University of Southern Queensland

Faculty of Engineering and Surveying

# Siphons As Furrow Irrigation Measurement Devices

A dissertation submitted by

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in fulfilment of the requirements of

**Courses ENG4111 and 4112 Research Project**

towards the degree of

**Bachelor of Engineering (Agriculture)**

Submitted: November, 2007

# Abstract

The aim of this project was to develop accurate entrance and exit loss coefficients for siphons used in furrow irrigation under different upstream conditions. Accurate entrance and exit loss coefficients are required to better estimate the discharge from siphons used in furrow irrigation. Accurate discharge information leads to improved understanding on how water is used on farms. A common measure of this usage is termed water use efficiency.

Research was conducted to discover the need for accurate entrance and exit loss coefficients and existing models that estimate siphon discharge. This project centres on the equation developed by Bos (1989). The equation is comprehendible except for the origin of the combined entrance and exit loss coefficient of 1.9. This value is higher than what is usually used for estimating entrance and exit losses.

A channel and siphon discharge measurement device was constructed to enable testing in the controlled environment of a hydraulics laboratory. A 4 m long siphon with an internal diameter of 55 mm was used in this project. The variables that were tested were the velocity passing the siphon entrance and the effective head across the length of the siphon.

The insufficient volume of data obtained is subject to experimental error and it is for these reasons clear conclusions regarding the aim could not be made. However, from the data gathered from this project, the velocity passing the entrance of the siphon has no effect on the entrance loss coefficient. In addition, the entrance loss coefficient generally decreases with increasing siphon discharge. The equation developed by Bos (1989) generally overestimates siphon discharge when compared to discharges obtained by the testing performed in this project. The project confirms that the use of the Blasius equation to estimate the friction factor for use in the Darcy-Weisbach equation is appropriate. Recommendations have been made in order to improve this project and other possible influential variables on siphon flow to be considered have been suggested.

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# ENG4111 Research Project Part 1 & ENG4112 Research Project Part 2

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Signature

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Date

# Acknowledgements

The following persons deserve recognition for their assistance with the development and execution of this project;

- Joseph Foley, for providing both technical and practical advice in the construction and operation of this project, and for always helping find a solution to any problems that were encountered;

- Prof. Rod Smith, for his technical input and supervision of the project;

- Glen Bartkowski, for his advice on my apparatus construction and setup location; and

- Daniel Eising, for his assistance in using the Hydraulic Facilities at USQ and seeking materials for use in the project.

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# 1 Introduction

## 1.1 Background to the Project

Furrow irrigation delivers water to 96% of the cotton crops in Australia (Spragge 2002). Use of siphon over bank irrigation is the most common method for applying water to the field. However, measuring the volume of water applied to a crop through siphons is difficult. The need for measuring water use has been generated from prolonged droughts which have led to farmers having less water to irrigate with. To maintain the same level of production with a decreasing amount of water, farmers need to become more water-efficient. To measure a farm’s water use efficiency, the amount of water applied to the crop needs to be measured. The most practical method to achieve this is to use siphons as a measurement device.

However siphons and the conditions under which they are used vary from farm to farm, and even vary along the length of the channel. Two of the parameters that affect a siphon’s discharge are the entrance and exit loss coefficients. Methods for determining the coefficients are not well established and where these coefficients have been developed, the process is unknown and has resulted in a higher than expected value.

## 1.2 Surface Irrigation Performance & Importance of Accurate Discharge Measurement

Surface irrigation is the term used to describe three methods of irrigation where water flows across the top of the field, namely border, furrow and level basin. All three techniques involve water flowing from one end of the field to the other, across the surface of the ground.

There are a number of variables that control surface irrigation:

- soil infiltration characteristics;
- surface roughness or retardance;
- longitudinal slope of the field;
- length of the field;
- inflow rate;
- time to cut-off;
- desired depth of application; and
- runoff at the end of the field.

(Hancock & Smith 2006)

The above variables are related and can be simplified to form the volume balance equation, (1.1).

$$Q_o t = V_I + V_S \tag{1.1}$$

where $Q_o =$ inflow to field/furrow [m³/s]

$t =$ time elapsed since irrigation commencement [s]

$V_I =$ volume infiltrated [m³]

$V_S =$ volume stored on surface [m³]

From Equation (1.1), it can be determined that the rate of inflow is directly proportional to the volume of water infiltrated, volume of water stored on the surface, and the length of the irrigation event.

The inflow rate to the field is the second most influential variable in the surface irrigation process, with the infiltration volume being the most important (Hancock & Smith 2006). Hancock and Smith (2006) state that "irrigation performance is sensitive to the discharge and care is required in its selection." Of the variables stated above only three can be easily managed and modified by the farmer, of which inflow rate is one. This adds more emphasis on the importance of inflow rate and consequently the accuracy needed when measuring it.

Two commonly used methods of measureming water use depend upon accurate inflow volumes. These are described in Equations (1.2) and (1.3), respectively.

$$\text{Application Efficiency (\%)} = \frac{\text{Volume added to the soil moisture store}}{\text{Volume delivered to field}} \times 100 \tag{1.2}$$

$$\text{Distribution Uniformity (\%)} = \frac{\text{Mean of the lowest 25\% of applied depths}}{\text{Mean applied depth}} \times 100 \tag{1.3}$$

The accuracy of these measures is highly dependent on the accuracy of the volume applied, which is calculated from the inflow rate.

Knowing the water use efficiency of a field, or the whole farm allows the farmer to make decisions with regard to irrigation practices and water acquisition. Making farms more water efficient will reduce the demand on water resource and will make agriculture more sustainable.

## 1.3 Siphon Irrigation

Siphon irrigation is a form of surface irrigation that utilises a number of lengths of tubing that siphon water from a channel of water termed a head channel, into furrows in a field. The furrows run the full length of the field, usually in between crop rows, and have a mild downhill slope to enable water to reach the far end of the field. The head channel conveys water along the top of the field from which the siphons draw water. The difference in height between the water surface in the head channel and the water surface in the furrow is the effective head that the siphon is operating under. As the water flows from one end of the head ditch to the other, the velocity and water level decreases which affects the uniformity of the discharge from the siphons.

Siphons vary in diameter from approximately 32 mm to 75 mm. Siphons larger in diameter result in starting difficulties. The most common siphon lengths are 3.6, 4.0 and 4.3 m (Wigginton 2007). The operating head can vary from 100 mm to 1 m. A large diameter (75 mm OD) siphon operating under one metre of head can output approximately 8.5 L/s.

## 1.4 Objectives of the Project

This project aimed to develop accurate entrance and exit loss coefficients for siphons used in furrow irrigation under different upstream conditions. Furthermore, the project attempted to have a better understanding of the development behind the head loss coefficient developed by Bos (1989). To achieve these aims, the following objectives had to be met:

- Conduct a search of background literature on previous studies and experiments relating to the aim, and the need for accurate discharge models of small long pipe siphon flow.
- Conduct a sensitivity analysis on a previous model published by Bos (1989).
- Construct apparatus that replicates field conditions, and:
- Conduct a static fluid analysis to determine if the location of the siphon in a static body of water has any effect on the entrance loss coefficient.
- Conduct a dynamic fluid analysis to determine the effect of passing velocity past the siphon entrance on the siphon discharge.
- Analyse discharges calculated from existing equations/models and compare those measured using the apparatus.
- Measure entrance and exit loss coefficients and compare those used in existing models.
- Analyse results and explain any inconsistencies with an existing model.
- Report all ideas, work and findings, discuss the significance of topic, and analyse all results, draw conclusions and submit as a dissertation.

# 2 Literature Review

A literature review was undertaken to gain knowledge on the subject of siphon hydraulics and its importance to the agricultural industry. Sources of information included engineering hydraulics text books, information packs produced by the horticultural industry and agricultural journals accessed via the internet.

## 2.1 Background Hydraulics

### 2.1.1 Energy of Fluid

Conservation of energy is one principle used to model hydraulic situations. Moore (2005) states that "it is based on the application of the application of Newtons second law of motion on an elemental control volume of fluid along a streamline." The outcome is the Euler equation and Moore (2005) states "when integrated along a streamline and expressed in terms of the section mean velocity", the Bernoulli equation (2.1) is produced.

$$\frac{p_1}{\rho g} + \frac{\alpha V^2{}_1}{2g} + Z_1 = \frac{p_2}{\rho g} + \frac{\alpha V_2{}^2}{2g} + Z_2 \tag{2.1}$$

The three components of the Bernoulli equation respectively are the pressure energy per unit weight of fluid, kinetic energy per unit weight of fluid and the potential energy per unit weight of fluid. These three components are referred to as the pressure, velocity and elevation head and have a distance dimension, usually metres. Any other term inserted into the Bernoulli equation must be in the form of energy per unit weight of fluid.

### 2.1.2 Application of the Energy Equation

Chadwick and Borthwick (2004) state that “Bernoulli’s equation can be applied to any continuous flow system.” Applying Bernoulli’s equation (2.1) to a submerged siphon (Figure 1) including losses yields Equation (2.2).

$$\frac{p_1}{\rho g}+\frac{\alpha V_1^2}{2g}+Z_1-h_f-h_m=\frac{p_2}{\rho g}+\frac{\alpha V_2^2}{2g}+Z_2 \tag{2.2}$$

where $p_1 =$ atmospheric pressure at 1 [N/m²]
$p_2 =$ atmospheric pressure at 2 [N/m²]
$\alpha =$ Coriolis coefficent [dimensionless]
$V_1 =$ velocity at 1 [m/s]
$V_2 =$ velocity at 2 [m/s]
$Z_1 =$ elevation at 1 [m]
$Z_2 =$ elevation at 2 [m]
$g =$ acceleration due to gravity [m/s²]
$\rho =$ density of fluid [kg/m³]

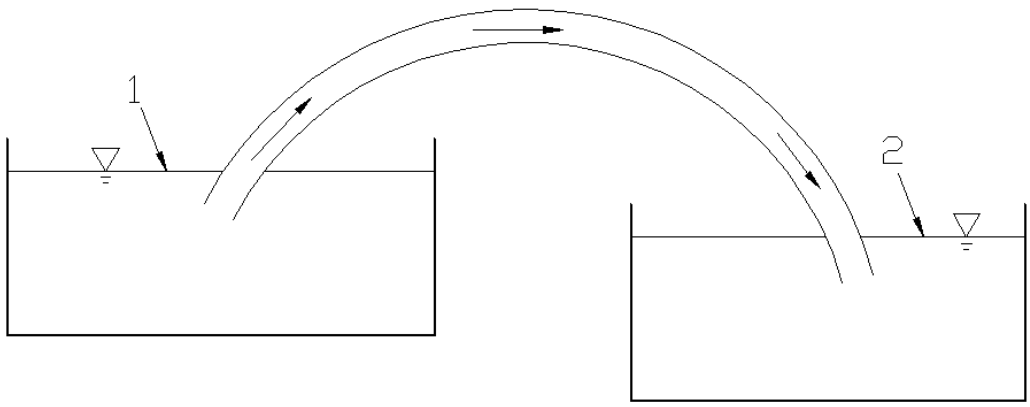


Figure 1: Simple diagram of a siphon operating with a submerged exit.

Assuming the change in atmosphere pressure between points 1 and 2 is negligible, and the velocity of both water bodies is zero, Equation (2.2) reduces to:

$$Z_1-h_f-h_m=Z_2 \tag{2.3}$$

The Darcy-Weisbach formula is used to calculate the pipe friction losses.

$$h_f = \frac{fLV^2}{2gD} \tag{2.4}$$

where $h_f =$ head loss due to friction [m]

$f =$ Darcy-Weisbach friction factor [dimensionless]

$L =$ length of pipe [m]

$V =$ mean section velocity through pipe [m/s]

$D =$ internal diameter of pipe [m]

The minor losses are defined as:

$$h_m = K\frac{\alpha V^2}{2g} \tag{2.5}$$

where $h_m =$ minor head loss [m]

$K =$ combined entrance and exit loss coefficient [dimensionless]

Substituting Equations (2.4) and (2.5) into (2.3) and rearranging slightly, the following equation is formed:

$$\Delta h - \frac{fLV^2}{2gD} - K\frac{\alpha V^2}{2g} = 0 \tag{2.6}$$

Solving Equation (2.6) for $V$ and multiplying by the cross-sectional area of the pipe, the following equation describes siphon discharge with a submerged exit:

$$Q = \frac{\pi \times D^2}{4} \times \sqrt{\frac{2g\Delta h}{K + \frac{fL}{D}}} \tag{2.7}$$

When Bernoulli's equation is applied a siphon with an unsubmerged exit (Figure 2), Equation (2.3) becomes:

$$Z_1 - h_f - h_m = Z_2 + \frac{\alpha V_2^{\ 2}}{2g} \qquad (2.8)$$

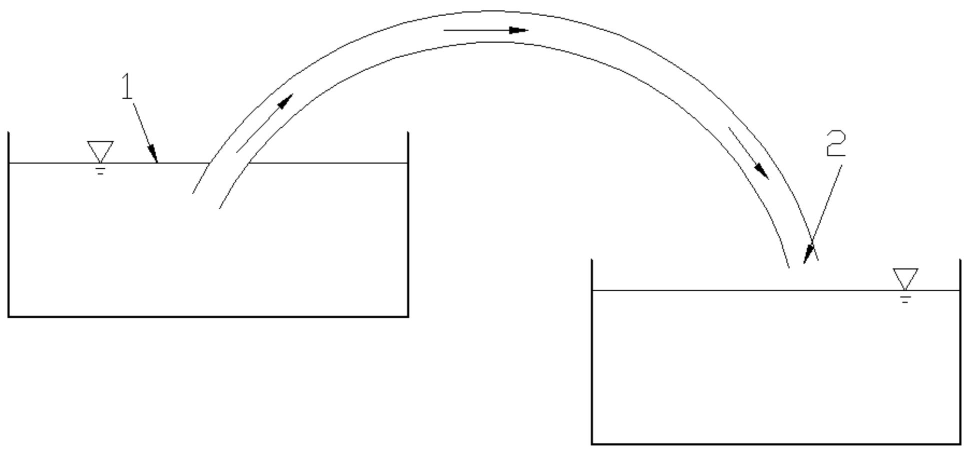


Figure 2: Simple diagram of a siphon operating with an unsubmerged exit.

Substituting Equations (2.4) and (2.5) into (2.8) and solving for $V$ results in the following equation:

$$V = \sqrt{\frac{2g\Delta h}{K + \frac{fL}{D} + 1}} \qquad (2.9)$$

Equation (2.9) differs from the velocity portion of Equation (2.7) in that there is an added loss quantity in the denominator.

### 2.1.3 Entrance and Exit Loss Coefficients

The entrance and exit loss coefficients refer to the efficiency of the entrance and exits of a pipe. Table 1 lists some values for the entrance loss coefficient for a pipe attached to a larger reservoir. The exit loss coefficient is usually 1 (Moore 2005).

Table 1: Entrance loss coefficients for different entrances.

| Entrance Type | K |
|---|---|
| conical | 0.18 |
| flush | 0.5 |
| re-entrant | 1.0 |
| bellmouth | 0.04 |

(Moore 2005)

### 2.1.4 Pipe Friction Equations

Early experiments conducted by Darcy and Weisbach indicated that head loss was proportional to the squared mean velocity (Chadwick & Borthwick 2004). Further development of their work led to the creation of what is known as the Darcy-Weisbach equation:

$$h_f = \frac{fLV^2}{2gD} \tag{2.10}$$

The pipe friction factor used in the Darcy-Weisbach equation can be determined using a number of different methods. One of these methods is using the Blasius equation (2.11), which is only valid for Reynold numbers up to $10^5$ and for use on 'smooth pipes' (Chadwick & Borthwick 2004).

$$f = \frac{0.3164}{\mathrm{Re}^{\frac{1}{4}}} \tag{2.11}$$

where $\mathrm{Re} =$ Reynolds Number [dimensionless]

Manning's roughness coefficient, *n*, has been used in some models to estimate the friction factor. Use of Manning's *n* is not appropriate as it was developed for use on open channel flow and not pipe flow.

## 2.2 Formulae Used & Previous Work on Estimating Siphon Discharge

Carter (2001) described inlet controlled flow through a pipe using Bernoulli's Energy Equation and the Darcy-Weisbach equation. The result of this is the equation given below.

$$Q = \left( \frac{2gA^2H}{\left( k_i + \frac{fL}{D} + k_o \right)} \right)^{0.5} \tag{2.12}$$

where Q = discharge through pipe [m³/s]

$A$ = cross-sectional of the pipe [m²]

$H$ = effective head [m]

$k_i$ = entrance loss coefficient [dimensionless]

$k_o$ = exit loss coefficient [dimensionless]

$f$ = Darcy-Weisbach friction factor [dimensionless]

$L$ = length of pipe [m]

$D$ = diameter of pipe [m]

Carter (2001) also stated that outlet controlled flow can be calculated using the following equation. It was found that this equation is not appropriate, as stated in Section 2.1.4.

$$Q = \sqrt{\frac{1.24gh_oD^3}{1.5D + fL}} \tag{2.13}$$

where $h_0$ = outlet head [m]

$f = \frac{124n^2}{D^{0.33}}$ [dimensionless]

where $n$ = Manning's roughness coefficient [dimensionless]

There has been little research on estimating discharge from a siphon. Bos (1989) described the mathematics for many discharge structures and details on equations for estimating the discharge through small pipes and siphons. Bos's (1989) analysis of a siphon uses the standard continuity equation:

$$Q = AV \tag{2.14}$$

Expanding on this using the standard equation for gravitational discharge (Tennakoon & Milroy 1999), Bos (1989) developed the following equation:

$$Q = \frac{\pi}{4} D_P{}^2 \left( \frac{2g\Delta h}{\xi} \right)^{0.5} \tag{2.15}$$

where Q = discharge through pipe [m³/s]
$D_P$ = diameter of pipe [m]
$\Delta$h = effective head [m]

$$\xi = 1.9 + f \frac{L}{D_P} \tag{2.16}$$

Equation (2.16) is the friction loss equation, containing a combined entrance and exit loss coefficient, and pipe friction losses. There are no other minor losses as the diameter of pipe is assumed to be constant and there are no bends or any circumstances that can cause an energy loss. The $f$ is the Darcy-Weisbach friction loss coefficient. Bos's (1989) equation (2.15) is comprehendible except for the origin of the combined entrance and exit loss coefficient of 1.9. This value is higher than what is usually used for estimating entrance and exit losses.

Wigginton (2007) used the Bos (1989) equation to develop a number of charts for the Cotton Cooperative Research Centre's (CRC) WATERpak. WATERpak is a guide for irrigation management for cotton farmers. Wigginton (2006) also used the Bos (1989) equation to reinforce the importance of the internal diameter of a siphon. Wigginton (2006) found that the metric equivalent of an imperial-manufactured siphon did not have the same diameter and noted that this will affect the siphon discharge.

More importantly, Wigginton (2007) remarked that “the more usually encountered equation based on Manning’s outlet control is theoretically inappropriate.” It was reported by Wigginton (2007) that the Bos (1989) equation is for use under field conditions and not laboratory situations.

Carter (2001) attempted a similar project to this one with little result due to inaccuracy of measurement devices used in replicating field conditions. The research conducted by Carter (2001) into Bos’s (1989)work and other efforts did not yield any new information that has not been found for this project.

Milroy and Tennakoon (1999) developed an equation for estimating the discharge of a siphon. However, it is not as easy to use as the Bos (1989) equation as all the parameters that effect the discharge, except for the head, have been combined into a single coefficient. The calibration factor is determined empirically (Milroy & Tennakoon 1999).

$$Q = Rh^{0.5} \tag{2.17}$$

where $R$ = a single calibration factor developed by Milroy & Tennakoon (1999) [$\mathrm{m}^{2.5} / s$]

## 2.3 Sensitivity Analysis

A sensitivity analysis was performed on Bos's (1989) equation to observe how the equation reacted to changes to its inputs, or more practically, measurement error of the field variables. From simply looking at the equation, it can be seen that the accuracy of the measurement of the siphon diameter is crucial due to the power it is raised to. However, in reality a siphon is not perfectly round for its entire length and Bos (1989) does not state the method for measuring the diameter. It is assumed that the internal diameter of a perfectly round siphon is used.

The sensitivity analysis was performed by varying each of the variables (head loss coefficient, effective head and diameter) one at a time and calculating the estimated siphon discharge using the Bos (1989) equation. The results from the analysis are shown in Table 2 and Figure 3.

Table 2: Change in discharge for a 25% increase in siphon variable (Siphon: L = 4 m, D = 70 mm)

| Parameter | Difference in discharge, Q ($m^3/s$) |
|---|---|
| Head loss coefficient (entrance & exit) (2.34) | -7.0% |
| Hydraulic Head (m) | 11.8% |
| Diameter (87.5 mm) | 62.3% |

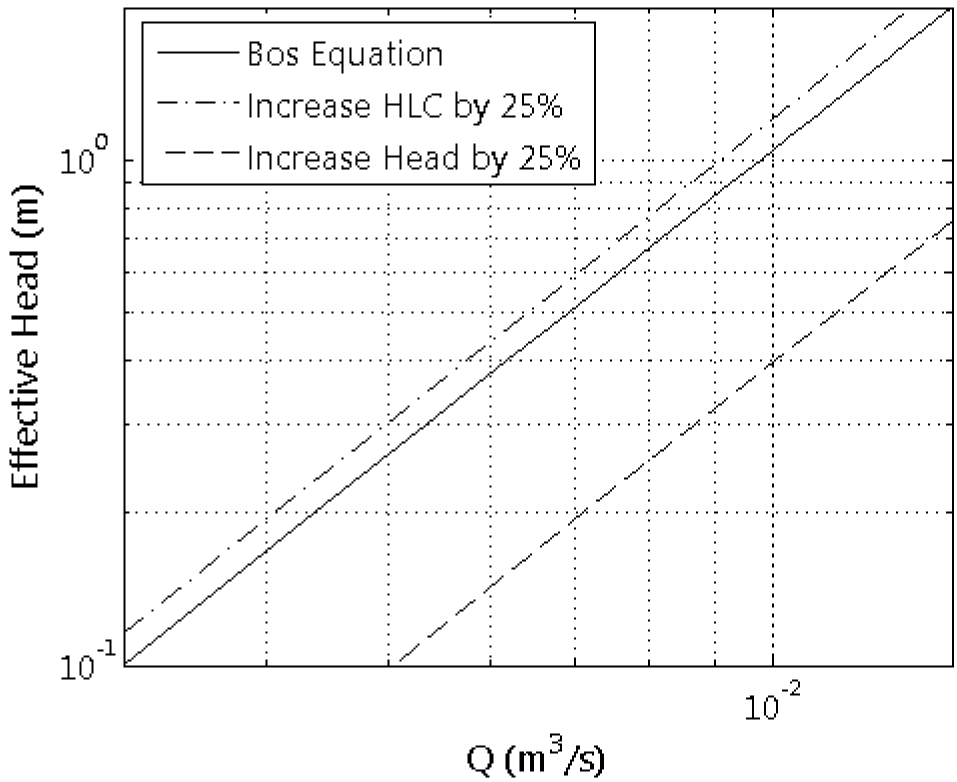


Figure 3: The effect of a 25% increase in the combined entrance and exit loss coefficient and diameter.

From Table 2 it can be observed that all three parameters will have an effect on the discharge of a siphon. In particular the diameter will have the biggest influence on discharge. The lower effect of the head loss coefficient (combined value of entrance and exit loss coefficient) could indicate that Bos (1989) is incorrect in concluding that it is equal to 1.9. This value could actually be lower than 1.9, with the error in discharge taken up in the measurement of the head and/or diameter.

A MATLAB © script was written to calculate and plot the figure above and can be found in Appendix B.

# 3 Experimental Methodology

To fulfil the objectives of this project, some experimental work had to be undertaken. This experimental work took place at the University of Southern Queensland (USQ) Toowoomba Campus. The Engineering Faculty’s Water Laboratory was used to do the experimental work. A water channel simulating an irrigation channel had to be constructed and supported in the laboratory. This option was preferred over using the hydraulic flumes located at the Agricultural Plot as the availability of water and ease of operation is greater at the laboratory. In addition it is easier to construct the channel from wood, than constructing an earthen channel at the Agricultural Plot, which would involve extensive earthworks. In general the setup and operation of the experiment was easier in the laboratory.

The experimental work involved a number of tasks. The static and dynamic tests investigated whether channel boundaries affect the entrance loss coefficient, under still conditions and water flowing past the entrance of the siphon. The field simulation gathered data (effective head, discharge, diameter) for comparison with existing models for estimating siphon discharge. The entrance and exit loss coefficients were measured and compared to Bos’s (1989) combined value.

After the experimental work was complete, the project advanced to the next stage which involved analysis of the results and comparison to existing models. Comments and conclusions were made on the method of the experimental work and the results obtained.

# 3.1 Construction of Apparatus and Setup of Equipment

Before any experimental work could commence, an experimental apparatus was constructed to represent an irrigation channel and furrow. The channel was made from 5-layer form ply and 75x38 mm pine studs. The internal dimensions of the channel measured 0.6 m wide, 0.5 m deep and 1.8 m long. A framework of eight studs equally spaced was fixed to the bottom of the channel. The channel was placed on four sawhorses for support and to raise the water surface above the floor to allow a range of effective heads to be tested.

On the upstream end of the channel, two holes measuring 78 mm in diameter were drilled in the side wall near the top to allow water to discharge out during the static tests. The purpose of these holes was to maintain a constant water level in the channel, with excess water spilling out. Refer Figure 4.

Figure 4: Holes in the side wall to maintain a constant water level in the channel while static tests were undertaken.

Approximately 400 mm from the end of the channel, a series of baffles were installed. Metal flyscreen mesh was used to dampen the turbulence in the supply water. The baffles (shown in Figure 5) spaced 50 mm apart. They were held in place with thin strips of wood. The tops of the baffles were folded over several times to add rigidity

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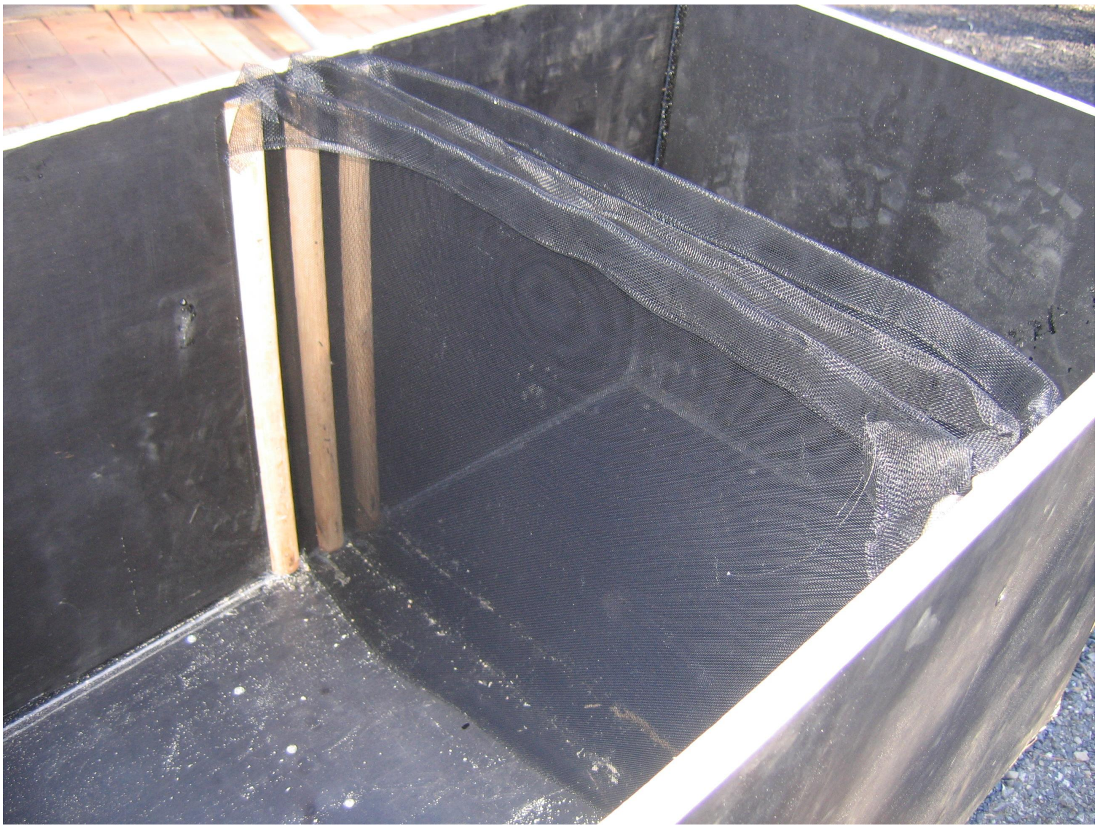

Figure 5: Metal flyscreen energy dissipators.

At the downstream end of the channel, a large vee was cut into the end wall where two interchangeable 90 ° thin plate vee-notch weirs could be placed, depending on the discharge in the channel. Figure 6 displays the smaller of the two weirs. The weirs were sealed against the channel wall with a thin strip of rubber and seventeen bolts. The purpose of the vee-notch weirs were to provide a simple and accurate method of measuring the channel discharge.  A plughole was also installed in the bottom of the channel to allow draining after testing was finished.

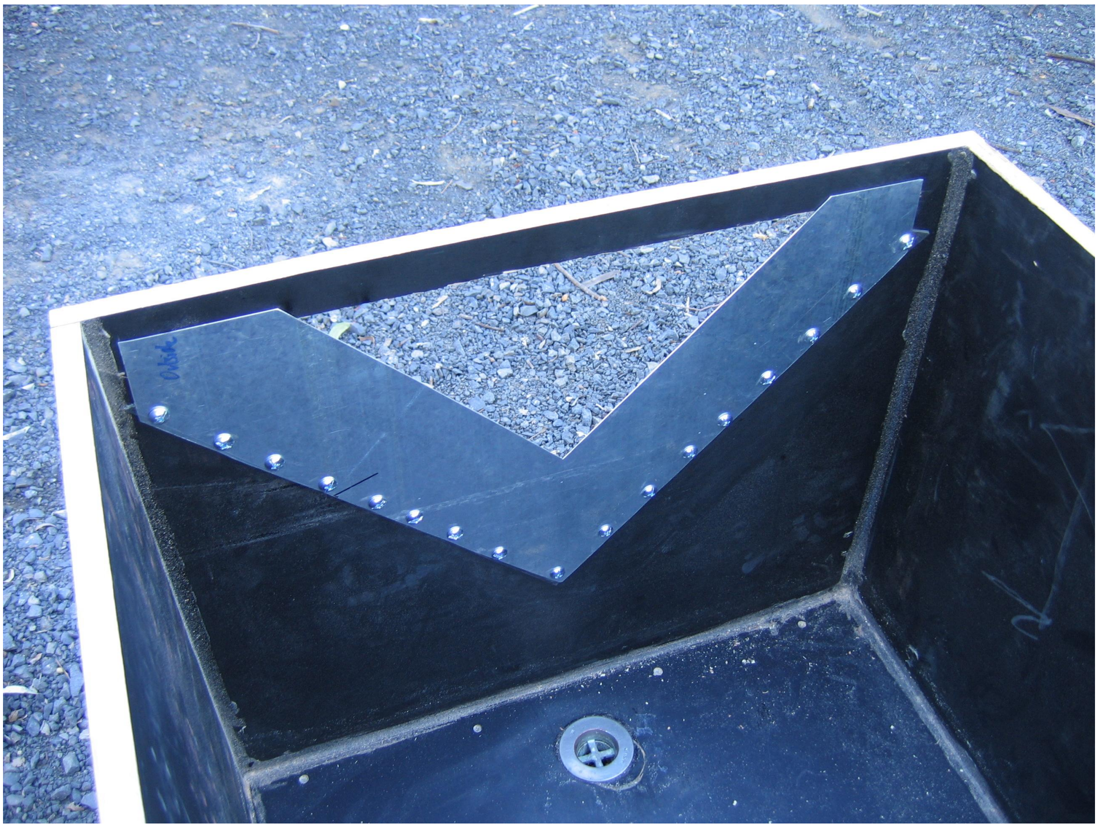

Figure 6: Small vee-notch weir and plug hole.

To simulate a furrow, a small box was constructed from similar material to that of the main channel. The siphon discharge measurement unit’s dimensions were 600 mm long, 170 mm wide and 600 mm deep. It is not as wide as desired, due to the weight of water it would contain when full. This was of concern as the siphon discharge unit had to be moved vertically to change the effective head across the siphon.

The siphon discharge measurement unit was supported by a four-legged frame that allowed it move freely within the legs via a rope and pulley system. Two metal stands were placed either side of the frame to add support. Figure 7 displays the siphon discharge setup.

Figure 7: Siphon discharge unit and supporting structure.

A 30 ° thin plate vee-notch weir was installed at one end of the unit and was used to measure the discharge from the siphon.

Five manometers were tapped into the siphon which is 4 m long and 62 mm in outside diameter. The internal diameter of the siphon was 55 mm. Moore (2005) states “manometers measure pressure differences using a column of fluid”, for which water was the fluid for this project. The manometers were 12.5 mm ID clear plastic tubing and were used to measure the entrance losses, exit losses and pipe friction losses. Two manometers were tapped into the main channel and the siphon discharge measurement unit and were used to measure the effective head. The five manometers were tapped at 50, 250, 550, 2000 and 3950 mm from the entrance of the siphon. These spacings allowed a detailed assessment of the energy levels at either end of the siphon, as well as a general sense of the energy movement overall. All seven manometers were connected to a manifold that had a vacuum applied to it to bring the water levels up to a practical height to make readings easier. Figure 8 displays the manometer board.

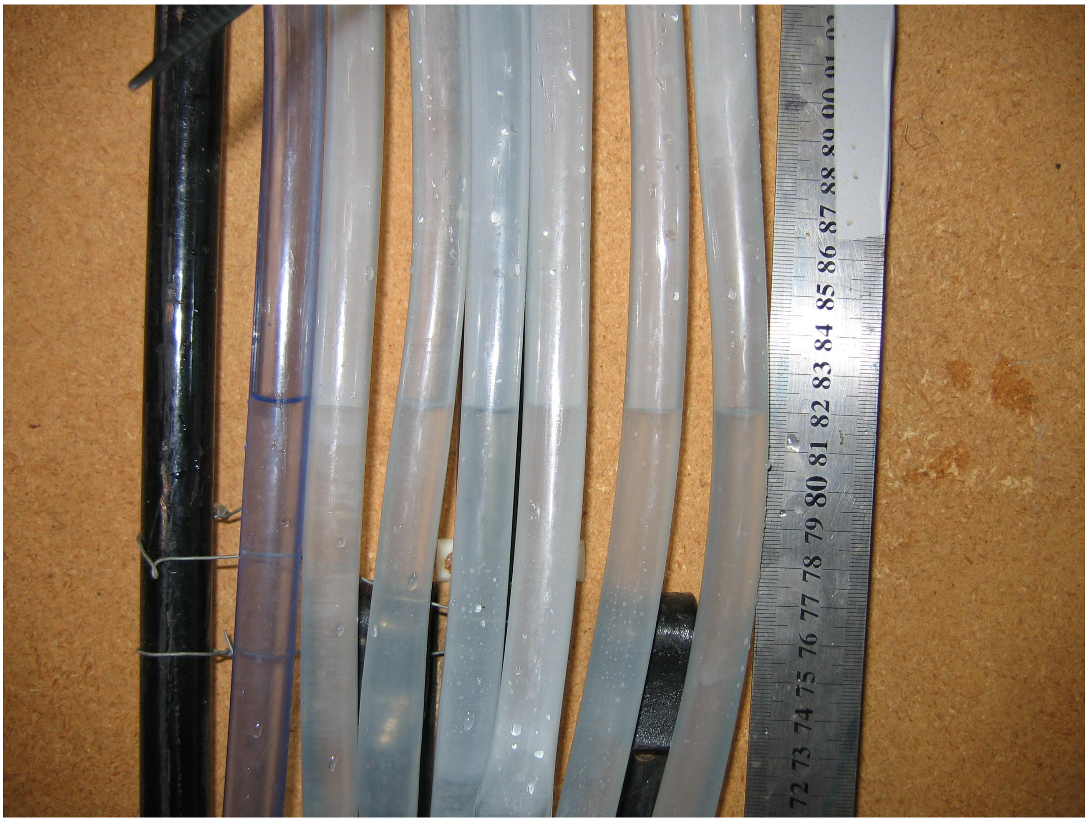

Figure 8: Manometer board with no discharge through the siphon.

The vacuum was generated using a hanging water column. The hanging water column was made from a 1.8 m length of 50 mm PVC pipe capped at one end. Two plastic tubes were secured to the inside of the pipe near the cap and ran the full inside and outside length of the pipe. The pipe was placed inside a 100 mm pipe of PVC pipe, with the capped end of the inner pipe at the top. The larger, outer PVC pipe contained water. The whole system was stood vertically and attached to the siphon discharge measurement unit frame. When the inner pipe is raised a vacuum is created in the top of the pipe and this is where the manifold is connected.


Figure 9: Top of the hanging water column.

An Ott Meter was used to measure the local velocity at the entrance of the siphon, however it was not very successful.

Figure 10 shows the entire setup in the Hydraulics Laboratory. All the water that discharges out of the setup falls onto the floor where it drains into a recirculation system for reuse. The water is supplied by constant head tanks attached to the end of the Engineering and Surveying Faculty building. The head supplied by the tanks in this project was approximately 15 m and the estimated maximum flow rate was 40 L/s.

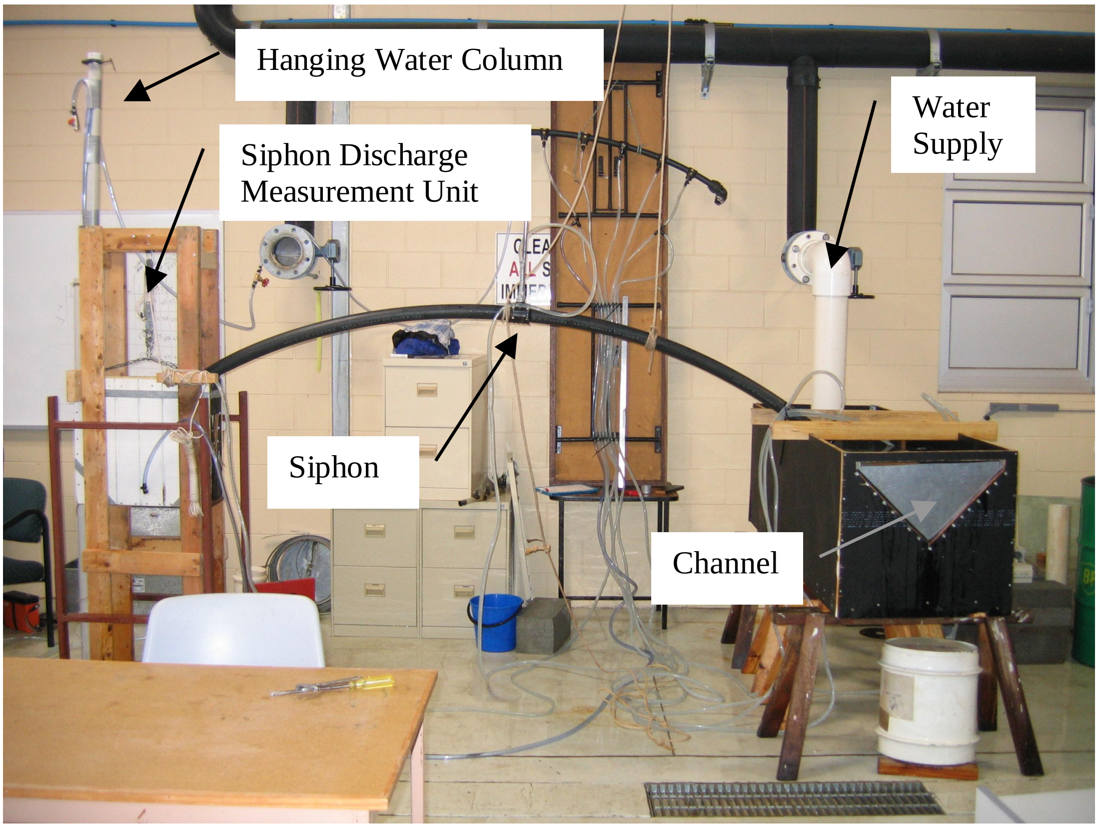


Figure 10: The experimental setup, with the siphon discharge unit on the left and the main channel on the right.

All parameters were kept constant except for:

- the discharge entering the channel, which varied the velocity in the channel; and
- the effective head, which was varied by raising or lowering the siphon discharge unit.

## 3.2 Static and Dynamic Analyses

The purpose of the static and dynamic analyses were to determine if the velocity flowing past the entrance of the siphon affects the entrance loss coefficient. This was done by measuring the entrance loss coefficient with no velocity in the channel and with velocity in the channel. In addition, the entrance of the siphon was placed on the bottom of the channel and in the middle of the body of water to see if the channel boundaries had an effect on the entrance loss coefficient.

The entrance loss coefficient was measured by using Equation (3.1), and a manometer close to the entrance of the siphon to measure the energy loss. Initially an Ott Meter was used to measure the local velocity at the entrance of the siphon, however this method was discarded as the channel velocity was not great enough to get consistent readings. From the following equation, the entrance loss coefficient can be obtained. The velocity used was the mean siphon velocity. Calculation of the exit loss coefficient was performed using the same equation, substituting $h_e$ with the exit energy loss and the resulting $K_e$ value refers to the exit loss coefficient

$$h_e = K_e \frac{\alpha V^2}{2g} \tag{3.1}$$

where $h_e$ = entrance head loss [m]

$K_e$ = entrance loss coefficient [dimensionless]

## 3.3 Field Simulation

A range of channel velocities and effective heads encountered in the field were to be simulated and the following data recorded:

- discharge at the end of the channel;
- discharge through the siphon; and
- seven manometer readings that were later used for head loss calculations at the entrance and exit of siphon, across the siphon, and to calculate the effective head.

However, due to some design issues only one channel velocity was achieved and a smaller range of effective heads than aimed for was obtained. The supply discharge to the main channel was not great enough to produce a mean channel section velocity greater than approximately 0.1 m/s. In addition the weir on the channel was at maximum capacity when the maximum supply discharge was being delivered.

## 3.4 Analysis of Results

The analysis of the results involved comparing theoretical values to practical values determined during testing. That is, comparing the channel velocity and siphon discharge to the entrance loss coefficient, siphon discharge to the discharge calculated from the Bos (1989) equation, and verifying the frictional losses with suitable models.

A number of steps were taken to reduce the recorded measurements to the appropriate discharges and energy levels. The discharge readings were measurements from the vertex of the weir to the water level, along the edge of the weir. This measurement was converted to a vertical distance above the weir and the discharge was calculated using the following weir equation:

$$Q = C_d \times \frac{8}{15}\sqrt{2g}\,\tan\left(\frac{\theta}{2}\right)h_1^{5/2} \tag{3.2}$$

where $C_d =$ weir coefficient [dimensionless]
$\theta =$ angle of vee [degrees]
$h_1 =$ height of water above weir crest [m]

The appropriate weir coefficient $C_d$ was obtained from the Standards Committee Australia (1991). Tables of the head-discharge relationships for the 90 ° and 30 ° weirs can be found in Appendix E and Appendix F, respectively.

The manometer readings gave the hydraulic levels of the water at various points. The measurements were distances of the water level in the manometers from an arbitrary datum. They were reduced to energy levels by subtracting the velocity head and the lowest manometer reading from each point. This set the water surface in the siphon discharge measurement unit as the datum point, and all energy levels were relative to this surface.

All further calculations using the manometer readings were performed in terms of energy.

Microsoft Excel © is a spreadsheet software package and was used to tabulate, calculate and plot all data and results in the project, except for the sensitivity analysis, where Mathworks' MATLAB © was used.

# 4 Results, Analysis and Discussion

The dataset obtained for this project is small and is suspect of containing experimental error. Anomalies in the data deemed to be highly erroneous have been removed from analysis, however complete datasets can be found in the relevant appendices. Possible sources of error include the reading of the channel and siphon discharge over the weirs, and the reading of the manometers.

Only a small range of effective head values were tested due to limitations of the siphon discharge measurement unit. The vee-notch weir on the unit was the maximum size for the given width, however it was too small and was only able to convey a siphon discharge of  up to approximately 3 L/s. Unfortunately the channel velocity could not be increased due to the limitations on the laboratory water supply, as previously mentioned.

## 4.1 Results of Static Tests

Table 3 lists the entrance and exit loss coefficients for various effective heads, under static channel conditions. Figure 11 illustrates the location of dimensions 'a' and 'b'.

Table 3: Entrance & Exit loss coefficients for static conditions.

| Effective head ($\Delta h$) (m) | Entrance Loss Coefficient | Exit Loss Coefficient | Distance from surface (mm) | | Siphon Discharge (L/s) |
|---|---|---|---|---|---|
| | | | a | b | |
| 0.09 | 0.93 | 1.14 | 220 | 175 | 1.38 |
| 0.13 | 0.83 | 1.12 | 220 | 175 | 1.82 |
| 0.13 | 0.19 | 1.55 | 210 | 180 | 1.97 |
| 0.20 | 0.81 | 1.13 | 220 | 175 | 2.30 |
| 0.20 | 0.68 | 1.13 | 210 | 180 | 2.34 |
| 0.25 | 0.56 | 1.12 | 205 | 180 | 2.79 |
| 0.28 | 0.82 | 1.15 | 220 | 175 | 2.79 |
| 0.29 | 0.65 | 1.11 | 90 | 100* | 2.93 |

** distance from water surface*

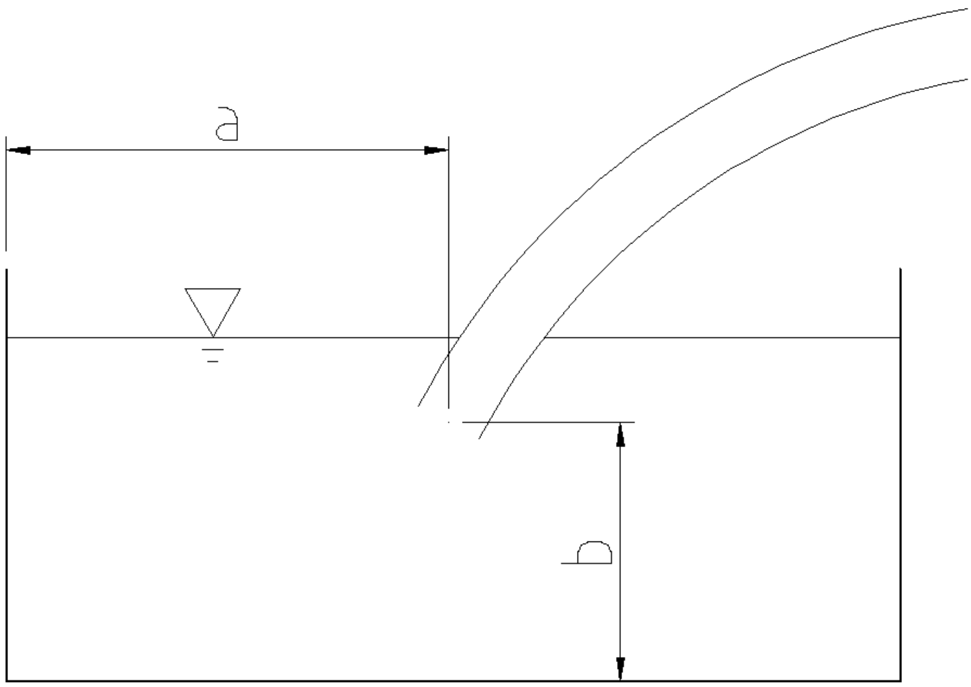


Figure 11: Diagram displaying distances of siphon entrance from channel walls.

From Table 3, it can be seen that the location of the siphon entrance with regard to the proximity to the channel walls does not have a significant effect on the entrance loss coefficient. Only one trial with the siphon entrance placed in the channel corner was taken, however it was removed from this data as the entrance and exit loss coefficients calculated from this set were unusually high. This may have been a result of error produced from the measuring devices. The full data set from the static tests can be found in Appendix C.

The energy grade lines for the static tests are shown in Figure 12. The entrance loss coefficient was calculated by extending the line of best fit fitted to the points at 0.25, 0.55, 2 and 3.95 m, to the y axis. These points were chosen because they give the best fit to the data relating to the friction losses. The difference between the intersection and the energy value of the channel was deemed to be the energy loss due to water entering the siphon. The exit loss was calculated in a similar manner, using the difference in energy between the extrapolated value at 4 m and the energy of the water in the siphon discharge unit. Using Equation (2.5) the loss coefficients could be calculated.

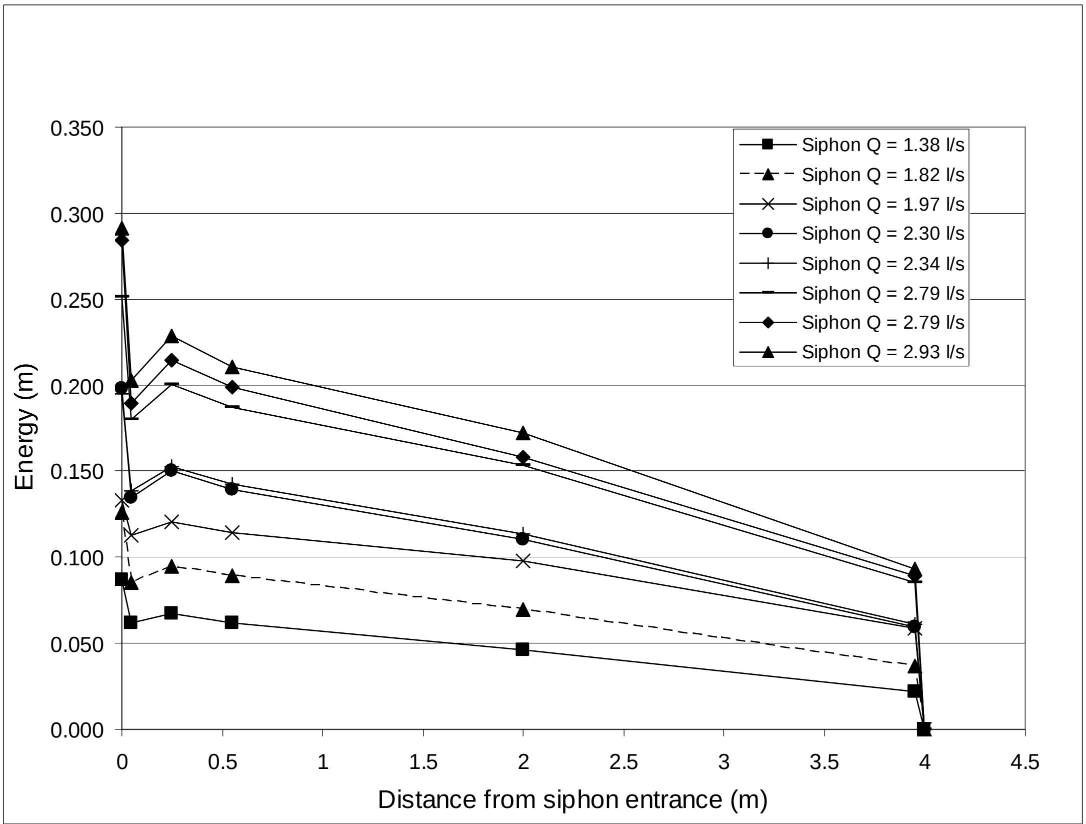


Figure 12: Energy Grade Lines (EGL) for the static tests.

The slope of the plots between distances 0.25 m and 3.95 m increase with discharge. This occurs because the friction loss is proportional to the square of the velocity of flow. The rapid decrease in energy at 0.05 m is caused by a contracted jet effect occurring a short distance upstream from the entrance of the siphon.

## 4.2 Results of Dynamic Tests

The results of the dynamic tests are given in Table 4. As the effective head applied across the siphon increased, both loss coefficients decreased. The complete data set can be found in Appendix D.

Table 4: Entrance & Exit loss coefficients for dynamic conditions.

| Effective head ( $\Delta h$ ) (m) | Channel Velocity (m/s) | Entrance Loss Coefficient | Exit Loss Coefficient | Distance from surface (mm) | | Siphon Discharge (L/s) |
|---|---|---|---|---|---|---|
| | | | | a | b | |
| 0.08 | 0.11 | 0.95 | 1.16 | 190 | 200 | 1.48 |
| 0.13 | 0.11 | 0.68 | 1.19 | 190 | 200 | 1.97 |
| 0.17 | 0.11 | 0.81 | 1.21 | 230 | 230 | 2.13 |
| 0.18 | 0.11 | 0.60 | 1.11 | 190 | 200 | 2.38 |
| 0.18 | 0.11 | 0.27 | 1.05 | 230 | 230 | 2.65 |
| 0.23 | 0.10 | 0.48 | 1.08 | 190 | 200 | 2.84 |

The energy grade lines for the dynamic tests are shown in Figure 13.

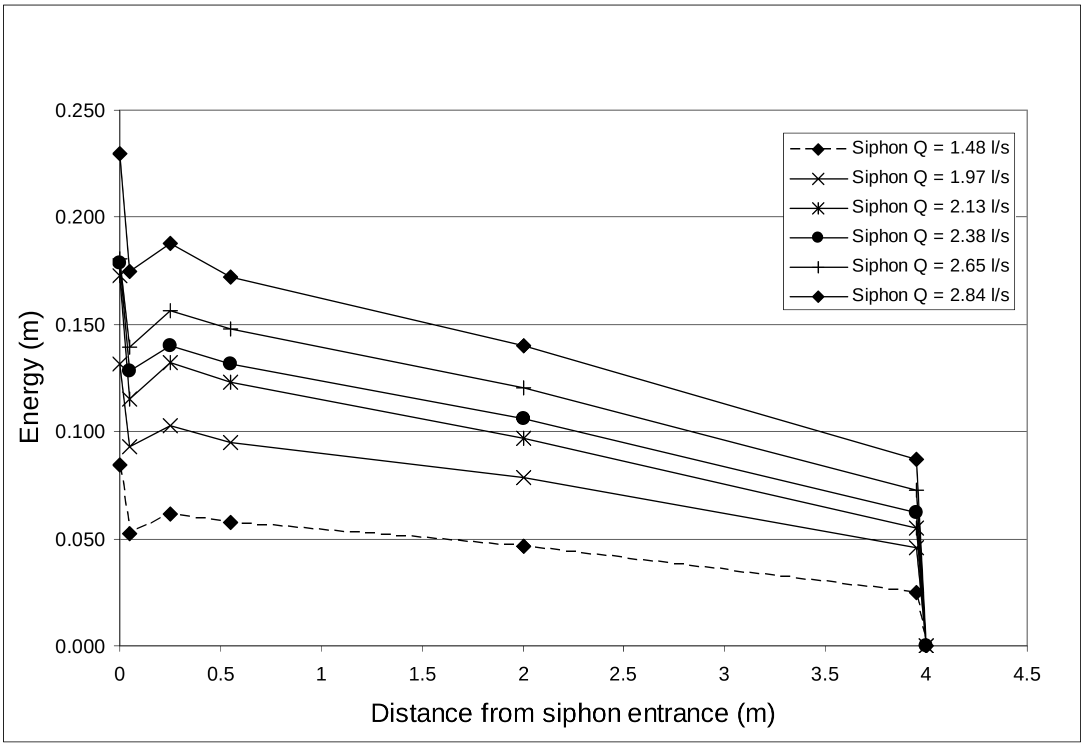


Figure 13: Energy Grade Lines (EGL) for the dynamic tests.

Similarly to the static tests, there is a contracted jet flow effect at the siphon entrance and the friction slope increases with discharge.

## 4.3 Entrance Loss Vs Channel Velocity & Siphon Discharge

The entrance loss coefficients were compared to channel velocity and siphon discharge to determine if there was any relationship for either case.

Table 5: Channel velocity and entrance loss coefficients.

| Channel Velocity (m/s) | Entrance Loss Coefficient |
|---|---|
| 0 | 0.93 |
| 0 | 0.83 |
| 0 | 0.19 |
| 0 | 0.81 |
| 0 | 0.68 |
| 0 | 0.56 |
| 0 | 0.82 |
| 0 | 0.65 |
| 0.10 | 0.95 |
| 0.10 | 0.68 |
| 0.10 | 0.81 |
| 0.11 | 0.60 |
| 0.11 | 0.27 |
| 0.11 | 0.48 |

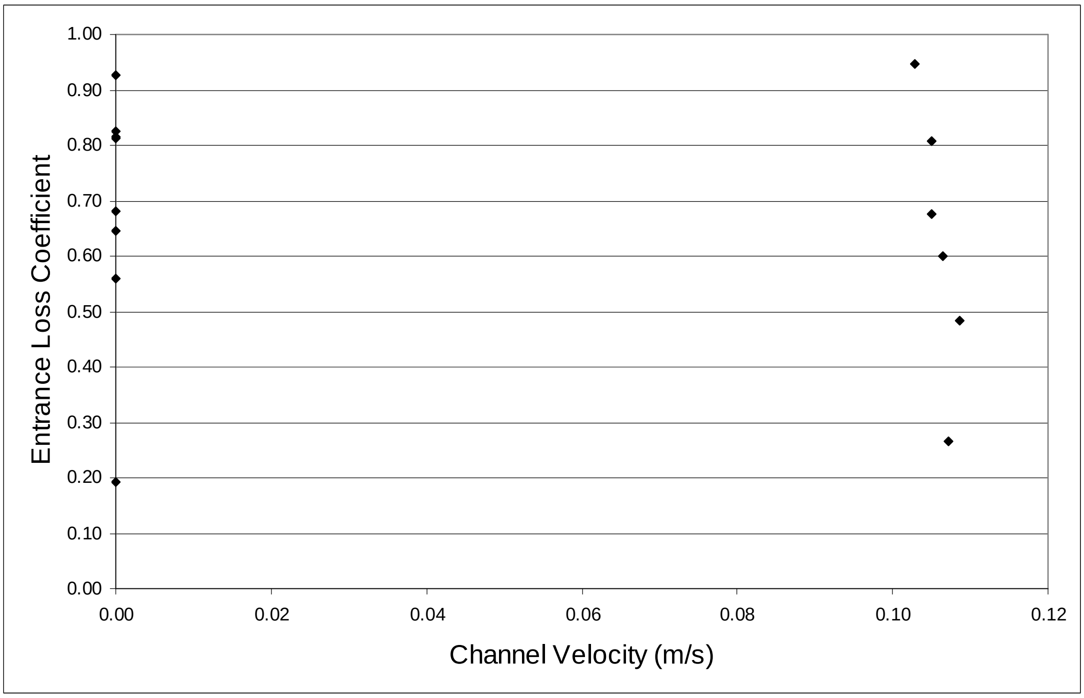


Figure 14: Entrance loss coefficient Vs channel velocity.

From Figure 14, it is not possible to determine if there is a definite relationship between entrance loss coefficient and channel velocity. The data points at 0 m/s and 0.10 m/s respectively, are to sparse to conclude if any relationship exists. However the entrance loss coefficients for static conditions are grouped together more tightly than those obtained under dynamic conditions.

The entrance loss coefficients from all tests were plotted against their respective siphon discharges in Figure 15.

Table 6: Entrance loss coefficient and siphon discharge, for both static and dynamic conditions

| Entrance Loss Coefficient | Siphon Discharge (L/s) |
|---|---|
| 0.93 | 1.38 |
| 0.95 | 1.48 |
| 0.83 | 1.82 |
| 0.19 | 1.97 |
| 0.68 | 1.97 |
| 0.81 | 2.13 |
| 0.81 | 2.30 |
| 0.68 | 2.34 |
| 0.60 | 2.38 |
| 0.27 | 2.65 |
| 0.56 | 2.79 |
| 0.82 | 2.79 |
| 0.48 | 2.84 |
| 0.65 | 2.93 |

The entrance loss coefficients of 0.19 and 0.27 were removed from Figure 15 as they were deemed to be erroneous.

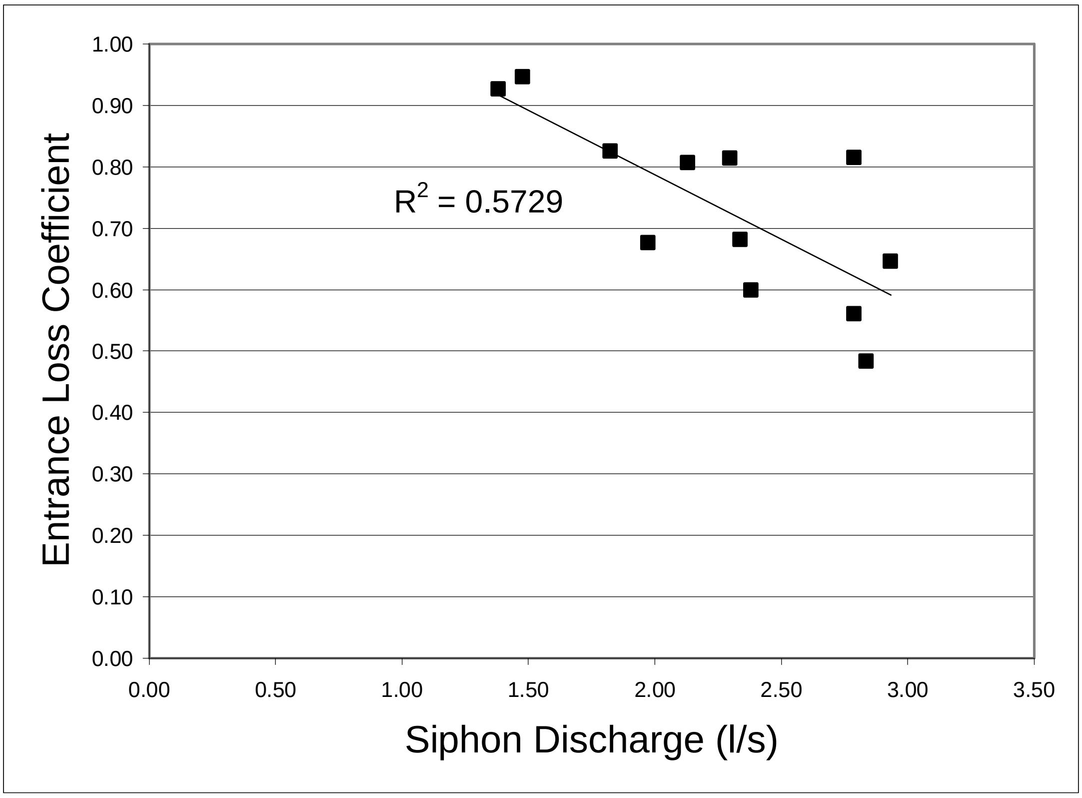


Figure 15: Entrance loss coefficient Vs siphon discharge.

The line of best fit in Figure 15 indicates there is a relationship between entrance loss coefficient siphon discharge, however the correlation coefficient does not reflect this. As the siphon discharge increases, the entrance loss coefficient generally decreases, regardless of channel velocity.

## 4.4 Comparison to the Bos (1989) Equation

The siphon discharges obtained from the experiment were compared to those modelled by Bos's (1989) equation, as shown in Table 7.

Table 7: Siphon discharges from experimental methods and from Bos's Equation.

| Channel Velocity (m/s) | Effective head (m) | Siphon discharge measured from experiment (L/s) | Siphon discharge calculated using Bos's (1989) equation (L/s) | % Difference |
|---|---|---|---|---|
| 0 | 0.09 | 1.38 | 1.62 | 17.39 |
| 0 | 0.13 | 1.82 | 1.98 | 8.79 |
| 0 | 0.13 | 1.97 | 2.04 | 3.55 |
| 0 | 0.20 | 2.30 | 2.51 | 9.13 |
| 0 | 0.20 | 2.34 | 2.50 | 6.84 |
| 0 | 0.25 | 2.79 | 2.86 | 2.51 |
| 0 | 0.28 | 2.79 | 3.04 | 8.96 |
| 0 | 0.29 | 2.93 | 3.09 | 5.46 |
| 0.11 | 0.08 | 1.48 | 1.60 | 8.11 |
| 0.11 | 0.13 | 1.97 | 2.03 | 3.05 |
| 0.11 | 0.17 | 2.13 | 2.33 | 9.39 |
| 0.11 | 0.18 | 2.38 | 2.39 | 0.42 |
| 0.11 | 0.18 | 2.65 | 2.42 | -8.68 |
| 0.10 | 0.23 | 2.84 | 2.75 | -3.17 |

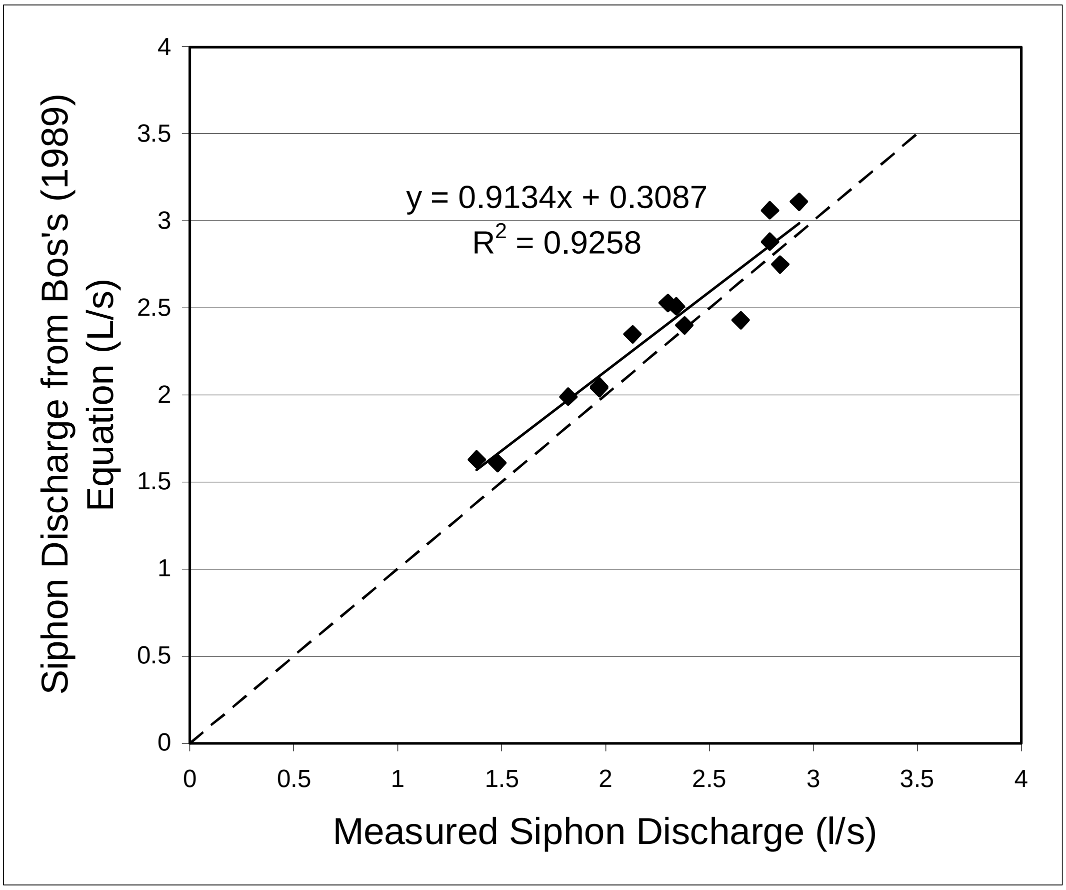


Figure 16: Comparison of measured siphon discharge to that obtained from the Bos (1989) Equation.

With comparison to the field simulation data obtained from this project, the Bos (1989) equation generally overestimates siphon discharge, as shown in Figure 16. This would indicate the energy loss model in the Bos (1989) equation is not great enough, or there was error in reading the siphon discharge during the tests. The black dashed line is a line of slope equal to 1. The solid black line is a line of best fit applied by the spreadsheet software.

The combined entrance and exit loss coefficients calculated from the testing are given in Table 8. The Bos (1989) equation uses 1.9 as the combined entrance and exit loss coefficient.

Table 8: Combined entrance and exit loss coefficients.

| Channel Flow Condition | Combined entrance and exit loss coefficient | % Difference |
|---|---|---|
| Static | 2.06 | -17 |
| | 1.95 | 2.6 |
| | 1.74 | -8.4 |
| | 1.95 | 2.6 |
| | 1.81 | -4.7 |
| | 1.68 | -11.6 |
| | 1.97 | 3.7 |
| | 1.75 | -7.9 |
| Dynamic | 2.10 | 10.5 |
| | 1.87 | -1.6 |
| | 2.02 | 6.3 |
| | 1.71 | -10.0 |
| | 1.31 | -31.1 |
| | 1.56 | -17.9 |

## 4.5 Comparing Total Energy Loss to Total Loss in Bos (1989)

To obtain a better understanding of the combined entrance and exit loss coefficient in the Bos (1989) equation, the total energy loss was compared to that calculated in the Bos (1989) equation. There is a consistent 81% underestimation by the energy loss model contained within the Bos (1989) equation.

Table 9: Comparison of total losses from gathered data and Bos's (1989) equation.

| Channel Flow Condition | Measured total loss from tests (m) | Total loss calculated from the Bos equation (m) | % Difference |
|---|---|---|---|
| Static | 0.08 | 0.016 | -80.6 |
| | 0.12 | 0.023 | -81.3 |
| | 0.13 | 0.024 | -81.5 |
| | 0.19 | 0.035 | -81.9 |
| | 0.19 | 0.034 | -81.8 |
| | 0.24 | 0.043 | -82.2 |
| | 0.28 | 0.049 | -82.2 |
| | 0.28 | 0.050 | -82.4 |
| Dynamic | 0.08 | 0.016 | -81.1 |
| | 0.13 | 0.024 | -81.8 |
| | 0.17 | 0.031 | -81.7 |
| | 0.17 | 0.031 | -82.0 |
| | 0.18 | 0.031 | -82.1 |
| | 0.23 | 0.040 | -82.5 |

## 4.6 Comparison Friction Losses to Smooth Pipes

To verify the friction losses across the siphon, the measured head loss was compared to the friction loss calculated by the Darcy-Weisbach equation. The Blasius equation (2.11) for smooth pipes was used to calculate the friction factor.

Reynolds Number was calculated using the following equation:

$$v = \frac{VD}{\mu} \tag{4.1}$$

where $\mu =$ kinematic viscosity @ 15 ° Celcius

Table 10: Measured and calculated frictional losses.

| Measured friction loss (m) | Friction loss calculated using the Darcy-Weisbach and Blasius equations (m) | % Difference |
|---|---|---|
| 0.037 | 0.034 | 10 |
| 0.045 | 0.030 | 50 |
| 0.057 | 0.056 | 2 |
| 0.058 | 0.049 | 19 |
| 0.062 | 0.056 | 11 |
| 0.077 | 0.064 | 20 |
| 0.078 | 0.078 | 0 |
| 0.084 | 0.094 | -10 |
| 0.091 | 0.075 | 21 |
| 0.091 | 0.073 | 25 |
| 0.101 | 0.106 | -4 |
| 0.115 | 0.102 | 12 |
| 0.125 | 0.102 | 22 |
| 0.135 | 0.112 | 21 |

From Table 10, approximately half of the measured frictional losses lie within ten percent of the calculated figure. The high number of different values suggests there was error in the measurement of the manometers for some tests.

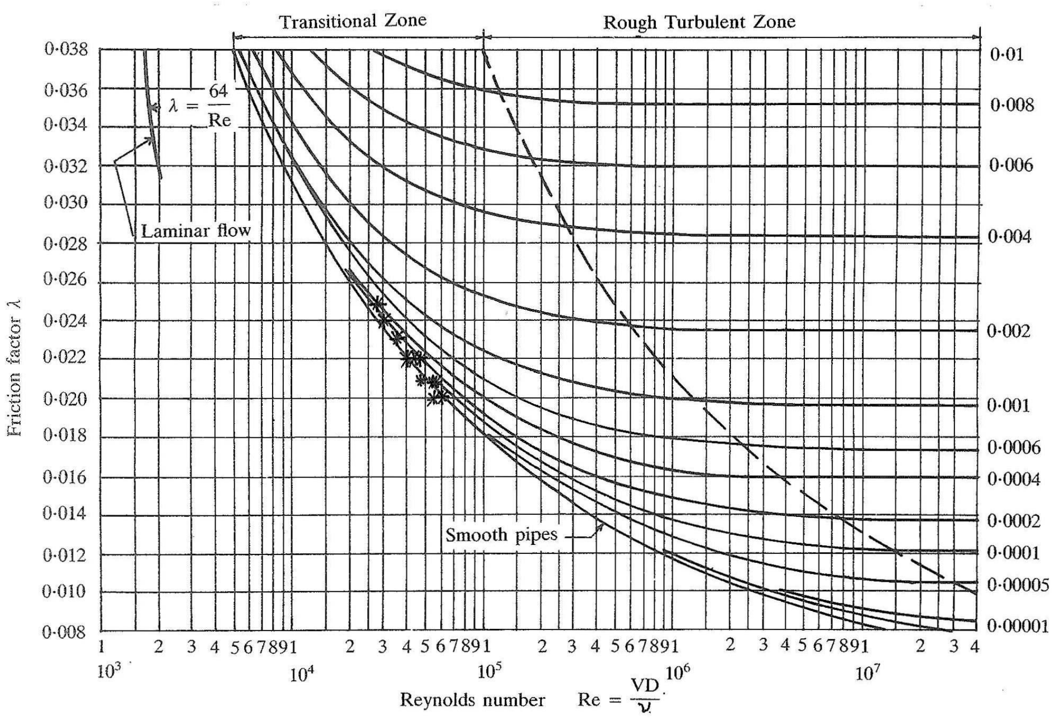


Figure 17: Moody Diagram with the Blasius friction factor plotted against Reynolds Number. (Nalluri & Featherstone 2001).

The calculated Blasius friction factor was plotted against Reynolds number on the Moody diagram, displayed as small asterisks. All of the points are located on or very close to the smooth pipes line, confirming that using the Blasius equation to determine the friction factor for use in the Darcy-Weisbach equation is a valid approach to modelling the friction loss through a siphon.

## 4.7 Effect of the Coriolis Coefficient (α) on Entrance and Exit Loss Coefficients

Moore (2005) defines the Coriolis co efficient as "a correction to account for the fact that the kinematic energy of individual fluid particles summed over the cross section is *not* the same as the kinematic energy bases on the section mean velocity." The coefficient is described below.

$$\alpha = \frac{1}{A}\int\left(\frac{u}{V}\right)^3 dA \tag{4.2}$$

where $u =$ local velocity [m/s]

The Coriolis coefficient was increased from 1 to 1.1 to fit the data better and to reduce the entrance and exit loss coefficients.

## 4.8 Channel Velocity Measurement using an Ott Meter

The purpose of using an Ott meter was to measure the channel velocity at a point a short distance upstream of the siphon. The velocity obtained represented the velocity of the water passing the entrance of the siphon. However the small channel velocity was not great enough to produce a consistent number of revolutions for any chosen time period. The small number of readings obtained can be found in Appendix G.

# 4.9 Developing a Best Fit Model for Project Data

A crude approach to developing a model to fit the data gathered from this project was to plot the siphon discharge against the effective head, and apply a line of best fit. Figure 18 displays the result of this approach, using a power fit to the data. The correlation coefficient suggests this approach is satisfactory for this project, however it is not recommended that the equation displayed in Figure 18 be used outside of this data set.

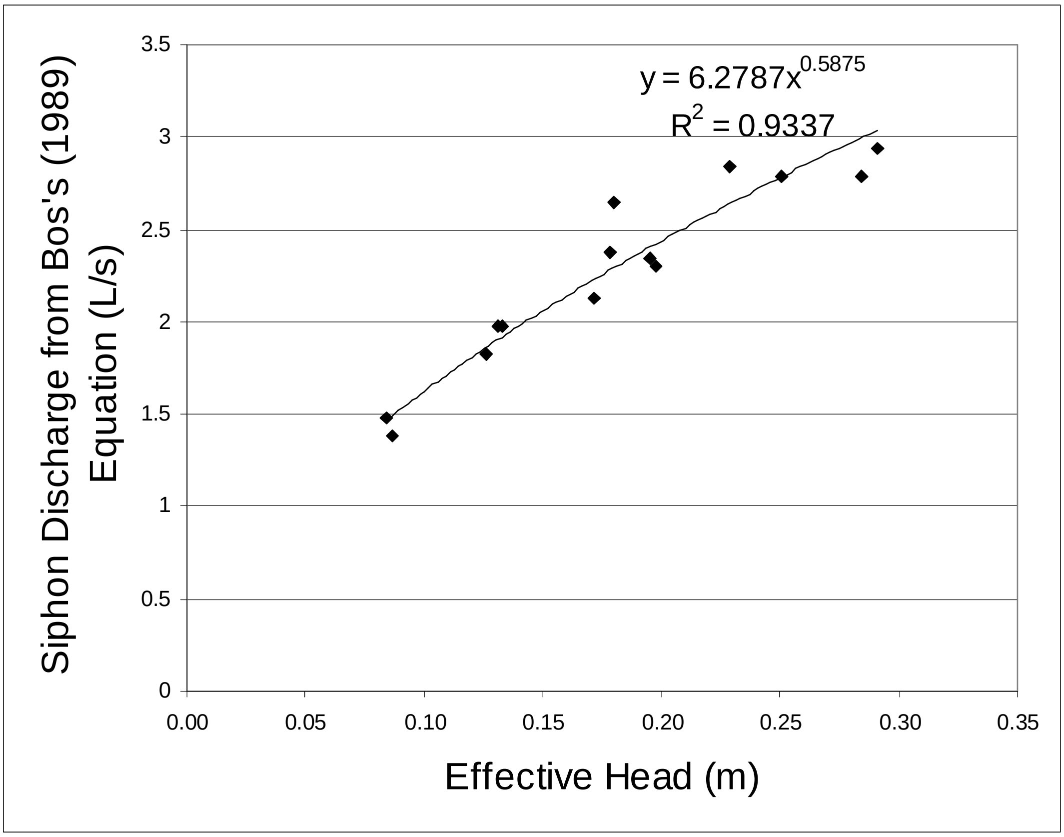


Figure 18: Using a power function to fit measured discharges with the effective head.

Another method to obtain a model to fit the data gathered from this project is to combine the Bos equation with the equation that describes the line of best fit (4.3) in Figure 16.

$$y = 0.9134x + 0.3087 \tag{4.3}$$

Rearranging (4.3) to make $x$ a function of $y$, and substituting the Bos equation in as $y$, yields the following equation:

$$x = \frac{y - 0.3087}{0.9134} \tag{4.4}$$

where $y =$ the discharge calculated from Bos's (1989) equation

This equation was then applied, using the previously calculated discharges from Bos's (1989) equation. The results of this combined equation are given in Table 11 and Figure 19.

Table 11: Comparison of siphon discharges obtaining from measurements, Bos's (1989) equation, and a developed model based on the Bos (1989) equation.

| Siphon discharge measured from experiment (L/s) | Siphon discharge calculated using Bos's (1989) equation (L/s) | % Difference | Siphon discharge calculated from Equation (4.4) | % Difference between Column 1 & 4 |
|---|---|---|---|---|
| 1.38 | 1.62 | 17.39 | 1.44 | 4.03 |
| 1.82 | 1.98 | 8.79 | 1.83 | 0.54 |
| 1.97 | 2.04 | 3.55 | 1.90 | -3.78 |
| 2.3 | 2.51 | 9.13 | 2.41 | 4.78 |
| 2.34 | 2.5 | 6.84 | 2.40 | 2.52 |
| 2.79 | 2.86 | 2.51 | 2.79 | 0.11 |
| 2.79 | 3.04 | 8.96 | 2.99 | 7.18 |
| 2.93 | 3.09 | 5.46 | 3.04 | 3.92 |
| 1.48 | 1.6 | 8.11 | 1.41 | -4.48 |
| 1.97 | 2.03 | 3.05 | 1.88 | -4.34 |
| 2.13 | 2.33 | 9.39 | 2.21 | 3.89 |
| 2.38 | 2.39 | 0.42 | 2.28 | -4.26 |
| 2.65 | 2.42 | -8.68 | 2.31 | -12.77 |
| 2.84 | 2.75 | -3.17 | 2.67 | -5.89 |

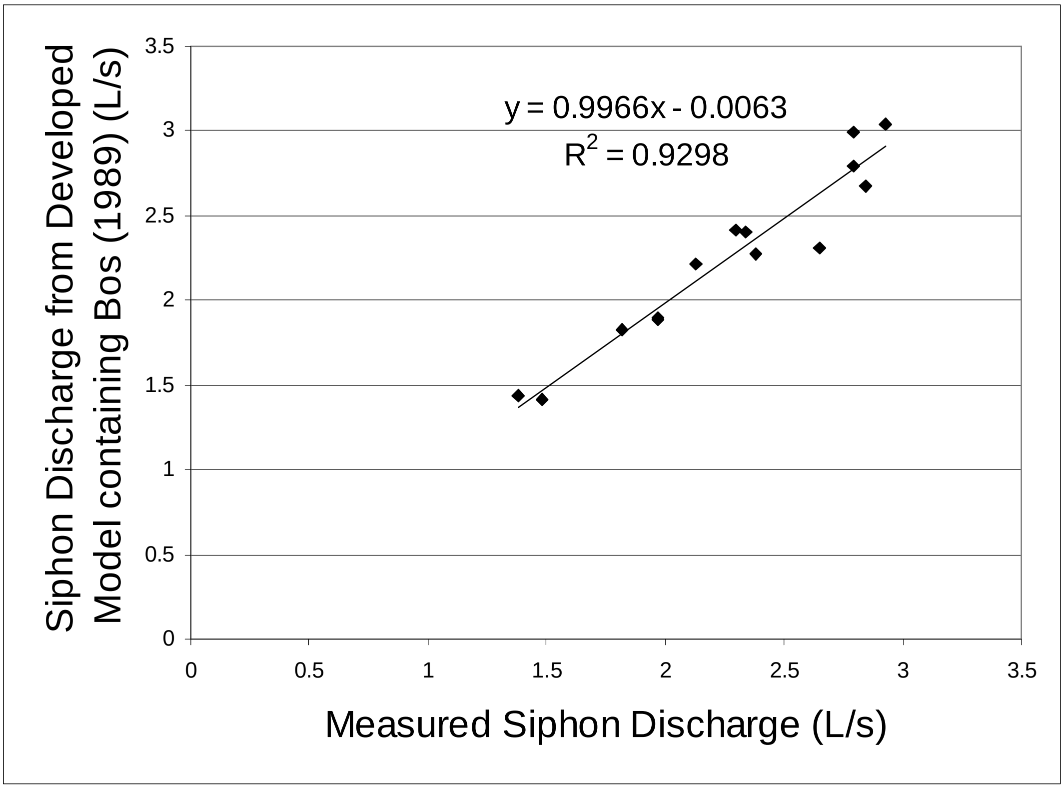


Figure 19: Developed model siphon discharge against measured siphon discharge.

This approach did not result in a more accurate model. A small increase in the correlation coefficient did occur, however it was not significant.

# 5 Conclusions

The aim of this project was to validate the Bos (1989) combined entrance and exit loss coefficient for small long pipe siphon flow used in over-bank furrow irrigation. To achieve this aim, research was conducted on estimating siphon discharge, and the need of accurate discharge estimates. To validate the Bos (1989) equation, testing apparatus was constructed to replicate field conditions, for different channel velocities and effective heads. Analyses were performed on the results to verify different portions of the results with valid models.

Although the objectives were met, the project was not entirely successful in achieving the aim. A more accurate combined entrance and exit loss coefficient was not developed. Reasons for this are:

- a limited number of replications were performed;
- the range of effective heads and channel velocities were not great enough; and
- the data that was produced is subject to experimental error caused by the construction and accuracy of the apparatus.

However, there are some initial outcomes of this project. The sensitivity analysis revealed that measurement of the siphon's internal diameter is critical for Bos's (1989) equation to be accurate.

From the data obtained, there appears to be no relationship between channel velocity and siphon discharge. A relationship between entrance loss coefficient and siphon discharge exists, in that as the siphon discharges increases, the entrance loss coefficient decreases. This indicates the entrance loss is dependent on the siphon discharge and not constant as stated in the equation developed by Bos (1989).

In addition, when compared to the experimental data, Bos's (1989) equation overestimated siphon discharge by up to 10% in general.

## 5.1 Further Work

Due to the small data set from this project, drawing distinct conclusions was not possible. It is recommended that the project be repeated with the following suggested changes and improvements:

- a larger range of channel velocities and effective heads.

This can be achieved by:

- a larger weir on the main channel able to convey a higher supply discharge and hence greater channel velocities;
- a location that can supply a higher discharge to meet the above suggestion;
- a manometer for both the channel and siphon discharge measurement unit, but not connected to the manifold. The purpose of these is to make reading the water level above the weirs easier as the level fluctuated as it went over the weirs;
- calibrating the weirs to obtain a more accurate weir coefficient;
- a larger siphon discharge measurement unit to enable a larger weir to be install, hence higher siphon discharges can be obtained. A wider unit will also eliminate the effects of the walls on the exit loss; and
- a method of attaching the manometers to the siphon that does not result in air leaks. A possible option is to plastic weld a short plastic tube for the manometer to attach to.

There are many other variables associated with siphon over bank irrigation such as:

- the effect of silt being deposited inside the siphon over time;
- siphon entrance orientation with regard to channel flow direction; and
- non-uniformity of cross-sectional shape along the length of the siphon.

These are a small number of possible directions that research that can take with regard to the aim of developing an accurate entrance and exit loss coefficient for use in the estimation of siphons used in siphon over bank irrigation.

# 6 Glossary

**Discharge (Q)**

The rate at which a fluid passes a given point (Chadwick, Morfett & Borthwick 2004). For this project, the rate at which water is exiting the siphon will be the siphon discharge; and the rate at which water is flowing out of the channel will be the channel discharge.

**Internal Diameter (ID)**

The internal diameter of the siphon, assuming a constant circular cross-section for its entire length.

**Outside Diameter (OD)**

The outside diameter of the siphon, assuming a constant circular cross-section for its entire length**.**

**Effective hydraulic head ($\Delta h$)**

The effective hydraulic head is the vertical distance between two water surfaces. For this project, these two surfaces are the water level in the head channel and the water level in the furrow (siphon discharge measurement unit). The effective head for a siphon discharging to atmosphere is measured from the water surface in the head channel to the centre of the siphon exit.

**Friction loss**

Nalluri and Featherstone (2001) state that “a continuous resistance layer is exerted by the pipe walls due to the formation of a boundary layer in which the velocities decreases from the centre of the pipe to zero at the boundary.” The energy loss caused by this resistance is termed the pipe friction loss.

**Entry and exit loss coefficients**

When a fluid moves from an open body into a pipe such as a siphon (or vice versa), streamlines converge/diverge and energy is “lost” during this process. The entry and exit loss coefficients are measures of how efficient the entrance/exit of the pipe can converge/diverge streamlines (Oregon State University 2006). The value for each coefficient typically ranges from 0 to 1, with 1 being a low efficient entrance or exit.

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# 8 Appendices

# Appendix A – Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

**ENG4111/4112 Research Project**
**PROJECT SPECIFICATION**

FOR: Paul John Muir (0050025913)

TOPIC: Siphons as furrow irrigation measurement devices

SUPERVISOR: Joseph Foley & Rod Smith

SPONSORSHIP: USQ

PROJECT AIM: The aim of this project is to validate the Bos combined entrance and exit loss coefficient for small long pipe siphon flow used in over-bank furrow irrigation.

PROGRAMME: **(Issue C, 12th September, 2007)**

1. Conduct search of background literature on previous studies and experiments relating to the Aim, and the need for accurate flow models of small long pipe siphon flow.
2. Conduct a sensitivity analysis on a previous model published by Bos (1989).
3. Conduct a static fluid analysis to determine if the location of the siphon in a static body of water has any effect on the entrance loss coefficient.
4. Conduct a dynamic fluid analysis to determine the effect of passing velocity past the siphon entrance on the siphon discharge.
5. Construct apparatus that replicates field conditions, and:
6. Analyse discharges calculated from existing equations/models and compare those measured using the apparatus.
7. Measure entrance and exit loss coefficients and compare those used in (6).
8. Analyse results and if any, attempt to explain any inconsistencies with an existing model.
9. Report all ideas, work and findings, discuss the significance of topic, and analyse all results, draw conclusions and submit as a dissertation.

AGREED ______________ (student) ______________ (supervisor)

Date: 1 / 11 / 2007 Date: 1 / 11 / 2007

Co-examiner:______________

# Appendix B – MATLAB Script for Sensitivity Analysis

```
clear;

clc;

f=0.02; % friction factor

l=4; % length of siphon

%use for variations; state new coeffs (var=0) OR percent variations

%(coeffs=1.9)

smallcoeff=1.9;



var=25; % %variation

var1=1+var/100;

%var2=1-var/100;

counter=0;

diam=0.07; % diameter of siphon

for head=[0.1:0.1:2]; %head values from 0.1 to 2m

   counter=counter+1;

   data(counter,1)=diam;

   data(counter,2)=head;

   data(counter,3)=pi./4*diam.^2*(2*9.81*head./(1.9+f*l/diam)).^0.5;

end
```

```
loglog(data(:,3),data(:,2),'k');

axis([min(data(:,3)) max(data(:,3)) 0.1 2]);

grid on;

hold on;


xlabel('Q (m^3/s)')

ylabel('Effective Head (m)')

%title('Effect of 25% increase in HLC & Diameter')

%coeff variations

counter=0;

for head=[0.1:0.1:2]; %head values from 0.1 to 2m

   counter=counter+1;

   datavc(counter,1)=diam;

   datavc(counter,2)=head;

   datavc(counter,3)=pi./4*diam.^2*(2*9.81*head./(var1*smallcoeff+f*l/diam)).^0.5;

end


loglog(datavc(:,3),datavc(:,2),'k-.');

hold on
```

```
%head variations
counter=0;
for head=[0.1:0.1:2].*var1; %head values from 0.1 to 2m
   counter=counter+1;
   datavh(counter,1)=diam;
   datavh(counter,2)=head;
   datavh(counter,3)=pi./4*diam.^2*(2*9.81*head./(1.9+f*l/diam)).^0.5;
end

%loglog(datavh(:,3),datavh(:,2),'g'); %no need to plot, only for comparison


%diam variations
counter=0;
diam=diam*var1;
for head=[0.1:0.1:2]; %head values from 0.1 to 2m
   counter=counter+1;
   datavd(counter,1)=diam;
   datavd(counter,2)=head;
   datavd(counter,3)=pi./4*diam.^2*(2*9.81*head./(1.9+f*l/diam)).^0.5;
end
```

```
loglog(datavd(:,3),datavd(:,2),'k--');

legend('Bos Equation','Increase HLC by 25%','Increase Head by 25%','Increase diameter by 25%','Location','NorthWest')


pause

close




%calc stats


%variation in HLC on Q

percentc=(datavc(:,3)-data(:,3))./data(:,3)*100;


%variation in H on Q

percenth=(datavh(:,3)-data(:,3))./data(:,3)*100;


%variation in D on Q

percentd=(datavd(:,3)-data(:,3))./data(:,3)*100;
```

# Appendix C – Static Test Data

| | Measured/Input | |
|---|---|---|
| ***Variables*** | Channel | Siphon |
| Channel Width (m) | 0.6 | 0.165 |
| Weir Angle (°) | 90 | 30 |
| $P_s$ (m) | 0.195 | 0.214 |
| Cd | 0.58 | 0.58 |
| ID (mm) | | 55 |
| Alpha | 1.1 | 1.1 |

red text = dta

| Distances from walls | | | | Manometers (mm) | | | | | | | | Ott Reading | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | | |
| | | | | FWS Channel | 50mm | 250mm | 550mm | 2000mm | 3950mm | FWS Discharge Bucket | | | |
| a (mm) | b (mm) | Channel Weir Measurement (mm) | Siphon Weir Measurement (mm) | 0 | 50 | 250 | 550 | 2000 | 3950 | 4000 | Siphon centreline above FWS (m) | revs/30sec. | Ott n |
| *210* | *170* | *0* | *88* | *768* | *753* | *754* | *752* | *746* | *737* | *723* | | *0* | *0.00* |
| 220 | 175 | 0 | 111 | 618 | 574 | 579 | 574 | 558 | 534 | 531 | | 0 | 0.00 |
| 220 | 175 | 0 | 124 | 596 | 522 | 532 | 526 | 507 | 474 | 470 | | 0 | 0.00 |
| 210 | 180 | 0 | 128 | 774 | 715 | 723 | 717 | 700 | 661 | 641 | | 0 | 0.00 |
| *240* | *160* | *0* | *130* | *605* | *530* | *539* | *533* | *519* | *480* | *405* | *0.06* | *0* | *0.00* |
| 220 | 175 | 0 | 136 | 665 | 549 | 565 | 554 | 525 | 474 | 467 | | 0 | 0.00 |
| 210 | 180 | 0 | 137 | 813 | 702 | 716 | 706 | 677 | 625 | 618 | | 0 | 0.00 |
| *160* | *40* | *0* | *140* | *844* | *633* | *678* | *673* | *643* | *582* | *567* | | *0* | *0.00* |
| 205 | 180 | 0 | 147 | 818 | 670 | 690 | 677 | 643 | 575 | 567 | | 0 | 0.00 |
| 220 | 175 | 0 | 147 | 692 | 520 | 545 | 530 | 489 | 420 | 408 | | 0 | 0.00 |
| *240* | *160* | *0* | *147* | *663* | *527* | *542* | *530* | *496* | *441* | *395* | *0.045* | *0* | *0.00* |
| 90 | 100 | 0 | 150 | 855 | 681 | 707 | 689 | 651 | 572 | 564 | | 0 | 0.00 |

Red italic text = erroneous data

DTA = Discharge To Atmosphere

| Effective Head (m) | Channel H (m) | Channel Q (l/s) | Channel Depth (m) | Channel Velocity (m/s) | Channel Ott Velocity (m/s) | Siphon H (m) | Siphon Q (l/s) | Siphon V (m/s) | Total Q (l/s) | Velocity Head Channel (m) | Velocity Head Siphon (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.05 | 0.00 | 0.00 | 0.20 | 0.00 | 0.02 | 0.09 | 0.77 | 0.325521 | 0.77 | 0.00 | 0.01 |
| 0.09 | 0.00 | 0.00 | 0.20 | 0.00 | 0.02 | 0.11 | 1.38 | 0.581675 | 1.38 | 0.00 | 0.02 |
| 0.13 | 0.00 | 0.00 | 0.20 | 0.00 | 0.02 | 0.12 | 1.82 | 0.767233 | 1.82 | 0.00 | 0.03 |
| 0.13 | 0.00 | 0.00 | 0.20 | 0.00 | 0.02 | 0.12 | 1.97 | 0.830611 | 1.97 | 0.00 | 0.04 |
| 0.20 | 0.00 | 0.00 | 0.20 | 0.00 | 0.02 | 0.13 | 2.05 | 0.863438 | 2.05 | 0.00 | 0.04 |
| 0.20 | 0.00 | 0.00 | 0.20 | 0.00 | 0.02 | 0.13 | 2.30 | 0.966541 | 2.30 | 0.00 | 0.05 |
| 0.20 | 0.00 | 0.00 | 0.20 | 0.00 | 0.02 | 0.13 | 2.34 | 0.984406 | 2.34 | 0.00 | 0.05 |
| 0.28 | 0.00 | 0.00 | 0.20 | 0.00 | 0.02 | 0.14 | 2.47 | 1.039185 | 2.47 | 0.00 | 0.06 |
| 0.25 | 0.00 | 0.00 | 0.20 | 0.00 | 0.02 | 0.14 | 2.79 | 1.173995 | 2.79 | 0.00 | 0.08 |
| 0.28 | 0.00 | 0.00 | 0.20 | 0.00 | 0.02 | 0.14 | 2.79 | 1.173995 | 2.79 | 0.00 | 0.08 |
| 0.27 | 0.00 | 0.00 | 0.20 | 0.00 | 0.02 | 0.14 | 2.79 | 1.173995 | 2.79 | 0.00 | 0.08 |
| 0.29 | 0.00 | 0.00 | 0.20 | 0.00 | 0.02 | 0.14 | 2.93 | 1.234812 | 2.93 | 0.00 | 0.09 |

Actual EGL (Measurements - Lowest + Velocity Head) (m)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FWS Channel | 50mm | 250mm | 550mm | 2000mm | 3950mm | FWS Discharge Bucket | | | | | | |
| 0 | 0.05 | 0.25 | 0.55 | 2 | 3.95 | 4 | | hf (m) | Re | Blasius Friction Factor | Darcy-Weisbach frict. Loss (m) | Bos Q (L/s) | Bos Losses (m) |
| *0.045* | *0.036* | *0.037* | *0.035* | *0.029* | *0.020* | *0.000* | | *0.02* | *15434* | *0.028* | *0.011* | *1.12* | *0.0091* |
| 0.087 | 0.062 | 0.067 | 0.062 | 0.046 | 0.022 | 0.000 | | 0.04 | 27579 | 0.025 | 0.030 | 1.62 | 0.0163 |
| 0.126 | 0.085 | 0.095 | 0.089 | 0.070 | 0.037 | 0.000 | | 0.06 | 36377 | 0.023 | 0.049 | 1.98 | 0.0229 |
| 0.133 | 0.113 | 0.121 | 0.115 | 0.098 | 0.059 | 0.000 | | 0.06 | 39382 | 0.022 | 0.056 | 2.04 | 0.0239 |
| *0.200* | *0.167* | *0.176* | *0.170* | *0.156* | *0.117* | *0.000* | | *0.06* | *40939* | *0.022* | *0.060* | *2.51* | *0.0358* |
| 0.198 | 0.134 | 0.150 | 0.139 | 0.110 | 0.059 | 0.000 | | 0.09 | 45827 | 0.022 | 0.073 | 2.51 | 0.0350 |
| 0.195 | 0.138 | 0.152 | 0.142 | 0.113 | 0.061 | 0.000 | | 0.09 | 46674 | 0.021 | 0.075 | 2.50 | 0.0344 |
| *0.277* | *0.127* | *0.172* | *0.167* | *0.137* | *0.076* | *0.000* | | *0.10* | *49272* | *0.021* | *0.083* | *2.99* | *0.0486* |
| 0.251 | 0.180 | 0.200 | 0.187 | 0.153 | 0.085 | 0.000 | | 0.12 | 55664 | 0.021 | 0.102 | 2.86 | 0.0434 |
| 0.284 | 0.189 | 0.214 | 0.199 | 0.158 | 0.089 | 0.000 | | 0.13 | 55664 | 0.021 | 0.102 | 3.04 | 0.0492 |
| *0.268* | *0.209* | *0.224* | *0.212* | *0.178* | *0.123* | *0.000* | | *0.10* | *55664* | *0.021* | *0.102* | *2.96* | *0.0464* |
| 0.291 | 0.202 | 0.228 | 0.210 | 0.172 | 0.093 | 0.000 | | 0.14 | 58547 | 0.020 | 0.112 | 3.09 | 0.0501 |

| | | | Trend Line | | Entrance | | | |
|---|---|---|---|---|---|---|---|---|
| Channel Velocity (m/s) | Siphon Discharge (L/s) | Effective Head (m) | m | b | E (Channel) | E (extrapolated from trend to 0m) | hm (m) | Coefficient |
| *0.00* | *0.77* | *0.05* | *-0.0045* | *0.038* | *0.05* | *0.04* | *0.01* | *1.21* |
| 0.00 | 1.38 | 0.09 | -0.0120 | 0.069 | 0.09 | 0.07 | 0.02 | 0.93 |
| 0.00 | 1.82 | 0.13 | -0.0154 | 0.099 | 0.13 | 0.10 | 0.03 | 0.83 |
| 0.00 | 1.97 | 0.13 | -0.0164 | 0.126 | 0.13 | 0.13 | 0.01 | 0.19 |
| *0.00* | *2.05* | *0.20* | *-0.0155* | *0.181* | *0.20* | *0.18* | *0.02* | *0.46* |
| 0.00 | 2.30 | 0.20 | -0.0240 | 0.155 | 0.20 | 0.16 | 0.04 | 0.81 |
| 0.00 | 2.34 | 0.20 | -0.0241 | 0.158 | 0.20 | 0.16 | 0.04 | 0.68 |
| *0.00* | *2.47* | *0.28* | *-0.0259* | *0.181* | *0.28* | *0.18* | *0.10* | *1.58* |
| 0.00 | 2.79 | 0.25 | -0.0303 | 0.208 | 0.25 | 0.21 | 0.04 | 0.56 |
| 0.00 | 2.79 | 0.28 | -0.0330 | 0.221 | 0.28 | 0.22 | 0.06 | 0.82 |
| *0.00* | *2.79* | *0.27* | *-0.0267* | *0.230* | *0.27* | *0.23* | *0.04* | *0.50* |
| 0.00 | 2.93 | 0.29 | -0.0353 | 0.236 | 0.29 | 0.24 | 0.06 | 0.65 |

| Exit | | | | | |
| --- | --- | --- | --- | --- | --- |
| E (extrapolated from trend to 4m) | E (Bucket) | hm (m) | Coefficent | Sum | |
| *0.02* | *0.00* | *0.02* | *3.33* | *4.54* | |
| 0.02 | 0.00 | 0.02 | 1.14 | 2.06 | |
| 0.04 | 0.00 | 0.04 | 1.12 | 1.95 | |
| 0.06 | 0.00 | 0.06 | 1.55 | 1.74 | |
| *0.12* | *0.00* | *0.12* | *2.84* | *3.30* | *DTA* |
| 0.06 | 0.00 | 0.06 | 1.13 | 1.95 | |
| 0.06 | 0.00 | 0.06 | 1.13 | 1.81 | |
| *0.08* | *0.00* | *0.08* | *1.28* | *2.86* | |
| 0.09 | 0.00 | 0.09 | 1.12 | 1.68 | |
| 0.09 | 0.00 | 0.09 | 1.15 | 1.97 | |
| *0.12* | *0.00* | *0.12* | *1.59* | *2.08* | *DTA* |
| 0.09 | 0.00 | 0.09 | 1.11 | 1.75 | |

# Appendix D – Dynamic Test Data

| | Measured/Input | |
|---|---|---|
| ***Variables*** | Channel | Siphon |
| Channel Width (m) | 0.6 | 0.165 |
| Weir Angle (°) | 90 | 30 |
| $P_s$ (m) | 0.195 | 0.214 |
| Cd | 0.58 | 0.58 |
| ID (mm) | | 55 |
| Alpha | 1.1 | 1.1 |

red text = dta

| Distances from walls | | | | Manometers (mm) | | | | | | | | Ott Reading |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | |
| | | | | FWS Channel | 50mm | 250mm | 550mm | 2000mm | 3950mm | FWS Discharge Bucket | | |
| a (mm) | b (mm) | Channel Weir Measurement (mm) | Siphon Weir Measurement (mm) | 0 | 50 | 250 | 550 | 2000 | 3950 | 4000 | Siphon centreline above FWS (m) | revs/30sec. |
| 190 | 200 | 292 | 114 | 567 | 514 | 523 | 519 | 508 | 486 | 483 | | 0 |
| *230* | *230* | *291* | *117* | *486* | *419* | *426* | *423* | *405* | *382* | *378* | | *39* |
| *230* | *140* | *290* | *127* | *680* | *609* | *618* | *612* | *600* | *567* | *480* | *0.07* | *61* |
| 190 | 200 | 290 | 128 | 593 | 516 | 526 | 518 | 502 | 469 | 462 | | 0 |
| 230 | 230 | 290 | 132 | 525 | 423 | 440 | 431 | 405 | 363 | 353 | | 62 |
| 190 | 200 | 287 | 138 | 623 | 517 | 529 | 520 | 495 | 451 | 445 | | 0 |
| 230 | 230 | 288 | 144 | 570 | 460 | 477 | 468 | 441 | 393 | 390 | | 57 |
| *120* | *100* | *284* | *147* | *760* | *631* | *648* | *636* | *604* | *544* | *458* | *-* | *43* |
| *230* | *230* | *282* | *148* | *649* | *475* | *498* | *484* | *441* | *372* | *288* | | *63* |
| 190 | 200 | 285 | 148 | 667 | 533 | 546 | 530 | 498 | 445 | 438 | | 0 |
| *230* | *230* | *285* | *150* | *772* | *545* | *568* | *553* | *525* | *440* | *327* | | *57* |
| *230* | *230* | *285* | *150* | *700* | *524* | *549* | *534* | *491* | *424* | *311* | | *57* |

Red italic text = erroneous data
DTA = Discharge To Atmosphere

| Ott n | Effective Head (m) | Channel H (m) | Channel Q (l/s) | Channel Depth (m) | Channel Velocity (m/s) | Channel Ott Velocity (m/s) | Siphon H (m) | Siphon Q (l/s) | Siphon V (m/s) | Total Q (l/s) | Velocity Head Channel (m) | Velocity Head Siphon (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | 0.08 | 0.21 | 26.54 | 0.40 | 0.11 | 0.02 | 0.11 | 1.48 | 0.621777 | 28.02 | 0.00 | 0.02 |
| 1.30 | 0.11 | 0.21 | 26.32 | 0.40 | 0.11 | 0.10 | 0.11 | 1.58 | 0.663495 | 27.89 | 0.00 | 0.02 |
| 2.03 | 0.20 | 0.21 | 26.09 | 0.40 | 0.11 | 0.14 | 0.12 | 1.94 | 0.814483 | 28.03 | 0.00 | 0.04 |
| 0.00 | 0.13 | 0.21 | 26.09 | 0.40 | 0.11 | 0.02 | 0.12 | 1.97 | 0.830611 | 28.06 | 0.00 | 0.04 |
| 2.07 | 0.17 | 0.21 | 26.09 | 0.40 | 0.11 | 0.14 | 0.13 | 2.13 | 0.897031 | 28.22 | 0.00 | 0.05 |
| 0.00 | 0.18 | 0.20 | 25.42 | 0.40 | 0.11 | 0.02 | 0.13 | 2.38 | 1.002468 | 27.80 | 0.00 | 0.06 |
| 1.90 | 0.18 | 0.20 | 25.64 | 0.40 | 0.11 | 0.13 | 0.14 | 2.65 | 1.115011 | 28.29 | 0.00 | 0.07 |
| 1.43 | 0.30 | 0.20 | 24.76 | 0.40 | 0.10 | 0.10 | 0.14 | 2.79 | 1.173995 | 27.55 | 0.00 | 0.08 |
| 2.10 | 0.36 | 0.20 | 24.33 | 0.39 | 0.10 | 0.14 | 0.14 | 2.84 | 1.194063 | 27.17 | 0.00 | 0.08 |
| 0.00 | 0.23 | 0.20 | 24.98 | 0.40 | 0.10 | 0.02 | 0.14 | 2.84 | 1.194063 | 27.82 | 0.00 | 0.08 |
| 1.90 | 0.45 | 0.20 | 24.98 | 0.40 | 0.10 | 0.13 | 0.14 | 2.93 | 1.234812 | 27.91 | 0.00 | 0.09 |
| 1.90 | 0.39 | 0.20 | 24.98 | 0.40 | 0.10 | 0.13 | 0.14 | 2.93 | 1.234812 | 27.91 | 0.00 | 0.09 |

Actual EGL (Measurements - Lowest + Velocity Head) (m)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FWS Channel | 50mm | 250mm | 550mm | 2000mm | 3950mm | FWS Discharge Bucket | | | | | | | |
| 0 | 0.05 | 0.25 | 0.55 | 2 | 3.95 | 4 | | hf (m) | Re | Blasius Friction Factor | Darcy-Weisbach frict. Loss (m) | Bos Q (l/s) | Bos Losses (m) |
| 0.085 | 0.053 | 0.062 | 0.058 | 0.047 | 0.025 | 0.000 | | 0.04 | 29481 | 0.024 | 0.034 | 1.60 | 0.016 |
| *0.109* | *0.066* | *0.073* | *0.070* | *0.052* | *0.029* | *0.000* | | *0.04* | *31459* | *0.024* | *0.038* | *1.82* | *0.020* |
| *0.201* | *0.166* | *0.175* | *0.169* | *0.157* | *0.124* | *0.000* | | *0.05* | *38618* | *0.023* | *0.054* | *2.50* | *0.036* |
| 0.132 | 0.093 | 0.103 | 0.095 | 0.079 | 0.046 | 0.000 | | 0.06 | 39382 | 0.022 | 0.056 | 2.03 | 0.024 |
| 0.173 | 0.115 | 0.132 | 0.123 | 0.097 | 0.055 | 0.000 | | 0.08 | 42532 | 0.022 | 0.064 | 2.33 | 0.031 |
| 0.179 | 0.128 | 0.140 | 0.131 | 0.106 | 0.062 | 0.000 | | 0.08 | 47531 | 0.021 | 0.078 | 2.39 | 0.031 |
| 0.181 | 0.140 | 0.157 | 0.148 | 0.121 | 0.073 | 0.000 | | 0.08 | 52867 | 0.021 | 0.094 | 2.42 | 0.031 |
| *0.303* | *0.250* | *0.267* | *0.255* | *0.223* | *0.163* | *0.000* | | *0.10* | *55664* | *0.021* | *0.102* | *3.14* | *0.052* |
| *0.362* | *0.267* | *0.290* | *0.276* | *0.233* | *0.164* | *0.000* | | *0.13* | *56615* | *0.020* | *0.106* | *3.43* | *0.062* |
| 0.230 | 0.175 | 0.188 | 0.172 | 0.140 | 0.087 | 0.000 | | 0.10 | 56615 | 0.020 | 0.106 | 2.74 | 0.040 |
| *0.446* | *0.303* | *0.326* | *0.311* | *0.283* | *0.198* | *0.000* | | *0.13* | *58547* | *0.020* | *0.112* | *3.82* | *0.077* |
| *0.390* | *0.298* | *0.323* | *0.308* | *0.265* | *0.198* | *0.000* | | *0.13* | *58547* | *0.020* | *0.112* | *3.57* | *0.067* |

| Channel Velocity (m/s) | Siphon Discharge (L/s) | Effective Head (m) | Trend Line | | Entrance | | | | Exit | | | | Sum | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | m | b | E (Channel) | E (extrapolated from trend to 0m) | hm (m) | Coefficient | E (extrapolated from trend to 4m) | E (Bucket) | hm (m) | Coefficent | | |
| 26.54 | 1.48 | 0.08 | -0.0098 | 0.064 | 0.08 | 0.06 | 0.02 | 0.95 | 0.03 | 0.00 | 0.03 | 1.16 | 2.10 | |
| *26.32* | *1.58* | *0.11* | *-0.0120* | *0.076* | *0.11* | *0.08* | *0.03* | *1.33* | *0.03* | *0.00* | *0.03* | *1.13* | *2.46* | |
| *26.09* | *1.94* | *0.20* | *-0.0133* | *0.179* | *0.20* | *0.18* | *0.02* | *0.58* | *0.13* | *0.00* | *0.13* | *3.38* | *3.96* | *DTA* |
| 26.09 | 1.97 | 0.13 | -0.0148 | 0.105 | 0.13 | 0.11 | 0.03 | 0.68 | 0.05 | 0.00 | 0.05 | 1.19 | 1.87 | |
| 26.09 | 2.13 | 0.17 | -0.0204 | 0.136 | 0.17 | 0.14 | 0.04 | 0.81 | 0.05 | 0.00 | 0.05 | 1.21 | 2.02 | |
| 25.42 | 2.38 | 0.18 | -0.0206 | 0.145 | 0.18 | 0.14 | 0.03 | 0.60 | 0.06 | 0.00 | 0.06 | 1.11 | 1.71 | |
| 25.64 | 2.65 | 0.18 | -0.0223 | 0.162 | 0.18 | 0.16 | 0.02 | 0.27 | 0.07 | 0.00 | 0.07 | 1.05 | 1.31 | |
| *24.76* | *2.79* | *0.30* | *-0.0274* | *0.274* | *0.30* | *0.27* | *0.03* | *0.38* | *0.16* | *0.00* | *0.16* | *2.12* | *2.50* | *DTA* |
| *24.33* | *2.84* | *0.36* | *-0.0335* | *0.297* | *0.36* | *0.30* | *0.06* | *0.81* | *0.16* | *0.00* | *0.16* | *2.04* | *2.85* | |
| 24.98 | 2.84 | 0.23 | -0.0263 | 0.191 | 0.23 | 0.19 | 0.04 | 0.48 | 0.09 | 0.00 | 0.09 | 1.08 | 1.56 | |
| *24.98* | *2.93* | *0.45* | *-0.0333* | *0.336* | *0.45* | *0.34* | *0.11* | *1.28* | *0.20* | *0.00* | *0.20* | *2.37* | *3.65* | |
| *24.98* | *2.93* | *0.39* | *-0.0331* | *0.330* | *0.39* | *0.33* | *0.06* | *0.70* | *0.20* | *0.00* | *0.20* | *2.31* | *3.01* | |

# Appendix E – Head - Discharge Relationship for 90 ° Weir

# *V-Notch Weir - 90°*

***Variables***

| | |
|---|---|
| Channel Width (m) | 0.6 |
| Weir Angle (°) | 90 |
| $P_s$ (m) | 0.195 |
| Cd | 0.58 |

| *Weir Measurement (cm)* | *H (m)* | *Q (L/s)* | *Water Depth (m)* | *Channel Velocity (m/s)* |
|---|---|---|---|---|
| 0.0 | 0.00 | 0.00 | 0.20 | 0.00 |
| 1.0 | 0.01 | 0.01 | 0.20 | 0.00 |
| 2.0 | 0.01 | 0.03 | 0.21 | 0.00 |
| 3.0 | 0.02 | 0.09 | 0.22 | 0.00 |
| 4.0 | 0.03 | 0.18 | 0.22 | 0.00 |
| 5.0 | 0.04 | 0.32 | 0.23 | 0.00 |
| 6.0 | 0.04 | 0.51 | 0.24 | 0.00 |
| 7.0 | 0.05 | 0.75 | 0.24 | 0.01 |
| 8.0 | 0.06 | 1.04 | 0.25 | 0.01 |
| 9.0 | 0.06 | 1.40 | 0.26 | 0.01 |
| 10.0 | 0.07 | 1.82 | 0.27 | 0.01 |
| 11.0 | 0.08 | 2.31 | 0.27 | 0.01 |
| 12.0 | 0.08 | 2.87 | 0.28 | 0.02 |
| 13.0 | 0.09 | 3.51 | 0.29 | 0.02 |
| 14.0 | 0.10 | 4.22 | 0.29 | 0.02 |
| 15.0 | 0.11 | 5.02 | 0.30 | 0.03 |
| 16.0 | 0.11 | 5.90 | 0.31 | 0.03 |
| 17.0 | 0.12 | 6.86 | 0.32 | 0.04 |
| 18.0 | 0.13 | 7.92 | 0.32 | 0.04 |
| 19.0 | 0.13 | 9.07 | 0.33 | 0.05 |
| 20.0 | 0.14 | 10.31 | 0.34 | 0.05 |
| 21.0 | 0.15 | 11.64 | 0.34 | 0.06 |
| 22.0 | 0.16 | 13.08 | 0.35 | 0.06 |
| 23.0 | 0.16 | 14.62 | 0.36 | 0.07 |
| 24.0 | 0.17 | 16.26 | 0.36 | 0.07 |
| 25.0 | 0.18 | 18.00 | 0.37 | 0.08 |
| 26.0 | 0.18 | 19.86 | 0.38 | 0.09 |
| 27.0 | 0.19 | 21.82 | 0.39 | 0.09 |
| 28.0 | 0.20 | 23.90 | 0.39 | 0.10 |
| 29.0 | 0.21 | 26.09 | 0.40 | 0.11 |
| 30.0 | 0.21 | 28.40 | 0.41 | 0.12 |
| 31.0 | 0.22 | 30.82 | 0.41 | 0.12 |

# Appendix F – Head - Discharge Relationship for 30 ° Weir

# *V-Notch Weir - 30°*

***Variables***

| | |
|---|---|
| Channel Width (m) | 0.17 |
| Weir Angle (°) | 30 |
| $P_s$ (m) | 0.214 |
| Cd | 0.58 |

| *Weir Measurement (cm)* | *H (m)* | *Q (L/s)* | *Water Depth (m)* |
|---|---|---|---|
| 0.0 | 0.00 | 0.00 | 0.21 |
| 1.0 | 0.01 | 0.01 | 0.22 |
| 2.0 | 0.02 | 0.07 | 0.23 |
| 3.0 | 0.03 | 0.20 | 0.24 |
| 4.0 | 0.04 | 0.40 | 0.25 |
| 5.0 | 0.05 | 0.70 | 0.26 |
| 6.0 | 0.06 | 1.11 | 0.27 |
| 7.0 | 0.07 | 1.63 | 0.28 |
| 8.0 | 0.08 | 2.27 | 0.29 |
| 9.0 | 0.09 | 3.05 | 0.30 |
| 10.0 | 0.10 | 3.97 | 0.31 |
| 11.0 | 0.11 | 5.04 | 0.32 |
| 12.0 | 0.12 | 6.27 | 0.33 |
| 13.0 | 0.13 | 7.66 | 0.34 |
| 14.0 | 0.14 | 9.21 | 0.35 |
| 15.0 | 0.14 | 10.95 | 0.36 |
| 16.0 | 0.15 | 12.87 | 0.37 |

# Appendix G – Ott Meter Measurements

The most recent calibration (29/11/01) of the Ott Meter provided by USQ returned the following equations:

$$n < 1.64; \quad V = 0.0612n + 0.0168 \text{ m/s}$$
$$1.64 < n < 6.21; \quad V = 0.0530n + 0.0302 \text{ m/s}$$
$$n > 6.21; \quad V = 0.0489n + 0.0558 \text{ m/s}$$

These equations are used to convert the number of revolutions per second, *n*, to a velocity reading (m/s). The table below contains the Ott meter readings and associated velocities.

Table 12: Channel Velocities calculated using an Ott Meter

| Revolutions per 30 seconds | *n* | Velocity (m/s) |
|---|---|---|
| 39 | 1.30 | 0.10 |
| 61 | 2.03 | 0.14 |
| 62 | 2.07 | 0.14 |
| 57 | 1.90 | 0.13 |
| 43 | 1.43 | 0.10 |
| 63 | 2.10 | 0.14 |
| 0 | 0.00 | 0.02 |
| 57 | 1.90 | 0.13 |
| 57 | 1.90 | 0.13 |