University of Southern Queensland

Faculty of Health, Engineering, and Sciences (HES)

Hydraulic Investigation into the Practical Applicability of the ISLEX Smart Siphon

A dissertation submitted by

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Limitations of Use

Abstract

Produced commercially within Australia since the 1960s, cotton has developed into one of Australia's leading agricultural industries and fundamental global agricultural exports. The cotton growth throughout rural Australia is generally bound by Ayr (QLD) to the north, Toowoomba (QLD) to the East, Leeton (Southern NSW) to the South and Menindee (NSW) to the West. The extent of these bounds resulting in approximately 700,500 Hectares of farming cotton, both commercial and privately managed.

A major issue throughout the rural community is the ability to effectively prepare and maintain increasingly larger areas of land, with the decreasing labour available. This is particularly evident within the cotton and furrow irrigation industry, where a large majority of the labour distribution is allocated to the effective management of water. This lack of labour and increase in management requirement presents the potential to introduce automated systems throughout the regional area, thus presenting the farmer with the capability to manage the irrigation remotely and without the requirement for further labour allocations.

The literature review has revealed that not only is the cotton industry throughout Australia increasing in the required capacity and output from crop yield, but also that the labour in regional areas is becoming scarce. This presents the opportunity for an automated system which can be used to efficiently replace the labour requirements.

The final intention of the project is to provide accurate and efficient hydraulic information to users of the ISLEX Smart Siphon regarding the installation and maintenance of the siphon. The rating curves will provide insight into the capacity of the siphon when operated are varying head levels, further to this it will provide the expected flow rates at the outlet of each flow rate, potentially mitigating the erosion effect the water flow may have on the field.

Candidates Certification

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in dissertations are entirely my own efforts, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been submitted for assessment in any other course or institution, except where specifically stated.

Nicholas Leggat

[redacted]

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GLOSSARY OF TERMS

BPH – Bales Per Hectare

WUE – Water Use Efficiency

PTB – Pipe Through Bank

ET – Evapotranspiration

EGL – Energy Grade Line

HGL – Hydraulic Grade Line

RMSE – Root Mean Square Error

CFD – Computational Fluid Dynamics

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1. INTRODUCTION

1.1 BACKGROUND INFORMATION

1.1.1 AUTRALIAN COTTON INDUSTRY

Produced commercially since the 1960s, cotton has developed into one of Australia's leading agricultural industries and fundamental global agricultural exports. The cotton growth throughout Australia is generally bound by Ayr (Queensland) to the north, Toowoomba (Queensland) to the East, Leeton (Southern New South Wales) to the South and Menindee (New South Wales) to the West, thus resulting in approximately 700,500 hectares of farming cotton (Cotton Australia, 2017), which is both commercially and privately managed (**Error! Reference source not found.**).

Figure 1.1. Australian Cotton Growing Region (Cotton Australia, 2017)

While China and India currently have the highest total cotton production, the implementation of advanced techniques and innovative methods has seen Australia's cotton production increase more than double the average number of Bales Per Hectare (BPH) throughout the cotton growth areas. The Australian Cotton Industry is an important contributor to the world cotton market, with total exports in excess of two billion dollars annually (Cotton Australia, 2013). Further to this, it provides an economic foundation for rural communities since it "employs up to 14,000 people in many regional and remote communities" (Qunying Luo, 2017). The recent increase in efficiency of Australian methods has resulted in a higher yield over a smaller area. This is achieved through the use of a range of techniques, including:

1. Variety Selection
2. Water/Irrigation Availability
3. Crop Management

In addition to this, the significant improvement in the size of cotton yields has been "attributed to better water management" (Cotton Australia, 2013), with irrigated cotton producing a 330% higher yield per hectare when compared to dryland. This significant yield increase presents potential improvements to existing methods and technology.

1.1.2 IRRIGATED COTTON

Cotton itself requires a few basic conditions to thrive, these include "Long vegetation periods, Constant temperatures between 18 and 30°C, ample sunshine and fairly dry conditions, deep, well drained soils with a good nutrient content and A minimum of 500mm of water between germination and boll formation" (M Retifiq Chaundry, 2003). Throughout Australia, cotton is generally grown using gravity surface-irrigation systems. Gravity surface-irrigation systems include the use of siphoned systems, Pipes Through Bank (PTB) systems and bank-less irrigation systems. The requirement for irrigation techniques stems from the increased yield produced per unit area. While dryland cotton relies on the areas rainfall and soil nutrients in order to yield, irrigated cotton (Figure 1.2) is supplied the required water at regular intervals, whether the area be in drought or not. Although irrigation is more expensive to due to the installation and maintenance of the respective equipment (pumps, channels and siphons etc.) it has the potential to guarantee the producer a yield, whereas dryland cotton relies entirely on the uncertain weather events in the region.

Figure 1.2: Water Flowing Through Furrows

While the irrigation of cotton does not necessarily guarantee a high yield, it does stabilise the yield over an extended period of time. This stability gives the producer an increased ability to forecast the potential profit (or loss) of a season. In all crop farming, the evapotranspiration of the field is heavily influenced by the climate in which it grows. “The dryer and hotter the climate is, the more water the plant must transpire to keep cool and produce biomass” (Cotton Inc., 2017), however it is not only the climate that creates a variation in the irrigation requirements. The lasting soil water content dictates the amount of water which can be supplied to the roots of the plant in order to fulfil the demands of transpiration. Hence, a lack of available water can lead to water stress within the plant.

Water stress is caused by poor soil water conditions, thus the plants feedback mechanisms limit the water loss created by the plants leaves. When the stomata supplying nutrients to the plant closes, the temperature of the respective plant rises and consequently the plant undergoes water stress. Although the stress to the plant may not be immediately apparent, over time it causes the plants growth processes to slow which effectively reduces the overall yield of the plant. The adoption of irrigated fields mitigates the effect of increased temperatures and minimal rainfall events on cotton plantations, and provides the farmer with more control over the plant growth (Jerry Berlin, 1982).

Therefore, the water use efficiency (WUE) should be considered as one of the highest priorities when irrigating and maintaining the cotton plant, however this usage of water is also a limiting factor for field allocations. The most frequently used method is the consideration of the yield per total unit of applied water. This includes the irrigation throughout the seasons as well as the total rainfall the plant received over the course of its growth. This yield per total unit total of applied water is heavily reliant upon the efficiency of the irrigation methods. Therefore, the water management practices of the irrigator must be proficient in order to minimise water losses (Figure 1.3) of the yield due to deep leaching and runoff. Thus, the irrigation system must uniformly distribute the flow of water across the selection of field designated to be irrigated.

Figure 1.3: Tail Drain Water Backing Up Furrows

1.1.3 LABOUR SHORTAGES IN RURAL AREAS

Although the provisions for housing, meals and transport to accommodate irrigation labour is readily available, there has been a major decrease in labour supply within rural Queensland and particular regions where cotton is of major economic value. The attraction and retention of "a skilled labour force is a critical yet complex issue for rural and remote communities" (K. Becker, 2013) and hence, this results in a significantly increased demand for labour with sparse allocations throughout the industry.

The labour shortage is predominantly due to the "lack of services and amenities available" (K. Becker, 2013), all of which are now considered to be general comforts in everyday life. Although the majority of employment throughout the cotton industry are relatively well-paying jobs, there is still a shortage of readily available labourers and workers to effectively manage irrigated seasons as rural workers are regularly choosing to look for more stable work elsewhere. This is an obvious detriment to the current cotton production situation however it does present the opportunity to adapt and improve efficiency.

1.2 PROJECT INTRODCTION

A major issue within rural communities is the ability to effectively prepare and maintain increasingly larger areas of land with a decreasing labour force. This is particularly evident within the cotton and the furrow irrigation industry where the majority of the labour is allocated to the effective management of water. This lack of labour and increased management requirements presents opportunities to introduce automated systems throughout the regional areas. This gives farmers the capability to manage the irrigation remotely and does not require additional labour allocations.

For those farmers with the labour available there is still the desire to reduce the time spent conducting mundane irrigation management tasks rather than spending time on other priorities. Any new proposal should therefore be installed and configured once at the beginning of the season and require minimal alteration throughout the remainder of the season. Finally the system should be flexible such that it can be adapted to the specific characteristics of the site (e.g. head level, flow rate, field length, soil type etc.)

As the lack of labour and increased time constraints become more evident, ISLEX Australia, a national plastics manufacturer, have provided a potential solution, The ISLEX Smart Siphon (Figure 1.4). The concept is relatively basic in theory and provides the desired automation throughout the furrow irrigation community. This Smart Siphon design uses inserts at the entry location to restrict the pipe flow in order to manage the field run time under the available head within the head ditch.

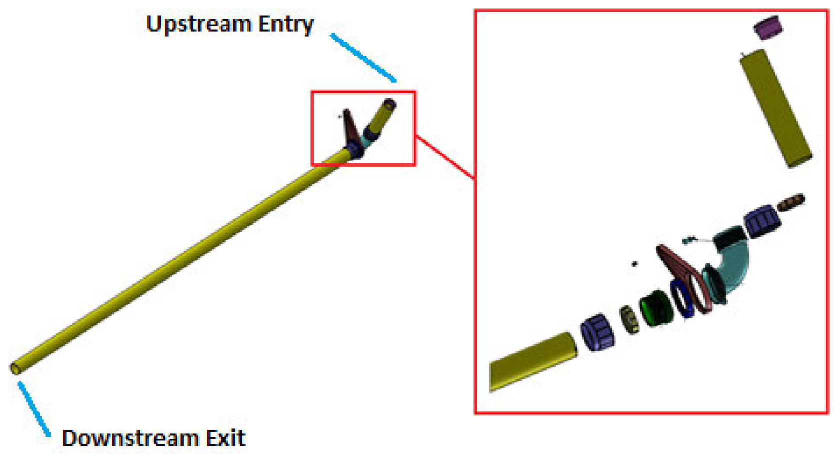

Figure 1.4: ISLEX Smart Siphon

The hydraulic performance of the standard polyethylene siphons has previously been measured including the production of look-up table to describe the potential flow data for each siphon size under a range of varying head levels. This data, referred to as "rating curves", enables growers and farm managers to select the appropriate siphon size for each set of irrigation siphons. It is hypothesised that the hydraulic behaviour of the Smart Siphon will differ significantly when compared to the standard irrigation siphon.

1.3 PROBLEM DEFINITION

1.3.1 GENERAL PROBLEM

The amount of accessible and financially viable labour has significantly decreased over the past decade. This creates an increased demand for efficient automated systems within the cotton industry in order to minimise the shortage of skills. The ISLEX Smart Siphon (Figure 1.5) proposes to reduce labour and eventually become a fully automated system, however, there have been several issues regarding the use of the systems within a practical environment.

Figure 1.5. ISLEX Smart Siphon between Irrigation Events (Islex Australia, 2016)

The primary issue that arose during the field testing of the Smart Siphons was the ability to accurately estimate the field irrigation time and manage the individual watering bays. There are four major reasons that this occurs:

1. Varying Flow Rate
2. Varying Flow Velocities
3. Inconsistent Row Length
4. Inconsistent Row Grade

The flow rate, flow velocities and row length are variable and, hence, can be altered through the use of various methods. These alternation methods will be defined further within the report, however the predominant technique is the use of flow restriction, usually located at several points within the irrigation siphon system. The inconsistent row grade however, for the purposes of this exercise, can be defined as a farm management issue and should therefore be managed accordingly.

1.3.2 EXISTING PROBLEMATIC SITUATION

Existing irrigation systems involve a heavy reliance on labour in the field, which is becoming less readily available. Previously, farming managers were able to close individual siphons as required, giving the manager complete control over the water quantity applied to the plants. Further to this, the previous accessibility to labour, and workers on call 24 hours a day, allowed issues to be resolved relatively fast.

However, in recent years, as the labour availability has decreased, managers have had to undertake work themselves, where previously several labourers would have individually closed siphons depending on the flow progress through the field. This causes a significant loss of time to the manager – time which could be used identifying other issues throughout the farm.

1.3.3 POTENTIAL SOLUTIONS

There are several possible solutions to the problems defined previously. These include opportunities which require far greater than the prescribed time and are therefore unviable. In discussions with ISLEX, the most critical concerns have been defined as the flow rates and how they are affected by the varying head levels. For this reason the effects of this will consequently be the focus of the research. Subsequently, these experiments are considered to be some of the most pressing areas required for the near development of the ISLEX Smart Siphon.

During the most recent crop irrigation season there were several ISLEX Smart Siphon trial sites enacted. However, because the sites lacked a consistent installation procedure, the findings varied and hence they were general in nature and difficult to analyse. Although no technical data was taken the trial sites did provide the opportunity to prove that the mechanisms themselves did work and further to this worked with multiple siphons activated at once. A general analysis has previously been conducted through the use of a Computer Fluid Dynamics (CFD) software, however the results did not incorporate any losses throughout the system and therefore a practical analysis of the system is required.

The commercial implementation of the ISLEX Smart Siphon relies heavily on the feasibility of the irrigation method as well as the assurance that the device will not have an adverse impact on the yield or run times of the fields.

1.3.4 INTENTIONS OF THE PROJECT

The intentions of the project are predominantly based around the requirements in the field. It aims to provide accurate and efficient hydraulic information to users of the ISLEX Smart Siphon regarding its installation and maintenance. This can be done by informing users of general installation and operation limits; however the individual flow rates and field running times are wholly particular to each field. There is no possibility within the timeframe to conduct neither an analysis of each individual soil type, nor the reaction of the flow over the soil.

Rating curves will also be analysed since they provide insight into the capacity of the siphon when operated at varying head levels. Finally, this report will provide the expected flow rates at the outlet of each Smart Siphon. Should the time permit there is further opportunity to investigate how to mitigate the erosion effect that the water flow may have on the field, this will be discussed further later in the report.

1.4 RESEARCH OBJECTIVES

In order to achieve the previously defined outcomes of educating users about the installation of the Smart Siphon, the following objectives have been identified:

1. Examine and define the ISLEX Smart Siphon as well as provide background into the practical use of the Siphon.

2. Evaluate the hydraulic performance of the smart siphon through practical measurement in a controlled environment.

3. Generation of rating tables and equations to predict the flow rate from operating head and pipe characteristics.

If time and resources permits

4. Propose and test improved designs to reduce runoff effects.

5. Collate observations on the performance of the smart siphon including erosion potential.

6. Design an experiment to study the erosion downstream of siphons and smart siphons.

1.5 EXPECTED OUTCOMES

This dissertation will investigate the hydraulic performance of the ISLEX Smart Siphon identify the characteristics required for an efficient installation. Further to this, examine how existing installations can be optimised to improve productivity. This data is entirely dependent on the flow rate through the system and how the flow rate is affected by the head levels within the head ditch.

This report aims to provide cotton growers and interested farmers with the required flow rate data and characteristics for efficient irrigation set up and ways in which to optimise further irrigation events. In addition to this, this report may generate increased interest in the ISLEX Smart Siphon due to its automation and increased control over irrigation systems.

2. LITERATURE REVIEW

2.1. GENERAL USE OF IRRIGATION

There are three fundamental uses of irrigation within the cotton industry; these include the extension of their growth period, watering of the plant itself and finally the control of the plants biomass through dry and extremely hot weather events. In order to sustain plant growth in areas where there is an insufficient occurrence of natural rainfall, other means must be utilised to supply the plant with water, such as irrigation. Within many dry regional zones throughout Queensland and Northern New South Wales surface irrigation is essential to supplement the expected rainfall in order to produce a profitable crop.

Further to this, "irrigation can also be used to extend the growing period, allowing a wider range of crops to be grown, or to increase the yield of existing crops" (Jones, 1966). Initially the "goal of irrigation development and practices was to permit permanent civilisation to establish in semi-arid and arid lands" (Jones, 1966), however this has been reformed and irrigation is now predominantly used to "increase agricultural production" (Jones, 1966) within the Southern QLD and North NSW regions. Throughout regions such as Arizona where cotton is still a major part of the local economy there is the requirement to have a fully irrigated crop as there is very little opportunity for the plant to obtain any water from rain alone. Had it not been for "Arizona's generous sunshine and fertile soil" (Department of Agriculture - Arizona, 2015) there may not be any opportunity to grow cotton throughout the region, however the use of irrigation makes this possible.

2.2. FLOOD AND FURROW IRRIGATION

The use of furrow and corrugation irrigation distribution systems can be traced back to the Egyptians watering their crops and "ancient Mesopotamians [creating] their garden cities in the arid wastelands of Sumer" (Jones, 1966). Furrows, corrugations and surface channels move the water throughout the field in open channel flow, and these methods are used to "meet [the] crops evapotranspiration[1] need" (Opaka, 1992). The infiltration of the required water into the plant "it the process of water movement

[1] Evapotranspiration: The process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants.

through the soil surface into the soil matrix[2]" (C. M. Burt, 1997). This technique of furrow irrigation (Figure 2.1) is suited to the majority of soil types found throughout Northern New South Wales and Southern Queensland, apart from "sands that have a very high infiltration rate and poor lateral distribution" (Opaka, 1992). The ideology behind furrow irrigation is to provide the crop with a uniformly applied volume of water through to the root zone. This is still a highly contentious topic however since the use of surface irrigation has a "low water application efficiency" (Opaka, 1992) which results in "part or whole of the root zone [suffering] periods of poor aeration" (Hodgson, 1982) and as a result the plant is waterlogged.

Figure 2.1. Furrow Irrigation Through the use of regular siphons (Shaw, 1977)

In furrow irrigation (Figure 2.1), water flows through "evenly spaced furrows or corrugates that are typically 0.1-0.3m wide on fields with a slope of 0.1-3%" (Bjorneberg, 2005). During irrigation, water generally flows through the field for 12-24 hours at a time, however this is heavily dependent on the furrow dimensions, soil inflow rate and water and management variations. Due to there being a correlation between the erosion of the furrow soil, field slope and inflow rate, the flow rate and velocity of the irrigation must be carefully managed. This is particularly predominant within Rill erosion which occurs when "hydraulic shear exceeds the soil critical shear and sediment load is less than rill transport

[2] Soil Matrix: Soil is composed of a mixture of minerals, organic matter, air and water. Each required for plant growth, decomposition and microbial communities.

capacity[3]. If sediment load exceeds transport capacity, sediment deposition occurs” (D. L. Bjorneberg, 1999) This is of particular importance for fields where the slope increases towards the end of the field as the velocity of the water will increase as it flows toward the end, resulting in significant furrow erosion as the hydraulic shear increases. This is defined within the Soil Detachment Capacity:

$$D_c = K_r(\tau - \tau_c)^a$$

Equation 1. Soil Detachment Capacity

Where:

D_c =Detachment rate for clear water

K_r =Rill Erodibility

τ =Soil Critical Shear ($\tau = \gamma RS$ where γ is the specific weight, R is hydraulic radius and S is hydraulic gradient, this approximately equals the slope of the furrow.

τ_c =Soil Critical Shear

a = Constant equal to 1 for the purpose of this report

This proves that the increased furrow slope is proportional to the Soil Detachment capacity which is potentially evident through irrigation. Thus directly leading to the capacity of soil to be transferred by the flow.

[3] Sediment Transport Capacity: Maximum load of sediment that any given flow rate can carry.

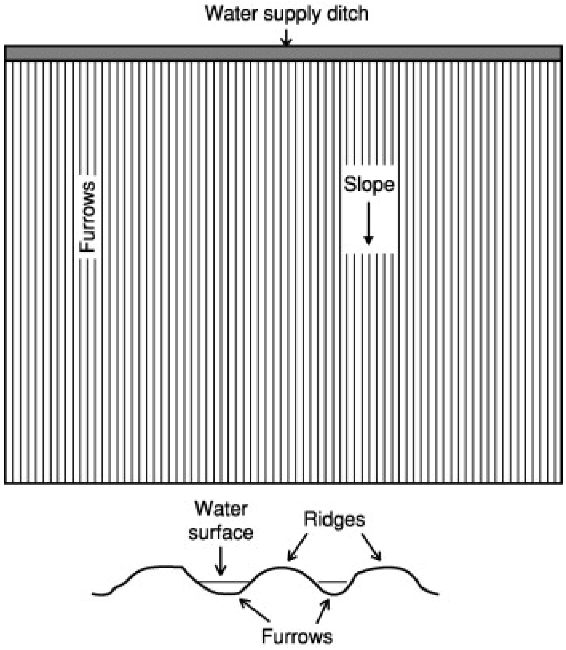

Figure 2.2. Furrow Irrigation Field Layout (Natural Resources Management and Environment Department, 2017)

Furrow irrigation (Figure 2.2) has optimal effects if the "principle of high frequency and low volume application of water as dictated by the crops requirements" (Opaka, 1992) is followed. Abiding by this rule helps to avoid water logging[4] which, in turn, stresses the plants and minimises their growth potential. The application of the principle is dictated by the design of the furrow, which accounts for the crop to be planted. It is also known that "furrow spacing's can range from 0.75m for most row crops to 2.0m for grain crops" (Shaw, 1977). Further to this, the "furrows usually run normal to the contour on slopes up to about 2 percent" however majority of irrigated cotton is grown on slopes less than 1% as this provides a greater opportunity for the water to absorb into the root system of the plant. The major factors defining the furrow length is a medium between the capacity of the irrigation method and the optimisation of labour and materials used to maintain the field. If the fields are too short then the efficiency of the plant is reduced and a large amount of the land is wasted on supply channels and drains. If the fields are too long then the uniformity of the irrigations will decrease as well as an increase in irrigation times and potential for water to not flow the entire way through the furrows. There must therefore be a judgement made into the suitability of the area to support a furrow irrigated crop, this decision also incorporates the soil type and stability throughout the area.

[4] Water logging occurs when the roots of a plant cannot respire due to excess water within the soil profile.

Hydraulically, the flow throughout the field can be defined as “unsteady, spatially varied flow and is therefore difficult to analyse” (Shaw, 1977), however the flow of water across the field can be categorised into three distinct phases, being:

1. Advance – “the movement of the ‘front’ of the inflowing water towards the far end of the furrow.” (Shaw, 1977)

2. Vertical Recession – “the decrease in depth of water at the upstream end after inflow has been cut off, until depth at this end is zero.” (Shaw, 1977)

3. Horizontal Recession – “the time taken by water to disappear at any station within the border after the inflow at the upstream end has stopped” (Pathak, n.d.)

Analysis of all flow phases would be very time intensive. Hence, for the purpose of this investigation, there will only be a focus on a distinct area within the flow being the initial advance once leaving the delivery siphon. The combination of all three phases of flow can lead to irrigation efficiency, otherwise known as the water application efficiency. The erosion of the soil at the siphon exit location within the furrow has a significant impact on the remaining flow downstream.

2.3. SIPHON USE IN IRRIGATION

The inception of furrow irrigation into the cotton and grain industry throughout Australia “relies almost exclusively on overbank siphon pipes to transfer water from the head ditch to the irrigation furrow” (Gillies, 2010), as this is the case throughout majority of irrigated land it will be difficult to convince ‘set-in-their-ways’ farmers who have used the same equipment for years. Although an effective and relatively accurate way of controlling flow conditions there is a major downfall of the hand siphon, the equipment is extremely labour intensive. Each siphon must be primed in order to start the flow of water through them; this presents very little opportunity to automate a system.

The concept behind regular siphon irrigation involves "one end of the siphon [to] be submerged in the water in the head ditch (Figure 2.3), while the other end could either be free draining or submerged in the furrow (Figure 2.4)" (R.K. Koech, 2010).

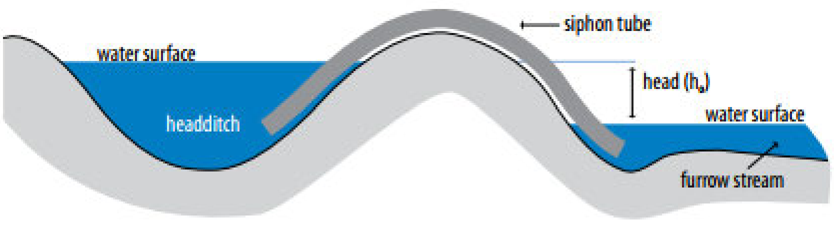

Figure 2.3. Siphon Operating with Submerged Flow (D.Wigginton, 2013)

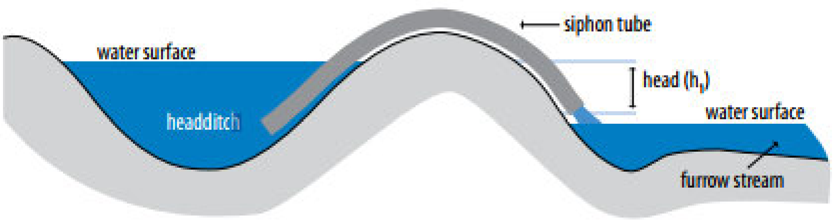

Figure 2.4. Siphon Operating with Free Outflow (D.Wigginton, 2013)

With the discharged system flow approximately equal to:

$$Q = \frac{\pi D^2}{4}\left(\frac{2g\Delta h}{1.9 + \frac{fL}{D}}\right)^{0.5}$$

Where:

Q = Discharge

D = Internal Siphon Diam

g = Acceleration due to gravity

Δh = Operating Head Difference (shown in Figure 2.3 and Figure 2.4)

f = friction head loss coefficient

L = Siphon Length

2.4. CLOSED CONDUIT SINGLE-PHASE HOMOGENEOUS FLOW

Single phase flow of homogeneous fluids is defined to be the flow of a "single liquid or gas [where] the density is constant throughout the flow" (Hashem, 2000). This flow is most likely to be encountered within the experimental analysis as the flow of water through a closed conduit, in this case the irrigation siphon, is considered to be a Newtonian fluid flowing with a constant temperature and therefore can be assumed to have a constant density. A flow with these particular conditions can therefore be investigated using the conservation of fluid energy equation, affectionately known as Bernoulli's Energy Equation.

2.4.1. BERNOULLI'S ENERGY EQUATION

The application of Bernoulli's Energy Equation is the considered to be the application of the conservation of energy principle to fluid flows. Within the design of a pipe structure the "main considerations are the head losses, forces and stresses acting on the pipe material and discharge" (John Roberson, 1998). Further to this, there increased potential for stresses applied to the pipe material by the addition of fittings and joints. The energy distribution throughout the system can therefore be defined by applying the steady flow form of the energy equation,Equation 3, which can is exemplified in Figure 2.5:

$$\frac{p_1}{\gamma} + \frac{\alpha_1 V_1^2}{2g} + z_1 + h_p = \frac{p_2}{\gamma} + \frac{\alpha_2 V_2^2}{2g} + z_2 + h_t + h_L$$

Equation 2. Bernoulli's Energy Conservation Equation

Where:

$\frac{p}{\gamma} = pressure\ head$

$\frac{\alpha V^2}{2g} = velocity\ head$

$z = elevation$

$h_p = head\ supplied\ by\ pump$

$h_t = head\ extracted\ by\ turbine$

$h_L = head\ loss\ between\ section\ 1\ and\ section\ 2$

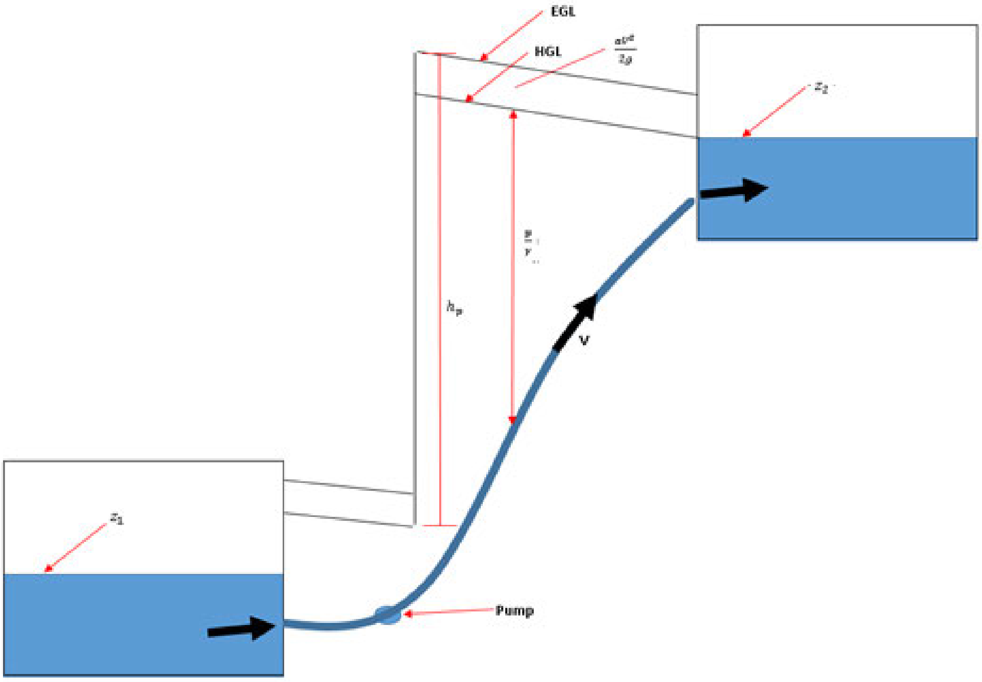

Figure 2.5. Bernoulli's Equation Definition Diagram (Leggat, 2017)

2.4.2. VELOCITY HEAD

The velocity head within hydraulic engineering is considered to be the vertical distance that a fluid would have to fall to obtain a specified velocity. Throughout realistic (Newtonian fluid[5]) hydraulic engineering it is safe to assume that the water flow throughout the system is predominately turbulent and therefore the velocity of the fluid will be approximately uniform across the area of the conduit. Should the flow be non-uniform then there is the requirement to apply "the variation in kinetic energy from one stream tube to another is accounted for by a correction factor, α" (C, 2010) Therefore, for the purpose of uniform flow through a pipe, the "value of α is usually assumed to be unity, and the velocity head is then simply $\frac{V^2}{2g}$" (John Roberson, 1998). Thus providing the equation:

$$\frac{p_1}{\gamma}+\frac{V_1^2}{2g}+z_1=\frac{p_2}{\gamma}+\frac{V_2^2}{2g}+z_2+h_L$$

Equation 3. Revised Bernoulli's Equation (without pump or turbine)

NOTE: As there will be neither pump nor turbine throughout the analysis, these can be disregarded.

2.4.3. SYSTEM FRICTION HEAD LOSSES

The term for head loss (h_L) is required to account for the transfer of energy to heat. Head loss occurs as a result of the resistance of fluids to the pipe surfaces', otherwise known as friction, as well as the "viscous dissipation of turbulence usually occurring with separated flow, such as in bends, fittings or outlet works" (John Roberson, 1998). For the purpose of this analysis, the head loss and velocity distribution can be assumed for turbulent flow through a smooth pipe.

While the flow is turbulent through a smooth pipe it can be assumed that the "shear stress is primarily in the form of Reynolds stress, which varies linearly across the pipe section except in the pipe wall within the viscous sublayer" (John Roberson, 1998). Subsequently, the velocity distribution can take

[5] Newtonian Fluid: A fluid in which viscous stresses are linearly proportional to the local rate of change of the fluids deformation with respect to time.

separate forms depending on the relative distance from the pipe wall. Therefore, it is understood that within viscous sublayer Equation 4 holds, and within the outside viscous sublayer Equation 5 holds.

$$\frac{u}{u^*} = \frac{u_* y}{\nu} \; for\ the\ cases\ where\ 0 < \frac{u_* y}{\nu} < 5$$

Equation 4 (Shear Velocity Relationship 0<uy<5)

$$\frac{u}{u_*} = 5.75\log_{10}\left(\frac{u_* y}{\nu}\right) + 5.5\ for\ the\ cases\ where\ 20 < \frac{u_* y}{\nu} \leq 10^5$$

Equation 5 (Shear Velocity Relationship 20<uy<10^5)

Where:

$u = velocity$

$y = distance\ from\ pipe\ wall$

$\nu = kinematic\ viscosity$

$u_* = shear\ velocity = \sqrt{\frac{\tau_o}{\rho}}$

$\tau_o = shear\ stress\ at\ pipe\ wall$

Following from this the head loss for turbulent flow through a smooth pipe can be defined as Equation 6.

$$h_f = f\frac{L}{D}\frac{V^2}{2g}$$

Equation 6. Friction Head Loss

As illustrated, this equation makes use of the friction coefficient, f. As a result of this, it is necessary to use the Moody diagram (Figure 2.6. Moody Diagram Figure 2.6) to estimate this coefficient. This method utilises the Reynolds number and relative roughness of a pipe to provide a friction coefficient estimate.

$$Re = \frac{VD}{\nu}$$

Equation 7. Reynolds Number Using Kinematic Viscosity

Where:

$V =$ Mean Velocity through pipe

$D =$ Pipe Diameter

$\nu =$ Kinematic viscosity of the fluid

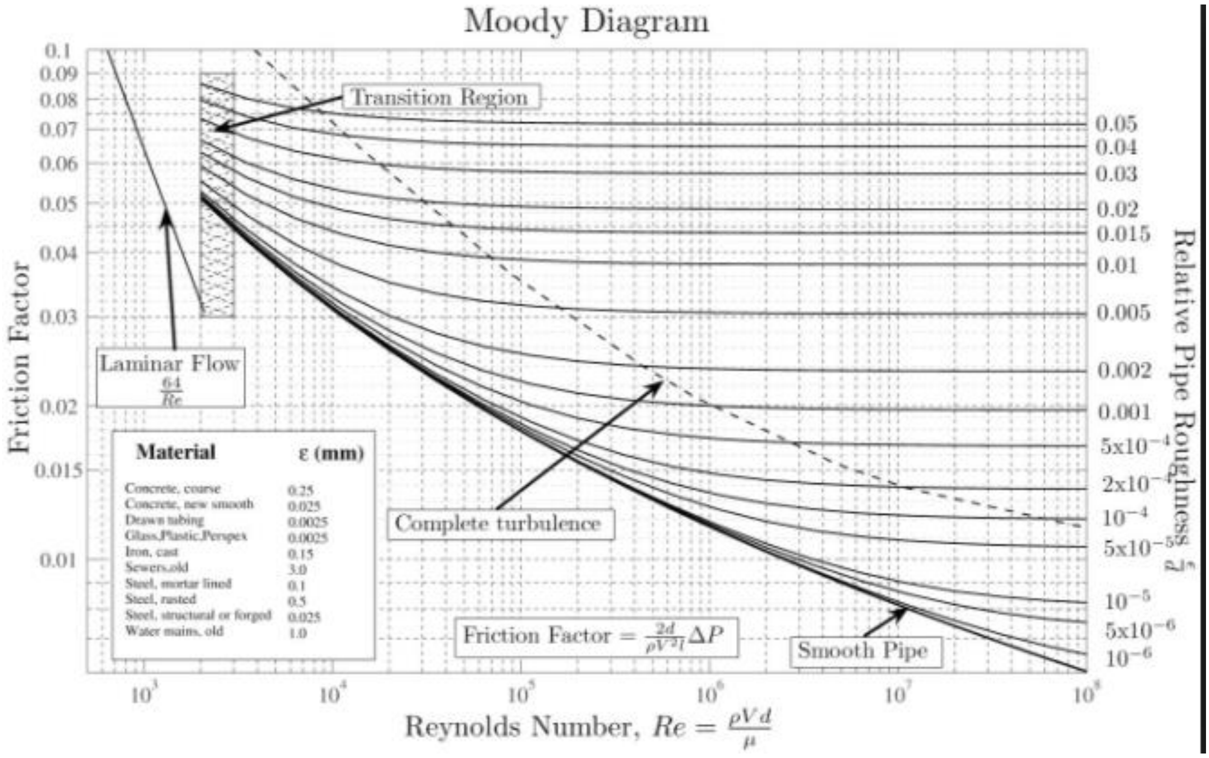

Figure 2.6. Moody Diagram (AutoDesk University, 2014)

An issue that arises when attempting to solve this type of problem analytically in that although the Moody Diagram has an acceptable error margin it is difficult to solve for the friction coefficient using computer aided methods, such as Excel, since each individual number must be read from the graph which mitigates the effectiveness of computer aided equipment. Due to this being a potential issue, two analytical equations were selected to accurately predict the value for the friction coefficient with improved accuracy (P. Rollmann, 2015). The equations being The Colebrook White seen in Equation 8, and The Barr which is shown in Equation 9 are displayed below:

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{k}{3.7D} + \frac{2.51}{Re\sqrt{f}}\right)$$

Equation 8. Colebrook-White Equation for Friction Coefficient

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{k}{3.7D} + \frac{5.1286}{Re^{0.89}}\right)$$

Equation 9. Barr Equation for Friction Coefficient

As the Colebrook-White equation requires iteration of both sides of the equation there is a significant amount of 'Guess and Check' involved in finding the solution. Since it is generally accepted that the Barr equation is approximately equal to the Colebrook-White equation, thus is it reasonable to assume that the initial iteration of the Colebrook-White equation is equal to the solution of the initial Barr equation. This assumption results in Equation 10.

$$f = \left(-2\log\left(\frac{k}{3.7D} + \frac{5.1286}{Re^{0.89}}\right)\right)^{-2}$$

Equation 10. Solution for f from Barr Equation

2.4.4. SINGLE PHASE FLOW MINOR LOSSES

The major loss locations throughout the Smart Siphon system are predicated to be the elbow joint mechanism connecting the pipe through bank (PTB) to the inlet pipe, the Entry losses, exit losses and the sudden expansion/contraction energy losses. Further to this there is also the formation of a phenomenon known as Vena Contracta, this will be briefly covered however for the purpose of this report and testing there will be an assumption that this is not present and therefore negligible. The addition of components throughout the system will "interrupt the smooth flow of fluid, causing minor [energy] losses from flow separation and mixing" (G. Anderson, n.d.). The total minor loss throughout a system is then calculated as a summation of the appropriate loss coefficients multiplied against the velocity head of the system:

$$h_m = \sum K_L \frac{V^2}{2g}$$

Equation 11. Minor Head Loss Equation

Where:

h_m = Minor Head Loss

K_L = Minor Loss Coefficients (generally given by manufacturer data)

V = Velocity

2.4.4.1. LOSSES THROUGH ELBOW JOINT

While fluid is traveling through a system there are several requirements to change the direction of flow to suit the existing or required conditions, the change in direction also associates a head loss due to the decrease in energy in the manoeuvre. Friction loss is applied to the flow through the pipe in addition to the "radial pressure created by the centrifugal force acting on the fluid" (Thermopedia, 2011). This centrifugal force causes the flow acting at the centre of the pipe to move toward the external wall while travelling through the bend, whilst then acting towards the inside wall immediately following the bend (Figure 2.7).

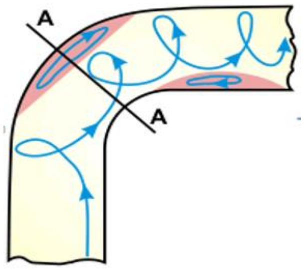

Figure 2.7. Flow through Pipe Bend (Thermopedia, 2011).

If the curvature of the bend is strong enough, the pressure differential on the outer and inner walls of the bend, as detailed in Figure 2.7, has the potential to lead to flow separation and effectively an increase in pressure loss. These losses are not only attributed to friction losses but also to the momentum losses throughout the bend.

2.4.4.2. ENTRY/EXIT LOSSES

The shape and resulting 'aggressiveness' of the entry significantly impact the velocity and flow profile of the fluid entering the system, this can be used in the favour of someone trying to control the flow through the system. Ideally the entrance to any hydraulic system should be a well-rounded entrance (Figure 2.8) which provides a gradual area restriction and therefore minimises the potential for unexpected flow events at the inlet.

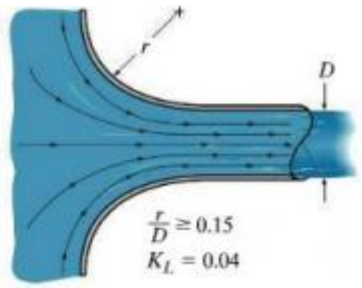

Figure 2.8. Well-Rounded Entrance to a pipe (G. Anderson, n.d.)

The second entrant type to be assessed is the re-entrant style of flow entry (Figure 2.9). This entry type increases the flow velocity at the entry point as there is a build-up of eddies[6] which constrict the entry area, thus increasing the flow velocity to maintain the flow rate, this is known as Vena Contracta. As previously stated the phenomenon of Vena Contracta will be disregarded in the report as there is the assumption that the entry flow is at full pipe flow.

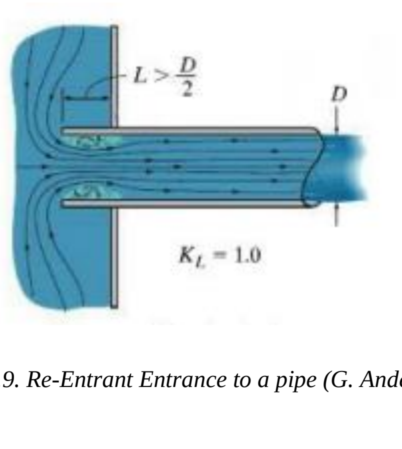

Figure 2.9. Re-Entrant Entrance to a pipe (G. Anderson, n.d.)

[6] Eddies: A flow type which is not consistent with the remaining flow, within pipe flow regularly resulting in a momentary velocity increase.

The exit losses for the purpose of this report will be assumed as 1.0 as there is no interation with surrounding flow and therefore there is no increased minor loss.

2.4.4.3. SUDDEN EXPANSION/CONTRACTION LOSSES

A sudden expansion occurs when two pipes or varying size are connected in series resulting in an immediate restriction or expansion of the pipe area. The resulting head loss is caused by the subsequent increase or decrease in the pressure head of the pipe.

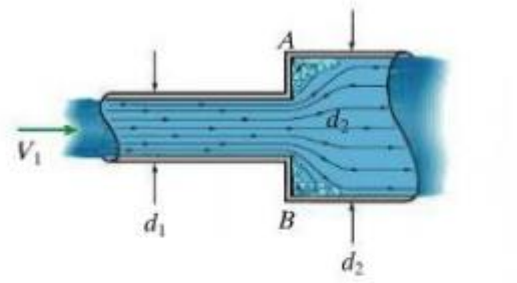

Figure 2.10. Sudden Expansion in pipe flow ((G. Anderson, n.d.)

As the variation in expansion/contractions can vary depending on the degree of change the following equations become apparent:

$$K_L = \left(1 - \frac{d_1^2}{d_2^2}\right)^2$$

Equation 12. Sudden Expansion/Contraction Loss Coefficient Equation

Where $d_1 and\ d_2$ are the internal diameters of the pipe system. Following this the resulting loss coefficient, K_L, is substituted to solve for the head loss associated with the expansion/contraction:

$$h_L = K_L \frac{V_1^2}{2g}$$

Equation 13. Resulting Head Loss Equation due to Sudden Expansion/Contraction

Alternatively to this if both flow velocities are known there is the potential to use the difference in flow velocities to solve for the head loss between the two:

$$h_L = \frac{(V_1 - V_2)^2}{2g}$$

Equation 14. Sudden Expansion/Contraction Head Loss Equation (Using Velocity)

Where $V_1 and\ V_2$ are the velocities at pipe diameter 1 and 2 respectively.

2.4.4.4. SUMMATION OF MINOR HEAD LOSSES

Once all minor loss coefficients and any apparent sudden expansion/contraction losses have been found the remaining step is to enter these into Equation 11Equation 11. Minor Head Loss EquationEquation 11. Minor Head Loss Equation. The result of this being the total losses throughout the system in its entirety. Therefore if:

$$h_m = \sum K_L \frac{V^2}{2g}$$

$$= (K_{Entry} + K_{Joint} + K_{Exit}) \frac{V^2}{2g}$$

Equation 15. Minor Head Loss (3 locations)

Thus proving it is theoretically viable to assume that the summation of all loss coefficients throughout a system as a whole is an accurate method of solving for the respective system head loss.

2.5. ENERGY TRANSFER FROM CLOSED CONDUITS TO OPEN CHANNEL

The objective of surface furrow irrigation is to transfer irrigation water from a water supply to the field furrow with minimal losses. Following this, the flow generally follows the length of the furrow which is usually the same as the length of the field, however this is not always the case. Upon outflow from the supply channel there is large potential for soil erosion within the vicinity of the flow output. The "basic equations governing the flow of fluids in closed conduits are the continuity (Equation 16), momentum (Equation 17) and energy (Equation 18) equations" (Chin, 2000) provide a method for the design of delivery systems and flow requirements.

$$\int v_1 dA_1 = \int v_2 dA_2$$

Equation 16: Flow Continuity Equation

$$\sum F_x = \rho \int v_2^2 dA_2 - \rho \int v_1^2 dA_1$$

Equation 17: Flow Momentum Equation

$$\frac{dW_p}{dt} = \int p\mathbf{v}.\mathbf{n}\, dA$$

Equation 18: Flow Energy Equation

These three equations are in a generalised form, however the distinction between the conduit flow and open channel flow parameters can be made. The assumption that comes with using these equations is that the conduit is flowing at capacity throughout the irrigation with constant boundary conditions such as the supply head level, velocity and pipe dimensions. Following this theory it is accurate to assume that the fluid flow transferred from the pipe into the field itself is as follows:

$$\int v_{Siphon} dA_{siphon} = \int v_{Furrow} dA_{Furrow}$$

Equation 19. Continuity Equation in terms of field conditions

Therefore the remaining conditions of momentum and energy can be solved for, thus providing the siphon exit flow conditions as well as the initial furrow flow conditions.

The full pipe conduit flow is then transferred to open channel flow. This transfer is often where significant soil erosion can occur. For simplicity, the flow once leaving the conduit can be defined as open channel flow. Channel flow has similar conditions to conduit flow in the conservation of energy, however the boundary conditions vary significantly, ultimately resulting in distinct differences between results.

The main difference between conduit and open channel flow is that throughout the open channel flow the surface is exposed to the atmosphere, whereas this is not the case for conduit flow. It is for this reason that it is considered more difficult to analyse than conduit flow since "the location of the free surface is not constrained and the depth of flow depends on such factors as discharge and the shape and slope of the channel" (Chin, 2000).

2.6. EROSION OF SOIL DUE TO WATER FLOW

Soil erosion can be categorised into various types of erosion, however the majority of these are consistent with rainfall events within an area. The most prominent types of erosion within furrow and siphon irrigation is typically gully erosion and splash erosion, or a combination of the two (Figure 2.11). Gully erosion occurs when the "runoff concentrates and flows strongly enough to detach and move soil particles" (Queensland Government, 2015). This is mainly caused in areas with dispersible subsoils, those of which are extremely common throughout Queensland. In Queensland, the subsoils are commonly "a highly erodible, clay subsoil with a high exchangeable sodium percentage (Figure 2.11)" (Department of Natural Resources, 2006).

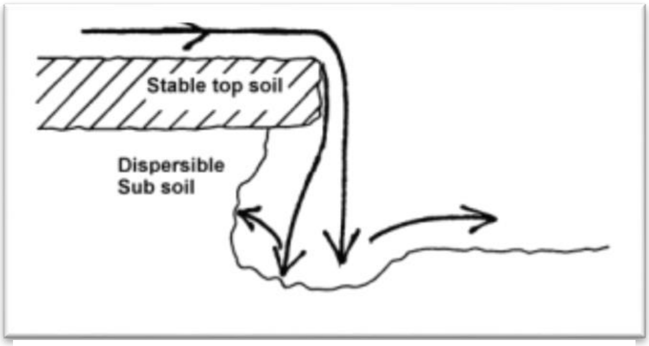

Figure 2.11. Soil Erosion Caused by Fluid Outflow (ONTARIO, 2012)

Furrows and corrugations are generally designed to withstand a regular flow, with the assumption that the flow of water in is generally in the direction of the furrow. In practice however, this assumption may not always hold. This variation in directional flow has the potential increase the flow to "a velocity sufficient to detach and transport soil particles" (Department of Natural Resources, 2006). These detached soil particles then continue to travel in the direction of flow, which subsequently causes further erosion in areas downstream.

Splash erosion occurs when a water flow "strikes the ground surface, [and] the soil particles become loose and splashed due to its impact force" (Soil Management India, 2017). The majority of the damage is caused by the "momentary build-up of the pressure gradient towards the edges" (Soil Management India, 2017) of the flow which effectively "disintegrates the soil" (Soil Management India, 2017) and dislodges the particles.

It is known that the effect of the flow is proportional to the kinetic energy it retains. When the flow of water strikes bare soil the soil splash[7] refracts into the air (Figure 2.12), "carrying with it, in [a] muddy splash, fine particles of earth" (Soil Management India, 2017).

[7] Soil Splash: When water flow strikes the ground surface, the soil particles become loose and splashed due to its impact force.

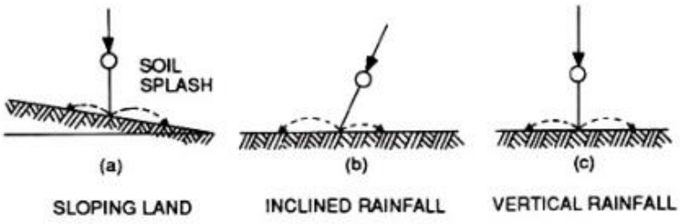

Figure 2.12. Effect of varying angles of incidence on soil splash (Magdalena Ryżak, 2015)

2.6.1. IRRIGATION INDUCED FURROW ERROSION

The action of furrow erosion is the redistribution of the fields topsoil by "eroding upper ends of fields and depositing sediment on downslope portions causing a several fold topsoil depth difference on individual fields" (D. L. Carter, 1984). As majority of irrigation furrows are long enough to incorporate the three major phases of erosion (detachment, transport and deposition) there seems to be no discernible uniformity between furrows. Although there is obvious variation between soil varieties as well as the associated shear capacity of the respective soil there are several known elements which impact the influence of furrow erosion "including inflow rate, slope and soil type" (Giráldez, 2004).

Although the erosion throughout the field itself is somewhat predictable the erosion of the initial rotorbuck[8] is far more difficult to predict. This lack of information results in heavy maintenance throughout the irrigation season equating to time lost on higher priority issues. Although it is a common and reoccurring issue throughout majority of siphon irrigated land there has been minimal investigation into the potential causes. The effects of the outflow as well as the associated flow characteristics and siphon location would provide grounds for further research, however for the purpose of this dissertation it is considered to be outside the scope of works.

[8] Rotorbuck: The initial embankment of soil used to direct the siphon outflow toward the field.

2.7. LITERATURE OVERVIEW

For the purpose of this report the previous literature review was conducted in order to achieve a background knowledge into the research objectives as defined below:

1. Examine and define the ISLEX Smart Siphon as well as provide background into the practical use of the Siphon.
2. Evaluate the hydraulic performance of the smart siphon through practical measurement in a controlled environment.
3. Generation of rating tables and equations to predict the flow rate from operating head and pipe characteristics.

If time and resources permits

4. Propose and test improved designs to reduce runoff effects.
5. Collate observations on the performance of the smart siphon including erosion potential.
6. Design an experiment to study the erosion downstream of siphons and smart siphons.

Objective 1 is explained further in the following section however the use of the ISLEX Smart Siphon was generally defined as a potential solution to the labour shortage throughout rural QLD and NSW. The use of siphons as in irrigation method was also investigated including the areas predominately using furrow irrigation as a major technique. Section 2.4 investigating the single phase flow through a closed conduit provides the hydrological background required to understand the analysis methodology used for the conduct of the testing. The use of Bernoulli's equation defines that within a hydraulic system the transfer of energy remains constant that therefore it is accurate to assume that the flow through the system will be constant (with the assumption of minimal fluid losses within the system) and is then reinforced within section 2.5.

The final section, 2.6, defines the potential for erosion throughout the system including a general overview into how erosion is created by fluid flow as well as the more detailed erosion produced by irrigation through a furrow. Although the achievement of these objectives is subject to time constraints, the background information into the erosion reaction from siphon irrigation could provide some background information into further research opportunities.

3. **METHODOLOGY**

3.1. OBJECTIVE OUTLINE

In order to achieve the aims and objectives of the dissertation the following tasks must be accomplished:

1. Background information gathered
2. Design of experiment
3. Conduct of siphon testing
4. Tabulation and analysis of data

The Smart Siphon system itself is relatively simple in its design and uses the concept of hydrostatic pressure to increase or decrease the flow rate throughout the system. While the Siphon Entry is raised (Figure 3.1) the water cannot flow through the system, therefore the flow is able to move to the surrounding bays which may be irrigated at the same time.

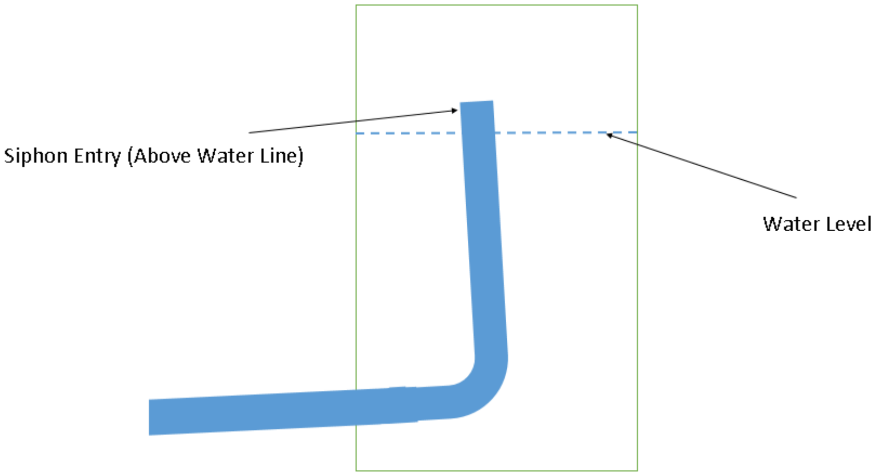

Figure 3.1. Smart Siphon Entry Raised.

Once the Siphon entry head has lowered (Figure 3.2) the flow of water is free to flow through the system as a result of the build up hydrostatic pressure.

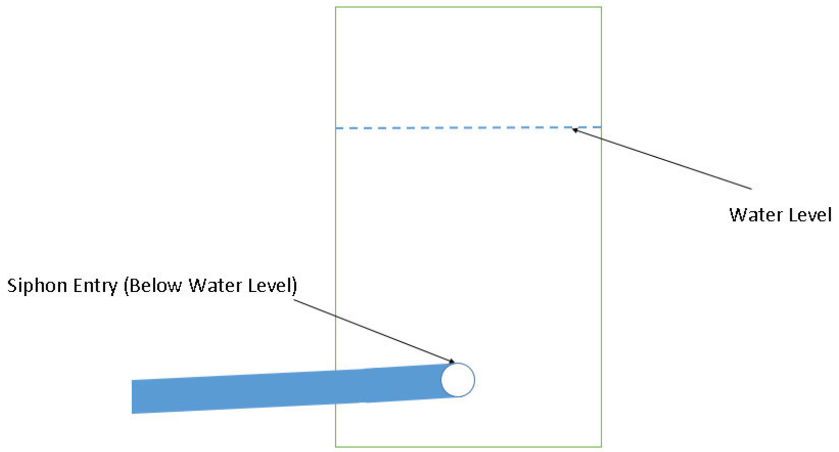

Figure 3.2. Smart Siphon Entry Lowered

3.1.1. BACKGROUND INFORMATION

In order to provide an accurate account of issues currently faced in the field there must be a standardised benchmark to analyse against. Further to this, an understanding of the general flow conditions throughout the field is required in order to accurately simulate the conditions and maximise testing effectiveness.

The collection of this information will largely be conducted via communication with the Managing Director of ISLEX Plastics. Interviews will be conducted in hope that it will provide well-rounded feedback on the use of the siphons, installation methods used, and technical data on the flow characteristics upstream of the siphon prior to entering the field.

3.1.1.1. THEORETICAL RESULTS

To understand issues that may arise and appreciate that the testing results are generally correct a theoretical set of results is required. These results should include a rating curve which largely corresponds to the recorded practical. It should be noted however that it is likely that the practical experiment will display some outlying results which will not correlate with the theorised results. For the purpose of a hypothetical analysis of the system there is an analytical analysis of the system required.

It is assumed that the system can be treated as a steady flow of an incompressible fluid through a pipeline or conduit. Under this assumption, there should there be no issues with components such as the varying head levels or the pipe dimensions accuracy. Hence, the design of the system, which can be seen in Figure 3.3, is proposed.

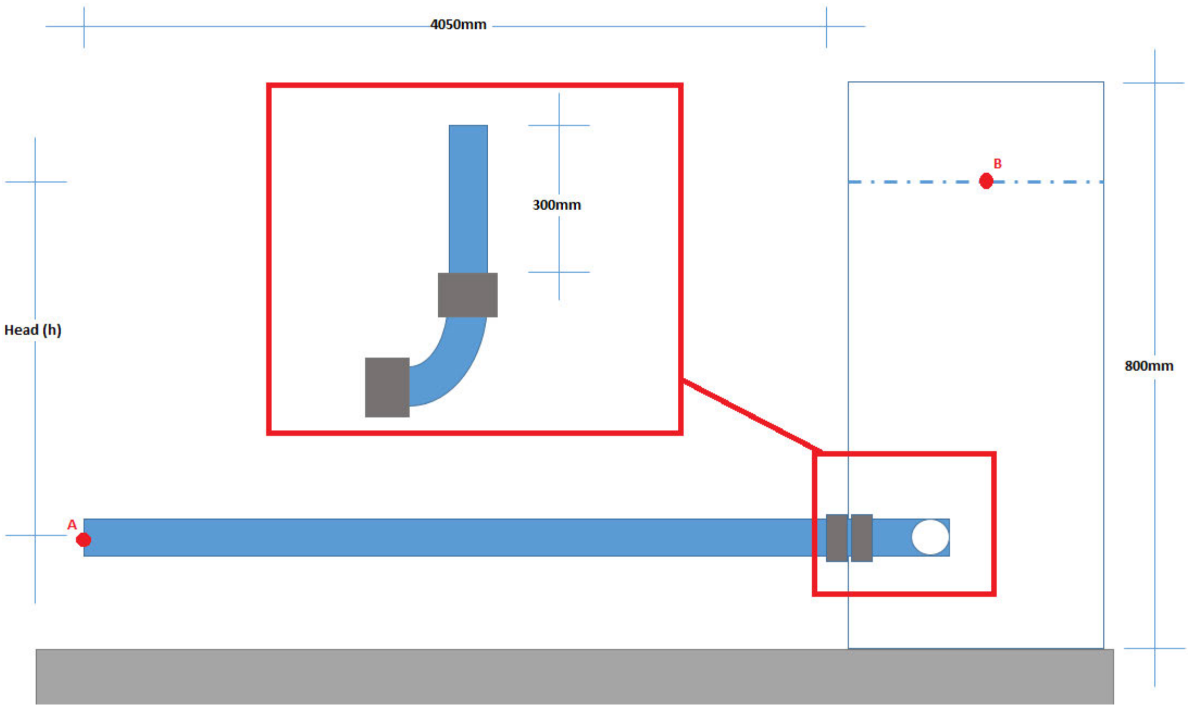

Figure 3.3. Theoretical Analysis Assumption.

Now under this assumption we can apply Bernoulli's principle to the system, seen in Equation 20

$$\frac{p_A}{\rho g} + \frac{V_A^2}{2g} + Z_A = \frac{p_B}{\rho g} + \frac{V_B^2}{2g} + Z_B - h_f - h_m$$

Equation 20: Bernoulli's Principle

Through analysing the system it is understood that the following figures equate to zero for the following reasons:

$p_B = p_A = 0$ Water surface at B and free outflow discharge at A both equal zero.

$V_B = 0$ There is no flow velocity at the surface.

$Z_A = 0\ m$ Difference in head is zero.

Therefore, the resultant simplified equation is shown in Equation 21.

$$Z_B = \frac{V_A^2}{2g} - h_m - h_f$$

Equation 21. Bernoulli's Re-Arranged to solve for ΔZ

Since we are trying to solve for the flow rate, Q, it is necessary to transform each component of the equation into terms that are consistent with the flow rate.

Now transferring each equation into terms of Q it is known that Equation 22, Equation 23 and Equation 24 hold the following formations:

$$\frac{V_A^2}{2g} = \frac{8Q^2}{\pi^2 D^4}$$

Equation 22. Velocity Head in terms of Q

$$h_m = \frac{\sum k\, V^2}{2g} = \sum k \frac{8Q^2}{\pi^2 D^4}$$

Equation 23. Minor Losses in terms of Q

$$h_f = \frac{flV^2}{2gD} = \frac{8flQ^2}{g\pi^2 D^5}$$

Equation 24. Friction Head in terms of Q

Subsequently we can substitute the respective values above into the previously simplified Bernoulli's Equation 20. As such, the following simplification occurs:

$$Z_B = \frac{8Q^2}{\pi^2 D^4} - \sum k \frac{8Q^2}{\pi^2 D^4} - \frac{8flQ^2}{g\pi^2 D^5}$$

$$Z_B = Q^2 \left(\frac{8}{\pi^2 D^4} - \sum k \frac{8}{\pi^2 D^4} - \frac{8fl}{g\pi^2 D^5} \right)$$

$$Q = \sqrt{\frac{Z_B}{\left(\frac{8}{\pi^2 D^4} - \sum k \frac{8}{\pi^2 D^4} - \frac{8fl}{g\pi^2 D^5} \right)}}$$

Equation 25. Resolved Flow Rate Solution

A similar process is enacted to determine the friction factor. By utilising the Moody diagram in Figure 2.6. Moody Diagram for the above system, we find the following is true.

$$Re = \frac{VD}{\nu} = \frac{4Q}{\pi D \nu}$$

Equation 26. Reynolds Number

$$Relative\ Roughness = \frac{k}{D}$$

Hence, we can solve for the flow rate out of the system and thereby solve for the flow velocity and other characteristics within the system.

3.1.1.2. RESULTS ANALYSIS

Following the conduct of the testing there was an apparent requirement to analyse the raw data and transfer this data into usable information. For the purposes of the experiment it is assumed that the unknown value throughout the system is the loss coefficient of the respective designated location for implementation. It is assumed that the unknown losses throughout the experiments are as follows:

Restriction	Entry Size	Unknown Loss	Comment
No Restriction	79mm	Elbow Join	Baseline Test
12.56mm	66.44mm	Entry Loss	
16mm	63.00mm	Entry Loss	
18.78mm	60.22mm	Entry Loss	
Nill	68.38mm	Elbow Joint	68.38mm Riser
Nill	54.00mm	Elbow Joint	54.00mm Riser
Nill	40.10mm	Elbow Joint	40.10mm Riser
Nill	40.22mm	Entry Loss	Spiral Entry Pattern
Nill	54.58mm	Entry Loss	Spiral Entry Pattern
Nill	69.00mm	Entry Loss	Spiral Entry Pattern
Nill	78.58mm	Entry Loss	Spiral Entry Pattern

Table 3.1. Loss Unknowns Compared to Restriction Type

In order to solve for these unknown loss coefficients, it is proposed that the root mean squared error (RMSE) is calculated throughout the data. Following this, the loss coefficient can then be solved for via Excel by objectively minimising the RMSE and reducing the error. Hence, the most accurate loss coefficient is derived.

3.1.1.3. COMPUTATIONAL FLUID DYNAMICS TESTING

In order to understand the experimental results a Computational Fluid Dynamics (CFD) test of the siphon and respective restrictors is conducted by IGNI Ferroque Consulting Engineers. The test is designed to display where major fluctuations in flow velocity and pressure throughout the system occur. Additionally, this test will highlight areas where there may be flow disruptions, which in turn may decrease the flow rate or pressure throughout the system.

3.1.1.3.1. CFD TESTING CONDITIONS

For the purpose of the CFD testing two sized Smart Siphons were investigated, a 75mm Diameter and a 90mm Diameter. During the initial design proposal (at the time of the CFD testing) ISLEX were investigating the possibility of using a 75mm variant, hence it has been included in the testing regime. Further to these siphon types, ISLEX also requested an analysis of the effectiveness of applying restriction 'plates' to the entry of the siphon with three options modelled : no restriction, 67.7mm and a 45.3mm restriction. As the practical testing to be conducted does not investigate a 75mm Siphon the results are disregarded for the purpose of this report.

3.1.1.3.2. 90mm SMART SIPHON CFD TESTING RESULTS (250mm Head)

The CFD testing results for the unrestricted 90mm Smart Siphon displayed a minute increase in velocity at entry (as expected) however it was evident that the high velocity was lost once the flow reached the elbow connection (Figure 3.4). The flow velocity appears to be relatively constant across the entire area of the siphon with no apparent flow velocity increases (Figure 3.5).

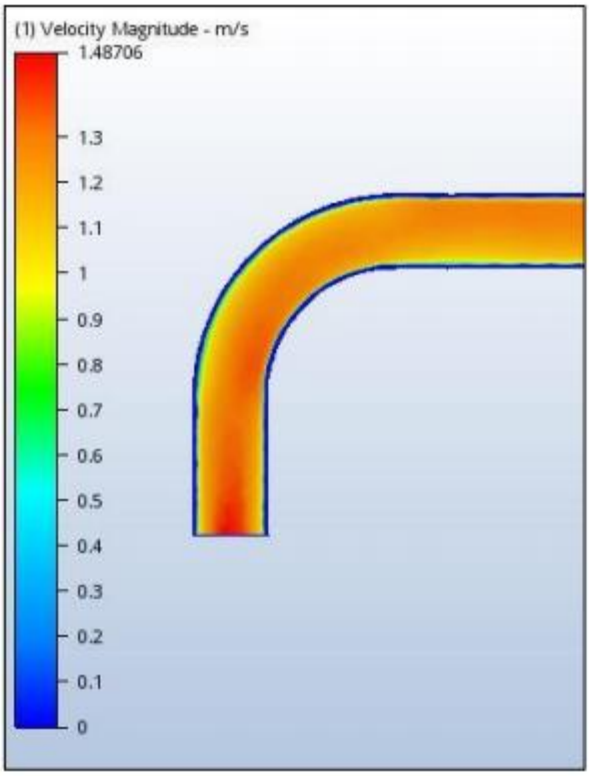

Figure 3.4. CFD Velocity at inlet of 90mm Smart Siphon under 250mm Head (Green, 2016)

Figure 3.5. 90mm Smart Siphon CFD Flow Profile (Green, 2016)

The second CFD testing results for the 67.7mm restriction applied to the 90mm Smart Siphon displayed a significant jump in velocity at entry (Figure 3.6), however the velocity throughout the remainder of the siphon is significantly reduced (averaging approximately 1.05 m/s). The flow velocity appears to be relatively constant across the entire area of the siphon with no apparent flow velocity increases or decreases which also provides evidence that there is no significant pressure variations (Figure 3.7).

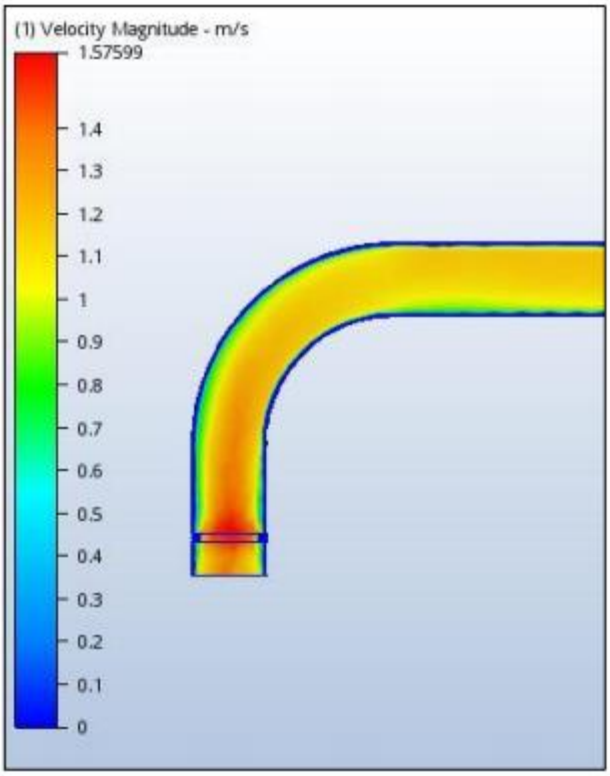

Figure 3.6. CFD Velocity at inlet of 90mm Smart Siphon (Restricted to 67.7mm) under 250mm Head (Green, 2016)

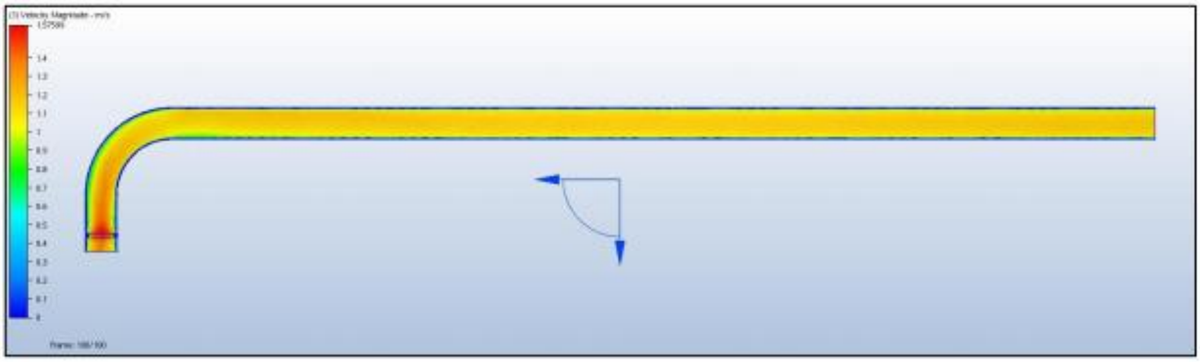

Figure 3.7. 90mm Smart Siphon (Restricted to 67.7mm) CFD Flow Profile (Green, 2016)

The final CFD testing under 250mm head are the results for the 45.3mm restriction applied to the 90mm Smart Siphon. This displays a major jump at the inlet (Figure 3.8), resulting in a maximum velocity of 2.50 m/s, however the velocity throughout the remainder of the siphon is substantially reduced (averaging approximately 0.8 m/s). The flow velocity appears to be relatively constant across the entire area of the siphon with no apparent flow velocity increases or decreases which also provides evidence that there is no significant pressure variations (Figure 3.9).

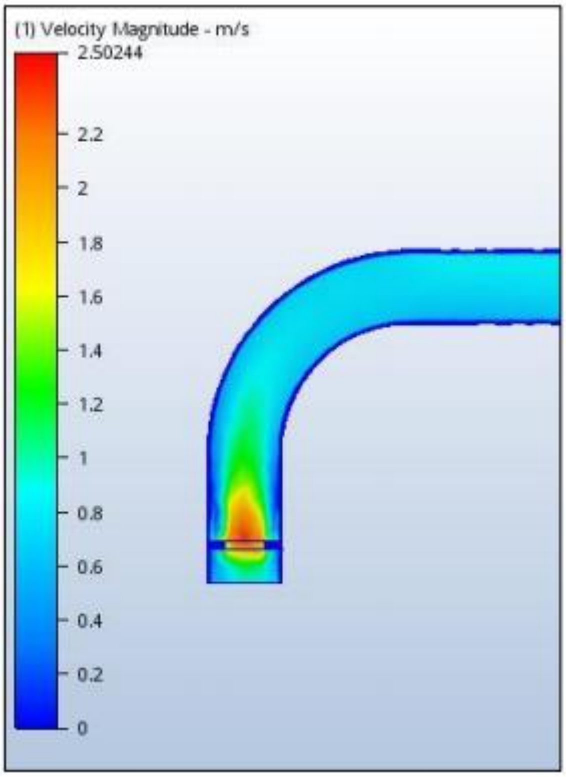

Figure 3.8. CFD Velocity at inlet of 90mm Smart Siphon (Restricted to 45.3mm) under 250mm Head (Green, 2016)

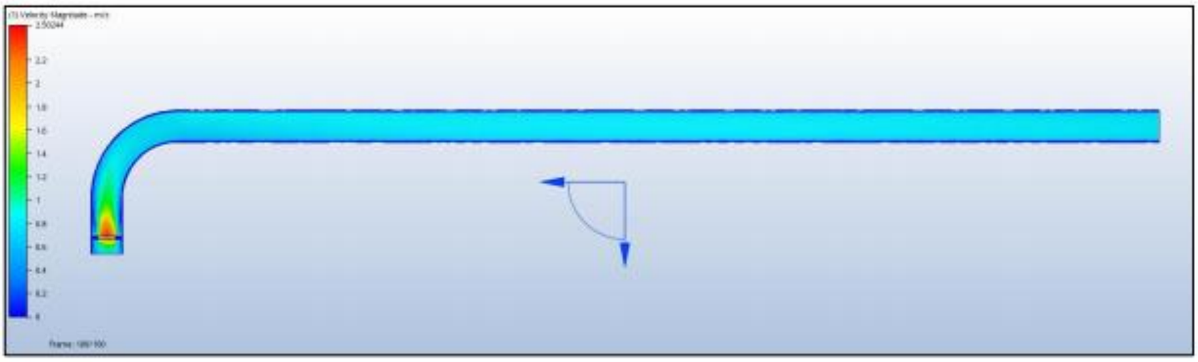

Figure 3.9. 90mm Smart Siphon (Restricted to 45.3mm) CFD Flow Profile (Green, 2016)

3.1.1.3.3. 90mm SMART SIPHON CFD TESTING RESULTS (500mm Head)

The CFD testing results for the unrestricted 90mm Smart Siphon under 500mm head displayed minimal increase in velocity at entry however it was evident that there was a velocity increase on the inside wall of the elbow joint before the velocity dissipated through the remainder of the siphon

(Figure 3.10). The flow velocity appears to be relatively constant across the entire area of the siphon with no apparent flow velocity increases (Figure 3.11) however the average velocity throughout the remainder of the siphon is generally larger when compared against Figure 3.4.

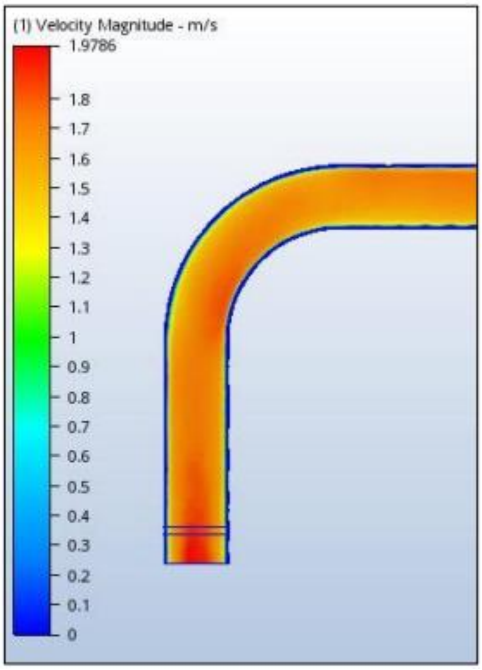

Figure 3.10. CFD Velocity at inlet of 90mm Smart Siphon under 500mm Head (Green, 2016)

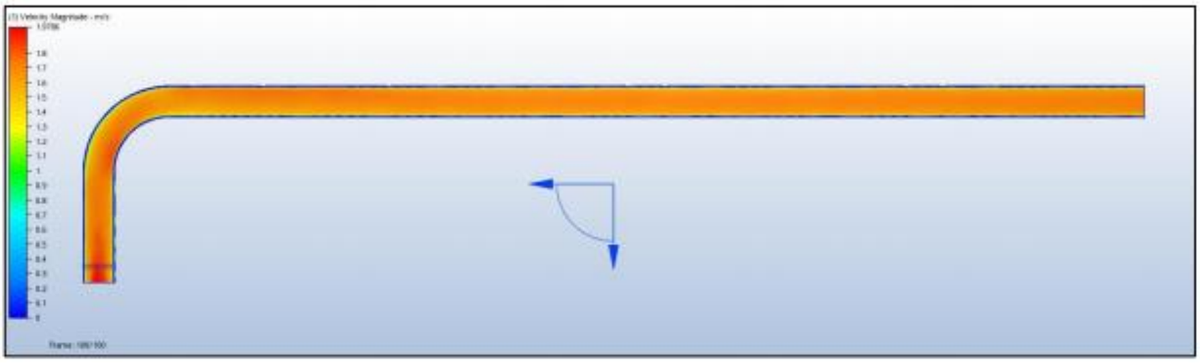

Figure 3.11. 90mm Smart Siphon CFD Flow Profile under 500mm head (Green, 2016)

The CFD testing results for the 90mm restricted to 67.7mm Smart Siphon under 500mm head displayed an increase in velocity at entry however the velocity dissipated through the remainder of the siphon (Figure 3.12) extremely quickly. The flow velocity appears to be constant across the entire area of the siphon with no apparent flow velocity increases (Figure 3.13) throughout the remainder of the siphon.

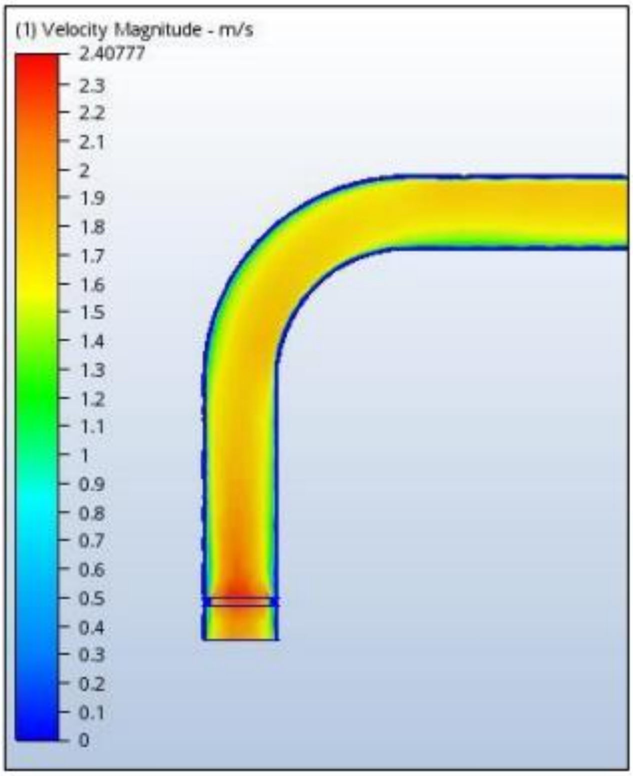

Figure 3.12. CFD Velocity at inlet of 90mm Smart Siphon (Restricted to 67.7mm) under 500mm Head (Green, 2016)

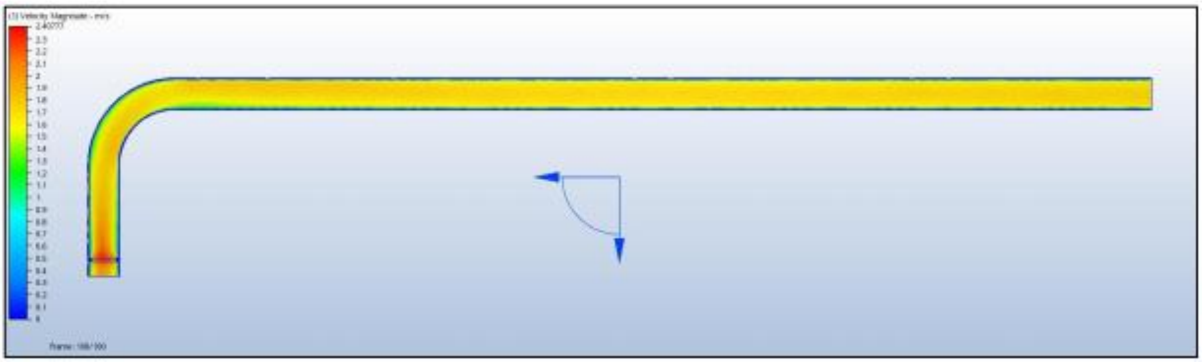

Figure 3.13. 90mm Smart Siphon (Restricted to 67.7mm) CFD Flow Profile under 500mm head (Green, 2016)

The CFD testing results for the 90mm restricted to 45.3mm Smart Siphon under 500mm head displayed an massive increase in velocity (Figure 3.14) reaching 3.38 m/s at entry, however the velocity dissipated through the remainder of the siphon (Figure 3.15) extremely quickly dropping down to approximately 1.1m/s.

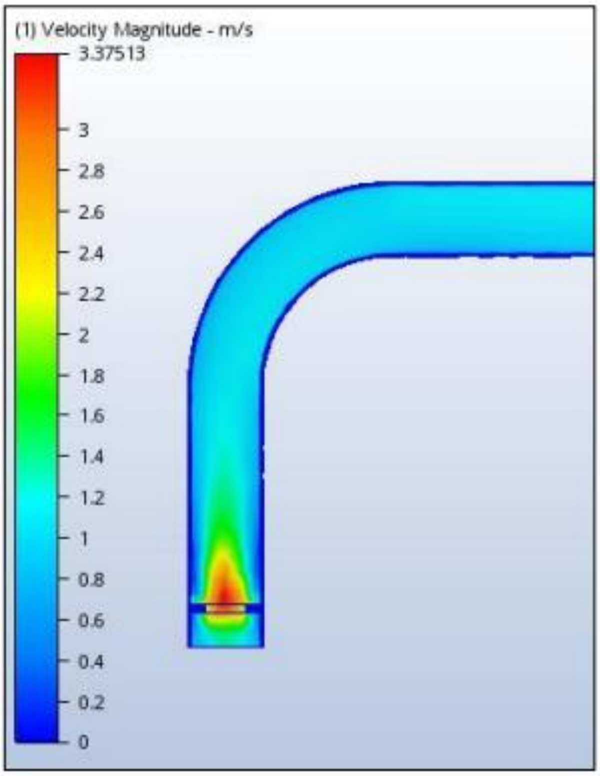

Figure 3.14. CFD Velocity at inlet of 90mm Smart Siphon (Restricted to 45.3mm) under 500mm Head (Green, 2016)

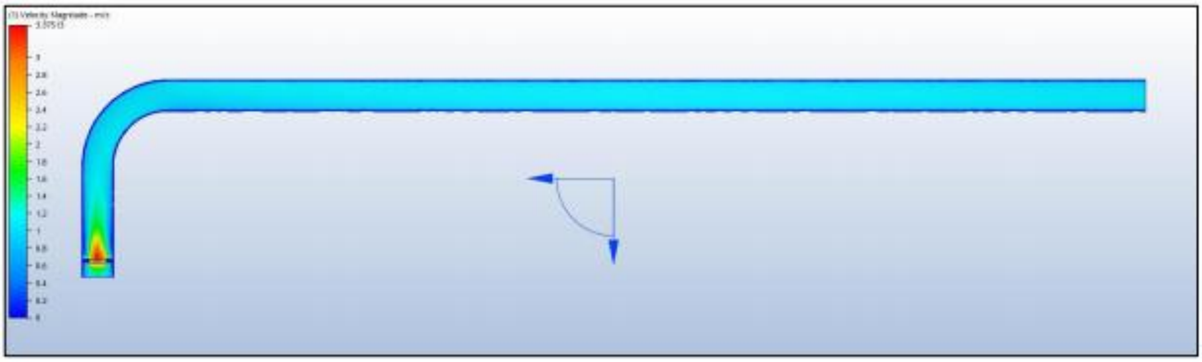

Figure 3.15. 90mm Smart Siphon (Restricted to 45.3mm) CFD Flow Profile under 500mm head (Green, 2016)

3.1.1.3.4. CFD TESTING RESULT COMPARISON

Overall the application of the restrictor plates performed the required task of reducing the average flow velocity throughout the system when analysed through CFD techniques. With that in mind the resulting data provides little insight into the reaction of the Smart Siphon under varying head levels as well as multiple restrictor sizes. The results do however provide a dataset which can be compared against once solutions to the practical testing are known.

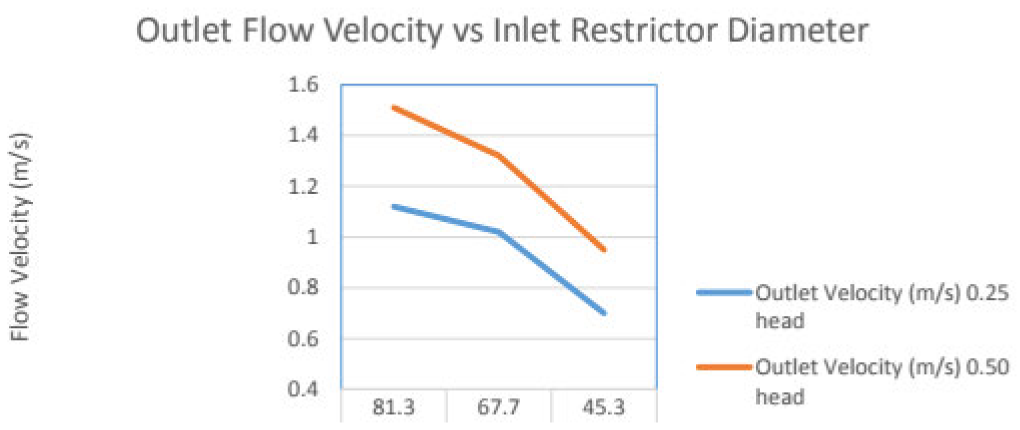

Figure 3.16. Outlet Velocity Vs Restrictor Diameter (Green, 2016)

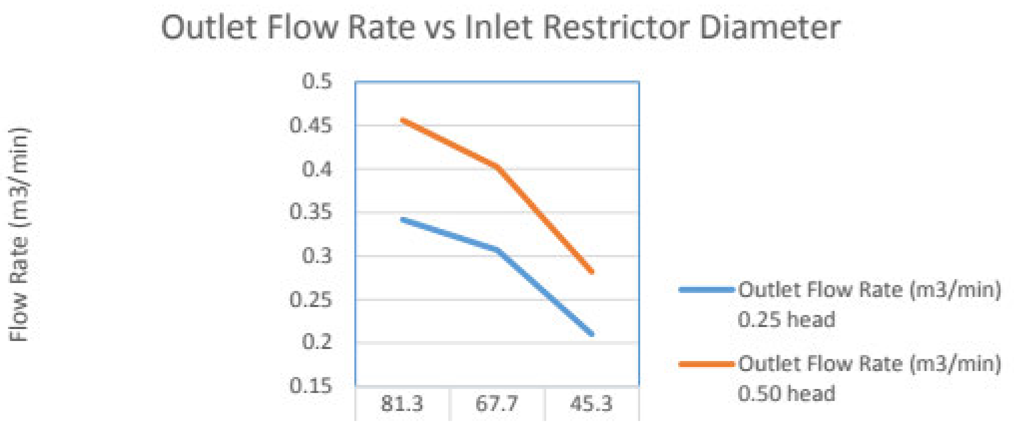

Figure 3.17. Outlet Flow Rate Vs Inlet Restrictor Diameter (Green, 2016)

The tests (Figure 3.16 and Figure 3.17) do show a definitive correlation between the use of restrictors and the reduction in flow rate, however a sample of three tests does not provide adequate data to compare a range of restrictors are varying head levels.

3.1.2. EXPERIMENT DESIGN

In order to ensure test accurately, there must be a sufficient control over the conditions. This control must include the ability to maintain constant head levels throughout the entire testing time as well as monitoring the channel flow rate. The channel flow rate, although only to be used in one of the three testing objectives, has the potential to provide detailed insight into the effects of the siphon once submerged in water.

The testing of the mechanism itself is relatively simple since the entire system is situated within a single enclosure. This enclosure has the capacity to accurately maintain a constant head level.

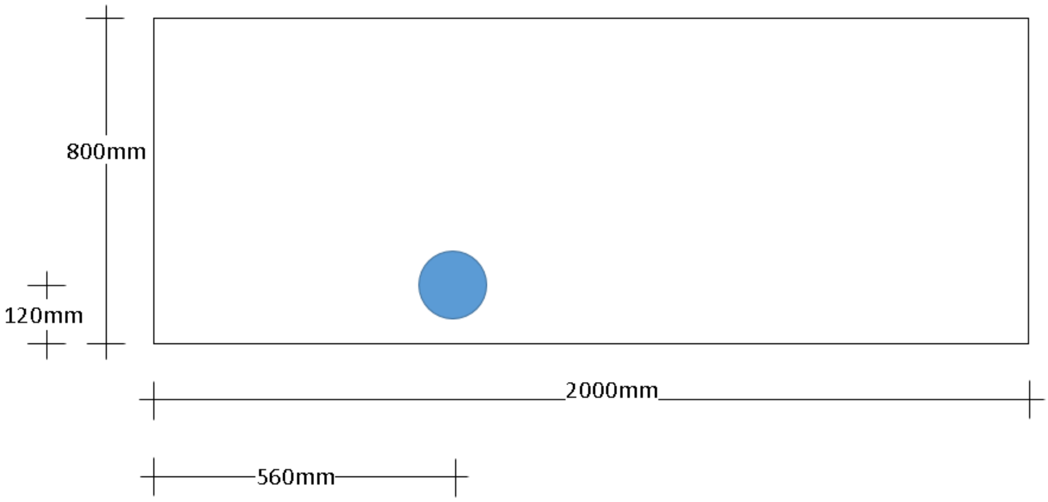

Figure 3.18. Front view of testing rig.

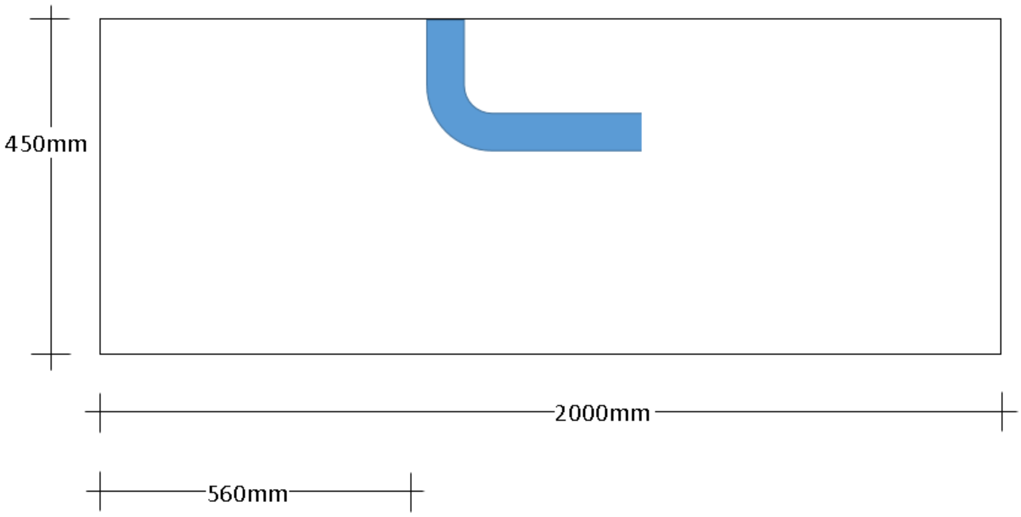

Figure 3.19. Top view of testing rig incorporating lowering elbow.

Since the outlet pipe is expected to be approximately 3.2 meters long, it is expected that the difference in displacement between the top of the water level and the outlet location is understood (Figure 3.20).

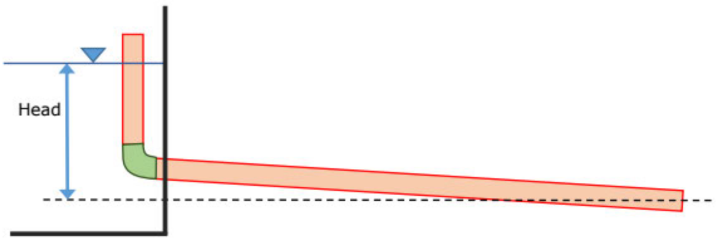

Figure 3.20. Variation in pipe outlet and water height.

It is assumed that the pipe will not be level and instead be resting on the ground and that the water head will be measured from a reference point which is located on the testing tank. A correction factor also needs to be included to achieve the required head measurements.

Throughout the system there is expected to be three major loss locations which are illustrated in Figure 3.21. Major loss locations.

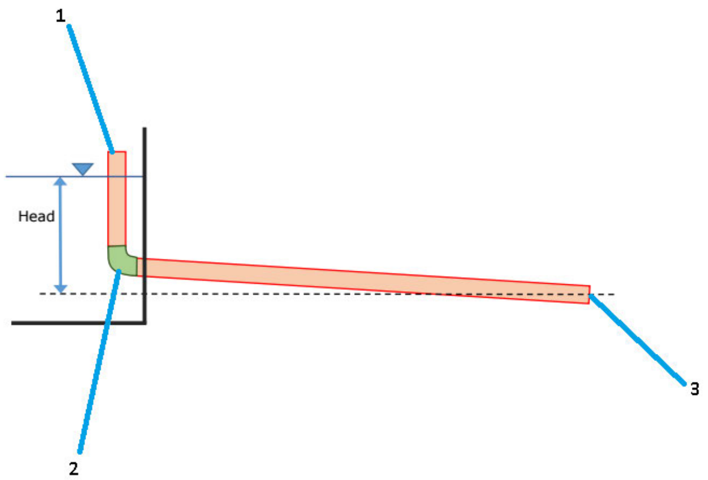

Figure 3.21. Major loss locations.

These major loss locations are expected to be analysed and effectively solved for as follows:

Loss One Location – Entry Losses

- All Restriction Insert Tests

Loss Two Location – Elbow Joint Losses

- Initial Baseline Test (In order to achieve assumed loss coefficient for the location)
- Extended Restriction Riser Tests (As the assumed loss at location One = 1)

Loss Three Location – Exit Loss

- Assume 1.0 throughout every test as free outflow is obtained.

3.1.3. SIPHON TESTING

The testing of the siphons will be broken into three testing objectives:

1. The effect of channel flow velocity on the siphon entry;
2. The effect of the addition of area restrictors at the siphon entry on the outlet flow and velocity; and
3. The effect an additional spiral pattern at the siphon entry, effectively doubling the inflow area.

These tests have been selected since they have been identified throughout a number of trial studies as areas with discrepancy.

Initially, there will be a baseline test which will provide grounding for the remainder of the tests. This will act as a reference point when making further assumptions on the effectiveness of the processes to be applied. The testing will be entirely conducted within the University of Southern Queensland's Hydraulics Laboratory, and all tests will be uniformly operated.

Since the majority of the testing focuses on the addition of elements to the siphon entry, it will be assumed that the friction applied by the remainder of the system (via the elbow joint and siphon pipe) is a constant and will not vary significantly.

3.1.3.1 BASELINE TESTING

This initial test will be conducted using the unaltered entry pipe and no flow is to be considered within the channel. The testing aims to provide a basis for the remainder of the experimental results since it will provide practical data on the flow rates and friction effects of the system. The testing is to be conducted at head levels ranging from 100mm through to 500mm at 50mm intervals. This will provide a steady flow rate and can be used for comparison against the remaining analysis. These primary test results will be the product of the hydrostatic pressure applied to the pipe entry at each of the various head levels.

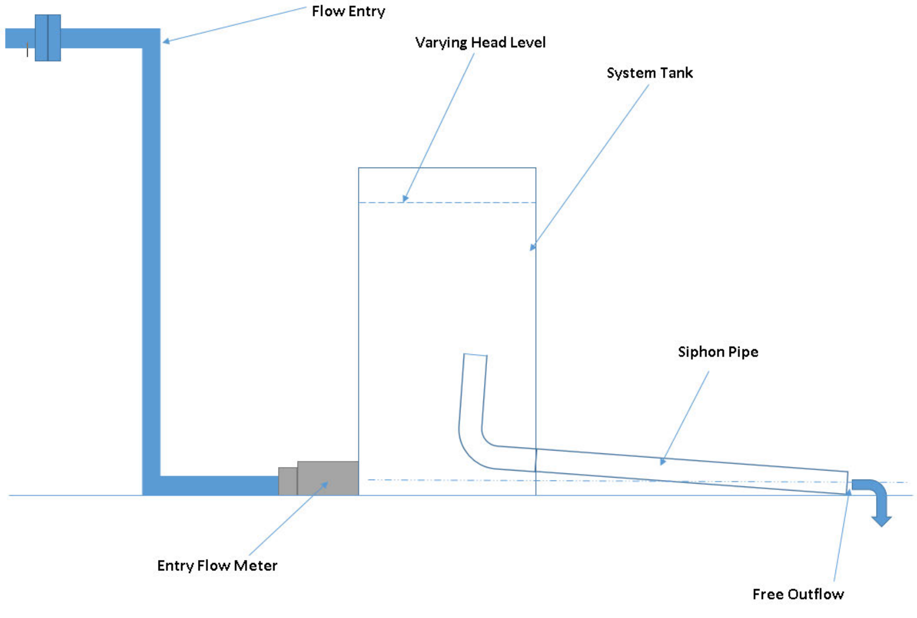

Figure 3.22. Baseline Testing Setup

3.1.3.2 THE EFFECT OF CHANNEL FLOW VELOCITY ON SIPHON ENTRY DIRECTION

This test is expected to define the effects of a channel flow velocity which may be running with or against the entry of the siphon entry. The test is proposed to be run at a constant head level of 400mm and the effects of the flow will be noted at separate locations along a field with 200 pipes. These locations and effects are proposed to be taken as follows:

- Pipe 1 – Effective flow of 200 open siphons traveling within channel (2.39291 m/s)
- Pipe 50 – Effective flow of 150 open siphons traveling within the channel (1.79469 m/s)
- Pipe 100 – Effective flow of 100 open siphons traveling within the channel (1.19646 m/s)
- Pipe 150 – Effective flow of 50 open siphons traveling within the channel (0.59823 m/s)
- Pipe 200 – Assuming there is no channel flow at this point (0 m/s)

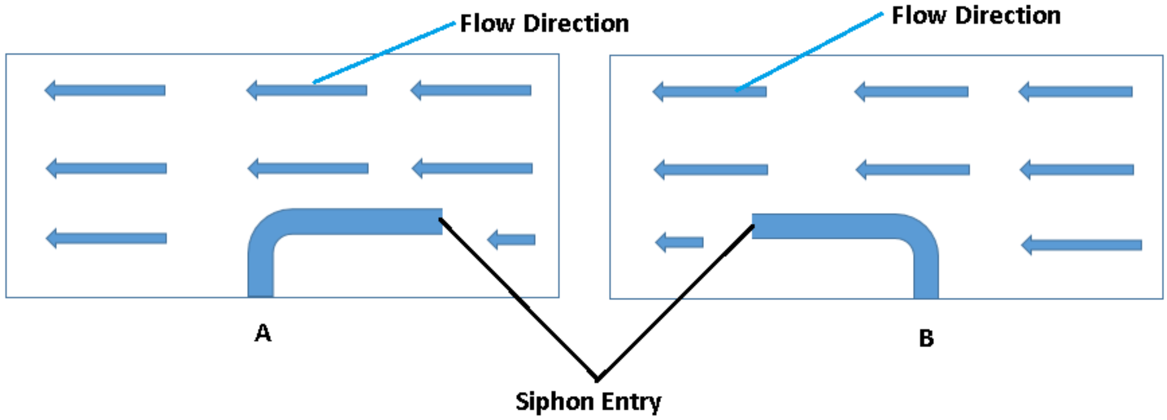

Figure 3.23. Plan view of testing Pipe Direction compared to flow

It is theorised that if the siphon entry is facing upstream (Figure 3.23. Plan view of testing Pipe Direction compared to flow, A) there will be an increase in outlet flow rate. Conversely, when the siphon entry is facing downstream (Figure 3.23, B) there is a comparative decrease in the flow rate. This theory will be carried out on the full pipe and there will be no inclusion of restrictors.

3.1.3.3 EFFECTS OF RESTRICTOR ADDITION AT SIPHON ENTRY

Similar to the baseline method, further testing will be conducted to analyse the effect of hydrostatic pressure when applied to the entry of the siphon. Such restriction is hypothesised to decrease the exit flow rate and effectively reduce the flow velocity at the exit point. The entry flow velocity will be measured and compared against the exit flow velocity and the exit flow rate. This should provide an accurate insight into the analytical friction coefficients as compared to the measured friction head loss throughout the system. The testing is to be conducted under the following varying restriction measurements:

- **No Restriction on Entry** – Flow rate measured at 50mm intervals from 100mm head through to 500mm head. (Reference Figure 3.24. Inlet Diagram and Section: No Restrictor Applied)
- **Entry Restricted to 66.44mm** – Flow rate measured at 50mm intervals from 100mm head through to 500mm head. (Reference Figure 3.25. Inlet Diagram and Section: Entry Restricted to 66.44mm Diameter)
- **Entry Restricted to 63.00mm** – Flow rate measured at 50mm intervals from 100mm head through to 500mm head. (Reference Figure 3.26. Inlet Diagram and Section: Entry Restricted to 63.00mm Diameter)
- **Entry Restricted to 60.22mm** – Flow rate measured at 50mm intervals from 100mm head through to 500mm head. (Reference Figure 3.27 Inlet Diagram and Section: Entry Restricted to 60.22mm Diameter)

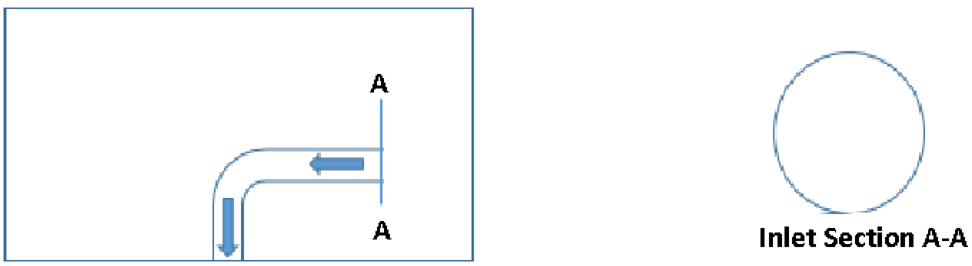

Figure 3.24. Inlet Diagram and Section: No Restrictor Applied

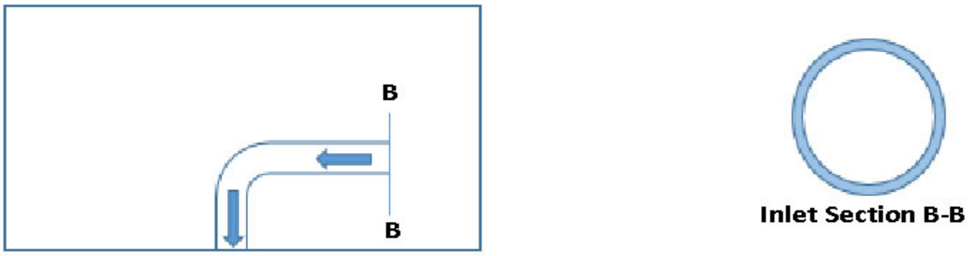

Figure 3.25. Inlet Diagram and Section: Entry Restricted to 66.44mm Diameter

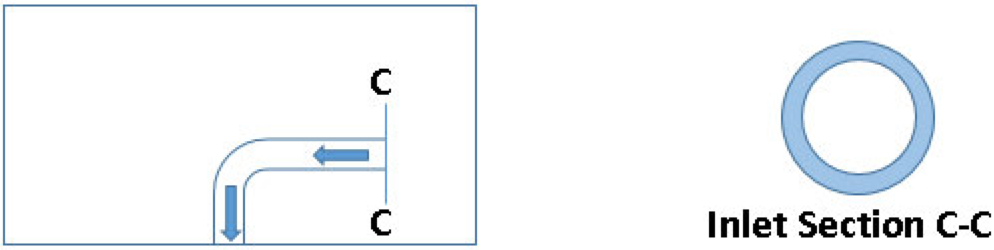

Figure 3.26. Inlet Diagram and Section: Entry Restricted to 63.00mm Diameter

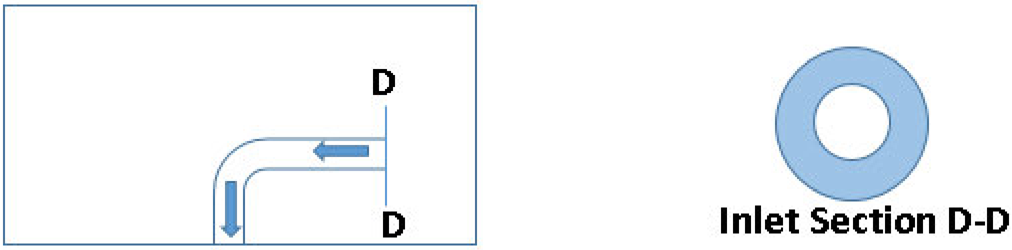

Figure 3.27 Inlet Diagram and Section: Entry Restricted to 60.22mm Diameter

The addition of the restrictors will create a sudden expansion within the system which, in theory, should produce a significant pressure head. This large pressure head should result in a decreased pressure throughout the remainder of the system.

3.1.3.4 EFFECT OF ADDITIONAL SPIRAL PATTERN APPLIED TO SIPHON ENTRY

The next series of testing will incorporate a spiral entry pattern applied to the entry of the siphon system. The addition of the spiral pattern will increase the effective surface area in which the water is allowed to enter the system (Figure 3.28). The addition of this entry surface area will theoretically reduce the entrance velocity and, in turn, reduce the losses at the elbow joint and also the friction losses throughout the system. The results of these spirals will be compared to the baseline tests to identify what effective outcomes.

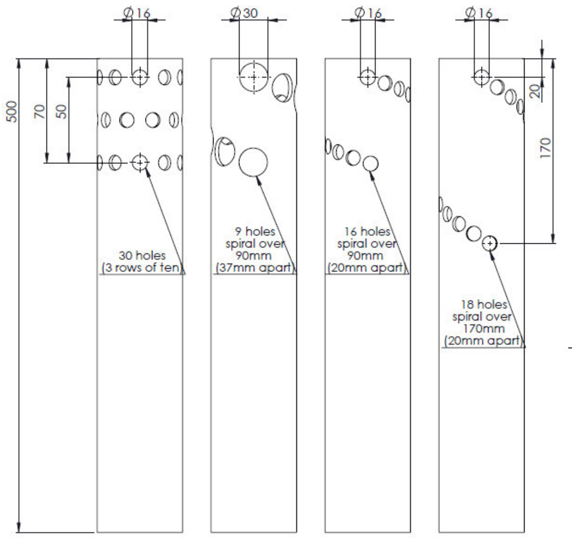

Figure 3.28. Spiral Entry to Siphon (ISLEX, 2016).

3.1.3.5 EFFECT OF RISER RESTRICTION APPLIED TO SIPHON ENTRY

The final series of tests will be conducted on the effect of additional restriction of the siphon entry riser. Restriction of the siphon entry will increase the velocity throughout the initial segment of the system and effectively increase the loss coefficient effect. The additional riser restriction is projected to transfer any unknown loss coefficients to the elbow joint, thus providing an insight into the flow particulars through the area. The testing is to be conducted under the following restriction conditions:

- **Riser Restricted to 68.38mm** – Flow rate measured from 100mm head through to 700mm head. (Reference Figure 3.29)
- **Riser Restricted to 54.00mm** – Flow rate measured from 100mm head through to 700mm head. (Reference Figure 3.30)
- **Riser Restricted to 40.10mm** – Flow rate measured from 100mm head through to 700mm head. (Reference Figure 3.31)

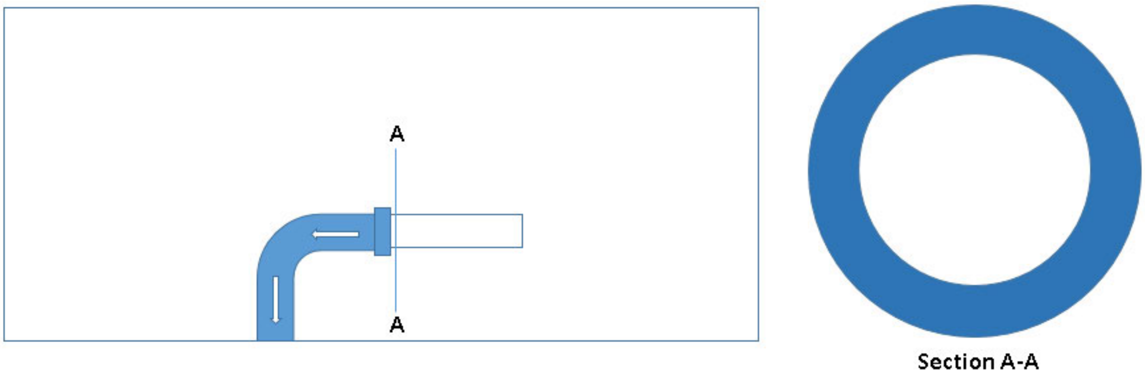

Figure 3.29. Inlet Diagram and Section: Entry Riser Restriction to 68.38mm

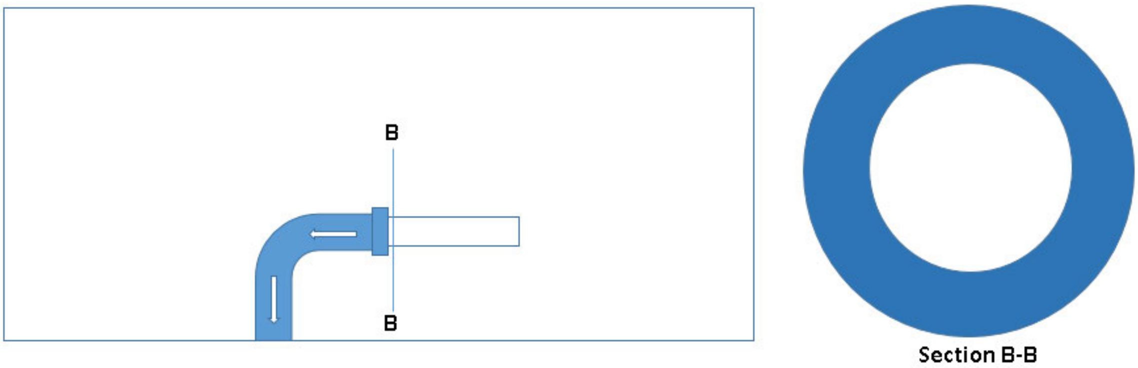

Figure 3.30. Inlet Diagram and Section: Entry Riser Restriction to 54.00mm

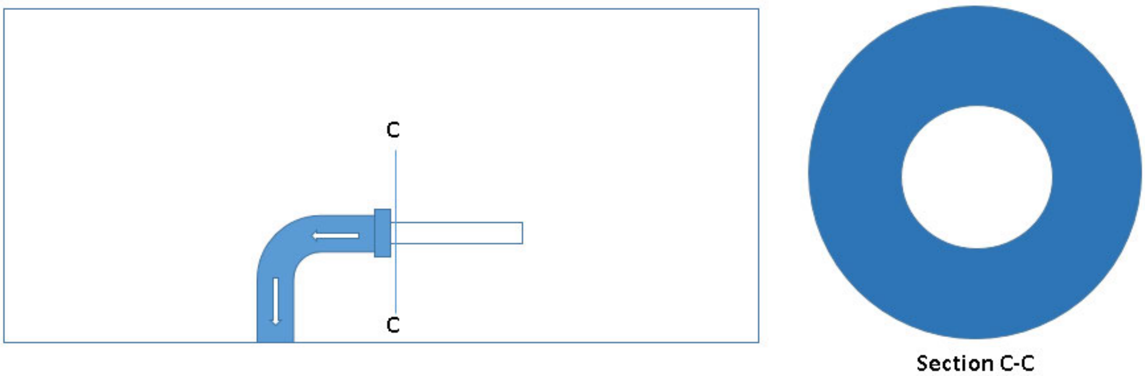

Figure 3.31. Inlet Diagram and Section: Entry Riser Restriction to 40.22mm

3.1.4. COLLECTION OF TECHNICAL DATA

Throughout all of the testing phases, data regarding the flow velocities and rates throughout the system will be collected. Hence, a single stationary flow meter location is defined to be at the exit of the system. This flow meter will provide data, at constant intervals, about the exit flow rate of the system throughout each test. The flow meter is not directly attached to the system to avoid interference with the friction coefficients, hence providing a flow rate reading without effecting the remainder of the system.

The second means of collecting data will be done through the use of the SonTek FlowTracker2. This device provides accurate flow velocity readings with a three-dimensional capacity, such that it describes velocities in the x, y and z directions (Figure 3.32). Although the use will predominantly be the velocity in a single direction, there is the potential to use results to further understand the variation in flow throughout the elbow section.

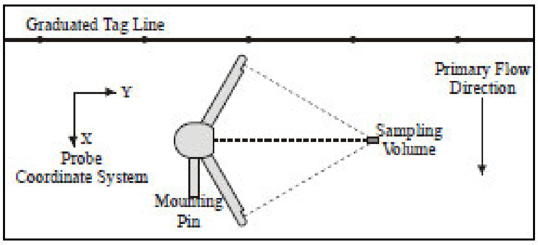

Figure 3.32. FlowTracker Velocity Sample (SonTek Quickstart Guide)

The data collection is conducted through the use of an acoustic transmitter and two receivers (Figure 3.33). This velocity data will be obtained from a sample which is defined to be 6mm in diameter and 9mm in length. This allows finite velocity readings to be taken at various locations throughout the system. Further to this, it also monitors the flow rates to ensure that the correct channel flow rates are being applied to the entry of the siphon.

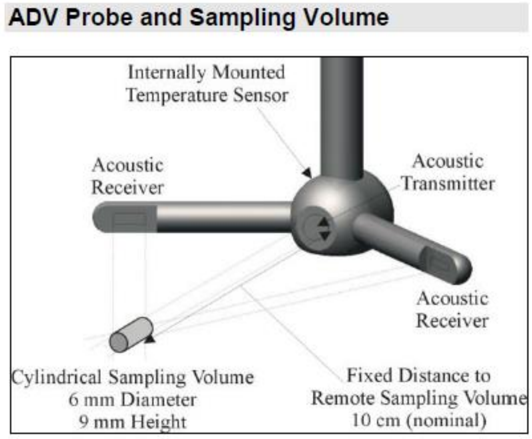

Figure 3.33. FlowTracker2 Velocity Probe (SonTek Quickstart Guide)

To further monitor this, a dedicated flow rate tracker will also be added within the system. Fortunately, for hydraulic systems the inward flow is equal to the outward flow and therefore the tracker can be placed anywhere in the system to gather the required data.

3.1.5. TABULATION AND ANALYSIS OF DATA

Data collection will occur consistently throughout the conduct of the experiments and this data will be entered into a prepared spreadsheet. . The spreadsheet facilitates data manipulation and the calculations described later in this section. Plotting the data enables easy identification of any outliers and provides an opportunity to identify and rectify potential problems which may cause issues while performing the more detailed analysis. Specifically, the flow rate and velocity data will be input into the worksheet to immediately provide detailed information on the resultant flow velocities, friction losses and the relationship between the operational head and resultant flow information. This data, although relatively trivial, is extremely important to the production and commercialisation of the Smart Siphon.

3.1.5.1. ANALYSIS OF TABULATED DATA

In order to understand the data, the tabulated data must be further analysed to formulate the installation and service recommendations. The recommendations aim to provide the installer and the manager with information on how to accurately and efficiently control the implementation of the siphon throughout the field. It should be noted that these recommendations are general in nature so that they can be applied across a range of soil types. Further to this, rectification recommendations could be provided regarding specified rows that are not running as efficiently as neighbouring rows.

Once the data has been analysed data it will be transformed into a form which can be used in practice. The optimal way to convey this information is via easily understood rating tables and graphs. The optimal way to convey this information is via easily understood rating tables and graphs. The most effective field use will be determined by comparing the flow rates of each modification type against the respective head levels. This comparison will produce a rating table which is both easy to follow and includes the required technical information. This concept of the rating table is explained further in Annex S where the 'Raw Data' of head height, cumulative totals at the beginning and end of the trial, and the time taken to obtain the sample, is recorded. Following this, the spreadsheet will automatically calculate the flow rate of the recorded time period, as well as the flow velocities at the entry location as well as the free outflow exit.

The tabulated results are then transferred to an analytical spreadsheet which incorporates the losses throughout the system, including all minor losses as well as the friction losses in both the inlet pipe as well as the PTB. In order to assign the correct loss coefficient to the respective test there, three existing coefficients will be used. These values will act to optimise the unknown loss coefficient.

The steps and methodology surrounding the analysis are as follows:

1. Use measured flow to solve for flow rates and velocities throughout the system Annex T(1).

2. Use these values to solve for the Reynolds number, thus predicting the initial iteration of the friction value (f) using the Barr equation (Equation 9) as previously discussed.

3. Using the previously solved value, iterate the process four times until the value is correct to four decimal places. This value is the assumed friction coefficient for the inlet pipe.

4. If relevant, solve for any expansion losses throughout the inlet pipe.

5. Repeat steps two and three for the main PTB (Blue Section of Annex T(3)).

6. Use the solved values from the previous step to calculate the total head levels throughout the system, ensuring to leave an assumed loss value for the unknown value (Yellow Section of Annex T(1)).

7. Find the difference between the analytically derived data and the testing data, solve for the Root Mean Squared Error throughout the testing sample (Red Section of Annex T(1)).

8. Optimise the system and solve for the value of the unknown loss coefficient so that the RMSE is minimised, the resulting value is the Loss Coefficient (Highlighted Section in Figure 3.34).

9. Solve for the remainder of the system including the optimised value for the unknown loss coefficient.

90mm PN10 Testing Data - No Restriction						
PTB Internal Diam	79	mm				
Inlet Restriction Diam	79	mm	1			
Roughness	0.01	mm		1.39E-08		
vis	1.10E-06	kin Vis				
Entrance Coef (K1)	0.9					
Exit Coef (K2)	1					
Elbow Loss Coef (K3)	0.548454		RMSE on Head	41.3979	Fitted the Elbow loss	
Sudden Expansion Loss (K4)	0					
PTB Length	3.6	m				
Inlet Length Length	0.305	m				
Contraction	0					

Figure 3.34. Testing Data including all loss coefficients.

4. TESTING RESULTS AND OUTCOMES

4.1. GENERAL OUTCOMES

Each testing method was approached with a similar outlook on the results to be formed. The hypothesis to be tested was that the varying head levels effected the flow rates throughout the system in a way which provided the capacity to potentially provide the installed with 'Rating Curves', of which can be practically used within a field environment. The testing, however, came at a disadvantage in that the longer the test would have run, the more accurate the results would have been considered. With that in mind, however, maintaining a constant head level the entire time would have been very difficult. Therefore a middle ground averaging two minutes per test was devised, this time gave the system ample time to produce consistent flow as well as maintain a stable head level (Figure 4.1).

Figure 4.1. Head Level Measurements taken at stable flow

The results developed provided an insight into the flow dynamics throughout the system, it provided the ability to analyse each major head loss component throughout the system as well as provide data which was effectively used to develop rating curves for the proposed restrictor types.

Generally the testing ran relatively smooth; throughout the entirety of the tests the low head levels tend to incorporate vortexing at the inlet location, which results in the addition of unwanted air throughout the system. The formation of this will result in a reduced flow rate through the system however a detailed analysis of these effects is outside the scope of this investigation. Further to this at lower head levels the buoyancy of the plastic material tends to outweigh the water itself, thus resulting in the inlet wanting to raise out of the water and stop the flow. The mitigation technique used in this particular instance was to weight the inlet down in order to maintain full pipe inflow as well as reduce the effect of the buoyancy (Figure 4.2).

Figure 4.2. Weight Plate added to top of Inlet Pipe

Further to the previously stated, at low head levels the system tended not to flow at full pipe flow, thus resulting in ait throughout the system. For obvious reasons the flow rate and respective data was still solved for, however the data may not be reliable due to the introduction of unwanted air into the system (Figure 4.3). It should also be noted that within a field environment the tension of the rope applied to the rotating mechanism will vary between siphons, it is inaccurate to assume the inlet will be fully submerged parallel to the water surface, however the investigation into these effects is outside the scope of this analysis and can potentially be conducted in further research.

Figure 4.3. Pipe flow not at 'Full Pipe' flow

4.2. 90mm PN10 SIPHON OUTCOMES (Baseline, 66.44mm, 63.00mm and 60.22mm)

4.2.1. 90mm PN10 SIPHON OUTCOMES (Baseline, No Restriction)

4.2.1.1. 90mm PN10 SIPHON ANALYSIS

The initial testing of the siphon system was used to ascertain the loss coefficient for the elbow joint within the system. Once this has been conducted it can then be assumed that this value is a constant throughout the conduct of the testing. For the conduct of the initial test the assumptions were made as per Table 7.5 located in Annex U. For the purpose of this experiment previous data collected through siphon testing calculating the entry loss is assumed to be a factor of 0.9. The remainder of the minor and friction losses throughout the system are therefore calculated as per normal creating the ability to solve for the unknown elbow loss coefficient (Loss K3 in Table 7.5).

Now using the values solved for in Table 7.6 (Annex U) with an assumed Elbow loss coefficient = 0.9 we can use the solver function in excel to optimise the entire network in order to minimise the RMSE throughout the system (essentially creating the most logical coefficient for the unknown friction value). The resulting coefficient was found to be $K_3 = 0.56467$ with a resultant RMSE of 41.347.

The associated results concluded in the analysis then provide the regression of a polynomial nature (Blue Line in Figure 4.4 and Annex B):

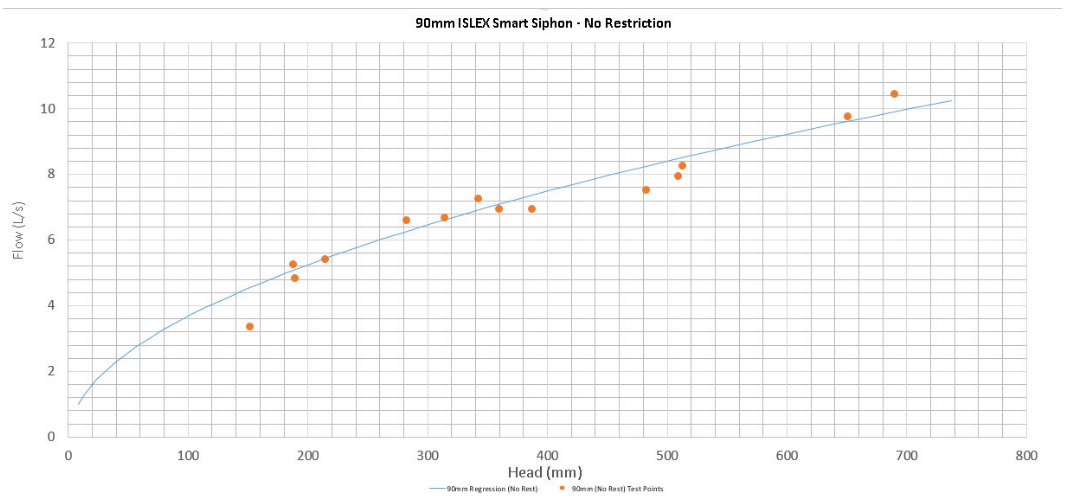

Figure 4.4. 90mm PN10 (No Restriction)) Rating Curve

4.2.1.2. 90mm PN10 SIPHON OBSERVATIONS

Throughout the analysis of the 90mm PN10 siphon the flow was generally constant throughout the testing period, including throughout the variation to head level applied to the siphon. A minor observation which was noted was that throughout analysis of the siphon performance under a head level of approximately 200mm the entrance tended to vortex (Table 4.1). The issue with vortexing at the entrance location is the fact that it then introduces unwanted air into the system, which has an unknown effect on the system as a whole. An example of this effect is potentially within the 7th test conducted in the second round of testing:

Table 4.1. PN10 90mm Unrestricted Test #7 Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
7	152	3.333	82.697	Outlier	0.6800	0.6800

This testing data has a measured head level of 152mm and a measured head level of 82.7mm when analytically solved for. This provides insight into the effect of the vortexing at throughout these head levels as well as the potential influence of the outflow not being full pipe flow. The assumption throughout the defined analysis is that the flow is full pipe which provides a constant medium to conduct the analytical section of the testing. Should the pipe flow not be full at low head levels it proves to be a difficult analysis to conduct as the varying outflow hydraulic radius has a significant impact on the outcome of the analysis.

4.2.2. 90mm PN10 SIPHON OUTCOMES (66.44mm Restriction Insertion)

4.2.2.1. 90mm PN10 SIPHON (66.44mm Restriction Insertion) ANALYSIS

The testing of the restriction to 66.44mm is solving for the unknown minor loss coefficient at the entrance (location of the restriction). The analysis was therefore set up with the data as per Annex V Table 7.10. For the purpose of this experiment the elbow loss coefficient is assumed to be consistent throughout the conduct of the initial testing, set at a constant of 0.54845 as per the ascertained value from 4.2.1. The remainder of the minor and friction losses throughout the system are therefore calculated as per normal creating the ability to solve for the unknown entrance loss coefficient using the method previously detailed.

Now using the values solved for through testing in Table 7.11 from Annex V including an assumed Entrance loss coefficient = 0.9 we can now use the solver function in excel to optimise the entire network in order to minimise the RMSE throughout the system (essentially creating the most logical coefficient for the unknown friction value). The resulting coefficient was found to be $K_1 = 0.88631$ with a resultant RMSE of 33.873

Substituting the optimised values from Annex V, Table 7.13 the resultant minor loss coefficient can be substitute into the regression equation resulting in the rating curve Figure 4.5 and Annex C:

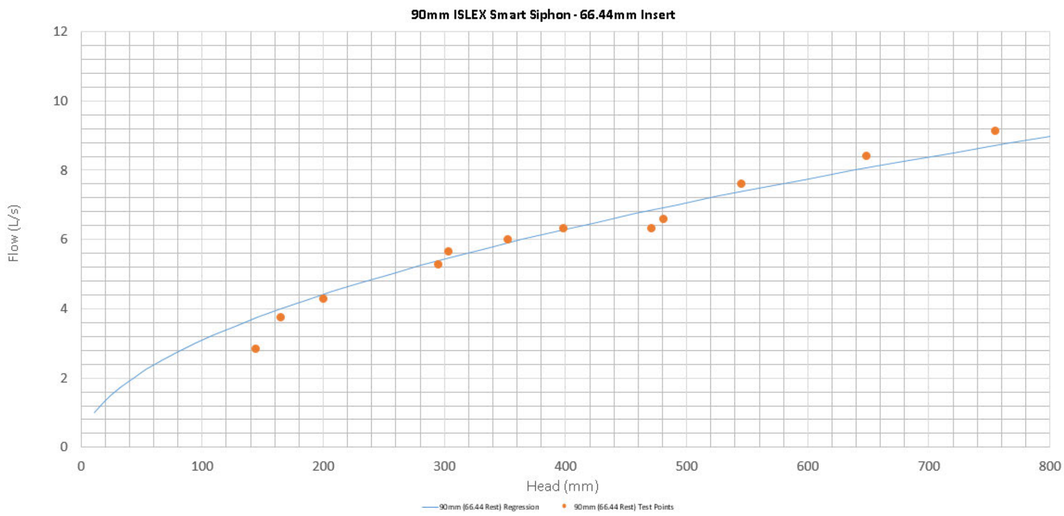

Figure 4.5. 90mm PN10 (66.44mm Restriction)) Rating Curve

4.2.2.2. 90mm PN10 SIPHON (66.44mm Restriction Insertion) OBSERVATIONS

As per the unrestricted siphon analysis a minor observation which was noted that throughout analysis of the siphon performance under a head level of approximately 200mm the entrance tended to vortex. The issue with vortexing at the entrance location is the fact that it then introduces unwanted air into the system, which has an unknown effect on the system as a whole. An example of this effect is potentially within the 8th test conducted in the second round of testing:

Table 4.2. PN10 90mm Unrestricted Test #7 Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
8	144	2.833333333	84.17257029	Outlier	0.817238	0.578034

This testing data has a measured head level of 144mm and a measured head level of 84.17mm when analytically solved for, this giving a head difference of over 60mm. This once again provides insight into the effect of the vortexing at throughout these head levels, further to this the flow at the exit point was no longer full pipe.

4.2.3. 90mm PN10 SIPHON OUTCOMES (63.00mm Restriction Insertion)

4.2.3.1. 90mm PN10 SIPHON (63.00mm Restriction Insertion) ANALYSIS

The testing of the restriction to 63.00mm is solving for the unknown minor loss coefficient at the entrance as per the methodology conducted in section 4.2.2. Using the solved values located in Annex W, Table 7.15 with an assumed Entrance loss coefficient = 0.9 we can now use the solver function in excel to optimise the entire network in order to minimise the RMSE in Table 7.18 located in Annex W. The resulting coefficient was found to be $K_1 = 0.78641$ with a resultant RMSE of 15.099.

The solution of this updated data set as well as the optimised assumption of the Entry minor loss coefficient the following polynomial regression can be found in Figure 4.6 and Annex D:

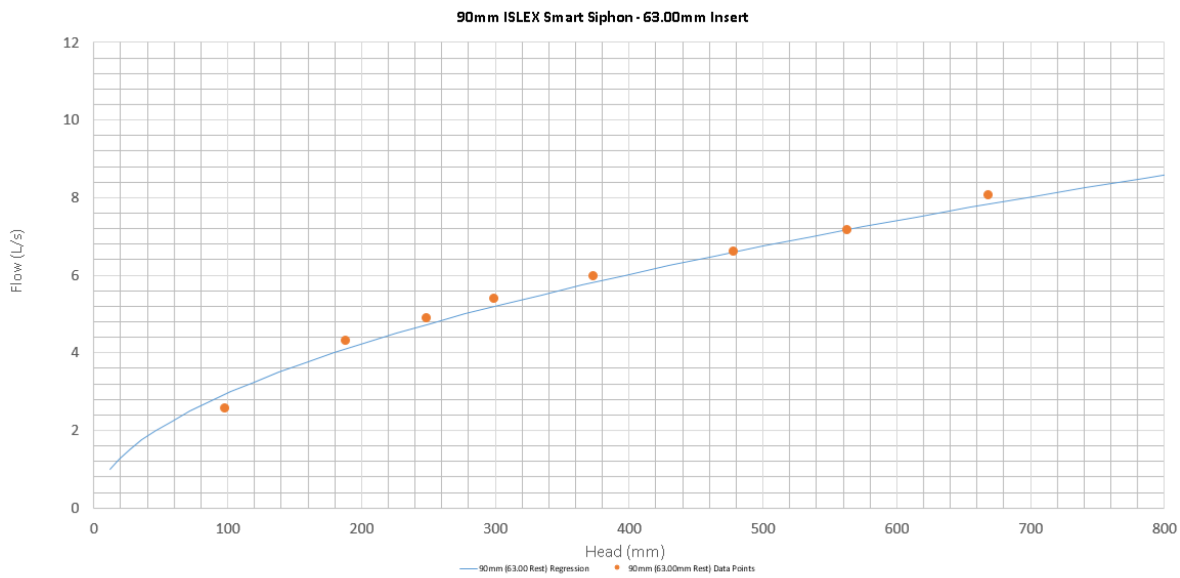

Figure 4.6. 90mm PN10 (63.00mm Restriction)) Rating Curve

4.2.3.2. 90mm PN10 SIPHON (63.00mm Restriction Insertion) OBSERVATIONS

As per the unrestricted siphon analysis a minor observation which was noted that throughout analysis of the siphon performance under a head level of approximately 200mm the entrance tended to vortex.

The issue with vortexing at the entrance location is the fact that it then introduces unwanted air into the system, which has an unknown effect on the system as a whole. An example of this effect is potentially within the first test conducted in the second round of testing:

Table 4.3. PN10 90mm (63.00mm Restriction Insertion) Test #1 Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
1	98	2.58333333	76.5378070	Outlier	0.82872314	0.52703127

This testing data has a measured head level of 98mm and a measured head level of 76.54mm, as this seems to be a constant relationship throughout the flows at a low head level there is no further requirement to discuss the issues which may arise from the data.

4.2.4. 90mm PN10 SIPHON OUTCOMES (60.22mm Restriction Insertion)

4.2.4.1. 90mm PN10 SIPHON (60.22mm Restriction Insertion) ANALYSIS

The testing of the restriction to 60.22mm is solving for the unknown minor loss coefficient at the entrance as per the methodology conducted in section 4.2.2. Using the solved values located in Annex X, Table 7.21 with an assumed Entrance loss coefficient = 0.9 we can now use the solver function in excel to optimise the entire network in order to minimise the RMSE in Table 7.23 located in Annex X. The resulting coefficient was found to be $K_1 = 0.87604$ with a resultant RMSE of 12.1189.

The solution of this updated data set as well as the optimised assumption of the Entry minor loss coefficient the following polynomial regression can be found in Figure 4.7 and Annex E:

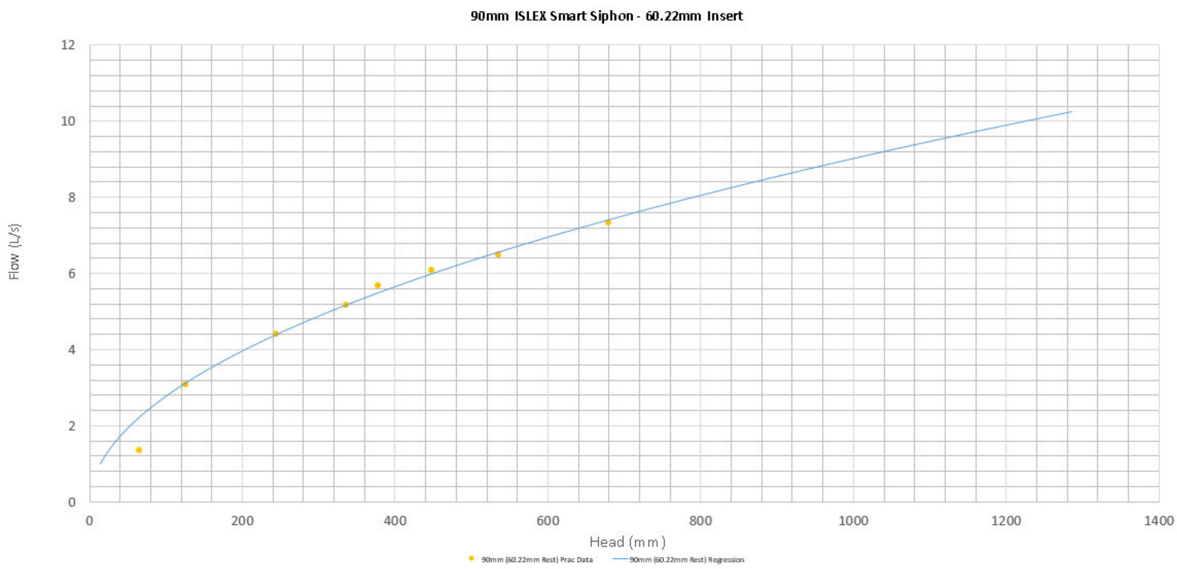

Figure 4.7. 90mm PN10 (60.22mm Restriction) Rating Curve

4.2.4.2. 90mm PN10 SIPHON (60.22mm Restriction Insertion) OBSERVATIONS

As per the unrestricted siphon analysis a minor observation which was noted that throughout analysis of the siphon performance under a head level of approximately 200mm the entrance tended to vortex. Several tests had been conducted at levels well below 200mm however none of the testing data could be considered reliable. The issue with vortexing at the entrance location is the fact that it then introduces unwanted air into the system, which has an unknown effect on the system as a whole. An example of this effect is potentially within the 1st test conducted in the second round of testing:

Table 4.4. PN10 90mm (63.00mm Restriction Insertion) Test #1 Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
1	65	1.33333333	24.8774489	Outlier	0.46813094	0.27201613

Although inconvenient, the lack of data surrounding the lower head levels (particularly in scenarios where a restriction has been applied) is not a significant loss. The application of restrictors throughout the system is ideally required to control the flow rate where the system is to be run at higher head levels. This creates the importance to test restrictors at mid-range to higher head levels as this is where they will be practically applied.

4.3. PN10 EXTENDED RISER RESTRICTORS

4.3.1. 68.38mm RESTRICTED RISER PN10 SIPHON OUTCOMES

4.3.1.1. 68.38mm RESTRICTED RISER PN10 SIPHON ANALYSIS

The testing of the extended restricted riser is solving for the unknown minor loss coefficient at the elbow (location of unknown losses through the expansion as well as the elbow effects). The analysis was therefore set up with the measures found in Annex Y, Table 7.24 and Table 7.25. For the purpose of this experiment the entrance loss coefficient is assumed to be consistent throughout the conduct of the testing, set at a constant of 0.9, this has been assumed from previous research conducted within the siphon irrigation investigation field. The remainder of the minor and friction losses throughout the system are therefore calculated as per normal creating the ability to solve for the unknown elbow loss coefficient using the method previously detailed, the losses also include to allowance for the sudden expansion loss within the system where the restricted riser is required to meet a 90mm pipe in order to be suitable for the elbow connection.

Using the values solved for in Table 7.28, Annex Y, with an assumed Elbow loss coefficient = 0.5 the solver function in excel can now be used to optimise the entire network in order to minimise the RMSE throughout the system (essentially creating the most logical coefficient for the unknown friction value). The resulting coefficient was found to be $K_3 = 0.27209$ with a resultant RMSE of 12.1189: The resulting allocation of the solved head loss coefficient then provides an adequate basis for the application of the regression model to be applied in Figure 4.8 and Annex F:

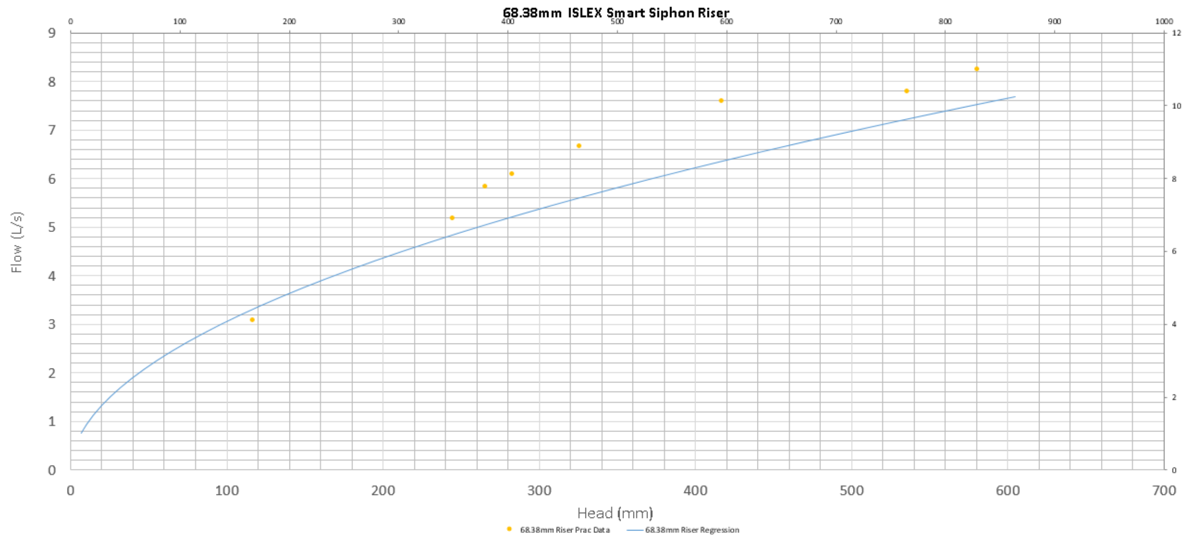

Figure 4.8. 68.38mm Extended Riser PN10 Rating Curve

4.3.1.2. 68.38mm RESTRICTED RISER PN10 SIPHON OBSERVATIONS

The selected extended restrictor generally had dependable results. One issue was located in test 3 (Table 4.5) at approximately 420mm head. For unknown reasons this data varied greatly to the remainder of the data and therefore is assumed to have been recorded incorrectly:

Table 4.5. 68.38mm Extended Riser PN10) Test #3 Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
3	417	7.583333	479.2457461	outlier	2.016314	1.547091793

4.3.2. 54.80 mm RESTRICTED RISER PN10 SIPHON OUTCOMES

4.3.2.1. 54.80mm RESTRICTED RISER PN10 SIPHON ANALYSIS

The testing of the extended restricted riser is solving for the unknown minor loss coefficient at the elbow (location of unknown losses through the expansion as well as the elbow effects,). It is for this reason that the Expansion and Elbow loss coefficients have been combined, this is under the assumption that as the two loss locations are at such a close proximity to each other there is difficulty recognising the separation between the two.

Using the values from Annex Z, Table 7.31 with an assumed Elbow loss coefficient = 0.5, this is assumed due to the proximity to previously developed data. The solver function in Excel is then used to optimise the entire network in order to minimise the RMSE in Table 7.33, Annex Z throughout the system (essentially creating the most logical coefficient for the unknown friction value). The resulting coefficient was found to be $K_{3/4} = 0.44280$ with a resultant RMSE of 21.449.

This optimised solution then provides the optimised data in Table 7.32 Annex Z which can then be substituted into the regression function to solve for the rating curve in Figure 4.9 and Annex G:

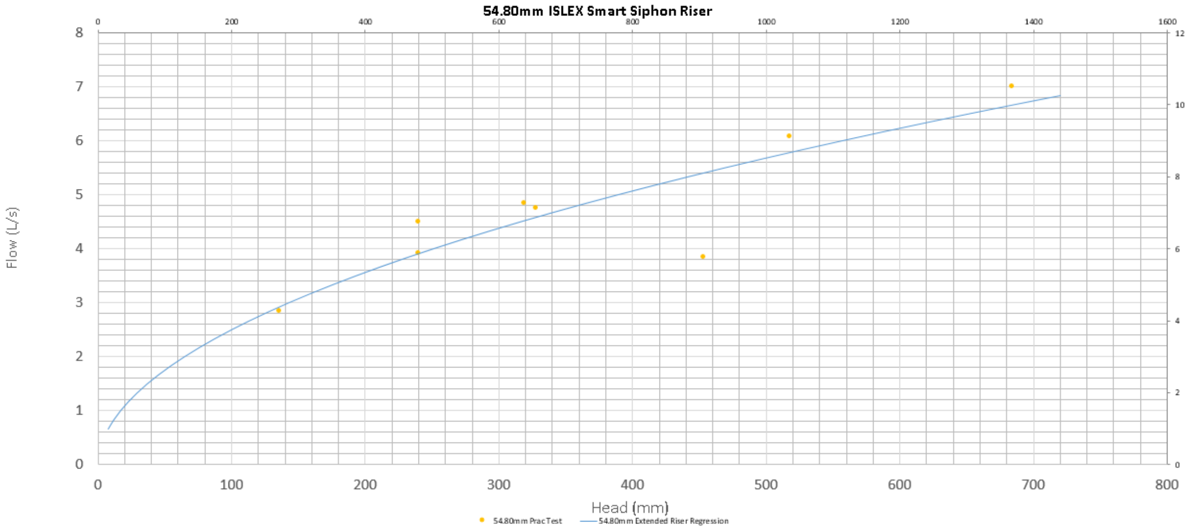

Figure 4.9. 54.80mm Extended Riser PN10 Rating Curve

4.3.2.2. 54.80 mm RESTRICTED RISER PN10 SIPHON OBSERVATIONS

The selected extended restrictor generally had dependable results. One issue was located in test 4 (Table 4.6) at approximately 450mm head, thus providing an RMSE value which is extremely large. For unknown reasons this data varied greatly to the remainder of the data and therefore is assumed to have been recorded incorrectly:

Table 4.6. 54.80mm Extended Riser PN10) Test #4 Data

Test #	Measured Head	Measured Flow Rate	Analytical Head (mm)	RMSE	Entrance Velocity	Exit Velocity (m/s)
4	453	3.83333333	208.060520	Outlier	1.62527025	0.782046401

4.3.3. 40.10mm RESTRICTED RISER PN10 SIPHON OUTCOMES

4.3.3.1. 40.10mm RESTRICTED RISER PN10 SIPHON ANALYSIS

The testing of the extended restricted riser is solving for the unknown minor loss coefficient at the elbow (location of unknown losses through the expansion as well as the elbow effects). Using a similar method as per 4.3.1 we use the data from Annex AA Table 7.34 in order to solver for an assumed Table 7.36 with an implicit Elbow loss coefficient = 0.5. The solver function in excel is now used to optimise the entire network in order to minimise the RMSE in Table 7.38 and inherently throughout the system. The resulting coefficient was found to be $K_{3/4} = 5.8722$ with a resultant RMSE of 24.152.

The inclusion of this minor loss value into the regression rating curve as follows in Figure 4.10 and in Annex H:

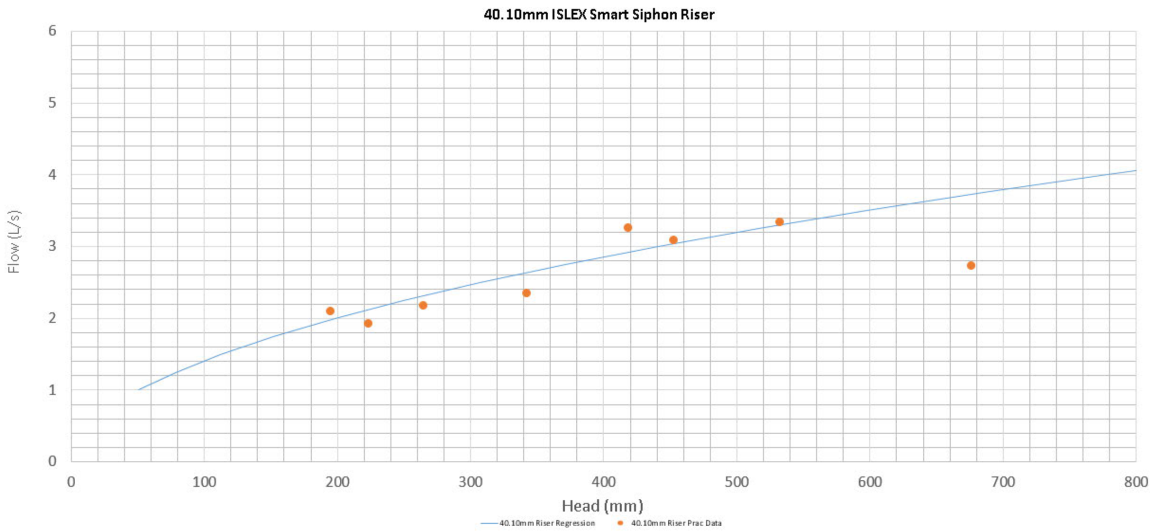

Figure 4.10. 40.10mm Extended Riser PN10 Rating Curve

4.3.3.2. 40.10mm RESTRICTED RISER PN10 SIPHON OBSERVATIONS

The selected extended restrictor generally had dependable results. Throughout this specific set of testing points the outflow was generally not at full pipe flow (Table 4.7), this making the analysis stage very difficult and may have ultimately resulted in the deletion of several points:

Table 4.7. 68.38mm Extended Riser PN10) Test #3 Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
2	343	2.333333333	268.263820	Outlier	1.82926578	0.476028
4	677	2.722222222	363.740087	Outlier	2.13414341	0.555366
5	419	3.25	516.317760	Outlier	2.54790591	0.663039

4.4. PN10 EXTENDED RISER (Including Spiral Entry Pattern) RESTRICTORS

4.4.1. 78.58mm RESTRICTED RISER PN10 SIPHON (Spiral Entry) OUTCOMES

4.4.1.1. 78.58mm RESTRICTED RISER PN10 SIPHON ANALYSIS

The testing of the extended restricted riser is solving for the unknown minor loss coefficient at the Entry of the siphon (location of unknown losses assumed to be a culmination of the losses throughout each spiral hole as well as the entry losses). The analysis was therefore set up as per the measures defined in Annex AB Table 7.39 which then results in an initial data Table 7.40.

For the purpose of this experiment the elbow loss coefficient is assumed to be consistent as per the associated loss solved in 4.2.1. For the purpose of the initial Spiral Patter the Elbow Losses are assumed to be $k_3 = 0.54845$. The remainder of the minor and friction losses throughout the system are therefore calculated as per normal creating the ability to solve for the unknown elbow loss coefficient using the method previously detailed in 4.2, the losses also include to allowance for the sudden expansion loss within the system where the restricted riser is required to meet a 90mm pipe in order to be suitable for the elbow connection.

Now using the values initially solved for with an assumed Entry loss coefficient = 0.9 in Table 7.41. The Excel solver function is now used to optimise the entire network in order to minimise the RMSE (Table 7.43) throughout the system (essentially creating the most logical coefficient for the unknown friction value). The resulting coefficient was found to be $K_1 = 2.78290$ with a resultant RMSE of 21.110.

Thus the incorporation of all optimised data results in the rating curve Figure 4.11 and Annex I):

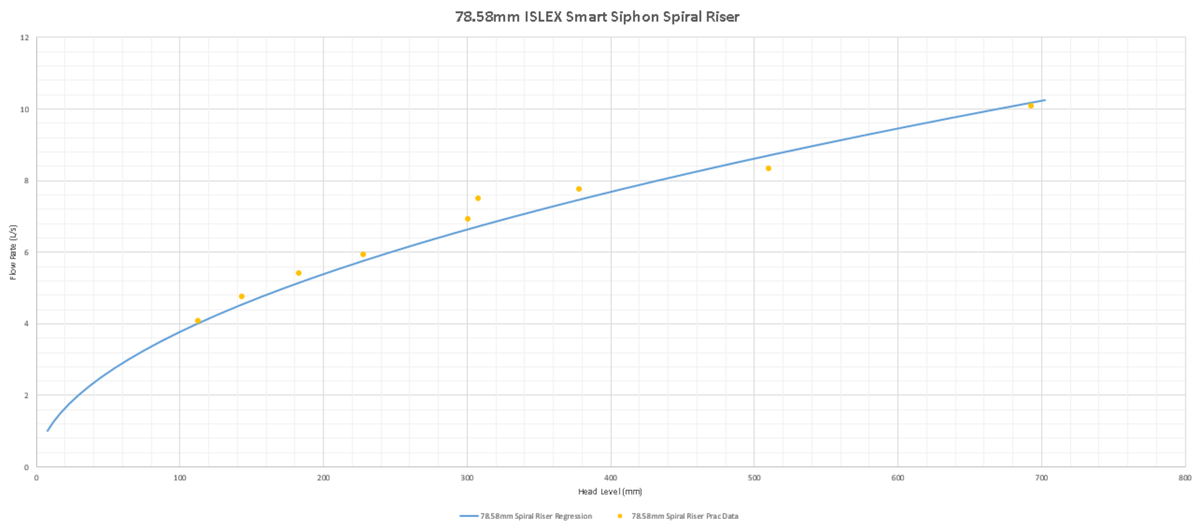

Figure 4.11. 78.58mm Extended Restricted (Spiral Entry) PN10 Rating Curve

4.4.1.2. 78.58mm RESTRICTED RISER PN10 SIPHON OBSERVATIONS

The selected extended restrictor generally had dependable results. One issue was located in test 6 (Table 4.8) at approximately 300mm head. For unknown reasons this data varied greatly to the remainder of the data and therefore is assumed to have been recorded incorrectly:

Table 4.8. 78.58mm Extended Restricted (Spiral Entry) Test #6 Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
6	308	7.5	381.2916804	Outlier	0.811949518	1.530090784

4.4.2. 69.00mm RESTRICTED RISER PN10 SIPHON (Spiral Entry) OUTCOMES

4.4.2.1. 69.00mm RESTRICTED RISER (Spiral Entry) PN10 SIPHON ANALYSIS

The testing of the extended restricted riser is solving for the unknown minor loss coefficient at the Entry of the siphon (location of unknown losses assumed to be a culmination of the losses throughout each spiral hole as well as the entry losses). The solution method is generally as per the previous section **Error! Reference source not found.**, for the purpose of the initial Spiral Patter the Elbow Losses are assumed to be $k_3 = 0.27209$ as found in 4.3.1 (with the assumption that the difference between 68.38mm and 69.00mm is negligible).

Using the values defined in Annex AC, Table 7.46 with an assumed Entry loss coefficient = 0.9, the solver function in excel can now be used to optimise the entire network. The resulting coefficient was found to be $K_1 = 3.22701$ with a resultant RMSE of 31.41052.

The culmination of these values then results in the rating curve Figure 4.12 and in Annex J:

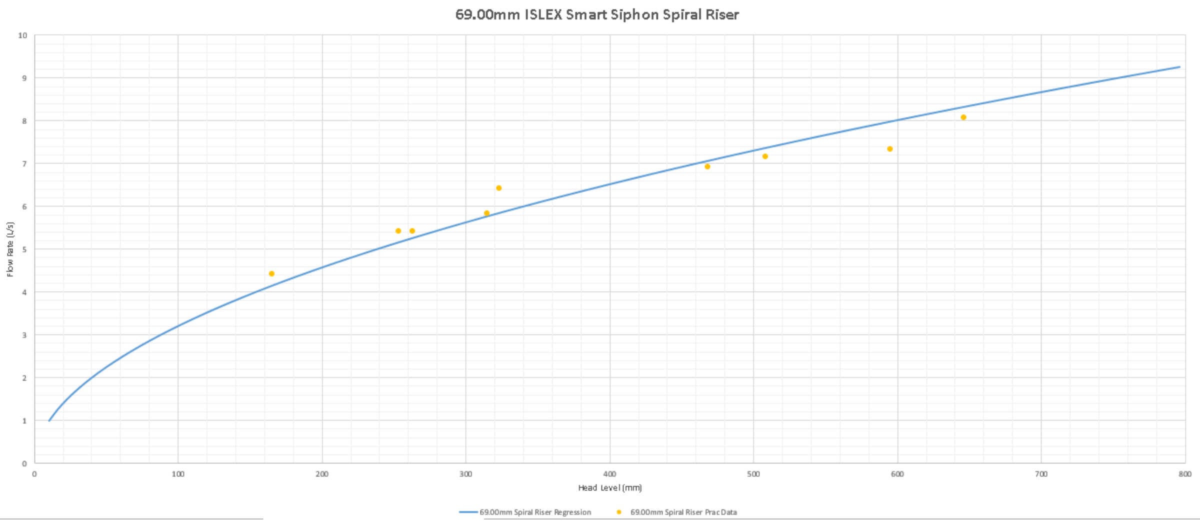

Figure 4.12. 69.00mm Extended Restricted (Spiral Entry) PN10 Rating Curve

4.4.2.2. 69.00mm RESTRICTED RISER PN10 SIPHON OBSERVATIONS

The selected extended restrictor generally had dependable results. One issue was located in test16 (Table 4.9) at approximately 600mm head. For unknown reasons this data varied greatly to the remainder of the data and therefore is assumed to have been recorded incorrectly:

Table 4.9. 69.00mm Extended Restricted (Spiral Entry) Test #1 Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
1	595	7.333333	488.1547302	Outlier	1.238426	1.496089

4.4.3. 54.58mm RESTRICTED RISER PN10 SIPHON (Spiral Entry) OUTCOMES

4.4.3.1. 54.58mm RESTRICTED RISER (Spiral Entry) PN10 SIPHON ANALYSIS

The testing of the extended restricted riser (Testing data Located in Annex AD) is solving for the unknown minor loss coefficient at the Entry of the siphon (location of unknown losses assumed to be a culmination of the losses throughout each spiral hole as well as the entry losses). The solution method is generally as per the previous section 4.4.1, for the purpose of the initial Spiral Patter the Elbow Losses are assumed to be $k_3 = 0.4428$ as found in 4.3.2 (with the assumption that the difference between 54.80mm and 54.58mm is negligible).

Using the values defined in Annex AD, Table 7.51 with an assumed Entry loss coefficient = 0.9, the solver function in excel can now be used to optimise the entire network. The resulting coefficient was found to be $K_1 = 14.921$ with a resultant RMSE of 15.6484.

The culmination of these values then results in the rating curve Figure 4.13 and in Annex K:

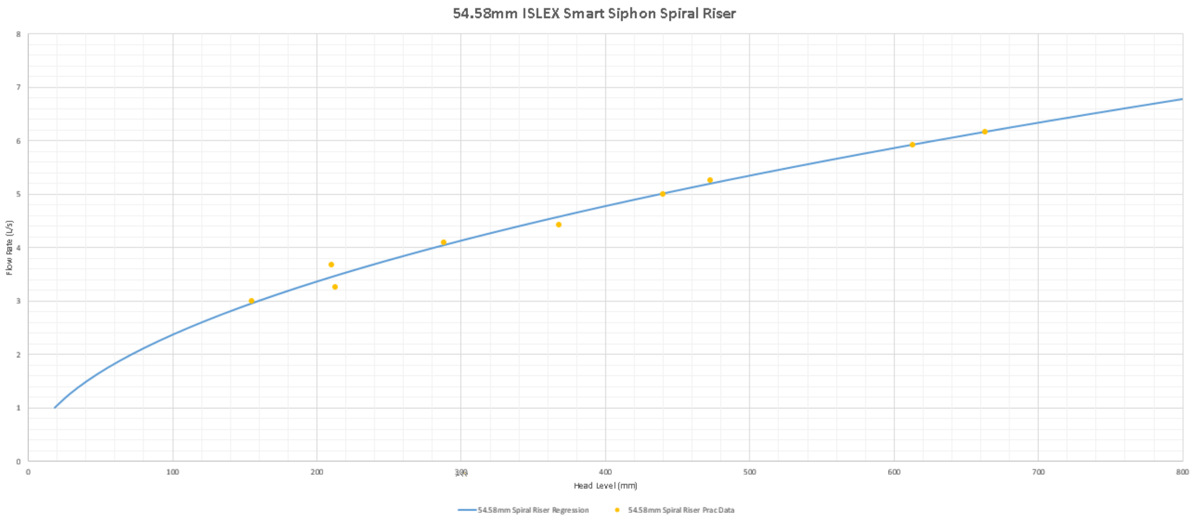

Figure 4.13. 54.58mm Extended Restricted (Spiral Entry) PN10 Rating Curve

4.4.3.2. 54.58mm RESTRICTED RISER (Spiral Entry) PN10 SIPHON OBSERVATIONS

The tested data, generally, did not have any major differences between the analytical and practically measured values throughout. This reinforces some confidence within the data correlation and analysis method selected. Throughout the testing phase of this particular entry size the out flow was not at full pipe throughout the experiment, this could potentially have some effect on the analysis method used however it does reinforce such a large loss coefficient at the entry point.

4.4.4. 40.22mm RESTRICTED RISER PN10 SIPHON (Spiral Entry) OUTCOMES

4.4.4.1. 40.22mm RESTRICTED RISER (Spiral Entry) PN10 SIPHON ANALYSIS

For the purpose of this experiment the elbow loss coefficient is assumed to be consistent respective of the siphon riser size in 4.3.3. For the purpose of the initial Spiral Patter the Elbow Losses are assumed to be $k_{3/4} = 5.87223$ (assuming at the difference between 40.22mm and 40.10mm is negligible). Now using the values found in Table 7.56 with an assumed Entry loss coefficient = 0.9. Following this the solver function in excel can now be used to optimise the entire network in order to minimise the RMSE (Table 7.58) throughout the system (essentially creating the most logical coefficient for the unknown friction value). The resulting coefficient was found to be $K_1 = 10.9109$ with a resultant RMSE of 30.237. The culmination of these values then results in the rating curve Figure 4.14 and in Annex L:

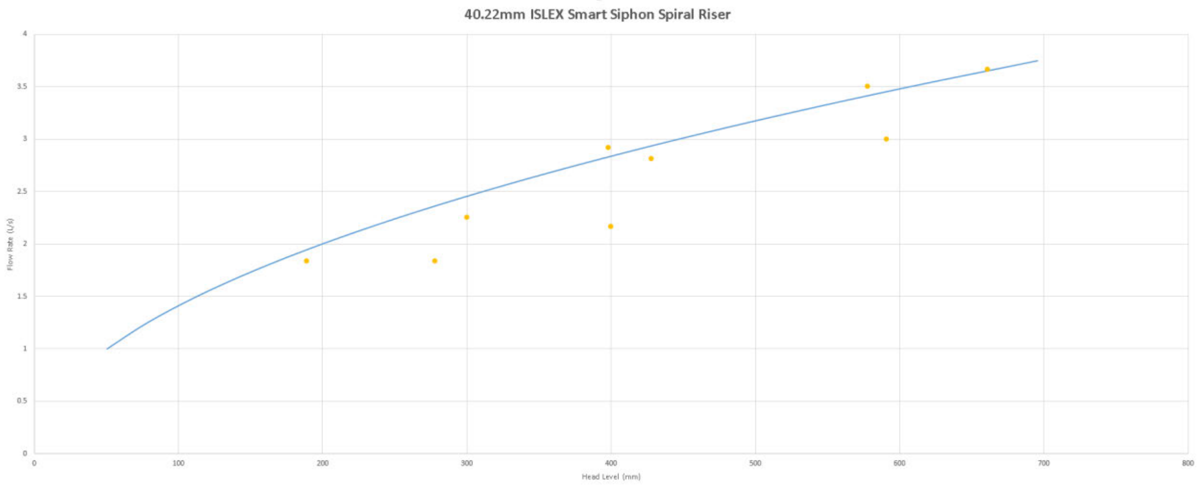

Figure 4.14. 40.22mm Extended Restricted (Spiral Entry) PN10 Rating Curve

4.4.4.2. 40.22mm RESTRICTED RISER (Spiral Entry) PN10 SIPHON OBSERVATIONS

The selected extended restrictor generally had dependable results. One issue was located in tests Two, Three and four varying from ranges between 270mm and 600mm. The outflows at these points (Table 4.10) may not have been as closely monitored resulting in varied head depths.

Table 4.10. 40.22mm Extended Riser PN10) Test #2, 3&4 Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
2	591	3	481.9903658		0.723786	0.612036
3	400	2.166667	252.3157791		0.522734	0.442026
4	278	1.833333	181.0176247		0.442314	0.374022

5. RESULT ANALYSIS AND DISCUSSION

The practical testing of the ISLEX Smart Siphon had the following objectives:

1. Evaluate the hydraulic performance of the smart siphon through practical measurement in a controlled environment.

2. Generation of rating tables and equations to predict the flow rate from operating head and pipe characteristics.

The siphons themselves were tested in three main categories; Restriction Insert, Extended Riser and an extended restricted riser with a spiral entry pattern. Each of these tested under constant conditions and equal test samples with varying head levels.

Generally the testing produced results which provide a high level of confidence as majority of the loss factors could be accounted for. However once the head level dropped below 150mm in each test the flow began to exit under full pipe flow. As the analysis was conducted under the assumption that the pipe was running at full capacity there is potential for error at these head levels. In an attempt to mitigate this effect the end of the siphon was raised to try and achieve full pipe flow prior to exit. This did achieve close to full pipe flow however as the flow rates were constant between the two variations there is an increased assurance that the analysis through the remainder of the system was correct.

5.1. RESTRICTION INSERT DISCUSSION

The initial insertion of restrictors did provide a discernible difference against the base test with no restriction applied. With the hypothesis that the application of the restriction would decrease the loss coefficient proportionally against the decrease in entry size, this was proven to be somewhat correct throughout the initial phase of testing. As the flow velocity increased at the entry due to the restrictor application it was expected that the losses due to entry would reduce however there would be an increase in expansion losses. This is generally displayed in Figure 5.1:

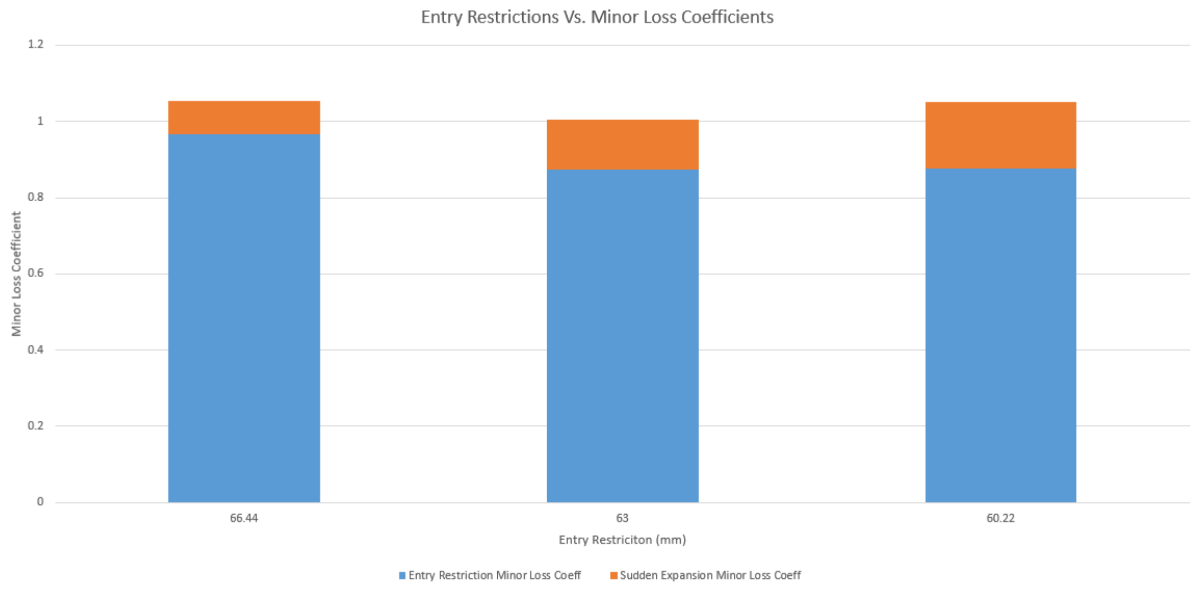

Figure 5.1. Restrictor Insert Loss Coefficients (Entry and Expansion)

Although the 63.00mm and 60.22mm restriction tend to display the predicted pattern, the 66.44mm restriction looks to have in increased entry minor loss coefficient (closer to a re-entrant minor loss coefficient value of 1.0 assumed in hydraulic engineering). However, once the flow velocities are accounted for in these loss coefficients the respective head loss does increase as displayed in Figure 5.2.

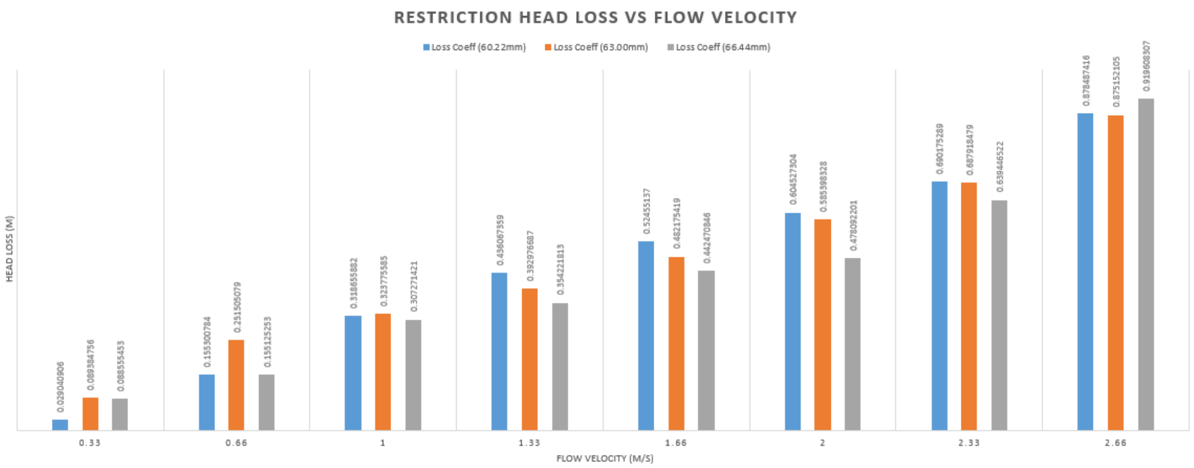

Figure 5.2. Restrictor Insert Head Loss Vs Flow Velocity.

Figure 5.2 displays an almost linear increase in head loss of the individual restrictor sizes when compared to flow velocities, further to this the head losses experienced by the 60.33mm restrictor are predominately greater than the losses experienced by the remaining restrictor types. This displays the correlation defined in Equation 11 where the increase in head loss is proportional to the flow velocity.

However once the flows themselves (Figure 5.3) were analysed and compared against one another the results seemed to be far more conclusive. Although the inserts did not provide the capacity of control originally thought, the tests did show that there is a definite decrease in flow rate as the supply head decreases. With the inclusion of the restrictor inserts there is the capability to perform minor flow alterations, however the restriction inserts themselves do not provide enough flow restraint to be used solely.

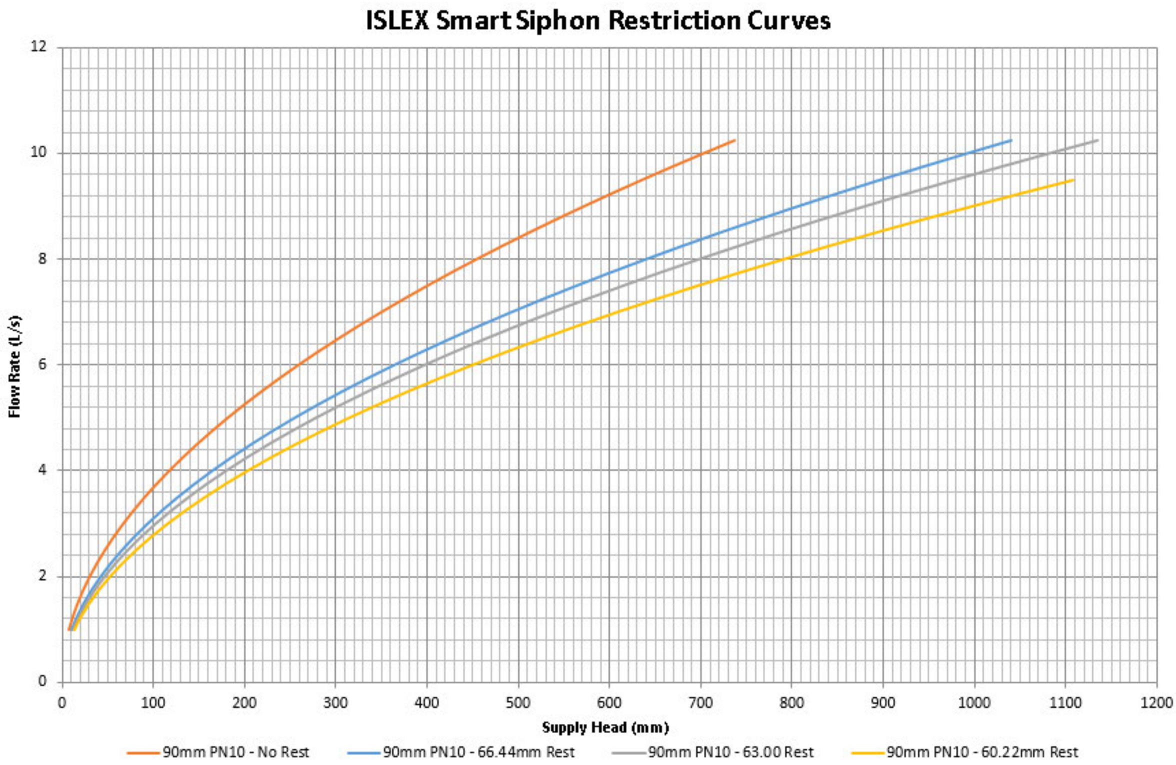

Figure 5.3. ISLEX Smart Siphon Restrictor Insert Rating Curves

5.1.1. RESTRICTION INSERT RECOMMENDATIONS

As previously discussed the insertion of the restrictors did provide the capacity to make minor changes to the flow rate, however for the maximum effect to be seen the restrictor was required to be applied to large flow rates with high head levels. For this reason it is predicted that there is potential for further research to be applied into how there could theoretically be a combination of two restriction types in order to achieve the required flow rate.

Further research into the field could potentially discuss the location of the restrictor throughout the system and the effects that this location may have on the flow. Further to this there is also further research which may be conducted into how the shape of the restriction affects the energy loss at that point.

5.1.2. RESTRICTION INSERT CONCLUSIONS

The use of restriction inserts look to be an effective method of making minor changes to the flow characteristics at higher head levels. The restriction inserts provide the ability to make minor changes, however if the assumed required flow rate is 6 L/s for example, the use of the restrictors only changes the head level required by 100mm between the three restrictor types. Therefore the Restrictor Inserts for the ISLEX Smart Siphon are not a viable option to be solely used to control the flow, there is further potential to apply the restrictor inserts in order to make minor adjustments to flow rates.

5.2. EXTENDED RISER DISCUSSION

The addition of the extended risers provided much needed control over the flow rate throughout the system. This can majorly be attributed to the mixture of minor losses (Figure 5.4) located in the elbow of the mechanism as well as the sudden expansion. Throughout the testing phase it became increasingly difficult to identify whether the minor losses were located in the sudden expansion or the elbow joint itself. For this reason the 54.80mm and 40.10mm risers only have a single value shown which is defined as the summation of the two loss coefficients (elbow and sudden expansion) solved as a single figure.

Figure 5.4. Restricted Riser Loss Coefficients (Entry and Expansion)

The pattern of the minor loss coefficients shows a minor increase between the 68.38mm Riser and the 54.80mm Riser, however the coefficient quickly jumps for the 40.10mm riser. This significant increase in minor loss is due to the mixture of a sudden expansion where the diameter changes from 40.10mm to a pipe to a 79mm pipe, almost double the diameter. Further to this the flow of water from the entry into the elbow mechanism is predicted to flow as per Figure 5.5.

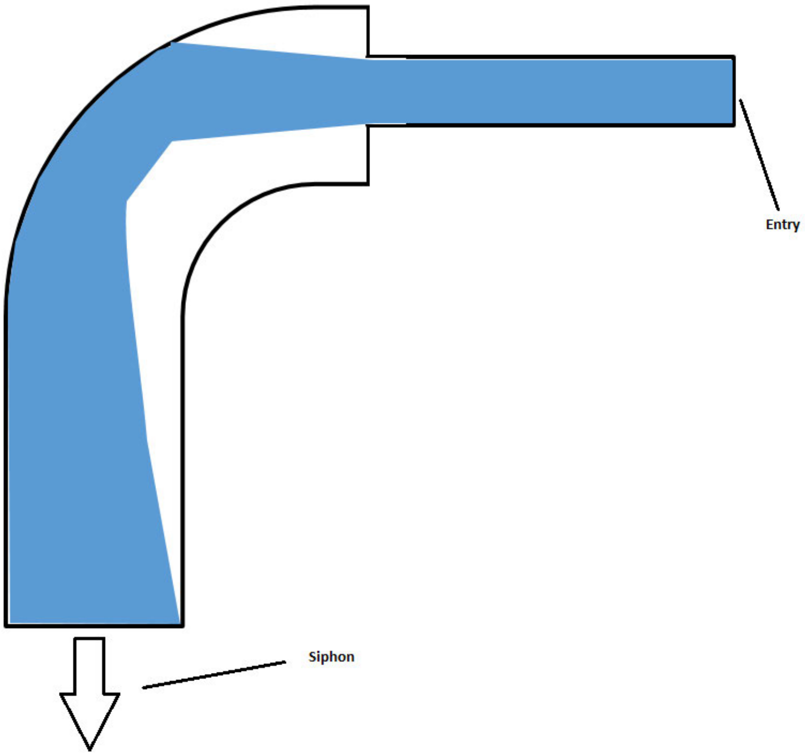

Figure 5.5. 40.10mm Riser Elbow Loss Prediction.

This pattern of flow makes it extremely difficult to predict as the inclusion of air voids through the analysis as well as the unknown effect the jet of water impacting the elbow has. The summation of the minor losses through this are therefore predicted to be extremely high as a detailed analysis of the losses and activity throughout the specified area has not been conducted, nor is it within the scope of this report. With that in mind however the increasing pattern of the Head loss throughout the system correlates with the expected outcomes and can therefore present a satisfactory level of confidence. Although the losses through the elbow mechanism require further investigation into how these losses are individually present, the summation of these losses is assumed to be correct which then relates back to the substantial head loss associated with the increased flow rate (Figure 5.6).

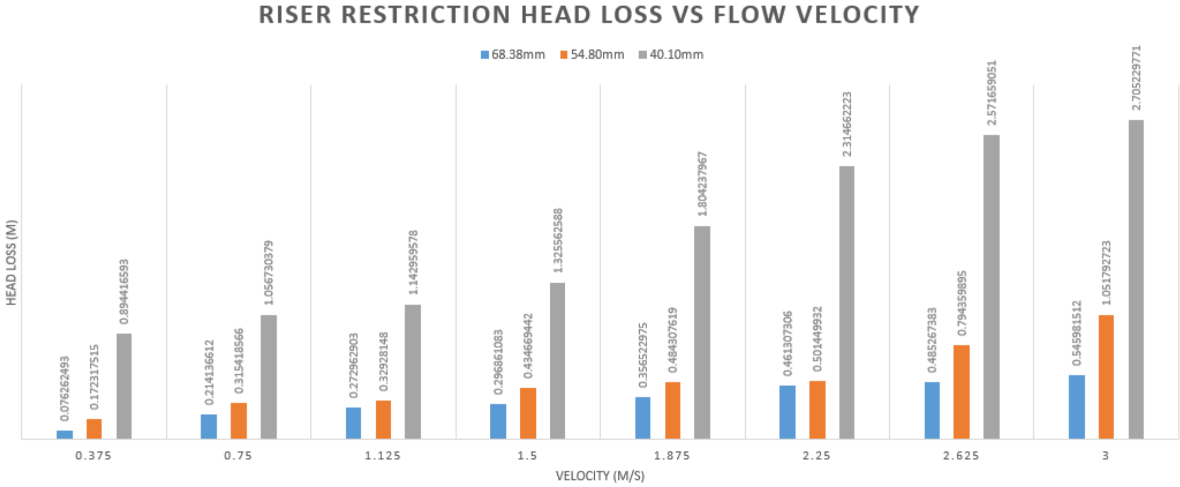

Figure 5.6. Riser Insert Head Loss Vs Flow Velocity.

The application of these minor losses through the system resulted in a substantial variation between the tests as detailed in Figure 5.7. When compared against the baseline test (Figure 5.7 Orange Curve) with no restriction applied the risers provide a significant control over the flow through the system. This is a more accurate representation of the control ISLEX have been striving to achieve through their research into the field.

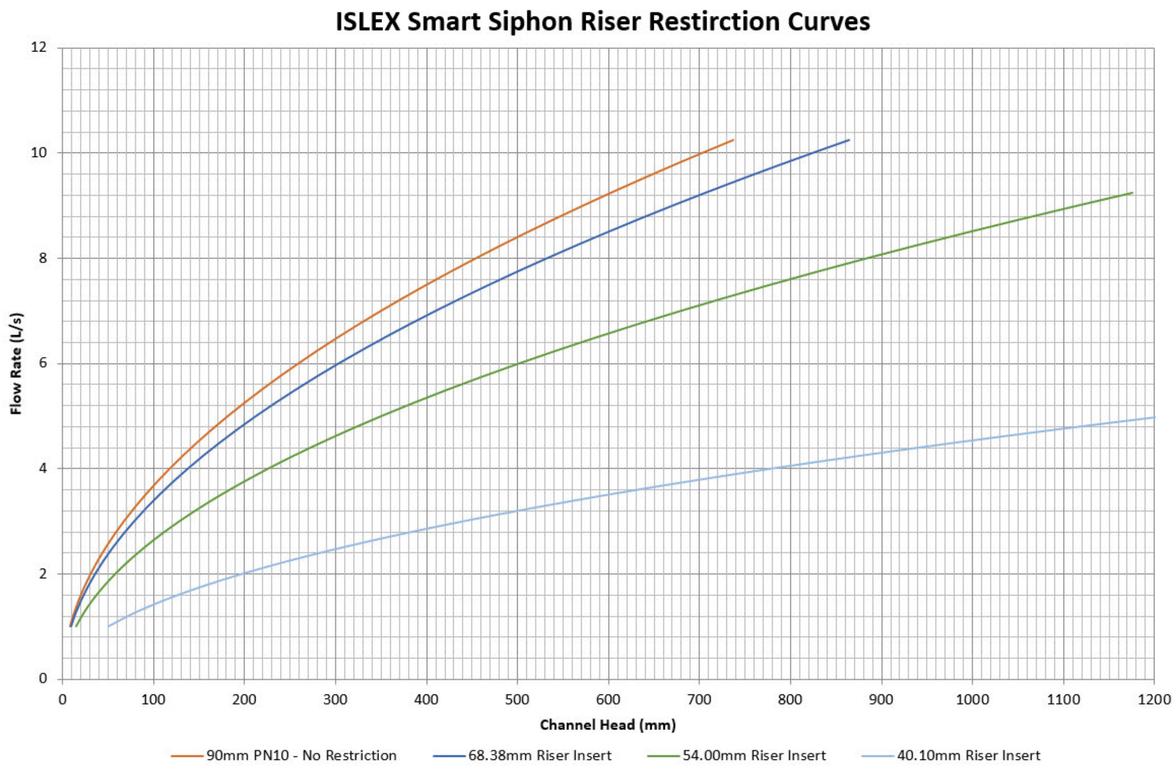

Figure 5.7. ISLEX Smart Siphon Riser Insert Rating Curves

5.2.1. RESTRICTED RISER RECOMMENDATIONS

The rating curves in Figure 5.7 display a substantial decrease in flow between the 54.00mm and the 40.10mm restriction, there is potential to have an intermediate restrictor between these two sizes which would incorporate the flow rates predicted through the 450mm to 1100mm+ head level range. To accompany this there is also opportunity to pursue further research into the losses associated within the elbow mechanism with the 40.10mm restriction applied. An increased understanding of the circumstances through this area can provide information on how to improve the Smart Siphon in the future.

5.2.2. RESTRICTED RISER CONCLUSIONS

The use of the restricted risers provides the operator with improved control of the flow of the system, far greater than the restrictor insertions previously discussed. Although the tested restrictor types did not cover every single flow possibility, they did provide a substantial insight into how the restricted risers perform under varying head levels.

5.3. EXTENDED RISER (SPIRAL ENTRY) DISCUSSION

The Spiral Entry Extended Riser performed similar to the extended riser tested in 5.2. For the purpose of this series of tests the Elbow and Expansion losses were carried through from section 5.2 and instead the entry losses were assumed to be unknown. This is due to the addition of 15 separate entry points (generally defined in Figure 5.8) where the flow is therefore not only entering the system from the regular entry point but also from the individual entry points surrounding the circumference.

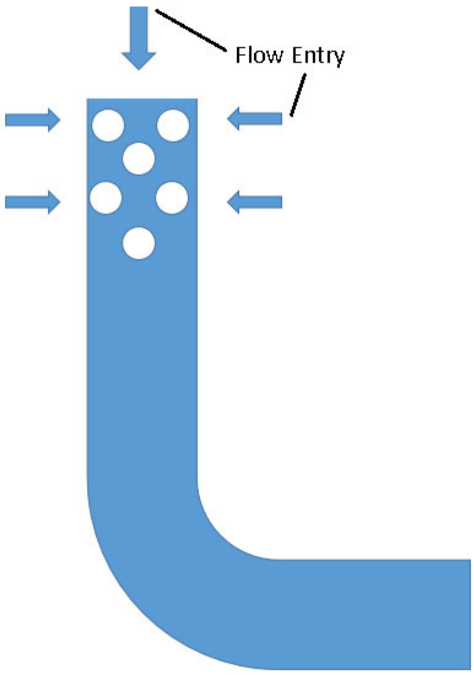

Figure 5.8. Spiral Siphon Entry (Not to scale)

As the losses throughout this area are extremely difficult to map the assumption has been made that the losses are a total throughout the initial area. This sum of losses throughout this area inherently reduces the friction losses however the minor losses throughout this area are significantly increased. This is particularly displayed in Figure 5.9 where the entry losses are compared against the elbow and expansion loss combinations. Majority of these losses are typical throughout the series of tests however the 54.54mm tests results in a significantly increased head loss due to the entry compared to the elbow/expansion losses. This presents the possibility that the testing conducted in the results section

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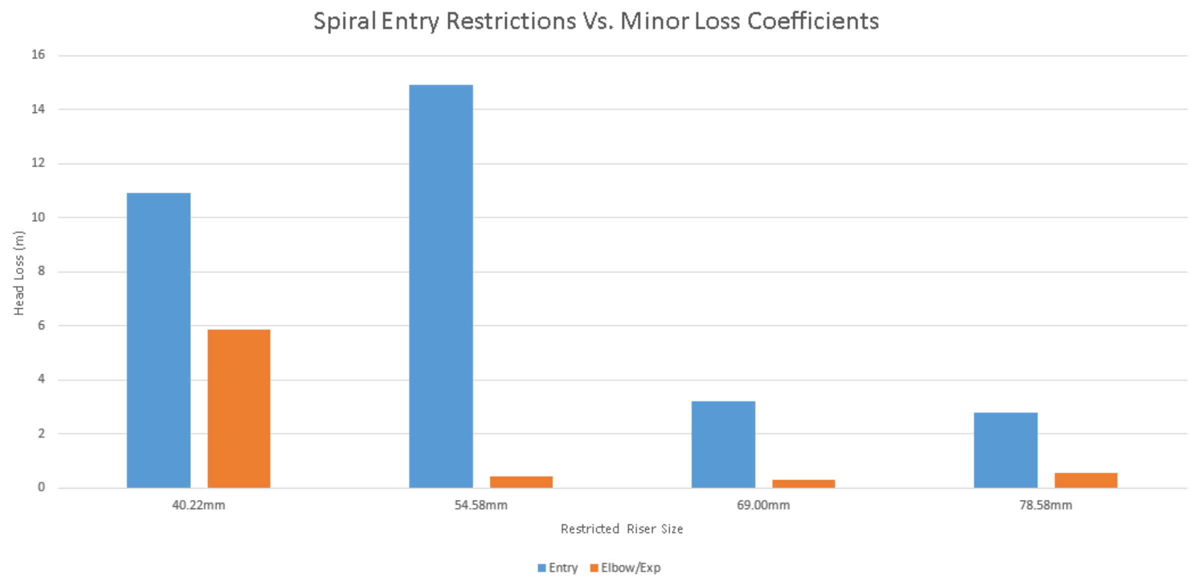

Figure 5.9. Restricted Spiral Riser Loss Coefficients (Entry and Expansion)

Once the Minor Head Losses are combined a clearer picture becomes apparent. The resultant total head losses throughout the system decreases gradually as the entry size increases, excluding the significant drop between the 54.58mm and 69.00mm riser sizes, this major loss can possible be attributed to the variation in secondary entry sizes (secondary entry sizes are constant, not proportional to the siphon size). This has the potential to have a significant difference on the 69.00mm and 78.58mm test as the losses experienced through the larger siphon sizes may not have impacted the flow characteristics as heavily at the smaller entry.

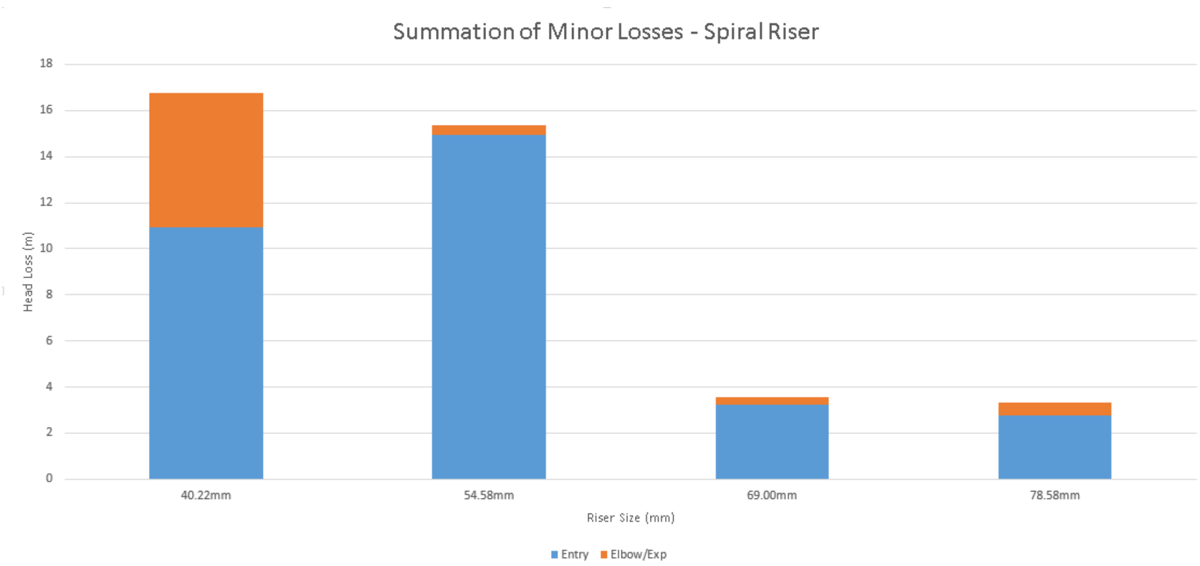

Figure 5.10. Summation of Minor Losses (Spiral Riser)

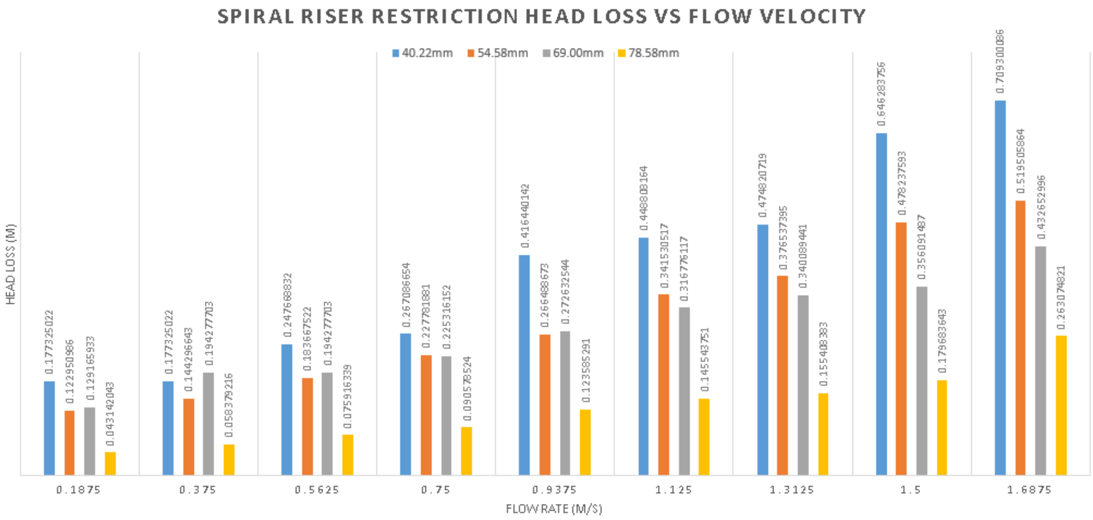

Figure 5.11. Spiral Riser Insert Head Loss Vs Flow Velocity.

As seen in previous results the increase in head loss due to minor losses increases as the flow velocity increases (Figure 5.11). This is somewhat seen in the initial three velocities; however the losses seem to be unstable at these points. As the flow velocity increases the head losses seen through the varying sized entry siphons approaches an almost linear correlation.

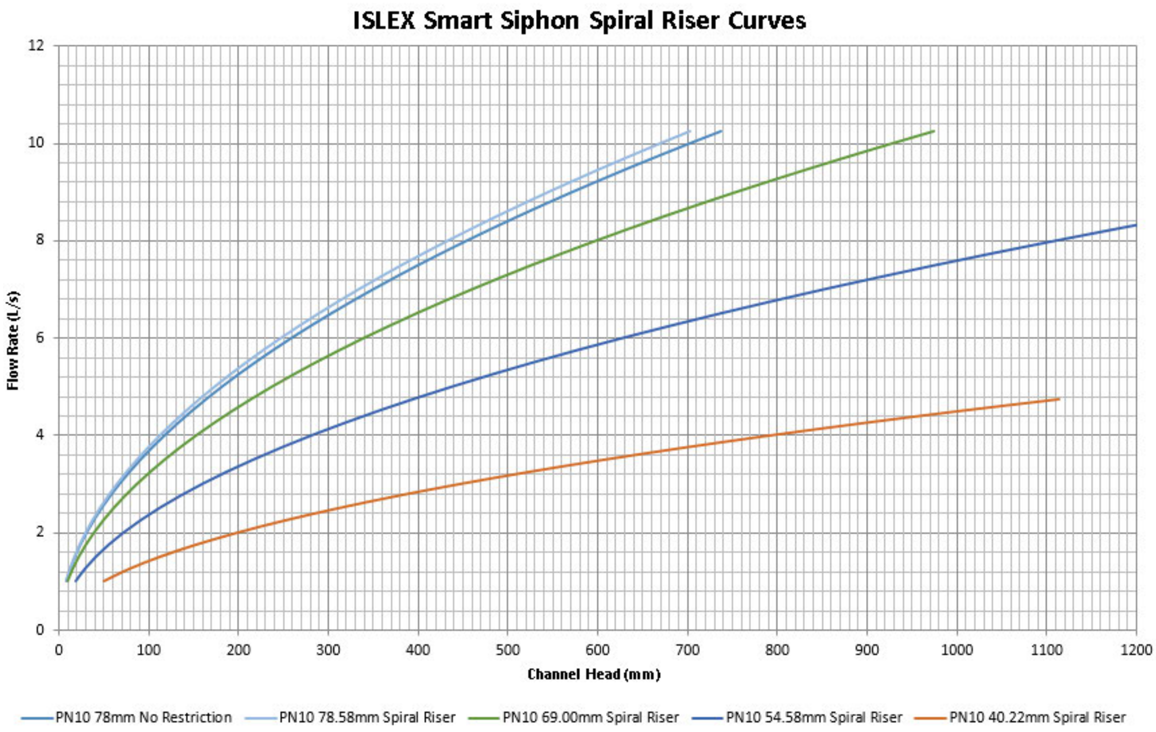

Figure 5.12. ISLEX Smart Siphon Spiral Riser Insert Rating Curves

With the inclusion of the significantly increased head losses throughout the testing phases the flow (Figure 5.12) looks to vary minimally compared against the previous sections flow rates shown in Figure 5.7. There are some slight differences between the results due to the difference in flow velocities between the two test series, however the difference is minimal and would have very little effect on the siphon flow within a field environment.

5.3.1. EXTENDED RISER (SPIRAL ENTRY) RECOMMENDATIONS

Similar to the previous section, the Extended Riser with a spiral entry pattern does provide an increased control over the velocity. There is, however, a minimal difference between the two other than a reduced entry velocity. The inclusion of the spiral pattern entry does present an increased susceptibility to cotton trash[9] which may be present through the supply channel. This immediately makes the entry more

[9] Cotton Trash: Biomass and plant litter carried by irrigation flow back into the supply channel and recycled through the system for the water to be used again.

vulnerable to the build-up of trash in the secondary inlets, thus increasing the flow velocity as the remaining inlets in order to maintain a constant flow rate.

Due to this it is unlikely that the extended riser with a spiral entry pattern will be used practically in the field. The research into the addition of the spiral pattern proved to be conclusive in that the addition makes minimal effect on the flow rate of the system as a whole and instead presents an opportunity for the system to lose efficiency due to the impact of the potential cotton trash.

5.3.2. EXTENDED RISER (SPIRAL ENTRY) CONCLUSIONS

Although the application of the restricted riser is an effective way of controlling the flow rate through the system, the addition of a spiral pattern of secondary entrances proves to make minimal effect on the system. Further to this the location and size of the secondary entry inlets presents the opportunity for trash and other matter to halt flow through multiple inlets, resulting in an increased flow velocity through the remaining points.

5.4. RESULTS OVERVIEW

The application of the extended restricted risers made the most impact on the system as a whole. The variation in entry sizes provided the capability to control flow characteristics throughout the system, however the sizes may need to be redefined in order to achieve the flow rate required. The testing of these generally display that there is a correlation between the head levels and the output flow rate. Although several diameters were tested, it is unreasonable to attempt and test each individual variable to the system and therefore the regression lines located on each siphon type is a guide only.

The addition of entry inserts did restrict the flow to an extent, however the restriction was minimal and therefore the variation between the separate flow types was negligible. The restriction inserts could be used in order to make smaller adjustments to the field flow, however majority of the losses throughout the system are presented by the spiral entry pattern.

The spiral riser had similar results to the extended riser, it is for this reason the testing of this equipment is excluded from the data pool. The spiral entry was academic in nature and was only required to be tested by ISLEX out of interest, within a practical setting the addition of the secondary entry points surrounding the circumference of the entry would present more issues than potential solutions to flow issues.

6. CONCLUSIONS

With a rapidly decreasing rate of available labour throughout rural Southern QLD and Northern NSW cotton farmers are consistently presented with the issue of achieving high yield with a minimum workforce. The lack of available labour requires the agriculture industry to be adaptive in integrating present and future automation technology to assist farmers and farm managers with maintenance of a larger area with a reduced workforce. The ISLEX Smart Siphon has been proposed as a potential contender in the race to automate irrigated cotton throughout Australia and further to that, international farms.

The Smart Siphon incorporates a rotating mechanism which lowers the siphon entry into the water, this mechanism can potentially be incorporated with automated actuators, however prior to any automation there is a requirement to ensure that the siphon has an effective control over the out flow and leading on from this the field run time. The testing aimed to achieve a hydraulic understanding of the system as a whole, including all minor loss locations and the potential flow characteristics throughout that area. Following the analysis of this data, the outcome is to provide a practical set of rating curves which farmers throughout the regions can use for the installation and maintenance of the equipment.

As outlined in the project intentions the research objectives to be achieved through the conduct of the testing included the analysis of siphon irrigation and flow, the definition of the ISLEX Smart Siphon, evaluation of the hydraulic performance of the smart siphon, generation of rating tables and graphs to assist farmers with the practical installation of the smart siphon and then if time and resources permitted to conduct further study into the erosion effects of the Smart Siphon and a cost analysis comparing the installation of the Smart Siphon against labour costs.

As the project approached the testing phase ISLEX provided further restriction samples to be attached to the Smart Siphon mechanism, with the reception of these samples came the ultimatum between conducting a detailed hydraulic analysis of each restriction type or branching out and striving to achieve results for the erosion analysis objectives, for obvious reasons the earlier was chosen as this data is required by ISLEX for installation in the field. The first objective was achieved through the detailed background information and literature review into the history is siphon irrigation as well as the hydraulic fundamentals behind the simplistic design of the Smart Siphon.

Following the review of literature as well as background knowledge of Hydraulic engineering the performance of the Smart Siphon was tested under varying flow rates and restrictor types. The outcome of this being the allocation of minor loss coefficients throughout the system in order to understand where that majority of head losses are located and what they are a result of. The testing was conducted in the hydraulics laboratory at the University of Southern Queensland and involved the measurement of flows through each restriction type with a varying head level. The restriction effects under varying head levels provided sound data which formed the fundamental basis for the analysis, however, as the head levels approached 100mm and below the flow became non-full pipe and therefore the analysis method altered. As this was not a specific section required for analysis it provides further opportunity for investigation in the case that a low head level is required.

Subsequent to the practical measurement and analysis, rating curves were then deducted for the siphon sizes tested. These curves are required to aid with the farmer's installation and maintenance as well as provide a general understanding into the flow rates which can be expected at different water head levels. The production of these curves in Annexes L, M and N display the correlation between the head level of the supply channel and the expected flow rate of the siphon at that level. The solution of these curves can confidently provide a basis into how the restrictions should be used throughout an irrigated cotton farm, as well as the reaction of the restrictions under diverse head levels.

Unfortunately the curves are far from perfect, the restriction sizes tested tended to have a large cavity between result curves, potentially in sections where a farmer may require a flow rate. As previously stated, it is impossible to satisfy each farmer's individual needs, however further testing into the area may provide an increased knowledge into the required restriction to be used. The testing could potentially incorporate the following:

1. The effect of low head levels on the flow characteristics throughout the system,
2. The effect of vortexing at the siphon entry,
3. The actions and reactions through an elbow joint incorporating a sudden expansion,
4. A detailed analysis into the erosion patterns surrounding the siphon exit, and
5. A cost analysis comparing the difference between the installation of the ISLEX Smart Siphon and current labour.

Following on from this an investigation into the erosion effects of the Smart Siphon both at the immediate exit and further downstream. An understanding into how the erosion affects the flow rate and the soil shear capacity is required; however for a location with such variation to the soils throughout the area it is difficult to conduct an analysis within the allocated time frame. With that in mind some possible recommendations to mitigate the effects of erosion at the siphon outlet are:

1. Increase the 'Free Fall' at the outlet location, the reduces the flow velocity at the siphon exit and reduces the waters shear capacity,
2. Select a siphon which reduces the velocity of the flow rate, this has a similar effect to the increased free outflow in that it reduces the waters shear capacity.

The siphon itself looks to be relatively sturdy and maintainable. The Smart Siphon rotating mechanism itself, however, looks to be extremely brittle. From personal experience anything that has such potential to break, will do so within the first several irrigations. The mechanism itself is required to increase its strength, keeping in mind the tension that the mechanism must withhold as well as a combination of the hydrostatic pressure applied while irrigating and the UV exposure during off-season. The mechanism is a critical part of the system and therefore it is proposed that it be made from a similar material (Polyethylene or the like).

In an ever-evolving field of study agriculture is consistently required to adapt to improving methods, equipment and technology. The implementation of the ISLEX Smart Siphon has the potential to revolutionise the irrigated cotton industry through the incorporation of existing siphon irrigation methods with current automation technology. With a fundamental knowledge into the hydraulic performance of the Smart Siphon under varying head levels and flow conditions, the farmer is provided with ample and easily accessible information into the effects on the flow characteristics associated with the inclusion of entry restriction.

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Annex A – Project Specification V2, 2017

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **NICHOLAS LEGGAT –** [redacted]

Title: Hydraulic Investigation into the Practical Applicability of the ISLEX Smart Siphon

Major: Civil Engineering

SUPERVISOR: Dr Malcolm Gillies

SPONSERSHIP: N/A

Enrolment: ENG4111 – ONC S1, 2017
ENG4112 – ONC S2, 2017

Project Aim: To theoretically and practically provide a hydrological analysis into the use of the modern Siphon systems within both an operational and controlled environment. The project then aims to provide feedback concerning the optimum installation methods and requirements.

Version: **V2, 2017**

PROGRAMME:

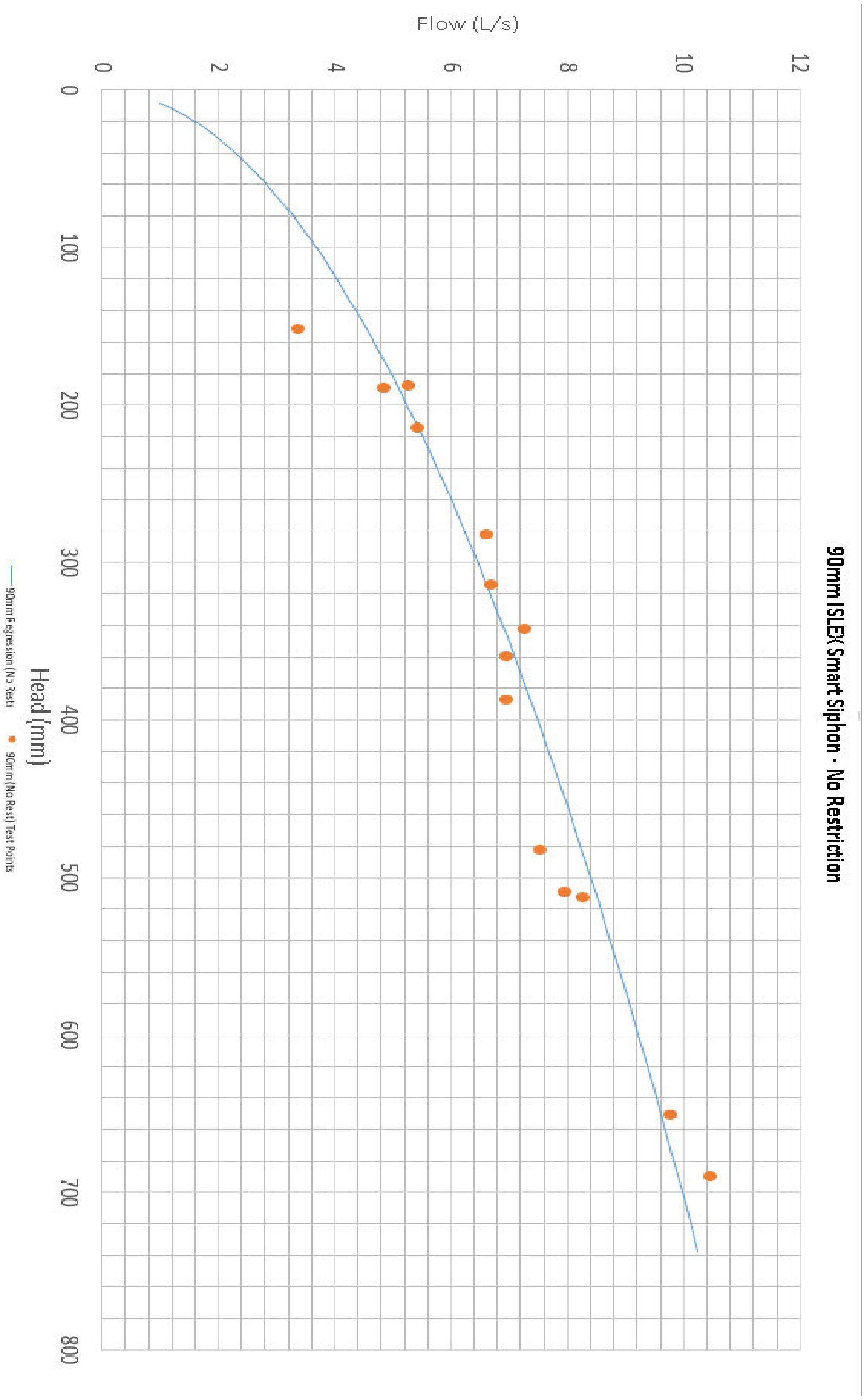
The objectives of this project are to:

7. Examine and define the ISLEX Smart Siphon as well as provide background into the practical use of the Siphon.
8. Evaluate the hydraulic performance of the smart siphon through practical measurement in a controlled environment.
9. Generation of rating tables and equations to predict the flow rate from operating head and pipe characteristics.

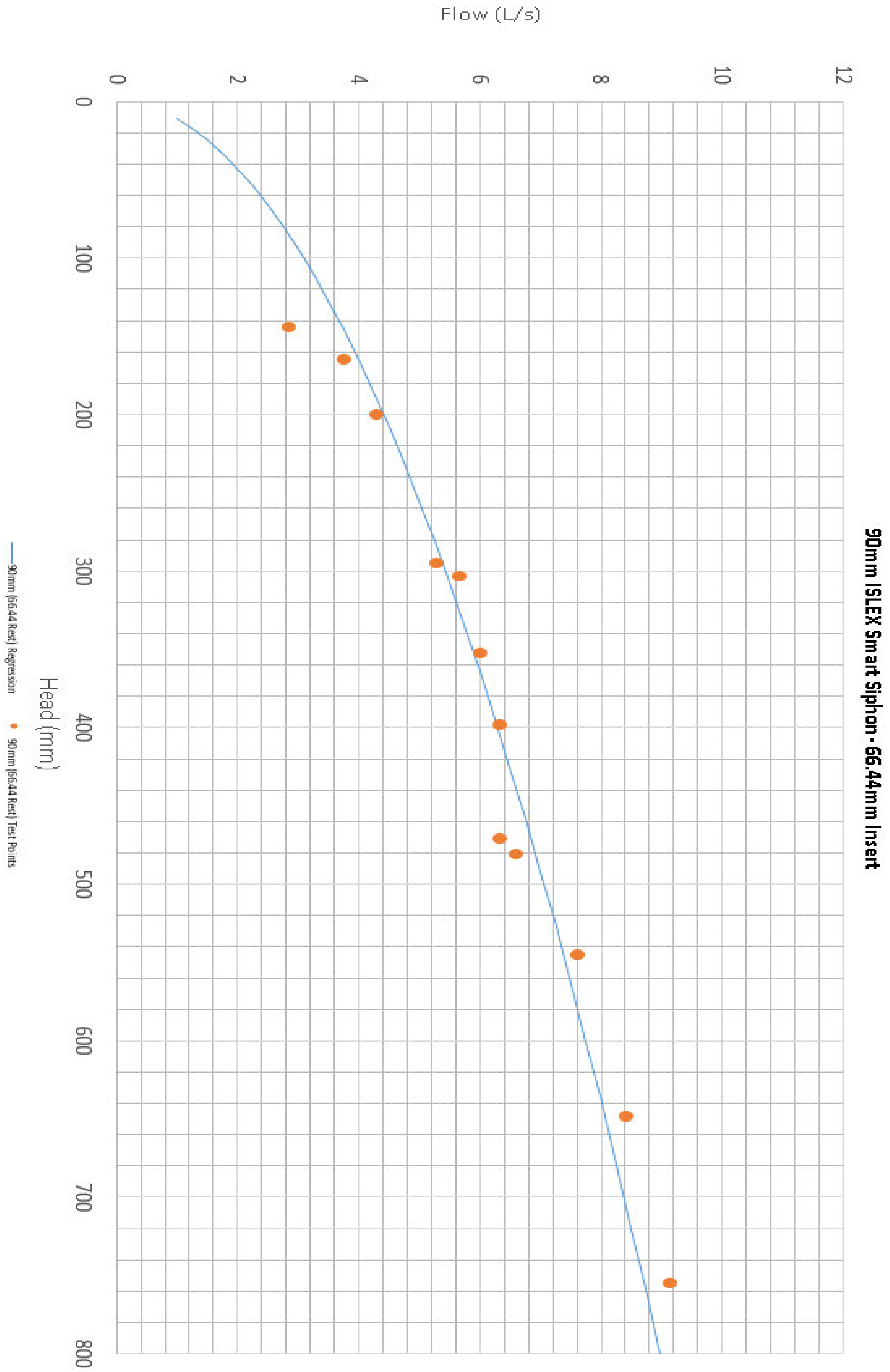
If time and resources permits

10. Propose and test improved designs to reduce runoff effects.
11. Collate observations on the performance of the smart siphon including erosion potential.
12. Design an experiment to study the erosion downstream of siphons and smart siphons.

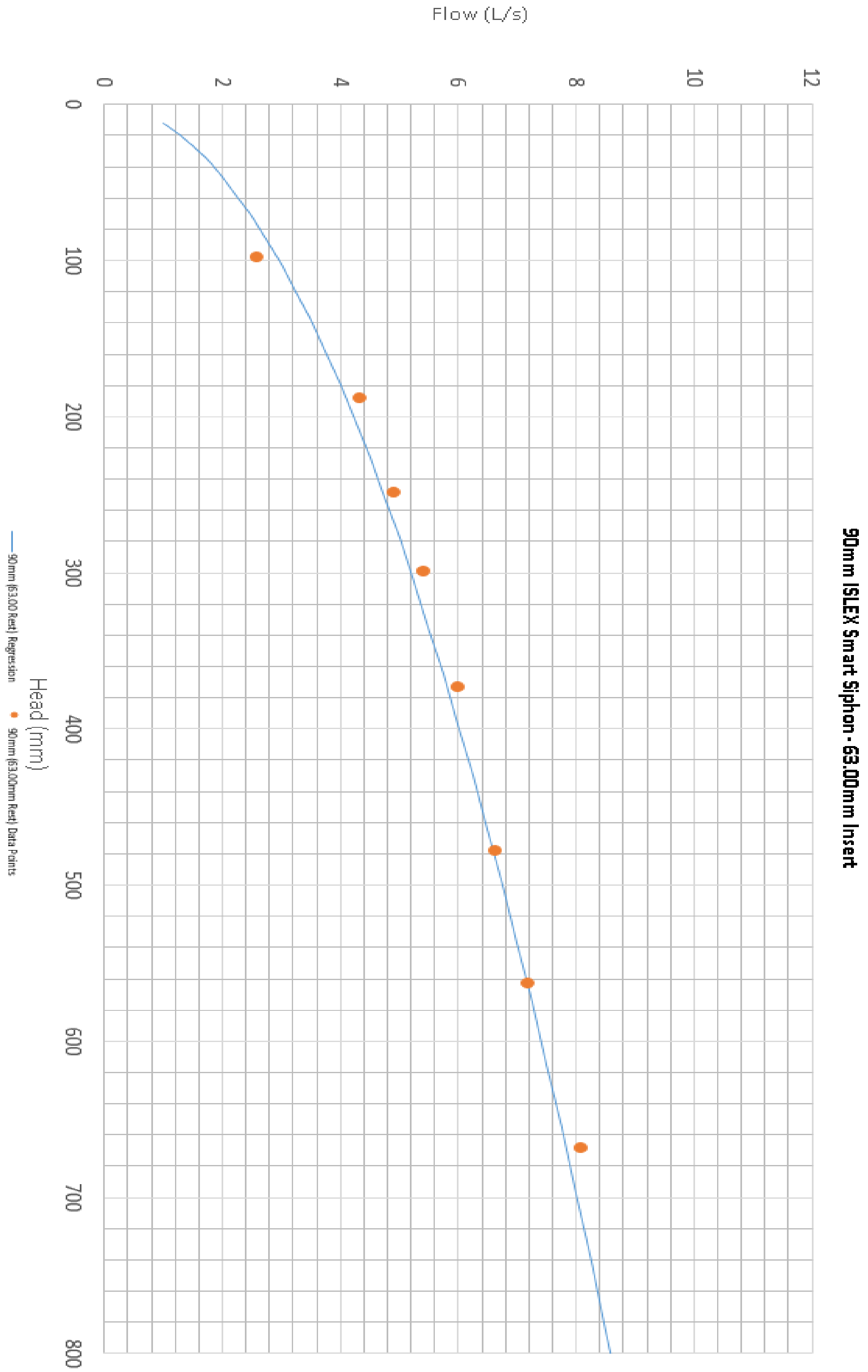
Annex B – 90mm PN10 Siphon (No Restriction) Rating Curve



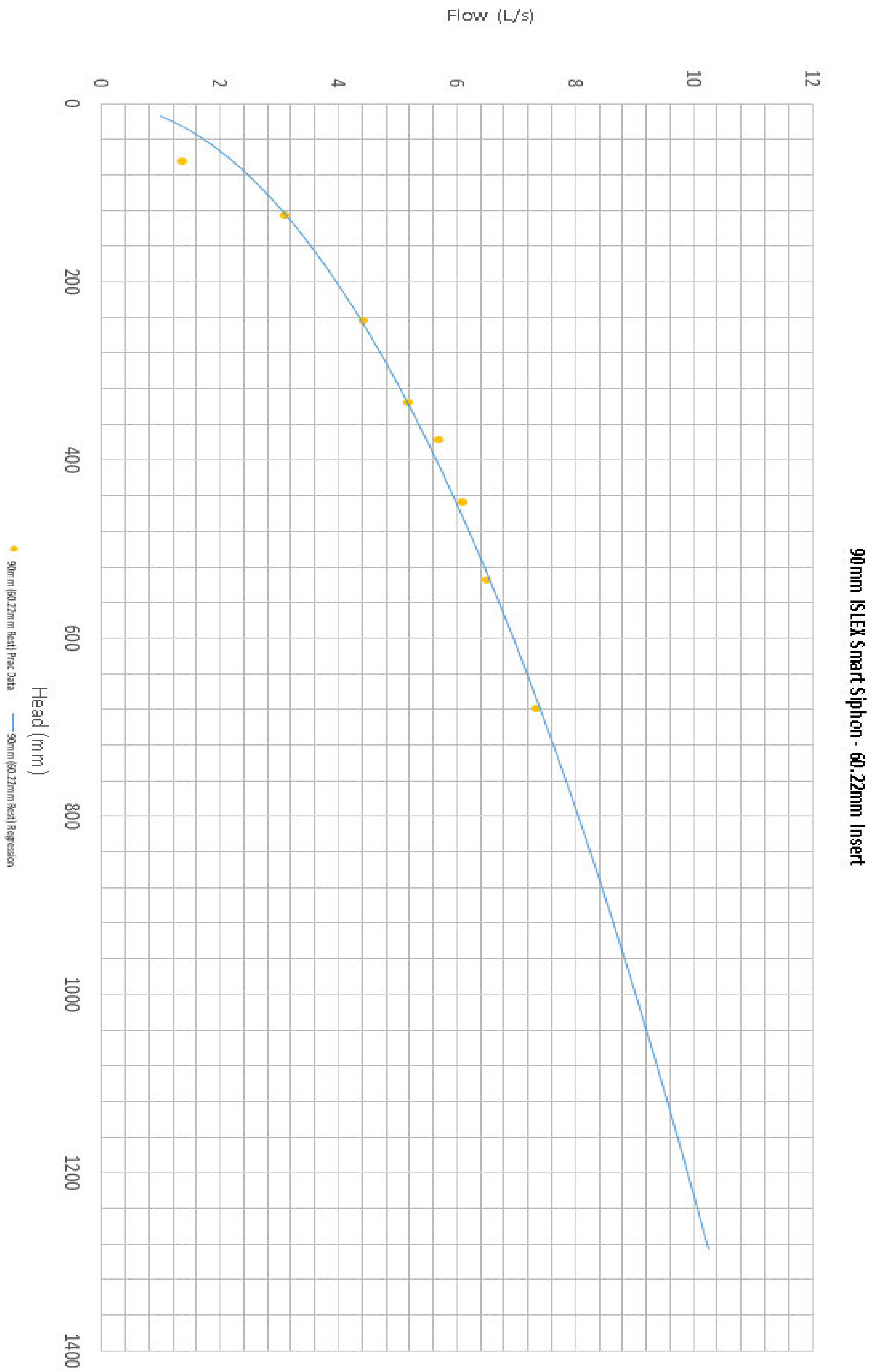
Annex C – 90mm PN10 Siphon (Restriction to 66.44mm Insert) Rating Curve



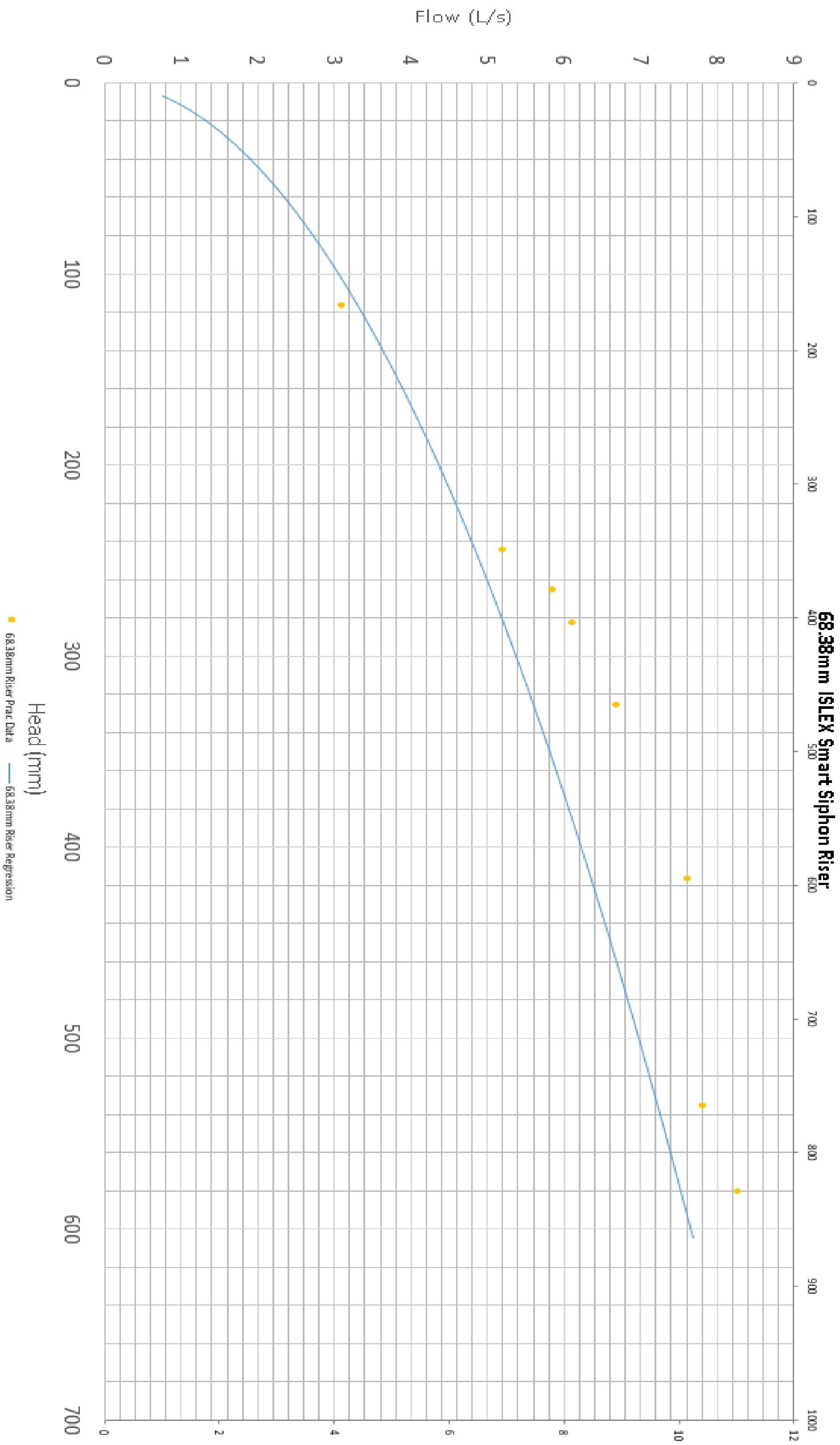
Annex D – 90mm PN10 Siphon (Restriction to 63.00mm Insert) Rating Curve



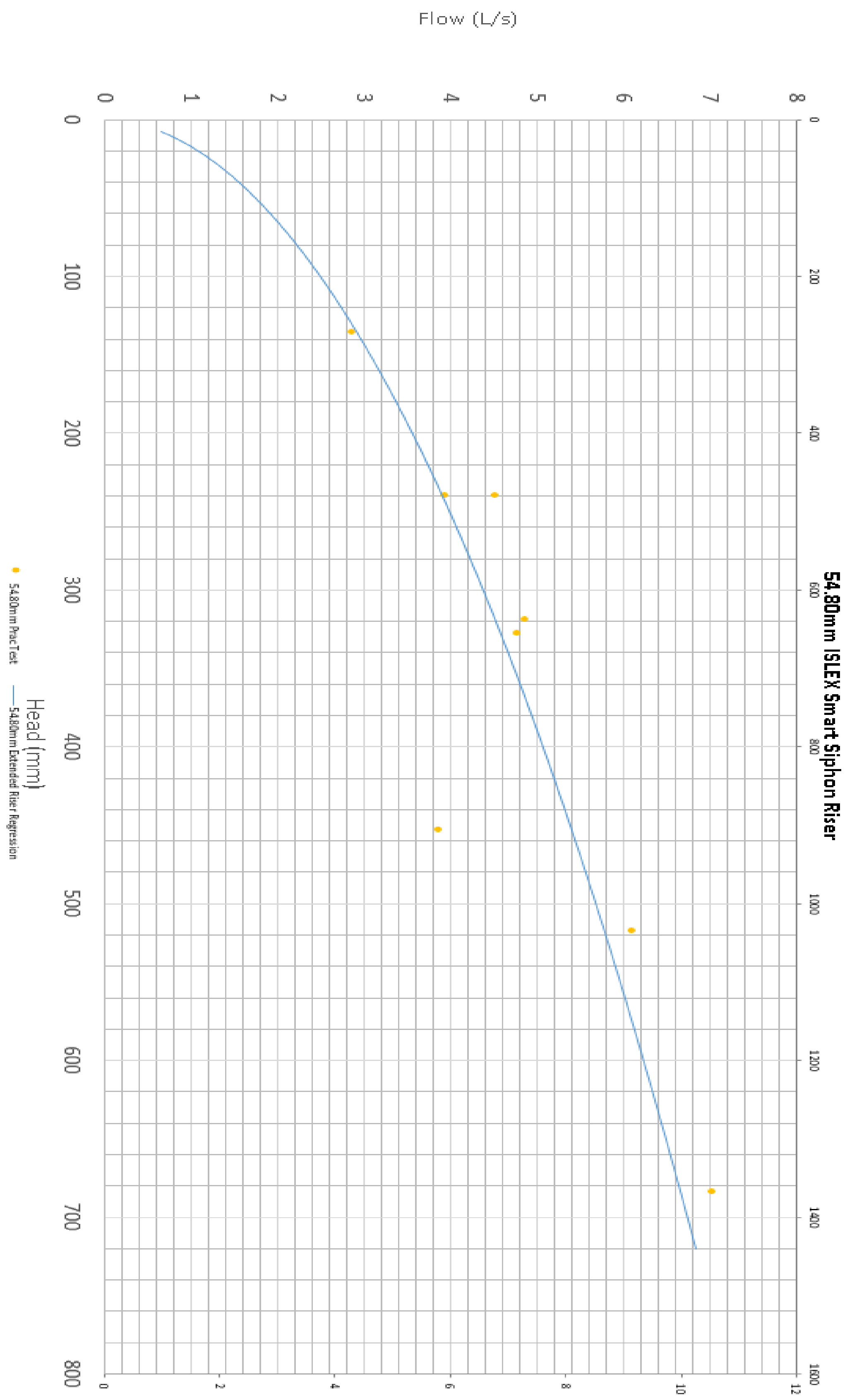
Annex E – 90mm PN10 Siphon (Restriction to 60.22mm Insert) Rating Curve



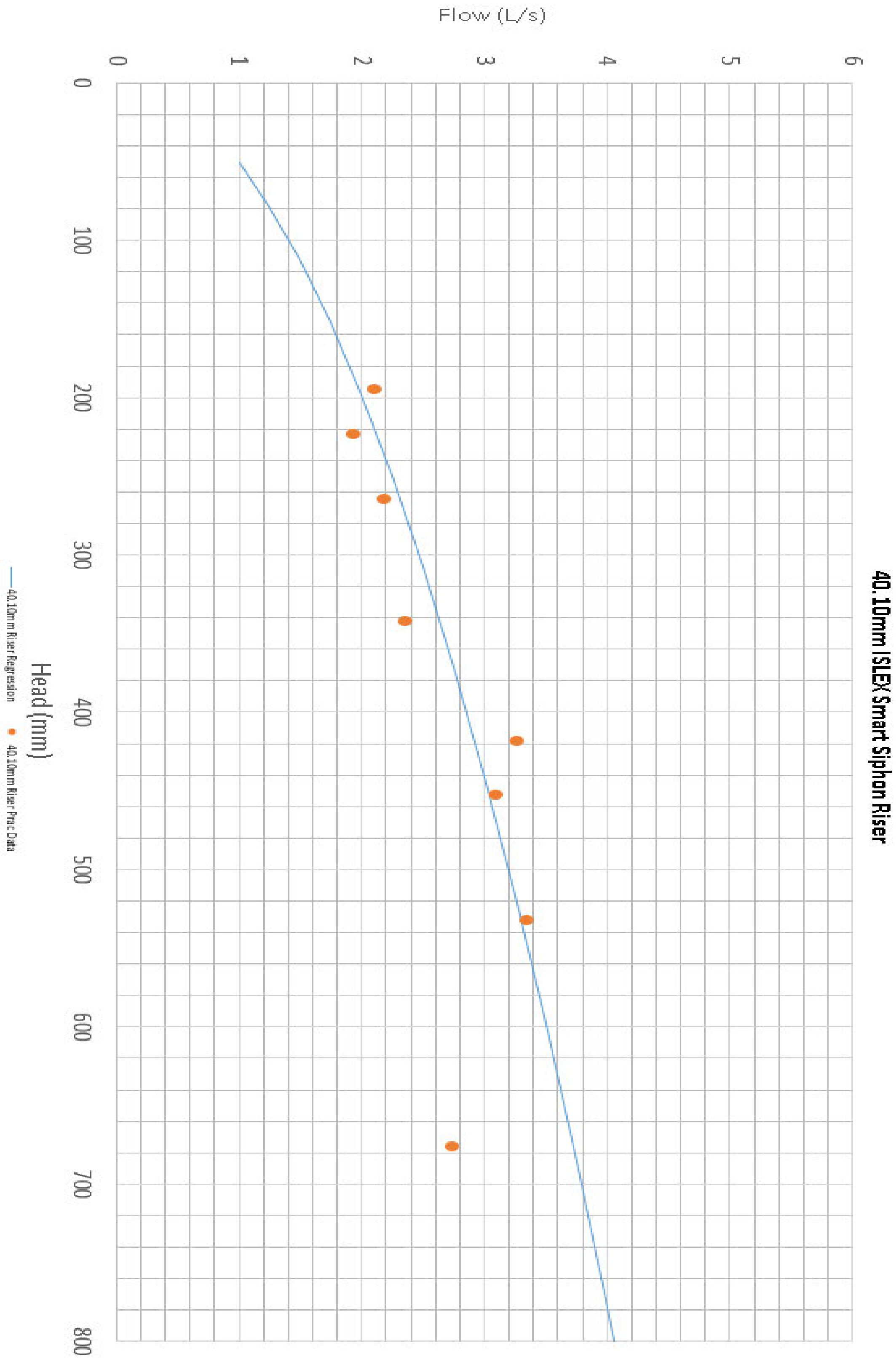
Annex F – 90mm PN10 Siphon (Entry Riser Restricted to 68.38mm) Rating Curve



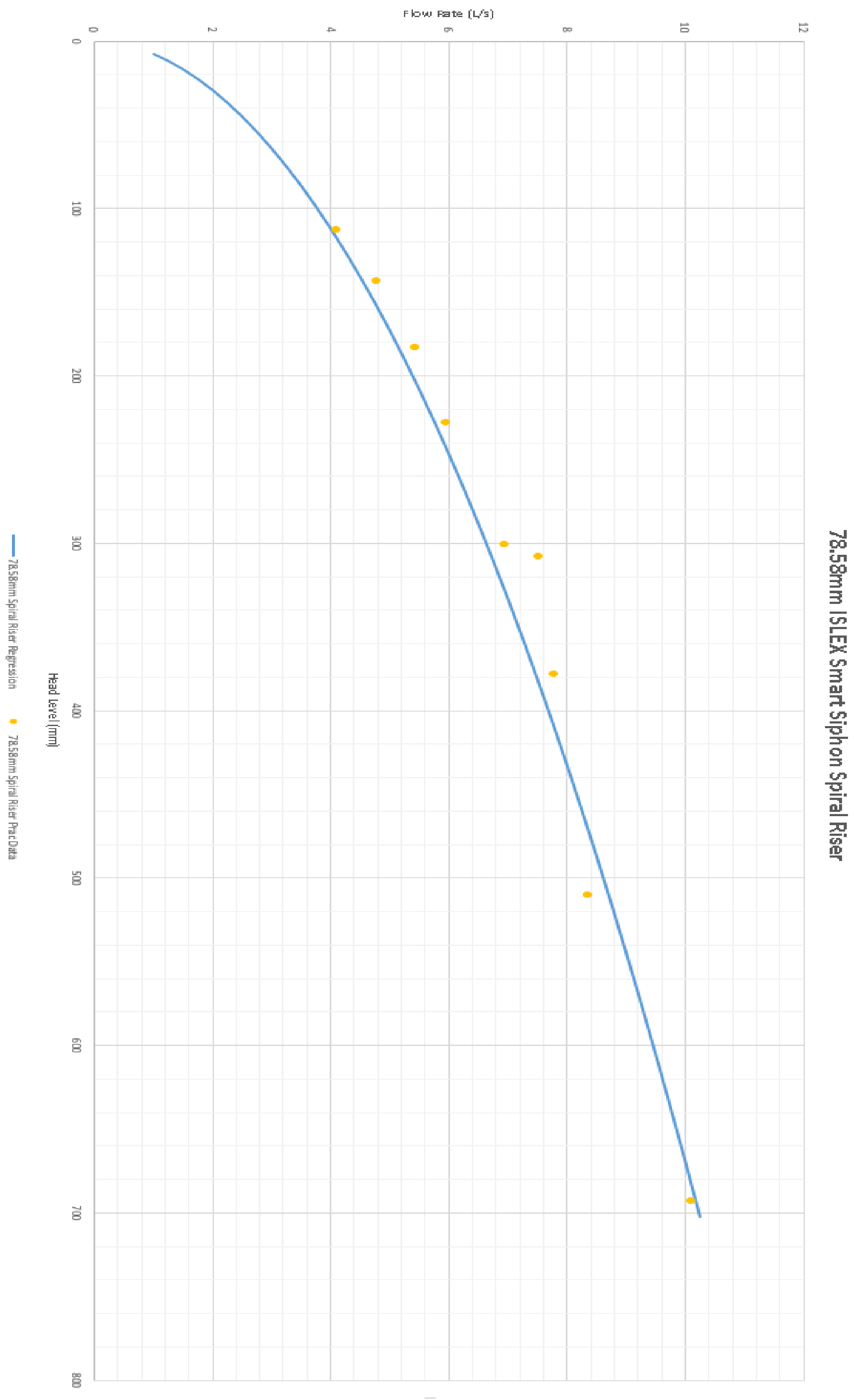
Annex G – 90mm PN10 Siphon (Entry Riser Restricted to 54.80mm) Rating Curve



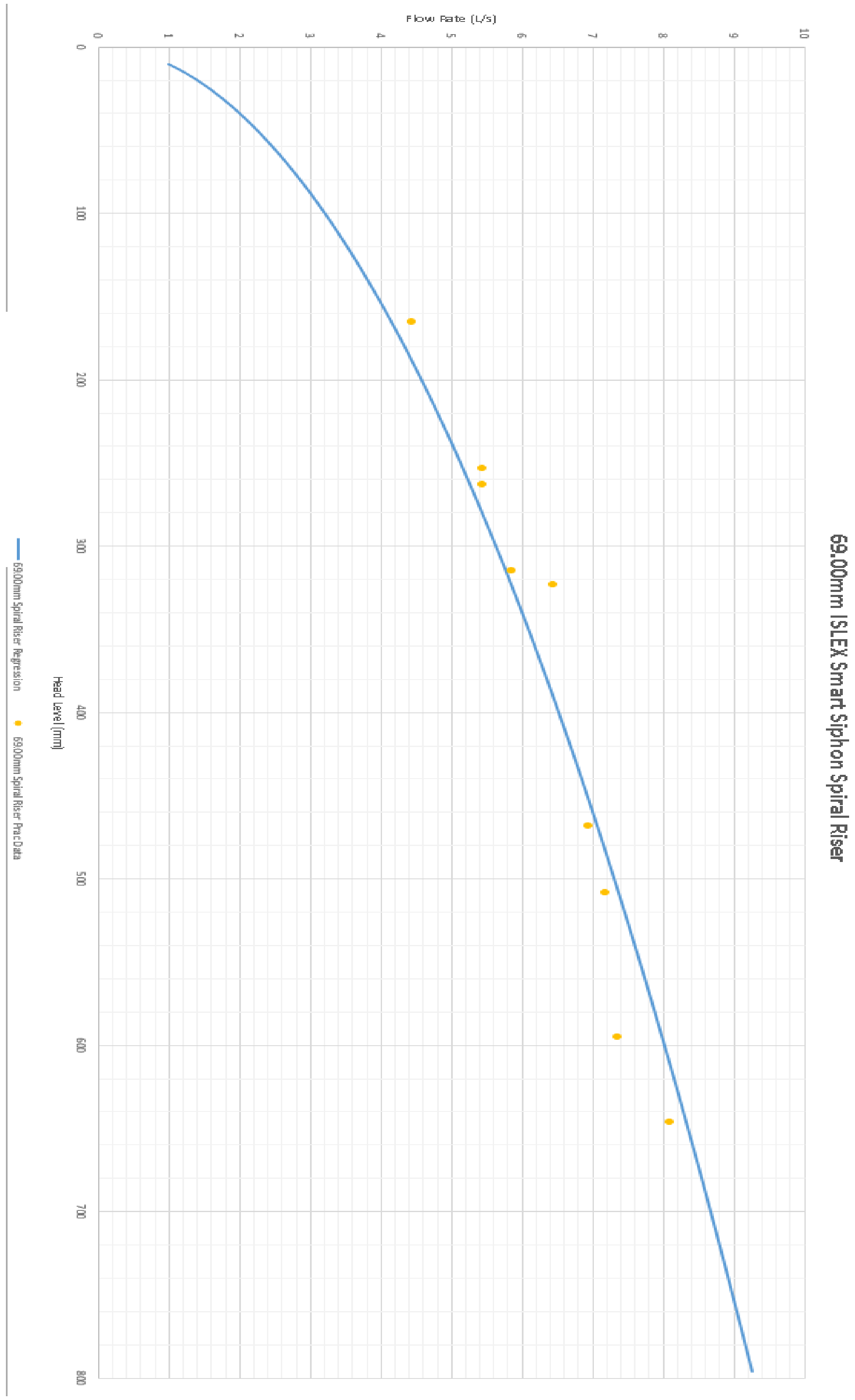
Annex H – 90mm PN10 Siphon (Entry Riser Restricted to 40.10mm) Rating Curve



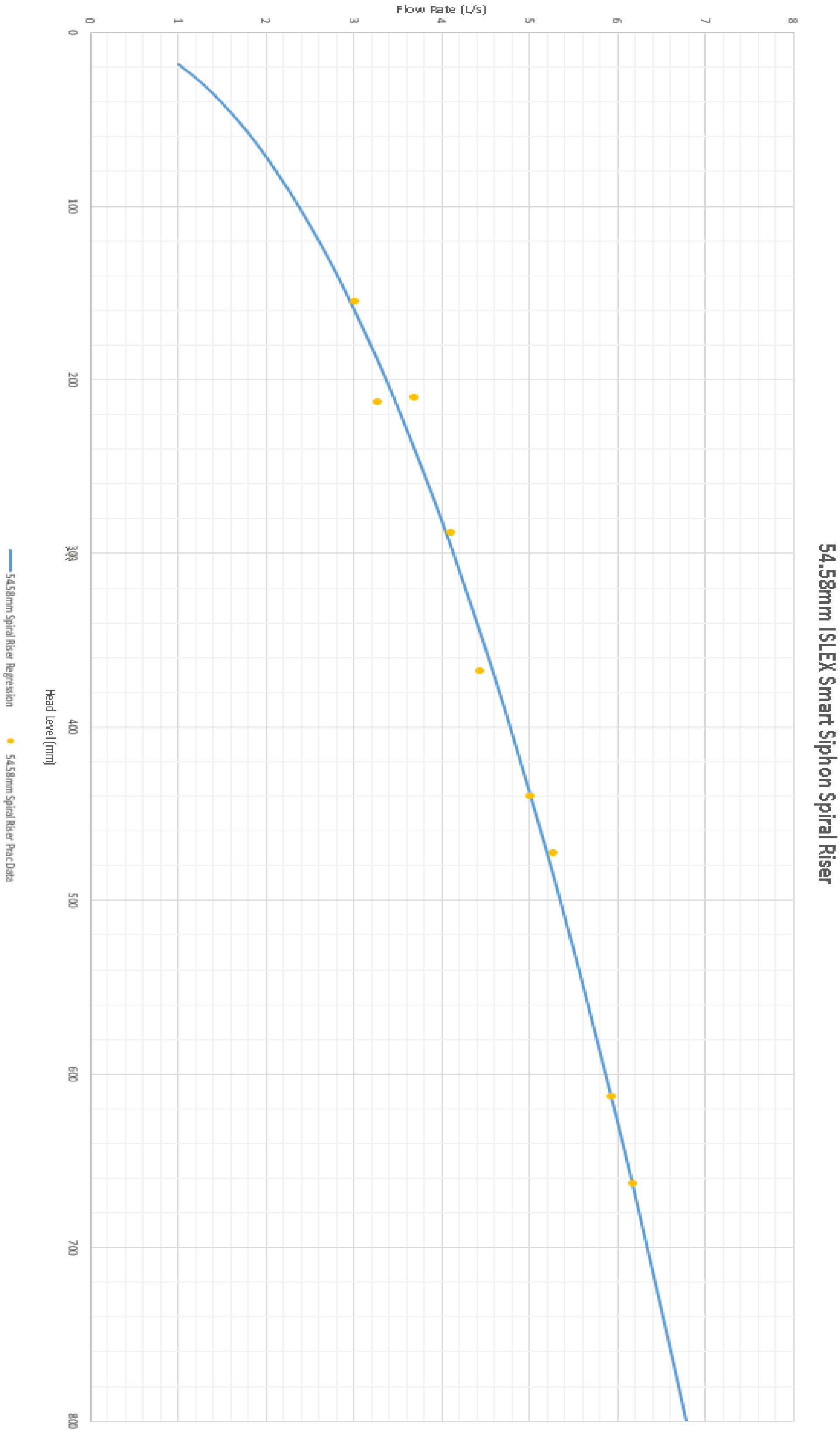
Annex I – 90mm PN10 Siphon (Entry Riser Restricted to 78.58mmSpiral Entry) Rating Curve



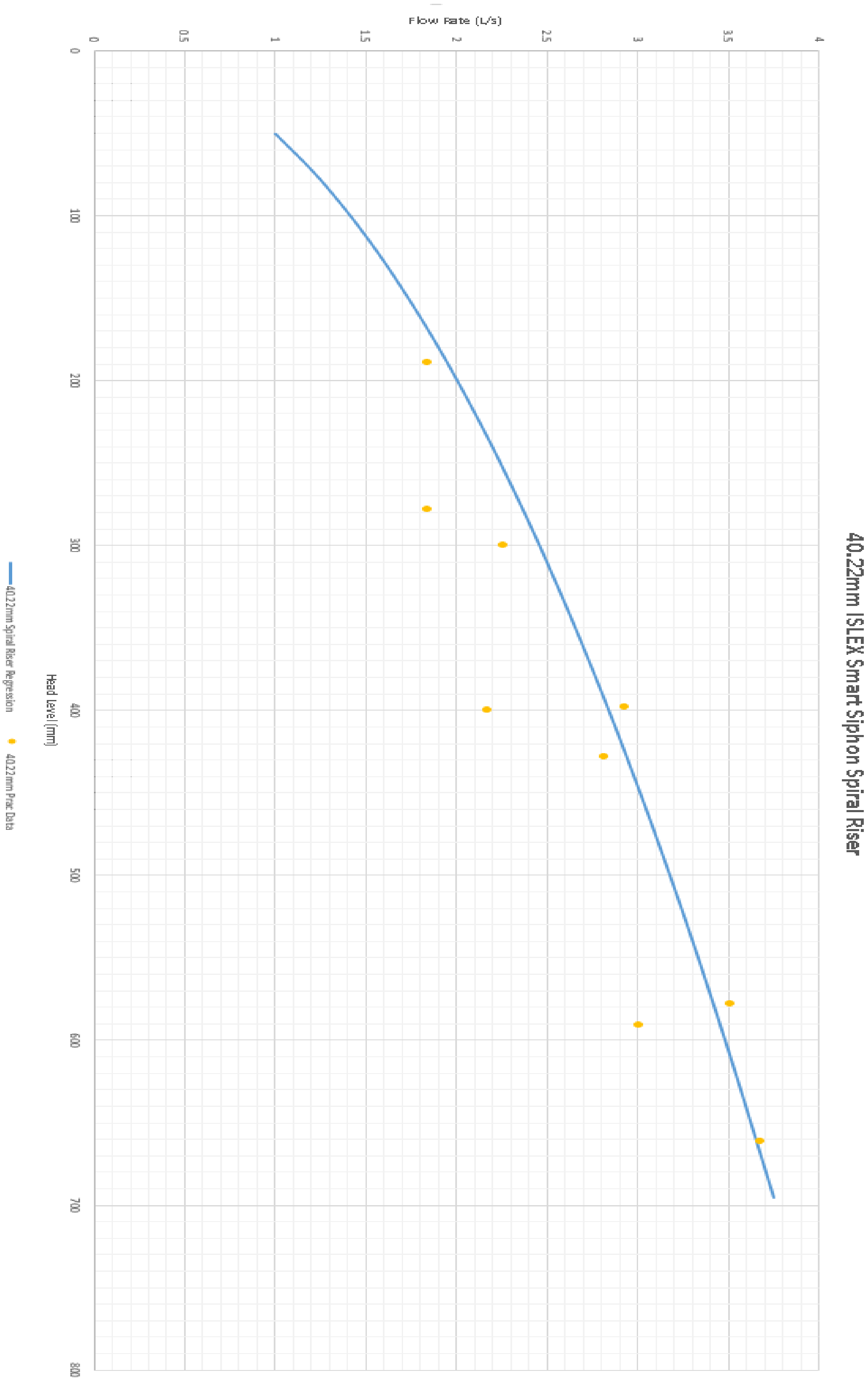
Annex J – 90mm PN10 Siphon (Entry Riser Restricted to 69.00mmSpiral Entry) Rating Curve



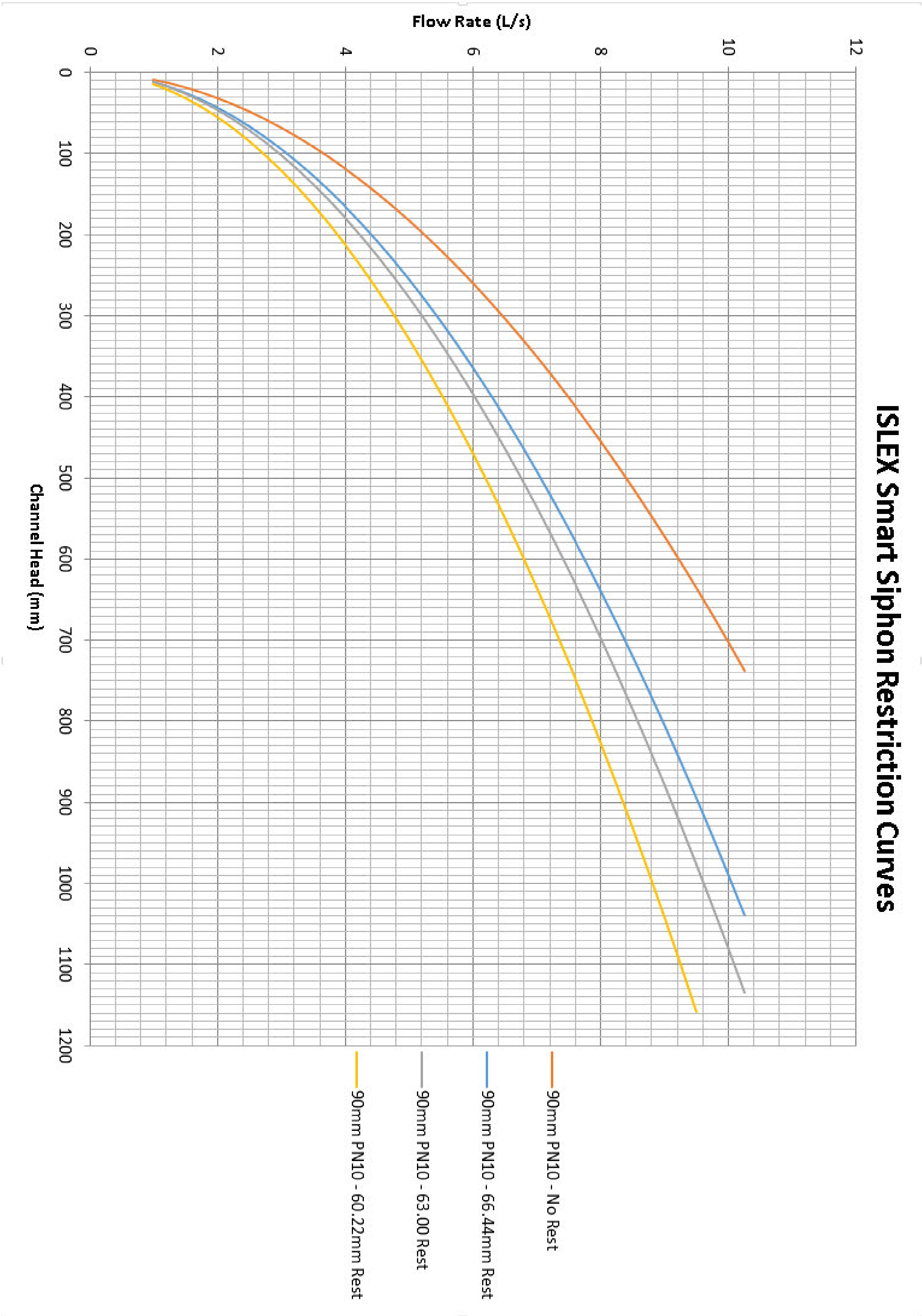
Annex K – 90mm PN10 Siphon (Entry Riser Restricted to 54.58 mm Spiral Entry) Rating Curve



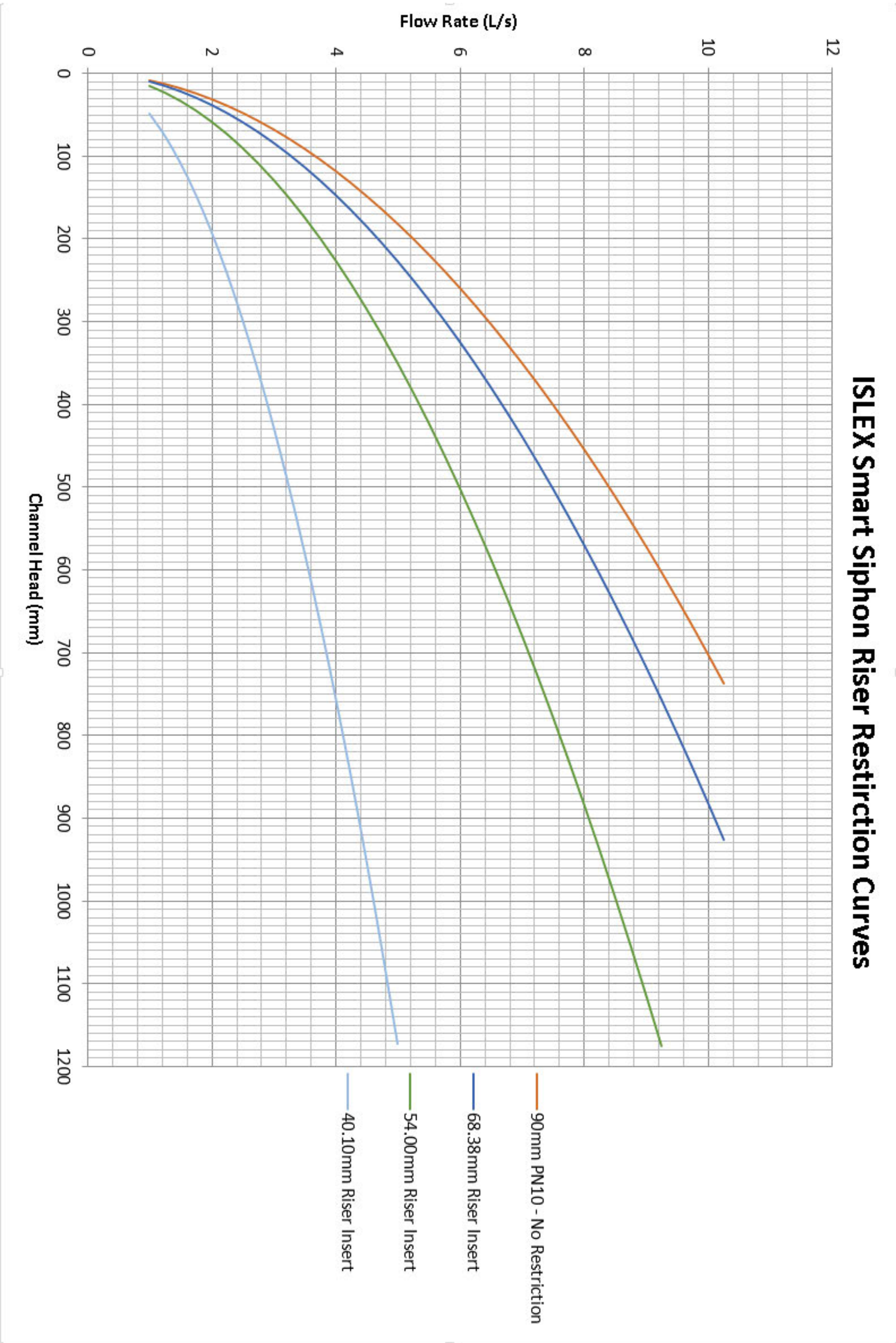
Annex L – 90mm PN10 Siphon (Entry Riser Restricted to 40.22mm Spiral Entry) Rating Curve



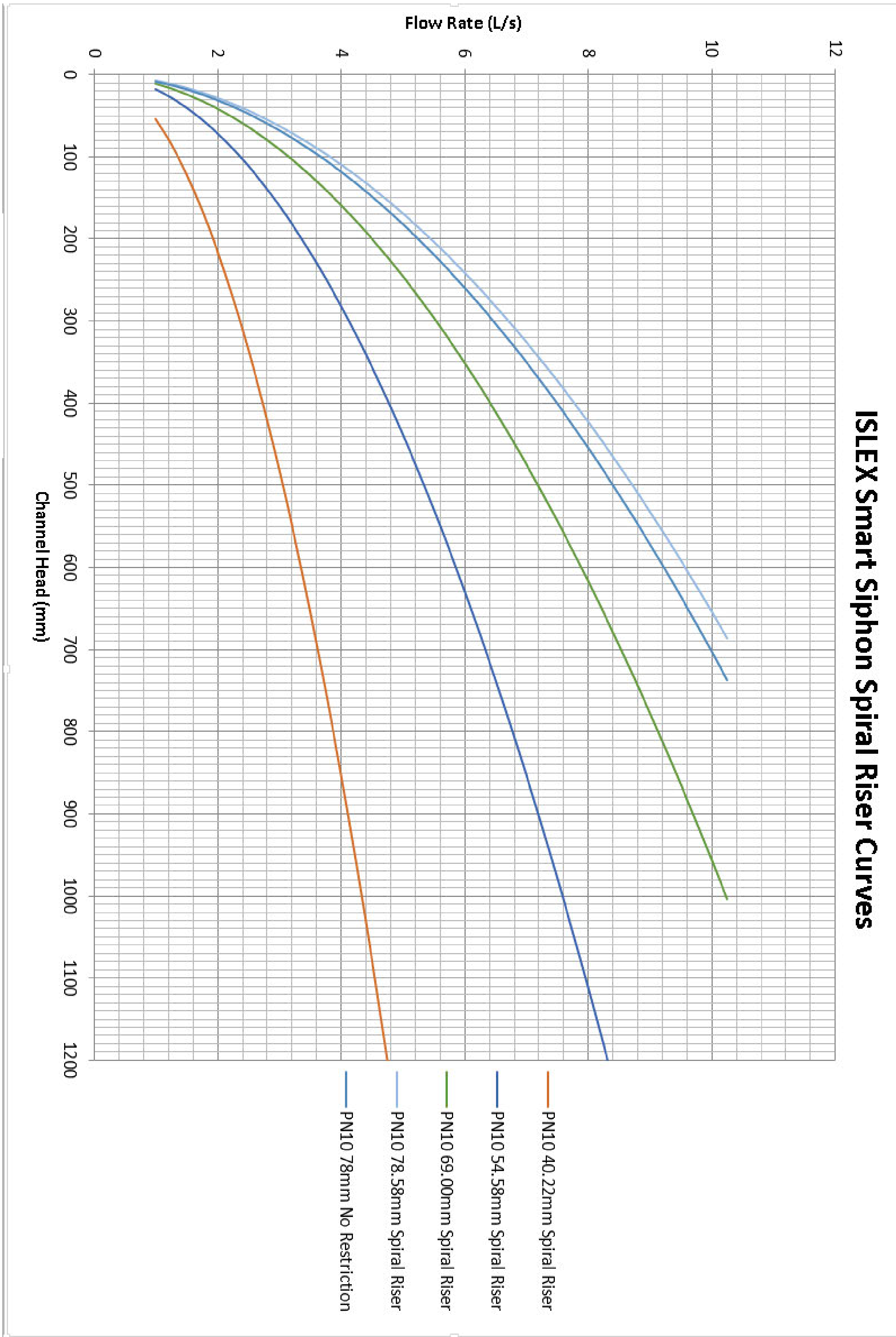
Annex M – ISLEX Smart Siphon Restrictor Insert Rating Curve



Annex N – ISLEX Smart Siphon Restricted Riser Insert Rating Curve



Annex O – ISLEX Smart Siphon Restricted Spiral Riser Insert Rating Curve



Annex P – Experiment Construction Works Risk Assessment

Table 7.1. Experiment Construction Works Risk Assessment

Hazard	Risk	Likelihood	Consequences	Control
Use of power tools	Significant	High	Death, serious injury	Wear all required PPE for conduct of use, wear long sleeve shirt and trousers, Toolbox Talk with any required labour
Work at night	Significant	Medium	Death, serious injury	Use of all required lighting to achieve satisfactory requirements.
Element exposure	Slight	Low	Burns, heatstroke, dehydration, temperature related illness	Wear and utilise correct PPE, i.e. sunscreen, long garments, hat, glasses
Noise	Slight	Severe	Loss of hearing	Wear and utilise hearing protection
Further equipment usage (vibration, manual handling)	Slight	Medium	Sprains and strains	Wear and utilise correct PPE, limit exposure to repetitive actions
Manual lifting	Slight	High	Sprains and strains	Conduct correct lifting techniques, two man lift to be conducted where an item is above 30kg.

Annex Q – Laboratory Works Risk Assessment

Table 7.2. Laboratory Works Risk Assessment

Hazard	Risk	Likelihood	Consequences	Control
Use of chemicals	Slight	Low	Inhalation, ingestion and supplementary health consequences	Abide by MSD's for chemicals used
Material spillage	Significant	Severe	Slips and falls	Maintain a clean work environment, ensure any
Equipment usage (vibration, manual handling)	Slight	Medium	Sprains and strains	Wear and utilise correct PPE, limit exposure to repetitive actions
Specific machine related hazards (pinch points, rotating components)	Slight	Low	Serious injury, sprains and strains	Ensure SOP is clearly understood before operating under supervision of trained personnel, ensure trained personnel present prior to conduct of works.

Annex R – External Works Risk Assessment

Table 7.3. External Works Risk Assessment

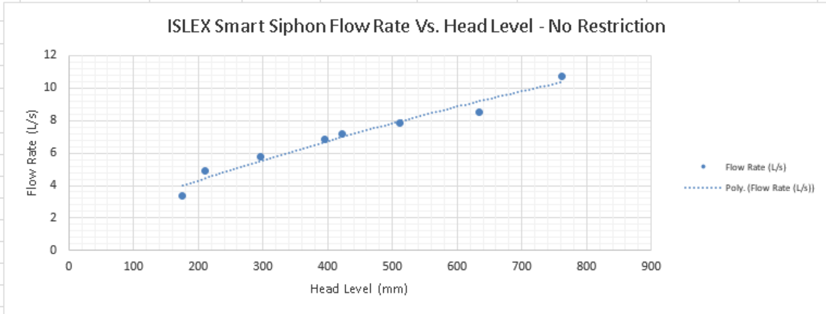
Hazard	Risk	Likelihood	Consequences	Control
Use of excavation equipment	Significant	High	Death, serious injury	Wear all required PPE for conduct of use, wear long sleeve shirt and trousers, Toolbox Talk with any required labour. Ensure all operators have required operation tickets
Work at night	Significant	Very Low	Death, serious injury	Use of all required lighting to achieve satisfactory requirements.
Element exposure	Slight	Low	Burns, heatstroke, dehydration, temperature related illness	Wear and utilise correct PPE, i.e. sunscreen, long garments, hat, glasses
Noise	Slight	Severe	Loss of hearing	Wear and utilise hearing protection
Further equipment usage (vibration, manual handling)	Slight	Medium	Sprains and strains	Wear and utilise correct PPE, limit exposure to repetitive actions
Manual lifting	Slight	High	Sprains and strains	Conduct correct lifting techniques, two man lift to be conducted where an item is above 30kg.

Annex S – Raw Data Collection Spreadsheet Sample

Entry Restriction:	78.36	mm	0.004822568	m2	Length	300	mm
Pipe Diam:	78.36	mm	0.004822568	m2	Head Differ	77	mm

SUMMARY TABLE

Head Level (mm)	**Flow Rate (L/s)**	**Entry Velocity (m/s)**	**Exit Velocity (m/s)**
762	10.75	2.229102788	2.229102788
634	8.5	1.762546391	1.762546391
512	7.833333333	1.624307458	1.624307458
297	5.75	1.192310794	1.192310794
395	6.833333333	1.416949059	1.416949059
422	7.166666667	1.486068525	1.486068525
210	4.916666667	1.019512128	1.019512128
176	3.333333333	0.691194663	0.691194663
0	0	0	#DIV/0!



Height	762	mm	Height	634	mm	Height	512	mm
Head Level	**685**	**mm**	**Head Level**	**557**	**mm**	**Head Level**	**435**	**mm**
Cum. Total Start	133.65	m3	Cum. Total Start	135.35	m3	Cum. Total Start	136.89	m3
Cum. Total End	132.36	m3	Cum. Total End	134.33	m3	Cum. Total End	135.95	m3
Difference	1.29	m3	Difference	1.02	m3	Difference	0.94	m3
=	1290	L	=	1020	L	=	940	L
Time	2	min	Time	2	min	Time	2	min
	120	Seconds		120	Seconds		120	Seconds
Flow Rate	10.75	L/sec	Flow Rate	8.5	L/sec	Flow Rate	7.83333333	L/sec
	0.01075	m3/s		0.0085	m3/s		0.00783333	m3/s
Entry Velocity	2.229102788	m/s	Entry Velocity	1.762546	m/s	Entry Velocity	1.62430746	m/s
Exit Velocity	2.229102788	m/s	Exit Velocity	1.762546	m/s	Exit Velocity	1.62430746	m/s

Annex T(1) – Example Solution of Measured Flow Rates converted to Velocities

			Flow Rates		Testing Data		
	Flow (L/s)	Entrance Velocity (m/s)	Calc Head		Flow	Head	RMSE
	7.928571	1.617525	0.446176	446.17555	7.928571	510	4073.56
	6.666667	1.360081	0.318124	318.1238401	6.666667	315	9.758377
	5.384615	1.098527	0.20985	209.8504613	5.384615	215	26.51775
	4.811321	0.981568	0.168582	168.5821919	4.811321	190	458.7225
Malcolm	10.43011	2.127868	0.762683	762.6830016	10.43011	690	5282.819
	6.923077	1.412391	0.342421	342.4212521	6.923077	360	309.0124
	5.25	1.071064	0.199762	199.7624535	5.25	188	138.3553
	6.583333	1.34308	0.310417	310.41655	6.583333	283	751.6672
	6.916667	1.411084	0.341803	341.8031022	6.916667	388	2134.153
	8.25	1.6831	0.482187	482.1865665	8.25	513	949.4677
	9.75	1.989118	0.668408	668.4076666	9.75	651	303.0269
	7.5	1.530091	0.400303	400.3026691	7.5	483	6838.849
Nicholas	3.333333	0.68004	0.082697	82.69686023	3.333333	152	
	7.25	1.479088	0.374675	374.6750011	7.25	343	1003.306
							41.3979

Annex T(2) – Example of Barr Equation then used for Colebrook-White iterations.

	Flow (L/s)	Entrance Velocity (m/s)	Entrance Loss	Re	f					HF
	7.928571	1.617525	0.120018	1.16E+05	0.01813	0.0182	0.0182	0.0182	0.0182	0.009347
	6.666667	1.360081	0.084854	9.77E+04	0.018688	0.0187	0.0187	0.0187	0.0187	0.006817
	5.384615	1.098527	0.055356	7.89E+04	0.019432	0.0195	0.0195	0.0195	0.0195	0.004628
	4.811321	0.981568	0.044196	7.05E+04	0.019851	0.0199	0.0199	0.0199	0.0199	0.003776
Malcolm	10.43011	2.127868	0.207698	1.53E+05	0.017325	0.0173	0.0173	0.0173	0.0173	0.015437
	6.923077	1.412391	0.091507	1.01E+05	0.018563	0.0186	0.0186	0.0186	0.0186	0.007301
	5.25	1.071064	0.052623	7.69E+04	0.019525	0.0196	0.0196	0.0196	0.0196	0.004421
	6.583333	1.34308	0.082746	9.65E+04	0.01873	0.0188	0.0188	0.0188	0.0188	0.006663
	6.916667	1.411084	0.091337	1.01E+05	0.018566	0.0186	0.0186	0.0186	0.0186	0.007289
	8.25	1.6831	0.129946	1.21E+05	0.018007	0.0180	0.0180	0.0180	0.0180	0.01005
	9.75	1.989118	0.181495	1.43E+05	0.017514	0.0175	0.0175	0.0175	0.0175	0.013641
	7.5	1.530091	0.107393	1.10E+05	0.018304	0.0183	0.0183	0.0183	0.0183	0.008446
Nicholas	3.333333	0.68004	0.021214	4.88E+04	0.021351	0.0215	0.0214	0.0214	0.0214	0.001951
	7.25	1.479088	0.100353	1.06E+05	0.018413	0.0184	0.0184	0.0184	0.0184	0.00794

Annex T(3) – Example of Main PTB Friction Calculations

	Flow (L/s)	Entrance Velocity (m/s)	Main V (m/s)	Elbow	Exit Loss	Re	f					HF
	7.928571	1.617525	1.617525	0.073138	0.133353	1.16E+05	0.01813	0.0182	0.0182	0.0182	0.0182	0.11032
	6.666667	1.360081	1.360081	0.05171	0.094282	9.77E+04	0.018688	0.0187	0.0187	0.0187	0.0187	0.080461
	5.384615	1.098527	1.098527	0.033734	0.061507	7.89E+04	0.019432	0.0195	0.0195	0.0195	0.0195	0.054626
	4.811321	0.981568	0.981568	0.026933	0.049107	7.05E+04	0.019851	0.0199	0.0199	0.0199	0.0199	0.04457
Malcolm	10.43011	2.127868	2.127868	0.12657	0.230776	1.53E+05	0.017325	0.0173	0.0173	0.0173	0.0173	0.182202
	6.923077	1.412391	1.412391	0.055764	0.101674	1.01E+05	0.018563	0.0186	0.0186	0.0186	0.0186	0.086175
	5.25	1.071064	1.071064	0.032068	0.05847	7.69E+04	0.019525	0.0196	0.0196	0.0196	0.0196	0.052181
	6.583333	1.34308	1.34308	0.050425	0.09194	9.65E+04	0.01873	0.0188	0.0188	0.0188	0.0188	0.078643
	6.916667	1.411084	1.411084	0.05566	0.101486	1.01E+05	0.018566	0.0186	0.0186	0.0186	0.0186	0.08603
	8.25	1.6831	1.6831	0.079188	0.144385	1.21E+05	0.018007	0.0180	0.0180	0.0180	0.0180	0.118618
	9.75	1.989118	1.989118	0.110602	0.201661	1.43E+05	0.017514	0.0175	0.0175	0.0175	0.0175	0.161009
	7.5	1.530091	1.530091	0.065445	0.119326	1.10E+05	0.018304	0.0183	0.0183	0.0183	0.0183	0.099692
Nicholas	3.333333	0.68004	0.68004	0.012927	0.023571	4.88E+04	0.021351	0.0215	0.0214	0.0214	0.0214	0.023034
	7.25	1.479088	1.479088	0.061155	0.111504	1.06E+05	0.018413	0.0184	0.0184	0.0184	0.0184	0.093723

Annex U – 90mm Siphon Test (No Restriction) Analysis Data

Table 7.4. 90mm PN10 Siphon Flow Data.

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
1	510	7.928	446.17	4073.560415	1.6175	1.6175
2	315	6.666	318.12	9.758376732	1.3600	1.3601
3	215	5.384	209.85	26.51774867	1.0985	1.0985
4	190	4.811	168.58	458.7225032	0.98157	0.98157
5	690	10.43	762.68	5282.818723	2.1278	2.1279
6	360	6.923	342.42	309.0123768	1.4123	1.4124
1	188	5.25	199.76	138.3553127	1.0711	1.0711
2	283	6.583	310.41	751.6672138	1.3431	1.3431
3	388	6.917	341.80	2134.15337	1.4111	1.4111
4	513	8.25	482.18	949.4676817	1.6831	1.6831
5	651	9.75	668.41	303.0268564	1.9891	1.9891
6	483	7.5	400.30	6838.848532	1.5301	1.5301
7	152	3.333	82.697	Outlier	0.6800	0.6800
8	343	7.25	374.68	1003.305693	1.4791	1.4791

Table 7.5. 90mm Raw Data with unknown Elbow Loss

PTB Internal Diam	**79mm**
Inlet Restriction Diam	**79mm**
Roughness	**0.01mm**
vis	**1.10E-06**
Entrance Coef (K1)	**0.9**
Exit Coef (K2)	**1**
Elbow Loss Coef (K3)	**????**
Sudden Expansion Loss (K4)	**0**
PTB Length	**3.6m**
Inlet Length Length	**0.305m**
Contraction	**0**

Table 7.6. PN10 90mm RMSE Table (K3 = 0.9).

Analytical Heights	**Testing Heights**	**RMSE**
493.0552521	510	287.1245
351.2684138	315	1315.398
231.472883	215	271.3559
185.8454824	190	17.26002
843.8113301	690	23657.93
378.1644389	360	329.9468
220.3172681	188	1044.406
342.7376883	283	3568.591
377.4801285	388	110.6677
532.944374	513	397.7781
739.3008026	651	7797.032
442.2512703	483	1660.459
90.98300367	152	Outlier
413.8736384	343	5023.073
	RMSE	59.14846

Table 7.7. Optimised Data Table.

PTB Internal Diam	**79mm**
Inlet Restriction Diam	**79mm**
Roughness	**0.01mm**
vis	**1.10E-06**
Entrance Coef (K1)	**0.9**
Exit Coef (K2)	**1**
Elbow Loss Coef (K3)	**0.564669**
Sudden Expansion Loss (K4)	**0**
PTB Length	**3.6m**
Inlet Length Length	**0.305m**
Contraction	**0**

Table 7.8. PN10 90mm Siphon (K3 Optimised)

Analytical Heights	**Testing Heights**	**RMSE**
448.3378195	510	3802.225
319.6525934	315	21.64663
210.8477693	215	17.24102
169.3784403	190	425.2487
766.4249475	690	5840.773
344.0698633	360	253.7693
200.7105195	188	161.5573
311.9073234	283	835.6333
343.4486618	388	1984.822
484.5277089	513	810.6714
671.6775267	651	427.5601
402.2374976	483	6522.582
83.07904856	152	Outlier
376.4829908	343	1121.111
	RMSE	41.34735

Annex V – 90mm Siphon Test (66.44mm Restriction) Analysis Data

Table 7.9. 90mm PN10 Siphon (66.44mm Restriction) Flow Data.

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
1	295	5.277777778	283.105777	141.4725419	1.522306	1.076731
2	200	4.298245614	189.579829	108.579963	1.239773	0.876894
3	755	9.130434783	828.4524224	5395.258359	2.633555	1.862719
4	545	7.613636364	580.0874257	1231.127444	2.196054	1.553274
1	165	3.75	145.2782253	388.9483984	1.081639	0.765045
2	303	5.666666667	325.3316629	498.703169	1.634476	1.156069
3	352	6	363.8243962	139.8163457	1.730622	1.224073
4	481	6.583333333	436.285215	1999.411994	1.898876	1.34308
5	398	6.333333333	404.4366067	41.42990534	1.826767	1.292077
6	648	8.416666667	706.1465365	3381.019711	2.427678	1.717102
7	471	6.333333333	404.4366067	4430.685332	1.826767	1.292077
8	144	2.833333333	84.17257029	Outlier	0.817238	0.578034

Table 7.10. 90mm (66.44mm Restriction) Raw Data with unknown Entry Loss

PTB Internal Diam	**79mm**
Inlet Restriction Diam	**66.44mm**
Roughness	**0.01mm**
vis	**1.10E-06**
Entrance Coef (K1)	**????**
Exit Coef (K2)	**1**
Elbow Loss Coef (K3)	**0.548454059**
Sudden Expansion Loss (K4)	**0.085671949**
PTB Length	**3.9m**
Inlet Length Length	**0.3m**
Contraction	**0**

Table 7.11. PN10 90mm (66.44mm Restriction Insertion) RMSE Table (K1 = 0.9).

Analytical Heights	**Testing Heights**		RMSE
275.1525702	295		393.9205
184.3048283	200		246.3384
804.6498997	755		2465.113
563.5364222	545		343.5989
141.2630676	165		563.442
316.1632239	303		173.2705
353.5455925	352		2.388856
423.9105982	481		3259.2
392.983989	398		25.16037
685.9200558	648		1437.931
392.983989	471		6086.498
81.88046052	144		Outlier
			33.96476

Table 7.12. PN10 90mm (66.44mm Restriction Insertion) Optimised Data Table.

PTB Internal Diam	**79mm**
Inlet Restriction Diam	**66.44mm**
Roughness	**0.01mm**
vis	**1.10E-06**
Entrance Coef (K1)	**0.886313036**
Exit Coef (K2)	**1**
Elbow Loss Coef (K3)	**0.548454059**
Sudden Expansion Loss (K4)	**0.085671949**
PTB Length	**3.9m**
Inlet Length Length	**0.3m**
Contraction	**0**

Table 7.13. PN10 90mm (66.44mm Restriction Insertion) Siphon (K1 Optimised)

Analytical Heights	**Testing Heights**	RMSE
273.5359349	295	460.7061
183.2325875	200	281.1461
799.8115998	755	2008.079
560.1721267	545	230.1934
140.446913	165	602.8541
314.2995702	303	127.6803
351.4562369	352	0.295678
421.39523	481	3552.729
390.6560341	398	53.93384
681.808652	648	1143.025
390.6560341	471	6455.153
81.41454711	144	Outlier
		33.87283

Annex W – 90mm Siphon Test (63.00mm Restriction) Analysis Data

Table 7.14. 90mm PN10 Siphon (63.00mm Restriction) Flow Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
1	98	2.58333333	76.5378070	Outlier	0.82872314	0.52703127
2	188	4.33333333	209.848729	477.3669875	1.39011624	0.88405245
3	248	4.91666666	268.618538	425.1241378	1.57724727	1.00305951
4	373	6	396.658514	559.7253145	1.92477633	1.22407262
5	478	6.61111111	479.691060	2.859684293	2.12081836	1.34874669
6	563	7.16666666	561.921944	1.162202816	2.29903839	1.46208675
7	668	8.08333333	711.624663	1903.111233	2.59310145	1.64909784
8	299	5.41666666	324.666141	658.750808	1.73764530	1.10506556

Table 7.15. 90mm (63.00mm Restriction) Raw Data with unknown Entry Loss

PTB Internal Diam	79mm
Inlet Restriction Diam	63mm
Roughness	0.01mm
vis	1.10E-06
Entrance Coef (K1)	????
Exit Coef (K2)	1
Elbow Loss Coef (K3)	0.548454
Sudden Expansion Loss (K4)	0.132528
PTB Length	3.9m
Inlet Length Length	0.3m
Contraction	0

Table 7.16. PN10 90mm (63.00mm Restriction Insertion) RMSE Table (K1 = 0.9).

Analytical Heights	**Measured Heights**	RMSE
77.49822299	98	Outlier
212.5510863	188	602.7558
272.0974232	248	580.6858
401.8393641	373	831.7089
485.9810129	478	63.69657
569.3134501	563	39.85965
721.0279449	668	2811.963
328.8885736	299	893.3268
		28.8444

Table 7.17. PN10 90mm (63.00mm Restriction Insertion) Optimised Data Table.

PTB Internal Diam	79mm
Inlet Restriction Diam	63mm
Roughness	0.01mm
vis	1.10E-06
Entrance Coef (K1)	0.786413
Exit Coef (K2)	1
Elbow Loss Coef (K3)	0.548454
Sudden Expansion Loss (K4)	0.132528
PTB Length	3.9m
Inlet Length Length	0.3m

Table 7.18. PN10 90mm (63.00mm Restriction Insertion) Siphon (K1 Optimised)

Analytical Heights	**Testing Heights**	RMSE
73.5221863	98	Outlier
201.36357	188	178.585
257.6951508	248	93.99595
380.3911079	373	54.62848
459.9411676	478	326.1214
538.7132759	563	589.845
682.0991944	668	198.7873
311.4080793	299	153.9604
	Total	15.09931

Annex X – 90mm Siphon Test (60.22mm Restriction) Analysis Data

Table 7.19. 90mm PN10 Siphon (60.22mm Restriction) Flow Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
1	65	1.33333333	24.8774489	Outlier	0.46813094	0.27201613
2	126	3.08333333	127.350180	1.822987216	1.08255281	0.62903732
3	245	4.41666666	257.322767	151.8506045	1.55068376	0.90105346
4	378	5.66666666	419.544629	1725.956206	1.98955652	1.15606859
5	448	6.08333333	482.264813	1174.077472	2.13584744	1.24107363
6	536	6.5	549.298549	176.8514191	2.28213837	1.32607868
7	679	7.33333333	696.287794	298.8678315	2.57472021	1.49608876
8	336	5.16666666	349.981935	195.4945115	1.81400742	1.05406254

Table 7.20. 90mm (60.22mm Restriction) Raw Data with unknown Entry Loss

PTB Internal Diam	79mm
Inlet Restriction Diam	60.22mm
Roughness	0.01mm
vis	1.10E-06
Entrance Coef (K1)	????
Exit Coef (K2)	1
Elbow Loss Coef (K3)	0.548454
Sudden Expansion Loss (K4)	0.175504
PTB Length	3.9m
Inlet Length Length	0.3m
Contraction	0

Table 7.21. PN10 90mm (60.22mm Restriction Insertion) RMSE Table (K1 = 0.9).

Analytical Heights	**Testing Heights**	**RMSE**
24.12922976	65	Outlier
123.3489613	126	7.028006
249.1128155	245	16.91525
406.0299196	378	785.6764
466.6895788	448	349.3004
531.5166523	536	20.10041
673.6541632	679	28.57797
338.7469561	336	7.545768
	RMSE	13.17543

Table 7.22. PN10 90mm (60.22mm Restriction Insertion) Optimised Data Table.

PTB Internal Diam	79mm
Inlet Restriction Diam	60.22mm
Roughness	0.01mm
vis	1.10E-06
Entrance Coef (K1)	0.876049
Exit Coef (K2)	1
Elbow Loss Coef (K3)	0.548454
Sudden Expansion Loss (K4)	0.175504
PTB Length	3.9m
Inlet Length Length	0.3m
Contraction	0

Table 7.23. PN10 90mm (60.22mm Restriction Insertion) Siphon (K1 Optimised)

Analytical Heights	**Testing Heights**	RMSE
23.86170785	65	Outlier
121.9183461	126	16.6599
246.1773896	245	1.386246
401.1978051	378	538.1382
461.1207341	448	172.1537
525.1588269	536	117.531
665.5616253	679	180.5899
334.7299474	336	1.613034
	Total	12.11889

Annex Y – 68.38mm Riser Restriction Analysis Data

Table 7.24. 68.38mm Extended Restricted Riser Flow Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
1	117	3.083333	83.20060775	1142.399	0.81982	0.629037322
2	245	5.166667	226.754164	332.9105	1.373752	1.05406254
3	417	7.583333	479.2457461	outlier	2.016314	1.547091793
4	536	7.777778	503.5464845	1053.231	2.068014	1.586760813
5	581	8.25	565.0255458	255.1832	2.193572	1.683099863
6	283	6.083333	311.7115893	824.3554	1.617482	1.241073636
7	326	6.666667	372.66597	2177.713	1.772583	1.360080697
8	266	5.833333	287.2273257	450.5994	1.55101	1.19007061

Table 7.25. 68.38mm Riser Raw Data with unknown Elbow Loss

PTB Internal Diam	79mm
Inlet Restriction Diam	68.38mm
Roughness	0.01mm
vis	1.10E-06
Entrance Coef (K1)	0.9
Exit Coef (K2)	1
Elbow Loss Coef (K3)	????
Sudden Expansion Loss (K4)	0.054155204
PTB Length	3.9m
Inlet Length Length	0.3m

Table 7.26. 68.38mm Extended Riser PN10 RMSE Table (K3 = 0.5)

Analytical Heights	**Measured Heights**	RMSE
87.796982	117	852.8163
239.6602725	245	28.51269
507.048942	417	Outlier
532.7937648	536	10.27994
597.9320936	581	286.6958
329.6035385	283	2171.89
394.1537678	326	4644.936
303.6789209	266	1419.701
	Total	414.436

Table 7.27. 68.38mm Extended Riser PN10 RMSE Optimised Data Table.

PTB Internal Diam	79mm
Inlet Restriction Diam	69.2mm
Roughness	0.01mm
vis	1.10E-06
Entrance Coef (K1)	0.9
Exit Coef (K2)	1
Elbow Loss Coef (K3)	0.272091
Sudden Expansion Loss (K4)	0.0541552
PTB Length	3.9m
Inlet Length Length	0.3m
Contraction	0

Table 7.28. 68.38mm Extended Riser PN10 RMSE Table (K3 Optimised)

Analytical Heights	**Testing Heights**	RMSE
83.22611899	117	1140.675038
226.7788091	245	332.0117969
479.2367472	417	
503.5330933	536	1054.10003
565.0003989	581	255.9872363
311.7279147	283	825.2930804
372.6742195	326	2178.482769
287.246441	266	451.4112557
	Total	29.85192314

Annex Z – 54.80mm Riser Restriction Analysis Data

Table 7.29. 54.80mm Extended Restricted Riser Flow Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
1	136	2.83333333	115.109918	436.395491	1.20128671	0.578034296
2	240	4.5	284.955476	2020.99484	1.90792595	0.918054471
3	319	4.83333333	327.866405	78.6131392	2.0492538	0.986058506
4	453	3.83333333	208.060520	Outlier	1.62527025	0.782046401
5	518	6.08333333	515.209325	7.78786408	2.57923323	1.241073636
6	684	7	679.048008	24.5222240	2.96788481	1.428084732
7	328	4.75	316.860062	124.098200	2.01392183	0.969057497
8	240	3.91666666	217.020577	528.053866	1.6606022	0.79904741

Table 7.30. 54.80mm Riser Raw Data with unknown Elbow Loss

PTB Internal Diam	79mm
Inlet Restriction Diam	54.8mm
Roughness	0.01mm
vis	1.10E-06
Entrance Coef (K1)	0.9
Exit Coef (K2)	1
Elbow/Expansion Loss Coef (K3/K4)	????
PTB Length	3.66
Inlet Length Length	0.245
Contraction	0m
PTB Internal Diam	79m

Table 7.31. 54.80mm Extended Riser PN10 RMSE Table (K3 = 0.5)

Analytical Heights	**Measured Heights**	RMSE
116.084034	136	396.6457
287.4126734	240	2247.962
330.701114	319	136.9161
209.8435899	453	Outlier
519.6998618	518	2.88953
684.9938185	684	0.987675
319.5978658	328	70.59586
218.8820137	240	445.9693
	Total	21.71887

Table 7.32. 54.80mm Extended Riser PN10 RMSE Optimised Data Table.

PTB Internal Diam	79mm
Inlet Restriction Diam	54.8mm
Roughness	0.01mm
vis	1.10E-06
Entrance Coef (K1)	0.9
Exit Coef (K2)	1
Elbow/Expansion Loss Coef (K3/K4)	0.442799
PTB Length	3.66
Inlet Length Length	0.245
Contraction	0m

Table 7.33. 54.80mm Extended Riser PN10 RMSE Table (K3 Optimised)

Analytical Heights	**Testing Heights**	RMSE
115.1099201	136	436.3954
284.9554796	240	2020.995
327.8664089	319	78.61321
208.0605234	453	Outlier
515.2093316	518	7.78783
679.0480162	684	24.52214
316.8600666	328	124.0981
217.0205799	240	528.0537
	Total	21.44916

Annex AA – 40.10mm Riser Restriction Analysis Data

Table 7.34. 40.10mm Extended Restricted Riser Flow Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
1	195	2.083333333	214.493399	379.99260	1.63327302	0.425025
2	343	2.333333333	268.263820	Outlier	1.82926578	0.476028
3	453	3.083333333	465.276453	150.71131	2.41724407	0.629037
4	677	2.722222222	363.740087	Outlier	2.13414341	0.555366
5	419	3.25	516.317760	Outlier	2.54790591	0.663039
6	265	2.166666667	231.754744	1105.2469	1.69860394	0.442026
7	224	1.916666667	181.958730	1767.4683	1.50261118	0.391023
8	533	3.333333333	542.827365	96.577102	2.61323683	0.68004

Table 7.35. 40.10mm Riser Raw Data with unknown Elbow Loss

PTB Internal Diam	79mm
Inlet Restriction Diam	40.10mm
Roughness	0.01mm
vis	1.10E-06
Entrance Coef (K1)	0.9
Exit Coef (K2)	1
Elbow/ Expansion Loss Coef (K3/K4)	????
PTB Length	3.635m
Inlet Length Length	0.265m
Contraction	

Table 7.36. 40.10mm Extended Riser PN10 RMSE Table (K3 = 0.5)

Analytical Heights	**Measured Heights**	RMSE
165.0298864	195	898.2077
206.2167905	343	Outlier
356.9315755	453	9229.142
279.2871849	677	Outlier
395.9433562	419	Outlier
178.2550096	265	7524.693
140.0928132	224	7040.416
416.2007728	533	13642.06
	Total	79.93176

Table 7.37. 40.10mm Extended Riser PN10 RMSE Optimised Data Table.

PTB Internal Diam	79mm
Inlet Restriction Diam	40.3mm
Roughness	0.01mm
vis	1.10E-06
Entrance Coef (K1)	0.9
Exit Coef (K2)	1
Elbow Loss Coef (K3)	5.87223
Sudden Expansion Loss (K4)	0
PTB Length	3.635m
Inlet Length Length	0.265m
Contraction	79

Table 7.38. 40.10mm Extended Riser PN10 RMSE Table (K3 Optimised)

Analytical Heights	**Testing Heights**	RMSE
214.4933991	195	379.9926
268.2638207	343	Outlier
465.2764536	453	150.7113
363.7400872	677	Outlier
516.3177605	419	Outlier
231.7547449	265	1105.247
181.9587303	224	1767.468
542.8273651	533	96.5771
	Total	24.15228

Annex AB – 78.58mm Riser (Spiral Entry) Restriction Analysis Data

Table 7.39. 78.58mm Extended Restricted (Spiral Entry) Riser Flow Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
1	693	10.08333	679.9166139	171.175	1.091621018	2.057122055
2	510	8.333333	468.3863032	1731.7	0.902166131	1.700100872
3	378	7.75	406.4945937	811.9419	0.839014502	1.581093811
4	113	4.083333	116.7643592	14.1704	0.442061404	0.833049427
5	183	5.416667	202.2162444	369.264	0.586407985	1.105065567
6	308	7.5	381.2916804	Outlier	0.811949518	1.530090784
7	143	4.75	156.6321795	185.8363	0.514234695	0.969057497
8	301	6.911111	325.0643964	579.0952	0.748196445	1.409950323

Table 7.40. 78.58mm Riser (Spiral) Raw Data with unknown Entry Loss

PTB Internal Diam	79
Inlet Restriction Diam	78.58
Roughness	0.01
vis	1.10E-06
Entrance Coef (K1)	????
Exit Coef (K2)	1
Elbow Loss Coef (K3)	0.548454059
Sudden Expansion Loss (K4)	0.000112459
PTB Length	3.635
Inlet Length Length	0.265
Contraction	79

Table 7.41. 78.58mm Extended Restricted (Spiral Entry) Riser PN10 RMSE Table (K1 = 0.9)

Analytical Heights	**Measured Heights**	RMSE
565.5574451	693	16241.6
390.2774521	510	14333.49
338.9382484	378	1525.82
98.01042403	113	224.6874
169.2152548	183	190.0192
318.023511	308	Outlier
131.2546137	143	137.9541
271.3416147	301	879.6198
	Total	61.71151

Table 7.42. 78.58mm Extended Restricted (Spiral Entry) RMSE Optimised Data Table.

PTB Internal Diam	79mm
Inlet Restriction Diam	78.58mm
Roughness	0.01mm
vis	1.10E-06
Entrance Coef (K1)	2.782895
Exit Coef (K2)	1
Elbow Loss Coef (K3)	0.548454
Sudden Expansion Loss (K4)	0.000112
PTB Length	3.635m
Inlet Length Length	0.265m
Contraction	

Table 7.43. 78.58mm Extended Restricted (Spiral Entry) PN10 RMSE Table (K3 Optimised)

Analytical Heights	**Testing Heights**	RMSE
679.9166137	693	171.175
468.3863031	510	1731.7
406.4945936	378	811.9419
116.7643591	113	14.1704
202.2162443	183	369.264
381.2916803	308	Outlier
156.6321794	143	185.8363
325.0643963	301	579.0952
	Total	21.10982

Annex AC – 69.00mm Riser (Spiral Entry) Restriction Analysis Data

Table 7.44. 69.00mm Extended Restricted (Spiral Entry) Riser Flow Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
1	595	7.333333	488.1547302	Outlier	1.238426	1.496089
2	646	8.083333	590.9745047	3027.805	1.365083	1.649098
3	508	7.166667	466.6240436	1711.97	1.21028	1.462087
4	263	5.416667	269.5600622	43.03442	0.914746	1.105066
5	323	6.416667	375.6759292	2774.754	1.083623	1.309078
6	468	6.916667	435.2276082	1074.03	1.168061	1.411084
7	315	5.833333	311.6680793	11.1017	0.985112	1.190071
8	253	5.416667	269.5600622	274.2357	0.914746	1.105066

Table 7.45. 69.00mm Riser (Spiral) Raw Data with unknown Entry Loss

PTB Internal Diam	79mm
Inlet Restriction Diam	69mm
Roughness	0.01mm
vis	1.10E-06
Entrance Coef (K1)	????
Exit Coef (K2)	1
Elbow Loss Coef (K3)	0.272091
Sudden Expansion Loss (K4)	0.056236
PTB Length	3.635m
Inlet Length Length	0.265m
Contraction	

Table 7.46. 69.00mm Extended Restricted (Spiral Entry) Riser PN10 RMSE Table (K1 = 0.9)

Analytical Heights	**Measured Heights**	RMSE
322.3876978	595	Outlier
389.566704	646	65758.04
308.3062528	508	39877.59
179.120275	263	7035.808
248.7605449	323	5511.497
287.7625919	468	32485.52
206.779332	315	11711.71
179.120275	253	5458.214
	Total	145.689

Table 7.47. 69.00mm Extended Restricted (Spiral Entry) RMSE Optimised Data Table.

PTB Internal Diam	79mm
Inlet Restriction Diam	69mm
Roughness	0.01mm
vis	1.10E-06
Entrance Coef (K1)	3.227009
Exit Coef (K2)	1
Elbow Loss Coef (K3)	0.272091
Sudden Expansion Loss (K4)	0.056236
PTB Length	3.635m
Inlet Length Length	0.265m
Contraction	

Table 7.48. 69.00mm Extended Restricted (Spiral Entry) PN10 RMSE Table (K3 Optimised)

Analytical Heights	**Testing Heights**	RMSE
504.2904527	595	Outlier
610.5794908	646	1254.612
482.0346586	508	674.199
278.363449	263	236.0356
388.0298416	323	4228.88
449.5818169	468	339.2295
321.8779243	315	47.30584
278.363449	253	643.3045
	Total	31.41052

Annex AD – 54.58mm Riser (Spiral Entry) Restriction Analysis Data

Table 7.49. 54.58mm Extended Restricted (Spiral Entry) Riser Flow Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
1	663	6.166667	664.1022387	1.214916	0.789217	1.258075
2	613	5.916667	611.8785804	1.257595	0.757222	1.207072
3	473	5.25	483.0046811	100.0936	0.671901	1.071064
4	213	3.25	187.2458499	663.2763	0.415939	0.663039
5	288	4.083333	293.8891556	34.68212	0.52259	0.833049
6	368	4.416667	343.1876111	615.6548	0.56525	0.901053
7	155	3	159.8856738	23.86979	0.383943	0.612036
8	440	5	438.5758038	2.028347	0.639906	1.020061

Table 7.50. 54.58mm Riser (Spiral) Raw Data with unknown Entry Loss

PTB Internal Diam	79
Inlet Restriction Diam	54.58
Roughness	0.01
vis	1.10E-06
Entrance Coef (K1)	????
Exit Coef (K2)	1
Elbow/Expansion Loss Coef (K3/K4)	0.4427992
PTB Length	3.635
Inlet Length Length	0.265

Table 7.51. 54.58mm Extended Restricted (Spiral Entry) Riser PN10 RMSE Table (K1 = 0.9)

Analytical Heights	**Measured Heights**	RMSE
218.9717363	663	197161.1
202.1081526	613	168832.1
160.3744831	473	97734.71
63.60752007	213	22318.11
98.7178013	288	35827.75
114.8509454	368	64084.44
54.53703771	155	10092.81
145.9407036	440	86470.87
	Total	278.7597

Table 7.52. 54.58mm Extended Restricted (Spiral Entry) RMSE Optimised Data Table.

PTB Internal Diam	79
Inlet Restriction Diam	54.58
Roughness	0.01
vis	1.10E-06
Entrance Coef (K1)	14.92146
Exit Coef (K2)	1
Elbow/Expansion Loss Coef (K3/K4)	0.4427992
Sudden Expansion Loss (K4)	0
PTB Length	3.635
Inlet Length Length	0.265
Contraction	

Table 7.53. 54.58mm Extended Restricted (Spiral Entry) PN10 RMSE Table (K3 Optimised)

Analytical Heights	**Testing Heights**	RMSE
664.1022393	663	1.214931
611.8785809	613	1.257581
483.0046815	473	100.0937
187.2458501	213	663.2762
293.8891559	288	34.68216
343.1876114	368	615.6546
159.8856739	155	23.86981
438.5758041	440	2.028334
	Total	15.6484

Annex AE – 40.22mm Restricted Riser (Spiral Entry) Analysis Data

Table 7.54. 40.22mm Extended Restricted (Spiral Entry) Riser Flow Data

Test #	Measured Head (mm)	Measured Flow Rate (L/s)	Analytical Head (mm)	RMSE	Entrance Velocity (m/s)	Exit Velocity (m/s)
1	661	3.666667	718.5593734	16.24734	0.884627	0.748044
2	591	3	481.9903658		0.723786	0.612036
3	400	2.166667	252.3157791		0.522734	0.442026
4	278	1.833333	181.0176247		0.442314	0.374022
5	428	2.809524	423.0209642	1325.428	0.677831	0.573177
6	300	2.25	271.9782627	2321.11	0.542839	0.459027
7	189	1.833333	181.0176247	456.4427	0.442314	0.374022
8	398	2.916667	455.719551	568.7966	0.703681	0.595035

Table 7.55. 40.22mm Riser (Spiral) Raw Data with unknown Entry Loss

PTB Internal Diam	79mm
Inlet Restriction Diam	40.22mm
Roughness	0.01mm
vis	1.10E-06
Entrance Coef (K1)	????
Exit Coef (K2)	1
Elbow/Expansion Loss Coef (K3/K4)	5.87223
Sudden Expansion Loss (K4)	0
PTB Length	3.635m
Inlet Length Length	0.265m

Table 7.56. 40.22mm Extended Restricted (Spiral Entry) Riser PN10 RMSE Table (K1 = 0.9)

Analytical Heights	**Measured Heights**	RMSE
265.7347262	661	156234.6
178.8598168	591	Outlier
94.20138782	400	Outlier
67.81146291	278	Outlier
157.1611907	428	73353.66
101.4673289	300	39415.22
67.81146291	189	14686.66
169.1956911	398	52351.41
	Total	223.2719

Table 7.57. 40.22mm Extended Restricted (Spiral Entry) RMSE Optimised Data Table.

PTB Internal Diam	79mm
Inlet Restriction Diam	40.22mm
Roughness	0.01mm
vis	1.10E-06
Entrance Coef (K1)	10.9109
Exit Coef (K2)	1
Elbow/Expansion Loss Coef (K3/K4)	5.87223
Sudden Expansion Loss (K4)	0
PTB Length	3.635m
Inlet Length Length	0.265m
Contraction	

Table 7.58. 40.22mm Extended Restricted (Spiral Entry) PN10 RMSE Table (K3 Optimised)

Analytical Heights	**Testing Heights**	RMSE
665.0307983	661	16.24734
446.1571874	591	Outlier
233.6250163	400	Outlier
167.6354809	278	Outlier
391.5935784	428	1325.428
251.8220999	300	2321.11
167.6354809	189	456.4427
421.8494558	398	568.7965
	Total	30.23742