PAPER 3

CSO Performance Evaluation - results of a field programme to assess the gross solids separation performance of various CSO's

by

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CSO Performance Evaluation - results of a field programme to assess the gross solids separation performance of stilling pond and side weir chambers

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ABSTRACT

Recent European legislation in the form of the Urban Wastewater Treatment Directive has highlighted the need for an integrated approach to pollution control in urban catchments. In particular there has been an increased awareness of the issues associated with the impact of sewerage derived pollutants which are discharged to receiving inland waters and bathing beaches. In this respect the design of the Combined Sewer Overflow chambers (CSO's) is of critical importance to the effective retention of the pollutants within the sewer system. New engineering technologies, and in particular screening technology, are emerging to meet the challenges created by the new legislation and significant research is required to improve understanding on the solids removal capabilities and the operational and maintenance characteristics of this new technology. To address these and other CSO related issues, the UK Water Industry in collaboration with the University of Sheffield, established a CSO Research Group and this paper describes the results of some of the research work carried out to date on behalf of the Group at the National CSO Test Facility at Hoscar Sewage Treatment Works, Wigan. This facility was established with funding from the Foundation for Water Research and North West Water

Initially the paper describes the layout and operation of the National CSO Test Facility and this is followed by a description of the test procedures developed to examine the solids separation performance of CSO chambers and screen arrangements. A comparison of the solids separation performance has been made of low and high side weir chambers and the extended stilling pond chamber (the latter two types of chamber were designed to recommendations outlined in the WRc report ER304E and the FWR report FR 0488). The results have subsequently been applied to assess the annual average efficiency performance of each type of chamber corresponding to a time series of storm events falling on a catchment of size and configuration appropriate for the geometry and design of chambers tested.

INTRODUCTION

Combined Sewer Overflow chambers (CSO's) are an essential component of combined sewer systems. These systems carry domestic and industrial effluents and storm rainwater within the same pipe and CSO chambers are required for the following reasons;

i) To act as a hydraulic control on the system and to restrict the continuation flow to the downstream sewer (or treatment works) to a design value, termed the setting.

ii) To provide a relief overflow to allow the spill of any excess flow above that of the setting, usually to the nearest watercourse.
iii) To prevent flooding as a result of excess hydraulic loading on the sewerage system.
iv) To be efficient in the retention of gross solids and pollutants for treatment.
v) To be self cleansing and maintenance free by avoiding blockage and complication in design.

The work of the CSO Research Group is associated with the development of technology to optimise the retention of pollutants within the sewer system and to minimise the spill of pollutants to receiving waters. In this respect the EC Urban Wastewater Treatment Directive placed the responsibility on member states to decide on measures to limit the pollution discharged from CSO and indicated that measures could be based on three techniques:

- a dilution ratio between the quality of the sewer flow and that in the receiving stream
- the capacity of the sewer in relation to the dry weather flow
- a specified number of overflows per year

As a consequence CSO design practice varies widely throughout Europe and the present trend is one of catchment wide integrated pollution control. In the UK the recommended design philosophy is outlined in the Urban Pollution Management Manual (1994) with a view to meeting the Environment Agency AMP 2 guidelines NRA (1993), which require that solids separation should be related to the retention of solids of dimension greater than 6mm in two dimensions and/or a performance equivalent to that of a 10mm bar screen. Where 6mm solids separation is required the spilled effluents should not contain a significant quantity of solid matter greater than 6mm in two dimensions. The following criteria were laid down to define the flowrate to be used for the hydraulic design of the 6mm solids separation:

Where time series data is available;

> At a maximum flow equivalent to 80% of the flow volume that would be discharged in an annual time series;

Or if sparse data is available;

> At a flowrate which is equal to 50% of the volume that would be discharged in a 1 in 1 year design event.

In addition the remaining flow, up to that resulting from a 1 in 5 year storm should also be subject to 10mm solids separation.

To achieve the effective retention of these gross solids within the sewer system, by good engineering design, four types of CSO chamber are recommended for use in UK practice. These are the stilling pond chamber with end weir, the high-side weir chamber, the vortex with peripheral spill weir and the Storm King TM hydrodynamic separator. Design criteria for these types of CSO chamber are outlined in the WRc report ER 304E (1989) and the Foundation for Water Research report FR 0488 (1994). However, in respect of the retention of gross solids in the form of pant liners, release tapes, condoms and cotton bud sticks, Saul et al (1993) showed that at high inflow rates of 60 litres/s (the design inflow rate for the stilling pond, side weir and vortex chamber was 61.2 litres/s) the retention efficiency of these types of particles was little better than the ratio of the continuation flow to inflow i.e. each type of chamber divided the particles in the same ratio as the flow split. These results suggest that the solids retention performance of CSO chambers designed to these recommendations may fall short in respect of meeting the regulatory guidelines. More recently, Balmforth and Blanksby (1996) have presented the results of a UKWIR funded study. Additional recommendations for the design of conventional CSO structures to meet aesthetic regulatory requirements were presented and software, termed *Aestheticiser* was developed to accompany the design guide. Their work identified the need for large chambers to meet the regulatory requirements for aesthetic pollution and as a consequence considerable attention was focused on the economic aspects of overflow design, with the *Aestheticiser* software providing cost comparisons of different chamber geometry to be easily made. There is therefore a considerable need to learn more about the performance of CSO chambers to retain the types of particulates found in combined sewer flow and of the performance of systems, and in particular screening devices, to remove solids of 6mm in two dimensions. **The work of the authors, under the umbrella of the CSO Research Group, aims to address these performance issues and this paper presents the initial findings of a four year rolling programme of research.**

NATIONAL CSO TEST FACILITY, WIGAN

A schematic diagram of the test facility is shown in Figure 1. Four large diameter screw pumps are used to elevate crude sewage to the inlet channel to the works. A 500mm diameter pipe, cast into the floor of the inlet channel, is used to transport the raw sewage to a 50m long, 800mm diameter inlet pipe to the test pad of the facility. The 500mm diameter pipe incorporates a magnetic flow meter and a computer controlled gate valve which are used to measure and control the flow rate into the inlet pipe of the test facility. At the downstream end of the inlet pipe there is a 15m x 5m reinforced concrete ground level test bed, on which the CSO chambers may be installed.

Two channels have been constructed to return the spilled flow and the continuation flow components from the CSO chamber under test back to the sewer system upstream of the screw pumps. Each flow component is discharged through a separate 300mm diameter pipe which incorporates a magflow meter to allow each flow rate component to be measured. These two pipes discharge into a collection chamber with a single pipe outlet to return the flow back to the inlet arrangement upstream of the screw pumps. The output from the three flow meters is monitored within a central control room and this room also houses the computer and associated calibration and control software for the operation of the gate valve.

PERFORMANCE EVALUATION CRITERIA

The selected criteria against which the performance of a particular system may be evaluated are as follows:

1 Use a system of mesh sacks to collect solids greater than 6mm in two dimensions.

2 Establish the pollutant load in the inflow at a flowrate of 45 litres/s by collecting all inflow solids for 20 minutes. Drain the sacks for 30 minutes and establish the solids collected by weight.

3 Set up the required flow conditions through the system. These may be steady state flows, individual time varying flow hydrographs or a time series of events.

4 Establish the solids in the spilled flow and in the continuation flow. In tests with a steady inflow the solids in the spilled flow and the continuation flow are collected for a duration of 20 minutes but in the hydrograph tests the solids are collected over the complete duration of the storm event. Visually examine the solids collected in each component of the flow and attempt to quantify the **visual aesthetic pollution** into four categories of occurrence, namely ***frequent, common, rare and never.***

5 Repeat Step 2 at the end of each test and compare the mass of solids in the inflow pre and post test. (This procedure is referred to as a strength test).

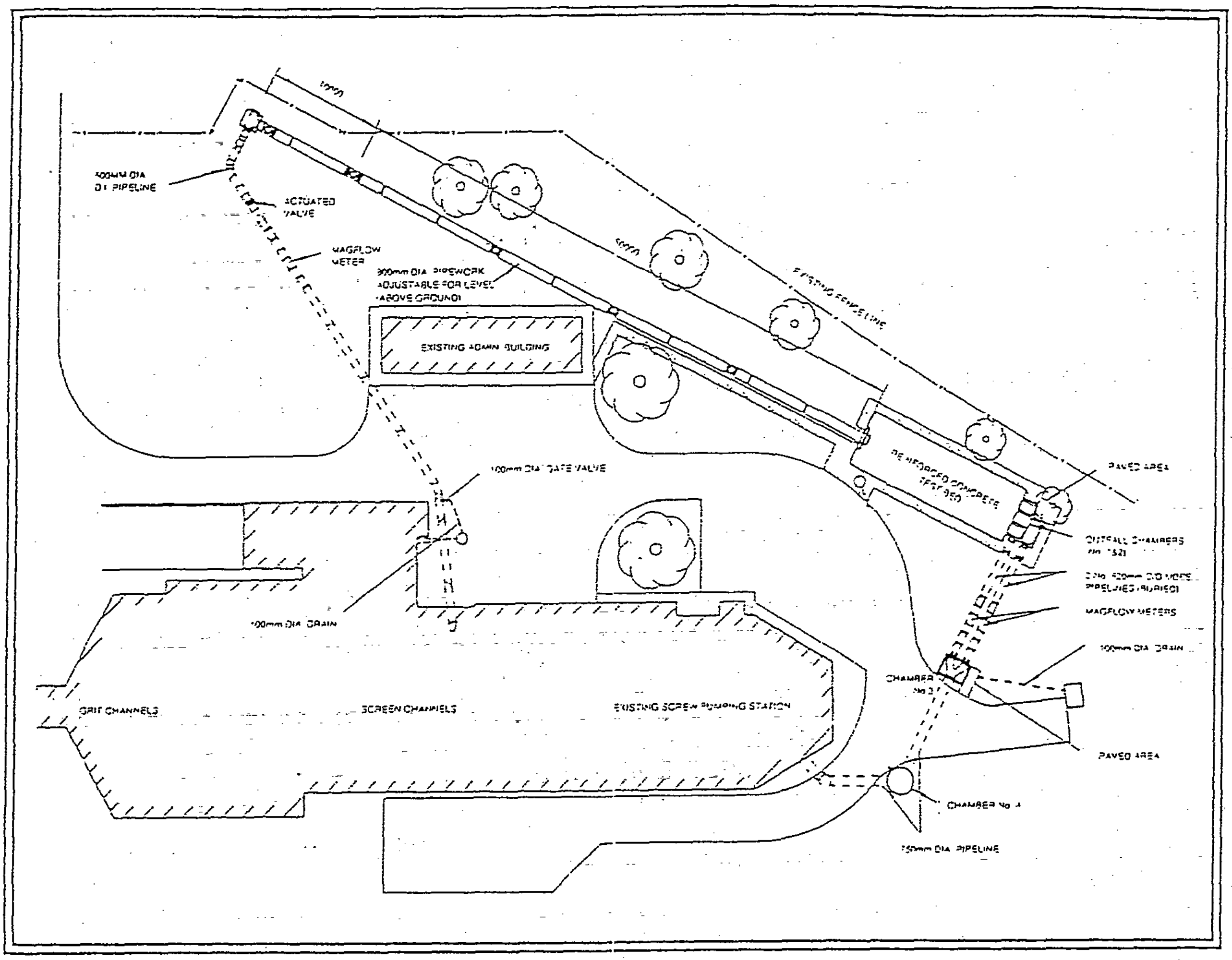

Figure 1 Schematic layout of the National CSO Test Facility

The following definitions were used to evaluate efficiency of CSO performance:

$$\text{TOTAL EFFICIENCY (TE)} = \frac{\text{Total Storm Load Retained}}{\text{Total Storm Inflow Load}} \quad (1)$$

$$\text{FLOW SPLIT (FS)} = \frac{\text{Total Storm Volume Retained}}{\text{Total Storm Inflow Volume}} \quad (2)$$

$$\text{TREATMENT (TF)} = \frac{\text{TE}}{\text{FS}} \quad (3)$$

Hence if the treatment factor is greater than unity the chamber design is effective in separating the pollutant load with the proportion of the total load retained greater than that obtained simply by splitting the flow. Conversely, if the treatment factor is less than unity there is a greater proportion of the pollutant load discharged to the watercourse than would occur simply as a ratio of the spilled flow and inflow.

RESEARCH PROGRAMME OF THE CSO RESEARCH GROUP

The CSO Research Group was formed in April 1996 and, in its first year of operation, is funded by all 10 of the Water Utility companies in England and Wales, with a view to identifying and meeting the CSO research needs of the industry. The chairman of the Group is Mr Barry Thompson of Northumbrian Water and from April 1997 onwards the Group is to be adopted by UKWIR, reporting to both the Sewerage and the Wastewater committees.

In the first year the research activity of the Group has been concerned with a solids separation performance evaluation of the four commonly found CSO structures in UK sewer systems, namely low and high side weir chambers, the extended stilling pond chamber and the Sharpe and Kirkbride stilling pond chamber (1959). **This paper describes the results of this performance evaluation and attempts to predict the annual solids retention performance for each type of structure.** The inlet pipe to each chamber was 267mm internal diameter and all other aspects of the geometric layout and dimensions of the chambers conformed to the design recommendations outlined in the WRc report ER304E and the FWR report FR 0488. The weir height in the low side weir chamber was 0.5D whilst that in the high side weir and stilling pond was 1.2D.

Research to be carried out in the near future includes a performance evaluation of **new and novel screen arrangements** which may be retrofitted into existing or new designs of CSO chamber and of several types of **propriety CSO screens.**

TEST PROGRAMME

Each of the chambers was tested for a range of steady state inflow and continuation flow conditions and for a series of summer and winter storm hydrographs. Steady state inflows of 30, 45, 60 and 100 litres/s were used with the ratio of the continuation flow to inflow set at 0.1, 0.2, 0.4 and 0.6 (with the exception of the 100 litres/s inflow rate at the value of 0.6 as a continuation flow rate of 60 litres/s was beyond the limit of the control penstock). In the time varying flow tests the profile peakedness of the hydrographs corresponded to the 50% summer and winter storm profiles as outlined in the Flood Studies Report (1975) and peak inflow rates were set at 30, 45 and 60 litres/s. The setting for the continuation flow was equal to 0.2 of the peak inflow in all tests. Hence a total of fifteen steady flow tests and six flow hydrographs were used to assess the performance of each chamber.

RESULTS OF CHAMBER PERFORMANCE EVALUATION

The results outlined in Table 1 highlight that there is some diurnal variability in the strength of the effluents (expressed as the mass of solids) which enter the chambers under test. Repeat tests have been carried out and it has been shown that consistent results are obtained provided that the differences in the results of the strength test carried out prior to and following each performance evaluation is within certain limits and provided that the tests are completed within an identified period of time. Industrial inputs cause the greatest variability and these inputs may clearly be recognised by mass and visual observation, for example, on a number of occasions there has been a large input of beans into the system.

It is concluded therefore that the CSO Test Facility at Wigan is providing good quality performance data and that the test results are repeatable with a good level of confidence.

In all tests it is not possible to distinguish between the retention efficiency performance of floating and sinking solids and hence the results of each test are expressed as a single data point. The steady flow results for each chamber tested highlight that the performance of each individual chamber may be represented as a series of individual efficiency curves which relate the inflow and the ratio of the continuation flow to inflow. Typical distributions for each type of chamber is shown if Figure 2. The shape of the efficiency cusp is unique to a particular geometry of chamber with performance of the low

Duration of Tests = 20 mins Drain Time = 30 mins		
Inflow litres/s	Time gmt	Mass solids gms
35	9.05	1450
35	11.51	3445
35	14.30	5035
35	17.10	4505
35	8.50	2615
35	11.30	3255
35	14.10	16400
35	16.47	14350

Table 1 Variability in the Strength of Effluent at the National CSO Test Facility.

side weir consistently poorer than the high side weir chamber. The performance of the stilling pond chamber and the high side weir were similar with the efficiency cusp for the stilling pond chamber slightly steeper than that of the high side weir chamber.

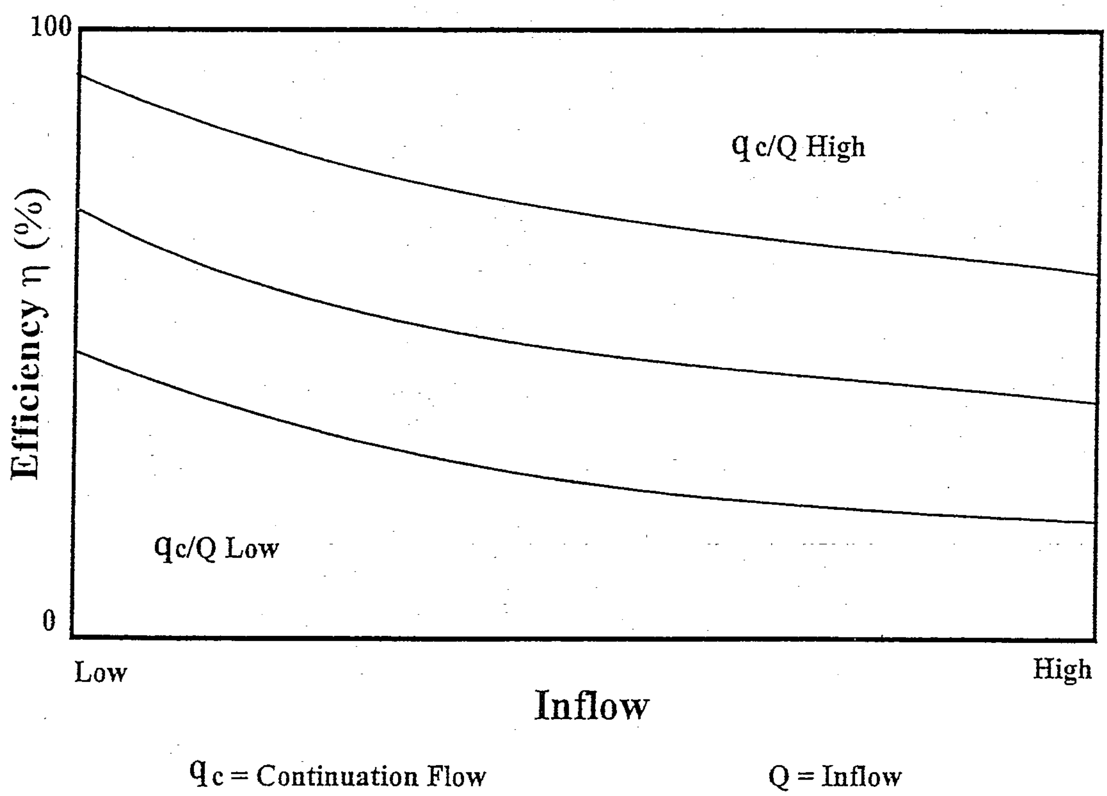

Figure 2 Typical Efficiency Cusp for Each of the Chambers Tested.

Similarly the results from the hydrograph tests were consistent but differences were recorded between the results of the summer and winter storm profile events. Clearly therefore it is important that, in any comparative performance evaluation between chambers, each chamber is tested using the same test programme i.e. the performance of each individual chamber is tested under a consistent set of flow conditions as **the results clearly indicate that it would be misleading and unrealistic to compare performance when the results are obtained for different storm events.**

PREDICTION OF ANNUAL SOLIDS REMOVAL PERFORMANCE

The results of the study have been applied to assess the annual average efficiency performance of each type of chamber corresponding to a time series of storm events falling on a catchment of size and configuration appropriate for the geometry and design of chambers tested. For comparative purposes with the recommendations outlined in FWR 0488 (1995) the ratio of the peak of the one year design storm to the setting was set at 0.3 giving a setting for all storms equal to 12.4 litres/s. This setting was approximately 1.9 times that of the Formula A setting for the selected catchment.

The methodology adopted was in all respects similar to that proposed by Saul (1994) in which each individual storm event is split into a number of discrete time intervals with the solids retention efficiency estimated from the steady state efficiency curve for each chamber corresponding to the average inflow and continuation flow magnitude at each time interval. The efficiency for each storm event in the series was derived by integrating the flow weighted efficiency at each time interval over the complete duration of the storm event. The annual solids separation performance was established by estimating the average of the sum of the flow weighted efficiency for all events in the time series. Clearly the peak inflow magnitude and storm volume for all events in the series was not of a sufficient magnitude to cause the chamber to spill and hence these storm events were considered to retain 100% of the solids in the inflow.

For the selected catchment and flow setting the following annual retention efficiency values were observed to describe the performance of each type of chamber:

Low side weir : 13%, High side weir : 28%, Stilling Pond : 30%.

Examination of the FWR Report 0488 (1995) highlights that at the corresponding flow ratio the total annual efficiency of both the side weir and the stilling pond chamber should be 20%. Many factors may be postulated to explain these recorded differences and these include the nature and characteristics of the effluent at Hoscar Sewage Treatment works, the method of solids collection and the procedures used to estimate the solids retention efficiency, particularly in the light of previous studies which have mainly been laboratory based. Similarly, there are limitations in the adopted methodology to predict the annual retention efficiency performance based on the results of the steady flow tests at Wigan. However it is stressed that the above results represent only a snap shot of the overall proposed 4 year programme of research to be completed by the CSO Research Group and conclusions are premature without much further data collection and analysis on a wider range of chambers and screen arrangements. What has been demonstrated is that the stilling pond and high side weir chambers both offer a similar solids separation performance when tested using live sewage under controlled conditions.

CONCLUSIONS

The National CSO Test Facility at Wigan is providing good quality and repeatable test data for the comparative solids separation performance of CSO chambers. Diurnal variations in the quality of the effluents which entered the facility were observed but these were found to have a limited impact on the results with the proviso that the quality did not exceed certain limits.

The performance of each type of chamber may be characterised by a series of efficiency cusps derived either under steady or time varying inflow conditions. For each chamber tested the retention efficiency performance is a function of the magnitude of the peak inflow and the ratio of the peak inflow to the continuation flow.

The cusp shape is a function of the characteristics of the inflow hydrograph with different results obtained for winter and summer storm hydrographs. Performance comparisons between chambers should therefore be carried out using the same hydraulic loading and test conditions.

The high side weir chamber performed consistently better than the low side weir and the performance of the stilling pond was similar to that of the high side weir. The efficiency cusp for the side weir was flatter when compared to that of the stilling pond but these differences in the cusp shape had little influence on the annual separation performance when the results were applied to an appropriately sized CSO chamber on a small domestic catchment.

In respect of the annual solids retention efficiency the performance the stilling pond and high side weir was very similar.

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UK WATER INDUSTRY COMBINED SEWER OVERFLOW RESEARCH CLUB

AN OVERVIEW OF ACTIVITIES AND ACHIEVEMENTS

1. Introduction

The increasing demands of gross solids separation in combined sewer overflows (CSOs) have resulted in considerable investigation in recent years into the performance of overflow structures and screen devices. The concerns are industry-wide and common to all water undertakings throughout the UK. It was therefore considered appropriate to instigate a national initiative - *the CSO Research Club* - in order to evaluate the performance of CSOs and to investigate new technologies. The key emphasis is on achievement of demanding standards in the most practical and cost-effective way possible. In the past each water company may have done its own testing, with little or no sharing of the knowledge gained. The CSO Research Club is intended to promote openness and co-operation within the water industry, to the ultimate benefit of customers, suppliers and the water environment.

The Club was established in January 1996 and is fully supported by the 10 Water Service plcs in England and Wales. The University of Sheffield provides a central co-ordinating role to all research undertaken on behalf of the Club, under the direction of Professor Adrian Saul, however it is intended that the work of the Club should be carried out by the most appropriate researcher and not exclusive to the University.

By April 1996 a formal constitution and terms of reference were agreed for the Club and the initial programme of research activities was formulated.

Close liaison is being maintained with the Environment Agency and all activities are closely co-ordinated with associated research work undertaken on behalf of the Agency. Water undertakings in Scotland and Northern Ireland have also been encouraged to participate and it is expected that the majority of these will join in due course.

2. Objectives

The primary objectives of the research programme formulated by the Research Club may be summarised as:

- To establish the criteria against which the performance of a particular CSO chamber may be evaluated and as to how the results of the fieldwork, laboratory work and numerical analysis may be validated and brought together to yield a meaningful comparison.
- To provide improved guidance on CSO design.
- To carry out a performance evaluation of promising novel screen arrangements.
- To disseminate the results of research work to practioners in the industry.
- To act as a centre for CSO information to which the industry may refer.

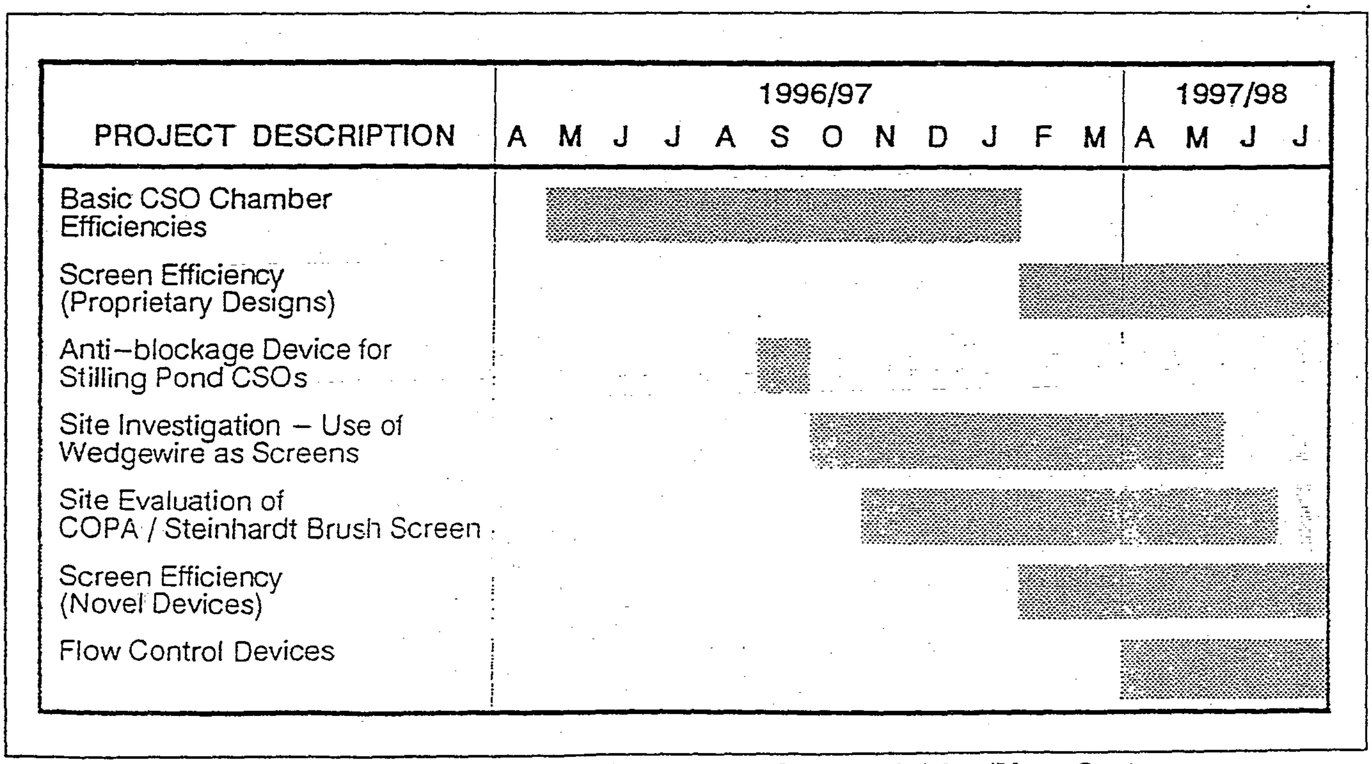
3. Achievements to Date

The first few months of the Research Club have seen significant progress; principal achievements include:

- establishment of full membership of all water service plcs in England and Wales,
- provision of a budget for the first year of research,
- agreement of a Contract and a Management Structure,
- establishment of a Management Committee.
- appointment of a Research Assistant by the University of Sheffield,
- commencement of research work and testing using the National CSO Test Facility,
- establishment of the Club as a focal point for CSO research activities, both within the water industry and for equipment suppliers.
- recognition of status and a research budget from UKWIR for the period 1997/98 to 1999/2000.

4. Present Programme

The present programme of activities is summarised below:



Outline Programme for CSO Research Club Activities (Year One)

One of the first research projects will establish basic data relating the separating performance of various configurations of CSO chamber and then go on to evaluate the enhanced performance achieved by adding screens/screening devices to the existing structures. It is envisaged that most of the testing work will be carried out at the National CSO Test Facility, based at Hoscar WWTW near Wigan and operated by North West Water. Supporting laboratory and hydraulic modelling services will be provided by the University of Sheffield.

Quarterly Interim Reports and an Annual Report are to be provided to the industry representatives on the Management Committee. In the first year of the programme it is proposed to produce:

- Tables and charts of separating performance criteria for four different designs of CSO structure

    - low sided weir,
    - high sided weir,
    - extended stilling pond
    - Sharpe & Kirkbride chamber

- Performance evaluation of 3 novel CSO screening arrangements, all having the following attributes:

    - effective separation of gross solids
    - reliable/low maintenance
    - low or reasonable cost

  In the first year of the research program tests will be carried out on three screen arrangements. The selection of the screens to be tested and the order of test priority will be agreed by the Management Committee. The performance evaluation of each screen arrangement will be assessed against the standard criteria established for each of the CSO chambers.

- Recommendations concerning the use of each screen in practice

5. Long Term Objectives

Later on in the programme it is proposed to expand the Testing Facility in order to enable some or all of the following to be carried out:

- Full scale testing of novel and existing, proprietary screens against established performance of "standard" CSO structures without screens.

- Evaluation of flow controls, including real time operation and control at CSO structures.

- Retrofitting options and post-construction appraisal of devices.

The initial thrust of the work is, however, very much screen orientated and one of the key objectives of the Club is the preparation of a "Selection and Design Guide" for CSO structures in order to meet environmental standards, particularly solids separation. It is, of course, intended that the key deliverables of the Research Club's activities will gain the endorsement of the Environment Agency and will be of great benefit to wastewater industry practitioners and regulators alike.