the high side weir at Dobcroft Road no plastic items were retrieved. The results for this site thus only refer to a small number of occasions. The same is true for the low side weir site (Retford Road) and the other high side weir site (Leyburn Road) but to a lesser extent.

From these results it might appear that the plastic items only take up an insignificant proportion of the total. However, it must be remembered that it does not require much of a weight of crisp packets, sweet wrappers, plastic packaging etc. to cause a considerable amount of aesthetic contamination.

Despite the popular conception that condoms are extremely common in sewage they were not taken as a separate category for the same reason as the tampons i.e. they were rarely found. They were, however, noted when they were obtained. It was only at the high side weir at Leyburn Road that they were found with any degree of regularity (four during the whole monitoring period). Only one was retrieved at the Dobcroft Road high side weir in a whole year of monitoring. Three were taken from the low side weir and 6 at the stilling pond site for similar monitoring periods as Dobcroft Road.

6.11.5 Leaves, Twigs and Other Organic Material

This category was taken to include leaf debris, twigs and other tree associated items e.g. conkers, other nuts and grass clippings. Other items classed as "organic", in the biological sense, have been included. On reflection, a separate "non-leaf organic material" category should have been used for items such as dead goldfish, dead blackbirds and live frogs as these items are unlikely to behave in the same way as leaves in an overflow in storm conditions.

Fortunately, the amount of non-leaf organic material was insignificant for the large majority of the events. At the stilling pond site (Chesterfield Road) there was a sandwich shop upstream of the site and pieces of tomato and lettuce were common. However, compared to the tree debris it is maintained that even at this site the proportion of non-leaf debris is small compared to the leaf debris and this is particularly so in the autumn/winter months.

No consistent proportions were found for any of the sites for spill or inflow for this category. The problem with the timing of the monitoring period at the Leyburn Road high side weir is thought to be important here. Generalisations as to the "leafiness" of the particular catchments can also be made. It certainly appeared that the Dobcroft Road and the Leyburn Road catchments had a particularly high proportion of trees along the roads and small parks.

This was true to a lesser extent at the Retford Road site, where there were some trees along the roads but no parks, and at the Chesterfield Road site, where although there was a reasonably large park in the middle of the catchment, there were fewer tree-lined roads.

It thus appears that the influence of tree litter is quite important, as is the time of year in which the sampling took place and the proportion of events recorded when the leaves are being shed. Leaf fall is probably the most significant factor in determining the proportions of the different categories of gross solid material.

At the stilling pond site the proportion of the total made up of this category was smaller than that made up by faeces and only just greater than that made up by plastic. At the Leyburn Road high side weir the proportion of the total made up with leaf debris is the largest category (not including the material adhering to the bag, to be discussed later). For the spill bags the greatest proportion is either taken up by sanitary towels (stilling pond site and low side weir site) or by the leaf debris category (the two high side weir sites).

Leaf debris, and all the organic materials included in this category, do not contribute to "aesthetic pollution" in the same way as the other categories included in this study. Tree debris is obviously not perceived as unsightly and all the items included in this category have the advantage of being biodegradable.

6.11.6 Absorbent and Non Absorbent Material

These categories arose out of the desire to have some way of grouping unidentifiable substances and uncommon things that did not fall into any of the other categories. The "non-absorbent" category was largely made up of grit and gravel, presumably from the roads. Some of the "miscellaneous absorbent" category was made up of what could be the insides of sanitary towels. However, the material was so disintegrated that further classification was not possible. The results for these categories are therefore variable between the different sites as they were between the different storms at a particular site. Further conclusions about such heterogeneous categories are not possible.

6.11.7 Material Adhering to the Mesh Bags ("Gunge")

Normal toilet paper probably produces the majority of the material in this category. From visual observations on site it appears that the vast majority of the gross solids coming into the sewer are such tissues and it is this material that causes the main problems with the "ragging up" of equipment. This material significantly reduces the mesh opening and often almost blinds the bottom of the bag. The values obtained for this material are probably an underestimate of the total amount of toilet paper as, when wet this material disintegrates to form this amorphous "gunge" some of which will pass through the mesh bag when forced by a jet of water.

The results obtained for this material show that at each site the proportion of the total taken up by this material is similar between the inflow and the spill but that there is a notable variation in the proportions found between the different sites. The average values for the inflow are 40.8% +/-8.3%, and for the spill 32.0% +/- 7.1%.

6.11.8 General Comment on Gross Solids Composition

The general conclusion that can be made from this investigation are that for the majority of the categories investigated there is similarity in the proportions of the total taken up by particular categories. Although it might be interesting to try to predict the composition of a catchment given its land use, area, etc. this would be difficult to achieve, except at a very general level, due to the variable nature of the material from day to day.

6.12 ESTIMATING THE EFFICIENCY OF THE SYSTEMS

6.12.1 Gross Solids

6.12.1.1 Treatment Factors for the Total Load of Gross Solids at Each Site

Although the efficiency of the stilling pond site in preventing the passage of gross solids over the weir seems to be very high (average value 87.2%) the treatment factors for this site, displayed in Table 5.30, suggest that the overflow has very little effect on separating out gross solids as the apparent difference is due only to the flow split. Where the treatment factor is greater than one some reduction in the concentration of gross solids in the spill is suggested. Of the 14 events examined a treatment factor greater than one was achieved on five occasions. The average value of the treatment factor for all the storms is 1.07 with the majority of the storms having a value between 0.88 and 1.00.

At the high side weir site (Dobcroft Road) the value of the treatment factor decreases significantly as the year proceeds from June to November (see Table 5.32). One explanation for this is that significantly the largest portion of the spill gross solids is made up of leaves and other plant debris. Towards the end of the year the amount of such material increases markedly making the overflow seem much less effective. This is investigated in more detail in the following section. The values for the first half of the year are similar to those from the stilling pond site suggesting again that the overflow has little effect preventing the passage of gross solids over the weir and the apparent difference is due solely to the flow split.

The treatment factors calculated for the low side weir site (Retford Road) site are notably less than those for the other three sites (see Table 5.34). The average value for all the events investigated is exactly 0.50. The values range from 0.19 to 0.84. These results suggest that the overflow definitely does not have any treatment effect on the flow being spilled and may actually have a deleterious effect i.e. by actually preferentially passing gross solid material over the weir. Dip plates are present at the site but it does not appear that they are particularly effective at reducing the proportion of gross solids passed over the weir.

Again, the efficiencies at the Leyburn Road site appear to be consistently high (average 86.1) but as the percentage of the flow that is carried to treatment is also high (average 84.4%) the resulting treatment factors (Table 5.36) are near to unity (average 1.01) suggesting that the distribution of the gross solids in the flow can be explained solely by the flow split. The range in the treatment factors is narrower than all the other sites (0.86-1.20), however, the survey period at this site was much shorter and confined to the winter months only.

6.12.1.2 Treatment Factors for the Different Categories of Material

Efficiencies were calculated for several categories of gross solid material (see Tables 5.28 to 5.36). This investigation was first undertaken at the stilling pond site (Chesterfield Road) and for the screens at this site where it was quite successful. However, at the Dobcroft Road high side weir site, problems with sampling error effects for particular categories of material meant that negative results were obtained. This suggested the ridiculous conclusion that more material was being spilled than ever came into the system. Problems with sampling error are detailed more fully in the following section. This resulted from too small a proportion of the spill being sampled (2-3% of total spill). This problem was rectified for the Leyburn Road high side weir where approximately 23% of the spill was sampled. The results of an investigation into the distribution of gross solids at the Leyburn Road site gives an understanding of the reasons for the overestimation of material found at the Dobcroft Road site. This discussion is found in Section 6.12.1.3.

Table 6.11 The Average Treatment Factors at Each Site for the Categories Used.

Site (No. Events)	Sanitary Towels	Leaves and Twigs	Thick Paper Towels	Plastic	Miscellaneous Material	Material Adhering to Mesh Bag
Chesterfield Road (14)	1.00	0.03	0.85	0.76	0.99	1.08
Dobcroft Road (14)	0.78	0.37	0.86	-	-	0.88
Retford Road (17)	0.50	0.40	0.40	0.70	0.80	0.60
Leyburn Road (7)	0.97	0.76	0.68	0.99	1.12	1.06

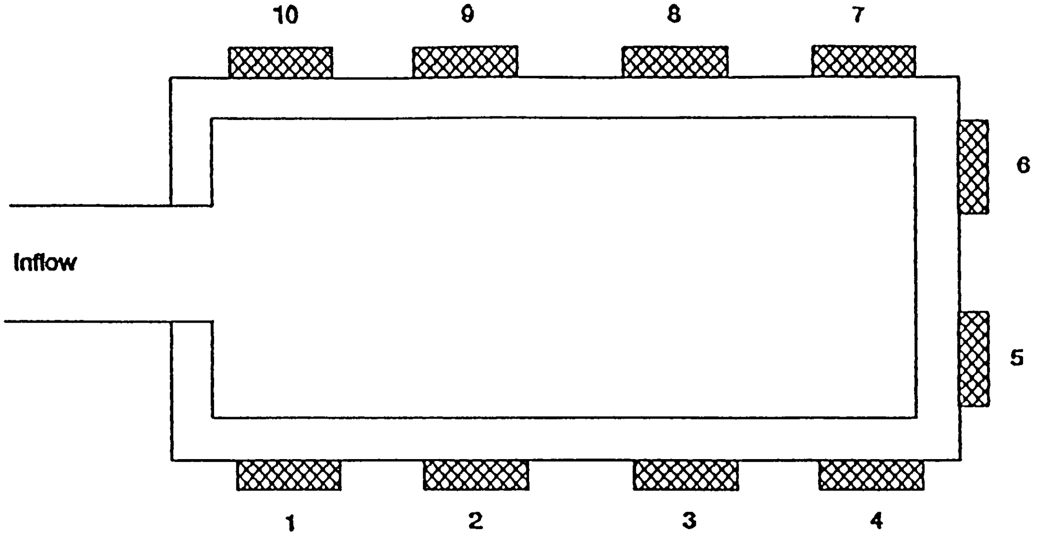
Although the number of storms contributing to these values is fairly small, some tentative conclusions can be made about the performance of the chambers with regard to the different materials. The treatment factors for the low side weir (Retford Road) site are consistently lower for all categories except leaves and twigs. Apart from the "miscellaneous material" category, the low side weir appears to preferentially pass all types of material over the weir by actually concentrating the gross solid material in the spilled flow. Low treatment factors are also found for the Dobcroft Road high side weir site but these can be explained by the sampling error previously mentioned.

Of the different types of material the leaves and twigs category appears to be preferentially passed over the weir most frequently. This category was found to consist largely of neutrally buoyant leaves which could not easily be separated out of the flow.

6.12.1.3 Gross Solids Distribution at the High Side Weir Site (Leyburn Road)

To overcome the sampling problem encountered at the Dobcroft Road high side weir it was decided that ten gross solids mesh bags should be installed around the weir at this site. It is estimated that these bags sampled approximately 23% of the spilled flow. A diagram of the positions of these bags is shown in Fig 6.19 (This figure was not drawn to scale).

Figure 6.19 Position of the Gross Solids Mesh Bags on the High Side Weir (Leyburn Road) (Not to Scale)



Using the Runge-Kutta method (see Chapter 3) it was possible to calculate the flow over different sections of the weir. The heights of all parts of the weir had been measured using a level and metre rule. The weir height was found to vary by 128mm over its length. Figure 6.20 shows the variation in height of the weir with the position of the mesh bags. As would be expected, it was calculated that the mesh bags fixed on the lowest part of the weir (bags 1 and 10) would receive the largest flow volume and the bags on the highest part of the weir (bags 5 and 6) would receive the smallest flow volume. If it was assumed that the concentration of gross solids in the flow was equal and the chamber had no effect on their distribution then, it would seem likely that the bags at the lowest point of the weir (bags 1 and 10) would receive the greatest mass of material in any given storm. This was not found to occur at the Leyburn Road site.

The average percentage of material in the mesh bags at each position is given in Table 6.12. From this it can be seen that bags 5 and 6 (on the highest part of the weir) consistently get the largest percentage of the total mass of gross solid material during a storm. The relationship between weir height and the percentage mass of material for a given bag position is investigated further in Figure 6.21. From this it can be seen that there is a highly significant relationship (R^2 is 0.72) between the % mass of material at a given position and the height of the weir at that position. The regression equation for this relationship is:

$$y = 106.9x - 145.7$$

Where: y is the % Solids in the Mesh Bag
x is the Height of the Weir (m)

This suggests that gross solid material is concentrated towards the end weir of the chamber. This is presumably because when the flow enters the chamber no strong eddies are formed to encourage the gross solid material to circulate. There is thus no obstruction to stop them simply being moved forward with the force of the flow. In the Leyburn Road chamber the ratio between the width of the chamber and the inlet pipe diameter is small (1.2:1). This means that there is relatively little "fanning out" of the flow on its entry into the chamber. This could be important in preventing the

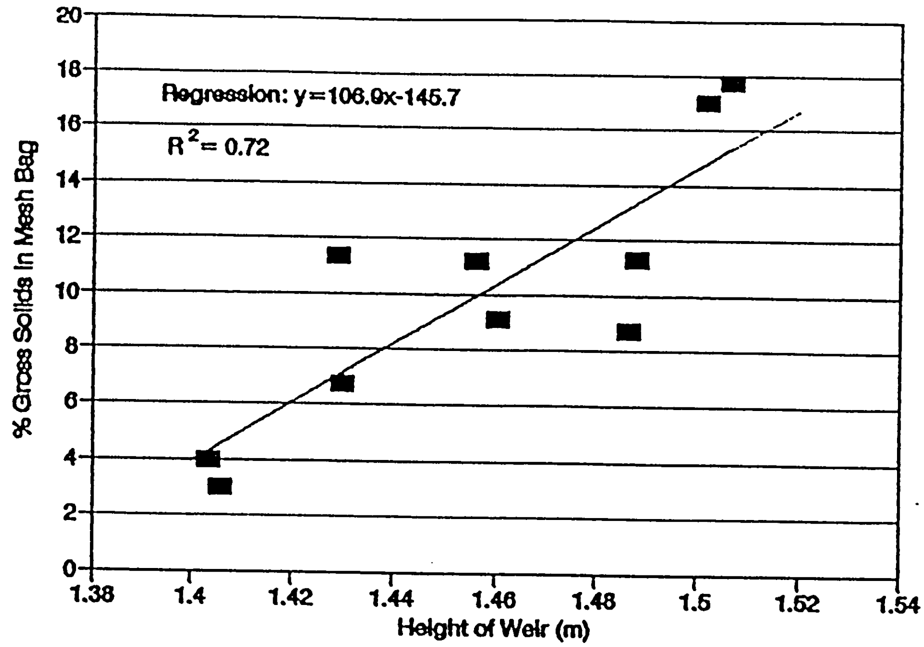


Figure 6.20 Graph Showing Weir Height Against Position of Gross Solids Mesh Bags on the Weir at the High Side Weir (Leyburn Road)

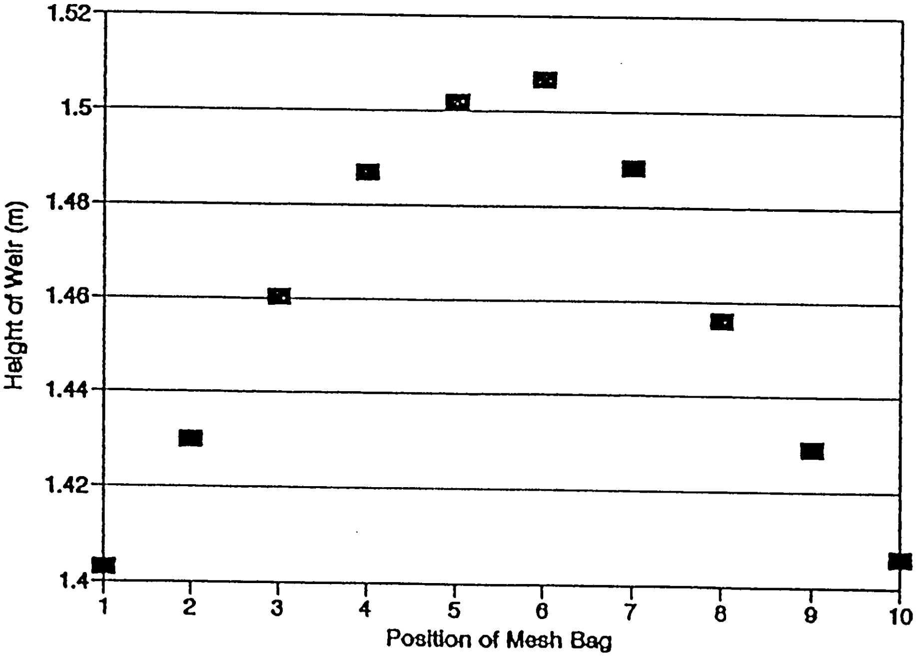


Figure 6.21 Graph Showing Weir Height Against the % of Total of Gross Solids for the Mesh Bags at Each Position

Table 6.12 Percentage Distribution of Gross Solids During Storm Events at Leyburn Road

	Date	Position of Mesh Bag									
		1	2	3	4	5	6	7	8	9	10
1	21 September 1992	5.1	8.2	9.1	8.9	10.3	16.2	13.1	16.1	12.3	0.8
2	25 September 1992 2 October 1992	5.8	10.2	8.9	8.9	11.1	25.4	8.2	11.6	8.0	1.9
3	24, 25, 27, 28 October 1992	4.2	6.6	9.2	7.4	23.3	13.9	15.5	9.2	8.5	2.3
4	2 November 1992	5.1	5.5	9.2	7.3	10.2	20.5	11.2	15.2	12.3	3.1
5	9 November 1992	4.6	8.5	8.8	11.3	15.7	7.9	13.0	9.3	18.5	2.3
6	11 November 1992	1.6	4.1	6.7	9.1	17.8	34.0	8.2	6.1	9.5	2.7
7	19, 21, 22, 24 November 1992	3.5	2.3	13.1	6.8	16.6	15.0	11.7	8.7	13.8	8.4
8	2-3 December 1992	2.0	8.0	7.5	10.1	30.9	8.8	9.3	13.1	7.8	2.5
Average		4.0	6.7	9.1	8.7	17.0	17.7	11.3	12.4	11.3	3.0
Standard Deviation		1.4	2.4	1.8	1.4	6.7	8.2	2.4	4.7	3.4	2.1

formation of eddies which could entrain the gross solid material and thus prevent it from passing over the weir. A greater ratio might force the flow to fan out more on entry to the chamber and encourage the formation of eddies in the corners of the upstream end of the chamber. At the Dobcroft Road high side weir the inlet diameter : chamber width is higher (1.8:1). However, as insufficient gross solid data was obtained at this site it is not possible to say whether this ratio has any influence on the formation of eddies in the flow.

This explanation also provides an understanding of the results obtained at the Dobcroft Road high side weir where it appeared that the spill gross solid data was overestimated. At this site only one spill bag was used. This bag was fixed on the end weir. From the findings at Leyburn Road it can be suggested that this position is likely to receive the greatest load of material of any position on the weir during a storm event. It was calculated that only 2-3% of the total spill was sampled during a storm. The total gross solid mass spilled was calculated by wrongly assuming that the concentration of gross solids in the flow would be equal at all positions along the weir. At the Leyburn Road site it was found that position 6 (equivalent to the spill bag position at Dobcroft Road) consistently received the greatest mass of material (on average 17.7% of the total). If the same processes are occurring at the Dobcroft Road site this will explain why the gross solid mass for the spill was overestimated.

PART 3 COMMENTS ON THE METHODOLOGY USED

Much was learnt about efficient working practice during the course of this study. At the original site (Chesterfield Road) installation of equipment took over four days of work. At the other three sites it took only one day as knowledge of the relevant installation equipment, tools and techniques had been obtained from the experience at Chesterfield Road. This was also true for the blocking test. Three prototype bungs were designed for the Chesterfield Road site before an accurate seal was obtained. At the Dobcroft Road site a different design had to be used as the continuation pipe was being blocked from within the chamber rather than at the end of the throttle pipe. Here two prototype designs were developed, the first being almost too successful as it was virtually impossible to shift at the end of the test when the storm water reached weir level. The experience gained at this site was then adapted for the other high side weir site at Leyburn Road where the first bung design was successful.

This learning process continued throughout the project as new difficulties constantly arose. The following sections describe some of the main problems encountered with the equipment used for the flow measurement and water quality sampling and the gross solids method used. Some suggestions as to how these problems could be rectified or avoided are also given.

6.13.1 Problems with the Flow Monitors

The flow loggers used were generally very reliable although there was a tendency for the depth readings to drift over time. For monitors installed at the inflow and continuation pipes regular checks could be made of the actual depth of the flow. These could then be compared to the monitored readings at the same time. For the spill in situ checks were not possible. Errors in the readings were not picked up until the survey had been completed when the equipment could be taken out of the chamber and tested for flow and depth in the Hydraulics Laboratory.

Other problems occurred rarely once the old flow monitors inherited from a previous project were replaced. These monitors had been installed for a short period of time at the Dobcroft Road site. They frequently broke down due to water logging, keypad failures and other miscellaneous problems.

Occasional problems with the operation of the new monitors were experienced. Twice the sensors on the monitor head became damaged by material in the sewer and the equipment had to be returned to the manufacturers for repair. If a spare monitor was not immediately available a significant amount of flow data could be lost and without the flow data any sample data obtained was of little use.

Projects of this nature are often under considerable financial constraints and spare equipment is not always considered to be essential. However, it is suggested that at least two spare monitors for every six monitors in the overflow chamber is a reasonable expense to ensure that the minimum amount of data is lost through damage (A flow monitor with spare batteries and a battery recharger costs approximately £2,500).

6.13.2 Problems Encountered with the Water Quality (Bottle) Samplers

The requirements of samplers for use in sewers was given in the Scottish Development Department's Working Party Report on Storm Sewage, "Storm Sewage Separation and Disposal" (1977).

"Samplers were required to be robust, portable, easy to install, easily serviced, not susceptible to blockages and able to draw representative samples which should be accurate over a wide range of concentrations of suspended solids."

For much of the project it seemed that no such piece of equipment could exist. The samplers used for the majority of this project were unreliable and, although blockages of the sampler pipe were rare, "ragging up" of the end of the tube was a problem. At the Chesterfield Road site a filter was attached to the end of the tube but this seemed to encourage the ragging up process and it was eventually lost, presumably pulled off by the weight of material that had built up over it. Both problems could be minimised by fixing the tube so that is faced downstream.

Other problems of basic function occurred. On a number of occasions the pumping mechanism failed although the distance and height that the samples were to be drawn were well within the design specifications of the sampler. At the Chesterfield Road and Dobcroft site the samplers became iced up and unable to function. At the Chesterfield Road site this problem could be solved as there was a heater in the trailer containing the equipment. At the Dobcroft Road site little could be done about this problem, although during such cold spells heavy rain was uncommon so little sample data were lost.

A third common reason for loss of sample data was the tendency of the distributor arm to become stuck. Sometimes this was due to human error as the arm had become stuck in a bottle that was standing proud from the other bottles in the carousel. On other occasions the samplers had to be returned to the laboratory, cleaned out and the arm regreased before normal function could be resumed.

At the last site new "Epic" samplers were required as they were to be stored in the overflow chamber and thus had to be intrinsically safe. These proved to be far more reliable than the original samplers. In only three months of the survey at this site full sets of sample data had been obtained from each of the eight storms sampled.

6.13.3 Comments on the Water Quality (Bottle) Sample Method Used

In retrospect it seems obvious that the sampling time should have been extended to cover a much longer time period. As it was, any storm that lasted over two hours was incompletely sampled. This meant that the full load on the parameters measured could not be determined nor the presence of secondary flushes in concentration reported in other studies (e.g. Ellis, 1986). With the original samplers samples were taken at fixed five minute intervals. An additional piece of equipment (a portable computer with the relevant software) would have been required in order to make the sampling regime flexible enough to cover a longer time period while still retaining sufficient coverage of the high concentrations occurring at the beginning of the storm. At the start of the project this was not thought to be important enough to justify the cost.

A sampling regime that would be suitable for projects of this nature was described by Saul & Marsh, 1990 (quoted in Chapter 2). Here the initial ten samples are taken at 3 minute interval, the next ten were taken a 7 minute intervals and the final four at 30 minute intervals. This gave a total monitoring period of 217 minutes. The Epic samplers used at Leyburn Road were more flexible and could be programmed directly to sample at different time intervals. This is a great advantage and the use of this type of equipment is recommended.

The float switches used to initiate sampling provided a considerable amount of trouble in the early part of the project e.g. the balls became waterlogged and so would not rise, on some the arms were too stiff and would jam in an off position, on other the arms were too loose so that the circuit was not completed when the arms had risen the required distance. It was later realised that the early versions had not been intrinsically safe (I.S.) so these had to be replaced with I.S. versions. By the end of the field monitoring, having learnt from these mistakes, no problems were caused by the float switches.

6.13.4 Comments on the Sample Analysis

a. Accuracy of Sample Analysis

In order to examine how much variation there can be in the bottle sample results a large sample was taken from the inflow at Dobcroft Road. This was then divided equally into ten bottles and taken to the laboratory to be tested for the usual parameters. The results of this are given in Table 6.13 below.

Sample Number	Suspended Solids (mg/l)	Ash (mg/l)	BOD (mg/l)	COD (mg/l)	pH	Conductivity (uS/cm)	Ammonia (mg/l)
1	106	4.1	57	140	7.3	214	3.65
2	96	4.2	52	175	7.2	213	3.60
3	89	4.0	56	161	7.2	211	3.64
4	90	4	49	171	7.3	216	3.63
5	103	4	62	180	7.2	215	3.85
6	101	4	51	159	7.2	211	3.62
7	87	4	55	163	7.2	212	3.74
8	97	4	61	174	7.3	209	3.92
9	110	4.1	60	187	7.3	210	3.94
10	93	4.1	59	168	7.3	213	3.08
Mean	97.2	4.06	56.2	167.8	7.25	212.6	3.75
Standard Deviation (S.D.)	7.69	4.06	4.44	13.1	0.05	2.37	0.14
% S.D. of Mean	7.9	1.7	7.9	7.8	0.73	1.1	3.6

There is some variation in the analysed values of these parameters but the standard deviation is less than 8% of the mean for all the parameters and, for ash, pH and conductivity the deviation is significantly less than this. Greater variations in the values of suspended solid, BOD and COD would be expected as these parameters are more prone to settlement and thus more susceptible to sampling error during the division of the original sample. From this investigation it appears that the analysis used to determine the water quality parameter values produces reasonably consistent and reliable results.

b. Unpredictable Nature of Overflow Events

Although local weather reports were quite accurate it was still not possible to obtain advance warning of a rain event that would cause a spill. Also, despite weekly maintenance checks of the sampling equipment, it is not always certain the an overflow event will produce any usable samples.

One of the main difficulties of a rain-dependent project is that the time at which samples are obtained is not controllable. The laboratories used were often very busy and, as such, not amenable to the influx of 48 or more samples after a storm event which could not have been planned for in advance. Luckily, only one set of data were lost because of this (BOD on 30 November 1992 at Leyburn Road).

c. Storage of Samples and Timing of Analysis

In order to obtain accurate estimations of the concentration of the water quality parameters measured it is necessary that the samples be analysed as soon as possible. Any samples that could not be analysed within 24 hours were discarded. The main reason for this restriction was due to the instability of the BOD (Biochemical Oxygen Demand) in samples during storage.

Much has been written about the pros and cons of the BOD Test which was introduced by a Royal Commission on Sewage Disposal over 80 years ago (NRA, 1990). Since then various adaptations and refinements have been made to the procedure but there is still some debate about its accuracy. As the BOD test was used in this study, a few comments will be made about this debate.

The BOD Test measures the biodegradable fraction of the sample by monitoring the assimilation of organic material by aerobic micro-organisms over a set period of time under strictly controlled conditions (Gray, 1989). The limitations of the test were outlined in a report by Tyers (1989) and in a National Rivers Authority document (Discharge Consent and Compliance Policy) the main points can be listed as follows:

- The suppression of nitrification by the addition of allylthiourea is not always fully effective.

- Poor stability is a problem with BOD when storage prior to analysis is necessary. A study (quoted in Tyers, 1989) found that the final effluent from a sewage treatment works stored for 48 hours at ambient temperature showed decreases in BOD of up to 34%.

- The test requires a lengthy analysis procedure, lasting 5 days, and the daily and time consuming preparation of standards.

The NRA recommend that the BOD test be replaced in their monitoring procedures by the calculation of the Total Organic Carbon (TOC) content of samples. This procedure is quicker and reliable and easily adapted to continuous monitoring. Others still prefer the BOD test. In his paper, Tyers describes various ways of minimising the instability of the BOD and ensuring as accurate an analysis as possible. Gray, comments that although TOC could be measured quickly and efficiently using a carbon analyser it is more useful, in terms of predicting the effects on the watercourse, to have a measure of the oxygen demand that will be exerted by these wastes on the watercourse.

The changes in stability of the BOD during storage tend to make the BOD values lower and therefore give the impression that the water sampled is less polluting than it actually is. In order to minimise the effects of BOD instability the samples collected in this study were brought into the laboratory as soon as possible after the storm event and immediately refrigerated at approximately 3'C.

A large amount of sample data were lost as the analysis laboratory and transport to collect the samples were not accessible during weekends and bank holidays. Thus only samples from Sunday afternoon to Friday morning were usable.

6.13.5 Comments on the Gross Solids Method Used

1. The problem of the inadequate sampling of the spill flow at Dobcroft Road has already been described in some detail. The results at this site were significantly affected by sampling errors leading to erroneous results for about proportions of the different materials in the in the spill flow. As large a proportion as possible of the flow should be sampled. However, the larger the sample the longer it takes to sort so, in practice, a compromise must be made between the proportion of the flow sampled and the sample size.

2. By sampling gross solids from the inflow the amount on gross solid material available to be spilled is reduced. When only 2-3% of the inflow is being sampled this effect is negligible. As the proportion of the inflow sampled increases, however, this effect will become more important.

3. Certain categories were not adequately sampled by this method e.g. faeces and toilet paper.

4. It was not always possible to be consistent in the time allowed for the draining of the gross solids bag before taking it to be sorted. Ideally, a dry mass would be taken but this would be impractical due to the volumes and nature of the material.

5. Certain materials e.g. plastic materials, did not appear significant when their mass was compared with the mass of, for example, sanitary towels. However, even a small mass of these materials can cause considerable aesthetic pollution.

6. The time of year when the samples are taken may be important as leaf fall may make a significant contribution to the total results.

7. Blinding of the bag by material adhering to the mesh reduces the size of the apertures. Thus what might have passed through the bag early on in the storm becomes trapped, giving variable results for certain materials, as the storm progresses.

8. For safe entry into the sewer a minimum of three people is required. As it is not always possible to obtain these people the samples collected may represent more than one storm event. This will also occur when two or more storms take place over a weekend or bank holiday, or when the storms are so close together that safe entry is not possible.

6.13.6 General Comments on the Methodology

a. Choice of Site

An important limiting factor was the relatively small number of sites available that were suitable for a study of this kind. There are around 230 storm overflow chambers in the Sheffield area but the majority of these could be rejected as suitable site for monitoring after only a brief inspection of the chamber drawings. The main reasons for this are:

- the chamber was of a design that was not being investigated in this study
- the chamber or pipe sizes are too small to install a monitor
- upstream bifurcations immediately before the chamber or other irregular pipe configurations that would complicate the hydraulic analysis
- difficult site access

The remaining chambers were visited and, again, the majority were rejected. Visual inspection reveals irregularities in the chamber design that are not obvious on paper. Often the manholes into the chamber were placed towards the middle of busy roads. Other reasons for rejecting a site included the presence of large quantities of silt in the chamber and upstream pipes and the presence of scumboards or screens which would make the installation of monitors impossible.

As a result of these complications only a handful of sites were found to be suitable. As a range of designs were to be looked at the choice was limited still further. Even when a site had been chosen and the monitoring equipment installed, other problems may become apparent. A second low side weir site was monitored for a period of 5 months in 1991 but as it did not appear to spill even during heavy rain it had to be abandoned and the equipment was moved to the Retford Road site.

b. Siting of Equipment

In all the chambers the choice of where to site equipment was strictly limited. Obviously, the aim was to obtain accurate data which was free from the influence of backwater, but the monitor also had to be installed safely and it had to be accessible so that it could be downloaded each week.

Samplers had to be installed so that they would take representative samples from the incoming flow. A number of studies have suggested ways to achieve this (Wood, 1968: Krajca, 1989: Tucker, 1976). The effect of the settlement of solids must be considered if samples are taken from low down in the inlet pipe or overflow chamber.

c. Miscellaneous Comments

Safe access to the chambers required a minimum of two trained people. This limited the number of times site visits could be made. This was particularly a problem at Leyburn Road where the samplers were stored in the manhole entry to the overflow chamber. At the other sites the samplers were stored in cabinets or, at Chesterfield Road, in a trailer, to which there was permanent access. This meant that only one person was needed to collect the samples and deliver them to the laboratory.

The rain dependent nature of the project meant that the length of the monitoring periods at each site were variable and unpredictable. It was originally intended that at least ten storms with full sample data would be obtained at each site. This aim might have been achieved if the monitors used at the last site had been used throughout. The first and second years of the project (1990-1991) were also unusually dry.

CONCLUSIONS

Pollution caused by combined sewer overflow discharge has been recognised as being one of the major factors contributing to the poor quality of many rivers and streams in the UK. Current research is thus being directed towards the development of computer models which can simulate the flows and pollutant loads in sewerage systems. In order to ensure that these models are accurate more information is needed on the behaviour of pollutant material in sewerage systems.

The techniques for monitoring the finely suspended and dissolved pollutant material in the field has now been fairly well established. However, the behaviour of the larger solids in the flow, particularly the gross solids, is still poorly understood. Although the majority of the pollutant material present in the discharge from a storm overflow is in the finely suspended and dissolved fraction it is the gross solid fraction which is most visible and offensive to the public and which causes most complaints to the Water Industry.

7.1 PRINCIPAL CONCLUSIONS

* The stilling pond and the two high side weir chambers performed well hydraulically. The low side weir was found to perform unsatisfactorily, hydraulically. The flow to treatment rose as the incoming flow increased and for some storm conditions a hydraulic jump was formed towards the downstream end of the chamber

* The combined sewer overflows monitored discharged significant amounts of pollutant material to the receiving watercourses.

* The stilling pond and the Leyburn Road high side weir were highly efficient in retaining the vast majority of the gross solid material present in the flow to treatment but this efficiency can largely be explained by the flow split.

* The low side weir had a poor efficiency in retaining gross solids in the flow to treatment. The chamber appeared to have a deleterious effect by preferentially passing all types of gross solid material over the weir.

7.2 DETAILED CONCLUSIONS

7.2.1 General

1. The range of dry weather flow sample concentrations varied considerably from one site to another although the concentrations are mostly within or just below the range of values given in the literature

2. The first foul flush effect was regularly observed at the stilling pond (Chesterfield Road) and low side weir (Retford Road) sites. Peak concentrations for suspended solids during a storm event were found to be 600 times greater than the dry weather flow for that time of day. The first flush effect was rarely observed at the other sites.

3. For the majority of the storms at each site the spill concentrations are of a similar magnitude to the inflow sample concentrations. For a large minority of suspended solid, BOD and COD samples, however, the concentrations of the spill samples were significantly less than the inflow samples. t-Tests suggest that at the stilling pond (Chesterfield Road) site and the high side weir site (Dobcroft Road) there is a significant reduction in the spill sample concentrations for the water quality (bottle) samples.

4. Although the load of material spilled during an overflow event was found to be small in comparison to the inflow load , large amounts of material can be spilled to the receiving watercourses during a storm event.

5. The peak rainfall intensity of a storm was found to have a considerable influence on the magnitude of the storm load of material brought in during a storm at the Chesterfield Road site. At other sites a number of other factors were found to be influential e.g. the delay time, the ADWP and the duration of the storm.

6. Strong correlations between the concentrations of different measured parameters were recorded the strongest being those for suspended solids and ash and BOD and COD. However, as these relationships are not consistent prediction of one parameter from another is not recommended.

7. The types of gross solids collected at each site were similar with leaf material and sanitary towels consistently the major items in term of total mass. Despite the public perception of their abundance in storm sewage discharged to watercourses, condoms were rarely found in either the spill or the inflow samples at any of the sites.

8. The efficiency of the stilling pond and the high side weir (Leyburn Road) in retaining gross solids appears to be explained by the flow split although for 5 of 14 storms at the stilling pond and 3 of 7 storms at the high side weir a treatment effect was observed.

9. The treatment factors at the low side weir site were noticeably less than those for the other three sites with all of them being less than unity (average 0.5). This suggests that the low side weir preferentially discharges gross solid material over the weir.

10. The treatment factors at the high side weir (Dobcroft Road) were lower than those at the stilling pond and the other high side weir site but this may be due to overestimation of the load of gross solid material from the spill caused by sampling too small a proportion of the spill flow.

11. Leaves and twigs tended to be preferentially passed over the weir at all sites. This is presumably due to the neutral buoyancy of this material. Sanitary towels seem largely to be discharged over the weir in proportion to the flow split at all sites except the low side weir.

12. The gross solids bags on the end weir of the Leyburn Road high side weir were consistently found to contain the largest proportion of the gross solid material in a given storm although the weir was highest at this point. Suggesting that the majority of the gross solid material is pushed forward to the end weir and the downstream end of the side weirs. Relatively little gross solid material was found in the bags on the upstream part of the side weirs.

13. The chambers investigated are not directly comparable as they are of different types, different dimensions, different storage capacities and have different dry weather flows.

14. Gross solids are not the major source of polluting material from combined sewer overflows but they are aesthetically objectionable and so give rise to a large number of complaints from the public. Overflow designs that are efficient in reducing gross solids will not necessarily be the ones that are efficient in reducing the discharge of highly polluting material, coarse, finely suspended and dissolved material from overflow structures.

7.2.2 Site Specific

1. The stilling pond site at Chesterfield Road is set to spill at 250 l/s for a DWF of 10-12l/s. The spill is set at 21-25 x DWF.

2. The high side weir at Dobcroft Road is set to spill at 113 l/s for a dry weather flow of 15 l/s. The spill is set at 7.5 x DWF.

3. At the low side weir at Retford Road, spill occurs at 30-35 l/s for a DWF of 11 l/s. The spill is set at 3 x DWF .

4. The high side weir at Leyburn Road is set to spill at approximately 300 l/s for a DWF of 13l/s. The spill is set at 22-25 DWF.

7.3 RECOMMENDATIONS

7.3.1 Recommendations For the Monitoring of Combined Sewer Overflows

1. The inflow monitor should be installed in an upstream pipe where depths are not influenced by backwater from the overflow.

2. The continuation flow monitor should be installed so that it is at the downstream end of the continuation pipe. If the monitor cannot be installed in this position depths should be recorded in the manhole downstream of the continuation pipe to ensure that the differential head across the continuation control can be determined.

3. Where possible, the inflow, continuation flow and spill flow should all be monitored. This will enable comparisons to be made to check the overall accuracy of the data, increasing the accuracy of calibration produced. Greater weight, however should be given to the inflow and continuation flow values because of the fact that the spill monitor is often not covered with water for long periods and it cannot be calibrated *in situ*.

4. Regular, reliable and comparable readings of depth and velocity should be taken at weekly site visits.

5. Continuous depth measurements should be taken in the overflow chamber e.g. using an Arx or similar depth logger.

6. Where possible, blocking tests should be undertaken early on in the monitoring period so that any potential problems in the monitoring can be identified.

7.3.2 Recommendations For Estimating the Pollution Performance of Combined Sewer Overflows

1. Samplers should be set to cover as long a period of the storm events as possible, while still retaining sufficiently small sampling interval at the start of the storm to cover the initial high concentrations.

2. The end of the sampler tube should be positioned to face downstream to prevent it becoming covered in rags.

3. The correct functioning of all sampling equipment should be checked at each site maintenance visit and after every storm event. If float switches are being used these must also be checked to ensure that they initiate the samplers at the correct height.

4. Gross solids bags on the inflow and spill must sample a sufficiently large proportion of the flow to minimise sampling error. For side weirs the gross solids bags should be fixed at intervals along the whole length of the weir.

5. Gross solids sampling bags must be positioned so that they do not interfere with the flow or cause it to back up.

7.4 SUGGESTIONS FOR FUTURE WORK

1. The methodology for investigating the pollution performance of combined sewer overflows, developed in this study, should be used to investigate chamber designs not covered in this study e.g. single side weirs, storage tank overflows.

2. A more detailed investigation of the behaviour of gross solids in the sewer overflow chamber should be undertaken to determine how the material is circulated in the flow and how it is influenced by turbulence in the flow. Also, how different design dimensions, such as the height of the weir, the width and length of the chamber can influence its behaviour.

3. The settling velocities of the common gross solid materials in combined sewage should be calculated. This information could be used to produce more representative synthetic particulate in model tests and in the design of overflow chambers.

4. More studies should be conducted on the composition of dry weather sewage for different catchments. It could thus be determined how consistent the proportions of different gross solid materials are between catchments of different sizes and with different land uses.

5. As sanitary towels were found to consistently provide a major proportion of the mass at each site for both the inflow and the spill a study to investigate means of preventing the disposal of such material in the sewer system. This could be done by public awareness campaigns or by legal means, although the latter would be hard to enforce.

6. This study dealt with only a very limited aspect of the problems concerning the discharge of combined sewage from combined sewer overflows. Studies that can deal with the entire system must be undertaken. These should consider the sources of pollutant or aesthetically objectionable material, its conveyance in the sewer system, the performance of overflows, the treatment of dry weather and combined sewage at sewage treatment works and the influence of effluent from combined sewer overflows and sewage treatment works on the receiving waters. The influence of material from separate systems and the runoff from ground surfaces should also be included. There should also be greater collaboration between ecologists and engineers so that new overflow designs are developed which take the physical, chemical and biological consequences of the storm discharges on the receiving waters into account.

REFERENCES

Aalderlink R.H., Estimation of Storm Water Quality Characteristics and Overflow Loads from Treatment Plant Influent Data, 2nd Wageningen Conference on Urban Storm Water Quality, 1989.

Ackers P., Brewer A.J., Birkbeck A.E. & Gameson A.L.H., Storm Overflow Performance Using Crude Sewage, Inst. Civil Engineers, 1967.

Ackers P., Harrison A.J.M. & Brewer A.J., Laboratory Studies of Storm Overflows With Unsteady Flow. Institution of Civil Engineers, Symposium on Storm Sewage Overflows, 1967.

Ackers P. Resistance of Fluids in Channels and Pipes. Hydraulic Research Paper No.1, H.M.S.O.,London, 1970.

Ashley R.M., Wakelin A.W. & Jefferies C.J., Development of a Flow Proportional Effluent Sampling System, Int. Conf, on Application of Computer Techniques to Environmental Studies, Greece, 1988.

Aspinwall D.M.V. & Ellis J.B., The Impact of Urban Runoff and Combined Sewage Overflows on River Quality, Proceedings, Developments in Storm Sewerage Management, Sheffield City Polytechnic & Institute of Public Health Engineers, March 24-25, 1986,Sheffield, pp 51-65.

Balmforth D.J., Flow Over Side Weirs, Ph.D. Thesis, Sheffield University, 1978.

Balmforth D.J., Improving the Performance of The Stilling Pond Storm Sewer Overflow, Proceedings 1st International Conf. Urban Storm Drainage Systems, Southampton, 1982.

Balmforth D.J., Notes from a Short Course on the Design and Operation of Storm Sewage Overflow Structures, Sheffield City Polytechnic, 23 January-13 March 1985.

Balmforth D.J., Storm Sewage Overflows and Sewerage Rehabilitation, The Public Health Engineer, vol. 13, pp 150-154, July 1985.

Balmforth D.J., Effectiveness of Storm Sewage Overflow Structures in Handling Gross Polluting Solids, Proceedings of the International Conference in Combined Sewage Overflows and Effects of Receiving Streams, Wageningen, Holland, 1986.

Balmforth D.J., The Pollution Aspects of Storm Sewage Overflows, J.IWEM, pp 219-225, 4 June, 1990.

Balmforth D.J. & Sarginson E.J., A Comparison of Methods of Analysis of Side Weir Flows, Chartered Municipal Engineer, October 1978.

Balmforth D.J. & Lea S.J., Development of a Vortex Storm Sewage Overflow With Peripheral Spill, Proc 3rd Int Conf. Urban Storm Drainage, Goteborg, 1984.

Balmforth D.J., Lea S.J. & Sarginson E.J., The Vortex Overflow - Theory into Practice, Proceedings 4th International Conf. Urban Storm Drainage, Lausanne, 1987.

Balmforth D.J. & Henderson R.J., Storm Overflow Structures: Selection and Design Guide, Water Research Centre ER304E, 1988.

Baughen A.J. & Eadon A.R., Measurement of the Performance of Sewerage Systems and Associated Hydraulic Structures - Recent Developments, Inst. of Wat. Polln. Control, pp 77-86, 1983.

Barty-King H., Water-the Book, Quiller Press, 1992

Beck M.B., Adeloye A.J., Lessard P.,Finney B.A. & Simon L., Storm Overflows: Modelling Impacts on the Receiving Waters and the Treatment Plants Proc. Semin. IAWPRC/IAHR 14th Biennial Conf., Brighton, U.K., July 1988.

Bennet N., Monitoring the Performance of Storm Overflows, Proc. Semin. Storm Overflows - Practice and Performance, Birmingham University and Hydro Research and Development, April 1991.

Braine C.D.C., Drawdown and Other Factors Relating to the Design of Storm Water Overflows in Sewers, Jnl. Institute Civil Engineers, vol. 28, pp 136-163.

Brombach H., Liquid-Solid Separation at Vortex-Storm-Overflows, Proceedings 4th International Conf. Urban Storm Drainage, Lausanne, 1987.

Brown P.M., An Investigation into the Hydraulic and Separating Qualities of Vortex Sewage Overflows, Internal Report, Dept. Civil Engineering, Sheffield City Polytechnic, 1977.

Cairney T., Hydraulics for Civil Engineering Technicians, Longman Technical Series, 1984.

Carter R.W. Computation of Peak Discharge at Culverts, Geological Survey Circular376, U.S. Department of Interior, 1957.

Catterson G.J., Flow Surveys, in Short Course on Developments in Drainage Modelling, Bradford University, 1991.

Chadwick E. A Report on the Sanitary Conditions of the Labouring Population, 1842.

Chandler J.R., A Biological Approach to Water Quality Management, Wat. Pollut. Control, pp 415-422, 1970

Chebbo G., Musquere P. & Bachoc A., Solids Transferred in Sewers, 5th International Conf. Urban Storm Drainage, Osaka, 1990.

CIRIA, Sediment Movement in Combined Sewage and Storm Water Drainage Systems, CIRIA Project Report 1, 1987.

CIRIA, Screenings and Grit Removal in Sewage, Preliminary Report, Tech. Note 119.

Clarke G.M. Statistics and Experimental Design, Publ. Edward Arnold, 1980.

Clifforde I.T. & Price R.K., Quality Modelling in Urban Storm Sewers - Current Developments, WRc Report.

Clifforde I.T., Fiddes D. & Tyson J., Urban Pollution Control in the United Kingdom, 5th International Conf. Urban Storm Drainage, Osaka, 1990.

Clifforde I.T., Saul A.J. & Tyson J.M., Urban Pollution of Rivers - The U.K. Water Industry Research Programme Int. Conf. on Water Quality Monitoring in Inland Natural Environments, Bournemouth, England, June 1986.

Collinge V.K., The Discharge Capacity of Side Weirs, Proc. Inst Civil Engineers, pp 288-304, February 1957.

Cootes T.C., Field Testing A Vortex Storm Sewer Overflow, Ph D Thesis, Sheffield City Polytechnic, 1990.

Cootes T.F., Balmforth D.J., Russell S.,Doughty G.M., Monitoring a Vortex Storm Sewage Overflow with Periferal Spill Water Science and Technology, Vol.22, No.10/11 pp 189-195, 1989.

Cootes T.F. & Green M.J., Monitoring a Vortex Storm Sewage Overflow with Periferal Spill, WRc Report UM 1193, March 1991.

Cordery I., Evaluation and Improvement of Quality Characteristics of Urban Stormwater,Water Research Laboratory, Report 147, New South Wales, Australia, 1976.

Crabtree R.W., Crockett C.P. & Toft A.R., Interim River Water Quality Planning Procedures for Controling Intermittant Pollution from Storm Sewage Overflows August 1988, Water Research Centre, ER 317E.

Crabtree R.W., Sediment in Sewers, J. IWEM, 3 December, 1989.

Davidson, R.N. & Gameson A.L.H., Field Studies on the Flow and Composition of Storm Sewage, Institution of Civil Engineers, Symposium on Storm Sewer Overflows, 1967

Davies J.W., Laboratory Study Related to the Modelling of Storm Water Quality in Combined Sewers, Proceedings 5th International Conf. Urban Storm Drainage, Osaka, 1990.

Davis P.S. & Parkinson A.D., Littleborough Combined Sewer Overflow - A New Approach to Planning and Design, Proceedings 5th International Conf. Urban Storm Drainage, Osaka, 1990.

Detectronic Ltd., Installation and Operating Instructions, I.S. Survey Logger and Rain Logger Systems, 1991.

Eadon A.R. & Williams D.W. Sewer System Performance Monitoring - The Options, WRc Swindon.

Eckhoff D.W., Friedland A.O. & Ludwig H.F., Characterisation & Control of Combined Sewer Overflows, San Francisco, Water Research, 3, pp531-543.

Ellis J.B., The Characterization of Particulate Solids and Quality of Water Discharged from an Urban Catchment, Proc. IAHS-UNESCO, pp 283-291, IAHS Publ No. 123, Amsterdam, 1977.

Ellis J.B., The Nature and Sources of Urban Sediments and Their Relation to Water Quality, in Hollis G.E. (Edit.) : Man's Impact on The Hydrogeological Cycle in the U.K., pp199-216, Geobooks, Norwich, 1979.

Ellis J.B., Blights and Benefits of Urban Stormwater Quality Control, in Featherstone R.E & James A. (Edit.): Urban Drainage Systems, Pitmans, London, 1982.

Ellis J.B., The Pollutional Aspects of Urban Runoff, NATO ASI Series, Vol. G10, Urban Runoff Pollution, Torno H.C., Marsalek J. & Desbordes M.(Edit.s), Springer-Verlag.1986.

Ellis J.B., The Quality of Urban Discharges, in Urban Discharges and Receiving Water Quality Impacts, edit. J.B. Ellis, Proc. Semin. IAWPRC/IAHR 14th Biennial Conf., Brighton, U.K., 1988.

Escritt L.B., Sewage Sampling, Water and Waste Treatment, vol 8(10), Nov/Dec pp 501-503, 1961.

Escritt L.B., Sewerage and Sewage Disposal, 3rd Edit. London, C.R. Books Ltd., 1965.

Fiddes D., Overview of International Urban Drainage Practice, Proceedings, Developments in Storm Sewerage Management, Sheffield City Polytechnic & Institute of Public Health Engineers, March 24-25, 1986, Sheffield, pp 51-65.

Field R., Design of a Combined Sewer Overflow Regulator/Concentrator, Jnl.Wat.Pol. Control, vol. 46, no. 7, pp 1722-1741, July 1974.

Francis J.R.D., A Textbook of Fluid Mechanics, Edward Arnold, 1962.

Frederick M.R. & Markland E., Performance of Stilling Ponds in Handling Solids, Institution of Civil Engineers, Symposium on Storm Sewage Overflows, 1967.

Gatehouse H.C., River Pollution By Storm Overflows - Some Attempt at Rationalisation, The Surveyor and Municipal Engineer, 16 May, 1964.

Geiger W.F., Characteristics of Combined Sewer Runoff, Proc. 3rd Int. Conf. on Urban Storm Drainage, Goteburg, Sweden, 1984.

Geiger W.F., Use of Field Data in Urban Drainage Planning, in NATO ASI Series vol. G10, Urban Runoff Pollution, Edit. H.C. Torno, J. Marsalek & M. Desbordes, Springer-Verlag, 1986.

Gray N.F., Biology of Wastewater Treatment, Oxford Scientific Publications, O.U.P., 1989

Green M.J., The Role of Flow Surveys in the Hydraulic Analysis of Sewerage Systems, Sewerage '81, Maintenance, Renovation and Repair of Sewerage Systems, Institution of Civil Engineers, June 1981.

Green M.J., Hydraulic Analysis of Sewerage Systems, Proceedings 1st International Conf. Urban Storm Drainage Systems, Southampton, 1982.

Green M.J. & Drinkwater A., Guide to Sewer Flow Surveys, Water Research Centre, 1985.

Green M.J., Assessment of Sewer Overflow Performance Water Research Centre, 1991.

Gujer W. & Krejci V., Urban Storm Drainage and Receiving Waters Ecology, 4th International Conf. on Urban Storm Drainage, Lausanne, 1987.

Hager W.H. Backwater Curves in Circular Channels, Jornal of Irrigation and Drainage Engineering, A.S.C.E., Volume 117 No.2, March/April 1991, pp 173-183.

Hall M.J. & Ellis J.B., Water Quality Problems of Urban Areas, Geojournal, vol.11(3), pp 265-275, 1985.

Halliwell A.R. & Saul A.J., Use of Hydraulic Models to Examine the Performance of Storm Sewer Overflows, Proc. Inst. Civil Engineers, vol. 69, pp 245-259, 1980.

Harremoes P., Overflow Quantity, Quality and Receiving Water Impact.- Proc. Semin. IAWPRC/IAHR 14th Biennial Conf., Brighton, U.K., July 1988.

Harremoes P., Pollution From Urban Runoff - Nutrient Loads, Triton Training Course, Integrated Urban Runoff, 1992.

Hedges P.D., Lockley P.E. & Martin J.R. A Field Study of an Hydrodynamic Separator Combined Sewer Overflow International Conference on Innovative Technologies in the Domain of Urban Storm Water Drainage, Lyon, France. 1992.

Hedley G. & King M.V., Suggested Correlations Between Storm Sewage Overflow Characteristics and Storm Overflow Performance, Procs Inst Civil Engineers, Vol. 48, pp 399-411, 1971.

Helliwell P., Storm Overflow - The Problem, Proc. Semin. Storm Overflows - Practice and Performance, Birmingham University and Hydro Research and Development, April 1991.

Henderson R.J. & Moys G.D., Development of a Flow Quality Model in the U.K., Proceedings 4th International Conf. Urban Storm Drainage, Lausanne, 1987.

Hogland W., Berndtsson R. & Larson M., Estimation of Quality and Pollution Load of Combined Sewer Overflow Discharge, Proceedings 3rd International Conf. Urban Storm Drainage, Goteborg, 1984.

Howard K., Saul A.J., Thornton R.C. & Pearson L.G., The Effects of Combined Sewer Overflows Upon Receiving Waters, Proceedings of the International Conference in Combined Sewage Overflows and Effects of Receiving Streams, Wageningen, Holland, 1986. TNO Committee on Hydrological Research No. 36 pp 185-196.

Hvitved-Jacobsen T., Conventional Pollutant Impacts on Receiving Waters, in NATO ASI Series vol. G10, Urban Runoff Pollution, Edit. H.C. Torno, J. Marsalek & M. Desbordes, Springer-Verlag, 1986.

Jeffries C., Methods for Estimating the Discharge of Gross Solids from Combined Sewer Systems. Water Quality International. 16th Biennial Conf. IAWPRC, Washington, 1992.

Jeffries C., The Design, Construction and Performance Assessment of a Storm King Storm Sewage Overflow, Jor. IWEM, April, 1991.

Kaul G., Combined Sewage Flows and their Level of Pollution in a Large, Flat Catchment, Korrespondenz Abwasser vol.32, no.1, pp 27-31, 1985.

King H. & Brater E.F., Handbook of Hydraulics, McGraw Hill, 1976.

Klein L., Aspects of River Pollution, London, Butterworths, 1959.

Krajca J.M., Water Quality Sampling, Ellis Harwood Series, 1989.

Kuichling, Report on the Adequacy of Existing Sewage Systems of the Black Bay District of Boston, U.S.A. 1909 (Reported in Watkins (below)).

Lavallee P., Lessard P. & Villeneuve J.P., Water Quality Variations in Running Waters Due to Combined Sewer Overflowing - Evaluation of the Negative Influences, Proceedings 3rd International Conf. Urban Storm Drainage, Goteborg, 1984.

Lessard P. & Lavallee P., Combined Sewer Overflows: The Quebec Experience, Proceedings 3rd International Conf. Urban Storm Drainage, Goteborg, 1984.

Lester W.F., Effects of Storm Overflows on River Quality. Institution of Civil Engineers, Symposium on Storm Sewage Overflows, 1967.

Lijklema L., Roijackers R.M.M. & Cuppen J.G.M., Biological Assesment of the Effects of Combined Sewer Overflow and Storm Water Discharge Proc. Semin. IAWPRC/IAHR 14th Biennial Conf., Brighton, U.K., July 1988.

Lindholm O.G., Dry Weather Deposition in Combined Sewers. Proc. 3rd Int. Conf. on Urban Storm Drainage, 1984, pp861-868

Lindholm O.& Aaby L., In-Pipe Flushing and Its Implication for Overflow Quality, in Urban Discharges and Receiving Water Quality Impacts, edit. J.B. Ellis, Proc. Semin. IAWPRC/IAHR 14th Biennial Conf., Brighton, U.K., 1988.

Lockley P.E., Hedges P.D. & Martin J.R., A Study of a Hydrodynamic Separator Combined Sewer Overflow - the First Year IWEM West Midlands, Aston University, May 1989.

Lonsdale K.G., Balmforth D.J., Nussey B.B. & Walsh A.M., Monitoring Combined Sewer Overflow Performance, Water Research Centre, UM 1388, 1993.

Lockwood A.P.M. (edit), Effects of Pollutants on Aquatic Organisms, Society for Experimental.Biology, Seminar Series, Cambridge University Press, 1976.

Malmqvist P.A., in Storm Runoff. Report 66 Chalmers Technical University, Gothenburg, 1982

Marshall R.J. & Hopkins P.D., Storm Sewer Overflow Screen Design and Operation, Proceedings, Developments in Storm Sewerage Management, Sheffield City Polytechnic & Institute of Public Health Engineers, March 24-25, 1986, Sheffield.

Mason C.F., Biology of Freshwater Pollution, Second Edition, Longman Scientific and Technical, 1991.

Mercer W.H., Reconstruction of Overflows, Institution of Civil Engineers, Symposium on Storm Sewage Overflows, 1967.

Ministry of Housing and Local Goverment, Technical Committee on Storm Overflows and the Disposal of Storm Sewage - Final Report H.M.S.O., 1970.

Moffa P.E., Freedman S.D. & DeGuida R.N., Urban Runoff and Combined Sewer Overflows, Jor. Wat. Polln. Cont. Fed., 1985, 57, (6), pp 565-566.

Morris G., Consent Standards for Storm Sewage Overflows Proc. Semin. Developments in Drainage Modelling, April 1991, Bradford University.

Mutzner H., Visible Pollution From Combined Sewer Overflows, Proceedings 4th International Conf. Urban Storm Drainage, Lausanne, 1987.

National Rivers Authority 1991, Water Quality Series No.4, The Quality of Rivers, Canals and Estuaries in England and Wales Report on the 1990 Survey December 1991.

National Rivers Authority 1991, Water Quality Series No.3, Proposals for Statutory Water Quality Objectives December 1991.

National Rivers Authority 1990, Water Quality Series No.1, Discharge Consent and Compliance Policy - A Blueprint for the Future July 1990.

O'Sullivan P., Review of the Performance of Storm Sewage Overflow Structures with Respect to Aesthetic Criteria Water Research Centre UM1037, March 1990.

Payne J.A., Assessment of the Impact of Discharges from Surface Water Systems on Receiving Water Quality, Ph.D. Thesis, Aston University, 1989.

Payne J.A., Moys G.D., Hutchings G.& Henderson R.J., Development, Calibration and Futher Data Requirements of the Sewer Flow Quality Model - MOSQITO Hydro Research and Development, 1989.

Reed E.C., An Assessment of the Problem in the U.K. Sewerage '81, Maintenance, Renovation and Repair of Sewerage Systems, Institution of Civil Engineers, June 1981.

Ruff S., Progress Report for the 7th Meeting of CSO Performance Group, Swindon, 1992.

Saul A.J., The Performance of Storm Sewage Chambers PhD Thesis Herriot-Watt University, 1977.

Saul A.J. & Murrell M.D., Design Considerations and Maintenance of Storm Sewer Overflows with Particular Emphasis on Storage, Proceedings, Developments in Storm Sewerage Management, Sheffield City Polytechnic & Institute of Public Health Engineers, March 24-25, 1986, Sheffield.

Saul A.J. & Delo E.A., Performance of High Side Weir Storm Sewage Chamber Incorporating Storage, U.S. Hydraulics and Hydrology, Water Research Publications, Colorado, 1981.

Saul A.J. & Delo E.A., Laboratory Tests on a Storm Sewer Overflow Chamber with Unsteady Flow, Proceedings 1st International Conf. Urban Storm Drainage Systems, Southampton, 1982.

Saul A.J. & Thornton R.C., Hydraulic Performance and Control Of Pollutants Discharged From A Combined Sewer Storage Overflow, Wat. Sci. Tech. vol. 21, Brighton, pp 747-756, 1989.

Saul A.J. & Marsh P.M., A Strategy for the Monitoring of Pollutants in Sewers Overflows and Tanks, Proceedings 5th International Conf. Urban Storm Drainage, Osaka, 1990.

Scottish Development Department Working Party on Storm Sewage (Scotland). Storm Sewage - Separation and Disposal H.M.S.O., Edinburgh, 1977.

Scottish Development Department, Applied Research and Development Report Number ARD 6, Settling Velocities of Particulate Matter in Sewage, October 1980.

Seager J. & Abrahams R.G., The Impact of Storm Sewage Discharges on the Ecology of a Small Urban River, Proceedings of 2nd Wageningen Conf., September 1989.

Sharpe D.E. & Kirkbride T.W., Stormwater Overflows: The Operation and Design of a Stilling Pond, Proc. Inst Civil Engineers, vol 13, pp 445-466, 1959.

Shaw C., Aspects of Public Health, in "The History of the City of Sheffield (1843-1993)" Volume 2, edit. Binfield C., Hey D., Childs R., Harper R., Tweedale G. & Martin D., Sheffield Academic Press, 1993.

Shuttleworth A.J., State of Rivers and Sewers in Britain - Is there a Pollution Problem?, Proceedings, Developments in Storm Sewerage Management, Sheffield City Polytechnic & Institute of Public Health Engineers, March 24-25, 1986, Sheffield.

Skeat W.,(ed.) The Manual of British Engineering Practice, 4th Edition, Institution of Water Engineers, Cambridge, 1969.

Smisson R.P.M., Storm King Overflow Dynamic Separation for Combined Sewer Overflows Results of Trials to Demonstrate Compliance With Performance Requirements. Hydro Research and Development Ltd., April 1989. Ref. A.700m (01/90).

Smisson R., Storm King Stormwater Overflows, Proc. Semin. Storm Overflows - Practice and Performance, Birmingham University and Hydro Research and Development, April 1991.

Stanbridge H. History of Sewage Treatment in Britain, Vol.1 Institution of Water Pollution Control, 1976.

Thornton R.C. & Saul A.J., Temporal Variations of Pollutants in Two Combined Sewer Systems, Proceedings 4th International Conf. Urban Storm Drainage, Lausanne, 1987.

Tucker C.G.J., Stormwater Pollution - sampling and measurement, Jnl. Inst. Municipal Engineers, Vol.101, Oct. 1974.

Tucker C.G.J.& Mortimer G.H., The Generation of Suspended Solids Loads in Urban Stormwater, Proceedings of the First International Conference on Urban Storm Drainage, 1978. pp 695-704.

Tyack J.N., Hedges P.D. & Smisson R.P.M., A Device for Determining the Settling Velocity Grading of Storm Sewage, 6th International Conf. Urban Storm Drainage, Niagara Falls, 1993.

Tyers R.G., Refinements of the BOD Test, J. IWEM, 3 August, pp 366-374, 1989.

Vanderborght J.P. & Wollast P. Continuous Monitoring of Waste Water Composition in Sewers and Stormwater Overflows 2nd Wageningen Conference on Urban Storm Water Quality, 1989.

Villeneuve J.P. & Lavallee P., Measured CSO Contribution to River Quality Deterioration and Methodologic Approach for Negative Influence Evaluation, in NATO ASI Series vol. G10, Urban Runoff Pollution, Edit. H.C. Torno, J. Marsalek & M. Desbordes, Springer-Verlag, 1986.

Walsh A., The Gross Solids Sampler-Development of a Sampler for Combined Sewer Overflows, Report UM 1172, Water Research Centre, November, 1990.

Wardle J., Development Work in Vortex Sewage Separation, Internal Report, Dept. Civil Engineering, Sheffield City Polytechnic, 1976.

Wardlaw A.C. Practical Statistics for Experimental Biologists Publ. Wiley, 1985.

Water Research Centre, Sewer Rehabilitation Manual, Swindon, 1983.

Water Research Centre, Assessment of Sewer Overflow Performance, Report U1193, 1992

Watkins L.H., Road Research Technical Paper No.55, Department of Scientific and Industrial Research, H.M.S.O. 1962.

Webber N.B., Fluid Mechanics for Civil Engineers, Chapman and Hall, 1971.

White J.B., The Design of Sewers publ. Edward Arnold, 1970.

Whitelaw & Solbe, River Catchment Management: an approach to the derivation of quality standards for farm pollution and storm sewage discharges, in Urban Discharges and Receiving Water Quality Impacts, edit. J.B. Ellis, Proc. Semin. IAWPRC/IAHR 14th Biennial Conf., Brighton, U.K., 1988.

Winder D., The Hydraulic Performance of Vortex Overflows, Internal Report, Dept. Civil Engineering, Sheffield City Polytechnic, 1976.

Wishart S.J., Lumbers J.P., Griffiths I.M., Expert Systems for the Interpretation of River Water Quality Data, J.I.W.E.M., April 1990.

Wood L.B. & Stanbridge H.H., Automatic Samplers, Wat. Pollut. Control, pp 495-520, 1968.

Wylie J.C., The Wastes of Civilisations Faber and Faber, 1959.

Appendices

APPENDIX 1: Scattergraphs
APPENDIX 2 Graphs of Bottle Sample Concentration and Inflow
APPENDIX 3 Graphs of Relationships between Sample Parameter Concentrations
APPENDIX 4 Flow Types

APPENDIX ONE: SCATTERGRAPHS

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Manhole number:  1                                      LOG (MEASURED VELOCITY) : LOG (DEPTH) GRAPH

DEPTH      VEL     NO  S.DEV                                         VELOCITY (Metres/Sec)
  MM       M/S        PERCENT    0.05      0.08      0.12      0.19      0.29      0.44      0.69      1.07      1.55
  54   *   0.46 * 112 *  16  *    +:::::::::+:::::::::+:::::::::+:::::::::+::::::3564:::::434:+:::::::::+:::::::::+
  58   *   0.45 * 821 *  37  *    +                          335 44534211       1357775456566511                  +
  63   *   0.48 *1908 *  22  *    +                            2 133444444311   11578877776556653                 +
  68   *   0.51 *3009 *  21  *    +                                     243354466677787788767776553  31           +
  73   *   0.50 *4454 *  59  *    +       1  1 2  3 4 5 5 55 555 444555556556567767777778737777778762341          +
  79   *   0.60 *6797 *  54  *    3   2   1  2    1   1 3 13 334 454444545556555666677767989898888888888542          +
  85   *   0.66 ***** *  42  *    4   4   4  4 4  4 4 3 3 43 321 2312444443455555667777787889999998988774         +
  91   *   0.70 ***** *  44  *    3   3   4  4 5  4 5 5 4 32 2 2 1321 33444454466677767788989999999999986433      +
  99   *   0.69 ***** *  70  *    6   6   6  5 5  6 5 4 4 54 444 45433434544545666777777889899999999999988751     +
 106   *   0.73 ***** *  68  *    6   6   6  5 6  5 6 6 6 55 565 5555443444555555566667787989999999999999987874   +
 115   *   0.76 ***** *  57  *    5   4   4  5 4  5 6 6 5 54 531 3443 33433454554456655567788999999888889898775   +
 124   *   0.84 *5475 *  34  *    +            1  4 3 3 1 33 1   11  1   21   11 1 23344667788888777777889876543  +
 133   *   0.90 *2095 *  39  *    +               3 3   3 3           1  1  1        32345667766666766667677765564+
 144   *   0.91 * 737 *  38  *    +                        1            11 2       1 12244555665454544455666664423+
 155   *   0.77 * 465 *  47  *    +          1 1  1                       1     1 1   3 33555665553442444455453431+
 167   *   0.85 * 277 *  45  *    1            1      1            1     1          11   1 245555544454444443323341
 180   *   0.76 * 157 *  64  *    +            1    1 1 1 1         1        1      11 3  3 334444444444233221 2  +
 194   *   0.65 * 122 *  50  *    +   1           1                2     2     1111212 133333444443432 3 1  11    +
 209   *   0.59 * 114 *  58  *    +   1                          1        111 13  3 2 13344444343332 1 3 111   1  +
 226   *   0.57 * 128 *  36  *    +               1            1         2  31  13133243444344444331 111          +
 244   *   0.45 * 215 *  56  *    1          1    1 1        1    1    1133342333 234555544 434313 1   1          +
 263   *   0.40 * 120 *  42  *    +            1                  1  33434434334313434434444331112 1              +
 283   *   0.34 * 165 *  46  *    +       1  1        1        1 3 133444432323433434443343132   1                +
 305   *   0.37 * 115 *  63  *    +       1             1         21232333123 3332444443334121                    +
 329   *   0.31 * 145 *  50  *    +       1             1    2 3 1334331 4343434434433323                         +
 355   *   0.30 * 140 *  55  *    1   1   1             1 1  1 1 32 333344433444433333313                         +
 383   *   0.23 * 192 *  79  *    2       2  3 2  3   2 3 33 433 2333333334445434442432 11                        +
 413   *   0.25 * 241 *  43  *    1       1    1  1 1 1 3 14 444 4443444454453343333312                           +
 445   *   0.23 * 209 *  45  *    +   1           3 3 2 2 43 444 4343443454453 4313 1                             +
 480   *   0.21 * 279 *  46  *    +   3   2    1  1 4 3 4 44 455 554444445444324312 1                             +
 517   *   0.22 * 231 *  41  *    +       1           4 4 44 443 444444555444334                                  +
 558   *   0.20 * 218 *  38  *    +            1  3 3 4 4 54 434 344444445444413 1                                +
 601   *   0.16 * 312 *  58  *    3   3      2 4  3 4 5 5 55 544 5444543443333  1                                 +
 648   *   0.16 * 250 *  53  *    1   3      1 1  3 5 5 5 54 443 4454444442111                                    +
 699   *   0.15 * 216 *  61  *    3   3   1    3  4 4 5 5 43 334 34444443421  1                                   +
 754   *   0.15 * 178 *  77  *    3       2    3  3 4 5 4 33 433 44444443331                                      +
 813   *   0.15 * 127 *  70  *    1   1   1  1 3  3 4 4 3 32 344 434344213                                        +
 876   *   0.15 * 146 *  73  *    +   1   3  3 3  4 4 4 3 43 434 4444343 2                                        +
 945   *   0.12 * 141 * 101  *    1   1   3  3 1  4 4 4 3 34 434 3354231 1  1                                     +
1019   *   0.13 * 136 *  95  *    2   1      3 3  4 3 3 3 43 434 444432 2                                         +
1099   *   0.11 * 652 *  83  *    5   5   6  6 6  6 6 5 5 55 555 556555441                                        +
1184   *   0.15 * 170 * 110  *    2   3   1  3 2  3 3     31 344 344444334343312                                  +
1277   *   0.14 *  81 * 138  *    2   3   3  3 3  2 2 3 3 32 2         113213 341 312 3                           +
1377   *   0.16 *  61 * 103  *    3   1   1  3 1  2 2 1 3 22 333 322      1     2  2 231  11                      +
1485   *   0.18 *  26 *  81  *    +   1        1  2 1 1 2 31 31  131                    1 1 1 1                   +
1601   *   0.23 *   6 *  56  *    +                        2   1       1 1              1                         +
1726   *   0.36 *   3 *  59  *    +                                   1  1                    1                   +
1861   *   0.36 *   2 *  84  *    +                              1                           1                    +
2007   *   0.00 *   0 *   0  *    +                                                                               +
2164   *   0.12 *   1 *   0  *    +                   1                                                           +
2333   *   0.76 *   3 *  14  *    +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::1:+:::11::::+:::::::::+

Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.1 Scatter Graph of Inflow Velocity at the Stilling Pond Site

```
Manhole number:  1                                LOG (FLOW) : LOG (DEPTH) GRAPH

DEPTH     FLOW     NO  S.DEV                              FLOW (Litres/Sec)                                 AV VEL BAND
  MM       L/S         PERCENT  10.00     17.74     31.49     55.87     99.15    175.93    312.19    553.97    983.00   25%    75%

   54 *   3.00 *  24 *   0 *   +::::::::+:::::::::+::::::::+:::::::::+::::::::+::::::::+:::::::::+::::::::+   0.51   0.52
   58 *   3.11 * 610 *  10 *   +                                                                          +   0.44   0.45
   63 *   3.38 *1823 *  18 *   +                                                                          +   0.38   0.50
   68 *   4.08 *2985 *  23 *   +                                                                          +   0.42   0.54
   73 *   5.13 *4140 *  33 *   2                                                                          +   0.38   0.57
   79 *   6.84 *6615 *  31 *   8 5                                                                        +   0.47   0.65
   85 *   8.70 ***** *  28 *   9 98 973                                                                   +   0.54   0.70
   91 *  10.86 ***** *  27 *   9 99 9998542                                                               +   0.59   0.79
   99 *  13.14 ***** *  29 *   9 99 99999988764                                                           +   0.59   0.80
  106 *  15.79 ***** *  39 *   8 89 999999999997876                                                       +   0.63   0.86
  115 *  18.58 ***** *  42 *   6 67 899999988899998752                                                    +   0.59   0.92
  124 *  23.13 *5474 *  35 *   2 13 4578888877878799987544                                                +   0.61   0.99
  133 *  28.59 *2094 *  39 *   1     13456777676767777777776563                                           +   0.67   1.04
  144 *  33.59 * 737 *  38 *   1 3     11344556665554555676654421                                         +   0.63   1.09
  155 *  32.93 * 463 *  40 *   +    1  11 222556666544444555534 1                                         +   0.59   0.93
  167 *  40.74 * 277 *  45 *   1  1        1 1 114555555555445443331                                      +   0.65   0.97
  180 *  43.28 * 156 *  52 *   +  1      1     122234444455544432 3                                       +   0.66   0.90
  194 *  42.12 * 122 *  50 *   +    2 11     21123  4334454442312 1 1                                     +   0.59   0.75
  209 *  44.60 * 113 *  45 *   +    1      2 112122123345444131113 1   1                                  +   0.53   0.68
  226 *  47.33 * 128 *  36 *   +       1     1121132134445344454 121                                      +   0.47   0.67
  244 *  44.53 * 214 *  47 *   2       1  1   233343325565544434211   1                                   +   0.42   0.52
  263 *  44.82 * 180 *  41 *   1            11143444443434444455 33 12                                    +   0.29   0.53
  283 *  42.92 * 165 *  48 *   +     1       2233454331442444443423 11                                    +   0.24   0.45
  305 *  53.24 * 115,*  64 *   + 1        1     132433 223333445433432                                    +   0.30   0.46
  329 *  51.58 * 145 *  49 *   +  1        1    3233423334444354533342                                    +   0.24   0.39
  355 *  58.21 * 140 *  57 *   +  1 1        1 1 1  3123344533454433343                                   +   0.26   0.37
  383 *  50.73 * 192 *  81 *   + 11  2 3  1131 21334333324334454554334311                                 +   0.17   0.32
  413 *  63.05 * 241 *  42 *   +     1   1  1  1 1123434444444454554343441                                +   0.19   0.31
  445 *  64.30 * 211 *  61 *   +        1      11322 31434434444445554343221                              +   0.17   0.29
  480 *  65.85 * 293 *  70 *   1    1      311    1323243443455554444554533111                            +   0.17   0.28
  517 *  80.68 * 232 *  49 *   +      1       1        21344444444545555544431                            +   0.18   0.27
  558 *  80.99 * 222 *  67 *   +                     1 22234345444434444445343 1                          +   0.15   0.26
  601 *  77.76 * 313 *  62 *   3      1      21 3    113313355555453454554444332 1                        +   0.13   0.22
  648 *  86.41 * 251 *  59 *   1 11         11 1  21    1 12345455533443455544431 1                       +   0.13   0.22
  699 *  92.29 * 216 *  60 *   +  2 1          1 12 23 1  22434445443134444444321                         +   0.12   0.22
  754 * 101.19 * 180 *  89 *   +    22    31    11 3     11  333343434343434544433                        +   0.12   0.23
  813 * 111.25 * 128 *  79 *   +      11     2   22  1   1 1 1 333334331314444443331                      +   0.12   0.22
  876 * 121.45 * 147 *  81 *   +       131     2  1        11113 32333433343444343454412                  +   0.12   0.22
  945 * 100.41 * 149 * 143 *   2        13     143   2   1 1  3 3 113333333334334444421  1                +   0.09   0.21
 1019 * 117.19 * 142 * 129 *   3           33     3   11  11 1    3 3342412343334554422                   +   0.11   0.21
 1099 * 111.68 * 888 * 113 *   + 5         154    343  341 343 5316 62616565455455555665541               +   0.08   0.20
 1184 * 137.30 * 189 * 194 *   +  5          3      4    33  2 31 1 3 2 313  313343445443444312           +   0.07   0.25
 1277 * 130.87 *  88 * 200 *   + 31          3     1 1 1   2  3  3 3 3 2 23 3322     11233133312 3        +   0.06   0.32
 1377 * 166.73 *  63 * 135 *   + 2                      3   3 1  1 3 1 2 21 3223 4322    1  112 23  2     +   0.10   0.20
 1485 * 197.75 *  26 *  82 *   +                              1      1 2 11 2313 1131            1 11 1   +   0.13   0.20
 1601 * 255.41 *   6 *  56 *   +                                             2 1      1 1         1       +   0.15   0.28
 1726 * 407.99 *   3 *  59 *   +                                                      1 1             1   +   0.25   0.68
 1861 * 392.68 *   2 *  88 *   +                                                 1                   1   -+   0.19   0.65
 2007 *   0.00 *   0 *   0 *   +                                                                          +
 2164 * 132.07 *   1 *   0 *   +                                          1                               +   0.12   0.12
 2333 * 876.48 *   3 *  13 *   +::::::::+:::::::::+::::::::+:::::::::+::::::::+::::::::+:::::::::+::::1::11   0.66   0.86

Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.2   Scatter Graph of the Inflow at the Stilling Pond Site

```
Manhole number:  2                                 LOG (MEASURED VELOCITY) - LOG (DEPTH) GRAPH

DEPTH      VEL     NO  S.DEV                                      VELOCITY metres/Sec
  MM       M/S         PERCENT  0.05      0.09      0.15      0.25      0.44      0.75      1.28      2.21      3.79
   40  *  0.02 *   26 *  17 *   +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+
   44  *  0.04 *   44 * 237 *   +        1 1                               11               11 1                 +
   48  *  0.05 *   38 * 302 *   1     1                  1   1    1                         11       11           +
   53  *  0.24 *  126 * 284 *   1                 1    1                45554     1         11  1    1           +
   58  *  0.34 *  216 * 171 *   1        1                           13466643     1         1   2                +
   63  *  0.37 *  189 * 150 *   1                           1         455655 1             1   11                +
   69  *  0.39 *  253 * 118 *   3            1  1     11     3    23354556551           112    2                 +
   76  *  0.34 *  574 *  64 *   1  1  1               2  323445666444345654575532          131                    +
   83  *  0.34 *  958 *  63 *   3  4  1       1 33 3334 45445436565775354 5576642        1 1 11                  +
   91  *  0.43 * 1394 *  48 *   3  2  2  2      1 2133 3434543556564565567687754    1  11 12 1                  +
  100  *  0.51 * 2308 *  45 *   4  3     2  1  1 1312 33444334454555765566888677657642  1221                     +
  109  *  0.53 * 4982 *  44 *   3  4  4  4 4 2 13 1 34 443133344666666766778889976787533 1 311                    +
  120  *  0.49 * 6372 *  47 *   4  3  4  4 5 4 33 3213  441344667777777738898988736766543  32 11                 +
  131  *  0.48 * 6617 *  51 *   3  3  4  4 5 5 33 3444 333334577777777773889897777777766642113       121         +
  143  *  0.51 * 9711 *  45 *   3  3     3 4 5 53 3243 43124456677777788899999887767758762 222 1   1311         +
  157  *  0.56 ***** *  36 *   2     2  3 4 4 55 4 1  333334455666777788999999977772886775333 1 12 23           +
  172  *  0.59 ***** *  36 *   1  4  1  1 1 3 44 54 1    123 2143567788899999998767899887665433 32111           +
  189  *  0.55 ***** *  32 *   2  2  1  2 1 1 24 4443 1 112212 3356778889999989766768888655 44 332 232           +
  207  *  0.56 * 9685 *  27 *   1           1 1  1233 1 3 321333344567889999998877676777775 53 13433342         +
  226  *  0.57 * 6800 *  31 *   +        2  11 21   1222     1222356778899998876666667765533223455432           +
  248  *  0.62 * 4506 *  34 *   1  1  1  1  1 33 111  11 1 1 1312  34567788999977666667754131233554431         +
  272  *  0.74 * 3657 *  44 *   1     2  2  1 22  1        11 1131233357787778788776667777533334455551         +
  298  *  0.93 * 2047 *  57 *   2  1     1    2  1    1 1  21 2133311355676666666666666776654444255411          +
  326  *  0.90 * 1397 *  66 *   +     2    1 3  1 2321 11  1      1232 3 346675456654566765667655343355631      +
  357  *  1.01 * 1082 *  89 *   +          1 1 2  3133 21 12           2657643455444560631466554334675 31     +
  391  *  1.15 *  857 *  95 *   +  1  1    1 2  1 2333 232 3          13 347553444444456655445665445566441     +
  429  *  1.24 *  756 *  99 *   +          1    1 1132 343432          113365513343333456555435565556 6544     +
  470  *  1.29 *  736 * 140 *   +            1    2 21 4346523 1 1        1 23423 2 134454555543455666666453  +
  514  *  1.35 *  861 * 135 *   +                   1 1 42156543111          21343  3333444344554357666566541 1+
  564  *  1.15 *  679 * 153 *   +  1                1 2  12355452112 565   11 1 3342 11122232236533456666545553 +
  617  *  0.46 * 4098 *  53 *   +           1              1 244454533 168994 11 1324321 1 21111 333 344555544554122
  676  *  0.53 * 1480 *  78 *   +     1              2   2224454433134982112  2422  2 33111 2   11444445554533+
  741  *  0.98 *  605 * 153 *   +     1      1               1 31544554566543111 13 343 1 23111 1   3355565555455432
  812  *  0.92 *  345 * 149 *   +  3        1 1                   33455541554231 2 1342 223   3   1135555434332 +
  889  *  0.91 *  542 * 136 *   +  1  2                      1   235665455544 11111443  3 124  1 3456654321 322
  974  *  0.52 *  492 *  66 *   +  1                              2346666666 44133123 341 2224322     2443   1 1
 1067  *  0.54 *  523 *  48 *   2           1                      11355667653333333321 113443433     1       +
 1169  *  0.57 *  316 *  69 *   +             1                  1   24566633121334444322 11212              +
 1281  *  0.70 *  436 *  59 *   +                               1       116676511 12565531 1   1            +
 1403  *  0.74 *  198 * 141 *   3  1                 1                       4651  122  554343    1         +
 1537  *  0.11 *   64 * 494 *   4  2  3                                     1    1121 22333     1           +
 1684  *  2.21 *    1 *   0 *   +                                                                  1           +
 1845  *  0.00 *    0 *   0 *   +                                                                              +
 2021  *  0.00 *    0 *   0 *   +                                                                              +
 2214  *  0.49 *    1 *   0 *   +                                          1                                   +
 2425  *  0.47 *    2 *   3 *   +                                         11                                   +
 2657  *  0.00 *    0 *   0 *   +                                                                              +
 2911  *  0.00 *    0 *   0 *   +                                                                              +
 3189  *  0.00 *    0 *   0 *   +                                                                              +
 3493  *  0.00 *    0 *   0 *   +                                                                              +
 3827  *  1.03 *    1 *   0 *   +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::1:::+:::::::::+:::::::::+

Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.3 Scatter Graph of Continuation Velocity at the Stilling Pond Site

```
Manhole number:  2                                              LOG (FLOW) / LOG (DEPTH) GRAPH

DEPTH    FLOW    NO  S.DEV                                      FLOW (Litres/Sec)                                   AV VEL BAND
  MM      L/S        PERCENT 3.00      5.25      9.20      16.10     28.20     49.37     86.44     151.35    265.00  25%    75%

  40 *   0.00 *   0 *   0 *  +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+
  44 *   4.97 *   5 *  53 *  2           1  1  1                                                             +   0.47   1.10
  48 *   4.51 *   7 * 156 *  +                 2   1  1                                                      +   0.29   1.47
  53 *   3.98 *  94 *  35 *  3    6   1         11 1    1                                                    +   0.46   0.48
  58 *   4.05 * 187 *  21 *  3    7   4  1         1  2                                                      +   0.41   0.42
  63 *   5.00 * 169 *  25 *  +    5   7  5           11  1                                                   +   0.45   0.47
  69 *   5.27 * 235 *  39 *  3    3   6  7  2        22  1 1                                                 +   0.40   0.48
  76 *   4.62 * 566 *  46 *  7    7   7  6  6  5       231                                                   +   0.27   0.42
  83 *   5.23 * 951 *  55 *  6    7   8  5  6  7 61     1  111                                               +   0.25   0.51
  91 *   7.36 *1382 *  47 *  5    6   7  6  7  7 87 5 2  1 2  12  1                                          +   0.38   0.51
 100 *  10.01 *2305 *  43 *  4    5   5  6  7  7 78 8 78 666642 132                                          +   0.45   0.60
 109 *  12.07 *4980 *  43 *  5    5   4  6  7  7 77 8 99 987776533  231                                      +   0.48   0.63
 120 *  12.46 *6372 *  48 *  5    4   4  6  8  8 88 8 39 998877666544 3111 1                                 +   0.41   0.58
 131 *  14.09 *6617 *  51 *  6    5   5  4  7  8 88 8 88 899887777777766522232   1 3                         +   0.40   0.59
 143 *  17.02 *9711 *  45 *  6    5   5  3  5  7 88 7 88 89999998886677887612 311  113 1                     +   0.45   0.60
 157 *  20.95 ***** *  36 *  5    6   5  3  4  4 56 7 77 88899999998776888889766431  221122                  +   0.48   0.61
 172 *  24.34 ***** *  36 *  4    4   5  5  1  2 33   45 77388999999998768899997554423122111                 +   0.50   0.66
 189 *  26.45 ***** *  32 *  3    3   4  4  5  3  3 1 33 46677889999999866778887655431232 322                +   0.48   0.62
 207 *  29.62 *9685 *  27 *  1        1  1  3  3 33 1 33 334455679999999988766777777543 33434331             +   0.50   0.61
 226 *  34.06 *6800 *  31 *  +        1  1  3  2  2 3 2    122 3366788999987666666776654331445533            +   0.52   0.63
 248 *  40.70 *4506 *  34 *  1    2   1     3  3 21   2 11  2221 33557399988876666677654 3144444442          +   0.55   0.71
 272 *  52.29 *3659 *  46 *  +    1   2  2  1  3 1          1 1 233 334678777887877666777764333455555        +   0.61   0.97
 298 *  60.38 *2049 *  61 *  2        1  1     2 1     1 1  12   4322144677666666677666677765543435543       +   0.62   1.21
 326 *  62.94 *1397 *  65 *  +        2  1  3  1 23 1 11  1      2222 324667755665556765567764443355641      +   0.59   1.30
 357 *  69.90 *1084 *  93 *  2           1  1  2 33 3 21 12             26567544555355666335655523457532     +   0.59   1.57
 391 *  80.29 * 857 *  95 *  1    1   1  1  2  1 24 3 23  3            3134565344443546665534666455566433    +   0.73   1.28
 429 *  86.94 * 756 *  98 *  +           1     1 13 2 34 432          11335662233333455655534555565566544   +   0.86   2.06
 470 *  89.91 * 736 * 139 *  +              1     22 1 45 6523 1 1     1 13432  2134445555543455666666553 +   1.13   2.30
 514 *  94.28 * 851 * 134 *  +                    1 1 43 56542111           12342 2233444344543477665566541 1+   1.27   2.29
 564 *  80.27 * 679 * 152 *  +    1               1 2  3 3555421123463  11 1 3432 2 132233355553356666545653 +   0.38   2.24
 617 *  32.64 *4098 *  53 *  +           1             1 244554533 17793 11  334321 121 21 2331334555543554122   0.41   0.43
 676 *  37.44 *1480 *  78 *  +        1              2   2233454431237921111 3322  2133 11 2  113445335455543+   0.44   0.45
 741 *  69.08 * 605 * 151 *  +        1     1            1131545545556653111113 344 1 32111 1  234556655455432   0.42   2.33
 812 *  64.99 * 345 * 148 *  +    3      1  1                   344464435422112 1342 233  21    134555534332 +   0.39   2.29
 889 *  63.61 * 542 * 134 *  1    1   2                   1   244655555544 1111 432 23 141    1345666543 3 322   0.41   2.22
 974 *  36.30 * 492 *  65 *  3    1                              3355767644133123 341 2234331    2343      1 1   0.42   0.50
1067 *  36.99 * 524 *  54 *  2           1                         1335667654333333111 23443431      1       +   0.46   0.53
1169 *  39.44 * 316 *  71 *  2              1                     1    456665321124444422211221              +   0.50   0.60
1291 *  47.95 * 438 *  72 *  +                                    1      11567631 113555511 1    1           +   0.61   0.96
1403 *  49.73 * 199 * 161 *  3    1                  1                        4651  122 1654142     1         +   0.66   1.18
1537 *   5.85 *  68 * 557 *  4    2   3                                          1    1211 31323     1        +   0.01   1.01
1684 * 151.35 *   1 *   0 *  +                                                                      1        +   2.11   2.17
1845 *   0.00 *   0 *   0 *  +                                                                               +
2021 *   0.00 *   0 *   0 *  +                                                                               +
2214 *  33.36 *   1 *   0 *  +                                           1                                   +   0.47   0.48
2425 *  33.36 *   2 *   0 *  +                                           2                                   +   0.47   0.48
2657 *   0.00 *   0 *   0 *  +                                                                               +
2911 *   0.00 *   0 *   0 *  +                                                                               +
3169 *   0.00 *   0 *   0 *  +                                                                               +
3493 *   0.00 *   0 *   0 *  +                                                                               +
3827 *  73.07 *   1 *   0 *  +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::!::+:::::::::+:::::::::+   1.02   1.05

Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.4 Scatter Graph of Continuation Flow at the Stilling Pond Site

```
Manhole number:  1                              LOG (MEASURED VELOCITY) / LOG (DEPTH) GRAPH

DEPTH       VEL    NO  S.DEV                               VELOCITY (Metres/Sec)
 MM         M/S       PERCENT  0.05      0.09      0.15      0.25      0.43      0.74      1.27      2.19      3.75
   40  *  0.46 ***** *  61 *  S::4::4::4+4:4:54:444:55566756678798878888899898999865555532+:::::::::+:::::::::+
   43  *  0.48 ***** *  55 *  5  4  3  4 3 3 34 444 5556675667788788899899989999876666654221                  +
   46  *  0.51 ***** *  52 *  5  4  3  3 4 4 44 434 555657677788788898998989999887666654311   1             1 1
   50  *  0.55 ***** *  64 *  4  4  4  4 3 2 33 355 6555554557677778888899898899998896665331                  +
   54  *  0.59 ***** *  57 *  5  4  3  3 4 4 33 434 44443545555677788988899998899999998775433                 +
   58  *  0.62 ***** *  55 *  5  4  5  4 5 5 43 434 3344444445466677888899898999999999876643                  +
   63  *  0.68 *9520 *  51 *  4  4  4  4 4 4 33 333 334333333553555566676678788899999988875321                +
   67  *  0.75 *9530 *  35 *  1  2  4  4 3 3 43 332  22323122 13444356567778889999999897753                   +
   73  *  0.83 *8184 *  28 *  +     3  1 1 3 11 342 12   31214342243354456688888899899967653                  +
   78  *  0.93 *5606 *  28 *  1  3  3  2 3 3 2   2    1 1    1 11      2245576776778889998753                  +
   84  *  0.98 *3494 *  41 *  3  4  4  4 2 1 31  1             11    1 11 234554567877999751                  +
   91  *  1.03 *1663 *  36 *  1  1  3  3 1    1     2   1    1     1 1     12334546766788751                  +
   98  *  0.94 *1000 *  42 *  +  1       2 1        111 12 1 22112 1  211334566555665678742                   +
  105  *  0.84 * 835 *  36 *  +        1     1  1       1 22 1 1111  3 43343457765555675564                   +
  114  *  0.89 * 242 *  29 *  +                      1             1       1355455124555531                   +
  122  *  0.92 *  67 *  36 *  +                 1                        1 2 2133333444432                    +
  132  *  0.83 *  62 *  52 *  +                 1      1 1     1        1 1  1 22345544 33                    +
  142  *  0.80 *  57 *  39 *  +                           1    11  11        22233334343 11                   +
  153  *  0.60 *  68 *  52 *  +          1              1  2 11 2  1    2313343333433                         +
  165  *  0.55 *  84 *  36 *  +                       1 11     3 1  1 3334342334433                           +
  178  *  0.49 *  81 *  29 *  +                          113     1121433343444221                             +
  191  *  0.42 *  94 *  36 *  +  1                1   1    2   1 344444443312 2                               +
  206  *  0.40 *  99 *  43 *  1     1    1                  11 1313444444421 1  1                             +
  222  *  0.34 * 140 *  55 *  1                 1   21 2 32 232443454543331  1                                +
  239  *  0.30 * 134 *  53 *  +               1  11    12 433332444454422 3  1                                 +
  258  *  0.27 * 129 *  54 *  1     1           11  1 3 3433344454443311 2                                    +
  278  *  0.23 * 146 *  61 *  +  1     1   1 11  33 233 34443545434  21                                       +
  299  *  0.23 * 147 *  48 *  2  1           2  13  233344344545411 31 1 1                                    +
  322  *  0.22 * 196 *  58 *  2  1     1     3  233 3244455455444423233                                       +
  347  *  0.19 * 233 *  56 *  1  2  1  1 3    1 234 445546544533212312                                        +
  374  *  0.18 * 254 *  55 *  1  3  1  3 3 3  4 334 4555565434233 211                                        +
  403  *  0.17 * 241 *  55 *  3     3  1 2 3 24 334 55555543343321                                            +
  434  *  0.16 * 248 *  55 *  3  1  3  3 3 4 34 454 545555443412 111                                          +
  468  *  0.16 * 268 *  46 *  2  1  2  4 4 4 44 455 5554554422333 2                                           +
  504  *  0.14 * 255 *  46 *  2  2  4  4 4 4 45 555 5544544133 21                                             +
  543  *  0.13 * 245 *  57 *  3  2  1  4 4 5 55 555 4444441323 2 1                                            +
  585  *  0.12 * 291 *  45 *  2  3  3  4 5 5 65 555 5544332212 11                                             +
  630  *  0.12 * 275 *  48 *  3  4  3  4 5 5 55 554 34433423311   1                                           +
  679  *  0.10 * 242 *  55 *  3  4  5  5 5 5 55 544 4333331     1                                             +
  732  *  0.10 * 231 *  56 *  4  4  5  5 5 5 55 444 4434322 1                                                 +
  788  *  0.09 * 229 *  53 *  3  4  5  5 5 5 54 444 3331112                                                   +
  849  *  0.09 * 203 *  51 *  4  5  5  5 5 5 55 433 3331121    1                                              +
  915  *  0.08 * 251 *  59 *  4  5  5  5 5 5 54 433 341111     1                                              +
  986  *  0.08 * 330 *  56 *  4  5  5  6 5 5 55 554 432  2                                                    +
 1062  *  0.09 *1601 *  61 *  6  7  7  7 7 7 77 666 655545333311  1                                           +
 1144  *  0.14 *1039 *  67 *  4  5  5  5 6 6 66 666 66555655454553352343112 1 1                               +
 1233  *  0.47 *   3 *   5 *  +                                       1 2                                     +
 1328  *  0.00 *   0 *   0 *  +                                                                               +
 1431  *  0.08 *   1 *   0 *  +        1                                                                      +
 1542  *  0.00 *   0 *   0 *  +                                                                               +
 1661  *  0.00 *   0 *   0 *  +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+

Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.5 Scatter Graph of Inflow Velocity at the High Side Weir Site (Dobcroft Road)

```
Manhole number:  1                             LOG (FLOW)   LOG (DEPTH) GRAPH

DEPTH     FLOW    NO  S.DEV                                        FLOW (Litres/Sec)                                      AV VEL SAND
  MM       L/S       PERCENT  9.00      15.95     28.23     50.12     88.34     157.48    279.13    494.77    877.00         25%     75%

  40 *   5.45 ***** *  36 *   6:6:653:::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+    0.34    0.59
  43 *   6.08 ***** *  39 *   9 7 666 4 3                                                                               +    0.37    0.53
  46 *   7.27 ***** *  42 *   9 9 977 654211 1               1   1                                                      +    0.39    0.61
  50 *   8.93 ***** *  38 *   9 9 999 87643 1                                                                           +    0.42    0.67
  54 *  10.42 ***** *  36 *   9 9 999 998765332                                                                         +    0.42    0.67
  58 *  12.41 ***** *  36 *   9 9 999 99999877613                                                                       +    0.47    0.73
  63 *  15.31 *9395 *  32 *   7 7 889 9999998886543                                                                     +    0.54    0.76
  67 *  18.28 *9489 *  29 *   6 6 778 8899999999886431                                                                  +    0.60    0.83
  73 *  22.45 *8178 *  28 *   4 4 556 6888888899989998643                                                               +    0.66    0.89
  78 *  28.59 *5595 *  25 *   1 1   3 34567676778998998753                                                              +    0.79    1.00
  84 *  34.36 *3463 *  25 *   +    2   1 2 3345644687889998752                                                          +    0.87    1.04
  91 *  39.74 *1659 *  29 *   +    1    2       313454676788975                                                         +    0.91    1.07
  98 *  40.82 * 998 *  36 *   2 1 321 211     1222355555666677641                                                       +    0.76    1.06
 105 *  40.43 * 835 *  37 *   + 1 31    211 31342345477655556666641                                                     +    0.64    1.00
 114 *  47.03 * 242 *  29 *   1                1       24555553445554                                                   +    0.67    1.03
 122 *  54.73 *  67 *  37 *   +                        1  2133333344443                                                 +    0.75    1.02
 132 *  56.25 *  62 *  52 *   1      1 1      1        1 1   11324434433                                                +    0.77    0.96
 142 *  60.17 *  57 *  38 *   +             1   1 111         2133434443111                                             +    0.71    0.90
 153 *  50.50 *  68 *  51 *   +           1  2 2   2  1    2223244324331                                                +    0.52    0.74
 165 *  52.04 *  84 *  36 *   +           11   1   22   1 11234444343432                                                +    0.47    0.64
 178 *  51.34 *  81 *  29 *   +                1 121     2 333434444432                                                 +    0.41    0.55
 191 *  49.79 *  94 *  36 *   +             1  1    2   1  2444444414112                                                +    0.37    0.47
 206 *  51.95 *  99 *  43 *   1    1                   1112134444543311      1                                          +    0.35    0.44
 222 *  48.95 * 140 *  55 *   +               1 11 21 23223334454544331     1                                           +    0.30    0.39
 239 *  49.21 * 134 *  53 *   +             1   1  11 23334234444544313     1                                           +    0.27    0.35
 258 *  50.01 * 129 *  56 *   1      1            11 1 3 433335445444211    11                                          +    0.24    0.32
 278 *  47.33 * 146 *  61 *   +     1     1  1 11  212233233344455443 11 1                                              +    0.21    0.29
 299 *  52.42 * 147 *  48 *   1    111            2 121134333444455443 311 11                                           +    0.20    0.27
 322 *  52.03 * 199 *  78 *   + 2   11  1      1    21 3133324445554544333211                                           +    0.19    0.26
 347 *  52.01 * 242 *  79 *   1    2     111  1 1111  1 12344445565555443213211                                         +    0.17    0.23
 374 *  52.75 * 259 *  81 *   2     21  1    22 111221221342335553455544333211                                          +    0.16    0.22
 403 *  58.52 * 243 *  65 *   + 1 3    1   21    3 11 211312434455555554433311                                          +    0.15    0.21
 434 *  61.02 * 249 *  60 *   +   21    13  12 1   21122242333445545555544333 111                                       +    0.14    0.20
 468 *  66.60 * 270 *  56 *   +      2 1        2  1 113314433444455555555444313312                                     +    0.13    0.20
 504 *  67.58 * 257 *  56 *   1        1   1    1 1 2  3323334434545455544443332 11                                     +    0.12    0.19
 543 *  67.20 * 247 *  64 *   + 1 2      11  113   13 111   3343454455454553543333231 1                                 +    0.10    0.17
 585 *  70.76 * 294 *  56 *   +   11      1 1    2  1 1 32131434455555555544444233211 1                                 +    0.10    0.15
 630 *  75.83 * 278 *  59 *   +      1      1      31 13 33 3234444455555553444333333311    1                           +    0.10    0.15
 679 *  70.06 * 248 *  75 *   +        13       2  31    23 331444544445554444433332 1       1                          +    0.08    0.13
 732 *  76.59 * 238 *  80 *   +          3      11    2   132 342434444444454453433332221                               +    0.08    0.14
 788 *  78.85 * 234 *  69 *   3            22      31   111  331343533445545434434333 1112                              +    0.07    0.12
 849 *  84.06 * 209 *  72 *   + 3             2     2     23   4 15 44354445444442332331 21    1                        +    0.07    0.12
 915 *  84.39 * 256 *  71 *   + 2 3           32      41  13     43 442445455544344433343121      1                     +    0.07    0.11
 986 *  91.48 * 336 *  69 *   +   13             3      342  243 44  25445455435444444433331 2                          +    0.06    0.12
1062 * 112.76 *1642 *  79 *   +    16             35      35   45  56 56476675767666666665555443332     1               +    0.07    0.13
1144 * 181.48 *1053 *  82 *   +     4 3            4       3    43  41 5    5 5363636644666565555555555445433342   211  1    0.10    0.20
1233 * 684.35 *   3 *   3 *   +                                                                               -  12     +    0.49    0.51
1328 *   0.00 *   0 *   0 *   +                                                                                         +
1431 * 111.70 *   1 *   0 *   +                                                1                                        +    0.08    0.08
1542 *   0.00 *   0 *   0 *   +                                                                                         +
1661 *   0.00 *   0 *   0 *   +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+

Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.6 Scatter Graph of Inflow at the High Side Weir Site
(Dobcroft Road)

```
Manhole number:  2                                   LOG (MEASURED VELOCITY) / LOG (DEPTH) GRAPH

DEPTH    VEL    NO  S.DEV                                    VELOCITY (Metres/Sec)
 MM      M/S      PERCENT   0.05      0.08      0.11      0.17      0.26      0.39      0.59      0.88      1.32
  40  *  0.11 *  3 *  58 *  +:::::::1:+::::::1::+:::::::::+::::1::::+:::::::::+:::::::::+:::::::::+:::::::::+
  42  *  0.09 *  1 *   0 *  +             1                                                                 +
  45  *  0.18 *  6 * 128 *  +             1                   1         11       1                          +
  48  *  0.24 *  6 *  78 *  +                  1   1         1           1      1   1                       +
  51  *  0.26 * 10 * 129 *  +       1                                   1  111  2   2                       +
  54  *  0.41 * 13 *  32 *  +                              1                1  322 1 2  1                   +
  57  *  0.33 * 16 *  99 *  1       1                        1                 11332'1                      +
  61  *  0.32 * 19 * 124 *  +   1            1   1                       1     221  13 21  1                +
  65  *  0.44 * 14 *  90 *  1                                       1            1 1 1132111                +
  69  *  0.31 * 17 * 120 *  +          1           1 1         1            1    21 13111  1                +
  73  *  0.50 * 15 *  30 *  +                                          1 1    11  1  213  2 11              +
  78  *  0.37 * 14 * 112 *  +   1                1 1                     1  1     1 11 11 12  1             +
  82  *  0.44 * 16 *  77 *  +          1                1                  1    1 111221 2     1 1          +
  87  *  0.47 * 18 *  88 *  +          1  1                                    1  11   32111211             +
  93  *  0.51 * 15 *  59 *  +                1                                     2221 11111 11            +
  99  *  0.48 * 20 * 118 *  +                      1              1   1              1  32 12133            +
 105  *  0.40 * 18 * 132 *  1       1  1                                 1       1  2 12 2 21111            +
 111  *  0.53 * 17 *  88 *  1                                          1           1  12  2131 11           +
 118  *  0.33 * 15 * 122 *  +       1     1      1      1 1                1   1    1  1 122   1            +
 125  *  0.59 * 18 *  58 *  +                1                                 1       12123 113 1          +
 133  *  0.35 * 10 * 219 *  +                                                    1  1     2111  1           +
 142  *  0.33 *  7 * 141 *  1                                 1          1            11   1 1              +
 150  *  0.32 *  5 * 191 *  +   1                    1                                      1  2            +
 160  *  0.46 * 17 * 106 *  +             1    1                1   2 1                     2 331           +
 169  *  0.44 *  8 * 131 *  +       1                      1                            1  2   3            +
 180  *  0.30 *  3 *  87 *  +                           1            1                       1               +
 191  *  0.57 * 10 *  93 *  +                1                        1                    1  312 1         +
 203  *  0.48 * 14 * 116 *  +   1                    1                   1   1 1             1233           +
 216  *  0.59 *  9 *  50 *  +                                            2    1             1 13            +
 229  *  0.45 *  7 * 180 *  1                                1                                  23          +
 243  *  0.69 *  9 *  35 *  +                                                1  1            1 1311         +
 259  *  0.34 *  1 *   0 *  +                                              1                                +
 274  *  0.49 *  3 *  28 *  +                                                 1  1          1               +
 291  *  0.26 *  2 * 228 *  +          1                                                         1          +
 309  *  0.36 *  6 * 118 *  +          1                                  1 11                 1 1          +
 329  *  0.55 *  4 *  20 *  +                                                     1 1  1      1             +
 349  *  0.57 *  6 *  24 *  +                                                 1     1   1 1 1 1             +
 371  *  0.16 *  3 * 138 *  +             2                                            1                    +
 393  *  0.62 *  2 *  60 *  +                                                 1                      1      +
 418  *  0.00 *  0 *   0 *  +                                                                               +
 444  *  0.73 *  2 *  11 *  +                                                              1    1           +
 471  *  0.00 *  0 *   0 *  +                                                                               +
 501  *  0.91 *  2 *   4 *  +                                                                     1 1       +
 532  *  0.24 *  2 *  15 *  +                                  1      1                                     +
 565  *  0.25 *  2 * 393 *  1                                                                             1 +
 600  *  0.89 *  3 *  47 *  +                                                        1                   2  +
 637  *  0.15 *  3 * 395 *  +          1                                                                    1
 676  *  0.13 *  4 * 367 *  +                                    1                                        1 +
 718  *  0.04 *  2 *  15 *  +                                                                               +
 763  *  0.03 *  2 *   0 *  +                                                                               +
 810  *  0.03 *  1 *   0 *  +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+

Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.7 Scatter Graph of Spill Flow Velocity at the High Side Weir Site (Dobcroft Road)

```
Manhole number:  2                                   LOG (FLOW) / LOG (DEPTH) GRAPH

DEPTH    FLOW    NO  S.DEV                                   FLOW (Litres/Sec)                                       AV VEL BAND
 MM       L/S       PERCENT  7.00      12.34     21.77     38.40     67.71     119.42    210.60    371.41    655.00   25%    75%

 40 *    0.00 *  0 *   0 *  +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+
 42 *    0.00 *  0 *   0 *  +                                                                                         +
 45 *    3.54 *  3 *  27 *  +                                                                                         +  0.25   0.41
 48 *    4.89 *  3 *  18 *  +                                                                                         +  0.31   0.44
 51 *    4.91 *  8 *  15 *  +                                                                                         +  0.29   0.36
 54 *    5.73 * 13 *  25 *  2 1                                                                                       +  0.37   0.39
 57 *    6.48 * 14 *  25 *  4 1                                                                                       +  0.40   0.42
 61 *    7.96 * 15 *  21 *  3 2 3 2 1                                                                                 +  0.38   0.48
 65 *    9.42 * 13 *  24 *  + 1 2 3 3 1                                                                               +  0.43   0.53
 69 *    7.96 * 15 *  60 *  1   3 3 2 1 1                                                                             +  0.32   0.48
 73 *   11.10 * 15 *  33 *  1 1 1 1 1 3212 1                                                                          +  0.37   0.56
 78 *   10.37 * 13 *  81 *  1 1        2111 3 1                                                                       +  0.29   0.60
 82 *   12.87 * 15 *  46 *  +    1   2 1 31 2   2                                                                     +  0.39   0.56
 87 *   15.34 * 17 *  55 *  +          1111 23123                                                                     +  0.46   0.61
 93 *   16.52 * 15 *  62 *  +             1 31111121                                                                  +  0.47   0.62
 99 *   19.38 * 19 *  59 *  + 1 1             1 31 323                                                                +  0.53   0.66
105 *   17.41 * 17 *  97 *  +          1    1 22212 211                                                               +  0.46   0.60
111 *   25.90 * 16 *  27 *  +          1        1 3 23 311                                                            +  0.52   0.68
118 *   15.03 * 15 * 127 *  1 1             1  1  1 1122 1                                                            +  0.14   0.59
125 *   29.56 * 18 *  59 *  +                   1   123222121                                                         +  0.55   0.69
133 *   34.28 *  8 *  20 *  +                       1 1  212  1                                                       +  0.48   0.56
142 *   19.75 *  7 * 138 *  +          1        1       11  1 1                                                       +  0.19   0.59
150 *   21.28 *  5 * 194 *  +   1                               1 11                                                  +  0.12   0.74
160 *   33.26 * 17 * 108 *  + 1             1  21                 3331                                                +  0.26   0.72
169 *   34.28 *  8 * 124 *  +           1                      1  2 12                                                +  0.17   0.71
180 *   26.30 *  3 *  88 *  +          1          1                  1                                                +  0.15   0.56
191 *   52.16 * 10 *  95 *  +   1                    1                12311                                           +  0.65   0.74
203 *   48.96 * 14 * 116 *  +           1                1 1  1         1331                                          +  0.34   0.74
216 *   66.36 *  9 *  51 *  +                             11  1           1 31                                        +  0.36   0.77
229 *   54.40 *  7 * 183 *  +                     1                             3                                     +  0.18   0.80
243 *   91.64 *  9 *  36 *  +                                    1  1           2311                                  +  0.71   0.79
258 *   12.00 *  2 * 301 *  +                                    1                                                    +  0.02   0.32
274 *   78.77 *  3 *  30 *  +                                        1   1        1                                   +  0.37   0.63
291 *   44.25 *  2 * 220 *  +            1                                             1                              +  0.08   0.80
309 *   69.01 *  6 * 119 *  +             1                            111               11                           +  0.33   0.78
329 *  117.73 *  4 *  20 *  +                                                    2  1     1                           +  0.48   0.55
349 *   79.63 *  7 * 247 *  +                                                 1    1   1 111                          +  0.38   0.67
371 *   40.64 *  3 * 142 *  +                    2                                     1                              +  0.09   0.52
393 *  167.34 *  2 *  67 *  +                                                    1                   1                +  0.38   1.05
418 *    2.99 *  2 *   0 *  +                                                                                         +  0.01   0.01
444 *   66.44 *  3 * 455 *  +                                                                 1    1                  +  0.02   0.79
471 *    3.97 *  3 *  49 *  1                                                                                         +  0.01   0.02
501 *   12.97 *  8 * 566 *  1                                                                            11           +  0.01   0.02
532 *   16.03 *  5 * 329 *  + 1                                             1     1                                   +  0.01   0.21
565 *  103.62 *  2 * 404 *  +                    1                                                               1    +  0.05   1.24
600 *  400.59 *  3 *  45 *  +                                                                    1               2    +  0.53   1.17
637 *   44.88 *  4 * 415 *  +      1       1                    1                                                     1  0.02   0.09
676 *   27.32 *  8 * 313 *  +        3       2                                      1                                 1  0.02   0.03
718 *   20.00 *  2 *  15 *  +                 1    1                                                                  +  0.03   0.04
763 *   18.99 *  2 *   3 *  +                  11                                                                     +  0.03   0.03
810 *   19.44 *  1 *   0 *  +:::::::::+:::::::1:+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+  0.03   0.03

Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.8 Scatter Graph of Spill Flow at the High Side Weir Site
(Dobcroft Road)

```
Manhole number:  1                                LOG (MEASURED VELOCITY) / LOG (DEPTH) GRAPH

DEPTH      VEL    NO   S.DEV                                   VELOCITY (Metres/Sec)
  MM       M/S       PERCENT  0.05      0.09      0.15      0.25      0.43      0.73      1.24      2.12      3.63
   40 * 0.33 *7154 *  29 *   1:::::1::2+1:3:33:44+55667777778788999999886543:::+:::::::::+:::::::::+:::::::::+
   43 * 0.34 *7013 *  29 *   2     1    2 3 33 13 455667777787889999988776422 2     1    1                   +
   46 * 0.35 *7611 *  29 *   3  2         1 32 34 44556667778888989999877744111  1 1  1                      +
   49 * 0.36 ***** *  29 *   3  1  2  3 4 4 44 34 4455566877889899999998875332 1312    1           1         +
   53 * 0.37 *9306 *  29 *   2  1  3  2 2 3 43 43 3434566777688988899999876535132  12                        +
   57 * 0.38 ***** *  27 *   +  3  1  1 3 2 23 33 3345556777889899999999986532 1   1 11                      +
   61 * 0.38 ***** *  27 *   +  1  1  1 3 2 22 32 144546677787888999999998865423 1 1  1      1     1         1
   65 * 0.38 ***** *  26 *   +        1   2 32 33 4445566777878988999999987655412                            +
   70 * 0.37 *7972 *  26 *   +  1  1  2 1 2 33 33 33345667678787889999988765433                              +
   75 * 0.36 *6066 *  26 *   3  1     1 2 1  2 23 24445557667788889989987654421                              +
   80 * 0.35 *5877 *  25 *   +            1 21 21 333445566687988888889876543            1                   +
   86 * 0.35 *4243 *  27 *   2  1  3  1 1 1 23 12  334444666778888888888775441                               +
   92 * 0.34 *2827 *  24 *   +          1 1  1  1   33334666778777877777643 3   1                            +
   99 * 0.34 *2197 *  27 *   +              1   1 13 2344666768777777776532  112                             +
  106 * 0.34 *1579 *  26 *   +               1  2  2 12445557676776777776531 1                               +
  114 * 0.34 *1402 *  25 *   +          1   1      1 333455676777766777543 1 1 1    1  1                     +
  122 * 0.34 *1062 *  28 *   +                    1122333355566666666667643 1111      1 111                  +
  131 * 0.37 *1206 *  32 *   +                  1 13111234555756566667776654443133321     13                 +
  140 * 0.40 *1142 *  42 *   +                        3135567564565666766665555543312 23331                  +
  150 * 0.43 * 755 *  49 *   +                        21255565655555666565555554454333233311    1            +
  161 * 0.43 * 556 *  47 *   +                        1  44554546555555465554444431211 323432                +
  173 * 0.45 * 451 *  48 *   +                          24345443455555645555544323   21 3123133  2           +
  185 * 0.47 * 384 *  48 *   +                          324445455555554555455554331212 113 2 32  1           +
  199 * 0.46 * 279 *  50 *   +                           12254544444555444443444431111      13121            +
  213 * 0.50 * 204 *  67 *   +                            1 5454431144544333434333323 21322313  22           +
  228 * 0.51 * 210 *  69 *   +                             3345333233344444434333333233333 313232            +
  245 * 0.53 * 165 *  69 *   +                           2 13354323231444543344313113211113 2223211          +
  263 * 0.56 * 140 *  74 *   +                           1 1434344 213333433331433133131 11 132232           +
  281 * 0.63 * 130 *  74 *   +                              3133341 313443443323331 13 233 1132233  1        +
  302 * 0.73 *  77 *  71 *   +                                1 311   23444322  3     1 322333122111         +
  324 * 0.64 *  29 *  77 *   +                               11  22   2 32231  11  1      1   211   1        +
  347 * 0.76 *  17 * 113 *   +                              1  1  1121   11  1             11 1 121          +
  372 * 0.67 *  18 *  93 *   +                                2 111  1   113 1 1         1     2 11          +
  399 * 1.47 *   6 *  37 *   +                                                   1        11    111          +
  428 * 2.07 *   2 *   3 *   +                                                                   11          +
  458 * 0.00 *   0 *   0 *   +                                                                               +
  492 * 0.00 *   0 *   0 *   +                                                                               +
  527 * 0.00 *   0 *   0 *   +                                                                               +
  565 * 0.00 *   0 *   0 *   +                                                                               +
  606 * 0.00 *   0 *   0 *   +                                                                               +
  650 * 0.00 *   0 *   0 *   +                                                                               +
  696 * 0.00 *   0 *   0 *   +                                                                               +
  747 * 0.00 *   0 *   0 *   +                                                                               +
  801 * 0.00 *   0 *   0 *   +                                                                               +
  858 * 0.00 *   0 *   0 *   +                                                                               +
  920 * 0.00 *   0 *   0 *   +                                                                               +
  987 * 1.06 *   1 *   0 *   +                                                        1                      +
 1058 * 0.00 *   0 *   0 *   +                                                                               +
 1134 * 0.00 *   0 *   0 *   +                                                                               +
 1216 * 0.00 *   0 *   0 *   +                                                                               +
 1304 * 1.24 *   1 *   0 *   +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::1:+:::::::::+

Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.9 Scatter Graph of Inflow Velocity at the Low Side Weir Site (Retford Road)

```
Manhole number:  1                                       LOG (FLOW) / LOG (DEPTH) GRAPH

DEPTH    FLOW    NO  S.DEV                                     FLOW (Litres/Sec)                                  AV VEL BAND
  MM      L/S         PERCENT 9.00     16.09     28.78     51.46     92.03    164.56    294.27    526.22    941.00  25%     75%

   40 *   3.30 *5646 *  16 *  +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+    0.28    0.38
   43 *   3.65 *6268 *  20 *  1    1                                                                          +    0.26    0.35
   46 *   4.06 *7212 *  24 *  1 1  1                                                                          +    0.24    0.39
   49 *   4.63 ***** *  27 *  3 31  1           1                                                             +    0.28    0.37
   53 *   5.28 *9237 *  27 *  4 31  2 1                                                                       +    0.31    0.38
   57 *   5.91 ***** *  26 *  7 42    1 11                                                                    +    0.29    0.41
   61 *   6.56 ***** *  27 *  9 64 3  1   1     1      1       1                                              +    0.30    0.41
   65 *   7.38 ***** *  25 *  9 97 54 3                                                                       +    0.32    0.41
   70 *   8.08 *7957 *  24 *  9 98 75 42                                                                      +    0.30    0.39
   75 *   8.72 *6055 *  24 *  9 99 86 542                                                                     +    0.29    0.39
   80 *   9.53 *5874 *  24 *  9 99 98 7543          1                                                         +    0.28    0.38
   86 *  10.38 *4233 *  24 *  9 98 88 875332                                                                  +    0.28    0.38
   92 *  11.42 *2827 *  25 *  8 88 88 88754321  1                                                             +    0.28    0.39
   99 *  12.36 *2194 *  25 *  7 78 88 77776522 12                                                             +    0.26    0.37
  106 *  13.86 *1577 *  25 *  5 77 77 777776551   1                                                           +    0.27    0.38
  114 *  15.44 *1402 *  26 *  4 66 77 77767777311  1 1    1 1                                                 +    0.26    0.38
  122 *  17.45 *1062 *  28 *  3 45 66 76666667665311111 1      1 2 1                                          +    0.27    0.39
  131 *  20.97 *1206 *  33 *  3 23 56 66666667677665443232321     121                                         +    0.28    0.43
  140 *  24.88 *1142 *  41 *  +  2 23 56666556657577655555544313 3323                                         +    0.28    0.47
  150 *  29.70 * 755 *  49 *  +     1 34465556546566665555545533333333211   1                                 +    0.30    0.50
  161 *  32.54 * 556 *  47 *  +        1 355555565566555555444442212 2233332                                  +    0.31    0.51
  173 *  37.63 * 451 *  48 *  +          13335445455655555554554432  12 23232221 11                           +    0.33    0.51
  185 *  43.79 * 384 *  48 *  +             234344555555555545555441321 1123 132 1                            +    0.33    0.57
  199 *  48.07 * 279 *  49 *  +                333545443455454444444444 12 1    12321                         +    0.32    0.56
  213 *  57.53 * 204 *  67 *  +                  1 45533434444434343433423 213133221111                       +    0.30    0.65
  228 *  65.98 * 210 *  69 *  +                    133554423343444344424333332233 323131                      +    0.30    0.68
  245 *  74.97 * 165 *  68 *  +                     12344433231334443344322133 11212221321                    +    0.32    0.66
  263 *  88.14 * 140 *  73 *  +                      1 134433421333344233333323133 2 123233                   +    0.33    0.77
  281 * 107.47 * 130 *  74 *  +                          13 343312324344332233 111132311313331 1              +    0.41    0.79
  302 * 135.75 *  77 *  73 *  +                              2311  12443431  21   1 33 33333  3               +    0.48    1.21
  324 * 134.14 *  29 *  76 *  +                               1 1 22  1223222  11  1    1   12 1  1           +    0.44    0.77
  347 * 181.10 *  17 * 116 *  +                                1   11 13   11 1           2  1 121            +    0.40    1.78
  372 * 170.51 *  18 *  96 *  +                                   2 111  1  1 221 1        1    11 11         +    0.35    1.19
  399 * 409.06 *   6 *  38 *  +                                                      1       1 1    21        +    1.22    1.86
  428 * 663.95 *   2 *   6 *  +                                                                        1 1    +    1.99    2.23
  458 *   0.00 *   0 *   0 *  +                                                                               +
  492 *   0.00 *   0 *   0 *  +                                                                               +
  527 *   0.00 *   0 *   0 *  +                                                                               +
  565 *   0.00 *   0 *   0 *  +                                                                               +
  606 *   0.00 *   0 *   0 *  +                                                                               +
  650 *   0.00 *   0 *   0 *  +                                                                               +
  696 *   0.00 *   0 *   0 *  +                                                                               +
  747 *   0.00 *   0 *   0 *  +                                                                               +
  801 *   0.00 *   0 *   0 *  +                                                                               +
  858 *   0.00 *   0 *   0 *  +                                                                               +
  920 *   0.00 *   0 *   0 *  +                                                                               +
  987 * 790.43 *   1 *   0 *  +                                                                            1  +    1.04    1.07
 1058 *   0.00 *   0 *   0 *  +                                                                               +
 1134 *   0.00 *   0 *   0 *  +                                                                               +
 1216 *   0.00 *   0 *   0 *  +                                                                               +
 1304 * 941.00 *   1 *   0 *  +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::1    1.24    1.28

Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.10 Scatter Graph of Inflow at the Low Side Weir Site
(Retford Road)

```
Manhole number:  3                                   LOG (MEASURED VELOCITY) . LOG (DEPTH) GRAPH

DEPTH       VEL     NO  S.DEV                                    VELOCITY (Metres/Sec)
 MM         M/S         PERCENT   0.05      0.08      0.12      0.18      0.27      0.41      0.62      0.94      1.43
  40  *   0.19 *4769 *  54 *    5:::5:::5:*6::6::7:7*7:7:77:77*89888977776676655444444441:::*:::::::::*:::::::::*
  43  *   0.20 *4631 *  50 *     5    5    5  6  6  6 7 7 7 77 77 7898888877766766454443333431                      +
  46  *   0.20 *4595 *  49 *     5    5    5  6  6  6 6 7 7 77 77 77898888977776766553433323341                      +
  49  *   0.20 *4721 *  43 *     4    5    5  5  5  5 6 7 7 77 77 8788888889777776655323132333                       +
  52  *   0.22 *4652 *  39 *     4    4    4  5  5  5 5 6 6 77 77 778988898897777665534333212333                     +
  55  *   0.22 *6520 *  39 *     5    5    4  5  5  5 5 5 6 77 77 988888688886878776545412334 33                     +
  59  *   0.23 *4944 *  37 *     4    4    4  4  5  5 5 5 6 66 77 7778888989889786755335441 3 33                     +
  63  *   0.24 *8539 *  36 *     5    5    5  5  5  5 5 6 6 67 77 888889888999898776645443333 24 2                   +
  67  *   0.25 *7008 *  34 *     5    4    4  4  5  4 5 5 6 67 77 777888898898989776644333222233211                  +
  72  *   0.25 *8474 *  33 *     4    4    5  4  5  5 5 6 6 67 77 77788888999999888665544433332331                   +
  77  *   0.26 *7855 *  34 *     5    3    4  4  5  5 5 5 5 66 77 7789878889999999887755554443 1 2                   +
  82  *   0.26 *6774 *  34 *     4    4    4  4  4  4 4 5 5 56 67 77777788888899988776654434323321                   +
  87  *   0.27 *5894 *  37 *     5    4    4  5  4  4 5 4 5 55 56 67777789889889938877566544433 2                    +
  93  *   0.28 *5921 *  34 *     4    3    3  4  4  2 4 4 4 55 66 667777783868898887766655444413  1                  +
  99  *   0.28 *3866 *  39 *     3    4    3  3  4  3 4 4 5 55 55 56666777778889787766665555443 1                    +
 106  *   0.28 *3870 *  40 *     4    4    3  3  4  5 5 6 6 55 56 6667777777778878776665666345 1                     +
 113  *   0.29 *3089 *  39 *     1    1    3  1  2  3 3 5 5 55 56 666666677777787767666666655523 1                   +
 121  *   0.29 *2915 *  45 *     1    1    2  2  3  4 5 5 5 56 66 66666667777778776766666665656432                   +
 129  *   0.28 *2547 *  48 *     3    3    1  3  2  4 5 5 4 55 66 66666667777777676565666666656451                   +
 137  *   0.27 *2418 *  51 *     4    3    2  3  4  4 5 4 4 56 66 6666777767777766554666666566553431                 +
 146  *   0.27 *2417 *  51 *     3    2    3  1  4  5 5 5 5 55 66 6677776666777767565455666665545431                 +
 156  *   0.25 *2532 *  56 *     +    3    4  4  5  5 6 6 6 66 66 6666676667777766554554555556454 1                  +
 167  *   0.24 *2459 *  48 *     3    3    3  4  4  4 5 6 6 66 76 66667777777777665545554445553444 11                +
 178  *   0.24 *2573 *  49 *     4    4    4  3  4  4 5 5 6 66 66 667666777777776755454444344535431                  +
 190  *   0.23 *2956 *  49 *     2    3    3  4  4  5 5 6 6 77 77 767777777777667676656554544453533 3                +
 202  *   0.23 *3067 *  43 *     3    4    3  4  5  4 5 5 5 67 77 7777777777776676655565555443434 3131   1          +
 216  *   0.24 *3405 *  40 *     3    1    4  4  4  4 4 5 6 66 67 77777787777777665555445554433 3332   1 1          +
 231  *   0.25 *2742 *  43 *     4    4    3  4  3  4 4 4 5 56 55 66677777777767676655544545451 43411               +
 246  *   0.26 *2021 *  42 *     2    3    3  3  3  4 4 5 5 55 55 555567777777667666554555444444 2333 111       1    +
 262  *   0.26 *1832 *  46 *     1    1    1  3  4  4 4 5 5 56 66 6666555666777767565455555544422121121      1     +
 280  *   0.28 *1957 *  38 *     1            2  2  1 1 3 3 45 65 66666666667666767665555555544424 12 1  1 211      +
 299  *   0.30 *1505 *  38 *     1                  1 2 3 45 55 55656666566677665656655454 5534321  111  1       +
 319  *   0.34 * 766 *  42 *     +               1        22 22 234555565555656564544455555454443       111 1     +
 340  *   0.30 * 533 *  38 *     +                    1          2144556666555554544543134433313433 12 1  1111     +
 363  *   0.25 * 734 *  31 *     +                  1 2 33 55 55455666666555443433 1  343311 1 2    1   1        +
 387  *   0.29 * 597 *  24 *     +  1                 1   1   34445566666656443331 1   34133  1     1            +
 413  *   0.39 * 119 *  37 *     +                                   112233334444433 22     2 443   1 1  1      +
 441  *   0.65 *  13 *  28 *     +                                    1                 1 311111  11            +
 471  *   0.69 *   4 *  15 *     +                                                        2 1     1             +
 502  *   0.67 *   1 *   0 *     +                                                         1                    +
 536  *   0.90 *   2 *   4 *     +                                                              1 1             +
 572  *   0.88 *   3 *  14 *     +                                                           1     11           +
 610  *   0.92 *   5 *  16 *     +                                                            11   11    1      +
 651  *   1.21 *   2 *   9 *     +                                                                       1   1  +
 695  *   1.16 *   2 *   4 *     +                                                                       1 1    +
 741  *   0.00 *   0 *   0 *     +                                                                              +
 791  *   0.86 *   3 *  32 *     +                                                        1    1           1    +
 844  *   0.63 *   2 *   2 *     +                                                        11                    +
 900  *   0.00 *   0 *   0 *     +                                                                    _         +
 961  *   0.00 *   0 *   0 *     +                                                                              +
1025  *   1.43 *   1 *   0 *    +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::1

Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.11   Scatter Graph of Continuation Flow Velocity at the Low Side Weir
Site (Retford Road)

```
Manhole number:  3                           LOG (FLOW) : LOG (DEPTH) GRAPH

DEPTH     FLOW    NO  S.DEV                                    FLOW (Litres/Sec)                                        AV VEL BAND
  MM      L/S       PERCENT   5.00      8.91      15.88     28.31     50.45     89.91     160.24    285.59    509.00   25%    75%

  40 *   2.03 *2310 *  11 *   +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+   0.23   0.23
  43 *   2.09 *3201 *  15 *   +                                                                               +   0.20   0.21
  46 *   2.17 *3578 *  20 *   5                                                                               +   0.19   0.19
  49 *   2.35 *4014 *  24 *   5  3                                                                            +   0.17   0.25
  52 *   2.55 *4384 *  27 *   5  4                                                                            +   0.16   0.24
  55 *   2.88 *6288 *  29 *   7  4  4                                                                         +   0.21   0.22
  59 *   3.24 *4819 *  29 *   7  5  4 3                                                                       +   0.19   0.26
  63 *   3.65 *8352 *  28 *   9  7  5 3 4                                                                     +   0.18   0.24
  67 *   4.23 *6928 *  28 *   9  8  5 4 4 4 1                                                                 +   0.21   0.27
  72 *   4.77 *8394 *  28 *   9  9  8 5 5 3 3                                                                 +   0.20   0.23
  77 *   5.39 *7786 *  29 *   9  9  9 7 6 5 42 1                                                              +   0.22   0.27
  82 *   6.06 *6720 *  28 *   9  9  9 9 7 6 44 31                                                             +   0.21   0.29
  87 *   6.77 *5937 *  29 *   8  9  9 9 8 7 65 512                                                            +   0.22   0.29
  93 *   7.73 *5879 *  28 *   7  8  9 9 9 8 76 6541 1                                                         +   0.24   0.30
  99 *   8.76 *3836 *  32 *   6  7  8 9 9 9 97 6665421                                                        +   0.24   0.31
 106 *   9.39 *3863 *  40 *   6  7  8 8 8 9 98 776666531                                                      +   0.22   0.32
 113 *  10.80 *3082 *  38 *   6  7  7 7 8 8 88 8766666554 1                                                   +   0.23   0.34
 121 *  11.79 *2910 *  44 *   6  6  7 7 7 7 88 87776666665431                                                 +   0.23   0.34
 129 *  12.69 *2640 *  46 *   6  6  7 7 7 7 78 887666666756641                                                +   0.21   0.32
 137 *  13.32 *2417 *  51 *   5  5  6 7 7 7 77 78776656676665341                                              +   0.21   0.31
 146 *  14.76 *2417 *  52 *   5  6  5 6 7 7 77 777777665566765555532                                          +   0.20   0.32
 156 *  14.93 *2332 *  56 *   5  6  6 6 7 7 67 777777766655556565542                                          +   0.19   0.30
 167 *  15.77 *2459 *  49 *   4  5  5 6 6 7 77 777777777775565355555442                                       +   0.17   0.29
 178 *  17.71 *2373 *  49 *   4  4  4 5 6 6 76 677777777876654454455543                                       +   0.19   0.30
 190 *  18.66 *2856 *  50 *   4  4  4 5 6 6 77 7777777778667756655555451                                      +   0.18   0.29
 202 *  20.56 *3070 *  44 *   4  3  4 5 5 5 56 77777777787777666655555544432  1                               +   0.18   0.29
 216 *  22.75 *3410 *  42 *   3  2  4 4 4 4 45 666777777877887766554555541343  1 1                            +   0.20   0.28
 231 *  26.50 *2749 *  48 *   4  4  3 4 3 4 44 555555666777887777665554545444 1                               +   0.21   0.30
 246 *  30.28 *2024 *  45 *   3  2  3 3 3 3 34 45455555555677787777666454545332 11     1                      +   0.23   0.31
 262 *  33.31 *1833 *  47 *   3  1    1 1 3 43 4354555666555665777776765555554331131  1                       +   0.21   0.32
 280 *  38.83 *1958 *  38 *   1     1       22 1 1313345655676777777776655565544311 11111                     +   0.23   0.33
 299 *  44.83 *1508 *  42 *   +       1            1132354555556666777766666655555432 111 1                   +   0.24   0.35
 319 *  56.23 * 766 *  43 *   + 1                 1    21131315454666656555555666555531  1 2 1                 +   0.26   0.46
 340 *  55.17 * 533 *  37 *   +                         1     2 445667565554553344424432112 121               +   0.25   0.35
 363 *  51.21 * 734 *  31 *   +                          1233455555666765554431134323 12   1  1               +   0.23   0.29
 387 *  62.48 * 598 *  28 *   +                1            1  1  3445666665555443  24232 1    1              +   0.26   0.32
 413 *  89.61 * 119 *  37 *   +                                       222444454433   12341  2  1              +   0.32   0.43
 441 * 164.38 *  13 *  29 *   +                                             1           133 2 11              +   0.64   0.75
 471 * 190.58 *   4 *  15 *   +                                                           2 1   1             +   0.64   0.74
 502 * 201.91 *   1 *   0 *   +                                                               1               +   0.70   0.72
 536 * 285.59 *   2 *   6 *   +                                                                   1 1         +   0.88   0.99
 572 * 302.58 *   3 *  13 *   +                                                                  1   11       +   0.80   1.04
 610 * 331.90 *   5 *  18 *   +                                                                   11  11   1  +   0.83   1.07
 651 * 466.74 *   2 *   9 *   +                                                                            1  1   1.21   1.44
 695 * 415.79 *   2 *   3 *   +                                                                          11   +   1.13   1.20
 741 *   0.00 *   0 *   0 *   +                                                                               +
 791 * 308.47 *   3 *  33 *   +                                                                1   1       1  +   0.64   1.25
 844 * 220.20 *   2 *   3 *   +                                                               11    -         +   0.60   0.63
 900 *   0.00 *   0 *   0 *   +                                                                               +
 961 *   0.00 *   0 *   0 *   +                                                                               +
1025 * 509.00 *   1 *   0 *   +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::1   1.40   1.44

Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.12 Scatter Graph of Continuation Flow at the Low Side Weir Site (Retford Road)

```
Manhole number:  2                               LOG (MEASURED VELOCITY) / LOG (DEPTH) GRAPH

DEPTH     VEL     NO  S.DEV                                     VELOCITY (Metres/Sec)
  MM      M/S       PERCENT  0.05      0.08      0.14      0.23      0.37      0.62      1.03      1.70      2.81
  40  *  0.34 *  76 *  12 *  +:::::::::+:::::::::+:::::::::+:::::::::+::1::::::+::14554431:::1:::::+:::::::::+
  42  *  0.85 *  43 *   8 *  +                                                  1 344442                     +
  45  *  0.84 *  74 *  10 *  +                                                 1132345543 1                  +
  48  *  0.83 *  70 *  18 *  +                               1                  121345543                    +
  51  *  0.93 *  49 *   8 *  +                                                   31235431                    +
  54  *  0.83 *  88 *   7 *  +                                                   13445532                    +
  57  *  0.93 *  61 *  13 *  +                                        1          21445441                    +
  60  *  0.83 *  53 *  11 *  +                                                    3345411   11               +
  64  *  0.80 *  68 *  20 *  +                              1                  1333444431  1                 +
  68  *  0.85 *  47 *  12 *  +                                                   21344423 2 2                +
  72  *  0.92 *  73 *  17 *  +                                               1312324444313 121               +
  76  *  0.93 *  86 *  28 *  +                           1  1                 12212345543233 1               +
  81  *  0.85 *  76 *  15 *  +                                                  2134454323311 2              +
  85  *  0.83 *  73 *  14 *  +                                             1 1  13344543233                  +
  90  *  0.87 *  87 *  13 *  +                                                  13334544422131               +
  96  *  0.86 *  86 *  15 *  +                                           1   1  1 2445444223 1               +
 102  *  0.92 *  67 *  13 *  +                                                  1  1344441242                +
 108  *  0.81 *  59 *  76 *  +                  1                              2 112344433123    1           +
 114  *  0.88 *  67 *  52 *  +      1               1                          121 3144443 3311 11           +
 121  *  1.00 *  31 *  15 *  +                                                     1113243 2211 1            +
 128  *  0.97 *  26 *  16 *  +                                                    1 3232322231               +
 136  *  0.45 *  25 * 376 *  +                                                    1 212321 322               +
 144  *  0.30 *  17 * 153 *  +                                                      131122 23                +
 153  *  1.09 *  19 *  15 *  +                                                     1   123222211             +
 162  *  0.41 *  23 * 335 *  +         2  1                        1                   2 213 211             +
 172  *  0.25 *  35 * 300 *  1   2  3 1  2 2 31              1          1            1 123 132111            +
 182  *  0.43 *  46 * 153 *  3            1        1111 2 11 11 311 121 1 1  111 11     131332 1             +
 193  *  0.75 *  53 *  53 *  +                                   12   2 12 3 31333312 1 1 2333222            +
 205  *  0.90 *  47 *  26 *  +                                                  2333343111 21232             +
 217  *  1.00 *  34 *  23 *  +                                                     11433   123131            +
 230  *  1.00 *  39 *  22 *  +                                                     1344313 2 2331            +
 244  *  0.99 *  26 *  16 *  +                                                      223233111 2 1            +
 258  *  0.98 *   9 *  21 *  +                                                      13  21    11             +
 274  *  1.15 *   6 *  27 *  +                                                        12       111           +
 290  *  1.21 *   7 *  22 *  +                                                         2      221            +
 308  *  1.12 *   9 *  23 *  +                                                       112    1  3             +
 325  *  1.16 *   6 *  21 *  +                                                         111   1 1 1           +
 346  *  1.19 *  10 *  22 *  +                                                         122    2 2 1          +
 367  *  1.37 *   3 *  23 *  +                                                           1      1  1         +
 389  *  1.41 *   7 *  16 *  +                                                             111  1 21         +
 412  *  1.44 *   3 *  14 *  +                                                              1    11          +
 437  *  1.55 *   4 *   9 *  +                                                                 1 2  1        +
 463  *  1.61 *   3 *   7 *  +                                                                  1  2         +
 491  *  1.72 *   4 *   7 *  +                                                                   1  3        +
 520  *  2.18 *   2 *  29 *  +                                                                     1         1
 551  *  0.00 *   0 *   0 *  +                                                                               +
 584  *  2.08 *   1 *   0 *  +                                                                         1     +
 620  *  0.00 *   0 *   0 *  +                                                                               +
 657  *  0.00 *   0 *   0 *  +                                                                               +
 696  *  0.00 *   0 *   0 *  +                                                                               +
 738  *  2.81 *   1 *   0 *  +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::1

Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.13 Scatter Graph of Spill Flow Velocity at the Low Side Weir Site (Retford Road)

```
Manhole number:  2                                        LOG (FLOW) / LOG (DEPTH) GRAPH

DEPTH    FLOW   NO  S.DEV                                    FLOW (Litres/Sec)                                         AV VEL RANG
 MM       L/S       PERCENT  3.00     5.35     9.55    17.04    30.40    54.23    96.76   172.63   309.00             25%    75%

  40 *   4.37 *  76 *  17 *  +::::6:::5+::::1::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+   0.63   0.79
  42 *   4.98 *  43 *  11 *  +    4  5  2                                                            +   0.73   0.75
  45 *   5.43 *  74 *  12 *  +    3  5  5  1                                                         +   0.67   0.80
  48 *   5.72 *  70 *  18 *  +       4  6  4                                                         +   0.71   0.74
  51 *   6.44 *  49 *  12 *  +       3  5  5 1                                                       +   0.66   0.79
  54 *   7.15 *  88 *  10 *  +          4  6 5 1                                                     +   0.72   0.75
  57 *   7.79 *  61 *  12 *  +    1        5 5 4                                                     +   0.68   0.77
  60 *   8.49 *  53 *  12 *  +             3 5 5 2  11                                               +   0.70   0.79
  64 *   8.90 *  68 *  18 *  1             3 4 5 43 1                                                +   0.66   0.79
  68 *  10.49 *  47 *  14 *  +              1 4 54 3  22                                             +   0.73   0.79
  72 *  10.98 *  73 *  18 *  +             1 3 3 45 52 322                                           +   0.69   0.81
  76 *  12.19 *  86 *  28 *  1    1         1 2 34 45 43332                                          +   0.68   0.82
  81 *  13.73 *  76 *  16 *  +                  4 45 54331111                                        +   0.71   0.84
  85 *  14.53 *  73 *  15 *  +                1 11 34 554332                                         +   0.74   0.83
  90 *  16.61 *  87 *  14 *  +                    13 3554442321                                      +   0.75   0.87
  96 *  18.15 *  36 *  15 *  +                  1  1  14445444212                                    +   0.76   0.87
 102 *  20.98 *  67 *  14 *  +                        1 2444432412                                   +   0.79   0.93
 108 *  21.56 *  58 *  35 *  1                        11 3235433132  1                               +   0.79   0.90
 114 *  23.56 *  67 *  51 *  +    1                    111114434334311  1                            +   0.79   1.00
 121 *  29.78 *  31 *  15 *  +                             1 133343311 1                             +   0.89   1.04
 129 *  31.36 *  26 *  17 *  +                              1 314131231                              +   0.85   1.10
 136 *  16.96 *  25 * 315 *  +                                111333  33                             +   0.74   1.11
 144 *  30.19 *  17 * 137 *  +                                 1 3122 32                             +   0.83   1.10
 153 *  44.62 *  19 *  16 *  +                                  1  1 3322311                         +   0.98   1.18
 162 *  18.61 *  23 * 333 *  +   3                     1             1113322 1                       +   0.09   1.14
 172 *  11.68 *  35 * 332 *  3   3   3 1           1       1         1  3213111!                     +   0.06   1.08
 182 *   2.55 * 153 * 355 *  3       1      2 2 21 11 131 2 211 1  121  1   2232311                  +   0.02   0.17
 193 *  43.16 *  53 *  54 *  +                          12  11 2131223333111 2213 311                +   0.57   1.17
 205 *  55.93 *  47 *  26 *  +                                       3323343111223 1                 +   0.77   1.09
 217 *  66.75 *  34 *  24 *  +                                          14431  32232                 +   0.85   1.25
 230 *  71.69 *  39 *  22 *  +                                            343131 2333                +   0.86   1.25
 244 *  77.79 *  26 *  17 *  +                                             1232332 12 1              +   0.90   1.09
 258 *  81.86 *   9 *  22 *  +                                               3  21    2              +   0.85   1.08
 274 * 103.52 *   6 *  26 *  +                                                 1 2     111           +   0.98   1.49
 290 * 117.03 *   7 *  22 *  +                                                   2     113           +   0.96   1.49
 308 * 114.37 *   9 *  22 *  +                                                   112   1 31          +   0.98   1.42
 326 * 126.77 *   6 *  23 *  +                                                    1 2   1 1 1        +   1.05   1.51
 346 * 136.16 *  10 *  21 *  +                                                     1 31    22 1      +   1.03   1.51
 367 * 159.81 *   3 *  22 *  +                                                        1     1 1      +   1.13   1.74
 389 * 156.32 *   7 *  18 *  +                                                         21 1  21      +   1.20   1.67
 412 * 156.75 *   3 *  10 *  +                                                         1  11         +   1.26   1.54
 437 * 167.71 *   4 *   9 *  +                                                           12  1       +   1.43   1.52
 463 * 176.00 *   3 *   6 *  +                                                            1 2        +   1.50   1.67
 491 * 188.29 *   4 *   5 *  +                                                             1 3       +   1.61   1.77
 520 * 237.36 *   2 *  30 *  +                                                              1        1   1.66   2.79
 551 *   0.00 *   0 *   0 *  +                                                                       +
 584 * 230.59 *   1 *   0 *  +                                                                 1     +   2.06   2.12
 620 *   0.00 *   0 *   0 *  +                                                                       +
 657 *   0.00 *   0 *   0 *  +                                                                       +
 696 *   0.00 *   0 *   0 *  +                                                                       +
 738 * 308.00 *   1 *   0 *  +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::!   2.75   2.53

Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.14 Scatter Graph of Spill Flow at the Low Side Weir Site (Retford Road)

```
Manhole number:  1                          LOG (MEASURED VELOCITY)    LOG (DEPTH) GRAPH

DEPTH      VEL     NO  S.DEV                                        VELOCITY (Metres/Sec)
 MM        M/S         PERCENT   0.05       0.08       0.13       0.21       0.34       0.55       0.88       1.42       2.29
 40  *    0.48 ***** *  75 *     5:::5::5::5:5:5:5:6:6:666:66677777877878788798898988808868888887766653 1::::::::+
 42  *    0.51 ***** *  87 *     5   5  6  6 5 5 5 5 5 555 55666666766777778978388839883888888888776665332        +
 45  *    0.53 ***** *  80 *     5   4  5  5 5 5 5 5 5 555 566566666767767677878883889888888888888777664411         +
 47  *    0.53 ***** *  90 *     6   6  6  6 6 6 6 6 6 666 666666767777787883798889898999998898888887765 3          +
 50  *    0.50 ***** * 104 *     6   6  6  6 6 6 6 6 7 777 7777777787787878887888987889999889888888877651 11        +
 53  *    0.53 *9139 * 103 *     5   5  5  5 5 5 5 5 5 666 666677667667676777677787878888888388877766653          +
 55  *    0.51 ***** * 117 *     6   6  6  6 6 6 6 6 6 667 77777777777777786878988889888888889899888877654         +
 59  *    0.52 ***** * 111 *     6   6  6  6 6 6 6 6 5 655 66666666766777677768779838783898988888877777765421      +
 62  *    0.55 *8562 * 105 *     6   6  6  6 6 6 6 6 6 656 5555555666666767776777787898888888888887776766554 1     +
 65  *    0.58 *9749 *  92 *     5   6  6  6 6 6 6 6 6 665 55554555666767677768777888788888888838777777666553      +
 69  *    0.56 *6553 * 105 *     5   5  6  6 6 6 6 6 6 665 5555545565565656066777787877778878878777766666655 3     +
 73  *    0.64 *5595 *  99 *     5   5  5  5 6 5 5 5 5 554 4344344444354656676766677877777777878877777666555 31    +
 77  *    0.69 *4931 * 106 *     5   5  5  5 5 5 5 5 5 554 55434232341435466657666667677777778788778777665563 2    +
 81  *    0.72 *2862 * 128 *     5   5  5  4 5 3 4 4 4 444 4443433321 2 21333 535455656677767777777777766544 54    +
 86  *    0.70 *2567 * 141 *     5   5  5  6 5 5 5 5 5 555 4443423431  22   3  113344455677677777777677665454 1    +
 91  *    0.71 *1480 * 144 *     1   3  4  4 5 5 5 5 5 555 544445434231 21     2  31    13556666676666666653454     +
 96  *    0.87 *  765 * 118 *    +   3  2  3 3 3 3 2 4 444 4443333332113 1      1113 1 1111344555556666666664231    +
101  *    1.19 *  466 *  64 *    +         1 1 2 1   3   1 2121  111 11   1      1   1  12 2 113455565566664431    +
107  *    1.16 *  482 *  82 *    +      1    1 1 1 1 1 111  231333131 13111  11             1 11334445565666543 31 +
113  *    1.24 *  317 *  77 *    +                          311211 312111 2      1        1  2 3 33455666543 21   +
119  *    1.08 *  271 * 140 *    1   1       1 2 3 3 3 231 2 2 1                 1  1   11     11 2132334456665 32 +
126  *    0.48 *  383 * 244 *    2   1  3  2 4 4 4 5 5 544 54431 3 2   1    1          1  1   11131333444565532 1 +
133  *    0.20 *  429 * 351 *    5   4  3  4 4 4 4 4 4 444 444343 331     1      1 11       11 31 223 13344455431  +
140  *    0.24 *  314 * 436 *    5   5  4  4 3 3 3 3 2 431 2 21 32                 1    1 2    123321 13313345554 3 +
148  *    0.17 *  293 * 412 *    5   5  5  4 4 3 3   1 11          1               11 1 1 11233 23 23  1222334554 31 +
156  *    0.10 *  321 * 432 *    5   4  4  4 4 1 2 2 3                              1 1212 31323121322 2 133132345431 +
165  *    0.13 *  272 * 519 *    5   3  3  1 1     1     1    1          31111111222 3 31 32 2 11 312 1233444541  +
174  *    0.24 *  181 * 408 *    3   4  3  3 2 2   2 1 21    1  111 1   1332213 32213 3 31 1 1113 212113  34441  +
184  *    0.58 *  112 * 195 *    3   2  3  2 1        1  11    1    1211 2211332323 223213 23 1    1  31111 3443 1 +
194  *    0.69 *  119 * 157 *    +         1   1   2 113    1 1  212333323 13312311  231 2 1  1  11 1211344431 +
205  *    0.82 *  127 * 162 *    +            2   1    2    3    1 2 2223133213123223 11 22        2  3   1  335543 +
217  *    0.58 *  110 * 223 *    +   1  1     2 1   2 1  11 22211231322121113 31 12  2211  1     1          1 1 33444421+
229  *    0.57 *  144 * 212 *    1         1 1 3 2 3 1 131 33 133 3321312 33112  11 2 11 12     3 1   1 21 3344433 +
242  *    0.56 *  134 * 229 *    2   3  2  1 2 2 1 2   133 313 322 1 1313 232 12  1 1    21213  11 11        34543321+
255  *    0.47 *  170 * 247 *    2   3  3  3   3 3 2 3 232 333123223312 2 11211122212  1 3 33 213   2212 334443431+
270  *    0.41 *  335 * 210 *    3   4  4  3 3 3 3 4 4 331 33343343323432343112113334333343434343331412343434344 31+
285  *    0.30 *  648 * 177 *    4   4  4  4 5 4 4 5 4 344 443454445455454454454444341443343433443332332343444433+
301  *    0.19 *1263 * 156 *    5   6  6  5 5 5 6 6 5 565 55555555655545455545555444444433344344333122322213441 1+
318  *    0.18 *  660 * 152 *    4   5  5  5 5 5 5 5 4 555 5545443444454434543443333331231232 14122 12131113133 +
335  *    0.31 *   73 * 209 *    +   3  1  1 3 2 3 1 3 333  1 3 2 221   1 23  1111111  1      11     212112      11 311
354  *    1.51 *   13 *  63 *    +                                   1                              1  11111      311
374  *    1.72 *    2 *  10 *    +                                                                        1   1    +
395  *    0.00 *    0 *   0 *    +                                                                                 +
417  *    2.18 *    4 *   3 *    +                                                                               121
441  *    0.00 *    0 *   0 *    +                                                                                 +
465  *    2.07 *    7 *  10 *    +                                                                           1 1 131
491  *    0.00 *    0 *   0 *    +                                                                                 +
519  *    2.18 *    1 *   0 *    +                                                                                1+
548  *    0.00 *    0 *   0 *    +                                                                                 +
579  *    1.94 *    2 *  13 *    +                                                                           1    1+
611  *    2.18 *    1 *   0 *    +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+::::::::1+

Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.15 Scattergraph of Inflow Velocity at the High Side Weir (Leyburn Road)

```
Manhole number:  1                                  LOG (FLOW) / LOG (DEPTH) GRAPH

DEPTH     FLOW    NO  S.DEV                              FLOW (Litres/Sec)                                AV VEL BAND
 MM        L/S       PERCENT 10.00     17.84     31.81     56.74    101.19    180.48    321.90    574.13   1024.00  25%   75%

  40 *    4.88 ***** *  42 *  7:66:2::::*:::::::::*:::::::::*:::::::::*:::::::::*:::::::::*:::::::::*:::::::::*  0.39  0.61
  42 *    5.63 *9671 *  44 *  8 76 531                                                                        *  0.38  0.68
  45 *    6.11 ***** *  47 *  9 87 6531                                                                       *  0.41  0.63
  47 *    6.81 ***** *  49 *  9 99 87652                                                                      *  0.40  0.71
  50 *    7.46 ***** *  55 *  9 99 9887641 1                                                                  *  0.42  0.73
  53 *    8.13 *8427 *  62 *  9 99 89876653                                                                   *  0.39  0.78
  55 *    8.81 ***** *  65 *  9 99 99988876652                                                                *  0.38  0.84
  59 *    9.74 *9508 *  62 *  9 98 88888877775431                                                             *  0.40  0.80
  62 *   11.18 *7936 *  57 *  9 88 898888877765642                                                            *  0.46  0.80
  65 *   12.10 *9277 *  58 *  9 99 8998888787676553                                                           *  0.44  0.81
  69 *   12.96 *6141 *  66 *  8 88 88888887787676566641                                                       *  0.45  0.81
  73 *   15.85 *5326 *  61 *  7 88 88877777787787666554                                                       *  0.49  0.93
  77 *   18.72 *4720 *  64 *  7 77 7777777778778977765653                                                     *  0.57  1.01
  81 *   22.65 *2686 *  58 *  3 55 556667777877877777765454                                                   *  0.63  1.04
  86 *   22.93 *2427 *  97 *  1 31 1343556667677877777755553                                                  *  0.71  1.08
  91 *   22.96 *1453 * 132 *  3     222   1355666677767666644521                                              *  0.73  1.17
  96 *   29.84 * 760 * 113 *  3 11   3211 12 34545666666665332                                                *  0.89  1.26
 101 *   43.55 * 465 *  59 *  1 21     1 1  21 2 24455666666543                                               *  1.07  1.37
 107 *   45.84 * 481 *  77 *  3 13 21 11        111234456666665331                                            *  1.11  1.41
 113 *   54.92 * 314 *  58 *  2 23 311   1         1 23334555665431                                           *  1.20  1.45
 119 *   52.97 * 267 * 117 *  *           11   11   1 3133445666541                                           *  1.26  1.52
 126 *   25.03 * 378 * 236 *  4 33 2 1  1         11  113133444565432                                         *  0.13  1.46
 133 *   18.11 * 343 * 270 *  5 44 231  1    111    11 3 223133445554                                         *  0.10  1.42
 140 *   24.22 * 251 * 340 *  2 21 31          1  1 11  3133 11333445552                                      *  0.08  1.55
 148 *   13.83 * 264 * 375 *  1        1       1 11 1113222212312222244553 1                                  *  0.04  1.41
 156 *   15.41 * 208 * 381 *  *                 11 23 33233113121 331334543                                   *  0.04  1.33
 165 *   27.81 * 171 * 392 *  *  1    1     2132 21232123213 2 11311 13335542                                 *  0.05  1.59
 174 *   31.65 * 149 * 299 *  3  3   1  1 2 1 1422322323223 22 1112321132 4543                                *  0.09  1.54
 184 *   51.89 * 112 * 197 *  *  1  11 1   22113 233343 31321231    13111134431                               *  0.35  1.62
 194 *   69.47 * 118 * 142 *  * 1  2132   11 32233332333331 32111 11  11112334432                             *  0.33  1.70
 205 *   85.69 * 127 * 162 *  1 11   11 21  1 13 3233313332113113   1121  1 34554                             *  0.37  1.79
 217 *   68.32 * 109 * 210 *  2 1  111 1111332 33 3 22123112 2112 1  1    11 3444321                          *  0.24  1.70
 229 *   70.15 * 144 * 209 *  1 12 132  22323113133131313321 111 21  21  3 1 1 3 344543                       *  0.23  1.63
 242 *   74.67 * 134 * 228 *  * 12  3 11 133312233  1232232121 1 1  12213 11 11   3454432                     *  0.19  1.65
 255 *   68.44 * 170 * 246 *  3 31  133123113 332 33233121121122321 122132222 32 23344443                     *  0.17  1.62
 270 *   64.80 * 335 * 209 *  3 42 32323333333 3324344314334322231334433434433333433444434432                 *  0.18  1.01
 285 *   51.09 * 648 * 177 *  4  4 3344433444334534454435555545454444431444344344433333343444431              *  0.16  0.57
 301 *   35.76 *1263 * 154 *  * 64 5454555556545655555655655555555555554444434444443332313224331              *  0.10  0.36
 318 *   35.07 * 660 * 152 *  4 44 45455354453355454555444454454544444323323323 3323 1331132231               *  0.09  0.31
 335 *   64.51 *  73 * 210 *  *  2 2 1 1 3 221 31133 11312121   231 12 211 1   1 1   3132    2 13 1           *  0.13  0.80
 354 *  339.56 *  13 *  63 *  *                                  1                    1 11111   312           *  1.29  2.01
 374 *  429.90 *   2 *   6 *  *                                                               1 1             *  1.62  1.82
 395 *    0.00 *   0 *   0 *  *                                                                               *
 417 *  626.19 *   4 *   3 *  *                                                                      22       *  2.11  2.23
 441 *    0.00 *   0 *   0 *  *                                                                               *
 465 *  677.34 *   7 *   9 *  *                                                                     11 13     *  1.8c  2.19
 491 *    0.00 *   0 *   0 *  *                                                                               *
 519 *  860.62 *   1 *   0 *  *                                                                            1  *  2.23  2.30
 548 *    0.00 *   0 *   0 *  *                                                                               *  -
 579 *  860.82 *   2 *  12 *  *                                                                          1   1*  1.77  2.23
 611 * 1024.00 *   1 *   0 *  *:::::::::*:::::::::*:::::::::*:::::::::*:::::::::*:::::::::*:::::::::*:::::::::1  2.19  2.26

Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.16 Scattergraph of Inflow at the High Side Weir (Leyburn Road)

```
Manhole number:  3                               LOG (MEASURED VELOCITY) / LOG (DEPTH) GRAPH

DEPTH    VEL   NO  S.DEV                                      VELOCITY (Metres/Sec)
 MM      M/S       PERCENT  0.05      0.07      0.10      0.15      0.22      0.32      0.46      0.67      0.97
  40 *  0.00 *   0 *   0 *   +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+
  43 *  0.06 *  31 *  48 *   3    4   3   3  3  2 1  2                                                       +
  46 *  0.06 *  12 *  75 *   2    3       1  1                1 1                                            +
  50 *  0.16 *   4 *  14 *   +                         1    2    1                                           +
  54 *  0.19 *   2 *   2 *   +                                  11                                           +
  58 *  0.23 *   1 *   0 *   +                                        1                                      +
  63 *  0.23 *   2 *   2 *   +                                        11                                     +
  68 *  0.38 *  12 *  23 *   +                                         1  1       1 212 211                  +
  73 *  0.43 * 218 *  11 *   +                                              1   1343545455553                +
  79 *  0.46 * 358 *  11 *   +                                                1  1335455566666431            +
  85 *  0.49 * 752 *  10 *   +                                                  13 344556667766533           +
  91 *  0.52 * 825 *  10 *   +                                                    1132545668776666543        +
  98 *  0.51 *1121 *  16 *   +                                               1 1333465656666767766542        +
 106 *  0.45 *2499 *  44 *   3    3   4   3  3  3 3  3 2  23 1 111        1243355666767688788657765522       +
 114 *  0.38 *3791 *  85 *   5    5   5   5  5  4 4  5 5 4 45 5 555 55555555555555665767788788777666643      +
 123 *  0.44 *18660 *  69 *  6    6   6   6  5  5 5  5 5 5 55 5 555 5555555555555666667677878798998877542    +
 133 *  0.39 ***** * 103 *   6    7   6   6  6  7 6  6 6 6 66 6 666 66666666666666767777788789899999877644   +
 143 *  0.43 ***** * 105 *   7    7   6   6  6  6 6  6 6 6 66 6 666 66666666666566656565777878999999837643 2 +
 154 *  0.42 ***** * 107 *   7    6   6   6  6  6 6  6 6 6 66 6 666 66666777666667667676776676879999887421   +
 166 *  0.54 ***** *  78 *   6    6   5   5  4  5 5  5 5 5 55 5 555 55555555555565655656677677689999988937641+
 179 *  0.56 *6392 *  53 *   5    3   4   3  3  3 3  2 3 3 33 3 133 233344433444554455657767767899997777653  +
 193 *  0.54 *1382 *  81 *   4    3   2   1  3  1 3  3 2 1  2 1 121  22 1112 1233333434455454564567787764332 +
 208 *  0.34 * 316 * 177 *   3    4   3   3  1  2 3  3 3 1  3 3 123  11 11 2 1113323311333 242454355555333   +
 224 *  0.35 * 294 * 171 *   3    3   3   3  2  3 3  2 3 2 13 1  22 11 2  11  11 31123213233413555555543431  +
 242 *  0.38 * 269 * 129 *   1    3   2   3  3  1 3  1   1 31 2  33 2 211132 112321 32 23334444655344422   1 +
 261 *  0.36 * 278 * 142 *   4    3   3   1  3  1    2   1 1  1 121 1 232 33 221 11 323 343455564332433    1 +
 281 *  0.33 * 186 * 147 *   3    2       2  2  3 2  1 3      1 322 22111131 32  11 1 232444444544443431 1   1
 303 *  0.29 * 219 * 147 *   3    2   3   1  3  3 2  2 3  33 3  323 33   2 2  2131  113234345445434 12 11    +
 326 *  0.28 * 167 * 175 *   4    3   3      2  3    3 3 3 21 2 11 2 1      1  2   1 12 1234434544311  11    +
 352 *  0.23 * 120 * 155 *   3    2   3   2  3  2 1  3 3 3 32 2 332 12       221 21 3 314313333333  121 1    +
 379 *  0.23 * 138 * 158 *   2    1   4   3  2  3 1  4 2 2 31 3 321 122  1 12   131232221  34334333112 1     +
 409 *  0.25 * 179 * 157 *   4    3   3      1  3 2  1 1 3 33 4 322 323212 1 13  222332  21 33453323131      +
 440 *  0.25 * 224 * 176 *   4    4   3   3  3  3 3  1 2 2 42   433 13221 111   33   113234 3334554443311    +
 475 *  0.25 * 252 * 150 *   4    4   3   3  4  4 2  3 2 3  2   3   33213323123334334332343342344443323 1    +
 512 *  0.27 * 257 * 131 *   3    3   3   4  3  2 3  3 4 1 33 4 431 32   3 12332343451311334424424441122     +
 552 *  0.22 * 177 * 191 *   3    3   3      2  3 3  3 3 3 33 3 332 1132 21  31 1111413 21 11 1333444333     +
 594 *  0.22 * 168 * 164 *   2    3   3   1  3  3 3  3 4 3 21 3 23  312 2 13331213213121   22  3444433312    +
 641 *  0.16 * 173 * 171 *   3    4   4   5  4  4 4  4 3 3 12 1 2       2   3331332 2 1 21  32332 1333321    +
 691 *  0.26 * 106 * 194 *   3    3   3   2  3    2   2 1 12 2  3     21  2 211 1111211 3   211311333433     +
 744 *  0.30 *  86 * 183 *   1    1       2     2 2  1  1 11 2'111   111 1    111    1 113 131233324343      +
 802 *  0.26 *  37 * 152 *   +    1   3   1     1        1       11 11 1    11     11 111 331      321       +
 865 *  0.09 *  16 * 210 *   +        2   1                       1                 1       1      1         +
 932 *  0.20 *   5 * 182 *   +                                      11          1                  1         +
1005 *  0.20 *   3 * 288 *   +                                                      1              1         +
1083 *  0.22 *   7 * 160 *   +                    1  1                           1      1 1         1        +
1167 *  0.26 *  12 * 124 *   1    1             1                           1     2 211      1 1             +
1256 *  0.23 *   7 * 119 *   1                              1   1      1   1                   11            +
1356 *  0.27 *   7 *  60 *   +                              2        1  2                  1  1              +
1462 *  0.53 *   2 *   2 *   +                                                              11               +
1575 *  0.41 *   2 *   6 *   +                                                      1  1                     +
1698 *  0.31 *   4 *  13 *   +:::::::::+:::::::::+:::::::::+:::::::::+::::1::11+:::1:::::+:::::::::+:::::::::+

Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.17 Scattergraph of Continuation Flow Velocity at the High Side Weir (Leyburn Road)

```
Manhole number:  3                                LOG (FLOW) / LOG (DEPTH) GRAPH

DEPTH    FLOW    NO  S.DEV                                FLOW (Litres/Sec)                                 AV VEL RANG
  MM      L/S       PERCENT 1.00      1.76      3.09      5.43      9.54     16.76     29.45     51.78     91.00  25%   75%

  40 +   0.00 +    0 +   0 +  +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+::::::::::+
  43 +   1.00 +    8 +   0 +  4                                                                                +  0.14  0.14
  46 +   1.00 +    4 +   0 +  3                                                                                +  0.13  0.13
  50 +   1.18 +    4 +  34 +  3           1                                                                    +  0.11  0.12
  54 +   1.97 +    2 +   0 +  +           2                                                                    +  0.20  0.20
  58 +   1.97 +    1 +   0 +  +           1                                                                    +  0.18  0.18
  63 +   2.40 +    2 +  22 +  +           1      1                                                             +  0.16  0.24
  68 +   4.94 +   12 +  28 +  +                  2         3  3                                                +  0.37  0.44
  73 +   6.07 +  218 +  14 +  +                        3   6  7  6                                             +  0.35  0.45
  79 +   7.26 +  358 +  12 +  +                            3  6  7 7 4                                         +  0.42  0.47
  85 +   8.61 +  752 +  11 +  +                               4  6 7 8 6 4                                     +  0.43  0.49
  91 +  10.21 +  825 +  12 +  +                                  3 5 7 8 765 1                                 +  0.45  0.54
  98 +  11.19 + 1121 +  15 +  +                                  3 5 7 7 877 641                               +  0.44  0.53
 106 +  10.95 + 2508 +  46 +  5           5      4     3   3     4 6 7 8 888 7765                              +  0.40  0.49
 114 +  10.05 + 3848 +  96 +  7           7      6     6   6  6  6 6 7 7 888 9876654                           +  0.36  0.51
 123 +  12.61 + 8605 +  85 +  8           7      7     6   6  6  6 6 7 7 788 9999987652                        +  0.44  0.52
 133 +  12.50 +++++++ 124 +  8           8      8     7   7  7  7 7 7 8 788 88999999997631                    +  0.33  0.58
 143 +  15.15 +++++++ 132 +  9           8      7     7   7  7  7 7 7 7 777 6677899999997741                  +  0.44  0.61
 154 +  16.55 +++++++ 131 +  8           8      7     7   7  7  7 7 7 7 877 77777777779999998632              +  0.29  0.63
 166 +  23.21 +++++++ 115 +  8           7      6     5   6  6  6 6 6 6 666 66666667787999989984              +  0.55  0.66
 179 +  22.96 + 6860 + 156 +  8           6      5     4   4  3  4 4 3 3 445 4455555668787999997531            +  0.53  0.65
 193 +  17.62 + 1649 + 293 +  8           5      4     3   3  3  3 3 2 3  23 131133444556566673875431          +  0.43  0.67
 208 +   7.85 +  473 + 431 +  7           5      4     4   4  2  4 3 2 3 323 2 12 3332423333455565442          +  0.02  0.65
 224 +  11.04 +  392 + 413 +  7           4      4     4   3  3  4 3 3 2 222 311111  23 333234445565441        +  0.01  0.66
 242 +  17.45 +  319 + 310 +  6           5      3     2   3  3  3 3 1 1 232 233 21133333223334445655331 1     +  0.10  0.62
 261 +  18.87 +  325 + 306 +  5           5      4     4   3  3  3 2 1 2   2 1113 1232333 21133455664334211    +  0.09  0.58
 281 +  14.93 +  239 + 382 +  6           4      4     3   3  2  1 2 3 2  13   113133 2133212 1 334455444411   1  0.03  0.59
 303 +  20.56 +  247 + 267 +  5           4      4     4   3  2  3 1 3 3 223  33333323 1111321 1334555553221111+  0.11  0.58
 326 +  23.31 +  183 + 265 +  3           4      4     3   3  3  3 3 2 1 3 3 332111 212    1  2 1 12244455421 2+  0.07  0.61
 352 +  14.71 +  148 + 338 +  5           4      3     1   3  3  2 3 2 2 121 333322123311     32 31333334414 221  0.05  0.51
 379 +  18.42 +  156 + 275 +  4           3      3     4      2  1 4 1 3 313 3311333 2213   1123233321344343212+  0.07  0.54
 409 +  12.72 +  239 + 392 +  6           5      4     4   4     3 3   1 321 133 34322333 21113342 314554342   +  0.02  0.54
 440 +  19.40 +  251 + 300 +  5           3      4     3   4     4 3 3 3 331 224 2 433323 12   4211343344554411+  0.07  0.58
 475 +  21.24 +  277 + 243 +  4           4      4     2   4     4 3 3 4 423 23  2 3  323  33244444334343453331+  0.09  0.51
 512 +  23.86 +  278 + 216 +  4           4      3     3   3     3 3 4 3 233 413 344313    33334454334544354332+  0.12  0.52
 552 +  17.71 +  198 + 296 +  4           4      4     4   3     3 3   2 333 333 33332232 3 31214233  113345443+  0.05  0.62
 594 +  13.76 +  207 + 335 +  5           4      4     3   2     3 3 1 3 333 432 1323 322 133333333   22 3444321  0.04  0.50
 641 +  13.49 +  190 + 245 +  4           3      4     4   3     4 4 5 4 444 331 212     2  333332 13 2333334421  0.07  0.34
 691 +  23.42 +  113 + 265 +  3           3      4     3   3     3 3 2 3  2  211 22 3  21  222 213231  32333443+  0.03  0.65
 744 +  16.37 +  113 + 390 +  4           4      4     3   1     1   2   221  11 12111111 1 11    112333333443 +  0.03  0.62
 802 +  13.52 +   48 + 387 +  4           2            3         1 3 1    1    1     112 1  2    1112 33   23  +  0.04  0.50
 865 +   6.14 +   21 + 248 +  1           3      3     3            2 1               1           1    2    1  +  0.03  0.08
 932 +  21.49 +    5 + 197 +  +                  1                                      2       1            1 +  0.21  0.34
1005 +   9.95 +    4 + 513 +  1                  1                                                 1         1 +  0.01  0.41
1083 +  23.90 +    7 + 165 +  +                         1                  11                   1    11      1 +  0.11  0.46
1167 +  12.83 +   16 + 371 +  3           1                 1     1       1                  1   2 31  1  1    +  0.02  0.40
1258 +  18.24 +    8 + 210 +  +           1                 1                     1 1     1  1            2    +  0.05  0.29
1356 +  28.99 +    7 +  59 +  +                                                   2     1 2            1 1     +  0.16  0.49
1462 +  57.96 +    2 +   0 +  +                                                                         2      +  0.52  0.53
1575 +  44.97 +    2 +   3 +  +                                                                    11          +  0.40  0.42
1693 +  34.41 +    4 +  13 +  +:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:1:1::::1+::::::::::+  0.27  0.32

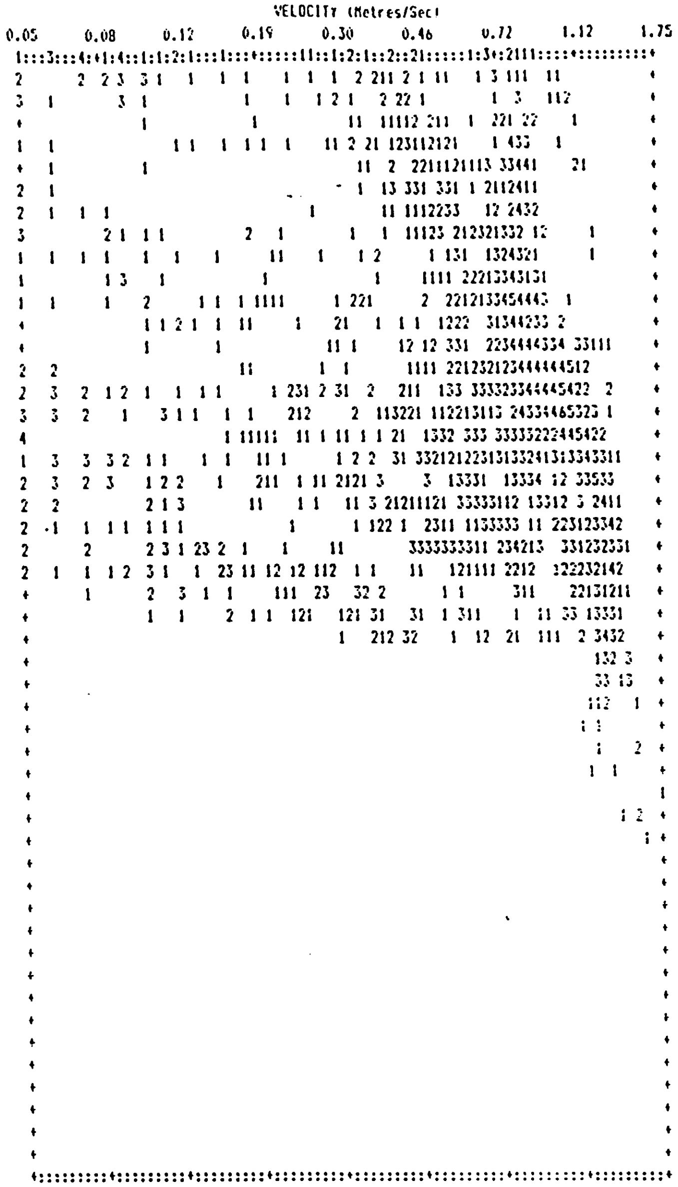
Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.18 Scattergraph of Continuation Flow at the High Side Weir (Leyburn Road)

Manhole number: 7

LOG (MEASURED VELOCITY) / LOG (DEPTH) GRAPH

DEPTH MM	VEL M/S	NO	S.DEV PERCENT
40	0.14	54	208
43	0.19	45	220
47	0.14	47	310
50	0.23	34	316
54	0.29	55	245
58	0.35	63	275
63	0.29	49	266
68	0.26	54	287
73	0.22	64	301
79	0.20	56	320
85	0.45	51	162
92	0.49	90	150
99	0.43	73	196
107	0.65	100	129
115	0.44	133	293
125	0.38	169	279
134	0.47	186	248
145	0.33	159	343
156	0.24	147	356
169	0.35	125	294
182	0.48	94	177
196	0.57	80	161
212	0.49	107	150
228	0.36	77	231
246	0.44	49	142
266	0.56	51	112
287	0.83	43	67
309	1.33	11	6
333	1.32	11	6
360	1.29	5	9
388	1.17	2	5
418	1.47	3	11
451	1.25	2	7
487	1.75	1	0
525	1.49	3	4
566	1.60	1	0
611	0.00	0	0
657	0.00	0	0
711	0.00	0	0
767	0.00	0	0
827	0.00	0	0
892	0.00	0	0
962	0.00	0	0
1038	0.00	0	0
1120	0.00	0	0
1208	0.00	0	0
1303	0.00	0	0
1406	0.00	0	0
1516	0.00	0	0
1635	0.00	0	0
1764	0.04	1	0



Each number used represents a number of reads: 1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.

Appendix 1.19 Scattergraph of Spill Flow Velocity at the High Side Weir (Leyburn Road)

```
Manhole number:  2                                               LOG (FLOW) / LOG (DEPTH) GRAPH

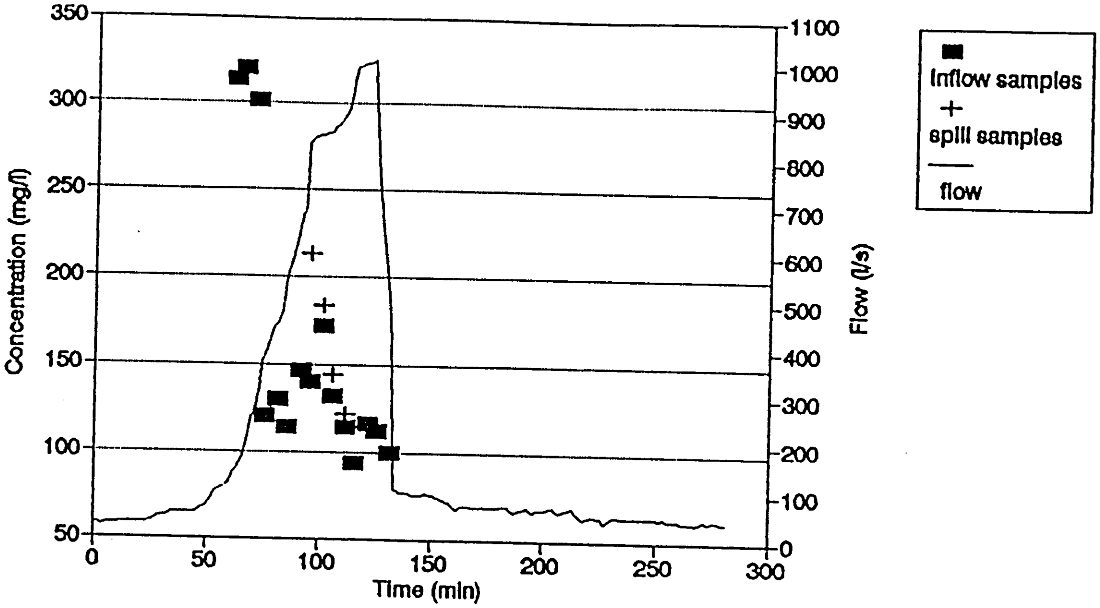
DEPTH     FLOW    NO  S.DEV                                       FLOW (Litres/Sec)                                       AV VEL BAND
  MM       L/S         PERCENT  6.00      10.76      19.30      34.63      62.11      111.41     199.85     358.47     643.00  25%    75%

  40 +    4.14 +  20 +  57 +  3::3:1:::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+  0.31   0.64
  43 +    4.66 +  24 +  62 +  1  3 3 1 1                                                                        +  0.29   0.68
  47 +    5.45 +  23 +  68 +  +    3 2 21 1                                                                     +  0.25   0.73
  50 +    6.63 +  24 +  51 +  3    2 3 22  1                                                                    +  0.38   0.69
  54 +    6.58 +  45 +  72 +  4  3 1   34 3  1                                                                  +  0.34   0.71
  58 +   10.15 +  50 +  45 +  2  3 3 3 23 44 2 12                                                               +  0.49   0.76
  63 +   10.20 +  37 +  36 +  3  3 3 3 22 32 331                                                                +  0.43   0.76
  68 +   11.43 +  38 +  51 +  +  1 2 3 34  1 23431                                                              +  0.48   0.76
  73 +   10.39 +  45 + 102 +  +  1 1 1 23  3 3332212    1                                                       +  0.43   0.68
  79 +   11.36 +  39 + 117 +  +  1 1 2     3 1113334      1                                                     +  0.31   0.75
  85 +   14.89 +  47 + 104 +  1        1   2 1122235323                                                         +  0.55   0.72
  92 +   17.05 +  86 +  96 +  3  1    2 13    11 321334543211                                                   +  0.52   0.76
  99 +   19.44 +  65 +  88 +  2       1 3   1 1 1 21311344333 2                                                 +  0.51   0.77
 107 +   28.64 +  96 +  62 +  1          2 1     31 3332 34444333333                                            +  0.67   0.90
 115 +   30.25 + 114 +  99 +  +  1 1       11     111113232234543543                                            +  0.71   0.95
 125 +   25.29 + 151 + 161 +  1  2     13 23 123  13  2311344434445411 2                                        +  0.40   0.93
 134 +   29.92 + 176 + 174 +  3  1   2    22 1 11 1321213 333333434555332                                       +  0.47   0.98
 145 +   27.76 + 142 + 230 +  +        31 2   22  11112 113314233334244543 1                                    +  0.34   1.02
 156 +   22.95 + 129 + 256 +  4    1   11  1 1 1   22 113133323331333323443211                                  +  0.09   0.91
 169 +   30.40 + 118 + 241 +  3  1 2 2  1     1211 21113 12  21131321133413 34533                               +  0.19   1.10
 182 +   40.42 +  94 + 175 +  +    2 1 3      11  1 1  1211213212333433 2333 33431                              +  0.37   0.95
 196 +   53.63 +  80 + 159 +  +  2   2 1  1         1       11221  23  34233 2213323421                         +  0.48   1.09
 212 +   50.61 + 107 + 152 +  +  1 1   22 22 131 1  1       11     333433131333113323 43                        +  0.41   0.85
 228 +   42.02 +  77 + 237 +  2  1 1 1 23 2    11231  213 211 11     2 11221 131 11232432                       +  0.15   1.09
 246 +   57.21 +  49 + 142 +  +       1     1 122 1 1     12 231123 2     1 1  1221   23333                     +  0.24   1.10
 266 +   81.96 +  51 + 114 +  +               1  1   2  11  112 1 3121 22 1 131  1 1 332 334                    +  0.31   1.16
 287 +  136.23 +  43 +  66 +  +                                     1 122 13   112 12  12 114431                +  0.46   1.27
 309 +  241.96 +  11 +   8 +  +                                                                33 21            +  1.24   1.43
 333 +  263.42 +  11 +   9 +  +                                                                113231           +  1.23   1.40
 360 +  280.46 +   5 +  11 +  +                                                                  121  1         +  1.17   1.28
 388 +  292.17 +   2 +   9 +  +                                                                   1  1          +  1.08   1.29
 418 +  330.04 +   3 +  13 +  +                                                                      1   11     +  1.19   1.55
 451 +  380.04 +   2 +  12 +  +                                                                       1   1     +  1.13   1.43
 487 +  606.51 +   1 +   0 +  +                                                                                1+  1.82   1.87
 525 +  158.20 +   4 + 738 +  +                                                                             111 +  0.01   1.55
 566 +  643.00 +   1 +   0 +  +                                                                                 1  1.62   1.67
 611 +    0.00 +   0 +   0 +  +                                                                                 +
 659 +    0.00 +   0 +   0 +  +                                                                                 +
 711 +    0.00 +   0 +   0 +  +                                                                                 +
 767 +    0.00 +   0 +   0 +  +                                                                                 +
 827 +    0.00 +   0 +   0 +  +                                                                                 +
 892 +    0.00 +   0 +   0 +  +                                                                                 +
 962 +    0.00 +   0 +   0 +  +                                                                                 +
1038 +    0.00 +   0 +   0 +  +                                                                                 +
1120 +    0.00 +   0 +   0 +  +                                                                                 +
1208 +    0.00 +   0 +   0 +  +                                                                                 +
1303 +    0.00 +   0 +   0 +  +                                                                                 +
1406 +    0.00 +   0 +   0 +  +                                                                                 +
1516 +    0.00 +   0 +   0 +  +                                                                                 +
1635 +    0.00 +   0 +   0 +  +                                                                                 +
1764 +   20.47 +   1 +   0 +  +:::::::::+:::::::::+1::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+:::::::::+  0.04   0.04

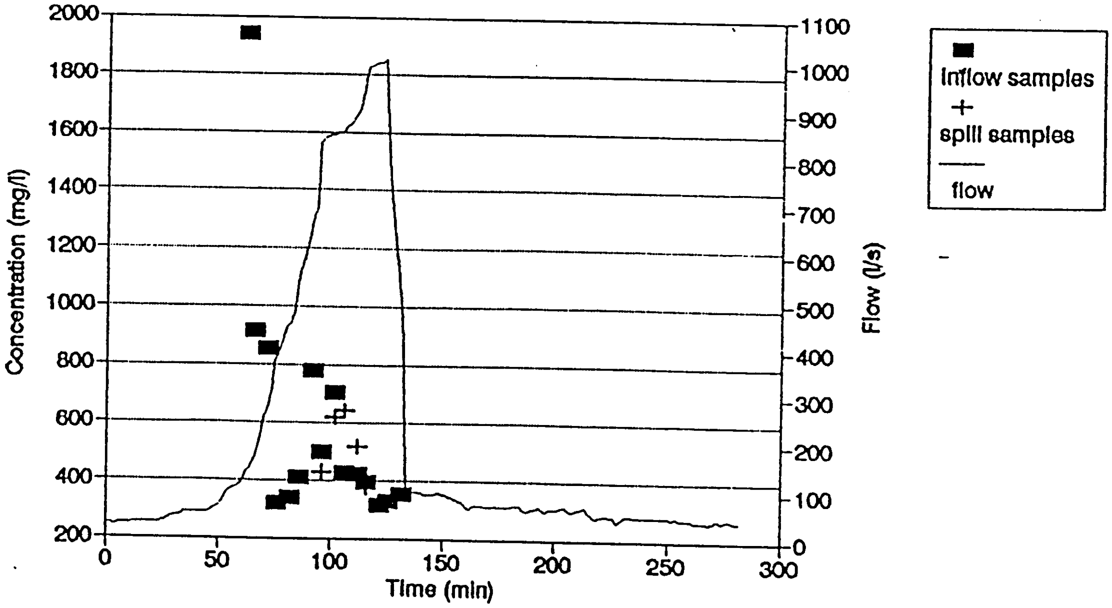
Each number used represents a number of reads:  1=1, 2=2, 3=3-6, 4=7-15, 5=16-39, 6=40-97, 7=98-244, 8=245-610, 9=611+ reads.
```

Appendix 1.20 Scattergraph of Spill Flow at the High Side Weir (Leyburn Road)

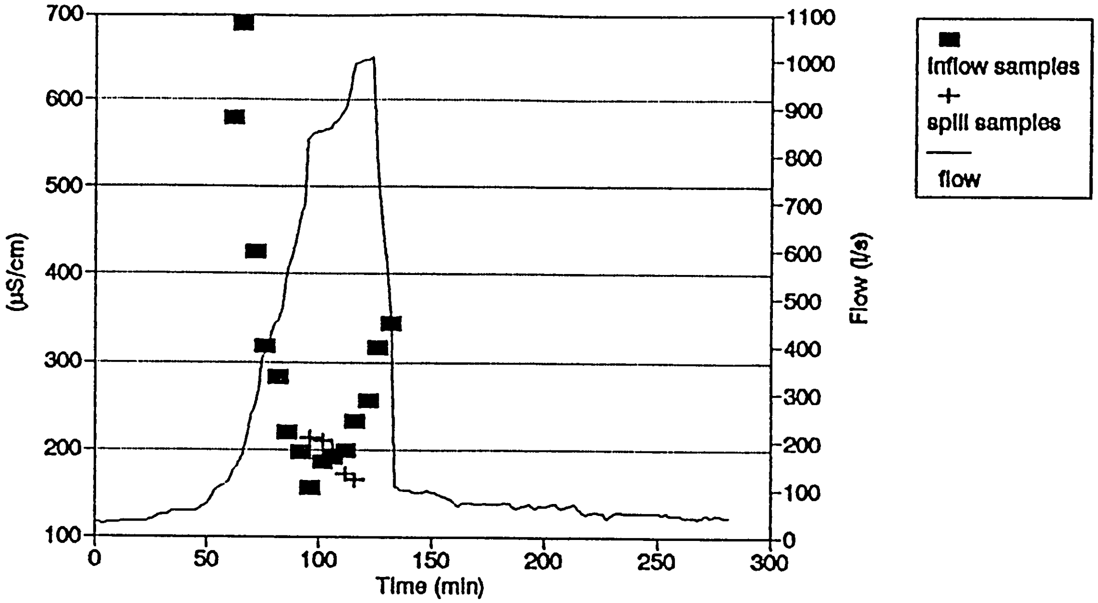
APPENDIX TWO: GRAPHS OF SAMPLE CONCENTRTION AND INFLOW



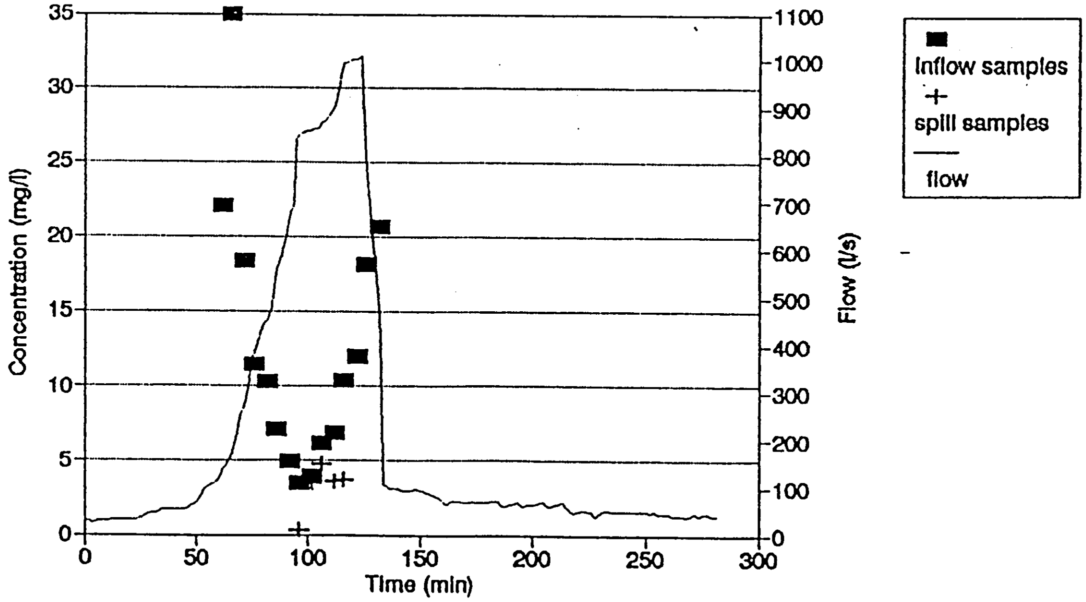
Chesterfield Road 3 October 1990
BOD



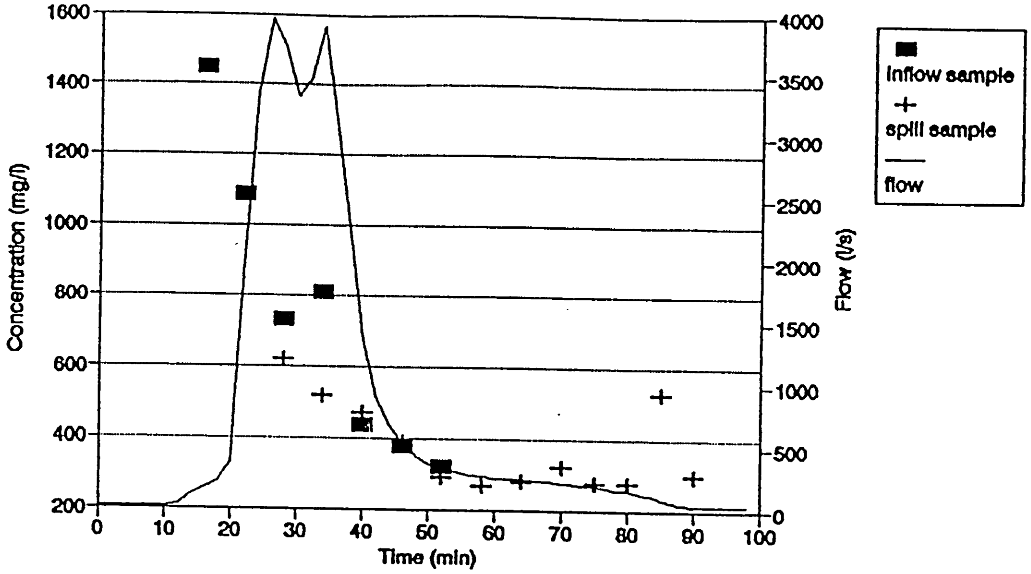
Chesterfield Road 3 October 1990
Suspended Solids



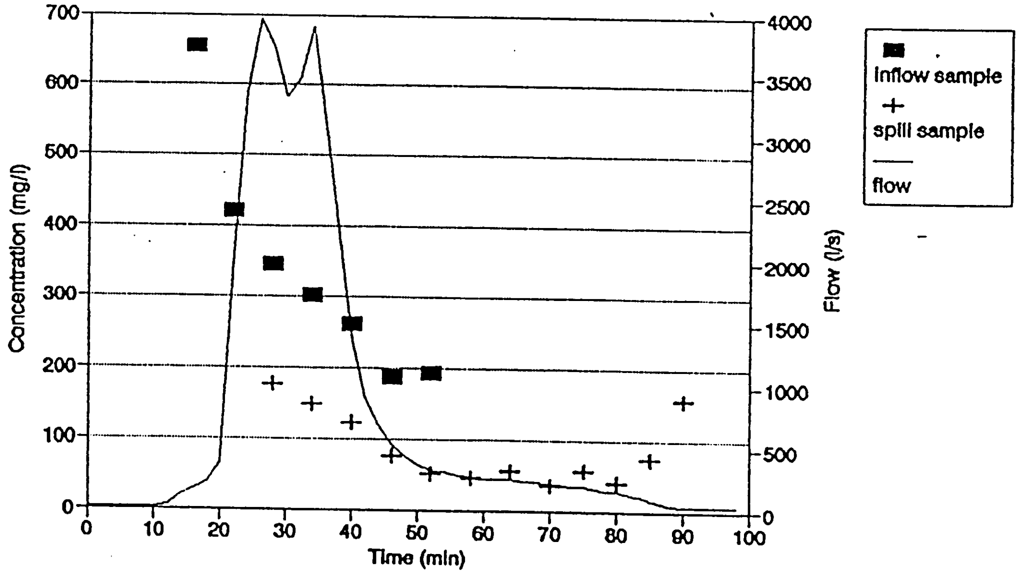
Chesterfield Road 3 October 1990
Conductivity



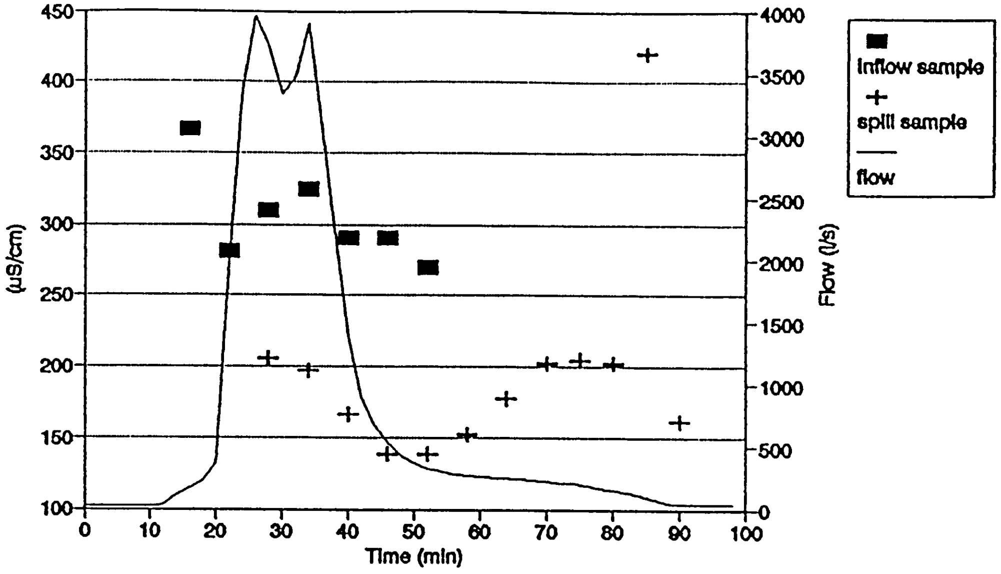
Chesterfield Road 3 October 1990
Ammonia



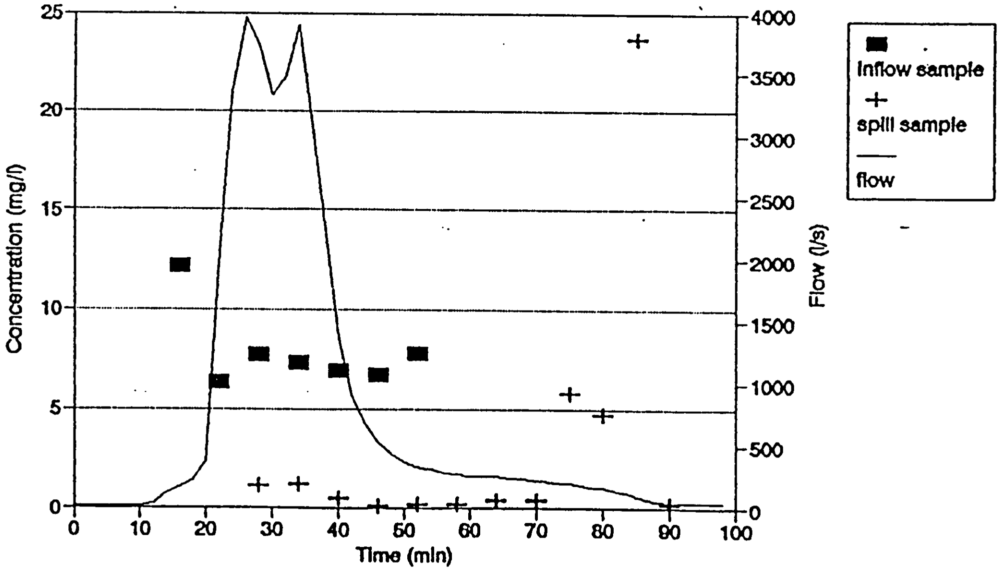
Chesterfield Road 15 October 1990
Suspended Solids



Chesterfield Road 15 October 1990
BOD



Chesterfield Road 15 October 1990
Conductivity



Chesterfield Road 15 October 1990
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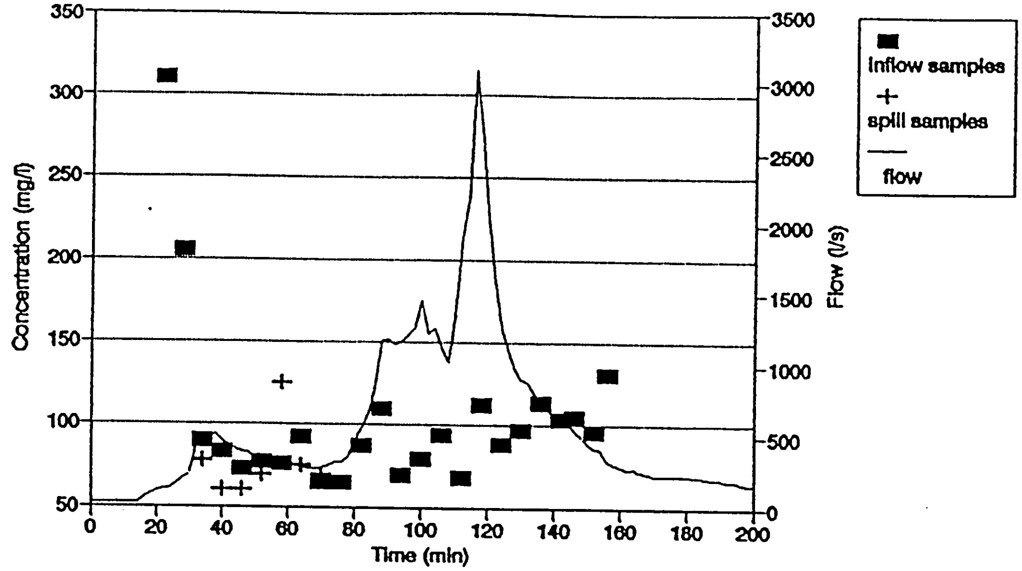
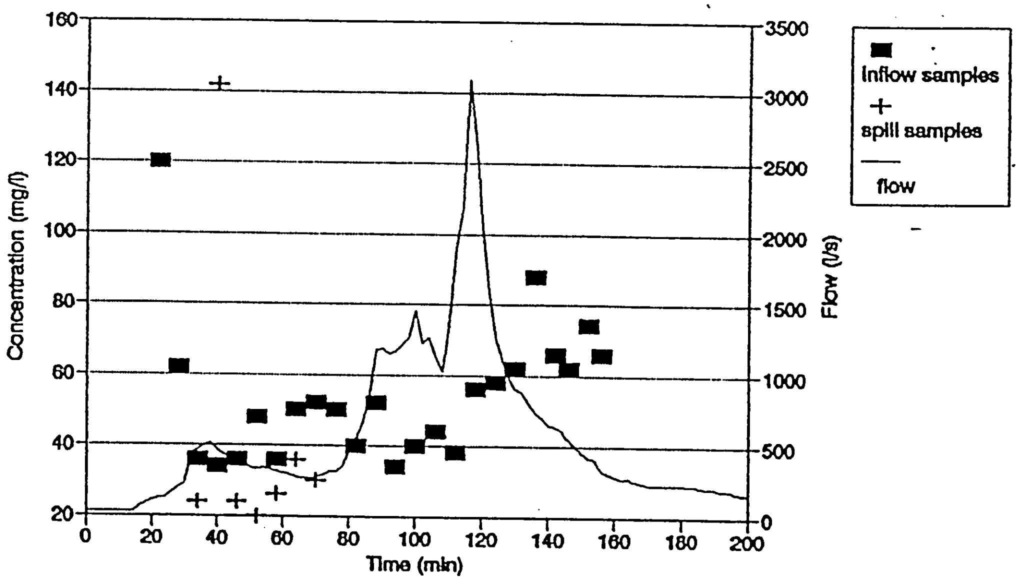


Chesterfield Road 17 October 1990
Suspended Solids



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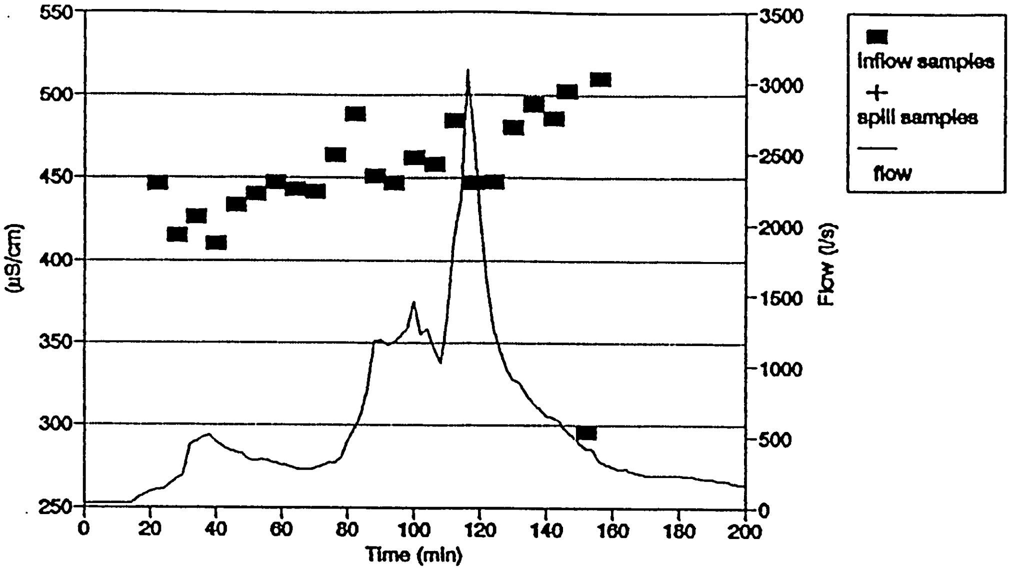

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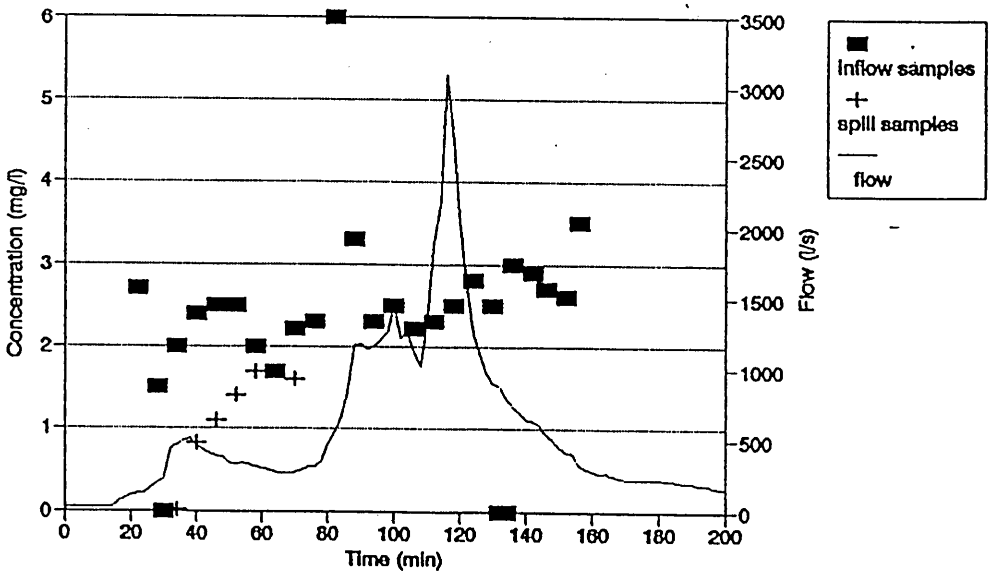

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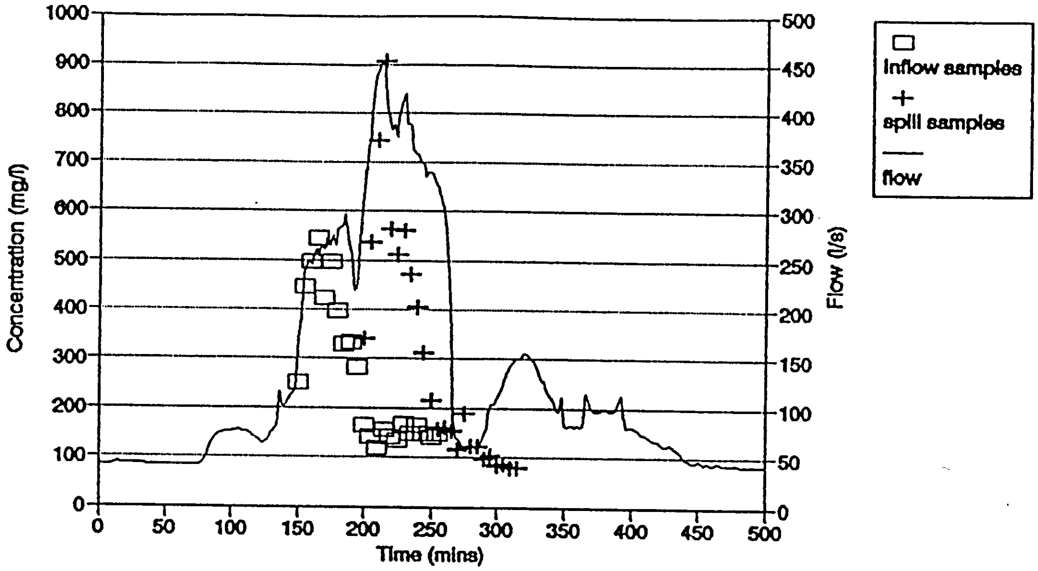
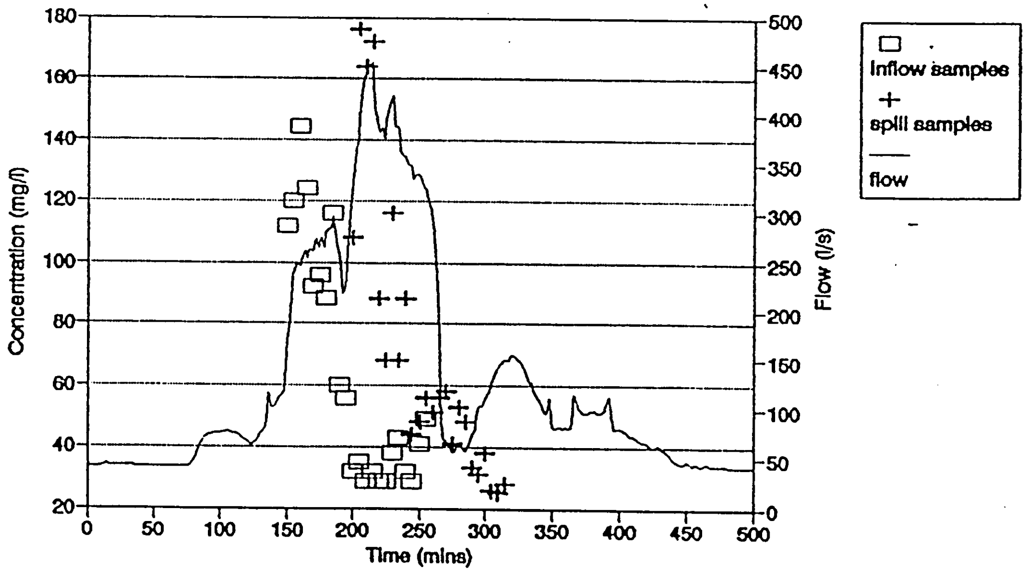


Chesterfield Road 8 March 1991
Suspended Solids



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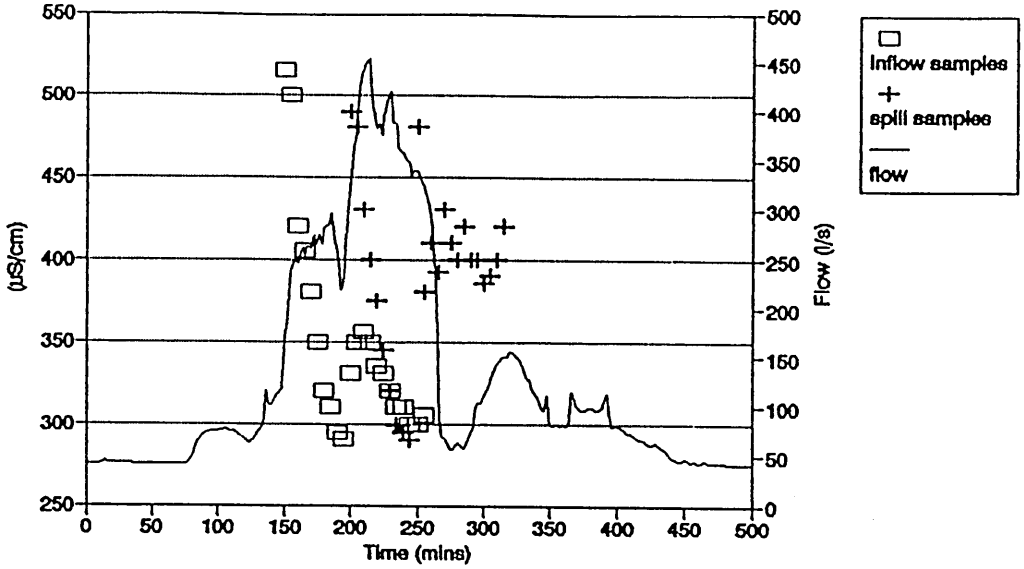

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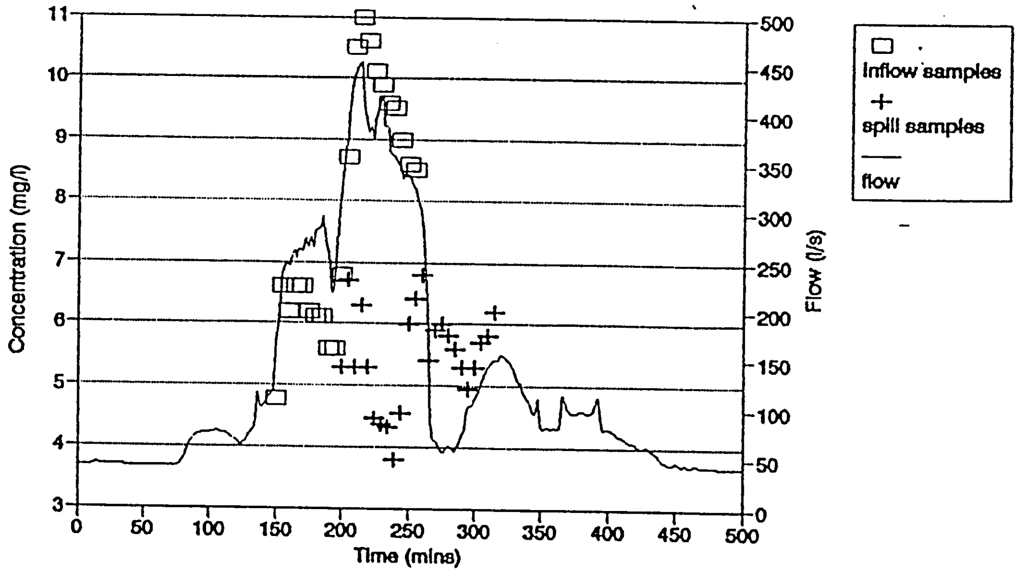

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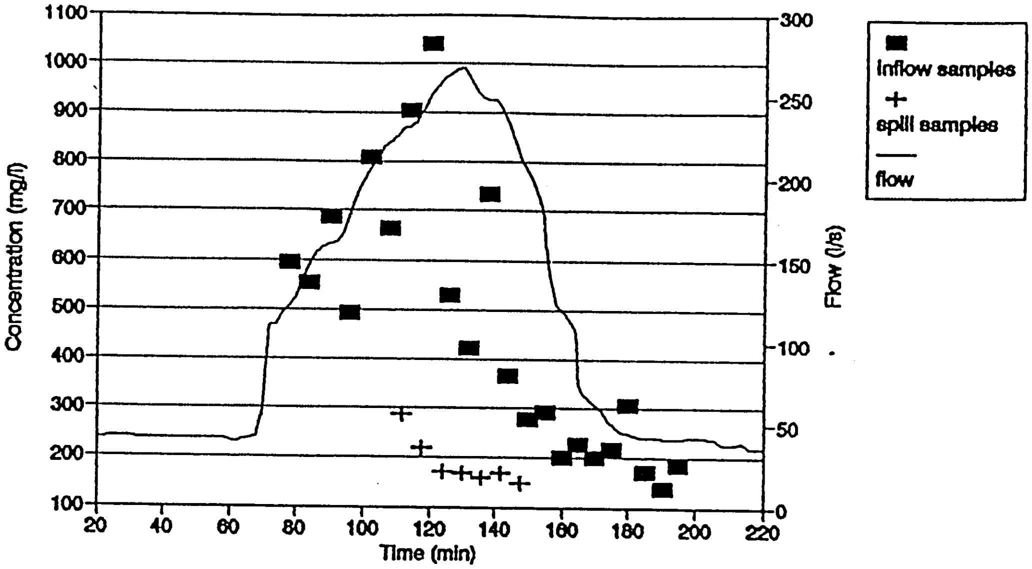
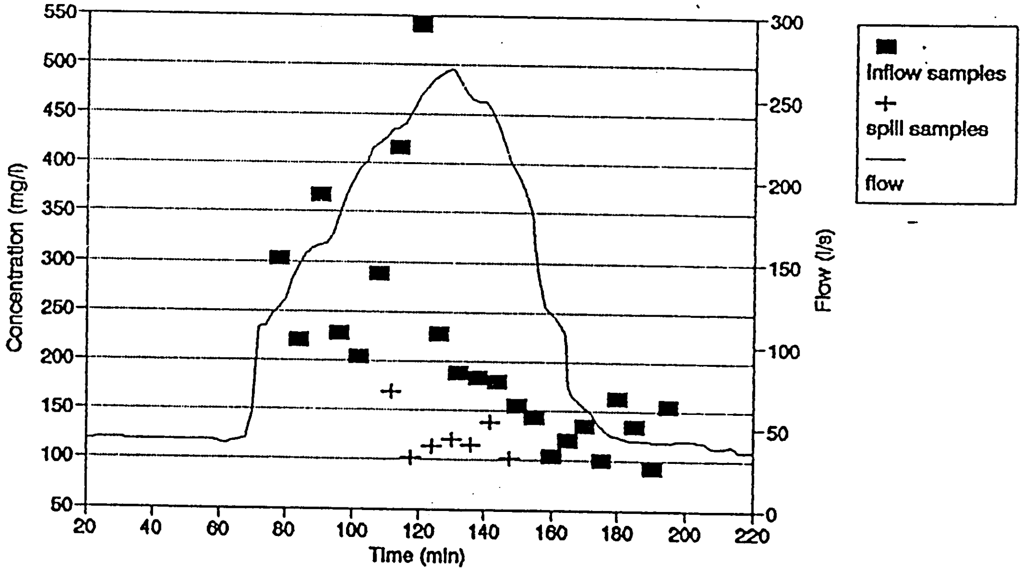


Chesterfield Road 19 April 1991
Suspended Solids



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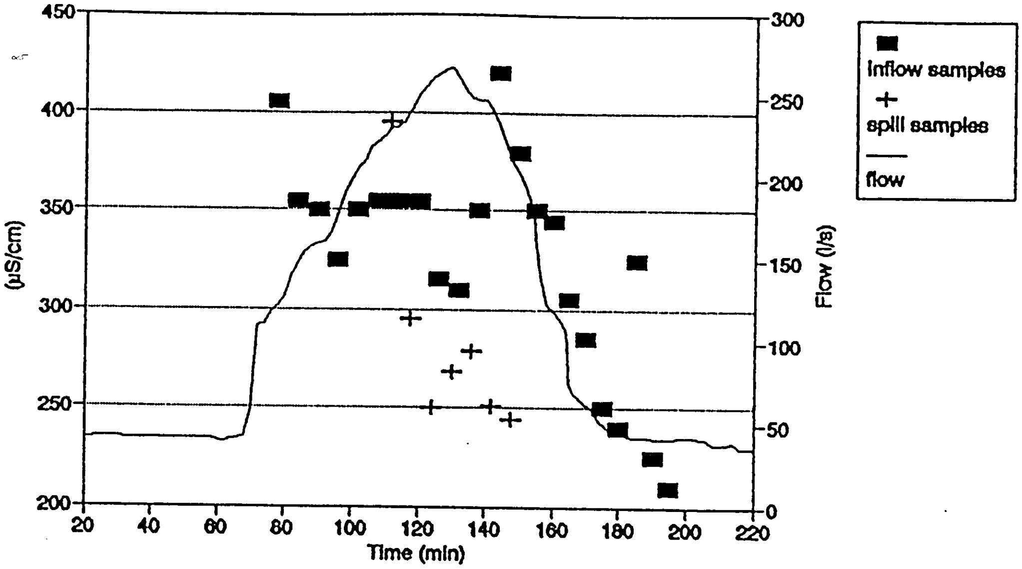

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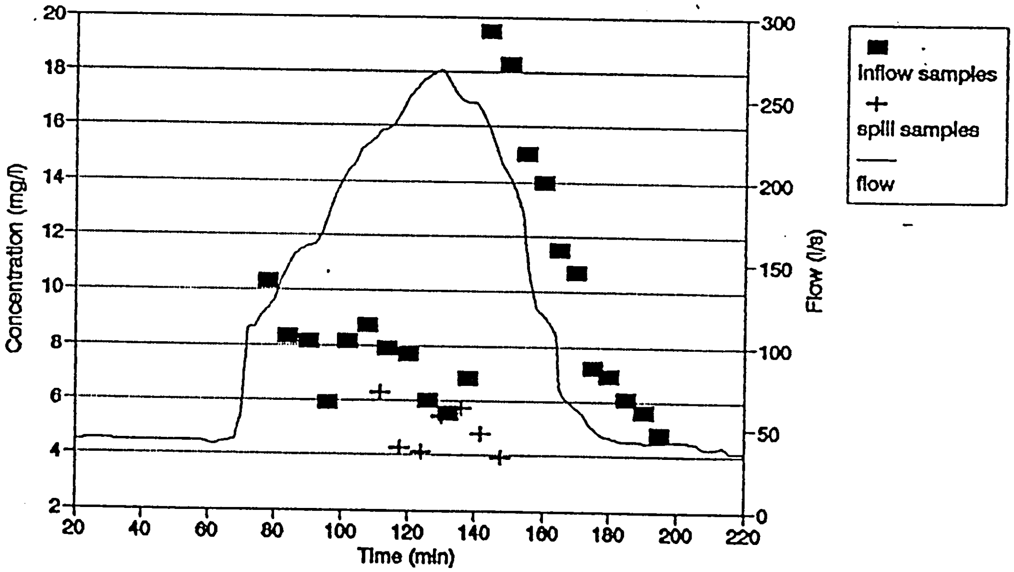

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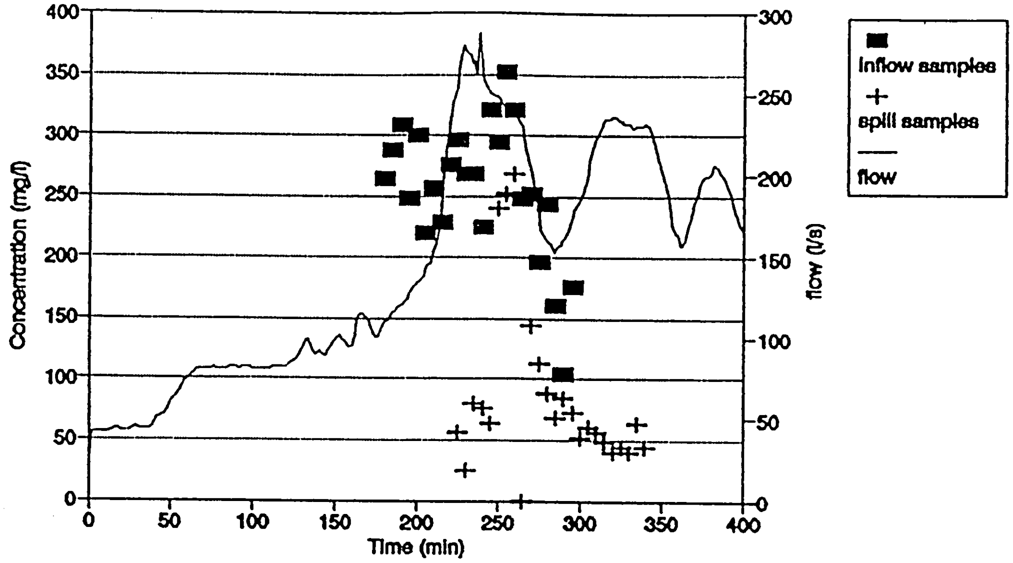
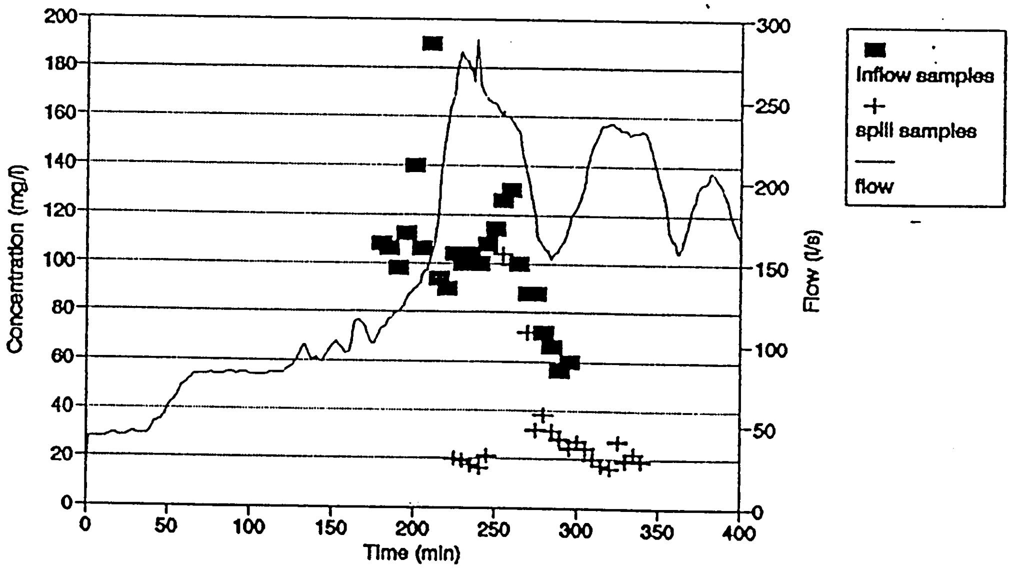


Chesterfield Road 29 April 1991
Suspended Solids



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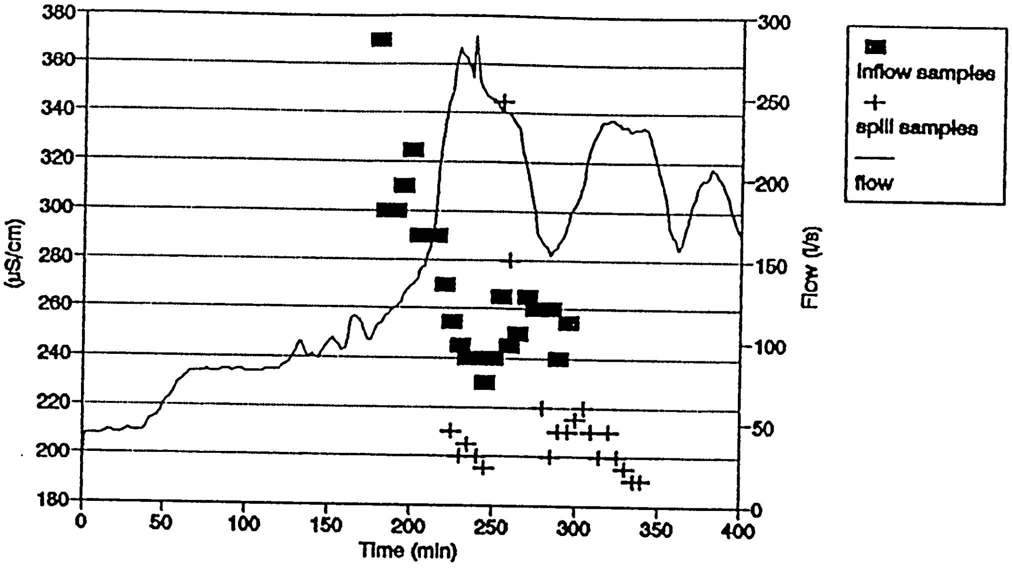

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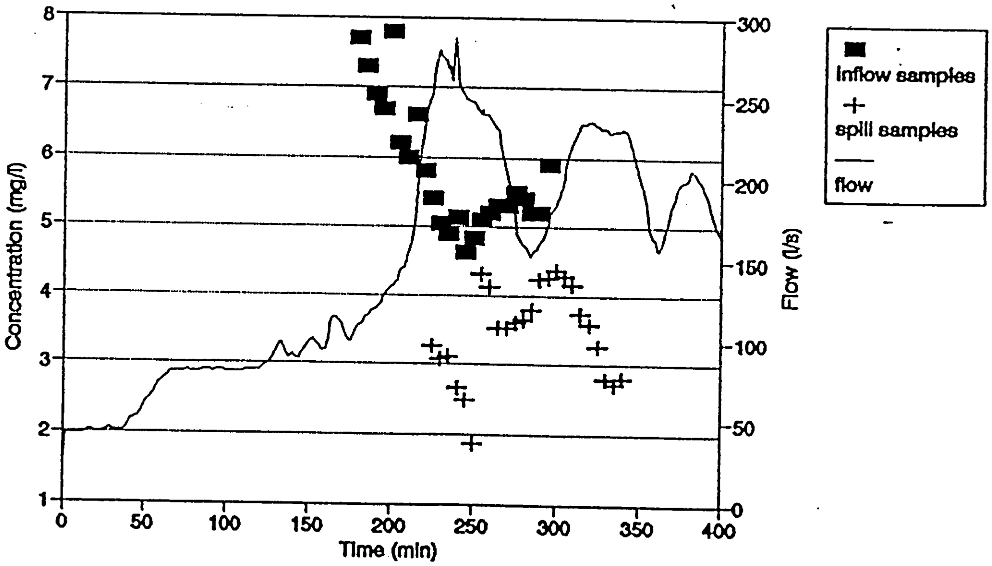

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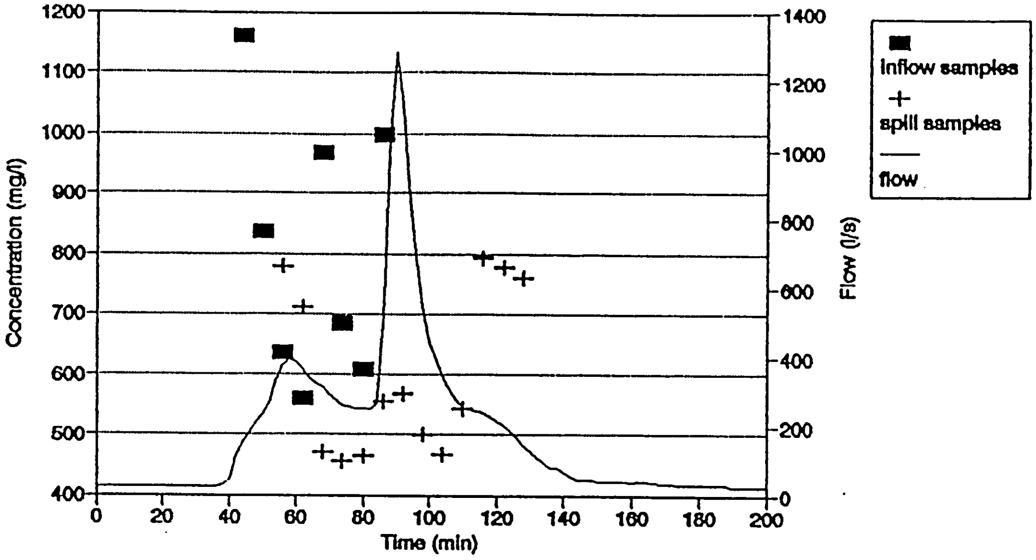
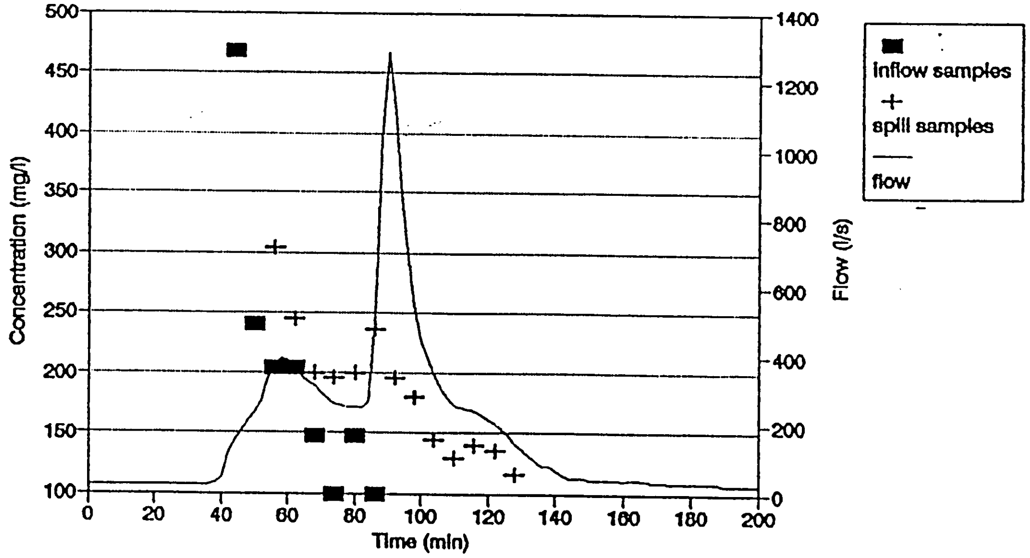


Chesterfield Road 13 June 1991
Suspended Solids



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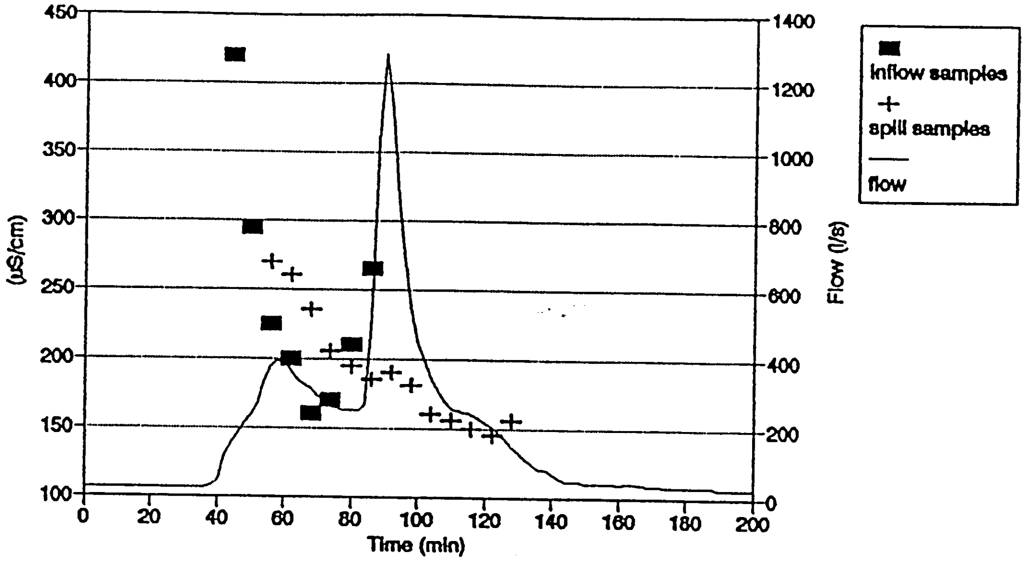

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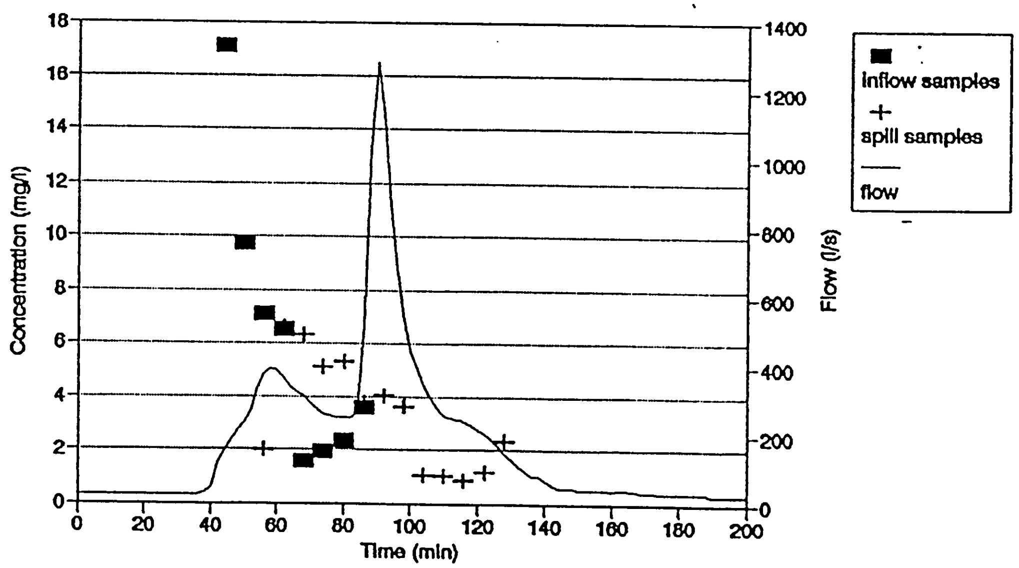

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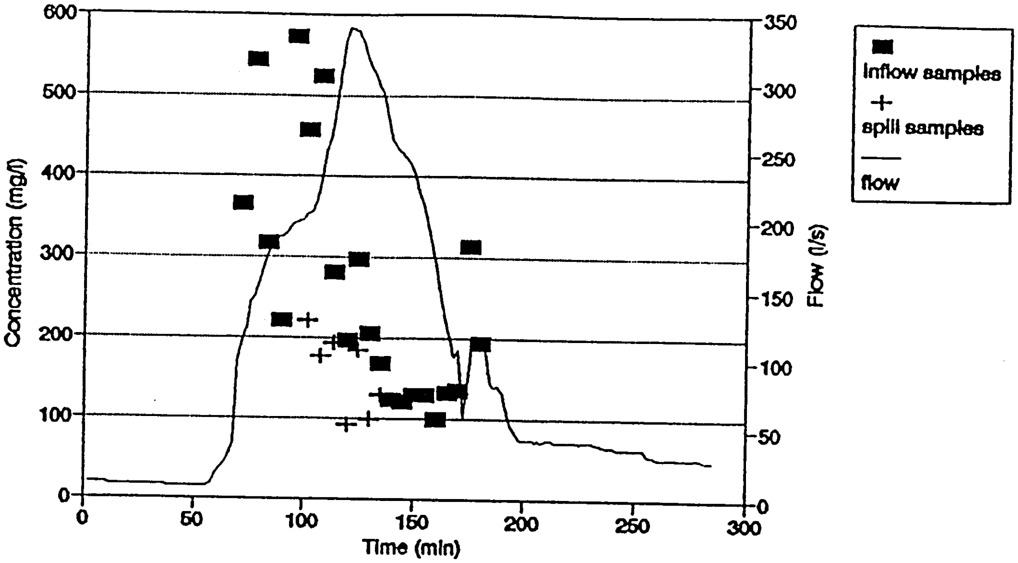

Chesterfield Road 25 June 1991
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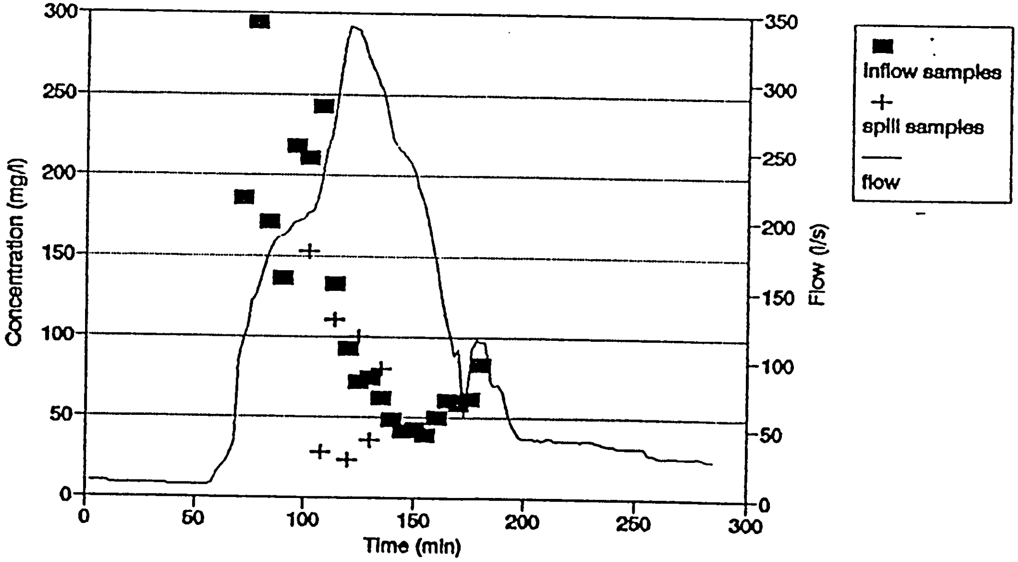

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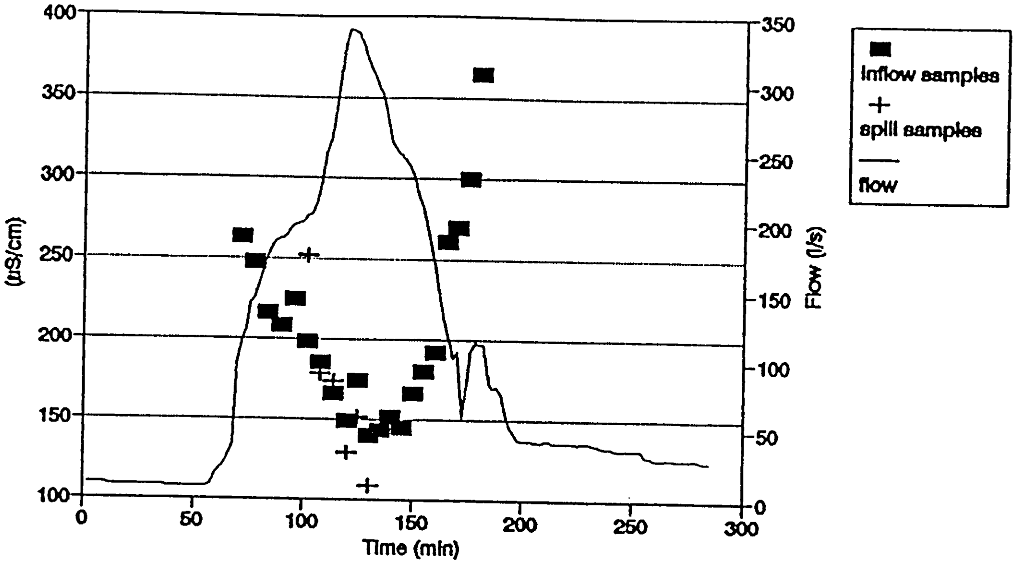

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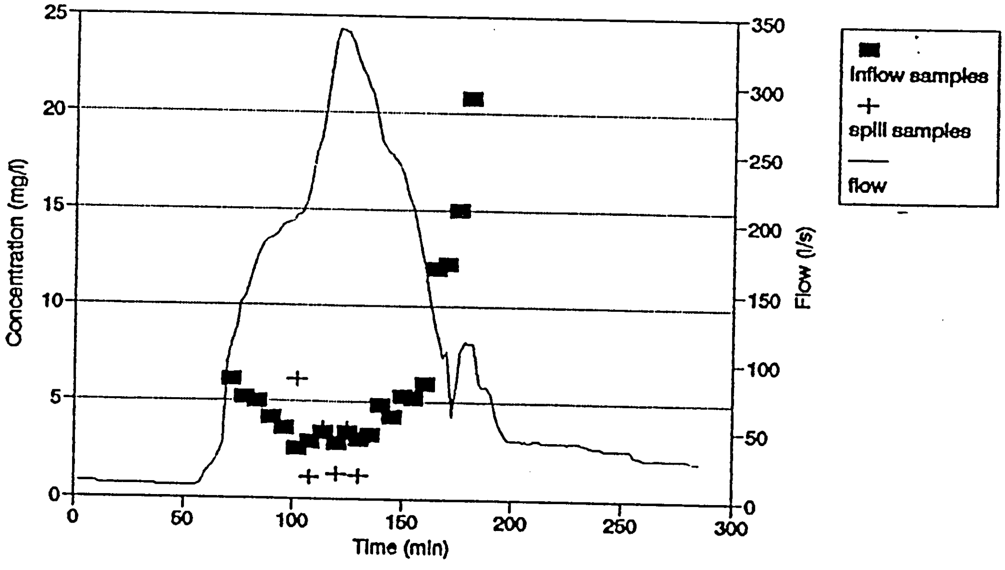

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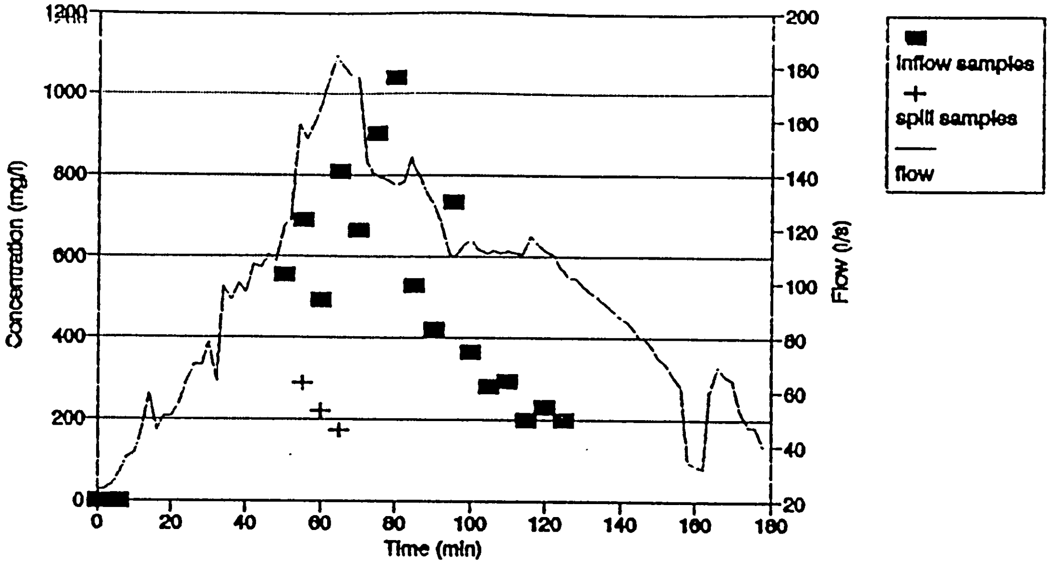

Dobcroft Road 19 April 1991
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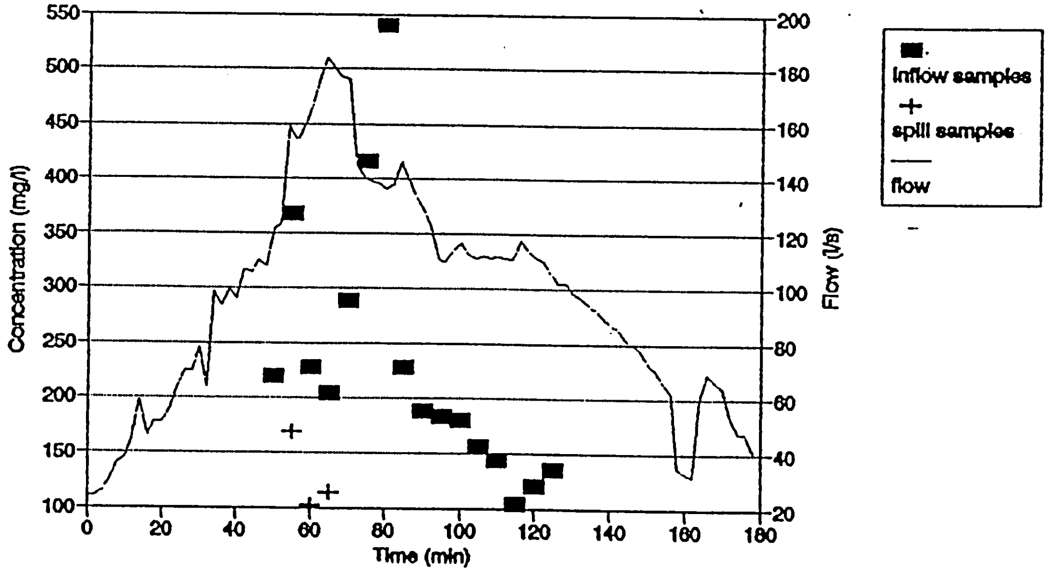

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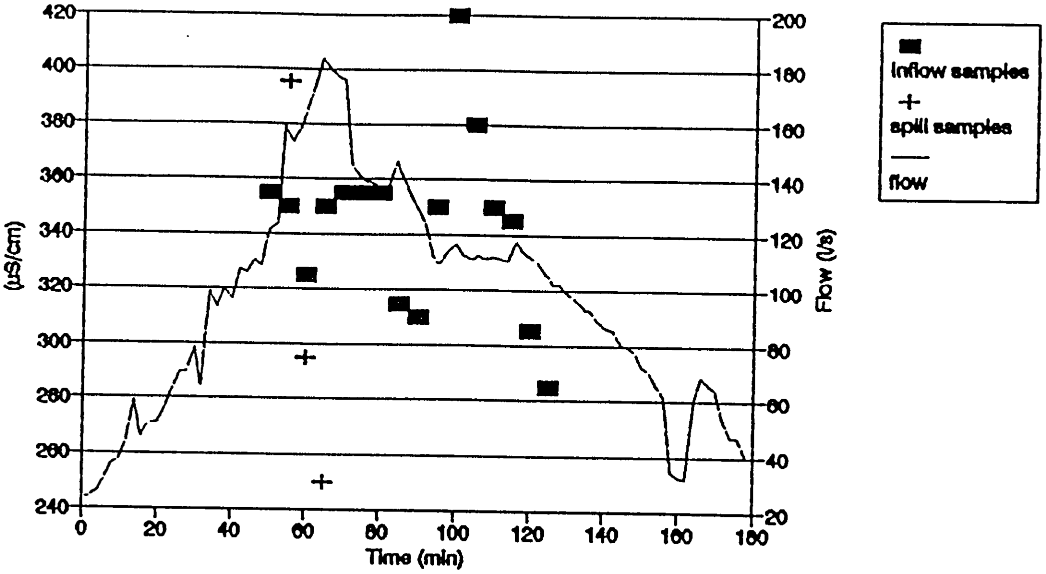

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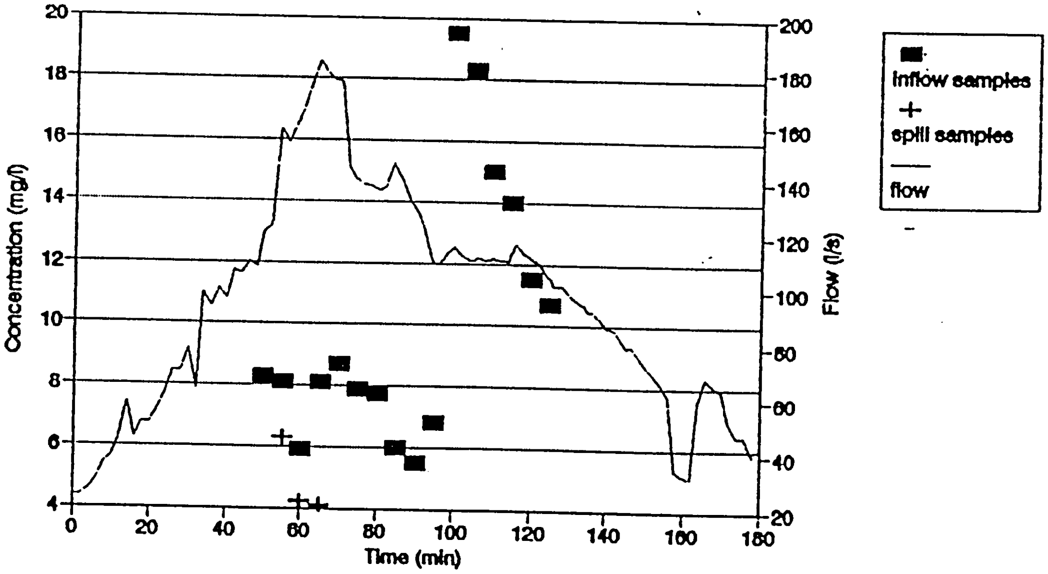

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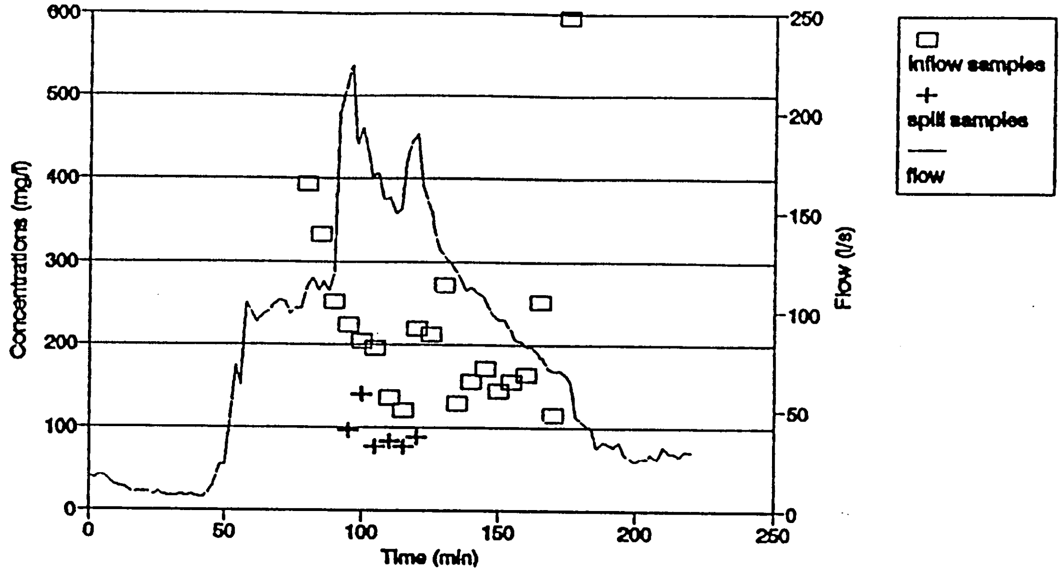

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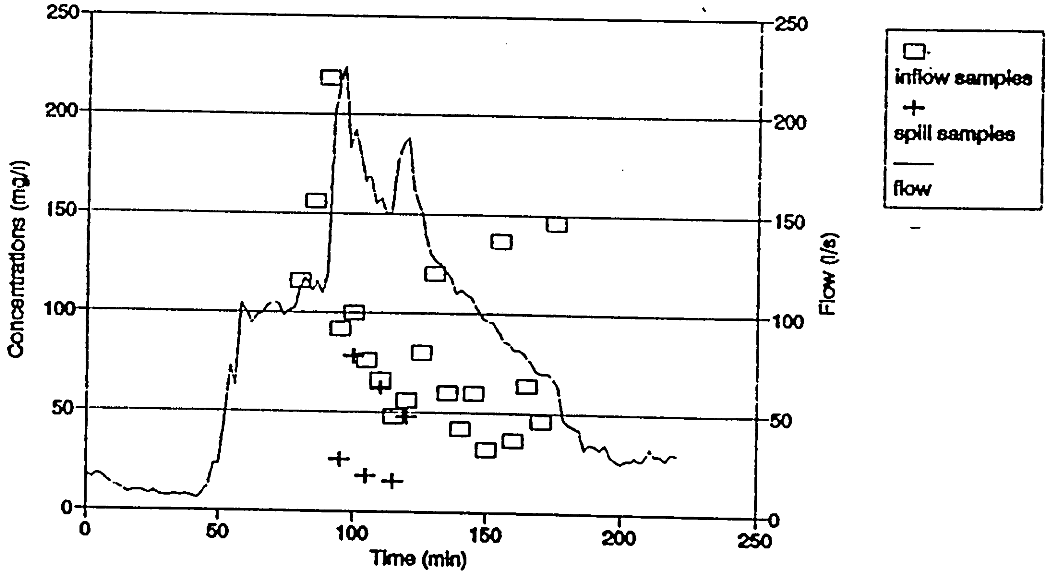

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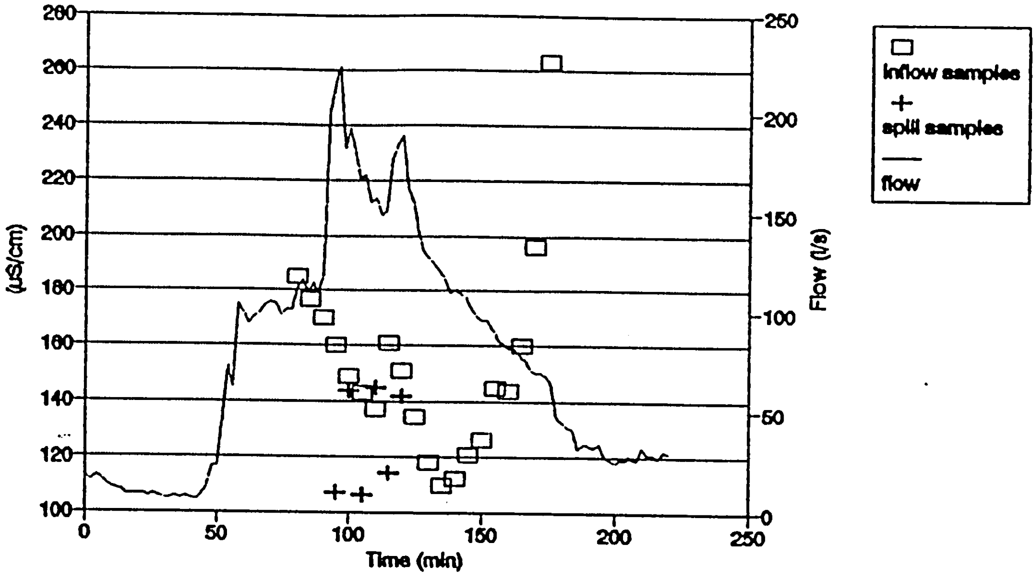

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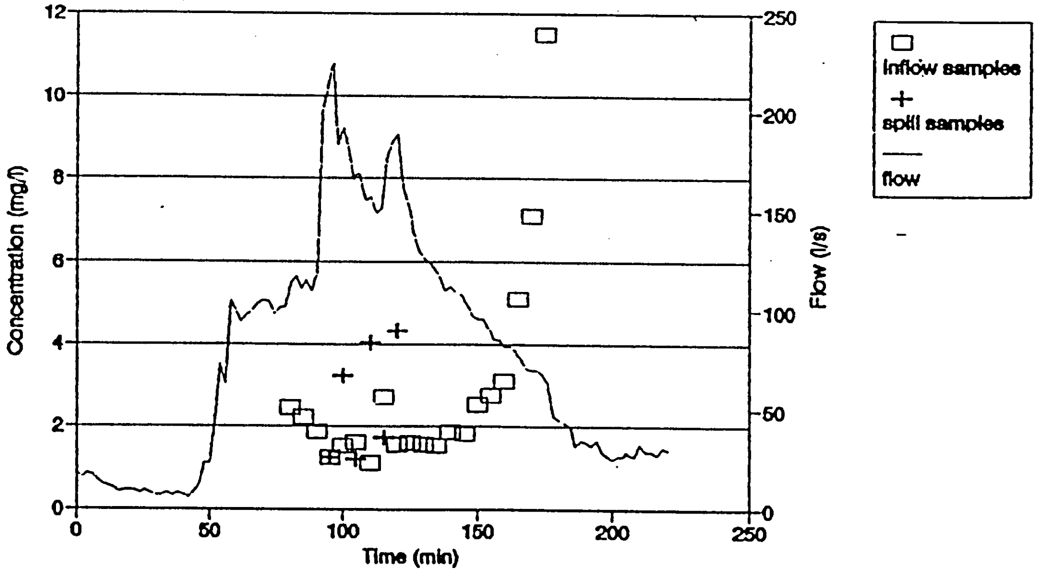

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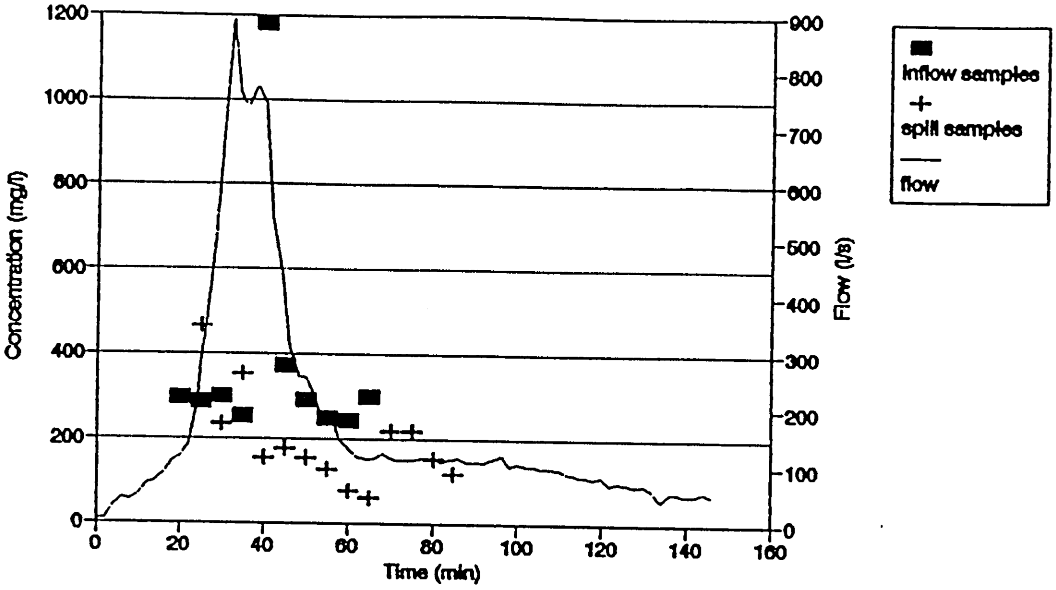

Dobcroft Road 27 September 1991
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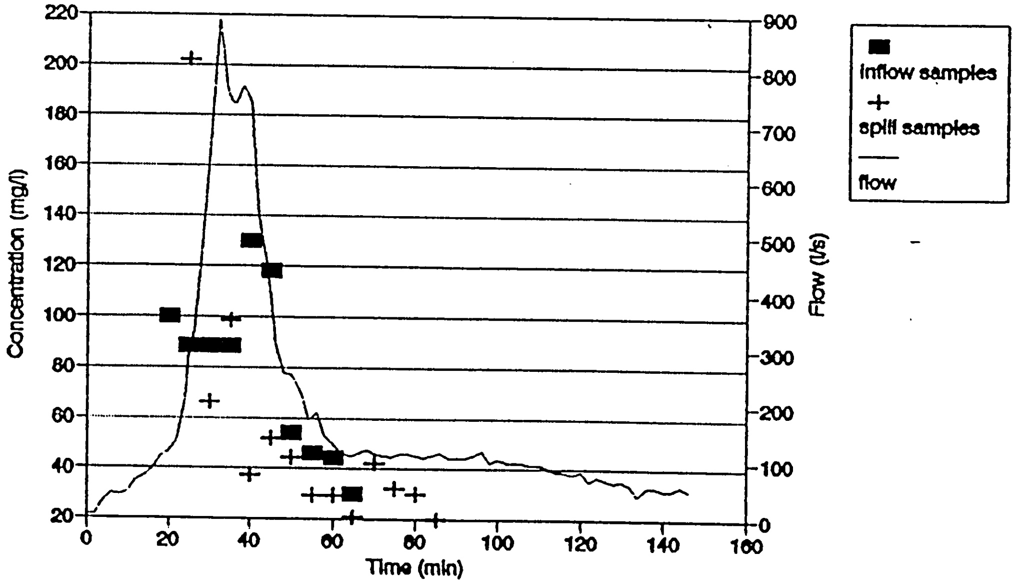

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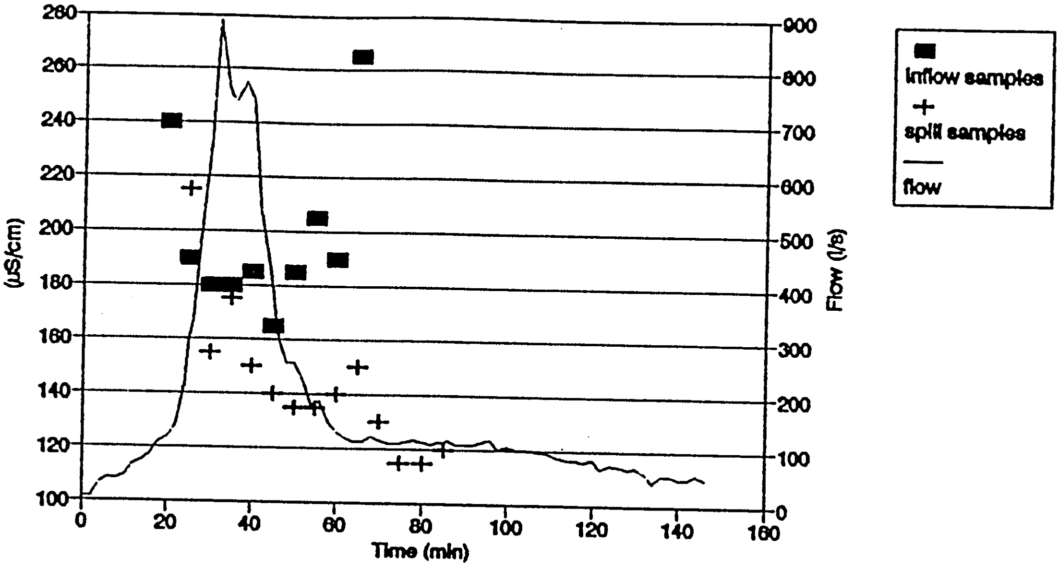

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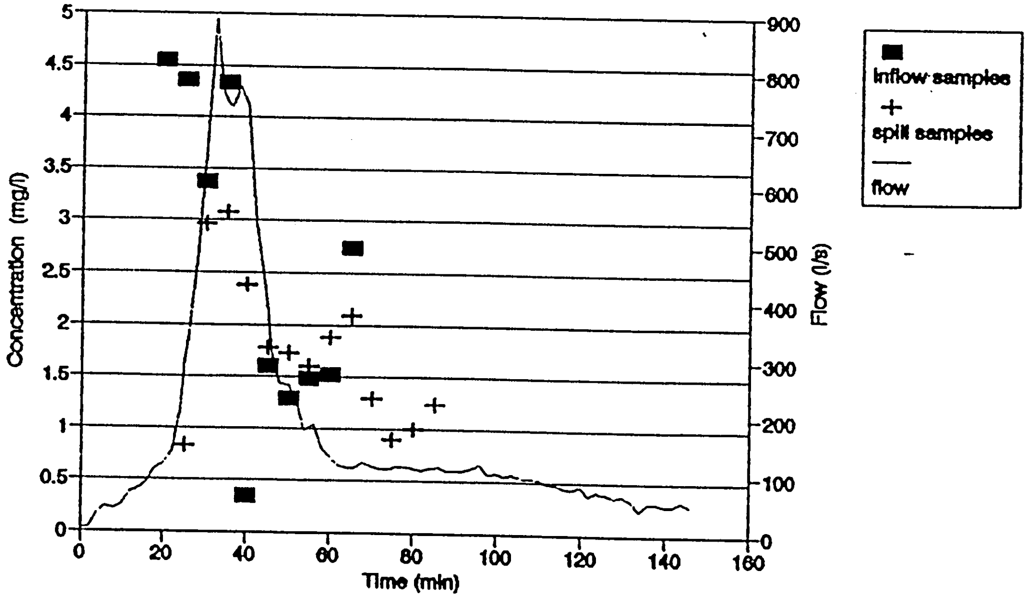

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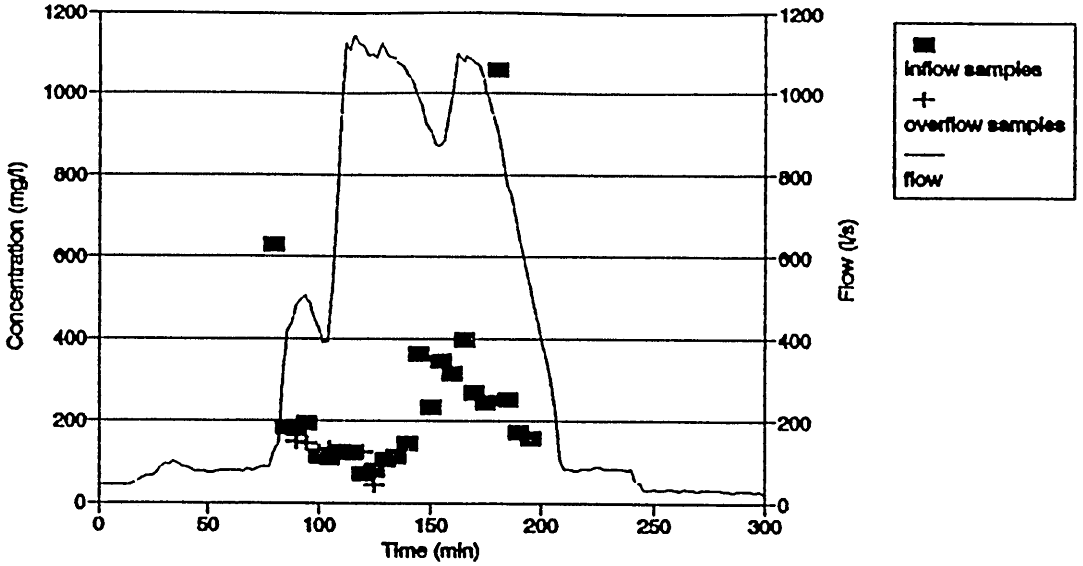

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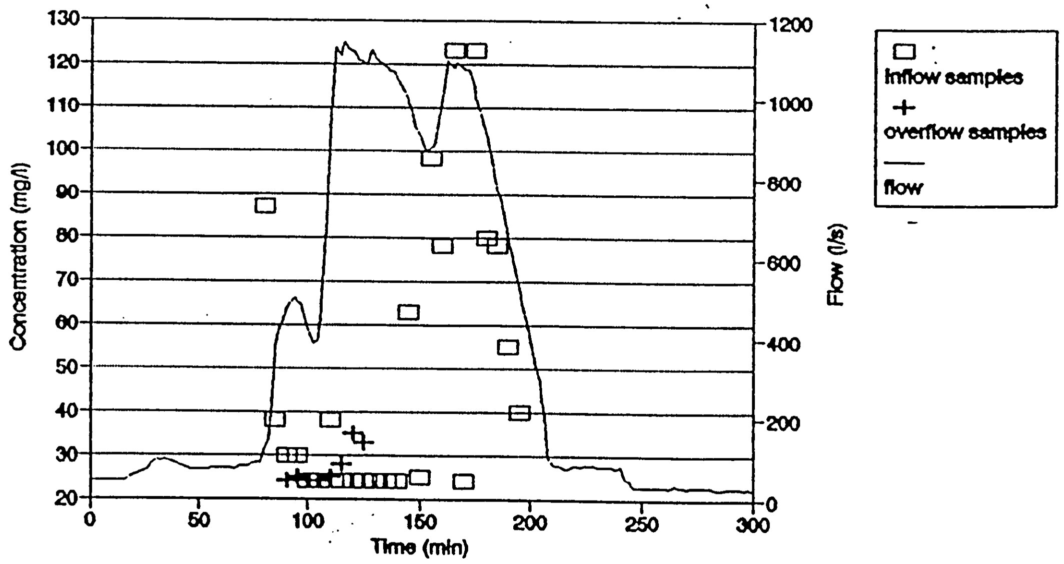

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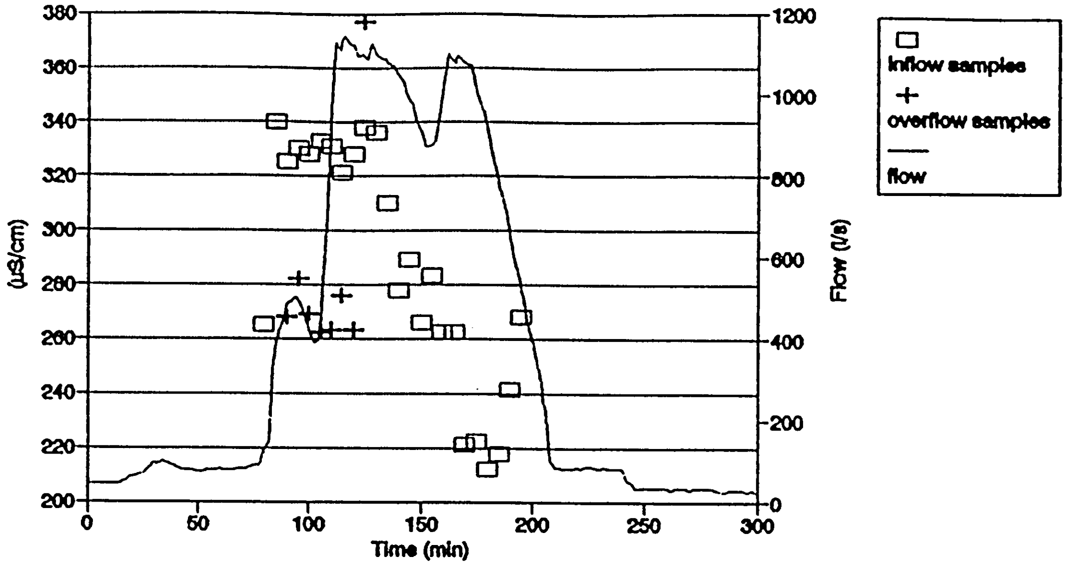

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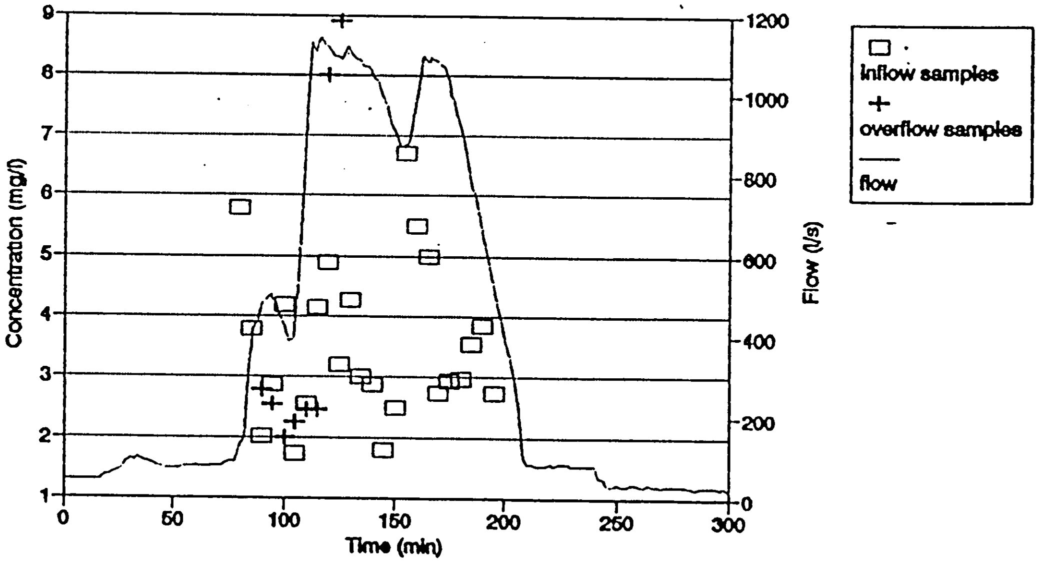

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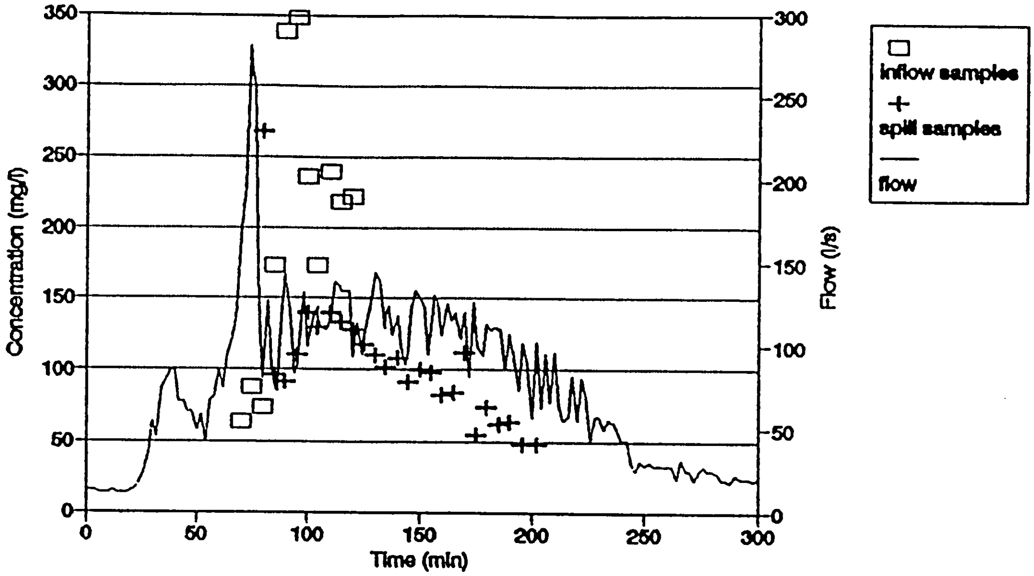
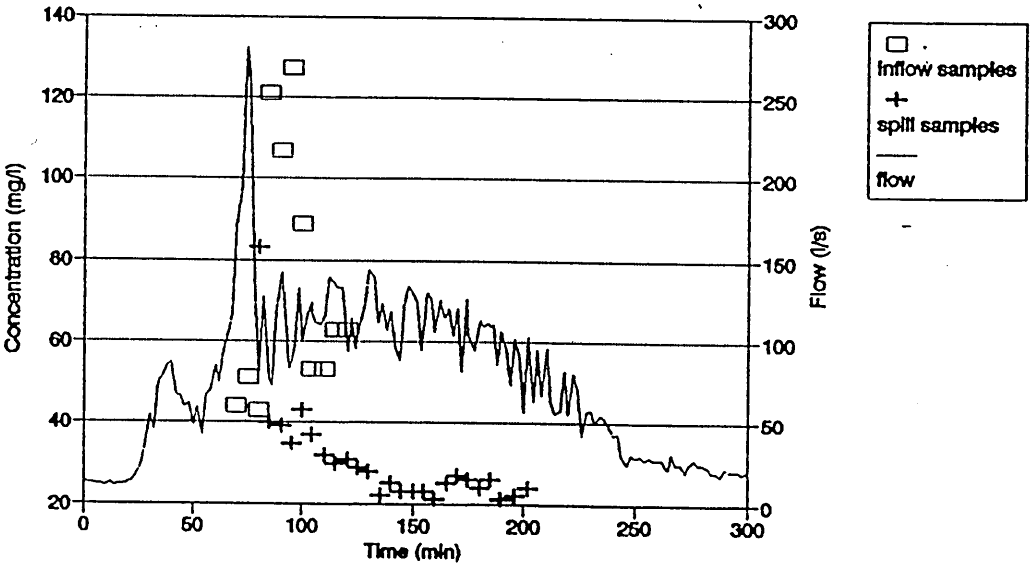


Dobcroft Road 17 October 1990 p.m.
Suspended Solids



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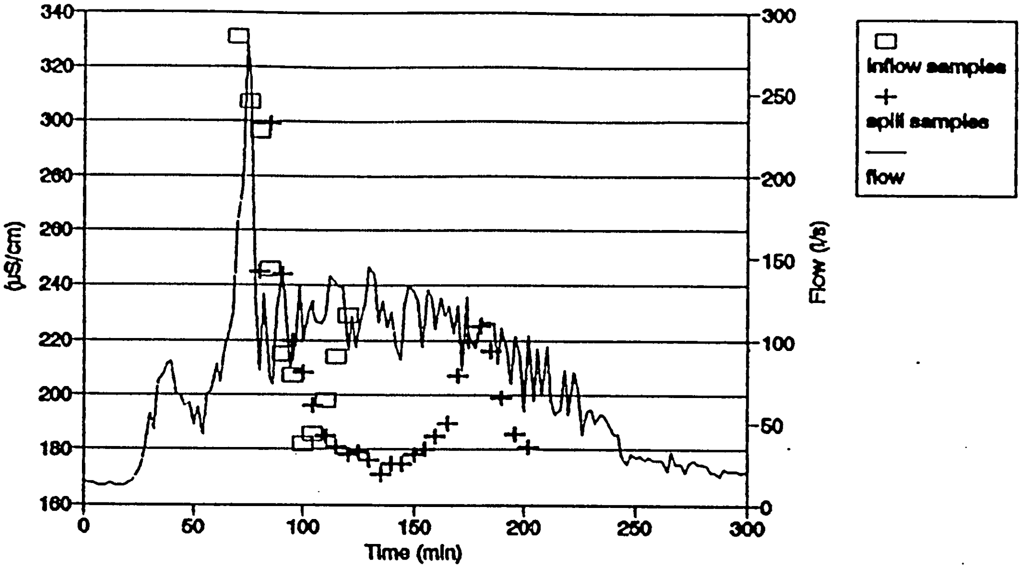

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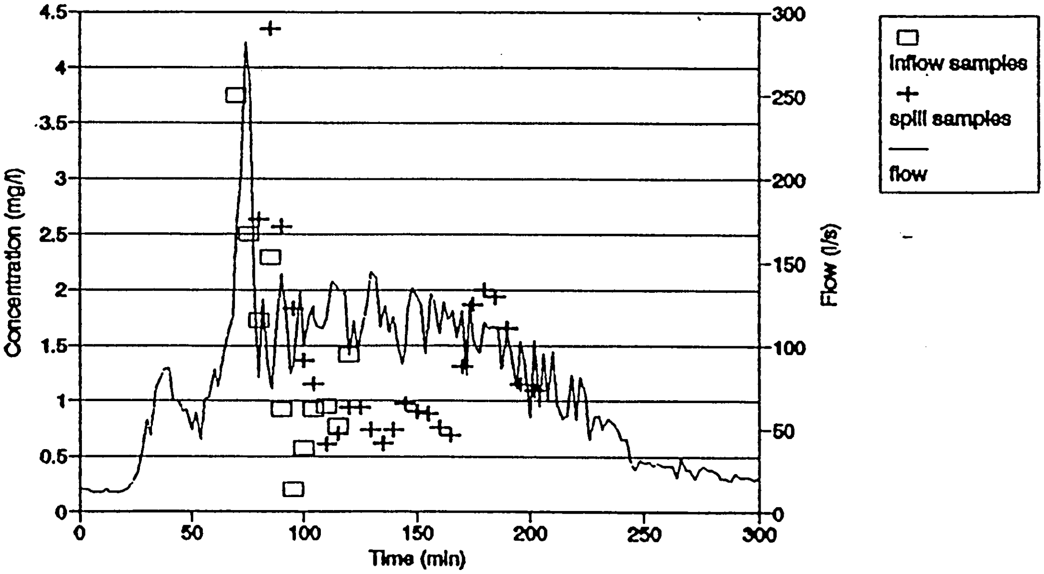

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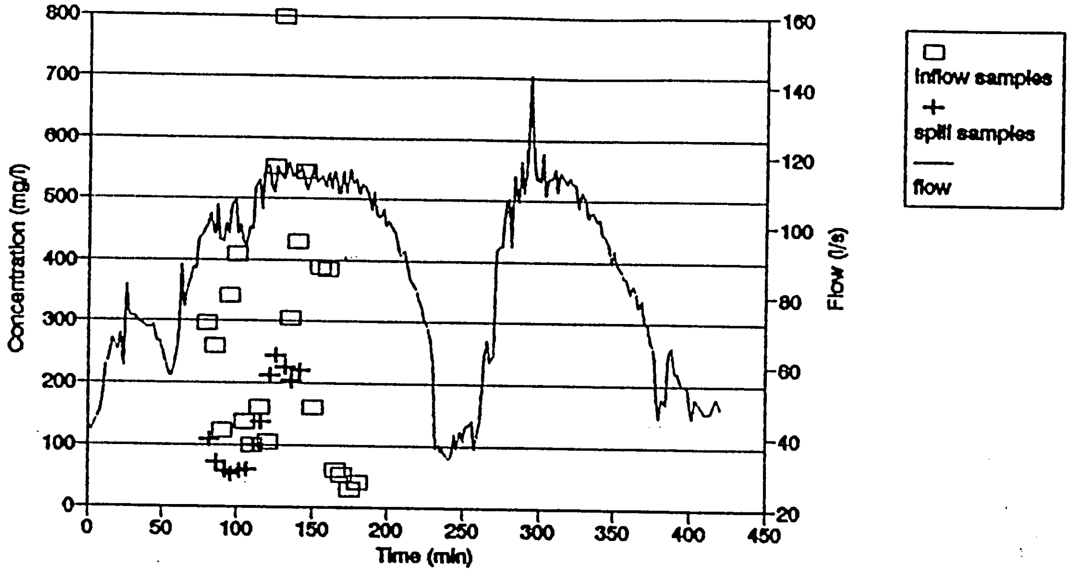
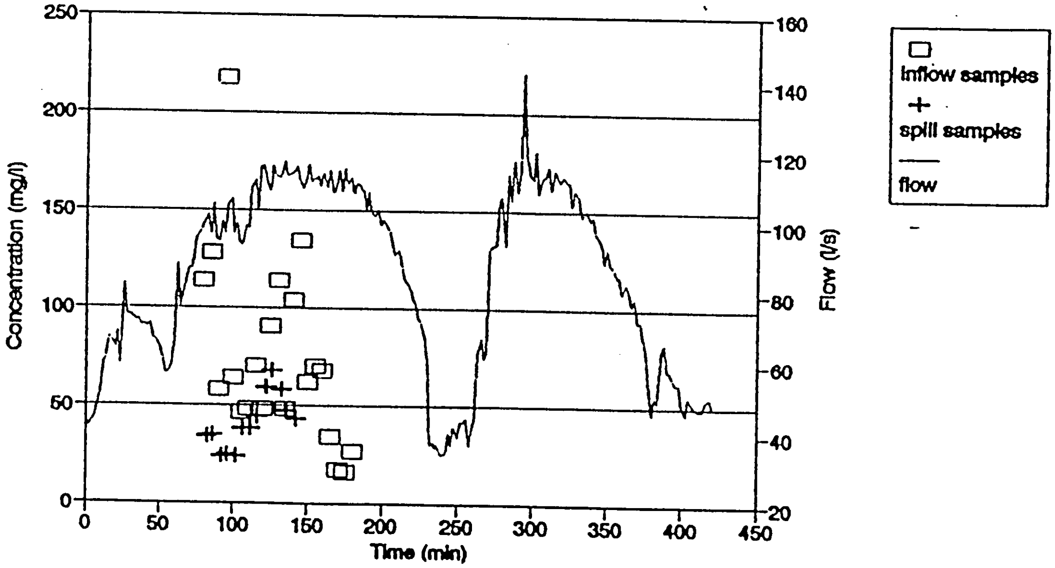


Dobcroft Road 29 October 1991
Suspended Solids



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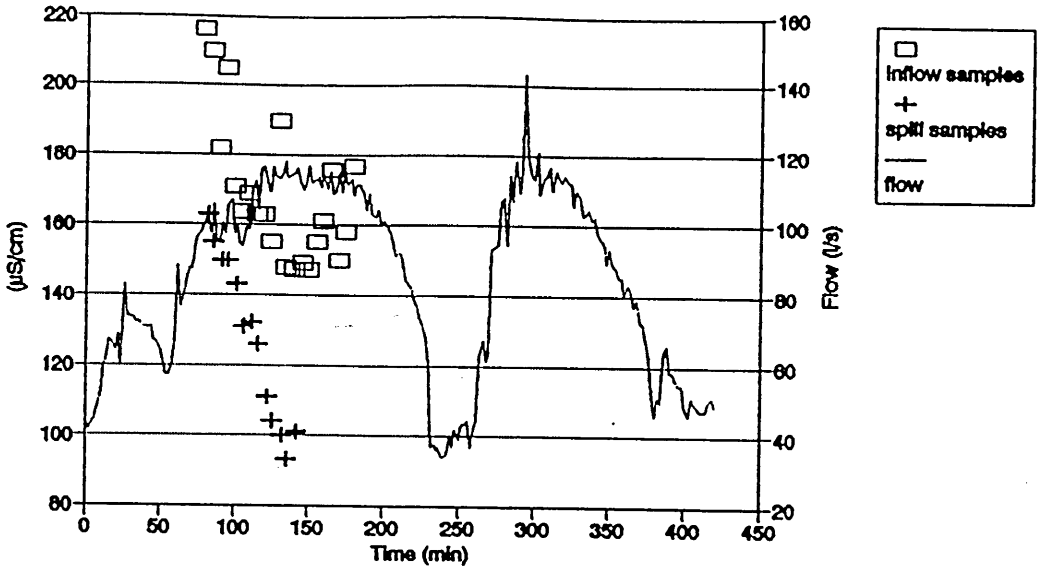

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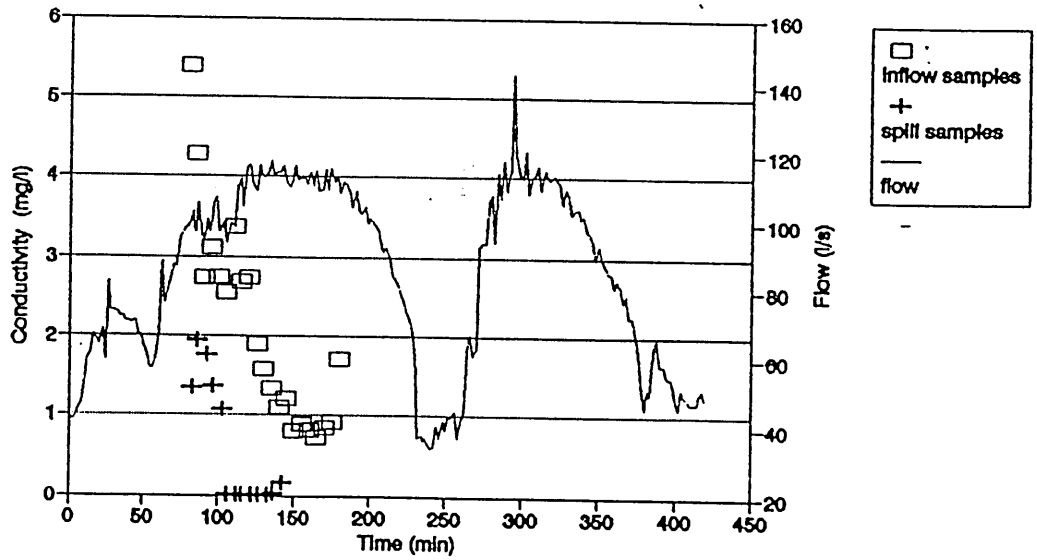

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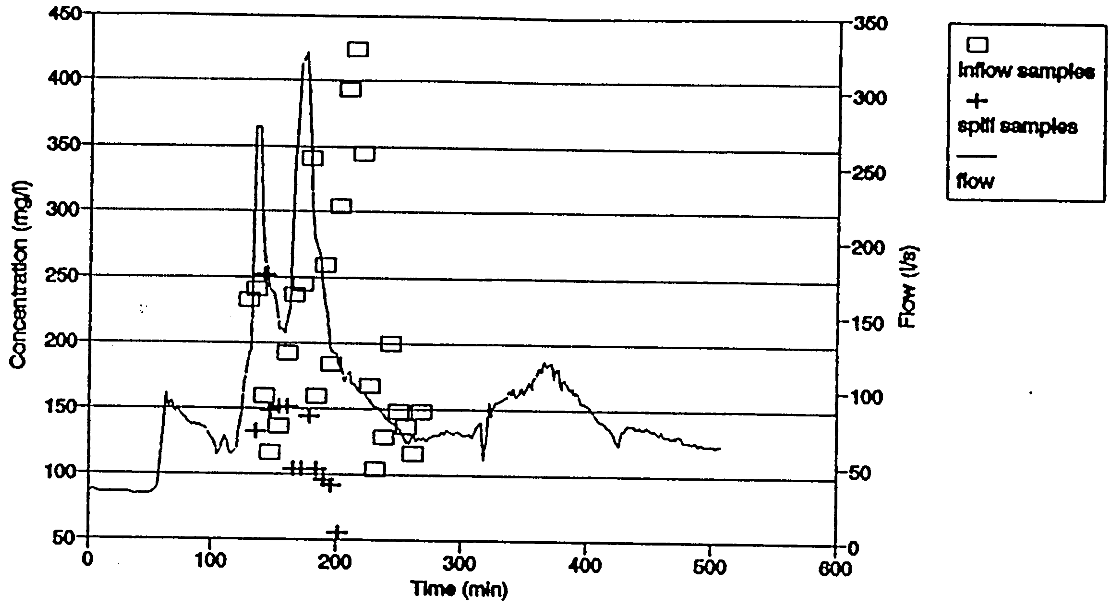

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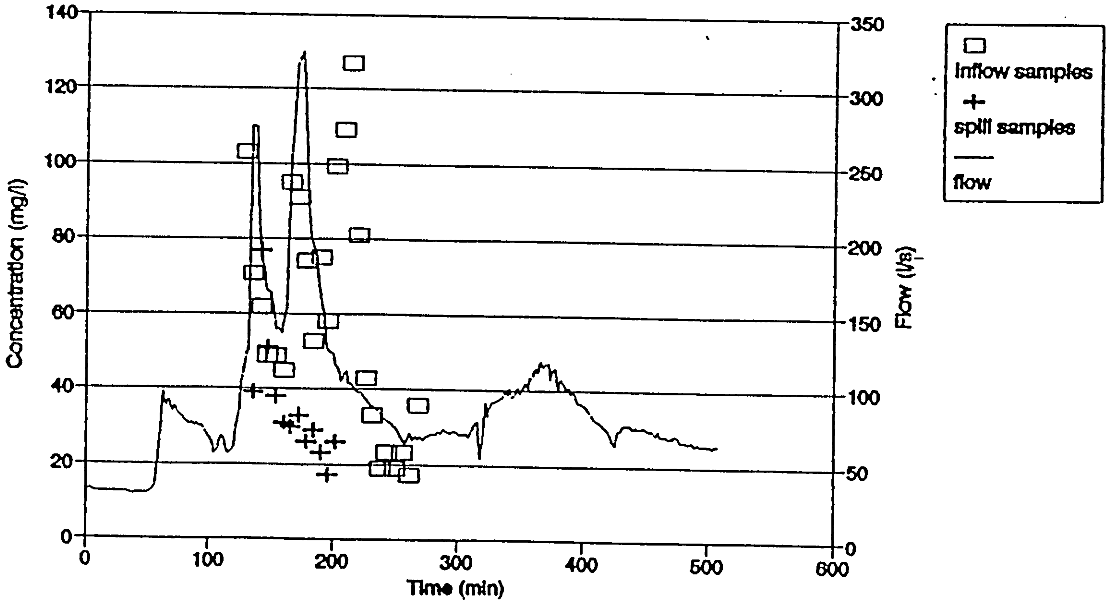
Suspended Solids



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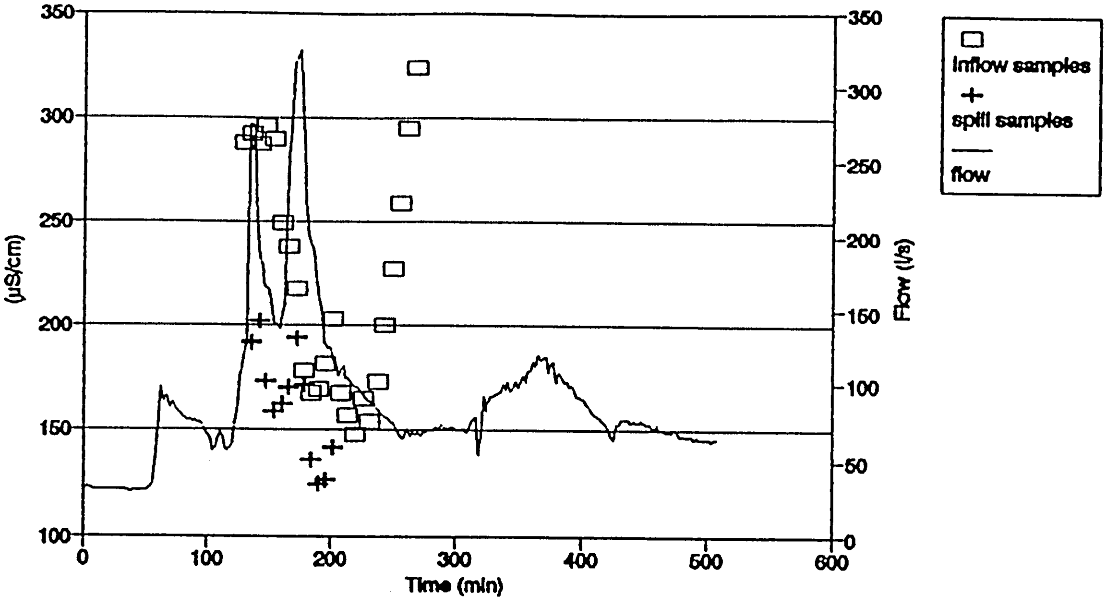

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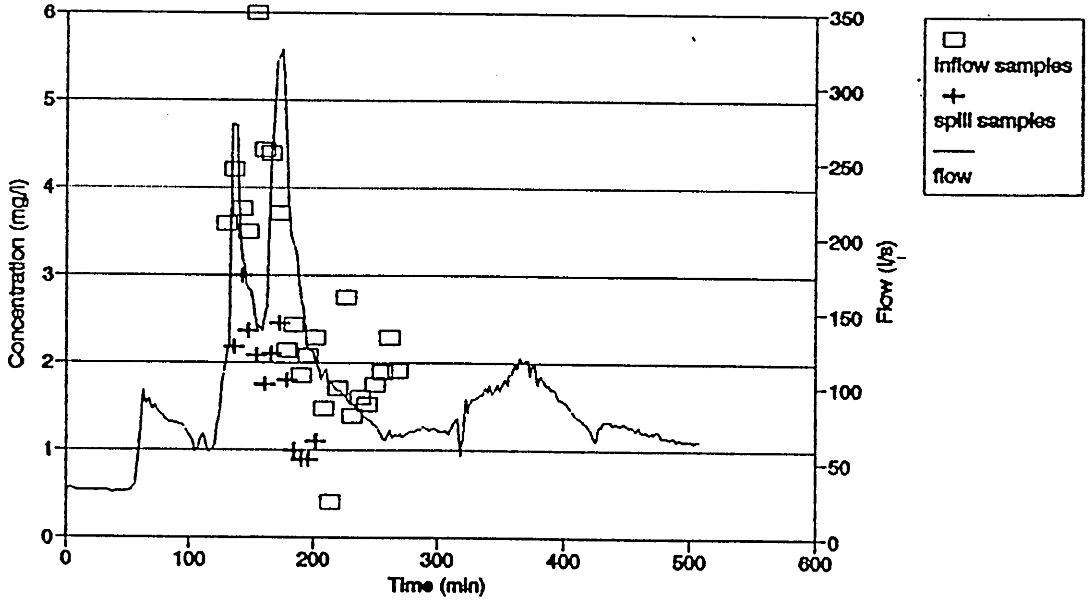

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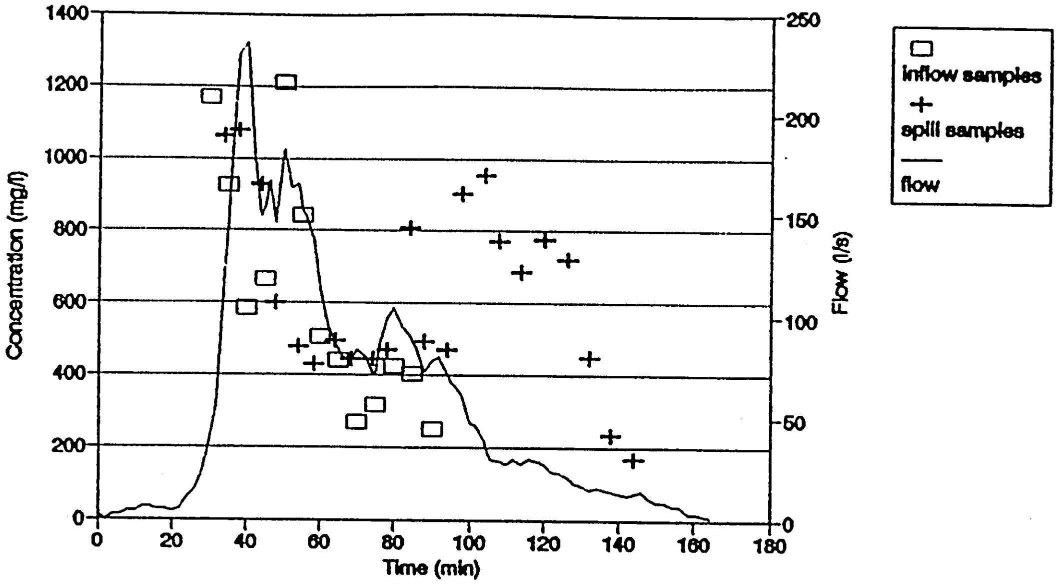
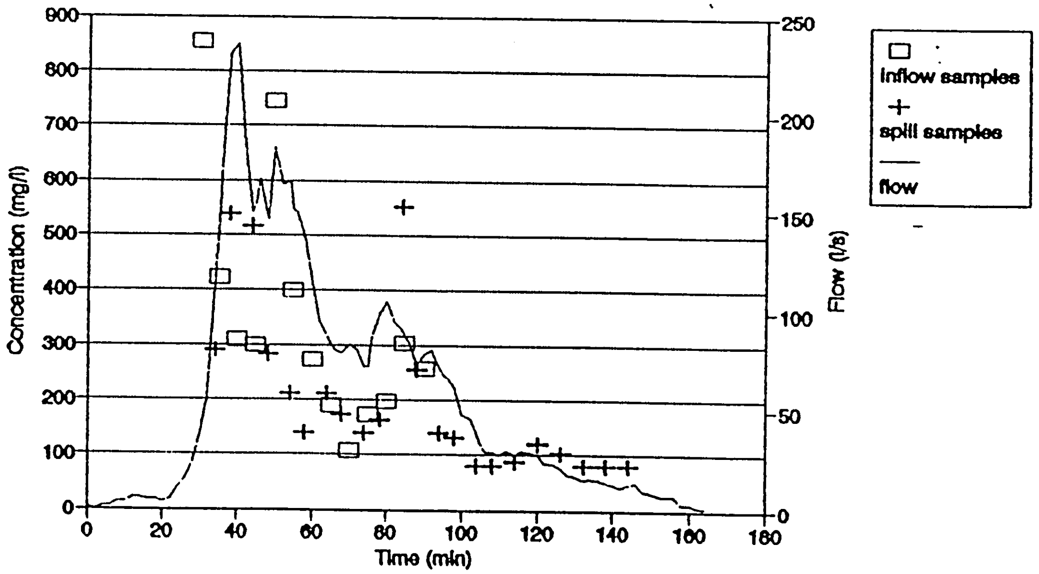


Retford Road 12 March 1991
Suspended Solids



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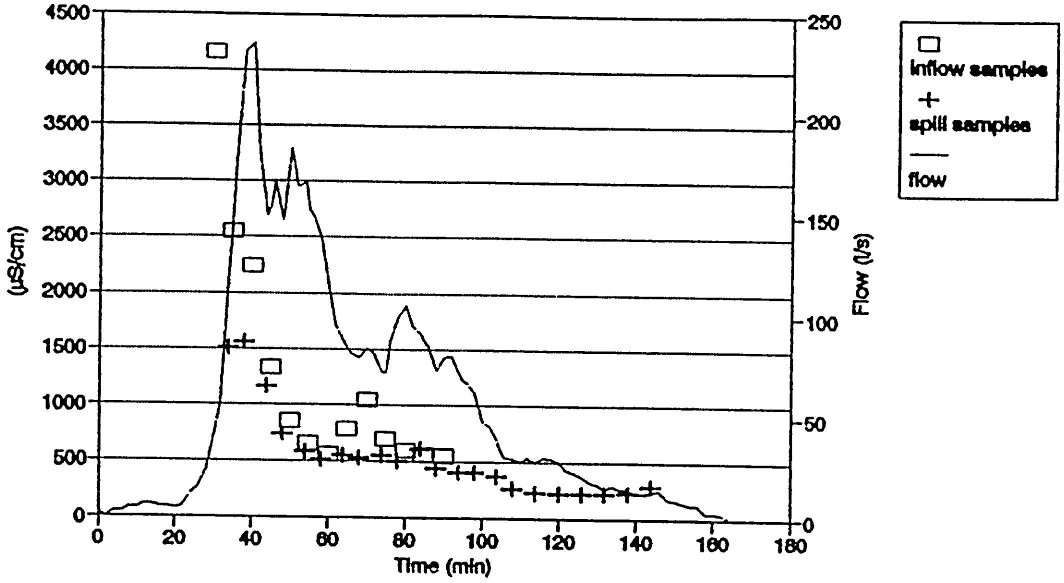

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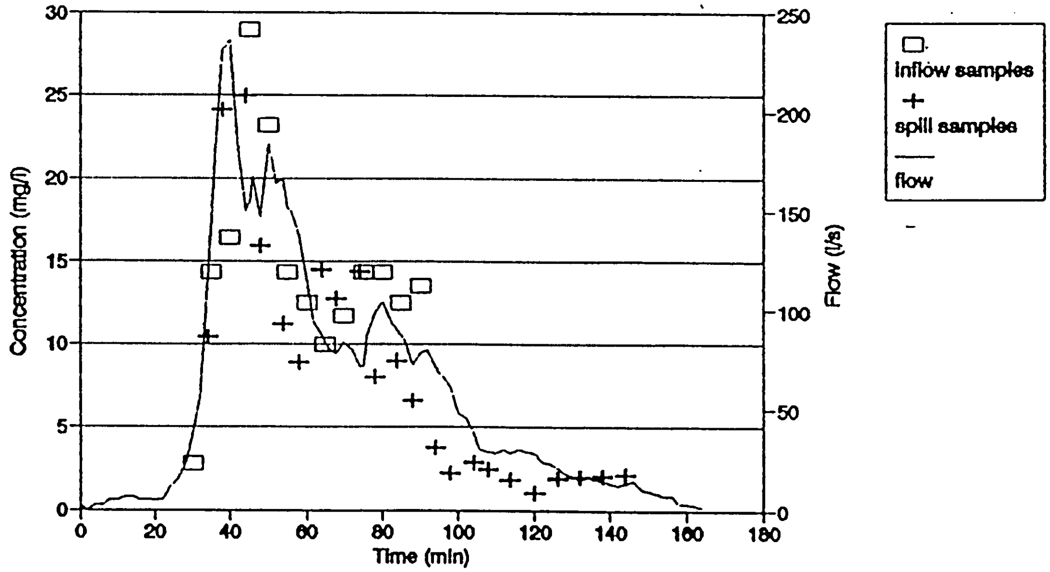

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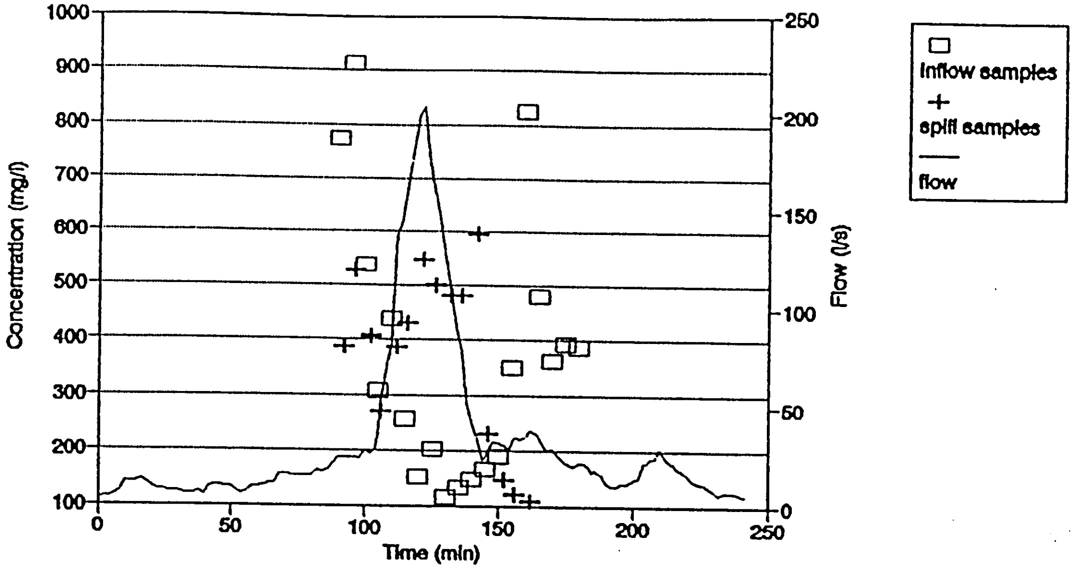

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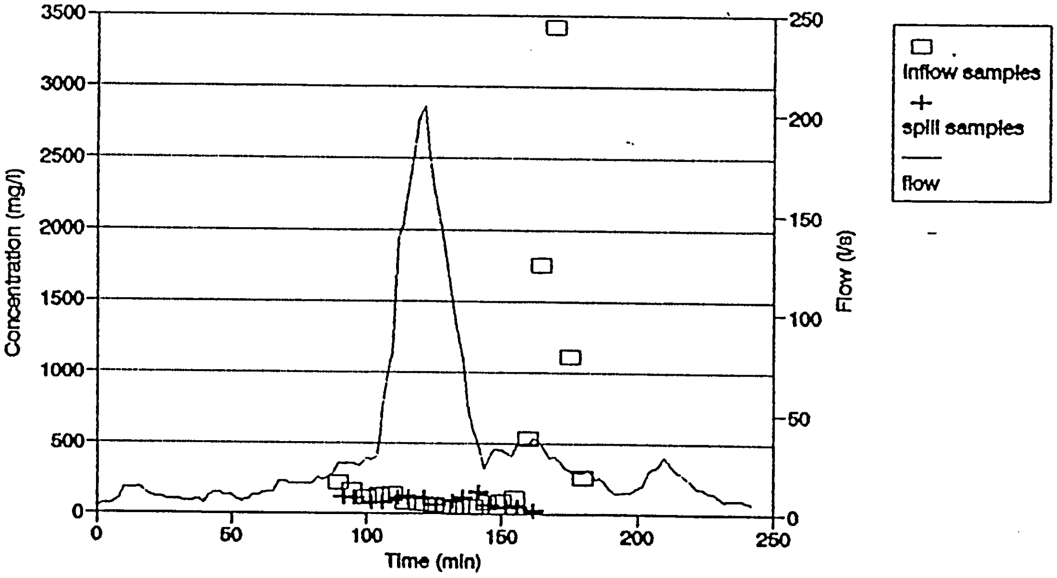
Suspended Solids



Retford Road 29 March 1991
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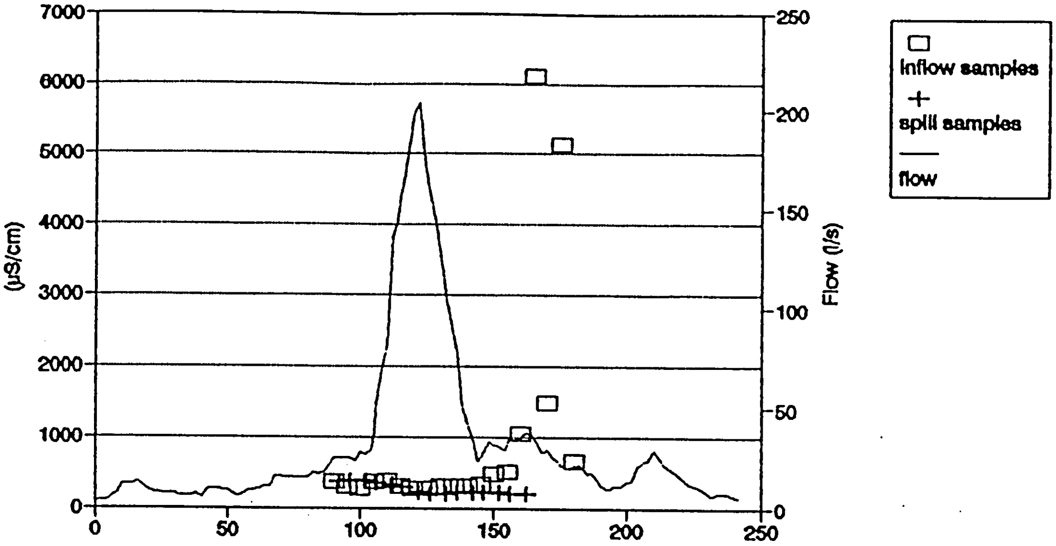

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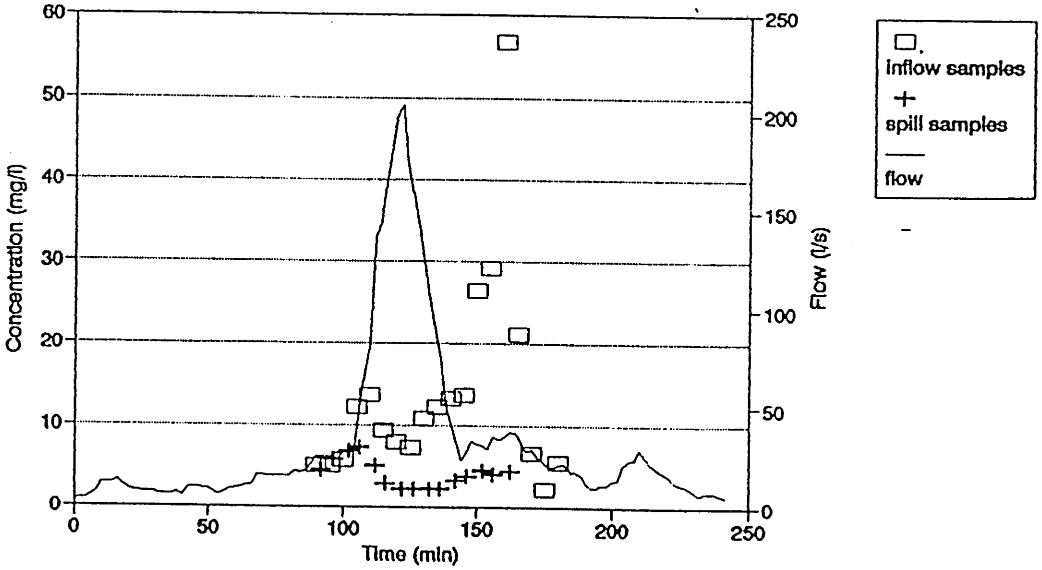

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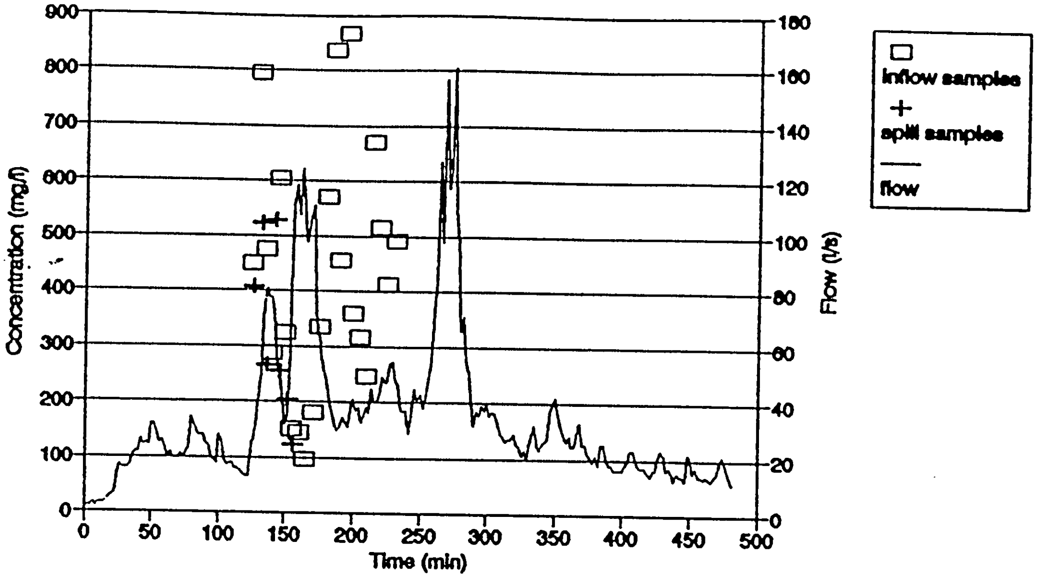
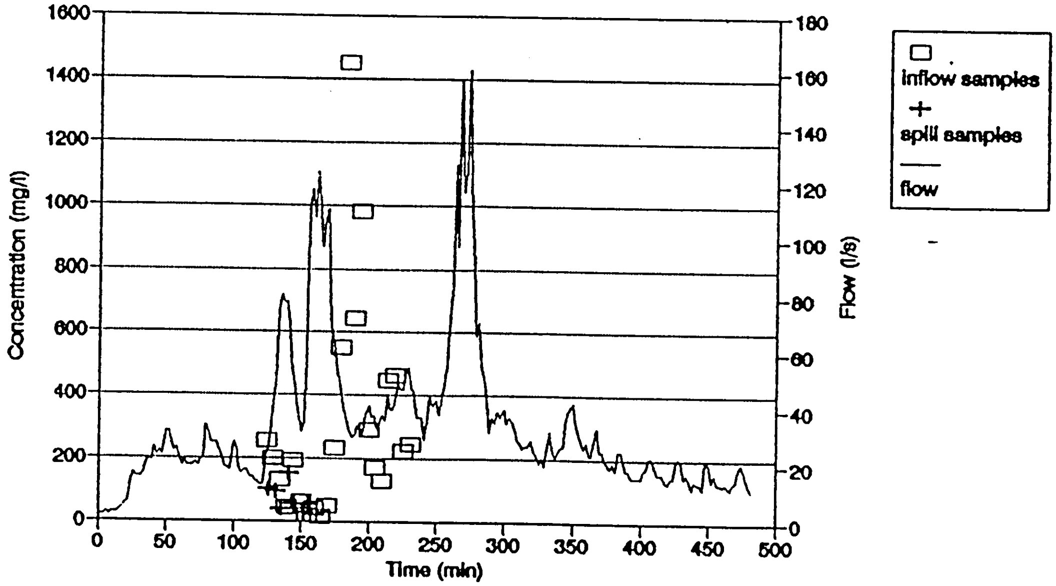


Retford Road 21 July 1991
Suspended Solids



Retford Road 21 July 1991
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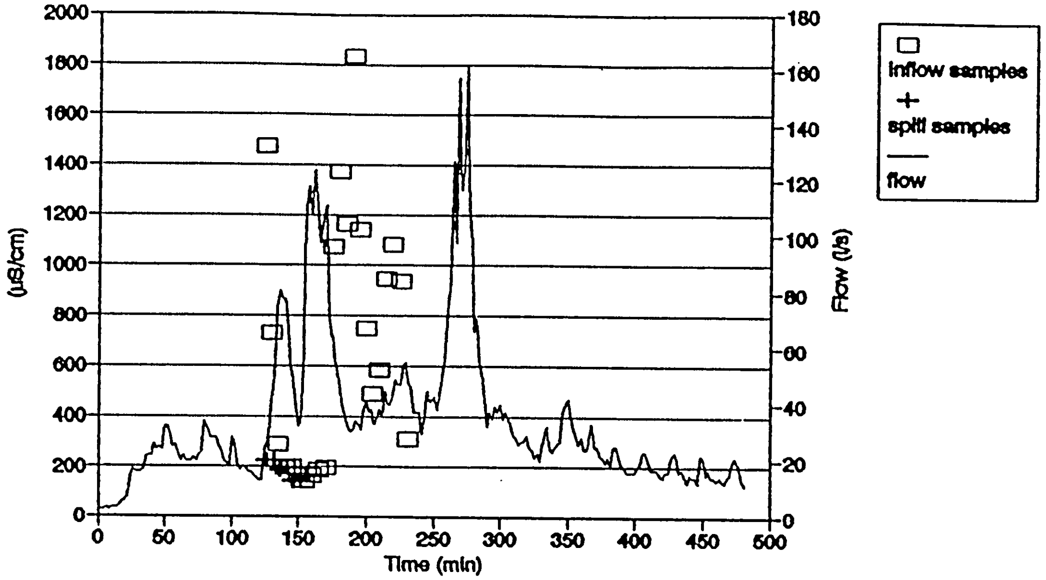

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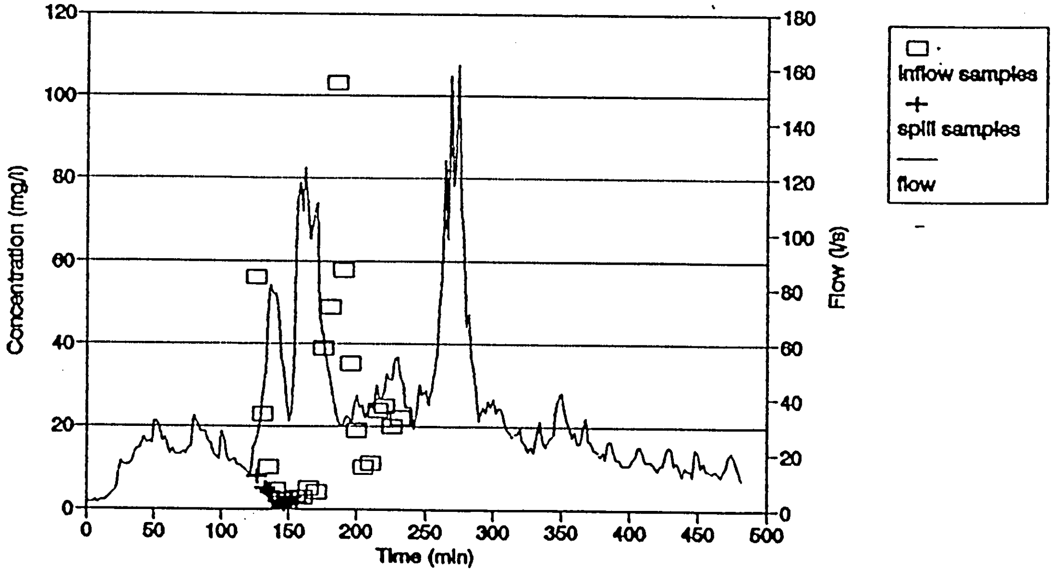

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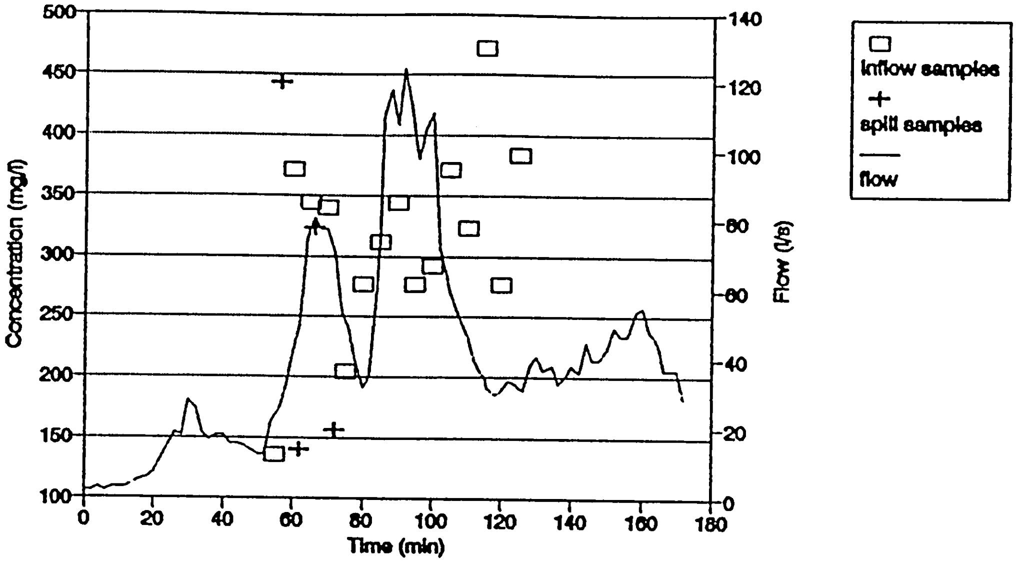
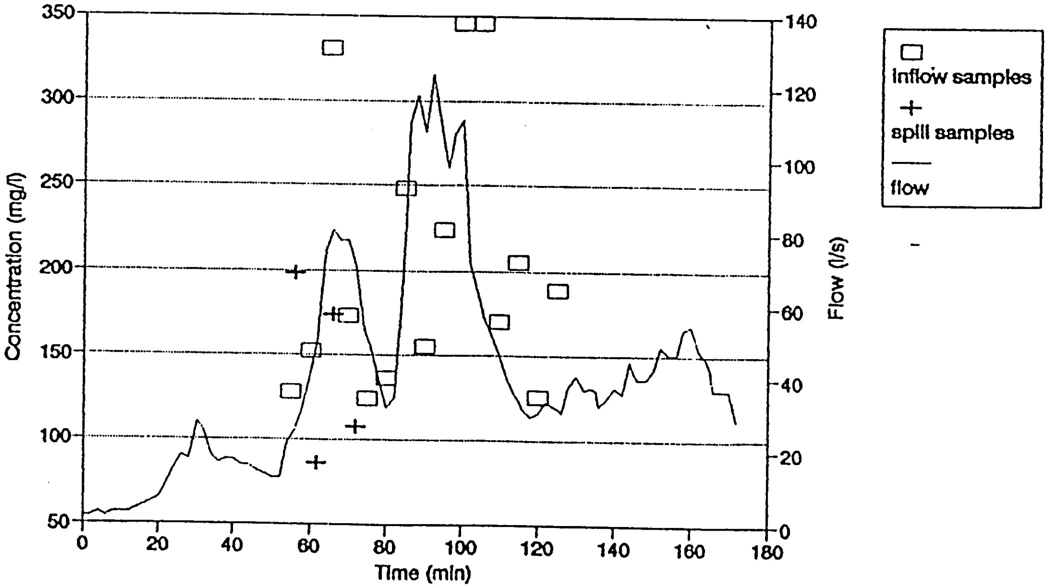


Retford Road 23 July 1991
Suspended Solids



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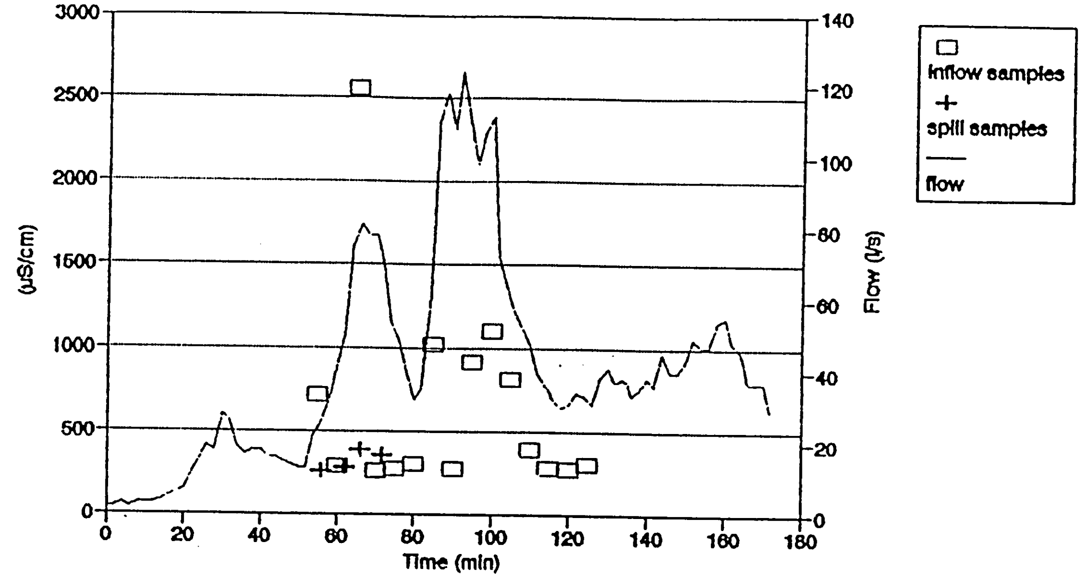

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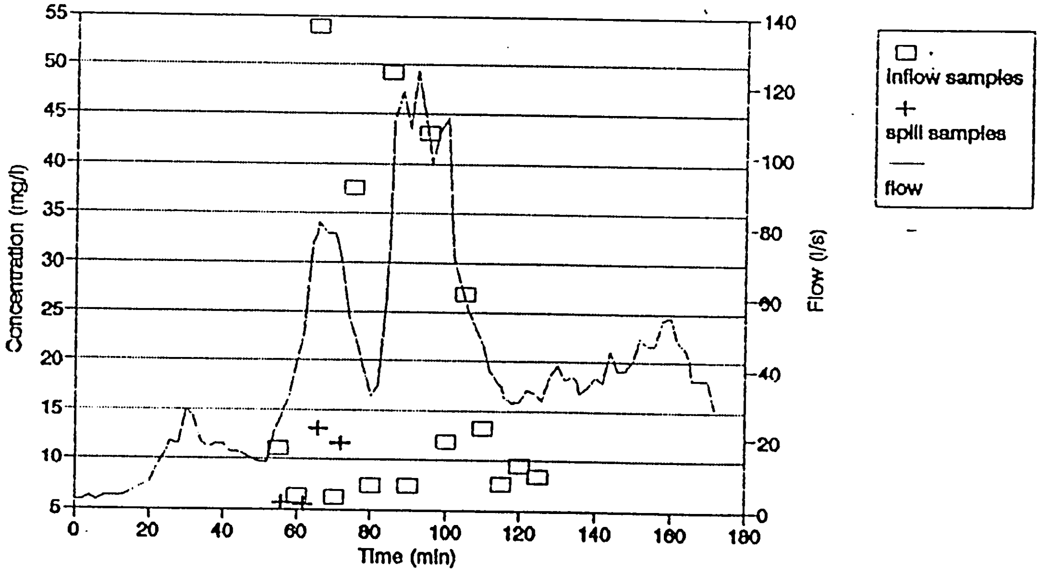

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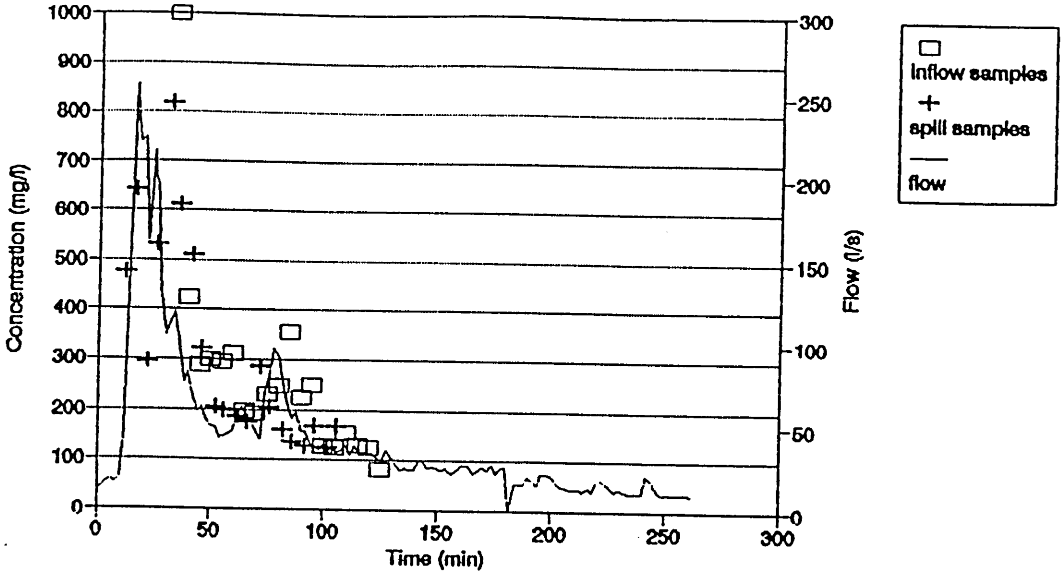

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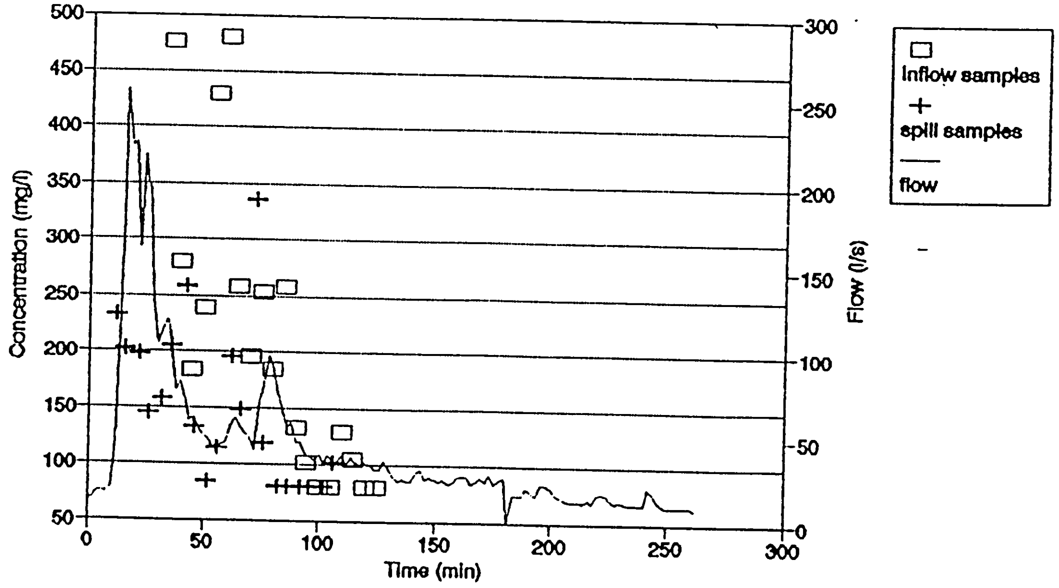

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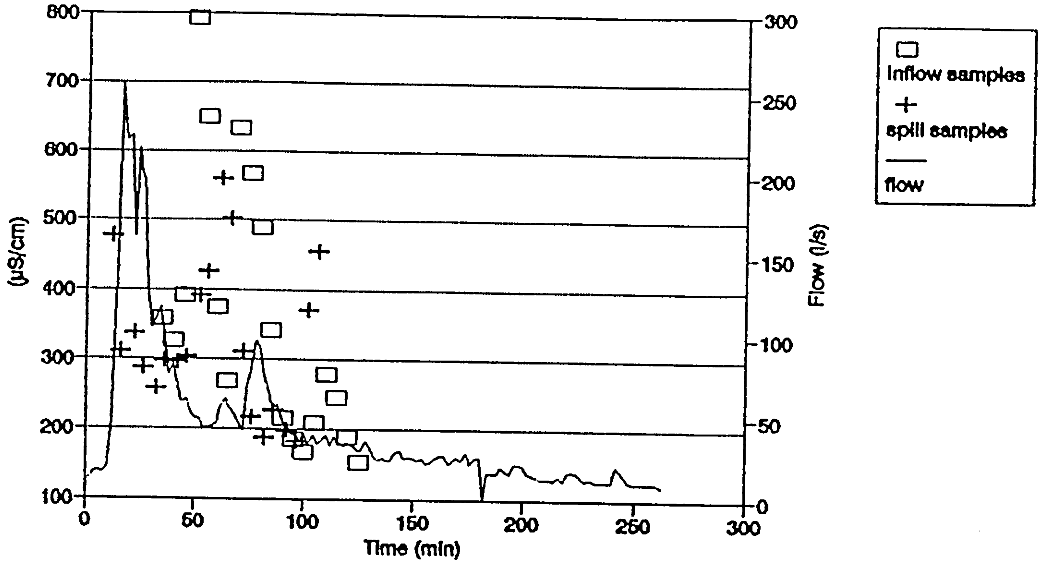

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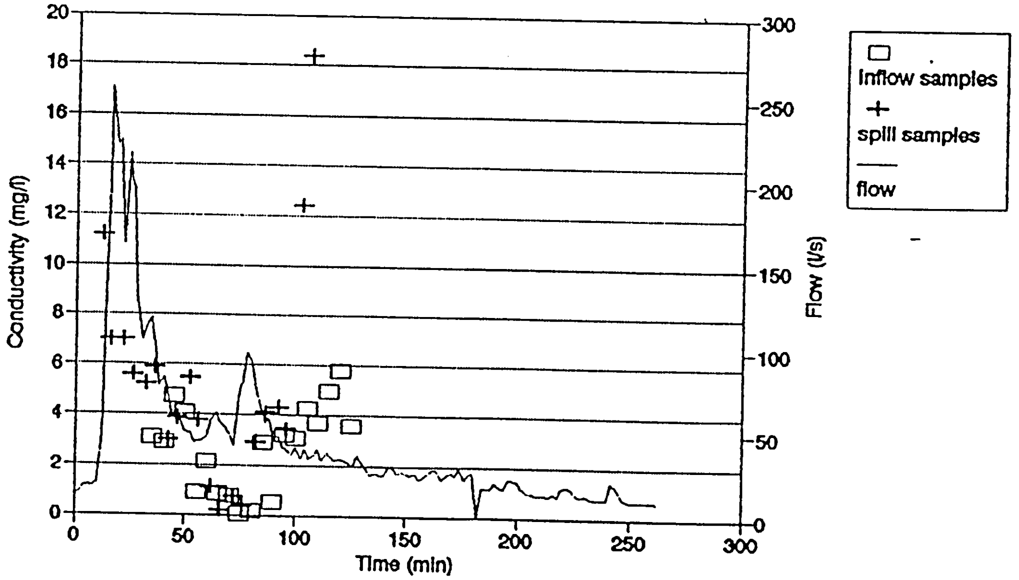

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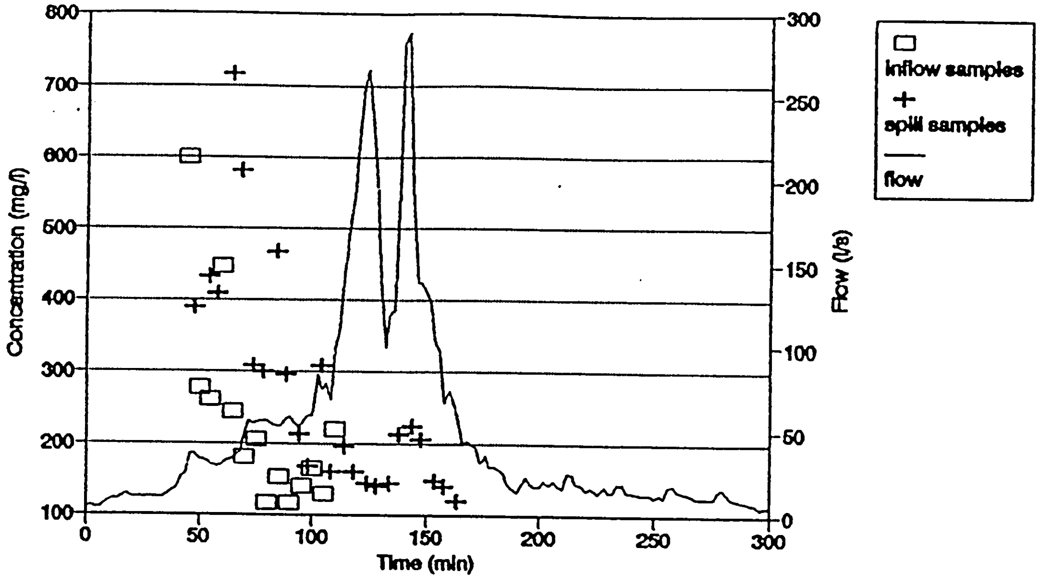

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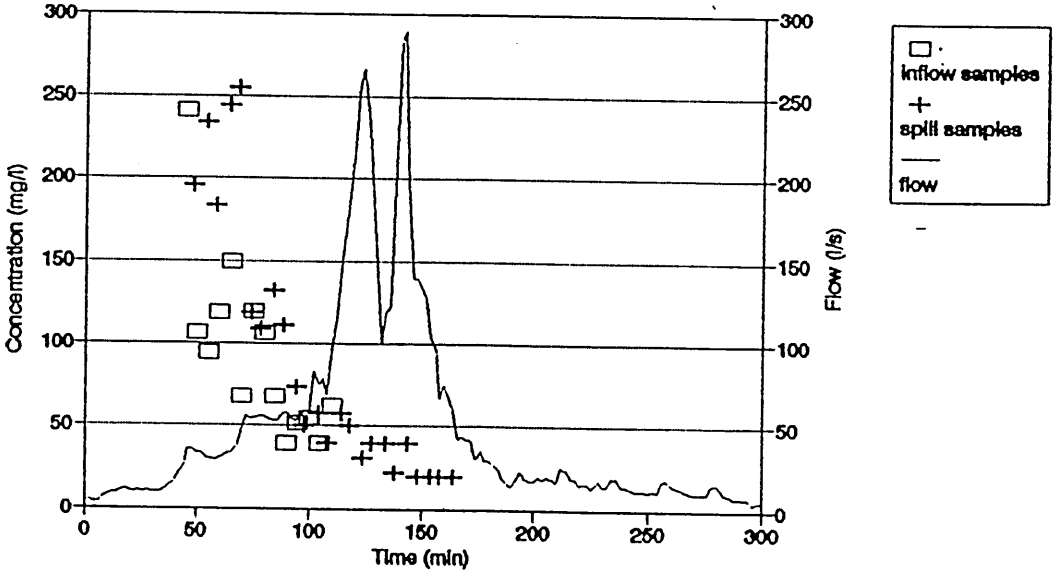

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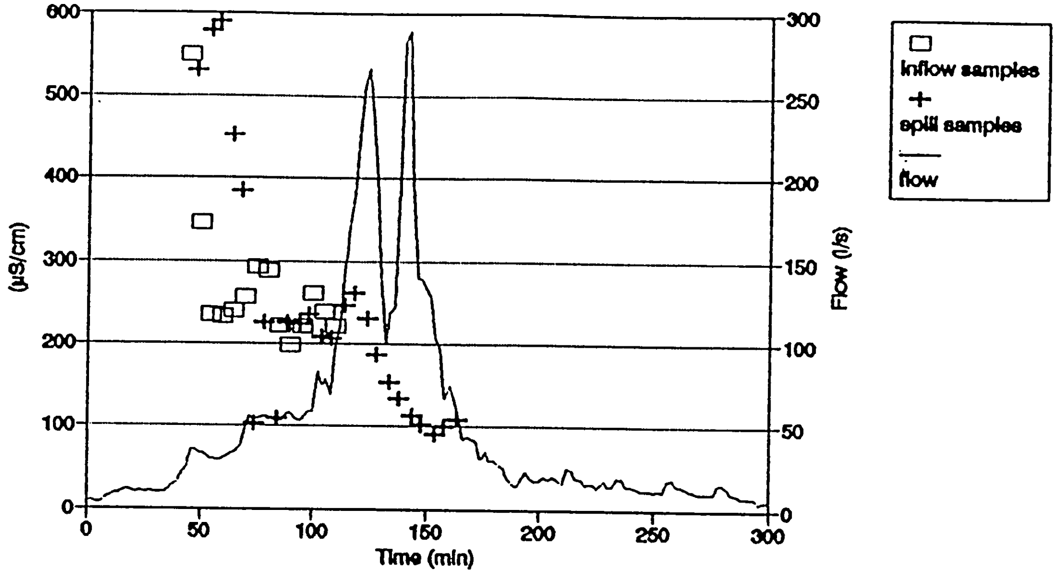

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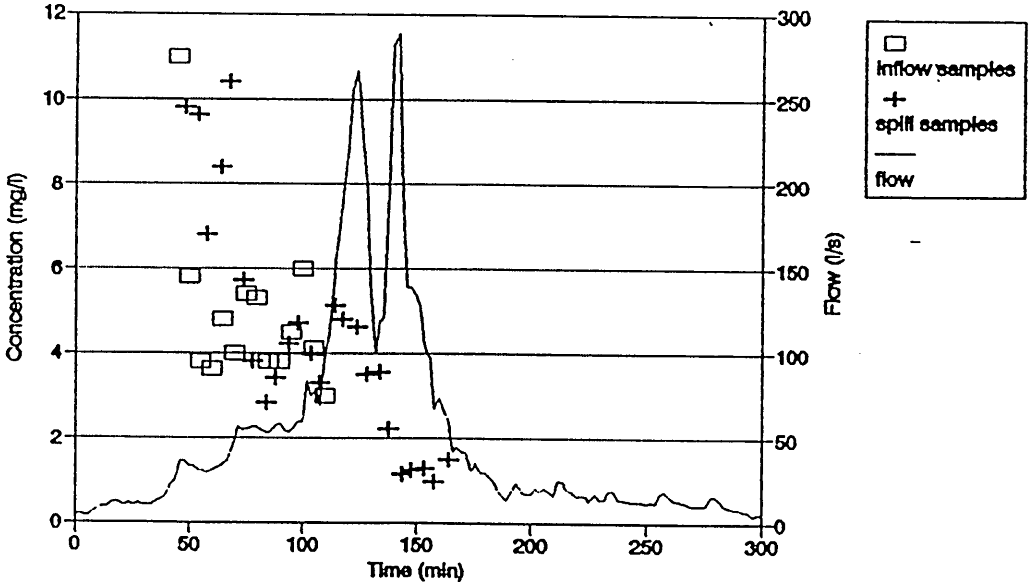

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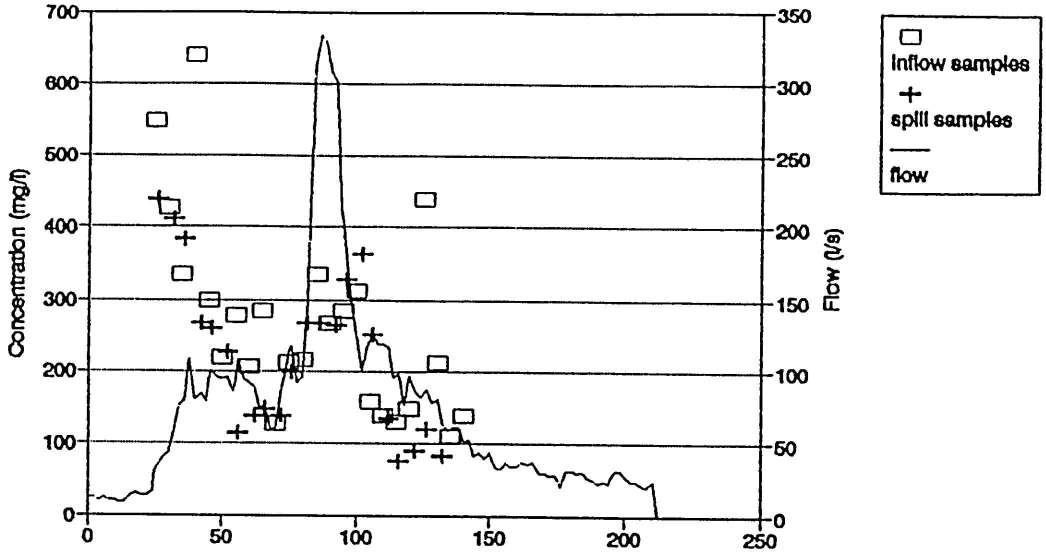

Retford Road 28 October 1991
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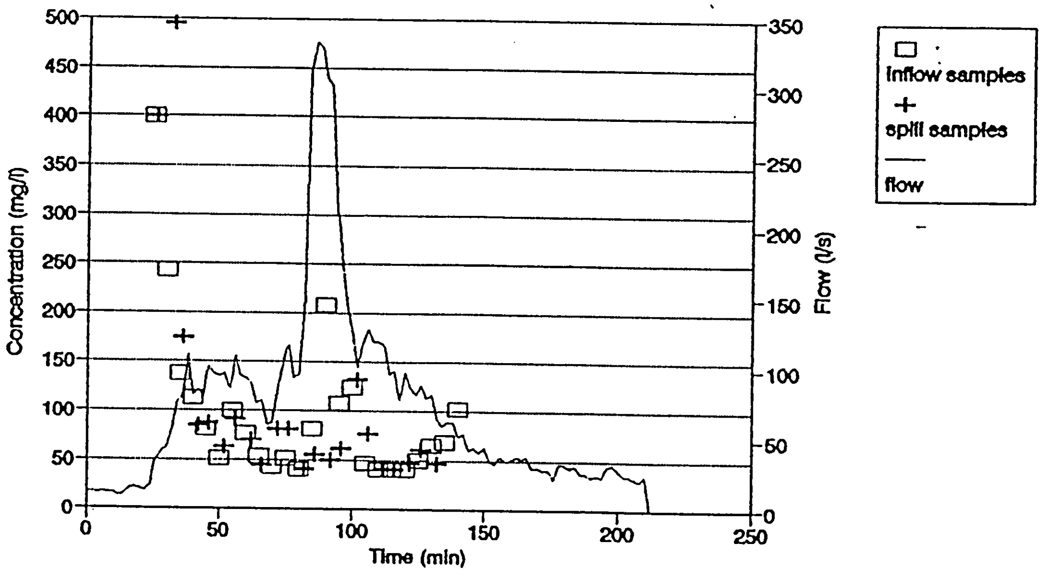

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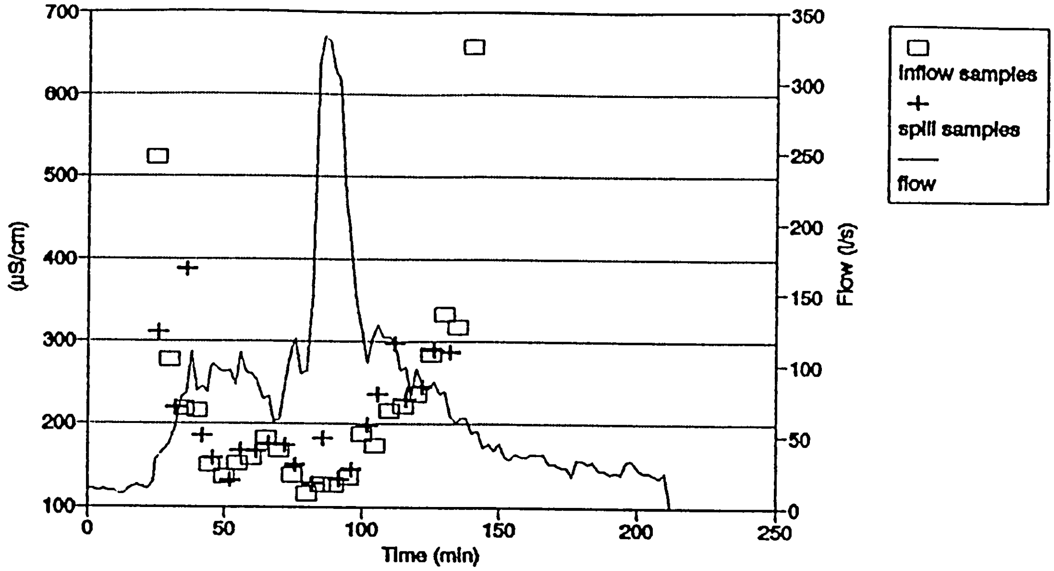

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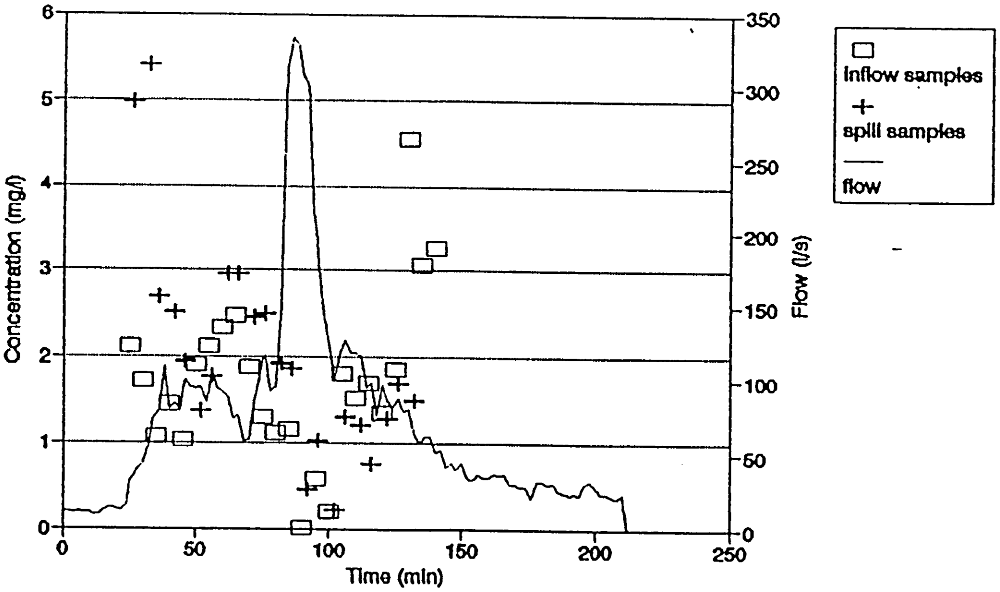

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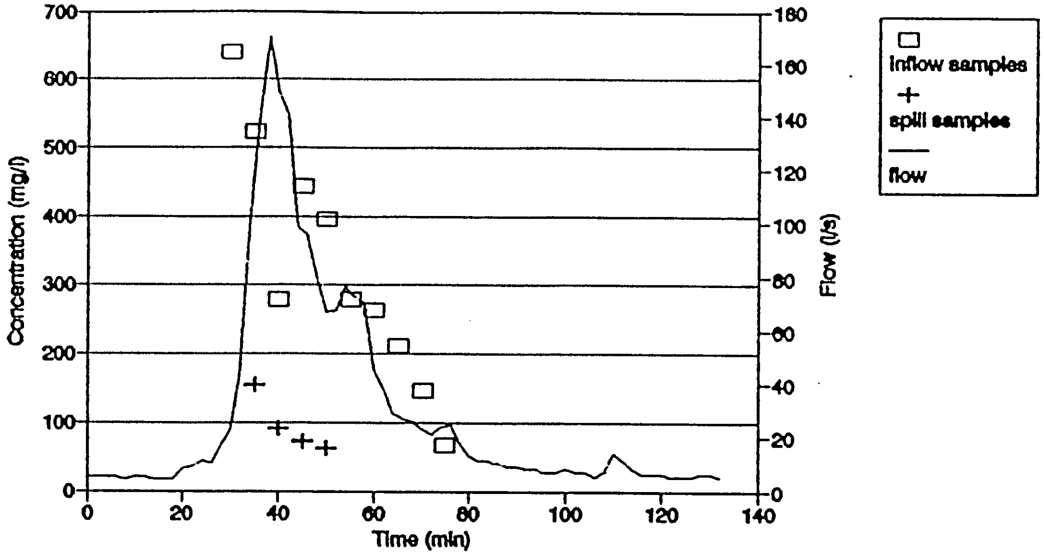

Retford Road 19 November 1991
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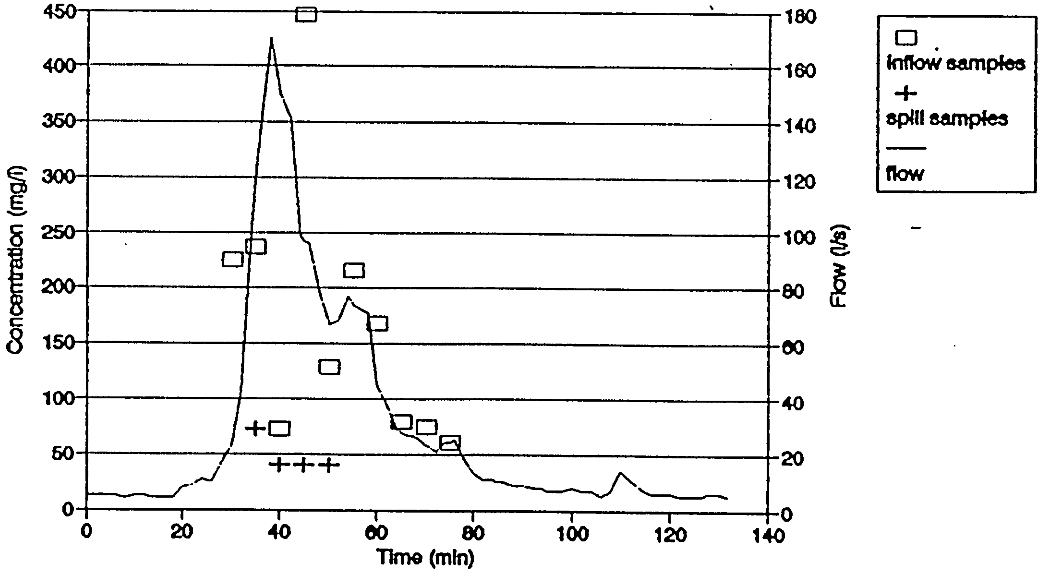

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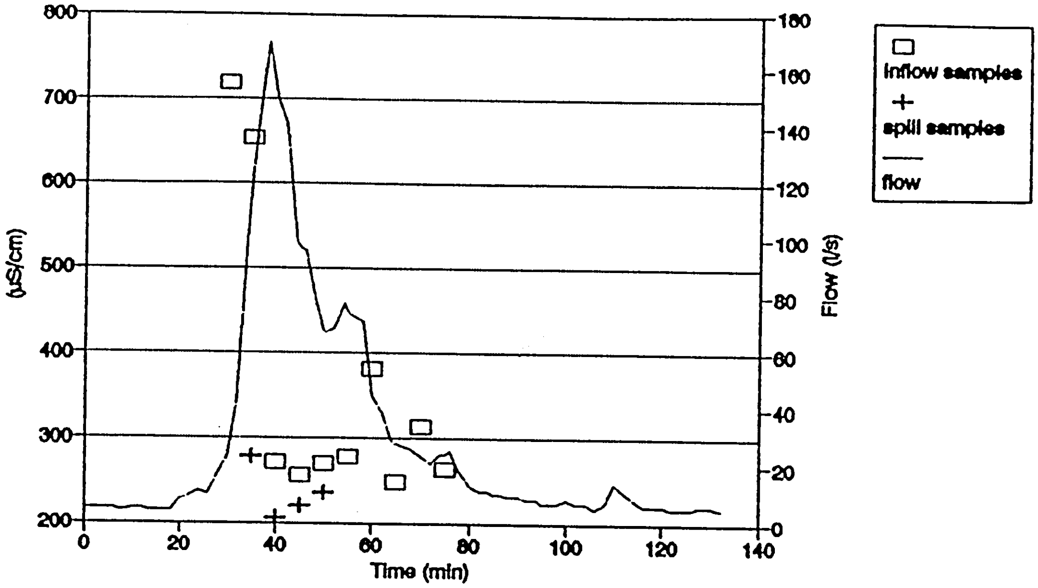

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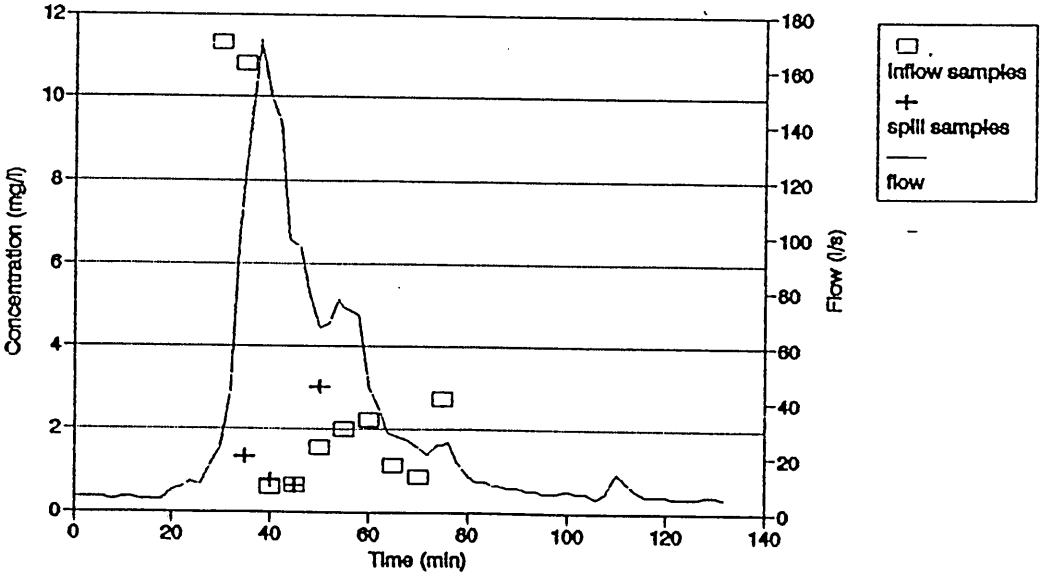

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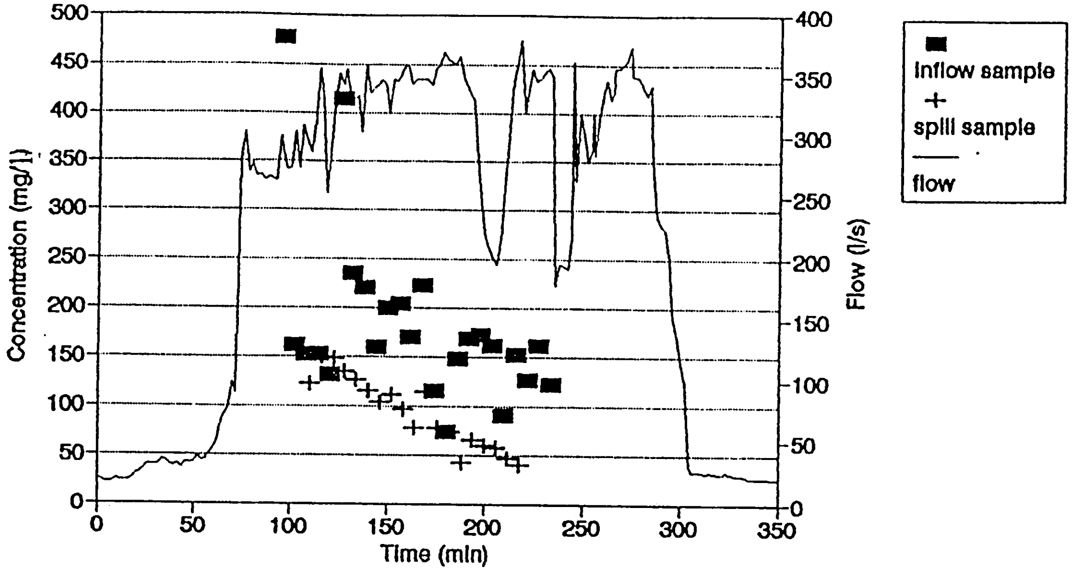
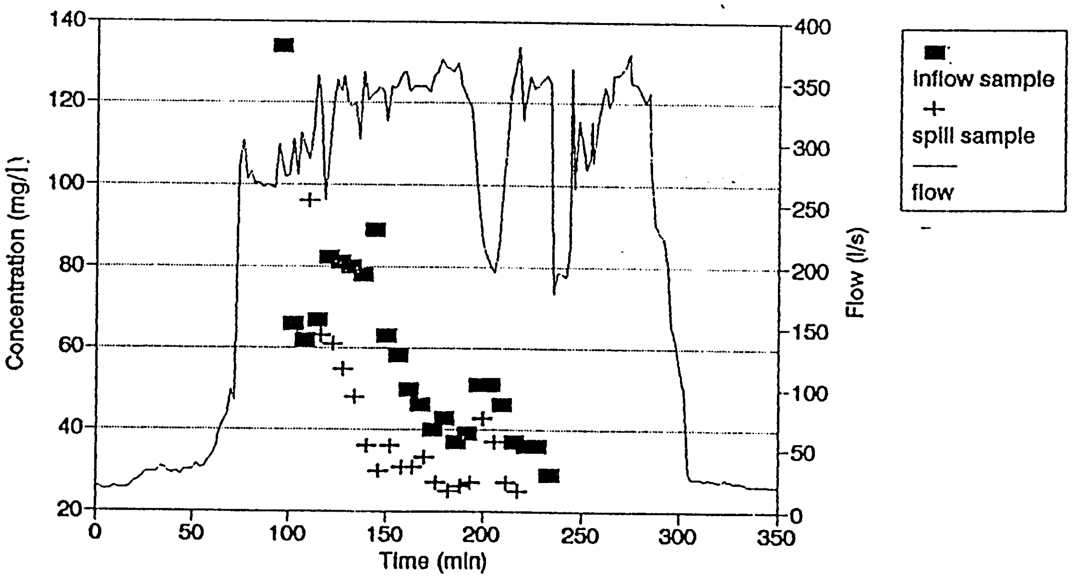


Leyburn Road 9 November 1992
Suspended Solids



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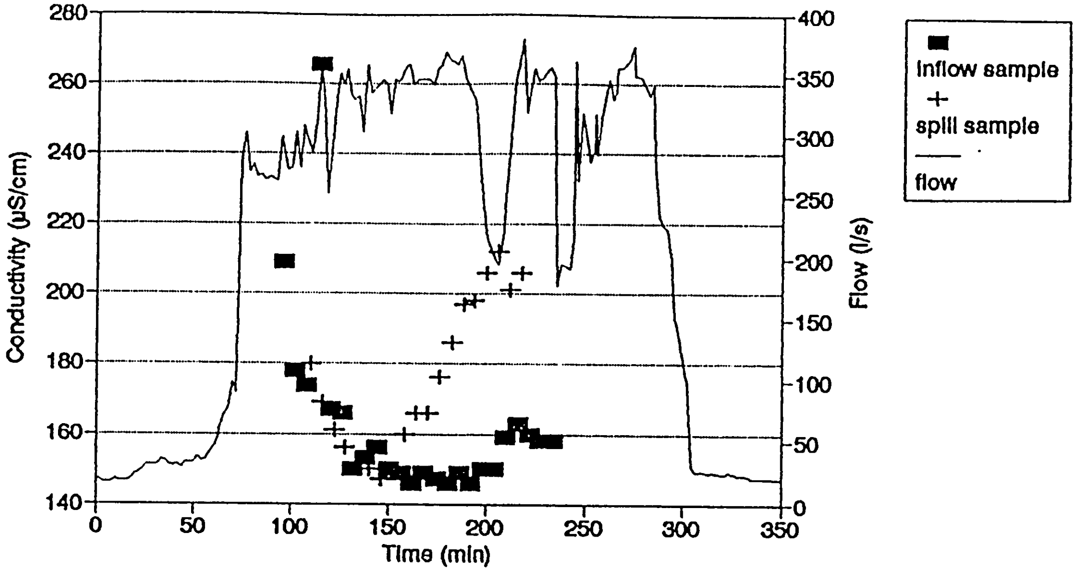

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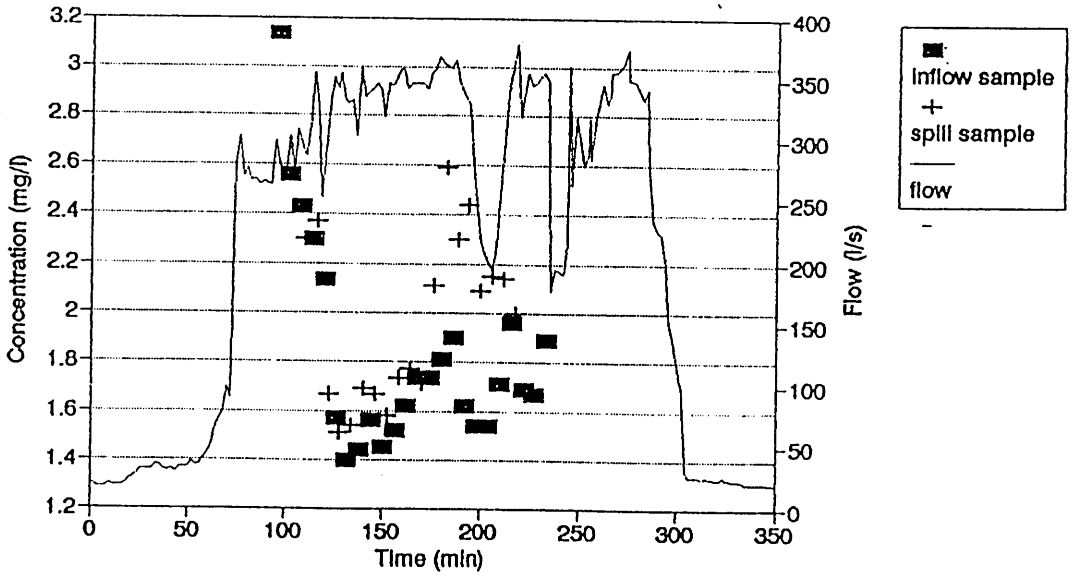

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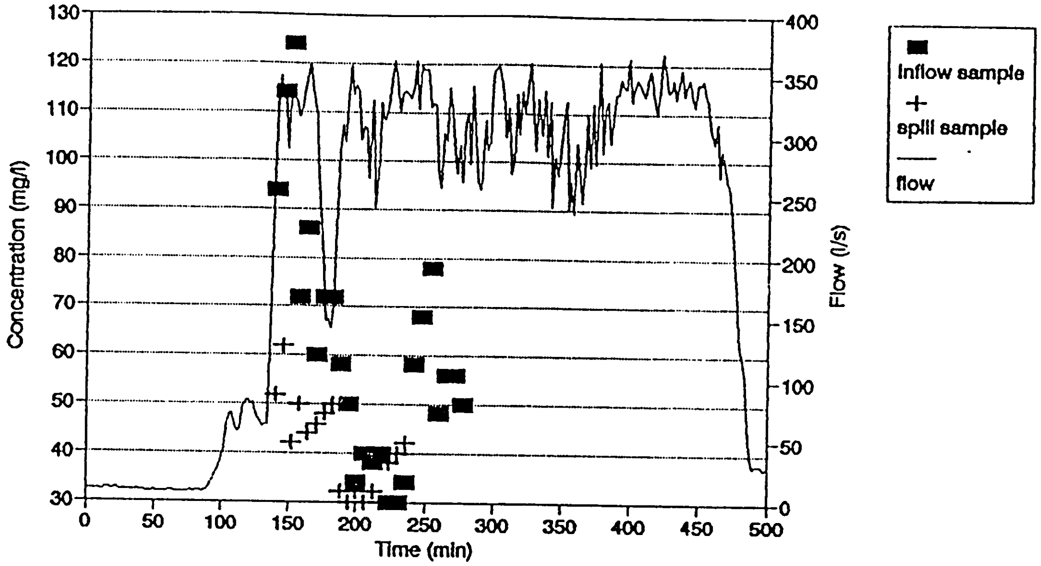

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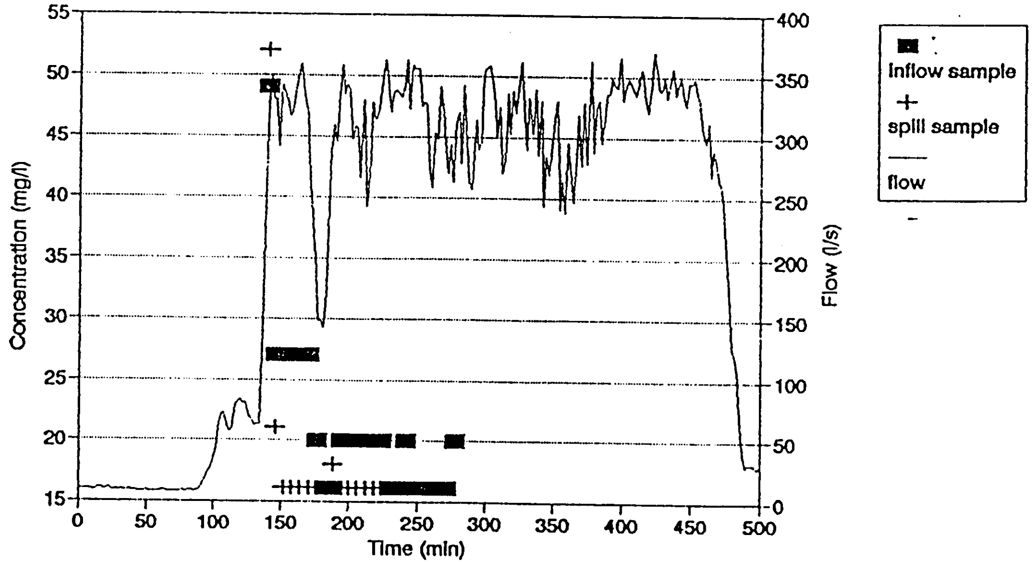

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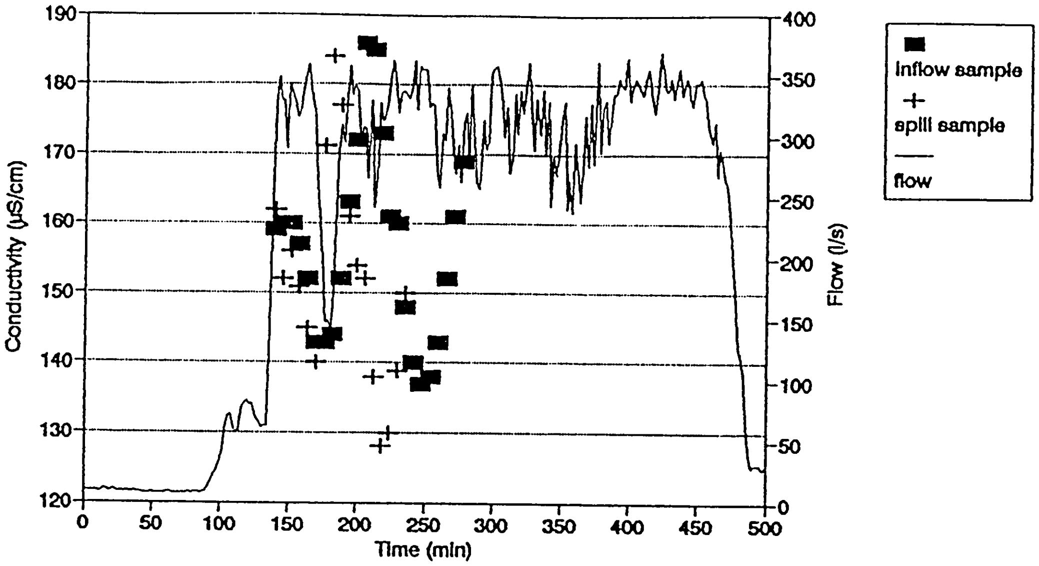

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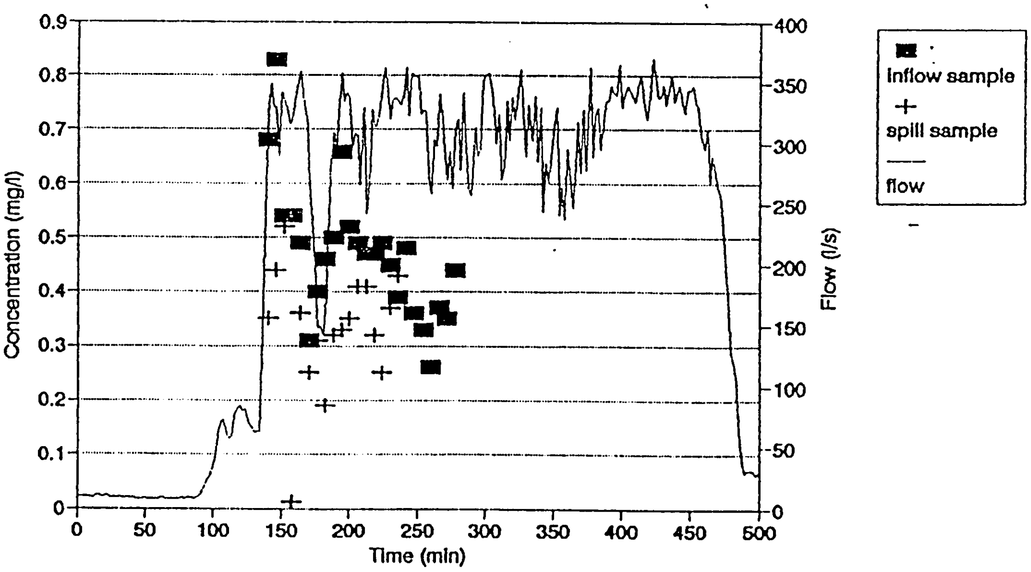

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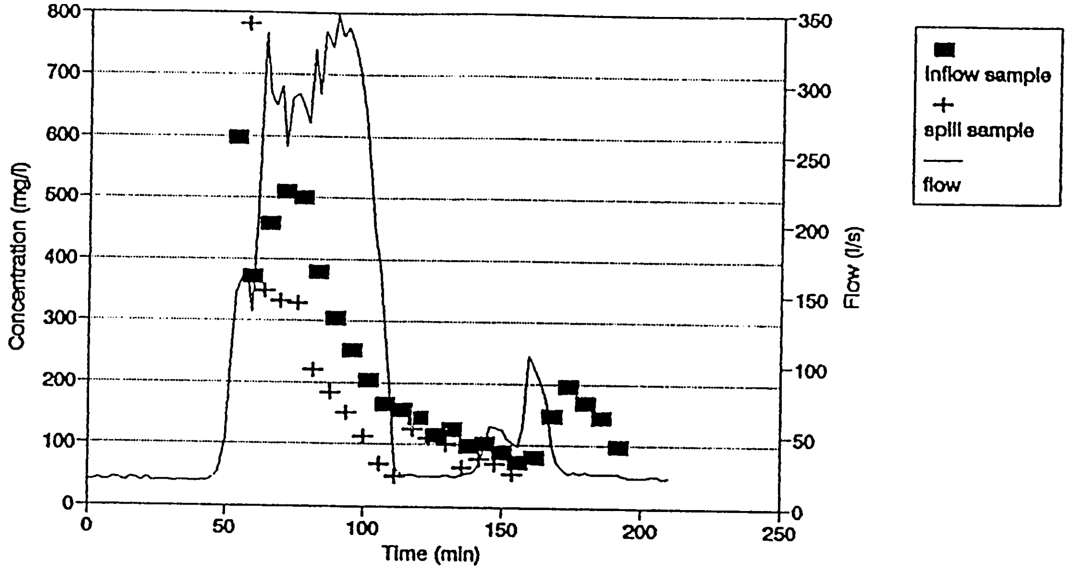

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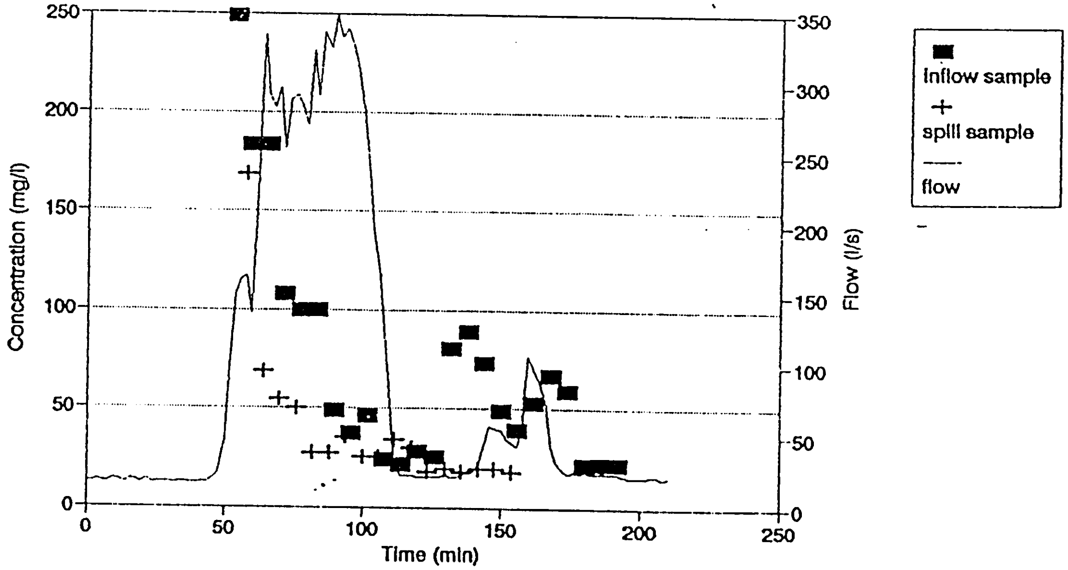

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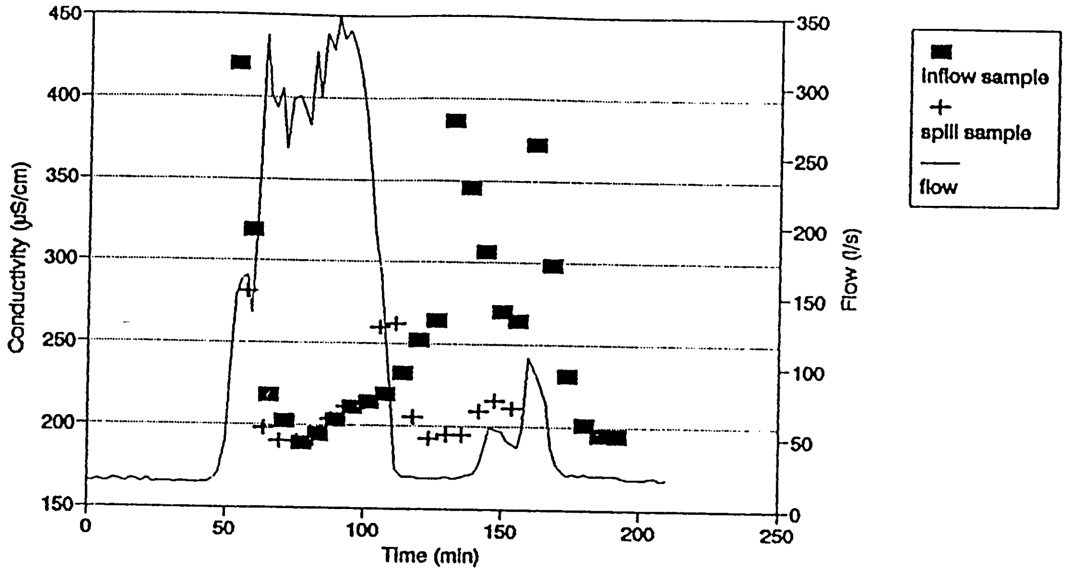

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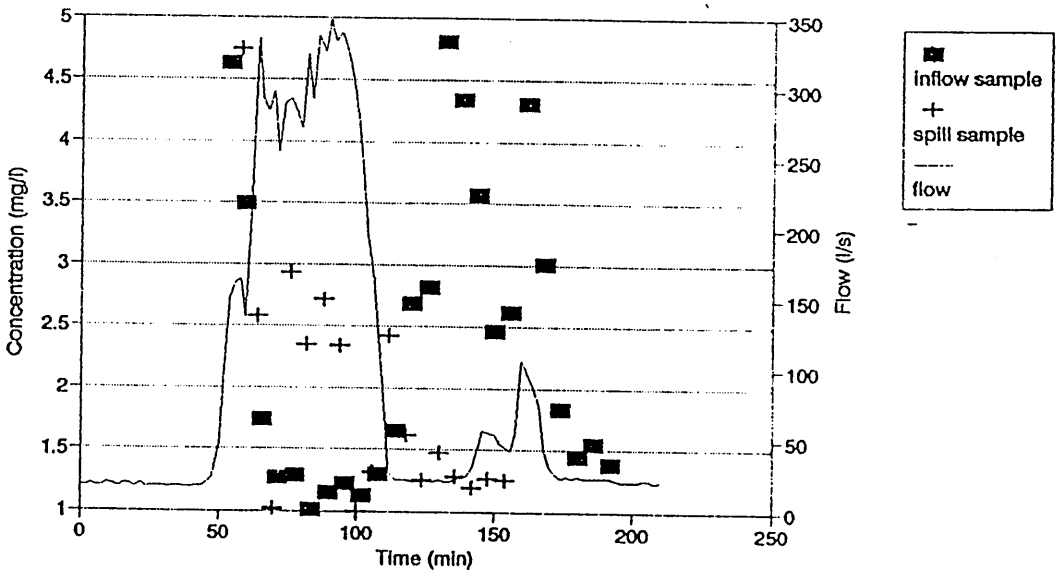

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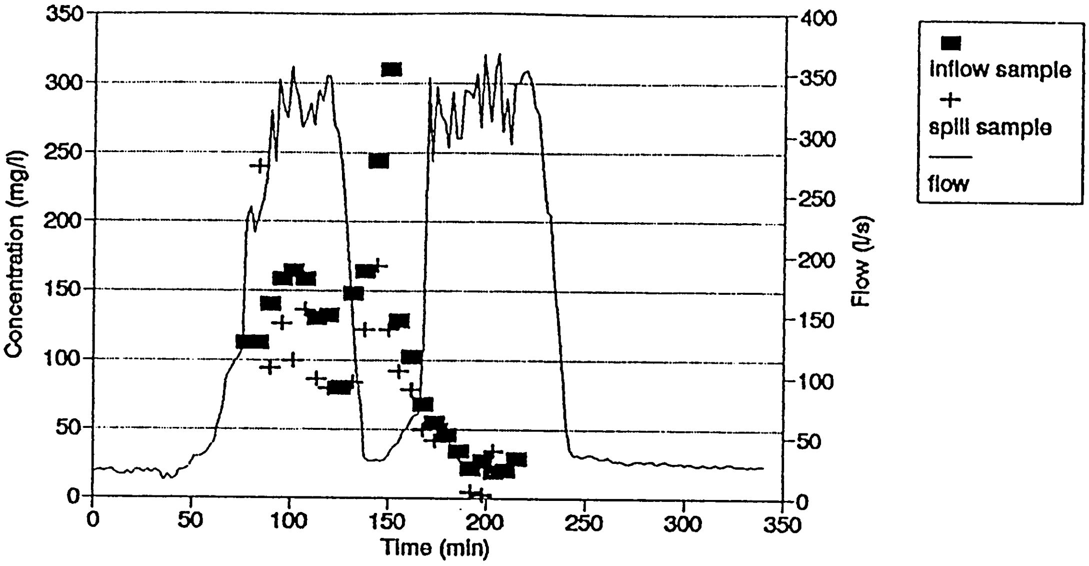

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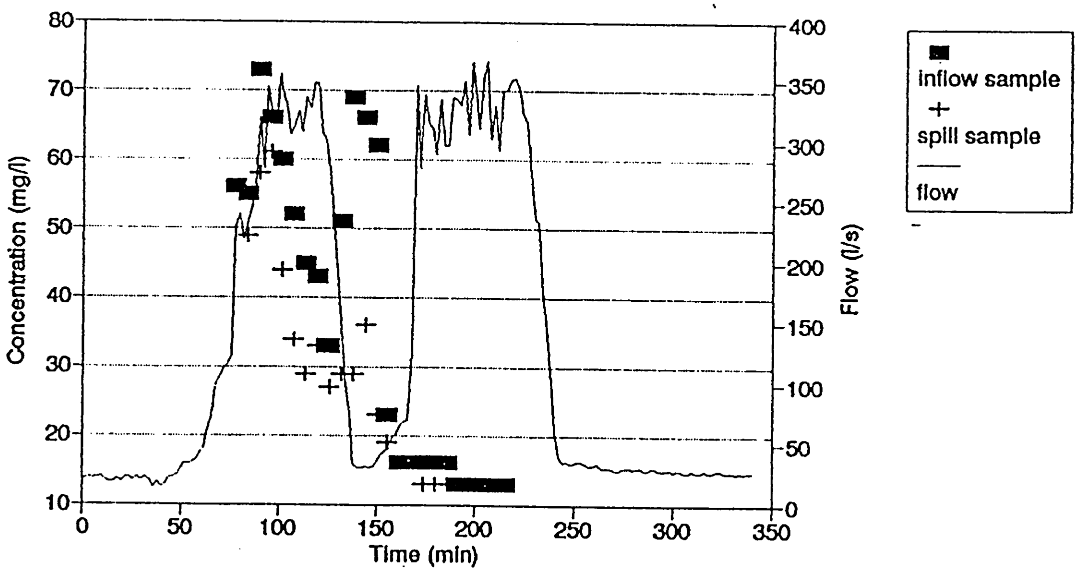

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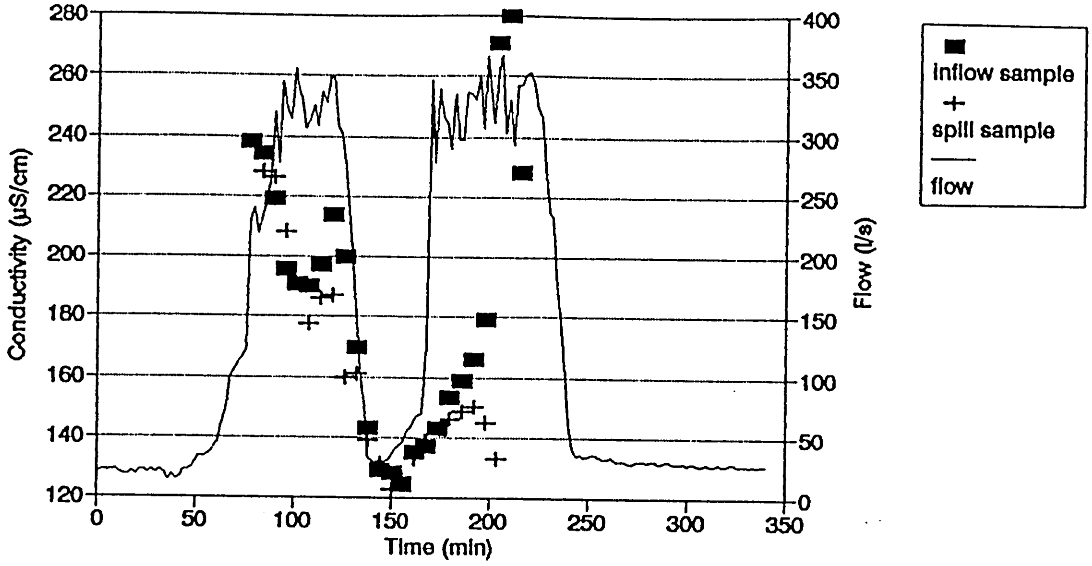

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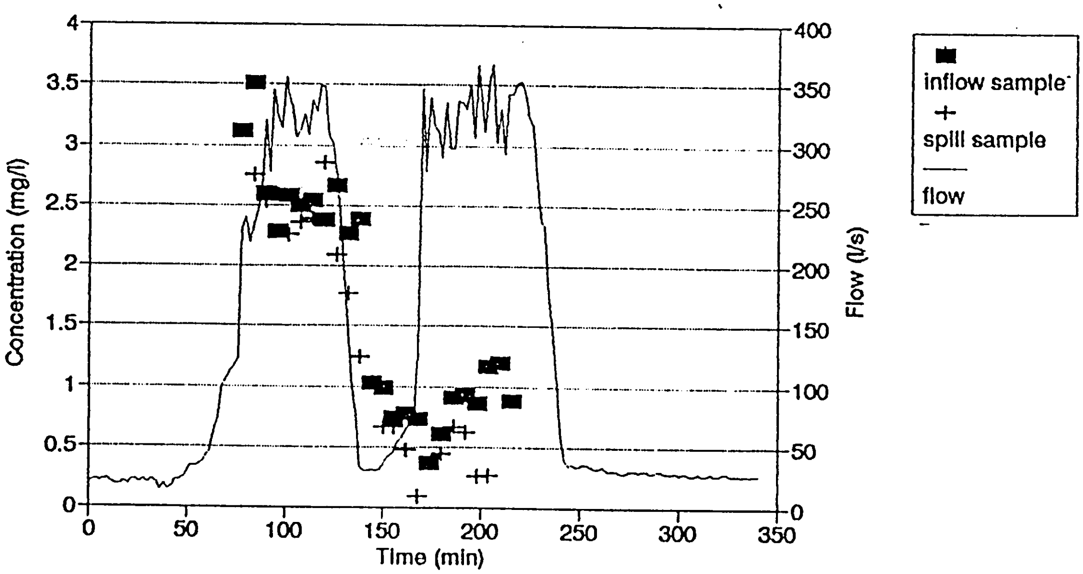

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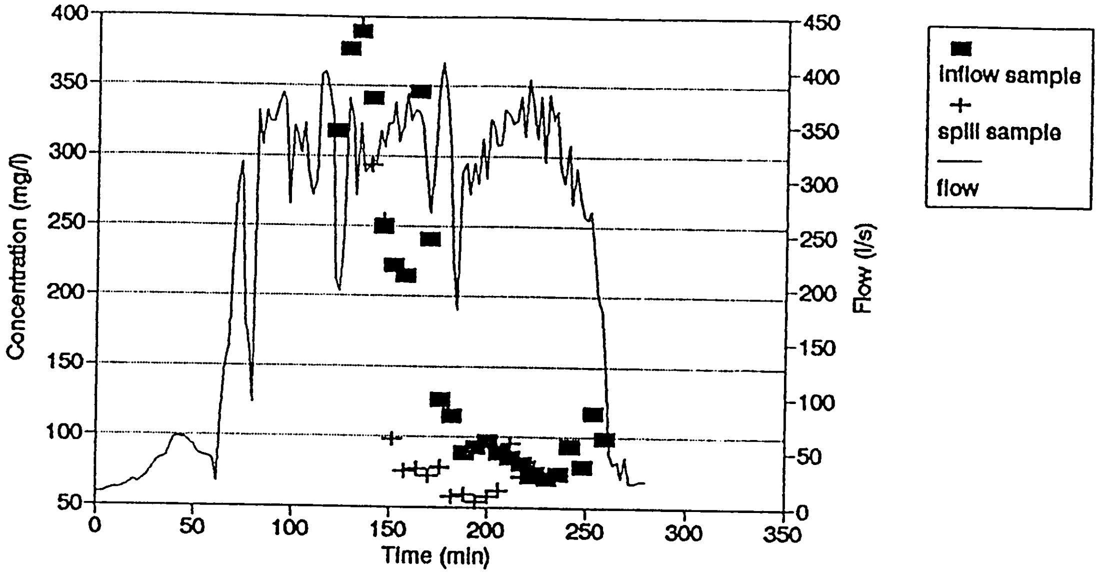

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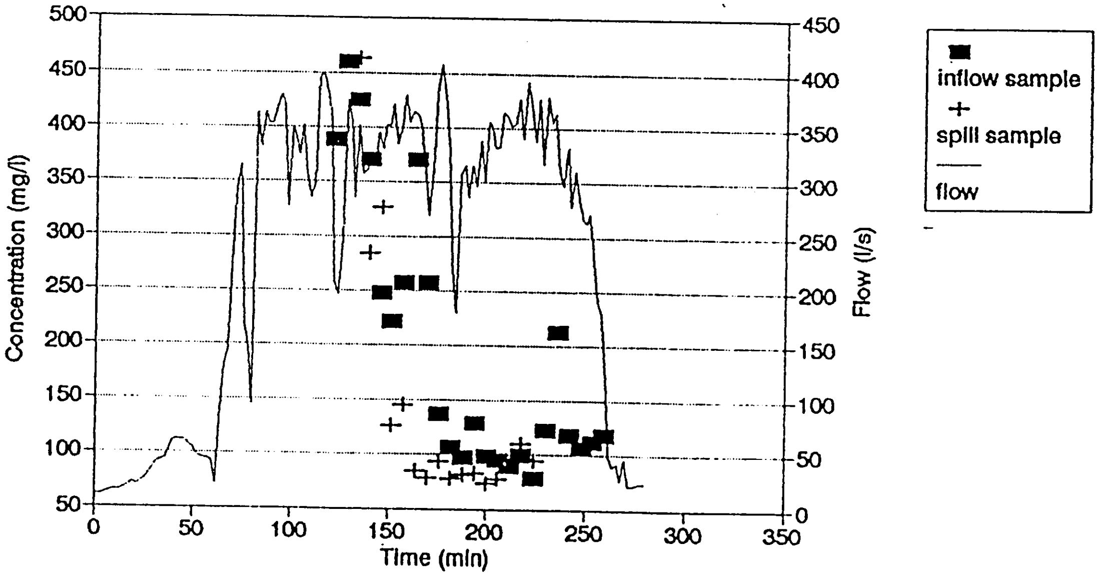

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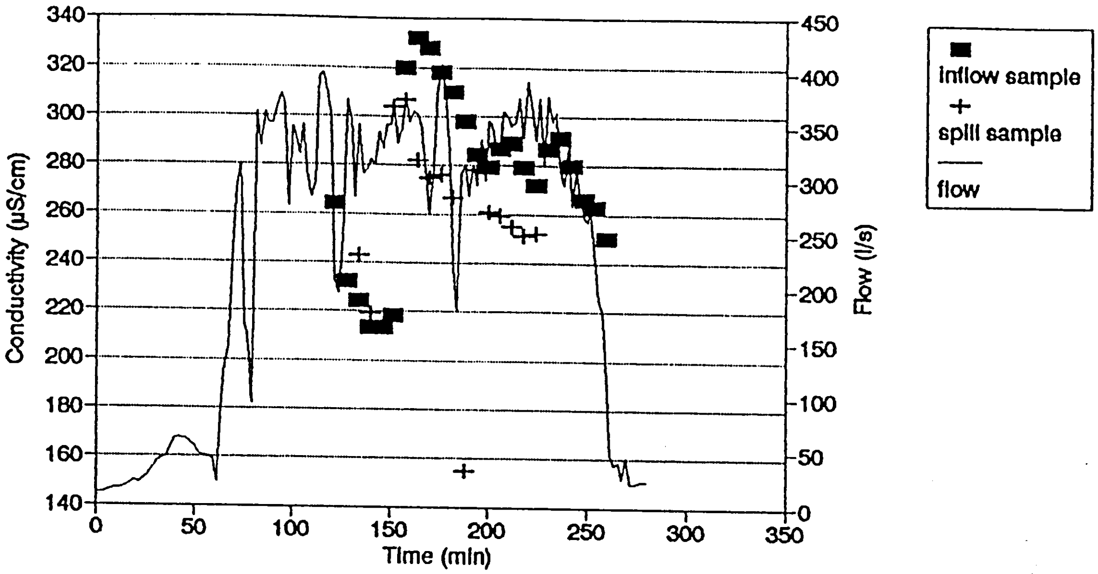

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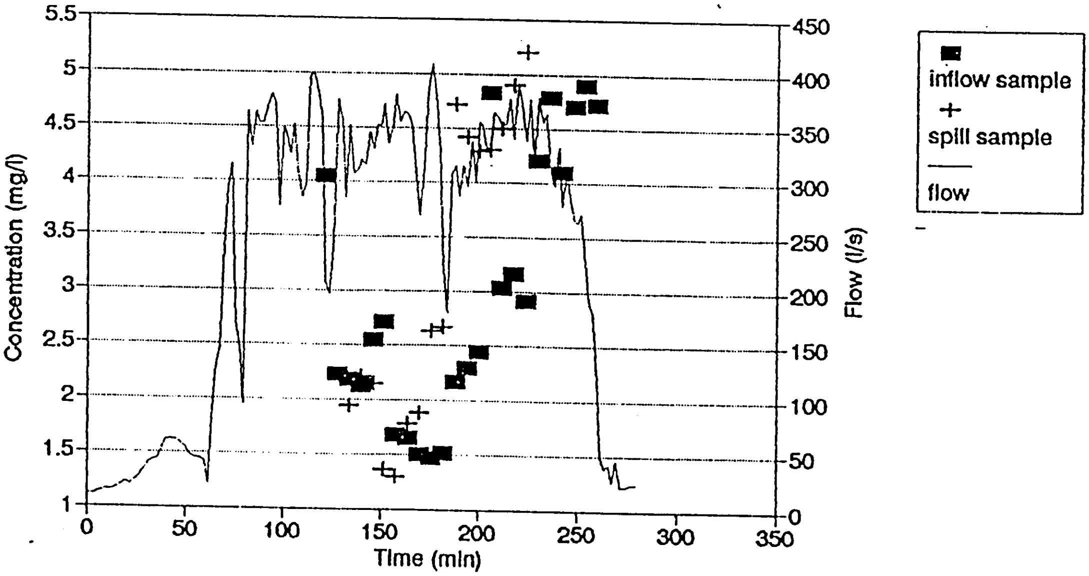

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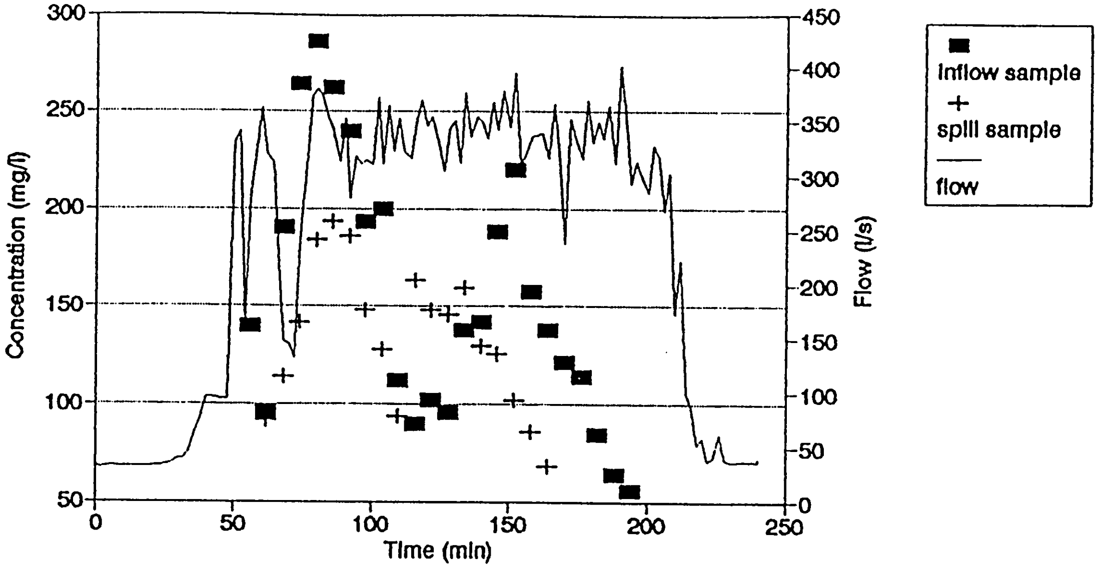

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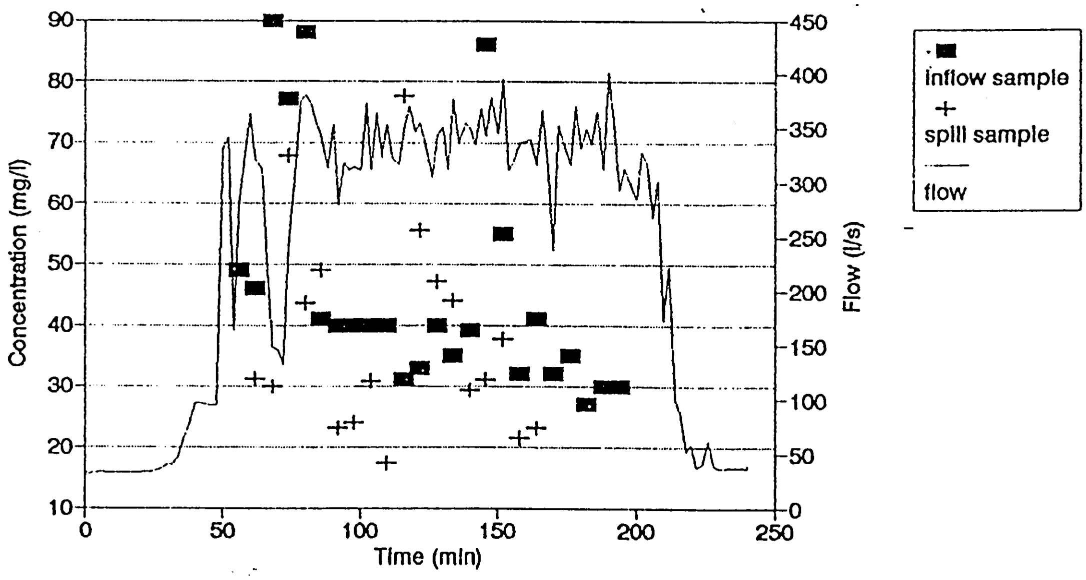

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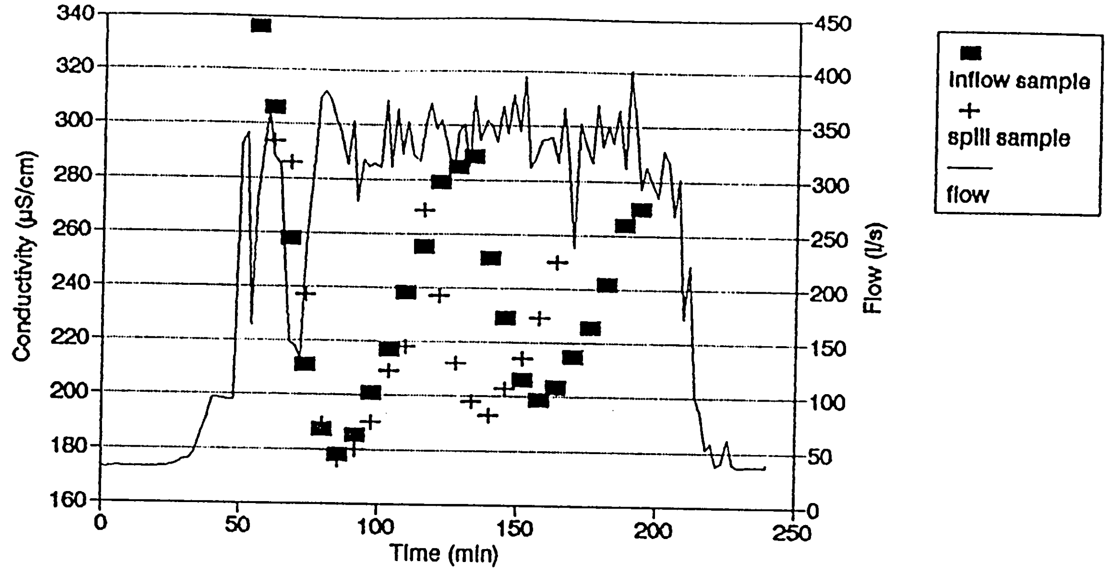

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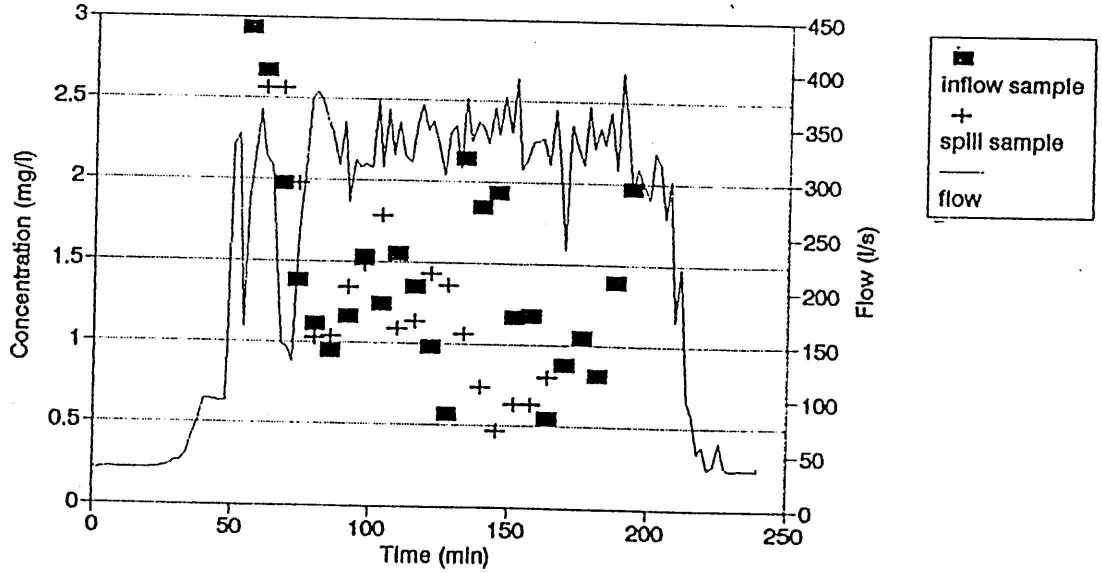

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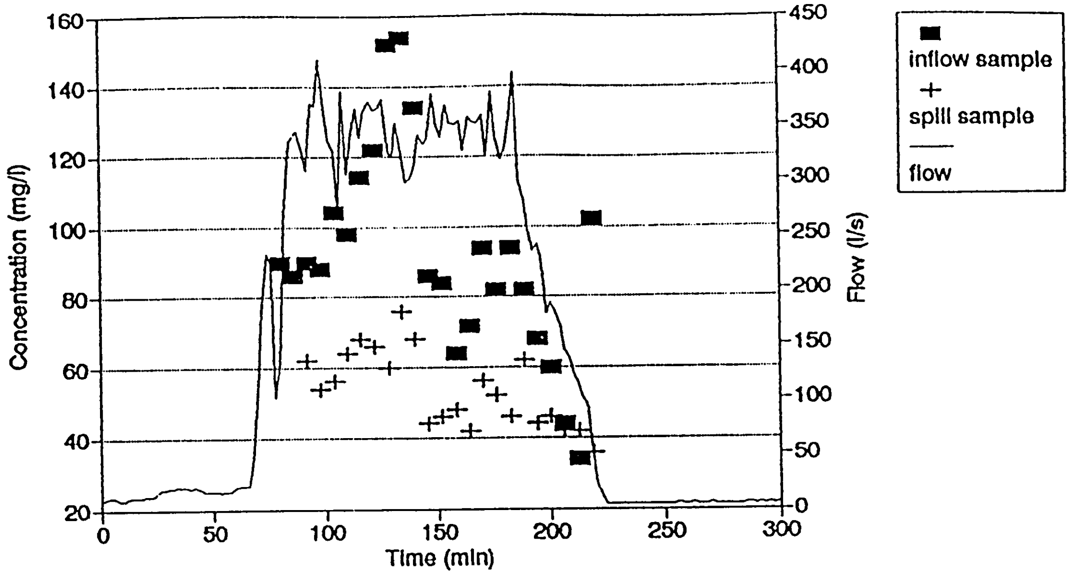
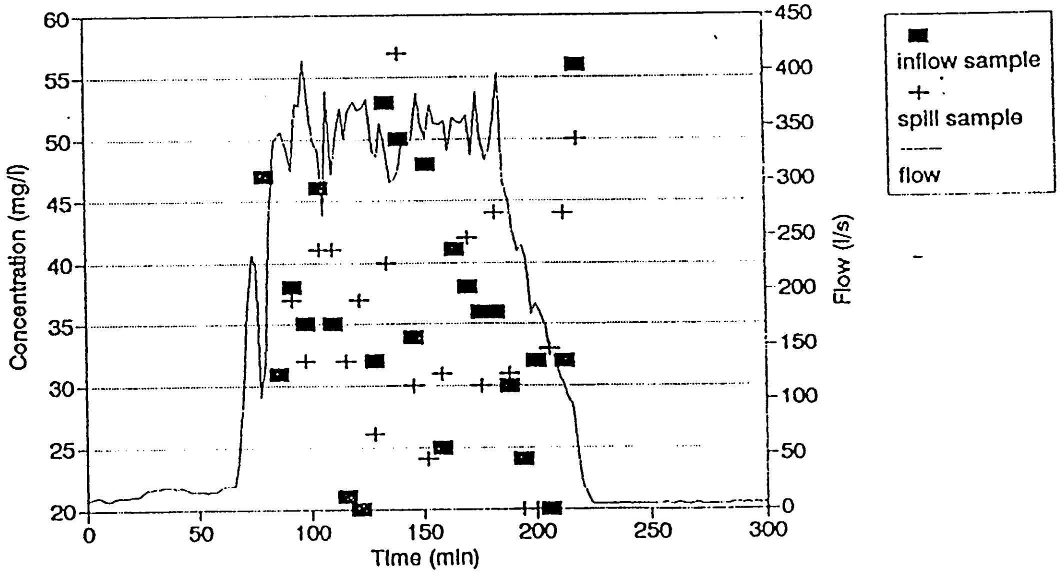


Leyburn Road 3 December 1992
Suspended Solids



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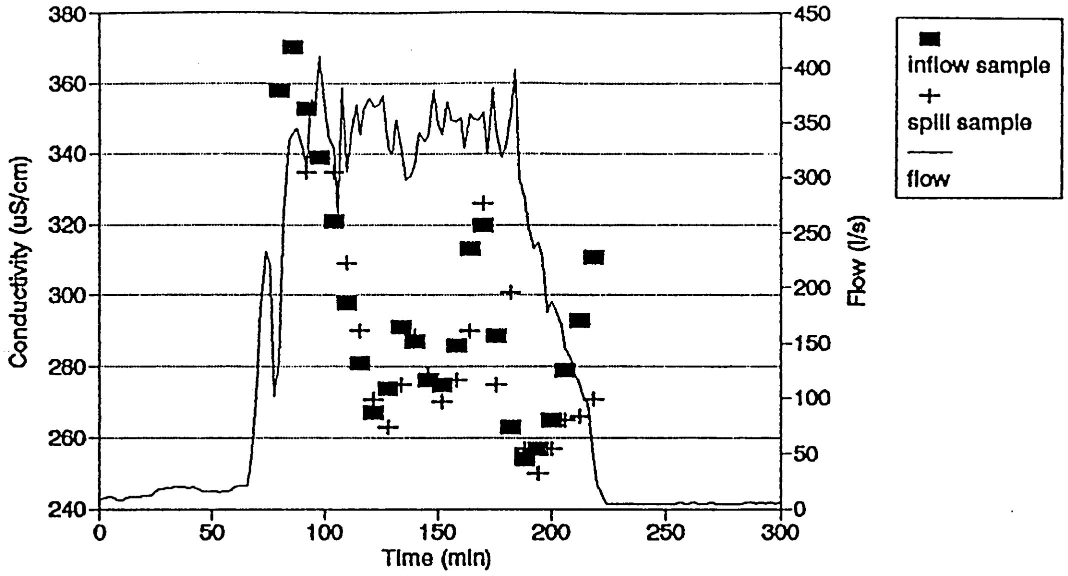

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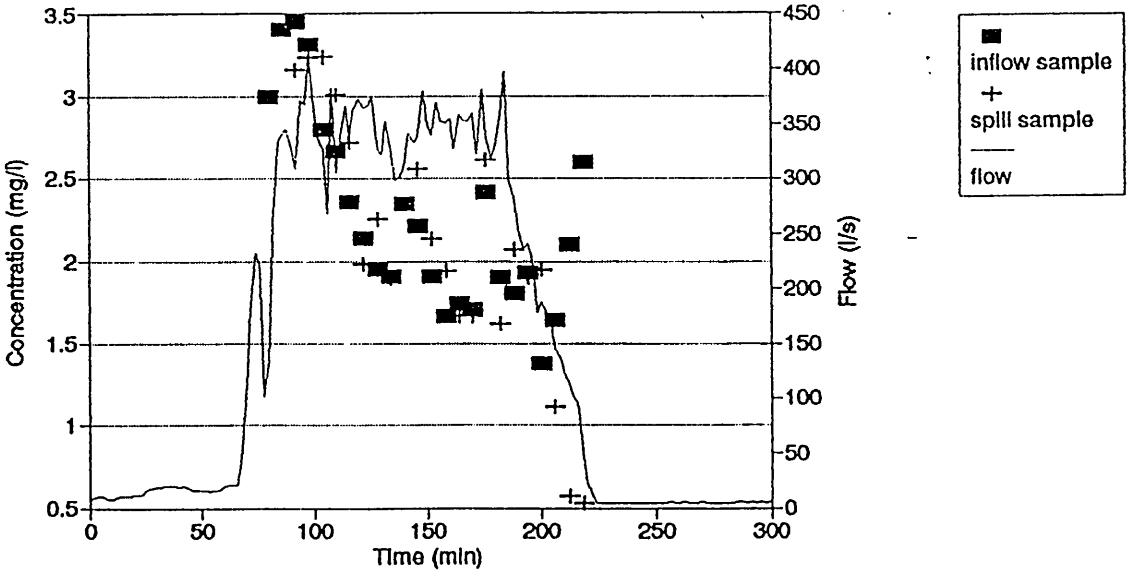
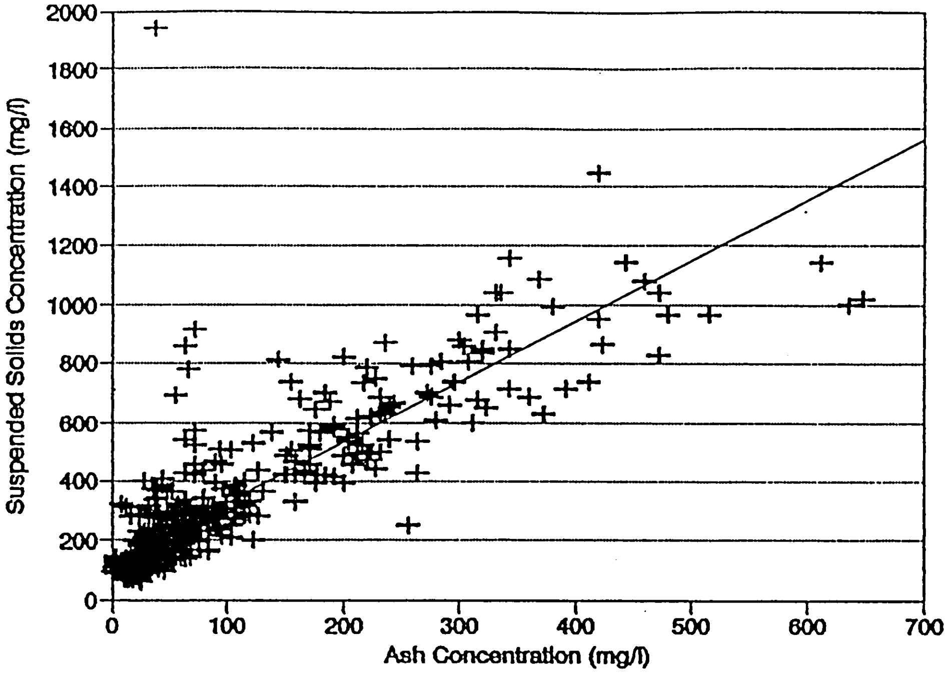
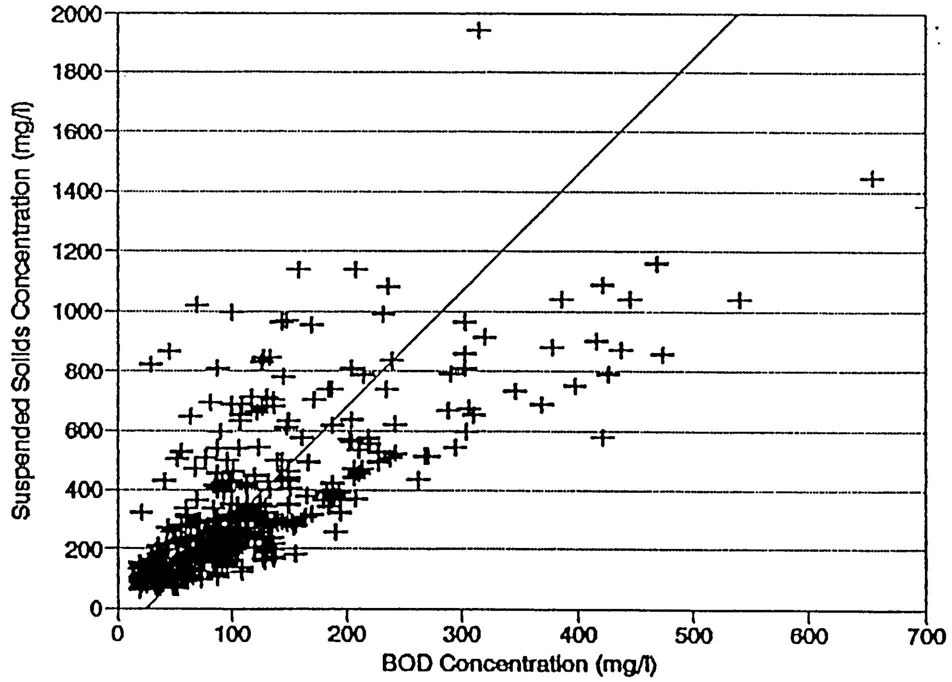


Leyburn Road 3 December 1992
Ammonia

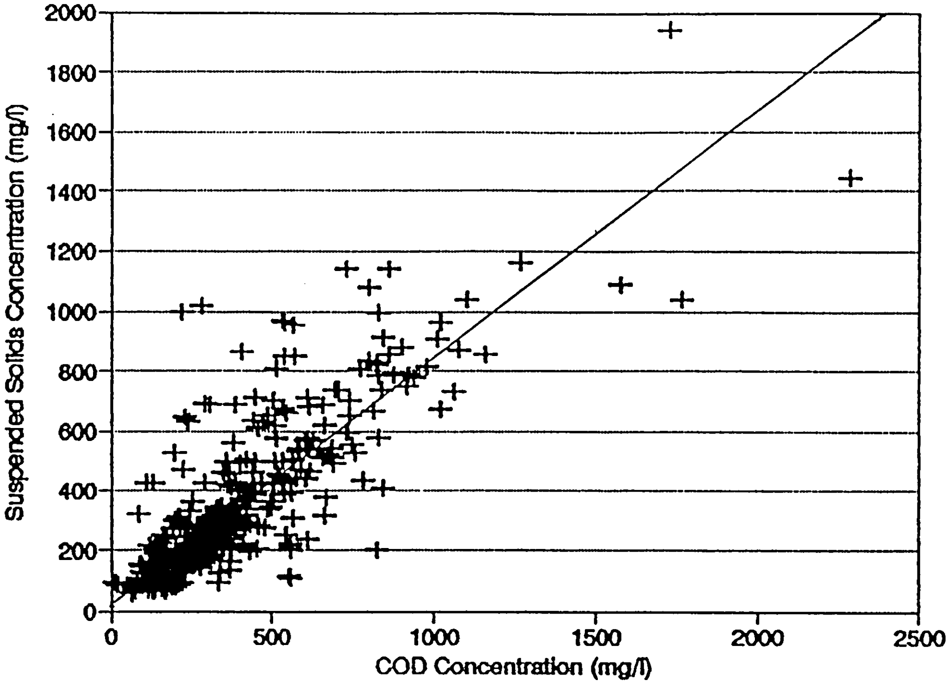
APPENDIX THREE: RELATIONSHIPS BETWEEN SAMPLE PARAMETER VALUES



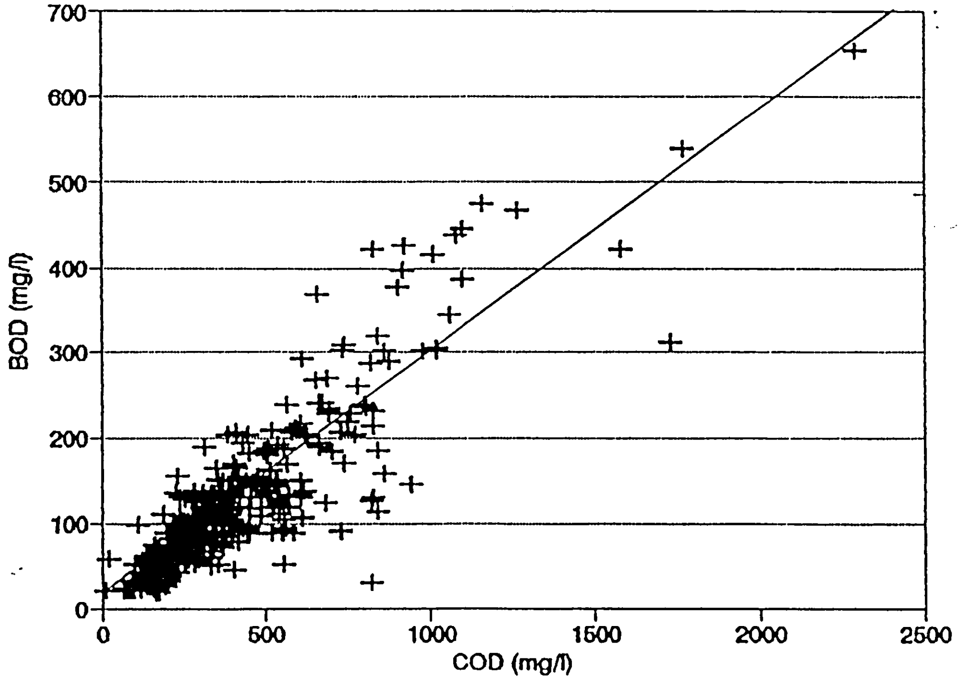
Appendix 3.1.1 Graph of Suspended Solids Concentration Against Ash Concentration for Inflow Samples at the Chesterfield Road Site
Regression: SS = 130.1 + 2.0 Ash $R^2 = 0.70$



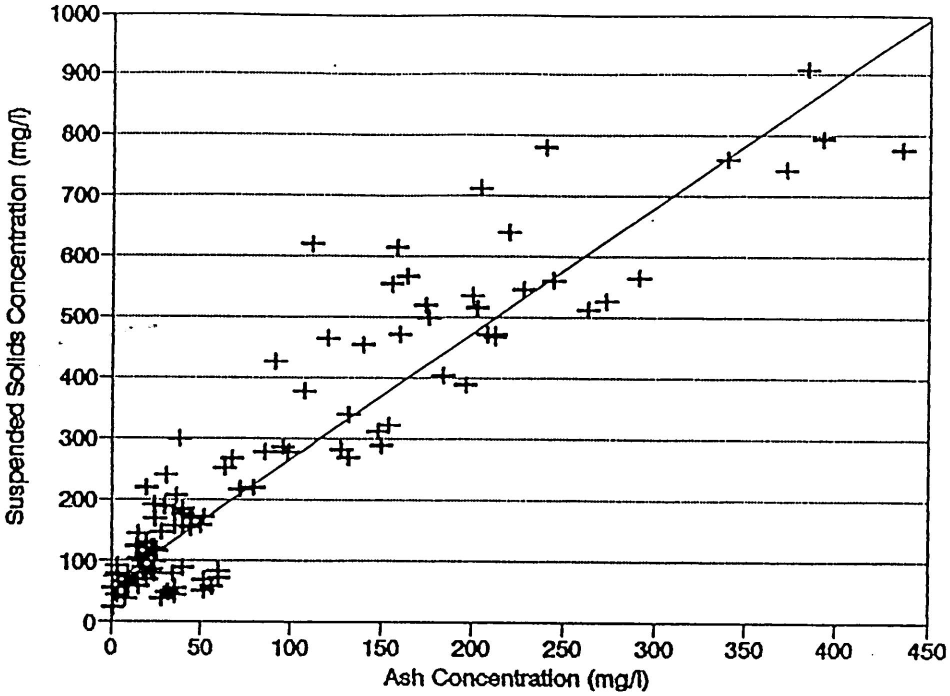
Appendix 3.1.2 Graph of Suspended Solids Concentration Against BOD Concentration for Inflow Samples at the Chesterfield Road Site
Regression: BOD = 29.4 + 0.3 SS $R^2 = 0.56$



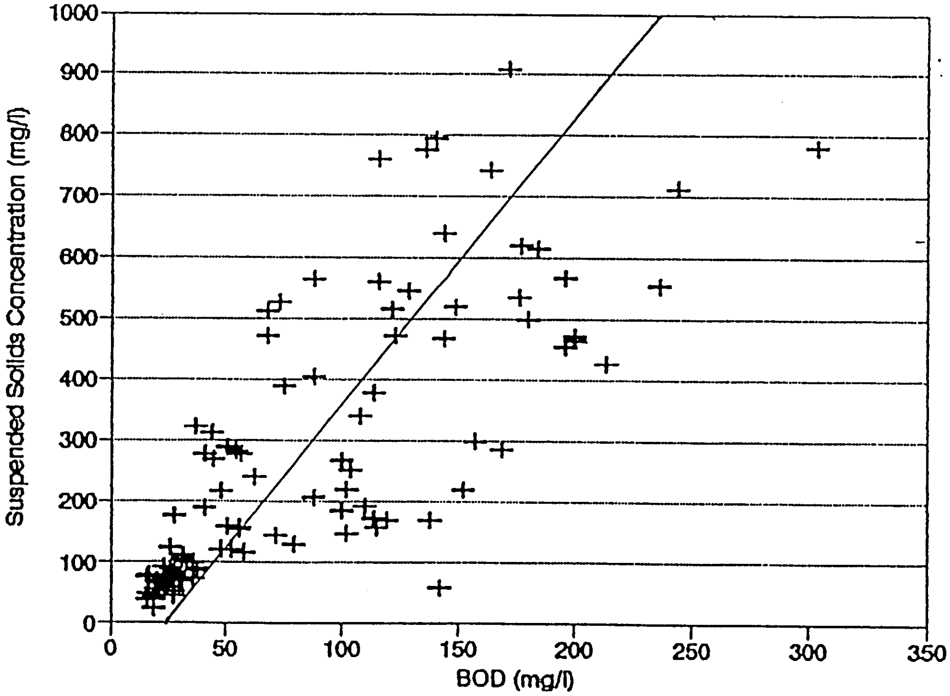
Appendix 3.1.3 Graph of Suspended Solids Concentration Against COD Concentration for Inflow Samples at the Chesterfield Road Site
Regression: SS = 21.1 + 0.8 COD $R^2 = 0.69$



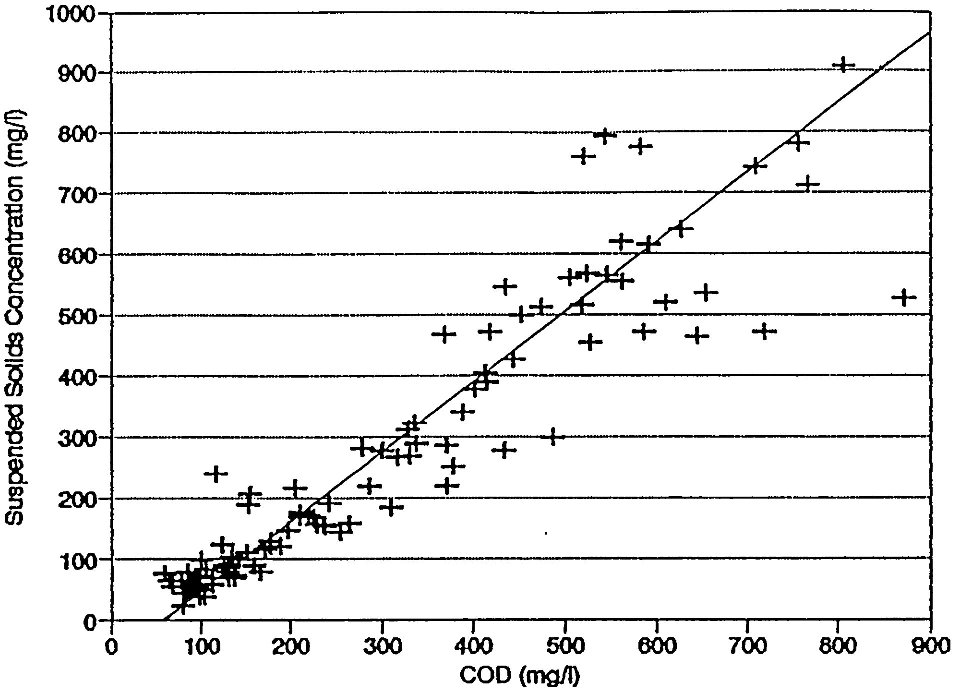
Appendix 3.1.4 Graph of BOD Concentration Against BOD Concentration for Inflow Samples at the Chesterfield Road Site
Regression: BOD = 2.1 + 0.3 COD $R^2 = 0.79$



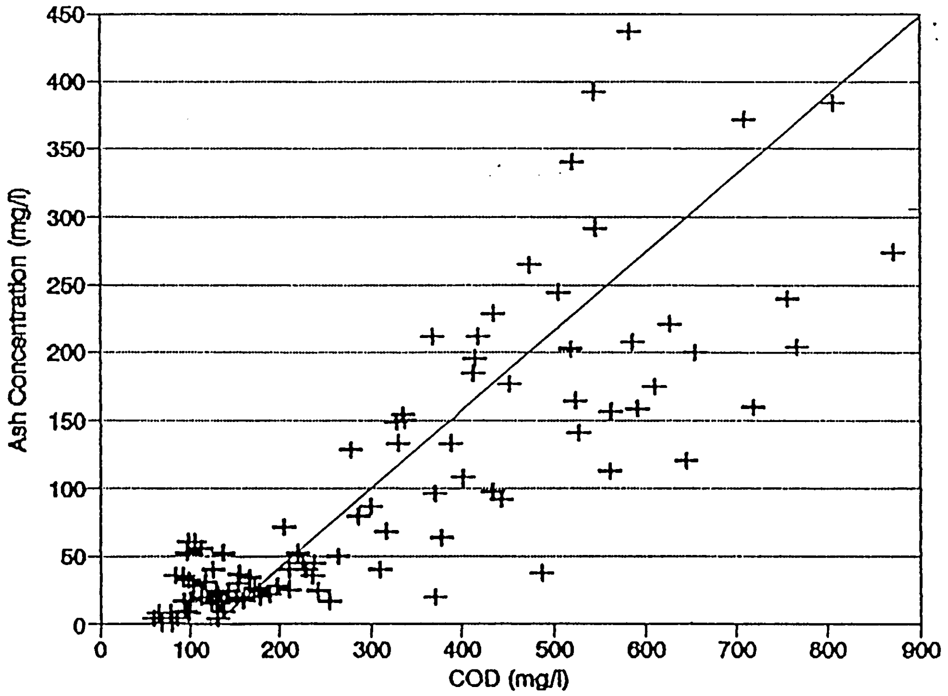
Appendix 3.1.5 Graph of Suspended Solids Concentration Against Ash Concentration for Spill Samples at the Chesterfield Road Site
Regression: SS = 71.8 + 2.1 Ash $R^2 = 0.86$



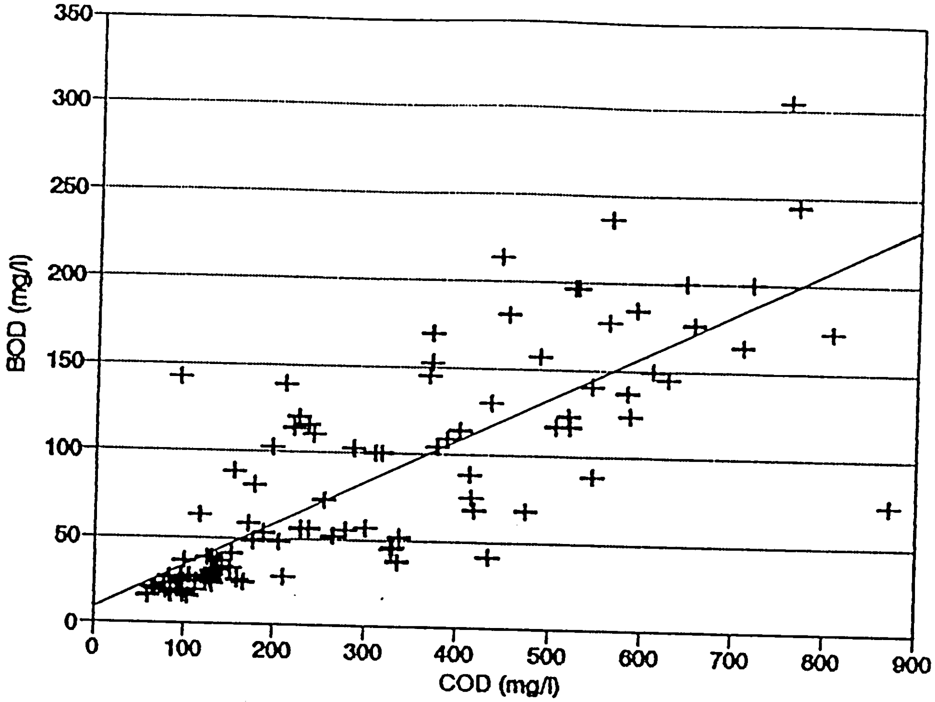
Appendix 3.1.6 Graph of Suspended Solids Concentration Against BOD Concentration for Spill Samples at the Chesterfield Road Site
Regression: BOD = 24.8 + 0.2 SS $R^2 = 0.59$



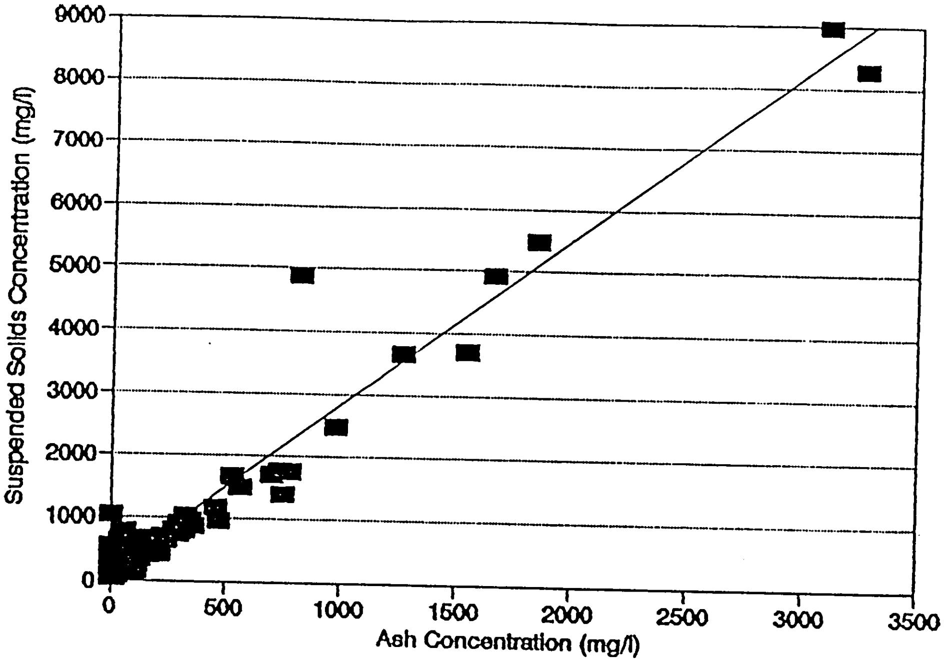
Appendix 3.1.7 Graph of Suspended Solids Concentration Against COD Concentration for Spill Samples at the Chesterfield Road Site
Regression: COD = 67.9 + 0.9 SS $R^2 = 0.87$



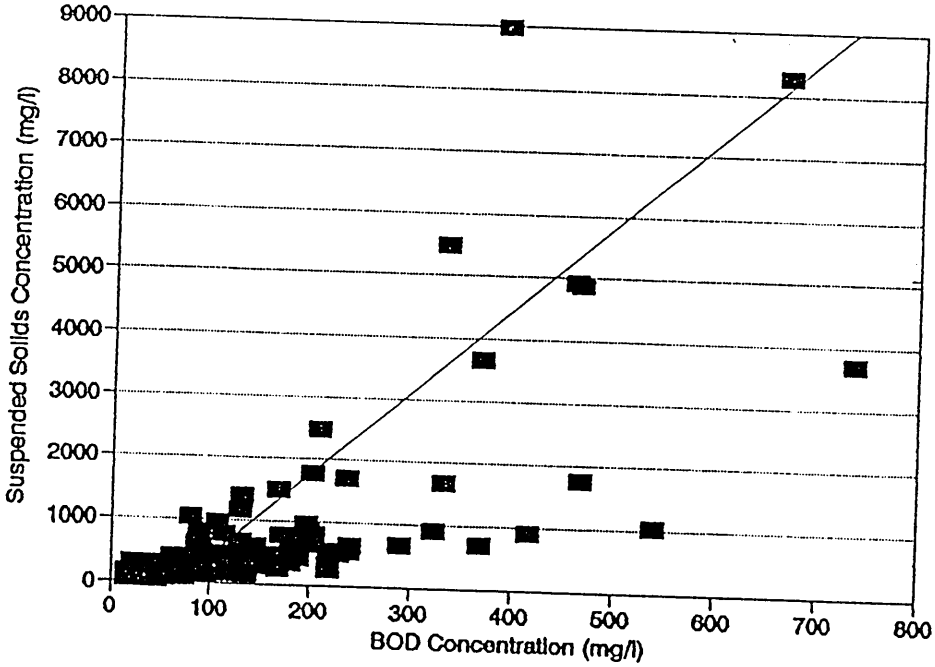
Appendix 3.1.8 Graph of Ash Concentration Against COD Concentration for Spill Samples at the Chesterfield Road Site
Regression: COD = 135.3 + 1.2 Ash $R^2 = 0.70$



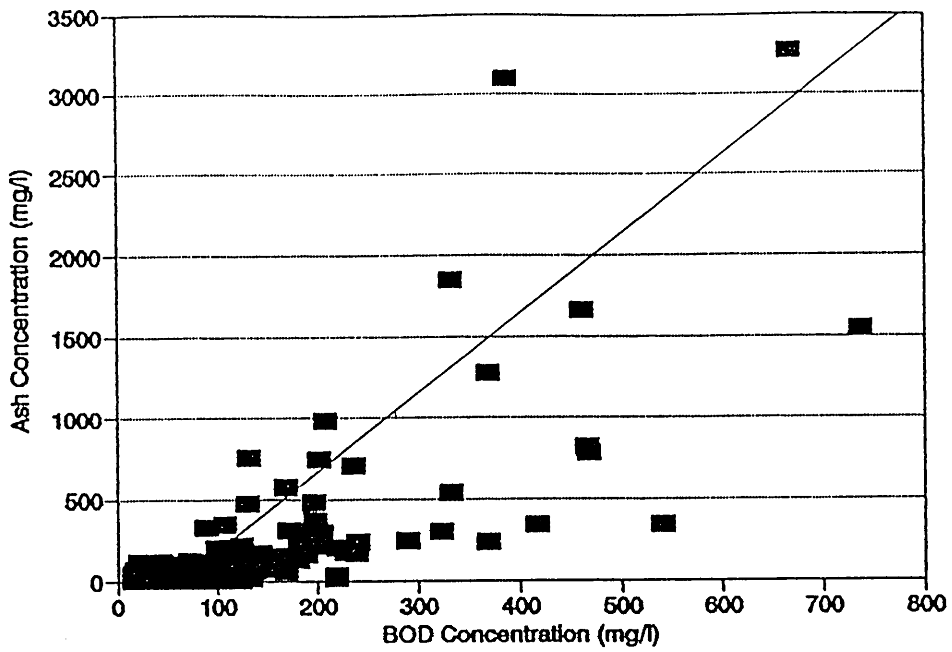
Appendix 3.1.9 Graph of BOD Concentration Against COD Concentration
for Spill Samples at the Chesterfield Road Site
Regression: BOD = 10.1 + 0.2 COD $R^2 = 0.63$



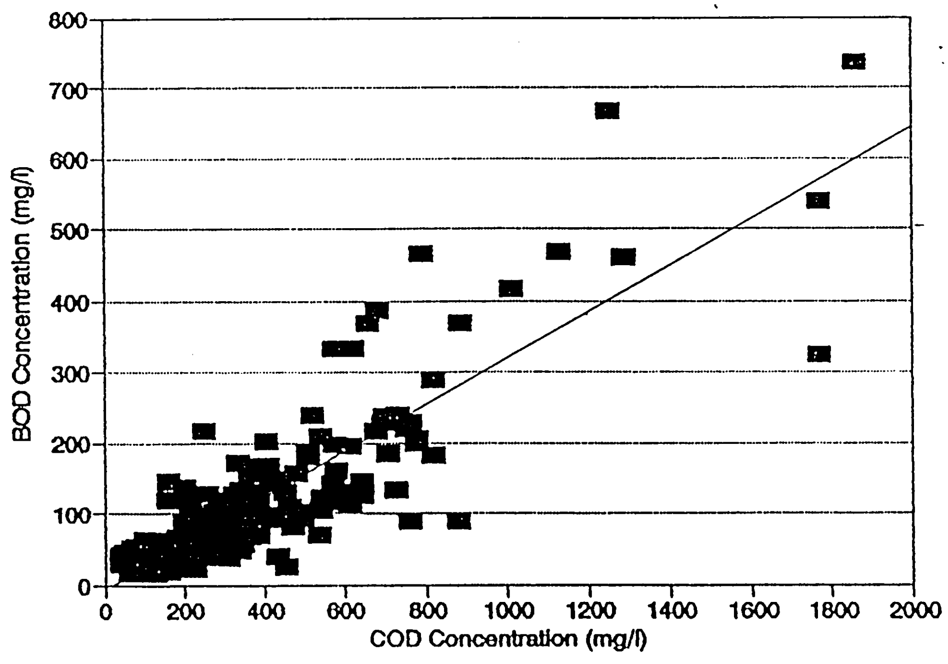
Appendix 3.2.1 Graph of Suspended Solids Concentration Against Ash Concentration for Inflow Samples at the Dobcroft Road Site
Regression: SS = 99.0 + 2.7 Ash $R^2 = 0.95$



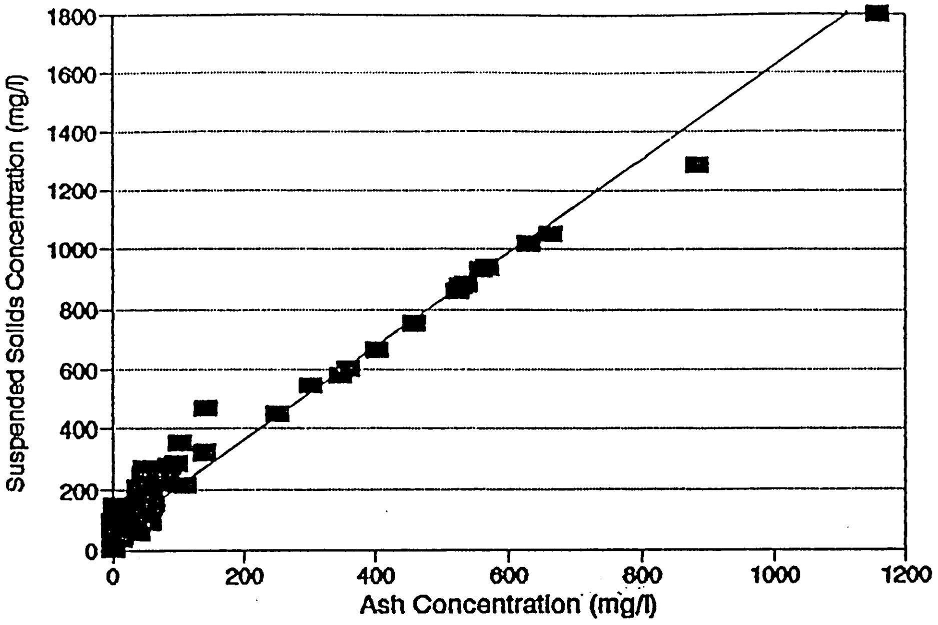
Appendix 3.2.2 Graph of Suspended Solids Concentration Against BOD Concentration for Inflow Samples at the Dobcroft Road Site
Regression: BOD = 67.4 + 0.1 SS $R^2 = 0.54$



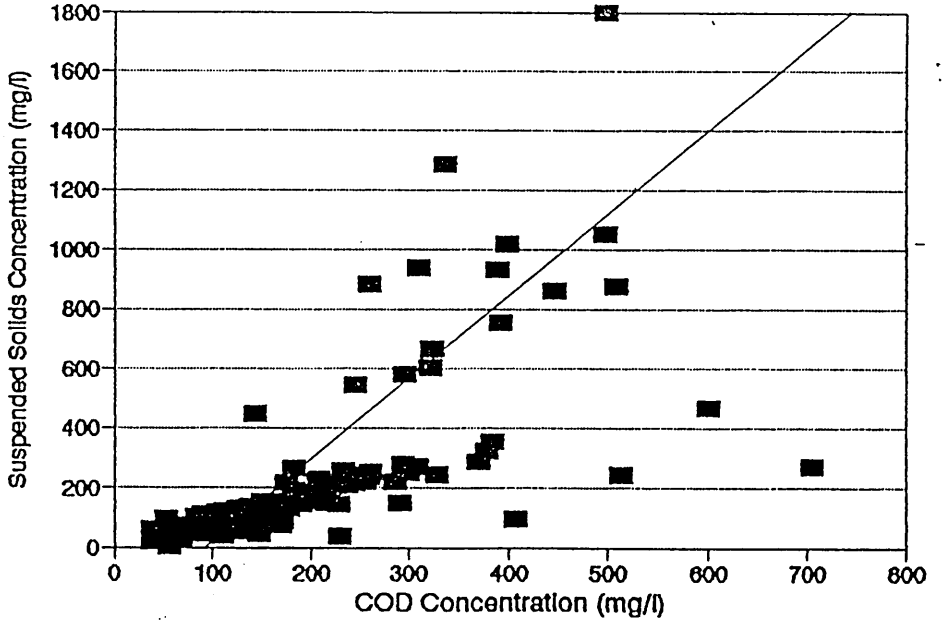
Appendix 3.2.3 Graph of Ash Concentration Against BOD Concentration for Inflow Samples at the Dobcroft Road Site
Regression: BOD = 74.1 + 0.2 Ash R² = 0.54



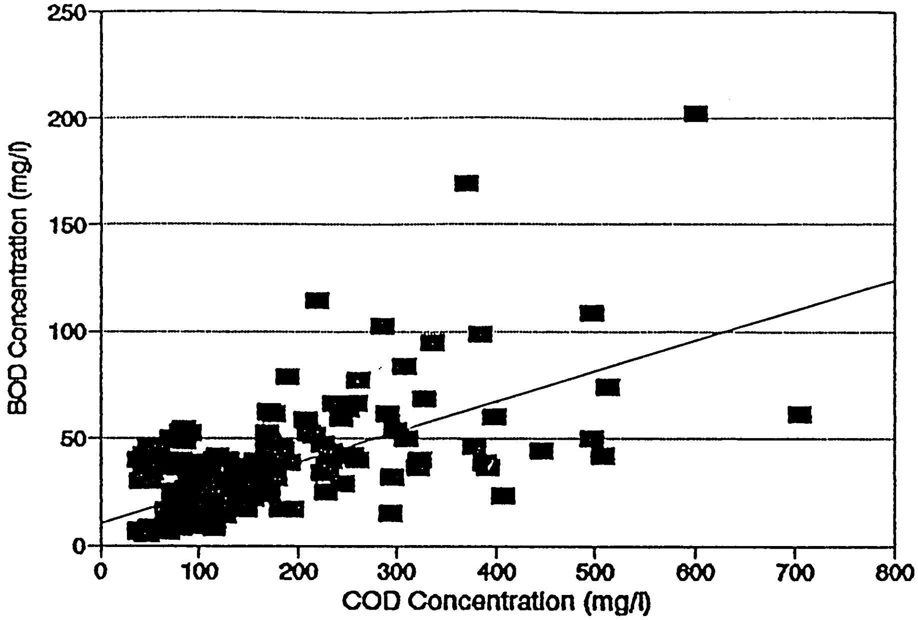
Appendix 3.2.4 Graph of BOD Concentration Against COD Concentration for Inflow Samples at the Dobcroft Road Site
Regression: BOD = 0.3 COD - 4.5 R² = 0.74



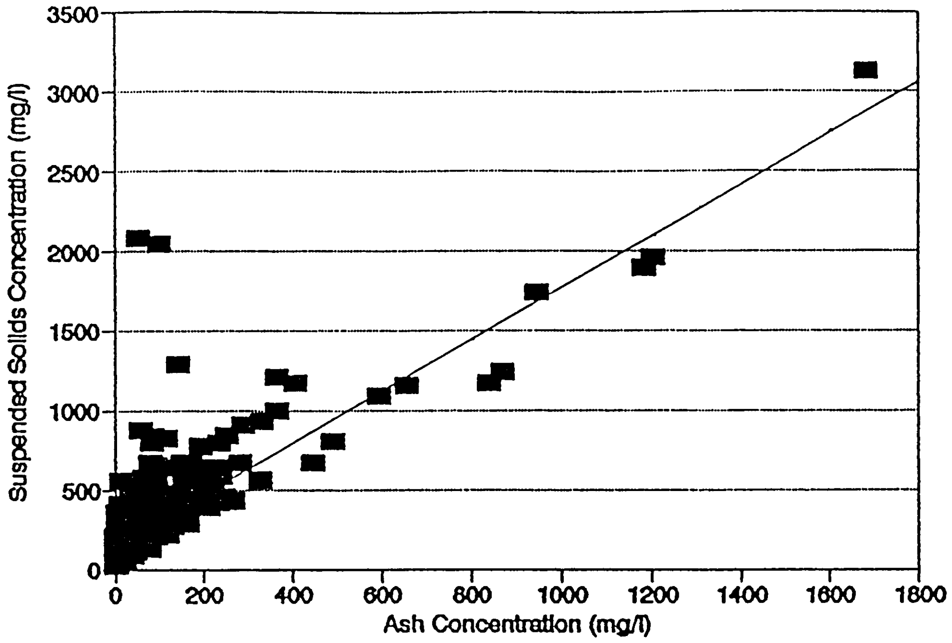
Appendix 3.2.5 Graph of Suspended Solids Concentration Against Ash Concentration for Spill Samples at the Dobcroft Road Site
Regression: Ash = 0.6 SS - 42 $R^2 = 0.97$



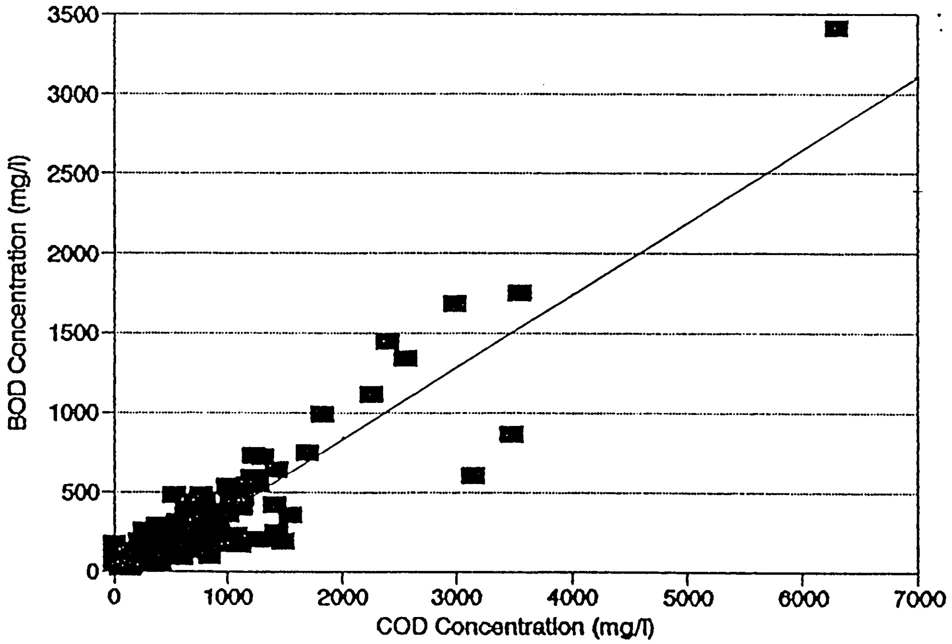
Appendix 3.2.6 Graph of Suspended Solids Concentration Against COD Concentration for Spill Samples at the Dobcroft Road Site
Regression: COD = 102.7 + 0.3 SS $R^2 = 0.51$



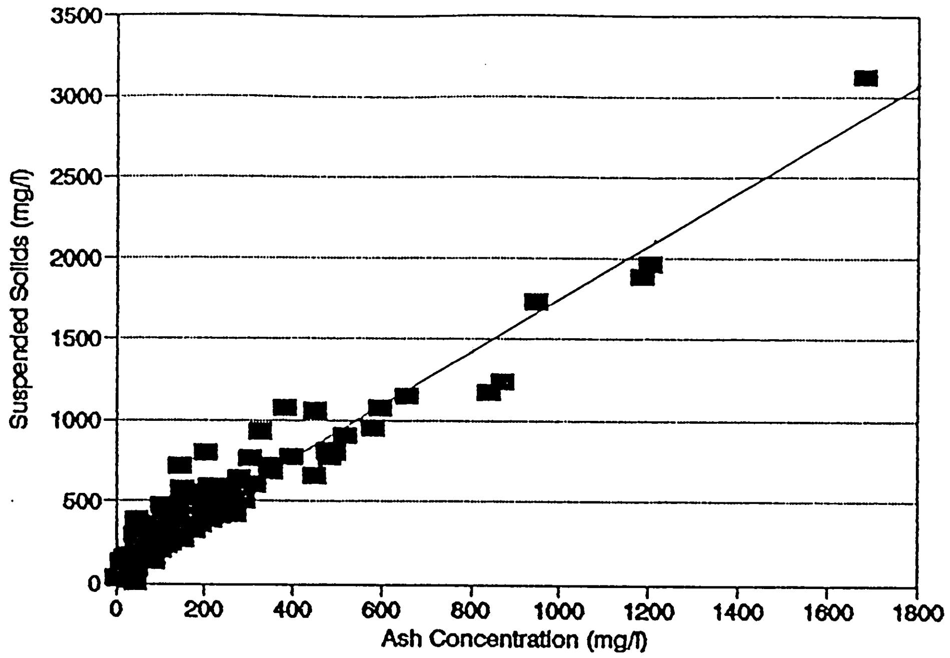
Appendix 3.2.7 Graph of BOD Concentration Against COD Concentration for Spill Samples at the Dobcroft Road Site
Regression: BOD = 12.3 + 0.1 COD $R^2 = 0.39$



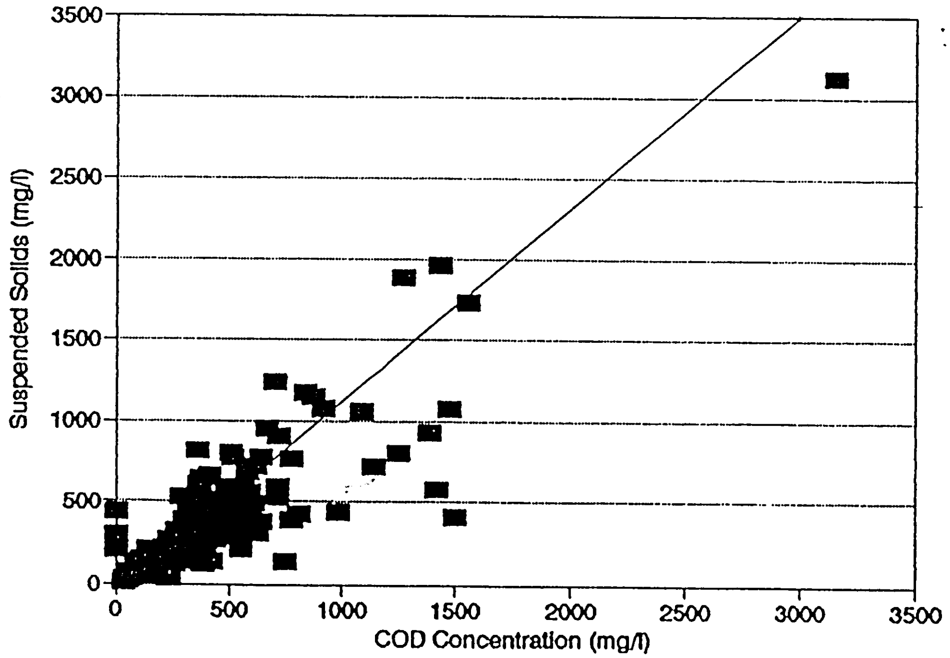
Appendix 3.3.1 Graph of Suspended Solids Concentration Against Ash Concentration for Inflow Samples at the Retford Road Site
Regression: SS = 168.8 + 1.6 Ash R^2 = 0.83



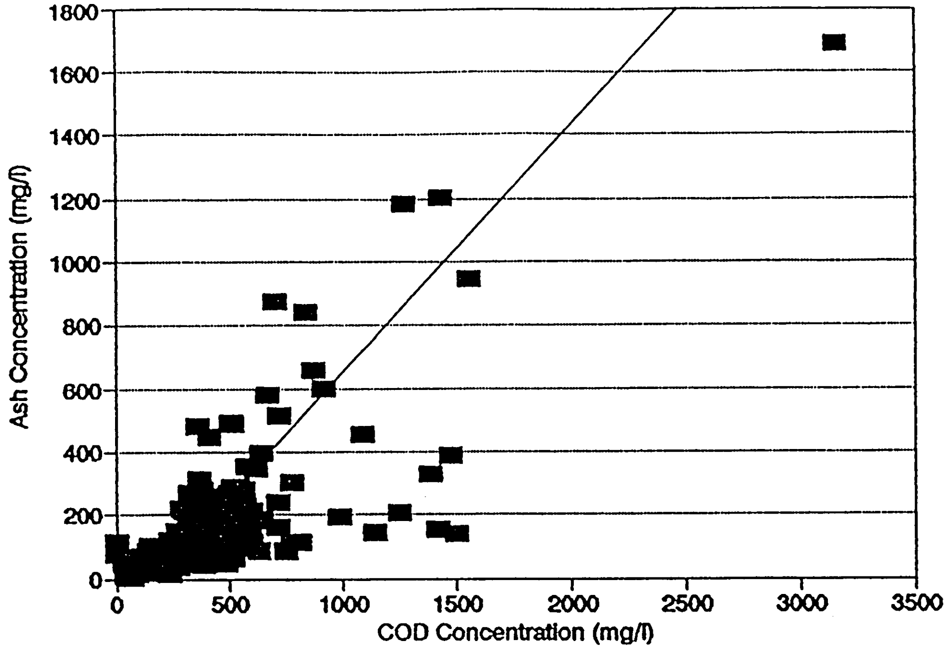
Appendix 3.3.2 Graph of BOD Concentration Against COD Concentration for Inflow Samples at the Dobcroft Road Site
Regression: BOD = 0.5 COD - 52.1 R^2 = 0.85



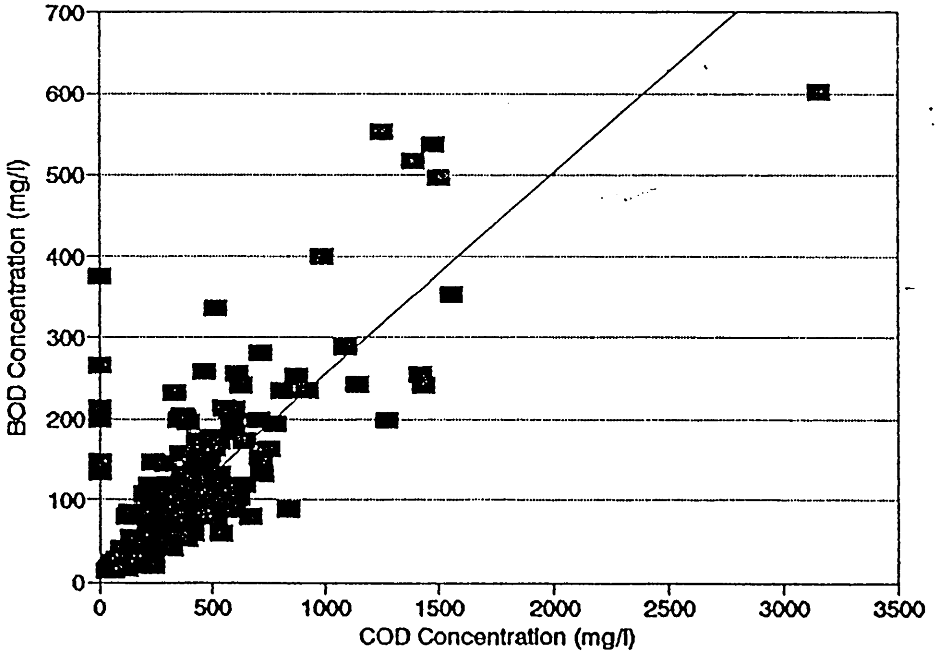
Appendix 3.3.3 Graph of Suspended Solids Concentration Against Ash Concentration for Spill Samples at the Retford Road Site
Regression: SS = 92.0 + 1.7 Ash $R^2 = 0.93$



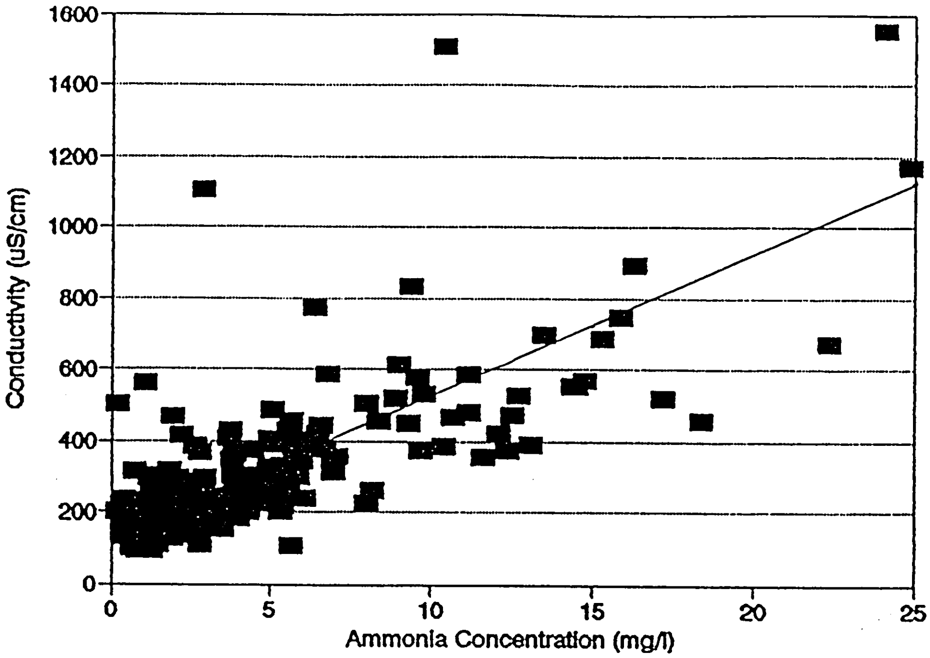
Appendix 3.3.4 Graph of Suspended Solids Concentration Against COD Concentration for Spill Samples at the Retford Road Site
Regression: COD = 117.7 + 0.8 SS $R^2 = 0.76$



Appendix 3.3.5 Graph of Ash Concentration Against COD Concentration for Spill Samples at the Retford Road Site
Regression: COD = 211.8 + 1.3 Ash $R^2 = 0.59$



Appendix 3.3.6 Graph of BOD Concentration Against COD Concentration for Spill Samples at the Retford Road Site
Regression: BOD = 10.9 + 0.2 COD $R^2 = 0.73$



Appendix 3.3.7 Graph of Conductivity Against Ammonia Concentration
for Spill Samples at the Retford Road Site
Regression: Conductivity = 134.7 + 37.1 Ammonia $R^2 = 0.57$

APPENDIX 4 FLOW CLASSIFICATION

Figure A. shows the basic features of a culvert. The diagram is split into four sections:
- the approach
- the entrance
- the outlet
- tailwater

The approach is usually taken to start at one culvert opening width upstream of the culvert entrance. There is and energy loss on entry to the culvert. The magnitude of this is related to the geometry of the entrance. In the culvert there will be energy loss due to friction. The discharge of the culvert can be determined by the application of the continuity and energy equations between the approach section and the downstream section. These equations are well described in all basic hydraulic textbooks (e.g. Cairney, 1984; Francis, 1962; Webber, 1971). The precise location of the downstream section will depend on the state of flow in the culvert. The following description of flow types is taken from "A Short Course on Drainage Modelling", Bradford University, 1991.

The flow through culverts is divided into six categories based on the relative heights of the head and tailwater depths. The six types are shown in Figure B. where:

D = maximum vertical dimension of culvert (m)
Y_1 = depth of flow in approach section (m)
Y_c = critical depth of flow (m)
z = elevation of the culvert entrance relative to the datum through the culvert exit (m)
Y_4 = tailwater depth (m)

Type I Flow

For this flow type critical depth occurs in the vicinity of the culvert entrance. For this to arise the following requirements must be met:

i The headwater-culvert diameter ratio (Y_1/D) cannot exceed 1.5.
ii The slope of the culvert barrel must be steep.
iii The tailwater elevation, h_4, must be less than the elevation of the water surface at the critical section.

The discharge Equation for this type of flow is:

$$Q = C_D A_C \sqrt{2g\left(h_1 - z + \frac{\alpha_1 u_1^2}{2g} - y_c - h_{L(1-2)}\right)}$$

Where:

C_D = discharge coefficient
A_C = flow area at critical depth (m²)
A_o = culvert area (m²)
$h_{L(1-2)}$ = head loss due to friction from section 1 to 2
$h_{L(2-3)}$ = head loss due to friction from section 2 to 3
L = length of the culvert barrel

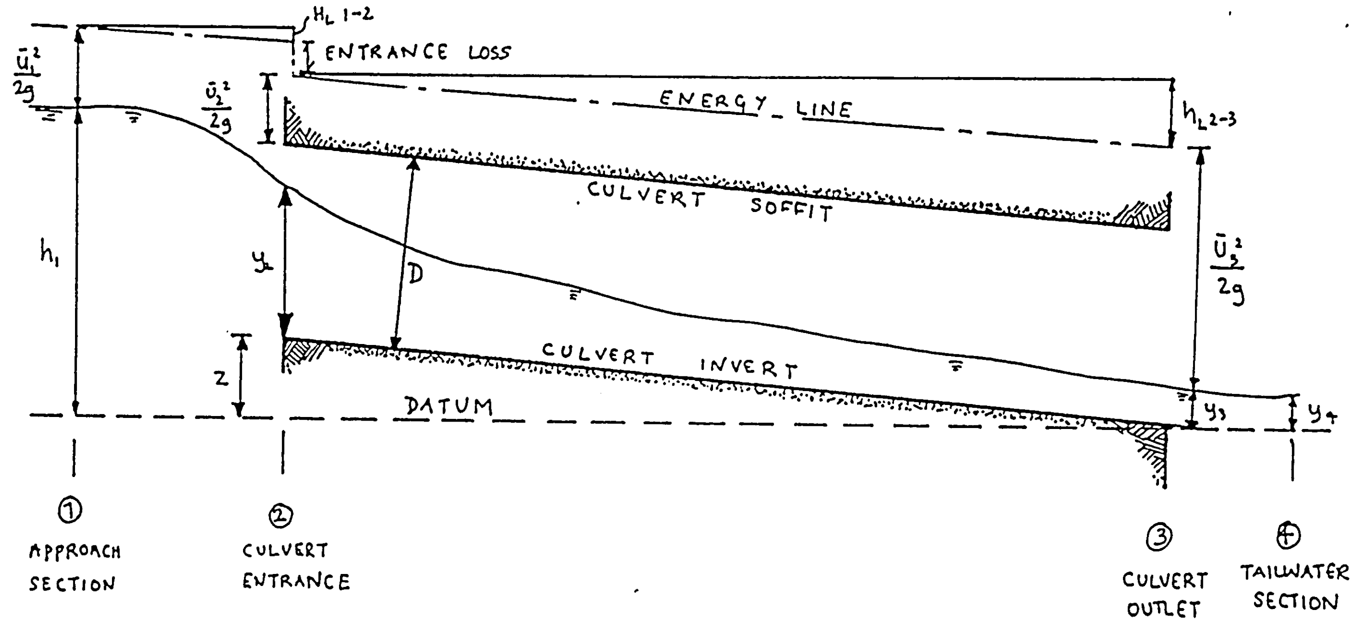
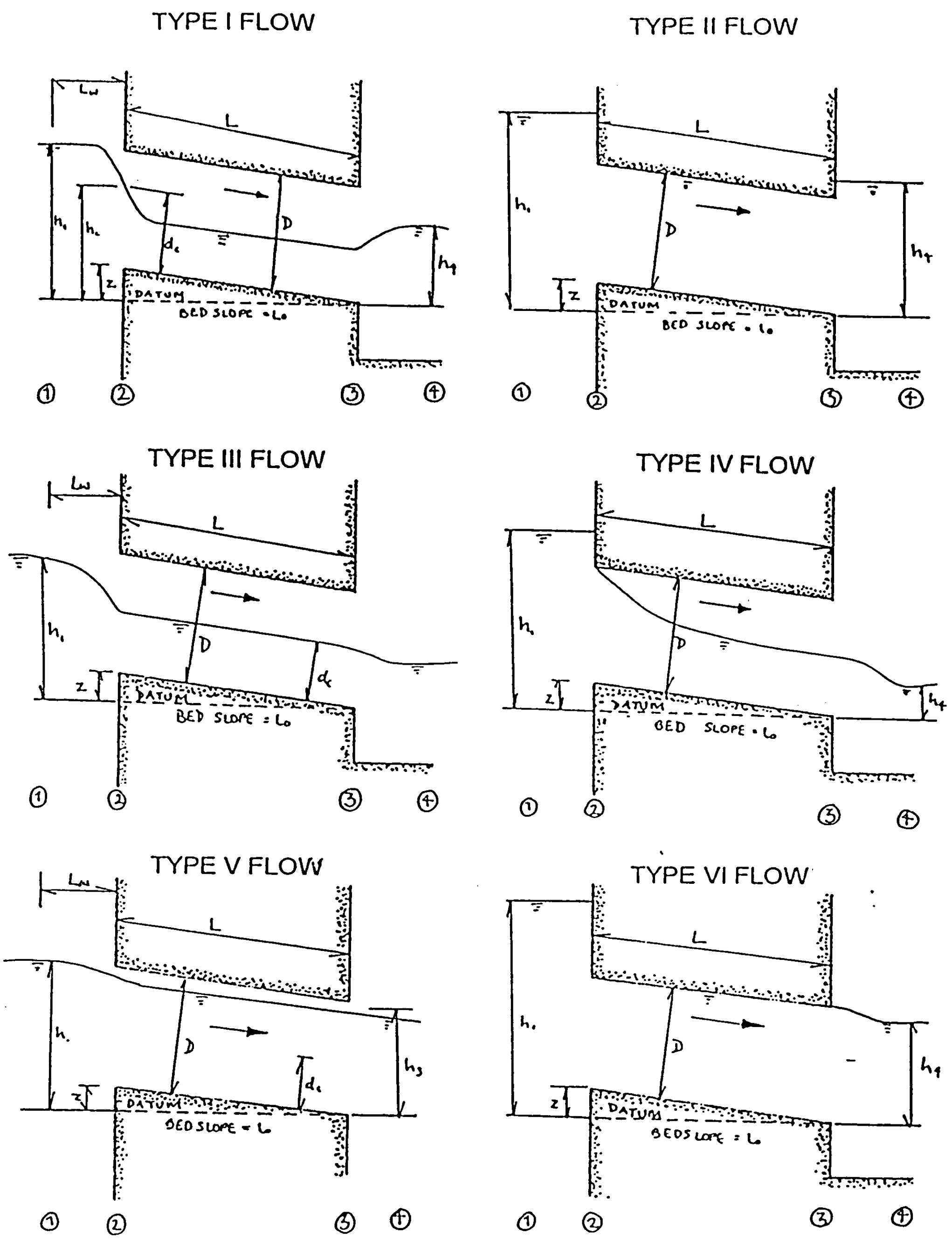


Figure A Basic Features of a Culvert (taken from Short Course on Drainage Modelling, Bradford University, 1991)


TYPE I FLOW

TYPE II FLOW

TYPE III FLOW

TYPE IV FLOW

TYPE V FLOW

TYPE VI FLOW

Figure B Flow Types (taken from Short Course on Drainage Modelling, Bradford University, 1991)

Type II Flow

In this type, critical depth occurs at the culvert outlet. For this to occur the following requirements must be met;

- i The headwater-culvert diameter ratio must not exceed 1.5.
- ii The slope of the culvert should be hydraulically mild.
- iii The tailwater elevation, h_4, must not exceed the elevation of the water surface at thecritical section.

The discharge Equation for this type of flow is:

$$Q = C_D A_C \sqrt{2g\left(h_1 + \alpha_1 \frac{u_1^2}{2g} - y_c - h_{L(1\text{-}2)} - h_{L(2\text{-}3)}\right)}$$

Type III Flow

In this type of flow the existence of a gradually varied flow profile is the controlling factor, critical depth cannot occur and the upstream water surface elevation is controlled by the tailwater elevation. This type of flow is subcritical throughout the culvert length.. The following requirements must be satisfied to achieve this:

- i The headwater-culvert diameter ratio must be less than 1.5.
- ii The tailwater elevation should not submerge the culvert exit; however it should exceed the elevation of the critical depth at the outlet.
- iii The lower limit of the tailwater should be such that:

- a) the tailwater elevation is greater than the elevation of critical depth at the culvert entrance (if flow conditions are such that critical depth would result at the entrance)
- b) the tailwater elevation is greater than the elevation of critical depth at the culvert exit(if the slope of the culvert is such that critical depths would occur at this sections under free-fall conditions).

The discharge Equation for this type of flow is:

$$Q = C_D A_3 \sqrt{2g\left(h_1 + \frac{\alpha u_1^2}{2g} - h_3 - h_{L(1\text{-}2)} - h_{L(2\text{-}3)}\right)}$$

Type IV Flow

In this type the culvert flows full. The flow rate can therefore be estimated directly from the energy equation. In this class the head loss incurred between section 1 and 2 and section 3 and 4 are neglected. The loss due to the rapid expansion of the flow field at the culvert outlet is assumed to be (h_3-h_4).

The discharge Equation for this type of flow is:

$$Q = C_D A_o \sqrt{\frac{2g(h_1 - h_4)}{1 + (29C_D{}^2 n^2 \frac{L}{R_0^{\frac{4}{3}}}}}$$

Type V Flow

In this flow class the flow is supercritical at the culvert inlet and the headwater-culvert diameter ratio exceeds 1.5. As the tailwater elevation is below the soffit of the culvert, the culvert flows partially full.

The discharge Equation for this type of flow is:

$$Q = C_D A_o \sqrt{2g(h_1 - z)}$$

Type VI Flow

In this flow class, the headwater-culvert diameter ratio exceed 1.5, the culvert flows full and the outlet is not submerged.

The discharge Equation for this type of flow is:

$$Q = C_D A_o \sqrt{2g(h_1 - h_3 - h_{L(2\text{-}3)})}$$

CHANNEL FLOW

With one exception (at critical depth), for every value of specific energy there are two types of flow

1. shallow and fast flow (supercritical)
2. deep and slow (subcritical)

Overflows should be designed to be subcritical (deep and slow flow). This requires that there is some control device at the downstream end of the chamber (e.g. a throttle pipe). There are also two important depths in channel flow:

1. Critical Depth
2. Normal Depth

These determine whether flow is subcritical or supercritical. The critical depth is the depth at which the minimum value of specific energy needed to pass the flow occurs. The critical depth occurs between subcritical and supercritical states of flow. The normal depth is the depth of flow in the channel where there exists a balance between acceleration down the channel and frictional retardation against the flow. It usually occurs in the middle reaches of long straight lengths of channel of reasonably uniform cross-section (Cairney, 1984). The position of the normal depth is influenced by the average velocity, the geometry of the cross-section, the roughness of the bed material and the slope of the bed.