EVALUATION OF STORMWATER POLLUTANT TRAPS (SPT's)

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Jim Davies, Principal Hydrologist and Managing Director JDA has extensive experience in providing consultancy services in hydrology and water resources management. He was WA representative on the Institution of Engineers Australia (IEAust) National Committee on Water Engineering from 1994-2000, and is a current Member and past Chairman of the Hydrology & Water Resources Panel of IEAust (WA Division). Jim is a member of the Institute of Public Works Engineering (IPWEA), Australian Water Association (AWA), International Association of Hydrogeologists (IAH) and Environmental Consultants Association (ECA).

Dina Rahmah is a Hydrologist / Environmental Engineer at JDA with experience in hydrologic and hydraulic modelling, surface water modelling, and groundwater modelling. Dina joined JDA in November 2003 and project experience includes evaluation of stormwater pollution traps, flood studies and management strategy, stormwater monitoring and reporting, preparation of Drainage and Nutrient Management Plan (DNMP) and Nutrient Irrigation Management Plan (NIMP), and groundwater & surface water monitoring and modelling.

Scott Wills is a Hydrologist at JDA, with 7 years experience in hydrologic and hydraulic modelling, monitoring and field techniques. Scott has specific expertise in Flood Management Strategy, Urban Drainage Strategy, groundwater investigations and determination of AAMGL, and development of artesian production bores. Scott has significant monitoring experience, conducting stormwater, surface water and groundwater sampling for numerous projects in Perth and surrounding regions.

ABSTRACT

As part of water sensitive urban design (WSUD) local authorities are increasingly looking to retro-fit existing developments, and prescribe for new developments stormwater pollutant traps (SPT's). SPT's are devices within a piped or open stormwater system which aim to trap a range of pollutants including leaves, sediment, plastics etc.

To provide some uniformity of approach an award was made by the IPWEA (WA) Foundation for Technical Advancement of Local Government Engineering in WA to Jim Davies to perform an evaluation of proprietary products in October 2003.

This paper describes the progress so far which has focussed on hydraulic and energy loss issues and distribution of a questionnaire survey of manufacturers and producers of SPT's.

Opinions expressed are those of the authors and not necessarily those of the Foundation or IPWEA.

1.0 INTRODUCTION

There has been increasing interest in improving the quality of water discharging from urban environments in Australia over recent years. The main impetus for this has been deteriorating water quality in receiving water bodies, especially lakes, rivers and wetlands. At a national level the Stormwater Industry Association (SIA) carried a questionnaire in its newsletter in 2002 requesting responses to alternative methods for testing Stormwater Pollutant Traps (SPTs) in an attempt to develop a level playing field to allow comparison between the various products on the market. The questionnaire proposed testing of SPTs with a mix of pollutants including sediment, leaf matter, gross pollutants and hydrocarbons in proportions to be determined by the questionnaire.

In Western Australia the IPWEA has received requests from members to investigate the claims made by manufacturers and suppliers of stormwater pollutant traps. In response The Foundation for the Technical Advancement of Local Government Engineering in WA has awarded a Fellowship to Jim Davies to carry out a project which aims to compare the performance of available SPT's, based on published brochures and manuals. To assist this process a questionnaire has been developed and circulated to Manufacturers/Suppliers regarding treatment flows, design flow, head loss at various flows, pollutant trapping efficiencies and other matters.

The IPWEA organised a Workshop in June 2003 in association with the State Conference to provide input from local practitioners to the project.

The paper describes the methodology used and progress to date. The project is scheduled to be completed later in 2005.

2.0 COMMERCIALLY AVAILABLE SPT's IN WA

SPTs commercially available in WA include:

- Humeceptor produced by Humes
- Humegard produced by Humes
- CleansAll produced by Rocla Pipeline Products
- Downstream Defender produced by Rocla Pipeline Products
- VersaTrap produced by Rocla Pipeline Products
- CDS Fibreglass Unit produced by CDS Technologies
- CDS Industrial Separators produced by CDS Technologies
- CDS Sewer Overflow Management Units produced by CDS Technologies
- CDS In-line Units produced by CDS Technologies
- ecoBite produced by Wormall
- Solid Pollutant Filter produced by Ecosol
- Geotrap produced by Geocrete

3.0 DEFINITIONS

- A **pollutant** is a material present in concentrations greater than that which naturally occurs in water, air or soil. Pollutants flushed through urban catchments and stormwater systems are known as **stormwater pollutants** which can be divided into two broad categories: gross pollutants and micro-pollutants. Thus the term of **Stormwater Pollutant Traps (SPTs)** is used in this project for defining a device that can intercept both gross and/or micro-pollutants.

- **Gross pollutants** are pieces of debris greater than 5 mm (Allison et.al. 1997). These typically include litter (mainly paper and plastics), vegetation (leaves and twigs) and coarse sediments transported by stormwater. A number of trapping devices has been designed to specifically remove gross pollutants, thus the name **Gross Pollutant Traps (GPTs)**.

- **Micro-pollutants** include fine particles and dissolved materials. Of common concern are Suspended Solids, excessive nutrients (Nitrogen and Phosphorus), heavy metals (include Lead, Zinc, Copper, Chromium, and Cadmium), toxic organic wastes (such as pesticides), pathogenic micro-organisms, and hydrocarbons (oils and grease) (Allison et.al. 1997).

- **Design Treatment Flow (DTF)** is the flow which passes through the SPT treatment chamber, before any bypass flow occurs of untreated water. Unit (L/s). Note that DTF is likely to be much less than pipe full flow as SPT's are typically designed for a smaller flow average recurrence interval (ARI) than the pipe.

- **DTF headloss** is the sum of head losses at DTF associated with entry to and exit from the SPT plus head loss through the treatment chamber. Unit (m).

- **Bypass flow** is the flow which can bypass the treatment chamber of the SPT. Unit (m).

- **Design Maximum Flow (DMF)** is the sum of treatment flow and bypass flow, for the available head loss. DMF will increase with head loss. The available head loss depends on site specific conditions such as available head before upstream flooding occurs. Because DMF occurs at a higher head loss than DTF, the treatment flow (at DMF) will exceed DTF. Note that DMF may be similar to the pipe full flow. Unit (m).

- **DMF headloss** is the head loss at DMF associated with entry to and exit from the SPT, and the head loss through the treatment chamber and bypass. Unit (m).

4.0 STORMWATER DRAINAGE HYDRAULICS

4.1 Relevant Publications

There are two publications readily available in Australia which provide the local government engineer with background information on stormwater drainage hydraulics.

Australian Rainfall and Runoff – a Guide to Flood Estimation was produced by the Institution of Engineers Australia in 1987 as an update to a previous version in 1977. It has since been reprinted in book form in 2001, referred to here as ARR 2001.

Relevant books for this report are:

- Book 7 Aspects of Hydraulic Calculations and
- Book 8 Urban Stormwater Management

Book 7 describes open channel flow hydraulics i.e. hydraulics of drains, creeks and rivers where there is no pressurised flow.

Book 8 is more relevant to pipe hydraulics and therefore to this investigation of SPT's.

ARR 2001 provides a useful description of stormwater pipe hydraulics including estimation of run-off rates, design of new pipe systems, evaluation of existing systems. The topics include energy loss in pipelines and in pits, which are treated separately, together with the hydraulic calculations to estimate the water surface profile, hydraulic grade line, and total energy line in a piped system. An understanding of these matters is a pre-requisite to analysis of stormwater pollutant traps introduced in to piped stormwater systems.

Argue (1986) was published within a few months of ARR 1987. Professor Argue, based at the University of Adelaide, produced an independent document from ARR 1987 with several differences of approach including:

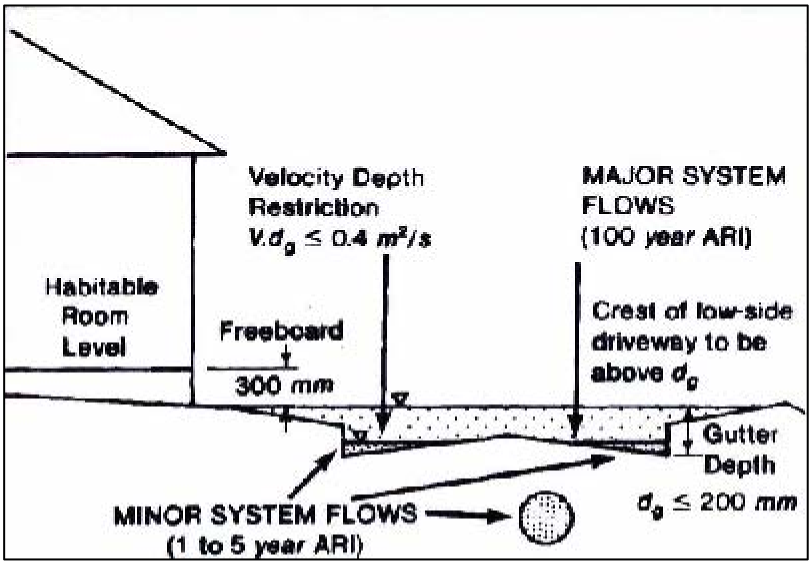
- Argue presented "major" followed by the "minor" drainage system.
- Argue presents greater emphasis on checking the major flow system.

The following sections summarise these two reports as a prelude to description of the implications for SPT's.

4.2 Major/minor concept of street drainage

The minor system is the gutter and pipe network capable of carrying runoff from minor storms. The major system comprises the many planned and unplanned drainage routes which convey runoff from major storms to receiving waterways, as illustrated in Figure 1.

Figure 1: Possible Major/Minor Design Standards (ARR 2001 Book 8, Fig. 1.3)



Typically the minor pipe system is designed to carry low ARI flows, say between 1 and 5 years, to prevent nuisance flooding of streets. That is, the pipes will generally flow part full except for short periods during storms equal to or in excess of design flows. In more severe events than the design ARI, overflows are routed along streets and drainage reserves, to convey a major storm such as a 100 year ARI event (ARR 2001).

4.3 Pipe System Hydraulics

4.3.1. Hydraulic Models

Figure 2 shows three different hydraulic models for pipeflow, indicating the hydraulic grade line (HGL), the total energy line (TEL) and water surface profile (WSP).

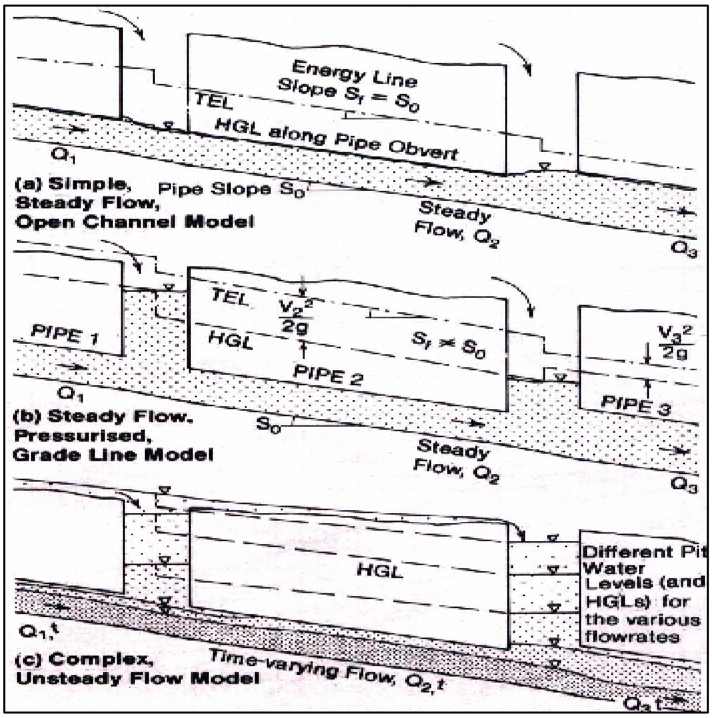


Figure 2: Hydraulic Models for Pipe Systems (ARR 2001 Book 8, Fig. 1.19)

Figure 2(a) assumes steady flows occur in each pipe and the hydraulic grade line is assumed to run along the obvert (upper inside surface) of the pipe so that flow condition can be described as flowing full but not under pressure. Pipe capacities can be calculated easily applying a friction formula such as Mannings formula to the pipe slope. No allowance is made for surcharged conditions upstream or downstream and the whole network is assumed to behave as a system of open channels. The total energy line is a distance of $v^2/2g$ above the HGL , and all 3 lines (TEL, HGL and pipe invert) are parallel. An energy loss occurs in each pit shown by the drop in TEL.

Figure 2(b) also assumes steady flow but includes pressure flows with the HGL located above the pipe obvert. Specific allowance is made for energy losses and pressure changes in pits which are greater in this case than for open channel flows with levels below pipe obverts. Pipe capacity is dependent on downstream water levels which may exert a backwater effect. HGL slope is greater than the pipe slope.

Figure 2(c) shows unsteady flows (i.e. changing with time). Water levels rise and fall and flow characteristics change during a storm event simulation. Various combinations of full and part full flows occur. This model must be applied by computer as it requires calculation at a large number of time steps during a storm. Some models allow for pit losses in simplistic ways, such as increasing pipe friction factors, rather than explicitly including loss coefficients.

All three of these models can be applied in designing new systems or in analysis of existing systems.

4.3.2. Pipe Friction

All three methods shown in Figure 2 require the estimation of friction losses along the pipe using a formula such as Mannings formula (ARR 2001).

4.3.3. Energy Losses and Pressure Changes in Pits

Significant energy losses may occur at pits and pipe junctions, particularly if pipes are surcharged (i.e. pressurised). The capacity of pressurised pipes is greater than that of open channel flow in the same pipes although energy losses are greater.

Pit energy losses are generally expressed as a function of the velocity (V) in the outlet or downstream pipe:

Head Loss = $K.v^2 2g$ where head loss (m)

K is a dimensionless energy loss coefficient

and g is acceleration due to gravity (m/s^2).

This head loss represents the change in TEL at the pit as shown in Figure 3. The change in the HGL is likely to be different to the change in TEL, because of different pipe diameters and different flow rates upstream and downstream of the pit.

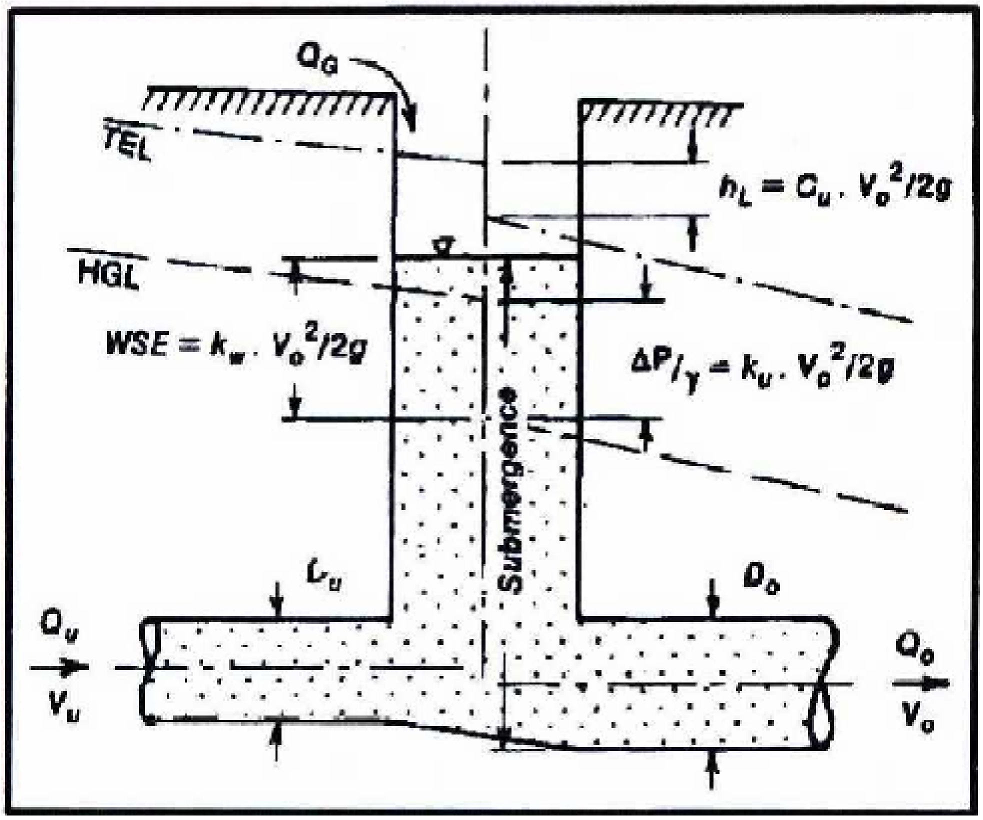


Figure 3: Idealised Grade Line at a Pit (ARR 2001 Book 8, Fig. 1.21)

The pressure head change is given by:

- Pressure head change = Ku $v^2/2g$
- Where pressure head (m)
- Ku is a dimensionless coefficient

A similar relationship can be applied to pit water levels which may be slightly higher than the HGL level due to the conversion of some potential energy to pressure energy as flow crosses a pit:

WSE = Kw $v^2/2g$ where WSE is the elevation of the pit water surface relative to the downstream HGL (m) and Kw is a dimensionless coefficient.

These features are also illustrated in Figure 3. For most pit configurations Ku and Kw are similar and water level in a pit can be assumed to coincide with the HGL level.

Energy losses are assumed to occur at the centre line of the pit, whereas losses actually occur across the pit and in the pipe immediately downstream.

Physical hydraulic model studies (scale or real size models) are the only means of deriving reliable values of energy losses and pressure changes for different types of pits and junctions. Examples of published work are included in ARR 2001.

Many hydraulic models (such as XP-STORM) allow the user to input appropriate values of K for pits. These values must be estimated by the user externally from the model.

In general, the K value for the expansion from a pipe to a pit is 0.3 and from a pit to a pipe is 0.2, a total value of 0.5. Hence if the downstream pipe velocity is 1 m/s the total energy loss ($0.5v^2/2g$) will be 0.5 x 0.05 = 0.025 m. At a velocity of 2 m/s, the total energy loss will be 0.1 m. In pipes with many pits these losses may exceed the pipe friction loss.

4.4 Hydraulic Calculations

Figures 4 & 5 show water surface, HGL and TEL profiles in a surcharged pipe system.

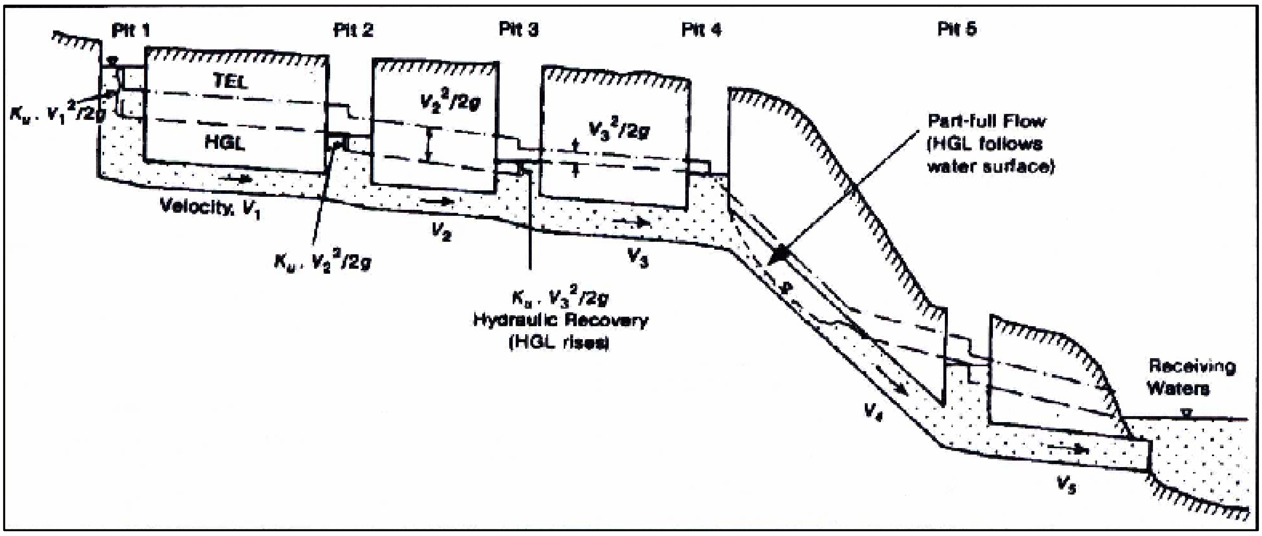


Figure 4: Flow Behaviour in a Surcharged Pipe System (ARR 2001 Book 8, Fig. 1.23)

4.4.1 Design of new system

In designing a new pipe system it is necessary to fix pipe sizes and locations by setting invert levels at each end of a pipe. The aim is to provide sufficient capacity to carry flows of a given design ARI corresponding to the minor flow.

4.4.2 Analysis of existing systems

In this case existing pipe sizes and inverts and estimates of pit loss coefficients are input in to a model to calculate water surface profile, HGL and TEL. Calculations normally commence at a downstream receiving water level and work in an upstream direction.
Any known locations of flooding available from local authority should be used to assist in calibration of pipe roughness coefficients and pit energy losses.

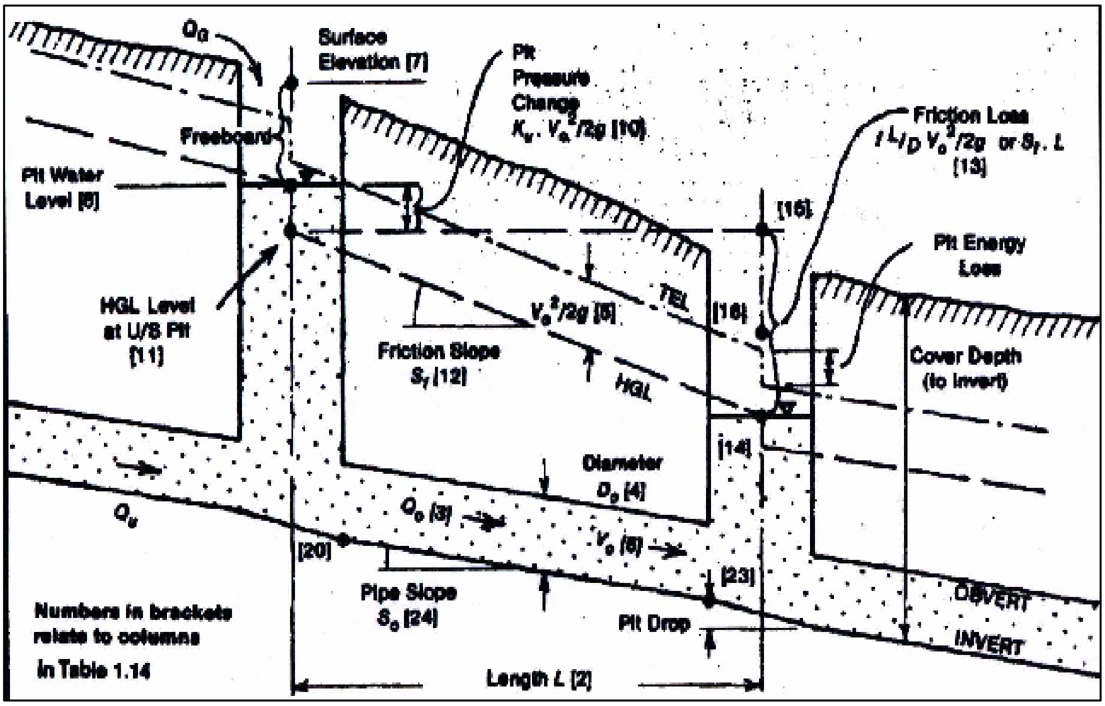


Figure 5: Pipe Reach Showing Features Identified in Calculations (ARR 2001 Book 8, Fig. 1.24)

4.5 Implications for SPT's

4.5.1 Design Treatment Flow (DTF)

SPT's are by convention, typically designed to treat flows up to approximately 0.25 year (3 month) ARI (that is a flow which is exceeded on average 4 times per year) and to bypass higher flows. Hence during design treatment flow (DTF), assuming the SPT is not blocked, the down-stream pipe will be only part full having been designed typically for 1 to 5 year ARI flow. Figures 6 & 7 shows schematics of a simplified SPT with a screen and baffle arrangement. Figure 6 shows conditions at less than design treatment flow (DTF) with downstream water level shown to be at pipe obvert. (Downstream water level should probably be shown below obvert for reasons given above, but the point is still valid). Figure 7 shows conditions at design treatment flow (DTF), with the upstream water level about to by-pass the screen by overtopping of the solid baffle.

Figure 6: Less than design treatment flow (DTF)

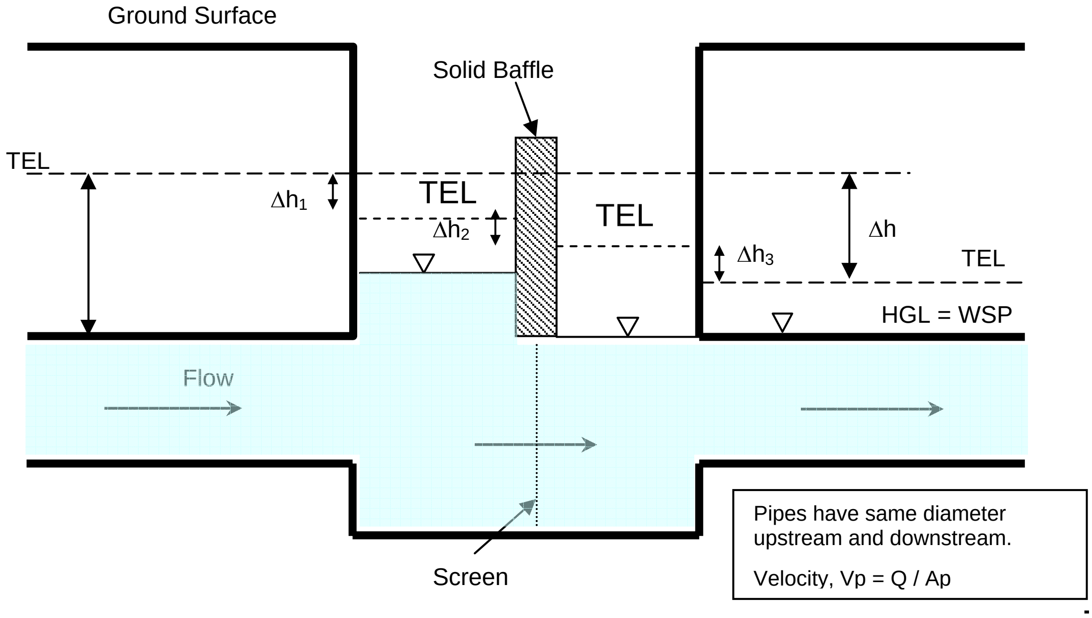
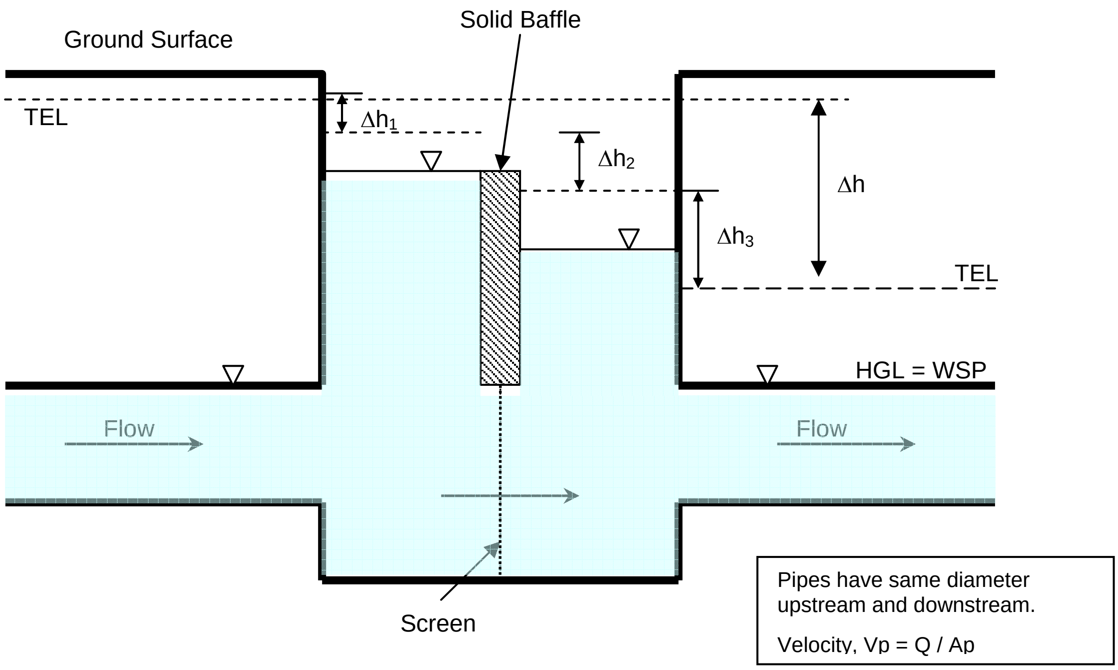


Figure 7: Design Treatment Flow (DTF)



Key to Figures 6 & 7

TEL – Total Energy Line

WSP – Water Surface Profile

HGL – Hydraulic Grade Line

Total Energy Loss = $\Delta h = \Delta h_1 + \Delta h_2 + \Delta h_3$

In Figure 7 the value of DTF depends not only on the head loss through the SPT but also on the downstream conditions. If the downstream pipe is just full with the water surface at the obvert, coincident with the HGL, then this will result in a higher estimated design treatment flow (DTF) than if the downstream pipe is surcharged.

Hence in specifying a design treatment flow (DTF), manufacturers should state the assumptions made regarding the downstream pipe flow conditions.

It can be seen that the total energy loss through the SPT at DTF comprises:

- The transition from the upstream pipe to the pit (Δh_1)
- The headloss through the SPT treatment system (Δh_2)
- The headloss in the transition from the pit to the downstream pipe (Δh_3)

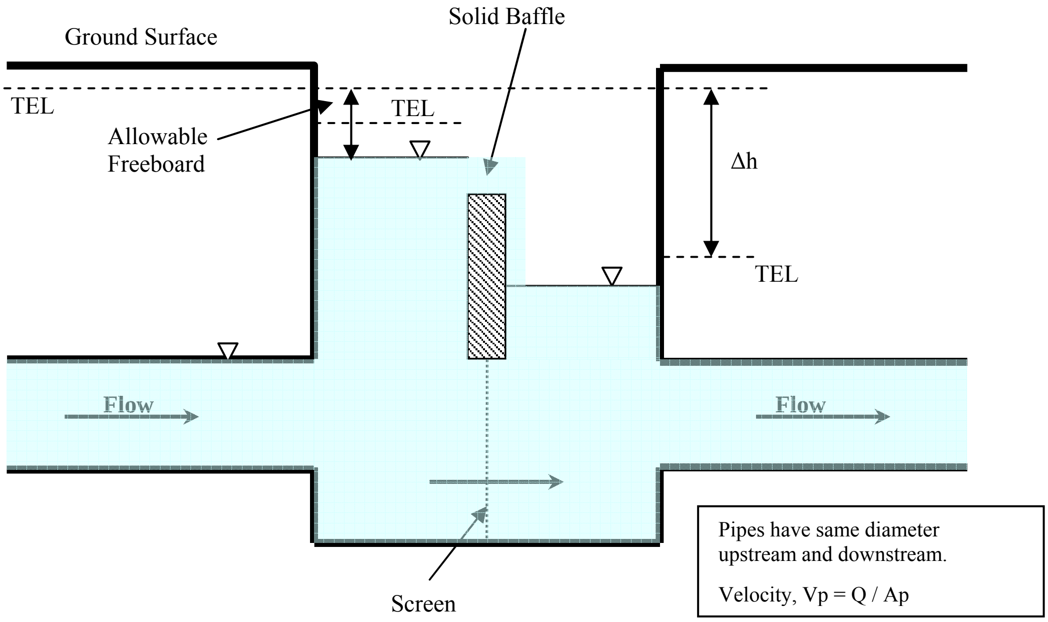
4.5.2 Design Maximum Flow (DMF)

The design maximum flow (DMF) refers to the flow, comprising treatment flow and by-pass flow, of an SPT with acceptable freeboard from flooding.

For example a water level on the upstream side of an SPT of say 0.15 m below the ground surface may be an acceptable freeboard condition at maximum design flow (see Figure 8).

In general the design maximum flow (DMF), including treatment flow and by-pass flow, will exceed the design treatment flow (DTF). Note also that the treatment flow will be greater than DTF when DMF occurs.

Figure 8: Design Maximum Flow



5.0 QUESTIONNAIRE

A comprehensive questionnaire was sent to SPT manufacturers, suppliers (as listed above) in September 2004 requesting details on design treatment flows and associated head losses, by-pass arrangements as well pollutant treatment efficiencies and the basis for statements made (brochures, manuals etc). A blank copy of the Questionnaire is available upon request to JDA. Responses have been received and are being interpreted.

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