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# Headloss/Flow Relationship in a Scale Model Stormwater Pollutant Trap

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**ABSTRACT:** The main focus of urban rainwater run-off disposal has traditionally been providing structurally sound drainage systems with the capacity to carry runoff from many different surfaces as quickly and efficiently as possible, without relating its quality at outfall (Espey, 1966). This has contributed to the decline of water quality in rivers and lakes and other receiving bodies.

Recent developments in stormwater quality management have seen the introduction off Stormwater Pollutant Traps (SPT), which are generally end-of the line devices designed to capture and store gross pollutants and some micro-pollutants, for subsequent removal and disposal.

The VersaTrap Series A SPT is an offline stormwater pollutant trap which utilises an upstream diversion weir pit to divert the Design Treatment Flow (DTF) into the treatment chamber. Treated flow is returned to the diversion pit downstream of the weir, re-entering the drainage system. Peak flows in excess of the DTF bypass the diversion pit over the weir into the pipeline downstream.

The measurement of head losses across a scale model at a range of flow rates through the SPT provides data from which a mathematical relationship between flow rate and head loss can be established for the device.

By varying the weir height in the diversion weir pit and measuring the previously established flow rates associated with the head losses, the relationship between the weir height and diverted flow can be established. This allows the designer to specify the weir height required to divert the flow rate associated with a specific peak flow or treatment flow.

## INTRODUCTION

Today, global warming and climate change have resulted in no place that is safe and secure from the flood and their consequences, which in their nature are one of the most severe natural disasters that affect the world; especially geographic areas with river, seas, or oceans in their vicinity.

Flood prevention and mitigation has a long history of study in both hydrology and hydraulics. With increasing population and building of urban areas, the hydrological and hydraulic properties of these areas have been greatly changed, leading to increased flood hazard and damage (Espey, 1966). Rainwater runoff is one the major sources of water pollution, responsible for a moderate to high percentage of rivers and lakes with poor water quality. Some of this water can be diverted into the settling ponds in wetlands to drip down into underground aquifers for later usage as bore water. While natural ecosystems can absorb some pollutants, metropolitan centres produce waste streams that are too concentrated and which move too quickly via concrete drains and pipes to be assimilated by receiving waters. The results are algal blooms, fish kills, closed beaches and shrinking fisheries, all of which have direct effects on the health, prosperity and amenity of urban areas (Parliament of the Commonwealth of Australia 2006). To prevent pollution in the rivers and lakes, the best strategy is to clean and filter the stormwater and runoff by using catchments and traps at the source or at the end of the pipe system before discharging into those receiving bodies. So stormwater pollutant traps act as a frontier control point in the stormwater network. Stormwater

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infiltration systems, having been commonly used in areas without conventional urban drainage systems, are now recognised as useful techniques to reduce the impacts of urbanisation on receiving waters (Butler and Parkinson, 1997; Argue and Pezzaniti and J.R. Argue, 2006; Fletcher *et al.,* 2006).This will prevent the entrance of the coarse sediment, trash and debris into the engineered waterways, water quality control ponds, and rivers, lakes and sea or ocean.

## TREATMENT MECHANISM IN SCALED MODEL

The performance requirements of the Stormwater Pollutant Traps (SPTs) vary in proportion to a number of site specific conditions including catchment type, anticipated pollutants, run-off flow, capture and entrapment objectives, groundwater level, ground water, soil permeability and classification of receiving water, among others. The stormwater or runoff water which is captured by the stormwater network during the first flush of any storm event enters the diversion pit, where it is then diverted to the off-line SPT.

The pollutant removal efficiency of the SPT—one of the major issues considered in the design, selection and installation of this type of the trap—is affected by the degree to which the screen is blocked. This also affects the head loss across the SPT, and needs to be taken into account in the establishment of the flow/head loss and flow/weir height relationship formulae.

In this research we tested the system under a 0% blocked screen, then increased it to 22% blockage and after that adding 10% increment each time until we reached a 66% total blockage of the screen. The main reason for limiting the state of blockage to 66% in this research is that the published performance data for the VTA is stated as applying to a 50% screen blocked condition, and it is recommending that cleaning be carried out at or before this stage is reached. The actual data which was used, however, is as measured in the laboratory at 75% blocked, which provides a reasonable factor of safety.

The Versa Trap SPT utilises three distinct processes in the separation of pollutants from contaminated water:

1. The vortex phenomenon encourages solids to move inwards to the low velocity region at the centre of the cylindrical treatment chamber, where they settle to the sediment sump or rise to the surface. The vortex is generated by tangential introduction if the influent into the cylindrical chamber above the screen.
2. The stainless steel screen captures all suspended particles of size greater than screen aperture size. The aperture size is generally 5 mm, by common definition of a gross pollutant, but may be varied to suit the characteristics of gross pollutants generated by a particular catchment.
3. Fine sediment passing through the screen will settle (depending on size and specific gravity) in the exit chamber, where vertical velocities determine the capture performance.

The inlet pipe to the storm pollutant trap is connected to the inner cylinder of the trap (which is called the active or treatment chamber) at a tangent, creating a vortex inside the basket. The run-off water carrying gross pollutants passes through the stainless steel basket which is inserted inside the treatment chamber, leaving pollutants trapped in the basket. Treated water then passes out of the SPT via the outer cylinder (which is also called the external or exit chamber) as shown in Figure 1.

The flow rate created in the laboratory model by a base-mounted centrifugal pump capable of circulating up to 12 l/s of flow in the piping network.

## METHODS AND MATERIALS

A series of tests with different screen blockage and flow rates were conducted in the open laboratory environment of the Civil Engineering Department of the Curtin University of Technology in Western Australia with the aforementioned pump connected to the reservoir which is equipped with a 90° v-notch and an attached hook gage weir box measuring the water level above the v-notch. The pump and reservoir connected to a scaled SPT model network via a valve and PVC pipes, tees, and elbows, returning the circulated water to the reservoir. Two piezometer tubes were installed on the pipe at section 1 and 2 (Chow (1956, Reissued 1988)), as shown in the Figure 2.

When depths are shallow and as a result the velocities are low for a reliable current-meter measurement of discharge, a V-notch weir is particularly suitable because of its sensitivity at low flows.

For a circular pipe carrying stormwater and running part-full, the following formulas for flow rate, angle, and area of the pipe are used,

$$Q = \frac{8}{15} C \tan\frac{\theta}{2}\sqrt{2g_c h^5} \qquad \ldots (1)$$

$$\alpha = \cos^{-1}(\alpha - \frac{y}{r}) \qquad \ldots (2)$$

$$\text{A} = r^2(\alpha - \frac{\sin 2\alpha}{2}) \qquad \ldots (3)$$

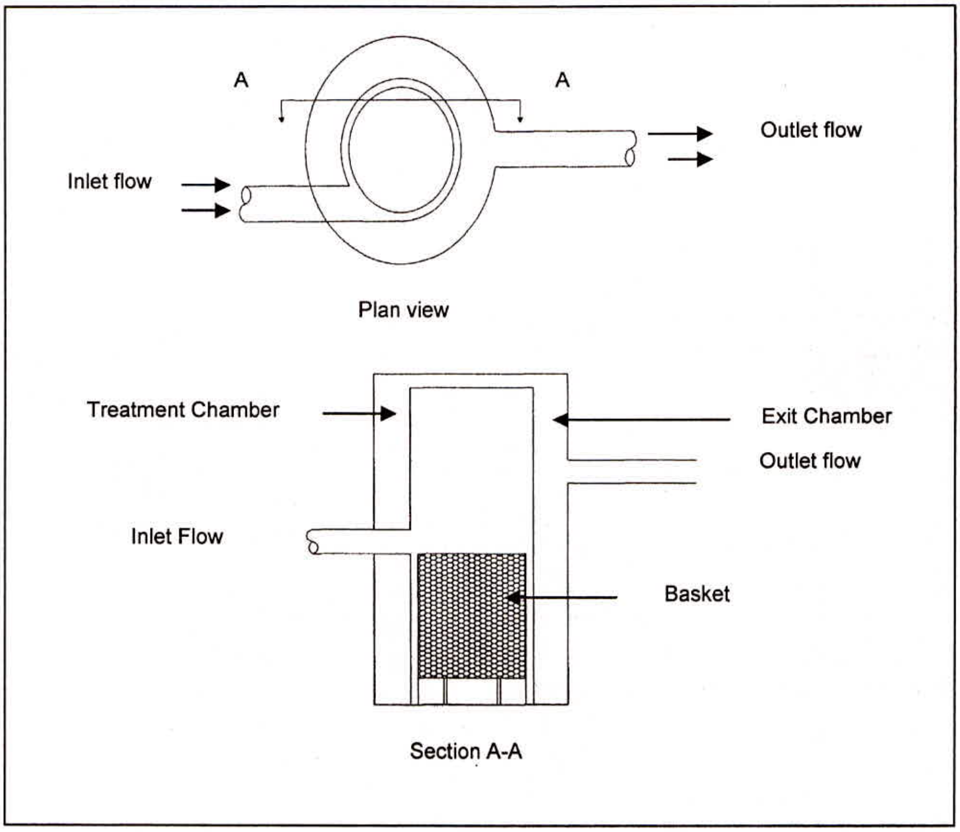


**Fig. 1:** Stormwater Pollutant Trap (SPT)

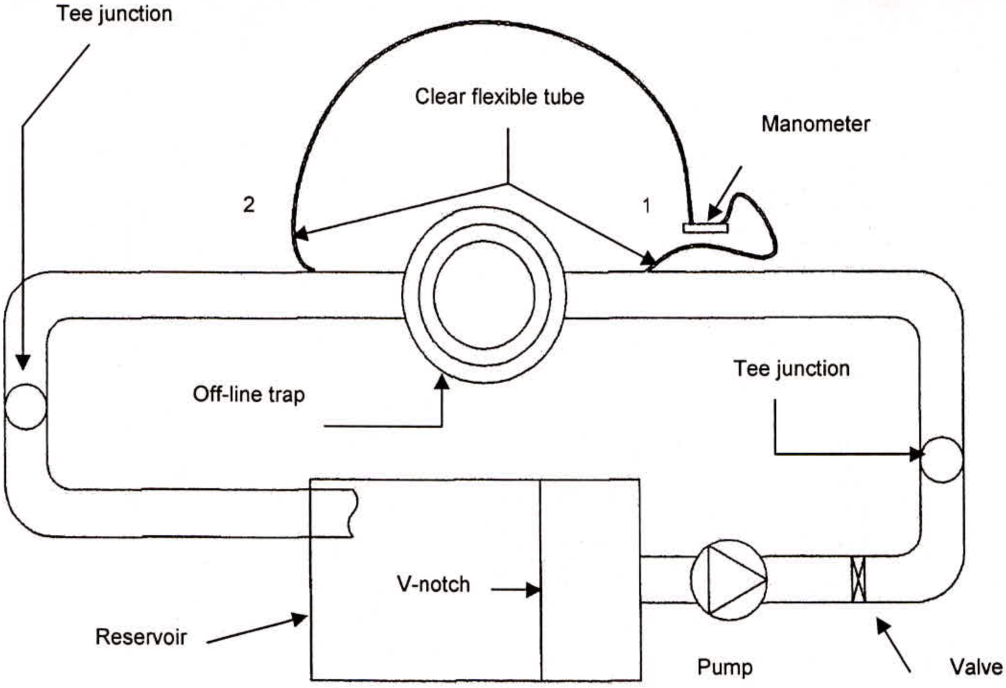


**Fig. 2:** Off-line SPT laboratory network piping plan

Where:

$Q$ flow rate in $m^3$/sec.

$C$ coefficient of discharge

$h$ water level over weir's notch in meters

$\theta$ triangular – notch weir angle

$g_c$ gravity 9.81 m/$sec^2$

$\alpha$ angle in radian

$y$ height of water in pipe in meter

$r$ radius of pipe in meter

$C$ is the coefficient of discharge

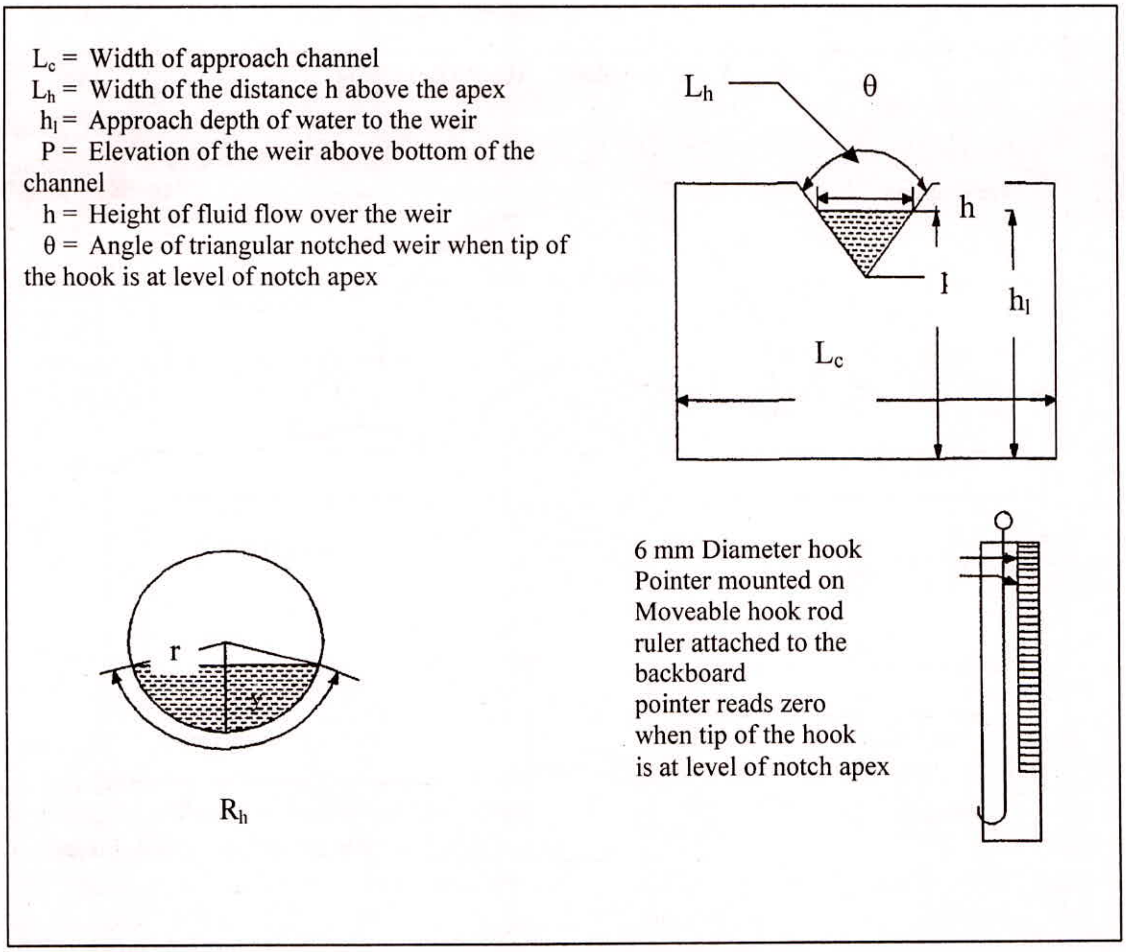
$A$ is area of pipe in $m^2$ (ASME 1971).

In this experiment a stainless steel 90° V-notch was selected and attached to the 1000 mm wide ($L_c$) reservoir with maximum h of 156 mm and considering all requirements of the V-notch weir (ASME 1971). Also a hook gauge weir box was assembled and attached to the reservoir with the pointer reading zero when tip of the hook is at the level of notch apex as shown in Figure 3.

The value of the coefficient, $C$, to be used in the equation (1) for a V-notch weir is mainly dependent on the notch angle, $\theta$, and only slightly on the head, h, as shown in Figure 3 below (ASME 1971).

The scaled SPT model was built based on the drawing with 100 mm PVC pipe for network piping and assembled using PVC.U Pipe Cement as shown in Figure 4, below.

The reservoir was filled up to the apex of the weir with water and the zero point of the hook gauge weir was calibrated for accurate reading for each set of experiment. The flow rates were adjusted by opening the valve of the network which was located after pump a fraction of turn each time. Flow rates were determined using the vee notch weir. The head loss across the model was determined by comparing the heights of the water in the inlet and outlet manometers. Results were tabulated and charted to establish the mathematical relationship between head loss and flow rate. This process was repeated several times for each percent of screen blockage.



$L_c$ = Width of approach channel
$L_h$ = Width of the distance h above the apex
$h_l$ = Approach depth of water to the weir
P = Elevation of the weir above bottom of the channel
h = Height of fluid flow over the weir
$\theta$ = Angle of triangular notched weir when tip of the hook is at level of notch apex

6 mm Diameter hook
Pointer mounted on
Moveable hook rod
ruler attached to the
backboard
pointer reads zero
when tip of the hook
is at level of notch apex

**Fig. 3:** V-notch and hook gauge weir box

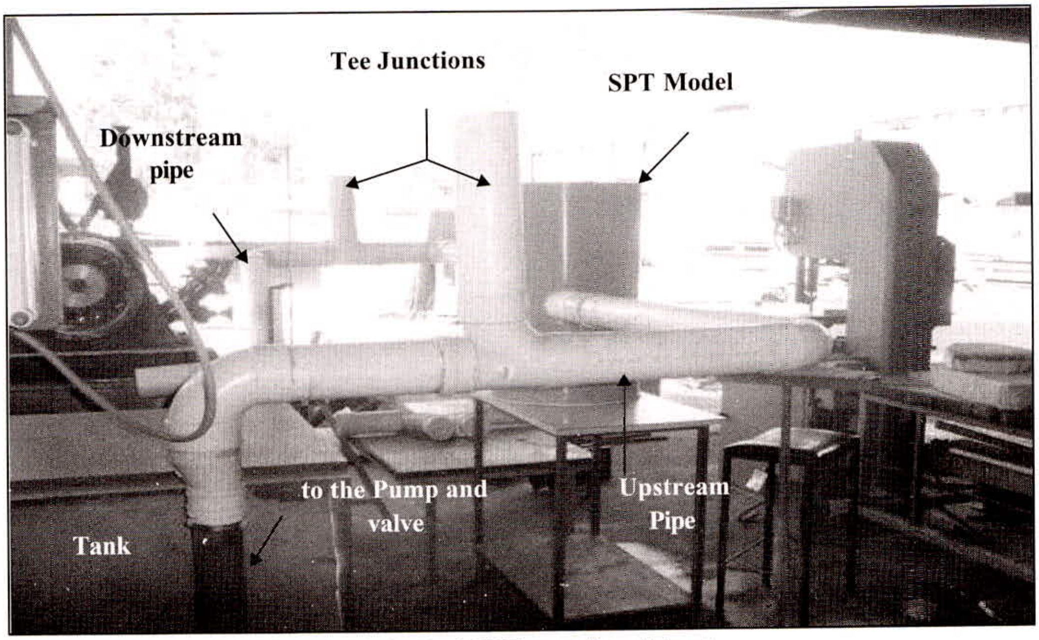


**Fig. 4:** Scaled SPT experimental setup

There are mainly three ways to calculate the head loss in the pipe, (a) Hazen-Williams equation, equation 1, (b) Manning's equation, equation 2 and (c) Darcy-Weisbach equation, equation 3 (White, 2003),

$$H_L = \frac{10.74L}{D^{2.63}}\left(\frac{Q}{C}\right)^{1.85} \text{ Hazen-Williams equation} \quad \ldots (4)$$

$$H_L = \frac{5.29L(nQ)^2}{D^{16/3}} \text{ Manning's equation} \quad \ldots (5)$$

$$H_L = f\frac{L}{D}\frac{V^2}{2g} \text{ Darcy-Weisbach equation} \quad \ldots (6)$$

Since the manometers were connected to the network close to the SPT, the friction loss of the short length of the network's pipe run of the system was consequently negligible and not considered, but the friction of the entrance and exit and blocked basket had been considered as a whole system in this experiment.

## RESULTS AND DISCUSSION

By considering the fact that the outlet pipe is 143 mm above the inlet pipe, the flow from the outlet pipe is possible only when the inlet pipe is full and at least 143 mm above the entrance level. The recorded data was tabulated and analysed and 44% upto 66% blockage were amongst the best situated data which the combined curve illustrates in Graph 1.

The head loss across the weir pit is an important consideration when designing a pipeline. The inlet head loss for each percentage of the screen is plotted in below graph and as it can be seen that the blocked screen in range of 44% to 66% are in a very close relation to each other with the $R^2$ (quadratic regression) value of over 0.99 implying that by using second degree polynomial,

$$h_{L(i)} = -1.58Q^2 + 29.5Q + 258 \quad \ldots (7)$$

where $h_{L(i)}$ is inlet head loss in millimetre, one can estimate the entrance head loss by entering desired value of flow rate (Q) is in litre per second in the above equation.

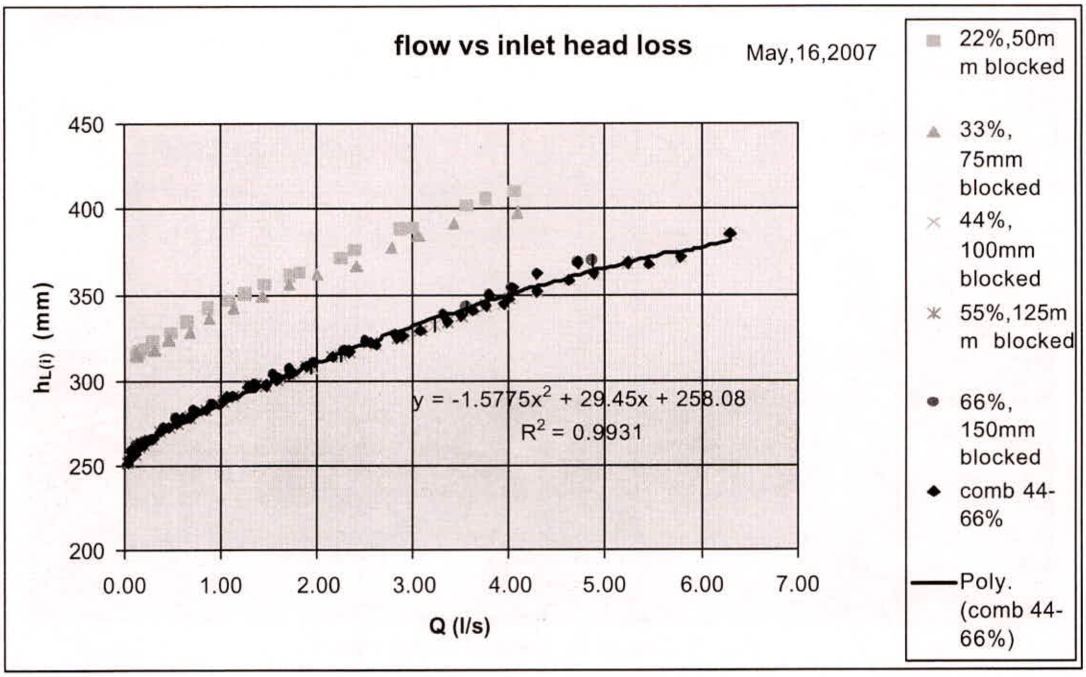
For the outlet flow each increment of flow data has been measured and plotted versus the screen percentage blocked and the final graph is based on all the possible graphs and the quadratic regression value of the results which is shown in the below graph.

Therefore as a result the outlet head loss for the SPT can be estimated by using the second degree polynomial of the form,

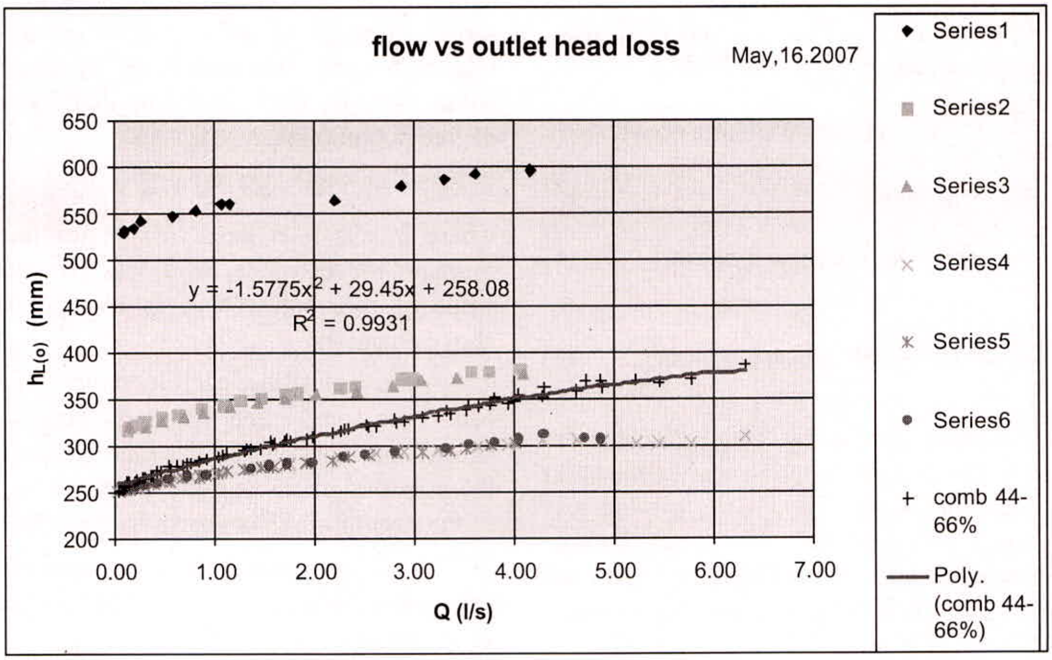
$$h_{L(e)} = -1.58\,Q^2 + 29.5Q + 258 \quad \ldots (8)$$

where $h_{L(e)}$ is the outlet or exit head loss in millimetre and flow rate (Q) is in litre per second. The graph for the combination of 44% to 66% (average of 55%) blocked outlet head loss is shown in Graph 2.

By knowing the head loss values of entering water and exit water and deducting the inlet and outlet head losses from each other one can get total head loss for the flow in SPT for all values of flow in and out of the system as shown in Graph 3.



**Graph 1:** Flow versus inlet head loss



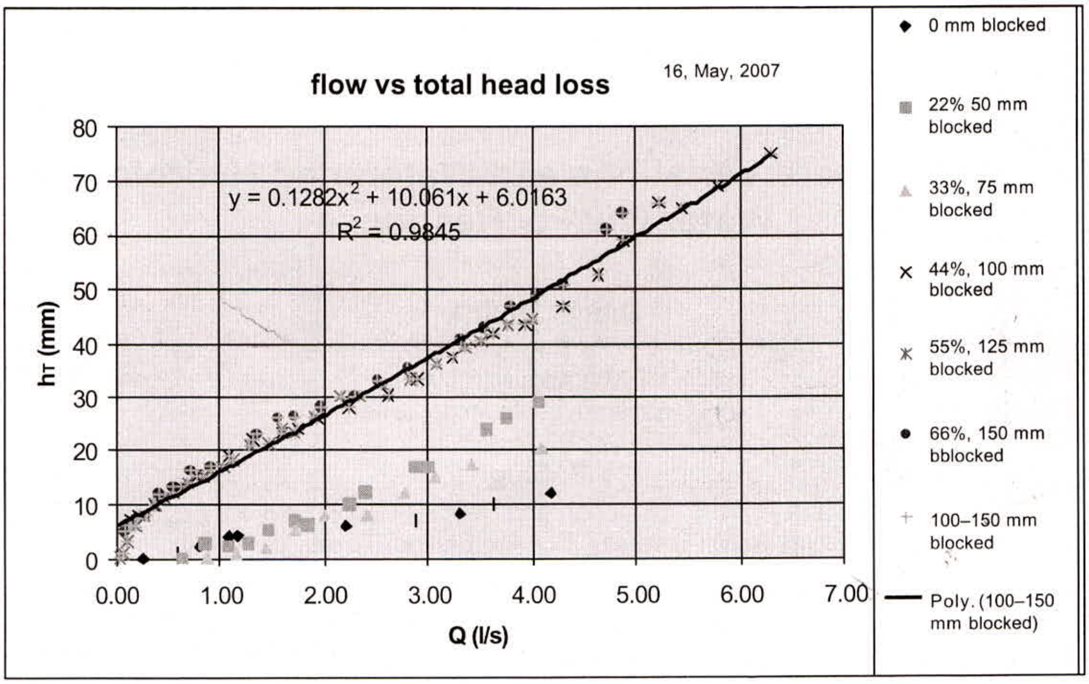
**Graph 2:** Flow versus outlet head loss

Since the values of the screen blockage from zero upto 33% are in the lower range of the total pressure drop as shown in graph 3, the graph of the flow versus total head loss has been plotted using the mean square values of the forty-four to sixty-six percentages of total blockages.

Therefore the above graph could be used for estimating the total head loss of any SPT, using the graph of combined data for 100 to 150 mm (44% to 66%) screen blocked or using the following equation

$$h_T = 0.13\,Q^2 + 10\,Q + 6 \qquad \dots (9)$$

to estimate the total head loss in millimetres. One could substitute $Q$ in litre per second in above equation. Since the experiment was conducted using a scale model the relationships represented by these formulae hold good for the full size units.



**Graph 3:** Flow *vs.* total head loss for combined 44%–66% blocked basket

## CONCLUSIONS

The first stage of the research project i.e. establishing a relationship between flow rate and head loss across a VTA – has been satisfactorily achieved. This relationship, depicted in graph 3 is formulated in equation (9) below,

$$h_T = 0.13\,Q^2 + 10\,Q + 6 \qquad \ldots (10)$$

The above equation provides a mathematical model which satisfies the correlation criteria to a level of 0.98, and can be used with confidence in the establishment of the relationship between flows, head loss and weir height in a diversion weir pit feeding a VTA SPT. This will be the next stage of the research project.

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