CHEMICAL CONSTITUENTS ASSOCIATED WITH SEWAGE SETTLING VELOCITY PROFILES

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Chemical constituents associated with sewage settling velocity profiles

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THESIS SUMMARY

A methodology has been developed to measure the chemical constituents associated with the settling velocity fractions that comprise a wastewater settling velocity profile (SVP).

31 wastewater samples were collected from fifteen different catchments in England and Wales. For each catchment, settling velocity and associated chemical constituent profiles were determined. The results are mainly for Suspended Solids (SS), Chemical Oxygen Demand (COD), Phosphorus (P) and Total Kjeadahl Nitrogen (TKN), however these are supplemented by the results from 5 events for a suite of heavy metals.

COD, P, Hg, Mn and Pb were found to be predominantly associated with the solid phase and TKN, Al, Cu and Fe with the liquor phase of the wastewater samples.

The results in the thesis are expressed as mass of pollutant (g) per mass total SS (kg). COD and P were found to be mainly associated with the sinkers and had a particular affinity for solids with settling velocities in the range 0.9-9.03mm/sec. TKN was mainly associated with the soluble phase, however of the solids that did settle, a peak was found to be associated within the settling velocity range 0.9-9.03mm/sec.

The relationships identified for COD and P were generally found to be unaffected by flow conditions and catchment characteristics. However, TKN was found to be affected by catchment type.

Data on the distribution of heavy metals was limited and no specific relationships with solids were identified.

16 mean pollutant profiles are presented in the thesis. Presentation of the data in this form will enable the results to be of use to the design of sedimentation devices to predict removal efficiencies for solids and associated pollutants. The findings of the research may also be applied to modelling tools to provide further characteristics on the solids that are modelled than is currently used. This would enhance the overall performance of tools used in integrated catchment modelling.

Key words: wastewater, settling column, pollution, sedimentation, settling velocity measurement.

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CHAPTER 1

INTRODUCTION

In the developed world it is common practice for wastewater from domestic, industrial and commercial sources to be collected in sewerage systems and conveyed to a central point for treatment. In the combined sewerage system, overflows are generally constructed along the network to prevent overloading of the system during wet weather events. The wastewater is treated at a wastewater treatment works (WWTW) to render it suitable for discharge into the receiving water, with the overflow discharges generally receiving minimal treatment prior to discharge from the sewerage system into the receiving waters. If such discharges from overflows and wastewater treatment plants are not controlled and treated, acute and chronic pollution in the receiving water occurs - this subsequently alters the balance of the aquatic ecosystem.

The European Urban Wastewater Treatment Directive (UWWTD), introduced in 1994, sets out standards for the control and treatment of wastewater discharges. Under the Directive, a minimum standard of treatment is defined for WWTW discharges, with wet weather discharges, such as combined sewer overflows and storm tank discharges also requiring treatment to minimise pollution in the receiving watercourse. In addition to the UWWTD, there are also many European and UK water quality standards in force for the protection of the quality and use of watercourses, with the overall aim of these regulatory measures being the effective management and control of water pollution.

This Chapter outlines the need for the research into chemical characterisation of settling velocity profiles (section 1.1 and 1.2), the aim of the research (section 1.3) and the background to the project (section 1.4.)

1.1.WASTEWATER AND WATER POLLUTION

1.1.1.WASTEWATER TREATMENT

Conventional WWTW incorporate three treatment stages, preliminary, primary and secondary, to treat wastewater to the required discharge consent standard. Historically the general standard applied in the UK was the Royal Commission 20 mg/l biochemical oxygen demand (BOD) and 30 mg/l suspended solids (SS) standard (see Chapter 3). In situations where the wastewater discharge has to comply to higher consent standards, such as for discharges into sensitive waters, tertiary treatment is also required. Examples of conventional treatment processes employed at WWTW, and the matter removed by each process is given in Table 1.1.

Table 1.1. Examples of conventional WWTW processes.
(Metcalf and Eddy, 1979 and Lester, 1983)

Primary sedimentation tanks (PST) are a key process employed at WWTW to remove settleable particulate matter from wastewater. These tanks operate by gravity settlement under quiescent conditions with the removal of settleable matter dependent on the settling velocity of the individual particle or flocs. This is in turn dependent on the characteristic of the particle or flocs, such as size, shape and density.

PST have been used to remove particulate matter (e.g. suspended solids) from wastewater since their introduction in the early 1900s. Randall et al (1982) and Harrison (1983) also report that the removal of biodegradable organic matter is comparable with suspended solid removal, indicating that organic matter (and therefore pollutant matter) is associated with the suspended solids.

At overflows on the sewerage network, sedimentation devices are also employed (eg. hydrodynamic/vortex separators) to provide a degree of treatment, in addition to flow separation. Overflow devices on the network have traditionally been designed to relieve the overloaded sewerage system and WWTW of excess flows. Over the past decade, increasing awareness of the pollution effects of overflow spills have led to the water industry and regulatory bodies reviewing the water quality aspects of overflows (see Chapter 3). This has led to a degree of treatment (eg. gross solids removal) being required at these locations.

There are four main overflow devices currently used: the high side weir, the stilling pond, the vortex overflow with peripheral spill and the hydrodynamic separator (eg. Storm King ^{TM}). Removal of solids in these devices is achieved by gravity sedimentation. In the vortex overflow with peripheral spill and the hydrodynamic separator removal of solids is assisted by a swirling flow action combined with gravity.

1.1.2. WATER POLLUTION

Control and treatment of wastewater discharges is required to minimise the pollution of receiving waters from the chemical, biological and physical constituents present in such discharges. There is no universal definition of water pollution, but in the European Dangerous Substance Directive (76/464/EEC) it is defined as the:

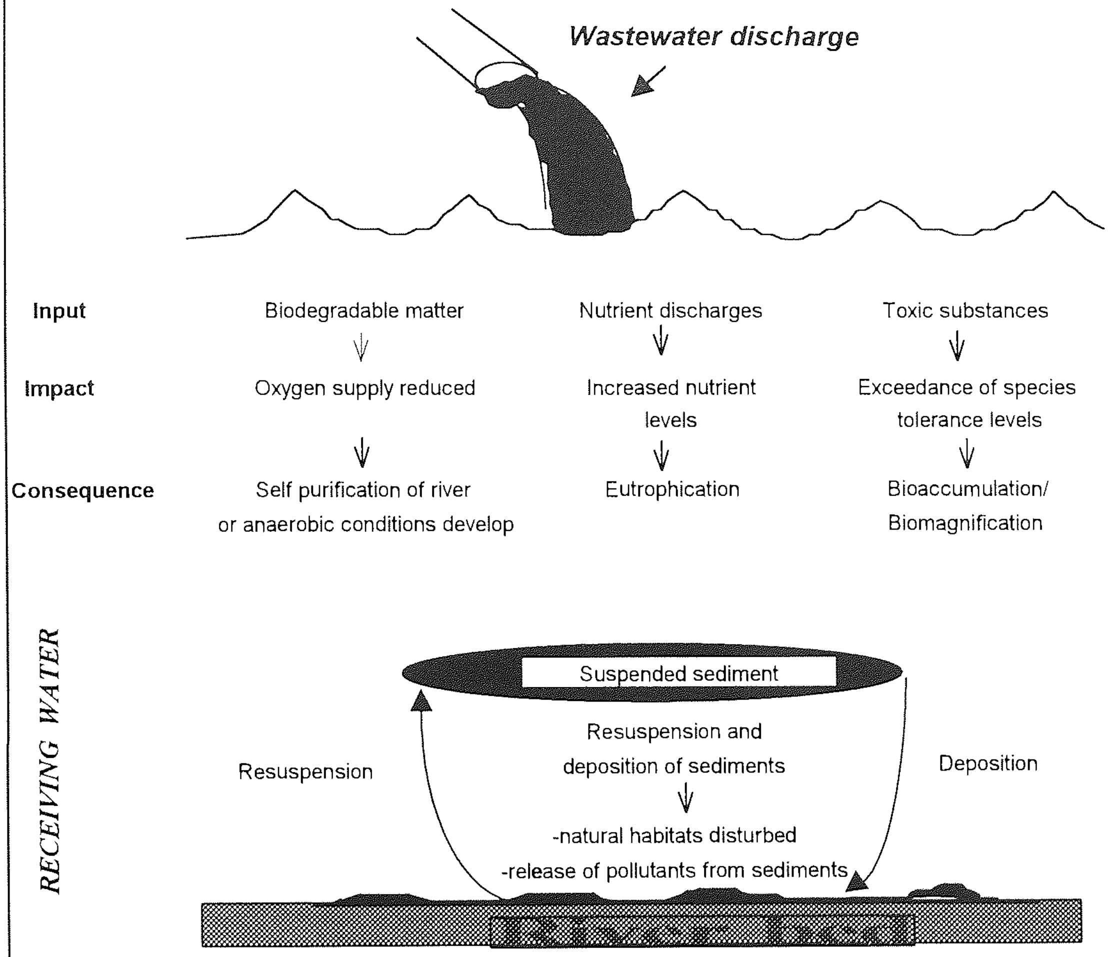
> 'discharge by man of substances or energy into the aquatic environment, the results of which are such to cause hazards to human health, harm to living resources and the aquatic ecosystem, damage to amenities or interference with other legitimate uses of water.'

The water pollution that can result from wastewater discharges is well documented, with reviews given in Bolton and Klein (1961), Weiner et al (1988) and Harrison (1983). Welch (1992) discusses the ecological effects of wastewater discharges, with the effects of nutrients discharges on water bodies reported by Cooper et al (1994) and Sedlak (1991). A summary of the main pollutant effects of wastewater discharges on water bodies is given in Figure 1.1.

Chemical constituents in wastewater are of primary interest in this research. These constituents are associated with two main groups, organic and inorganic matter, examples of which are given in Table 1.2.

Table 1.2. Examples of chemical constituents in wastewater and their pollution potential. (Metcalf and Eddy, 1979)

If wastewater discharges are not treated to remove chemical constituents, pollution of the receiving water can occur, with the resultant effects as shown in Figure 1.1. To prevent such pollution occurring, it is essential to collect, treat and regulate wastewater discharges. There is also a need to review and update existing processes employed for wastewater treatment to ensure discharges from both WWTW and sewerage overflows meet UK (eg. Water Resources Act) and European (eg. UWWTD) legislative standards for both treated effluent discharges and water quality



Potential effects of a wastewater discharge

Natural ecosystem disturbed
Water quality standards breached
Water Use affected eg.fishing, bathing, water supply

Figure 1.1. Summary of the main potential pollutant effects of wastewater discharges on receiving waters

1.2. NEED FOR RESEARCH?

The current design practice for PST at WWTW is based on original design criteria developed in the early 1900s that incorporates standard values for surface loading and retention times. These criteria however do not account for the variable nature of wastewater between sites.

The variation in the nature of wastewater, particularly the settleable matter, affects the efficiency of the sedimentation process. For example, if a particular wastewater has a low proportion of settleable solids, the removal efficiencies of solids in the sedimentation tank will be lower than if the wastewater contained a higher proportion of settleable solids. Also, the potential of PST to remove chemical pollutants (e.g. chemical oxygen demand, heavy metals and nutrients) associated with the settleable matter has not been thoroughly investigated (see Chapter 4). It is probable that a large percentage of PST at WWTW are not operating at their full potential, as current design does not consider the variable nature of wastewater between sites.

The increase in urbanisation over the past decades has also led to a decrease in permeable areas, resulting in a rise in the volume of surface runoff during wet weather events. Discharges from sewerage overflows (eg. combined sewer overflows) have increased in volume and occurrence, and have been identified by the UK water industry (eg. Foundation Water Research, 1994) as a major contributory pollutant source responsible for the degradation in water quality of large lengths of UK water courses.

To reduce pollution from sewerage overflows, there has been considerable research and development into the design of overflow devices, in particular those devices which use dynamic separation (eg. hydro dynamic and vortex separators). The dynamic separators operate on a similar principle to PST in that an acceleration force field (eg. gravity) effects removal of settleable matter. The knowledge on the potential of these devices, to remove pollutants associated with the settleable matter, as with PST, would benefit from further investigation (see Chapter 2).

One option for improving the performance of sedimentation devices and other wastewater treatment processes, is to characterise the wastewater to be treated, both at the wastewater treatment works and at overflows along the sewerage network, so that the nature of the wastewater can be identified and appropriate treatment applied.

Settling velocity (v_s) is a parameter that is used to characterise wastewater and is currently used within sewer models (eg. HYDROWORKS) to describe sediment transport processes. However, there is limited knowledge on sediment transport in sewers, in particular sediment characteristics and transformation processes (see Chapter 2). Research on the characterisation of wastewater using settling velocity and associated pollutant profiles will therefore contribute to understanding in-sewer processes and aid in the development of urban drainage quality models, and the design of wastewater treatment processes.

Particle size has also been used to characterise wastewater (Levine et al., (1985) and Xanthopoulos and Hahn, (1990)). Particle size can be determined by sieving or laser techniques. However, this parameter does not directly assess the form or settleability of a particle and requires additional calculations (eg. Stokes Law) to determine a particle's settleability. The best estimate of settling velocities for sewer particle is also stated in the IAWQ, Scientific and Technical Report on Sewer Solids (IAWQ,1996a) as being obtained by settling velocity measurement and not based on physical parameters.

1.3. AIM OF RESEARCH

With the increasing control of wastewater discharges and monitoring of water quality in receiving watercourses, by UK and European legislation, there is a need for practicable and economical wastewater treatment processes that provide a high level of treatment. Sedimentation devices (eg. PST and hydrodynamic/vortex separators) are one option for such treatment.

To improve the performance and design of PST and hydrodynamic/vortex separators, an understanding of the fundamental processes and characteristics within the system are required. If it was known which chemical pollutants are associated with the solids removed from sedimentation devices (eg. PST and separators), and the solid settling velocities identified, it is hypothesized that the removal efficiencies of these devices for chemical pollutants could be improved through relevant modifications to the design procedures. Information on wastewater characterisation, in particular sewage grading curves, will also contribute to the development of sewer system modelling, and lead to a better understanding of in-sewer processes.

The aim of the thesis was:

> To determine whether the individual chemical characteristics of sewage are associated with specific settling velocity fractions, and hence whether sewage grading curves can be used to improve the design of separation devices.

In order to achieve this aim, three objectives were identified.

- To identify a simple method of determining the chemical characteristics of sewage solids associated with the various settling velocity fractions that comprise a sewage grading curve.

- To analyse the chemical characteristics of sewage samples from a variety of catchments to determine the settling velocity fractions with which individual chemical parameters are associated.

- To examine the potential for using sewage grading curves in optimising the design of gravity, or assisted gravity, separation devices for the removal of specific quality parameters.

The settling velocity data derived from the settling column tests carried out in this research is presented in accordance with the standard procedure recommended in Hedges and Chebbo (1996). Within this document settling velocity is expressed as mm/sec, with a positive sign indicating that a particle sinks or settles (termed sinkers), and a negative sign indicating that a particle rises (termed floaters). The notation employed to denote settling velocity is given as v_s.

Hedges and Chebbo (1996) recommend that the settling velocity profile is expressed as a cumulative graph. The vertical axis shows the percent of solid by weight with a settling velocity less than the value shown on the horizontal axis, and is plotted to a natural scale.

Settling velocity (mm/sec) is plotted to a log scale on the horizontal axis, with values increasing from left to right. If the proportion of floaters (with a negative settling velocity) or those of neutral buoyancy are to be included it is necessary to employ a linear scale for the horizontal axis. In this research only the particles that sink/settle (sinkers) in the settling column test are plotted. The resulting curve is generally s -shaped and known as the Sewage Settling Velocity Grading Curve (SSVGC) or Settling Velocity Profile (SVP). In this research, the term settling velocity profile is used. An example of a SVP is shown in Figure 1.2.

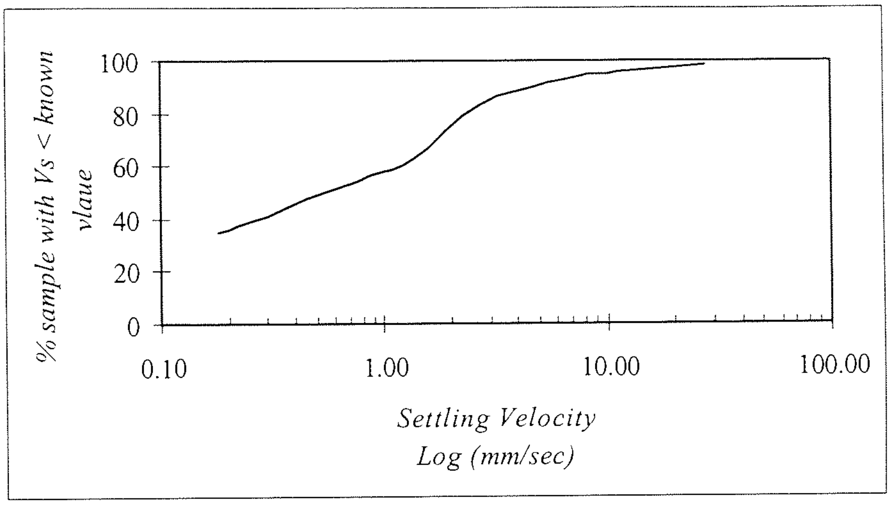


Figure 1.2. Example of a typical SVP
(Site A: DWF sampling conditions).

1.4. PROJECT BACKGROUND

A group of researchers, from Smisson Foundation and Aston University, developed an interest in characterising the settleable material in wastewater as the result of a study on a hydrodynamic separator at James Bridge, Walsall (Hedges and Lockley, 1990). Smisson (1990) carried out a review of research on the use of sewage grading curves that suggested further research was required to explore their determination and use.

The development of a settling technique to determine sewage grading curves was initially reported by the Scottish Development Department (1977), with Tyack et al (1992) from Aston University modifying the technique to produce a practicable and refined version. The next step was to use this device to explore the relationship between grading curves and catchment characteristics (Tyack, 1996) and subsequently to characterise the chemical constituents associated with settleable matter in wastewater.

As a consequence of the above, this project was established and funded by the Smisson Foundation, with assistance from Hydro Research and Development and South West Water. The Smisson Foundation is a nonprofit making organisation with the aims of promoting research and education into methods of protecting and conserving the environment. Hydro Research and Development are a commercial wastewater engineering company and South West Water, one of the ten privatised water companies in England and Wales established following the 1989 Water Act.

The research project commenced in October 1992 and concluded in December 1995. The first six months of the research programme (October 1992-April 1993) was based at Aston University, Birmingham. The remainder of the research programme (April 1993-December 1995) was then carried out at Hydro Research and Development's offices and laboratory in Clevedon, Bristol.

1.5. LAYOUT OF THESIS

Chapter 1 introduced the reader to water pollution, wastewater treatment and the origins, aims and objectives of this research. A background of the characterisation of wastewater, focusing on particulate matter, is presented in Chapter 2 and a review of pollution control in UK and Europe in Chapter 3. The design, operation and performance of sedimentation devices are discussed in Chapter 4. The Laboratory Procedures and Methodology used in the research are presented in Chapters 5 and 6. The Results of the study and their subsequent Discussion are given in Chapters 7 and 8. The application of the results are discussed in Chapter 9 and the thesis then ends with the Conclusion and Recommendations for future work in Chapter 10.

For guidance to the reader key points of the research are given below.

1. The Aston settling column technique was employed in the research. This method collects three broad settling column groupings:

   Residue - the liquor remaining at the end of the experiment in the central column that typically contains matter in suspension such as colloidal and very fine material;

Floaters - the rising solid fraction containing lighter, buoyant particles such as particles of fat, and

Sinkers - the settleable fraction typically characterised by containing the heavier, larger settleable particles and flocs.

The focus of this research is on the sinker fraction (that which settles).

2. The majority of the wastewater samples collected relate to DWF conditions, however some of the samples were collected under wet weather (storm) conditions.

3. The analytical results of the chemicals associated with the settling velocity fractions are predominantly for Suspended Solids (SS), Chemical Oxygen Demand (COD), Phosphorus (P) and Total Kjeadahl Nitrogen (TKN), however these are supplemented by the results from 5 events for a suite of heavy metals.

1.6. KEY TERMS IN THESIS

Key terms used in the thesis are described below.

Pollutants: where the term pollutant is used after chapter 7, this refers to the chemical constituents determined in the research (eg. COD, P, TKN and heavy metals).

DWF and wet weather conditions: DWF conditions are classified as flows < 3DWF and wet weather flows (or storm) are classified as those with flows >3DWF.

Settling velocity (v_s): the average velocity with which a particle settles through a liquid under the influence of gravity, determined by timing the fall over a known distance.

Sewage grading curve/Settling velocity profile: The data from the settling column tests are displayed as a Sewage grading curve/Settling velocity profile. The terms are synonymous and in this research the term settling velocity profile is used.

Settling column groupings: as described in section 1.5. three broad settling column groupings are derived from the settling column test: Residue, Floaters and Sinkers.

Hydrodynamic and Vortex separators: Hydrodynamic and Vortex separators rely on dynamic separation to remove settleable matter from wastewater. The terms hydrodynamic and vortex are used interchangeably. Hydrodynamic is usually applied to prefabricated devices such as Storm King manufactured by HRD/UFT. The term Vortex is generally applied to those devices that have a peripheral spill which originate from the USA such as the USEPA swirl concentrator.

1.7. LIST OF KEY ABBREVIATIONS

Key abbreviations in the thesis are given below:

COD:	chemical oxygen demand
DWF:	dry weather flow
P:	phosphorus
PST:	primary sedimentation tank
SS:	suspended solids
SVP:	settling velocity profile
TKN:	Total Kjeadahl Nitrogen
UWWTD:	Urban Waste Water Treatment Directive
v_s:	settling velocity
WWTW:	Waste Water Treatment Works

CHAPTER 2

WASTEWATER CHARACTERISATION

In wastewater, chemical pollutants are present in both soluble and particulate states, with the proportion in each state dependent on the characteristics of individual pollutants. In this research, the chemical pollutants associated with particulate matter are of primary interest, as it is the removal of this matter which is the primary purpose of sedimentation devices.

2.1. SOURCES AND TYPES OF PARTICULATE MATTER IN SEWERAGE SYSTEMS

The particulate matter that reaches the WWTW is mainly derived from domestic/human wastewater (eg. food and faecal matter), surface runoff (eg. from roads, buildings and street surfaces) and matter eroded from the sewer itself.

In wastewater suspensions, particle sizes range from below 1 μm to more than 1000 μm. Particulate matter found in wastewater has been classified by Metcalf and Eddy (1979) as shown in Figure 2.1. This matter ranges in size from approximately 1 milli-micron to 1 micron in diameter (representative of solids that consist of the dissolved and colloidal fractions), up to the larger solids, the suspended solids, that are generally measured as having a diameter greater than 1 micron.

In surface runoff, particulate matter comprises of mineral substances eg. grits and stones and organic matter that builds up on catchment surfaces in dry weather. This matter generally consists of larger solids (eg. >1 micron) that are mobilised during wet weather events and are transported from source into the sewerage system by surface runoff. The particulate matter in road sediments (Xanthopoulos and Hahn, 1990, Hamilton et al., 1984, and Morrison et al., 1990), roof runoff (Quek and Forster, 1993) and urban runoff (Roberts et al, 1988 and Ellis et al, 1981) have all been found to be associated with a variety of pollutants that include biochemical oxygen demand (BOD), chemical oxygen demand (COD) and heavy metals. An overview of pollutants associated with highway drainage is given by CIRIA (1994).

Figure 2.1 Classification of size and range of particles found in wastewater
(Metcalf and Eddy, 1979)

The movement of particulate matter from surfaces in the drainage catchment (eg. road and street surfaces) during wet weather events is given by CIRIA (1995) to involve several steps. These are:

- release from the street/road surface;
- transportation to the collection system by overland flow during wet weather events;
- transfer into the sewerage system;
- transportation under open channel flow condition as suspended or bed load in the system;
- deposition and/or re-erosion in-sewer;
- discharge to the watercourse via combined sewer overflow (if in operation);
- settlement in the WWTW.

In an ideal sewerage system, particulate matter entering the system (from all sources) is progressively carried downstream where it is eventually trapped and removed immediately prior to the outlet of the system, eg. the WWTW. However, during wet weather events, excess flows in the system are discharged from overflows along a combined sewer network. The pollutant loads carried by and ultimately discharged from the sewer either at the WWTW or through the overflows, is dependent on several processes. These processes are summarised in Section 8 of the Urban Pollution Manual (Foundation Water Research ,1994) as involving the following factors:

- type of foul input e.g. domestic and industrial;
- build up and wash-off of surface sediments;
- deposition and erosion of sewer sediment;
- sediment transport in sewers;
- advection and dispersion of pollutants;
- biochemical reactions.

One of the most important processes in the sewer system is the deposition and re- erosion of sewer sediments, although this does not occur in all sewers. Deposition of sewer sediments can consequently reduce the hydraulic capacity of the sewer, with the associated problems, (given in CIRIA, 1995) of sewer surcharge, flooding, and premature operation of storm sewage overflows. There is also a polluted load associated with these solids, that is consequently discharged into the receiving water (see section 2.3.1.).

The occurrence of sediment deposition results from suspended matter in the wastewater settling out of the sewer flow and depositing on the bed of the sewer, leading to a build up of sewer sediments (sewer sedimentation). As the flow increases in the sewer either as part of the normal daily dry weather flow (DWF) cycle, or during storm events, the deposited sediments may be eroded and become resuspended in the flow. As sediments are eroded from the sewer bed, interstitial water and pollutants are also released into the sewer flow. Once entrained in the flow, the eroded sediments may move down the sewer either in suspension or as bed load.

Much research has been undertaken in the field of sediment deposition and transport in sewers (Kleijwegt et al, 1990; Ashley and Crabtree, 1992 ; Arthur et al, 1996; Jefferies and Ashley, 1994; CIRIA,1996; Chebbo and Bachoc, 1993 and Stotz and Krauth, 1984), and the pollutant load associated with solids in CSO discharges (Xanthopoulos and Augustin, 1992; Benoist and Lijklema, 1990; Saul and Thornton, 1989; Chebbo and Bachoc, 1992, and Michelbach and Wöhrle, 1992a,b and 1993a, b).

The occurrence and problem of sewer sedimentation is also internationally recognised, as reflected by the International Workshops on Sewer Sediments (Verbanck et al, 1994) and the 1995 International Conference on Sewer Solids (IAWQ, 1996b) which addressed this problem. There is, however, a lack of fundamental knowledge on the pollutant transformations and accumulative processes in the sewer system. In the management of urban drainage such knowledge is required for dealing with the function of the sewer itself and when establishing boundary conditions to the WWTW and the receiving water.

2.2. SEWER SEDIMENT CLASSIFICATION

To aid in understanding the processes involved in sewer sedimentation, Crabtree (1989) proposed a five category classification system for combined sewer sediments, with each category having distinct characteristics in terms of appearance, composition and polluting potential. Crabtree's classification system is given in Table 2.1., with an example of the distribution of sediment types in a typical combined sewer given in Figure 2.2.

Examination of the rheological characteristics (eg. critical yield stress) indicated that the sediments ranged from weakly cohesive (sediment type C) up to highly cohesive immobile material (sediment Type B). Crabtree (1989) also concludes that Type A and C sediments deposits were the most significant source of pollutants, with the resuspension of Type C deposits being responsible for the high pollutant loads associated with extreme rainfall events.

Type C sediments are believed to be the source of material discharged during the frequently observed 'first foul flush' in many sewage systems in response to average storm events. This has been confirmed by Ashley and Crabtree (1992), Chebbo and Bachoc (1993) and Michelbach and Wöhrle (1993b). Type A, B and E sediment deposits are most significant in terms of restricting sewer flows and their removal is a common operational requirement. Based on Crabtree's classification system, particulate matter reaching the WWTW will therefore primarily consist of Type C sediment.

Table 2.1. Classification of sewer sediments (Crabtree, 1989)

Figure 2.2. Typical sequence of sediment deposits in a combined sewer pipe (Crabtree, 1989)

2.2.1. APPLICATION OF THE CLASSIFICATION OF SEWER SEDIMENTS

The understanding of in-sewer processes, in particular sewer sedimentation, is invaluable for the development of sewer system modelling. The classification of sewer sediments, shown in Table 2.1, has been applied to the development of sewer models, such as HYDROWORKS (incorporating MOSQITO), SWMM and MOUSETRAP to predict the effects of wet weather discharges on the water quality in receiving waters.

Gent et al (1995) report on the development of the sewer quality model, MOSQITO, in modelling the behaviour of sediments and associated pollutants. In MOSQITO, sewer sediments are modelled by classifying them into fractions based on particle size, specific gravity and settling velocity. Each sediment type is also given a potency factor that expresses the amount of pollutant attached to the sediment. MOSQITO has now been incorporated into the HYDROWORKS sewer model.

However, there are limitations to modelling in-sewer processes. This is due to the diversity and complexity of the natural phenomena being modelled, and the lack of knowledge available on the fundamental processes occurring in these systems; eg. sewer sedimentation. The main problems associated with sewer modelling are summarized by Berlamont and Torfs (1995) and include sediment erosion, flow regime and the variability of sediment supply.

The development of sewer models is reported by several researchers (eg: Fries, 1996 and Schütze et al, 1996) as being important for urban storm drainage management, in which the sewer, WWTW, and river system can be considered as a unity. With the on-going development of sewer models recognised as a benefit to the overall understanding of urban drainage systems, this enables a holistic approach to be adopted for managing the environmental impacts of wastewater discharges.

2.3. COMBINED SEWER OVERFLOW DISCHARGES.

During storm events, excess flows in the combined sewerage system (containing resuspended sediment deposits) are discharged through combined sewer overflows (CSOs) into receiving waters.

In theory, CSOs in the UK are designed based on the receiving watercourse flow acting as a diluting medium to the CSO discharge, with the overflow not commencing operation until the flow in the sewer has reached a level corresponding to 'Formula A' defined by the Technical Committee on Storm Overflows and the Disposal of Storm Sewage (DoE, 1970) as :

$$\text{Formula A} = DWF + 1360P + E \ (l/d) \qquad \text{Equation. 2.1.}$$

where;

$DWF = PG + I + E$

P = population served

G = water consumption per head per day (l/h/d)

I = infiltration (l/d)

E = industrial effluent discharged in 24 hours (l/d)

However, over the past decades, increasing urbanisation has led to an increase in impervious surfaces. This has resulted in a reduction of runoff directly reaching watercourses, or infiltrating in the ground and an increase in that entering the sewerage systems. As a result of this, in highly urbanised areas during wet weather events, sewer flows rise at a more rapid rate than in the watercourse. This often results in the overflows commencing operation before there has been a comparable rise in the receiving water and consequently the dilution capacity of the receiving water is reduced. Premature operation of overflows in dry weather also occurs, particularly in overloaded sewerage systems, or those that have a build up of sediments.

2.3.1. POLLUTANTS IN WET WEATHER DISCHARGES

Combined sewer discharges are generally found to contain the highest load of pollutants in comparison to highway runoff and separate storm runoff (Table 2.2). Durachlag et al (1992) also report that WWTW receive increased polluted loads during wet weather events when serviced by a combined system.

Table 2.2. Pollutant discharges in urban sewers and catchments
(Hall and Ellis, 1985 and Moffa, 1990)

Thornton and Saul (1986 and 1987) carried out research into the pollutant effects of CSOs and report that a first flush of pollutants was observed to occur in the majority of storm events. The pollutants studied were total suspended solids, total dissolved solids ammonia and COD. They also reported that the important aspects relating to the magnitude of the first flush were the antecedent dry weather period and the subsequent flushing and transport of accumulated in pipe sediments deposited at the time of storm. Ashley et al (1992) investigated erosion and movement of sediments and associated pollutants in combined sewers and identified the release of a highly polluting foul flush from CSOs at the start of wet weather flow.

The effects of combined overflow discharges on receiving waters are well documented (Ellis and Thevenot, 1994; Novotony, 1994, and Moffa, 1990), with the pollutant impact being categorised as either acute (hours/days) or long term (months/years). Examples of acute and long term pollution associated with CSO discharges are given in Tables 2.3 and 2.4.

Moffa (1990) also recognises that the impact of a CSO discharge on the receiving water is dependent on various factors, that include: rate and volume of discharge, assimilative capacity of the receiving water, nature of the receiving water, and frequency of discharges. Due to these factors the impact of intermittent discharges from CSO has to be assessed on a site by site nature to consider the characteristics of each site.

Table 2.3. Examples of acute pollution caused by CSO discharges

(Ellis and Thevenot,1994, Novotony, 1994, and Moffa, 1990)

Table 2.4. Examples of long term pollution caused by CSO discharges

(Ellis and Thevenot, 1994; Novotony, 1994, and Moffa, 1990)

2.3.2. CHARACTERISATION OF CSO DISCHARGES

With legislation moving towards treatment standards at CSOs (eg: UWWTD), there is a need to characterise the discharges from CSOs in order to develop suitable treatment processes. In a response to this, various researchers (Saget et al, 1993; Chebbo and Bachoc 1992 ; Michelbach and Wöhrle, 1992a , 1992b, 1993a, 1993b; Pisano,1996 and Tyack, 1996) have investigated the characterisation of such discharges, in particular the settleable solids, with the aim of using this to develop and/or improve the performance of hydrodynamic/vortex separation devices. Within their research, wastewater and stormwater solids are categorised into settling velocity fractions by employing settling velocity apparatus. The techniques employed to measure the wastewater settling velocity profiles are summarised in section 2.4. and the results of the application of settling velocity measurement are discussed in section 2.5.

2.4. TECHNIQUES EMPLOYED TO CHARACTERISE WASTEWATER AND STORMWATER INTO SETTLING VELOCITY FRACTIONS

There are several techniques (eg. Cergrene: Institute Filtration/Separation (IFTS) column and the Andréasan pipette, Aston and the UFT settling columns) currently employed to characterise settleable solids into settling velocity fractions. The basic mechanism of these devices are that the sample is placed in the settlement device, and sub samples are collected at timed intervals from a set point. In the IAWQ Scientific and Technical Report on Sewer Solids (IAWQ,1996a), Hedges and Chebbo (1996) present an Appendix on the standardisation of terminology for settling velocity measurement techniques. Within this appendix the main settling techniques in use are classified into two methods.

1. Those where the sewage sample is introduced to the device in a fully mixed state are referred to as the 'homogenous method (eg. the Cergrene Andréasan pipette).

2. Those where the solids are concentrated prior to being loaded into the top of the device are referred to as top induced methods (eg. Cergrene IFTS column, Aston and UFT settling columns).

As these techniques were developed by individual research groups, there are different principles associated with each device, and as can be seen from Table 2.5, there is no one standard method employed.

The settling depths for the different techniques vary, with 1.62m for the Aston column, 1.8m for the Cergrene IFTS column, 0.7m for the UFT device, and 0.20m for the Cergrene Andréasan pipette. The diameters are however similar for three of the devices (51mm for Cergrene IFTS column, 54mm for Aston and 50mm for the UFT device).

The pretreatment methods also vary for the different methods. A settlement period is used in the Aston (3 hours) and UFT (2 hours) techniques, with the particles separated into two size fractions (>50μm and <50μm) by wet sieving in the Cergrene method. In both the Aston and Cergrene methods all particles in the sample are measured. However in the UFT method, the residue in the Imhoff Cone is not drained or weighed, thus a proportion of the sewage sample is lost.

Two types of water are used in the three methods: residue (which is the sewage liquor remaining after 3 hours settlement of the wastewater/stormwater) in the Aston method, and drinking water in the UFT and Cergrene methods. The typical mass of solids derived from the tests also vary. This is attributable to the different sample volumes, pretreatment and settlement times used.

In Aiguier et al (1996 and 1997) a comparison of settling velocity profiles determined for the same wastewater sample by the Aston, UFT and Cergrene methods is reported. Findings of the comparison tests showed that settling velocities measured by the UFT method were greater than those produced by both the Aston and Cergrene methods (ratios between 2 and 30). This is explained by Aiguier et al (1997) to be due to the UFT method not representing a full settling velocity profile within the sewage, as the method only reports on the settleable solids (eg. those particles which could settle within two hours in an Imhoff Cone and with a settling velocity greater than 0.01cm/sec). The raw data for the UFT method was analysed in relation to the initial mass and showed that the differences between the results of the UFT test with the Aston and Cergrene methods were significantly reduced (ratio between 1.1 and 10).

	DEVICE			
	ASTON	UFT	CERGRENE	
Method	FL[1],M(t)[3]	FL[1],M(t)[3]	FL[1],M(t)[3]	HS[2],C(t)[4]
Pretreatment	3h settlement in the column	2h settlement in an Imhoff Cone	By sieving size >50μm	By sieving size<50μm
Typical solid mass	Between 0.5g and 4g SS	Around 1g settleable solids	1g of SS >50μm	Cv[5]=0.2-0.5% TSS<50μm
Apparatus	Column	Column with a cone	IFTS column	Andréasen pipette
Settling depth (m)	1.62	0.7m	1.8m	0.2m
Diameter (m)	0.054	0.050	0.051	0.10
Original sample volume	approx. 5 litres	5 litres	1-2litres	1-2litres
Nature of liquor in device	Sewage	Drinking water	Drinking water	Drinking water
Range of settling velocity	0.018-2.7cm/sec	0.01-17.5cm/sec	0.0197-8cm/sec	0.0014-0.41cm/sec

[1] =floating layer; [2]=Homogenous suspension, [3] =mass of deposition with respect to time; [4] = concentration with respect to time; [5]= concentration by volume.

Table 2.5 Methods for measuring the settling velocity profiles of wastewater solids (amended from Aiguier et al 1996)

When the settling velocity curves for each method were plotted in relation to the initial mass, the methods produced different settling velocity curves for identical samples. These differences are explained by Aiguier et al (1997) to be attributable to the differences in the methods employed.

Aiguier et al (1996) also examines pretreatment methods used in the different settling column techniques and recommends that the measurement of settling velocity profiles should be done after sampling, preferably within 24 hrs with refrigerated storage, and that particles should settle in sewage liquor.

Due to differences in the methodologies currently employed for characterising sewer solids (described above) comparison of results between the different research groups can only be tentative as no uniform procedure is employed. Consequently there is a need to define a method which could be used by the different research groups in order to eliminate the influence of test procedures.

2.5. APPLICATION OF SETTLING VELOCITY MEASUREMENT TO CHARACTERISE SETTLEABLE SOLIDS IN WASTEWATER.

The current interest in settling velocity measurement to characterise settleable solids in wastewater had its origins in wet weather discharge studies (Hedges and Lockley, 1990, Michelbach and Wörhle 1992a, Chebbo and Bachoc, 1992 and Pisano, 1996) particularly from CSO, and the determination of the pollutant loads associated with settleable solids in these discharges. The driving force behind these studies has been the need to investigate the potential of improving the removal efficiency of overflow treatment devices to minimise the pollutant impact of wet weather discharges on receiving waters.

The research has shown that solids in storm overflows (both from combined and separate sewer systems) are the main vectors of pollution and that they have a high organic matter content. In the settling velocity research reported in the following sections, the unit used to express settling velocity was found to vary depending on the researcher and for comparative purposes, all results are reported in the standard unit: mm/sec. This is the standard unit recommended by Hedges and Chebbo (1996) in their report to the Sewer Sediment Working Group of IAWQ on Sewage Settling Velocity Standardisation of terminology and data presentation. It is also the unit used by Tyack (1996) in reporting results from the Aston Settling Column.

2.5.1. CHARACTERISATION OF WASTEWATER DISCHARGES

As part of the French research programme on solids transferred into sewer networks, Chebbo and Bachoc (1992) report that solids in storm and combined sewer discharges are the main vectors of pollution and that solids have a high organic content, are predominantly fine in size (median diameter 25-44μm) and have median settling velocities in the range 1.11-3.05mm/sec. Within the research, the Cergrene method of measuring settling velocity was employed (as described in Table 2.5.). The pollutants investigated by Chebbo and Bachoc (1992) included COD, BOD, TKN and Pb. In Table 2.6 the average proportion of these pollutants associated with the solid phase is given and show that the pollutants were mainly associated with the solid phase.

Table 2.6. Particulate pollutants in storm and combined sewers.
(Chebbo and Bachoc, 1992)

Characterisation of the solids in the sewer networks by Chebbo and Bachoc (1992) showed that fine particles, described as those <100μm, were found to predominate in the solids transferred in suspension in the downstream sections of the sewer network. The particles with a dimension < 100μm represented 66-85% of the total solids mass and had a median diameter of 25-44μm. These results were also found to be homogenous for the four sites studied and the nine rainfall events sampled. However, the results did suggest that the proportion by mass of particles with a dimension >100μm was greater in the combined networks than in the separate system, and the particle size characteristics of the solids transferred in suspension depended to some extent on the characteristics of the rainfall event.

The solids were further characterised by Chebbo and Bachoc (1992) into those with a diameter >50μm and those with diameters <50μm. The results showed that for solids with a diameter >50μm the mean V_{50} (only 50% of the mass of the sample particles fall with a velocity slower than V_{50}) was 13.89mm/sec for the storm sewer and 10.8 mm/sec for the combined sewer. For solids <50μm the mean settling velocity was 1.13 mm/sec for the storm sewer and 0.67mm/sec for the combined network. These results suggest that for the V_{50}, slightly higher settling velocities were found in the storm sewer samples. By comparison, the V_{50} mean settling velocity of all the solids (those >50μm and <50μm), was 2.0mm/sec for the storm sewer and 2.3mm/sec for the combined sewer. The results again indicate a slight difference between the mean settling velocities for the two sewer types, with solids in the combined sewer network having a higher settling velocity. This difference between the mean settling velocities was found to be attributable to the greater variation in the settling velocity of solids collected from the combined sewer over the different rain events, both for samples taken at the same site and at different sites.

As part of the German Ministry of Research and Technology's research programme into 'Rain caused wastes loads in receiving waters', Michelbach and Wöhrle (1992a and 1992b) examined the use of settling velocity measurement to improve the performance of CSO devices for stormwater treatment. In their research settleable solids are defined as those that settle in an Imhoff Cone within 2 hours and it is assumed that particles which do not settle within this period are unsettleable.

In Michelbach and Wöhrle (1992a and 1992b) the results of 98 settling velocity curves for combined sewage are presented (reproduced in Figure 2.3.). The curves show that the median settling velocity for solids in the combined sewage samples was 4.0mm/sec and that about 80 % of the settleable material had a settling velocity of more then 2.8mm/sec. 55 settling velocity profiles were presented for DWF samples (reproduced in Figure 2.4.) and show that a median settling velocity of 3.5mm/sec, indicating that the median settling velocity for solids in the DWF samples was lighter than the combined sewage solids. The heavy metals, lead, cadmium, copper, nickel and zinc, associated with the combined sewage solids were also determined, with the settling velocity fraction centred on 4.0mm/sec reported as having the highest load of settleable solids and heavy metals.

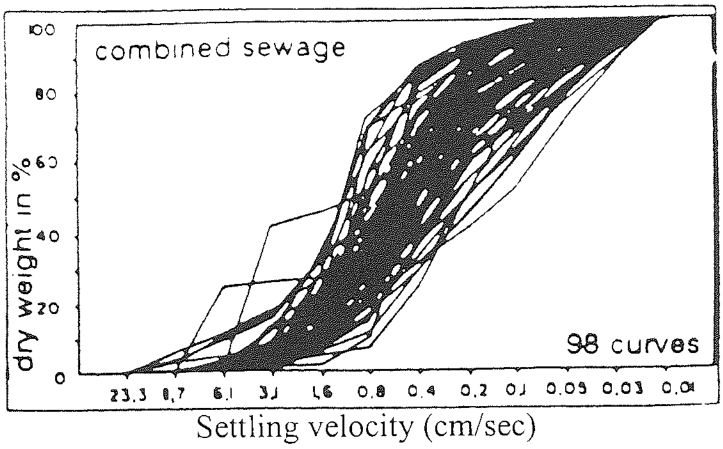


Figure 2.3. Settling velocity profiles of combined sewage reproduced from Michelbach and Wöhrle (1992a).

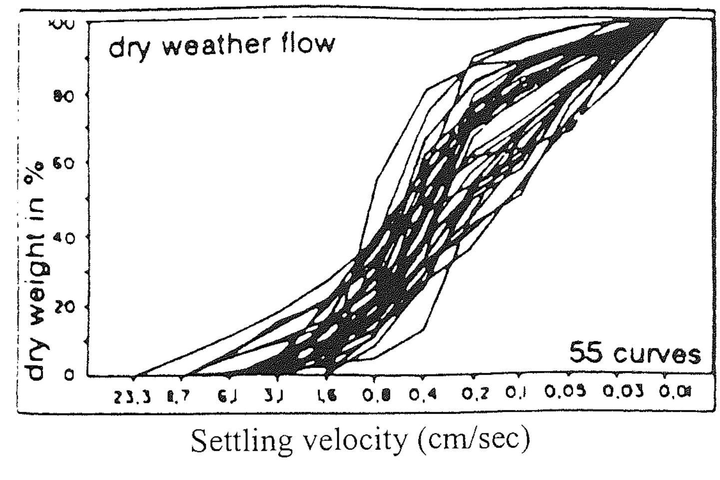


Figure 2.4. Settling velocity profiles of wastewater collected during DWF conditions reproduced from Michelbach and Wöhrle (1992a).

The COD association with settleable solids for combined sewage has also been examined by Michelbach and Wöhrle, (1993b). Results are reported for one sample which had a total COD of 520mg/l, of which 350mg/l was found to be associated with the settleable fraction (equivalent to 67% of the total COD). Further examination of the settleable fraction, by a settling column test, indicated that 70% of the COD associated with the solids had a settling velocity >2.8mm/sec.

Pisano (1996) reports on work in the USA on wastewater settling column profiles and identifies that three methodologies are in use in the USA for measuring settling velocity profiles: the multi-port column, the UFT and Aston column techniques. Pisano presents sewage settling velocity profiles for dry weather flow, storm water, combined sewage and CSO. On comparison of the mean settling velocities reported for each sample type, shown in Table 2.7, it can be seen that each sample type exhibits different solids characteristics.

Solids with the highest mean settling velocities (>2.17mm/sec) were found to be present in the CSO and combined sewage sediment samples, with the storm water samples being characterised by containing solids with the lowest settling velocities (<0.11mm/sec). The range of the median for the solids settling velocities was found to be greatest for sewer solids in the combined network and those discharged from CSO, indicating a greater variation in solids from these sources in comparison to the DWF and stormwater samples.

Table 2.7. Comparison of solid settling velocity profiles from different sample types (Pisano, 1996)

In the UK, research by Tyack (1996) and Tyack et al (1996) investigated relationships between the settling velocity profiles of wastewater and its contributing catchment. The Aston settling column technique described in Table 2.5 was used in the study. Twenty nine settling velocity grading profiles were determined and these were categorised into catchment size (large, medium and small) and catchment type (agricultural, industrial or domestic). No relationships were identified between catchment characteristics and settling velocity profiles. The twenty nine SVPs determined by Tyack (1996) are shown in Figure 2.5. In Figure 2.6. the mean and minimum SVPs are presented, these form the envelope within which all the SVPs lay. The mean settling velocity profile (shown in Figure 2.6.) shows that 50% of the solids had settling velocities less than 0.5mm/sec.

In Table 2.8. a comparison of solid characterisation (by settling velocity) reported in this section is presented. From the table it is evident that the results for solid characterisation in the CSO samples exhibit a similar range of settling velocity, eg. 2.17-4.00mm/sec. There is however a wide variation in the settling velocities reported for the samples collected under DWF and storm flow conditions.

WASTEWATER TYPE	MEAN SETTLING VELOCITY (mm/sec)			
	Chebbo and Bachoc (1992)	Michelbach and Wohrle (1992a and 1992b)	Pisano (1996)	Tyack (1996)
DWF	nd.	3.50	0.45	0.5
CSO	2.30	4.00	2.17	nd.
Storm overflow	2.00	nd.	0.11	nd.

Table 2.8. Summary of settling velocity data for DWF, CSO and storm overflows.
nd. = not determined

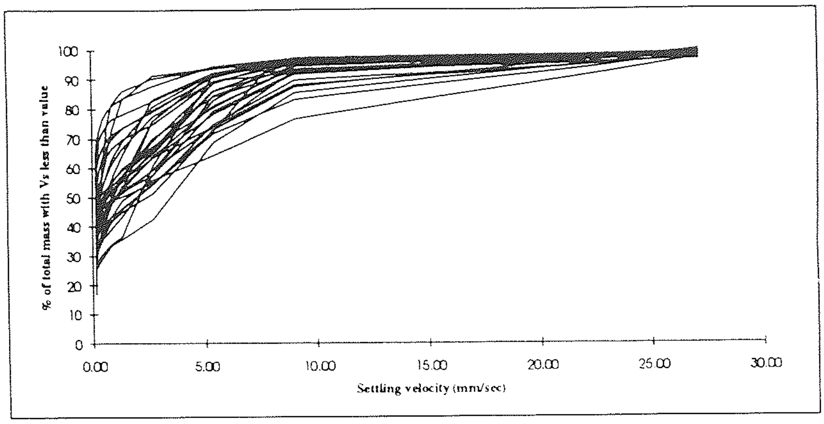


Figure 2.5. Twenty nine settling velocities profiles reproduced from Tyack (1996).

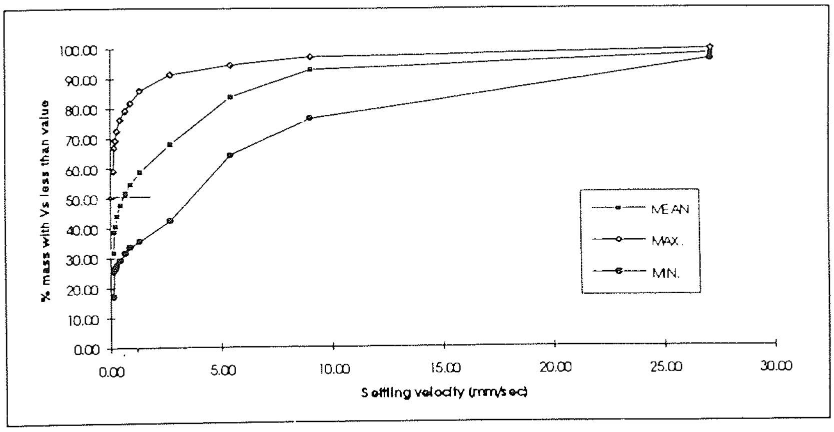


Figure 2.6. Mean settling velocites profiles reproduced from Tyack (1996).

2.5.2. APPLICATION OF WASTEWATER CHARACTERISATION TO THE DESIGN OF OVERFLOW TREATMENT DEVICES

In section 2.5.1. solids in combined sewer overflow discharges were reported as having mean settling velocities ranging from 2.17mm/sec up to 4.00mm/sec, with Pisano (1996) reporting a range of 0.10-54.5mm/sec. To improve the solids removal efficiency of overflow devices on sewer networks, several researchers have investigated the application of settling velocity profiles to the design of storm tanks and overflow devices. The profiles have been used to determine a settling velocity threshold for the maximum removal of settleable solids.

2.5.2.1. Storm/Stilling Tanks

The removal efficiency of a stilling tank treating combined and storm sewer overflow discharges was investigated by Chebbo and Bachoc (1992). The results are shown in Table 2.9. and indicate a high removal (eg. >69%) for Total Settleable solids (TSS), COD, BOD and lead. The lower value for TKN (eg. >44%) is explained by either its rather high level in the dissolved form, or to its association with fine solids.

Table 2.9. Performance of a stilling tank (Chebbo and Bachoc, 1992)

In Saget et al (1993) design settling velocity thresholds are reported for a stilling tank, but with an operating efficiency of 80%. The results are presented in Table 2.10.

Table 2.10. Settling velocity thresholds for a stilling tank operating at 80% efficiency (Saget et al,1993)

From Table 2.10., a design settling velocity of 0.7m/hr (equivalent to 0.194 mm/sec) indicates that 80% of TSS might be removed from storm overflow discharges and a design settling velocity of 0.06mm/hr (equivalent to 1.67×10^{-2} mm/sec) is required for the combined overflow discharges to attain 80% TSS removal. For combined sewers, 0.06m/hr also appears to be the lowest settling velocity threshold for all pollution parameters. These results were however gathered from a limited number of rainfall events and are only a first estimate of settling velocity thresholds to be adopted for the sizing of stilling tanks. The application of stilling tanks to the treatment of storm overflow discharges may however be difficult due to the low settling velocity threshold required to allow an acceptable level of treatment (eg. 1.67×10^{-2}mm/sec).

In Germany the ATV A 128 guideline for the design of stormwater tanks with overflow for combined sewage recommends a maximum surface loading of $10m^3/m^2/hr$ (Michelbach and Wöhrle (1993a). This surface loading corresponds to a settling velocity of 2.8mm/sec. Michelbach and Wöhrle (1993a) applied the UFT device (described in Table 2.5) to the settleable solids alone. In their paper the mean settling curve for 98 combined sewage samples is presented and shows that about 70% of the settleable solids have a settling velocity >2.8mm/sec and the median settling velocity is 4.0mm/sec. Results for heavy metals associated with the combined sewage solids (from six samples) are reported by Michelbach and Wöhrle (1992b) and indicate that 82% of lead, 72% of copper and 67% of zinc are associated with solids that have a settling velocity >2.8mm/sec. This therefore indicates that >67% of settleable solids and the associated copper, lead and zinc will be removed by stormwater tanks designed to remove solids with a settling velocity of 2.8mm/sec.

Further research on the performance of a stormwater tank (designed with a maximum surface loading of $10m^3/m^2/hr$) treating combined sewage is reported by Michelbach and Weiß (1996). The tank was tested over seven wet weather events and the settling efficiency of the tank was examined by determining the cumulative distribution of settleable solids in the inflow and outflow of the tank. The median settling velocity from 19 inflow samples was found to be 2.1mm/sec, and was 0.35mm/sec from 18 outflow samples.

The removal efficiency of the tank for settleable solids and associated pollutants is shown in Table. 2.11.

Table 2.11. Mean concentrations at the inflow and outflow of a stormwater tank and removal efficiency (Michelbach and Weiß, 1996).

From Table 2.11 it is evident that the tank was efficient at removing settleable solids (80%), with the removal of total solids being less (65%). However, this was reported by Michelbach and Weiß (1996) to be due to the sample containing a lot of very fine unsettleable solids. COD removal was reported as 37% which was due to its association with the soluble form. Results for ammonia, nitrate and phosphate, are also low. This is expected as they are recognised to predominantly occur in the soluble form.

The total efficiency of the stormwater tank was also measured giving 78% for total solids, 84% for settleable solids, 55% for COD and 65-90% for copper, lead, cadmium and nickel. Based on these results, the tank appear to be an effective option for the removal of solids and associated pollutants from such discharges.

2.5.2.2. Dynamic separators

Andoh (1994 and 1995), Andoh and Smisson (1993) and Smisson (1967) have investigated the application of settling velocity profiles to the design of hydrodynamic separators (eg. Storm King^{TM} and Swirl Flo^{TM}). Andoh (1994) presents an empirical mathematical model, derived from sedimentation principles, that is applied to the design of hydrodynamic separators. The model enables the prediction of a separator's removal efficiency at differing settling velocities and is shown in Equation 2.2.

$$\frac{D^2 S_V}{Q} = K_a^{K_b} \sqrt{\frac{N}{R}\left(\frac{1-P}{P}\right)} \quad . \qquad \text{Equation. 2.2}$$

where,

D = Diameter of separator; S_v = Settling velocity of particle in fluid; Q = Flow rate
N = Ratio between solids concentration in the baseflow to that in the overflow;
R = Ratio of overflow to baseflow; P = Baseflow proportion; K_a =Empirical Coefficient, K_b =Empirical Coefficient. (Andoh, 1994).

An important aspect of the design equation is that a settling velocity distribution of solids in the inflow is required to gauge the treatability of the wastewater, and to determine the settling velocity threshold for the device. The Aston column and methodology are used to determine the settling velocity threshold.

The efficiency of dynamic separators in removing suspended solids is reported by Andoh (1994) and Smisson (1967) to be 60-70%, with Brombach (1992) reporting that COD removal is associated with SS removal and that 70-78% of COD is removed in vortex separators treating CSO. Ghosh et al (1992) report 45-89% of the COD is removed from vortex separators treating CSO.

2.6. SUMMARY OF WASTEWATER CHARACTERISATION

The current state of knowledge relating to the characterisation of sewer solids and the chemicals associated with them has been reviewed in this chapter. The increasing application of this knowledge to the design of overflow devices to improve their pollutant removal efficiency has also been discussed. A review of the quality parameters regulated in UK and European legislation for water quality and wastewater discharges is now given in Chapter 3.

CHAPTER 3

POLLUTION CONTROL

Over recent decades, UK Acts and European Directives relating to water quality and wastewater discharges have been passed, with the aim of effectively managing water resources by controlling and monitoring pollutant discharges. A brief history of the development of UK and European Union water pollution control is given in this Chapter, together with key examples of Acts and Directives.

3.1. UK POLLUTION CONTROL

The early impetus for legislation in the UK was driven by two events, the cholera epidemics in England and pollution of the River Thames. A review of these events is reported by Barty-King (1992) and resulted in the early development of todays modern sewerage systems.

Following these early pollution events, a Royal Commission on Sewage Disposal was appointed by Parliament to review methods of treating and disposing sewage. In the 8th Royal Commission Report on sewage disposal (1912), the first UK effluent standard was produced. This standard, 20 mg/l Biochemical Oxygen Demand and 30 mg/l Suspended Solids, is based upon 80% compliance (ie. four samples out of every five have to comply with the standard), and a dilution of 8:1 in the receiving watercourse. An ammonia standard, 10 mg/l of Ammonia, was also recommended by the Commission to control nutrient discharges.

Although the Royal Commission standard is not enacted in law, it has until recently been uniformly applied to effluent discharges. However, the Royal Commission standard is now gradually being replaced by European standards (see Section 3.2.1).

Table 3.1 gives examples of key UK Acts passed between 1960-1995 for the control and regulation of water resources.

YEAR	UK ACT
1963	Water Resources Act
1967	Water (Scotland) Act
1973	Water Bill
1974	Control of Pollution Act
1989	Water Act
1990	Environmental Protection Act
1991	Water Resources Act
1991	Water Industry Act
1995	Environment Act

Table 3.1. Examples of key UK Acts regarding the control and regulation of water resources, 1960-1995.

Under the 1990 Environmental Protection Act the concept of integrated pollution control (IPC) was introduced. Under IPC, emissions to air, water and the generation of wastes are treated with a holistic approach, with the objective of reducing the impact on the total environment.

The Environment Agency (EA) for England and Wales and the Scottish Environment Protection Agency (SEPA), were both established in April 1996 under the 1995 Environment Act. The Environment Agency incorporates the National River Authorities (or River Purification Boards in Scotland), Her Majesty's Inspectorate of Pollution, and Waste Regulation Authorities and is responsible for the control of pollution in all environmental media eg. air, soil, water and biota

Prior to the establishment of the EA and SEPA the National Rivers Authority (in England and Wales) and the River Purification Boards (in Scotland) carried out the regulatory role of water pollution control.

3.1.1. RIVER SURVEYS.

The first documented classification system for river water quality in the UK was reported in the 1978 National Water Council (NWC) Report. This classification system has five quality classes ranging from Class 1(Good) to Class 4 (Bad) based on the parameters BOD, dissolved oxygen and ammonia.

The NWC system has been in use since 1978 for the five-year national water quality surveys that assess the general quality of rivers, canals and estuaries in England and Wales. The 1978 NWC Report also recommends that River Authorities embark upon a programme of specifying the use of surface waters and setting water quality objectives. New measures to replace the NWC system were proposed in 1991, under the NRA document, *Proposals for statutory water quality objectives* (NRA, 1991). These proposals include:

- the replacement of the NWC scheme with a General Quality Assessment system; and
- the introduction of Statutory Water Quality Objectives.

These new measures aim to provide a firm framework for setting discharge consents, periodically reviewing surface water quality, and incorporating standards from European legislation. Parameters to be included are: dissolved oxygen, BOD, ammonia, dissolved copper and total zinc. Further information on these measures can be found in DOE (1992), Everard (1994) and NRA (1994).

3.2. EUROPEAN POLLUTION CONTROL

The UK, as a member state, has to comply with the European Union (EU) environmental legislation. To enable management of the environment throughout Europe, the EU issues Environmental Directives. These Directives are subsequently implemented through laws or regulations in the EU Member States. EU Directives regarding water pollution are set either to control:

- water pollution caused by particular kinds of pollution, or
- the pollution of waters designated for particular types of use, such as bathing water or fisheries.

Examples of key EU directives are given in Table 3.2.

DIRECTIVE NUMBER	DIRECTIVE
75/440/EEC	Abstraction Drinking Waters
76/160/EEC	Bathing Waters
78/659/EEC	Protection Freshwater Fisheries
79/923/EEC	Protection Shellfish Fisheries
76/464/EEC	Dangerous Substances
80/68/EEC	Protection of Ground waters
91/676/EEC	Nitrates from Agricultural
91/271/EEC	Urban WasteWater Treatment

Table 3.2. Examples of key EU Environmental Directives.

As can be seen from Table 3.2. there are many EU Directives in force to control water pollution and water use. For the purpose of this research, the Urban WasteWater Treatment Directive is of key interest as it specifies standards for the treatment of wastewater.

3.2.1. Urban WasteWater Treatment Directive (UWWTD).

The Urban WasteWater Treatment Directive 91/271/EEC (UWWTD) was adopted by the Council of European Communities in May 1991. It is the first EU legislation directed specifically to wastewater treatment and discharge.

In the Directive there are minimum standards for the collection, treatment and discharge of urban wastewater and three types of treatment are defined for wastewater: appropriate; primary; and secondary. Primary and secondary treatment are the traditional processes adopted at conventional WWTW, with appropriate treatment being a new term defined in Article 2 Section 9 of the Directive as:

> 'The treatment of urban wastewater by any process and/or disposal system that after discharge allows the receiving water to meet the relevant quality objectives and the relevant provisions of this and other community Directives'

Under the UWWTD the selection of the required treatment for a WWTW is dependent upon the nature of the receiving water course, and the organic load of the discharge. Standards for wastewater effluent in the Directive incorporate the parameters' Biochemical Oxygen Demand, Suspended Solids and Chemical Oxygen Demand that can be applied as either a percent reduction or concentration (see Table 3.3).

PARAMETER	CONCENTRATION	MINIMUM PERCENT REDUCTION
1. Primary treatment		
Biochemical Oxygen Demand	N/A	20
Chemical Oxygen Demand	N/A	N/A
Suspended Solids	N/A	50
2. Secondary treatment		
Biochemical Oxygen Demand	25 mg/l O_2	70-90
Chemical Oxygen Demand	125 mg/l O_2	75
Suspended Solids	35mg/l SS	90

Table 3.3. Primary and secondary UWWTD effluent standards (UWWTD 91/271/EEC).

In the UK, the current general standard for WWTW discharges is 20 mg/l BOD and 30 mg/l SS. This implies that compliance to the new UWWTD Directive standards for BOD (eg. 25 mg/l) and SS (eg. 35mg/l) should not pose a problem. The COD standard (125mg/l), however, is a new parameter that may pose a problem at WWTWs which receive industrial discharges due to the higher concentration of COD associated with such wastewater, as shown in Table 3.4.

Source of wastewater	COD (mg/l)
Domestic	250-1,000
Industrial	>1,500

Table 3.4. Typical concentrations of COD in wastewater from domestic and industrial sources (Metcalf and Eddy, 1979 and Binyon and Baker, 1995)

To meet the required COD standard, removal of COD from industrial wastewater may require advanced treatment. Binyon and Baker (1995) review the options available for industry to treat their wastewater and suggest the following:

- direct discharge to the sewer;
- tankered off site;
- partial treatment on site followed by discharge to the sewer;
- full treatment on site, followed by discharge to a receiving watercourse.

Adams (1992) reports that the capital cost of industry treating wastewater at source ranges from £1.5 million for partial treatment in a simple facility, up to £5 million in a sophisticated facility. Alternatively, Horan (1992) suggests that instead of on site wastewater treatment industrial processes should be modified to achieve waste minimisation.

Receiving watercourses are also categorised under the UWWTD depending on the sensitivity of the water eg. "less sensitive" and "sensitive" (as defined in Annex 11. Section B of the UWWTD) and have to comply to nutrient standards eg. phosphorus and nitrogen.

The UWWTD also introduces the requirement to treat coastal discharges to primary and secondary standards that have a population equivalent of between 10,000 and 150,000. An exception to this is for coastal waters designated as less sensitive, in which primary treatment will suffice. The current practice for coastal discharges is to discharge crude wastewater through long sea outfalls with minimal treatment. Anderson (1992) estimates that 88% of existing coastal discharges in the UK that discharge into less sensitive areas currently only receive preliminary treatment. This suggests that compliance to the new regulations will require the upgrading of the majority of existing coastal discharges in the UK.

The UWWTD also requires pollution from Combined Sewer Overflows (CSOs) to be monitored and requires the identification of satisfactory and unsatisfactory CSOs. The criteria for unsatisfactory CSOs is given by the DOE/Welsh Office (1993) and includes the following:

- causes significant visual or aesthetic impact due to solids, fungus and has a history of justified public complaint;
- causes or makes a significant contribution to a deterioration in river chemical or biological class;
- operates in dry weather conditions;.
- causes or makes a significant contribution to a failure to comply with Bathing Water Quality Standards for identified bathing waters;
- causes a breach of water quality standards (EQS) and other EC Directives.

Morris (1994) reports that in the UK there are about 25,000 CSO discharges, of which it is estimated that about one third could be unsatisfactory.

3.2.2. Compliance to the UWWTD

To aid the UK water industry in complying with the UWWTD, an Implementation Group was set up, and various government documents applying to the directive published, these include:

- *The Urban Waste Water Treatment (England and Wales) Regulations 1993: A Guidance Note Issued by the Department of Environment and the Welsh Office (DoE/Welsh Office, 1993).*
- *Asset management plan (AMP 2) effluent guidelines. NRA guidance note, Version One, 1993* (NRA, 1993).

3.3. SUMMARY OF UK AND EU ENVIRONMENTAL LEGISLATION

There are many UK and EU Acts and Directives which aim to protect watercourses from pollution. As long as measures in these legislative documents are enforced, effective management of the aquatic environment can be maintained. The UWWTD in particular requires the UK water industry to provide primary treatment at coastal discharges, advanced treatment processes at WWTW discharging into sensitive areas and to minimise pollution from CSOs, with an estimated cost given by Wright (1992) of £2.5 billion to £10 billion.

To comply to quality standards imposed by UK and EU legislation, there is a need to review existing treatment processes and develop alternative methods to remove the pollutants being monitored from wastewater and wet weather discharges. Separation devices are one option for wastewater treatment. These devices are discussed in Chapter 4.

CHAPTER 4
SEDIMENTATION DEVICES

In Chapter 2, the application of wastewater settling velocity profiles in the assessment of the efficiency of sedimentation devices (eg. stilling and storm tanks) and hydrodynamic/ vortex separators was discussed and it was identified that these devices have the potential to provide a high removal efficiency for settleable solids (eg. the sinker fraction, >67%), and their associated pollutant loads (eg. > 65% for heavy metals) from wet weather discharges.

PST at WWTW also employ physical sedimentation to remove settleable matter from the treatment stream. The characterisation of the wastewater to be treated, by the use of settling velocity profiles, could also therefore be employed in assessing the removal efficiency of these devices.

As sedimentation is the principal process behind the operation of the treatment processes mentioned above, a brief review of the principles of sedimentation is given in this chapter. This is followed by examples of the performance of PST. The performance of wet weather overflow devices (eg. stilling tanks and hydrodynamic separators) was discussed in Section 2.5.2.

4.1. PRINCIPLES OF SEDIMENTATION

In sedimentation devices, suspended matter is removed from the treatment stream by gravity settlement. During the process of sedimentation, settleable matter with specific gravity greater than water (eg. one) is removed from the process stream by settling to the bottom of the device. The rate of settlement of particles from solution is dependent on the settling velocity of the individual particle, which is in turn dependent on the characteristics of the particle, such as particle size, shape and density.

In wastewater, there is a broad range of particulate matter which varies in characteristics (eg. density, size and settling velocity). Due to these different characteristics and interactions between particulate matter, four types of settling have been identified that occur during the sedimentation process and are described by Metcalf and Eddy (1979) as: discrete, flocculent, hindered and compression. Discrete and flocculent settling both occur in sedimentation, with flocculent settling being predominant in sewage.

The original work on settlement theory was carried out in the early 1900s when the basic principle of particle settling velocity was defined by Stokes Law, and the design of an ideal sedimentation tank proposed by Hazen. The early work by Hazen on quiescent settlement of discrete particles in sedimentation tanks is reported in Camp (1946). Hazen's work identified that the removal of discrete particles is dependent on the ratio of flow rate to surface area of a settlement tank. This ratio, Surface Loading, is based on the theory that all particles with a settling velocity greater than that derived from dividing the inflow (the maximum rate of flow to be treated per day) to the sedimentation tank by the available surface area will be removed. Surface loading is defined in Equation 4.1. (Institute of Water Pollution Control, 1980). Examples of typical surface loadings used for the design of different sedimentation devices are given in Table 4.1.

$$\text{Surface loading } (m^3/m^2d) = \frac{\text{Maximum flow } (m^3/d)}{\text{Tank surface area } (m^2)} \qquad \text{Equation 4.1}$$

Table 4.1. Comparison of surface loadings used in sedimentation devices (Andoh, 1994; Institute Water Pollution Control, 1980; Michelbach and Wöhrle,1993a)

Levine et al (1985) report that particles larger than 50 μm are effectively removed by primary sedimentation. After primary sedimentation, colloidal particulate matter (< 10μm) dominate in the effluent. The colloidal matter is subsequently removed in secondary treatment (eg. activated sludge).

Research by Stones (1953 and 1956) showed that biological changes also take place in sedimentation tanks. This contradicts Hazen's idealisation of a purely physical operation in these tanks, and suggests that the processes occurring in sedimentation tanks involve different factors (eg. physical and biological).

In applying Stokes law and Hazen's work to the settlement of suspended matter in sedimentation devices, the following limitations in their application have to be considered:

- Stokes law and Hazen's work was developed on the basis of discrete particles, and
- quiescent conditions in the sedimentation tank are assumed.

In the real life situation, wastewater particles vary in size, shape and density and, with the exception of grit removal, are predominantly flocculant in character. The medium the particles are contained in is also constantly moving due to: dissipation of energy at the inlet; a difference of density and temperature between wastewater entering the tank and its contents; short circuiting, and upward draw at the outlet. These factors mainly affect sedimentation adversely. However, they do give a positive effect to settling, in that the flocculent particles in the wastewater continuously contact other particles, giving the particles an opportunity to coalesce and form larger particles that settle at a faster rate.

4.2. DYNAMIC SEPARATION

In hydrodynamic/ vortex separators (eg. Storm King^{TM} and FluidSep^{TM}) the sedimentation process involves the phenomena of dynamic separation. This was first explored by Smisson (1967), who studied the vortex motion of wastewater in circular tanks. This motion assists the removal of settleable solids, and is the basis behind vortex/hydrodynamic separators. A review of the processes involved in hydrodynamic separation is given by Andoh (1995) and an example of a typical hydrodynamic separator is shown in Figure 4.1.

Figure 4.1. Schematic diagram of a typical hydrodynamic separator
(Brombach, 1992)

Andoh and Smisson (1993) report higher sedimentation efficiencies for dynamic separators than for traditional sedimentation tanks for wastewater treatment (See Table 4.2).

Table 4.2 Comparison of observed solids removal between a Swirl-Flo and a primary sedimentation tank (Andoh and Smisson, 1993).

4.3. PERFORMANCE OF PRIMARY SEDIMENTATION TANKS

The performance of PST (and other sedimentation devices) is generally assessed in terms of removal of suspended or settleable solids. In Chapter 3, the legislative control of wastewater discharges was discussed, with examples of regulatory parameters given eg. suspended solids, BOD, COD, nutrients and heavy metals. The efficiency with which a sedimentation device removes such pollutants is generally measured as the percent of pollutants removed from the influent stream. Examples of PST employed to treat wastewater are shown in Figure 4.2.

Figure 4.2. Examples of horizontal, radial and vertical flow primary sedimentation tanks (Tebutt, 1983).

4.3.1. SUSPENDED SOLIDS REMOVAL

Reported removals of SS in PST range from 40% to 75%, with typical values given in Table 4.3. Randall et al (1982) report that BOD and COD removal from PST is associated with SS removal , with Tebutt (1983) and Petrask and Kugelman (1983) reporting COD removals of 57% and 60% respectively.

Table 4.3. Performance of primary sedimentation tanks for the removal of suspended solids (Lowe and Sidwick, 1987)

4.3.2. HEAVY METALS

The removal of heavy metals by sedimentation is largely a physical process dependent upon the settlement of precipitated metal, or the association of metals with settleable particulate matter. At the WWTW, removal of heavy metals during primary sedimentation is important for two reasons :

- the metal loading carried forward to the biological treatment stage is reduced, and this reduces the risk of impairment of the efficiency of biological treatment by metal toxicity: and,

- PST removals contribute to the total removal efficiency for the WWTW, thus reducing contamination of the receiving water by heavy metals.

The chemical speciation of heavy metals in wastewater is reported by Lester (1987) to be dependent upon various factors which include influent metal concentration, hardness, alkanity and pH of the wastewater. Individual heavy metals also have different proportions associated with the soluble and insoluble phases.

Goldstone et al (1990a) report that cadmium, chromium and copper removals in PST are primarily associated with SS removals. The speciation of these metals in the crude wastewater is also variable: 70% of total cadmium, 63% of total chromium, and 9% of total copper are in the soluble form. The soluble heavy metals concentrations are also reduced in the PST due to their absorption onto solids (primarily the returned sludge liquor solids). Goldstone et al (1990b) also report that lead removal is primarily associated with SS removal, whereas nickel and zinc are not significantly removed during the sedimentation process.

Percent removals for heavy metals in PST have been found to range from 19% for chromium, up to 74% for zinc, with average heavy metal removals ranges from 28% for nickel, to 72% for cadmium. Examples of these are given in Table 4.4.

Kempton et al (1987b) investigating particle size and metal speciation in wastewater, reports maximum concentrations for silver, copper and lead with particles in the range 20-35μm, and in the range 64-125μm for manganese. Copper and lead however are mainly associated with the smaller particles (0.2μm-35 μm). Particle size profiles for PST influent and effluent for copper and lead were similar suggesting little change in the equilibrium during the settling process. This reflects the association of these metals with the smaller less settleable particles. The silver and manganese profiles moved towards the smaller particles after sedimentation due to the removal of the larger particles (with which these metals are associated). Kempton's results suggest the association of metals with particles vary with the particular metal, and that heavy metals removals form PST is subsequently dependent on the affinity of metals to the larger particle sizes.

HEAVY METAL	% REMOVED BY PRIMARY SEDIMENTATION TANKS					
	Author					
	A	B	C	D	E	Mean
Cadmium	...	...	72	...	...	72
Chromium	19	...	...	51	...	35
Copper	29	45	70	...	26	43
Lead	34	40	73	...	35	46
Nickel	40	20	...	23	...	28
Zinc	...	40	...	74	38	51

A=Petrask and Kugelman, 1983; B=Stones, 1958,1959a,1959b,1960;
C=Lester et al, 1979; D=Stoveland et al, 1979; E= Kempton et al, 1987a, 1987b.

Table 4.4. Removal of heavy metals by primary sedimentation tanks

Chen et al (1974) also report that different metals are associated with solids of different sizes in primary effluent. Approximately 60-85% of cadmium, chromium, copper, mercury and zinc are retained by 0.2 μm filters, whereas nickel, lead and manganese are mainly in the dissolved state, (with < 20% of the total concentration retained by 0.2μm filters). Cadmium, chromium and zinc bind more easily to particles greater than 8μm, whereas manganese, nickel and lead are associated with smaller particles.

4.3.3. NUTRIENT REMOVAL

As nutrients are considered to exist mainly in the dissolved form, their removal in sedimentation devices is not expected to be significant. Nutrient removals in PST are reported to be 10-20% for nitrogen and phosphorus (Welch ,1992 and Franzini and Linsley, 1979) with Petrask and Kugelman (1983) reporting ammonia removals of 5%. This suggests that a small proportion of nutrients (5-20%) are associated with settleable solids.

Hedges and Lockley (1990) report on the removal of ammonia and total oxidised nitrogen from a hydrodynamic separator. The baseflow and overflow concentration of ammonia were very similar, as were the Total oxidised nitrogen concentration in these flows. Since these pollutants mainly occur in the soluble form their removal would not be expected. However, when a Treatment Factor was applied to the data, the results indicated that a degree of treatment had taken place.

The Treatment Factor compares the proportion of flow passed to treatment with the proportion of pollutant passed to treatment. This relates the flow to the pollutant to enable a check that any improvement in quality is not just the results of splitting the flow. If the device provides no treatment but just divides the flow the Treatment Factor will be 1. A value >1 indicates that some treatment has taken place. A value <1 indicates that no treatment has taken place. The Treatment Factors for ammonia and total oxidised nitrogen were 1.2 and 1.5 respectively, indicating some treatment had taken place.

4.4. SUMMARY OF SEDIMENTATION DEVICES

Traditional design principles for sedimentation devices have not incorporated settling velocity as a parameter. However new techniques, such as dynamic separators employ settling velocity measurement in their design (eg. Equation 2.2). Thus there is a need to investigate further the use of this parameter and in particular to assess the association of pollutants with solids.

If it were known how pollutants were distributed within the settling velocity grading curve, then the design of sedimentation devices could be focused on the removal of those solids associated with the highest proportion of pollutants. A methodology has been developed to characterise the pollutants associated with wastewater settling velocity profiles and is described in Chapters 5 and 6.

CHAPTER 5

LABORATORY PROCEDURES

One of the objectives of the research project was to develop a simple method for determining the chemical characteristics of sewage solids associated with the various settling velocity fractions that comprise a sewage settling velocity profile. The first steps in reaching this objective involved setting up the required laboratory facilities, and selecting and testing the laboratory equipment.

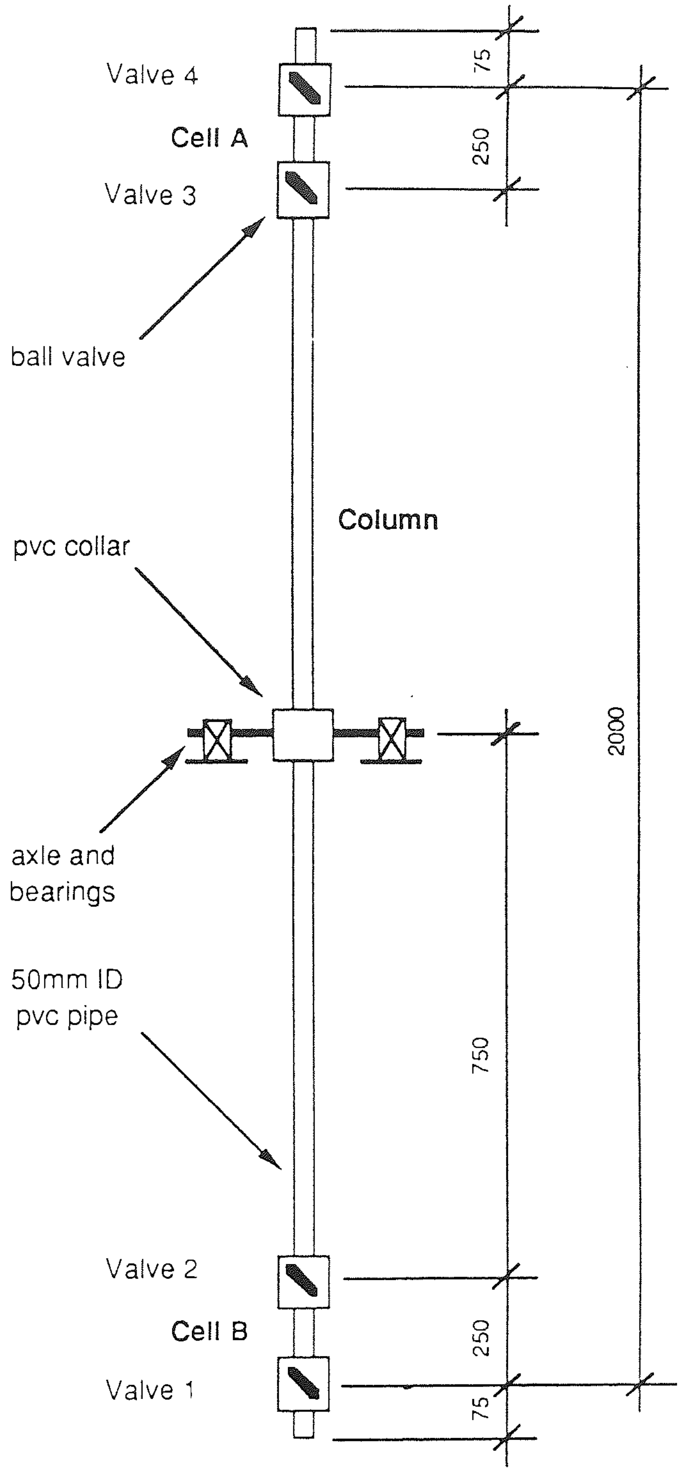
5.1. LABORATORY FACILITIES

The project was carried out at one of the sponsor's (Hydro Research and Development) premises, where the layout of the research laboratory was designed. The design of the laboratory involved planning the layout of the laboratory, including work areas , storage and ventilation requirements (Muir, 1971; Everett and Hughes, 1975 and Irving Sax and Lewis, 1986). To comply with the Control of Substances Hazardous to Health (COSHH) Regulations, a Safety Code for the laboratory and COSHH statements for hazardous substances used in the project were produced (Hall, 1992; Hawkins,1988 and FSA,1990).

5.2. SETTLING COLUMN

Settling columns are used to separate particulate matter from wastewater/storm water and to enable further characterisation of the separated matter. At Aston University, Hedges and Lockley, (1990) developed a settling column method for storm sewage based on original work in the 1970s by WRc and Heriott-Watt University (Scottish Development Department, 1977).

The settling column method developed by Hedges and Lockley uses a vertical PVC pipe with valves at either end, termed the 'settling column', with a central settlement length of 1.5m (Figure 5.1.) This is the distance between the two inner valves (Valves 2 and 3) taken as the mid point of each valve. The average settlement length depth is 1.62m. This is calculated from the addition of the central settlement length (1.5m) plus half of the end cell length (0.12m).



NB: All dimensions in mm

Figure 5.1. Schematic Diagram of a Settling Column

The basic principle behind the test is that the settleable (the sinkers) and floatable fraction (the floaters) in a sample separate out in the column under gravity, and are captured in the end cells of the column. The methodology is given in Appendix A.

The sinkers are typically characterised by containing the heavier, larger settleable particles and flocs, with the floaters having the lighter, buoyant particles; eg. corn, fat and, hairs. The fluid that is left at the end of the experiment in the central column, termed the residue, typically contains matter in suspension, such as colloidal and very fine material with effectively neutral buoyancy.

The sinkers are reintroduced to the top of the column. As the particles that settle out in the column have travelled over a known distance during a known time, the settling velocity can be determined (eg. division of distance travelled by time). The mass of solids settled out in each fraction is determined by filtering, drying and then weighing the solid mass collected from that sample (HMSO, 1980). The dry mass of all the sub samples, including the residue left in the column at the end of the test, is used to obtain the total sample mass. Each filtered sub sample collected yields the mass of solids with a specific settling velocity range.

The results of the settling column test are then displayed as a settling velocity profile, on a log scale. An example of a typical settling velocity profile, from a DWF sample, is shown in Figure 5.2.

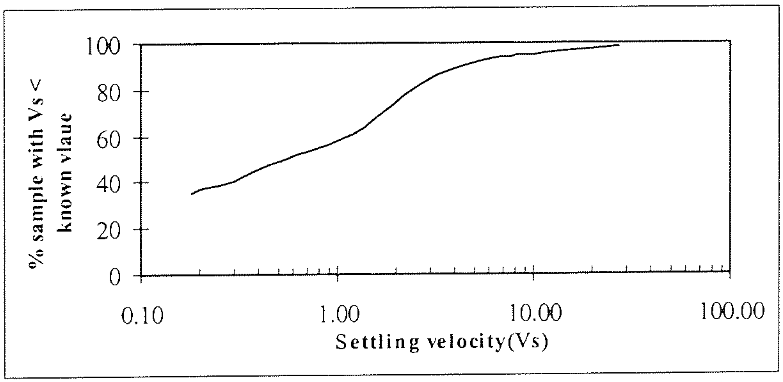


Figure 5.2. Typical settling velocity profile for a DWF sample

The Aston settling column technique was further developed during 1991-1994 for the application to dry weather flow and storm wastewater (Tyack, 1996). Part of the criteria of this research programme was to use the modified Aston method developed by Tyack.

5.2.1. SETTLING COLUMNS

Two settling columns (identical in configuration except for their diameter) were required in the project to carry out the settling velocity profile and chemical characterisation tests. Each column had an average settlement length of 1.62m. The columns had the following characteristics.

Column 1: a translucent PVC settling column of internal diameter 68mm and an average capacity of 7270 ml was used for the chemical characterisation test, and

Column 2: an opaque PVC settling column of internal diameter 54 mm and an average capacity of 5147 ml was used for the determination of the sewage settling velocity profile.

Due to the capacity of the columns (7270ml for column 1, and 5147ml for column 2) a wastewater sample of at least 13 litres was required for the two tests. To allow for spillages and crude suspended solids and chemical constituent analysis, an extra 2 litres was collected to give a total required sample volume of 15 litres. The procedures adopted for sample collection and preparation are given in section 6.2.

The total sample is riffled then split into two sub samples; one for the settling velocity profile test and one for the chemical characterisation test. The methodology for these tests are given in sections 6.3. and 6.4.

5.2.2. COMPARISON OF THE LARGE AND SMALL SETTLING COLUMNS

As the two columns to be used in the project had different internal diameters and two techniques for determining the associated solids were to be used (filtering, drying and weighing for settling velocity profile, and centrifuge, drying and weighing for the chemical constituent tests) it was important to show that these columns, and the techniques to be adopted for solid retrieval, gave comparable settling velocity profiles.

Clear settling columns of the same configuration (see Figure 5.1) , but with varying diameters, 34mm, 54mm and 68mm, were used by Tyack (1996) to study the effects of boundary conditions in settling columns. The results of Tyack's research showed that the smaller the pipe diameter (34mm) the greater the effect of the walls on those particles closest to the boundary, and as the diameter increased (54mm and 68mm) the effects of the walls was reduced. The observed effects of the walls on the settling velocity profile of the 54mm diameter column were also found to be not significantly dissimilar to the larger 68mm diameter column.

To verify that the two columns used in this research produced similar results, sewage settling velocity profiles were determined for four wastewater samples (samples C3, G4, I and E). The methodology developed by Tyack (1996) for the determination of settling velocity profiles was used in these tests and is given in Appendix A, Section A1. An exception to the test procedure was that the solid mass collected in samples from the large diameter column test were determined by centrifuge, drying and weighing rather than filtration.

The distribution of the solid mass for the four samples , C3, G4, I and E, showed that in general a peak of mass was associated with solids that had settling velocities in the range 0.9-9.0mm/sec regardless of the settling column used. A student t-test was applied to the settling velocity profile data to identify if there were any significant differences in the profiles between the small and large column results for each sample. The outcome of the t-tests indicated that there were no significant differences between the profiles obtained for the same sample from the different columns at a level of 5% significance for three of the samples (Sample C3, I and E). The results are shown in Appendix B. An example of the settling velocity profiles and distribution of solid mass determined for Sample I, are given in Figures 5.3 and 5.4.

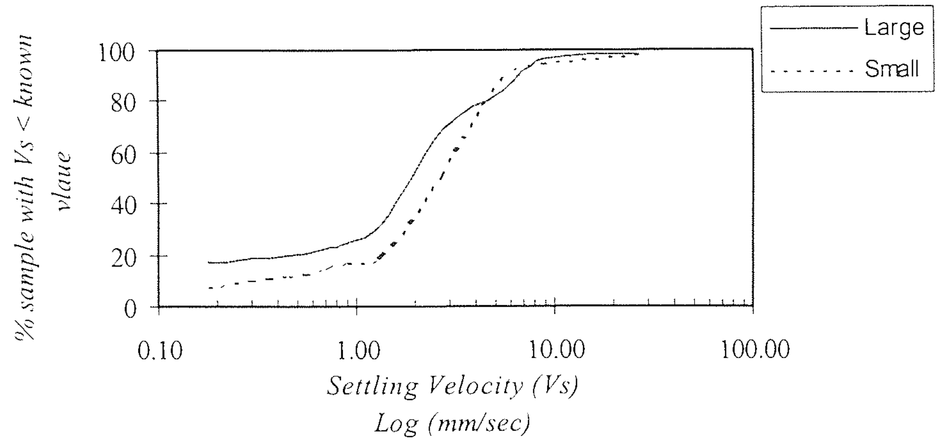


Figure 5.3 Comparison of the SVP from the small and large settling column for Sample I.

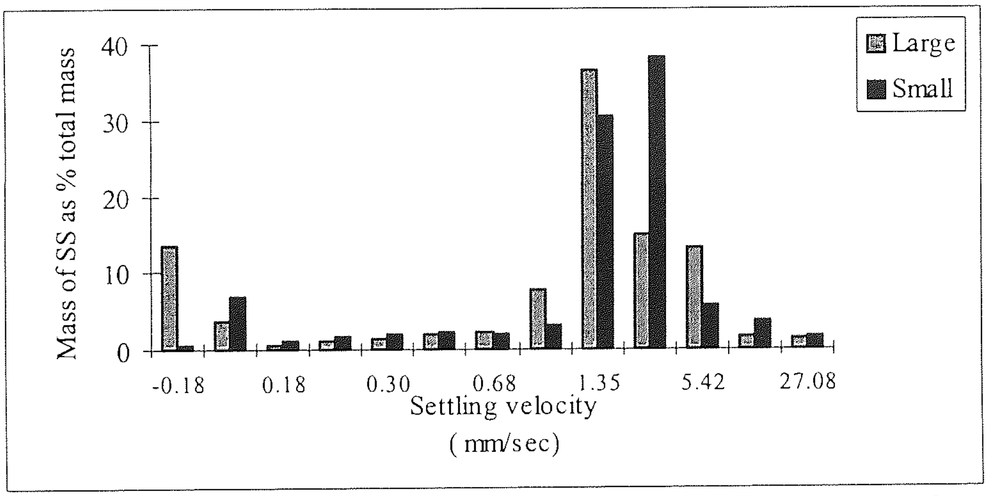


Figure 5.4. Comparison of the results of the distribution of suspended solids mass from the small and large settling column for sample I.

The settling velocity profiles obtained for Sample G4 were found to be significantly different in the t-test. The settling velocity profiles for Sample G4 are shown in Figure 5.5. The discrepancy between the profiles for the small and large columns is explained by the sample preparation, in which the sample was not riffled prior to the start of the two settling column tests. Therefore the samples used in each settling column did not represent a well mixed sewage. This has resulted in the settling profiles for Site G4 being significantly different.

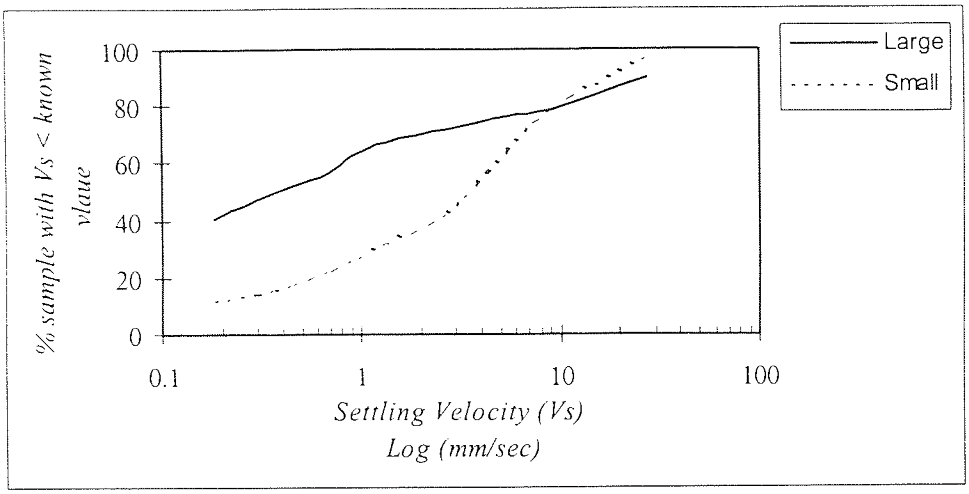


Figure 5.5 Comparison of the SVP derived for site G from the small and large column

The results of the comparison study indicated that using two settling columns in parallel did not give significantly different settling velocity profiles for the same wastewater sample (Site C, E and I), indicating that it was valid to use these two columns in the study. The study also highlighted the importance of ensuring the wastewater sample is well mixed/riffled prior to analysis.

5.2.3. SOLID RETRIEVAL

Matter in wastewater is present in suspended, particulate or colloidal forms. Two techniques are generally used to retrieve the particulate matter from wastewater:

- centrifuge, and
- filtration.

The centrifuge method separates the sample into two layers: supernatant (liquor) and sludge by centrifugal forces. The supernatant is decanted from the centrifuge vial, and the remaining sludge is dried in an oven at 105° centigrade (HMSO, 1980). The dried sludge/solids are then weighed.

In the filtration method, a sample is filtered through a glass fibre filter paper (0.45μm or 1.2μm) using a suction pump. The filter paper is then dried in an oven at 105° centigrade. The dried sludge/solids are then weighed (HMSO, 1980). Alternatively, if a cellulose acetate filter paper is used, this paper can be directly placed in a beaker with a strong oxidising agent, such as nitric acid, after filtration has completed. The solution is then evaporated to near dryness and the residue is dissolved in acid for subsequent analysis (Harrison et al, 1991).

The selection of the method of solid retrieval is discussed in section 5.3.2.

5.3. ANALYTICAL EQUIPMENT

The selection of the analytical equipment employed in the research was based on several criteria:

- accuracy;
- precision (repeatability);
- detection limits; and
- cost.

The accuracy of an analytical technique relates to the degree of agreement between a measured value and a true value (Harrison et al, 1991). It was therefore important to have a good degree of accuracy in the technique being used. The analytical precision of a method is also important and is shown by the repeatability of results (Harrison et al, 1991). The chemical determinants in this research are being used solely to give an indication of the association of pollutants with particulate matter, and not as an indication of water quality. Therefore, although accuracy and precision are required in the selected analytical techniques, they do not have to be as strict as for commercial laboratories which have to comply with standard guidelines.

The detection limit is the minimum weight or concentration of a particular determinand that can be detected by an analytical technique (Harrison et al, 1991). Most instrument manufacturers present a minimum readable value as the instrument detection limit in their specifications. It is consequently important to identify, if possible, the concentration range of parameters to be detected in the research to enable suitable equipment to be selected.

A database on the catchment characteristics of seventy seven WWTW in England and Wales was collected and reported by (Whithams,1993). The database was collected as part of Tyack's (1996) research project and included data on catchment area, population equivalent, sewerage system, WWTW and wastewater quality data for seventy seven WWTW catchments in England and Wales. Thirty five sites in the database had a complete set of data. This quality data was referred to give an indication of the typical range of chemical constituent concentrations in wastewater. The available data for parameters of interest (eg. COD, SS, nutrients and heavy metals) was summarised and is given in Table 5.1.

Table 5.1. Summary of wastewater quality data for crude and primary effluent from the catchment information database (Whithams, 1993)

From Table 5.1. it is evident that typical heavy metal concentrations in crude wastewater are low, eg. < 2.00mg/l, indicating their detection may require analytical techniques with low limits of detection. SS, COD, and nutrients (eg ammonia and total nitrogen) were found to be within the general range expected for wastewater. No data were available for phosphorus.

As the project had a specified budget for laboratory costs, the capital and running costs also had to be considered in the selection of suitable equipment.

5.3.1. ANALYTICAL TECHNIQUES AVAILABLE

Various analytical techniques are in use for the determination of chemical constituents in wastewater. The main techniques available are introduced in the following sections.

5.3.1.1. Segmented flow analysis

Segmented flow analysis is used for routine batch determinations (up to 80 samples per hour) for a wide range of determinands (eg. chlorine and compounds of phosphorus and nitrogen). This analysis is based on the principle of pumping a liquid through a system of tubing, and dividing the liquid by air bubbles into equal parts or segments. The liquid is a reagent to which the sample to be analysed is added. On addition of the sample, a colour change occurs in the reagent, that relates to the determinand concentration that is subsequently measured by colourimetry. Either a single determinand is detected in a sample, or a sample can be divided between several modules so that various determinands are detected simultaneously in the one sample. The advantage of segmented flow analysis is that different analytical measurements can be made from one sample, reducing the sample volume required (Crompton, 1991).

5.3.1.2. Mass Spectrometry (MS)

MS is used to detect organic and inorganic matter. In a typical MS the analyte is introduced, usually in a gaseous form, into a source where it is bombarded with a stream of electrons. The bombardment by electrons causes the formation of positive ions by knocking electrons from the analyte atoms or molecules. The positive ions exhibit an accelerating energy that generates a mass spectrum for individual ions in the sample (Harrison et al, 1991). Detection limits for plasma MS are low, eg. 0.007 mg/l for Cadmium and 0.08mg/l for lead.

5.3.1.3. Atomic Absorption (AA)

AA has been widely used for the detection of heavy metals since it was introduced in 1955 (American Public Health Association, 1985). In the technique, a fine spray of the analyte is passed into a suitable flame (eg. oxygen acetylene) which converts the elements to an atomic vapour. Radiation is then passed through the vapour at the right wavelength to excite atoms in the vapour. The amount of radiation adsorbed is measured, and directly related to the atom concentration. The advantage of the method is that it can detect a particular element with little interference from other elements. There are however two limitations of the technique: it does not have high sensitivity, and only one element at a time can be detected (Crompton, 1991; Marr and Cresser 1983).

The Graphite Furnace AA (GFAA) was developed in 1961 to improve the detection limits of direct AA. Instead of being sprayed as a fine mist into the flame, a measured portion of analyte is injected into an electrically heated graphite boat or tube. The GFAA allows a larger volume of sample to be handled (eg. 10ml) and is also more sensitive than direct AA eg. the detection limit of lead is $50\mu g/l$ by AA and is $5\mu g/l$ for GFAA (Crompton, 1991).

5.3.1.4. High Performance Liquid Chromatography (HPLC)

HPLC is a chromatographic technique used for the separation of a wide range of compounds in the liquid phase. Chromatography is described in Braithwaite and Smith (1985) as the process in which the components of a mixture are separated on an adsorbent column in a flowing system. Chromatogrphy is based on the partition or adsorption of individual components between a mobile (ie. liquid) and stationary phase (ie. column or film). The sample mixture is introduced in a mobile phase (liquor) and moves over the stationary phase and undergoes a series of adsoprtion interactions between the mobile and stationary phase as it moves through the chromatographic system. The difference in the chemical and physical properties of the individual components in the sample determine their relative affinity for the stationary phase and therefore components will move through the system at differing rates. The least retarded component (ie. moves fastest through the system) will be eluted first.

A basic HPLC system consists of a chromatographic column or film, a pump to move the liquid through the column, a detector and a chart recorder or computer for data acquisition. HPLC can detect most compounds and is highly sensitive, with detection limits of $1\mu g/l$ for organic compounds (Telliard, 1987, and Harrison et al, 1991).

5.3.1.5. Test Kits

'Test Kits' are compact units designed for on-site analysis and small laboratories. These kits are designed to detect physical (eg. settleable solids) or chemical constituents (eg. nutrients and heavy metals) in wastewater and water samples. The detection of chemical constituents using such tests involves colourimetric techniques. Colourimetric techniques are based on the formation of complexes (adsorption) or a chelate (fluorescence) between the ion being detected and the reagents added. A spectrophotometer is used to detect the amount of light emitted or adsorbed from a sample over a broad range of wavelengths, with the degree of light emittence or absorbtion indicative of the concentration of the chemical parameter. A disadvantage of test kits is that they are not as sensitive as segmented flow, MS, AA or HPLC.

The portability of some test kits has prompted their use by pollution inspectors concerned with sewage pollution, industrial effluents and accidental spillages (Crompton, 1991 and EPA, 1993). Due to their ease of use and portability test kits enable measurements to be taken on site allowing immediate detection of pollutants in the affected water course or waste stream.

5.3.1.6. Chemical Oxygen Demand (COD) Test

The detection of COD requires a rigorous test that oxidizes biodegradable and chemically degradable organic matter to stable, inert products.

The traditional technique adopted to detect COD in wastewater is the potassium dichromate test that takes four to five hours. A known amount of potassium dichromate is added to a known volume of sample. The resultant sample is then boiled with an acid, such as sulphuric acid for a specific time. The excess potassium dichromate remaining after boiling is measured, and the difference between the potassium dichromate originally added and the potassium dichromate remaining, indicates the amount used for oxidizing the organic matter. The more potassium dichromate used, the more organic matter there is in a sample, and the higher the COD of the sample (Benefield and Randall, 1980).

Test kits are also available for COD analysis (HACH, 1992a). These units comprise of a heater (or digestion unit) and vials, which contain all the necessary chemical reagents (eg. potassium dichromate). A known quantity of wastewater sample is transferred into a vial, which is then placed in the digester for a set time (typically two hours). During the digestion, organic matter in the sample is oxidised to stable end products. After the selected digestion time, the vials are left to cool, and the concentration of the COD in the sample is measured by a spectrophotometer.

5.3.2. ANALYTICAL TECHNIQUE SELECTED

Segmented flow analysis, AA, GFAA, and MS is generally used in laboratories with a fast turnover of samples, due to their ability to process samples quickly; eg. 80 samples per hour for segmented flow analysis. Although these methods are sensitive and have low detection limits (eg. 1μg/l) they are beyond the scope of this research due to their costs. For example a DIONEX HPLC unit will cost over £7000.00. A typical cost for analysis of an element at a commercial laboratory can be £5.00, and would be equivalent to approximately £3,500 for the determination of a suite of heavy metals associated with the settling velocity fractions for five wastewater samples. Camlab Test kits and equipment were therefore selected for the project as they offered the following:

- wide range of chemical tests;
- good after sales service, and
- costs were within the budget of the project.

The equipment selected was:

- DR/2000 Spectrophotometer Model 45250 (Figure 5.6)
- Camlab COD Reactor Model 45600 (Figure 5.7), and
- Digesdahl Digestion Apparatus Model 23130 (Figure 5.8).

Twelve parameters were initially selected for detection using test kits: nutrients (ammonia, nitrate, phosphorus and total nitrogen), chloride, COD and heavy metals (cadmium, chromium, copper, lead, nickel, and zinc). A wide range of parameters were selected for the feasibility study so that the performance of each analytical test could be assessed, and the tests which would be applicable to the development of the methodology for the detection of chemical constituents associated with wastewater settling velocity fractions identified. The results of this investigation are reported in section 5.3.4.

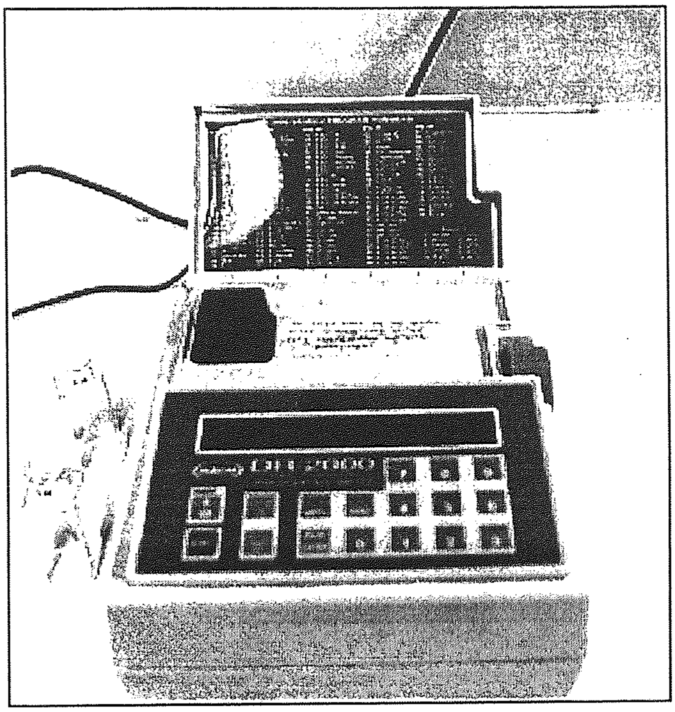


Figure 5.6. DR/2000 Spectrophotometer

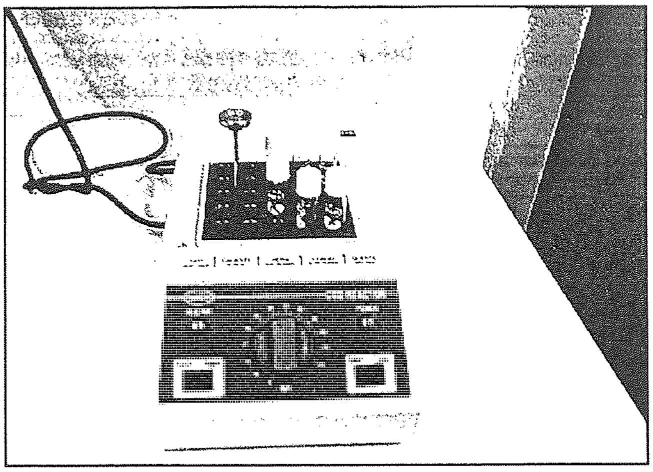


Figure 5.7. COD digestion reactor

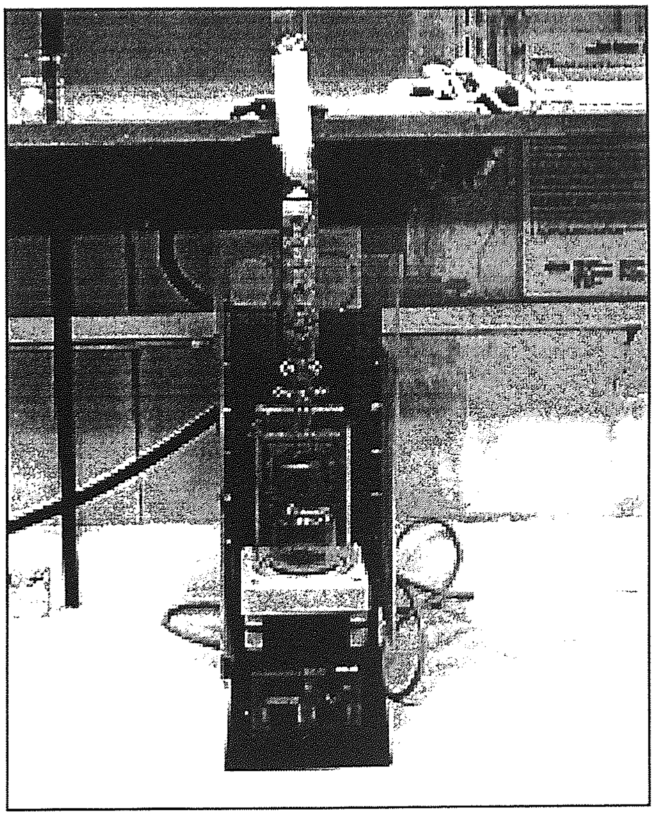


Figure 5.8. Digesdahl Digestion Apparatus

Trial runs of the centrifuge method showed that the wastewater supernatant contained fine suspended material indicating that the method did not recover all the solid material in the samples. Filtration, using cellulose acetate filters that are then digested in acid, was considered as an alternative appraoch. However, in this method, toxic fumes are generated by the oxidising agent (eg. nitric acid). For health and safety reasons, a fume cupboard was required to contain and disperse the fumes. As a fume cupboard was not available in the laboratory, this method could not be considered any further. The centrifugal method was therefore selected and its limitations in collecting fine material had to be accepted and the procedure in accordance with HMSO (1980) was applied.

5.3.3. FEASIBILITY STUDY OF THE SELECTED ANALYTICAL EQUIPMENT AND CHEMICAL TESTS

Twelve parameters were selected in the first stage of the research programme:

- nutrients (ammonia, nitrate, phosphorus and total nitrogen),
- chloride,
- COD, and
- heavy metals (cadmium, chromium, copper, lead, nickel and zinc).

The feasibility of detecting these parameters in both crude wastewater samples and in the wastewater settling velocity fractions was investigated. The results obtained from the test kits were compared with those from higher specification equipment (eg. plasma emission spectrometry and automated colourmetric techniques). The main purpose of the feasibility study was:

1. to investigate whether the analytical tests were sensitive enough to detect the selected parameters in crude wastewater and wastewater settling velocity fractions. To provide an indication of the feasibility of detecting the parameters in wastewater samples from different catchment types, samples were collected from WWTW serving a large industrial catchment, and a medium, agricultural catchment;

2. to carry out an accuracy check on each analytical test using standard solutions and standard additions, and

3. to determine the number of chemical parameters that could be practicably determined from the settling velocity fraction volume (eg. 800ml from the small column).

5.3.3.1. Detection of selected parameters

Several settling velocity column tests, using the methodology in Appendix A, A1, were carried out to obtain settling velocity fractions, for which the chemical parameters (listed above) associated with these fractions were determined. At this stage in the project an Aston column with an internal diameter of approximately 54mm was used, with an end cell volume of approximately 800ml.

The determination of COD, phosphorus, ammonia, TKN, nitrate and chloride associated with the crude and wastewater settling velocity fractions was found to be feasible, and showed good levels of accuracy in the trial tests. The determination of cadmium, chromium, lead and nickel in the wastewater samples was, however, found not be viable. This was due to inconsistencies between results for each of the heavy metal tests. This was believed to have been due to the levels of metals present, eg. generally < 2mg/l, being at or below the detection limit for the test method. Analysis for cadmium, chromium, cobalt, lead and nickel was not carried forward into the next stage of selection. The determination of Zn was also found to be inconsistent.

The initial copper test selected (Method No. 8506 in Hach, 1992b) covered the range 0-5.00 mg/l. In the trial tests, the results for copper analysis indicated that copper concentrations were present in levels <1mg/l, and that a test with a lower range of detection was required. An alternative method (Method No. 8143 in Hach, 1992b), that covering the range 0- 210 μg/l, was therefore adopted. This test occasionally showed inconsistency between readings. To check the accuracy of the copper results, total, soluble and particulate fractions of copper were determined in each settling velocity fraction, since in theory, the difference between the copper in the total fraction and the soluble fraction should equal the copper associated with the particulate fraction.

The results showed however that there was a problem with the pretreatment methods (refer to section 5.3.6. for pretreatment methods) for the samples and/or the copper test itself, as the particulate copper mass was generally greater then the total copper mass.

The pretreatment methods used in the copper test were also applied to the total nitrogen analysis. The total nitrogen results showed that the total nitrogen, as expected, was found to be greater than the nitrogen associated with the particulate fraction. This indicated that the pretreatment methods were not accountable for the discrepancy in the copper results. The results of the copper tests did however show a low degree of repeatability for some samples (eg. examples of three readings for the soluble copper sample from the comparison sample test 2, are 3.0μg/l, 5.6 μg/l and 7.6 μg/l). These results indicated that results for the copper tests would be tentative where inconsistency in readings occurred.

During the course of the study, money became available for heavy metal analysis of five wastewater samples (site B, sample event 1 and 2, site D sample event 2, site G sample event 3 and site K sample event 3). This analysis was carried out by Clayton Environmental. Pre-treated samples were sent to the laboratory for the determination of aluminium, antimony, arsenic, barium, cadmium, chromium, copper, iron, lead, mercury, manganese , nickel, selenium, vanadium and zinc associated with the total and particulate fractions. The pretreatment involved liquid digestion for the total heavy metal content of the samples, and solid retrieval with subsequent digestion for the heavy metals associated with the particulate fraction (see section 5.3.6. for pretreatment methods). The resultant digestate for each fraction was sent to Claytons laboratories for analysis.

At Claytons laboratory, high specification equipment (eg. plasma mass spectrometry) was used to detect the heavy metals present in the prepared samples. Levels of antimony, cadmium, nickel, chromium, vanadium, barium, arsenic, selenium in the wastewater fractions were however found to be present below the detection limits of their analytical techniques or that they were not present.

5.3.3.2. Chemical constituent sample volumes

From the feasibility study reported in section 5.3.3.1. the detection of COD, phosphorus, ammonia, nitrate, total nitrogen, chloride and copper were put forward as suitable parameters for analysis in the sampling programme. It was not possible however to determine all these parameters from a single settling velocity fraction. This was because the sample volume (for the settling velocity fractions) available for analysis was restricted to 800ml using the small diameter column. Examples of typical sample volumes required for analysis of each of these parameters, using the HACH test kits, are given in Table 5.2.

From Table 5.2. it is evident that there is a restriction to the number of parameters that can be determined from an 800ml sample. It was therefore decided that a settling column with a larger end cell volume was required.

At Aston University a translucent column (internal diameter 68mm) with an end cell of approximately 1200ml, was available for use on the project (as described in section 5.2.1.). This column had previously been used in a parallel research project by Tyack (1996) in which the methodology for the determination of wastewater settling velocity profiles, used in this project (Appendix A1), was developed.

Parameter	Required minimum sample volume (ml)		
	Soluble	Total	Particulate
COD	100	200-250	N/A
Phosphorus	100	40	N/A
Ammonia	75	40	N/A
Nitrate	75	40	N/A
Total nitrogen	N/A	40	800-1000
Chloride	75	40	N/A
Copper	100	40	800-1000
Sub total volume	525	440-490	1600-2000
Total volume	2565ml -3015ml		
Available volume	800 ml		

Table 5.2. Example of sample volume required for the detection of a range of chemical parameters (HACH, 1992b)

As described in section 5.2.2. the large (68mm) and small (54mm) diameter columns were compared and it was concluded that it would be acceptable to use the large diameter column for the determination of the chemical constituents associated with the settling velocity fractions. The use of the large diameter column provided an increased volume of sample available for the chemical constituent analysis (eg. settling velocity fraction volume of 1200ml).

The final selection of chemical parameters to be determined in the research was based on sample volume requirements, the analytical precision of the tests, comparison studies (described in section 5.3.7.) and quality standards in current legislation (eg. European UWWTD and the UK Water Quality Objectives discussed in Chapter 3). Based on the aforementioned points, the parameters finally selected for determination during the sampling programme were:

- COD,
- total nitrogen,
- phosphorus and
- copper .

The determination of the soluble fractions (COD, phosphorus and copper) required approximately 200ml. The sub sample used for the determination of the soluble pollutants was homogenized, after which 10ml was used for the soluble COD determinations (2ml required per COD vial, 3 vials used), a maximum of 100ml for phosphorus (this volume varies depending on whether dilution of the sample is required) and a maximum of 100ml for copper. The pretreatment methods for the detection of the parameters in the soluble phase are described in section 5.3.5.3.

200ml was required for the determination of total COD and total phosphorus. This sub sample was again homogenised. Approximately 40ml was required for the total phosphorus determination and 10ml (2ml required per COD vial, 3 vials used) for Total COD. Total nitrogen and copper were determined separately by digesting a known volume of sample (a maximum of 40ml for each parameter). The pretreatment methods for the detection of the total parameters are described in section 5.3.5.1.

Approximately 800ml of the settling velocity fraction was available for the collection of solid mass. The solid mass was retreived from the sample by the centrifuge method and was dried and digested (in accordance with the methodology described in section 5.2.3.). The resultant digestate (100ml) was used for both the particulate nitrogen (20ml) and copper determinations (80ml). The pretreatment methods for the detection of the parameters in the solid phase are described in section 5.3.5.2.

A sweep heavy metal anaylsis at Clayton Environmental was carried out for Samples : B1, B2, G3, K3 and D2. For these samples, the digestate remaining after the particulate nitrogen was determined was used for the heavy metal analysis.

As the programme proceeded the results for copper were found to be inconsistent, with the copper test subsequently being omitted from the programme.

A summary of the sub sample volumes used for the heavy metal, nutrient and COD analysis are given in Table 5.3.

PARAMETER	Sub sample volume (ml)
Particulate heavy metal and TKN	800
Total TKN, COD and phosphorus	150
Soluble phosphorus, COD (and heavy metals if required)	200
Total heavy metals-Claytons analysis	50
Total volume	1200ml

Table 5.3. Sub sample volumes required for the selected analytical tests

5.3.4. PRESERVATION OF SUB SAMPLES

To retain the integrity of the chemical species in the sub sample volumes identifed in Table 5.3., the samples were preserved to retard any chemical and biological changes. The sub samples for the determination of the soluble and particulate fractions were to be analysed within 24 hours and were stored in a fridge The sub samples for the analysis of the total chemical constituent content were analysed after 24 hours and required to be chemically fixed, with the type of preservative dependent on the determinand to be detected (Table 5.4.). Prior to analysis the chemically preserved samples had to be neutralized from their acidic state (pH <2) to release the fixed parameter.

Table 5.4. Preservatives required for the determination of chemical constituents (Hach, 1992b and HMSO, 1980)

5.3.5. PRETREATMENT OF SAMPLES FOR THE DETERMINATION OF CHEMICAL CONSTITUENTS

When it was impracticable to determine the chemical constituents directly associated with the particulate fraction (eg. in the COD and phosphorus determinations), the total and soluble mass was determined to enable that associated with the particulate fraction to be found by subtraction. However, the detection of the various parameters in all these fractions required pretreatment of the sample.

5.3.5.1.Total Mass

The detection of the total phosphorus, copper and TKN in wastewater samples by the HACH tests required a volume of sample to be digested. The digestion process uses oxidising agents to break down and dissolve compounds in a sample. A known volume of preserved sample was digested with sulphuric acid, to dehydrate and char the sample. Hydrogen peroxide was then added to the sample for complete sample decomposition. After sample decomposition, the sample (or digestate) was left to cool, and the volume adjusted to 100ml with distilled water. The diluted digestate was then acidified to pH 3-4 with potassium hydroxide (8N and 1N standard solutions) before colourmetric analysis (Hach, 1992c).

The preserved sample for Total COD required homogenisation before it was processed in the COD reactor (Hach, 1992a). A food blender was used for this purpose.

5.3.5.2. Particulate Mass

To determine the copper and TKN associated with the particulate fraction in the samples, a known mass of dried solid, collected by the centrifuge method, was digested in accordance with the procedures specified in Hach (1992c). Solid mass digested ranged from 0.01g-0.5g. The mass avaliable for digestion varied between settling velocity fractions and flow conditions. Analysis on the digested sample (the digestate) was then carried out to determine the TKN and copper present.

5.3.5.3. Soluble Mass

The standard technique to separate the particulate and soluble fractions in wastewater is to use filtration. A buchner filter funnel, aspirator and membrane filters (Table 5.5) were therefore used to prepare the samples for the determination of soluble copper, phosphorus and COD by colourmetric analysis. The filtered sample was then homogenised (using a food blender) prior to the analysis for the selected parameters. The soluble COD was processed in the COD unit, prior to colourmetric analysis.

Table 5.5. Size of filter for the separation of soluble fractions in samples (HMSO, 1980)

5.3.6. QUALITY CONTROL OF THE ANALYTICAL TESTS

Quality control for each analytical test employed was regularly performed by analysis of standard reference material. Blanks were also run with each test to account for reagent interference. Any interferences found were subtracted from the results obtained.

5.3.7. COMPARISON OF THE SELECTED TECHNIQUES WITH HIGHER SPECIFICATION EQUIPMENT

A comparison of the HACH analytical techniques for the determination of the selected chemical constituents with higher specification equipment (eg. plasma emission spectrometry and automated colourmetric techniques) at South West Waters laboratories, Countess Wear, was carried out. A sample of wastewater was collected from the inlet of a WWTW (serving a medium sized catchment classified according to section 7.2.) and divided into two for each set of analytical tests. The HACH and South West Waters analytical techniques were then compared by calculating the difference (in percent) between the results determined for each parameter.

Two comparison studies were carried out: test 1 at the feasibility stage of testing (in conjunction with section 5.3.3.1.), and test 2 after the final list of parameters were selected. The results for each comparison study are detailed below.

In test 1, the results for the parameters: nickel, cadmium, lead, zinc and chromium, copper, COD, chloride, ammonia and phosphorus were compared. No comparison test was available at this time at South West Water for total nitrogen and nitrate. The results of this study are given in Table 5.6. with the key findings summarized as follows:

- For the heavy metal tests, the concentrations of nickel, cadmium, lead and chromium in the wastewater samples were not detected by HACH tests. The results for the copper were found to be inconsistent. The results for zinc were found to differ by over 50% with the higher specification techniques.

- The detection of COD, chloride, copper and ammonia using the HACH tests were found to show a difference of 0%, 12%, 10% and 14% respectively with the results determined from the higher specification techniques

- The phosphorus results between the two laboratories differed by 29%.

From comparison study 1, the indications were that it was not appropriate to carry on with the determination of nickel, cadmium, lead, and chromium, as they were present in levels that could not be detected by the higher specification equipment or the HACH tests. The results for zinc showed that it was detected in the total and soluble fractions by the HACH kits, and in all three fractions (total, soluble and particulate) by the higher specification test. The results from the HACH kits however were 54-59% higher than the higher specification equipment, indicated that the HACH kits were giving inaccurate results for zinc and may be due to an interference or problem with the method. It was therefore decided not to proceed with the detection of zinc in the sample programme. Total copper was present within the detection range, indicated by both the South West Water and HACH results. As heavy metals are an important quality parameter, it was decide to carry on with the copper test to investigate if an improvement to the technique could be made.

The results of Test 2 are shown in Table 5.7. and show that the differences reported for the two tests ranged from a maximum of 15% for Total COD, to a minimum of 0.2% for soluble phosphorus. Considering that the wastewater sample had been divided into two sub samples, and that different operators had carried out the analytical tests, the results of test 2 indicated that the HACH analytical tests for COD, TKN and phosphorus were credible. The copper test however was recognised to be unreliable.

5.4. NEXT STAGE

After the appropriate equipment was selected for the project and the analytical techniques tested, the next stage in producing a methodology for the determination of chemical constituents associated with wastewater settling velocity fractions involved developing the catchment sampling and test procedures. The criteria required for this are given in Chapter Six.

PARAMETER (results as mg/l)	HACH METHOD	SOUTH WEST WATER METHODS	COMPARISON OF RESULTS (%DIFFERENCE)
Chloride (as Cl)	55.0	48.5	12
Ammonia(as N)	30.4	26.3	14
Total Phosphorus (as P)	4.2	3.0	29
Total COD	337	337	0
Total Cadmium	nd	<0.007	
Particulate Cadmium	nd	<0.007	
Soluble Cadmium	nd	<0.007	
Total Nickel	nd	<0.03	
Particulate Nickel	nd	<0.03	
Soluble Nickel	nd	<0.03	
Total Chromium	nd	<0.02	
Particulate Chromium	nd	<0.02	
Soluble Chromium	nd	<0.02	
Total Lead	0.09	<0.08	
Particulate Lead	nd	<0.08	
Soluble Lead	nd	<0.08	
Total Zinc	0.29	0.120	59
Particulate Zinc	nd	0.074	
Soluble Zinc	0.10	0.046	54
Total Copper	0.05	0.045	10
Particulate Copper	nd	<0.04	
Soluble Copper	nd	<0.04	

Table 5.6. Comparison of test procedures, results of test 1(27/7/93)

Note. where no concentration was detected this is indicated by (nd).

Parameter (results as mg/l)	Standard methods	Comparison methods	Comparison of results (%difference)
Total Phosphorus	12.34	12.30	0.33
Soluble Phosphorus (as P)	5.85	5.86	0.20
Total TKN	41	42	2
Total COD	555	481	15
Soluble COD	117	123	5
Total Copper	nd	0.07	>100
Particulate Copper	1.35	<0.04	
Soluble Copper	nd	0.07	

Table 5.7. Comparison of test procedures, results of test 2 (25/4/94)

Note. where no concentration was detected this is indicated by (nd).

CHAPTER 6

METHODOLOGY

After the laboratory was equipped and the analytical equipment selected for the project was tested, the sampling programme and test methodology was developed.

6.1. SAMPLING PROGRAMME

The catchments selected for the collection of wastewater samples were chosen from a database containing catchment area, population equivalent, sewerage system, WWTW and wastewater quality data for seventy seven WWTW catchments in England and Wales. WWTW for sampling were selected based on catchment size and type (see section 7.2). In the early stage of the sampling programme, sample collection and settling velocity profile tests were carried out in parallel with the Aston University research project ' The effect of catchment characteristics on sewage settling velocity grading' (Tyack, 1996).

6.2. COLLECTION OF SAMPLE

The collection of a representative sample of wastewater from a WWTW is difficult due to the variable nature and composition of wastewater, with the collection of a representative distribution of solids entrained within the wastewater flow also difficult (Scottish Development Department, 1977). General methods of sampling are given in the American Public Health Association (1985) Standard Methods, in which Composite or Grab sampling is recommended for the collection of wastewater.

6.2.1. COMPOSITE SAMPLING

Composite sampling involves either collecting samples over a predetermined time interval or collecting several discrete samples and then combining the samples into one main sample. Automatic samplers are generally used to collect composite samples with the sample collected through a suction tube (Marr and Cresser, 1983). A disadvantage of using automatic samplers however is that the diameter of the suction tube restricts the size of solid collected. Due to the restriction in the size of solid collected when composite sampling (eg.

by the automatic sampler), this method was rejected as it would not provide a representative wastewater sample.

6.2.2. GRAB SAMPLING

The alternative to composite sampling is Spot or Grab sampling. This form of sampling involves the collection of one large sample. A continuous sampler, or a bucket is generally used to collect the sample (Metcalf and Eddy, 1979).

The bucket method involves lowering a container attached to a piece of rope into a flow channel to collect the sample. This method is more flexible than using automatic or continuous samplers, as there are no restrictions on the size of solids collected. The collection of a large grab sample has also been advised by the Sewerage Management Planning Research Club for the analysis of the settling velocity of sediment particles (Sewerage Management Planning Research Club, 1993). For these reasons, the bucket method was selected to collect grab samples in the project. Tyack (1996) also used this method to collect wastewater samples.

6.2.3. TIME OF SAMPLING

A grab sample from the inlet channel of the WWTW (before the screening and grit removal processes) in the chosen catchments was collected at mid morning (10.30 am - 11.30 am). Mid morning was chosen to collect the wastewater samples as it is generally accepted that this is when most WWTW experience their peak diurnal flow (Metcalf and Eddy, 1979).

The peak diurnal flow at WWTW is dependent on the time of concentration for a sewerage system. Generally, smaller catchments (in terms of area) have a shorter time of concentration than larger catchments and it follows that smaller catchments will have a peak in diurnal flow earlier than larger ones. To make allowance for this, the small sites in the sampling programme were sampled between 9.00-10.00am.

6.2.4. SAMPLING PROCEDURE

A grab sample of approximately 15 litres of wastewater was collected from the WWTW in the selected catchments (refer to 5.2.1 for sample volume). The sample was decanted into three five litre plastic containers on site and transported to the laboratory where it was stored overnight in a fridge. The sample required overnight storage as there was not enough time to sample and test on the same day. This forms part of the standard test procedure.

The morning after the sample was collected, two settling column tests were carried out. One to determine the sewage settling velocity profile, and one to collect settling velocity fractions for the determination of the chemical constituents associated with the settling velocity profile. Before the start of the tests, the total sample (15 litres) was riffled to ensure it was homogeneous. Approximately 7 litres was required for the determination of the sewage settling velocity profile (see section 6.3.), and 8 litres for the determination of the chemical constituents associated with the settling velocity profile (see section 6.4.)

6.3. DETERMINATION OF THE SEWAGE SETTLING VELOCITY PROFILE

The Aston University settling column was used to determine the settling velocity profiles of the wastewater samples collected. The test procedure was developed by Tyack (1996), and the main points are detailed below. The full test procedure is given in Appendix A, Section A1.

i. A small settling column (internal diameter 54mm) was used in the test. With reference to Figure 5.1. the entire length of the settlement column, including the end cells, was filled with the prepared sample. The column was left in a vertical position, with cell A uppermost and valves 2 and 3 open, for three hours. This resulted in the sinking fraction being collected in the bottom cell (cell B) and the floating fraction in the top cell (cell A). At the end of the three-hour settlement period, valves 2 and 3 were closed and the contents of the end cells drained into separate containers.

ii. With cell B upper most and valve 2 closed, the sinking fraction was poured back into cell B. Valve 1 was closed and cell A was filled with clean water. With cell B uppermost, valves 2 and 3 were opened and the stop clock started.

iii. After a preselected interval, t_1, valve 3 was closed and cell A emptied into a container by opening valve 4. Thirty seconds after t_1, the column was rotated through 180 degrees and cell A was filled with clean water. One minute after t_1, the column was rotated through 180 degrees so that cell B was uppermost. Valve 3 was opened and the test continued. This sequence was repeated at intervals until the last sub sample had been withdrawn from cell A, 2.5 hours after the start of the test. Time intervals used to collect the settling velocity fractions were 1, 3, 5, 10, 20, 30, 40, 60, 90, 120 and 150 min. Eleven fractions are collected. The contents of cell B were then drained into a container, as were the contents of the central column.

iv. Samples were then filtered onto prepared filter papers, dried and then weighed to obtain the mass of suspended solids (HMSO, 1980)

v. The dry mass of all the sub samples, including the residue left in the column at the end of the test, was used to obtain the total sample mass. Each filtered sub sample collected yields the mass of solids with a specific settling velocity range.

vi. The results of the test were displayed as a settling velocity profile.

6.4. METHODOLOGY FOR THE DETERMINATION OF CHEMICAL CONSTITUENTS ASSOCIATED WITH SEWAGE SETTLING VELOCITY PROFILES

The application of the standard procedure for the settling column test, given in Section 6.3, to the determination of chemical constituents associated with settling velocity fractions was investigated. This investigation identified that modifications to the test procedure were required to enable the chemical characterisation of the settling velocity fractions. The reasons for the modifications are given in sections 6.4.1-6.4.3. The methodology is given in Appendix A.

6.4.1. SIZE OF SETTLING COLUMN

As explained in section 5.3.4.2., a larger settling column (internal diameter 68mm) was required for the chemical characterisation tests to provide a greater sample volume (eg. 1200ml) for the settling velocity fractions for the chemical characterisation tests.

6.4.2. SINKER FRACTIONS FOR CHEMICAL ANALYSIS

Five settling velocity fractions were collected instead of the eleven (described in section 6.3.iii) in the settling velocity test procedure. This was required to provide an adequate mass of solids (eg. in the range 0.1-0.5g) for the determinations of TKN and heavy metals associated with the solids.

In section 5.2.2. a comparison of settling velocity profiles obtained from the small and large columns was reported. When carrying out these tests, it was noted that the mass of solid collected in each settling velocity fraction, both from the large and small columns, was generally found to be <0.10g. To enable greater sample mass to be collected, it was decided to bulk the settling velocity fractions in the original methodology.

The settling velocity results for the large diameter (68mm) column from the comparative tests (samples C3, E, G4 and I) reported in section 5.3.1.1. were used to determine which of the eleven settling velocity fractions in the original methodology were to be bulked. Of these four samples, one (sample C3) was carried out using the bulked fractions to check the final decision on bulking (see Table 6.4.).

The distribution of the solid mass collected in the settling velocity profiles using the original methodology (samples E, G4 and I) are given Table 6.1. From Table 6.1. it is evident, with the exception of G4, that the highest mass of solids is associated with the samples taken over the 5-30 min interval, with the mass of solid in the other settling velocity fractions generally being less than 0.10g. The results for sample G4 however show a different distribution of mass, with a peak of solid mass associated with samples taken at 1-3 min, and 10-30min. It must be noted however that the settling velocity profile for this sample was found to be significantly different from the profile determined for this sample with the small column due to the sample preparation (see section 5.2.2.). This may therefore not represent a typical solid distribution for this sample.

On examination of the settling velocity fractions determined from the three large column tests using the original methodology, a general grouping of the solid mass collected has been made. This grouping is based on the visual characteristics of the solid matter collected and is described in Table 6.2. This grouping was subsequently found to be consistent over the sampling programme, which covered over 30 column tests.

Sample time (min)	Settling velocity (mm/sec)	Mass SS (g)		
		Sample I	Sample E	Sample G4
1	27.08	0.028	0.008	0.455
3	9.03	0.032	0.038	0.565
5	5.42	0.225	0.052	0.118
10	2.71	0.254	0.085	0.228
20	1.35	0.624	0.224	0.228
30	0.90	0.132	0.030	0.247
40	0.68	0.039	0.012	0.188
60	0.45	0.036	0.048	0.218
90	0.30	0.026	0.046	0.208
120	0.22	0.022	0.050	0.169
150	0.18	0.011	0.042	0.174
N/A	-0.2<R<0.2	0.110	0.510	1.285
N/A	<0.18	0.229	0.227	0.889
	Total	1.768	1.372	4.972

Table 6.1 Distribution of solid mass in the settling velocity profiles for samples I, E and G4.

Sample time (min)	Characteristics of solid collected in settling velocity fraction
1-3	Typically large individual particles, such as grit /corn.
5-10	Heavy mass of solids, dark in appearance.
20-30	Heavy mass of solids, finer than those collected in time period 5-10, dark in appearance.
40-60	Fine solids, light in appearance.
90-150	Very fine solids, light in appearance, mainly in suspension.

Table 6.2. Description of solids collected in settling velocity fractions.

On the basis of the distribution and physical description of the solid mass collected in the settling velocity fractions from the comparative tests discussed above, the settleable solids were grouped into five fractions to enable adequate solid mass to be acquired for chemical analysis. These are given in Table 6.3.

An example of the solid mass collected from a settling column test using the bulked fractions is given in Table 6.4. This shows, that in general, a solid mass >0.10g for each fraction, with a peak mass of solids collected between the 3 and 30 min time interval. It is important to note however that there is no guarantee that the selected wastewater settling velocity fractions will have a solid mass >0.10g due to the variable nature of wastewater.

Sample time (min)	Settling velocity (mm/sec)
3	>9.03
10	2.71-9.03
30	0.90-2.71
60	0.45-0.90
150	0.18-0.45
Residue	-0.18<R<0.18
Floaters	<-0.18

Table 6.3. Bulked settling velocity fractions for chemical constituent tests.

Sample time (min)	Settling velocity (mm/sec)	Mass SS (g) Sample C3
3	>9.03	0.336
10	2.71-9.03	0.347
30	0.90-2.71	0.245
60	0.45-0.90	0.114
150	0.18-0.45	0.082
Residue	-0.18<R<0.18	0.208
Floaters	<-0.18	0.109
Total		1.124

Table 6.4. Example of solids collected in a settling velocity profile using the selected bulked fractions

6.4.3. COLLECTION MEDIA IN THE SETTLING COLUMN TEST

In the methodology for the settling velocity grading (Appendix A, A1.), tap water is used in the end cells to collect the settling velocity fractions. For the chemical characterisation analysis, distilled water was used to prevent contamination of the settling velocity fractions from background concentrations of chemical parameters, in particular heavy metals, that may be present in the tap water.

6.4.4. CHEMICAL CONSTITUENT DETERMINATION

In this procedure, chemical constituent (eg. heavy metals, phosphorus, total nitrogen and chemical oxygen demand) are determined in the settling velocity fractions instead of suspended solids. The analytical procedures used are described in Chapter 5.

6.5. SUMMARY OF TEST MODIFICATIONS

The modifications to the settling velocity test for the determination of the associated chemical constituents, discussed in sections 6.4.1.-6.4.3., were used to develop the final test procedure that is given in Appendix A, A2. A summary of these modifications is given below.

i. A large diameter settling column (internal diameter 68mm) was used to provide a settling velocity fraction sample of adequate volume, 1200ml opposed to 800ml in the smaller diameter (54mm) column)

ii. The time intervals employed in the collection of settling velocity fractions were 3, 10, 30, 60 and 150 mins.

iii. Distilled water was used in the end cells instead of tap water to collect the settling velocity fractions.

iv. Chemical constituents (heavy metals, phosphorus, total nitrogen and chemical oxygen demand) were determined in the settling velocity fraction instead of suspended solids. Phosphorus, COD and TKN are determined using HACH test kits and heavy metals are determined using plasma mass spectrometry by a commercial company.

After the methodology for the determination of chemical constituents associated with sewage settling velocity profiles was developed, a 16 month sampling programme was carried out. The presentation and interpretation of the data collected in the programme is given in Chapter Seven.

CHAPTER 7

RESULTS

Wastewater samples were collected from the inlet to fifteen wastewater treatment works (WWTW) located in England and Wales. Due to the confidentiality of the catchment information collected for each WWTW, the sites are only identified by the labels A-O.

The WWTW were selected to exhibit a wide range in both size and type of catchment served. The intentions were to take at least two samples at each site, with in practice a total of 31 samples being collected. Of these thirty one samples, seven were collected and tested in parallel with the research project by Tyack (1996). The samples were mainly collected under DWF conditions (< 3DWF). For each of the fifteen WWTW sampled, settling velocity and associated chemical constituent profiles were produced. Where practicable, COD, phosphorus, TKN and heavy metal profiles were determined for each catchment. The settling velocity profile data are included as Appendix C and the associated chemical constituent profile data are presented in Appendix D (COD, P and TKN) and Appendix E (heavy metals).

Statistical analysis was applied to the settling velocity profile, chemical constituent, flow conditions and catchment characteristic data to detect any relationships between these parameters.

To assess whether the settling velocity and chemical constituent profiles for each site varied between sampling events, Analysis of Variance (ANOVA) was applied to the data for each site at a significance level of 5%. The ANOVA test for single factor analysis was used. The results of the ANOVA are presented in section 7.3.1. for the settling velocity profile data and section 7.4.1. for the chemical constituent data. Further information on the use of the ANOVA statistic is given in Hinton (1995).

Descriptive statistics were used to summarize the results for the catchment characteristics examined; eg. flow conditions (DWF or storm,) catchment type and catchment size. Chi-squared analysis was also applied to the results to further examine any relationships identified. Due to the size of the data set it was not considered appropriate to carry out a more sophisticated analysis on the results.

7.1. PRESENTATION OF RESULTS

The settling velocity data derived from the settling column tests carried out in this research are presented as a settling velocity profile (shown in Figure 7.1) and as described in Section 1.3.

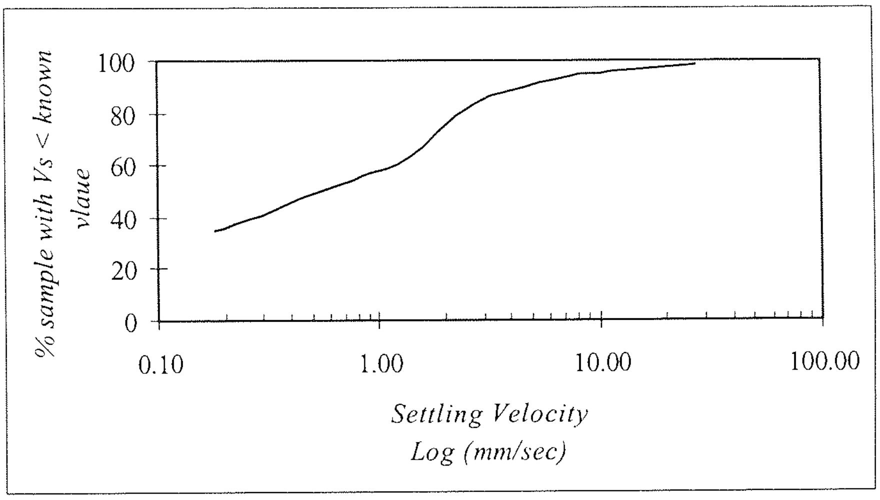


Figure 7.1. Example of a typical SVP
(Site A: DWF sampling conditions).

To enable the results of the chemical constituent analysis to be of use to other researchers, a meaningful way of presenting the chemical constituents association with sewage settling velocity profiles was investigated.

Previous researchers (eg. Michelbach and Whörle, 1992a and 1993b) have displayed the results of pollutants associated with settling velocity profiles as a concentration of pollutant in each fraction: eg. heavy metals as μg/l and COD as mg/l. The use of these units is a direct consequence of the techniques employed to detect the parameters of concern; eg. the analytical process involves solid digestion in acid before the quantity of pollutant present is determined from an aqueous solution. The concentration is therefore a function of the initial solid mass used in the analysis and thus the values obtained may not be comparable unless they are either expressed against a common denominator, or a suitable adjustment is made.

An alternative to presenting the results as a concentration is to present them as the mass of pollutant per mass of solids. Crabtree (1989) and Ashley and Crabtree (1992) present the association of pollutants (eg. COD, BOD, and ammonia) with sewer sediments as mg/kg (and g/kg) of dry solids.

As the above illustrates, there is no standard method in use for presenting the association of pollutants with solids, and hence several options were considered for this research. These options are described in Table 7.1.

OPTION	DESCRIPTION
A	Plot the concentration of chemical constituent against settling velocity
B	Plot the mass of chemical constituent against settling velocity
C	Plot the mass of chemical constituent per mass of solids in that settling velocity fraction against settling velocity
D	Plot the mass of chemical constituent in a settling velocity fraction per mass of total settleable solids in the whole sample against settling velocity
E	Plot the mass of chemical constituents in a settling velocity fraction per mass of the total settleable solids in the whole sample per 0.1mm/sec settling velocity interval against settling velocity

Table 7.1. Options for presentation of chemical constituent data

The analytical techniques in use for the project to determine the chemical constituents in the wastewater samples yield the results as a concentration (Option A). However, as the project investigated the pollutants associated with settleable solids in wastewater, and the solids were collected as a mass in the settling column tests, the expression of the results as a mass of pollutant in each fraction was considered to be more appropriate.

To further examine the relationship between the pollutant and solid mass determined in the settling velocity profile tests, the mass of pollutant was related directly to the mass of SS. Two options were considered for this: option (C) or option (D).

Option (D) was selected as it shows the pollutant mass contribution from each settling velocity fraction in relation to the overall solid mass, and will indicate which, if any, of the settling velocity fractions are major contributors to pollutant mass. This will be beneficial for the design of sedimentation devices (eg. vortex separators and primary sedimentation tanks) to enable the identification of settling velocity thresholds for the removal of settleable solids and associated pollutant loads. Presenting the results in this format is also compatible with research on sewer sediments (Crabtree, 1989 and Ashley and Crabtree, 1992). The application of the results in engineering design is discussed in Chapter 8.

The mass of SS was found to be significantly higher than the chemical constituent mass therefore the results were expressed as mass pollutant in g (or mg) per mass SS in kg, and displayed as either a bar chart and/or a cumulative graph depending on the feature/application of the results being discussed. In this study the initial mass of SS per v_s fraction is not determined directly from the solids analysed, but assumed to be identical to that obtained from the settling velocity profile determination. As a consequence perfect compatibility is not possible and for some cases the mass of COD exceeds the estimated mass of solids present.

Another factor that had to be considered when presenting the results was the difference in size of the seven settling velocity fractions. This is illustrated by the number of 0.1mm/sec settling velocity intervals in each fraction, which range from 2.7 for settling velocity fraction 0.18-0.45, to 63.2 for settling velocity fraction 2.71-9.03. The ranges of magnitude for the seven settling velocity fractions are shown in Table 7.2.

Option (E) considers displaying the results as the mass of pollutant (g) per mass SS (kg) per 0.1mm/sec settling velocity. This would enable a true comparison between the quantities of pollutant in each settling velocity fraction. However, the drawback of this method is that only those samples falling directly within the settling velocity intervals can be considered in this way.

Fractions with a settling velocity greater than 9.00mm/sec or less than - 0.2mm/sec (floaters) are tails to the distribution and hence cannot be allocated units of g/kg per 0.1mm/sec settling velocity.

SETTLING VELOCITY FRACTION (mm/sec)	NUMBER 0.1 mm/sec SETTLING VELOCITY INTERVALS
0.18-0.45	2.7
0.45-0.90	4.5
0.90-2.71	18.1
2.71-9.03	63.2
>9.03	Not determinable
-0.2<Residue<0.2	4.0
Floaters (<0.2)	Not determinable

Table 7.2.The range in magnitude of the seven settling velocity fractions.

As one of the aims of the research was to identify the association of pollutants with sewage settling velocity fractions, it was considered important to present the results of the distribution of the pollutant mass across the seven settling velocity fractions. The presentation of the results accounting for the difference in magnitude between the settling velocity fractions was therefore not selected as it would have omitted the results for those solids with a settling velocity >9.03mm/sec and those within the floater fraction.

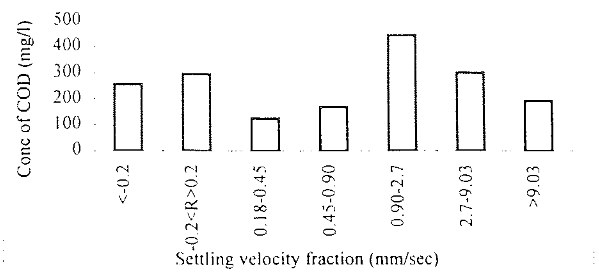
The results in this research are therefore reported as the mass pollutant (g) per kg dry total solids (Option D). At the 2nd International Conference on the Sewer as a Physical, Chemical and Biological reactor, Aalborg, Denmark, 26th-28th May 1997, (recently published in Water Science and Technology Vol 37 No 1 1998) a paper on this research was presented (Hedges et al, 1997). Discussions regarding the paper took place and the consensus of opinion was that presenting the results as mass of pollutant/kg dry total solids was preferable, as it would enable comparisons with other research, specifically sewer solids.

It must be noted however that the results yield different outcomes in the sinker fractions when they are expressed as the mass of pollutant per mass SS per 0.1mm/sec v_s interval. For example, in Table 7.3. the COD results for Site A have been presented for options (A)-(E) as bar charts. The results for the concentration of pollutant (Figure 7.2a), the mass of pollutant (Figure 7.2b), the mass of pollutant per SS in that fraction (Figure 7.2c), and the mass of pollutant per total SS in the sample (Figure 7.2d) show that in the sinker fractions, there is a peak mass/concentration of COD associated with solids that have a settling velocity in the range 0.9-2.7mm/sec. There is also a peak of mass associated with the residue fraction. However, when the results are presented as the mass of pollutant per mass SS per 0.1mm/sec v_s interval (Figure 7.2e), the peak mass of pollutant in the sinker fraction is associated with solids that have lighter settling velocities - in the range 0.18-0.45mm/sec. Care therefore needs to be taken when discussing or comparing results.

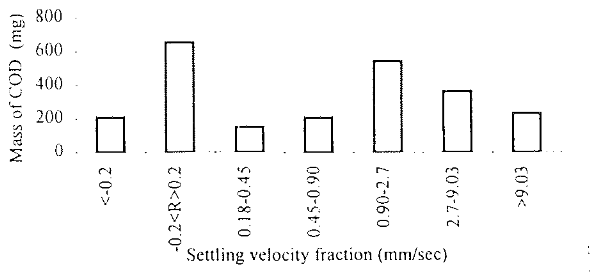
SITE A

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Mass SS (g)	Conc COD (mg/l) Option (A)	Mass COD (mg) Option (B)	gCOD/kgSS in vs interval Option (C)	gCOD/kgSS Option (D)	gCOD/kgSS per0.1mm/secVs Option (E)
<-0.2	N/A	0.203	258	211	1038	97	N/A
-0.2<R>0.2	4	0.448	297	654	3217	302	75
0.18-0.45	2.7	0.285	127	154	759	71	26
0.45-0.90	4.5	0.216	171	209	1025	96	21
0.90-2.7	18.1	0.612	447	545	2682	252	14
2.7-9.03	63.2	0.284	303	370	1819	171	3
>9.03	N/A	0.120	193	235	1158	109	N/A
Total		2.167		2379	11697	1098	

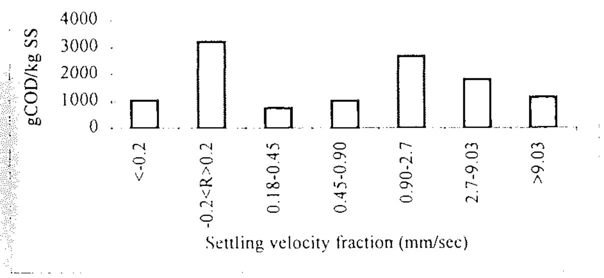
Table 7.3. Alternative ways of presenting the chemical constituents associated with settling velocity fractions results.

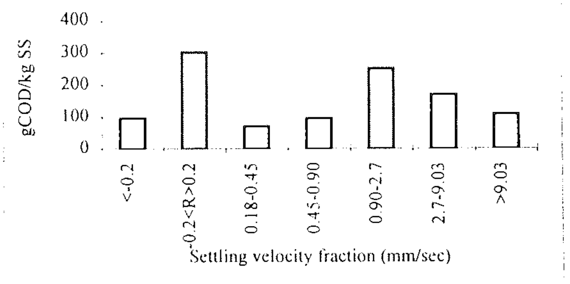


A. Option (A) Concentration of COD (mg/l) in v_s fraction



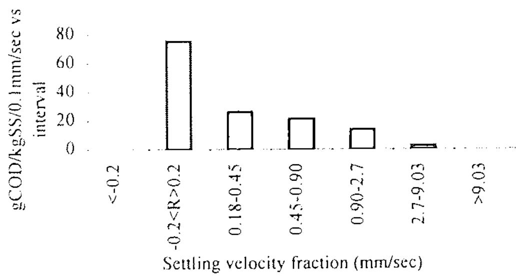
B. Option (B) Mass of COD (mg) in v_s fraction





C. Option (C) Mass gCOD/kgSS in settling settling velocity

D. Option (D) Mass gCOD/kgSS total sample mass



E. Option (E) Mass gCOD/kgSS total sample mass per 0.1v_s interval

Figure 7.2. Alternative ways of presenting the results of the chemical constituents associated with solids.

7.2. SITE CHARACTERISTICS

Wastewater samples were collected from the inlet to fifteen WWTW located in England and Wales. The catchments selected for the collection of wastewater samples were chosen from a database (described in section 5.3.) containing catchment information and wastewater quality data for WWTW catchments in England and Wales (Whithams, 1993). Information on the WWTW catchments sampled was also collected on site to verify data in the database. Due to the confidentiality of the catchment information collected for each WWTW, the sites sampled are labelled A-O.

To investigate whether catchment characteristics affect the distribution of chemical constituents within the settling velocity profile, the fifteen catchments were categorised according to size and type.

Catchment size was classified as large, medium and small based upon the population equivalent for each catchment: large >50,000; medium >5,000 and <50,000; and small <5,000. Population equivalent was selected to categorise catchment size as it is a parameter used to estimate the pollutant load of wastewater. Five large, six medium and four small catchments were sampled. The population equivalent and area of these catchments are given in Table 7.4.

CATEGORY	NUMBER OF SITES/EVENTS	POPULATION EQUIVALENT	CATCHMENT AREA (ha)
Large	5 sites (11 events)	1,315,325 to 96,000	34,754 to 2,485
Medium	6 sites (13 events)	23,000 to 8,000	1,400 to 400
Small	4 sites (7 events)	4,500 to 685	500 to 200

Table 7.4. Characteristics of the large, medium and small catchments sampled.

The catchments sampled in the research programme were also grouped into three types: domestic; domestic/ industrial; and domestic/agriculture based on the use of the catchment. This information was available from the database on catchment characteristics produced by

Whithams (1993) and from information collected on site. The majority of the catchments sampled had a high proportion of area associated with residential use. To further characterise these catchments, the industrial/commercial, and the agriculture use of the catchment was assessed. Where a significant proportion of the catchment area was used for these purposes, the site was classified accordingly (eg. either as dom/ind or dom/agric). Five domestic (dom), six domestic/industrial (dom/ind) and four domestic/agricultural (dom/agric) catchments were sampled (see Table 7.5.)

CATCHMENT TYPE	SAMPLE	
	Number of sites	Number of events
Domestic	5	10
Domestic/Industrial	6	13
Domestic/Agricultural	4	8

Table 7.5. Catchment types.

The wastewater samples were also collected under two different flow conditions, DWF and storm. At WWTW, processes are generally designed to treat up to 3 DWF and flows in excess of this are generally diverted to storm tanks. Flows > 3DWF were therefore defined in this research as high flows (or storm). In Table 7.6. the number of samples taken at each site under DWF and storm flow conditions are shown, with the corresponding flow rate. From Table 7.6. it can be seen that five storm flow and twenty six DWF samples were taken in the study programme. However, the storm flows were not very high (eg. 3.00-3.06 DWF) and were not markedly different from the highest DWF (eg. 2.58 DWF).

The characteristics of the fifteen catchments sampled (labelled A-O) in the research programme are given in Table 7.7.

	Site reference														
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Number of times site sampled	3	2	3	2	1	2	4	1	1	2	3	2	2	2	1
DWF (l/sec)	5208	900	428	355	210	71	53	48	151	48	40	10	8	13	5
Sample flow Sample No.	1.16	0.78	1.49	0.88	2.04	2.00	**3.06**	**3.01**	1.29	1.02	0.70	2.40	1.05	2.27	0.94
(as DWF) 2	1.33	**3.00**	1.20	1.21		1.62	1.75			0.84	1.13	2.58	1.30	2.12	
3	**3.00**		2.03				1.75				1.25				
4							**3.00**								

Table 7.6. Flow data for wastewater samples. Values shown in bold are those classified as high flow conditions.

Site reference	DWF (l/s)	Population equivalent	Total area (hectare)	Use of catchment area (hectare)						Catchment type	Sewer system
				Impermeable	Industrial	Commerce	Farmland	Residential	Parkland		
A	5,208	1,315,325	34,754	148	4000	3600	0	26574	706	D/I	P-S
B	900	203,000	5,300	Industrial/Commerce/Domestic						D/I	S
C	428	150,000	5,000	0	500	750	1500	2250	0	D/A	P-S
D	355	118,300	1,295	0	91	39	0	1165	0	D	P-S
E	210	96,000	2,485	0	224	224	0	1864	149	D/I	P-S
F	70	23,000	750	0	75	75	38	562	0	D/I	C
G	53	21,300	1,400	63	67	67	0	1203		D	S
H	48	15,000	631	24	15	14	235	255	88	D/A	C
I	151	14,250	450	0	36	9	67	338	0	D	C
J	48	12,595	400	0	140	0	20	240	0	D/I	P-S
K	40	8,000	400	0	88	0	0	263	0	D/I	P-S
L	10	4,500	500	Domestic						D	C
M	8	2,600	200	10	0	0	0	160	30	D	P-S
N	13	1,372	250	Agriculture/Domestic						D/A	P-S
O	5	685	220	6	0	0	103	42	69	D/A	C

Table 7.7. Catchment data for the sites sampled in the research programme

Key
Catchment type : D=domestic; D/I=domestic/industrial; D/A=domestic/agriculture
Sewer system : P-S=partially seperate; C=combined;S=seperate
Impermeable area : roads, pavements etc.

7.3. SEWAGE SETTLING VELOCITY CHARACTERISTICS

7.3.1. REPEATABILITY OF ANALYSIS

An analysis of variance was undertaken on similar settling velocity profiles at each site to determine whether or not the results from the different sampling events were significantly different. Two or more DWF events were sampled from ten sites and two storm events were taken from Site G (see Table 7.6). The results of the analysis of variance, attached at Appendix C, show that at a level of 5% significance, the settling velocity profiles determined for each site under either DWF or storm conditions, from separate sampling events, are not significantly different. Consequently the decision was taken to determine the mean settling velocity profiles for each site for DWF and storm conditions and to use these in subsequent analyses.

7.3.2. DISTRIBUTION OF SUSPENDED SOLIDS

7.3.2.1. Distribution of the suspended solids in the floater, residue and sinker groupings

To investigate the broad distribution of the total solid mass within the settling velocity profiles, the settling velocity fractions were combined into three broad groupings:

- residue - the liquor remaining at the end of the experiment in the central column that typically contains matter in suspension such as colloidal and very fine material;
- floaters - the rising solid fraction containing lighter, buoyant particles such as particles of fat, and
- the sinkers - the settleable fraction typically characterised by containing the heavier, larger settleable particles and flocs.

The results demonstrate that the solids in the wastewater sampled were mainly associated with the sinker fraction, with the smallest proportion in the floater fraction (see Table 7.8 and 7.9.).

DESCRIPTIVE STATISTIC	Mass of Floaters as % total SS mass	Mass of Residue as % total SS mass	Mass of Sinkers as % total SS mass
Mean	14	23	63
Standard Deviation	5.2	8.0	7.2
Range	2.0-21.9	16.6-44.9	45.2-71.1

Table 7.8. Descriptive statistical analysis of the solid distributions in the three broad settling velocity groupings : DWF flow conditions (14 sites).

DESCRIPTIVE STATISTIC	Mass of Floaters as % total SS mass	Mass of Residue as % total SS mass	Mass of Sinkers as % total SS mass
Mean	17	32	51
Standard Deviation	n/a	n/a	n/a
Range	9.7-36.2	14.4-54.1	32.9-75.9

Table 7.9. Descriptive statistical analysis of the solid distributions in the three broad settling velocity groupings : storm flow conditions (4 sites).

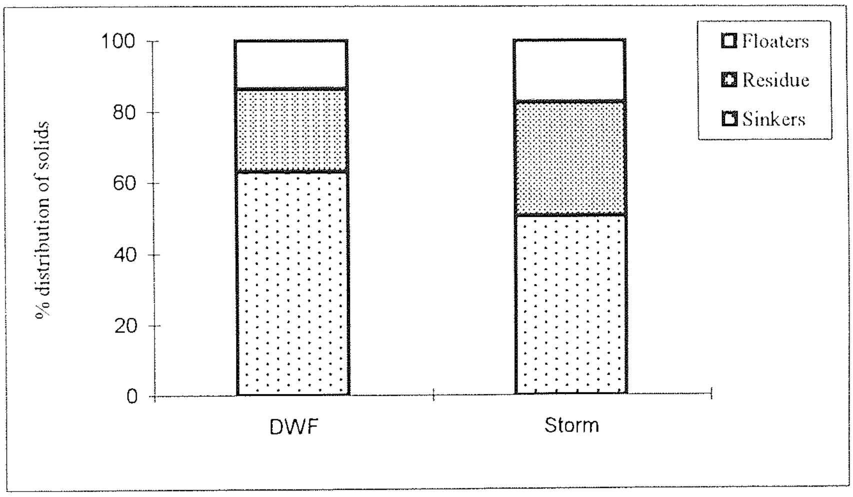


Figure 7.3. Comparison of the distribution of solids in the three broad settling column groupings (DWF and storm flow conditions).

An overlap between the range of results for all three groupings was found for the samples collected under storm conditions, whereas the DWF samples showed a slight overlap between the floater and residue results, indicating that there may be a greater variation in the characteristics of wastewater samples collected under storm flow conditions than those collected under DWF conditions.

7.3.2.2. Distribution of suspended solids in the five sinker fractions

To enable comparison of the distribution of the solids within the sinker fraction associated with the chemical constituent test, the eleven fractions determined within the settling velocity profile were combined into the five fractions used in the chemical constituent tests: 0.18-0.45, 0.45-0.90, 0.90-2.70, 2.70-9.03, and >9.03 mm/sec (as discussed in section 6.2). For compatibility, these five fractions are used in this analysis.

Descriptive statistical analysis on the distribution of the solid mass in the sinker fractions showed that for the fourteen sites sampled under DWF conditions, and the four sites sampled under storm conditions, the highest percent of solids (mean value >60%) were found in the settling velocity range 0.90-9.03mm/sec (see Tables 7.10. and 7.11.). Within this settling velocity range, 33% (mean value) of the DWF solids are associated with the settling velocity fraction 0.90-2.7mm/sec, and 35% (mean value) of the storm solids are associated with the settling velocity fraction 2.7-9.03mm/sec. The range of results showed a degree of overlap between the five fractions, regardless of flow conditions, indicating that there is degree of varaibility between the solid distribution in these fractions. A comparison of the DWF and storm results are shown in Figure 7.4.

The results, in general, indicate that a high proportion of solids in the wastewater sampled were associated with settleable solids that had settling velocities >0.9mm/sec.

Descriptive statistic	Settling velocity fraction (mm/sec) 0.18-0.45	0.45-0.90	0.90-2.70	2.70-9.03	>9.03
Mean	16	15	33	27	9
Standard Deviation	8.2	7.0	9.2	17.6	4.6
Range	5.3-32.1	4.8 -25.1	18.5 -45.7	5.9 -59.0	4.2 - 20.2

Table 7.10. Descriptive statistics on the percent of total sinkers mass in each sinker fraction : DWF conditions (14 sites).

Descriptive statistic	Settling velocity fraction (mm/sec) 0.18-0.45	0.45-0.90	0.90-2.70	2.70-9.03	>9.03
Mean	12	9	29	35	15
Standard Deviation	n/a	n/a	n/a	n/a	n/a
Range	6.7-19.0	5.9-11.3	17.1-40.8	27.0 - 45.7	6.6 -37.0

Table 7.11. Descriptive statistics on the percent of total sinkers mass in each sinker fraction : storm flow conditions (4 sites).

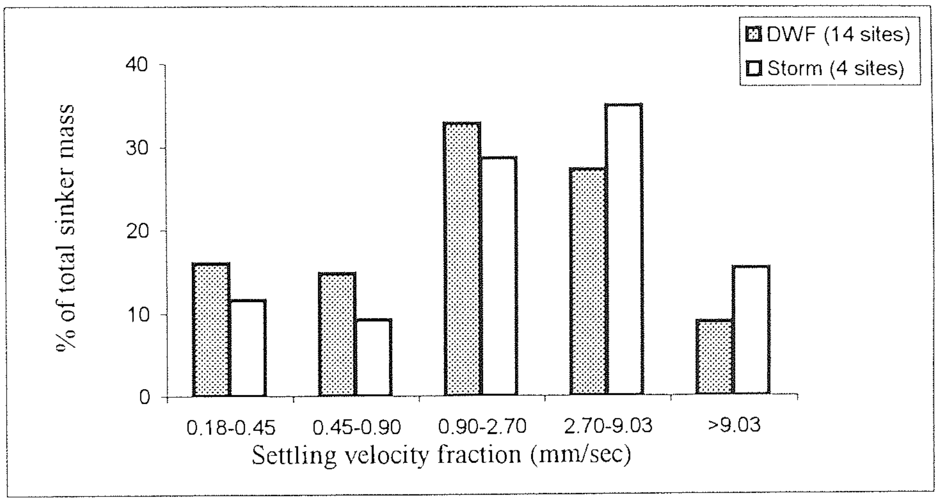


Figure 7.4. Mean distribution of solids in the five sinker settling velocity fractions (DWF and storm flow conditions).

7.3.2.3. Settling velocity profiles

The settling velocity profiles determined for the fourteen sites sampled under DWF conditions are shown in Figure 7.5.

The DWF settling velocity profiles appear to fall within a general envelope, with the exception of one outlier - Site D. Site D is a large site (population equivalent 118,000) and is a domestic catchment. The mean flow rate during sampling at this site was 371l/sec (1.04 DWF) which lies within the range of flows sampled from all the WWTW (4.7l/sec-15,624l/sec). No unique characteristic has been identified for this site to suggest why it shows an outlier profile.

The settling velocity profiles representing the WWTW sampled under storm conditions are shown in Figure 7.6. The profiles show no specific trend and fall within a wide envelope. Due to the small sample number (eg. four profiles) no further conclusions can be drawn for the storm profiles.

The DWF and storm SVP are both plotted on Figure 7.7. and shows that these profiles fall within a general envelope, indicating that flow conditions and catchment characteristics do not appear to affect the SVP. Site D is not plotted on Figure 7.7. due to the SVP exhibiting an outlier profile.

Tyack (1996) also reports that catchment characteristics and flow conditions do not affect wastewater SVP. A comparison between the settling velocity envelopes produced by Tyack (1996), reproduced in Figures 7.8, and those from this research, Figure 7.9., show that similar envelopes have been produced.

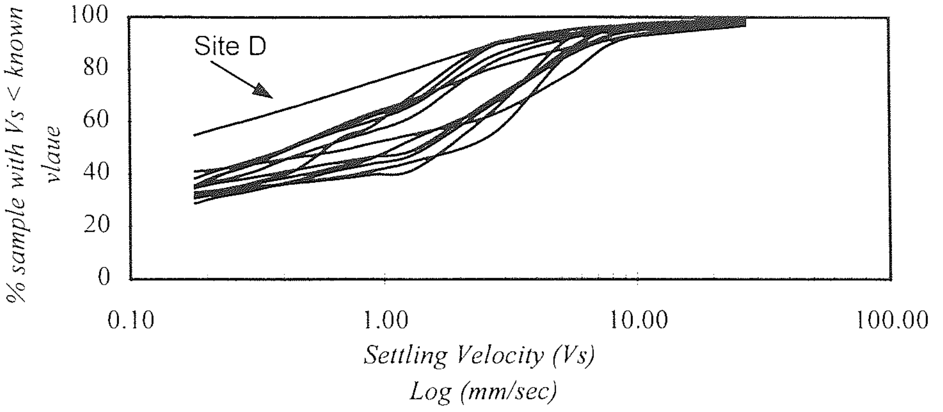


Figure 7.5. SVP's for 14 sites (26 events) sampled under DWF conditions

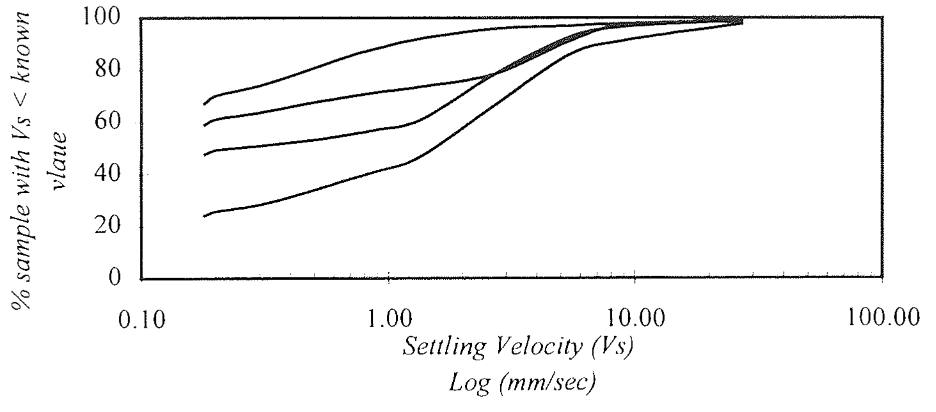


Figure 7.6. SVP's for 4 sites (5 events) sampled under storm flow conditions.

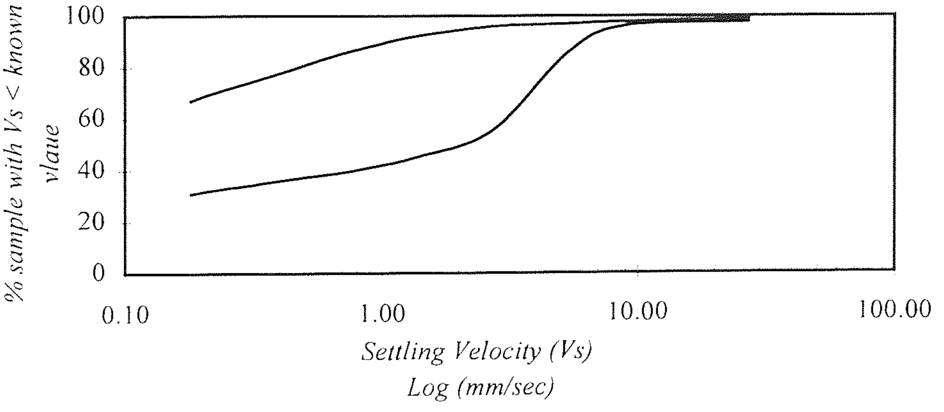


Figure 7.7. Envelope containing all SVP's (both DWF and storm flow conditions) .

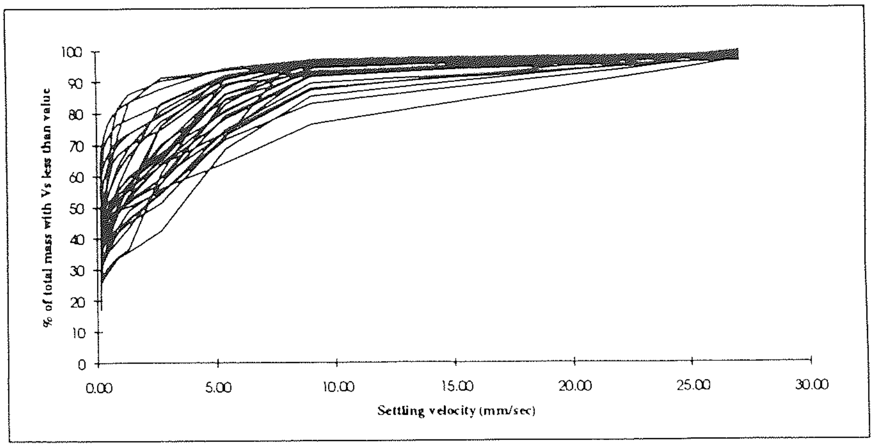


Figure 7.8. Twenty nine wastewater SVP's reproduced from Tyack 1996.

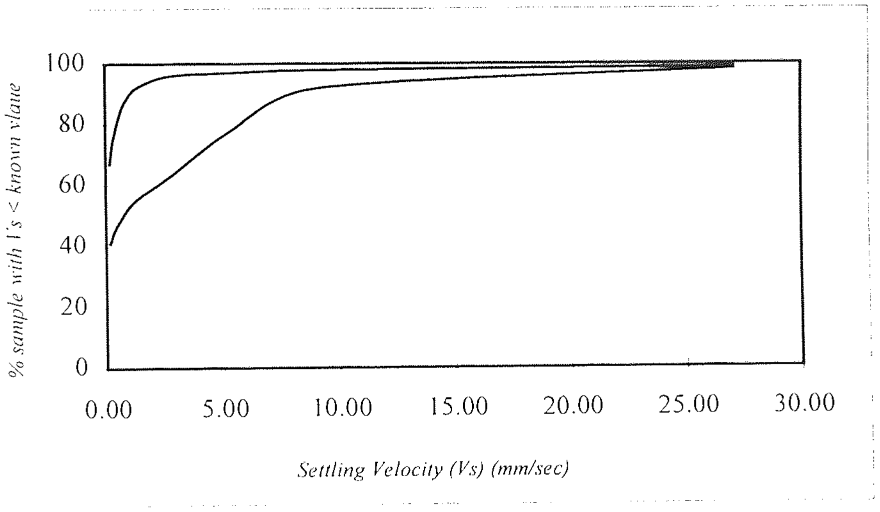


Figure 7.9. Envelope of all wastewater SVP's for both DWF and storm flow conditions obtained by author.

7.3.3. EFFECT OF CATCHMENT SIZE ON THE DISTRIBUTION OF SOLIDS IN THE WASTEWATER SETTLING VELOCITY PROFILES

To examine if the distributions of solid mass is affected by catchment size, the sites were grouped into small, medium and large catchments based on population equivalent (see Table 7.4). Five large, five medium and four small sites were sampled under DWF conditions, and two large and two medium sites were sampled under storm flow conditions. The results are given in Appendix C. Due to the small number of storm sites sampled any conclusions drawn should be treated with caution.

7.3.3.1 Effect of catchment size on the distribution of solids in the floater, residue and sinker groupings

Under DWF conditions, the large, medium and small sites showed the highest proportion of solids (>60% mean value) in the sinker fraction, and the lowest proportion of solids (mean value : <16%) in the floater fraction, indicating that regardless of catchment size most of the solids in the wastewater are associated with the settleable fraction (see Table 7.12 and Figure 7.10.). In comparison, catchment size was found to affect the distribution of solids in the samples collected under storm conditions (see Table 7.13 and Figure 7.11).

7.3.3.2. Effect of catchment size on the distribution of solids in the five sinker fractions

In section 7.3.2.2. it was reported that the peak percent of solid mass in the five sinker fractions was associated with the settling velocity range 0.9-9.03mm/sec regardless of flow conditions. A peak percent distribution of solid mass is also reported in this settling velocity fraction regardless of catchment size, and flow conditions (see Table 7.14. and 7.15. and Figures 7.12 and 7.13).

The mean results also show that the small sites sampled during DWF conditions, had a higher proportion of solids in the lighter settling velocity fractions, 0.18-0.90mm/sec, (41%) than the large (29%) and medium (23%) sites. This indicates that wastewater from the small catchments may be harder to settle as it contains a higher proportion of lighter solids.

Catchment size	No. of sites	Mass of Floaters as % total SS mass	Mass of Residue as % total SS mass	Mass of Sinkers as % total SS mass
Large	5			
Mean		14	24	62
Range		10.0-20.6	16.5-44.9	45.2-71.1
Medium	5			
Mean		11	22	67
Range		2.0-18.3	17.3-31.0	64.3-69.1
Small	4			
Mean		16	24	60
Range		10.0-21.9	18.2-30.9	51.1-65.2

Table 7.12. Effect of catchment size on the distribution of solids in the three broad settling velocity groupings : DWF conditions.

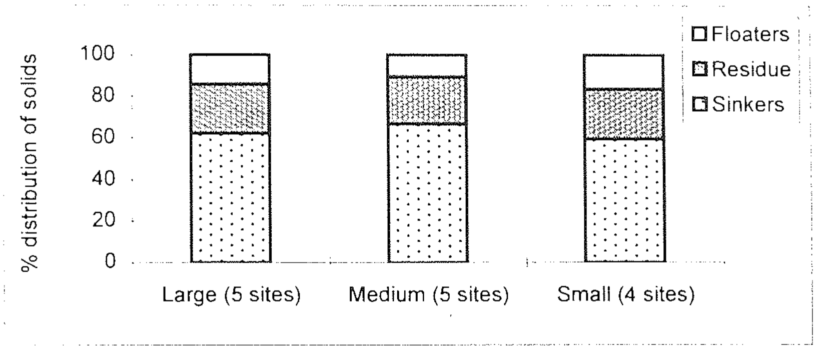


Figure 7.10. Comparison of the effect of catchment size on the distribution of solids in the three broad settling velocity groupings : DWF conditions.

Catchment size	No. of sites	Mass of Floaters as % total SS mass	Mass of Residue as % total SS mass	Mass of Sinkers as % total SS mass
Large	2			
Mean		11	46	43
Range		10.7-13.0	37.0-54.1	32.9-52.4
Medium	2			
Mean		23	19	58
Range		9.7-36.2	14.4-22.8	41.0-75.9

Table 7.13. Effect of catchment size on the distribution of solids in the three broad settling velocity groupings : storm flow conditions.

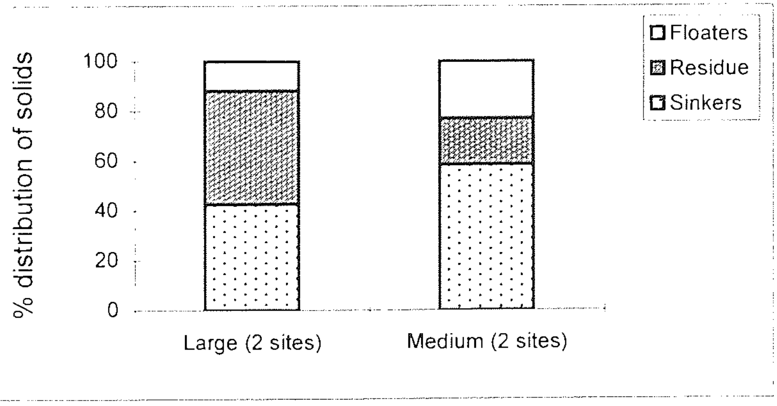


Figure 7.11. Comparison of the effect of catchment size on the distribution of solids in the three broad settling velocity groupings : storm flow conditions.

Catchment size	No.of sites	% of total sinkers mass				
		0.18-0.45	0.45-0.90	0.90-2.70	2.70-9.03	>9.03
Large	5					
Mean		15	14	35	26	11
Range		7.2-24.7	9.0-20.0	30.9-40.4	14.2-43.7	4.6-20.2
Medium	5					
Mean		13	12	36	34	6
Range		5.3-23.2	4.8-24.3	20.4-45.7	10.3-59.0	4.3-8.9
Small	4					
Mean		22	19	27	22	11
Range		9.2-32.0	9.2-25.1	18.5-43.6	5.9-49.2	4.3-13.8

Table 7.14. Effect of catchment size on the mean distribution of solids across the five sinker fractions : DWF conditions.

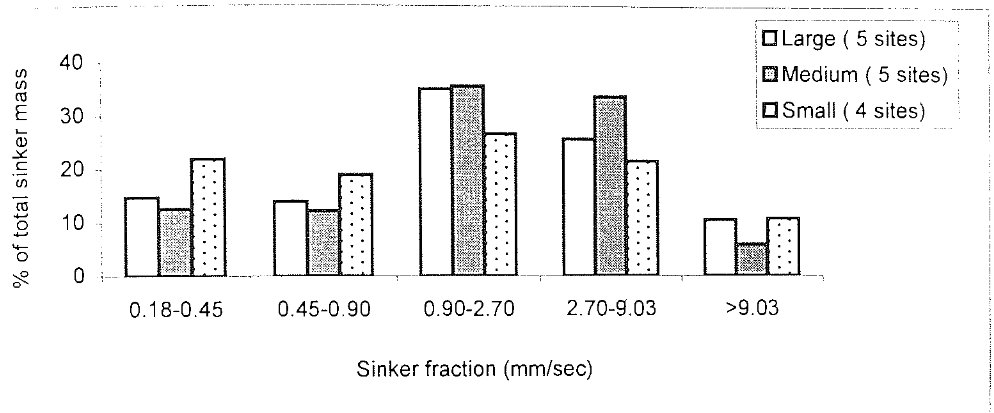


Figure 7.12. Effect of catchment size on the distribution of solids in the sinker fraction (DWF conditions).

Catchment size	No.of sites	% of total sinkers mass				
		0.18-0.45	0.45-0.90	0.90-2.70	2.70-9.03	>9.03
Large	2					
Mean		8	7	32	31	22
Range		6.7-9.5	5.9-8.6	23.3-40.8	27.0-34.5	6.6-37.0
Medium						
Mean	2	15	11	25	39	9
Range		11.4-19.0	11.1-11.3	17.1-33.6	32.5-45.7	6.9-11.5

Table 7.15. Effect of catchment size on the mean distribution of solids across the five sinker fractions : storm flow conditions.

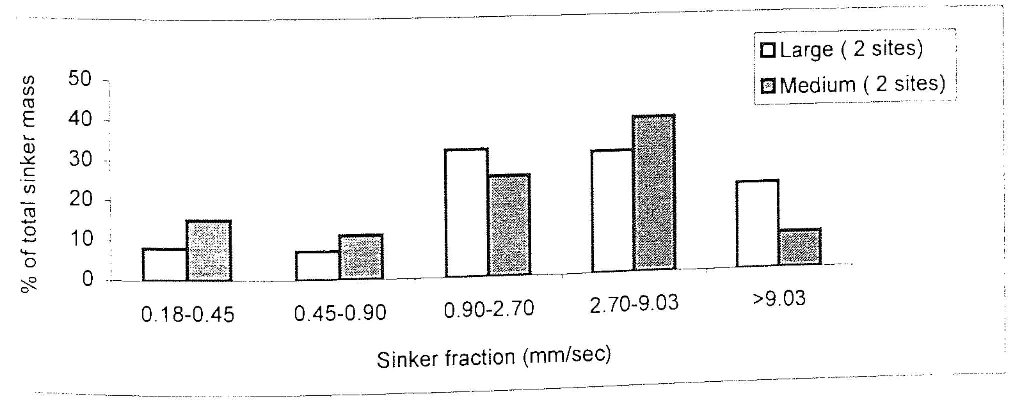


Figure 7.13. Effect of catchment size on the distribution of solids in the sinker fraction (storm flow conditions).

The ranges of values reported were also found to overlap between fractions, indicating a degree of variability is associated with the solid distributions identified.

7.3.3.3. Effect of catchment size on the settling velocity profiles

The settling velocity profiles for the large, medium and small WWTW sampled during DWF and storm conditions are shown in Figures 7.14., 7.15., 7.16., 7.17 and 7.18. These Figures confirm the observations identified above, that catchment size does not appear to affect the distribution of the settling velocity profiles.

7.3.4. EFFECT OF CATCHMENT TYPE ON THE DISTRIBUTION OF SOLIDS IN THE WASTEWATER SETTLING VELOCITY PROFILES

7.3.4.1. Effect of catchment type on the distribution of solids in the floater, residue and sinker fractions

The effect of catchment type on the distribution of solids in the three broad settling velocity groupings under DWF and storm flow conditions are presented in Tables 7.16 and 7.17 and Figures 7.19 and 7.20.

The mean results for the DWF conditions show that the highest proportion of solids (>61%) was associated with the sinker fraction and the lowest proportion of solids (<15%) was associated with the floater fraction, regardless of catchment type (see Table 7.16). A trend was also identified of an increasing proportion of solids in the lighter fractions (eg. floater and residue) from the dom/ind, through the domestic category to the dom/agric catchments (see Figure 7.19.). This suggests that catchment type produces different profiles. The high proportion of solids within the lighter fractions for the domestic (39%) and dom/agric (40%) catchments indicates that wastewater from these catchments would be harder to settle than wastewater from the dom/ind catchment types. There was also a slight overlap in the range of values reported for the floater and residue groupings, indicating that the distribution of solids between these fractions is variable.

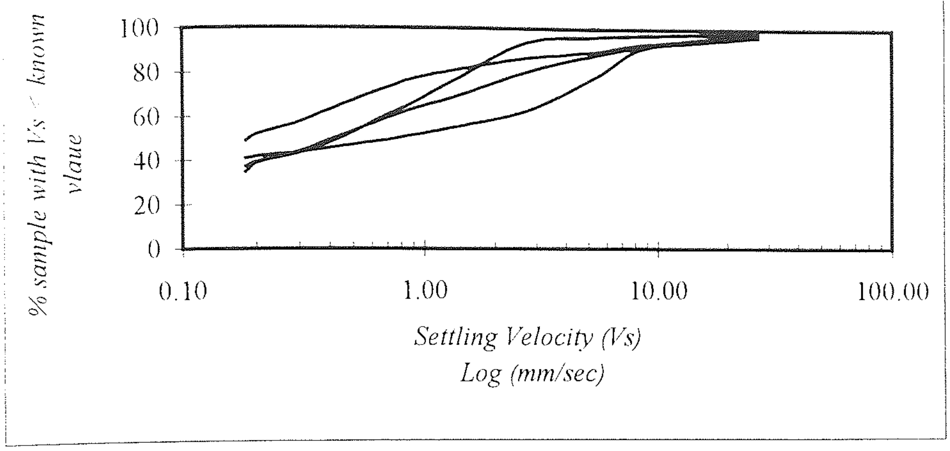


Figure 7.14. SVPs for small sites sampled during DWF conditions (4 sites).

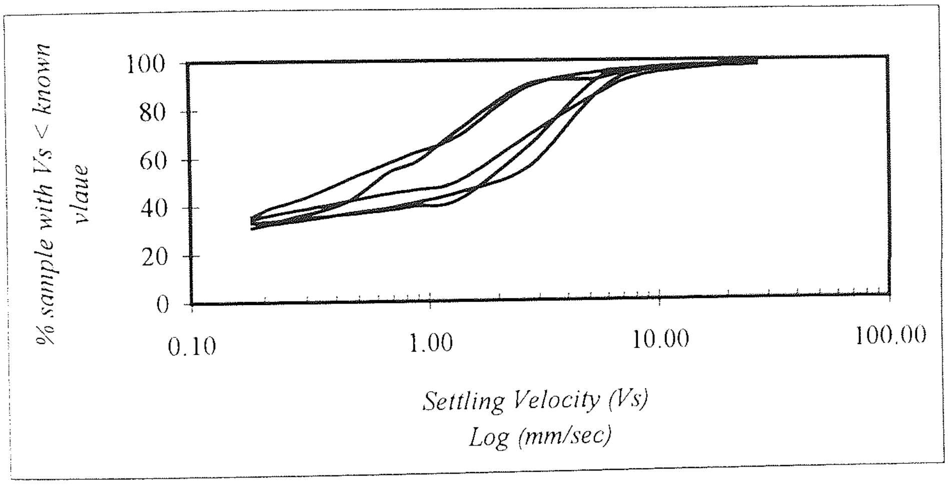


Figure 7.15. SVPs for medium sites sampled during DWF conditions (5 sites).

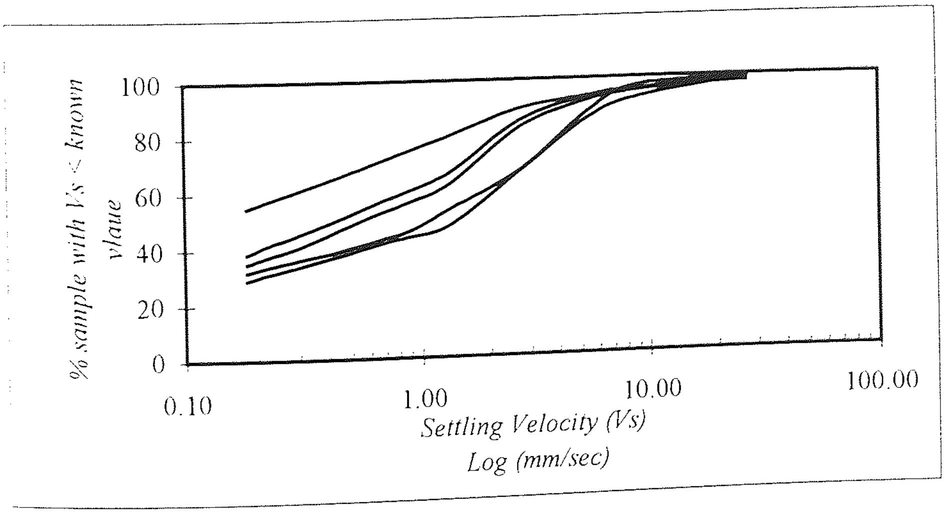


Figure 7.16. SVPs for large sites sampled during DWF conditions (5 sites).

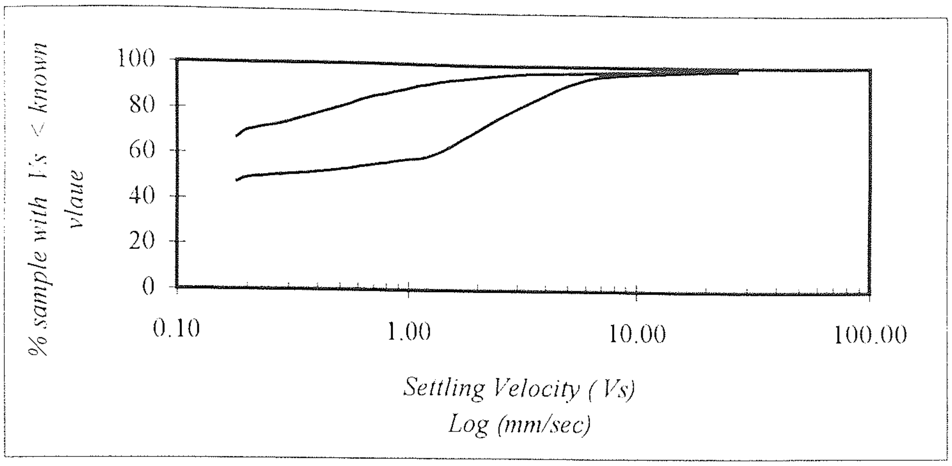


Figure 7.17. SVPs for large sites sampled during storm flow conditions (2 sites).

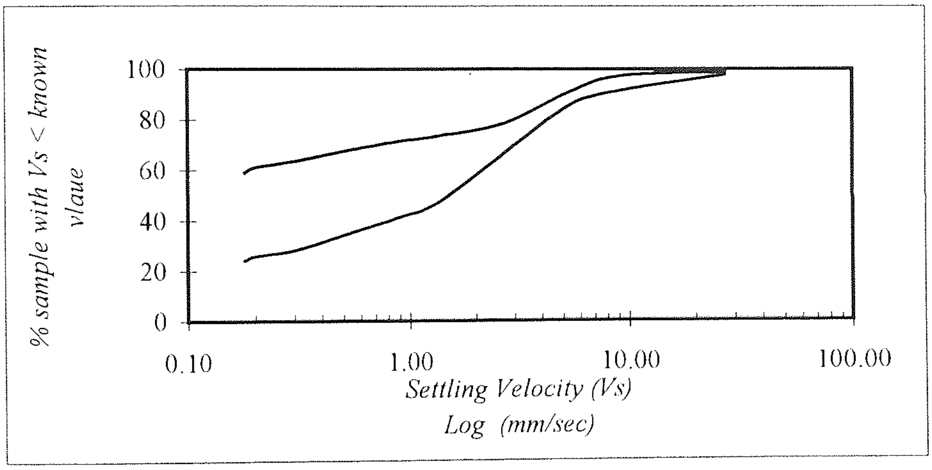


Figure 7.18. SVPs for medium sites sampled during storm flow conditions (2 sites)

Under storm conditions (see Table 7.17. and Figure 7.20.) the mean results show a greater distribution of solids in the sinker fraction for the domestic catchment type (76%) than for the dom/ind (43%) and dom/agric catchments (41%). It must be noted however that only one domestic, one dom/agric and two ind/dom catchments were sampled under storm conditions, and that no definitive conclusions can therefore be drawn regarding the effect of catchment types under storm conditions.

7.3.4.2. Effect of catchment type on the distribution of solids in the five sinker fractions

The effect of catchment type on the distribution of solids in the five sinker fractions (during both DWF and storm flow conditions) are shown in Tables 7.18 and 7.19 and Figures 7.21 and 7.22.

The mean results show a peak distribution of solids (that ranges from 56% - 66%) in the settling velocity fractions covering the range 0.90-9.03mm/sec regardless of catchment type. Within this range the dom/ind and domestic sites show a greater proportion of solids in the 0.9-2.7mm/sec settling velocity fraction regardless of flow conditions. The dom/agric catchments show a different distribution, with larger percent of heavier solids (eg. those with settling velocities in the range 2.7-9.03mm/sec regardless of flow conditions. This indicates wastewater from these catchments may be easier to treat due to a greater component of heavier, more settleable solids.

7.3.4.3. Effect of catchment type on the settling velocity profiles

The settling velocity profiles for the dom/ind, domestic and dom/agric catchment types under DWF and storm flow conditions are shown in Figures 7.23-7.26.

The profiles do not appear to be significantly affected by catchment type or flow conditions (eg. DWF or storm). This indicates that the distribution of settleable solids in the sinker phase can be regarded as independent of catchment type.

Catchment type	No. of sites	Mass of Floaters as % total SS mass	Mass of Residue as % total SS mass	Mass of Sinkers as % total SS mass
Dom/ind	6			
Mean		14	20	66
Range		9.3-20.6	16.8-25.4	61.7-69.1
Dom	5			
Mean		13	26	61
Range		2.0-18.3	17.3-44.9	45.2-67.0
Dom/agric	3			
Mean		15	25	60
Range		10.0-21.9	16.5-30.9	51.1-71.1

Table 7.16. Effect of catchment type on distribution of solids mass in the three broad settling column test groupings: DWF conditions.

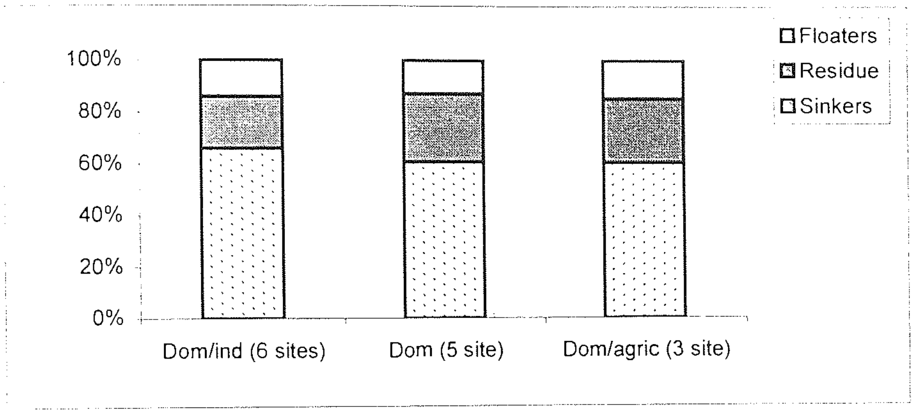


Figure 7.19. Comparison of the effect of catchment type on distribution of solids mass in the three broad settling column test groupings: DWF conditions.

Catchment type	No. of sites	Mass of Floaters as % total SS mass	Mass of Residue as % total SS mass	Mass of Sinkers as % total SS mass
Dom/ind	2			
Mean		11	46	43
Range		10.7-13.0	37.0-54.1	32.9-52.4
Dom	1			
Mean		10	14	76
Dom/agric	1			
Mean		36	23	41

Table 7.17. Effect of catchment type on distribution of solids mass in the three broad settling column test groupings: storm flow conditions.

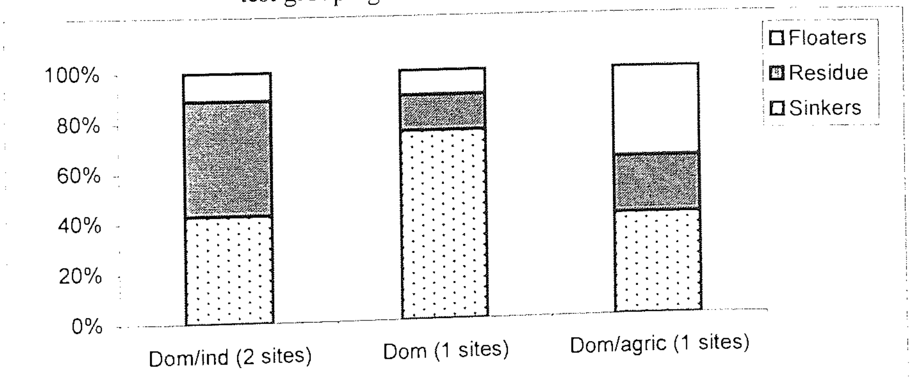


Figure 7.20. Effect of catchment type on the distribution of solids in the three main settling velocity fractions : storm flow conditions.

Catchment type	No. of sites	% of total sinkers mass Settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.70	2.70-9.03	>9.03
Dom/Ind	6					
Mean		12	13	35	31	9
Range		7.2-18.8	6.6-24.3	20.4-45.7	10.3-59.0	4.3-20.2
Dom	5					
Mean		20	17	36	20	7
Range		5.3-25.3	4.8-25.1	26.0-43.6	5.9-47.6	4.3-12.0
Dom/agric	3					
Mean		18	14	23	33	13
Range		9.2-32.0	9.0-23.1	18.5-32.1	13.2-49.2	10.5-13.8

Table 7.18. Effect of catchment type on the mean distribution of solids across the five sinker fractions : DWF conditions.

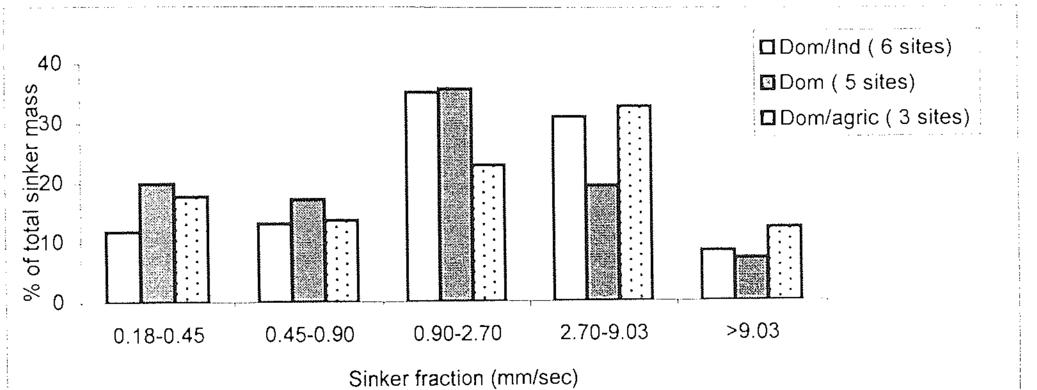


Figure 7.21. Effect of catchment type on the mean distribution of solids across the five sinker fractions (DWF conditions).

Catchment type	No. of sites	Settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.70	2.70-9.03	>9.03
Dom/Ind	2	8	7	32	31	22
Dom	1	11	11	34	32	11
Dom/agric	1	19	11	17	46	7

Table 7.19. Effect of catchment type on the mean distribution of solids across the five sinker fractions : storm flow conditions.

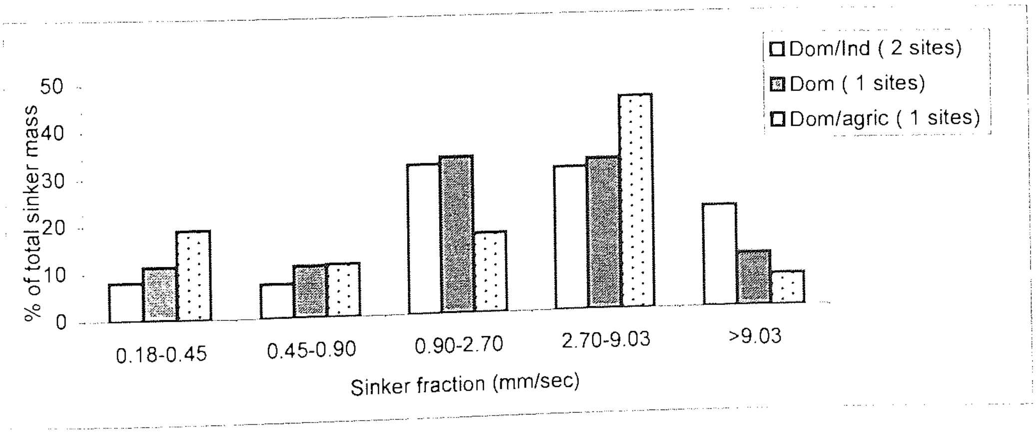


Figure 7.22. Effect of catchment type on the mean distribution of solids across the five sinker fractions (storm flow conditions).

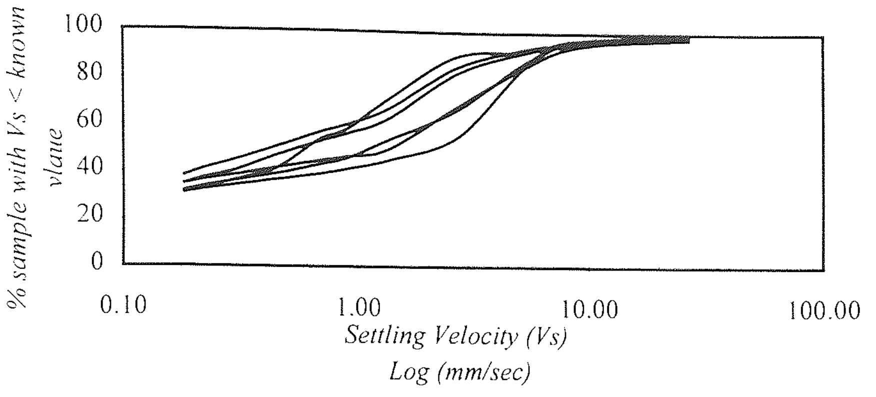


Figure 7.23. SVPs for dom/ind catchment type (6 sites) (DWF conditions)

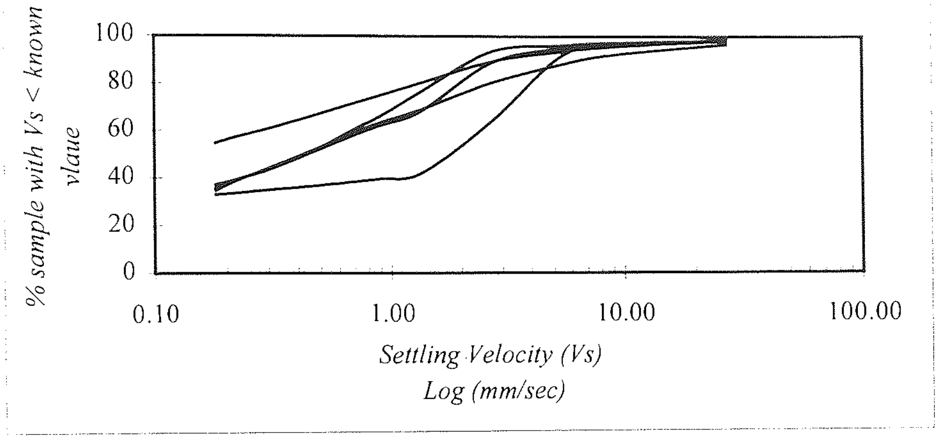


Figure 7.24. SVPs for domestic catchment type (5 sites) (DWF conditions)

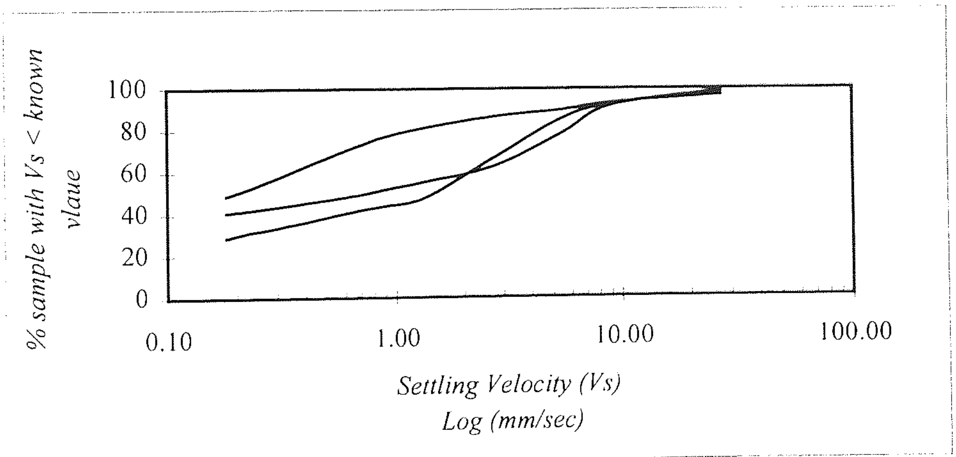


Figure 7.25. SVPs for dom/agric catchment type(3 sites) (DWF conditions)

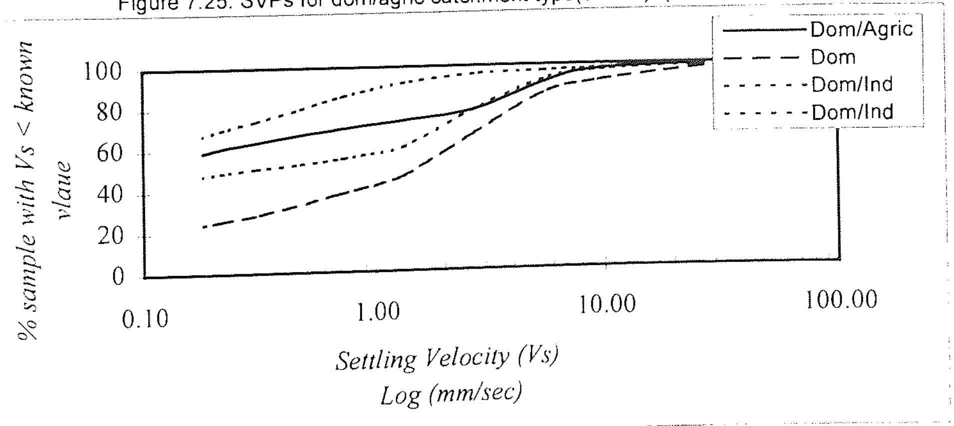


Figure 7.26. SVPs for all catchment types : storm flow conditions.

7.4. SEWAGE CHEMICAL CHARACTERISTICS : COD, P AND TKN

The parameters COD, P and TKN associated with the solids in the settling velocity fractions were determined (as described in Chapter 5). For each wastewater sample a full set of results for each of the seven settling velocity fractions was not always obtained. This was due to several reasons: low solid mass available for digestion (<0.01g); the solids formed a fine layer after drying that was difficult to remove from the drying receptacle; parameters were below the detection limits of the analytical techniques; and experimental error. Therefore, the number of sites contributing to the mean values for each pollutant vary. The full results are included in Appendix D.

7.4.1. REPEATABILITY OF ANALYSIS

An analysis of variance (ANOVA) was undertaken for the COD, P and TKN profiles for each sample event for each site, to identify if the profiles from the different sampling events were significantly different. The ANOVA results are attached at Appendix D. The analysis demonstrates that the profiles determined for COD, P and TKN from separate sampling events at the same site were not significantly different at a level of 5% significance. Mean profiles were therefore produced for COD, P and TKN at each site. The number of sites and events sampled varied for each parameter, and are given in Table 7.20.

PARAMETER	FLOW CONDITIONS			
	DWF		Storm (>3 DWF)	
	Number of sites	Number of events	Number of sites	Number of events
COD	15	25	3	4
P	11	21	2	2
TKN	10	20	2	2

Table 7.20. Number of sites and events for the COD, P and TKN analysis.

7.4.2. PROPORTION OF COD, P and TKN ASSOCIATED WITH THE PARTICULATE AND SOLUBLE PHASE OF THE CRUDE SAMPLES.

The distribution of the total COD, P and TKN mass between the soluble and particulate phase in the original crude sample was undertaken to examine the significance of the particulate fraction as a source of chemical constituents.

The distribution of COD, P and TKN in the crude samples is presented as the percent of the total pollutant mass associated with the particulate and soluble phase. The mean, standard deviation (where applicable) and the range of the results are given in Table 7.21. and the mean distributions of mass are illustrated in Figures 7.27. and 7.28.

PARAMETER	DWF			Storm		
	No. of sites	% particulate	% soluble	No. of sites	% particulate	% soluble
COD	14			3		
Mean		63	37		64	36
Std. Dev.		11.0	11.0		n/a	n/a
Range		35.2-77.4	22.6-64.8		52-75	25-48
P	11			2		
Mean		65	35		66	34
Std. Dev.		13.1	13.0		n/a	n/a
Range		42.8-83.9	16.1-57.2		61.3-70.6	29.6-38.7
TKN	10			1		
Mean		9	91		11	89
Std. Dev		3.7	3.7		n/a	n/a
Range		3.6-16.3	83.7-96.4		n/a	n/a

Table 7.21. Distribution of COD, P and TKN in the particulate and soluble phase of the crude samples : DWF and storm flow conditions.

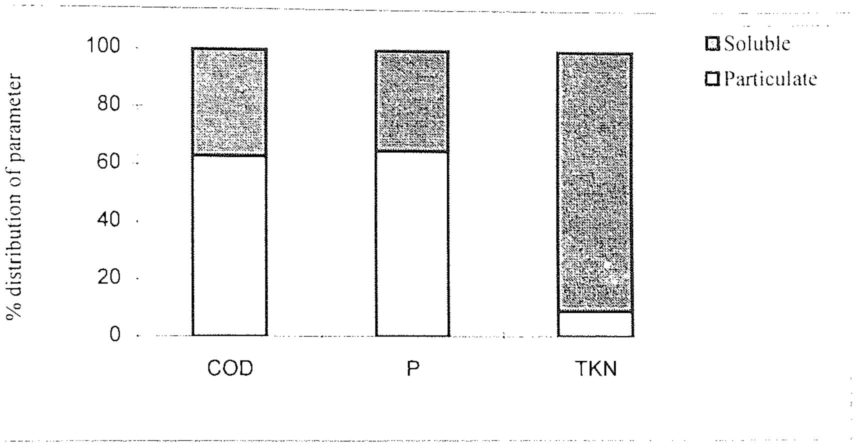


Figure 7.27. Distribution of COD, P and TKN in crude wastewater (DWF conditions)

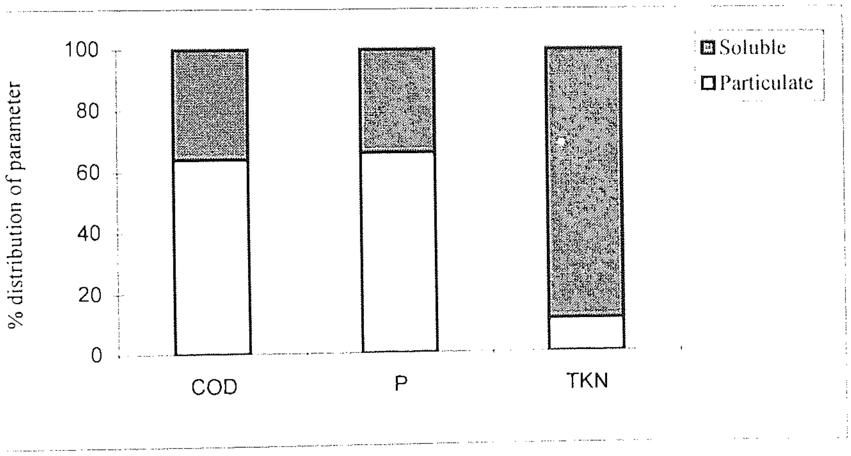


Figure 7.28. Distribution of COD, P and TKN in crude wastewater (storm flow conditions)

The mean results show that regardless of flow conditions, COD and P mass were found to be mainly associated with the particulate phase of the crude wastewater (eg. 63% - 66%). The associated range of values showed a slight overlap between the soluble and particulate phase, indicating a degree of variability in the distribution of COD and P. The association of COD and P with the particulate phase is typical for COD and P, as they are generally considered to be associated with organic particles. Michelbach and Wöhrle (1993b) also report that COD is primarily associated with the particulate fraction of wastewater (67%).

The highest mean proportion of TKN mass, 91% for the DWF sample, and 89% for the storm sample, was found to be associated with the soluble fraction in the crude sample. No overlap in the ranges was reported between the particulate and soluble phase. The results for TKN clearly indicate that its removal is not achievable by purely physical settlement as it is mainly associated with the soluble phase. It is acknowledged that nitrogen is generally present in the soluble phase, and at WWTW that have consents specify low nitrogen levels, removal of this parameter is generally acheived by the use of biological or chemical treatment.

The results in general confirm that the particulate phase of wastewater is an important source of COD and P, and that physical sedimentation can contribute significantly to their removal. The association of TKN with the soluble phase shows that this parameter may not be so readily removed by physical sedimentation.

7.4.3. DISTRIBUTION OF COD, P AND TKN IN THE THREE BROAD SETTLING COLUMN GROUPINGS

The distribution of chemical constituents associated with the three broad settling column groupings was initially examined to identify any trends in the distribution. For comparative purposes, the results are expressed as a proportion of the total mass of pollutant per kg dry total solids and are summarised in Tables 7.22. and 7.23 and Figure 7.29.

The results for the COD and P show that the highest mean proportion of mass (48%-60%) was associated with the sinkers and the lowest mean proportion with the floaters (8%-13%), regardless of flow conditions. This implies COD and P are mainly associated with settleable watewater solids (eg. the sinkers fraction) and that a significant quantity of these parameters could potentially be removed by physical sedimentation.

PARAMETER	No. of sites	Proportion of the total mass of pollutant per kg dry solids expressed as a %		
		Floaters	Residue	Sinkers
COD	12			
Mean		7.9	32.9	59.2
Std. Dev.		1.8	8.0	9.1
Range		(5.8-12.0)	(23.1-49.6)	(38.4-69.6)
P	11			
Mean		12.6	28.7	58.7
Std. Dev.		4.5	11.2	11.0
Range		(4.9-19.2)	(13.2-50.8)	(34.1-73.9)
TKN	4			
Mean		13.4	21.5	65.1
Range		(4.0-29.0)	(9.4--36.4)	(59.4-74.9)

Table 7.22. Distribution of pollutants in the three broad settling column groupings (DWF conditions).

PARAMETER	No. of sites	Proportion of the total mass of pollutant per kg dry solids expressed as a %		
		Floaters	Residue	Sinkers
COD	3			
Mean		7.9	32.6	59.6
Range		(7.3-8.5)	(23.8-38.7)	(52.8-68.9)
P	2			
Mean		8.4	43.4	48.2
Range		(6.3-11.8)	(32.3-50.3)	(43.4-56.0)

Table 7.23. Distribution of pollutants (mg/kg total dry solids) in the three broad settling column groupings (storm flow conditions).

The data presented for TKN are for samples collected under DWF conditions only due to the low solid mass available for digestion (<0.01g) in the storm samples. In section 7.4.2. it is reported that TKN was found to be mainly associated with the soluble phase of the crude wastewater sample (89-91%). However, the distribution of TKN in the three broad settling column fractions was found to be mainly associated with the sinker fraction.

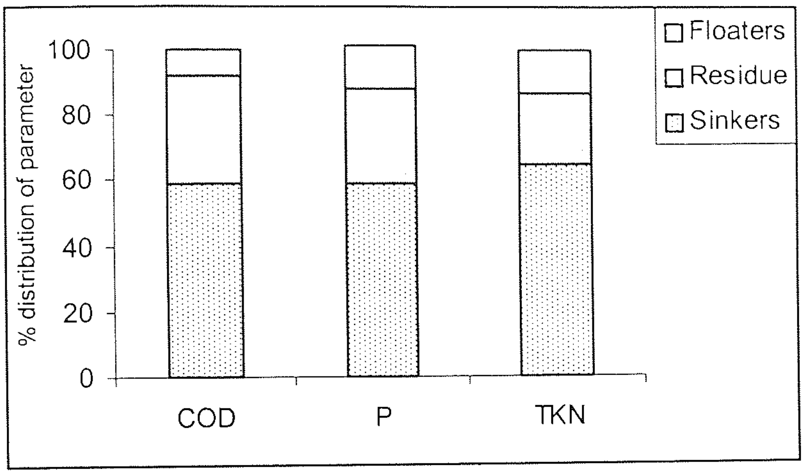


Figure 7.29. Distribution of COD, P and TKN in the three broad settling column groupings (DWF conditions)

7.4.4. DISTRIBUTION OF COD, P AND TKN IN THE FIVE SINKER FRACTIONS.

To further investigate the distribution of COD, P and TKN mass in the sinker fraction, this fraction was separated into the five settling velocity ranges: 0.18-0.45, 0.45-0.90, 0.90-2.70, 2.70-9.03, >9.03 mm/sec (in accordance with the methodology in section 6.2). The results are presented as the proportion of the total sinker pollutant mass per kg dry total solids and as the mass of pollutant/per kg dry total solids in each fraction.

From Table 7.24. and Figures 7.30 to 7.32 it is evident that there is a specific settling velocity range (0.90-9.03mm/sec) within which most of COD, P and TKN mass was associated, and within this range there was a definitive peak of pollutant mass. Under DWF conditions, this peak of pollutants was associated with the lighter fraction (0.9-2.7mm/sec), and under storm flow conditions with the heavier solids (2.7-9.03mm/sec). No complete set of results was obtained for TKN under storm conditions this due to either low solid mass available for digestion and/or the solids being too fine to remove for digestion after drying.

The results indicate a shift of the peak of COD and P mass into the slightly heavier settling velocity range (eg. 2.7-9.03mm/sec) for the samples collected under storm flow conditions.

PARAMETER	v_s range within which the highest mass of constituent was found		Definitive peak within v_s range			
			DWF		Storm	
	v_s (mm/sec)	%	v_s (mm/sec)	%	v_s (mm/sec)	%
COD	0.9-9.03	DWF 62% Storm 55%	0.9-2.7	33%	2.7-9.03	29%
P	0.9-9.03	DWF 59% Storm 56%	0.9-2.7	32%	2.7-9.03	32%
TKN	0.9-9.03	DWF 55%	0.9-2.7	39%	nd	nd

Table 7.24. Summary of the distribution of COD, P and TKN across the five sinker fractions in all the DWF and storm flow samples.

The mass/kgSS of COD and P was also found to be consistently less for the storm flow samples than the DWF. This may be due to a greater proportion of inert material (non-organic) material entrained in the storm flow arising from surface runoff.

In general, however, the distributions are very similar for COD, P and TKN.

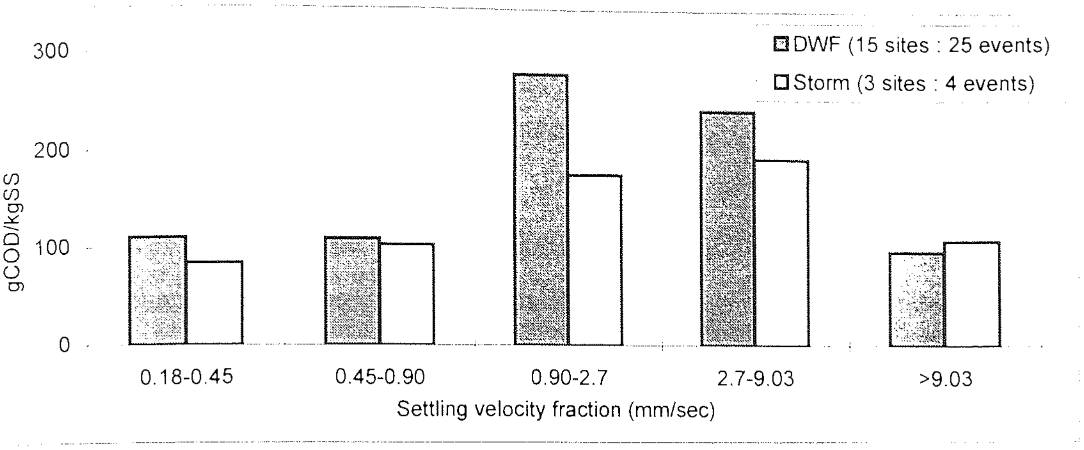


Figure 7.30. Distribution of COD associated with SS (DWF and storm flow conditions)

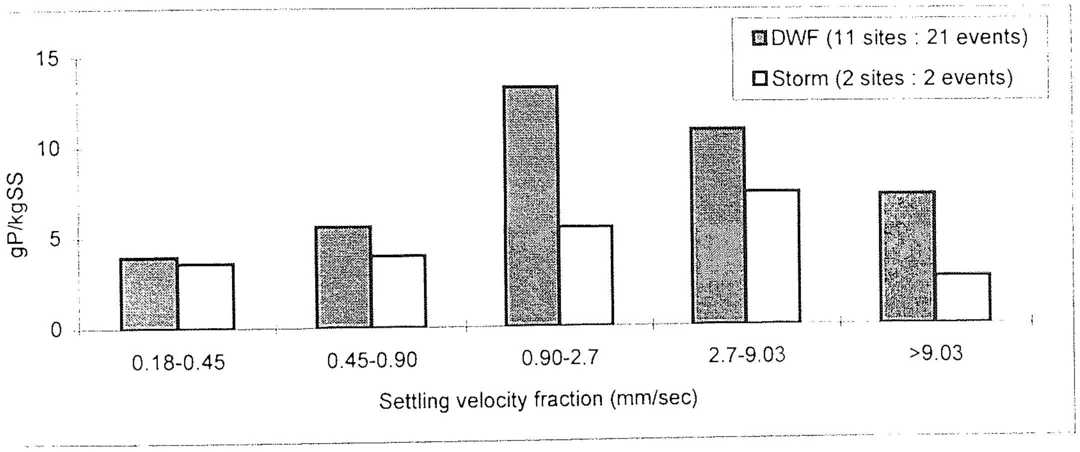


Figure 7.31. Distribution of P associated with SS (DWF and storm flow conditions)

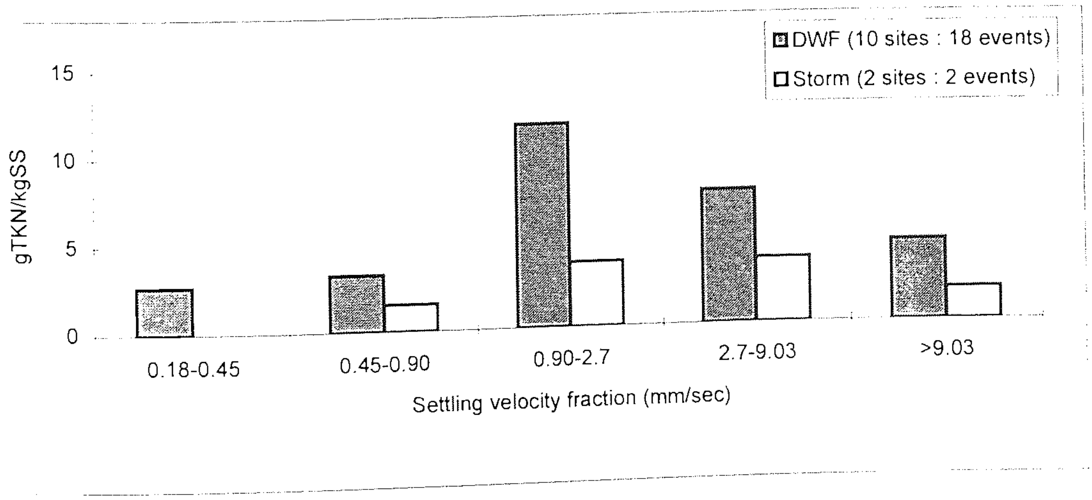


Figure 7.32. Distribution of TKN associated with SS (DWF and storm flow conditions)

7.4.5. EFFECT OF CATCHMENT SIZE ON THE DISTRIBUTION OF COD, P AND TKN.

7.4.5.1. The effect of catchment size on the distribution of COD, P and TKN in the particulate and soluble phase of the crude samples.

The effect of catchment size on the distribution of COD, P and TKN between the particulate and soluble phase are tabulated in Appendix D.

The results show that the highest proportion of COD and P are associated with the particulate phase (as reported in section 7.4.2.), regardless of catchment size and flow conditions, and the highest proportion of TKN was found to be associated with the soluble phase (as reported in section 7.4.2.) regardless of catchment size.

Since the results are from a small sample size (ranging from one to five sites), and conclusions drawn can only be tentative but the results indicate that catchment size does not appear to affect the distribution of these parameters.

7.4.5.2. The effect of catchment size on the distribution of COD, P and TKN in the three broad settling column test groupings.

The effect of catchment size on the distribution of COD, P and TKN in the three broad settling column test groupings are presented in Appendix D for both DWF and storm flow conditions. No results are available for the effect of catchment size on the distribution of TKN in samples collected from the small sites or under storm flow conditions for the reasons specified at the beginning of this section (eg. 7.4.).

The results are shown in Figures 7.33 to 7.37.and show a general increase in pollutant mass from the floaters to the sinkers, regardless of pollutant, catchment size or flow conditions. An exception to this trend was for the P results for the large catchments under storm conditions, the results showed the highest proportion of P mass in the residue. As the results for the large catchments are only from one site, this result cannot be considered to be of significance.

7.4.5.3. The effect of catchment size on the distribution of COD, P and TKN in the five sinker fractions.

A summary of the peak distribution of COD, P and TKN are shown in Table 7.25., which shows that regardless of catchment size and flow conditions, the peak mass of COD, P and TKN was generally found to be associated with solids that have settling velocities in the range 0.9-9.03mm/sec.

PARAMETER	Peak v_s (mm/sec)	CATCHMENT SIZE		
		Large %	Medium %	Small %
COD	0.9-9.03mm/sec	DWF 61% Storm 61%	DWF 65% Storm 56%	DWF 52% Storm nd
P	0.9-9.03mm/sec	DWF 59% Storm 24%	DWF 62% Storm 32%	DWF 49% Storm nd
TKN	0.9-9.03mm/sec	DWF 65% Storm 24%	DWF 75% Storm nd.	DWF 41% Storm nd.

Table 7.25. Summary of the effect of catchment size on the distribution of COD, P and TKN across the five sinker fractions (DWF and storm flow conditions).

Further investigation of this settling velocity range shows that in general the settling velocity fraction 0.90-2.7mm/sec contained the highest proportion of COD and P regardless of catchment size under DWF conditions. The distributions for COD, P and TKN are shown in Figures 7.38, 7.39 and 7.40.

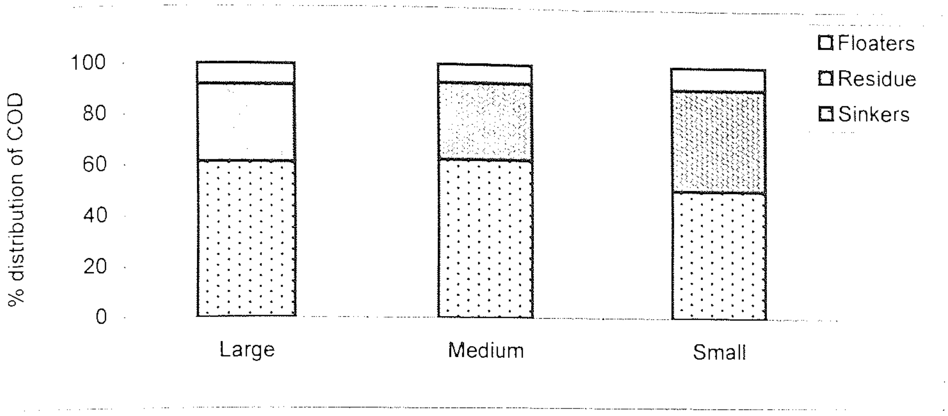


Figure 7.33. Effect of catchment size on the distribution of COD in the three broad settling velocity groupings : DWF conditions.

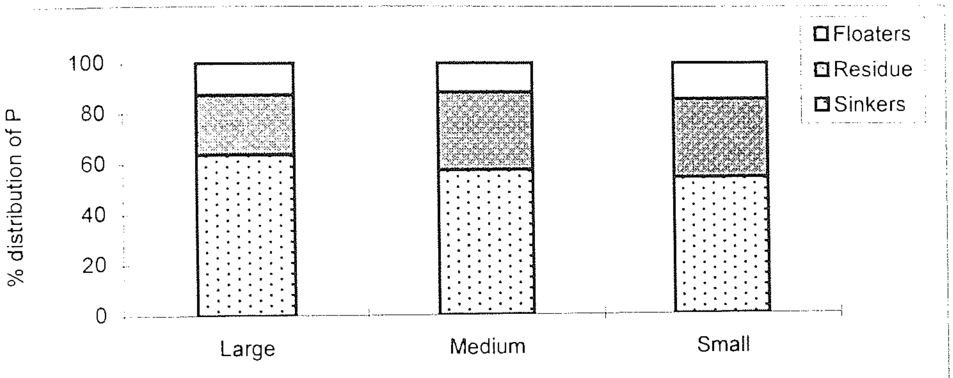


Figure 7.34. Effect of catchment size on the distribution of P in the three broad settling velocity groupings : DWF conditions.

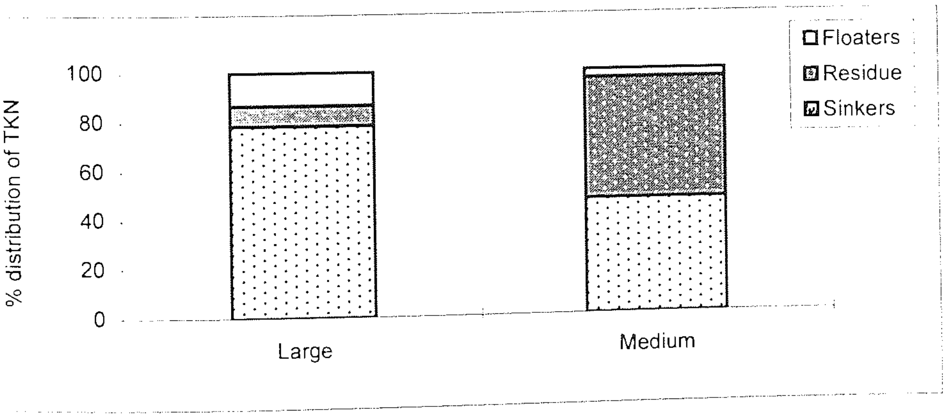


Figure 7.35. Effect of catchment size on the distribution of TKN in the three broad settling velocity groupings : DWF conditions.

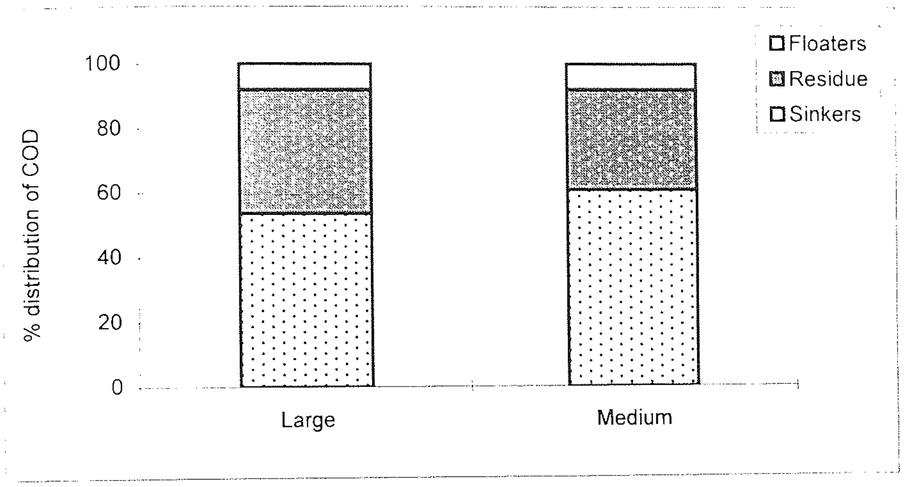


Figure 7.36. Effect of catchment size on the distribution of COD in the three broad settling velocity groupings : storm conditions.

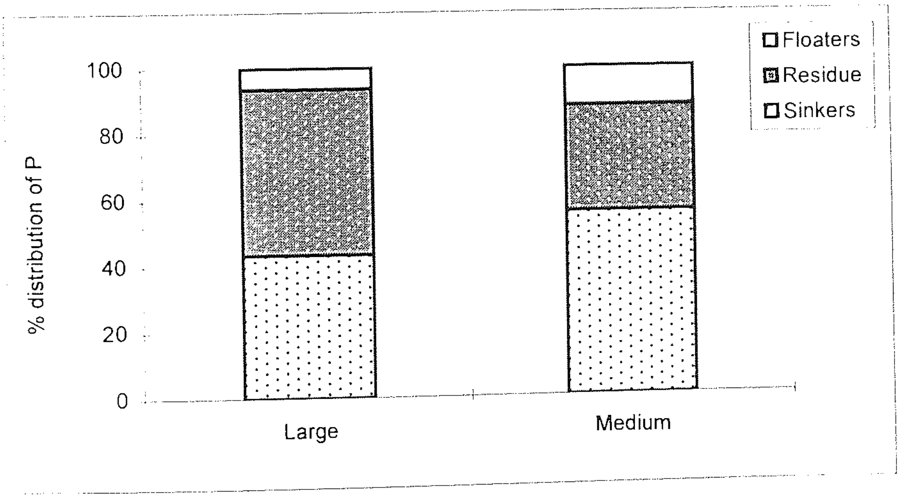


Figure 7.37. Effect of catchment size on the distribution of P in the three broad settling velocity groupings : storm conditions.

Under storm conditions, pollutants were mainly found to be associated with the heavier solids in the fraction (eg. 2.7-9.03mm/sec). These results are summarised in Table 7.26. and Figures 7.41. and 7.42., and indicate that samples collected under storm flow conditions contain pollutants associated with the heavier solids.

PARAMETER	Fraction in which peak occurs v_s (mm/sec)	CATCHMENT SIZE		
		Large	Medium	Small
COD	DWF 0.9-2.7mm/sec Storm 2.7-9.0mm/sec	DWF 34% Storm 32%	DWF 38% Storm 28%	DWF 27% Storm nd.
P	DWF 0.9-2.7mm/sec Storm 2.7-9.0mm/sec 0.9-2.7mm/sec	DWF 31% Storm 17% n/a	DWF 38% n/a Storm 19%	DWF 24% Storm nd.
TKN	DWF 0.9-2.7mm/sec	DWF 36%	DWF 49%	DWF15%.

Table 7.26. Summary of the effect of catchment size on the peak distribution of COD, P and TKN across the five sinker fractions (DWF and storm flow conditions).

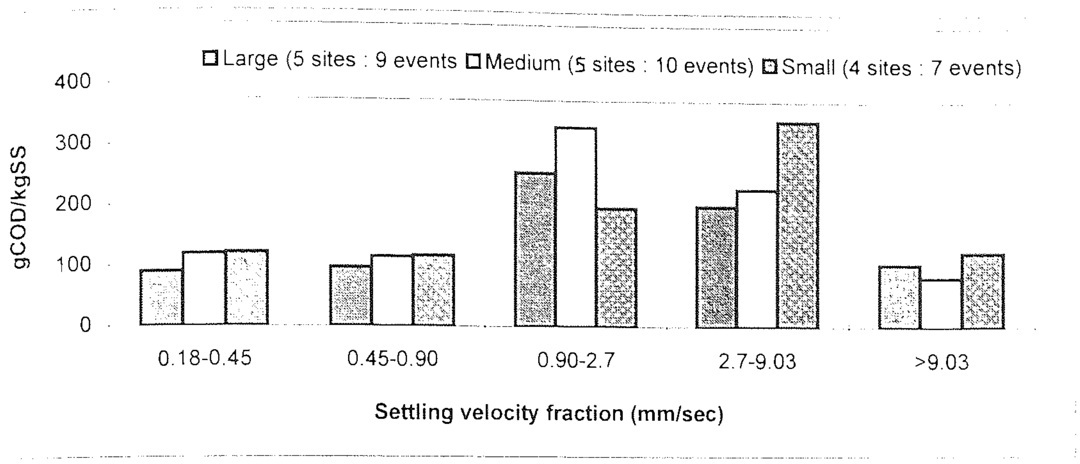


Figure. 7.38. Effect of catchment size on the distribution of COD associated with SS (DWF conditions)

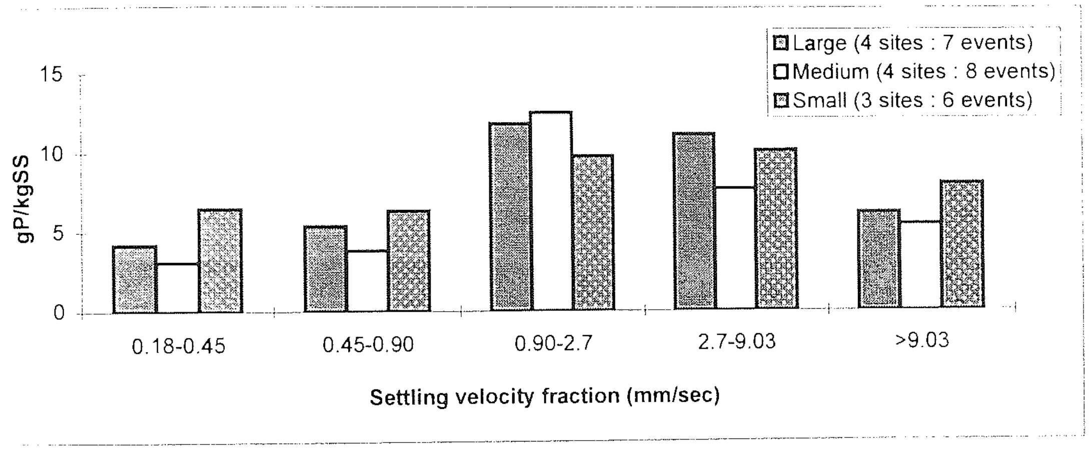


Figure. 7.39. Effect of catchment size on the distribution of P associated with SS (DWF conditions)

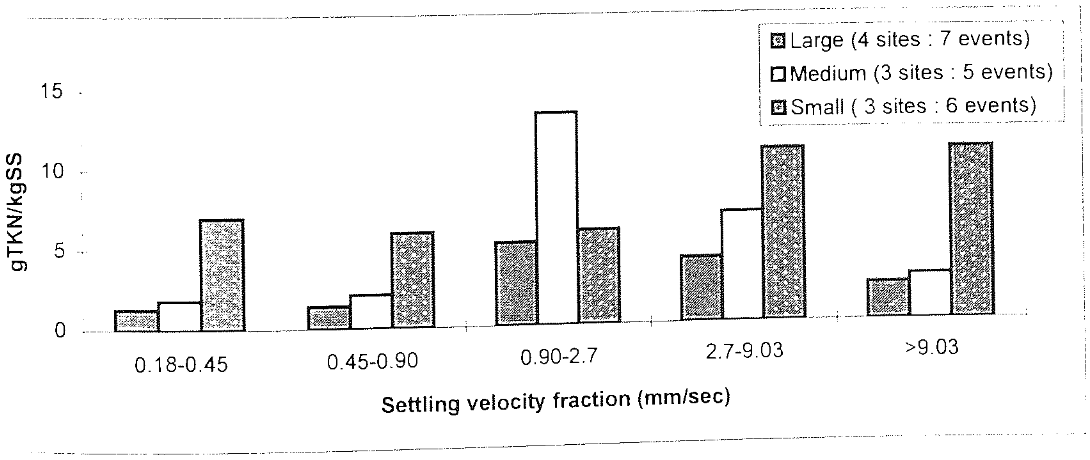


Figure. 7.40. Effect of catchment size on the distribution of TKN associated with SS (DWF conditions)

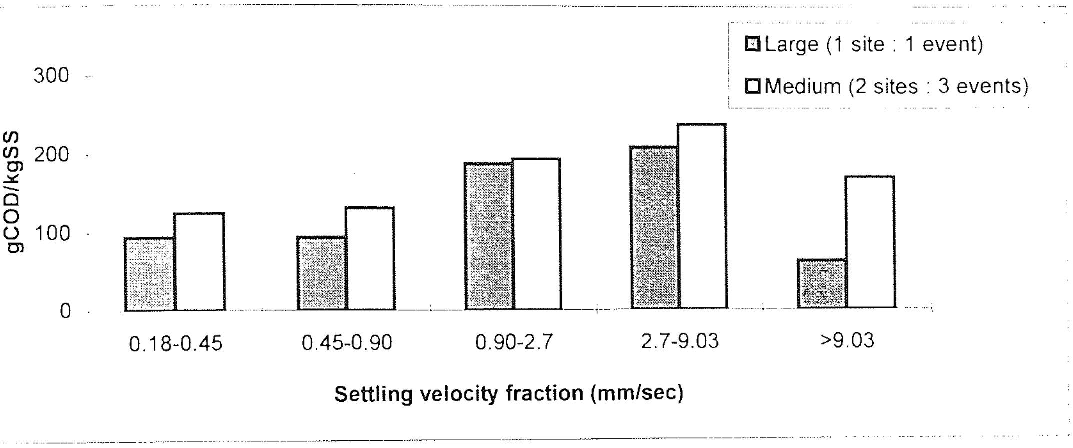


Figure 7.41. Effect of catchment size on the distribution of COD associated with SS (storm flow conditions)

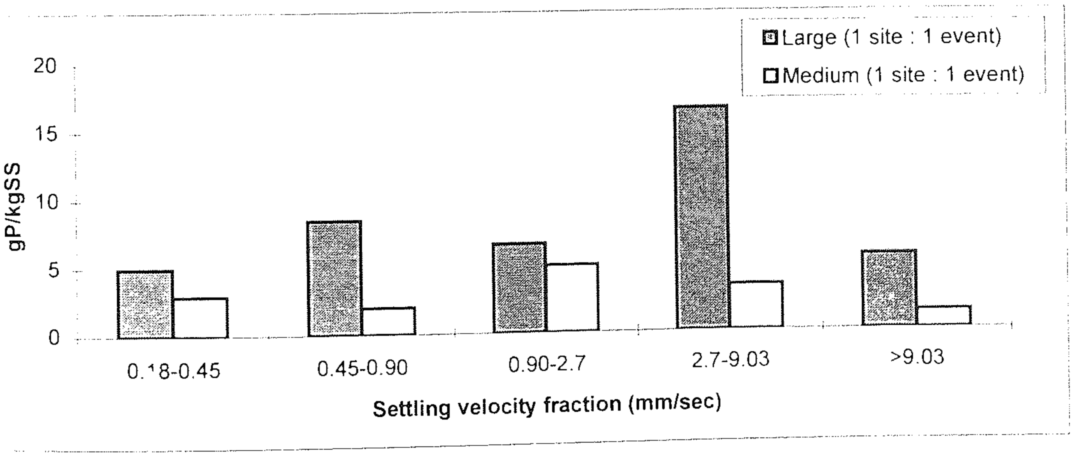


Figure 7.42. Effect of catchment size on the distribution of P associated with SS (storm flow conditions)

7.4.6. EFFECT OF CATCHMENT TYPE ON THE DISTRIBUTION OF COD, P AND TKN

The results of the effect of catchment type on the distributions of COD, P and TKN are in Appendix D and are summarised in the following sections

7.4.6.1.The effect of catchment type on the distribution of COD, P and TKN in the particulate and soluble phase of the crude samples

Catchment type was found not to affect the distribution of COD, P and TKN between the particulate and soluble phases.

7.4.6.2. The effect of catchment type on the distribution of COD, P and TKN in the three broad settling column test groupings.

The results for COD, P and TKN under DWF conditions are shown in Figures 7.43, 7.44 and 7.45.

Catchment type was found not to affect the distribution of COD in the three broad settling column test groupings. For all catchment types the highest mean proportion of mass was found to be associated with the sinkers (53%-69%), and the lowest mean proportion of mass (7%-9%) with the floaters. This was also regardless of flow conditions.

The distribution of P in the samples collected under DWF conditions was found to be affected by catchment type. A mean peak of P was found in the sinker fraction (that represents >58% of the total P mass) and the lowest mass in the floater fraction (this represent 12% of the total P mass) for the domestic and dom/ind catchments. The distribution of P between the residue (44%) and sinker (42%) fractions were found however to be similar for the dom/agric catchment type, indicating that wastewater from this type of catchment may be harder to treat for the removal of P, if it is associated with the less settleable solids.

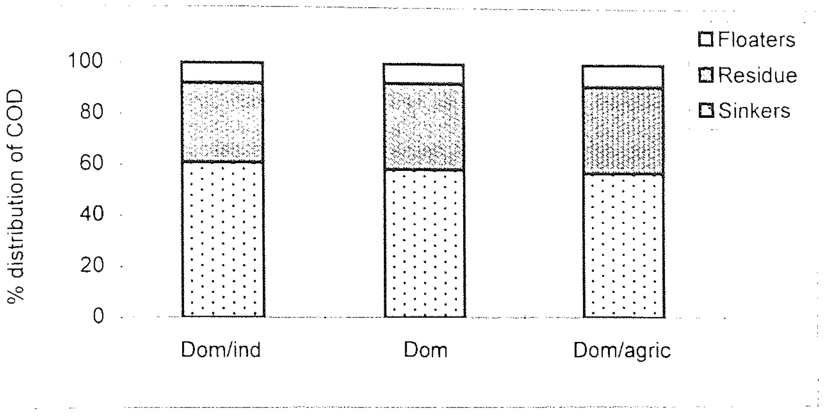


Figure 7.43. Effect of catchment type on the distribution of COD in the three broad settling velocity groupings : DWF conditions.

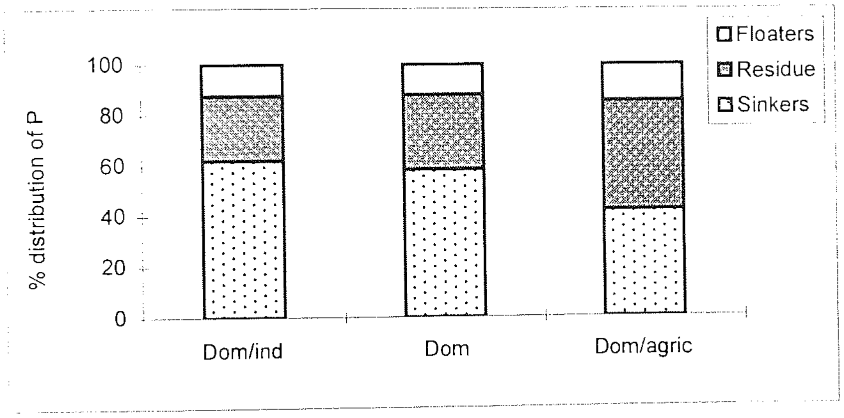


Figure 7.44. Effect of catchment type on the distribution of P in the three broad settling velocity groupings : DWF conditions.

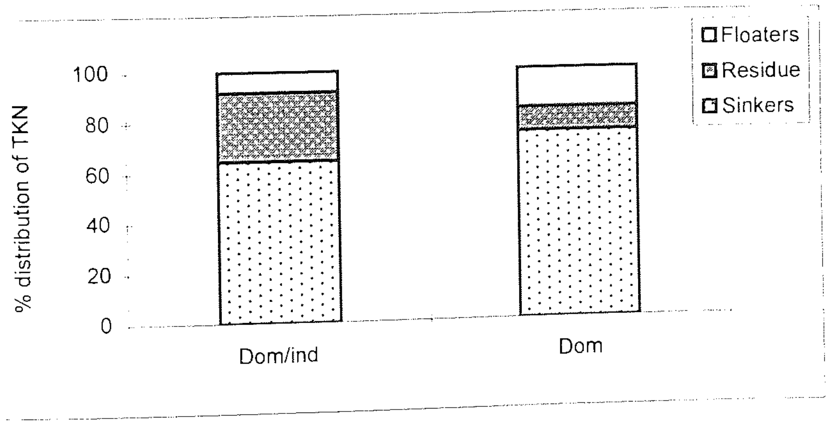


Figure 7.45. Effect of catchment type on the distribution of TKN in the three broad settling velocity groupings : DWF conditions.

Under storm flow conditions the highest mass of P was found to be associated with the sinker fraction for the domestic catchment (representative of one site), and with the residue for the dom/ind catchment (representative of one site). Due to the small sample size (eg. 2 sites), no conclusions can be drawn from the storm results for P.

The results for TKN are from dom/ind sites and domestic catchments (see Figure 7.45.) and show that the TKN was mainly associated with the sinker fraction. No specific distribution of mass was found between the floater and residue fractions.

7.4.6.3. The effect of catchment type on the distribution of COD, P and TKN in the five sinker fractions.

The results of the effect of catchment type on the distribution of COD, P and TKN under DWF conditions are shown in Figures 7.46., 7.47. and 7.48.

For all three catchment types under DWF conditions, the peak COD and P was found to be generally associated with solids having a settling velocity in the range 0.9-2.7mm/sec, indicating that catchment type does not affect the distribution. Under storm flow conditions, the distribution of COD in the dom/agric catchments and the P in the dom/ind showed a predominant peak of mass in the settling velocity fraction 2.71-9.03mm/sec, indicating an association with the heavier solids.

The DWF TKN results showed a peak in the settling velocity fraction 0.9-2.7mm/sec for the dom/ind catchments and an even spread of TKN mass for the domestic catchments. The dom/ind sites were also found to contain a higher mass of TKN, which was possibly due to the presence of industry in those catchments. The distribution of TKN for the domestic catchment is from only one site, and therefore no conclusion can be drawn from this result.

The results in general imply however that catchment type does not affect the association of COD, P and TKN with the heavier, settleable solids.

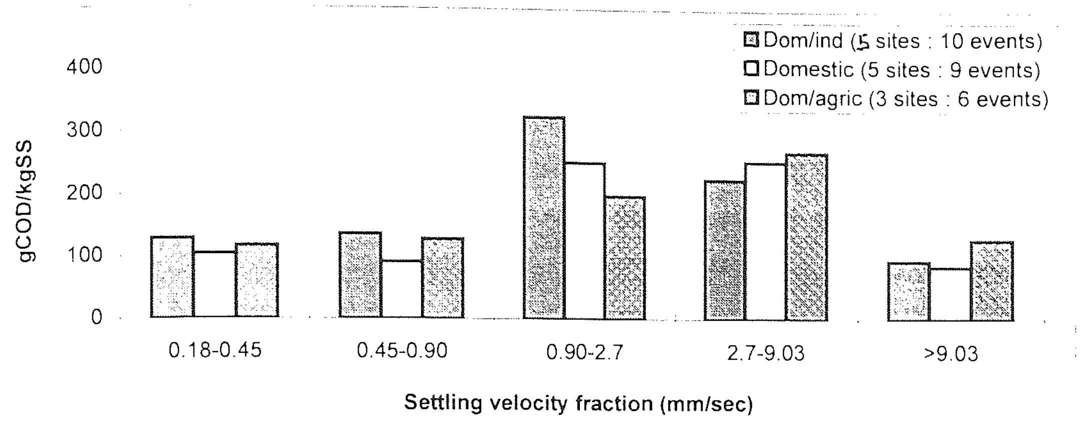


Figure 7.46. Effect of catchment type on the distribution of COD association with SS (DWF conditions)

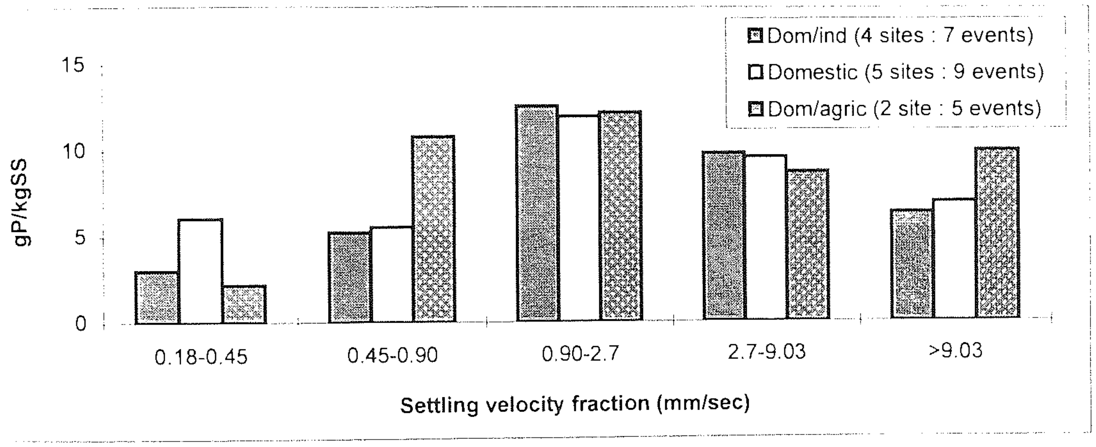


Figure 7.47. Effect of catchment type on the distribution of P association with SS (DWF conditions)

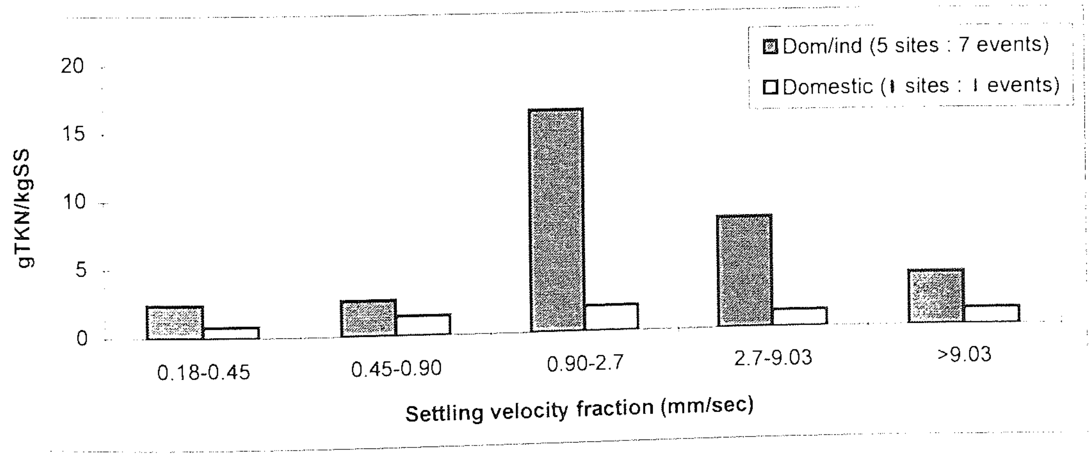


Figure 7.48. Effect of catchment type on the distribution of TKN with SS (DWF conditions)

7.4.7. SUMMARY OF COD, P AND TKN RESULTS

The results discussed in section 7.4. have enabled the identification of several relationships between solids and associated COD, P and TKN.

COD and P were identified to be associated with the particulate phase of the wastewater samples regardless of catchment characteristics (eg. size, type and flow conditions). TKN was found to be mainly associated with the soluble phase in the wastewater samples regardless of catchment characteristics.

In three broad settling column fractions, COD, P and TKN were found to be mainly associated with the sinker fraction, and least with the floaters. For COD and TKN, this relationship was found to be unaffected by catchment characteristics. The distribution of P, however appeared to be affected by catchment type as the distribution of P between the residue and sinkers was similar for the dom/agric catchments under DWF.

For the five sinker fractions, the peak mass of COD, P and TKN was found to be associated with the settling velocity fraction 0.9-9.03mm/sec regardless of flow conditions. Within this fraction a peak mass of COD and P was found in the 0.9-2.7mm/sec settling velocity fraction for DWF conditions, and with the heavier 2.7-9.03mm/sec fraction for storm flow conditions, regardless of catchment size or type. The distribution of TKN was found however to be affected by catchment type. The TKN was found to peak in the fraction 0.9-2.7mm/sec for DWF conditions for the dom/ind catchments, however the domestic catchments showed an even distribution of TKN mass over the five fractions.

The results overall indicate that :

- TKN is mainly associated with the soluble phase of wastewater;
- COD and P are mainly associated with the solid phase of wastewater;
- COD, P and TKN have an affinity for a particular range of settleable solids (0.9-9.03mm/sec), and
- there is the potential for the removal of COD and P from wastewater by sedimentation devices.

7.5. SEWAGE CHEMICAL CHARACTERISTICS : HEAVY METALS.

The heavy metals associated with the solids in the settling velocity fractions were determined (as described in Chapter 5). As stated in section 5.3.3.1. five wastewater samples were analysed at Clayton for a suite of heavy metals. The samples were analysed from the following sites: B (sample event 1 and 2); D (sample event 2); G (sample event 3) and K (sample event 3). Of these five samples, four were taken during DWF conditions and one, Site B (sample event 2), was taken during storm conditions. In some cases not all the sites sampled have a full set of heavy metal results for the following reasons: low solid mass available for digestion (<0.01g) and/or heavy metals not being present at detectable levels. For these reasons the results are only available for those samples collected under DWF conditions. The number of sites contributing to the mean values presented is also dependent on the data available for each site. The results for the heavy metals are in Appendix E.

It must also be noted that due to the size of the data set, any conclusions drawn within this section are tentative.

7.5.1. REPEATABILITY OF ANALYSIS

As the heavy metals results were from one sample event for each site, the repeatability of analysis could not be examined.

7.5.2. PROPORTION OF HEAVY METALS ASSOCIATED WITH THE PARTICULATE AND SOLUBLE PHASE OF THE CRUDE SAMPLES

The distribution of the total heavy metal mass between the soluble and particulate phases in the original crude samples was determined. This analysis was undertaken to examine the significance of the particulate fraction as a source of heavy metals.

The distribution of heavy metals in the crude samples are presented as the percent of the total pollutant mass associated with the particulate and soluble phase.

Several factors affected the results of the crude heavy metal analysis:

1. The results of two samples for the Cu and Al analysis showed a greater mass of heavy metal associated with the particulate phase than the total sample mass. This indicated that the methodology may require adjustment for future use or that the techniques were not sensitive enough for the analysis. The methodology/analytical procedures were however followed strictly in the research programme and the maximum possible mass for digestion was used to minimise error due to small sample mass and thorough mixing of the liquor sample (for the digestion of the total metal) was practised.

2. Two of the results for Pb were also found to be below the detection limits of the test. These results are therefore not included in Table 7.27.

3. Due to sample error, a full set of crude results for site D2 was not obtained.

Due to the factors discussed above, the number of sites contributing to the mean DWF results for the crude heavy metals vary. No results are available for Zn due to low solid mass available for digestion and/or levels being less than the detection limits of the analytical techniques.

Heavy metals are generally regarded as being associated with particulate matter. The results (summarised in Table 7.27.) indicate that Mn and Pb follow this pattern, with a closer distribution between the soluble and particulate phase identified for Cu, Al and Hg. In contrast, Fe was found to be mainly associated with the soluble phase (68%).

Heavy metal	No. of sites	Flow conditions : DWF	
		% particulate	% soluble
Al	2		
Mean		45.4	54.6
Range		(23.2-67.6)	(32.4-76.8)
Cu	1	44.5	55.5
Fe	3		
Mean		31.7	68.3
Range		(16.1-53.2)	(46.8-83.9)
Hg	3		
Mean		54.7	45.3
Range		(17.7-95.0)	(5.0-82.3)
Mn	2		
Mean		73.5	26.5
Range		(67.1-80.0)	(20.0-33.0)
Pb	1	73.6	26.4

Table 7.27. Distribution of heavy metals in the particulate and soluble phase of the crude samples (DWF conditions).

7.5.3. DISTRIBUTION OF HEAVY METALS IN THE FLOATER, RESIDUE AND SINKER GROUPINGS

The distribution of heavy metals associated with the three broad settling column groupings was initially examined to identify any trends in the distribution. For comparative purposes, the results are expressed as a proportion of the total sample heavy metal per kg dry total solids.

A comparison of the distribution of heavy metals across the three broad settling column groupings are shown in Figure 7.49.

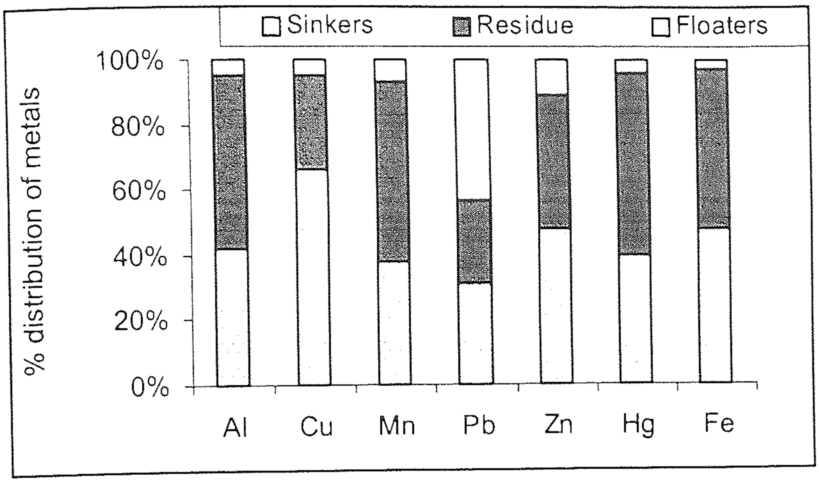


Figure 7.49. Distribution of metals in the three broad settling column groupings.

The peak of heavy metal mass was found to occur in the sinkers for Zn and Cu and with the residue for Al, Mn and Hg . A close distribution of metal mass between the residue and sinkers was found for Fe. Pb was found to be mainly associated with the floater fraction. The results indicate that the association of metals with the settling column groupings varies depending on the metal of interest.

7.5.4. DISTRIBUTION OF HEAVY METALS IN THE FIVE SINKER FRACTIONS

To further investigate the distribution of heavy metal mass in the sinker fraction, this fraction was separated into five sub fractions based on the settling velocity ranges: 0.18-0.45, 0.45-0.90, 0.90-2.70, 2.70-9.03, >9.03 mm/sec (in accordance with the methodology in section 6.4). The mean distributions of Al, Cu, Fe, Pb, Mn, Hg and Zn associated with the five sinker fractions are reported from four DWF events (given in Figures 7.50 to 7.56.) and show that:

- The distributions for Pb, Zn, Hg, Fe, Al, Mn are all fairly similar and peak in the settling velocity range 0.45-0.9mm/sec.
- Cu showed a noticeable peak with solids that have settling velocities >9.03mm/sec.

Similarities in sinker mass were also noted between some of the metals:

- The Al, Fe and Zn total sinker mass ranged from 2.7-5.8g/kg.
- The Cu and Mn total sinker mass ranged from 0.25-0.31g/kg.
- The Hg and Pb total sinker mass ranged from 0.02-0.2g/kg.

7.5.5. EFFECT OF CATCHMENT SIZE ON THE DISTRIBUTION OF HEAVY METALS

The samples analysed for heavy metals were from two large and two medium catchments. Due to the size of this data set, any conclusions drawn are tentative.

7.5.5.1. The effect of catchment size on the distribution of heavy metals in the particulate and soluble phase of the crude samples.

Results for Cu, Mn and Pb were only available for the medium sites, therefore the effect of catchment size on the distribution of these metals could not be determined. The results for Al, Hg and Fe are tabulated in Appendix E and show that catchment size did appear to affect the distribution of Hg and Al and that the distribution of Fe was found to be unaffected.

7.5.5.2. The effect of catchment size on the distribution of heavy metals in the three broad settling column test groupings.

The results are presented in Appendix E. No comparison between catchment size for Al, Pb and Hg are available due to incomplete data sets for the medium catchment results. This was due to low solid mass available for digestion and/or the metals being present in undetectable levels.

In general a peak of mass was found to be associated with the sinker group, regardless of catchment size, for Cu, Fe and Zn. Mn, however, showed a peak of mass in the residue for the large sites.

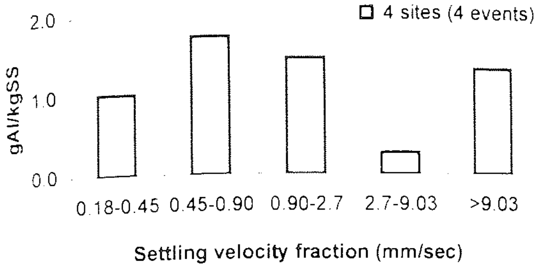


Figure 7.50. Distribution of Al associated with SS (DWF conditions)

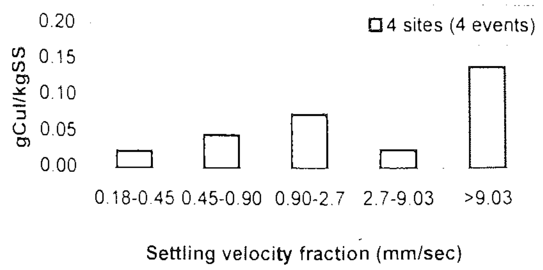


Figure 7.51. Distribution of Cu associated with SS (DWF conditions)

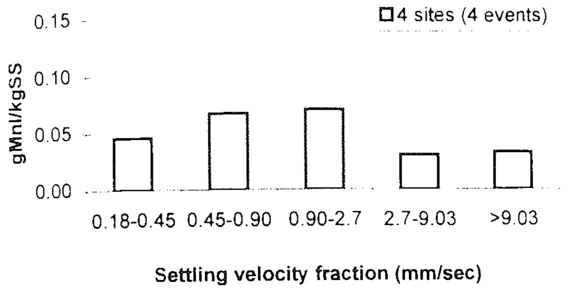


Figure 7.52. Distribution of Mn associated with SS (DWF conditions)

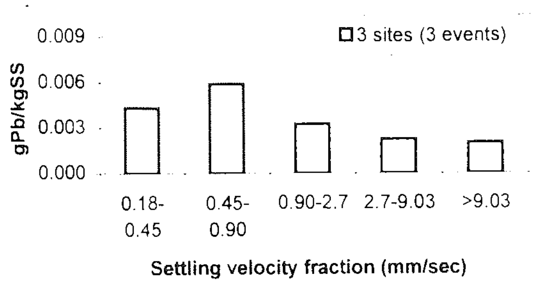


Figure 7.53. Distribution of Pb associated with SS (DWF conditions)

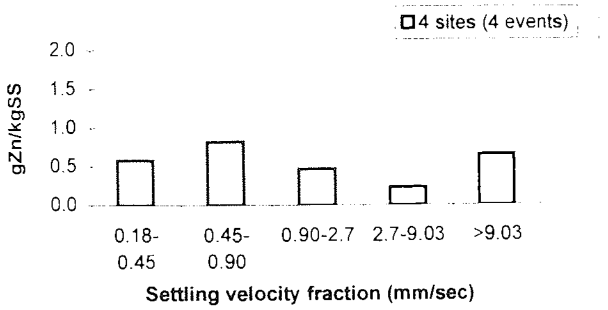


Figure 7.54. Distribution of Zn associated with SS (DWF conditions)

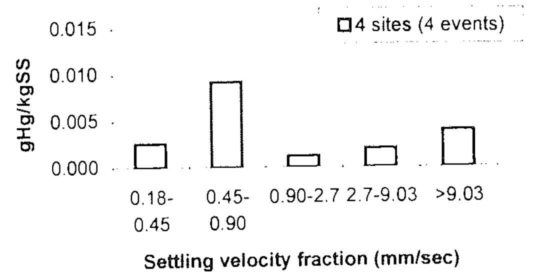


Figure 7.55. Distribution of Hg associated with SS (DWF conditions)

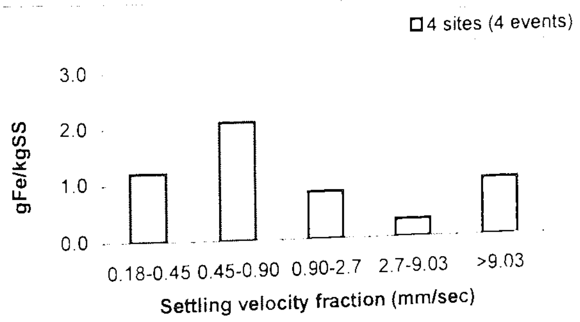


Figure 7.56. Distribution of Fe associated with SS (DWF conditions)

7.5.5.3. The effect of catchment size on the distribution of heavy metals in the five sinker fractions

The results of the effect of catchment size on the distributions of Al, Cu, Fe, Pb, Mn, Hg and Zn in the five sinker fractions are shown in Appendix E.

The large sites in general did not show any specific distributions of metal mass. There was a tendency however for the medium sites to show a peak of metal mass associated within the settling velocity range 0.45-9.00mm/sec.

7.5.6. EFFECT OF CATCHMENT TYPE ON THE DISTRIBUTION OF HEAVY METALS

The effect of catchment type on the association of heavy metals and solids was investigated. The sites analysed for heavy metals were classified as dom/ind (2) and domestic (2) catchments. No dom/agric sites were sampled for heavy metals. Due to the size of the data set only general observations can be made from the results.

7.5.6.1. The effect of catchment type on the distribution of heavy metals in the particulate and soluble phase of the crude samples

Catchment type did not appear to affect the distribution of Mn, Hg or Fe identified in section 7.5.2.. The distribution of Al was however affected. In section 7.5.2. Al was found to be mainly associated with the soluble phase of the crude samples (55%). The dom/ind catchments were also found to contain most of the mass (77%) in this phase, whereas the domestic catchments were found to contain most of the mass in the particulate phase (68%).

Results for Cu and Pb were only available for the dom/ind catchments therefore the effect of catchment type on the distribution of these metals could not be determined.

7.5.6.2. The effect of catchment type on the distribution of heavy metals in the three broad settling column test groupings

The results for the effect of catchment type on the distribution of Al, Cu, Fe, Pb, Mn, Hg and Zn in the three broad settling column groupings are shown in Appendix E.

The dom/ind sites showed a general peak of metal mass associated with the sinker fraction. The domestic catchments were found to show a peak mass associated with the residue fraction for Al, Hg and Zn, whereas Cu, Fe and Mn were found to peak with the sinkers. No complete distributions were available for Pb due to the reasons stated at the beginning of section 7.5.

7.5.6.3. The effect of catchment type on the distribution of heavy metals in the five sinker fractions

The results for the effect of catchment type on the distribution of Al, Cu, Fe, Pb, Mn, Hg and Zn in the three broad settling column groupings are shown in Appendix E.

The dom/ind catchments showed a general peak of metal mass within the settling velocity range 0.45-2.7.mm/sec. No specific distribution of metal mass was reported for the domestic catchments.

7.5.7. SUMMARY OF HEAVY METAL RESULTS

The association of heavy metals with the settleable solids in wastewater was found to be dependent on the metal of concern and catchment characteristics.

7.6. THE ASSOCIATION OF CHEMICAL CONSTITUENTS WITH SEWAGE SETTLING VELOCITY FRACTIONS

The analysis of the settling velocity profile and associated COD, P, TKN and heavy metals has been undertaken in several stages. Relationships between the solids and associated COD, P, TKN and heavy metals in three broad settling column fractions and the five sinker fractions have been identified. Patterns visible in bar charts indicate that COD, P, TKN and heavy metals appear to be associated with solids of certain settling velocities. Catchment characteristics (eg. catchment size, type, and flow conditions) have also been found to affect the relationships identified. The extent of the effect of catchment characteristics however has been found to vary between chemical constituents.

The results are discussed further in Chapter 8 together with their implications for engineering design in Chapter 9.

CHAPTER 8

GENERAL DISCUSSION

8.1. INTRODUCTION

After completing the development of a methodology for determining the association of pollutants and suspended solids, and the analysis of the results, it is now appropriate to discuss the success of the research in meeting the objectives set at the start of the project. These objectives were:

- To identify a simple method of determining the chemical characteristics of sewage solids associated with the various settling velocity fractions that comprise a settling velocity profile.

- To analyse the chemical characteristics of sewage samples from a variety of catchments to determine the settling velocity fractions with which individual chemical parameters are associated.

- To examine the potential for using settling velocity profiles in optimising the design of gravity, or assisted gravity, separation devices for the removal of specific quality parameters.

The work reported in the thesis demonstrates that these objectives were satisfied. A description of how Objectives 1 and 2 were met are described in this Chapter and Objective 3, the application of the research, is discussed in Chapter 9.

8.2. PROJECT DESIGN

8.2.1. SAMPLE PROGRAMME

The sampling programme was undertaken over a period of 16 months. To examine the repeatability of determining wastewater settling velocity and associated chemical constituent profiles, it was necessary to sample each site at least twice, if possible, under the same flow conditions (eg. DWF or storm). The test methodology involved two aspects:

- a settling column test to produce the settling velocity profile, and

- the determination of the chemical characteristics of sewage solids associated with the various settling velocity fractions that comprise a settling velocity profile.

The settling column test adopted had been developed and tested by Tyack (1996), and took approximately two days for each wastewater sample. The method for determining the chemical characteristics of sewage solids associated with the various settling velocity fractions that comprise a settling velocity profile was developed in the research programme and is detailed in Appendix A. This procedure took approximately seven days for each wastewater sample. The method developed was successfully implemented during the sample programme. However, limitations associated with the test were identified during the programme and are discussed in Section 8.2.2.

Fifteen sites and thirty one events were sampled in the research programme. Four sites were sampled once, seven sites were sampled twice, three sites were sampled three times and one site was sampled four times.

Given the time required for sample collection and analysis, the sampling programme was successfully carried out in the time available and provided a representative range of sites to enable the effect of catchment characteristics on SVP to be investigated. Of the 15 sites sampled, the number of sites within each catchment type ranged from 4-6. An important aspect of the research was to sample each site at least twice, if possible, however there was a practicable restriction on the number of sites within each catchment type that could be investigated. In section 9.5.2. it is recommended that further work in this area is carried out to verify the relationships for catchment characteristics identified in this research. The relationships identified for those samples collected under storm (or high flows) are tentative. This is due both to the small data set for storm conditions as the majority of samples were collected under DWF conditions, and the storm flows being close to the DWF criteria (eg. < 3DWF).

8.2.2. THE TEST METHOD

During the research programme, limitations associated with the methodology were identified. These limitations are discussed below.

1. The analytical methods employed (HACH test kits) were found not to be sensitive enough for the detection of heavy metals in the wastewater samples. Late in the programme funds were made available by the project sponsors to send wastewater samples from five wastewater events to Clayton Environmental for analysis by higher specification equipment.

2. The solids collected in the settling column fractions were retrieved by centrifuge, drying and weighing prior to digestion for the determination of the heavy metals associated with the solids. The results of the analysis from Clayton's laboratories for the heavy metals associated with the solids in the crude wastewater samples, showed that for Cu and Al the particulate metal mass was greater than the total metal mass.

   The total metal mass was determined by digesting a known volume of the liquor sample. The discrepancy between the particulate and total metal results may be attributable to the low mass of solids available for digestion and/or working close to the limits of detection of the analytical techniques. This suggests that the methodology for determination of the heavy metals may need to be refined or may be beyond the capacity of the techniques available at the current time.

3. The floater, residue and sinkers with settling velocities in the range 0.18-0.45mm/sec were characterised by light and fine solids. The solids retrieved for these settling velocity fractions were found to form a very fine layer after drying, which proved difficult to remove from the drying receptacle. Resuspension of the solids also did not enable all the dried solid mass to be extracted for digestion. For these fractions, the solids mass was therefore occasionally found to be quite low (<0.01g). This was a characteristic particularly noted for the samples collected under storm flow conditions.

Future methods may therefore need to incorporate a method of solid retrieval, drying and weighing that maximises the solid mass available for digestion.

Although there are certain areas, identified above, that require improvement, overall the methodology developed and used in the study was found to be suitable for the research programme. The main limitation in the methodology was the feasibility of detecting heavy metals. As described above this was due to the analytical techniques employed not being sensitive enough to detect the heavy metals of concern or that the metals were not present in the wastewater samples.

The repeatability of carrying out settling velocity and associated chemical constituents profiles tests was also examined. The ANOVA statistic was applied to the settling velocity and chemical constituents profiles determined for different sampling events, under the same flow conditions, for each site. The results of the ANOVA indicated that for both settling velocity and chemical constituents, the profiles were not significantly different at a level of 5% significance. This demonstrates that there was a satisfactory degree of repeatability.

One of the objectives of the study was to develop a simple method of determining the chemical constituents associated with sewage settling velocity profiles that could be easily used. This aim was achieved using readily available analytical equipment and a methodology was developed, that with practice and careful use, can be easily employed.

8.3. FACTORS AFFECTING ANALYSIS

This section considers the factors that may have had an influence on the outcome of the analysis of the results.

8.3.1. SAMPLE ANALYSIS

Various limitations have been identified in the sample analysis that may have had an influence on the results:

A. two settling columns were employed;
B. limits of detection;

C. finance/time and

D. inadequate sample size.

A. Two Settling Columns

As discussed in section 5.2.1. it was necessary to use two columns in the methodology; one for the determination of the settling velocity profile and one for the determination of the associated chemical constituents. Comparability test were carried out (see section 5.2.2.) which indicated that the SVPs obtained from the two columns were comparable, however there is a possibility that there was a degree of difference in the grading curves. The COD mass was also found occasionally to be greater than the SS mass (see section 7.1.2.).

A new methodology therefore may need to be developed to overcome the weaknesses described above. A methodology that would allow the use of one column would be ideal. However, this would require a method of solids determination that would not require the use of the whole settling velocity fraction (eg. laser technology), so that it would also enable a range of chemical constituents to be determined from the same fractions. It may also lead to a larger diameter column being required, this would decrease the ease of use of the column as the increased sample volume would make it heavier. It must also be noted that at the commencement of the research programme (and to date) no methodologies had been published for the chemical characterisation of solids using settling column techniques. Therefore no alternative methods were available for consideration.

B. Limits of Detection

The detection of the heavy metals was frequently found to be below the limits of detection of the test kits employed (see section 5.3.3.1.). This suggests that the use of more sophisticated analysis would be required for future work, however, this would be more expensive. Alternatively, the findings may indicate that the levels of metals in wastewater are so low that they are insignificant regarding removal. This hypothesis would have to be explored using sophisticated analysis, and if again the metals could not be detected, further thought would have to be given to the investigation of heavy metals associated with solids employing settling velocity techniques and the importance of metal removal by sedimentation devices.

C. Finance/time

The finances available for the research required an economic method for the determination of chemical constituents associated with settling velocity fractions to be developed. Test kits were therefore employed as cost effective techniques (see section 5.3.2.). The drawback of these kits however were that the sample analysis took a long time (Section 8.2.1.). Although the sub samples for the determination of the soluble and total chemical constituents were required to be preserved (see section 5.3.4.), the chemical constituents (eg. TKN and heavy metals) associated with the solids could not be determined until the solid material was retrieved (after centrifuge, drying and weighing). The time lapsed between the collection of the settling velocity fraction to the determination of the chemical analysis, may have led to a slight deterioration in the chemical constituents to be analysed. However, this was not considered to have a significant effect on the data collected.

D. Inadequate Sample Size

In the methodology developed, approximately 800ml was available in the settling velocity fraction for the determination of the chemical constituents associated with the particulate phase. The particulate mass retrieved in the samples collected under storm flow conditions, was generally found to be low (eg. <0.01g), particularly for the lighter settling velocity fractions, and was not adequate for digestion (see section 5.3.3.2.). This resulted in some cases for data on the chemical constituents selected associated with the full settling velocity fraction range (eg floaters, residue and sinker fractions) being unavailable for such samples. If the sample size was increased (eg. to at least 1000ml) this would provide the opportunity for a greater solid mass to be collected and may enable data to be collected for the full settling velocity range.

The settling velocity fraction sample size also restricted the range of chemical constituents that could be determined when employing the test kits (see section.5.3.3.2.).

8.3.2. CATCHMENT DATA COLLECTION.

The catchment data used in the project was collected from privatised water companies by Whithams (1993). Catchment information (eg. DWF, catchment type and population) was also collected from the individual WWTW when the wastewater samples were collected. Where this information was provided, it was found generally to agree with the data collected by Whithams.

8.3.3. STATISTICS

Due to the small data sets descriptive statistics were the main approach employed in the analysis of the results. A chi - squared test, at a level of 5% significance, was also carried out on the mean pollutant SVP and SS SVP (shown in Figures 9.4 - 9.19) to determine the effect of catchment characteristics on the mean sinker profiles. The SVPs obtained for different catchment size, type and storm conditions (defined as flows > 3DWF) were compared against mean DWF SVP conditions. The results showed that the distribution of P and SS under storm flow conditions were found to be significantly different from these obtained under DWF conditions (see Appendix D). As the results for the storm conditions are from a small number of sites, further work is required in this area to determine whether these distributions are typical.

Many of the results are considered to be tentative due to the small data set (in particular the heavy metal results) and a more in depth study is therefore required to obtain more data to confirm the findings. If the results are to be used for sewer models and settlement devices (see section 9.2.), more data is also needed. Interested parties for such research may be universities, research organisation or wastewater engineering companies that are currently active in the development or refinement of existing devices and models.

The data collected in this study was mainly from DWF events and the storm events sampled were only just over 3 DWF. More work is therefore required on the characterisation of chemical constituents associated with solids in storm events.

8.3.4. PRESENTATION OF RESULTS

The results were presented in this research as mass of pollutant per kg dry total solids. This style of presentation was selected as it is compatible with other researchers (see section.7.1.2.). The distribution of results, however, gives a false impression of the distribution in the grading curve since the fractions are not of equal width (Figure 7.2.). It was not considered realistic to use mass of pollutant per kg dry total solids per 0.1mm/sec settling velocity as the tails to the distribution (eg. floaters and solids with v_s >9.03mm/sec) would be lost. Without the tails a complete distribution of pollutants in the wastewater sample cannot be presented. The only remaining option, therefore, is to use the grading curve of pollutant distribution as used for the distribution of solids. This has the advantage that the distribution can be used for design purposes. An example of the application of such a distribution is given in Section 9.1.2.

8.4. RESULTS OF ANALYSIS

A summary of the findings of the research are described below and where applicable comparison is made with other research in the field. There is however limited data in this field and it must be noted that, as described in section 2.4., due to the differences in the methodologies currently employed for characterising sewer solids any comparison between such research (eg. Chebbo and Bachoc, 1992; Michelbach and Wöhrle, 1992a and 1992b; Pisano, 1996) can only be tentative as no uniform procedure is employed. The findings of Tyack's research (Tyack, 1996), however, can be directly related to this research as the same settling column technique (eg. the Aston column) was used in both projects.

8.4.1. DISTRIBUTION OF SOLIDS

The distribution of solids in the three main settling column fractions (floaters, residue and sinkers) showed that the sinker fraction generally contained the highest proportion of SS mass regardless of flow conditions, catchment size or type. Tyack (1996) also found that the peak mass of solids in wastewater settling column fractions were associated with the sinkers regardless of catchment characteristics. Exceptions to the distribution identified in this research were reported for samples collected during storm flow conditions (from the large and domestic/industrial catchments) which showed the highest proportion of SS mass in the residue fraction. These results however were representative of a small data set (eg. two sites for each catchment type) and therefore cannot be considered as universally conclusive for such catchments under storm flow conditions.

Wastewater samples collected by Tyack (1992) were classified as DWF (1-6 DWF) and storm (>6 DWF). For the samples collected under DWF conditions Tyack (1992) reports no evidence of a change in the wastewater SVP due to an increase in flow. No conclusions were made by Tyack (1992) on the effect of storm conditions (eg flows > 6 DWF) on the distribution of solids in wastewater as only 1 sample was collected under such conditions.

The floater fraction was found to contain the lowest proportion of SS mass regardless of flow conditions, catchment size or type. This was also reported by Tyack (1996). Exceptions to this again occurred with samples taken during storm flow conditions (from the medium and dom/agric catchments) that showed the lowest proportion of SS mass in the residue. These results again cannot be considered as a conclusive representation of such catchments due to the small number of sites sampled (eg. two medium and one dom/agric catchment).

The results above suggest that the settling velocity characterisation of solids found within samples collected during storm flow conditions is more varied than those collected under DWF conditions. Chebbo and Bachoc (1992) and Pisano (1996) also report that there is a greater variation in wastewater solids collected during storm events.

The distribution of solids across the five sinker fractions showed that regardless of flow conditions, catchment size or type, the peak mass of SS was found to be associated with solids that had settling velocities in the range 0.9-9.03mm/sec. The results of the storm samples in general, however, must be treated with caution due to the small number of sites sampled under these conditions (eg. five). Examination of the SVP data presented by Tyack (1996) also shows that, in general, a peak of solids was found within the v_s range 0.9-9.03mm/sec.

The settling velocity profiles determined were found to fall within a general envelope (see Figure 7.9.) regardless of flow conditions, catchment type and size. This suggests that the wastewater profiles are unaffected by the characteristics of the contributing catchment , and agrees with the results reported by Tyack (1996).

In Figure 8.1 the SVP produced in this research are overlayed onto the envelope produced by Tyack (1996) and show that they fall within a similar range. SVPs produced by Michelbach and Wöhrle (1992a) for DWF and combined sewer overflow samples also show similar profiles. These profiles are presented in Section 2.5, Figures 2.3 and 2.4.

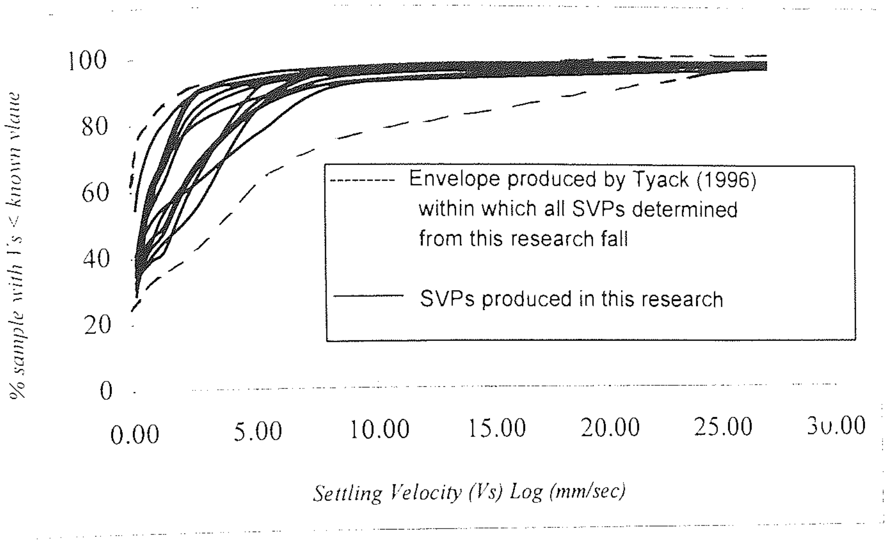


Figure 8.1. Comparison of the SVPs produced in this research with Tyack's (1996).

A comparison between the v_s with which 50% of the solids were found to be associated by the different research groups mentioned above is shown in Table 2.8. In this research on average 50% of the solids were found to be associated with v_s <1.00mm/sec, this is higher than those reported by Tyack (1996) eg. <0.5mm/sec. Tyack's results are also similar to those reported by Pisano (1996) for DWF conditions eg. 0.45mm/sec. The profiles produced by Michelbach and Wöhrle (1992a) report a much higher settling velocity range: v_s <4mm/sec for CSO and <3.5mm/sec under DWF conditions.

The higher v_s reported by Michelbach and Wöhrle (1992a) is probably due to the settling column procedure they used with the UFT device. As mentioned in Section 2.4., this methodology does not consider the whole wastewater sample as the residue is excluded. Due to this the SVPs determined by Michelbach and Wöhrle (1992a) will be spread over a greater range of the vertical axis of the SVP graph (eg. 100%) than those determined from the Aston column where 100% includes the residue and floaters, which in themselves contribute approximately 30%. The SVPs from the UFT device will therefore tend to have a greater distribution of solids associated with v_s values than those determined by the Aston column. A direct comparison cannot therefore be made between the SVPs determined by these two methodologies.

Chebbo and Bachoc (1992) provide data on the characterisation of solids collected under storm conditions for CSOs. Their data is summarised in Table 2.8. and shows that mean settling velocities for CSO conditions were found to be 2.3mm/sec. However, these results again cannot be directly compared to those obtained in this research as they represent solids collected further upstream in the sewer network and during storm events. A different settling column technique is also employed by Chebbo and Bachoc (1992) in which solids are separated by sieving prior to analysis. This in itself is likely to affect the true distribution of solids in the sample due to disaggregation of the solids by the sieving process. Due to these differences in the technique employed by Chebbo and Bachoc (1992) from the Aston method, the results obtained from the two methods cannot be directly compared.

8.4.2. DISTRIBUTION OF POLLUTANTS

8.4.2.1. Crude samples.

COD and P were found to be predominantly associated with the particulate phase of crude wastewater samples (63% - 66%) whilst TKN was found to be predominantly associated with the soluble phase (89% - 91%). The distributions were generally found to be unaffected by flow conditions and catchment characteristics. The association of COD and P with the particulate phase is typical for COD and P, as they are generally considered to be associated with organic particles. Michelbach and Wöhrle (1993b) and Chebbo and Bachoc (1992) also report that COD is primarily associated with the particulate fraction of wastewater (67% and 83-92% respectively). It is also acknowledged that nitrogen is generally present in the soluble phase.

Hg, Mn and Pb were found to be predominantly associated with the particulate phase of crude wastewater samples and Al, Cu and Fe were found to be predominantly associated with the soluble phase of crude wastewater. Heavy metals are generally considered to be associated with particulate matter (CIRIA, 1994, Morrison et al., 1990, Roberts et al, 1988 and Xanthopoulos and Augustin, 1992) and the results show that 3 of the metals determined follow this pattern. Due to the size of the data set, no conclusions could be made on the effect of flow conditions and catchment characteristics on these distributions.

8.4.2.2. Three broad settling column groupings

The distribution of COD, P, TKN, Cu and Zn showed a general trend of increasing mass from the floater to the sinker groupings under DWF conditions (as shown in Table 8.1). Al, Fe, Hg and Mn showed a greater mass of pollutant associated with the residue fraction. The distribution of COD and P (the only parameters for which storm flow data were available) was found to be unaffected by flow conditions (compare Table 8.2 with Table 8.1).

Catchment size (note that no results were reported for the effect of catchment size on the distribution of TKN) was not found to affect the distribution of COD and P. Catchment type was found, however, to affect the distribution of TKN and P. Due to the size of the data set for heavy metals, no conclusions can be drawn regarding the effect of catchment size and type on the association of metals with the three broad sewage settling velocity fractions.

It must also be noted that, in addition to the results discussed in detail in Section 7.5, heavy metal analysis was undertaken for the detection of As, Ba, Cd, Cr, Ni, Sb, Se and V in the wastewater samples. These metals however were found to be present in levels below the detection limits of the analytical techniques employed. The heavy metal results reported in this research however cannot be compared with other research in the field as there is no comparable data in literature.

PARAMETER	SETTLING COLUMN GROUPING		
	Floater	Residue	Sinker
COD/P/TKN/Cu	5%-13%	22%-33%	59%-66%
Al/Hg/ Mn/ Fe	3-7%	49-56%	38-48%
Pb	43%	26%	31%
Zn	11%	41%	48%

Table 8.1. Summary of the distribution of chemical constituents in the three broad settling column groupings (DWF conditions)

PARAMETER	SETTLING COLUMN GROUPING		
	Floater	Residue	Sinker
COD/P	8%	33%-43%	48%-60%

Table 8.2. Summary of the distribution of COD and P in the three broad settling column groupings (storm flow conditions).

8.4.2.3. Five sinker fractions

Within the five sinker fractions , COD, P and TKN showed an affinity for solids within the settling velocity range 0.9-9.03mm/sec and this was unaffected by flow conditions and catchment size (note that no results were reported for the effect of catchment size on the distribution of TKN). Catchment type was only found to affect the distribution of TKN. The COD associated with settleable solids for combined sewage was examined by Michelbach and Wöhrle (1993b) who found that 67% of the total COD was associated with the settleable solids. Further examination of the settleable fraction, by a settling column test, indicated that 70% of the COD associated with solids had a v_s >2.8mm/sec. Although their procedure is not directly comparable with that employed in the thesis (see section 8.3.1.), this is within the range identified in this research eg. 0.9-9.03mm/sec.

The affinity of heavy metals for particular settling velocity fractions in the sinker fraction was found to vary between metals and covered the settling velocity range 0.18mm/sec to > 9.03mm/sec. Cu is one of the most common metals found in wastewater and in this research was found to have an affinity for the heavier solids (ie. those with a settling velocity > 9.03mm/sec), indicating that a significant proportion can be removed by physical sedimentation. Al, Fe, Hg, Mn and Zn were also examined and were found to be associated with lighter solids (eg. those in the range 0.45-0.90mm/sec) and may prove more difficult to remove by sedimentation. Due to the size of the data set for heavy metals, no observations can be made regarding the effect of catchment size and type on the association of metals with the five sinker fractions.

Michelbach and Wöhrle (1992b) report that Cu, Pb, Cd, Ni and Zn have an affinity for solids within the settling velocity fraction 4.0mm/sec. As described in section 8.3.1.

Michelbach and Wöhrle (1992b) adopted a different settling column technique to the Aston column, and due to differences in the methodologies, results from these studies cannot be directly compared. However, in general heavy metals were found to be associated with heavier solid fractions by Michelbach and Wöhrle (1992b).

This research has identified that COD, P and TKN have an affinity for solids within the same settling velocity range and that the association of Al, Cu, Fe, Hg, Mn, Pb and Zn with solids is dependent on the metal of interest.

The second objective of the research was to analyse the chemical characteristics of sewage samples from a variety of catchments to determine the settling velocity fractions with which individual chemical parameters are associated. Relationships between COD, P, TKN and heavy metals with wastewater solids have been reported in the thesis and the effect of catchment characteristics are described. This objective has therefore been met, however several factors affecting the analysis (discussed in section 8.3.), such as the limitation in heavy metal results, have been identified.

8.5 APPLICATION OF RESEARCH

Objectives 1 and 2 of the research have been met and were described in the previous sections. Objective 3, the application of the research, is discussed in Chapter 9.

CHAPTER 9

ENGINEERING APPLICATION

This research provides data on the relationships between COD, P, TKN and heavy metals with the settling velocity profile. Previous to this research limited data has been published on such relationships. In order for the findings of this research to be used by engineers and other research groups, an explanation is required. Towards this end, 16 profiles for pollutant and settling velocity profiles are presented in Section 9.1.

In this chapter the potential for using wastewater characteristics is discussed in terms of optimising the design of separation devices for the removal of specific quality parameters and the application to wastewater/water quality modelling.

9.1. SEDIMENTATION DEVICES

As described in Section 4.1. the design of sedimentation devices is based on design criteria developed in the early 1900s that have limitations, such as the assumption of ideal sedimentation.

Wastewater characterisation, using settling velocity, could be used to gauge the performance of such devices. If a client specifies a removal rate for solids and/or pollutants the SVP and the associated pollutant load of the wastewater to be treated could be determined. This would provide information on the settling velocity threshold required to meet the pre- determined removal rate. The sedimentation device could then be modified to accommodate the requirements to optimise the pollutant/SS removal in order to meet the specified removal rate.

9.1.1. LIMITATIONS ASSOCIATED WITH SETTLING VELOCITY PROFILES

Before considering the application of settling velocity measurement to the design of sedimentation devices, the limitations of this methodology should be recognised.

Smisson (1990) explored the use of settling velocity and reported that there are two main limitations in its use:

1. the boundaries associated with using settling velocity have to be identified, in particular, the lower limit of settlement;

2. the effect of the characteristics of the wastewater to be treated on the shape of the SVP has also to be considered.

In the sedimentation process, colloidal and semi colloidal material is not generally removed. Smisson (1990) estimated that in current wastewater treatment facilities, the lower limit for sedimentation is the settling velocity 1.00mm/sec, and thus only solids with a settling velocity in excess of this will be removed. This implies that only chemical constituents associated with solids having a settling velocity >1.00mm/sec will be removed by sedimentation devices.

The shape of the SVP will also affect the efficiency of sedimentation devices. If in a wastewater sample there is more material at the coarse end of the settling velocity range, then the sedimentation process will be more effective than if the majority of the material is at the fine end. Two parameters which might be used to assist in defining the settleability of a sewage are:

- the median settling velocity and
- the spread of the settling velocity profile.

The median settling velocity represents the proportion of solids that are associated with 50% of the settleable solids in the full grading curve. If the results are to be applied to wastewater modelling, a standard value, such as this, may be required to represent the wastewater characteristics. The application of wastewater characterisation using settling velocity in modelling is discussed further in section 9.2.

Uniformity coefficients are generally used to analyse particle size distributions in soil mechanics and sediment transport, and were used by Tyack (1996) to investigate the gradient of the middle portion of the S-shaped SVP. The coefficient is a measure of the gradient and hence an indication of the uniformity of the settling velocity distribution plotted on a logarithmic scale. The use of a coefficient of v_s80/v_s60 would compare two points on the rising end of the SVP and examines the proportion of solids in the sample with a v_s less than 80% and less than 60% (see Figure 9.1.). If the coefficient value is small this indicates a significant proportion of solids in the sample between these points as there is not much difference between the two v_s values. However if the coefficient is large this indicates a shallower slope indicating a gradual distribution of solid mass between these two points.

An example of the use of a uniformity coefficient is shown on Figure 9.1. From Figure 9.1 it can be seen that 80% of the solids (v_s80) have a settling velocity < 2.5mm/sec and 60% (v_s60) have a corresponding settling velocity 1.1mm/sec, this gives a uniformity coefficient of 2.2 (v_s80/v_s60). If the solids were distributed over a narrower v_s range then the uniformity coefficient would be smaller.

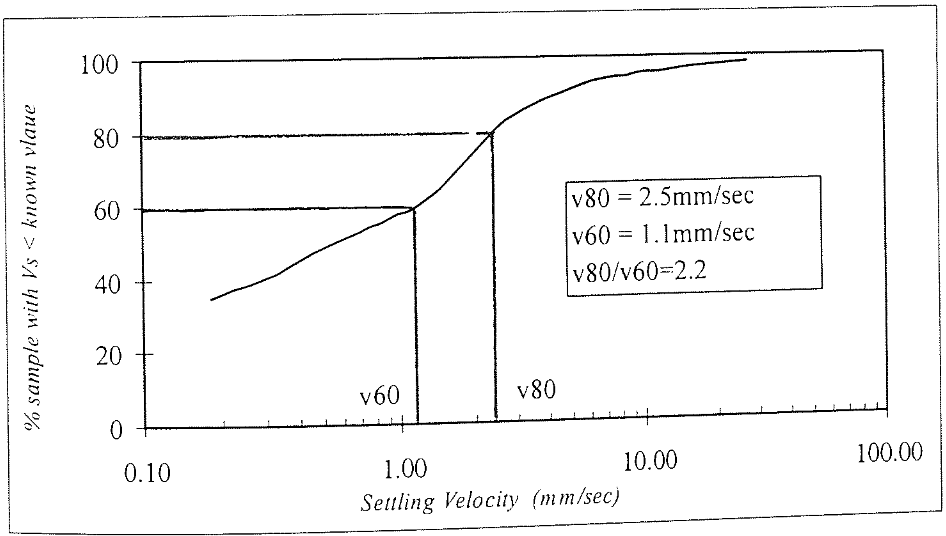


Figure 9.1. Application of an uniformity coefficient to the SVP for Site A (DWF conditions)

The coefficients v_s80 and v_s60 were selected for the wastewater samples investigated in this research as the sloping portion of the SVPs determined consistently fall in this range (see Figure 8.1.). A lower value than v_s60 such as v_s40 would not be appropriate as in some cases the curves fall out with this range.

The above discussion introduces the reader to the potential application of an uniformity coefficient to aid the interpretation of SVPs. This concept is not however discussed in great detail in the thesis and it is an aspect that requires to be explored in greater depth for the full potential of the use of such a coefficient to be realised.

9.1.2. APPLICATION OF POLLUTANT PROFILES

The association of COD and P with the particulate phase of wastewater (eg. 63-66% of the total) indicates that removal of these pollutants by physical sedimentation is particularly appropriate. The removal of TKN however is less realistic due its association with the soluble phase (89-91% of total). The removal of heavy metals by physical sedimentation requires further work before any specific relationships can be identified, but the results provide a guide to what is achievable.

Within the settleable solid fraction (eg. the sinkers) solids with v_s in the range 0.9-9.03mm/sec were identified to have an associated pollutant load for the parameters COD, P and TKN. In Section 8.4.4. it is suggested that the pollutant results are presented as a grading curve (or pollutant profile) for design purposes. The cumulative distribution of solids and associated pollutants are plotted against settling velocity, giving a profile of the distribution of the pollutants in the wastewater. From this profile, an initial assessment of the potential of a sedimentation device to remove such pollutants can be made. This is achieved by selecting the design v_s of the device on the x-axis of the curve and reading off the corresponding proportion of pollutants associated with solids with v_s less than that particular $v_{s,}$ hence the percentage which can be removed is simply 100 less this value.

An example of this is shown on Figures 9.2 and 9.3. The SVP and the associated distribution of COD for Site A are shown in Figure 9.2. with both profiles together on Figure 9.3. If a primary sedimentation device was required to remove 50% of the COD from the wastewater stream, it can be determined from Figure 9.3. that the removal of 50% of the solids corresponds to solids that have a v_s of > 0.8mm/sec. The device would thus have to be sized to enable all particles with v_s of > 0.8mm/sec to be removed.

The results discussed above imply that low settling velocities (eg. 0.8mm/sec) may be required for optimum removal of pollutants associated with 50% of the settleable solids. Due to the lack of information regarding the performance of sedimentation devices, in terms of the settling velocity fractions removed, a comparison between the settling velocities identified in this research for peak of removal of pollutants and those that are currently experienced for devices designed using standard citation is not practicable.

To aid designers and researchers in utilising the results of this research a set of representative mean grading curves for SS, COD, P, TKN, Al, Cu, Fe, Hg, Mn, Pb and Zn are presented in Figures 9.4-9.19. This is the first set of such curves to be published and using the methodology described above, these curves can be used to give an initial indication of the potential removal efficiency of sedimentation devices for pollutants associated with solids.

Figure 9.8. shows that under DWF conditions, TKN, COD and P exhibit similar profiles, indicating that there is the potential for similar design criteria for the removal of these parameters from wastewater by sedimentation.

The heavy metal profiles are all presented on Figure 9.19. Al, Fe, Hg, Mn, Pb and Zn follow a similar distribution, showing a general association with the lighter solids, however the profile for Cu shows a greater association with the heavier solids. The application of these curves is discussed further in Chapter 10.

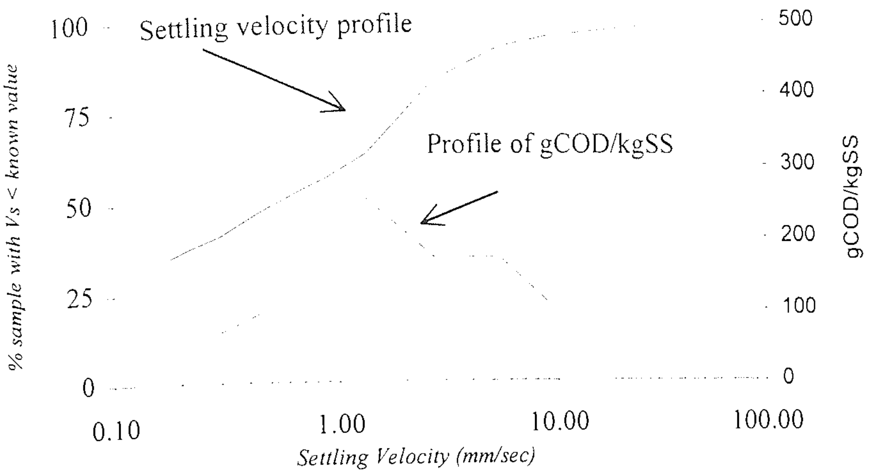


Figure 9.2. Relationship between SVP and COD/SS mass for Site A (DWF conditions)

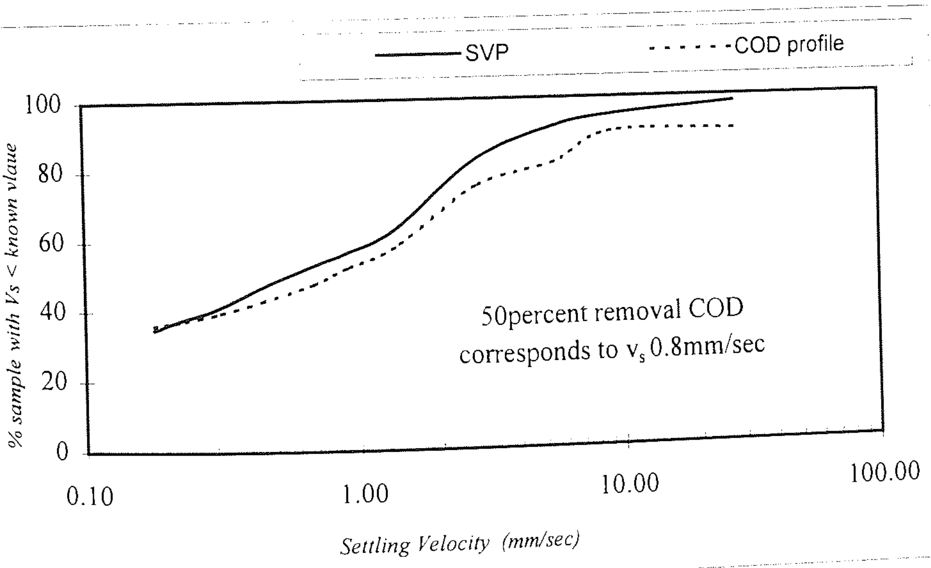


Figure 9.3. Application of COD and SS profiles to the design of sedimentation devices (Site A DWF conditions)

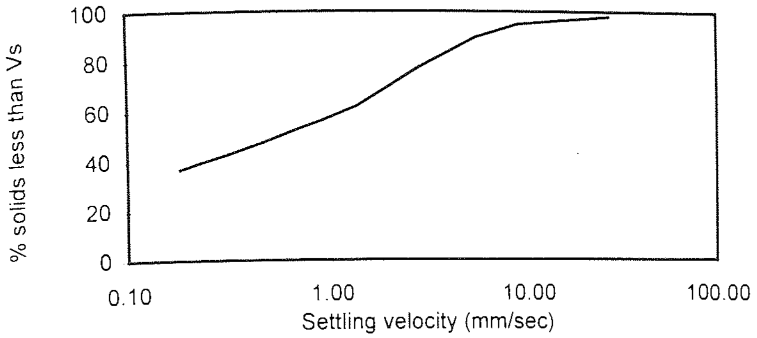


Figure 9.4. Mean settling velocity profile : DWF conditions (14 sites)

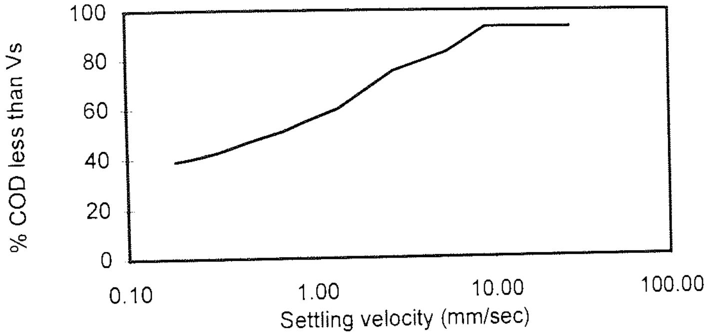


Figure 9.5. Mean COD profile : DWF conditions (15 sites)

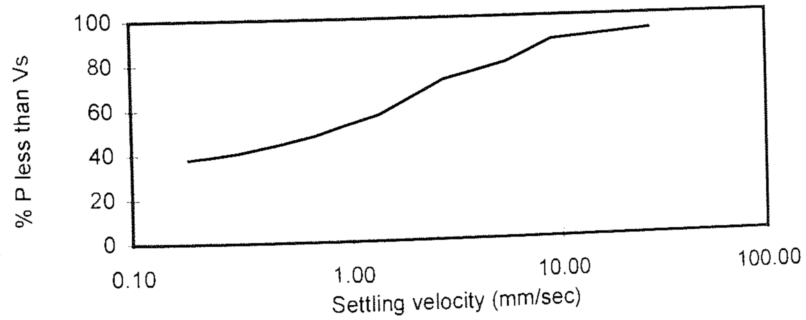


Figure 9.6. Mean P profile : DWF conditions (11 sites)

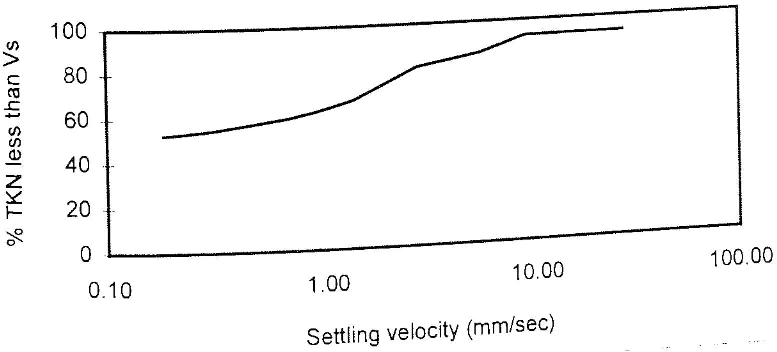


Figure 9.7. Mean TKN profile : DWF conditions (10 sites)

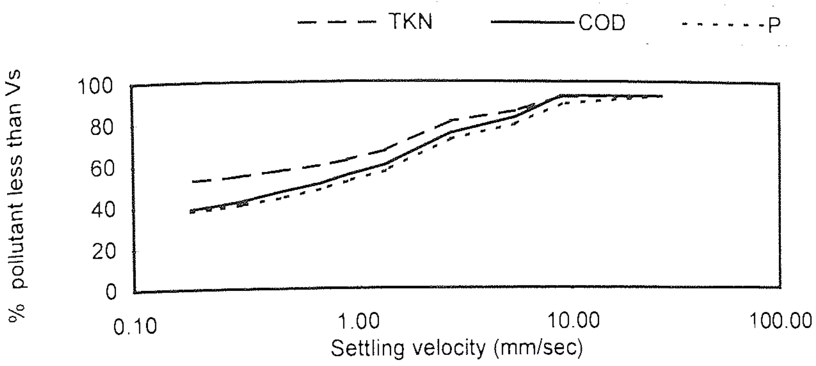


Figure 9.8. Comparison of mean SVP's for TKN, COD and P : DWF conditions

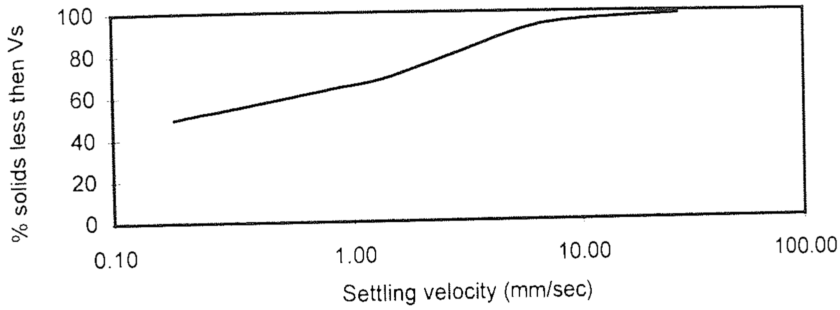


Figure 9.9. Mean settling velocity profile : storm flow conditions (4 sites)

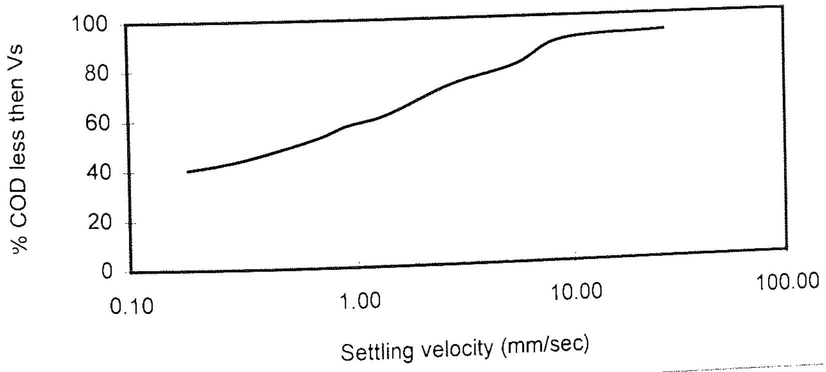


Figure 9.10. Mean COD profile : storm conditions (3 sites)

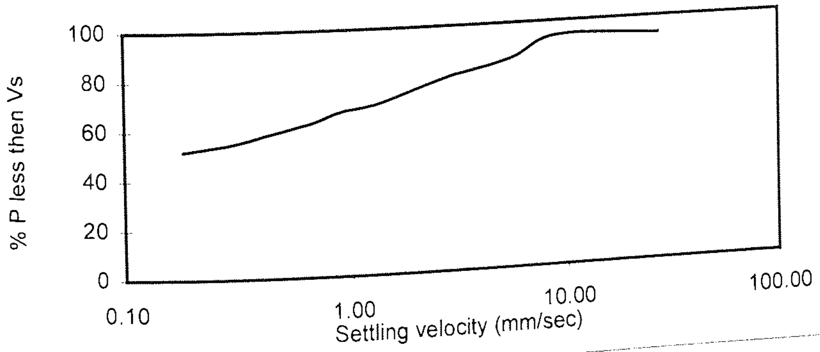


Figure 9.11. Mean P profile : storm conditions (2 sites)

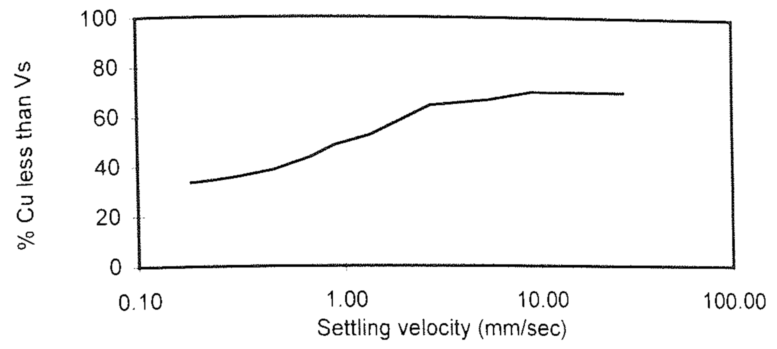


Figure 9.12. Mean Cu profile : DWF conditions (4 sites)

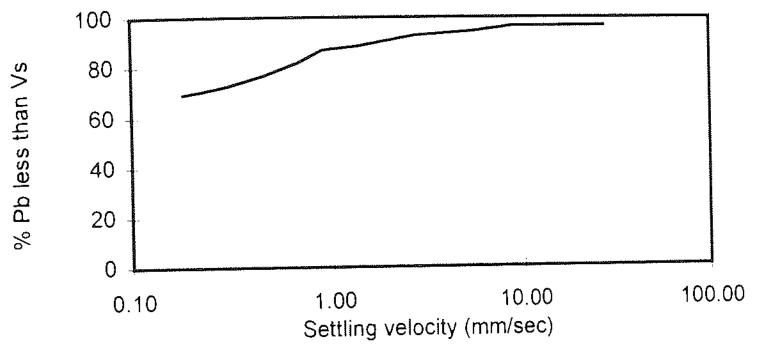


Figure 9.13. Mean Pb profile : DWF conditions (4 sites)

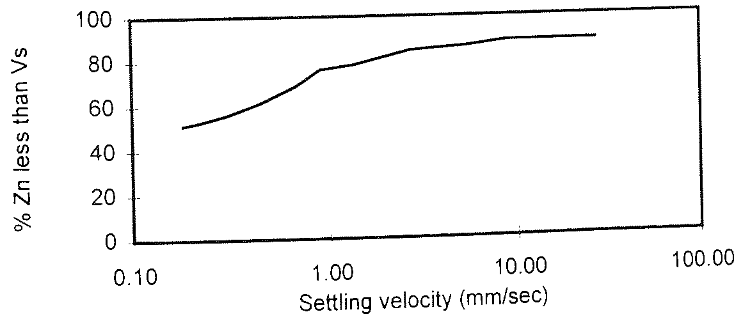


Figure 9.14. Mean Zn profile : DWF conditions (4 sites)

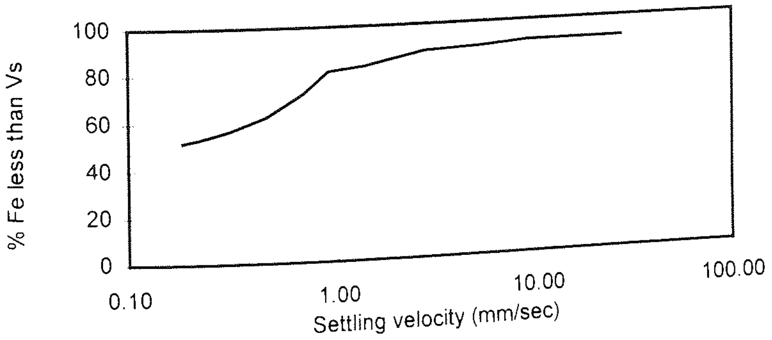


Figure 9.15. Mean Fe profile : DWF conditions (4 sites)

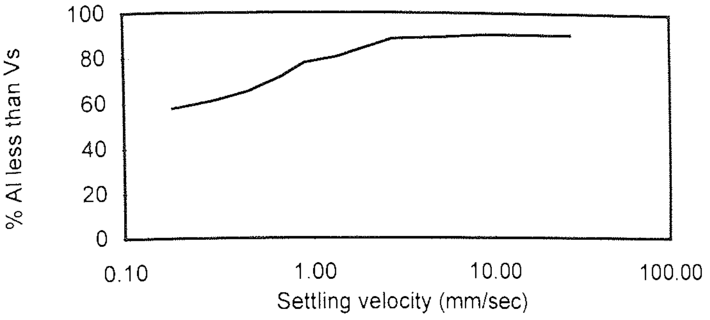


Figure 9.16. Mean Al profile : DWF conditions (4 sites)

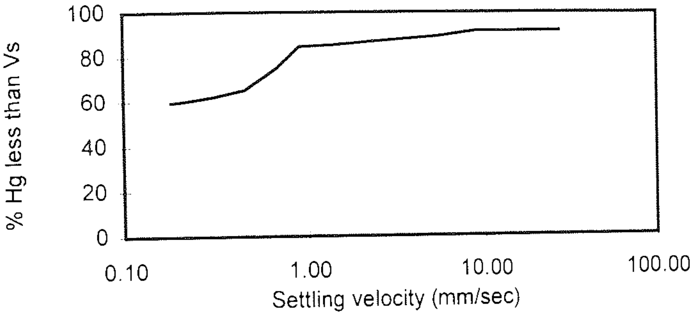


Figure 9.17. Mean Hg profile : DWF conditions (4 sites)

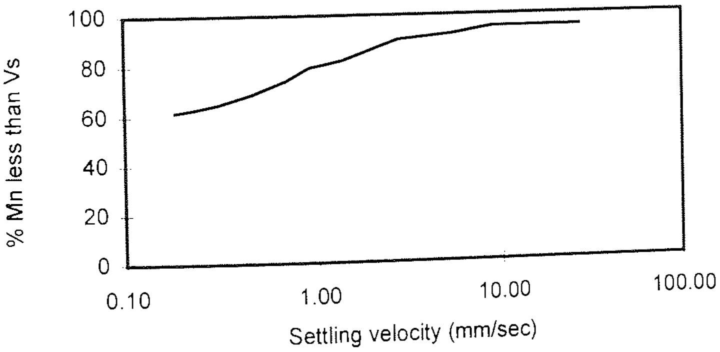


Figure 9.18. Mean Mn profile : DWF conditions (4 sites)

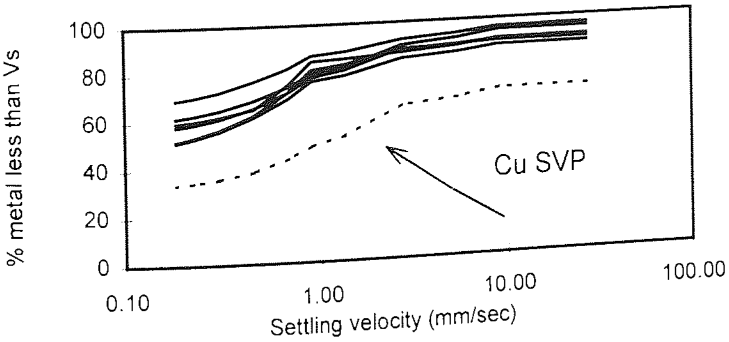


Figure 9.19 Comparison of mean SVP's for heavy metals : DWF conditions

Pollutant	% associated with solids	% associated with solids (sinker fraction) Vs>0.1mm/sec	Mass pollutant per kg dry total solids (g/kg)
COD	63	59	887-2095
P	65	59	22-129
TKN	9	65	9-128
Al	45	42	9-17
Cu	45	66	0.4-0.5
Fe	32	48	6-33
Hg	55	40	0.01-0.12
Mn	74	38	0.5-1.1
Pb	74	31	0.02-0.08
Zn	nd	48	5.5-11.8

Table 9.1. Summary of representative values of pollutants and their association with solids under DWF conditions.

Pollutant	% associated with solids	% associated with solids (eg. sinker fraction) Vs>0.1mm/sec	Mass pollutant/kgSS
COD	64	60	717-1947
P	66	48	26-98

Table 9.2. Summary of representative values of pollutants and their association with solids under storm flow conditions.

The data in Tables 9.1 and 9.2 are a summary of the pollutant load associated with solids in the wastewater samples. Also shown in Tables 9.1 and 9.2 are the proportions associated with the specific sinker fraction. The ranges of the total pollutant/SS mass determined from the wastewater samples are also presented in the Tables. The data presented can be used to give an indication of the pollutant load associated with solids. Using COD as an example, from Table 9.1. it can be seen that 63% of the COD was found to be associated with the solid phase of the wastewater samples. The mass of COD associated with the solids in the sinker fraction ranged from 887-2095g/kg dry total solids and 59% of this solid mass was found to be associated with the sinkers (see Table 9.1). If it is assumed that all of the COD associated with the sinkers is removed (eg. 59%) in a settlement device, using a mass of 887g/kg, this equates to 523g/kg being removed and would represent 37% of the total COD. Such information can be applied to sedimentation devices to determine their potential ability to remove pollutants of concern. It must, however be noted, that as discussed in section 9.1.1., if the lower limit of settlement is 1mm/sec, the device efficiency would be less and the profiles presented in Figures 9.4 to 9.19 used to evaluate their performance.

9.2. WASTEWATER/WATER QUALITY MODELLING

To enable urban pollution management to be carried out effectively, integrated catchment modelling may be required, where the sewer, the WWTW and the receiving water course are modelled. Within such models, there is the potential to apply wastewater characterisation (in the form of settling velocity and associated pollutant loads) to improve the modelling of wastewater solids.

9.2.1. SEWER MODELLING

As mentioned in Section 1.2 settling velocity is a parameter that is used within sewer models (eg. HYDROWORKS, SWMM and MOUSETRAP) to describe sediment transport processes. The output from sewer models may form inputs to WWTWs (eg. STOAT) and river water quality models (eg. MIKE 11).There is however limited knowledge on sediment transport in sewers and in particular sediment characteristics.

In sewer models, such as HYDROWORKS, sewer sediments are modelled by classifying them into sediment fractions (generally fine or coarse), which are characterised by particle size, density and settling velocity. The pollutants attached to the sediments (such as COD, BOD and ammonia) are generally modelled using a potency factor. The potency factor may be related to a decay coefficient, or a conservative assumption may be made that there is no change in the pollutant load attached to that sediment. If further information were available on the characteristics of such sediments, in particular settling velocity and associated pollutant loads, this would provide the opportunity to improve such models. At present, where general assumptions are made about the pollutant potential of sediments (eg. conservative), this could be replaced with specific factors for the distribution of the pollutants associated with solids with a particular settling velocity (eg. heavier solids may have more pollutants than lighter solids) and could be built into the model to provide a more detailed representation of the pollutant loads than is presently provided. The actual factors used could represent a percentage distribution of pollutants associated within a particular settling velocity range, or a mean settling velocity with an associated pollutant load (as suggested in section 9.1.). It is recommended in section 10.5. that this aspect of the research is explored further.

9.2.2. WWTW MODELLING

WWTW models, such as STOAT, represent the main physical and biological processes in a WWTW and are able to simulate performance under varying input conditions. The processes within the works are represented by linking together appropriate modules for each process (eg. storm tanks, primary sedimentation tanks, activated sludge tanks etc.). Determinants modelled include flow, SS, BOD, COD, Ammonia and dissolved oxygen. Models for primary sedimentation tanks have been developed by Lessard and Beck (1988) and are incorporated into STOAT. The main wastewater characteristics used in WWTW models are the flow and pollutant loads.

In section 9.1, 16 profiles are presented for SS, COD, P TKN and heavy metals and the use of these profiles was explained. Such profiles have not been published before and it is suggested that WWTW models, in particular the components for primary sedimentation tanks, could be improved determining the settleability of the wastewater to be treated. Initial studies could employ the data/profiles derived in this research. The use of settling velocity characterisation in WWTW models would enable site specific characteristics to be modelled.

9.2.3. INTEGRATED CATCHMENT MODELLING

In integrated catchment modelling, the output from sewer (eg. CSO spills) and WWTW (eg. effluent discharges and storm spills) models are inputs for water quality models such as MIKE11 and ISIS. Within these water quality models, the settlement, resuspension and transport of pollutant bed and suspended solids can be represented. The sediment particles in river models are generally modelled using standard sediment transport formulae (eg. cohesive or non-cohesive formulae) and as such can be transported, deposited or re-eroded, which is dependent upon the hydraulic characteristics of the channel and the sediment particle characteristics. Pollutants attached to sediments can be modelled by specifying a pollutant concentration per dry weight of sediment (eg. g/kg). From this the polluting effect of a range of polluted sediments can be realistically modelled as sediments are either deposited, eroded or transported through the receiving watercourse. With a more accurate representation of sewer derived sediments, as presented in this research, this would in turn improve input conditions in river water quality models, thereby improving the overall integrated catchment modelling.

The above information on modelling techniques has been derived from "The Urban Pollution Management (UPM) Manual", (Foundation Water Research, 1994). Further information on integrated catchment modelling can be found in Fries (1996), Schütze et al (1996) and Fiddes D. and Clifforde I.T. (1990).

CHAPTER 10
CONCLUSION

The overall aim and objectives of the project, as stated in Section 1.3, have been met. Within this chapter, the success of meeting each objective and recommendations for future work are described.

10.1. TEST METHOD

A methodology (see section 6.4 and Appendix A) has been developed for the determination of COD, P TKN and heavy metals associated with settling velocity profiles (SVP). The method utilises the Aston settling column and from the collection of the wastewater sample to completion of analysis (for the settling velocity and pollutant profiles) takes approximately 7-10 days for each wastewater sample collected. The methodology has been successfully employed in the research and a degree of repeatability has been confirmed.

10.2. THE ASSOCIATION OF CHEMICAL CONSTITUENTS WITH SEWAGE SETTLING VELOCITY FRACTIONS

A sampling programme was undertaken over a period of 16 months. Fifteen sites and thirty one events were sampled in the research programme. Four sites were sampled once, seven sites were sampled twice, three sites were sampled three times and one site was sampled four times. The programme was successfully carried out and provided a representative range of sites to enable the effect of catchment characteristics on SVP to be investigated

COD (63%), P (65%), Hg (55%), Mn (74%) and Pb (74%) were found to be mainly associated with the particulate phase in wastewater and TKN (91%) , Al (55%), Cu (55%) and Fe (68%) with the soluble phase. The association of COD with the particulate phase and TKN with the soluble phase are typical representations for these parameters. Heavy metals are generally considered to be associated with particulate matter and the results confirmed that 3 of the metals determined follow this pattern.

The distribution of COD, P, TKN and heavy metals associated with settling velocity profiles are presented as 16 representative pollutant profiles and a single SS profile (see Figures 9.4 - 9.19). This is the first time such profiles have been reported for settling velocity measurement and are an original contribution to knowledge in this field. In the settling velocity distributions, COD, P and TKN showed a particular affinity for solids with settling velocities in the range 0.9-9.03mm/sec, and this was generally found to be unaffected by catchment characteristics. Data on the distribution of heavy metals was limited and no specific relationships with solids were identified.

Although other research on settling velocity techniques has been carried out (eg. using the Cergrene and UFT columns), due to the different methodologies employed results obtained by the different research groups cannot be directly compared (see section 8.4). The majority of other research also focuses on solids distribution.

10.3 APPLICATION OF SETTLING VELOCITY PROFILES

The application of the characterisation of wastewater using settling velocity and associated pollutants is discussed in Chapter 9. The main areas where this research is applicable are identified as in the design of sedimentation devices, and in modelling of wastewater/water quality. For sedimentation devices, identification of the settleability of the wastewater to be treated and the potential for removing pollutants of concern can be determined from pollutant profiles. It is also suggested that settling velocity characterisation should be an input to models (such as HYDROWORKS and STOAT) to enable the movement of pollutants, particularly those associated with sediments to be simulated more accurately.

10.4. RECOMMENDATIONS FOR FUTURE WORK

Three main areas have been identified that may benefit from further research:

- development of the chemical constituent methodology;
- relationships between wastewater and catchment characteristics, and
- application of the research to the design of sedimentation devices and modelling tools.

10.4.1. DEVELOPMENT OF THE CHEMICAL CONSTITUENT METHODOLOGY

On the basis of the discussions in Chapter 7 and experience in the experimental techniques, the following areas of research are identified as being of potential benefit.

The determination of the heavy metals associated with the wastewater settling velocity fractions (determined in this research by centrifuge, drying, weighing followed by digestion and subsequent chemical analysis) was occasionally found to be either near the lower limits of the analytical techniques or that the heavy metals were not present. To maximise the solid mass used for digestion and subsequent determination of heavy metals, the identification of an alternative method of solid retrieval may be of benefit. Filtration, using acetate filters that can be directly digested, would enable the solid mass retained by filtration to be used in the digestion process. Limiting the range of heavy metals studied to those that are more commonly found in wastewater (eg. zinc and copper) and are important regarding toxicity and pollution potential in receiving waters, may also benefit future research.

10.4.2. RELATIONSHIPS BETWEEN WASTEWATER AND CATCHMENT CHARACTERISTICS.

The effect of catchment type, size and flow conditions on the chemical characteristics of wastewater was investigated in the project.

a. Domestic/industrial, domestic and domestic/agriculture catchments, and small, medium and large catchments were sampled in the research programme. Further work in this area, using different catchments from those sampled, would provide an opportunity for the tentative relationships identified to be verified. This further research would not be costly, as the methodology has already been developed.

b. Further research into the association of heavy metals with settling velocity fractions, together with the effect of catchment characteristics and flow conditions on these associations is required.

c. Of the thirty one samples collected in the research programme, five were sampled during storm flow conditions (>3DWF). The application of the methodology and results from this research to the design of CSOs employing sedimentation devices and for those at WWTW treating storm flows provides a starting point. There would be clear benefits from additional information on the characteristics of wastewater storm flows. Therefore, it is suggested that further wastewater characterisation studies are carried out on storm flows entering the WWTW. The methodology developed in this research could be applied to such studies.

d. The use of settling velocity measurement and the chemical characterisation of wastewater could also be applied to the monitoring of CSOs pollutant removal performance. Tyack (1996) recommends that settling velocity measurements could be used to investigate the variation in the settling velocity profile of a storm sewage as a storm event progresses and recedes. The chemical characterisation of the storm sewage could also now be included in such a study. The effect of catchment size and type on the performance of CSOs could also be explored in more detail.

10.4.3. SEDIMENTATION DEVICES/MODELLING TOOLS.

In section 9.1. it is shown that settling velocity pollutant profiles can be used to ascertain potential removal efficiencies of specific pollutants from a wastewater stream. It is therefore recommended that this is investigated further by carrying out field tests on CSOs and primary sedimentation tanks.

The main application of the research to modelling is the provision of a method to enable further characterisation of solids, in terms of settling velocity and pollutant loads, to be incorporated into models such as HYDROWORKS and STOAT. At present general terms, such as potency factors are used to simulate pollutant transport. The representation of settling velocity and associated pollutant loads would introduce site specific characteristics into such models and enhance modelling tools. Further work into the incorporation of these parameters and their distributions into modelling tools is therefore recommended.

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GLOSSARY

BOD: biochemical oxygen demand. Biodegradable matter such as carbohydrates, fats and proteins are generally unstable and are oxidised biologically to stable end products such as carbon dioxide, water and nutrients. Due to the pollution potential of biodegradable matter, it is a key parameter monitored in wastewater effluent and water quality. The load of biodegradable matter in a sample is measured by determining the oxygen required to oxidise this matter.

COD: chemical oxygen demand. COD is a measure of the biodegradable and chemical degradable organic matter in a sample.

Dry Weather Flow (DWF): the average daily flow to a wastewater treatment works during dry weather conditions that includes discharges from residential, commercial and industrial properties and infiltration into the sewer system.

3 DWF: The basis of flow to treatment calculated by 3PG + I + 3E where:
P= population served G = water consumption per head per day(l/h/d)
I= Infiltration allowance (l/d) E= Trade effluent flows to sewer as applicable (l/d).

Floaters: particles with a negative settling velocity characterised by lighter, buoyant particles such as corn, fat and, hairs.

Floaters fraction: particles with a settling velocity greater than or equal to -0.18mm/sec.

Formula A: is used to calculate the flow for the operation of storm overflows and was set by the Technical Committee on Storm Overflows and the Disposal of Storm Sewage (1970).
Formula A: (PG+I+E) + 1360P +E (litres per day)

Gross solids: any particles which measures more than 6mm in any direction.

Hydrodynamic and Vortex separators: Hydrodynamic and Vortex separators rely on dynamic separation to remove settleable matter from wastewater. The terms hydrodynamic and vortex are used interchangeably. Hydrodynamic is usually applied to prefabricated devices such as Storm King manufactured by HRD/UFT. The term Vortex is generally applied to those devices that have a peripheral spill which originate from the USA such as the USEPA swirl concentrator.

Population equivalent (p.e.): population * BOD load

Residue: neutrally buoyant material typically contains matter in suspension, such as colloidal and very fine material and is collected in the central section of the column after settlement.

Residue fraction : particles with a settling velocity less than 0.18mm/sec and greater than -0.18mm/sec.

Sedimentation: sedimentation is the process by which suspended matter is removed from the surrounding liquor by gravity settlement. During the process of sedimentation, settleable matter with specific gravity greater than water (eg. one) is removed from the process stream by settling to the bottom of the device. The rate of settlement of particles from solution is dependent on the settling velocity of the individual particle, which is in turn dependent on the characteristics of the particle, such as particle size, shape and density.

Settling velocity: the average velocity with which a particle settles through a liquid under the influence of gravity, determined by timing the fall over a known distance.

Settling velocity profile/ Sewage Settling Velocity Grading Curve: The terms settling velocity profile and sewage settling velocity grading curve are synonymous and are the terms used to describe the presentation of the results of a settling column test. The profile is a cumulative graph. The vertical axis shows the percent of solid by weight with a settling velocity less than the value shown on the horizontal axis, and is plotted to a natural scale. Settling velocity (mm/sec) is plotted to a log scale on the horizontal axis, with values increasing from left to right. If the proportion of floaters (with a negative settling velocity) or those of neutral buoyancy are to be included it is necessary to employ a linear scale for the horizontal axis. The resulting curve is generally s -shaped and known as the Sewage Settling Velocity Grading Curve (SSVGC) or Settling Velocity Profile (SVP).

Sinkers: particles with a positive settling velocity typically characterised by containing large settleable particles and flocs in wastewater.

Sinker fraction : particles with a settling velocity greater than or equal to 0.18mm/sec.

TKN: Total Kjealdahl Nitrogen also referred to as crude protein. Used to determine the ammonia plus organic nitrogen present in a sample.

Treatment Factor: The Treatment Factor is the term applied to compare the proportion of flow passed to treatment with the proportion of pollutant passed to treatment, in the assessment of the performace of hydrodynamic separaetores. The factor relates the flow to the pollutant to enable a check that any improvement in quality is not just the results of splitting the flow. If the device provides no treatment but just divides the flow the Treatment Factor will be 1. A value >1 indicates that some treatment has taken place. A value <1 indicates that no treatment has taken place.

APPENDIX A

A1. TEST METHOD FOR SETTLING VELOCITY ANALYSIS

A2. TEST METHODOLOGY FOR CHEMICAL CONSTITUENTS ASSOCIATED WITH SETTLING VELOCITY ANALYSIS

A1. TEST METHOD FOR SETTLING VELOCITY ANALYSIS

(Tyack, 1996)

Refer to Figure 5.1 Schematic diagram of a settling column

Method

1. With cell A at the bottom and valve 4 shut fill the column with well mixed sewage sample (approximately 5 litres required)

2. A sample of at least 1 litre, preferable more, of raw sewage should be retained so that the initial concentration can be ascertained.

3. Close valve 3, re-open and close. Repeat this until all air trapped behind the ball valve is released (approx. 4 times)

4. Repeat (3) for valve 2. Top up with sewage if necessary

5. Repeat (3) for valve 1. Top up with sewage if necessary. There should be some liquid above the closed valve 1 when finished to ensure the column is full

6. Gently rotate the column through about 90° and back again in order to catch the liquid left above valve 1. Make sure that there is a container under valve 1 to catch the sewage! Open valves 2 and 3.

7. Lock column into vertical position and leave undisturbed for 3 hours. Ensure that cell A is at the bottom, valves 2 and 3 are open and valves 1 and 4 are closed. This will result in floaters collecting in cell B and sinkers collecting in cell A.

8. After 3 hours close valves 2 and 3. Open valves 4, drain cell A and retain the contents These are the sinkers.

9. Rotate column through 180° drain cell B and retain the contents. These are the floaters.

10. Rotate column through 180° so that cell B is at the top .In this position fill cell B with clean water, loosen valve 1 ensuring the air space behind the valve is filled (ie. to above the valve then close-open-close the vale until all the air is released)

11. Rotate column through 180° so that cell A is uppermost. Lock the column in the upright position. Open valve 4.

12. With the lid firmly sealed shake the retained sinkers up thoroughly to break up any flocs that have formed. Pour the contents of the bucket into cell A, purge valve 4 of air by opening and closing the valve. Close valve 4, open valve 3, and immediately start the stop clock. Immediately open valve 2.

13. After a preselected time, t_1 close valve 2. Open valve 1 and drain cell B.

14. 30 secs after time t_1, rotate column through 180°, refill cell B with clean water as in (9)

15. 1 min after time t_1, reverse rotation, so that cell B is again at the bottom. Start timer for next sample period and open valve 2

16. After time period dt where dt= $(t_2\text{-}t_1)$ repeat steps (12) to (14) and continue for as long as required [See 'Principles (d)]

17. After final samples have been taken from cell B, close valve 3. Rotate the column through 180°, drain cell A and retain the contents. These are the remaining sinkers.

18. Drain the main column separately so that residual concentration and hence mass of SS for the sample can be determined.

19. Filter the samples, including the floaters, the remaining sinkers, the residue and the retained crude sample, on previously washed, dried and weighed filter papers. Dry the samples and weigh the papers again to obtain the mass of suspended solids.

Principles

(a) Steps (1) to (6) are preparation of the sewage to allow the sinkers and floaters to separate.

Three hours settlement is allowed so that no particles remain in the column that have settling velocities than the longest sample time (150 minutes in this case). All these particles will have collected in end cells A and B.

(b) In steps (7) to (10) the sinkers and floaters are removed form the column. The residue is left in the column to simulate real conditions by maintaining the density and background liquor quality.

(c) In steps (12) to (16) samples of sinkers are obtained, each of which relates to a distinct range of settling velocities.

If column C is L cm long and first samples are obtained after t_1 secs, only particles with terminal velocities greater than $V_1= (L+d1)/t_1$ cm/sec are captured in cell A, where dl is taken as half the end cell length.

When the column is inverted to refill the sample cell, the direction of rise/fall of the particles is reversed. It has been found that inverting the column for a standard 30 sec enables all activity to be completed. Having previously allowed 30 secs for emptying the cell, on returning the column to its original vertical position the particles will have risen and fallen over the same distance and so returned to the positions they were in after time t_1.

In allowing a further period of dt, the particles collected in the next sample have fallen for $t_2= t_1 + dt$. Hence the time allowed between closing valves 2 and 3 at the end of the previous sampling period and the next sample being taken is (dt + 1) mins

All solids with $V_1 > (L+ dl) /t_1$ were collected in the first sample. Hence solids collected in the second sample have settling velocity greater than $V_2 = (L+ dl) /t_2$ but less than V_1. Similarly, for the next sample:

$V_1 > V_2 > V_3$, (where $V_3=(L +dl)/t_3$) and so on.

(d)Time intervals used to date for storm and foul sewage:

Sinkers: $t_1 = 1$ min, $t_2 = 3$ mins $t_3 = 5$ mins $t_4 = 10$ mins $t_5 = 20$ mins $t_6 = 30$ mins $t_7 = 40$ mins $t_8 = 60$ mins $t_9 = 90$ mins $t_{10} = 120$ mins $t_{11} = 150$ mins

However each situation must be judged on its merits.

Analysis

1. Filter a known volume of raw sewage. Mass of SS enables the concentration to be found. Knowing the volume of sewage in the column and the concentration the *starting mass* can be determined.

2. Each filtered sample yields the mass of solids with that specific settling velocity range.

3. From the residual sewage in the column after the experiment, and retained residue from the end cell after sinkers have been tested, the mass remaining can be determined by filtering.

4. The sum of all the mass of all the samples, plus the residual mass should give the original value, or a close approximation.

5. Knowing all the above data the graphs of % samples with a settling velocity less than a known value, and mass distributions can be plotted.

A2. TEST METHODOLOGY FOR CHEMICAL CONSTITUENTS ASSOCIATED WITH SETTLING VELOCITY ANALYSIS

Method

1. With cell A at the bottom and valve 4 shut fill the column with well mixed sewage sample (approximately 7 litres required)

2. A sample of at least 1 litre, preferable more, of raw sewage should be retained so that the initial concentration can be ascertained.

3. Close valve 3, re-open and close. Repeat this until all air trapped behind the ball valve is released (approx. 4 times)

4. Repeat (3) for valve 2. Top up with sewage if necessary

5. Repeat (3) for valve 1. Top up with sewage if necessary. There should be some liquid above the closed valve 1 when finished to ensure the column is full

6. Gently rotate the column through about 90° and back again in order to catch the liquid left above valve 1. Make sure that there is a container under valve 1 to catch the sewage! Open valves 2 and 3.

7. Lock column into vertical position and leave undisturbed for 3 hours. Ensure that cell A is at the bottom, valves 2 and 3 are open and valves 1 and 4 are closed. This will result in floaters collecting in cell B and sinkers collecting in cell A.

8. After 3 hours close valves 2 and 3. Open valves 4, drain cell A and retain the contents These are the sinkers.

9. Rotate column through 180° drain cell B and retain the contents. These are the floaters.

10. Rotate column through 180° so that cell B is at the top .In this position fill cell B with distilled water, lose valve 1 ensuring the air space behind the valve is filled (ie. to above the valve then close-open-close the vale until all the air is released)

11. Rotate column through 180° so that cell A is uppermost . Lock the column in the upright position. Open valve 4.

12. With the lid firmly sealed shake the retained sinkers up thoroughly to break up any flocs that have formed. Pour the contents of the bucket into cell A, purge valve 4 of air by opening and closing the valve. Close valve 4, open valve 3, and immediately start the stop clock. Immediately open valve 2.

13. After a preselected time, t_1 close valve 2. Open valve 1 and drain cell B.

14. 30 secs after time $t_{1,}$ rotate column through 180°, refill cell B with distilled water as in (9)

15. 1 min after time t_1, reverse rotation, so that cell B is again at the bottom . Start timer for next sample period and open valve 2

16. After time period dt where dt= (t_2-t_1) repeat steps (12) to (14) and continue for as long as required [See 'Principles (d)]

17. After final samples have been taken from cell B, close valve 3. Rotate the column through 180°, drain cell A and retain the contents. These are the remaining sinkers.

18. Drain the main column separately so that residual mass of chemical constituents for the sample can be determined.

19. Determine the selected chemical constituents associated with the solids in the column samples.

Principles

(a) Steps (1) to (6) are preparation of the sewage to allow the sinkers and floaters to separate.

Three hours settlement is allowed so that no particles remain in the column that have settling velocities than the longest sample time (150 minutes in this case). All these particles will have collected in end cells A and B.

(b) In steps (7) to (10) the sinkers and floaters are removed form the column. The residue is left in the column to simulate real conditions by maintaining the density and background liquor quality.

(c) In steps (12) to (16) samples of sinkers are obtained, each of which relates to a distinct range of settling velocities.

If column C is L cm long and first samples are obtained after t_1 secs, only particles with terminal velocities greater than $V_1 = (L+d1)/t_1$ cm/sec are captured in cell A, where dl is taken as half the end cell length.

When the column is inverted to refill the sample cell, the direction of rise/fall of the particles is reversed. It has been found that inverting the column for a standard 30 sec enables all activity to be completed. Having previously allowed 30 secs for emptying the cell, on returning the column to its original vertical position the particles will have risen and fallen over the same distance and so returned to the positions they were in after time t_1.

In allowing a further period of dt, the particles collected in the next sample have fallen for $t_2 = t_1 + dt$. Hence the time allowed between closing valves 2 and 3 at the end of the previous sampling period and the next sample being taken is (dt + 1) mins

All solids with $V_1 > (L + dl)/t_1$ were collected in the first sample. Hence solids collected in the second sample have settling velocity greater than $V_2 = (L + dl)/t_2$ but less than V_1.
Similarly, for the next sample:
$V_1 > V_2 > V_3$, (where $V_3 = (L + dl)/t_3$) and so on.

(d)Time intervals used to date for storm and foul sewage:

Sinkers: t_1 = 3 mins, t_2 = 10 mins t_3 = 30 mins t_4 = 60 mins t_5= 150 mins

However each situation must be judged on its merits.

(e) Chemical constituents determined

To date, COD, nutrients (total nitrogen and phosphorus) and heavy metals (aluminium, copper, iron, lead, mercury, manganese and zinc) have been determined in the settling velocity fractions.

Analysis

1. Determine the particulate and soluble mass of the selected chemical constituents in the raw sewage. This enables the proportion of chemical constituents associated with solids in the original sample to be known.

2. Determine the mass of chemical constituents associated with solids in each specific settling velocity range (sinkers and floaters).

3. From the residual in the column after the experiment, and the retained residue from the end cell after the sinkers have been tested, the chemical constituents mass remaining can be determined.

4. The sum of the chemical constituents mass in all the samples, plus the residual chemical constituents mass should give the original value, or a close approximation.

5. Knowing all the above data the chemical constituents mass distributions can be plotted.

APPENDIX B

COMPARISON OF LARGE AND SMALL SETTLING COLUMNS

SITE E

Small column data

Settling velocity (mm/sec)	Mass SS (g)	Sample volume (ml)	Normalize mass to g per litre	% of total SS	% sample < known value
27.08	0.013	760	0.017	1.34	98.66
9.03	0.028	755	0.037	2.91	95.75
5.42	0.119	760	0.157	12.28	83.48
2.71	0.270	760	0.355	27.85	55.62
1.35	0.174	760	0.229	17.95	37.67
0.9	0.101	760	0.133	10.42	27.25
0.68	0.039	760	0.051	4.02	23.23
0.45	0.049	755	0.065	5.09	18.14
0.3	0.04	755	0.053	4.15	13.99
0.22	0.031	760	0.041	3.20	10.79
0.18	0.027	760	0.036	2.79	8.01
-0.2<R>0.2	0.312	3993	0.078	6.13	1.88
<-0.18	0.195	8130	0.024	1.88	0.00
Total	1.398		1.276	100.00	

Site E
Large Column data

Settling velocity (mm/sec)	Mass SS (g)	Sample volume (ml)	Normalize mass to mass per litre	% of total SS	% sample < known value
27.08	0.008	900	0.009	0.74	99.26
9.03	0.038	900	0.042	3.50	95.76
5.42	0.052	900	0.058	4.79	90.97
2.71	0.085	930	0.091	7.58	83.39
1.35	0.224	900	0.249	20.64	62.75
0.9	0.030	930	0.032	2.67	60.08
0.68	0.012	900	0.013	1.11	58.97
0.45	0.048	900	0.053	4.42	54.55
0.3	0.046	980	0.047	3.89	50.66
0.22	0.05	1000	0.050	4.15	46.51
0.18	0.042	1000	0.042	3.48	43.03
-0.2<R>0.2	0.510	2000	0.255	21.14	21.89
<-0.18	0.227	860	0.264	21.89	
Total	1.372		1.206	100.00	

SITE G (Sample 4)

Small column data

Settling velocity (mm/sec)	Mass SS (g)	Sample volume (ml)	Normalize mass to mass per litre	% of total SS	% sample < known value
27.08	0.025	750	0.033	2.69	97.31
9.03	0.176	750	0.235	18.97	78.34
5.42	0.133	750	0.177	14.33	64.01
2.71	0.201	750	0.268	21.66	42.35
1.35	0.098	750	0.131	10.56	31.79
0.9	0.051	750	0.068	5.50	26.29
0.68	0.038	750	0.051	4.09	22.20
0.45	0.043	750	0.057	4.63	17.57
0.3	0.03	750	0.040	3.23	14.33
0.22	0.012	750	0.016	1.29	13.04
0.18	0.008	750	0.011	0.86	12.18
-0.2<R>0.2	0.311	4020	0.077	6.25	5.93
<-0.18	0.055	750	0.073	5.93	0.00
Total	1.181		1.237	100.00	

Site G
Large Column data

Settling velocity (mm/sec)	Mass SS (g)	Sample volume (ml)	Normalize mass to mass per litre	% of total SS	% sample < known value
27.08	0.455	750	0.607	10.13	89.87
9.03	0.565	815	0.693	11.58	78.29
5.42	0.118	870	0.136	2.27	76.03
2.71	0.228	875	0.261	4.35	71.67
1.35	0.228	870	0.262	4.38	67.30
0.9	0.247	900	0.274	4.58	62.71
0.68	0.188	500	0.376	6.28	56.43
0.45	0.218	750	0.291	4.85	51.58
0.3	0.208	835	0.249	4.16	47.42
0.22	0.169	770	0.219	3.67	43.75
0.18	0.174	850	0.205	3.42	40.34
-0.2<R>0.2	1.285	1780	0.722	12.06	28.28
<-0.18	0.8890	525	1.693	28.28	0.00
Total	4.972		5.988	100.00	

SITE C (Sample 3)

Small column data

Settling velocity (mm/sec)	Mass SS (g)	Sample volume (ml)	Normalize mass to mass per litre	% of total SS	% sample < known value
27.08	0.001	750	0.001	0.09	99.91
9.03	0.174	750	0.232	15.03	84.89
5.42	0.198	750	0.264	17.10	67.79
2.71	0.304	750	0.405	26.25	41.54
1.35	0.086	750	0.115	7.43	34.11
0.9	0.043	750	0.057	3.71	30.40
0.68	0.034	750	0.045	2.94	27.46
0.45	0.042	750	0.056	3.63	23.84
0.3	0.04	750	0.053	3.45	20.38
0.22	0.036	750	0.048	3.11	17.27
0.18	0.03	750	0.040	2.59	14.68
-0.2<R>0.2	0.295	3455	0.085	5.53	9.15
<-0.18	0.106	750	0.141	9.15	
Total	1.389		1.544	100.00	

Small column -combine mass data to give same fractions as large column for comparison

SETTLING VELOCITY mm/sec	Mass SS (g)	% of total SS	% sample < known value
9.03	0.233	15.11	84.9
2.71-9.03	0.669	43.35	41.5
0.90-2.71	0.172	11.14	30.4
0.45-0.90	0.101	6.56	23.8
0.18-0.45	0.141	9.15	14.7
-0.2<R>0.2	0.085	5.53	9.2
<-0.18	0.141	9.15	0.0
Total	1.544	100.0	

Site C

Large column data

Settling velocity (mm/sec)	Mass SS (g)	Sample volume (ml)	Normalize mass to mass per litre	% of total SS	% sample < known value
9.03	0.336	800	0.420	24.21	75.79
2.71-9.03	0.347	800	0.434	25.00	50.79
0.90-2.71	0.245	650	0.377	21.73	29.06
0.45-0.90	0.114	700	0.163	9.39	19.68
0.18-0.45	0.082	700	0.117	6.75	12.92
-0.2<R>0.2	0.208	1900	0.109	6.31	6.61
<-0.18	0.109	950	0.115	6.61	0.00
Total	1.124		1.735	100.00	

SITE I

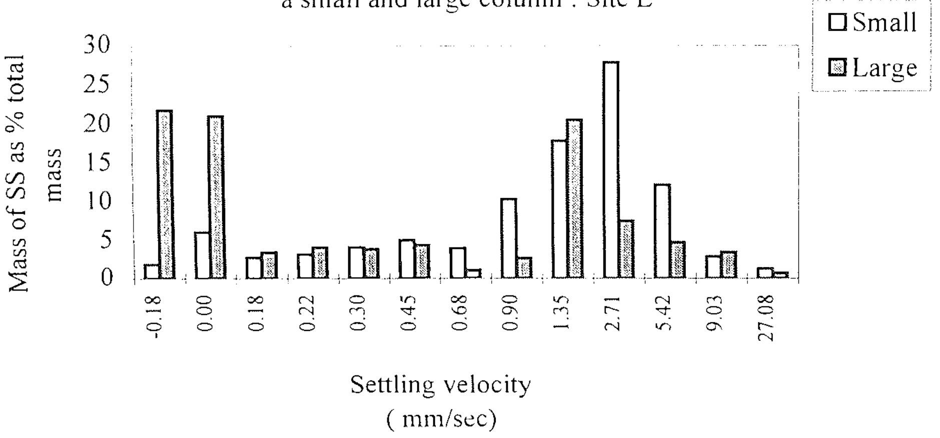
Small column data

Settling velocity (mm/sec)	Mass SS (g)	Sample volume (ml)	Normalize mass to mass per litre	% of total SS	% sample < known value
27.08	0.024	750	0.032	1.67	98.33
9.03	0.055	745	0.074	3.84	94.49
5.42	0.084	750	0.112	5.83	88.66
2.71	0.55	750	0.733	38.18	50.48
1.35	0.439	750	0.585	30.47	20.01
0.9	0.047	750	0.063	3.26	16.74
0.68	0.03	750	0.040	2.08	14.66
0.45	0.034	750	0.045	2.36	12.30
0.3	0.03	750	0.040	2.08	10.22
0.22	0.025	745	0.034	1.75	8.47
0.18	0.015	750	0.020	1.04	7.43
-0.2<R>0.2	0.618	4685	0.132	6.87	0.56
<-0.18	0.04	3710	0.011	0.56	0.00
Total	1.991		1.921	100.00	

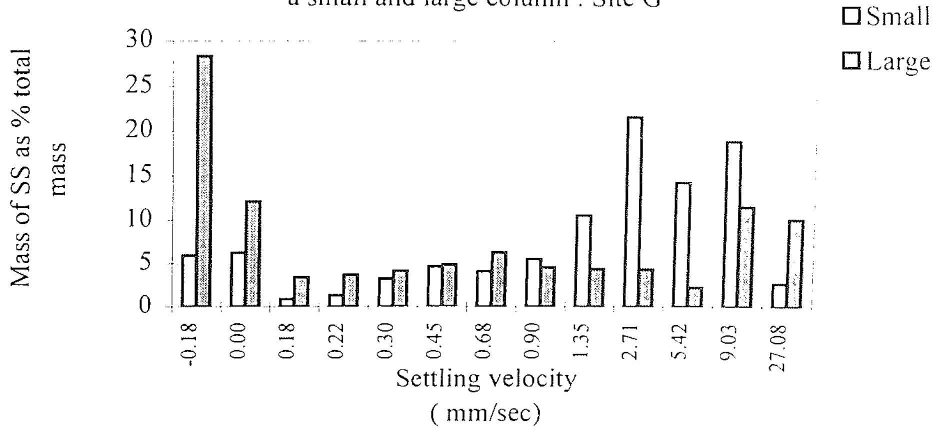
Large Column data

Settling velocity (mm/sec)	Mass SS (g)	Sample volume (ml)	Normalize mass to mass per litre	% of total SS	% sample < known value
27.08	0.028	900	0.031	1.46	98.54
9.03	0.032	900	0.036	1.67	96.87
5.42	0.225	800	0.281	13.21	83.66
2.71	0.254	800	0.318	14.91	68.75
1.35	0.624	800	0.780	36.63	32.12
0.9	0.132	800	0.165	7.75	24.37
0.68	0.039	800	0.049	2.29	22.08
0.45	0.036	800	0.045	2.11	19.97
0.3	0.026	900	0.029	1.36	18.61
0.22	0.022	900	0.024	1.15	17.46
0.18	0.011	900	0.012	0.57	16.89
-0.2<R>0.2	0.110	1500	0.073	3.44	13.44
<-0.18	0.2290	800	0.286	13.44	0.00
Total	1.768		2.129	100.00	

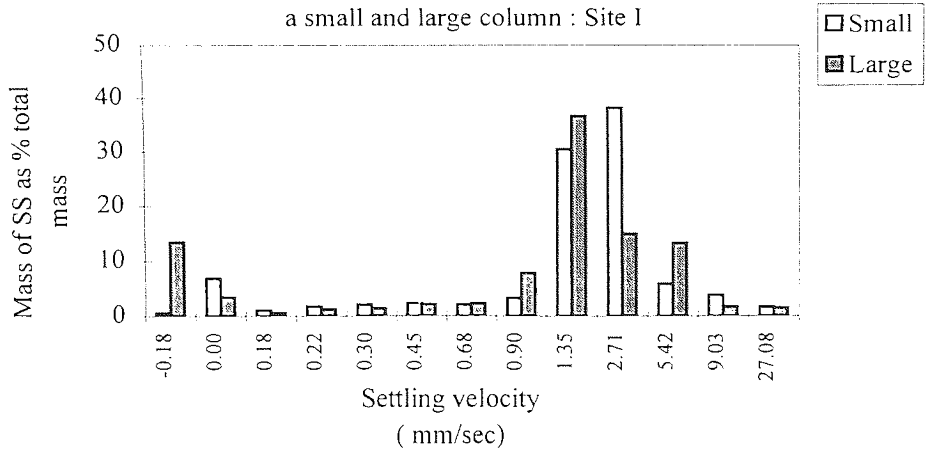
Comparison of the distribution of SS mass in SGC's derived from a small and large column : Site E



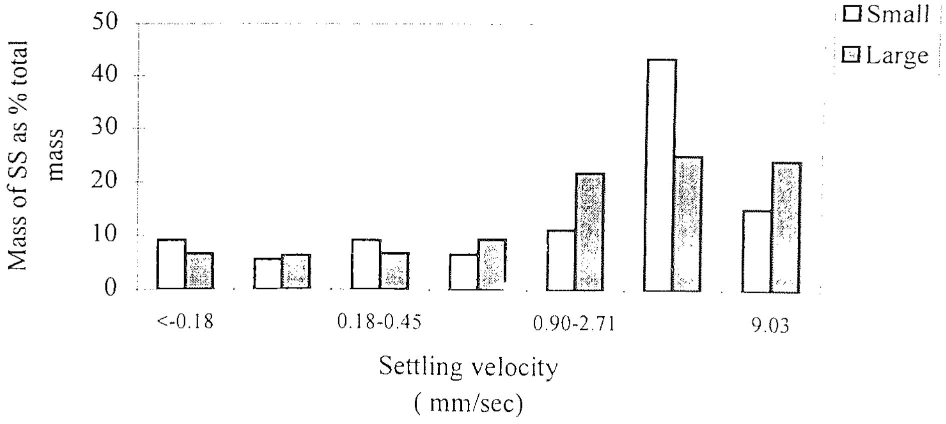
Comparison of the distribution of SS mass in SGC's derived from a small and large column : Site G

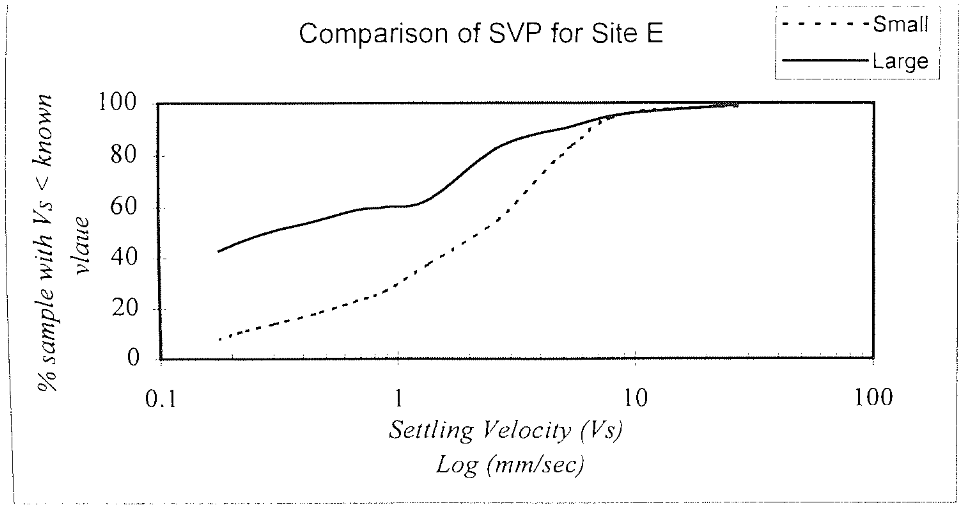


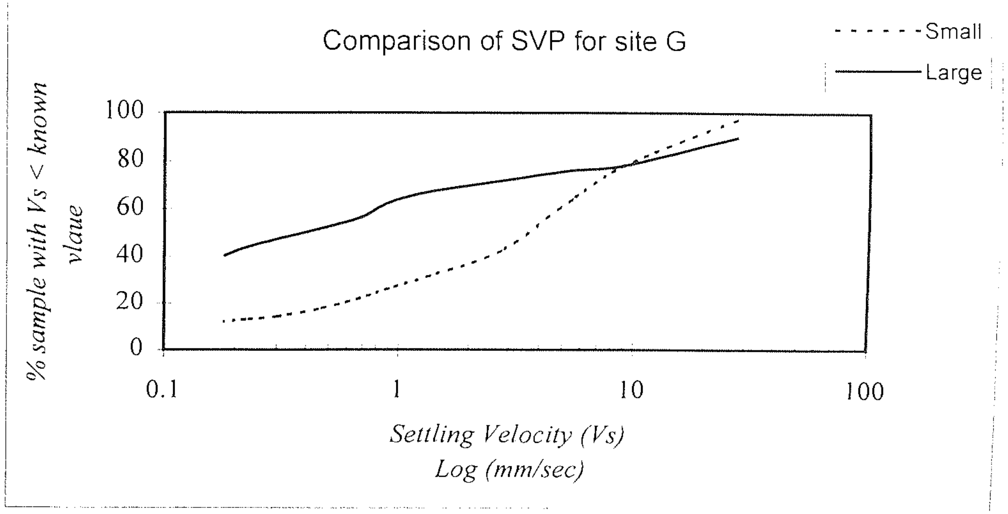
Comparison of the distribution of SS mass in SGC's derived from a small and large column : Site I

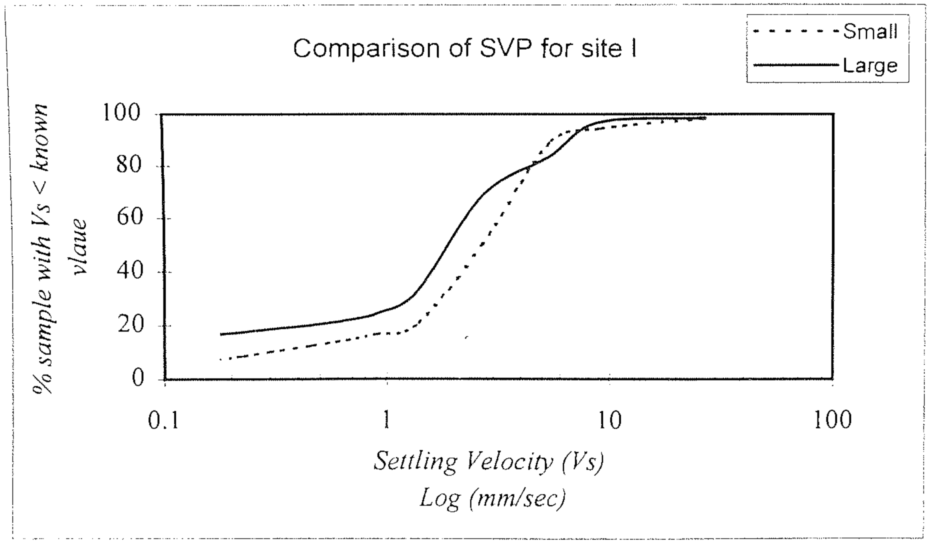


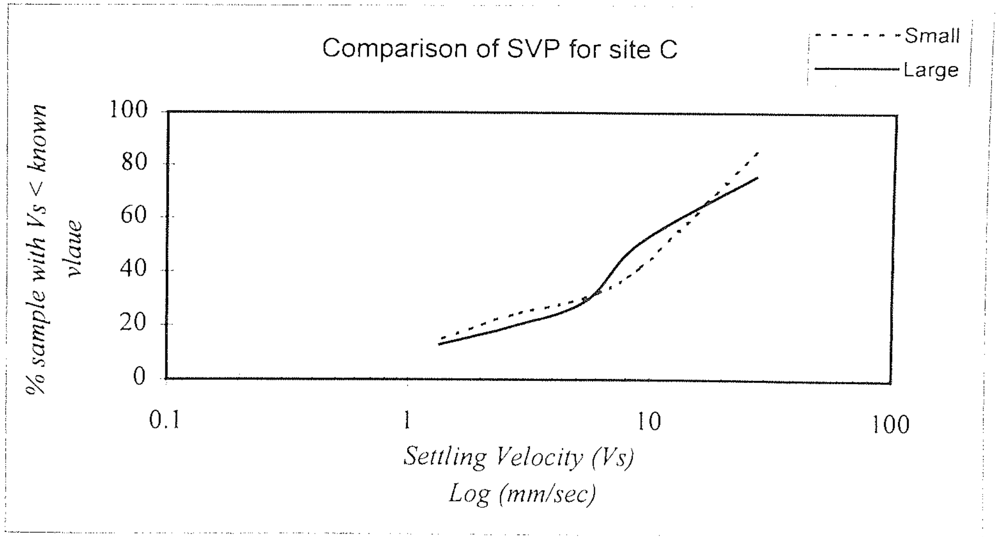
Comparison of the distribution of SS mass in SGC's from a small and large column : Site C




Comparison of SVP for Site E


Comparison of SVP for site G


Comparison of SVP for site I


Comparison of SVP for site C

t-Test: Two-Sample Assuming Equal Variances

Site E

	Small column	*Large column*
Mean	39.54	63.99
Variance	1237.63	562.20
Observations	12	12
Pooled Variance	899.91	
Hypothesized Mean Difference	0	
df	22	
t Stat	**-1.996**	
P(T<=t) one-tail	0.029	
t Critical one-tail	1.717	
P(T<=t) two-tail	0.058	
t Critical two-tail	**2.074**	

Site I

	Small column	*Large column*
Mean	35.20	42.73
Variance	1401.83	1139.84
Observations	12	12
Pooled Variance	1270.84	
Hypothesized Mean Difference	0	
df	22	
t Stat	**-0.518**	
P(T<=t) one-tail	0.305	
t Critical one-tail	1.717	
P(T<=t) two-tail	0.610	
t Critical two-tail	**2.074**	

Site G

	Small column	*Large column*
Mean	35.44	59.47
Variance	862.08	325.06
Observations	12	12
Pooled Variance	593.57	
Hypothesized Mean Difference	0	
df	22	
t Stat	**-2.42**	
P(T<=t) one-tail	0.01	
t Critical one-tail	1.72	
P(T<=t) two-tail	0.02	
t Critical two-tail	**2.07**	

Site C

	Small column	*Large column*
Mean	34.08	32.48
Variance	750.63	687.64
Observations	6	6
Pooled Variance	719.14	
Hypothesized Mean Difference	0	
df	10	
t Stat	**0.104**	
P(T<=t) one-tail	0.460	
t Critical one-tail	1.812	
P(T<=t) two-tail	0.919	
t Critical two-tail	**2.228**	

APPENDIX C

SETTLING VELOCITY PROFILE DATA

SITE A

SAMPLE 1

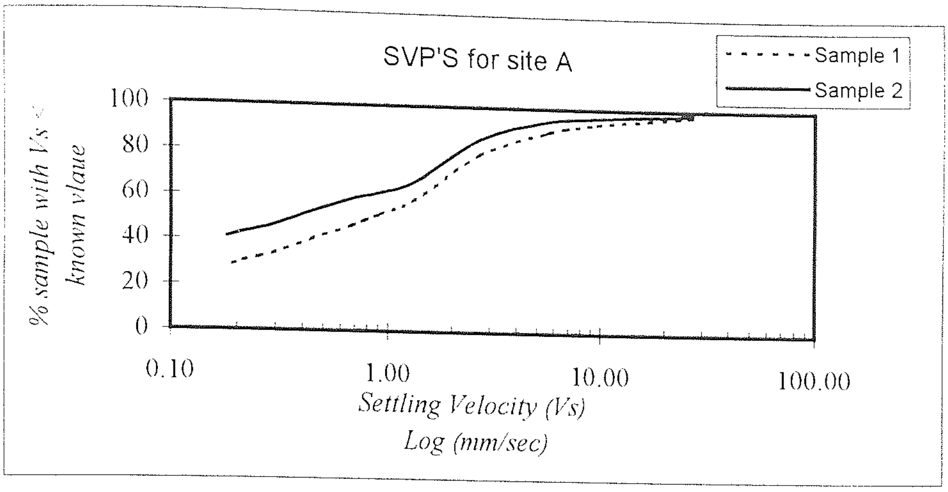
SETTLING VELOCITY mm/sec	MASS SS (mg)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.033	2.41	97.59
9.03	0.059	4.30	93.29
5.42	0.057	4.16	89.13
2.71	0.138	10.07	79.07
1.35	0.278	20.28	58.79
0.90	0.102	7.44	51.35
0.68	0.063	4.60	46.75
0.45	0.082	5.98	40.77
0.30	0.091	6.64	34.14
0.22	0.047	3.43	30.71
0.18	0.035	2.55	28.15
-0.2<R>0.2	0.209	15.24	12.91
<-0.18	0.177	12.91	
Total	1.371	100.00	
Normalise total SS mass to large column volume (g)			1.94

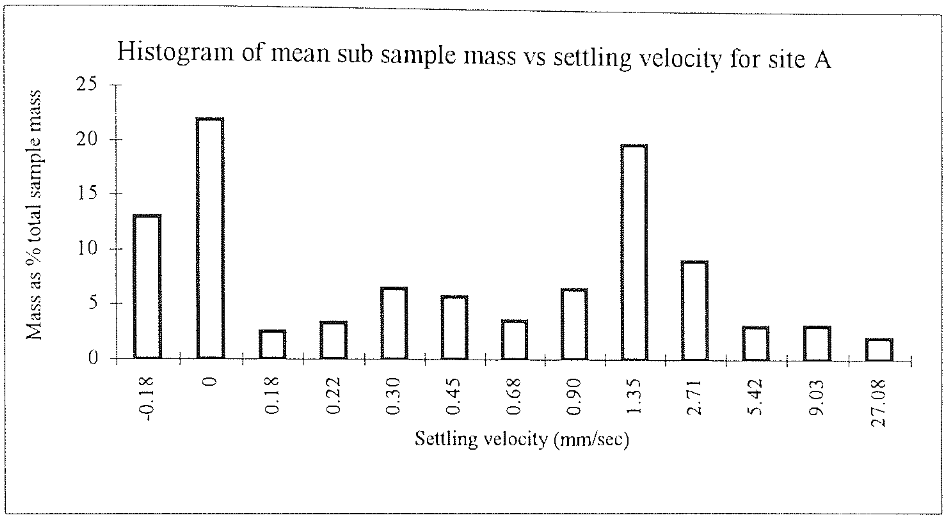
SAMPLE 2

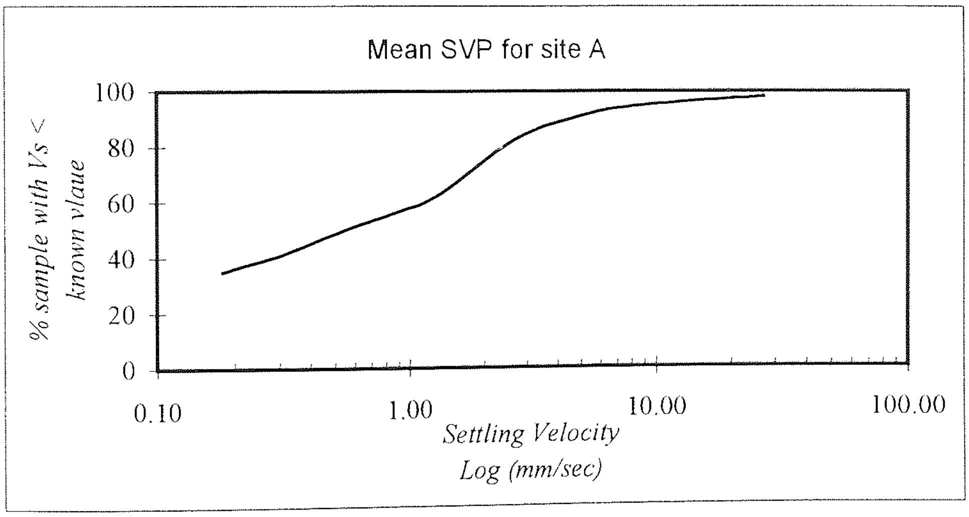
SETTLING VELOCITY mm/sec	MASS SS (mg)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.025	1.68	98.32
9.03	0.030	2.01	96.31
5.42	0.031	2.08	94.22
2.71	0.123	8.26	85.96
1.35	0.289	19.41	66.55
0.90	0.083	5.57	60.98
0.68	0.038	2.55	58.43
0.45	0.082	5.51	52.92
0.30	0.094	6.31	46.61
0.22	0.047	3.16	43.45
0.18	0.036	2.42	41.03
-0.2<R>0.2	0.416	27.94	13.10
<-0.18	0.195	13.10	
Total	1.489	100.00	
Normalise total SS mass to large column volume (g)			2.103

SITE A
MEAN SVP

SETTLING VELOCITY mm/sec	MEAN MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.029	2.03	97.97
9.03	0.045	3.11	94.86
5.42	0.044	3.08	91.78
2.71	0.131	9.13	82.66
1.35	0.284	19.83	62.83
0.90	0.093	6.47	56.36
0.68	0.051	3.53	52.83
0.45	0.082	5.73	47.10
0.30	0.093	6.47	40.63
0.22	0.047	3.29	37.34
0.18	0.036	2.48	34.86
-0.2<R>0.2	0.313	21.85	13.01
<-0.18	0.186	13.01	
Total	1.430	100.00	
Normalise total SS mass to large column volume (g)			2.020

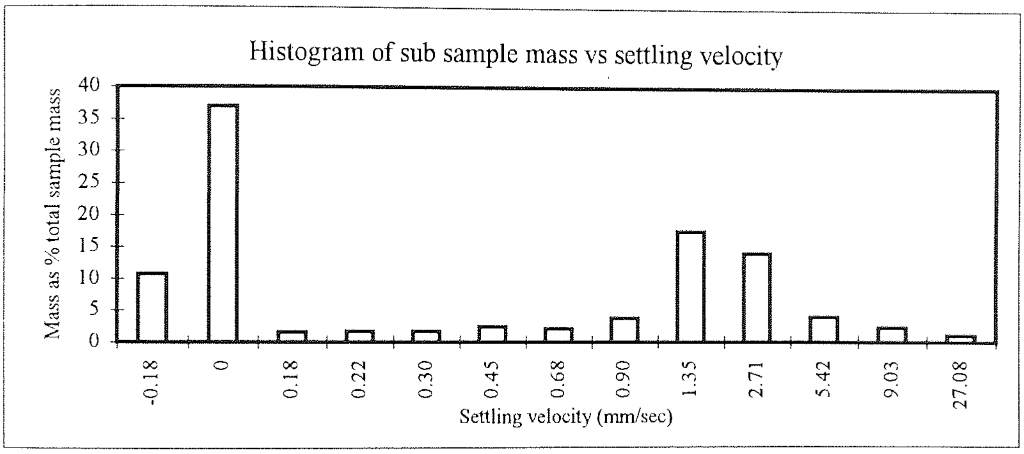

SVP'S for site A
Sample 1
Sample 2
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs)
Log (mm/sec)

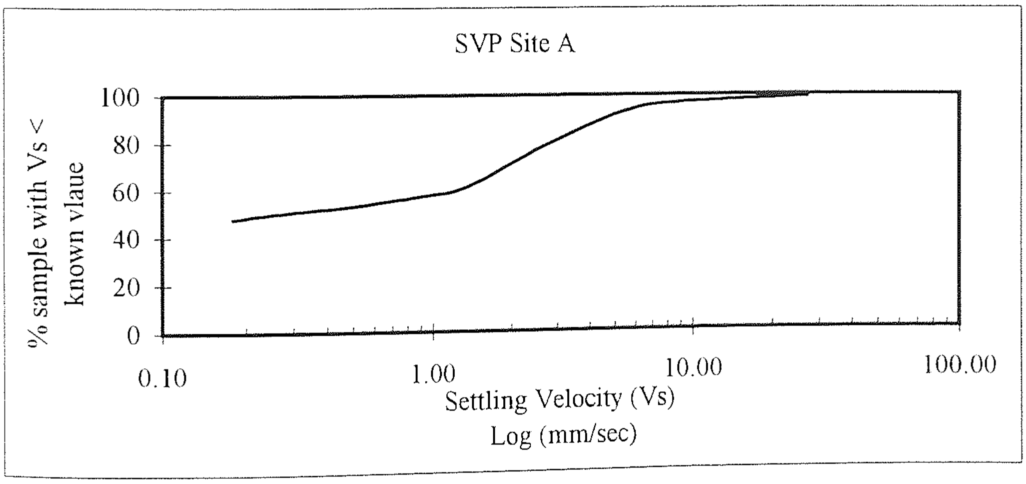

Histogram of mean sub sample mass vs settling velocity for site A
Mass as % total sample mass
25
20
15
10
5
0
-0.18
0
0.18
0.22
0.30
0.45
0.68
0.90
1.35
2.71
5.42
9.03
27.08
Settling velocity (mm/sec)


Mean SVP for site A
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity
Log (mm/sec)

SITE A

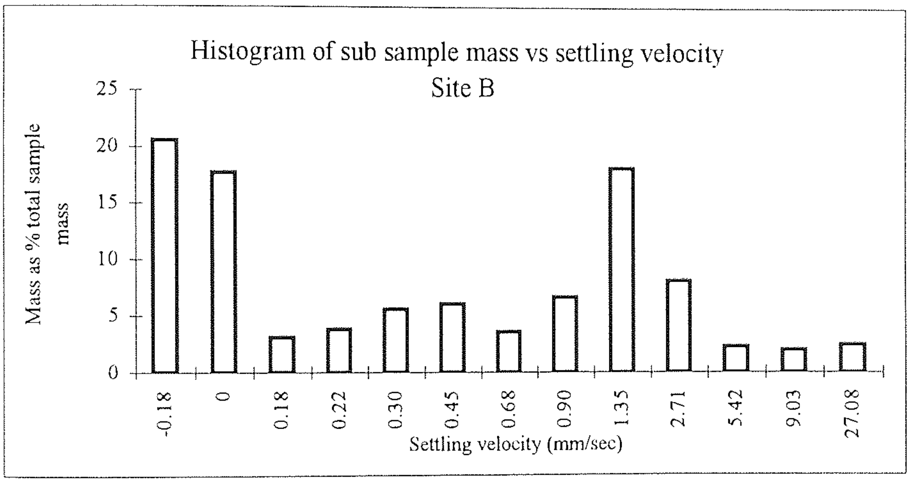
Settling Velocity mm/sec	**Sample 3** MASS SS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.012	1.08	98.92
9.03	0.026	2.35	96.56
5.42	0.044	3.98	92.59
2.71	0.156	14.10	78.48
1.35	0.194	17.54	60.94
0.90	0.042	3.80	57.14
0.68	0.023	2.08	55.06
0.45	0.027	2.44	52.62
0.30	0.019	1.72	50.90
0.22	0.019	1.72	49.19
0.18	0.017	1.54	47.65
-0.18<R>0.18	0.409	36.98	10.67
<-0.18	0.118	10.67	
Total	1.106	100	
Normalise mass to large column volume			1.507

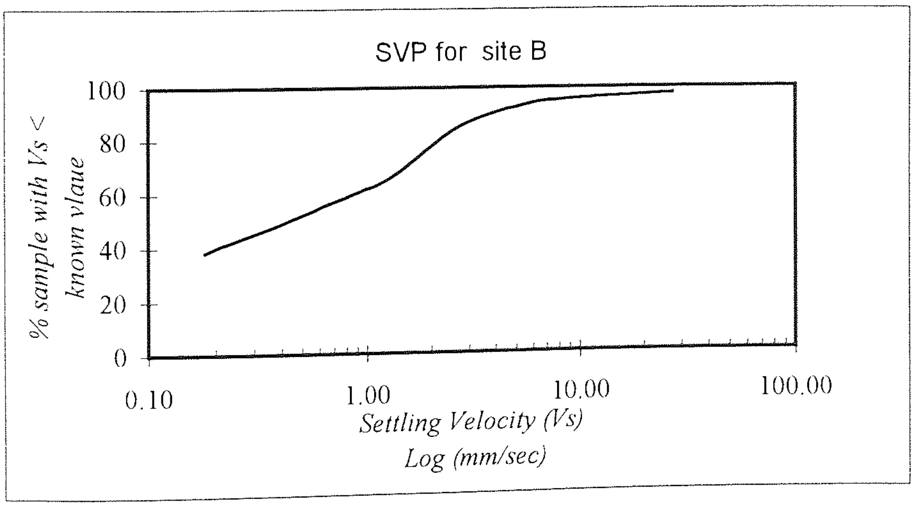




SITE B SAMPLE 1

SETTLING VELOCITY mm/s	MASS SS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.031	2.46	97.54
9.03	0.025	1.99	95.55
5.42	0.029	2.30	93.25
2.71	0.102	8.10	85.15
1.35	0.228	18.11	67.04
0.90	0.084	6.67	60.37
0.68	0.045	3.57	56.79
0.45	0.076	6.04	50.75
0.30	0.07	5.56	45.19
0.22	0.048	3.81	41.38
0.18	0.039	3.10	38.28
-0.2<R>0.2	0.223	17.71	20.57
<-0.18	0.259	20.57	
Total	1.259	100.00	
Normalise total SS mass to large column volume			1.78

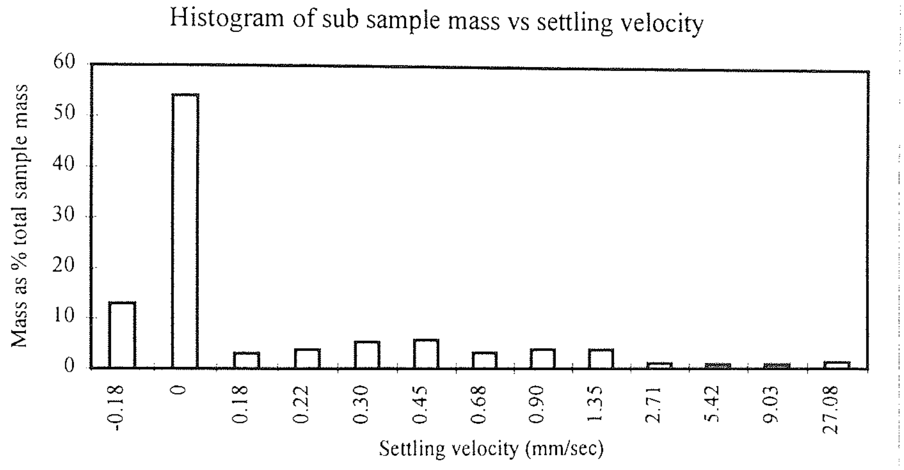


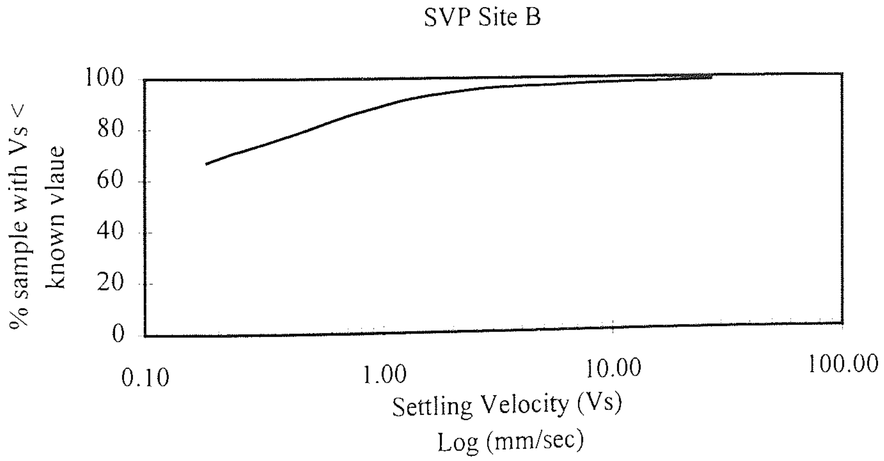


SITE B

	Sample 2		
SETTLING VELOCITY	MASS SS	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
mm/s	(g)		
27.08	0.011	1.34	98.66
9.03	0.007	0.85	97.81
5.42	0.007	0.85	96.95
2.71	0.009	1.10	95.86
1.35	0.031	3.78	92.08
0.90	0.032	3.90	88.19
0.68	0.026	3.17	85.02
0.45	0.047	5.72	79.29
0.30	0.044	5.36	73.93
0.22	0.031	3.78	70.16
0.18	0.025	3.05	67.11
-0.2<R>0.2	0.4440	54.08	13.03
<-0.18	0.107	13.03	0.00
Total	0.821	100.00	

Normalise mass to large column volume 1.160





SITE C

SAMPLE 1

SETTLING VELOCITY mm/sec	MEAN MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.029	1.95	98.05
9.03	0.013	0.87	97.18
5.42	0.025	1.68	95.51
2.71	0.237	15.90	79.61
1.35	0.481	32.26	47.35
0.90	0.072	4.83	42.52
0.68	0.036	2.41	40.11
0.45	0.08	5.37	34.74
0.30	0.081	5.43	29.31
0.22	0.049	3.29	26.02
0.18	0.041	2.75	23.27
-0.2<R>0.2	0.143	9.59	13.68
<-0.18	0.204	13.68	
Total	1.491	100.00	
Normalise total SS mass to large column volume			2.11

SAMPLE 2

SETTLING VELOCITY mm/sec	MEAN MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.025	1.51	98.49
9.03	0.096	5.81	92.68
5.42	0.108	6.53	86.15
2.71	0.298	18.03	68.12
1.35	0.287	17.36	50.76
0.90	0.064	3.87	46.88
0.68	0.034	2.06	44.83
0.45	0.064	3.87	40.96
0.30	0.056	3.39	37.57
0.22	0.032	1.94	35.63
0.18	0.027	1.63	34.00
-0.2<R>0.2	0.312	18.87	15.12
<-0.18	0.250	15.12	
Total	1.653	100	
Normalise total SS mass to large column volume			2.33

SAMPLE 3

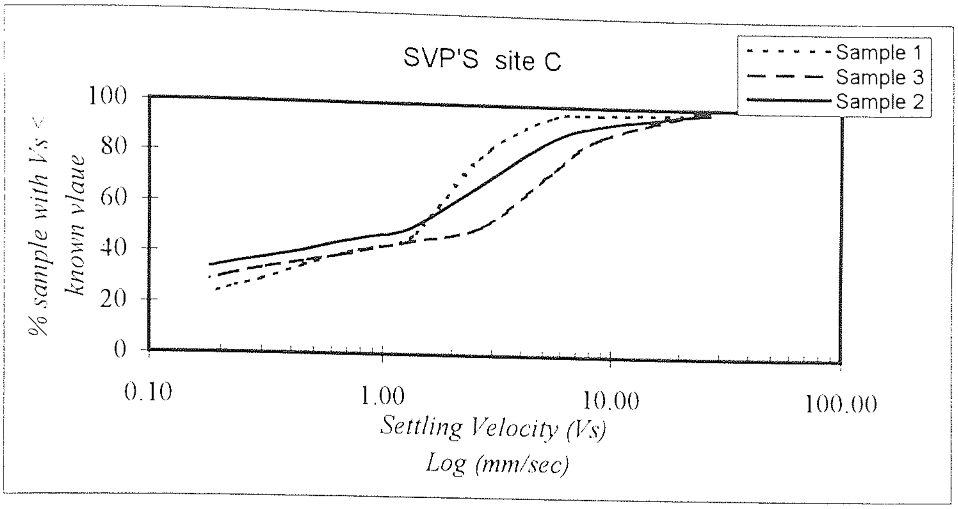
SETTLING VELOCITY mm/sec	MEAN MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.001	0.07	99.93
9.03	0.174	12.53	87.40
5.42	0.198	14.25	73.15
2.71	0.304	21.89	51.26
1.35	0.086	6.19	45.07
0.90	0.043	3.10	41.97
0.68	0.034	2.45	39.52
0.45	0.042	3.02	36.50
0.30	0.04	2.88	33.62
0.22	0.036	2.59	31.03
0.18	0.03	2.16	28.87
-0.2<R>0.2	0.295	21.24	7.63
<-0.18	0.106	7.63	
Total	1.389	100	

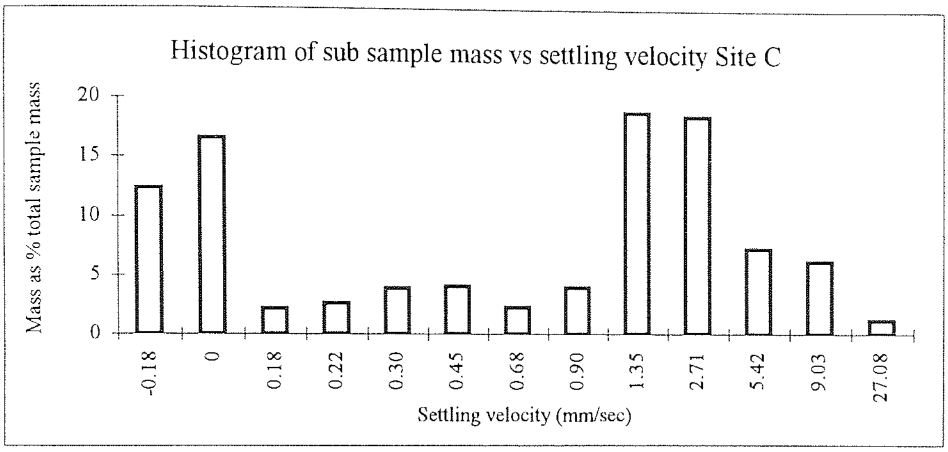
Normalise total SS mass to large column volume 1.96

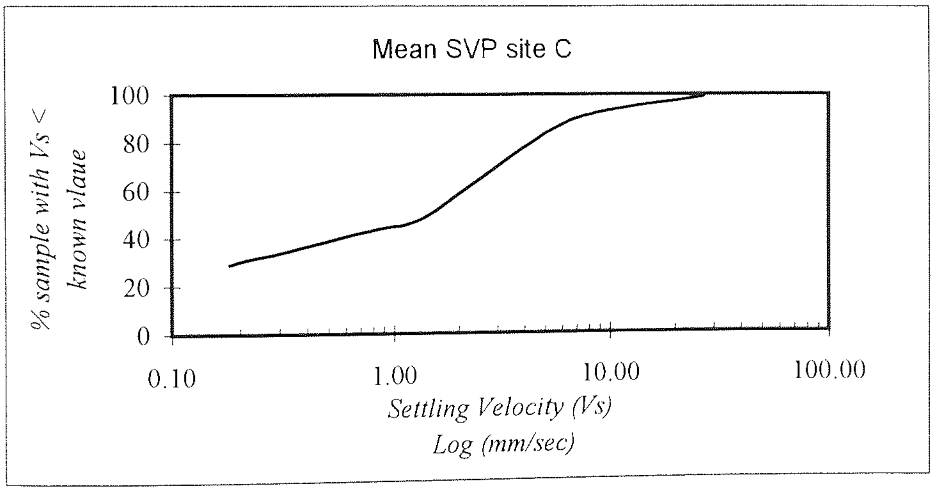
MEAN SVP FOR SITE C

SETTLING VELOCITY mm/sec	MEAN MASS SS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.018	1.21	98.79
9.03	0.094	6.24	92.54
5.42	0.110	7.30	85.24
2.71	0.280	18.51	66.73
1.35	0.285	18.84	47.89
0.90	0.060	3.95	43.94
0.68	0.035	2.29	41.65
0.45	0.062	4.10	37.55
0.30	0.059	3.90	33.64
0.22	0.039	2.58	31.06
0.18	0.033	2.16	28.90
-0.2<R>0.2	0.250	16.55	12.35
<-0.18	0.187	12.35	0.00
Total	1.511	100.00	

Normalise total SS mass to large column volume 2.13


SVP'S site C
Sample 1
Sample 3
Sample 2
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs)
Log (mm/sec)


Histogram of sub sample mass vs settling velocity Site C
Mass as % total sample mass
20
15
10
5
0
-0.18
0
0.18
0.22
0.30
0.45
0.68
0.90
1.35
2.71
5.42
9.03
27.08
Settling velocity (mm/sec)


Mean SVP site C
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs)
Log (mm/sec)

SITE D

SAMPLE 1

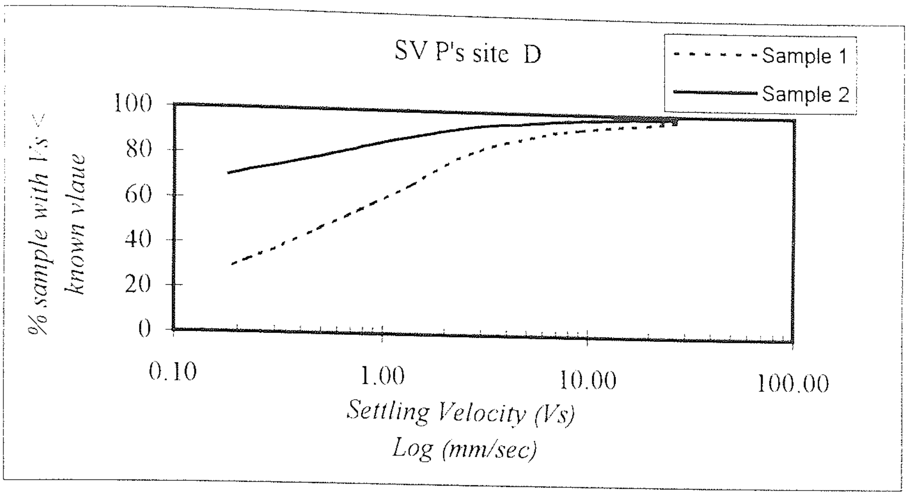
SETTLING VELOCITY mm/s	MASS SS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.040	2.78	97.22
9.03	0.058	4.03	93.18
5.42	0.052	3.62	89.57
2.71	0.108	7.51	82.06
1.35	0.222	15.44	66.62
0.90	0.118	8.21	58.41
0.68	0.077	5.35	53.06
0.45	0.115	8.00	45.06
0.30	0.110	7.65	37.41
0.22	0.073	5.08	32.34
0.18	0.052	3.62	28.72
-0.2<R>0.2	0.182	12.66	16.06
<-0.18	0.231	16.06	
Total	1.438	100.00	
Normalise total SS mass to large column volume			2.03

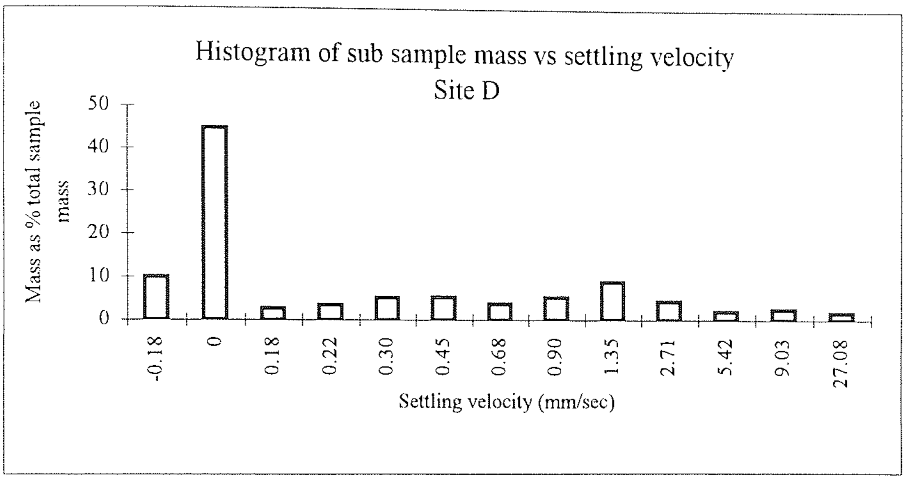
SAMPLE 2

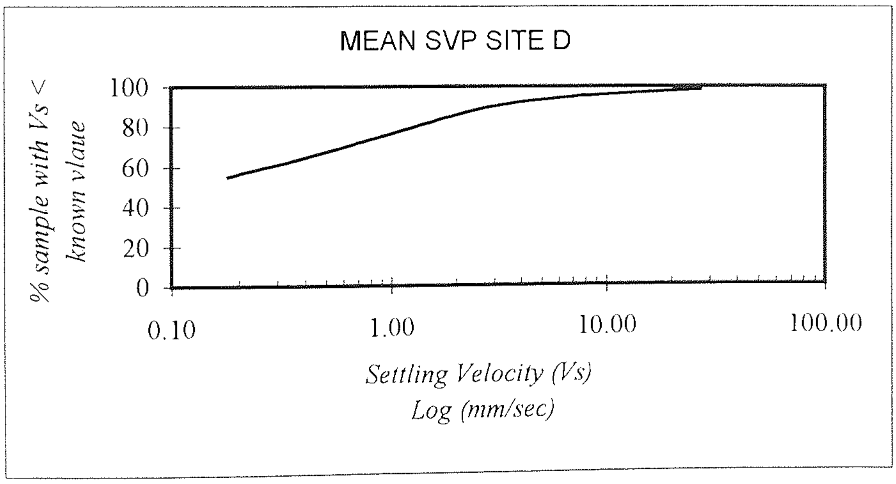
SETTLING VELOCITY mm/s	MASS SS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.029	1.17	98.83
9.03	0.041	1.66	97.17
5.42	0.03	1.21	95.95
2.71	0.06	2.43	93.52
1.35	0.129	5.22	88.30
0.90	0.089	3.60	84.70
0.68	0.067	2.71	81.98
0.45	0.095	3.85	78.14
0.30	0.089	3.60	74.53
0.22	0.061	2.47	72.06
0.18	0.051	2.06	70.00
-0.2<R>0.2	1.571	63.60	6.40
<-0.18	0.158	6.40	
Total	2.470	100.00	
Normalise total SS mass to large column volume			3.49

MEAN SVP

SETTLING VELOCITY mm/sec	MEAN MASS SS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.035	1.77	98.23
9.03	0.050	2.53	95.70
5.42	0.041	2.10	93.60
2.71	0.084	4.30	89.30
1.35	0.176	8.98	80.32
0.90	0.104	5.30	75.03
0.68	0.072	3.68	71.34
0.45	0.105	5.37	65.97
0.30	0.100	5.09	60.88
0.22	0.067	3.43	57.45
0.18	0.052	2.64	54.81
-0.2<R>0.2	0.877	44.86	9.95
<-0.18	0.195	9.95	0.00
Total	1.954	100	
Normalise total SS mass to large column volume			2.76

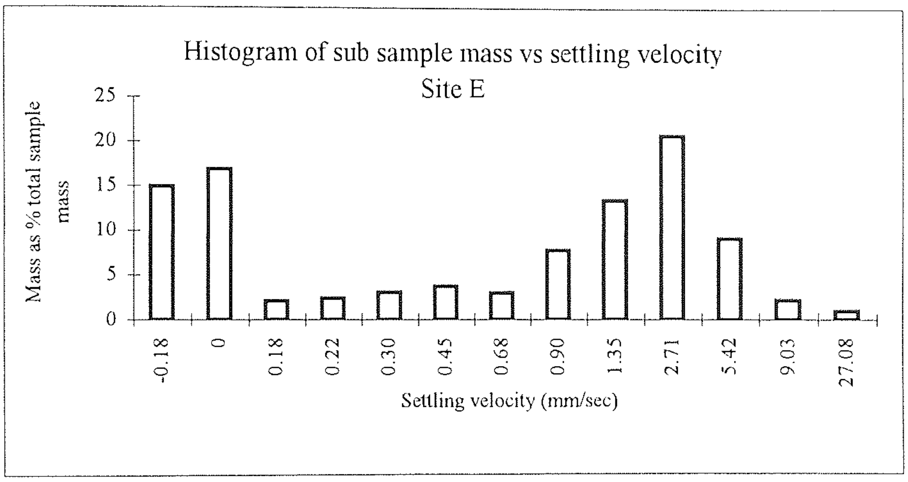

SV P's site D
Sample 1
Sample 2
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs)
Log (mm/sec)

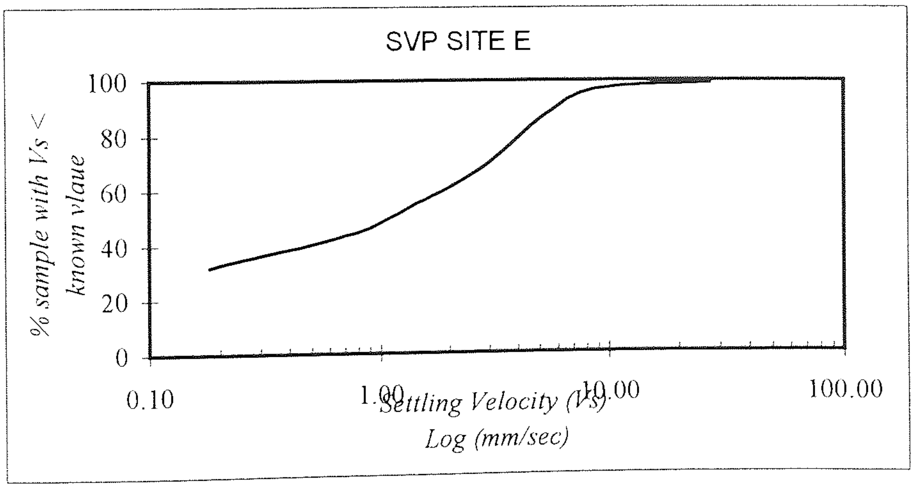

Histogram of sub sample mass vs settling velocity
Site D
Mass as % total sample mass
50
40
30
20
10
0
-0.18
0
0.18
0.22
0.30
0.45
0.68
0.90
1.35
2.71
5.42
9.03
27.08
Settling velocity (mm/sec)


MEAN SVP SITE D
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs)
Log (mm/sec)

SITE E

SETTLING VELOCITY mm/sec	MASS SS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.013	1.00	99.00
9.03	0.028	2.14	96.86
5.42	0.119	9.11	87.75
2.71	0.27	20.67	67.08
1.35	0.174	13.32	53.75
0.90	0.101	7.73	46.02
0.68	0.039	2.99	43.03
0.45	0.049	3.75	39.28
0.30	0.04	3.06	36.22
0.22	0.031	2.37	33.84
0.18	0.027	2.07	31.78
-0.2<R>0.2	0.22	16.85	14.93
<-0.18	0.195	14.93	
Total	1.306	100.00	
Normalise total SS mass to large column volume			1.78





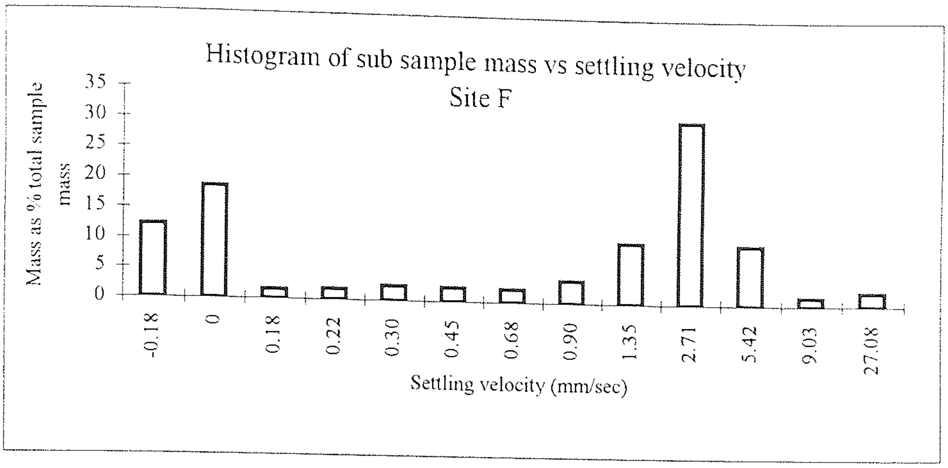
SITE F

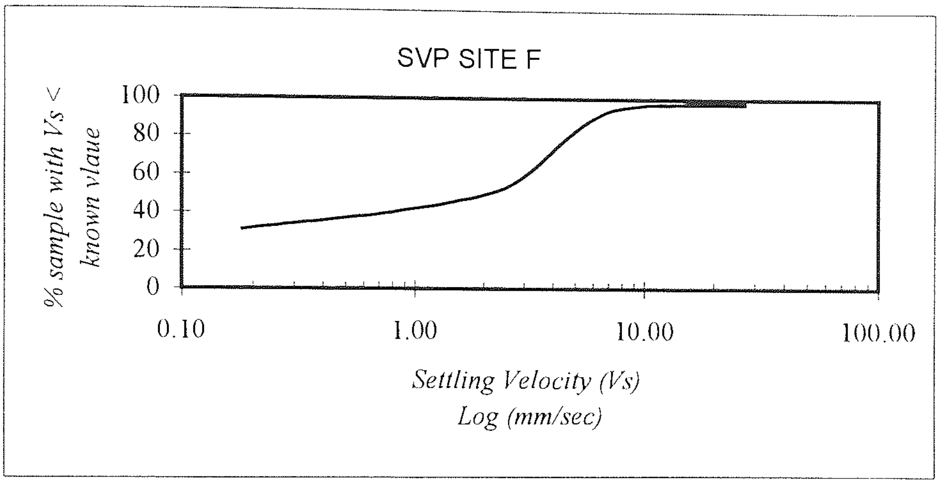
Sample 1

SETTLING VELOCITY mm/sec	MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.022	2.34	97.66
9.03	0.014	1.49	96.18
5.42	0.095	10.08	86.09
2.71	0.289	30.68	55.41
1.35	0.097	10.30	45.12
0.90	0.036	3.82	41.30
0.68	0.021	2.23	39.07
0.45	0.022	2.34	36.73
0.30	0.023	2.44	34.29
0.22	0.017	1.80	32.48
0.18	0.015	1.59	30.89
-0.18<R>0.18	0.176	18.68	12.21
<-0.18	0.115	12.21	0.00
Total	0.942	100.00	
Normalise total SS mass to large column volume			1.33

Sample 2

SETTLING VELOCITY mm/sec	MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.012	1.96	98.04
9.03	0.013	2.12	95.92
5.42	0.011	1.80	94.12
2.71	0.14	22.88	71.24
1.35	0.197	32.19	39.05
0.90	0.059	9.64	29.41
0.68	0.029	4.74	24.67
0.45	...	...	...
0.30	....	...	...
0.22	...	...	...
0.18	...	...	...
-0.18<R>0.18	0.151	24.67	0.00
<-0.18	...	...	...
Total	0.612	100	
Normalise total SS mass to large column volume			...


Histogram of sub sample mass vs settling velocity
Site F
Mass as % total sample mass
35
30
25
20
15
10
5
0
-0.18
0
0.18
0.22
0.30
0.45
0.68
0.90
1.35
2.71
5.42
9.03
27.08
Settling velocity (mm/sec)


SVP SITE F
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs)
Log (mm/sec)

SITE G

Sample 1

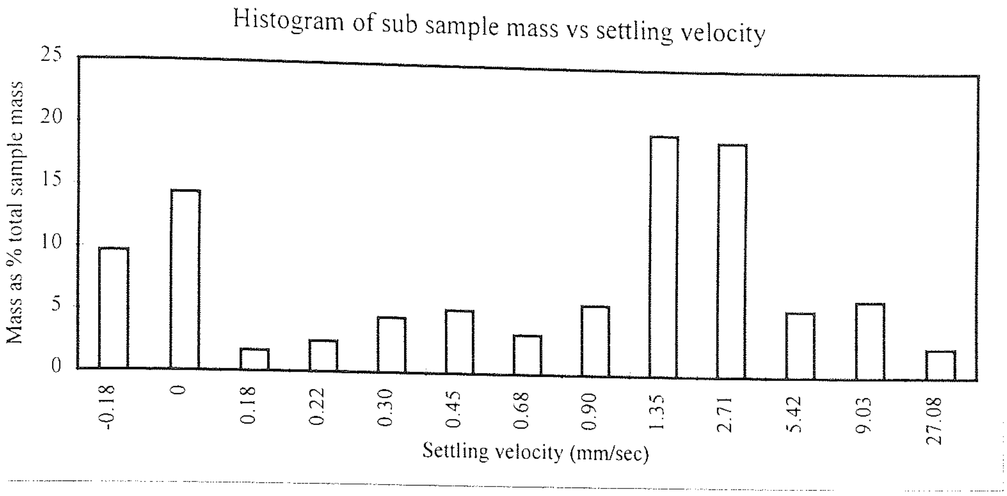
SETTLING VELOCITY mm/sec	MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.06	2.54	97.46
9.03	0.048	2.03	95.43
5.42	0.062	2.62	92.81
2.71	0.479	20.25	72.56
1.35	0.602	25.45	47.10
0.90	0.153	6.47	40.63
0.68	0.077	3.26	37.38
0.45	0.141	5.96	31.42
0.30	0.129	5.45	25.96
0.22	0.076	3.21	22.75
0.18	0.051	2.16	20.59
-0.18<R>0.18	0.199	8.41	12.18
<-0.18	0.288	12.18	
Total	2.365	100.00	
Normalise mass to large column volume			3.340

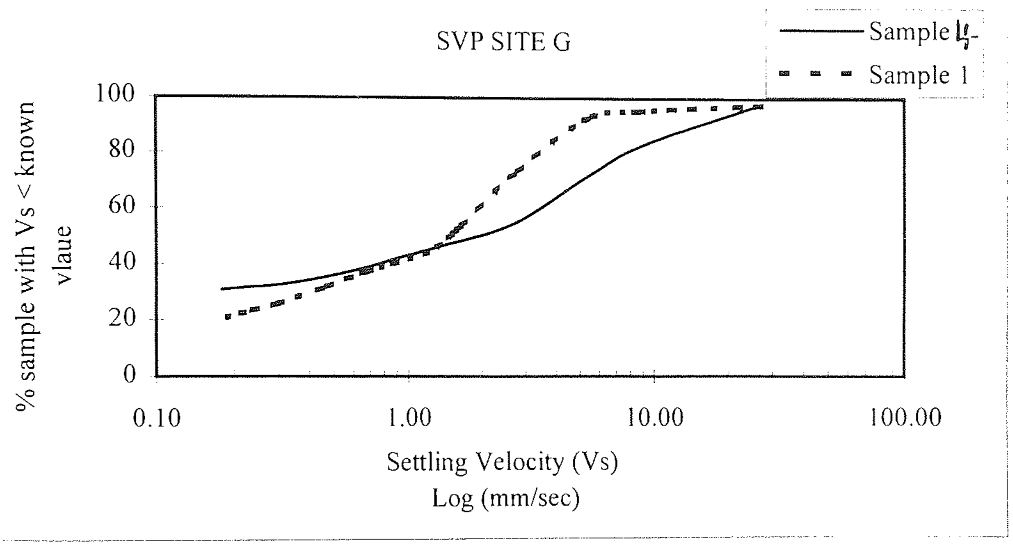
Sample 4

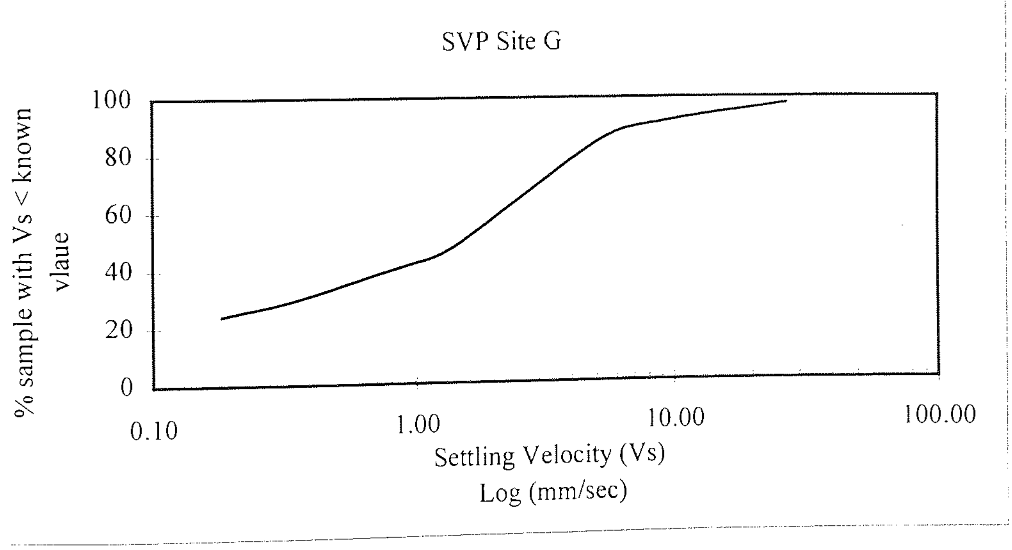
SETTLING VELOCITY mm/sec	MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.025	2.12	97.88
9.03	0.176	14.90	82.98
5.42	0.133	11.26	71.72
2.71	0.201	17.02	54.70
1.35	0.098	8.30	46.40
0.90	0.051	4.32	42.08
0.68	0.038	3.22	38.87
0.45	0.043	3.64	35.22
0.30	0.03	2.54	32.68
0.22	0.012	1.02	31.67
0.18	0.008	0.68	30.99
-0.18<R>0.18	0.311	26.33	4.66
<-0.18	0.055	4.66	0.00
Total	1.181	100.00	
Normalise mass to large column volume			1.668

MEAN SVP

SETTLING VELOCITY mm/sec	MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.0425	2.40	97.60
9.03	0.112	6.32	91.29
5.42	0.0975	5.50	85.79
2.71	0.34	19.18	66.61
1.35	0.35	19.74	46.87
0.90	0.102	5.75	41.12
0.68	0.0575	3.24	37.87
0.45	0.092	5.19	32.68
0.30	0.0795	4.48	28.20
0.22	0.044	2.48	25.72
0.18	0.0295	1.66	24.06
-0.18<R>0.18	0.255	14.38	9.67
<-0.18	0.1715	9.67	
Total	1.773	100.00	
Normalise mass to large column volume			2.504


Histogram of sub sample mass vs settling velocity
Mass as % total sample mass
25
20
15
10
5
0
-0.18
0
0.18
0.22
0.30
0.45
0.68
0.90
1.35
2.71
5.42
9.03
27.08
Settling velocity (mm/sec)


SVP SITE G
Sample 4
Sample 1
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs)
Log (mm/sec)


SVP Site G
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs)
Log (mm/sec)

Sample 2

SETTLING VELOCITY mm/sec	MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.032	1.77	98.23
9.03	0.032	1.77	96.47
5.42	0.036	1.99	94.48
2.71	0.146	8.06	86.42
1.35	0.336	18.54	67.88
0.90	0.104	5.74	62.14
0.68	0.083	4.58	57.56
0.45	0.135	7.45	50.11
0.30	0.138	7.62	42.49
0.22	0.069	3.81	38.69
0.18	0.065	3.59	35.10
-0.18<R>0.18	0.316	17.44	17.66
<-0.18	0.32	17.66	
Total	1.812	100.00	

Normalise total SS mass to large column volume 2.559

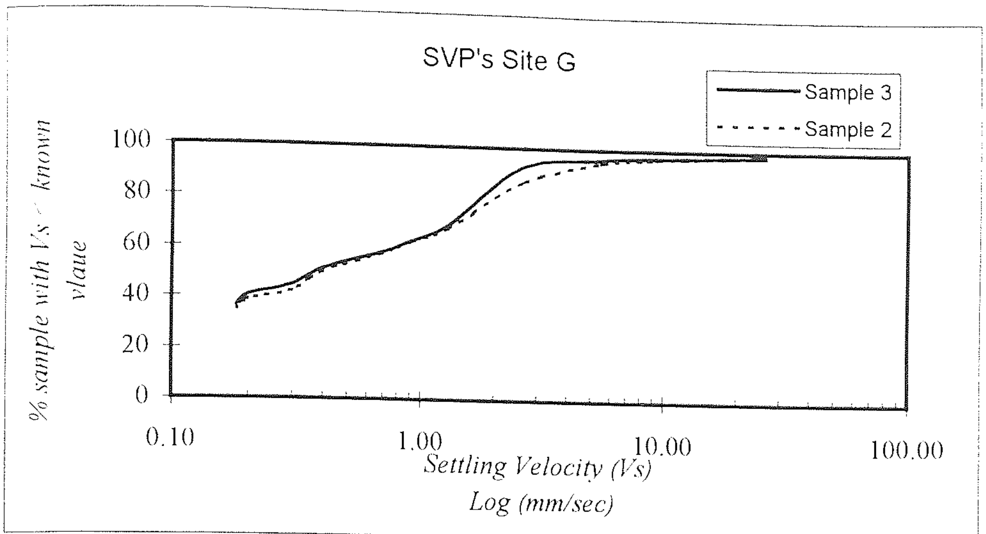
Sample 3

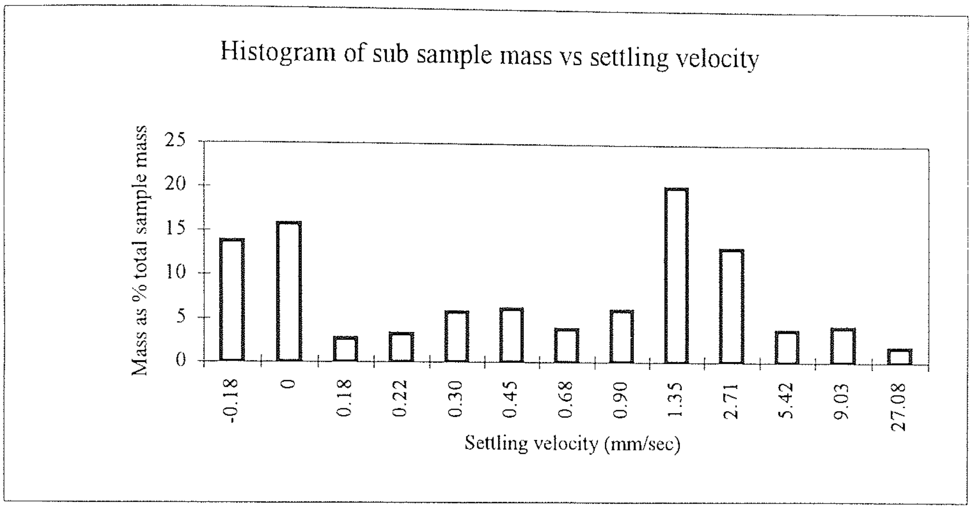
SETTLING VELOCITY mm/sec	MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.024	1.81	98.19
9.03	0.014	1.06	97.13
5.42	0.015	1.13	96.00
2.71	0.048	3.63	92.37
1.35	0.308	23.26	69.11
0.90	0.091	6.87	62.24
0.68	0.056	4.23	58.01
0.45	0.089	6.72	51.28
0.30	0.086	6.50	44.79
0.22	0.057	4.31	40.48
0.18	0.054	4.08	36.40
-0.18<R>0.18	0.227	17.15	19.26
<-0.18	0.255	19.26	
Total	1.324	100.00	

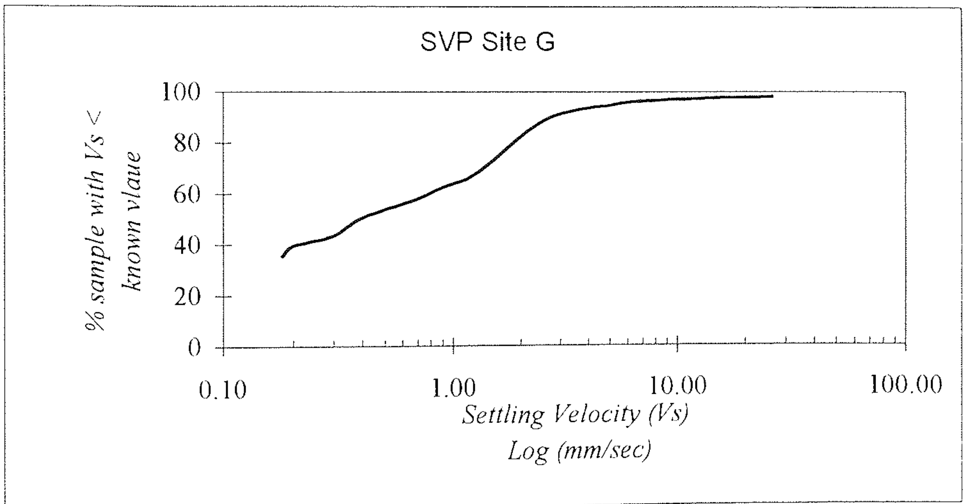
Normalise total SS mass to large column volume 1.870

MEAN SVP

SETTLING VELOCITY mm/sec	MEAN MASS SS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.028	1.79	98.21
9.03	0.023	1.47	96.75
5.42	0.026	1.63	95.12
2.71	0.097	6.19	88.93
1.35	0.322	20.54	68.40
0.90	0.098	6.22	62.18
0.68	0.070	4.43	57.75
0.45	0.112	7.14	50.61
0.30	0.112	7.14	43.46
0.22	0.063	4.02	39.45
0.18	0.060	3.79	35.65
-0.18<R>0.18	0.272	17.32	18.34
<-0.18	0.288	18.34	0.00
Total	1.568	100.00	
Normalise total SS mass to large column volume			2.21

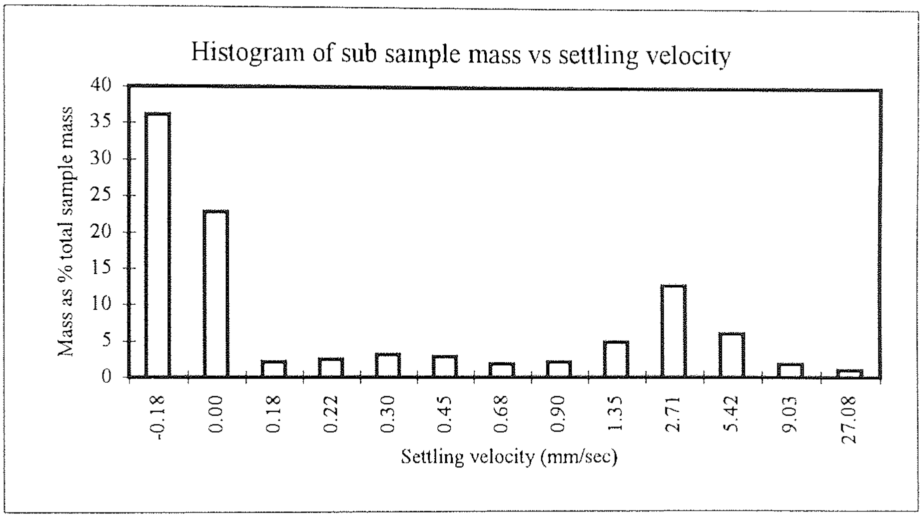

SVP's Site G
Sample 3
Sample 2
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs)
Log (mm/sec)

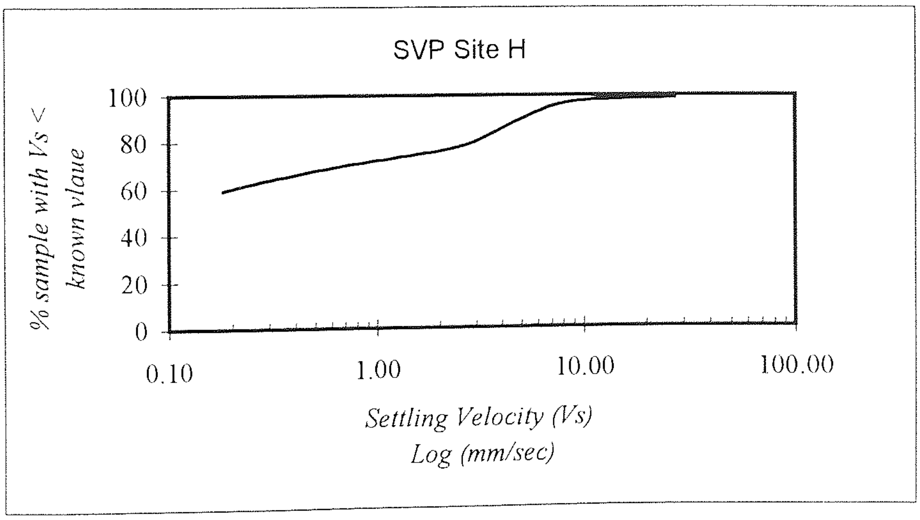

Histogram of sub sample mass vs settling velocity
Mass as % total sample mass
25
20
15
10
5
0
-0.18
0
0.18
0.22
0.30
0.45
0.68
0.90
1.35
2.71
5.42
9.03
27.08
Settling velocity (mm/sec)


SVP Site G
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs)
Log (mm/sec)

SITE H

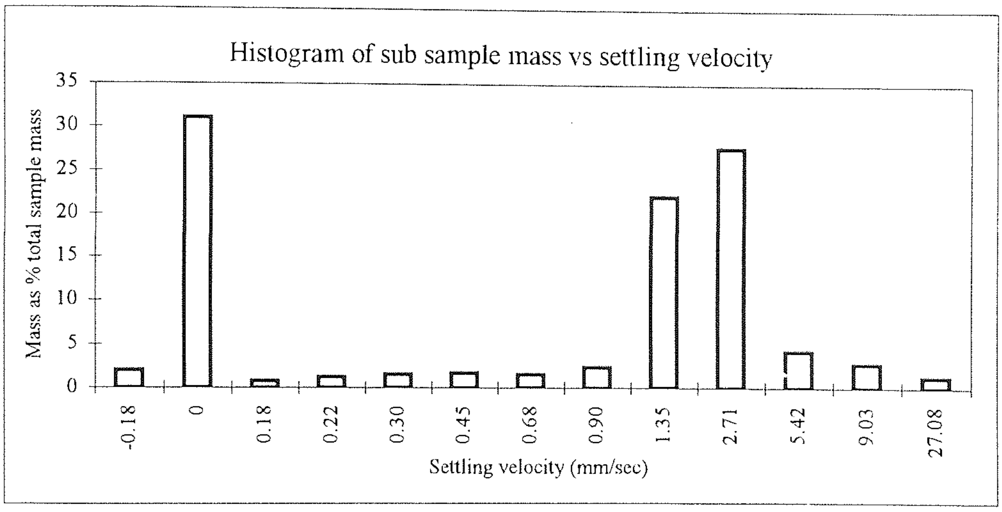
SETTLING VELOCITY mm/sec	MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.009	1.02	98.98
9.03	0.016	1.81	97.18
5.42	0.054	6.10	91.07
2.71	0.112	12.66	78.42
1.35	0.043	4.86	73.56
0.90	0.019	2.15	71.41
0.68	0.016	1.81	69.60
0.45	0.025	2.82	66.78
0.30	0.028	3.16	63.62
0.22	0.022	2.49	61.13
0.18	0.019	2.15	58.98
-0.18<R>0.18	0.202	22.82	36.16
<-0.18	0.32	36.16	
Total	0.885	100.00	
Normalise mass to large column volume			1.206

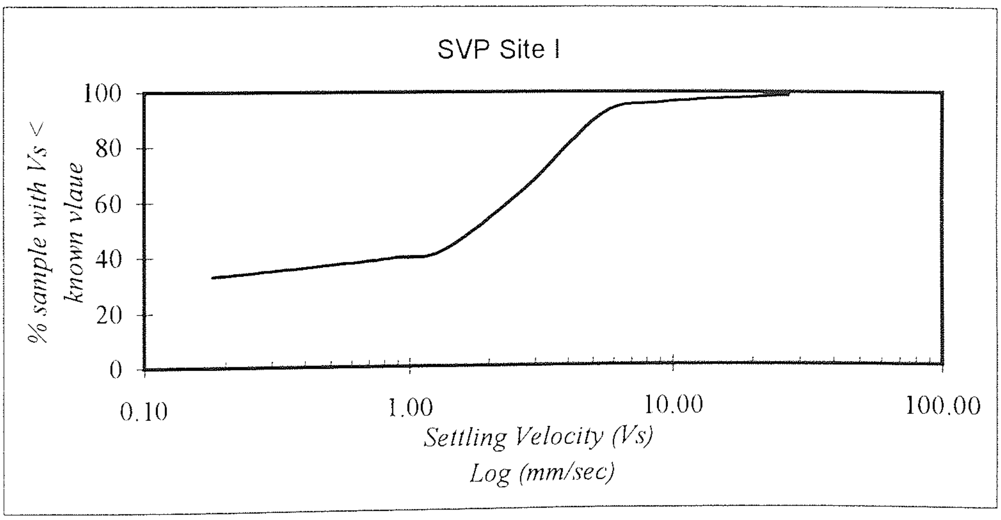




SITE I

SETTLING VELOCITY mm/sec	MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.024	1.21	98.79
9.03	0.055	2.76	96.03
5.42	0.084	4.22	91.81
2.71	0.55	27.62	64.19
1.35	0.439	22.05	42.14
0.90	0.047	2.36	39.78
0.68	0.03	1.51	38.27
0.45	0.034	1.71	36.56
0.30	0.03	1.51	35.06
0.22	0.025	1.26	33.80
0.18	0.015	0.75	33.05
-0.18<R>0.18	0.618	31.04	2.01
<-0.18	0.04	2.01	0.00
Total	1.991	100.00	
Normalise total SS mass to large column volume			2.714





SITE J

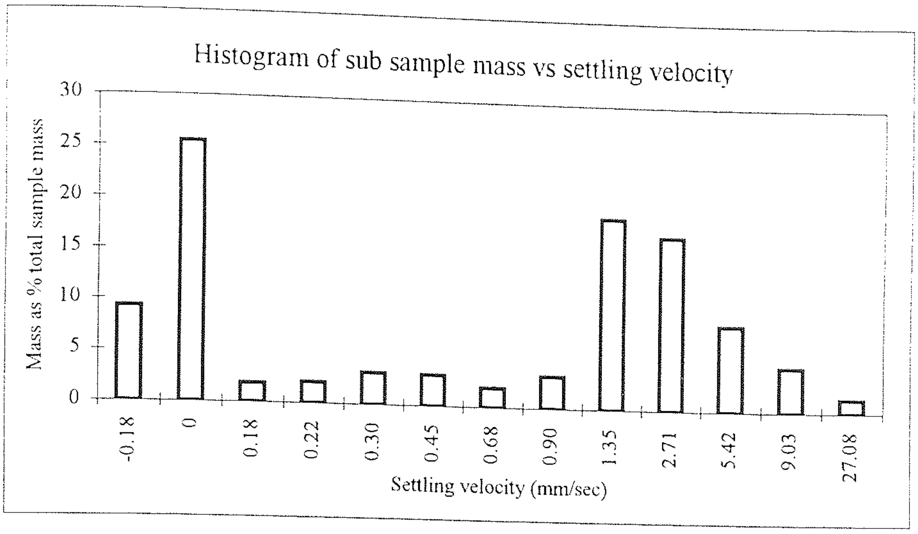
Sample1

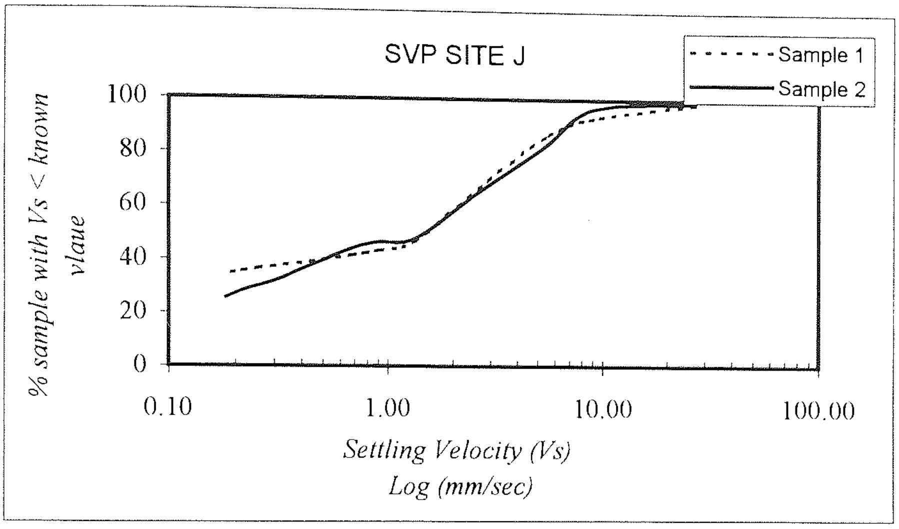
SETTLING VELOCITY mm/sec	MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.086	1.60	98.40
9.03	0.294	5.48	92.91
5.42	0.369	6.88	86.03
2.71	0.990	18.46	67.57
1.35	1.103	20.57	47.01
0.90	0.210	3.92	43.09
0.68	0.097	1.81	41.28
0.45	0.112	2.09	39.19
0.30	0.106	1.98	37.22
0.22	0.090	1.68	35.54
0.18	0.079	1.47	34.07
-0.18<R>0.18	1.460	27.22	6.84
<-0.18	0.367	6.84	0.00
Total	5.363	100.00	
Normalise total SS mass to large column volume			7.575

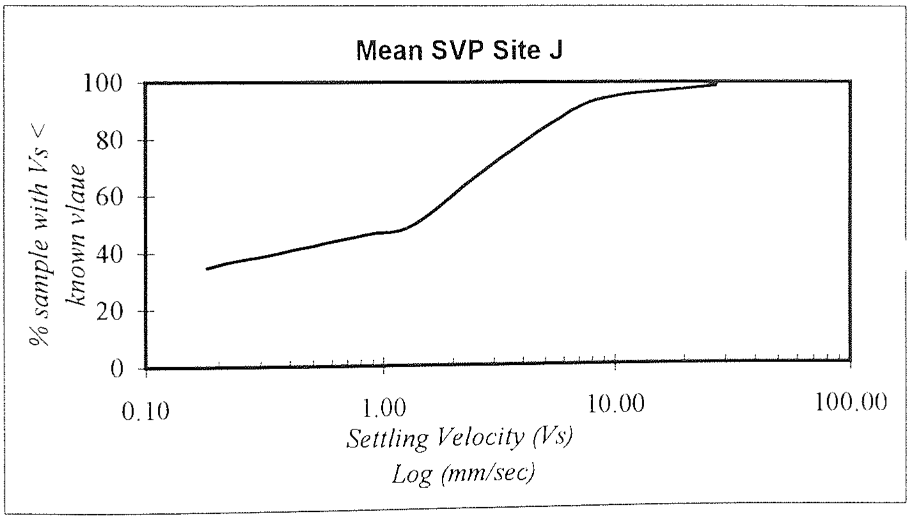
Sample 2

SETTLING VELOCITY mm/sec	MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.022	1.02	98.98
9.03	0.055	2.54	96.45
5.42	0.299	13.80	82.65
2.71	0.364	16.80	65.85
1.35	0.387	17.86	47.99
0.90	0.037	1.71	46.29
0.68	0.053	2.45	43.84
0.45	0.126	5.81	38.02
0.30	0.139	6.41	31.61
0.22	0.070	3.23	28.38
0.18	0.065	3.00	25.38
-0.18<R>0.18	0.550	25.38	
<-0.18	...	...	
Total	2.167	100.00	
Normalise total SS mass to large column volume			3.061

MEAN SVP SETTLING VELOCITY mm/sec	MEAN MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.054	1.37	98.63
9.03	0.175	4.42	94.21
5.42	0.334	8.46	85.75
2.71	0.677	17.15	68.61
1.35	0.745	18.87	49.74
0.90	0.124	3.13	46.61
0.68	0.075	1.90	44.71
0.45	0.119	3.01	41.70
0.30	0.123	3.10	38.60
0.22	0.080	2.03	36.57
0.18	0.072	1.82	34.75
-0.18<R>0.18	1.005	25.45	9.29
<-0.18	0.367	9.29	0.00
Total	3.949	100.00	
Normalise total SS mass to large column volume			5.577


Histogram of sub sample mass vs settling velocity
Mass as % total sample mass
30
25
20
15
10
5
0
-0.18
0
0.18
0.22
0.30
0.45
0.68
0.90
1.35
2.71
5.42
9.03
27.08
Settling velocity (mm/sec)


SVP SITE J
Sample 1
Sample 2
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs)
Log (mm/sec)


Mean SVP Site J
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs)
Log (mm/sec)

SITE K

Sample 1

SETTLING VELOCITY mm/sec	MEAN MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.028	0.77	99.23
9.03	0.03	0.82	98.41
5.42	0.291	7.97	90.45
2.71	0.038	1.04	89.41
1.35	0.867	23.73	65.67
0.90	0.606	16.59	49.08
0.68	0.162	4.43	44.65
0.45	0.659	18.04	26.61
0.30	0.11	3.01	23.60
0.22	0.062	1.70	21.90
0.18	0.057	1.56	20.34
-0.18<R>0.18	0.407	11.14	9.20
<-0.18	0.336	9.20	
Total	3.653	100.00	
Normalise total SS mass to large column volume			5.160

Sample 2

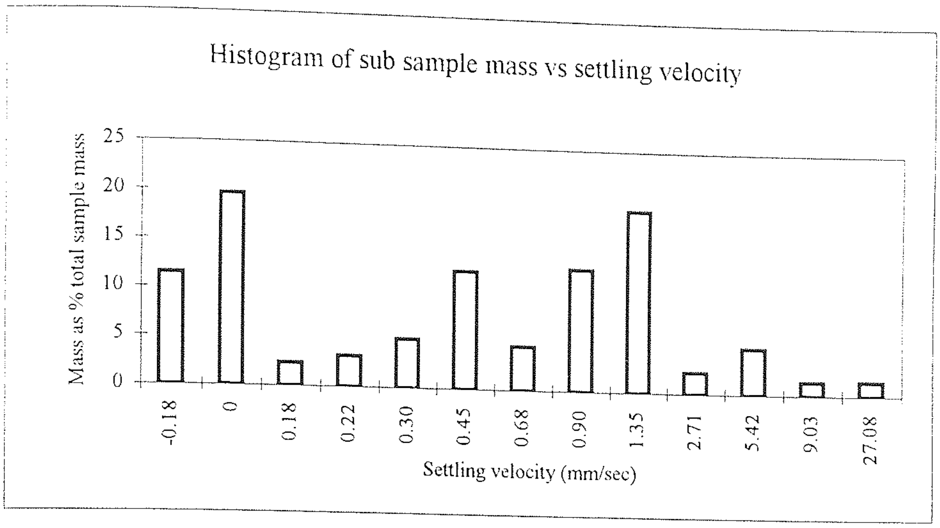
SETTLING VELOCITY mm/sec	MEAN MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.080	2.23	97.77
9.03	0.073	2.04	95.73
5.42	0.072	2.01	93.72
2.71	0.124	3.46	90.25
1.35	0.551	15.39	74.86
0.90	0.344	9.61	65.25
0.68	0.169	4.72	60.53
0.45	0.240	6.70	53.83
0.30	0.236	6.59	47.23
0.22	0.152	4.25	42.99
0.18	0.104	2.91	40.08
-0.18<R>0.18	0.986	27.54	12.54
<-0.18	0.449	12.54	
Total	3.580	100.00	
Normalise total SS mass to large column volume			5.057

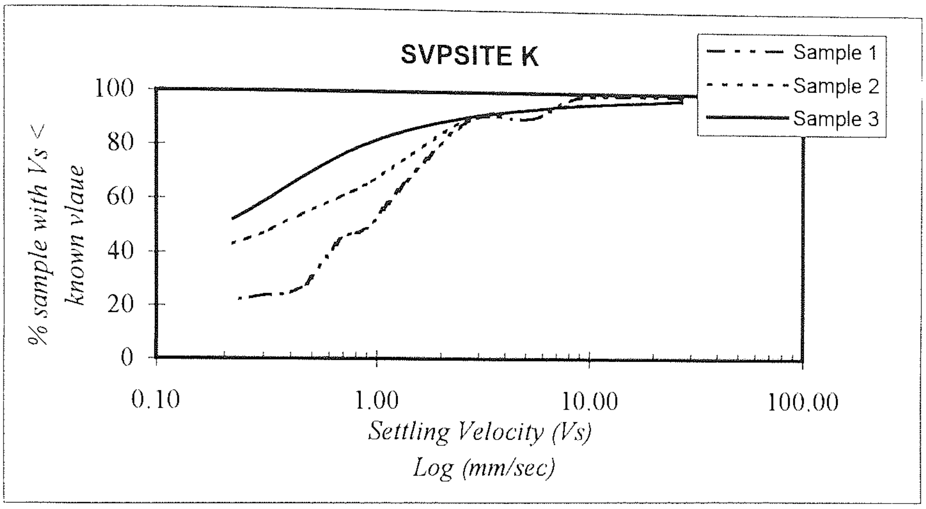
Sample 3

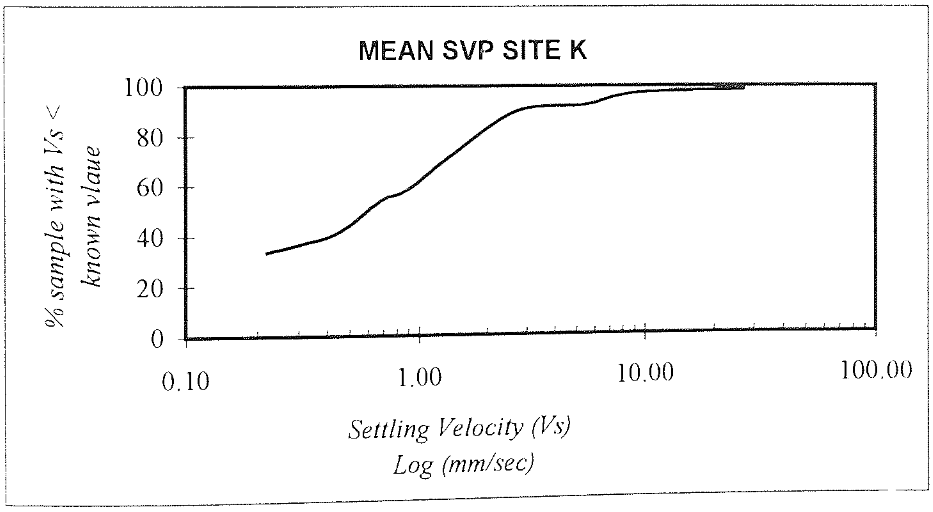
SETTLING VELOCITY mm/sec	MEAN MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.010	2.44	97.56
9.03	0.008	1.96	95.60
5.42	0.007	1.71	93.89
2.71	0.013	3.18	90.71
1.35	0.022	5.38	85.33
0.90	0.021	5.13	80.20
0.68	0.018	4.40	75.79
0.45	0.034	8.31	67.48
0.30	0.036	8.80	58.68
0.22	0.027	6.60	52.08
0.18	0.019	4.65	47.43
-0.18<R>0.18	0.105	25.67	21.76
<-0.18	0.089	21.76	
Total	0.409	100.00	
Normalise total SS mass to large column volume			0.578

MEAN SVP

SETTLING VELOCITY mm/sec	MEAN MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.039	1.54	98.46
9.03	0.037	1.45	97.00
5.42	0.123	4.84	92.16
2.71	0.058	2.29	89.87
1.35	0.480	18.84	71.03
0.90	0.324	12.71	58.32
0.68	0.116	4.57	53.76
0.45	0.311	12.21	41.55
0.30	0.127	5.00	36.55
0.22	0.080	3.15	33.39
0.18	0.060	2.36	31.04
-0.18<R>0.18	0.499	19.60	11.44
<-0.18	0.291	11.44	
Total	2.547	100.00	
Normalise total SS mass to large column volume			3.598


Histogram of sub sample mass vs settling velocity
Mass as % total sample mass
25
20
15
10
5
0
-0.18
0
0.18
0.22
0.30
0.45
0.68
0.90
1.35
2.71
5.42
9.03
27.08
Settling velocity (mm/sec)


SVPSITE K
Sample 1
Sample 2
Sample 3
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs)
Log (mm/sec)


MEAN SVP SITE K
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs)
Log (mm/sec)

SITE L

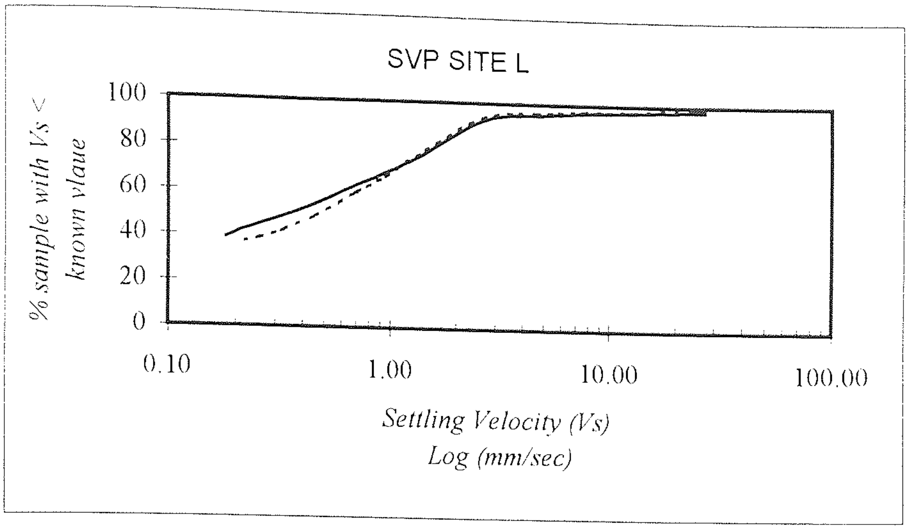
SAMPLE 1

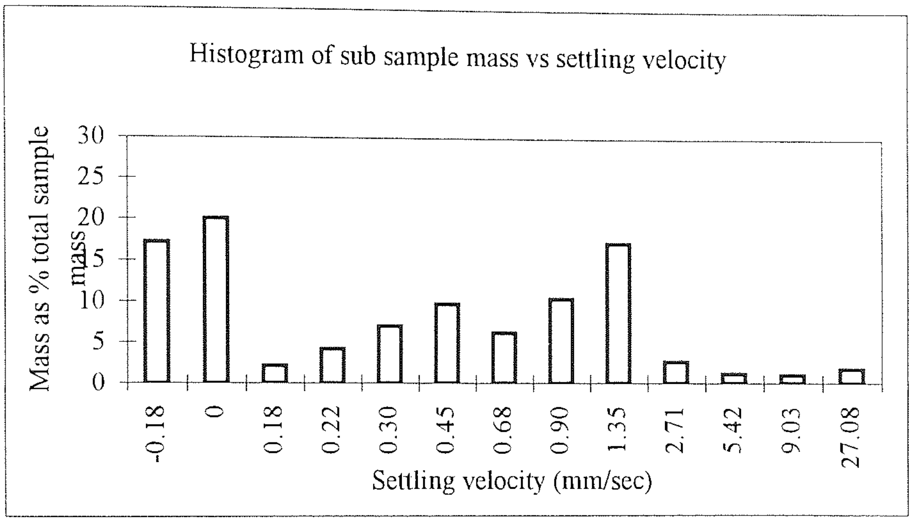
SETTLING VELOCITY mm/sec	MASS SS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.015	1.57	98.43
9.03	0.009	0.94	97.49
5.42	0.01	1.05	96.44
2.71	0.024	2.51	93.93
1.35	0.165	17.26	76.67
0.90	0.109	11.40	65.27
0.68	0.062	6.49	58.79
0.45	0.1	10.46	48.33
0.30	0.069	7.22	41.11
0.22	0.039	4.08	37.03
0.18	...	...	...
-0.18<R>0.18	0.2	20.92	16.11
<-0.18	0.154	16.11	0.00
Total mass	0.956	100.00	
Total mass normalised to large column volume			1.350

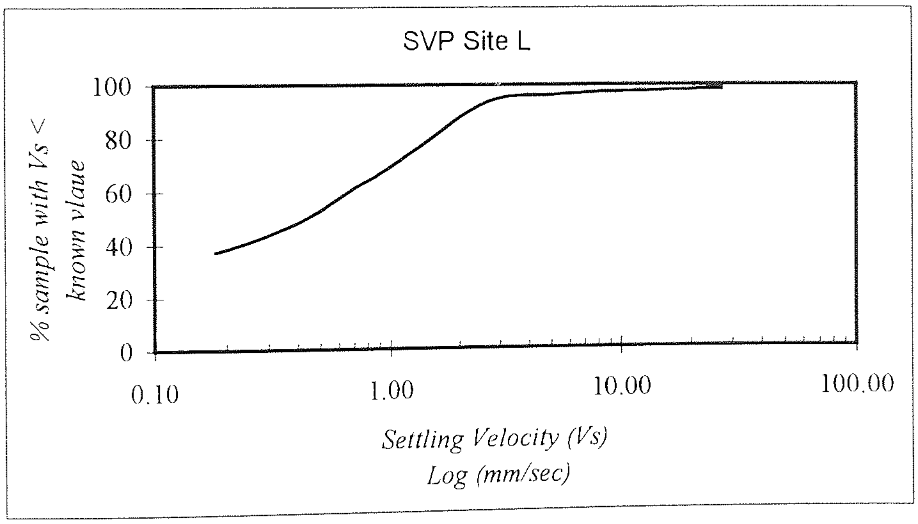
SAMPLE 2

SETTLING VELOCITY mm/sec	MASS SS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.017	2.04	97.96
9.03	0.009	1.08	96.88
5.42	0.011	1.32	95.55
2.71	0.024	2.88	92.67
1.35	0.143	17.19	75.48
0.90	0.068	8.17	67.31
0.68	0.045	5.41	61.90
0.45	0.068	8.17	53.73
0.30	0.055	6.61	47.12
0.22	0.037	4.45	42.67
0.18	0.030	3.61	39.06
-0.18<R>0.18	0.156	18.75	20.31
<-0.18	0.169	20.31	0.00
Total mass	0.832	100.00	
Total mass normalised to large column volume			1.175

SETTLING VELOCITY mm/sec	**MEAN SVP** MEAN MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.024	1.69	98.31
9.03	0.014	0.97	97.33
5.42	0.016	1.12	96.21
2.71	0.036	2.60	93.62
1.35	0.237	17.05	76.57
0.90	0.143	10.31	66.26
0.68	0.085	6.09	60.17
0.45	0.134	9.66	50.50
0.30	0.097	6.96	43.55
0.22	0.058	4.15	39.40
0.18	0.030	2.16	37.24
-0.18<R>0.18	0.278	20.04	17.20
<-0.18	0.239	17.20	0.00
Total mass	1.387	100.00	
Total mass normalised to large column volume			1.959


SVP SITE L
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs) Log (mm/sec)


Histogram of sub sample mass vs settling velocity
Mass as % total sample mass
30
25
20
15
10
5
0
-0.18
0
0.18
0.22
0.30
0.45
0.68
0.90
1.35
2.71
5.42
9.03
27.08
Settling velocity (mm/sec)


SVP Site L
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs) Log (mm/sec)

SITE M

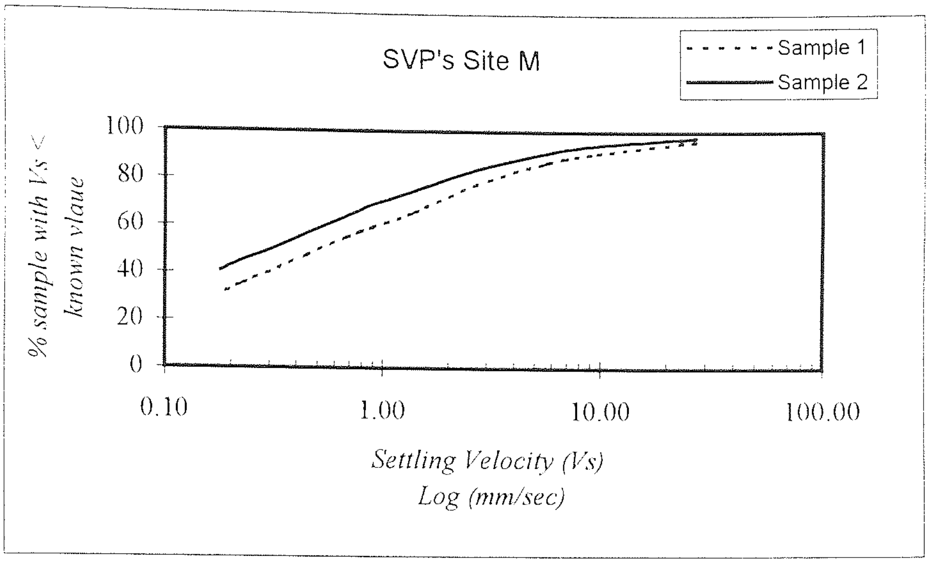
SAMPLE 1

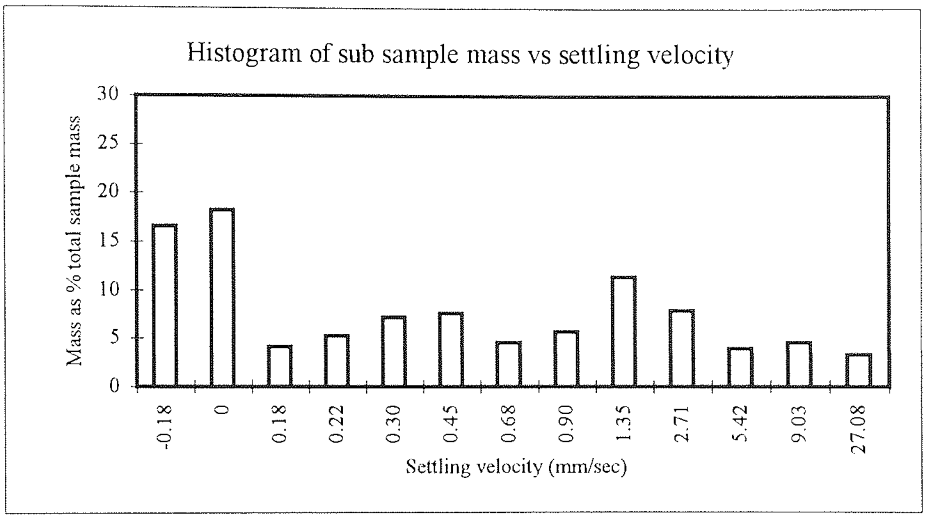
SETTLING VELOCITY mm/sec	MASS SS (g)	% OF TOTAL SS	% SAMPLE < NOWN VALUE
27.08	0.045	3.89	96.11
9.03	0.062	5.36	90.74
5.42	0.050	4.33	86.42
2.71	0.099	8.56	77.85
1.35	0.145	12.54	65.31
0.90	0.067	5.80	59.52
0.68	0.049	4.24	55.28
0.45	0.090	7.79	47.49
0.30	0.082	7.09	40.40
0.22	0.062	5.36	35.03
0.18	0.051	4.41	30.62
-0.18<R>0.18	0.200	17.30	13.32
<-0.18	0.154	13.32	0.00
Total mass	1.156	100.00	
Total mass normalised to large column volume			1.633

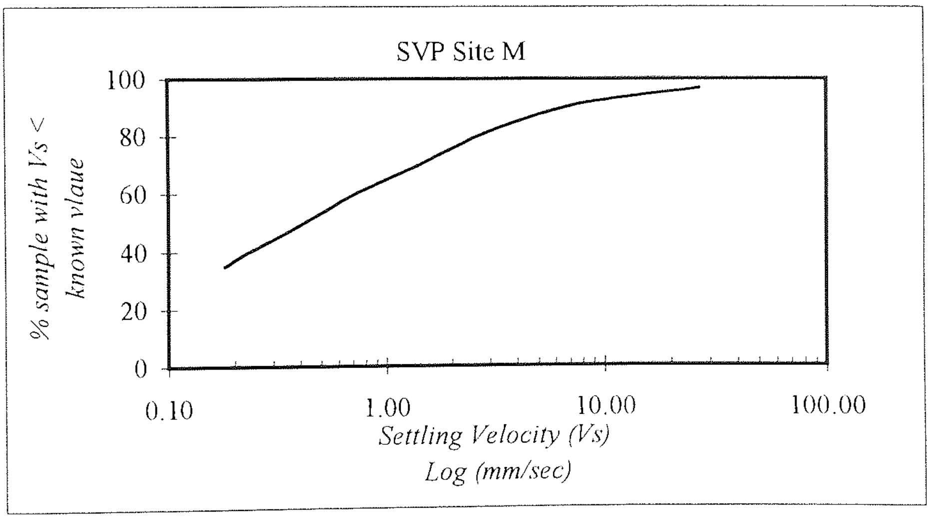
SAMPLE 2

SETTLING VELOCITY mm/sec	MASS SS (g)	% OF TOTAL SS	% SAMPLE < NOWN VALUE
27.08	0.019	2.39	97.61
9.03	0.027	3.40	94.21
5.42	0.027	3.40	90.82
2.71	0.054	6.79	84.03
1.35	0.076	9.56	74.47
0.90	0.043	5.41	69.06
0.68	0.04	5.03	64.03
0.45	0.057	7.17	56.86
0.30	0.057	7.17	49.69
0.22	0.04	5.03	44.65
0.18	0.03	3.77	40.88
-0.18<R>0.18	0.156	19.62	21.26
<-0.18	0.169	21.26	0.00
Total mass	0.795	100.00	
Total mass normalised to large column volume			1.123

SETTLING VELOCITY mm/sec	**MEAN SVP** MEAN MASS (g)	% OF TOTAL SS	% SAMPLE < NOWN VALUE
27.08	0.0320	3.28	96.72
9.03	0.0445	4.56	92.16
5.42	0.0385	3.95	88.21
2.71	0.0765	7.84	80.37
1.35	0.1105	11.33	69.04
0.90	0.0550	5.64	63.40
0.68	0.0445	4.56	58.84
0.45	0.0735	7.53	51.31
0.30	0.0695	7.12	44.18
0.22	0.0510	5.23	38.95
0.18	0.0405	4.15	34.80
-0.18<R>0.18	0.1780	18.25	16.56
<-0.18	0.1615	16.56	0.00
Total	0.9755	100	
Total mass normalised to large column volume			1.378


SVP's Site M
Sample 1
Sample 2
100
80
60
40
20
0
% sample with Vs < known vlaue
0.10
1.00
10.00
100.00
Settling Velocity (Vs) Log (mm/sec)


Histogram of sub sample mass vs settling velocity
30
25
20
15
10
5
0
Mass as % total sample mass
-0.18
0
0.18
0.22
0.30
0.45
0.68
0.90
1.35
2.71
5.42
9.03
27.08
Settling velocity (mm/sec)


SVP Site M
100
80
60
40
20
0
% sample with Vs < known vlaue
0.10
1.00
10.00
100.00
Settling Velocity (Vs) Log (mm/sec)

SITE N

Sample 1

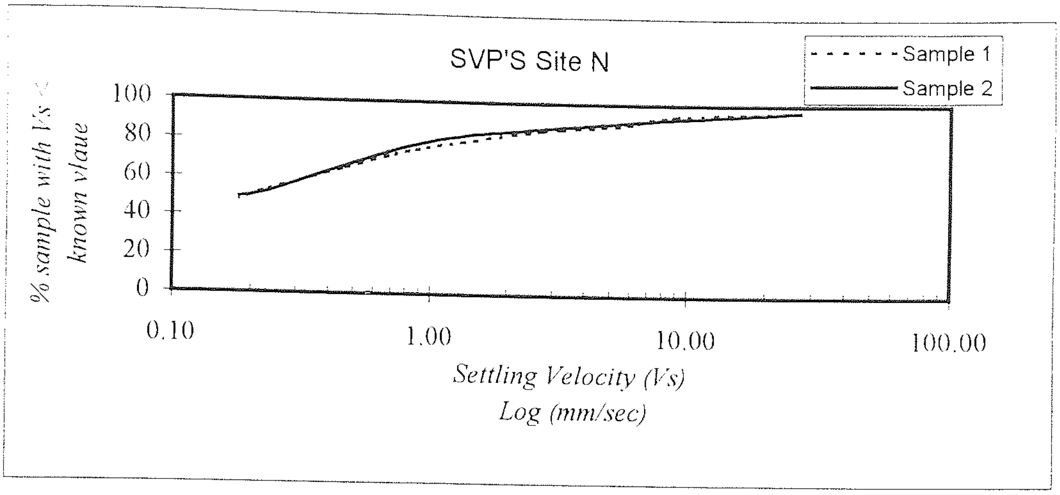
SETTLING VELOCITY mm/sec	MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.008	2.96	97.04
9.03	0.008	2.96	94.07
5.42	0.014	5.19	88.89
2.71	0.008	2.96	85.93
1.35	0.017	6.30	79.63
0.90	0.011	4.07	75.56
0.68	0.011	4.07	71.48
0.45	0.018	6.67	64.81
0.30	0.019	7.04	57.78
0.22	0.014	5.19	52.59
0.18	0.012	4.44	48.15
-0.18<R>0.18	0.07	25.93	22.22
<-0.18	0.0600	22.22	
Total mass	0.27	100	
Total mass normalised to large column volume			0.381

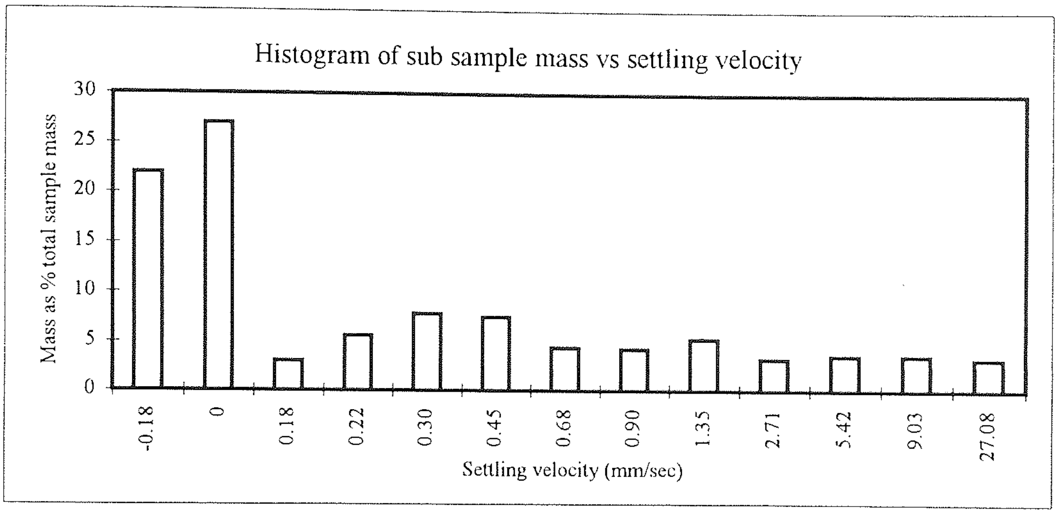
Sample 2

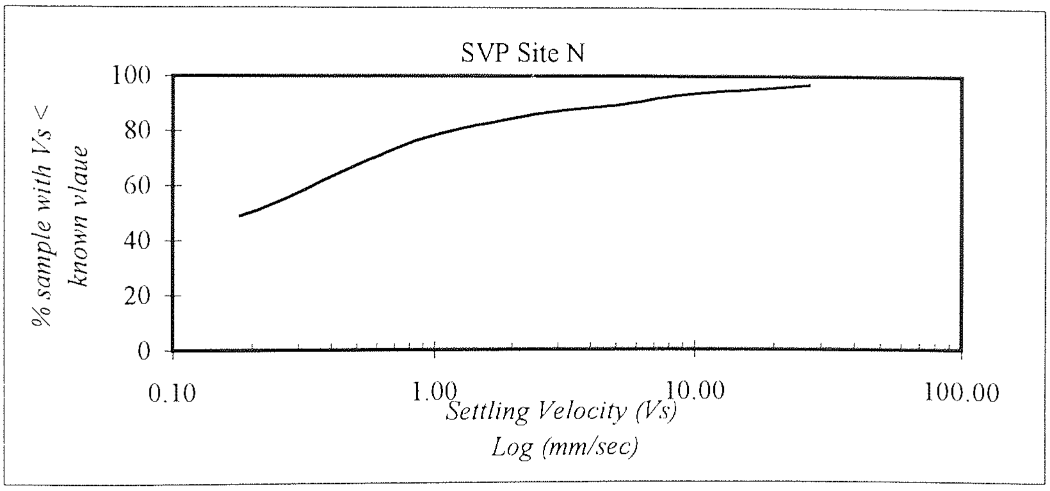
SETTLING VELOCITY mm/sec	MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.011	3.41	96.59
9.03	0.013	4.02	92.57
5.42	0.007	2.17	90.40
2.71	0.011	3.41	87.00
1.35	0.014	4.33	82.66
0.90	0.014	4.33	78.33
0.68	0.015	4.64	73.68
0.45	0.026	8.05	65.63
0.30	0.027	8.36	57.28
0.22	0.019	5.88	51.39
0.18	0.006	1.86	49.54
-0.18<R>0.18	0.09	27.86	21.67
<-0.18	0.07	21.67	
Total mass	0.323	100.00	
Total mass normalised to large column volume			0.456

MEAN SVP

SETTLING VELOCITY mm/sec	MEAN MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.010	3.20	96.80
9.03	0.011	3.54	93.25
5.42	0.011	3.54	89.71
2.71	0.010	3.20	86.51
1.35	0.016	5.23	81.28
0.90	0.013	4.22	77.07
0.68	0.013	4.38	72.68
0.45	0.022	7.42	65.26
0.30	0.023	7.76	57.50
0.22	0.017	5.56	51.94
0.18	0.009	3.04	48.90
-0.18<R>0.18	0.080	26.98	21.92
<-0.18	0.065	21.92	
Total	0.297	100.00	
Total mass normalised to large column volume			0.419

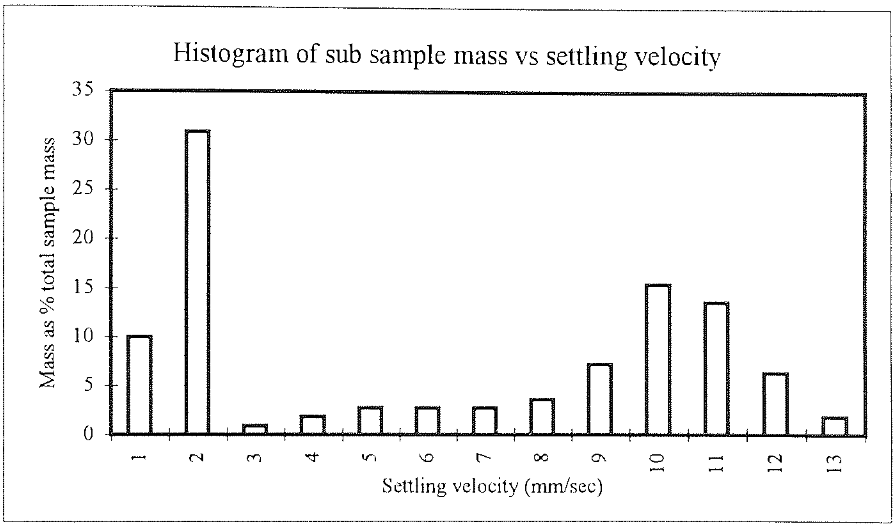

SVP'S Site N
Sample 1
Sample 2
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs)
Log (mm/sec)

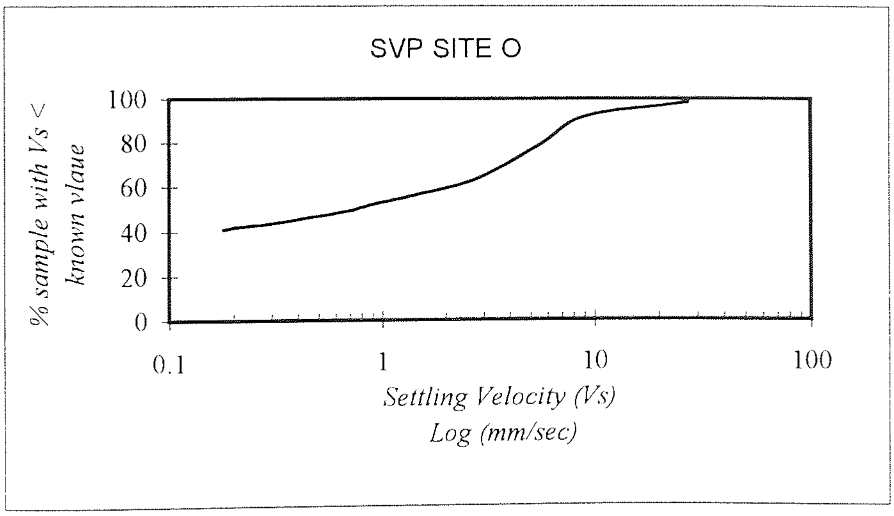

Histogram of sub sample mass vs settling velocity
Mass as % total sample mass
30
25
20
15
10
5
0
-0.18
0
0.18
0.22
0.30
0.45
0.68
0.90
1.35
2.71
5.42
9.03
27.08
Settling velocity (mm/sec)


SVP Site N
% sample with Vs < known vlaue
100
80
60
40
20
0
0.10
1.00
10.00
100.00
Settling Velocity (Vs)
Log (mm/sec)

SITE O

SETTLING VELOCITY mm/sec	MASS (g)	% OF TOTAL SS	% SAMPLE < KNOWN VALUE
27.08	0.02	1.82	98.18
9.03	0.07	6.36	91.82
5.42	0.15	13.64	78.18
2.71	0.17	15.45	62.73
1.35	0.08	7.27	55.45
0.90	0.04	3.64	51.82
0.68	0.03	2.73	49.09
0.45	0.03	2.73	46.36
0.30	0.03	2.73	43.64
0.20	0.02	1.82	41.82
0.18	0.01	0.91	40.91
-0.2<R>0.2	0.34	30.91	10.00
<-0.2	0.11	10.00	
Total	1.10	100.00	
Total mass normalised to large column volume			1.554





ANALYSIS OF VARIANCE DATA

Site A

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	12	662.65	55.2212497	803.599738
Sample 2	12	757.89	63.15760018	692.8882984

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	377.9139539	1	377.9139539	**0.505067792**	0.484748493	**4.300943601**
Within Groups	16461.3684	22	748.2440182			
Total	16839.28235	23				

Site C

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	12	627.36	52.28034876	986.4299305
Sample 2	12	651.18	54.26497278	685.5801802
Sample 3	12	575.95	47.99616031	693.7479166

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	246.3640519	2	123.1820259	**0.156206203**	0.856011532	**3.284924333**
Within Groups	26023.3383	33	788.5860091			
Total	26269.70235	35				

Site D

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	12	699.72	58.31015299	755.9023707
Sample 2	12	941.58	78.46491228	615.1570657

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2437.285932	1	2437.285932	**3.555332275**	0.072629088	**4.300943601**
Within Groups	15081.6538	22	685.5297182			
Total	17518.93973	23				

Anova: Single Factor

Site G

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 2	12	747.240618	62.27005151	723.7235371
Sample 3	12	765.256798	63.7713998	727.8742325

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	13.52428013	1	13.52428013	**0.018633647**	0.893	**4.30**
Within Groups	15967.57547	22	725.7988848			
Total	15981.09975	23				

Anova: Single Factor

Site J

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	12	629.162782	52.43023184	768.9608467
Sample 2	11	605.445316	55.04048328	720.5426239

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	39.10306371	1	39.10306371	**0.052423683**	0.82111	**4.32**
Within Groups	15663.99555	21	745.9045501			
Total	15703.09862	22				

Anova: Single Factor

Site K

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	12	638.543663	53.2119719	1153.28856
Sample 2	12	774.776536	64.56471136	717.4963978
Sample 3	12	866.503667	72.20863896	547.2809044

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2192.750728	2	1096.375364	**1.36023015**	0.27061	**3.28**
Within Groups	26598.72449	33	806.0219542			
Total	28791.47521	35				

Anova: Single Factor
SITE L
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	11	729.6025105	66.327501	817.6096675
Sample 2	12	790.625	65.885417	684.7227417

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.121647126	1	1.1216471	**0.001499524**	0.9694765	**4.32**
Within Groups	15708.04683	21	748.00223			
Total	15709.16848	22				

Anova: Single Factor
SITE M
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	12	698.0968858	58.17474	680.2079444
Sample 2	12	787.5471698	65.628931	568.8702619

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	333.3897211	1	333.38972	**0.533817209**	0.4727163	**4.30**
Within Groups	13739.86027	22	624.5391			
Total	14073.24999	23				

Anova: Single Factor
Site N
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	12	838.1481481	69.845679	480.5451636
Sample 2	12	846.749226	70.562436	494.8063483

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.08243918	1	3.0824392	**0.006320673**	0.9373516	**4.300944**
Within Groups	10728.86663	22	487.67576			
Total	10731.94907	23				

APPENDIX D

COD, P AND TKN DATA

CRUDE DATA : COD

COD : DWF Site/Sample	COD mass (mg) Total	 Soluble	 Particulate	% total mass Soluble	 Particulate
A2	4726	1527	3199	32	68
A1	4944	1883	3061	38	62
Mean	4835	1705	3130	35	65
B1	4369	1439	2930	33	67
C1	nd	nd	nd	nd	nd
C2	7045	1752	5293	25	75
C3	4355	1032	3322	24	76
Mean	5700	1392	4307	24	76
D1	6383	2857	3526	45	55
D2	5191	2835	2355	55	45
Mean	5787	2846	2941	49	51
E	4829	1091	3739	23	77
H	2530	1141	1389	45	55
I	2443	1003	1439	41	59
F1	nd	nd	nd	nd	nd
F2	4687	2086	2600	45	55
G2	7764	1999	5765	26	74
G3	5787	2021	3766	35	65
Mean	6776	2010	4765	30	70
J1	10040	4217	5823	42	58
J2	9851	3780	6070	38	62
Mean	9945	3999	5947	40	60
K1	11319	4587	6732	41	59
K2	17928	6070	11857	34	66
K3	nd	nd	nd	nd	nd
Mean	14624	5329	9295	36	64
L1	3206	938	2268	29	71
L2	3766	851	2915	23	77
Mean	3486	894	2592	26	74
M1	7626	2944	4682	39	61
M2	3461	nd	nd	nd	nd
Mean	7626	2944	4682	39	61
N1	1200	632	567	53	47
N2	2552	814	1738	32	68
Mean	1876	723	1152	39	61
O	4435	2872	1563	65	35

COD : Storm Site/Sample	COD mass (mg) Total	 Soluble	 Particulate	% total mass Soluble	 Particulate
A3	nd	nd	nd	nd	nd
B2	2712	916	1796	34	66
H	2530	1134	1396	45	55
GI	3061	545	2515	18	82
G4	2784	909	1876	33	67
Mean	2923	727	2196	25	75

CRUDE DATA : P

P : DWF		P mass (mg)		% total mass	
Site/Sample	Total	Soluble	Particulate	Soluble	Particulate
A1	480	102	378	21	79
A2	407	111	296	27	73
Mean	443	107	337	24	76
B1	214	109	105	51	49
C1	322	156	166	48	53
C2	313	207	105	66	34
C3	nd	nd	nd	nd	nd
Mean	317	181	136	57	43
D1	614	105	508	17	83
D2	247	65	182	26	74
Mean	430	85	345	20	80
E	nd	nd	nd	nd	nd
H	nd	nd	nd	nd	nd
I	111	49	62	44	56
F1	nd	nd	nd	nd	nd
F2	nd	nd	nd	nd	nd
G2	582	138	443	24	76
G3	345	157	188	45	55
Mean	463	148	316	32	68
J1	531	257	275	48	52
J2	909	285	624	31	69
Mean	720	271	449	38	62
K1	518	164	355	32	68
K2	1482	460	1021	31	69
K3	218	64	154	29	71
Mean	739	229	510	31	69
L1	200	116	84	58	42
L2	275	102	173	37	63
Mean	237	109	129	46	54
M1	603	79	525	13	87
M2	286	65	222	23	77
Mean	445	72	373	16	84
N1	105	33	72	32	68
N2	128	39	89	30	70
Mean	117	36	81	31	69
O	nd	nd	nd	nd	nd

P : Storm		P mass (mg)		% total mass	
Site/Sample	Total	Soluble	Particulate	Soluble	Particulate
A:3	nd	nd	nd	nd	nd
B2	141	55	87	39	61
H	nd	nd	nd	nd	nd
GI	nd	nd	nd	nd	nd
G4	167	49	118	30	70

CRUDE DATA : TKN

TKN : DWF	TKN mass (mg)			% total mass	
Site/Sample	Total	Soluble	Particulate	Soluble	Particulate
A1	451	65	385	15	85
A2	872	58	814	7	93
Mean	662	62	600	9	91
B1	429	51	378	12	88
C1	865	51	814	6	158
C2	516	51	465	10	90
C3	nd	nd	nd	nd	nd
Mean	691	51	640	7	93
D1	792	749	43	95	5
D2	298	262	36	88	12
Mean	545	506	40	93	7
E	nd	nd	nd	nd	nd
H	nd	nd	nd	nd	nd
I	nd	nd	nd	nd	nd
F1	nd	nd	nd	nd	nd
F2	313	269	44	86	14
G2	734	683	51	93	7
G3	nd	nd	nd	nd	nd
Mean	367	342	25	93	7
J1	836	589	247	70	30
J2	1389	1272	116	92	8
Mean	1112	931	182	84	16
K1	734	603	131	82	18
K2	2101	1905	196	91	9
K3	240	225	15	94	6
Mean	1025	911	114	89	11
L1	nd	nd	nd	nd	nd
L2	785	734	51	94	6
M1	596	582	15	98	2
M2	218	204	15	93	7
Mean	407	393	15	96	4
N1	131	127	4	97	3
N2	174	153	22	88	13
Mean	153	140	13	92	8
O	nd	nd	nd	nd	nd

TKN : Storm	TKN mass (mg)			% total mass	
Site/Sample	Total	Soluble	Particulate	Soluble	Particulate
A:3	nd	nd	nd	nd	nd
B2	254	225	29	89	11
H	nd	nd	nd	nd	nd
GI	nd	nd	nd	nd	nd
G4	nd	nd	nd	nd	nd
Mean	nd	nd	nd	nd	nd

APPENDIX D - COD RESULTS

SITE A(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per0.1mm/secVs
<-0.2	N/A	0.203	211	97	9	...
-0.2<R>0.2	4	0.448	654	302	27	75
0.18-0.45	2.7	0.285	154	71	6	26
0.45-0.90	4.5	0.216	209	96	9	21
0.90-2.7	18.1	0.612	545	252	23	14
2.7-9.03	63.2	0.284	370	171	16	3
>9.03	N/A	0.120	235	109	10	...
Total		2.167	2379	1098	100	

SITE B(1 event)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per0.1mm/secVs
<-0.2	N/A	0.283	245	131	8	...
-0.2<R>0.2	4	0.320	944	506	31	126
0.18-0.45	2.7	0.255	255	137	8	51
0.45-0.90	4.5	0.197	231	124	8	27
0.90-2.7	18.1	0.508	756	405	25	22
2.7-9.03	63.2	0.213	464	248	15	4
>9.03	N/A	0.091	118	63	4	...
Total		1.867	3013	1614	100	

SITE C(3events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per0.1mm/secVs
<-0.2	N/A	0.204	212	92	8	...
-0.2<R>0.2	4	0.359	757	328	27	82
0.18-0.45	2.7	0.213	167	72	6	27
0.45-0.90	4.5	0.157	209	90	8	20
0.90-2.7	18.1	0.560	391	169	14	9
2.7-9.03	63.2	0.634	682	295	25	5
>9.03	N/A	0.183	347	150	13	...
Total		2.310	2765	1197	100	

SITE D(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per0.1mm/secVs
<-0.2	N/A	0.213	211	73	8	...
-0.2<R>0.2	4	1.257	926	319	36	80
0.18-0.45	2.7	0.355	235	81	9	30
0.45-0.90	4.5	0.288	223	77	9	17
0.90-2.7	18.1	0.454	503	173	19	10
2.7-9.03	63.2	0.203	295	102	11	2
>9.03	N/A	0.137	193	67	7	...
Total		2.906	2588	891	100	

SITE E(1event)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per0.1mm/secVs
<-0.2	N/A	0.213	...	...	...	...
-0.2<R>0.2	4	0.288	...	...	...	...
0.18-0.45	2.7	0.158	202	104	11	39
0.45-0.90	4.5	0.142	220	114	12	25
0.90-2.7	18.1	0.441	655	339	36	19
2.7-9.03	63.2	0.624	439	227	24	4
>9.03	N/A	0.066	282	146	16	...
Total		1.933	1799	931	100	

MEAN RESULTS FOR LARGE SITES

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per 0.1mm/sec
<-0.2	N/A	0.223	220	98	8	...
-0.2<R>0.2	4	0.534	820	367	30	92
0.18-0.45	2.7	0.253	203	91	7	34
0.45-0.90	4.5	0.200	218	98	8	22
0.90-2.7	18.1	0.515	570	255	21	14
2.7-9.03	63.2	0.392	450	201	17	3
>9.03	N/A	0.119	235	105	9	...
Total		2.237	2717	1215	100	

No. of sites=5

No. of events =9

MEAN RESULTS FOR ALL SITES SAMPLED DURING DWF CONDITIONS

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per 0.1mm/sec
<-0.2	N/A	0.207	242	104	8	...
-0.2<R>0.2	4	0.525	995	426	31	107
0.18-0.45	2.7	0.244	259	111	8	41
0.45-0.90	4.5	0.224	257	110	8	24
0.90-2.7	18.1	0.560	652	279	20	15
2.7-9.03	63.2	0.452	567	243	18	4
>9.03	N/A	0.121	230	99	7	...
Total		2.332	3200	1372	100	

No. of sites=15

No. of events =25

SITE F(1event)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per0.1mm/secVs
<-0.2	...	0.126	201	140	7	...
-0.2<R>0.2	4	0.252	1104	768	37	192
0.18-0.45	2.7	0.089	306	213	10	79
0.45-0.90	4.5	0.070	318	221	11	49
0.90-2.7	18.1	0.216	456	318	15	18
2.7-9.03	63.2	0.625	439	306	15	5
>9.03	...	0.059	187	130	6	...
Total		1.437	3010	2095	100	

SITE G(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per0.1mm/secVs
<-0.2	...	0.314	276	118	6	...
-0.2<R>0.2	4	0.389	1394	594	31	149
0.18-0.45	2.7	0.381	463	197	10	73
0.45-0.90	4.5	0.295	319	136	7	30
0.90-2.7	18.1	0.682	938	400	21	22
2.7-9.03	63.2	0.199	794	339	18	5
>9.03	...	0.083	253	108	6	...
Total		2.345	4437	1892	100	

SITE I(1event)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per0.1mm/secVs
<-0.2	N/A	0.044	198	65	7	...
-0.2<R>0.2	4	0.842	626	205	23	51
0.18-0.45	2.7	0.114	141	46	5	17
0.45-0.90	4.5	0.104	112	37	4	8
0.90-2.7	18.1	0.791	954	312	35	17
2.7-9.03	63.2	1.031	597	195	22	3
>9.03	N/A	0.129	81	27	3	...
Total		3.054	2709	887	100	

SITE J(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per0.1mm/secVs
<-0.2	N/A	0.401	765	127	10	...
-0.2<R>0.2	4	1.441	2154	357	28	89
0.18-0.45	2.7	0.447	616	102	8	38
0.45-0.90	4.5	0.316	680	113	9	25
0.90-2.7	18.1	1.413	1803	299	23	17
2.7-9.03	63.2	1.645	1187	197	15	3
>9.03	N/A	0.372	569	94	7	...
Total		6.034	7773	1288	100	

SITE K(3events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per 0.1mm/sec
<-0.2	N/A	0.319	329	85	6	...
-0.2<R>0.2	4	0.716	1877	482	33	121
0.18-0.45	2.7	0.435	482	124	8	46
0.45-0.90	4.5	0.695	507	130	9	29
0.90-2.7	18.1	1.307	1384	355	24	20
2.7-9.03	63.2	0.296	827	212	14	3
>9.03	N/A	0.124	303	78	5	...
Total		3.892	5708	1467	100	

MEAN RESULTS FOR MEDIUM SITES

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	% total	gCOD/kgSS per 0.1mm/sec
<-0.2	N/A	0.241	354	106	7	...
-0.2<R>0.2	4	0.728	1431	427	30	107
0.18-0.45	2.7	0.293	402	120	8	44
0.45-0.90	4.5	0.296	387	115	8	26
0.90-2.7	18.1	0.882	1107	330	23	18
2.7-9.03	63.2	0.759	769	229	16	4
>9.03	N/A	0.153	278	83	6	...
Total		3.352	4727	1410	100	

No. of sites=5

No. of events =9

SITE L(2 events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per0.1mm/secVs
<-0.2	N/A	0.261	133	64	...	...
-0.2<R>0.2	4	0.399	666	321	...	80
0.18-0.45	2.7	0.299	131	63	...	23
0.45-0.90	4.5	0.355	116	56	...	12
0.90-2.7	18.1	0.617	330	159	...	9
2.7-9.03	63.2	0.084	950	458	...	7
>9.03	N/A	0.060	...	...	...	...
Total		2.075	2326	...	...	

SITE M(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per0.1mm/secVs
<-0.2	N/A	0.177	230	157	9	...
-0.2<R>0.2	4	0.255	1210	825	46	206
0.18-0.45	2.7	0.262	196	134	7	50
0.45-0.90	4.5	0.192	223	152	8	34
0.90-2.7	18.1	0.269	320	218	12	12
2.7-9.03	63.2	0.187	268	183	10	3
>9.03	N/A	0.124	208	142	8	...
Total		1.466	2655	1810	100	

SITE N(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per0.1mm/secVs
<-0.2	N/A	0.072	81	190	12	...
-0.2<R>0.2	4	0.109	336	787	50	197
0.18-0.45	2.7	0.079	35	83	5	31
0.45-0.90	4.5	0.057	59	137	9	30
0.90-2.7	18.1	0.046	87	204	13	11
2.7-9.03	63.2	0.033	52	121	8	2
>9.03	N/A	0.033	27	63	4	...
Total		0.427	677	1585	100	

SITE O(1event)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per0.1mm/secVs
<-0.2	N/A	0.120	162	97	6	...
-0.2<R>0.2	4	0.488	718	431	26	108
0.18-0.45	2.7	0.098	326	196	12	73
0.45-0.90	4.5	0.098	264	159	9	35
0.90-2.7	18.1	0.195	373	224	13	12
2.7-9.03	63.2	0.521	660	396	24	6
>9.03	N/A	0.146	292	175	10	...
Total		1.665	2796	1679	100	

MEAN RESULTS FOR SMALL SITES

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	% total	gCOD/kgSS per0.1mm/secVs
<-0.2	N/A	0.157	151	108	7	...
-0.2<R>0.2	4	0.313	732	520	34	130
0.18-0.45	2.7	0.184	172	122	8	45
0.45-0.90	4.5	0.175	165	117	8	26
0.90-2.7	18.1	0.282	278	197	13	11
2.7-9.03	63.2	0.206	483	343	22	5
>9.03	N/A	0.091	176	125	8	...
Total		1.408	2157	1532	100	

No. of sites=4

No. of events =7

STORM SAMPLES

SITE B(1event)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per0.1mm/secVs
<-0.2	N/A	0.117	116	97	8	...
-0.2<R>0.2	4	0.637	556	466	38	117
0.18-0.45	2.7	0.163	112	94	8	35
0.45-0.90	4.5	0.119	112	94	8	21
0.90-2.7	18.1	0.102	224	188	16	10
2.7-9.03	63.2	0.026	250	210	17	3
>9.03	N/A	0.029	76	63	5	...
Total		1.193	1447	1213	100	

SITE G(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per0.1mm/secVs
<-0.2	N/A	0.188	166	61	8	...
-0.2<R>0.2	4	0.366	762	278	39	69
0.18-0.45	2.7	0.249	35	13	2	5
0.45-0.90	4.5	0.243	185	67	9	15
0.90-2.7	18.1	0.735	383	140	19	8
2.7-9.03	63.2	0.712	303	111	15	2
>9.03	N/A	0.251	132	48	7	...
Total		2.743	1967	717	100	

SITE H(1event)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per0.1mm/secVs
<-0.2	N/A	0.352	174	143	7	...
-0.2<R>0.2	4	0.275	565	464	24	116
0.18-0.45	2.7	0.112	288	236	12	88
0.45-0.90	4.5	0.067	238	195	10	43
0.90-2.7	18.1	0.101	303	248	13	14
2.7-9.03	63.2	0.270	447	367	19	6
>9.03	N/A	0.041	357	294	15	...
Total		1.218	2371	1947	100	

MEAN RESULTS FOR STORM SITES

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass COD (mg)	gCOD/kgSS	%total	gCOD/kgSS per0.1mm/secVs
<-0.2	N/A	0.219	152	88	8	...
-0.2<R>0.2	4	0.426	628	365	33	91
0.18-0.45	2.7	0.175	145	85	8	31
0.45-0.90	4.5	0.143	178	104	9	23
0.90-2.7	18.1	0.313	303	177	16	10
2.7-9.03	63.2	0.336	333	194	17	3
>9.03	N/A	0.107	188	110	10	...
Total		1.718	1928	1122	100	

No. of sites=3

No. of events =4

APPENDIX D - P RESULTS

SITE A(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	%total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.203	21	9	13	...
-0.2<R>0.2	4	0.448	21	10	13	2
0.18-0.45	2.7	0.285	8	4	5	1
0.45-0.90	4.5	0.216	17	8	11	2
0.90-2.7	18.1	0.612	36	17	23	1
2.7-9.03	63.2	0.284	35	16	22	0
>9.03	N/A	0.120	21	10	13	...
Total		2.167	159	73	100	

SITE B(1event)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	%total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.283	9	5	8	...
-0.2<R>0.2	4	0.320	44	24	37	6
0.18-0.45	2.7	0.255	8	4	6	2
0.45-0.90	4.5	0.197	12	7	10	1
0.90-2.7	18.1	0.508	20	11	17	1
2.7-9.03	63.2	0.213	18	10	15	0
>9.03	N/A	0.091	9	5	7	...
Total		1.867	120	64	100	

SITE C(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	%total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.204	10	4	12	...
-0.2<R>0.2	4	0.359	13	6	16	1
0.18-0.45	2.7	0.213	7	3	9	1
0.45-0.90	4.5	0.157	5	2	6	0
0.90-2.7	18.1	0.560	16	7	20	0
2.7-9.03	63.2	0.634	21	9	26	0
>9.03	N/A	0.183	8	3	10	...
Total		2.310	81	35	100	

SITE D(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	%total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.213	29	10	16	...
-0.2<R>0.2	4	1.257	52	18	28	4
0.18-0.45	2.7	0.355	15	5	8	2
0.45-0.90	4.5	0.288	14	5	7	1
0.90-2.7	18.1	0.454	33	12	18	1
2.7-9.03	63.2	0.203	25	9	13	0
>9.03	N/A	0.137	18	6	10	...
Total		2.906	186	64	100	

SITE E

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	% total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.213	...	...	...	...
-0.2<R>0.2	4	0.288	...	...	...	...
0.18-0.45	2.7	0.158	...	...	...	...
0.45-0.90	4.5	0.142	...	...	...	...
0.90-2.7	18.1	0.441	...	...	...	...
2.7-9.03	63.2	0.624	...	...	...	...
>9.03	N/A	0.066	...	...	...	...
Total		1.933	0	0		

MEAN RESULTS FOR LARGE SITES

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	% total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.223	17	8	13	...
-0.2<R>0.2	4	0.534	32	15	24	4
0.18-0.45	2.7	0.253	9	4	7	2
0.45-0.90	4.5	0.200	12	5	9	1
0.90-2.7	18.1	0.515	27	12	19	1
2.7-9.03	63.2	0.392	25	11	18	0
>9.03	N/A	0.119	14	6	10	...
Total		2.237	136	61	100	

No. of sites=4
No. of events =7

MEAN RESULTS FOR ALL SITES SAMPLED DURING DWF CONDITIONS

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	% total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.200	19	8	13	...
-0.2<R>0.2	4	0.496	38	16	25	4.1
0.18-0.45	2.7	0.254	9	4	6	1.5
0.45-0.90	4.5	0.229	13	6	9	1.2
0.90-2.7	18.1	0.592	31	13	20	0.7
2.7-9.03	63.2	0.416	25	11	17	0.2
>9.03	N/A	0.121	17	7	11	...
Total		2.309	152	66	100	

No. of sites=11
No. of events =21

SITE F

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	%total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.126	...	...	...	...
-0.2<R>0.2	4	0.252	...	...	...	...
0.18-0.45	2.7	0.089	...	...	...	...
0.45-0.90	4.5	0.070	...	...	...	...
0.90-2.7	18.1	0.216	...	...	...	...
2.7-9.03	63.2	0.625	...	...	...	...
>9.03	N/A	0.059	...	...	...	...
Total		1.437	0	0	...	

SITE G(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	%total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.314	11	5	5	...
-0.2<R>0.2	4	0.389	88	37	39	9
0.18-0.45	2.7	0.381	15	6	7	2
0.45-0.90	4.5	0.295	18	8	8	2
0.90-2.7	18.1	0.682	46	20	21	1
2.7-9.03	63.2	0.199	30	13	13	0
>9.03	N/A	0.083	17	7	8	...
Total		2.345	224	95	100	

SITE I(1event)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	%total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.044	6	2	8	...
-0.2<R>0.2	4	0.842	17	6	26	1
0.18-0.45	2.7	0.114	6	2	9	1
0.45-0.90	4.5	0.104	4	1	6	0
0.90-2.7	18.1	0.791	19	6	28	0
2.7-9.03	63.2	1.031	12	4	19	0
>9.03	N/A	0.129	3	1	5	...
Total		3.054	67	22	100	

SITE J(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	%total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.401	36	6	16	...
-0.2<R>0.2	4	1.441	64	11	29	3
0.18-0.45	2.7	0.447	10	2	5	1
0.45-0.90	4.5	0.316	11	2	5	0
0.90-2.7	18.1	1.413	42	7	19	0
2.7-9.03	63.2	1.645	30	5	14	0
>9.03	N/A	0.372	26	4	12	...
Total		6.034	218	36	100	

SITE K(3events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	%total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.319	36	9	14	...
-0.2<R>0.2	4	0.716	67	17	26	4
0.18-0.45	2.7	0.435	11	3	4	1
0.45-0.90	4.5	0.695	18	5	7	1
0.90-2.7	18.1	1.307	62	16	24	1
2.7-9.03	63.2	0.296	32	8	13	0
>9.03	N/A	0.124	28	7	11	...
Total		3.892	255	65	100	

MEAN RESULTS FOR MEDIUM SITES

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	% total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.241	22	7	12	...
-0.2<R>0.2	4	0.728	59	18	31	4
0.18-0.45	2.7	0.293	10	3	5	1
0.45-0.90	4.5	0.296	13	4	7	1
0.90-2.7	18.1	0.882	42	13	22	1
2.7-9.03	63.2	0.759	26	8	14	0
>9.03	N/A	0.153	18	5	10	...
Total		3.352	191	57	100	

No. of sites=4

No. of events =8

SITE L(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	%total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.261	4	2	4	...
-0.2<R>0.2	4	0.399	34	17	39	4
0.18-0.45	2.7	0.299	5	2	6	1
0.45-0.90	4.5	0.355	5	2	6	1
0.90-2.7	18.1	0.617	10	5	11	0
2.7-9.03	63.2	0.084	20	10	23	0
>9.03	N/A	0.060	10	5	12	...
Total		2.075	88	43	100	

SITE M(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	%total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.177	34	23	19	...
-0.2<R>0.2	4	0.255	37	26	21	6
0.18-0.45	2.7	0.262	21	15	12	5
0.45-0.90	4.5	0.192	17	12	10	3
0.90-2.7	18.1	0.269	26	18	15	1
2.7-9.03	63.2	0.187	19	13	11	0
>9.03	N/A	0.124	20	13	11	...
Total		1.466	175	119	100	

SITE N(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	%total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.072	8	19	15	...
-0.2<R>0.2	4	0.109	28	66	51	16
0.18-0.45	2.7	0.079	1	2	2	1
0.45-0.90	4.5	0.057	5	11	8	2
0.90-2.7	18.1	0.046	5	12	9	1
2.7-9.03	63.2	0.033	4	9	7	0
>9.03	N/A	0.033	4	10	8	...
Total		0.427	55	129	100	

SITE O

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	%total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.120	...	...	...	...
-0.2<R>0.2	4	0.488	...	...	...	...
0.18-0.45	2.7	0.098	...	...	...	...
0.45-0.90	4.5	0.098	...	...	...	...
0.90-2.7	18.1	0.195	...	...	...	...
2.7-9.03	63.2	0.521	...	...	...	...
>9.03	N/A	0.146	...	...	...	...
Total		1.665	0	0	...	

MEAN RESULTS FOR SMALL SITES

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	% total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.157	15	11	14	...
-0.2<R>0.2	4	0.313	33	24	31	6
0.18-0.45	2.7	0.184	9	6	9	2
0.45-0.90	4.5	0.175	9	6	8	1
0.90-2.7	18.1	0.282	14	10	13	1
2.7-9.03	63.2	0.206	14	10	14	0
>9.03	N/A	0.091	11	8	11	..
Total		1.408	106	75	100	

No. of sites=3

No. of events =6

STORM SAMPLES

SITE B(1event)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	%total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.117	7	6	6	...
-0.2<R>0.2	4	0.637	59	49	50	12
0.18-0.45	2.7	0.163	6	5	5	2
0.45-0.90	4.5	0.119	10	8	9	2
0.90-2.7	18.1	0.102	8	7	7	0
2.7-9.03	63.2	0.026	20	17	17	0
>9.03	N/A	0.029	7	6	6	...
Total		1.193	116	98	100	

SITE G(1event)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	%total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.188	9	3	12	...
-0.2<R>0.2	4	0.366	23	9	32	2
0.18-0.45	2.7	0.249	8	3	11	1
0.45-0.90	4.5	0.243	6	2	8	0
0.90-2.7	18.1	0.735	14	5	19	0
2.7-9.03	63.2	0.712	9	3	13	0
>9.03	N/A	0.251	4	1	5	...
Total		2.743	72	26	100	

SITE H

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	%total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.352	...	...	...	...
-0.2<R>0.2	4	0.275	...	...	...	...
0.18-0.45	2.7	0.112	...	...	...	...
0.45-0.90	4.5	0.067	...	...	...	...
0.90-2.7	18.1	0.101	...	...	...	...
2.7-9.03	63.2	0.270	...	...	...	...
>9.03	N/A	0.041	...	...	...	...
Total		1.218	0	0		

MEAN RESULTS FOR STORM SITES

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass P (mg)	gP/kgSS	%total	gP/kgSS per0.1mm/secVs
<-0.2	N/A	0.152	8	4	8	...
-0.2<R>0.2	4	0.501	41	21	43	5
0.18-0.45	2.7	0.206	7	4	7	1
0.45-0.90	4.5	0.181	8	4	8	1
0.90-2.7	18.1	0.419	11	6	12	0
2.7-9.03	63.2	0.369	15	7	15	0
>9.03	N/A	0.140	5	3	6	...
Total		1.968	94	48	100	

No. of sites=2 : 2 events

APPENDIX D - TKN RESULTS

SITE A(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per 0.1mm/secVs
<-0.2	N/A	0.203	4	2	...	...
-0.2<R>0.2	4	0.448	...	...	...	...
0.18-0.45	2.7	0.285	4	2	...	1
0.45-0.90	4.5	0.216	4	2	...	0
0.90-2.7	18.1	0.612	31	14	...	1
2.7-9.03	63.2	0.284	18	8	...	0
>9.03	N/A	0.120	8	4	...	...
Total		2.167	67	...	...	

SITE B(1event)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per 0.1mm/secVs
<-0.2	N/A	0.283	13	7	29	...
-0.2<R>0.2	4	0.320	5	3	12	1
0.18-0.45	2.7	0.255	4	2	8	1
0.45-0.90	4.5	0.197	5	3	11	1
0.90-2.7	18.1	0.508	9	5	19	0
2.7-9.03	63.2	0.213	4	2	8	0
>9.03	N/A	0.091	6	3	13	...
Total		1.867	45	24	100	

SITE C(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.204	4	2	...	...
-0.2<R>0.2	4	0.359	...	...	...	...
0.18-0.45	2.7	0.213	4	2	...	1
0.45-0.90	4.5	0.157	2	1	...	0
0.90-2.7	18.1	0.560	9	4	...	0
2.7-9.03	63.2	0.634	16	7	...	0
>9.03	N/A	0.183	6	3	...	...
Total		2.310	40	...	...	

SITE D(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.213	4	1	16	...
-0.2<R>0.2	4	1.257	2	1	9	0.21
0.18-0.45	2.7	0.355	2	1	9	0.31
0.45-0.90	4.5	0.288	4	1	16	0.33
0.90-2.7	18.1	0.454	5	2	21	0.10
2.7-9.03	63.2	0.203	4	1	14	0.02
>9.03	N/A	0.137	4	1	14	...
Total		2.906	26	9	100	

SITE E

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.213	...	...	...	...
-0.2<R>0.2	4	0.288	...	...	...	...
0.18-0.45	2.7	0.158	...	...	...	...
0.45-0.90	4.5	0.142	...	...	...	...
0.90-2.7	18.1	0.441	...	...	...	...
2.7-9.03	63.2	0.624	...	...	...	...
>9.03	N/A	0.066	...	...	...	...
Total		1.933	0	0		

MEAN RESULTS FOR LARGE SITES

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.226	6	2	13	...
-0.2<R>0.2	4	0.788	4	2	8	...
0.18-0.45	2.7	0.277	3	1	7	0
0.45-0.90	4.5	0.214	4	1	8	0
0.90-2.7	18.1	0.533	13	5	28	0
2.7-9.03	63.2	0.334	10	4	22	0
>9.03	N/A	0.133	6	2	13	...
Total		2.505	47	19	100	

No. of sites=4

No. of events =7

MEAN RESULTS FOR ALL SITES SAMPLED DURING DWF CONDITIONS

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% TOTAL	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.299	7.653	2	8	...
-0.2<R>0.2	4	0.818	28.173	9	28	2
0.18-0.45	2.7	0.286	5.033	2	5	1
0.45-0.90	4.5	0.218	5.643	2	6	0
0.90-2.7	18.1	0.648	28.518	9	29	1
2.7-9.03	63.2	0.671	16.623	5	17	0
>9.03	N/A	0.164	7.778	3	8	...
Total		3.104	99	32	100	

No. of sites=10

No. of events =18

SITE F(1event)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.126	9	6	5	...
-0.2<R>0.2	4	0.252	53	37	29	9
0.18-0.45	2.7	0.089	9	6	5	2
0.45-0.90	4.5	0.070	7	5	4	1
0.90-2.7	18.1	0.216	63	44	35	2
2.7-9.03	63.2	0.625	31	21	17	0
>9.03	N/A	0.059	12	8	7	...
Total		1.437	184	128	100	

SITE G

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.314	...	...	...	...
-0.2<R>0.2	4	0.389	...	...	...	...
0.18-0.45	2.7	0.381	...	...	...	...
0.45-0.90	4.5	0.295	...	...	...	...
0.90-2.7	18.1	0.682	...	...	...	...
2.7-9.03	63.2	0.199	...	...	...	...
>9.03	N/A	0.083	...	...	...	...
Total		2.345	0	0	0	

SITE I

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.044	...	...	...	...
-0.2<R>0.2	4	0.842	...	...	...	...
0.18-0.45	2.7	0.114	...	...	...	...
0.45-0.90	4.5	0.104	...	...	...	...
0.90-2.7	18.1	0.791	...	...	...	...
2.7-9.03	63.2	1.031	...	...	...	...
>9.03	N/A	0.129	...	...	...	...
Total		3.054	0	0		

SITE J(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.401	6	1	4	...
-0.2<R>0.2	4	1.441	53	9	36	2
0.18-0.45	2.7	0.447	5	1	4	0
0.45-0.90	4.5	0.316	6	1	4	0
0.90-2.7	18.1	1.413	37	6	25	0
2.7-9.03	63.2	1.645	29	5	20	0
>9.03	N/A	0.372	9	2	6	...
Total		6.034	144	24	100	

SITE K(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.319	7	2	...	...
-0.2<R>0.2	4	0.716	220	57	...	14
0.18-0.45	2.7	0.435	...	...	...	...
0.45-0.90	4.5	0.695	11	3	...	1
0.90-2.7	18.1	1.307	52	13	...	1
2.7-9.03	63.2	0.296	20	5	...	0
>9.03	N/A	0.124	12	3	...	...
Total		3.892	323	24		

MEAN RESULTS FOR MEDIUM SITES

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.282	7	2	3	...
-0.2<R>0.2	4	0.803	108	29	49	7
0.18-0.45	2.7	0.324	7	2	3	1
0.45-0.90	4.5	0.360	8	2	4	0
0.90-2.7	18.1	0.979	51	13	23	1
2.7-9.03	63.2	0.855	26	7	12	0
>9.03	N/A	0.185	11	3	5	...
Total		3.788	219	58	100	

No. of sites=3

No. of events =5

SITE L(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.261	...	...	...	...
-0.2<R>0.2	4	0.399	...	...	...	...
0.18-0.45	2.7	0.299	17	8	...	3.05
0.45-0.90	4.5	0.355	23	11	...	2.48
0.90-2.7	18.1	0.617	23	11	...	0.62
2.7-9.03	63.2	0.084	28	14	...	0.21
>9.03	N/A	0.060	29	14	...	...
Total		2.075	121	...		

SITE M(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.177	...	...	...	...
-0.2<R>0.2	4	0.255	...	...	...	...
0.18-0.45	2.7	0.262	2	2	...	0.62
0.45-0.90	4.5	0.192	2	1	...	0.28
0.90-2.7	18.1	0.269	1	1	...	0.05
2.7-9.03	63.2	0.187	2	2	...	0.03
>9.03	N/A	0.124	5	4	...	...
Total		1.466	13	...	0	

SITE N(2events)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.072	2	4	...	...
-0.2<R>0.2	4	0.109	...	...	...	...
0.18-0.45	2.7	0.079	...	...	...	...
0.45-0.90	4.5	0.057	1	3	...	1
0.90-2.7	18.1	0.046	1	3	...	0
2.7-9.03	63.2	0.033	...	...	...	...
>9.03	N/A	0.033	11	26	...	...
Total		0.427	15	...		

SITE O

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.120	...	...	...	...
-0.2<R>0.2	4	0.488	...	...	...	...
0.18-0.45	2.7	0.098	...	...	...	...
0.45-0.90	4.5	0.098	...	...	...	...
0.90-2.7	18.1	0.195	...	...	...	...
2.7-9.03	63.2	0.521	...	...	...	...
>9.03	N/A	0.146	...	...	...	...
Total		1.665	0	0	0	

MEAN RESULTS FOR SMALL SITES

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.157	2	1	...	...
-0.2<R>0.2	4	0.313	...	...	...	...
0.18-0.45	2.7	0.184	10	7	...	2.57
0.45-0.90	4.5	0.175	9	6	...	1.38
0.90-2.7	18.1	0.282	9	6	...	0.33
2.7-9.03	63.2	0.206	15	11	...	0.17
>9.03	N/A	0.091	15	11	...	...
Total		1.408	59	...		

No sites=3

No events=6

STORM SAMPLES

SITE B(1event)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.117	...	...	...	...
-0.2<R>0.2	4	0.637	...	...	...	...
0.18-0.45	2.7	0.163	...	...	...	...
0.45-0.90	4.5	0.119	2	83	...	19
0.90-2.7	18.1	0.102	2	83	...	5
2.7-9.03	63.2	0.026	2	83	...	1
>9.03	N/A	0.029	...	...	...	...
Total		1.193	7	...		

SITE G(1event)

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.188	3	112	...	...
-0.2<R>0.2	4	0.366	...	....	...	...
0.18-0.45	2.7	0.249	...	...	...	...
0.45-0.90	4.5	0.243	4	125	...	28
0.90-2.7	18.1	0.735	12	417	...	23
2.7-9.03	63.2	0.712	12	417	...	7
>9.03	N/A	0.251	4	125	...	...
Total		2.743	35	...	0	

Mean storm samples

SETTLING VELOCITY (mm/sec)	No. 0.1mm/sec Vs intervals	Normalised SS mass to large column volume (g)	Mass TKN (mg)	gTKN/kgSS	% total	gTKN/kgSS TKN per0.1mm/secVs
<-0.2	N/A	0.152	3.280	2	...	...
-0.2<R>0.2	4	0.501	...	...	...	...
0.18-0.45	2.7	0.206	...	...	...	...
0.45-0.90	4.5	0.181	3.050	2	...	0
0.90-2.7	18.1	0.419	7.320	4	...	0
2.7-9.03	63.2	0.369	7.320	4	...	0
>9.03	N/A	0.140	3.660	2	...	...
Total		1.968	25	...		

No sites=2

No events=2

Pollutant	No. of sites	% of total sinker mass settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
COD	15					
Mean		13.2	13.1	33.2	28.9	11.7
Std.Dev.		3.3	4.2	8.8	5.6	4.4
Range		7.5-17.9	5.9-22.5	19.5-50.6	20.0-38.0	4.3-19.3
P	11					
Mean		9.6	13.7	32.4	26.6	17.7
Std.Dev.		4.5	4.2	5.2	4.2	4.3
Range		5.0-20.7	9.4-24.6	19.5-42.0	18.4-40.1	6.9-22.7
TKN	10					
Mean		9.0	10.9	39.0	25.7	15.5
Std.Dev.		n/a	n/a	n/a	n/a	n/a
Range		6.4-13.6	7.1-37.3	6.1-42.6	5.2-33.3	10.6-45.1

Results of COD, P and TKN associated
with settling velocity fractions (DWF conditions)

Pollutant	No. of sites	% of total sinker mass settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
COD	3					
Mean		12.6	15.5	26.4	29.0	16.4
Std.Dev.		n/a	n/a	n/a	n/a	n/a
Range		3.4-14.5	14.5-17.8	18.5-36.9	27.4-32.3	9.8-21.9
P	2					
Mean		15.5	17.2	23.9	32.0	11.5
Std.Dev.		n/a	n/a	n/a	n/a	n/a
Range		11.8-20.0	13.6-20.0	15.7-34.0	23.2-39.1	9.3-13.3
TKN	0	...	...	...	...	...

Results of COD, P and TKN associated
with settling velocity fractions (storm flow conditions)

Catchment size	No. of sites	DWF conditions % of total COD/SS mass Floaters	 Residue	 Sinkers	No. of sites	Storm conditions % of total COD/SS mass Floaters	 Residue	 Sinkers
Large	4				1			
Mean		8.2	30.5	61.3		8.0	38.5	53.5
Range		7.7-8.9	27.4-35.8	56.1-65.0				
Medium	5				2			
Mean		7.2	30.4	62.5		7.9	31.3	60.8
Range		5.8-9.8	23.1-36.7	56.7-69.6		7.3-8.5	23.8-38.7	52.8-68.8
Small	3				0			
Mean		7.0	34.0	59.0		...	...	...
Range		5.8-12.0	25.7-49.6	(38.4-68.5)				

The effect of catchment size on the distribution of COD/SS
in the three broad settling column groupings (DWF and storm flow conditions)

Catchment size	No. of sites	DWF conditions % of total P/SS mass Floaters	 Residue	 Sinkers	No. of sites	Storm conditions % of total P/SS mass Floaters	 Residue	 Sinkers
Large	4				1			
Mean		12.6	23.8	63.7		6.3	50.3	43.4
Range		7.7-15.6	13.2-36.6	55.8-73.9				
Medium	4							
Mean		11.6	31.0	57.4	1			
Range		4.9-16.4	25.6-39.2	54.3-66.0		11.8	32.3	56.0
Small	3							
Mean		14.4	31.3	54.3	0	...	...	...
Range		4.3-19.2	21.4-50.8	34.1-59.4				

The effect of catchment size on the distribution of P/SS
in the three broad settling column groupings (DWF and storm flow conditions)

Catchment size	No. of sites	DWF conditions % of total TKN/SS mass Floaters	 Residue	 Sinkers
Large	2			
Mean		13.2	8.3	78.5
Range		n/a	n/a	n/a
Medium	2			
Mean		3.4	49.4	47.2
Range		n/a	n/a	n/a
Small	0	...	...	...

The effect of catchment size on the distribution of TKN/SS
in the three broad settling column groupings : DWF conditions.
(No results for storm)

Catchment type	No. of sites	DWF conditions % of total COD/SS mass			No. of sites	Storm conditions % of total COD/SS mass		
		Floaters	Residue	Sinkers		Floaters	Residue	Sinkers
Dom/ind	5				1			
Mean		7.9	31.2	60.9		8.0	38.5	53.6
Range		(5.8-9.80	(27.7-36.7	(56.7-63.6)		n/a	n/a	n/a
Dom	4				1			
Mean		7.6	34.0	58.4		8.4	38.7	52.8
Range		(6.2-8.6)	(23.1-45.6)	(45.8-69.6)		n/a	n/a	n/a
Dom/agric	3				1			
Mean		8.5	34.2	57.3		7.3	23.8	68.8
Range		(5.8-12.0)	(25.7-49.6)	(38.4-68.5)		n/a	n/a	n/a

The effect of catchment type on the distribution of COD/SS
in the three broad settling column groupings (DWF and storm flow conditions)

Catchment type	No. of sites	DWF conditions % of total P/SS mass			No. of sites	Storm conditions % of total P/SS mass		
		Floaters	Residue	Sinkers		Floaters	Residue	Sinkers
Dom/ind	4				1			
Mean		12.4	25.6	62.0		6.3	50.3	43.4
Range		7.67-16.37	13.19-36.58	54.27-73.88		n/a	n/a	n/a
Dom	5				1			
Mean		11.9	29.8	58.3		11.8	32.3	56.0
Range		4.3-19.2	21.4-39.2	55.9-66.0		n/a	n/a	n/a
Dom/agric	2				0			
Mean		14.4	43.5	42.1		...	...	...
Range		12.1-15.1	16.3-50.8	34.1-71.6				

The effect of catchment type on the distribution of P/SS
in the three broad settling column groupings (DWF and storm flow conditions)

Catchment type	No. of sites	DWF conditions % of total TKN/SS mass		
		Floaters	Residue	Sinkers
Dom/ind	3			
Mean		8.1	27.3	64.6
Range		4.0-29.0	11.6-36.4	59.4-66.5
Dom	1			
Mean		15.7	9.4	74.8
Range		n/a	n/a	n/a
Dom/agric	0	...	...	...

The effect of catchment type on the distribution of TKN/SS
in the three broad settling column groupings : DWFconditions.
(No results for storm)

Catchment size	No. of sites	% of total sinker mass settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Large	5					
Mean		12.4	13.4	33.5	27.0	13.7
Range		9.3-16.2	11.6-15.4	21.7-41.5	20.4-38.0	6.5-19.3
Medium	5					
Mean		13.7	12.9	37.6	26.8	8.9
Range		7.5-17.9	5.9-18.6	26.8-50.6	23.6-31.7	4.3-11.7
Small	4					
Mean		15.6	18.2	26.5	25.5	14.2
Range		13.6-17.0	13.8-22.5	19.5-33.6	20.0-34.4	10.3-15.2

The effect of catchment size on the distribution of COD/SS
in the five sinker fractions (DWF conditions)

Catchment size	No. of sites	% of total sinker mass settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Large	4					
Mean		10.8	13.9	30.5	28.8	16.0
Range		6.7-12.6	8.9-18.1	28.4-31.0	27.5-36.6	13.2-17.6
Medium	4					
Mean		9.5	11.7	38.4	23.6	16.7
Range		7.1-13.5	9.4-14.1	35.5-42.0	21.3-28.2	6.9-21.6
Small	3					
Mean		15.9	15.5	24.0	24.9	19.7
Range		5.0-20.7	10.0-24.6	19.4-27.8	18.4-40.1	18.8-22.7

The effect of catchment size on the distribution of P/SS
in the five sinker fractions (DWF conditions)

Catchment size	No. of sites	% of total sinker mass settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Large	4	9.2	10.0	36.3	28.3	16.3
Medium	3	6.8	7.9	49.2	25.6	10.6
Small	3	17.1	14.6	26.8	26.8	...

The effect of catchment size on the distribution of TKN/SS
in the five sinker fractions (DWF conditions)

Catchment size	No. of sites	% of total sinker mass settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Large	1					
Mean		14.5	14.5	29.0	32.3	9.8
Range		n/a	n/a	n/a	n/a	n/a
Medium	2					
Mean		10.5	16.2	27.7	28.3	17.3
Range		3.4-17.6	14.6-17.8	18.5-36.9	27.4-29.2	12.7-21.9
Small	0	...	...	...	...	...

The effect of catchment size on the distribution of COD/SS
in the five sinker fractions (storm flow conditions)

Catchment size	No. of sites	% of total sinker mass settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Large	1	11.8	20.1	15.7	39.1	13.3
Medium	1	20.0	13.5	34.0	23.2	9.3
Small	0	...	...	...	...	...

The effect of catchment size on the distribution of P/SS
in the five sinker fractions (storm flow conditions)

Catchment type	No. of sites	% of total sinker mass settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Dom/ind	5					
Mean		13.7	14.7	36.2	24.7	10.7
Range		10.2-17.9	12.6-18.6	26.8-41.5	23.6-25.8	6.5-15.6
Dom	5					
Mean		14.2	12.8	36.4	25.7	11.0
Range		7.5-16.7	5.9-18.3	26.4-50.6	20.4-31.7	4.3-17.1
Dom/agric	3					
Mean		13.3	16.0	24.9	30.8	15.0
Range		9.3-17.0	11.6-22.5	19.5-33.6	20.0-40.0	10.3-19.3

The effect of catchment type on the distribution of COD/SS
in the five sinker fractions (DWF conditions)

Catchment type	No. of sites	% of total sinker mass settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Dom/ind	4					
Mean		8.48	13.60	34.27	25.98	17.67
Range		6.7-11.5	9.6-18.1	29.6-41.2	21.3-30.2	13.2-21.6
Dom	5					
Mean		12.6	12.9	30.9	28.1	15.5
Range		6.7-20.7	9.4-16.6	19.5-36.7	18.4-40.1	6.9-20.5
Dom/agric	2					
Mean		5.9	19.6	29.4	25.0	20.2
Range		5.0-6.7	14.6-24.6	27.8-31.0	19.9-30.2	17.6-22.7

The effect of catchment type on the distribution of P/SS
in the five sinker fractions (DWFconditions)

Catchment type	No. of sites	% of total sinker mass settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Dom/ind	5					
Mean		7.8	7.7	48.3	24.6	11.7
Range		4.7-13.6	4.0-18.2	31.8-52.0	13.6-33.3	10.0-22.7
Dom	1					
Mean		12.5	21.9	28.1	18.8	18.8
Range		n/a	n/a	n/a	n/a	n/a
Dom/agric	0					

The effect of catchment type on the distribution of TKN/SS
in the five sinker fractions (DWFconditions)

Catchment type	No. of sites	% of total sinker mass settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Dom/ind	1	14.5	14.5	29.0	32.3	9.8
Dom	1	3.4	17.8	36.9	29.2	12.7
Dom/agric	1	17.6	14.6	18.5	27.4	21.9

The effect of catchment type on the distribution of COD/SS
in the five sinker fractions (storm flow conditions)

Catchment type	No. of sites	% of total sinker mass settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Dom/ind	1	11.8	20.1	15.7	39.1	13.3
Dom	1	20.0	13.5	34.0	23.2	9.3
Dom/agric	0	...	...	...	...	...

The effect of catchment type on the distribution of P/SS
in the five sinker fractions (storm flow conditions)

Anova: Single Factor analysis for COD associated with solids
DWF conditions

Site A
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	6	311.43	51.91	872.82
Sample 2	6	293.81	48.97	786.55

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	25.89	1	25.89	**0.03**	0.86	**4.96**
Within Groups	8296.87	10	829.69			
Total	8322.75	11				

Anova: Single Factor
Site C
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	6	356.33	59.39	835.80
Sample 2	6	268.21	44.70	808.08
Sample 3	6	205.70	34.28	587.62

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1908.81	2	954.40	**1.28**	0.31	**3.68**
Within Groups	11157.48	15	743.83			
Total	13066.29	17				

Anova: Single Factor
Site D
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	6	326.44	54.41	832.17
Sample 2	6	361.90	60.32	979.82

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	104.81	1	104.81	**0.12**	0.74	**4.96**
Within Groups	9059.96	10	906.00			
Total	9164.77	11				

Anova: Single Factor analysis for COD associated with solids
DWF conditions

Site G
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	6	307.00	51.17	971.46
Sample 2	6	326.77	54.46	921.97

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	32.58	1	32.58	**0.03**	0.86	**4.96**
Within Groups	9467.16	10	946.72			
Total	9499.74	11				

Anova: Single Factor
Site J
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	6	306.84	51.14	895.33
Sample 2	6	342.84	57.14	840.17

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	107.95	1	107.95	**0.12**	0.73	**4.96**
Within Groups	8677.51	10	867.75			
Total	8785.46	11				

Anova: Single Factor
Site K
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	6	313.60	52.27	875.06
Sample 2	6	293.83	48.97	1179.66
Sample 3	6	354.10	59.02	970.77

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	314.66	2	157.33	**0.16**	0.86	**3.68**
Within Groups	15127.40	15	1008.49			
Total	15442.07	17				

Anova: Single Factor analysis for COD associated with solids
DWF conditions

Site N
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	7	407.98	58.28	1468.32
Sample 2	7	395.39	56.48	1295.46

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	11.31	1	11.31	**0.01**	0.93	**4.75**
Within Groups	16582.71	12	1381.89			
Total	16594.02	13				

Site M
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	7	100	14.285714	222.74356
Column 2	7	100	14.285714	151.45858

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0	1	0	0	1	**4.75**
Within Groups	2245.2128	12	187.10107			
Total	2245.2128	13				

Anova: Single Factor analysis for COD associated with solids
(storm flow conditions)
Site G
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	6	326.51	54.42	951.93
Sample 2	6	351.21	58.54	841.98

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	50.83	1	50.83	**0.06**	0.82	**4.96**
Within Groups	8969.57	10	896.96			
Total	9020.40	11				

Anova: Single Factor analysis for P associated with solids (DWF conditions)

SITE A
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	5	273.02	54.60	336.43
Sample 2	5	196.45	39.29	1252.86

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	586.30	1.00	586.30	0.74	0.42	5.32
Within Groups	6357.14	8.00	794.64			
Total	6943.44	9.00				

Anova: Single Factor
Site C
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	6	261.72	43.62	656.54
Sample 2	6	287.21	47.87	865.41

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	54.16	1.00	54.16	0.07	0.80	4.96
Within Groups	7609.72	10.00	760.97			
Total	7663.88	11.00				

Anova: Single Factor
Site D
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	6	325.46	54.24	612.83
Sample 2	6	353.74	58.96	848.79

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	66.68	1.00	66.68	0.09	0.77	4.96
Within Groups	7308.10	10	730.80966			
Total	7374.78	11				

Anova: Single Factor analysis for P associated with solids (DWF conditions)

Site J
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	6	328.16	54.69	920.37
Sample 2	6	333.56	55.59	326.64

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.43	1	2.43	0.00	0.95	4.96
Within Groups	6235.07	10	623.51			
Total	6237.49	11				

Anova: Single Factor
Site K
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	6	313.88	52.31	855.34
Sample 2	6	323.14	53.86	543.25
Sample 3	6	319.47	53.24	984.38

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.25	2	3.63	0.005	0.995	3.682
Within Groups	11914.89	15	794.33			
Total	11922.14	17				

Anova: Single Factor
Site G
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	6	312.90	52.15	817.04
Sample 2	6	336.63	56.10	1024.29

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	46.93	1	46.93	0.05	0.83	4.96
Within Groups	9206.64	10	920.66			
Total	9253.57	11				

Anova: Single Factor analysis for P associated with solids (DWF conditions)

Site N

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	6	407.22	67.87	786.55
Sample 2	6	394.84	65.81	715.23

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12.75	1	12.75	0.02	0.90	4.96
Within Groups	7508.88	10	750.89			
Total	7521.64	11				

Anova: Single Factor analysis for TKN associated with solids (DWF conditions)

SITE D
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample1	5	334.70	66.94	197.60
Sample 2	5	266.92	53.38	1153.03

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	459.43	1.00	459.43	0.68	0.43	5.32
Within Groups	5402.55	8.00	675.32			
Total	5861.98	9.00				

Anova: Single Factor
SITEJ
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample1	5	283.77	56.75	705.89
Sample2	5	158.27	31.65	1160.82

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1575.10	1.00	1575.10	1.69	0.23	5.32
Within Groups	7466.87	8.00	933.36			
Total	9041.97	9				

Anova: Single Factor
SITEK
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample1	4	323.42	80.85	131.78
Sample3	4	289.96	72.49	264.61

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	139.93	1.00	139.93	0.71	0.43	5.99
Within Groups	1189.17	6.00	198.20			
Total	1329.11	7				

Chi-squared analysis - distribution of pollutants in the sinker fractions
Goodness of Fit

Comparison of catchment characteristics against the expected distribution
Expected distribution : DWF conditions

	X^2			
CHARACTERISTIC	SS	COD	P	TKN
Storm	10.6	3.7	10.0	nd
Large : DWF	0.7	0.5	0.6	0.6
Medium : DWF	3.9	1.4	1.8	5.5
Small :DWF	6.1	4.8	6.9	nd
Dom/Ind : DWF	1.9	1.2	0.3	nd
Dom : DWF	4.2	0.8	1.4	nd
Dom/agric : DWF	5.7	3.7	4.7	nd
Large : Storm	**26.5**	1.5	**35.6**	nd
Medium : Storm	7.7	4.9	**24.3**	nd
Dom/Ind : Storm	**26.5**	1.5	**35.6**	nd
Dom : Storm	4.0	9.5	**24.3**	nd
Dom/agric : Storm	**21.7**	17.1	nd	nd
P> 0.05	9.6			
Degrees Freedom (n-1)	4			

APPENDIX E

HEAVY METAL DATA

CRUDE DATA : HEAVY METALS

Al : DWF	Al mass (mg)			% total mass	
Site/Sample	Total	Soluble	Particulate	Soluble	Particulate
B1	24.7	19.0	5.7	77	23
D2	40.0	-34.9	74.9	P>T	
G3	56.7	18.4	38.3	32	68
K3	20.0	-30.8	50.7	P>T	

Cu : DWF	Cu mass (mg)			% total mass	
Site/Sample	Total	Soluble	Particulate	Soluble	Particulate
B1	1.5	-0.9	2.4	P>T	
D2	nd	nd	nd	nd	nd
G3	3.6	-0.4	4.0	-10	110
K3	10.6	5.9	4.7	55	45

Fe : DWF	Fe mass (mg)			% total mass	
Site/Sample	Total	Soluble	Particulate	Soluble	Particulate
B1	20.4	17.1	3.3	84	16
D2	nd	nd	nd	nd	nd
G3	20.4	15.1	5.2	74	26
K3	159.9	74.9	85.1	47	53

Zn : DWF	Zn mass (mg)			% total mass	
Site/Sample	Total	Soluble	Particulate	Soluble	Particulate
B1	8.7	nd	nd	nd	nd
D2	nd	nd	nd	nd	nd
G3	47.6	nd	nd	nd	nd
K3	196.3	nd	nd	nd	nd

Hg : DWF	Hg mass (mg)			% total mass	
Site/Sample	Total	Soluble	Particulate	Soluble	Particulate
B1	0.14	0.01	0.13	5	95
D2	nd	nd	nd	nd	nd
G3	3.20	1.56	1.64	49	51
K3	5.34	4.39	0.95	82	18

Mn : DWF	Mn mass (mg)			% total mass	
Site/Sample	Total	Soluble	Particulate	Soluble	Particulate
B1	nd	nd	1.53	nd	nd
D2	nd	nd	nd	nd	nd
G3	5.45	1.09	4.36	20	80
K3	12.80	4.22	8.58	33	67

Pb : DWF	Pb mass (mg)			% total mass	
Site/Sample	Total	Soluble	Particulate	Soluble	Particulate
B1	nd	nd	nd	nd	nd
D2	nd	nd	nd	nd	nd
G3	nd	nd	nd	nd	nd
K3	0.80	0.21	0.59	26	74

STORM: No results for storm flow conditions

Aluminum (Al) associated with solids

DWF

Site B1(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Al in digested SS (mg)	Mass Al in total SS fraction (mg)	gAl /kgSS	%total	gAl /kgSS per0.1mm/sec Vs
<-0.2	N/A	0.283	0.033	0.356	3.05	1.64	22	...
R	4	0.320	0.019	0.210	3.53	1.89	25	0.473
0.18-0.45	2.7	0.255	0.053	0.395	1.90	1.02	13	0.378
0.45-0.90	4.5	0.197	0.051	0.140	0.54	0.29	4	0.064
0.90-2.7	18.1	0.508	0.254	1.380	2.76	1.48	19	0.082
2.7-9.03	63.2	0.213	0.131	0.077	0.13	0.07	1	0.001
>9.03	N/A	0.091	0.010	0.249	2.27	1.21	16	...
Total		1.867	0.551	2.807	14.18	7.60	100	

Site D2(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Al in digested SS (mg)	Mass Al in total SS fraction (mg)	gAl /kgSS	%total	gAl /kgSS per0.1mm/sec
<-0.2	N/A	0.213	0.046	0.550	2.54	0.87	9	...
R	4	1.257	0.041	0.417	12.78	4.40	45	1.100
0.18-0.45	2.7	0.355	0.048	0.619	4.57	1.57	16	0.583
0.45-0.90	4.5	0.288	0.046	0.273	1.71	0.59	6	0.131
0.90-2.7	18.1	0.454	0.295	2.020	3.11	1.07	11	0.059
2.7-9.03	63.2	0.203	0.088	0.414	0.96	0.33	3	0.005
>9.03	N/A	0.137	0.032	0.646	2.76	0.95	10	...
Total		2.906	0.596	4.939	28.43	9.78	100	

Site G3(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Al in digested SS (mg)	Mass Al in total SS fraction (mg)	gAl /kgSS	%total	gAl /kgSS per0.1mm/sec
<-0.2	N/A	0.070	...	...	...	...	...	...
R	4	1.583	0.007	0.317	71.69	17.91	...	4.477
0.18-0.45	2.7	0.470	...	...	...	...	...	...
0.45-0.90	4.5	0.470	0.067	1.010	7.09	1.77	...	0.393
0.90-2.7	18.1	0.470	0.323	0.090	0.13	0.03	...	0.002
2.7-9.03	63.2	0.470	0.268	0.305	0.53	0.13	...	0.002
>9.03	N/A	0.470	0.022	0.350	7.48	1.87	...	...
Total		4.003	0.687	2.072	86.92	...	...	

Site K3(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Al in digested SS (mg)	Mass Al in total SS fraction (mg)	gAl /kgSS	%total	gAl /kgSS per0.1mm/sec
<-0.2	N/A	0.319	0.070	0.114	0.52	0.13	...	...
R	4	0.716	0.037	0.262	5.06	1.30	...	0.325
0.18-0.45	2.7	0.435	0.070	...	...	...	...	...
0.45-0.90	4.5	0.695	0.010	0.181	12.58	3.23	...	0.718
0.90-2.7	18.1	1.307	0.036	0.344	12.49	3.21	...	0.177
2.7-9.03	63.2	0.296	0.057	0.343	1.78	0.46	...	0.007
>9.03	N/A	0.124	...	...	...	...	...	...
Total		3.892	0.280	1.244	...	...	...	

STORM

Site B2(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Al in digested SS (mg)	Mass Al in total SS fraction (mg)	gAl /kgSS	%total	gAl /kgSS per0.1mm/sec
<-0.2	N/A	0.117	0.025	0.324	1.52	0.81	...	...
R	4	0.637	0.053	0.536	6.44	3.45	...	0.862
0.18-0.45	2.7	0.163	...	...	...	...	...	...
0.45-0.90	4.5	0.119	0.014	0.481	4.08	2.19	...	0.486
0.90-2.7	18.1	0.102	0.072	0.128	0.18	0.10	...	0.005
2.7-9.03	63.2	0.026	0.107	0.267	0.06	0.03	...	0.001
>9.03	N/A	0.029	0.005	0.163	0.95	0.51	...	...
Total		1.867	0.276	1.899	...	...		

MEAN RESULTS FOR ALUMINUM (DWF)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Al in digested SS (mg)	Mass Al in total SS fraction (mg)	gAl /kgSS	% total	gAl /kgSS per0.1mm/sec
<-0.2	N/A	0.221	0.050	0.340	2.039	0.64	5	...
R	4	0.969	0.026	0.301	23.267	7.35	53	1.837
0.18-0.45	2.7	0.379	0.057	0.507	3.238	1.02	7	0.379
0.45-0.90	4.5	0.412	0.044	0.401	5.479	1.73	13	0.384
0.90-2.7	18.1	0.685	0.227	0.959	4.622	1.46	11	0.081
2.7-9.03	63.2	0.295	0.136	0.285	0.849	0.27	2	0.004
>9.03	N/A	0.205	0.021	0.415	4.168	1.32	10	...
Total		3.167	0.561	3.21	43.66	13.786	100	

No. of sites=2

No. of events =2

SETTLING VELOCITY (mm/sec)	Mean (gAl/kgSS)	% in fraction	Range (gAl/kgSS) from	to
<-0.2	0.644	5	0.13	1.64
-0.2<R>0.2	7.347	53	1.30	17.91
0.18-0.45	1.022	7	1.02	1.57
0.45-0.90	1.730	13	0.29	3.23
0.90-2.7	1.459	11	0.03	3.21
2.7-9.03	0.268	2	0.07	0.46
>9.03	1.316	10	0.095	1.87
Total	13.786	100	2.935	30
Total sinker mass	5.796		1.505	10.340

Copper (Cu) associated with solids

Site B1(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Cu in digested SS (mg)	Mass Cu in total SS fraction (mg)	gCu /kgSS	%total	gCu /kgSS per0.1mm/sec
<-0.2	N/A	0.283	0.033	0.017	0.146	0.078	33	...
R	4	0.320	0.019	0.002	0.034	0.018	8	0.005
0.18-0.45	2.7	0.255	0.053	0.012	0.058	0.031	13	0.011
0.45-0.90	4.5	0.197	0.051	0.011	0.042	0.023	10	0.005
0.90-2.7	18.1	0.508	0.254	0.039	0.078	0.042	18	0.002
2.7-9.03	63.2	0.213	0.131	0.019	0.031	0.017	7	0.000
>9.03	N/A	0.091	0.010	0.006	0.055	0.029	12	...
Total		1.867	0.551	0.106	0.443	0.237	100	...

Site D2(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Cu in digested SS (mg)	Mass Cu in total SS fraction (mg)	gCu /kgSS	%total	gCu /kgSS per0.1mm/sec
<-0.2	N/A	0.213	0.046	0.011	0.05	0.017	4	...
R	4	1.257	0.041	0.012	0.37	0.127	26	0.032
0.18-0.45	2.7	0.355	0.048	0.011	0.08	0.028	6	0.010
0.45-0.90	4.5	0.288	0.046	0.016	0.10	0.034	7	0.008
0.90-2.7	18.1	0.454	0.295	0.104	0.16	0.055	11	0.003
2.7-9.03	63.2	0.203	0.088	0.014	0.03	0.011	2	0.000
>9.03	N/A	0.137	0.032	0.152	0.65	0.223	45	...
Total		2.906	0.596	0.320	1.442	0.496	100	...

Site G3(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Cu in digested SS (mg)	Mass Cu in total SS fraction (mg)	gCu /kgSS	%total	gCu /kgSS per0.1mm/sec
<-0.2	N/A	0.188	...	...	..	...	...	...
R	4	0.366	0.007	0.005	0.261	0.095	...	0.024
0.18-0.45	2.7	0.249	...	...	...	...	...	...
0.45-0.90	4.5	0.243	0.067	0.028	0.102	0.037	...	0.008
0.90-2.7	18.1	0.735	0.323	0.090	0.205	0.075	...	0.004
2.7-9.03	63.2	0.712	0.268	0.043	0.114	0.042	...	0.001
>9.03	N/A	0.251	0.022	0.007	0.080	0.029	...	...
Total		2.743	0.687	0.173	...	...	...	...

Site K3(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Cu in digested SS (mg)	Mass Cu in total SS fraction (mg)	gCu /kgSS	%total	gCu /kgSS per0.1mm/sec
<-0.2	N/A	0.319	0.070	0.008	0.036	0.009	...	...
R	4	0.716	0.037	0.043	0.832	0.214	...	0.053
0.18-0.45	2.7	0.435	0.070	0.011	0.068	0.018	...	0.007
0.45-0.90	4.5	0.695	0.010	0.011	0.765	0.196	...	0.044
0.90-2.7	18.1	1.307	0.036	0.031	1.126	0.289	...	0.016
2.7-9.03	63.2	0.296	0.057	0.040	0.207	0.053	...	0.001
>9.03	N/A	0.124	...	...	...	...	...	...
Total		3.892	0.280	0.144	...	...	...	..

Site B2(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Cu in digested SS (mg)	Mass Cu in total SS fraction (mg)	gCu /kgSS	%total	gCu /kgSS per0.1mm/sec
<-0.2	N/A	0.117	0.025	0.003	0.014	0.008	...	...
R	4	0.637	0.053	0.012	0.144	0.077	...	0.01931
0.18-0.45	2.7	0.163	...	...	...	...	...	...
0.45-0.90	4.5	0.119	0.014	0.003	0.025	0.014	...	0.00303
0.90-2.7	18.1	0.102	0.072	0.009	0.013	0.007	...	0.00038
2.7-9.03	63.2	0.026	0.107	0.010	0.002	0.001	...	0.00002
>9.03	N/A	0.029	0.005	...	...	...	...	...
Total		1.867	0.276	0.037	...	...	...	...

MEAN RESULTS FOR COPPER-DWF

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Cu in digested SS (mg)	Mass Cu in total SS fraction (mg)	gCu /kgSS	%total	gCu /kgSS per0.1mm/sec
<-0.2	N/A	0.271	0.050	0.012	0.066	0.023	5	...
R	4	0.665	0.026	0.016	0.396	0.136	29	0.0341
0.18-0.45	2.7	0.348	0.057	0.011	0.069	0.024	5	0.0088
0.45-0.90	4.5	0.356	0.044	0.017	0.135	0.046	10	0.0103
0.90-2.7	18.1	0.751	0.227	0.066	0.218	0.075	16	0.0041
2.7-9.03	63.2	0.356	0.136	0.029	0.076	0.026	6	0.0004
>9.03	N/A	0.160	0.021	0.055	0.412	0.142	30	...
Total		2.907	0.561	0.205	0.910	0.472	100	

No. of sites=4

No. of events =4

SETTLING VELOCITY (mm/sec)	Mean gCu/kgSS	% in fraction	Range (gCu/kgSS) from	to
<-0.2	0.023	5	0.009	0.078
-0.2<R>0.2	0.136	29	0.018	0.214
0.18-0.45	0.024	5	0.018	0.031
0.45-0.90	0.046	10	0.023	0.196
0.90-2.7	0.075	16	0.042	0.269
2.7-9.03	0.026	6	0.011	0.053
>9.03	0.142	30	0.029	0.223
Total	0.4720	100	0.15	1.0640
Total sinker mass	0.313		0.123	0.772

Manganese (Mn) associated with solids

Site B1(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Mn in digested SS (mg)	Mass Mn in total SS fraction (mg)	gMn /kgSS	%total	gMn /kgSS per0.1mm/sec
<-0.2	N/A	0.283	0.033	0.010	0.0858	0.0460	...	...
R	4	0.320	0.019	...	...	...	...	...
0.18-0.45	2.7	0.255	0.053	0.006	0.0289	0.0155	...	0.00574
0.45-0.90	4.5	0.197	0.051	0.006	0.0232	0.0124	...	0.00276
0.90-2.7	18.1	0.508	0.254	0.019	0.0380	0.0203	...	0.00112
2.7-9.03	63.2	0.213	0.131	0.008	0.0130	0.0070	...	0.00011
>9.03	N/A	0.091	0.010	0.004	0.0364	0.0195	..	...
Total		1.867	0.551	0.053	...	...	0.00	...

Site D2(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Mn in digested SS (mg)	Mass Mn in total SS fraction (mg)	gMn /kgSS	%total	gMn /kgSS per0.1mm/sec
<-0.2	N/A	0.213	0.046	0.038	0.1757	0.0605	10	..
R	4	1.257	0.041	0.025	0.7664	0.2637	44	0.06594
0.18-0.45	2.7	0.355	0.048	0.031	0.2290	0.0788	13	0.02919
0.45-0.90	4.5	0.288	0.046	0.036	0.2253	0.0775	13	0.01723
0.90-2.7	18.1	0.454	0.295	0.106	0.1631	0.0561	9	0.00310
2.7-9.03	63.2	0.203	0.088	0.031	0.0716	0.0246	4	0.00039
>9.03	N/A	0.137	0.032	0.023	0.0982	0.0338	6	...
Total		2.906	0.596	0.290	1.7294	0.5951	100	...

Site G3(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Mn in digested SS (mg)	Mass Mn in total SS fraction (mg)	gMn /kgSS	%total	gMn /kgSS per0.1mm/sec
<-0.2	N/A	0.188	...	...	...	...	...	...
R	4	0.366	0.007	0.008	0.4179	0.1523	...	0.03808
0.18-0.45	2.7	0.249	...	...	...	...	...	...
0.45-0.90	4.5	0.243	0.067	0.027	0.0980	0.0357	...	0.00794
0.90-2.7	18.1	0.735	0.323	0.070	0.1593	0.0581	...	0.00321
2.7-9.03	63.2	0.712	0.268	0.036	0.0956	0.0348	...	0.00055
>9.03	N/A	0.251	0.022	0.011	0.1257	0.0458	...	...
Total		2.743	0.687	0.152	...	...	0	...

Site K3(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Mn in digested SS (mg)	Mass Mn in total SS fraction (mg)	gMn /kgSS	%total	gMn /kgSS per0.1mm/sec
<-0.2	N/A	0.319	0.070	0.018	0.0819	0.0210	...	...
R	4	0.716	0.037	0.087	1.6837	0.4326	...	0.10815
0.18-0.45	2.7	0.435	0.070	0.028	0.1742	0.0447	...	0.01657
0.45-0.90	4.5	0.695	0.010	0.026	1.8073	0.4644	...	0.10319
0.90-2.7	18.1	1.307	0.036	0.051	1.8520	0.4758	...	0.02629
2.7-9.03	63.2	0.296	0.057	0.060	0.3111	0.0799	...	0.00126
>9.03	N/A	0.124	...	...	...	...	...	...
Total		3.892	0.280	0.270	...	...	0	...

Site B2(1 event)-STORM

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Mn in digested SS (mg)	Mass Mn in total SS fraction (mg)	gMn /kgSS	%total	gMn /kgSS per0.1mm/sec
<-0.2	N/A	0.117	0.025	0.006	0.0281	0.0150	...	...
R	4	0.637	0.053	0.006	0.0721	0.0386	...	0.00965
0.18-0.45	2.7	0.163	...	...	...	...	...	...
0.45-0.90	4.5	0.119	0.014	...	...	...	...	...
0.90-2.7	18.1	0.102	0.072	0.006	0.0085	0.0046	...	0.00025
2.7-9.03	63.2	0.026	0.107	0.006	0.0015	0.0008	...	0.00001
>9.03	N/A	0.029	0.005	...	...	...	...	...
Total		1.867	0.276	0.024	...	...	0	...

MEAN RESULTS FOR MANGANESE-DWF

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Mn in digested SS (mg)	Mass Mn in total SS fraction (mg)	gMn /kgSS	%total	gMn /kgSS per0.1mm/sec
<-0.2	N/A	0.271	0.050	0.022	0.1202	0.0414	6	...
R	4	0.665	0.026	0.040	1.0225	0.3518	55	0.08794
0.18-0.45	2.7	0.348	0.057	0.022	0.1325	0.0456	7	0.01688
0.45-0.90	4.5	0.356	0.044	0.024	0.1942	0.0668	10	0.01485
0.90-2.7	18.1	0.751	0.227	0.062	0.2035	0.0700	11	0.00387
2.7-9.03	63.2	0.356	0.136	0.034	0.0883	0.0304	5	0.00048
>9.03	N/A	0.160	0.021	0.013	0.0948	0.0326	5	...
Total		2.907	0.561	0.215	1.8560	0.6385	100	...

No. of sites=4

No. of events =4

SETTLING VELOCITY (mm/sec)	Mean gMn/kgSS	% in fraction	Range (gMn/kgSS) from	to
<-0.2	0.041	6.5	0.021	0.605
-0.2<R>0.2	0.352	55	0.152	0.433
0.18-0.45	0.046	7	0.016	0.079
0.45-0.90	0.067	10	0.012	0.464
0.90-2.7	0.070	11	0.020	0.476
2.7-9.03	0.030	5	0.007	0.080
>9.03	0.033	5	0.020	0.046
Total	0.6385	100	0.248	2.1823
Total sinker mass	0.245		0.075	1.145

Lead (Pb) associated with solids

Site B1(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Pb in digested SS (mg)	Mass Pb in total SS fraction (mg)	gPb /kgSS	%total	gPb /kgSS per0.1mm/sec
<-0.2	N/A	0.283	0.033	0.0021	0.0180	0.0097	28	...
R	4	0.320	0.019	0.0007	0.0118	0.0063	18	0.00158
0.18-0.45	2.7	0.255	0.053	0.0017	0.0082	0.0044	13	0.00163
0.45-0.90	4.5	0.197	0.051	0.0018	0.0069	0.0037	11	0.00083
0.90-2.7	18.1	0.508	0.254	0.0027	0.0054	0.0029	8	0.00016
2.7-9.03	63.2	0.213	0.131	0.0025	0.0041	0.0022	6	0.00003
>9.03	N/A	0.091	0.010	0.0012	0.0109	0.0059	17	...
Total		1.867	0.551	0.0127	0.0653	0.0350	100	...

Site D2(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Pb in digested SS (mg)	Mass Pb in total SS fraction (mg)	gPb /kgSS	%total	gPb /kgSS per0.1mm/sec
<-0.2	N/A	0.213	0.046	...	...	...	...	...
R	4	1.257	0.041	0.0010	0.0307	0.0105	...	0.00264
0.18-0.45	2.7	0.355	0.048	0.0009	0.0066	0.0023	...	0.00085
0.45-0.90	4.5	0.288	0.046	0.0010	0.0063	0.0022	...	0.00048
0.90-2.7	18.1	0.454	0.295	0.0012	0.0018	0.0006	...	0.00004
2.7-9.03	63.2	0.203	0.088	0.0008	0.0018	0.0006	...	0.00001
>9.03	N/A	0.137	0.032	0.0010	0.0043	0.0015	...	...
Total		2.906	0.596	0.0059	...	...	...	...

Site G3(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Pb in digested SS (mg)	Mass Pb in total SS fraction (mg)	gPb /kgSS	%total	gPb /kgSS per0.1mm/sec
<-0.2	N/A	0.188	...	...	...	...	...	...
R	4	0.366	0.007	...	...	...	...	...
0.18-0.45	2.7	0.249	...	...	...	...	...	...
0.45-0.90	4.5	0.243	0.067	...	...	...	...	...
0.90-2.7	18.1	0.735	0.323	...	...	...	...	...
2.7-9.03	63.2	0.712	0.268	...	...	...	...	...
>9.03	N/A	0.251	0.022	...	...	...	...	...
Total		2.743	0.687	...	...	...	...	...

Site K3(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Pb in digested SS (mg)	Mass Pb in total SS fraction (mg)	gPb /kgSS	%total	gPb /kgSS per0.1mm/sec
<-0.2	N/A	0.319	0.070	0.023	0.1047	0.0269	...	...
R	4	0.716	0.037	0.004	0.0747	0.0192	...	0.00480
0.18-0.45	2.7	0.435	0.070	0.003	0.0180	0.0046	...	0.00172
0.45-0.90	4.5	0.695	0.010	0.002	0.1321	0.0339	...	0.00754
0.90-2.7	18.1	1.307	0.036	0.004	0.1271	0.0327	...	0.00180
2.7-9.03	63.2	0.296	0.057	0.004	0.0228	0.0059	...	0.00009
>9.03	N/A	0.124	...	...	...	...	...	...
Total		3.892	0.280	0.040	...	...	0.00	...

Site B2(1 event)-STORM

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Pb in digested SS (mg)	Mass Pb in total SS fraction (mg)	gPb /kgSS	% total	gPb /kgSS per0.1mm/sec
<-0.2	N/A	0.117	0.025	0.002	0.0070	0.0038	...	...
R	4	0.637	0.053	0.004	0.0469	0.0251	...	0.00627
0.18-0.45	2.7	0.163	...	...	....	...	...	...
0.45-0.90	4.5	0.119	0.014	0.001	0.0102	0.0055	...	0.00121
0.90-2.7	18.1	0.102	0.072	0.002	0.0028	0.0015	...	0.00008
2.7-9.03	63.2	0.026	0.107	0.002	0.0005	0.0003	...	0.00000
>9.03	N/A	0.029	0.005	0.001	0.0047	0.0025	...	...
Total		1.867	0.276	0.012	...	...	...	...

MEAN RESULTS FOR LEAD-DWF

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Pb in digested SS (mg)	Mass Pb in total SS fraction (mg)	gPb /kgSS	% total	gPb /kgSS per0.1mm/sec
<-0.2	N/A	0.301	0.052	0.013	0.0733	0.0252	43	...
R	4	0.764	0.032	0.002	0.0438	0.0150	26	0.00376
0.18-0.45	2.7	0.348	0.051	0.002	0.0127	0.0043	7	0.00161
0.45-0.90	4.5	0.393	0.036	0.002	0.0173	0.0059	10	0.00132
0.90-2.7	18.1	0.756	0.195	0.002	0.0096	0.0033	6	0.00018
2.7-9.03	63.2	0.237	0.092	0.003	0.0066	0.0023	4	0.00004
>9.03	N/A	0.114	0.021	0.001	0.0060	0.0020	4	...
Total		2.914	0.478	0.024	0.1692	0.0581	100	...

No. of sites=3

No. of events =3

SETTLING VELOCITY (mm/sec)	Mean gPb/kgSS	% in fraction	Range (gPb/kgSS) from	to
<-0.2	0.0252	43	0.0011	0.0269
-0.2<R>0.2	0.0150	26	0.0063	0.0192
0.18-0.45	0.0043	7	0.0023	0.0046
0.45-0.90	0.0059	10	0.0022	0.0339
0.90-2.7	0.0033	6	0.0006	0.0327
2.7-9.03	0.0023	4	0.0006	0.0059
>9.03	0.0020	4	0.0015	0.0059
Total	0.0581	100	0.0146	0.1291
Total sinker mass	0.018		0.007	0.083

Zinc (Zn) associated with solids

Site B1(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Zn in digested SS (mg)	Mass Zn in total SS fraction (mg)	gZn /kgSS	%total	gZn /kgSS per0.1mm/sec
<-0.2	N/A	0.283	0.033	...	...	...	...	...
R	4	0.320	0.019	0.071	1.1950	0.6401	...	0.16003
0.18-0.45	2.7	0.255	0.053	0.115	0.5541	0.2968	...	0.10994
0.45-0.90	4.5	0.197	0.051	0.105	0.4052	0.2171	...	0.04824
0.90-2.7	18.1	0.508	0.254	0.174	0.3477	0.1862	...	0.01029
2.7-9.03	63.2	0.213	0.131	0.110	0.1789	0.0958	...	0.00152
>9.03	N/A	0.091	0.010	0.099	0.9018	0.4831	...	...
Total		1.867	0.551	0.674	3.5828	1.9191	...	...

Site D2(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Zn in digested SS (mg)	Mass Zn in total SS fraction (mg)	gZn /kgSS	%total	gZn /kgSS per0.1mm/sec
<-0.2	N/A	0.213	0.046	0.286	1.3221	0.4550	8	...
R	4	1.257	0.041	0.289	8.8600	3.0489	51	0.76223
0.18-0.45	2.7	0.355	0.048	0.226	1.6696	0.5746	10	0.21280
0.45-0.90	4.5	0.288	0.046	0.316	1.9779	0.6806	11	0.15125
0.90-2.7	18.1	0.454	0.295	0.542	0.8338	0.2869	5	0.01585
2.7-9.03	63.2	0.203	0.088	0.241	0.5569	0.1916	3	0.00303
>9.03	N/A	0.137	0.032	0.526	2.2460	0.7729	13	..
Total		2.906	0.596	2.426	17.4663	6.0105	100	...

Site G3(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Zn in digested SS (mg)	Mass Zn in total SS fraction (mg)	gZn /kgSS	%total	gZn /kgSS per0.1mm/sec
<-0.2	N/A	0.188	...	..	...	...	...	...
R	4	0.366	0.007	0.145	7.5749	2.7610	...	0.69026
0.18-0.45	2.7	0.249	...	...	...	...	...	...
0.45-0.90	4.5	0.243	0.067	0.131	0.4755	0.1733	...	0.03851
0.90-2.7	18.1	0.735	0.323	0.328	0.7466	0.2721	...	0.01504
2.7-9.03	63.2	0.712	0.268	0.186	0.4939	0.1800	...	0.00285
>9.03	N/A	0.251	0.022	0.127	1.4508	0.5288	...	...
Total		2.743	0.687	0.917	...	...	...	...

Site K3(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Zn in digested SS (mg)	Mass Zn in total SS fraction (mg)	gZn /kgSS	%total	gZn /kgSS per0.1mm/sec
<-0.2	N/A	0.319	0.070	0.523	2.3798	0.6115	...	...
R	4	0.716	0.037	0.489	9.4638	2.4315	...	0.60788
0.18-0.45	2.7	0.435	0.070	0.477	2.9670	0.7623	...	0.28233
0.45-0.90	4.5	0.695	0.010	0.600	41.7077	10.7160	...	2.38133
0.90-2.7	18.1	1.307	0.036	0.586	21.2799	5.4675	...	0.30207
2.7-9.03	63.2	0.296	0.057	0.474	2.4574	0.6314	...	0.00999
>9.03	N/A	0.124	...	...	...	...	...	...
Total		3.892	0.280	3.149	...	...	...	...

Site B2(1 event)-STORM

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Zn in digested SS (mg)	Mass Zn in total SS fraction (mg)	gZn /kgSS	%total	gZn /kgSS per0.1mm/sec
<-0.2	N/A	0.117	0.025	0.092	0.4305	0.2306	...	...
R	4	0.637	0.053	0.127	1.5257	0.8173	...	0.20431
0.18-0.45	2.7	0.163	...	...	...	...	...	...
0.45-0.90	4.5	0.119	0.014	0.160	1.3571	0.7269	...	0.16154
0.90-2.7	18.1	0.102	0.072	0.151	0.2149	0.1151	...	0.00636
2.7-9.03	63.2	0.026	0.107	0.137	0.0333	0.0178	...	0.00028
>9.03	N/A	0.029	0.005	0.097	0.5680	0.3043	...	..
Total		1.867	0.276	0.764	...	...	...	...

MEAN RESULTS FOR ZINC-DWF

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Zn in digested SS (mg)	Mass Zn in total SS fraction (mg)	gZn /kgSS	%total	gZn /kgSS per0.1mm/sec
<-0.2	N/A	0.250	0.058	0.405	1.7468	0.6053	11	...
R	4	0.665	0.026	0.260	6.6335	2.2986	41	0.57465
0.18-0.45	2.7	0.348	0.057	0.273	1.6669	0.5776	10	0.21393
0.45-0.90	4.5	0.356	0.044	0.288	2.3554	0.8162	14	0.18137
0.90-2.7	18.1	0.751	0.227	0.408	1.3481	0.4671	8	0.02581
2.7-9.03	63.2	0.356	0.136	0.253	0.6614	0.2292	4	0.00363
>9.03	N/A	0.160	0.021	0.251	1.8763	0.6502	12	...
Total		2.886	0.569	2.136	16.2884	5.6442	100	...

No. of sites=4
No. of events =4

SETTLING VELOCITY (mm/sec)	Mean gZn/kgSS	% in fraction	Range (gZn/kgSS)	
			from	to
<-0.2	0.605	11	0.455	0.6115
-0.2<R>0.2	2.299	41	0.6401	3.0489
0.18-0.45	0.578	10	0.2968	0.7623
0.45-0.90	0.816	14	0.1733	10.716
0.90-2.7	0.467	8	0.1862	5.4675
2.7-9.03	0.229	4	0.0958	0.6314
>9.03	0.650	12	0.4831	0.7729
Total	5.644	100	2.3303	22.011
Total sinker mass	2.740		1.235	18.350

Mercury (Hg) associated with solids

Site B1(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Hg in digested SS (mg)	Mass Hg in total SS fraction (mg)	gHg /kgSS	%total	gHg /kgSS per0.1mm/sec
<-0.2	N/A	0.283	0.033	0.0015	0.0128	0.0068	...	...
R	4	0.320	0.019	0.0001	0.0013	0.0007	...	0.00018
0.18-0.45	2.7	0.255	0.053	0.0002	0.0010	0.0005	...	0.00020
0.45-0.90	4.5	0.197	...	...	...	...	...	...
0.90-2.7	18.1	0.508	...	...	...	...	...	...
2.7-9.03	63.2	0.213	0.131	0.0002	0.0003	0.0001	...	0.00000
>9.03	N/A	0.091	0.010	0.0004	0.0034	0.0018	...	...
Total		1.867	0.246	0.0023	0.0188	0.0101	...	...

Site D2(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Hg in digested SS (mg)	Mass Hg in total SS fraction (mg)	gHg /kgSS	%total	gHg /kgSS per0.1mm/sec
<-0.2	N/A	0.213	0.046	0.001	0.0044	0.0015	4	...
R	4	1.257	0.041	0.001	0.0448	0.0154	40	0.00385
0.18-0.45	2.7	0.355	0.048	0.002	0.0146	0.0050	13	0.00186
0.45-0.90	4.5	0.288	0.046	0.005	0.0285	0.0098	26	0.00218
0.90-2.7	18.1	0.454	0.295	0.001	0.0016	0.0006	1	0.00003
2.7-9.03	63.2	0.203	0.088	0.002	0.0039	0.0014	4	0.00002
>9.03	N/A	0.137	0.032	0.003	0.0140	0.0048	12	...
Total		2.906	0.596	0.015	0.1119	0.0385	100	...

Site G3(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Hg in digested SS (mg)	Mass Hg in total SS fraction (mg)	gHg /kgSS	%total	gHg /kgSS per0.1mm/sec
<-0.2	N/A	0.188	...	...	...	...	...	...
R	4	0.366	0.007	0.010	0.5120	0.1866	...	0.04665
0.18-0.45	2.7	0.249	...	...	...	...	...	...
0.45-0.90	4.5	0.243	0.067	0.004	0.0141	0.0051	...	0.00114
0.90-2.7	18.1	0.735	0.323	0.001	0.0033	0.0012	...	0.00007
2.7-9.03	63.2	0.712	0.268	0.007	0.0175	0.0064	...	0.00010
>9.03	N/A	0.251	0.022	0.001	0.0118	0.0043	...	...
Total		2.743	0.687	0.023	...	...	...	...

Site K3(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Hg in digested SS (mg)	Mass Hg in total SS fraction (mg)	gHg /kgSS	%total	gHg /kgSS per0.1mm/sec
<-0.2	N/A	0.319	0.070	0.0003	0.0013	0.0003	...	...
R	4	0.716	0.037	0.0007	0.0130	0.0033	...	0.00083
0.18-0.45	2.7	0.435	...	...	...	...	...	...
0.45-0.90	4.5	0.695	0.010	0.0008	0.0549	0.0141	...	0.00314
0.90-2.7	18.1	1.307	0.036	0.0006	0.0225	0.0058	...	0.00032
2.7-9.03	63.2	0.296	0.057	0.0007	0.0035	0.0009	...	0.00001
>9.03	N/A	0.124	...	...	...	...	...	...
Total		3.892	0.210	0.0030	...	...	...	...

Site B2(1 event)-STORM

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Hg in digested SS (mg)	Mass Hg in total SS fraction (mg)	gHg /kgSS	%total	gHg /kgSS per0.1mm/sec
<-0.2	N/A	0.117	0.025	0.0003	0.0016	0.0009	...	...
R	4	0.637	0.053	0.0003	0.0037	0.0020	...	0.00050
0.18-0.45	2.7	0.163	...	...	...	...	...	...
0.45-0.90	4.5	0.119	0.014	0.0007	0.0057	0.0030	...	0.00068
0.90-2.7	18.1	0.102	0.072	0.0002	0.0003	0.0002	...	0.00001
2.7-9.03	63.2	0.026	0.107	0.0001	0.0000	0.00001	...	0.00000
>9.03	N/A	0.029	0.005	0.0001	0.0008	0.0004	...	...
Total		1.867	0.276	0.0017	...	...	...	...

MEAN RESULTS FOR MERCURY-DWF

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Hg in digested SS (mg)	Mass Hg in total SS fraction (mg)	gHg /kgSS	%total	gHg /kgSS per0.1mm/sec
<-0.2	N/A	0.271	0.050	0.001	0.0050	0.0017	4	...
R	4	0.665	0.026	0.003	0.0768	0.0266	56	0.00665
0.18-0.45	2.7	0.348	0.051	0.001	0.0076	0.0026	6	0.00097
0.45-0.90	4.5	0.356	0.041	0.003	0.0267	0.0093	19	0.00206
0.90-2.7	18.1	0.751	0.218	0.001	0.0036	0.0012	3	0.00007
2.7-9.03	63.2	0.356	0.136	0.002	0.0060	0.0021	4	0.00003
>9.03	N/A	0.160	0.021	0.002	0.0117	0.0040	8	...
Total		2.907	0.543	0.013	0.1372	0.0476	100	...

No. of sites=4

No. of events =5

SETTLING VELOCITY (mm/sec)	Mean gHg/kgSS	% in fraction	Range (gHg/kgSS) from	to
<-0.2	0.002	4	0.0003	0.0068
-0.2<R>0.2	0.027	56	0.0007	0.1866
0.18-0.45	0.003	6	0.0005	0.005
0.45-0.90	0.009	19	0.0051	0.0141
0.90-2.7	0.001	3	0.00001	0.0058
2.7-9.03	0.002	4	0.0001	0.0064
>9.03	0.004	8	0.0018	0.0048
Total	0.048	100	0.00851	0.2295
Total sinker mass	0.019		0.008	0.036

Iron (Fe) associated with solids

Site B1(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Fe in digested SS (mg)	Mass Fe in total SS fraction (mg)	gFe /kgSS	%total	gFe /kgSS per0.1mm/sec
<-0.2	N/A	0.283	0.033	0.111	0.9525	0.5102	16	...
R	4	0.320	0.019	0.115	1.9356	1.0368	33	0.25920
0.18-0.45	2.7	0.255	0.053	0.164	0.7903	0.4233	13	0.15678
0.45-0.90	4.5	0.197	0.051	0.050	0.1930	0.1034	3	0.02297
0.90-2.7	18.1	0.508	0.254	0.368	0.7353	0.3939	12	0.02176
2.7-9.03	63.2	0.213	0.131	0.104	0.1692	0.0906	3	0.00143
>9.03	N/A	0.091	0.010	0.125	1.1387	0.6099	19	...
Total		1.867	0.551	1.037	5.9145	3.1681	100	...

Site D2(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Fe in digested SS (mg)	Mass Fe in total SS fraction (mg)	gFe /kgSS	%total	gFe /kgSS per0.1mm/sec
<-0.2	N/A	0.213	0.046	0.296	1.3684	0.4709	7	...
R	4	1.257	0.041	0.264	8.0935	2.7852	39	0.69629
0.18-0.45	2.7	0.355	0.048	0.369	2.7261	0.9381	13	0.34745
0.45-0.90	4.5	0.288	0.046	0.295	1.8464	0.6354	9	0.14120
0.90-2.7	18.1	0.454	0.295	1.280	1.9692	0.6776	9	0.03744
2.7-9.03	63.2	0.203	0.088	0.457	1.0559	0.3634	5	0.00575
>9.03	N/A	0.137	0.032	0.862	3.6807	1.2666	18	...
Total		2.906	0.596	3.823	20.7403	7.1372	100	...

Site G3(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Fe in digested SS (mg)	Mass Fe in total SS fraction (mg)	gFe /kgSS	%total	gFe /kgSS per0.1mm/sec
<-0.2	N/A	0.188	...	...	...	...	...	...
R	4	0.366	0.007	0.150	7.8361	2.8562	...	0.71406
0.18-0.45	2.7	0.249	...	...	...	...	...	...
0.45-0.90	4.5	0.243	0.067	0.560	2.0326	0.7409	...	0.16464
0.90-2.7	18.1	0.735	0.323	0.045	0.1024	0.0373	...	0.00206
2.7-9.03	63.2	0.712	0.268	0.051	0.1354	0.0494	...	0.00078
>9.03	N/A	0.251	0.022	0.190	2.1705	0.7911	...	...
Total		2.743	0.687	0.996	...	...	...	...

Site K3(1 event)

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Fe in digested SS (mg)	Mass Fe in total SS fraction (mg)	gFe /kgSS	%total	gFe /kgSS per0.1mm/sec
<-0.2	N/A	0.319	0.070	0.180	0.82	0.21	...	...
R	4	0.716	0.037	1.975	38.22	9.82	...	2.46
0.18-0.45	2.7	0.435	0.070	1.180	7.34	1.89	...	0.70
0.45-0.90	4.5	0.695	0.010	2.080	144.59	37.15	...	8.26
0.90-2.7	18.1	1.307	0.036	1.260	45.76	11.76	...	0.65
2.7-9.03	63.2	0.296	0.057	0.758	3.93	1.01	...	0.02
>9.03	N/A	0.124	...	...	...	...	...	...
Total		3.892					...	

Site B2(1 event)-STORM

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Fe in digested SS (mg)	Mass Fe in total SS fraction (mg)	gFe /kgSS	%total	gFe /kgSS per0.1mm/sec
<-0.2	N/A	0.117	...	...	...	...	...	...
R	4	0.637	...	...	...	...	...	...
0.18-0.45	2.7	0.163	...	...	...	...	...	...
0.45-0.90	4.5	0.119	0.014	...	...	...	...	...
0.90-2.7	18.1	0.102	0.072	0.113	0.1608	0.0862	...	0.00476
2.7-9.03	63.2	0.026	0.107	...	...	...	...	...
>9.03	N/A	0.029	0.005	0.061	0.3572	0.1913	...	...
Total		1.867		...	...		...	

MEAN RESULTS FOR IRON-DWF

vs (mm/sec)	No. 0.1mm/sec Vs intervals	SS mass large column volume (g)	SSmass digest (g)	Mass Fe in digested SS (mg)	Mass Fe in total SS fraction (mg)	gFe /kgSS	%total	gFe /kgSS per0.1mm/sec
<-0.2	N/A	0.271	0.050	0.196	1.07	0.37	3	...
R	4	0.665	0.026	0.626	16.00	5.50	49	1.38
0.18-0.45	2.7	0.348	0.057	0.571	3.49	1.20	11	0.44
0.45-0.90	4.5	0.356	0.044	0.746	6.10	2.10	19	0.47
0.90-2.7	18.1	0.751	0.227	0.738	2.44	0.84	7	0.05
2.7-9.03	63.2	0.356	0.136	0.343	0.90	0.31	3	0.00
>9.03	N/A	0.160	0.021	0.392	2.94	1.01	9	...
Total		2.907	0.561	3.612	15.869	11.33	100	

No. of sites=4

No. of events =4

SETTLING VELOCITY (mm/sec)	Mean gFe/kgSS	% in fraction	Range (gFe/kgSS) from	to
<-0.2	0.3679	3	0.2100	0.5102
-0.2<R>0.2	5.5049	49	1.0368	9.8200
0.18-0.45	1.2009	11	0.9381	1.8900
0.45-0.90	2.0996	18	0.1034	37.1500
0.90-2.7	0.8402	7	0.0373	11.7600
2.7-9.03	0.3083	3	0.0494	1.0100
>9.03	1.0103	9	0.6099	1.2666
Total	11.3321	99	2.9849	63.4068
Total sinker mass	5.459		1.738	53.077

Catchment size	No. of sites	% of total Al/SS mass	
		% solids	% liquor
Large	1	23.2	76.8
Medium	1	67.6	32.4

The effect of catchment size on the distribution of Al/SS
in the solid and liquor phase of the crude samples (DWF conditions).

Catchment size	No. of sites	% of total Cu/SS mass	
		% solids	% liquor
Large	0	...	...
Medium	1	44.5	55.5

The effect of catchment size on the distribution of Cu/SS
in the solid and liquor phase of the crude samples (DWF conditions).

Catchment size	No. of sites	% of total Fe/SS mass	
		% solids	% liquor
Large	1	16.1	83.9
Medium	2		
Mean		39.4	60.6
Range		25.7-53.2	46.8-74.3

The effect of catchment size on the distribution of Fe/SS
in the solid and liquor phase of the crude samples (DWF conditions).

Catchment size	No. of sites	% of total Hg/SS mass	
		% solids	% liquor
Large	1	95.0	5.0
Medium	2		
Mean		34.5	65.5
Range		17.7-51.4	48.6-82.3

The effect of catchment size on the distribution of Hg/SS
in the solid and liquor phase of the crude samples (DWF conditions).

Catchment size	No. of sites	% of total Mn/SS mass	
		% solids	% liquor
Large	0	...	...
Medium	2		
Mean		73.5	26.5
Range		67.0-80.0	20.0-33.0

The effect of catchment size on the distribution of Mn/SS
in the solid and liquor phase of the crude samples (DWF conditions).

Catchment size	No. of sites	% of total Pb/SS mass	
		% solids	% liquor
Large	0	...	...
Medium	1	73.6	26.4

The effect of catchment size on the distribution of Pb/SS
in the solid and liquor phase of the crude samples (DWF conditions).

Catchment	No. of	% of total Al/SS mass		
size	sites	Floaters	Residue	Sinkers
Large	2			
Mean		14.5	36.2	49.3
Range		8.94-21.54	24.92-44.97	46.09-53.54
Medium	0	...	...	...
Small	0	...	...	...

The effect of catchment size on the distribution of Al/SS
in the three main settling column fractions (DWF conditions)

Catchment	No. of	% of total Cu/SS mass		
size	sites	Floaters	Residue	Sinkers
Large	2			
Mean		13.0	19.7	67.3
Range		3.53-32.91	7.59-25.52	59.5-70.95
Medium	2			
Mean		2	27	71
Range		n/a	n/a	n/a
Small		...	...	...

The effect of catchment size on the distribution of Cu/SS
in the three main settling column fractions (DWF conditions)

Catchment	No. of	% of total Mn/SS mass		
size	sites	Floaters	Residue	Sinkers
Large	1			
Mean		10.9	53.8	35.3
Medium	2			
Mean		2.2	29.9	68.0
Range		n/a	n/a	n/a
Small		...	...	...

The effect of catchment size on the distribution of Mn/SS
in the three main settling column fractions (DWF conditions)

Catchment	No. of	% of total Pb/SS mass		
size	sites	Floaters	Residue	Sinkers
Large	1	22.6	22.2	55.2
Medium	0	...	...	...
Small	0			

Table. The effect of catchment size on the distribution of Pb/SS
in the three main settling column fractions (DWF conditions)

Catchment	No. of	% of total Zn/SS mass		
size	sites	Floaters	Residue	Sinkers
Large	2			
Mean		11.75	39.37	48.88
Range		n/a	n/a	n/a
Medium	2			
Mean		4.6	19.6	75.7
Range		n/a	n/a	n/a
Small	0	...	...	...

Table. The effect of catchment size on the distribution of Zn/SS
in the three main settling column fractions (DWF conditions)

Catchment size	No. of sites	% of total Hg/SS mass Floaters	Residue	Sinkers
Large	2			
Mean		14.2	27.4	58.4
Range		n/a	n/a	n/a
Medium	0	...	...	...
Small	0	...	...	...

Table. The effect of catchment size on the distribution of Hg/SS in the three main settling column fractions (DWF conditions)

Catchment size	No. of sites	% of total Fe/SS mass Floaters	Residue	Sinkers
Large	2			
Mean		9.5	37.1	53.4
Range		6.6-16.1	32.73-39.02	51.17-54.38
Medium	2			
Mean		0.6	18.3	81.1
Small	0	...	...	...

Table. The effect of catchment size on the distribution of Fe/SS in the three main settling column fractions (DWF conditions)

Catchment size	No. of sites	% of total sinker mass in settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Large	2	30	10	30	5	25
Medium	0	...	...	...	...	...

The effect of catchment size on the distribution of Al/SS
in the five sinker fractions (DWF samples)

Catchment size	No. of sites	% of total sinker mass in settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Large	2	12	12	20	6	51
Medium	2	4	30	46	12	7

The effect of catchment size on the distribution of Cu/SS
in the five sinker fractions (DWF samples)

Catchment size	No. of sites	% of total sinker mass in settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Large	2	27	26	22	9	15
Medium	2	7	38	40	9	7

The effect of catchment size on the distribution of Mn/SS
in the five sinker fractions (DWF samples)

Catchment size	No. of sites	% of total sinker mass in settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Large	2	25	22	13	11	28
Medium	0	...	...	...	...	...

The effect of catchment size on the distribution of Pb/SS
in the five sinker fractions (DWF samples)

Catchment size	No. of sites	% of total sinker mass in settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Large	2	23	24	12	8	33
Medium	2	8	54	29	4	5

The effect of catchment size on the distribution of Zn/SS
in the five sinker fractions (DWF samples)

Catchment size	No. of sites	% of total sinker mass in settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Large	2	16	57	3	4	19
Medium	0	...	...	...	...	...

The effect of catchment size on the distribution of Hg/SS
in the five sinker fractions (DWF samples)

Catchment size	No. of sites	% of total sinker mass in settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Large	2	25	13	20	8	34
Medium	0					

The effect of catchment size on the distribution of Fe/SS
in the five sinker fractions (DWF samples)

Catchment type	No. of sites	% of total Al/SS mass	
		% solids	% liquor
Dom/ind	1	23.2	76.8
Domestic	1	67.6	32.4

The effect of catchment type on the distribution of Al/SS
in the solid and liquor phase of the crude samples (DWF conditions).

Catchment type	No. of sites	% of total Cu/SS mass	
		% solids	% liquor
Dom/ind	1	44.5	55.5
Domestic	0	...	...

The effect of catchment type on the distribution of Cu/SS
in the solid and liquor phase of the crude samples (DWF conditions).

Catchment type	No. of sites	% of total Fe/SS mass	
		% solids	% liquor
Dom/ind	2		
Mean		34.6	65.4
Range		16.1-53.2	46.8-83.9
Domestic	1	25.7	74.3

The effect of catchment type on the distribution of Fe/SS
in the solid and liquor phase of the crude samples (DWF conditions).

Catchment type	No. of sites	% of total Hg/SS mass	
		% solids	% liquor
Dom/ind	2		
Mean		56.3	43.7
Range		17.7-95.0	5.0-82.3
Domestic	1	51.4	48.6

The effect of catchment type on the distribution of Hg/SS
in the solid and liquor phase of the crude samples (DWF conditions).

Catchment type	No. of sites	% of total Mn/SS mass	
		% solids	% liquor
Dom/ind	1	67.0	33.0
Domestic	1	80.0	20.0

The effect of catchment type on the distribution of Mn/SS
in the solid and liquor phase of the crude samples (DWF conditions).

Catchment type	No. of sites	% of total Pb/SS mass	
		% solids	% liquor
Dom/ind	1	73.6	26.4
Domestic	0	...	...

The effect of catchment type on the distribution of Pb/SS
in the solid and liquor phase of the crude samples (DWF conditions).

Catchment type	No. of sites	% of total Al/SS mass		
		Floaters	Residue	Sinkers
Dom/ind	2	9.7	17.6	72.7
Domestic	2	5.1	65.7	29.1
Dom/agric	0	...	...	...

The effect of catchment type on the distribution of Al/SS
in the three main settling column fractions (DWF conditions)

Catchment type	No. of sites	% of total Cu/SS mass		
		Floaters	Residue	Sinkers
Dom/ind	2	8.4	22.1	69.5
Domestic	2	4.3	27.1	68.7
Dom/agric	0	...	...	...

The effect of catchment type on the distribution of Cu/SS
in the three main settling column fractions (DWF conditions)

Catchment type	No. of sites	% of total Mn/SS mass		
		Floaters	Residue	Sinkers
Dom/ind	1	3.2	41.4	55.4
Domestic	2	11.4	39.2	49.4
Dom/agric	0	...	...	...

The effect of catchment type on the distribution of Mn/SS
in the three main settling column fractions (DWF conditions)

Catchment type	No. of sites	% of total Pb/SS mass		
		Floaters	Residue	Sinkers
Dom/ind	1	22.3	15.5	62.2
Domestic	0	...	...	...
Dom/agric	0	...	...	...

The effect of catchment type on the distribution of Pb/SS
in the three main settling column fractions (DWF conditions)

Catchment type	No. of sites	% of total Zn/SS mass		
		Floaters	Residue	Sinkers
Dom/ind	2	5.2	13.0	81.8
Domestic	2	8.3	53.0	38.7
Dom/agric	0	...	...	...

The effect of catchment type on the distribution of Zn/SS
in the three main settling column fractions (DWF conditions)

Catchment type	No. of sites	% of total Hg/SS mass		
		Floaters	Residue	Sinkers
Dom/ind	2	50.7	5.8	43.5
Domestic	2	1.2	81.2	17.6
Dom/agric	0	...	...	...

The effect of catchment type on the distribution of Hg/SS
in the three main settling column fractions (DWF conditions)

Catchment type	No. of sites	% of total Fe/SS mass		
		Floaters	Residue	Sinkers
Dom/ind	2	1.1	16.5	82.4
Domestic	2	7.2	43.3	49.4
Dom/agric	0	...	...	...

The effect of catchment type on the distribution of Fe/SS
in the three main settling column fractions (DWF conditions)

Catchment type	No. of sites	% of total sinker mass in settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Dom/Ind	2	15	27	36	4	18
Domestic	2	32	24	11	5	28

The effect of catchment type on the distribution of Al/SS
in the five sinker fractions (DWF samples)

Catchment type	No. of sites	% of total sinker mass in settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Dom/Ind	2	7	30	45	10	8
Domestic	2	10	13	23	9	45

The effect of catchment type on the distribution of Cu/SS
in the five sinker fractions (DWF samples)

Catchment type	No. of sites	% of total sinker mass in settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Domestic	2	30	22	22	11	15
Dom/Ind	2	5	41	43	8	3

The effect of catchment type on the distribution of Mn/SS
in the five sinker fractions (DWF samples)

Catchment type	No. of sites	% of total sinker mass in settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Domestic	1	32	30	9	9	20
Dom/Ind	2	9	37	35	8	11

The effect of catchment type on the distribution of Pb/SS
in the five sinker fractions (DWF samples)

Catchment type	No. of sites	% of total sinker mass in settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Domestic	2	27	20	13	9	31
Dom/Ind	2	5	57	29	4	5

The effect of catchment type on the distribution of Zn/SS
in the five sinker fractions (DWF samples)

Catchment type	No. of sites	% of total sinker mass in settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Dom/ind	2	23	34	4	18	21
Domestic	2	9	53	5	1	31

The effect of catchment type on the distribution of Hg/SS
in the five sinker fractions (DWF samples)

Catchment type	No. of sites	% of total sinker mass in settling velocity fraction (mm/sec)				
		0.18-0.45	0.45-0.90	0.90-2.71	2.71-9.03	>9.03
Dom/ind	0	...	...	...	...	...
Domestic	2	29	21	11	6	32

The effect of catchment type on the distribution of Fe/SS
in the five sinker fractions (DWF samples)