APPENDIX A

PRELIMINARY GUIDELINES FOR THE INSTALLATION AND OPERATION OF "SLUDGE SIPHON" SYSTEMS

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A1 INTRODUCTION

The design and operation of settled sewage systems using conventional interceptor tanks is well documented (Smith 1993; USEPA 1991; WRC 1998a; WRC 1998b). In Chapter 11 (Recommendations for further research) it was suggested that experimentation be conducted to examine the flow behaviour of various concentrations of suspended sludge, using different pipeline sizes. It is therefore not possible, at this stage, to suggest guidelines for the reticulation network attached to a sludge siphon system other than to refer to what was observed in the experimental installation on the CSIR campus. However, for the correct operation of an interceptor tank containing a sludge siphon system, it will be of critical importance that certain installation and operating guidelines are adhered to. These are suggested below and are the direct outcome of the research and development carried out to date.

A2 PRELIMINARY GUIDELINES

A2.1 Installation guidelines

1. The activating plumbing fixture (i.e. washtub, bath, etc) should be as close as possible to the tank, and in any case not more than 6 m away. Longer distances tend to cause attenuation of the flow, with the result that a much larger volume of wastewater is required to activate the siphon, or it may not even activate at all. It is essential that wastewater enters the siphon system as rapidly as possible.

2. The excavation for the tank should have the base accurately trimmed in order to ensure that the bottom of the tank is horisontal. The level of the effluent pipe will be approximately 500 mm lower than in the case of a conventional interceptor tank, and the pipeline excavation will therefore be initially deeper than usual by this amount. It is recommended that the first 12 m of pipeline length has a minimum positive gradient of at least 0,25 % (i.e. 1:0,0025).

3. The effluent pipeline may contain sections with a negative gradient, as long as the elevation of the highest point in the pipeline does not exceed that of the crown of the siphon. It is essential, however, that a negative gradient not be introduced within the first 12 m of pipeline length commencing at an interceptor tank. This minimum distance is necessary to ensure full activation of the siphon, and thus full-bore pipe flow under maximum head, before the inertia of the standing septage at the vertical kink in the pipeline is able to be effectively overcome by the new flow. If this requirement is not complied with, it is likely that the siphon will not activate.

4. Where an effluent pipeline from an interceptor tank joins up with a collector pipeline, for example in the street reserve, the connecting joint should be made such that the effluent in the household pipeline has an unobstructed flow into the collector pipeline. This can be achieved by fitting the joint with the intersecting leg pointing in an upward direction, so that the incoming flow can "drop" into the collector pipeline.

5. Ensure pedestrian access to the tank is not obstructed, in order to facilitate inspection and maintenance if necessary. The tank should also be installed so that the inspection covers are accessible. If possible, the tank should be installed in a position where vehicular loads are unlikely, otherwise care should be taken that adequate protection is provided.

6. Normal tank ventilation through the incoming blackwater pipeline (i.e. not the pipeline from the activating fixture) should be ensured, as for any conventional septic tank system.

A2.2 Operating guidelines

1. The siphon should be activated, by means of the plumbing fixture connected for this purpose (the activating fixture), at least once a week if possible. Longer flushing intervals may lead to a larger accumulation of sludge in the tank, where the lower layers tend to be compacted by the mass of sludge above. In some cases this may require more than a single flush to activate the siphon properly.

2. The minimum flushing volume should be 25 litres, i.e. the activating fixture should contain at least this amount of wastewater before being emptied at the weekly period. Smaller flushes may not necessarily activate the siphon.

3. The interceptor tank should be treated with the same care as any conventional septic tank i.e. no harmful detergents and no materials other than proper toilet tissue paper should be flushed down the toilet. Items such as sanitary pads and wads of heavy paper or plastic should be specifically excluded.

4. It is essential that the waste pipe from the activating fixture be kept free-flowing. This means that, if the outflow rate decreases due to a blockage, even a minor one, the waste pipe should be cleared immediately. When performing this task, it is essential to ensure that the material responsible for the blockage is not pushed further down the waste pipe towards the tank. The U-trap (if there is one) beneath the fixture will probably need to be loosened and cleaned out.

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APPENDIX B

PRELIMINARY GUIDELINES FOR THE DESIGN AND OPERATION OF URINE DIVERSION SANITATION SYSTEMS IN SOUTH AFRICA

B1 INTRODUCTION

As mentioned in Chapter 11 (Recommendations for further research), most of the technical issues regarding the design and operation of urine diversion sanitation systems have been thoroughly researched in other countries (Dudley 1996; Esrey et al 1998; Gough 1997; Hanaeus et al 1997; Höglund et al 1998; Jönsson 1997; Mejia 1997; Winblad 1993; Winblad 1996b; Wolgast 1993). South African experience is currently very limited, and these guidelines are of necessity restricted to the learning experience associated with the pilot project in Eastern Cape. However, the generic structure of the guidelines is such that they are not confined to this specific experience only; rather, they are considered to be applicable generally, in all regions and for most population groups.

B2 PRELIMINARY GUIDELINES

B2.1 Design guidelines

1. Community participation in the project, from the conceptual stage right through to completion, is of primary importance. Due to the novelty of the technology especially, more social involvement than usual will be required during the project planning stage, so that the eventual users will know exactly what they are getting and how the units differ from conventional VIP or other composting toilets. It will be useful if a full-size pedestal can be shown to the communities during the initial introductory phase, as well as samples of the proposed building materials for the superstructure.

2. Toilet units may be free-standing or part of another structure, such as a dwelling for instance. The main criterion in the latter regard is adequacy of the other structure in terms of size, materials, durability and compatibility. Any suitable building material may be used, as long as it provides a sound, waterproof structure. Traditional building materials and methods may be especially suited to rural areas. However, proper provision for stormwater drainage around the toilet unit should be ensured.

3. The floor area of the toilet superstructure should provide sufficient space for the pedestal as well as containers for bulking agent (soil, ash, etc) and used cleansing materials. The need for a men's urinal inside the unit should be carefully researched as, besides its purchase and installation costs, it also requires additional floor area. It may be found that men will be satisfied without a special urinal being provided inside the toilet unit, as in rural areas particularly, they can often urinate in relative privacy outside. However, should this be a problem, for example in areas which are more densely populated, the feasibility of providing a common exterior urinal should be investigated. This may be a relatively informal

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type of structure serving a number of dwellings, and may be a simple arrangement consisting of a privacy wall enclosing a shallow pit filled with wood shavings or ash which is replaced when odour becomes a problem. This urine-soaked material makes an excellent soil conditioner and fertiliser, should this practice be acceptable to the community.

4. The floor slab of the toilet unit should be raised above the surrounding ground by about 600 mm, as this provides sufficient space in the area beneath the pedestal to collect the faeces, either in separate containers or simply in a heap on a hardened substratum. The latter option is preferable if the users are prepared to turn the heap periodically by rake or spade, as aeration is important to facilitate rapid pathogen die-off (see the operating guidelines below).

5. The toilet pedestal may be obtained commercially, in rotationally-moulded plastic, porcelain etc, or it may be custom-built by local entrepreneurs using any suitable material, such as mortar for instance. In the latter case, it is important that only moulds with proven designs are used, as the shape and size of the pedestal, especially the position of the urine collection compartment, are crucial factors. It is also important that the material used has a smooth finish, in order to minimise the accumulation of bacteria, etc, and to facilitate cleaning.

6. A vent pipe as found in a conventional VIP toilet is generally not required, as odour and flies are not a problem with this type of toilet if it is properly used. However, if the maintenance of aerobic conditions in the pile is likely to be problematic, then it may be preferable to install one. The installation of air bricks (with flyscreen gauze for safety) in the side walls of the faeces chamber can also help to facilitate ventilation. See the operating guidelines which follow.

B2.2 Operating guidelines

1. Care should be taken that no personal cleansing materials are deposited into the faeces receptacle. Due to the dry conditions inside the receptacle, these materials will not degrade easily. Furthermore, faeces covered by these materials will be prevented from dehydrating properly. Used cleansing materials should be kept inside a covered bin next to the toilet pedestal and disposed of when necessary, either by burning or burying.

2. Moisture should, as far as possible, be prevented from entering the faeces receptacle or pile. Therefore, should it become necessary to clean the rear chute of the pedestal, a dampened toilet brush should preferably be used, without actually washing or rinsing the chute walls, as excess water in the faeces receptacle will interfere with the dehydration process. However, water may be freely used to clean the urine bowl.

3. Should the reuse of urine as fertiliser be desired, it may be collected in any

suitable container, otherwise it should merely be led into a soakpit. Alternatively, the urine from a number of toilet units may be collected and reticulated to an evaporation pond if climatic conditions favour this process. Should the urine be reused, it will need to be diluted by the addition of at least four to five times as much water. The most suitable concentration for each crop will differ, and this should be experimentally determined by the user.

4. Desiccation of the faeces is very dependent on the achievement of aerobic conditions, as this facilitates the development of high temperatures in the pile. This in turn promotes the rapid destruction of pathogenic organisms. For this reason, a coarse bulking agent should preferably be used, for example wood shavings. Ash from wood fires has a high pH which is lethal to most pathogens, but due to its fine, powdery nature, it is not conducive to aeration of the pile. The best way to keep the pile aerobic is to turn it frequently, if users are prepared to do so (in which case the use of ash as a bulking agent will be satisfactory).

5. Reuse of the desiccated faeces for agricultural purposes should not be undertaken before at least six months after the last excreta has been added to the pile. During this period of storage the pile should be kept aerobic, as discussed above. In general, the product should not be used on edible root crops (carrots, beetroot, etc) unless it has been established that all pathogens have been destroyed. Disposal of the desiccated faeces, should agricultural reuse not be desired, can be undertaken in various ways. It can be buried, which is a relatively simple task due to the ease of access to the collection chamber, reduction in volume of the faeces, and general lack of odour and flies. Alternatively, it can be bagged and either disposed of in conjunction with other solid waste from the household, or made available as soil conditioner to persons wishing to make use of it. The disposal process makes entrepreneurial opportunities possible, as many people would probably be prepared to pay for its removal.

APPENDIX C

SEDIMENT TRANSPORT:
BRIEF REVIEW OF LITERATURE

C1 GENERAL

Septic tank sludge from domestic origin consists mostly of discrete and flocculent particles of fine sediment. The physical, chemical and biological properties of sludge are described in Chapter 6.5. Although the fluid/sludge mixture, while flowing in a pipeline, has been observed to be relatively homogenous, some sludge particles are deposited on the invert of the pipeline when the flow ceases or becomes too little to continue transporting the load in suspension (this occurs when the siphonic action ceases). These sludge particles remain as a deposited bed of sediment until such time as a sufficiently large wave of effluent picks them up again and transports them further down the pipeline. This process of deposition and subsequent re-suspension of sludge particles will be repeated continuously as long as there is a repetitive cycle of effluent flushes from the tank to the pipeline.

If open channel flow was being considered instead of pipe flow, the effect of this movable bed load of sludge particles would be the same as in a loose-boundary channel. In open channel flow the boundary of movable material deforms under the action of flowing water, while the deformed bed with its changing roughness (bed forms) interacts with the flow. A dynamic equilibrium state of the boundary can be expected if and when a steady and uniform flow has developed (Featherstone and Nalluri 1988). The resulting movement of the bed material (sediment) in the direction of flow is referred to as sediment transport and a certain critical bed shear stress (τ_c) must be exceeded to start the particle movement. This critical shear stress is termed the incipient (threshold) motion condition, below which the particles will be at rest and the flow is similar to that on a rigid boundary.

Sediment transport occurs only if there is an interface between a moving fluid and an erodible boundary (Chadwick and Morfett 1986). The activity at this interface is extremely complex, because once sediment is being transported, the flow is no longer a simple fluid flow, since two different materials are involved. Sediment transport may occur in one of two modes:

(a) by rolling or sliding along the bed of the channel – this is termed *bed load*; or
(b) by suspension of finer particles in the moving fluid – this is called *suspended load*.

C2 INCIPIENT (THRESHOLD) MOTION

In the case of an erodible boundary, or where sediment is deposited on a rigid bed (as in a pipeline) the sediment particles will only start to move when the applied force is sufficient to overcome their natural resistance to motion. The particles are usually non-uniform in size. At the fluid/sediment interface, the moving fluid will apply a shear force τ_0 (Chadwick and Morfett 1986); this is depicted in Figure C.1 for a granular bed material. A proportionate force will then be applied to the exposed surface of a sediment particle. If the shear force is gradually increased from zero, a point is reached at which particles will start to move at various places over the bed. A further small increase in τ (and therefore

in the velocity u) is usually sufficient to generate a widespread sediment motion of the bed load type. This is the critical bed shear stress τ_c and describes the "threshold of motion". After further increments in τ another point is reached at which the finer particles begin to be swept up into the fluid; this is the inception of suspended load transport.

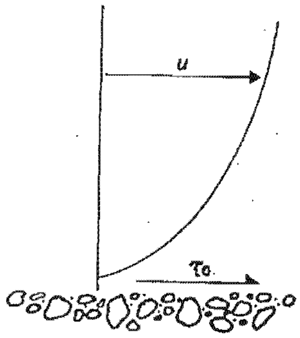

Figure C.1: Shear force on a granular bed, showing velocity profile
(Chadwick & Morfett 1986)

In practice, virtually all sediment transport in channels occurs either as bed load or as a combination of bed load and suspended load (Chadwick and Morfett 1986). The combined load is known as total load. In natural channels suspended load rarely occurs in isolation, except for certain cases involving very fine silts. However, experimental observations during this particular research project have shown that, in a pipeline flowing full, hydraulically transported septic tank sludge of domestic origin is, due to its fine particle size and low specific gravity, virtually entirely of the suspended load type. Only after the flow has diminished and reverted to open channel conditions does the velocity decrease to the extent that some of the solid particles slide or roll along the pipe invert before settling out.

Various bed load and suspended load formulae have been developed in order to analyse the movement of sediment particles in water (mostly in channel flow). Some formulae are based largely on the assumption that the particles are spherical (Graf 1984), which is not valid for sludge (see the description of septage in Chapter 6.5). The formulae may also assume that the suspensions are relatively dilute (Graf 1984), which was not always the case during this experimentation. Moreover, most formulae apply primarily to coarse sand or possibly to some gravels, or are based on a single "typical" particle size (Chadwick and Morfett 1986); others are based on a relative sediment density of 1,65 or on flow in wide channels (Featherstone and Nalluri 1988), neither of which are valid in this instance. These formulae are thus mostly inapplicable in the case of the rigid boundary type of pipe flow under investigation in this project. The following section describes some of the work done by Mara (1996), Graf (1984) and others in determining the flow behaviour of liquids transporting sediments in closed conduits. It is necessary to examine this behaviour in order to understand and thus be able to predict what happens when transported sediment

settles out on a pipe invert and has to be subsequently resuspended by a following wave of liquid in order for it to be transported further down the pipeline again.

The concept of threshold-of-motion value was addressed by Mara (1996) in a study on the self-cleansing criterion. This study found that the threshold-of-motion value for recently deposited solids is similar to the average boundary shear stress τ experienced by a pipe of internal diameter D (mm) laid at a gradient of 1 in D and flowing full:

$$\tau = \rho g \, (D/4) \, (0{,}001/D)$$
$$= 2{,}5 \text{ N/m}^2 \qquad \text{.......(C.1)}$$

The Metropolitan Water, Sewerage and Drainage Board in Sydney, Australia, has specified limiting gradients S (%), for self-cleansing, as

$$S = 0{,}0135/R \qquad \text{.......(C.2)}$$

where R = hydraulic radius, m

This formula is based on the above unit tractive force or boundary shear stress approach. The average boundary shear stress will be reduced for flows and proportional depths below half full.

Mara (1996) also addressed the relationship between bed-load movement and critical tractive force required to initiate motion of the bed-load. An empirical model for the removal of single grain particles of varying specific gravities was developed:

$$V = [\,(8Kg/f)\,(S_p - 1)\,D_g\,]^{1/2} \qquad \text{.......(C.3)}$$

where
V = wastewater velocity, m/s
K = dimensionless parameter with the value 0,4 to initiate motion and 0,8 for adequate cleansing
g = gravity constant, m/s^2
f = dimensionless friction factor
S_p = specific gravity of material removed, and
D_g = particle diameter, m.

Based on this model, the self-cleansing velocity is independent of the sewer diameter.

There is a direct relationship between the self-cleansing velocity and the critical boundary shear stress or tractive tension (Mara 1996):

$V = (K/n)\ R^{1/6}\ (\tau_c/w)^{1/2}$ ....(C.4)

where
n = Manning's roughness coefficient
R = hydraulic radius, m
τ_c = critical shear stress, N/m^2
w = specific weight of water, N/m^3

This model indicates that as the diameter of the sewer increases for a given tractive tension, the necessary self-cleansing velocity must increase. Therefore designs should not be based on a constant minimum velocity for all sewer sizes, otherwise larger sewers will be under-designed while smaller sewers will be over-designed.

C3 SEDIMENT TRANSPORT IN CLOSED PIPES

Consider a horisontal pipe, the bottom of which is covered with a plane, stationary bed of loose, cohesionless, solid particles of uniform size. The remainder of the pipe cross-section is filled with water. If the liquid starts to flow, energy dissipation takes place which, in turn, manifests itself as a pressure drop (Graf 1984). The loss of energy per unit length of pipe, $\Delta h/\Delta L$, is termed the *head loss* and is proportional to the flow velocity V^n, or

$(\Delta h/\Delta L) \propto V^n$ where $n > 1$ ....(C.5)

This relationship has been plotted for a specific case in Figure C.2 (Graf 1984). As soon as the liquid flows, hydrodynamic forces are exerted on the solid particles of the bed. Further increases in the flow cause a corresponding increase in the magnitude of these forces until, eventually, the particles in the movable bed are unable to resist them and start to move. This condition of initial movement of some bed particles is called the *critical condition*.

In Figure C.2 the data with the smallest head loss and velocity represent the critical condition for this particular case (point C on the curve). As the flow velocity is increased, the head loss increases proportionately. The quantity of moving solids, or *concentration*, increases at the same time. A bed (deposition) is noticeable, which first deforms and forms dunes, while at higher velocities these dunes are washed out. At lower flow velocities the movement of particles is generally restricted to a narrow band in the lower part of the pipe, while at higher velocities the movement is spread over the whole of the pipe cross-section.

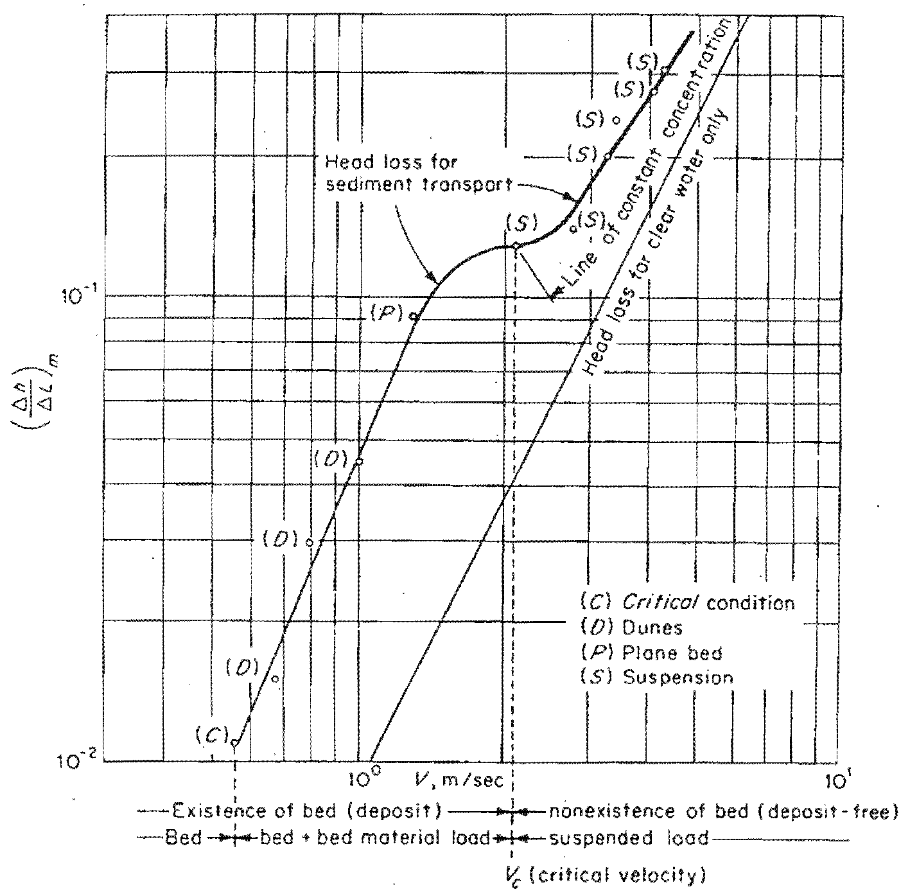

Figure C.2: Head loss vs velocity relationship for closed-conduit flow, for sand with d = 2,0 mm (Graf 1984)

Between the lower and upper legs of the curve there appears to be a discontinuity, where, although the flow velocity increases, the head loss remains more or less constant. In this region the stationary bed material (the deposition) is scoured away and starts to move. It should be noted that this specific example is valid only for material with a nominal diameter of 2,0 mm.

Along the entire upper leg of the curve, the concentration of transported solid particles remains constant. An increase in the flow velocity results in a proportionate increase in the head loss. All of the particles which originally formed the bed are now in suspension. At lower velocities the concentration distribution is such that the majority of the particles are transported in the lower half of the pipe cross-section, while at higher velocities the particle distribution may tend to become uniform over the entire cross-section.

Within the transition zone there is a velocity designated as the *critical velocity*, as indicated in Figure C.2. Below this velocity deposits will occur, while above it no deposit will be found in the pipe. Information on this velocity is important, as it defines two separate zones, namely:

1. For flow velocities below the critical velocity, deposits occur, while the sediment transport is due to an exchange between the stationary-bed and moving bed material;
2. for flow velocities larger than the critical velocity, no deposit will take place and the sediment is transported as suspended load.

If the sediment material is uniformly distributed over the entire cross-section, the flow is referred to as *pseudohomogeneous*, while if it is non-uniformly distributed it is called *heterogeneous*. In Figure C.2 above, this information is compared to the head loss vs velocity relation for water without sediment. It is clear that the head loss for a water and sediment mixture is greater than the head loss for water on its own.

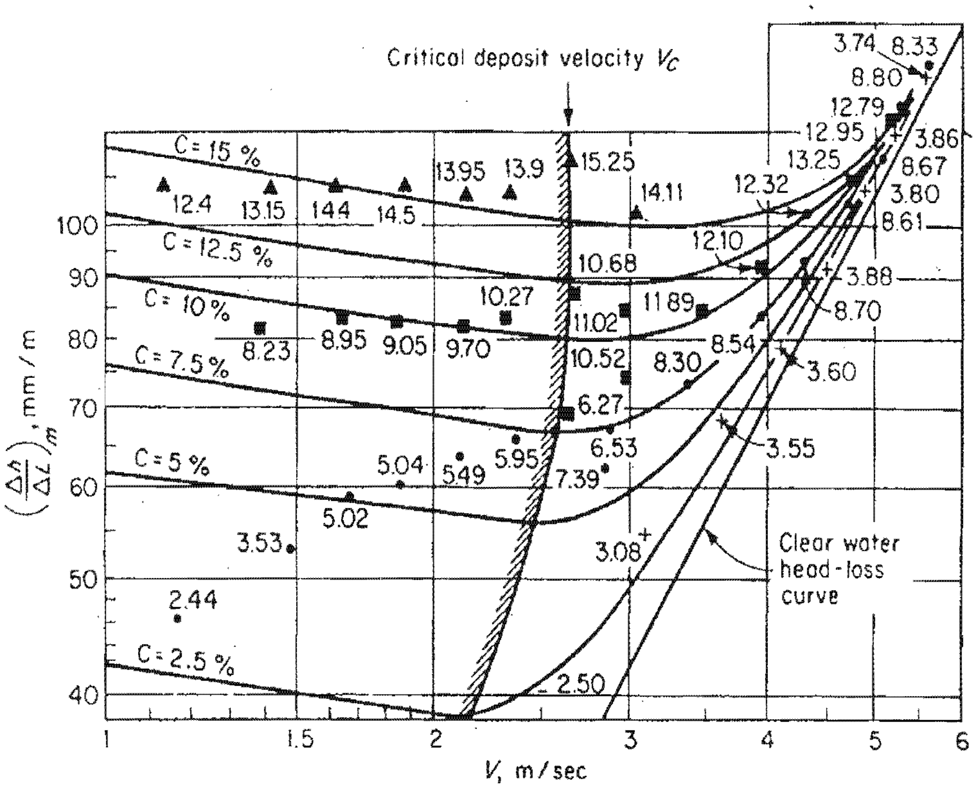

Figure C.3: Head loss vs velocity relationship with equiconcentration lines, for sand graded to 0,44 mm (Graf 1984)

Figure C.2 was obtained for an initial condition of a stationary bed of a given thickness. If the thickness of the stationary bed is changed and the experiment repeated, a further set of data becomes available. If this procedure is repeated for a number of different bed thicknesses, points of the same transport concentration can be connected to form lines of equiconcentration, as illustrated for a typical example in Figure C.3 (Graf 1984).

Settling and non-settling mixtures:

Settling mixtures are defined as those where the settling velocity of the solid particles is above 0,6 to 1,5 mm/s (Graf 1984). Non-settling mixtures have solid settling velocities below this range. Settling velocity is not only dependent on the physical properties of the individual particles, but also on the concentration of the mixture. In pseudohomogeneous flow the solid particles become fully suspended in the liquid and are almost uniformly distributed over the entire pipe cross-section, whereas with heterogeneous flow a suspension distribution over the pipe cross-section is evidenced. If the flow velocity is sufficiently high, most materials will behave as pseudohomogeneous suspensions, although investigations have indicated that pseudohomogeneous flow is usually limited to particles of less than d = 30 μ (Graf 1984). In mixed-size sediments, if a significant fraction of fine material exhibiting pseudohomogeneous flow is present in the mixture, it is responsible for a noticeable decrease in the head loss of the mixture.

Velocity and concentration distribution:

Visual and photographic observations together with hydraulic considerations allow a schematic representation of both concentration and velocity distributions, as shown in Figure C.4 (Graf 1984). Three kinds of flow are distinguished, namely, pseudohomogeneous flow, heterogeneous flow and bed material transport with a bed (deposit). Within the heterogeneous flow zone, two extremes are illustrated. For $V > V_c$ the suspended load will be fairly uniformly distributed, but for $V \approx V_c$ the suspended load will move close to the bottom of the pipe. The figure shows distributions of the local concentration and local liquid velocity for each kind of flow. A decrease in flow velocity, i.e. moving from graph A to graph D in Figure C.4, results in less uniform concentration distributions. The velocity distribution shows the same tendency - if the flow velocity V is below the critical velocity V_c, as shown in Figure C.4D, deposition occurs.

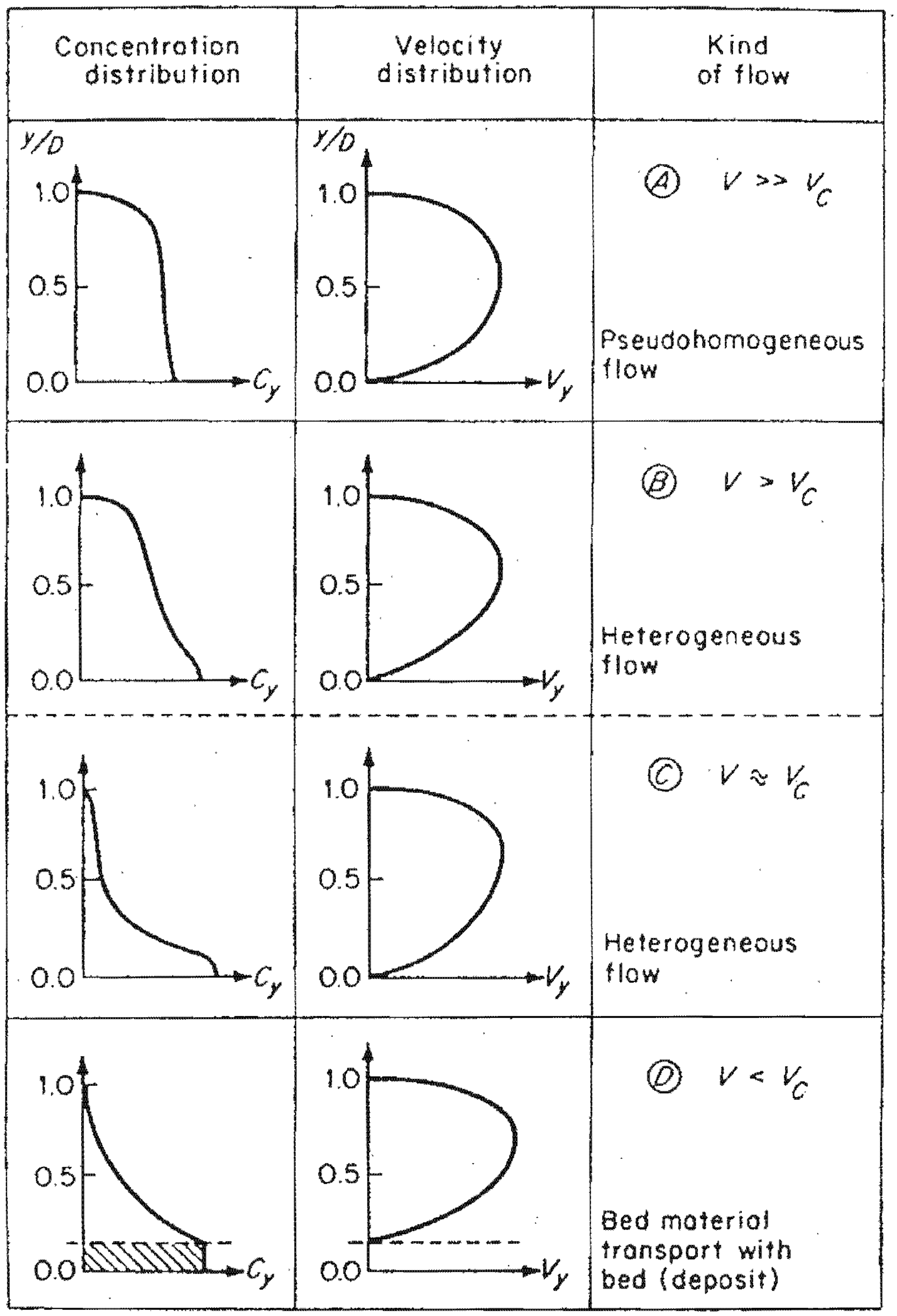

Figure C.4: Schematic representation of concentration and velocity distributions
(Graf 1984)

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Abbreviations:

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DFID	Department for International Development, United Kingdom
DWAF	Department of Water Affairs and Forestry, South Africa
HEATT	Health Education and Awareness Task Team, South Africa
UNCHS	United Nations Centre for Human Settlements (Habitat)
USEPA	United States Environmental Protection Agency, USA
WEDC	Water, Engineering and Development Centre, Loughborough University, UK
WRC	Water Research Commission, South Africa
WSSCC	Water Supply and Sanitation Collaborative Council Working Group on Promotion of Sanitation (World Health Organisation, Geneva)

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