University of Southern Queensland
Faculty of Engineering and Surveying

DESIGN AND TRIAL OF AN ALTERNATIVE OPTION FOR SUBURBAN SEWERAGE PUMP STATIONS

A dissertation submitted by

Bill Thomas Weston

in fulfilment of the requirements of

Courses ENG4111 and ENG4112 Research Project

towards the degree of

Bachelor of Engineering (Mechanical Engineering)

Submitted October 2007

Abstract

Collection and pumping of waste water represents a significant cost for urban communities in Australia. The flows in a sewerage system are not constant. In residential areas flows will be at a maximum in the morning and evening. Additionally during rain periods there is an increase of flow into the pump stations due to faults in the gravity sewers allowing inflows and infiltration.

It is common for multiple pump stations to feed into the same pressure main. This causes the pressure in the common pressure main to change depending on how many and which pumps are operating at any given time. Consequently the pump stations feeding into the common pressure main will operate at various flows. A given pump station will operate against maximum pressure during wet weather when all other pump stations are also operating, resulting in a decrease in the flow rate produced by the pump station. This is not desirable as the largest flow outputs are needed during wet weather conditions.

The purpose of this project is to devise an alternative pump configuration. The configuration will enable pumps to operate within their recommended operating range for normal and wet weather operating conditions. The design must comply with the current standards required by the waste water industry. It must also be cost competitive compared with current pump station designs, and be able to be operated and maintained effectively in a similar manner to existing designs.

The selected pump configuration consisted of three identical pumps. For normal dry weather operation each pump operates as a stand alone unit (i.e., duty / standby / standby). The pumps are equipped with piping and valving to enable two pumps to operate in series to deliver the higher pressures needed during wet weather operation. (i.e., duty / duty / standby). A prototype of this series pump configuration was designed and built. The prototype was run in a test tank to compare measured and theoretical pump performance. The tests undertaken in the test tank indicated that the pump configuration performed as predicted and it was therefore suitable for installation in an operating sewerage pump station.

The prototype pumps were installed in an existing sewerage pump station in July 2007. Monitoring of the performance showed that the pumps successfully operated within their recommended operating range for normal dry weather operation and for simulated wet weather operation. There has been no evidence of increased susceptibility to blockage with this pump configuration.

The proposed series pump arrangement appears to meet the goal of providing a cost effective alternative that uses identical fixed speed pumps. Each pump operates within the recommended range above and below the best efficiency point under all flow conditions. Longer term field testing is needed to demonstrate satisfactory reliability and performance of the pumps over an extended period.

University of Southern Queensland

Faculty of Engineering and Surveying

ENG4111 and ENG4112 Research Project

Limitations of Use

The Council of the University of Southern Queensland, its Faculty of Engineering and Surveying, and the staff of the University of Southern Queensland, do not accept any responsibility for the truth, accuracy or completeness of material contained within or associated with this dissertation.

Persons using all or any part of this material do so at their own risk, and not at the risk of the Council of the University of Southern Queensland, its Faculty of Engineering and Surveying or the staff of the University of Southern Queensland.

This dissertation reports an educational exercise and has no purpose or validity beyond this exercise. The sole purpose of the course "Project and Dissertation" is to contribute to the overall education within the student's chosen degree programme. This document, the associated hardware, software, drawings, and other material set out in the associated appendices should not be used for any other purpose: if they are so used, it is entirely at the risk of the user.

Professor Frank Bullen

Dean

Faculty of Engineering and Surveying

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

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

Bill Thomas Weston

Student Number: 0011220292

Bill Weston

Signature

Sunday, 28 October 2007

Date

Acknowledgments

This research project was initially carried out under the supervision of Dr. Ruth Mossad, and completed with the supervision of Dr. Ahmad Sharifian. Dr. Jonathan Harris provided supporting supervision locally. The author would like to thank Dr. Mossad for her encouragement and provision of ideas throughout the project specification and literature review process. Dr. Sharifian should also be acknowledged for accepting the role as supervisor at short notice, providing positive support and as a source of technical knowledge. The author would also like to thank Dr. Harris for giving up many hours of his personal time to help with this project, as well as much needed support and advice.

Acknowledgement must also go the project sponsor Citiwater Townsville. Without the financial support, access to their facilities and personnel, this project would not have been able to be undertaken. People that deserve special thanks include Vivek Kangesu and Grant Brinkman for their initial support and encouragement when the series pump configuration was a concept comprising of sketches on a whiteboard, Kevin McGrath and Mario DeJong for drafting, engineering advice and ensuring the pumps were installed in time for this paper to be completed. Finally, Lachlan Thomson and Matthew Wilkie for providing information and all the operating data and Darrel Davies and his entire crew for putting up with my requests and helping out whenever I needed it.

I would also like to thank my wife and daughter for their help and tolerance in the final weeks while collating this dissertation.

Table of Contents

List of Figures

List of Tables

List of Appendices

Chapter 1: Introduction

"The average rate payer has little concept of the size and complexity of our sewer network, as long as it disappears when they press the button they are happy" Retired sewerage engineer.

"Cost saving in design and construction can deliver major benefits. Sewage collection systems account for $16.23 billion of the total $20.4 billion current replacement cost of sewerage assets."
Dr John Langford,
Former Executive Director of Water Services Association of Australia

1.1 Background

Typical waste water collection systems consist of a network of gravity sewers to remove waste water from the point where it is generated. Ideally the waste water is transported to treatment plants by gravity, when this is not possible pump stations are used. Sewage pump stations have two basic hydraulic configurations, the pumps either discharge directly into a gravity sewer or into a pressure main.

The flows in a sewerage system are not constant. In residential areas flows will be at a maximum in the morning and evening and reduce to a minimum overnight and during the day. Additionally during rain periods there is an increase in inflow into the pump stations due to faults in the gravity sewers. These faults could be age related, such as cracks caused by tree roots or movement of soil, and also present in new pipes due to incorrectly fitted joints. To prevent pump stations from overflowing the pumps must be able to operate with higher flows than the incoming flow in both wet and dry weather. The flow rate that a pump operates at is termed the duty point.

The most common type of pump used in sewerage pumping stations is a centrifugal pump. The pressure developed by a centrifugal pump depends on the volume flow rate of fluid that is passing through it. At low flow rates the pump will develop a large pressure difference between the inlet and outlet and at high flow rates a lower pressure difference is generated. The performance of individual pumps is displayed on a pump performance curve which can be obtained from the pump manufacturer. Pump curves are normally provided for pure water and adjustments may be needed to account for fluids with significantly different density, viscosity or solids contents. The pressure is displayed as head in metres of water. As well as head (pressure), performance curves also show other information such as pump efficiency and input power as functions of flow rate. An example pump performance curve showing head versus flow rate is shown in figure 1.1. This is sometimes referred as the Flow-Head performance curve.

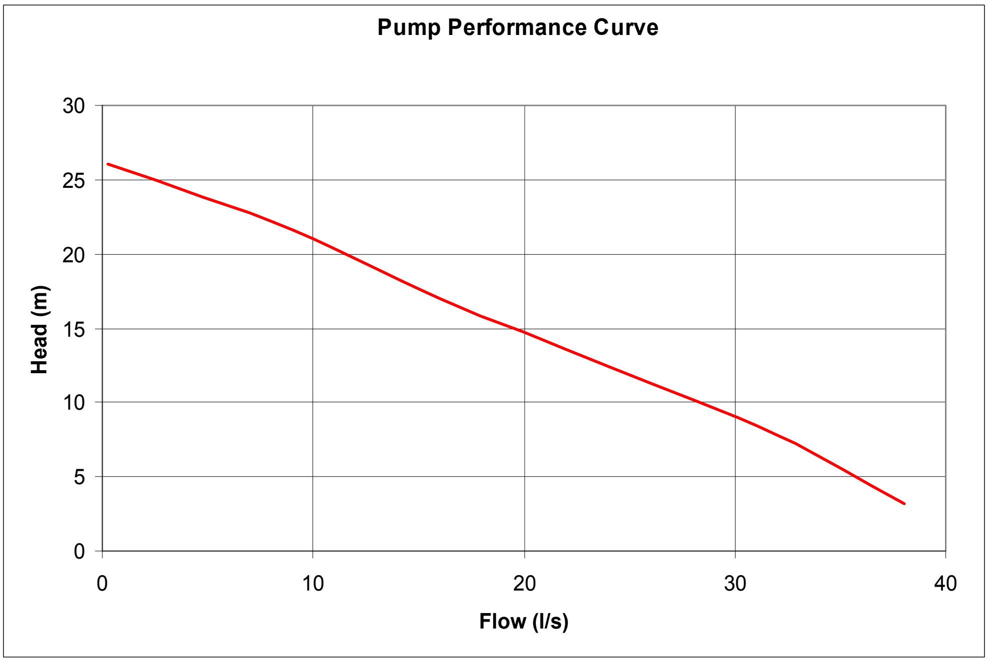


Figure 1.1 Example Flow-Head performance curve for Centrifugal pump.

Pump stations that discharge into a gravity sewer are called lifting stations. In this situation the system resistance curve remains essentially unchanged for dry or wet weather flows. Accordingly each pump operates over a very narrow range of flow rates as the system resistance remains essentially constant. This simplifies pump selection and this type of station will not be discussed further.

Often pump stations discharge directly into a pressure main and it is common for multiple pump stations to feed into the same main. The flow rate and pressure in the receiving pressure main can vary significantly depending on how many and which pump stations are operating at any given time. The changing flow though the main results in a changing pressure at each individual pump station.

Consequently the pumps in this type of station will operate over a considerable range of duty points. The pump station will usually operate at maximum pressure during wet weather when all other pump stations that discharge into the common pressure main are operating simultaneously.

1.2 Problem Identification

To enable the duty points of pumps to be determined system resistance curves are produced. For complex pressure main systems with a number of pump stations and possible flow paths the system resistance curve varies depending on how many other pumps stations are operating, and hydraulic analysis computer programs such as WaterCAD are used to determine the range of system resistance curves.

The operating flow rate requirements are either calculated from estimated population of the catchment or by taking flow records over a period of time. Example system resistance curves for a pump station discharging into a pressure main are shown in figure 1.2 Note the system curve for wet weather conditions represents the maximum system resistance, whereas the system curve for minimum dry weather conditions represents the minimum system resistance. In practice the system resistance can lie anywhere within these bounds.

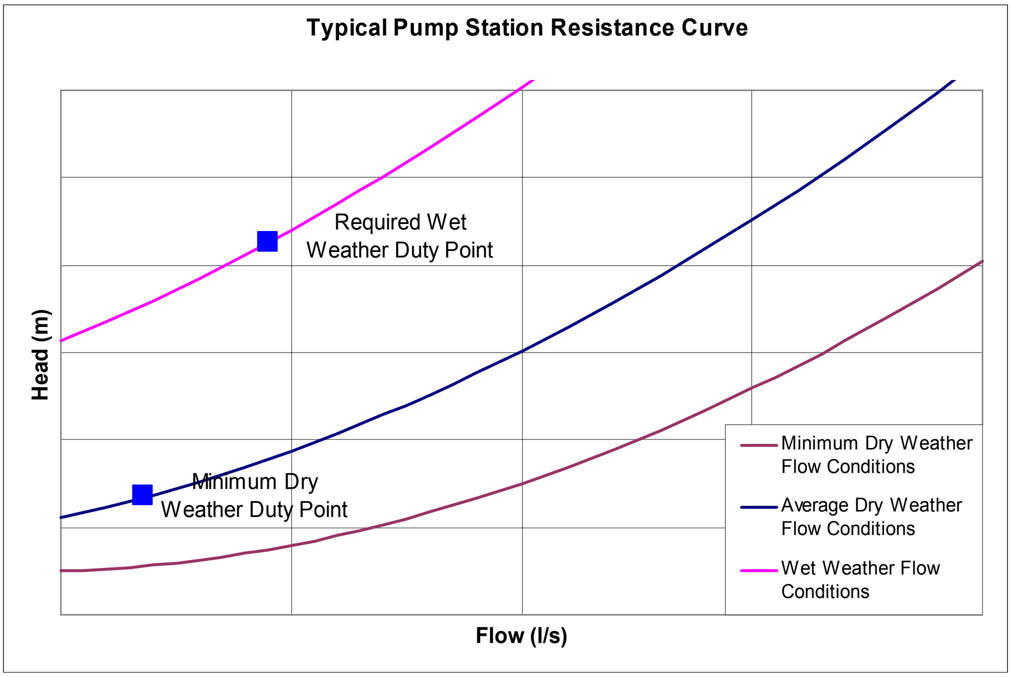


Figure 1.2 Pump station resistance curve courtesy of Citiwater Townsville.

For small and medium sized pump stations (flows less then 200 l/s) discharging into pressure mains the current design method used by Citiwater Townsville is to equip the pump stations with two constant speed pumps of different sizes. A small pump is installed to operate during normal dry weather conditions, and this pump operates the majority of the time. The small pump is sized to be able to handle the daily peak flows and is controlled by a level sensor in the wet well. For the station to be able to continue operating during the high demand rain periods a larger "wet weather" pump is also installed. The same resistance curve with the Flow-Head performance curves for these pumps is shown in figure 1.3. The flow rate achieved by each pump will be at the point where the resistance curve intersects with the respective Flow-Head performance curve.

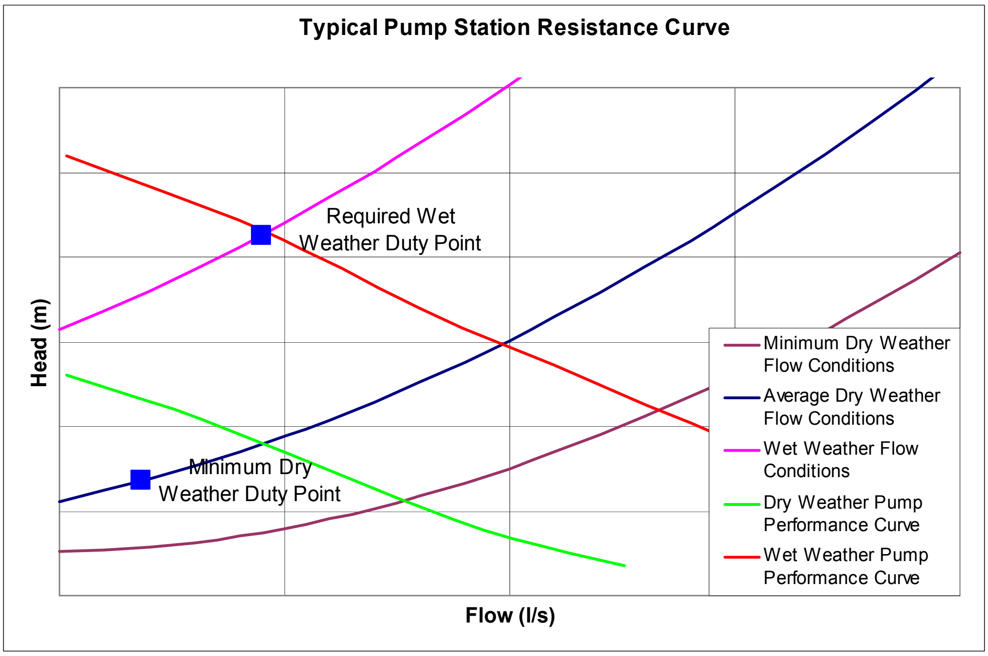


Figure 1.3 Pump station resistance curve with current method of pump selection.

If the small pump fails the larger wet weather pump automatically operates as a backup pump. The large pump is run intermittently through the dry season to prevent a build up of solids internally and to ensure it will run when it rains. Problems observed with this configuration include;

1. The larger wet weather pump is required to operate over a wide range of its performance curve. There is a high likelihood it will operate outside its recommended operating range (see section 2.2).

2. When the large pump runs as a standby pump the larger flows it produces will increase pressure in the discharge pressure main. In turn this will reduce the output of other pump stations in the system.
3. If the large pump fails during a rain event there is no backup pump capable of handling the wet weather flows. This could cause overflows of raw sewerage to the environment or into people's properties.
4. The purchase and installation cost of the large pump is generally more than double the cost for the small pump. This includes the cost of heavier electric cabling, switchboard components and larger piping.
5. Cost of maintaining the larger pump is higher due to the size of components.
6. The number of spare parts needed is doubled by having two different sized pumps in each station. This also increases the number of pump sizes used over the whole sewer system, making interchange of components between pump stations more difficult.

1.3 Research Objectives

This project will seek to provide an alternative pump configuration that will eliminate or reduce the problems identified above. This configuration must enable pumps to function within their preferred operating range for different system resistance curves caused by varying demand. The design must also comply with the current standards required by the waste water industry.

To carry out this investigation the author approached Citiwater Townsville for a suitable location to enable testing to be done in a sewerage pump station. Citiwater made pump station A11B available which was due for refurbishment in the 2006-2007 financial year.

Chapter 2: Literature Review

The literature review consists of three parts; firstly, an overview of the requirements to satisfy current industry standards in respect to pump sizing and configuration; secondly an investigation of the recommendations of operating ranges for centrifugal pumps; and lastly research into different pump configurations and their suitability for this application.

2.1 Pump Station Requirements

The Water Services Association of Australia (WSA) jointly with Standards Australia publishes a series of design codes for the operation of water and waste water infrastructure. The Sewerage Code of Australia requires a sewerage system to be able to convey a design flow. The design flow is the total of the peak daily dry weather flow (normal sewerage), with any flows from groundwater infiltration and the peak rainfall inflow (WSA 2002 p.52). To comply with this code Citiwater specify that pump stations must be able to convey a minimum of five times Average Dry Weather Flow (ADWF) under wet weather flow conditions (Citiwater 2004 pp.E-9 – E-10).

Citiwater also specify a duty point for dry weather flows as 2 x ADWF (Citiwater 2004 p. E-9) under average dry weather flow conditions. In practice this duty point is not used by operational staff (Davies D 2007, pers. comm., April 4), as they prefer the pumps to run a maximum of 5 hours a day under dry flow conditions (i.e. 4.8 x ADWF). Some of the reasons given for this preferred higher flow rate during dry weather are:

- During peak flow periods the output of the pump station is equal to or less than the inflow which can cause a build up of fats and oils
- Pumps operating for 12 hours a day will have increased rates a wear resulting in decreased performance.
- Allows for longer service intervals.

It is a requirement that the failure of any one piece of equipment will not prevent the pump station from operating (WSA 2005 p.54). Therefore pump stations normally have a minimum of two pumps installed (Citiwater 2004 p. E-9). As many of Citiwater's stations pump directly into a common pressure, pumps of different sizes are commonly used in a single pump station to achieve a wider range of flows as mentioned above. Sanks recommends the use a single pump size to reduce the number of spares and allow pumps to be interchangeable (Sanks 1989 p. 318). To enable peak demand to be met multiple pumps may be run simultaneously. In some cases the waste water authority may specify that only identical pumps must be installed in a station (Goulburn Valley Water 2007 p. 2). Installing identical "duty / standby" pumps, each provided with a variable speed drive, is another option for using a single pump size whilst covering a range of dry and wet weather flows. However, variable speed drives are considerably more expensive than fixed speed drives, which is a disadvantage of this approach.

To reduce the impact of noise in residential areas, small and medium sized pump stations (pumping capacity < 200 l/s) should be of a single well design (Citiwater 2004 p. E-8) and use submersible pumps. The maximum operating speed of the pump is normally 1500 rpm (WSA 2005 p.90), although higher speeds may be used with permission of the local authority. Other advantages of submersible pumps include lower construction cost as no building or dry wells are needed to house pumps (Sanks 1989 p. 774), less land use and pumps are self priming. The use of guide rails and auto coupling pump stands mean that service personnel do not need to enter a confined space to service pumps.

Pump Stations would satisfy the requirements recommended by WSA and Sanks if

1. The pumps installed could provide greater than 5 x ADWF in both normal and wet weather flow conditions
2. There are standby pumps for both normal and wet weather flow conditions
3. The pumps are of a submersible design operated at less than 1500 rpm and if possible the pumps are the same model.

2.2 Pump Operation and Selection

Pumps may be classified as either positive displacement or kinetic (Sanks 1989 pp.277 – 279). Note some texts refer to kinetic pumps as dynamic (Fox, McDonald & Pritchard 2004, p. 487) and in relation to pumps these terms are interchangeable. Positive displacement pumps due to their complexity and higher costs are rarely used (Sanks 1989 p. 309) in sewerage pump stations (except in high head applications) and will not be discussed further. The most common type of kinetic pump is the centrifugal pump, and is defined by Astall & Rogers as *"a machine that moves liquid by accelerating it radially outward in a rotating impeller to a surrounding stationary housing"*.

2.2.1 Best Efficiency Point

The input power and the pressure developed by a centrifugal pump is a function of the flow rate of the liquid through it. By recording the pressure and the input power for a range of flows pump manufacturers are able to publish a pump performance curves (*Figure 2.1*) for their range of pumps (Fox, McDonald & Pritchard 2004, pp. 502-509).

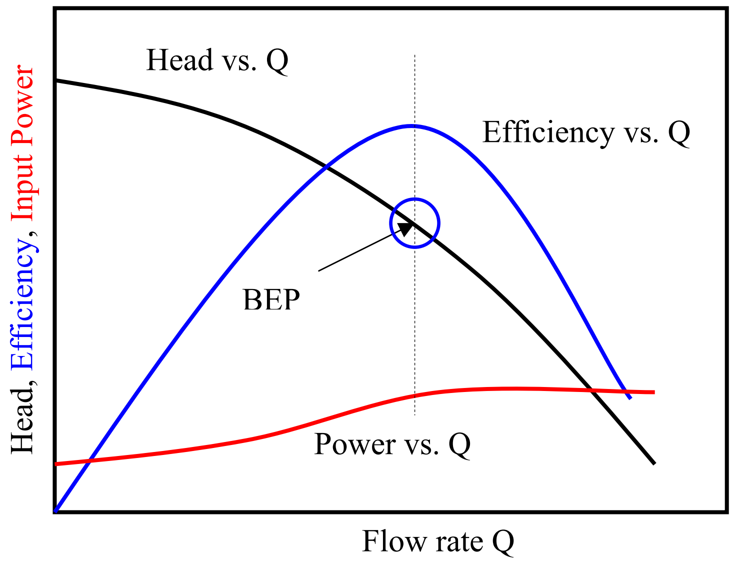


Figure 2.1Centrifual pump performance curve

The Best Efficiency Point (BEP) for a centrifugal pump is the flow rate at which the sum of all internal energy losses is at a minimum. The major losses incurred are caused by shock, friction and internal recirculation in the pump. To reduce energy consumption and wear a pump should be operated as close to the BEP as possible (Fox, McDonald & Pritchard 2004, p. 509).

The BEP is determined by the internal geometry of a pump. In its simplest form the pump impeller is a circular disc containing one or more vanes. If the entry and exit angle of these vanes are not parallel to the flow streams of the fluid shock losses will occur (Fox, McDonald & Pritchard 2004, pp. 491-509). In a correctly designed pump theses angles are both parallel to the stream lines for a single flow rate (the BEP).

As flows increase above the BEP the losses due to friction also increase. The losses due to friction may also cause the pressure in the inlet of the pump to fall below the vapour pressure of the fluid causing the fluid to vaporise (Astall & Rogers 2002 pp 29-31). When the pressure of the fluid increases as it passes through the pump the vapour collapses causing cavitation (see section 2.2.2) and damage to the pump.

If a pump is operated at flows less than the BEP part of the fluid recirculates from the high pressure area outside of the impeller back to the pump inlet. This recirculation increases as the flow out the pump decreases to a minimum at shut off (Astall & Rogers 2002 pp 29-31). As well as efficiency losses, recirculation causes an increase in the temperature of the pumped fluid (decrease of vapour pressure) and higher rates of wear. Wear in pumps from recirculation is accelerated when pumping sewerage as it contains a large amount of grit. This increased rate of wear causes further losses in efficiency (Sanks 1989 pp. 286-287).

The casing that surrounds the impeller is the volute. It is designed so that when a pump is operating at its BEP the radial loads on the pump shaft are at a minimum (figure 2.2). When the pump is operated with flows less or greater than BEP the load on the shaft and therefore bearing increase (Sanks 1989 p. 265).

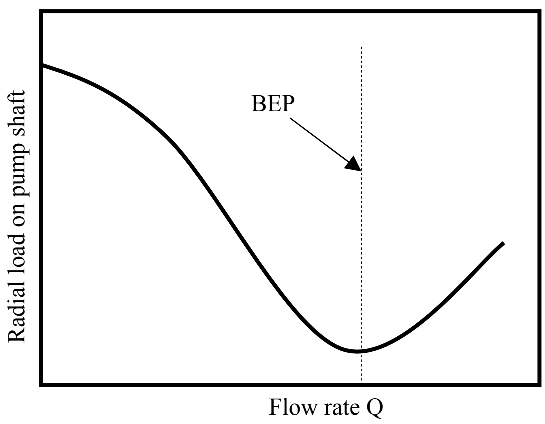


Figure 2.2 Radial forces on pump shaft courtesy of Sanks 1989.

2.2.2 Cavitation

Cavitation occurs when bubbles of vapour form in a low pressure area and then collapse as the fluid moves to a high pressure area inside the pump. The water vapour bubbles form if the pressure in an area of a pump is lower than the vapour pressure of the fluid. When the bubbles collapse the localized pressures that are produced as the fluid moves in to the empty space are very large (Fox, McDonald & Pritchard 2004, pp. 524-525).

Cavitation causes permanent pitting on the surfaces of the volute and impeller as well as reducing pump performance. It occurs when pumps are operated at flow rates either much greater or much less than their BEP (Sanks 1989 p. 255), in areas of low pressures (pump inlet at high flows) or high local velocities (caused by recirculation). The rough surface created by cavitation pitting creates further flow disturbances and increases the amount of cavitation accelerating the destruction of the pump (Astall & Rogers 2002 pp 29-33).

When cavitation occurs the bubbles collapsing sounds like pieces of gravel are rolling around in the pump. The level of noise increases dramatically which is undesirable in residential areas.

2.2.3 Recommended Operating Range

The range recommended by Tchobanoglous, (Sanks 1989 p. 255) for radial flow centrifugal pump for continuous operation is between 60 and 120 percent of BEP as shown in figure 2.3. Astall & Rogers on page 39 recommend between 50 and 110 percent of BEP as their recommended operating range.

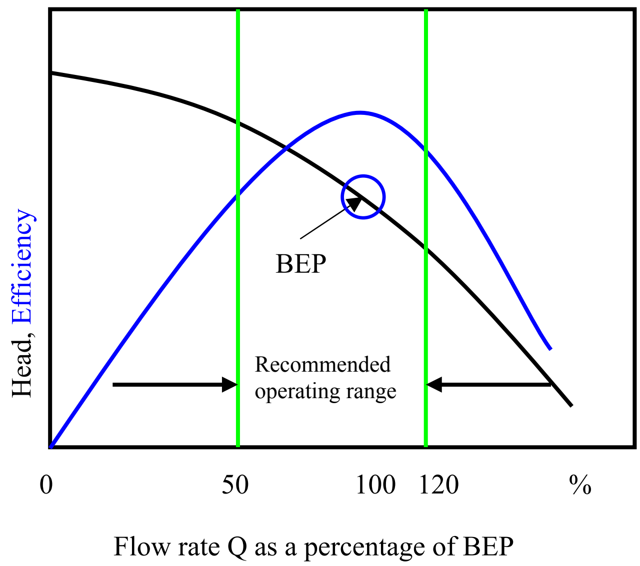


Figure 2.3 Recommended operating range for centrifugal pumps

By operating within this range the effects of recirculation, cavitation and high bearing loads will be avoided (Astall & Rogers 2002 p. 39). Operating for extended periods outside this range will damage and shorten the useful life of the pump (Sanks 1989 p. 255). Pump manufacturers will sometimes specify a desirable range of operation on their pump performance curves.

2.3 Pump Station Configuration Options

The pump station system resistance curves to be used for this investigation are shown in figure 2.4 and have been provided by Citiwater. The Average Dry Weather Flow (ADWF) has been also provided by Citiwater as 1.8 litres per second.

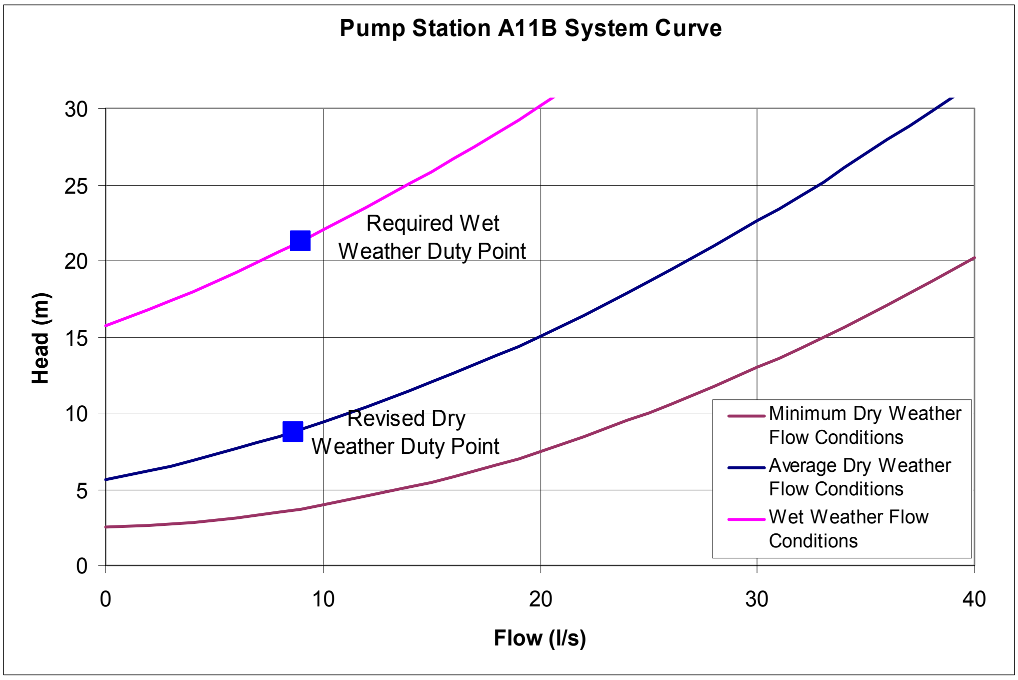


Figure 2.4 System resistance curve for Pump Station A11B

Citiwater has specified the Required Wet Weather Duty (from section 2.1) as 5 x ADWF or 9.0 litres per second at 21 m head. By taking into account the operation requirements listed in section 2.3 the dry weather duty point has been revised to 4.8 x ADWF corresponding to 8.6 litres per second at 8.7 m head.

The pump station is located in a small laneway less than 2 m to residential housing therefore pump speeds of greater than 1500 rpm may not be used (Citiwater 2007, pers. comm., April 4).

2.3.1 Current Citiwater Method

The current method used by Citiwater is to install one small pump to operate during normal dry weather and one large pump for wet weather conditions. The small pump is to operate at the average dry weather flow conditions, the minimum dry weather flow conditions and all points in between. The large pump must be able to operate in the range between wet weather flow conditions and minimum dry weather flow conditions. The large pump is used as the duty pump one week a month during dry conditions to prevent the build up of solids inside the impeller and to ensure it is in working order for the wet season (Citiwater 2007, pers. comm., April 4).

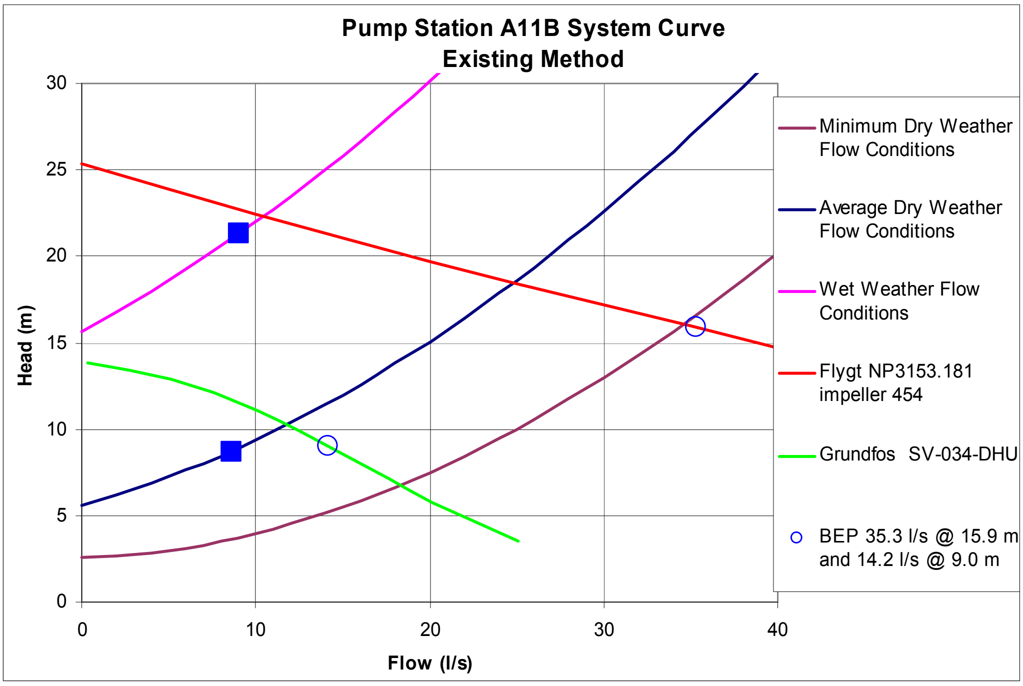


Figure 2.5 Pumps for Pump Station A11B selected using current method, pump performance curves courtesy of Grundfos and Flygt.

Pump 1 ITT Flygt model NP3153.181 HT	$ 17000.00
Pump 2 Grundfos SV-034-DHU	$ 3400.00
	$ 21400.00

For the pumps selected above the small pump will operate at approximately 12 litres per second for average conditions or at 85 % of BEP. During minimum flow the pump would operate at 18 litres per second corresponding to 125 % of BEP.

This is outside the recommended range by a small amount 5 % but considering it will only rarely operate in that condition it is considered acceptable.

When the large pump is used during dry weather it will operate between 25 and 35 litres per second, corresponding to 71 to 99 % of BEP which is inside the recommended operating range. For wet weather flow conditions the pump will operate at approximately 10 l/s which is 28 % of BEP. Accordingly it can be expected that this pump will experience high radial loads and higher rates of wear if operated during wet weather. As wet weather flow conditions occur less frequently than dry these problems would not impact significantly the pumps operation. A major disadvantage of this configuration is that the cost of the large pump is five times the cost of the small pump, and its higher capacity that is only required during wet weather.

Further if the large pump fails during wet weather the pump station wet well will overflow as the capacity of the small pump is insufficient to cope with the wet weather flows. This is not acceptable as it contradicts section 2.4 of the pump station code, namely that the failure of any one piece of equipment should not prevent the pump station from operating (WSA 2005 p.54).

2.3.2 Variable Frequency Drive

By using a variable frequency drive the flow out of the pump can be matched to the flow into the well by altering the speed of the impeller. To achieve wet weather duty the same large pump from section 2.3.1 is used. Figure 2.6 shows the performance curve of the pump at the different speeds required to achieve both duty points.

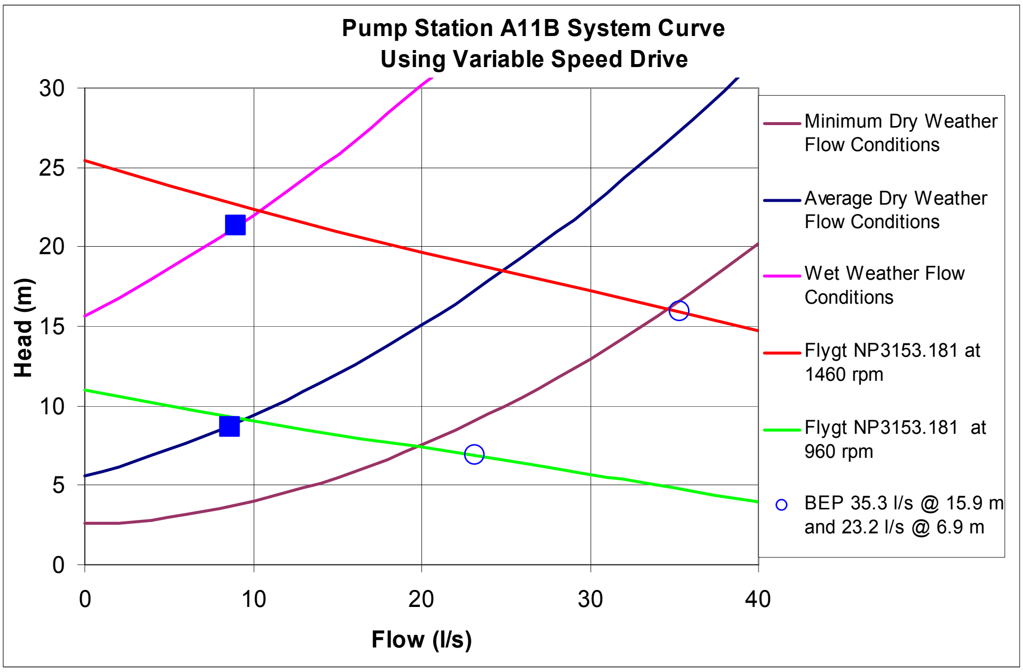


Figure 2.6 Pumps for Pump Station A11B selected using VFD method, pump performance curves courtesy of Flygt.

Pumps 2 of ITT Flygt model NP3153.181 HT	$ 34000.00
Variable Frequency Drives, 2 of	$ 4000.00
	$ 38000.00

When operating at the lower speed for dry weather flow conditions the pump will have an output of 9 to approximately 20 l/s or 39 to 86 % of BEP. For the wet weather duty point the pump will operate as in section 2.3.1 at 10 l/s or 28 % BEP. Of all the pump configurations considered the use of variable frequency drives is the most expensive mainly because two large pumps are required.

2.3.3 Parallel Operation

If two identical pumps are operated in parallel as shown in figure 2.7 the resulting performance curve is found by added the flow capacities at each head (Fox, McDonald & Pritchard 2004, p. 537).

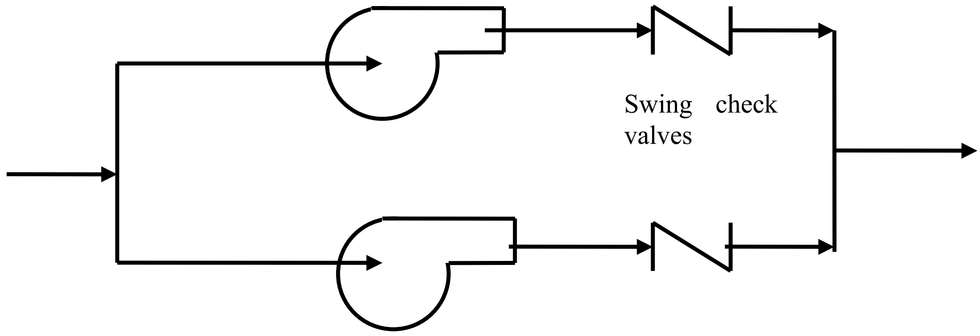


Figure 2.7 Schematic representation of pumps operating in parallel

The same system curve is shown in figure 2.8 for two smaller pumps operating in parallel. To satisfy the redundancy requirements of section 2.4 of the pump station code three pumps would need to be installed. During normal operation there would be one duty and two standby and for wet weather two duty pumps with one standby.

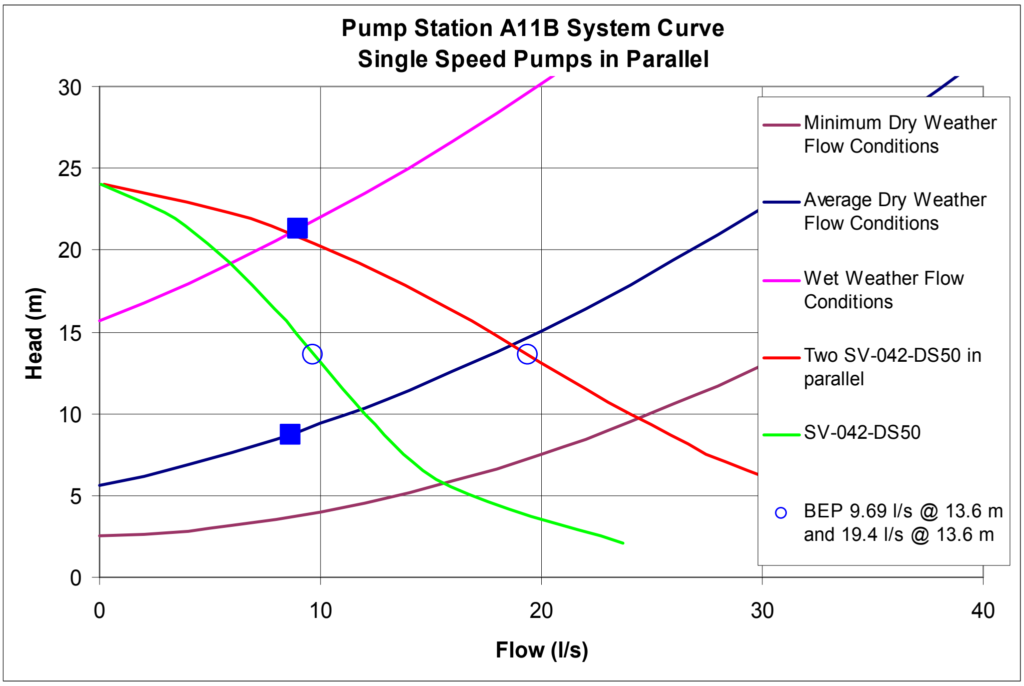


Figure 2.8 Pump Station A11B with pumps in parallel.

Pumps 3 of Grundfos SV-042-DS50 $ 10800.00

For normal flow conditions the single pump will operate between 12 and 16 litres per second which corresponds to 123 to 155 % of BEP, which is above the recommended maximum. For wet weather flows the two pumps will operate at 9 litres per second or 46 % of BEP, which is below the recommended minimum. These pumps also operate at 2900 rpm. All of the above factors make these pumps unsuitable for this application.

2.3.4 Series Operation

If two identical pumps are operated in series as shown in figure 2.9 the resulting performance curve is found by adding the heads for each flow capacity (Fox, McDonald & Pritchard 2004, p. 537).

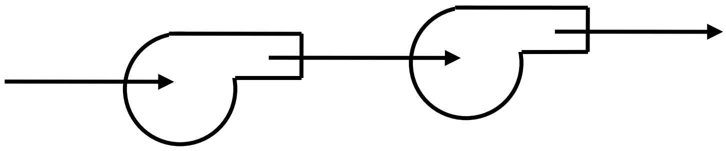


Figure 2.9 Schematic representation of pumps operating in series

The system curve for pumps in series is shown in figure 2.10

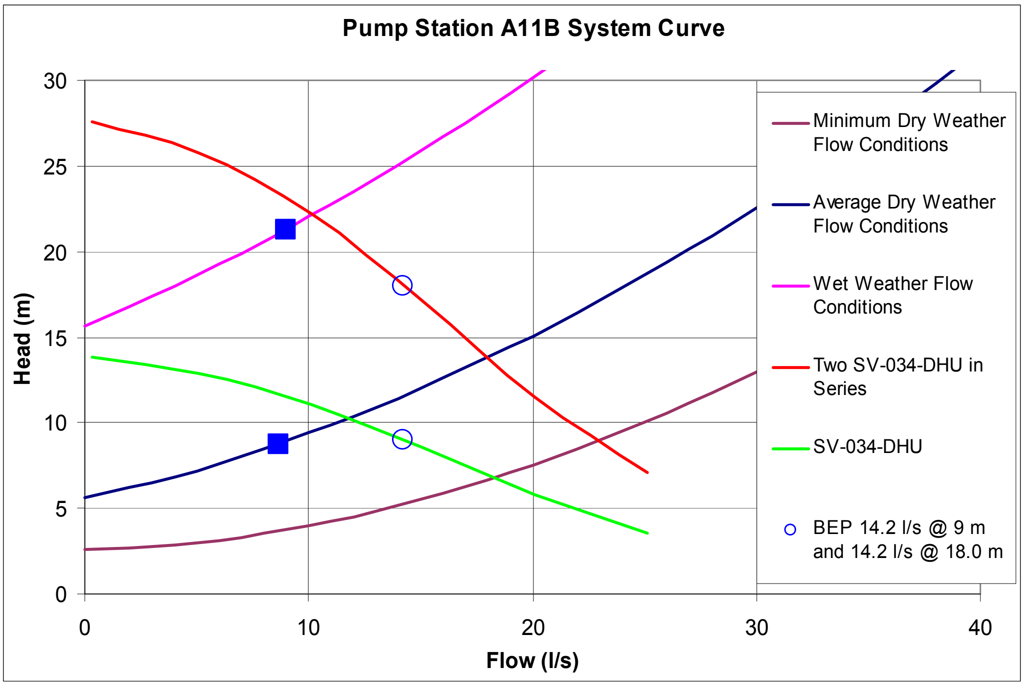


Figure 2.10 Pump Station A11B with pumps in series.

Pumps 3 of Grundfos SV-034-DHU	$ 10200.00
Modifications to pumps and pipework	$ 5000.00
	$ 15200.00

For normal flow conditions the single pump will operate between 12 and 18 litres per second which is 85 to 125 % of BEP. For wet weather flows the two pumps will operate at 10 litres per second or 70 % of BEP. The pumps operate at 1450 rpm. All these factors are acceptable.

The current method for pumps to operate in series requires then to be permanently connected as shown in figure 2.9. Therefore two pumps would have to be connected in series and a third pump installed to operate by itself for normal operation. This arrangement is not acceptable as the failure of any one of the three pumps would prevent the pump station from operating properly.

If pumps could operate as a stand alone pump for normal operation but have piping and valving that connected them in series for wet weather operation this problem would be overcome. A possible arrangement is shown in figure 2.11.

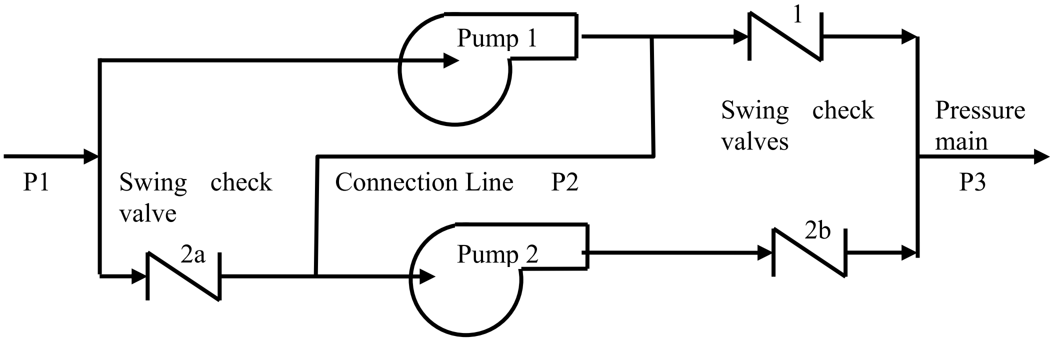


Figure 2.11 Pipe configuration that will allow pumps to operate in series or singularly.

Normal operation requires either pump to run. If pump 1 is running pressure produced by the pump closes check valve 2a forcing the fluid into the pressure main. If pump 2 is operating fluid is drawn in through check valve 2a through the pump and into pressure main (P3). Check valve 1 closes preventing recirculation. When a single pump is operating there will be some flow through the pump that is not running.

For wet weather operation both pumps need to operate. Pressure at P3 is greater than the pressure Pump 1 can produce therefore check valve 1 is forced closed. P2 is greater than P1 forcing 2a closed and the fluid into Pump 2. This allows the pumps to operate in series resulting in the performance curve shown in figure 2.10.

To enable a back up for failures in wet weather three pumps would need to be connected in this manner as show in figure 2.12. During normal operation there would be one duty pump and two standby pumps and for wet weather two duty pumps with one standby.

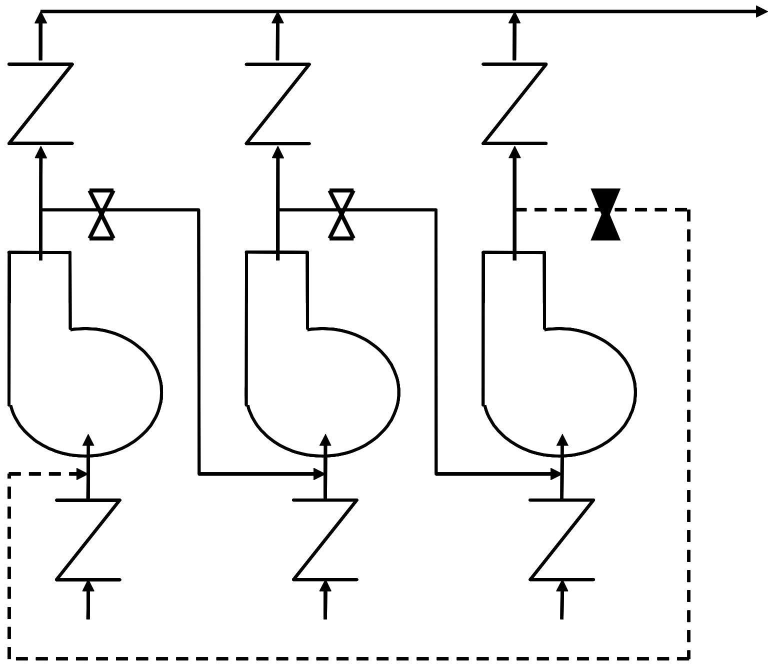


Figure 2.12 Proposed pump arrangement for pumps to operate in series or singularly.

The author has been unable to find any reference of a pump arrangement as shown in figure 2.11. Therefore to asses the suitability of this arrangement further investigation and prototype testing will need to be done.

2.3.5 Summary

Table 2.1 lists all the above configurations and allocates a quantitative score to predicted operating performance. The score ranges from 5 as satisfying all requirements to 0 as not being suitable at all. A total of the quantitative scores for each configuration are given at the bottom of table 2.1.

Pump Configuration	Current Method	Variable Speed	Parallel operation	Series operation
Dry weather operating range (% of BEP)	85 - 125	39 - 86	123 -155	85 - 125
Suitability Score	4	4	0	4
Wet weather operating point (% of BEP)	28	28	46	70
Suitability Score	3	3	4	5
Backup Provision for Pump Failure	None if large pump fails in wet weather	One duty one standby in wet and dry weather	One duty two standby in dry weather, two duty and one standby in wet weather	
Suitability Score	0	5	5	5
Cost	$21,400.00	$ 38,000.00	$10,800.00	$15,200.00
Comparative Score	2.5	1.4	5.0	3.6
Total	**9.5**	**13.4**	**14.0**	**17.6**

Table 2.1 Comparison of pump configuration options

2.4 Conclusions: Chapter 2

Of the alternatives to the current Citiwater design all three pump station configurations satisfy the requirements of the pump station code. Only the variable frequency drive method and the proposed series operation allow the pumps to operate within the recommended operating range.

The use of variable frequency drives is recognised as an acceptable solution for large pump stations or to maintain continuous flow into a treatment plant. The major problem of variable frequency drives is the extra cost of the drive and the need to install larger pumps. For normal dry weather operation less than half of the pumps flow capacity is utilised. For the small and medium sized stations which make up 98 of the 102 pump stations at Citiwater, this extra cost is significant.

The suitability of the series configuration in a sewerage system is unknown without further investigation. This project will design and build a prototype of this series configuration and assess its performance.

Chapter 3: Prototype Design

To assess the suitability of the series pump configuration a working prototype was designed. The prototype design aims to incorporate all the operational functions of the proposed series configuration referred to in figure 2.12. The eventual plan was to test the prototype in the actual sewerage system therefore the design would have to comply with the requirements discussed in section 2.1

3.1 Design Process

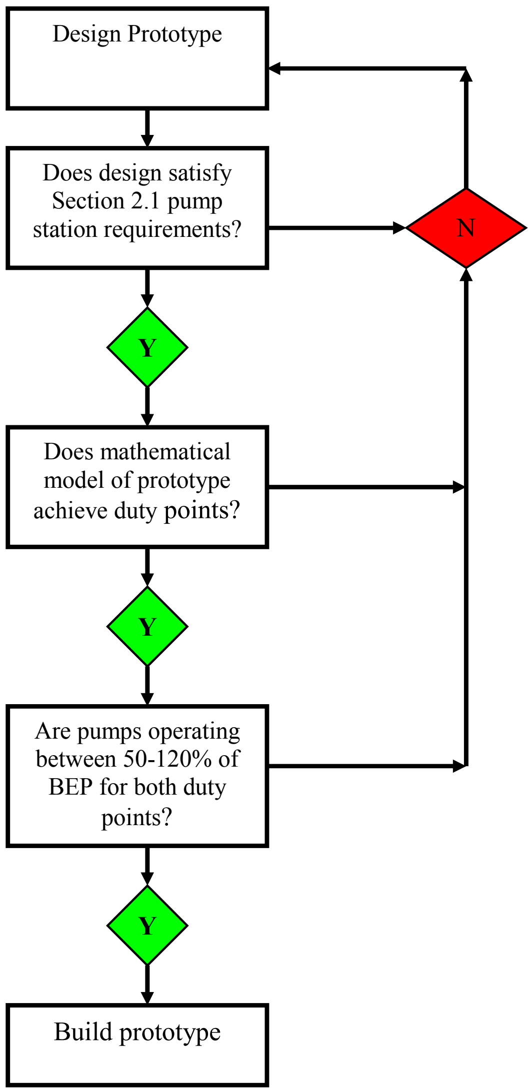


Figure 3.1 Design process flow diagram.

3.2 Design Considerations

The recommendations from both WASA and Citiwater state small to medium pump station should be of a wet well design to as discussed in section 2.1. This requires the pumps to be able to be removed from wet well for maintenance. The major difference between the proposed series pump configuration and existing designs was the need for two pipes to be connected to the pump instead of one. This was achieved by modifying the manufacturer's current auto couple design which is explained in detail in section 3.2.1.

Some other design considerations that were included in prototype design included

- When operated in series the pressure produced by second pump should be less than the pressure rating of the pump.
- Where possible "off the shelf" components such as valves, swing check valves, pump auto couples and pipe fittings were used.
- The pipework between the two pumps (the series connection) must be a design that does not allow air to build up and become trapped. Entrapped air can reduce the flow through the pipe and may cause loss of prime in pump (Astall & Rogers 2002 Sec. 2 p 5)
- The volutes of both pumps must be fully submersed at well start height to ensure they were always fully primed when they needed to run.
- The two pumps can not be connected together rigidly as vibrations produced when only one pump is running may cause the bearings in the stopped pump to brinnel.

3.3 Component Design

Two components were identified as not being readily available products and therefore had to be designed;

1. The under pump valve which is a non return (swing check) valve that has two inlets to allow automatic switching between single pump operation and series pump operation.
2. An auto couple that would allow connections to the inlet and outlet of a submersible pump and;

3.3.1 Under pump valve

The non return valve that is fitted to the inlet side of the pump was modified to incorporate a second inlet making it a three way valve. This modification was done to make the valve more compact and to decrease flows through the pump that was not operating.

Making the under pump valve and pipework more compact meant that the pump could be positioned closer to the bottom of the well. This allows the volute of the pump to be fully submerged at lower well levels. Figure 3.2 shows a reduction in length of 290 mm was achieved by moving the inlet to be part of the valve.

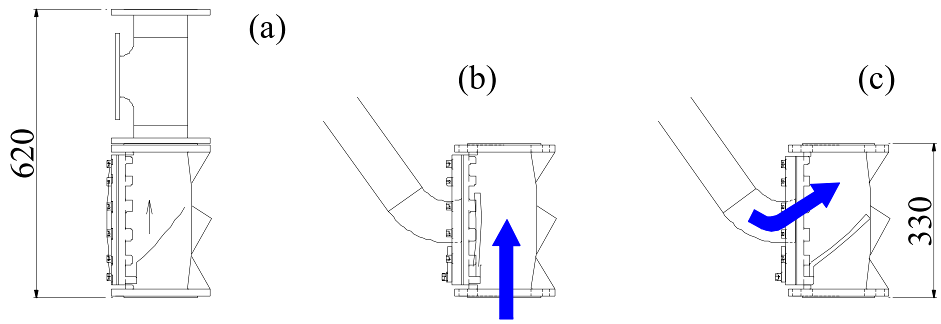


Figure 3.2 Under pump valve a) if not modified, b) modified single pump operation and c) modified series pump operation.

When the pump is operating as a single pump some of the inlet flow will be drawn in through the adjacent pump as explained in section 2.3.4. Figure 3.2 (b) shows that the pipe that is connected to the adjacent pump is shut off when the pump is operating as a single pump. It is hoped that this will reduce flows through the non operating pump and reduce the risk of blockage.

3.3.2 Auto Couple Design

A sewerage wet well is a confined space with a high probability of hydrogen sulphide gas being present. The risk assessment (Appendix B) identified entry into the wet well for routine maintenance of pumps as an unacceptable risk. Current submersible pump designs utilise an auto coupling device that takes advantage of the pumps weight to form the seal between the pump outlet and sewerage system piping, (refer to figure 3.3). A pedestal remains in the well and is permanently attached to the pressure main. It has guide rails to ensure pump is located correctly when lowered down into the well.

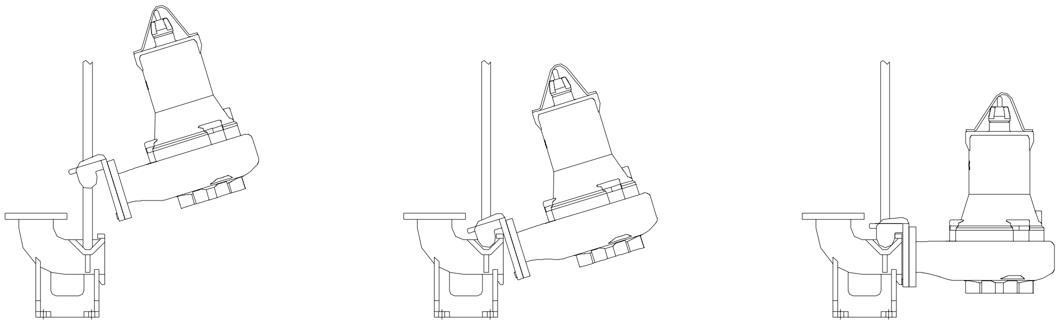


Figure 3.3 Submersible pump being lowered onto pedestal.

To allow the modified pump to be removed from the wet for maintenance a system to connect the pump to two pipes had to be developed. The extra swing check valve that was to be connected to the inlet of the pump was identified as a possible blockage point and was therefore connected to the bottom of the pump. This would allow the valve to be removed and inspected by simply lifting the pump out of the well.

An extra auto couple was purchased and the pump pedestal modified to enable the two auto couples to be arranged side by side as shown in figure 3.4. Detailed information on the load carrying capacity and the force required for the auto couple to seal was not available. The loads on an unmodified pump were calculated and used to dimension the new auto couple design. Factors taken into consideration included the use of two auto couples to share the load, providing space for the extra pipework and higher pressures produced by the pump when operating in series. Details of these calculations may be found in appendix D.

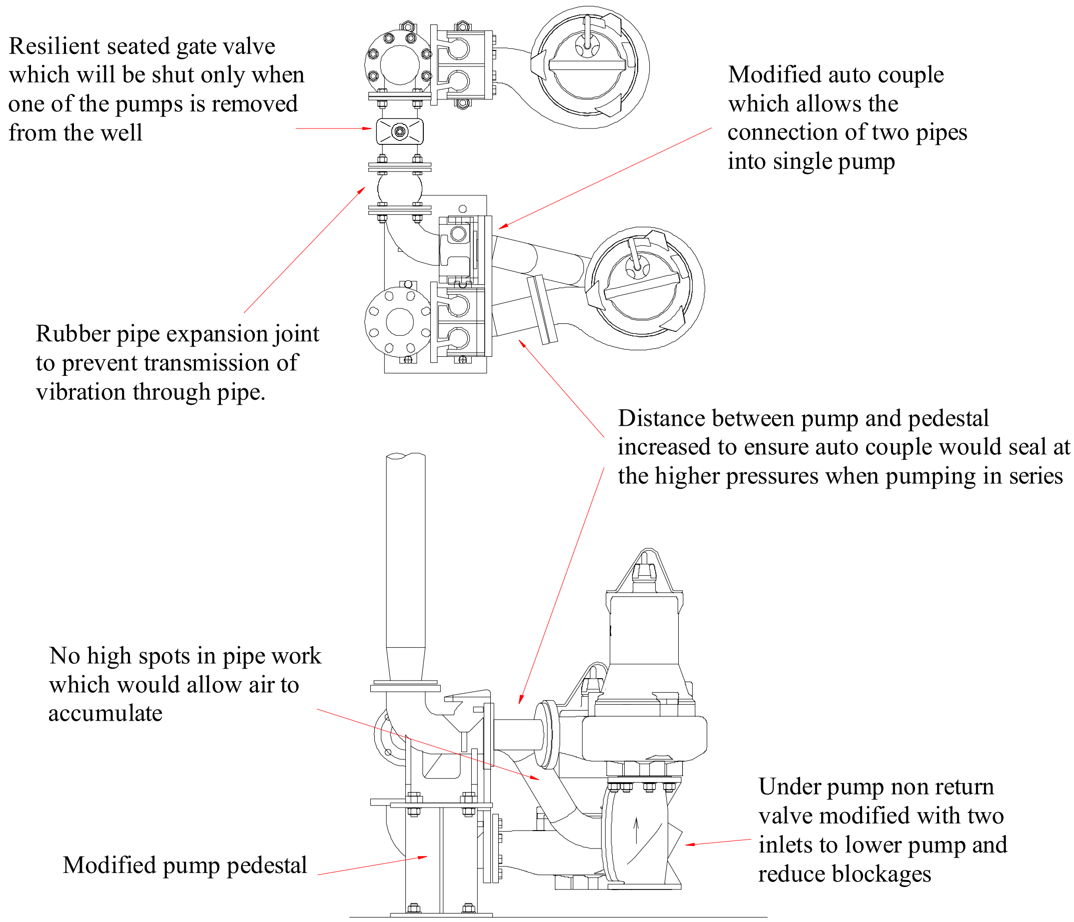


Figure 3.4 Final prototype design showing key design features.

Figure 3.4 illustrates the solutions the author used to meet the design requirements listed in section 3.2. Full detail arrangement and construction drawings are shown in appendix C. All design drawings were done by the Citiwater draftsperson Kevin McGrath under the direction of the author.

3.3.3 Pump Casing Pressure Rating

From the manufacturer's specification the maximum head produced by a singular pump is 14 m. For water at 25°C the corresponding discharge pressure (P_1) is

$$\begin{aligned} \therefore P_1 &= \rho g h \qquad (3.1) \\ &= 997 \times 9.81 \times 14 \\ &= 137 \text{ kPa gauge} \end{aligned}$$

The maximum discharge pressure able to be developed by two pumps in series is

$$2P_1 = 274 \text{ kPa} . \qquad (3.2)$$

Also from the manufacturer's specifications (refer appendix E) the rating of the pump casing is PN 10, which corresponds to a nominal working pressure of 1000 kPa (AS/NZS 4129-2000). Therefore the maximum pressure able to be produced by the two pumps operating in series is within the pressure rating of the pump.

3.3.4 Materials

Where applicable the guide lines from WSA 101-2005 were used for material choice. Table 3.1 summarises materials used in major components.

Component	Material	Notes
Pumps and pedestal	Grey Cast Iron with manufacturer's coating	WSA 101-2005 page 8
Guide rail and pipe	316 stainless steel	WSA 101-2005 page 8
Valves	Ductile Iron with nylon coating	See appendix E
Valve discs	EPDM with ductile iron core	
Expansion joint	Nitrile	Hydrocarbons often present in raw sewerage

Table 3.1 Material use summary.

Full details of materials used in purchased components may be found in appendix E, which contains the manufacturer's specifications.

3.4 Model Calculations

To check if the above design would operate with acceptable performance before it was constructed a mathematical model was created. To calculate the overall performance of the series pump configuration, flow head data from the pump manufacturer's performance curve was used. The head loss due to friction was subtracted from various flows, to obtain an estimate of the performance curves after the pumps have been modified. The friction losses taken into account are caused by the length of pipe and the extra pipe fittings needed to connect the two pumps. They are estimated by the following equations;

Pipe friction loss: $$H_l = f\frac{LV^2}{d2g} \quad (3.3)$$

Fitting friction loss: $$H_l = k\frac{V^2}{2g} \quad (3.4)$$

where H_l is head loss [m]

f is the friction factor obtained from the Moody diagram

L is the length of pipe [m]

V is the velocity of sewage through the pipe [m/s]

d is the diameter of the pipe [m]

g is the acceleration due to gravity [m/s^2]

k is the resistance coefficient of the valves and fitting obtained from Chart 14 of AS-2200:2006.

The values for the flow head curve were then plotted over the system curve for the pump station to be used in this trial. A plot of pumps connected in a conventional series configuration as shown in figure 2.9 is also included for comparison. The plot is shown in figure 3.5. Detail of the calculations and values used may be found in appendix F.

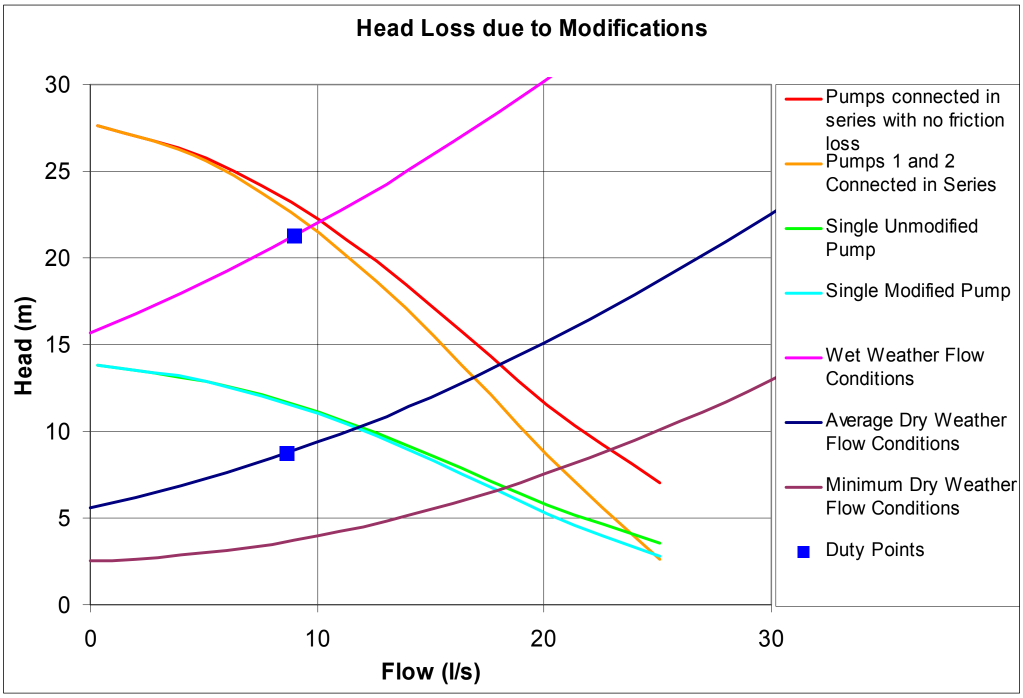


Figure 3.5 Performance estimates after pumps have been modified

Figure 3.5 shows that when the two pumps are operating under wet weather conditions there will be a loss in flow of approximately 0.5 l/s compared to the ideal model that ignores friction in the connecting pipes and fittings. It is also shown that for average flow conditions the loss in flow from the pump is negligible and for minimum flow there is a flow loss of less than 0.5 l/s. The model shows resulting flows will still exceed both required duty points and would be acceptable for construction of prototype.

Chapter 4: Prototype Testing

The prototype pumps were installed in a testing tank to check the system components operated as intended and to confirm the mathematical model from section 3.4. The tests were also used to measure the flows through the non operating pump when the pumps were operating as a single pump.

Figure 4.1 Prototype pumps installed in test tank.

4.1 Flow and Pressure measurement

The flow rate in the test circuit was controlled with a butterfly valve (shown as control valve). The flow rate of each pump was measured by two magnetic flow metres installed as shown in figure 4.2.

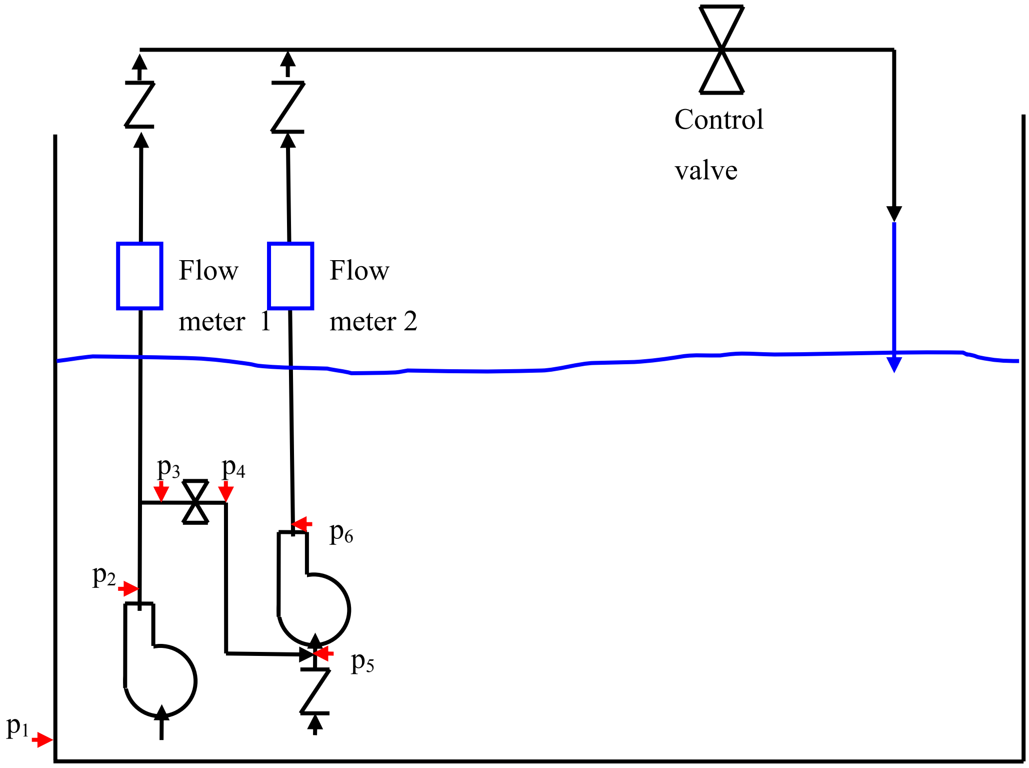


Figure 4.2 Schematic of test tank showing location of flow metres and pressure tappings

The pumps were installed in the test tank and pressure measurement lines were attached to the prototype at the locations shown in figure 4.2. The black flexible tubes that can be seen in figure 4.1 are the pressure lines. The pressure tapping shown above as P_1 was level with the inlets of both pumps. It was connected to one side of a differential pressure gauge to provide a reference pressure as illustrated in figure 4.3.

Pressure lines p_2 to p_6 were attached to a manifold that was connected to the other side of the differential pressure gauge. Before measurements were taken all the air in the pressure lines was bled out.

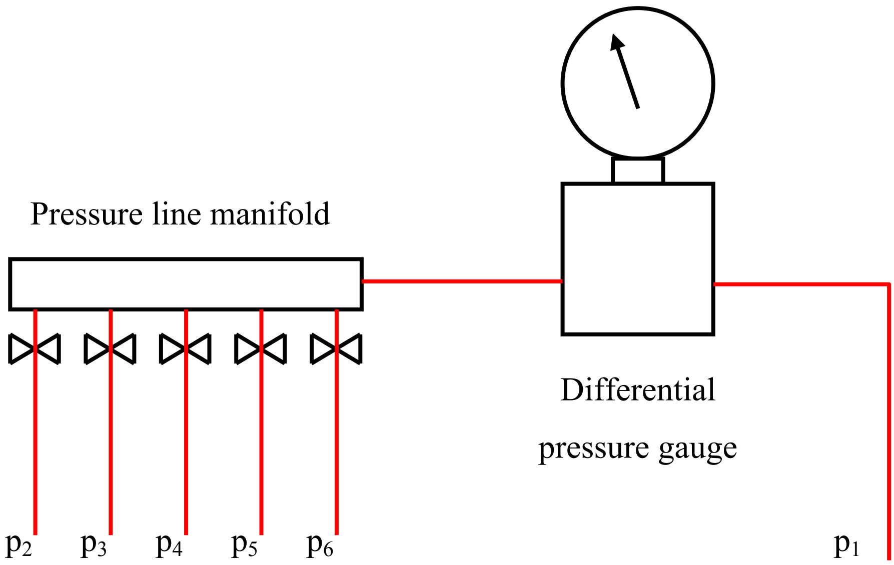


Figure 4.3 Arrangement of pressure gauge which enabled all pressures to be measured with one instrument

This arrangement allowed the pressure difference to be recorded with one instrument. Also, there was no need to take into account the difference in height between the gauge location and the pressure tapping points.

The value displayed on the pressure gauge is $\Delta p_{x\text{-}1}$ with x determined by which valve is open on the manifold. As the water in the test tank is recirculated, after a short period of time the level in the tank will achieve steady state and p_1 will be constant. Therefore the pressure difference between any two measurement points in the prototype may be calculated with equation 4.1.

$$\Delta p_{a-b} = \Delta p_{a-1} - \Delta p_{b-1} \qquad (4.1)$$

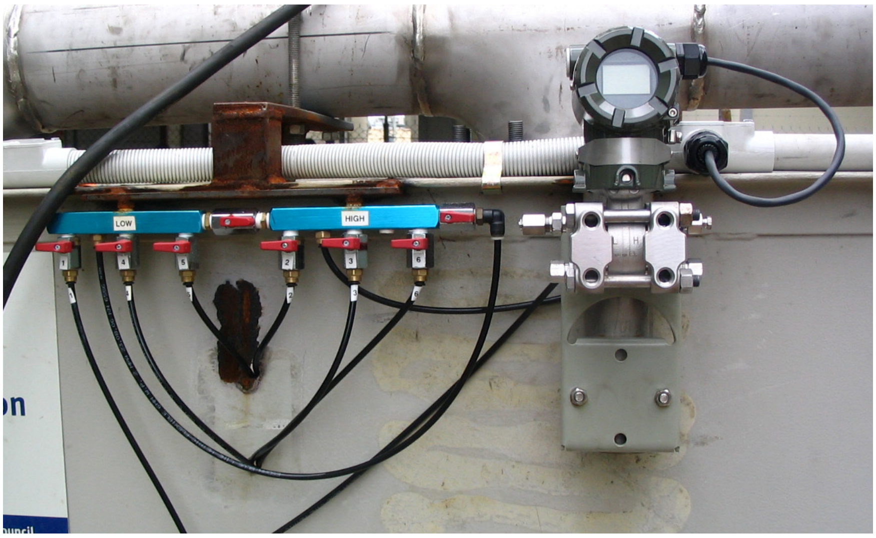


Figure 4.4Differential pressure gauge and manifold connected to the side of the test tank.

4.2 Test Tank Results

The purpose of the first series of tests was to determine the validity of the mathematical model from section 3.4. The model is a prediction of the final head flow performance curve. The values used in the model were flow in litres per second and pump head (H_P) which is the energy per unit of weight of flowing fluid, (Fox, McDonald & Pritchard 2004, pp. 336) and measured in metres. The flow rate through each pump can be obtained directly from the flow metres but H_P must be calculated from a combination of pressure and flow rate measurements. H_P is described by Fox et al. on page 501 with equation (4.2)

$$H_P = \left(\frac{p}{\rho g} + \frac{V^2}{2g} + z\right)_{\text{discharge}} - \left(\frac{p}{\rho g} + \frac{V^2}{2g} + z\right)_{\text{suction}} \qquad (4.2)$$

Where p is absolute pressure, ρ density of the fluid, g is gravitational acceleration (9.81 m.s^{-2}), V is the velocity of the fluid and z is the relative height in metres.

The pressure at the suction is measured with pressure tapping p_1 where $V \approx 0$ m/s. $z_{\text{discharge}} = z_{\text{suction}}$ as both pressures are measured with the same instrument, see section 4.1 above. So equation 4.2 reduces to

$$H_P = \left(\frac{p_{\text{discharge}} - p_{\text{suction}}}{\rho} + \frac{V_{\text{discharge}}^2}{2} \right) \frac{1}{g} \qquad (4.3)$$

V may be obtained by equation 4.4

$$V_{\text{discharge}} = \frac{Q}{A} = \frac{4Q}{\pi D^2} \qquad (4.4)$$

Where D is the discharge internal diameter in metres and Q is the flow rate of the fluid in m^3/s. The diameter of each pump discharge is 80 mm.

4.2.1 Pump 1 Performance

The first pump tested was pump No. 1 which is the unmodified pump. Its measured performance in the test tank was compared to the manufacturer's data from appendix E. Table 4.1 shows the test and calculated data.

Pump 1 Test Results (unmodified pump)			
Test data		Calculated data	
Q (l/s)	p_{2-1} (kPa)	V (m/s)	H_P (m)
29.7	8	5.91	2.60
27.3	18	5.43	3.34
24.8	30	4.93	4.31
22.2	43	4.42	5.39
20	54	3.98	6.33
18.1	63	3.60	7.10
15.8	79	3.14	8.58
13.6	92	2.71	9.78
11.1	106	2.21	11.09
9.6	112	1.91	11.64
7.1	121	1.41	12.47
4.2	128	0.84	13.12
2.2	132	0.44	13.51
0	135	0.00	13.80

Table 4.1 Test results for Pump 1

Figure 4.5 shows this data on a pump head flow curve compared to the performance data supplied by the pump manufacturer. It shows test results and the performance claimed by the manufacturer are very similar. The test results showed a small increase in head produced at flow rates above 20 l/s. This difference may be due to small variations in pump performance of the same model pump where as the performance data published by the manufacturer is the average.

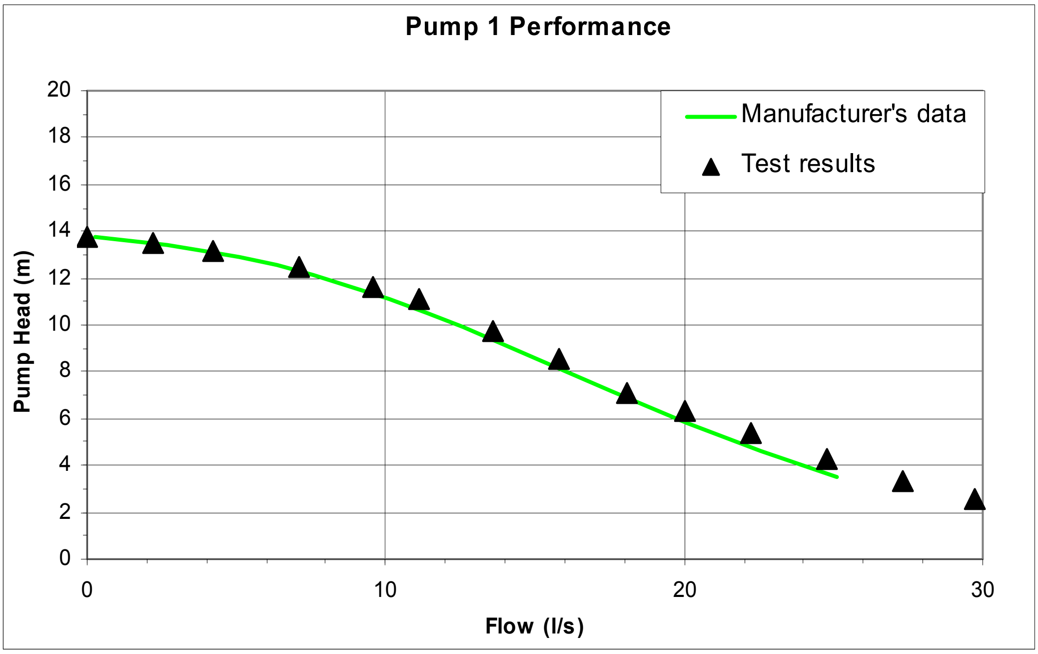


Figure 4.5 Manufacturer's head flow curve with test results

4.2.2 Pump 2 Performance

Pump 2 is the modified pump with the non return valve on pump inlet. The model calculations in section 3.4 predicted a small decrease in performance when the pump was operating at flow rates above 15 l/s. This was due to the frictional loss as the fluid flows through the swing check valve on the bottom of the pump. The results from pump testing are shown in table 4.2.

Pump 2 Test Results (modified pump)			
Test data		Calculated data	
Q (l/s)	p_{6-1} (kPa)	V (m/s)	H_P (m)
25.9	23	5.15	3.70
23.6	33	4.70	4.50
20.5	50	4.08	5.96
18.2	64	3.62	7.21
15.7	82	3.12	8.88
14.1	91	2.81	9.71
12.1	102	2.41	10.72
9.7	113	1.93	11.74
7.5	120	1.49	12.38
4	130	0.80	13.32
2.3	133	0.46	13.61
0	136	0.00	13.91

Table 4.2 Test results for Pump 2

Figure 4.6 shows that the performance of the pump was not noticeably affected by the head loss through the swing check valve as predicted. This may be due to flow being drawn in through pump 1 as well as through the bottom of the valve. This would have the effect of lowering the velocity in the bottom half of the swing check valve and therefore frictional losses. The flow through pump 1 when it is not operating may be a potential cause of blockage in the pump. This will be discussed in more detail in section 3.4.

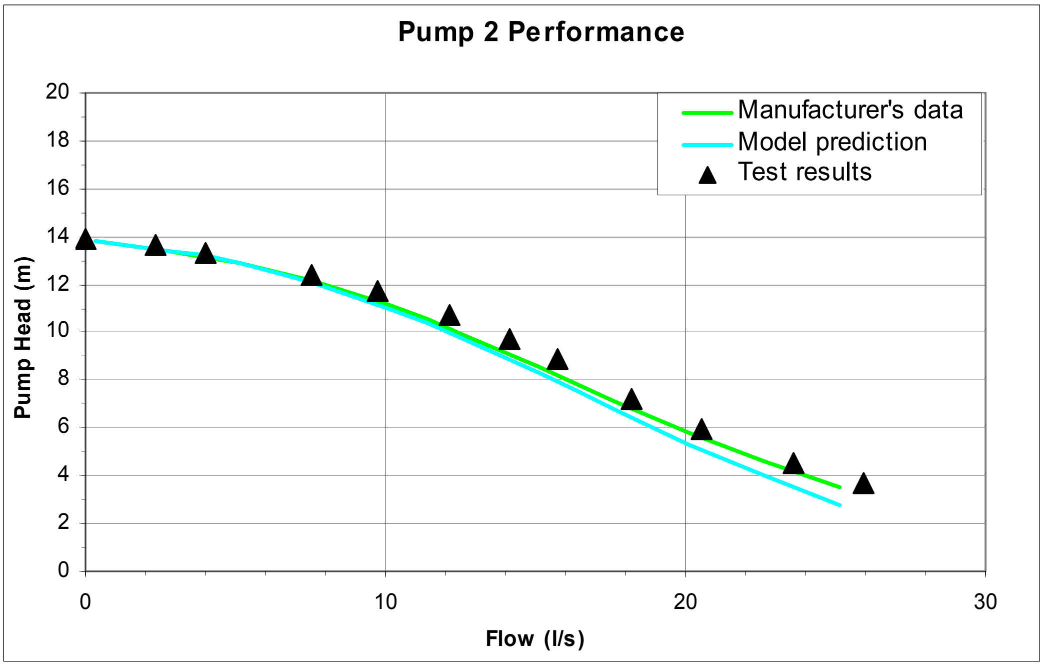


Figure 4.6 Manufacturer's head flow curve with test results for pump 2

4.2.3 Both Pumps Operating Performance

With both pumps running at the same time and with the control valve fully open to simulate low system resistance, it was observed that significant flows were recorded flowing out the pipe above pump 1. This indicates the check valves above pump 1 and below pump 2 were not fully closed and the pumps were operating in parallel. Table 4.3 shows that this only happens at head pressures of less than 5 metres which is below the minimum system curve and therefore would not occur when the pumps are operating in pump station.

Pumps 1 & 2 Both Running Test Results					
Test data				Calculated data	
Q_1 (l/s)	Q_2 (l/s)	Q Total (l/s)	p_{6-1} (kPa)	V (m/s)	H_P (m)
17.7	26.8	44.5	17	5.33	3.19
14	27	41	20	5.37	3.52
12.6	26.2	38.8	22	5.21	3.63
11.3	25.6	36.9	26	5.09	3.98
7.6	24.6	32.2	30	4.89	4.29
5.1	24.8	29.9	33	4.93	4.61
2.3	23.4	25.7	36	4.66	4.79
0.5	22.9	23.4	38	4.56	4.94
0	21.8	21.8	66	4.34	7.71
0	18.4	18.4	110	3.66	11.93
0	15.7	15.7	150	3.12	15.83
0	13.3	13.3	179	2.65	18.66
0	11.5	11.5	202	2.29	20.92
0	9	9	224	1.79	23.07
0	6.1	6.1	246	1.21	25.23
0	2.7	2.7	262	0.54	26.80
0	0	0	272	0.00	27.81

Table 4.3 Test results for Pumps 1 and 2 operating at the same time

Figure 4.7 illustrates the predicted performance curve closely matches the actual test performance. The transition between series and parallel operation discussed above can be observed by the sharp turn in the performance curve at the flow rate of 24 l/s.

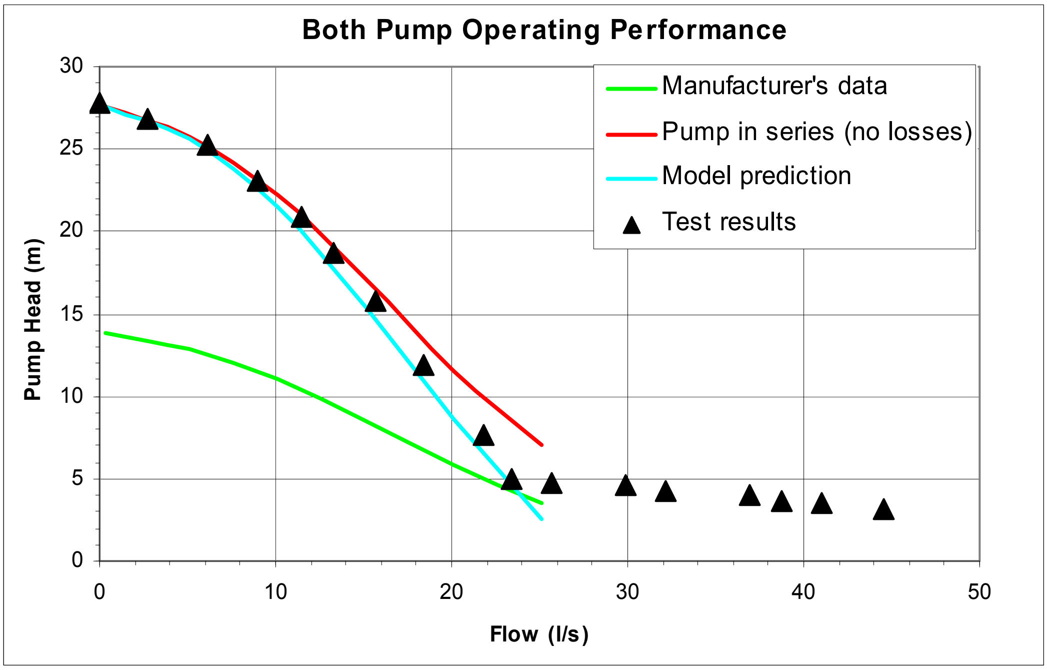


Figure 4.7 Head flow curve for Pump 1 + Pump 2

The performance of the pumps in both operating modes (single pump and in series) are generally consistent with and slightly exceed the mathematical models from section 3.4. They are therefore appropriate to install in sewerage system.

4.3 Flows through Standby Pump

As mentioned above when a single pump was operating alone there is a significant flow through the non operating pump. This may allow solids to accumulate in the volute of the pump and increase the risk of blockage.

When pump 1 was operating the flow through the non operating pump could be measured with the flow metre above pump 2. It can be seen from table 4.4 that the flows of up to 25 % of the total flow were observed going through pump 2 while it was not running.

Q_1 (l/s)	Q_2 (l/s)	Q Total (l/s)	Flow though standby pump
16.4	2.7	19.1	14%
10.1	2.5	12.6	20%
8.6	2.8	11.4	25%
6	0.8	6.8	12%
3	0.1	3.1	3%

Table 4.4 Flow rate thorough non operating pump 2 with pump 1 running

To estimate the flows through pump 1 when pump 2 was running equation 4.5 was used

$$\left(\frac{p}{\rho}+\frac{V^2}{2}+z\right)_2-\left(\frac{p}{\rho}+\frac{V^2}{2}+z\right)_4=K\left(\frac{V^2}{2}\right) \qquad (4.5)$$

where K is the loss coefficient of the pipe fittings between pressure tapping points 2 and 4 (see figure 4.2) . As the pipe diameter at point 2 and 4 are equal $V_2 = V_4$, the pressures are measured on the same elevation $z_2 = z_4$ and $\rho \approx 1000$ kg/m^3 equation 4.5 reduces to

$$p_2 - p_4 = K\left(\frac{V^2}{2}\right) \text{ kPa} \qquad (4.6)$$

where pressure is measured in kPa.

The loss coefficient K was obtained from test data when both pumps were running and all flow was going through the connecting pipe. These results are summarised in table 4.5.

Q_1 (l/s)	Q_2 (l/s)	Q Total (l/s)	Δp_{2-4} (kPa)	V_4 (m/s)	K
0	23	23	20	4.6	1.9
0	21.1	21.1	16	4.2	1.8
0	13.1	13.1	6	2.6	1.8
0	9.3	9.3	4	1.9	2.3
0	4.4	4.4	1	0.9	2.6
0	2.1	2.1	0.5	0.4	5.7

Table 4.5 Loss coefficient for connecting pipework

A value of K = 1.9 was chosen as the best fit of the above data and this is shown graphically in figure 4.8.

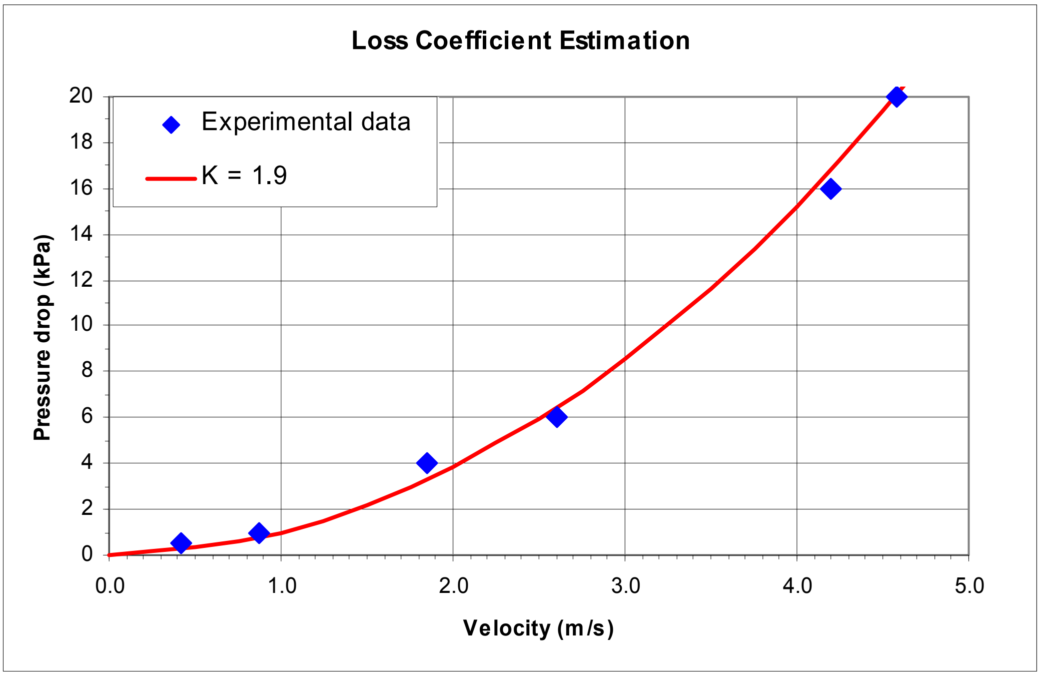


Figure 4.8 Loss coefficient $K_{2\text{-}4}$ estimation

Therefore from above the flow through pump one when only pump 2 is operating may be estimated with equation 4.7.

$$Q = VA$$

$$Q_{\text{Pump 1}} = \sqrt{\frac{2\left(p_2 - p_4\right)\text{kPa}}{1.9}} \times \frac{\pi d^2}{4} \ \text{m}^3/\text{s} \tag{4.7}$$

Results from test data and equation 4.7 are summarised in table 4.6 and show flows of approximately 25 % of the total flow pass through the standby pump

Q_2 (l/s)	$\Delta p_{2\text{-}4}$ (kPa)	$Q_{\text{pump 1}}$ (l/s)	Flow though standby pump
26.3	1.5	6.3	24%
19.3	0.8	4.6	24%
14.9	0.5	3.6	24%
8.3	0.2	2.3	28%
2.4	0	0.0	0%

Table 4.6 Flows thorough pump 1 when not operating

Tests showed that up to 25 % of the pump stations output will pass through a stationary pump when only one pump is operating. To prevent solids build up it is recommended the pumps should operate with alternating duty which is discussed in more detail in section 5.1.

Chapter 5: Operation in Pump Station

5.1 Pump Control Method

The switching between single pump operation and two pumps operating in series must be simple and self controlling. This is achieved by the starting and stopping of the pumps based on level in the wet well. This eliminates the need for control valves or actuators to be located in the corrosive environment of the wet well. All controlling of the pumps is done by a PCL controller located in the switchboard. There were only minor changes to the logic currently used by Citiwater in other pump stations. This approach was followed to decrease unforseen problems that may occur with completely new logic.

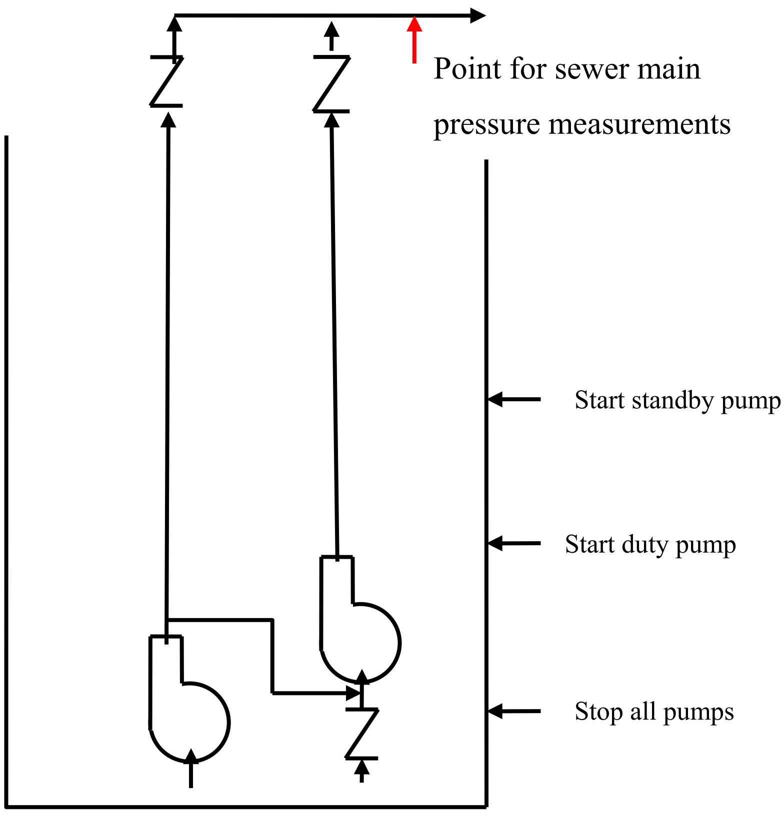


Figure 5.1 Schematic of pump start and stop levels

The operation of the pumps is dictated by well level which is measured by a hydrostatic pressure sensor. For normal dry weather operation only one pump is required to achieve the necessary flow rate. When the well level fills to "start duty pump" as shown in figure 5.1 the duty pump will start. When the well is drawn down to “stop all pumps” level the duty pump is stopped. To prevent solids accumulating in the pump that is not operating the duties will alternate between each pump.

If the well level rises to “start first pump” causing the duty pump to start and then the level continues to rise the flow into the well is greater than the output of a single pump. The most common reason for this is that the flow out of the pump has been reduced due to an increase in pressure in the receiving main caused by other pump stations in the sewerage system activating. When the level rises to “start standby pump” the second pump will start causing the pumps to operate in series. Both pumps will continue to operate until the well level has been lowered to the “stop all pumps” level. The start stop levels used when the pumps were installed is summarised in table 5.1.

Control function	Level (m)
Stop all pumps	0.6
Start duty pump	1.2
Start standby pump	2.0

Table 5.1 Initial control level for pumps

5.2 Dry Weather Operation

The prototype pumps were installed in sewerage pump station A11B during July 2007 and commenced operating on the 22nd July 2007. There was no significant rain in Townsville during the time period that this data presented below was collected, therefore all operation was been under dry weather flow conditions. The main operating criterion from section 2.2.3 was that the pumps operated between 50 and 120 percent of their best efficiency point in regard to flow. The best efficiency flow rate for the pumps used in the prototype is 14.2 l/s (see section 2.3.4 figure 2.10), consequently the pumps should operate between 7.1 and 17.0 litres per second.

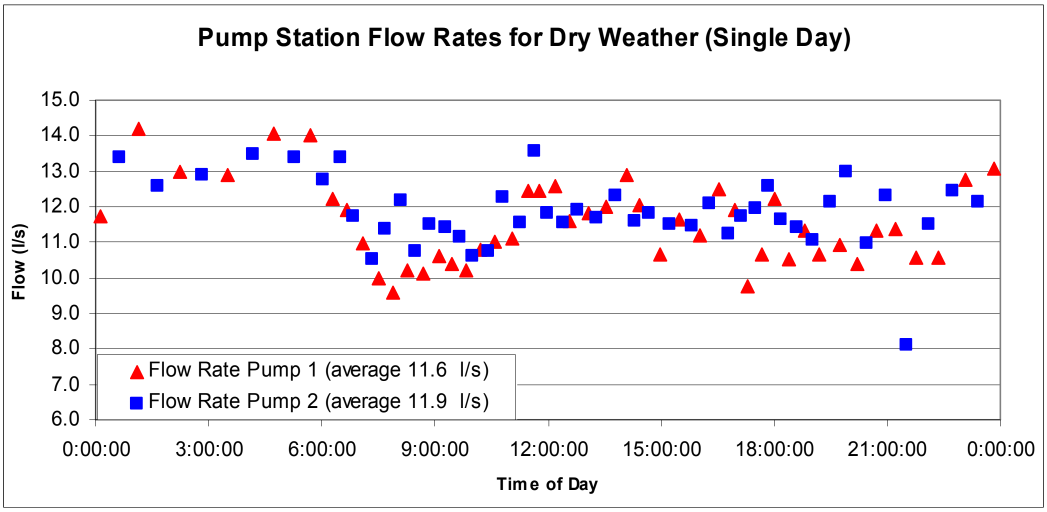


Figure 5.2 Pump station flow rate pump station over single day

As mentioned in chapter 1 the flow demands of a pump station change throughout the day with in flows peaking in the morning between 7 and 9 o'clock and at minimum during the night between 1 and 6 AM this is shown in figure 5.2 the flow rate displayed is the flow rate while the pump is running. Overnight there is less demand on the sewerage network and when the pumps operate it is less likely that any other pumps will be operating at the same time.

During this "low flow period" the system curve that the pump will operate on will be the minimum dry weather curve, as explained in section 1.2 and 2.3.4.This type of behaviour can be seen in figure 5.3. When the pumps are not operating the pressure in the sewer main is approximately 0 kPa. When one of the pumps starts the pressure in the sewer main increases to 17 kPa. The pressure spike that occurred just after 1:15 AM is a result another pump running elsewhere in the sewerage network. The flow from each pump is at a maximum when the pump starts as the well has reached the start duty pump level. The flow steadily reduces to a minimum at the pump stop level as the fluid has to be lifted higher as the level in the well lowers.

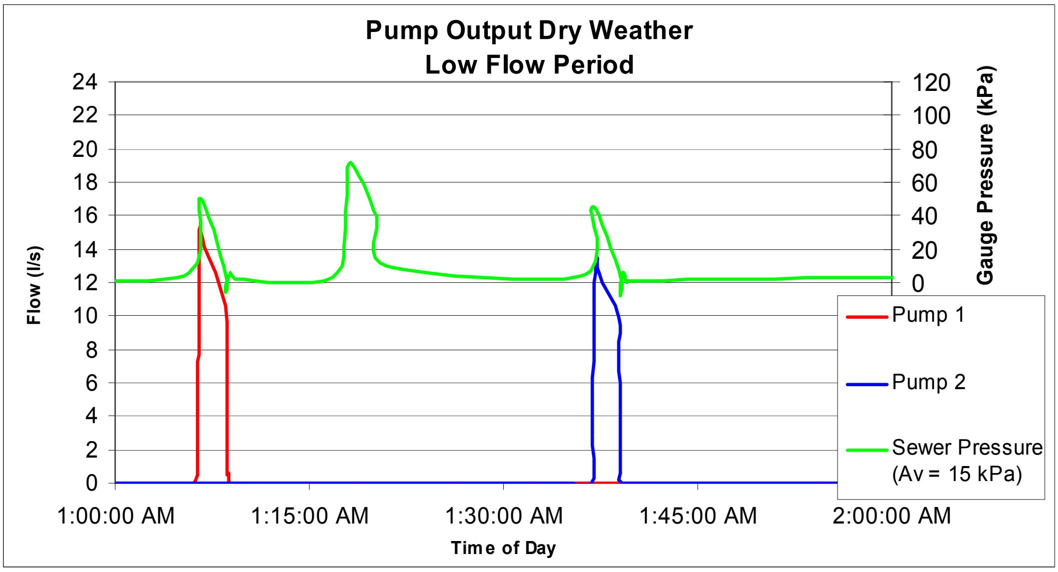


Figure 5.3 Pump station outflow and pressure during low flow period

This low flow period is when the pumps will have the highest possible flow rate. The maximum flow shown is approximately 15 l/s. As this occurs when no other pumps are operating it is unlikely that a higher flow will occur without changes to the sewerage pipe network or the start level in the well is increased. As this is inside the recommended operating range of 8.5 to 17 l/s this is acceptable. From figure 4.5 and 4.6 there is approximately 1.5 metres of pump head difference between 15 and 17 l/s. Therefore the start duty pump level (figure 5.1) could be raised up to 1.5 metres without causing the pumps to operate outside the recommended operating maximum of 17 l/s.

The minimum flow rate is expected when the inflow into the sewerage network is at a maximum. During this period there is a higher probability that some of the other pump stations in the sewerage network will be operating at the same time with the effect of increasing the pressure at pump station A11B.

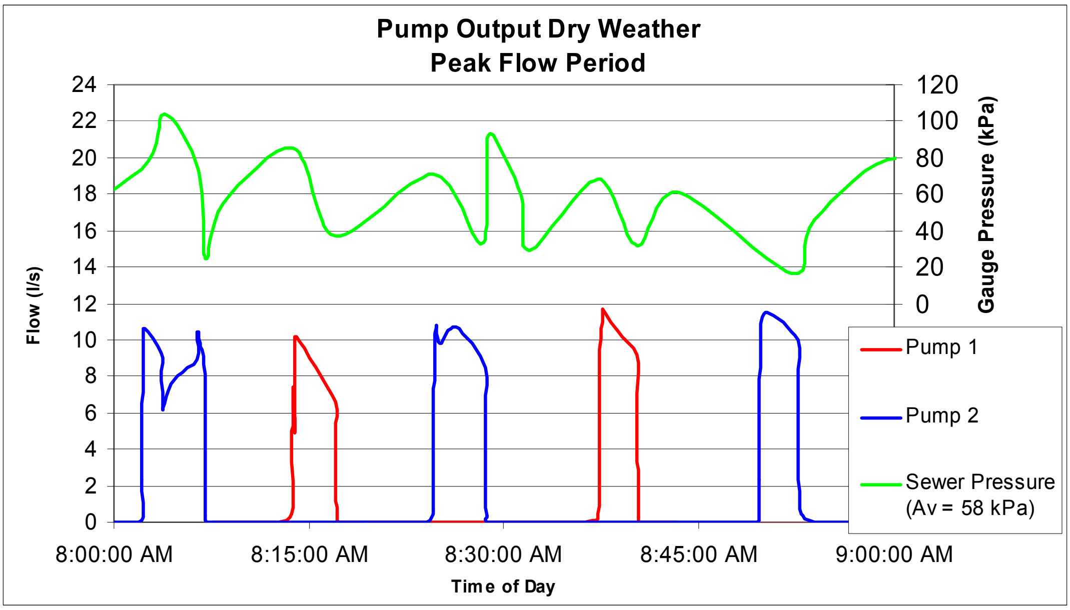


Figure 5.4 Pump station outflow and pressure during peak flow time

Figure 5.4 shows the pressure in the sewer main fluctuates about an average value of 58 kPa depending on which and how many other pumps stations are operating. It is also illustrates how this pressure change affects the flow rate from pump station A11B with a large decrease in flow from pump 2 at 8:03 AM when the sewer main pressure increased to 100 kPa due to another pump starting somewhere else in the sewerage network.

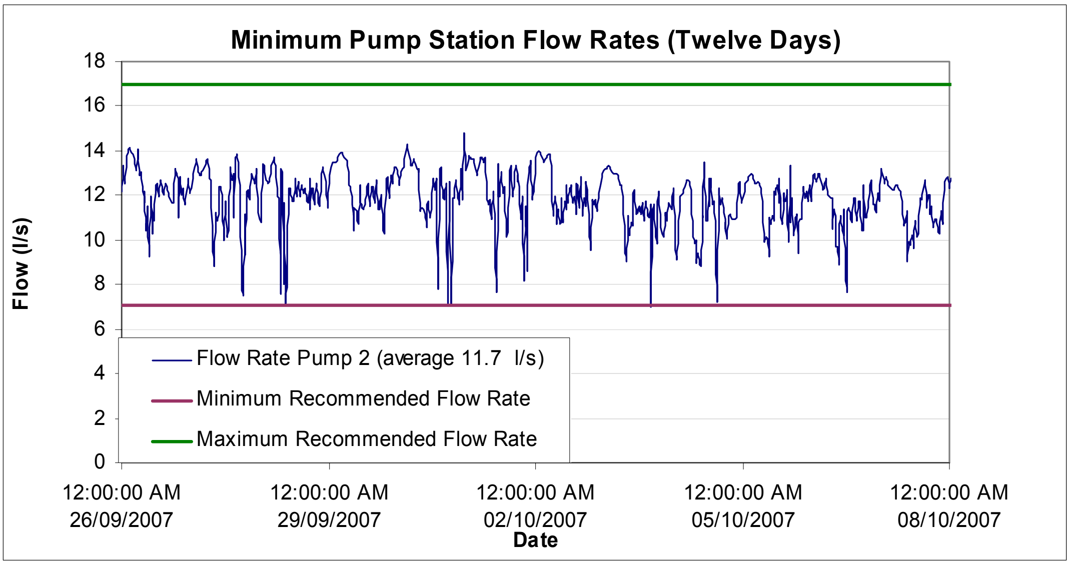


Figure 5.5 Pump station outflow over twelve days

Figure 5.5 shows the flow rates achieved by Pump 2 over a twelve day period. The flow shown is the last flow recorded before the pump was stopped. Also shown is the flow range recommended by Sanks, Astall & Rogers (refer section 2.2) It can be seen for most of the time the Pump 2 is operating within this range except for the odd occasion when it operated at the minimum recommended flow rate. The average flow rate achieved over this period was 11.7 l/s which exceeded the minimum required by Citiwater of 8.6 l/s (section 2.3).

5.3 Simulated Wet Weather Operation

In the time between the installation of the pumps in the pump station and the writing of this dissertation there has been no significant rain event in Townsville. Consequently the testing of the prototype pumps under these "real life" wet weather conditions has not been possible. Due to major road works in a nearby sewerage network an opportunity became available to simulate the higher inflow rates that occur under wet wether flow conditions. A section of the nearby network had to be relocated, while this work was done and all flow had to be diverted into the sewerage network of pump station A11B. It was estimated that with the diversion operating the pressure the sewer main at pump station A11B during the daily peak period would be of a similar magnitude to wet weather flow conditions (Davies D 2007, pers. comm., October 9).

At the time sewage flows were diverted pump station A11B was shut down and allowed to fill to the start standby pump level of 2 metres. While doing this it was observed that the well filled at constant rate until it reached a level of 1.6 metres when the level then rose at a slower rate. This was due to the fluid reaching the level of the pipes in the gravity sewerage system meaning a greater volume had to be filled.

Both pumps were then started manually to record the flow rates and pressure for these conditions. The pump controller was then switched on to observe automatic operation of the pumps. A plot of flow rate, sewer main pressure and well level is shown in figure 5.6. The well level has been multiplied by a factor of 10 for clarity.

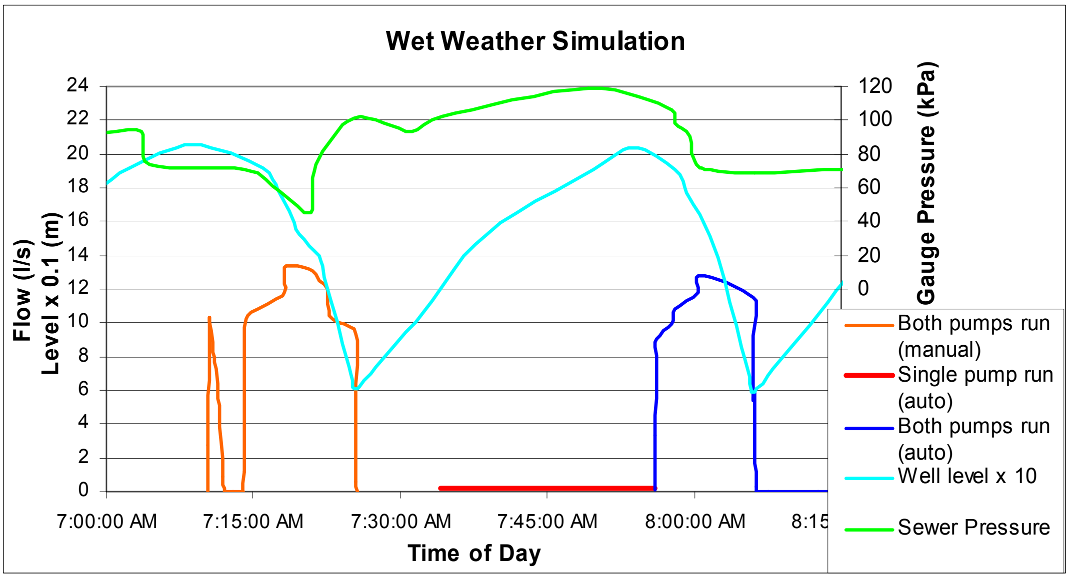


Figure 5.6 Pump station outflow and pressure during simulated wet weather flow conditions

The flow rates achieved when both pumps were operating in series was between 9 and 13.5 litres per second which is between 63 and 95 percent of BEP. This is similar to the flow rate predicted for wet weather flow conditions of 10 litres per second see figure 2.10 in section 2.3.4. The well was pumped down to the stop level within10 minutes. During wet weather this is expected to be much longer as there would be a higher flow rate coming in to pump station A11B.

When the pump station was operated in automatic mode the duty pump started and ran for 22 minutes with no flow before the second pump started enabling series pumping. To run for this length of time with no flow on a regular basis would result in wasted energy costs and higher rates of wear (refer section 2.2). To prevent this happening again it is recommended the start level of the standby pump be a maximum of 0.1 m above the start level of the duty pump. It is expected this problem would be less of an issue during wet weather as the well level will increase at a higher rate due to higher inflows.

5.4 Resistance to Blockage

As mentioned in section 4.3 there is a significant flow through the non running standby pump when the pump station is operating under dry weather conditions. To lower the risk of blockage the pump controller runs each pump with an alternating duty. Some of the operating data of the prototype pumps from installation (22/07/2007) to date (22/10/2007) are listed in table 5.2.

	Each Pump	Total
Cumulative Run Time (hours)	144 and 146	190
Number of starts	3822 and 3821	7643
Litres of sewerage pumped	6.1 million	12.2 million
Number of blockages	0	0

Table 5.2 Operating statistics for prototype pumps

From the pump station log during the same time period last year there were two recorded blockages. This information shows that there has not been an increase in the blockage rate up to this point. To further gauge this pump configuration's resistance to blockage it should be reassessed at the end of the wet season after it has had more operating hours under all flow conditions.

5.5 Summary of Operational Testing

Testing of the series pump configuration in operation yielded favourable results. The measured flow rate produced by the pump station exceeded the design requirement, and the pumps operated within the desired range around the best efficiency point (BEP). Testing of the wet weather performance was limited as there was no rainfall during the test period. However, simulated wet weather conditions obtained by diverting sewage flows from an adjacent catchment showed that the pumps successfully operated in series and were able to produce the flow rate necessary for wet weather conditions. One minor control issue arose that caused a pump to start and run under zero flow conditions. However, that can be addressed by adjusting the start levels of the standby pump. The pumps operated for a total run time of 190 h in service, and no blockage problems were encountered.

Chapter 6: Conclusions

6.1 Pump Station Configurations

It is common practice at Citiwater to provide pump stations discharging into common rising mains. The pump stations have a single small fixed speed pump to accommodate dry weather flows, and a single large fixed speed pump to provide the additional head and flow needed for wet weather conditions. Whilst this configuration is quite cost effective, it results in the larger pump having to run at duty points well above and well below the best efficiency point (BEP), causing increased energy consumption and increased pump wear.

This project considered several alternative pump configurations that would meet design guidelines and allow the pumps to operate within the recommended range above and below the BEP. Pump configurations considered include parallel pumps, variable speed pumps, and series pumps. The series pump configuration was demonstrated to have potential as an alternative arrangement compared with current practice, and was examined in detail by theoretical analysis, design and construction of a prototype. The prototype series pump arrangement was tested for performance in a test tank and later installed in a working sewerage pump station.

6.2 Series Pump Configuration Suitability

Based on a particular design scenario where system resistance curves were known for dry and wet weather, it was demonstrated that the same model pumps could operate within their recommended operating range both as a single pump for dry weather flow conditions and also when two pumps were connected in series for wet weather flow conditions. Modifications could be made to two standard submersible pumps that enabled them to operate as a single pump or to automatically switch to work together in series when required. These modifications were feasible and cost effective when compared to other sewerage pump station configurations.

A series pump system was designed and constructed. Particular components designed as part of this project included a modified auto coupling unit, pipework connecting the output of one pump to the inlet of the other pump, and a non return valve on the inlet of one of the pumps. The series pump system was installed in a test tank and instrumented with pressure tappings and magnetic flow meters. Tank tests were carried out over the full range of pump operation. Measured pump curves for the individual pumps showed very close agreement with the pump manufacturer's performance curves. The test tank measurements showed that there is some performance loss in connecting the pumps in a series arrangement due to the connecting pipework and inlet non return valve. The test results demonstrated quite good agreement between the measured and predicted performance losses, although the measurement performance loss was less than predicted by the mathematical model. For operation as a single unit, performance losses due the modifications were negligible when compared to manufacturer's published performance curves. When the pumps operated together in series, testing showed larger performance losses due to friction at higher flow rates. At the flow rate required for wet weather operating conditions the performance loss was acceptable.

The series pump arrangement has been installed in one of Citiwater's operating sewerage pump station since July 2007. For dry weather conditions and single pump operation each pumps operated within its recommended operating range both during the peak daily flow periods and for the minimum flow periods overnight. During a simulated wet weather event the pumps operating in series also produced flow rates that were within the recommended range. Due to a large difference between the "start duty pump" and "start standby pump" levels it was found the duty pump ran for an unacceptable length of time with a flow rate of zero when under automatic control.

In the time that the pumps have been installed in the sewerage pump station no blockages have been recorded. The series pump configuration has not shown any increased susceptibility to blockage.

Based on the results of the tank testing and operational testing in service, indications are that the proposed series pump configuration has successfully achieved the goals of providing a cost effective alternative pump station configuration using identical pump types. Further field testing is needed to confirm the long term behaviour of the pumps and their reliability in comparison to conventional installations.

The most appropriate type of pump station configuration (e.g., large and small pumps, variable speed pumps, series pumps or other arrangement) will need to be individually assessed during detailed design for each application, as it is dependent on the range of system curves that will be encountered at a particular site, and on the suitability of the available pumps.

6.3 Recommendations

It is recommended that the trial of the series pump configuration be continued and monitored over the coming wet season to assess the performance of the station under actual wet weather conditions.

For this type of series pump configuration the difference in height between the “start duty pump” level and the “start standby pump” level should be as small as practical i.e. less than 0.1 m. This is to prevent damage to the duty pump during wet weather flow conditions caused from running for an extended period with zero or very low flow rates.

6.4 Further Work

As the pumps have only been operating in a single sewerage pump station for three months conclusions relating to long term reliability of the pump configuration are not yet possible. Future work may be to install several pump stations with the series pump configuration and monitor the pumps performance and reliability over an extended time period and in different locations.

References

AS 2200-2006, *Australian Standard, Design charts for water supply and sewerage,* 2^{nd} edn., Standards Australia, Sydney.

AS/NZS 4129-2000, *Australian/New Zealand Standard, Fittings for polyethylene (PE) pipes for pressure applications*, Standards Australia, Sydney.

Astall, R & Rogers G 2002, *Pumping Fundamentals (course notes),* Strategic Achievement, Scarborough.

AVK, 2007, *Series 741/50 Flexi Check resilient seated non return valve,* brochure, Accessed at < http://www.avkvalves.com.au/>on Friday the 6^{th} of April 2007

Citiwater 2004, *Technical Services Design Guidelines,* JWP, Townsville.

Fox, RW, McDonald, AT, Pritchard PJ 2004, *Introduction to Fluid Mechanics*, 6^{th} edn, John Willey & Sons, Hoboken.

Flygt, 2005, *Flyps 3.1 Flygt product selection CD*

Goulburn Valley Water 2007, *Sewerage Pump Station Design Manual,* Goulburn Valley Water Authority, Shepparton.

Grundfos, 2007, *Webcaps – Online pump selection*,
Accessed at <http://www.grundfos.com/web/homeau.nsf>on Friday the 6^{th} of April 2007.

Sanks, RL (ed.) 1998, *Pumping Station Design,* 2^{nd}. edn. Butterworth-Heinemann, Boston.

Tyco Flow Control, 2007, *Rubber Expansion Joints – Type FSF, Sizes 32 – 600 mm,* brochure, Accessed at <http://www.tycovalves-pc.com/products.asp>on Friday the 6th of April 2007

Tyco Water, 2007, *Resilient Seated gate Valves – Figure 500, Dn80 - DN600* brochure, Accessed at <http://www.tycowater.com/pipeline_components2/Products/>on Friday the 6th of April 2007

WSA 02-2002, *Sewerage Code of Australia,* 2nd edn, Water Services Association of Australia and Standards Australia, Sydney.

WSA 04-2005, *Sewage Pumping Station Code of Australia,* 2nd edn, Water Services Association of Australia and Standards Australia, Sydney.

WSA 101-2005, *Industry Standard for Submersible Pumps for Sewerage Pumping Stations,* Water Services Association of Australia and Standards Australia, Sydney.

Appendices

Appendix A Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR: Bill Weston

TOPIC: Design and trial of an alternative option for suburban sewerage pump stations to overcome problems associated with pumps operating with different system curves

SUPERVISORS: Dr. Ruth Mossad, USQ
Dr Jonathan Harris, Maunsell Australia Pty Ltd

SONSORSHIP: Citiwater, a business unit of Townsville City Council

PROJECT AIM: Typical sewage collection systems have multiple pump stations feeding in to a common pressure main. This project will seek to provide an alternative pump configuration that will enable pumps to function within their preferred operating range for different system curves caused by varying demand.

PROGRAMME: Issue A, 26 March 2007

1. Evaluate the current pump station designs in relation to installation, operating and maintenance costs.
2. Conceptual design and modelling of the alternate pump station to estimate flows from pump station in both wet and dry weather systems.
3. Design and build experimental model of alternate pump configuration.
4. Test experimental model to evaluate pump system performance; calculate efficiency and losses due to friction in the added pipe work. Compare results with mathematical model.

As time permits

5. Test experimental model in sewage pump station to evaluate interaction with system, reliability and susceptibility to blockages.
6. Evaluate the alternate pump station design in relation to installation, operating and maintenance costs.

AGREED:

Bill Weston	28 / 3 / 07	Bill Weston (Student)
Ruth Mossad	5 / 4 / 07	Dr. Ruth Mossad (Supervisor)
J Harris	28 / 3 / 07	Dr Jonathan Harris (Supervisor)
David Ross	10 4 07	DAVID ROSS

Appendix B Risk Assessment

	Likelihood	Consequence	Risk Priority
Risk; New design may fail resulting in sewage overflows to environment	Possible	Important	High (unacceptable)
Controls; 1. build prototype and asses in test tank 2. use pump station that if failure occurs overflow will be back into the sewer network of the adjacent pump station	New risk scores		
	Unlikely	Minor	Low (acceptable)

	Likelihood	Consequence	Risk Priority
Risk; Inhalation of poisonous gasses from entry into the confined space of sewage wet well to install prototype pumps	Certain	Catastrophic	High (unacceptable)
Controls; 1. Installation to be done by competent people (Citiwater fitters) 2. Use of Citiwater's confined space procedures	New risk scores		
	Possible	Minor	Low (acceptable)

	Likelihood	Consequence	Risk Priority
Risk; Entry into the confined space of sewage wet well to service prototype pumps	Possible	Catastrophic	High (unacceptable)
Controls; 1. All service parts of prototype must be able to removed from well for service.	New risk scores		
	Unlikely	Minor	Low (acceptable)

Appendix C Loads on Auto Couple

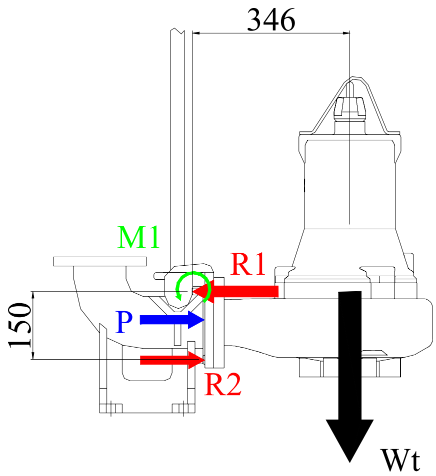


Figure D.1Free body diagram of unmodified pump

Grundfos SV-034-DHU   From manufacturer specifications (Appendix E)

Max head   14 m $\therefore P_{\max} = \rho g h$

$= 997 \times 9.81 \times 14$

$= 137$ kPa gauge

Internal pipe area   D =80 mm $\therefore A = \dfrac{D^2 \pi}{4}$

$= 5027 \text{ mm}^2$

$F_P = P_{\max} \times A$

$= 689$ N

Pump Mass   120 kg $\therefore Wt = mg$

$= 120 \times 9.81$

$= 1.177$ kN

$$\sum M_1 = 0.150 \times R_2 + 0.075 \times F_P - 0.346 \times Wt = 0$$

$$R_2 = \frac{0.346 \times 1177 - 0.075 \times 689}{0.15}$$

$= 2.37$ kN

$$\sum F_x = R_1 + R_2 + F_P = 0$$

$R_1 = -3.06$ kN

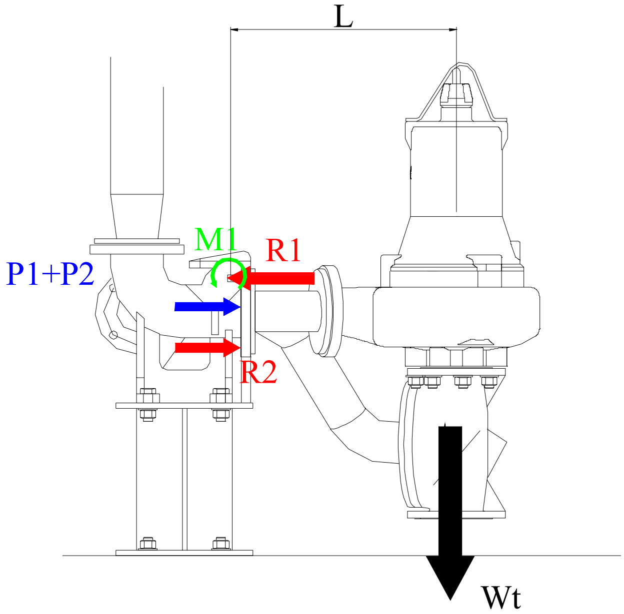


Figure D.2 Free body diagram of modified pump

$P_2 = 2P_1$ $\quad$ P_1 = 137 kPa gauge $\quad$ P_2 = 274 kPa gauge

For both auto couples D =80 mm $\quad \therefore A = 5027 \text{ mm}^2$

$$F_P = A(P_1 + P_2)$$
$$= 2.07 \text{ kN}$$

Estimated mass of modified pump 152 kg $\quad \therefore Wt = 1.49 \text{ kN}$

To ensure load on auto couple lugs at R_1 is less than unmodified version

$$R_1 \leq 6.12 \text{ kN}$$

which is double the value of than unmodified pump as there are two auto couples.

To find L_{MAX} $\quad \sum F_x = R_1 + R_2 + F_P = 0$

$$\therefore R_2 \leq 4.05 \text{ kN}$$

$$\sum M_1 = 0.150 \times R_2 + 0.075 \times F_P - L_{MAX} \times Wt = 0$$

$$L_{MAX} = \frac{0.15 \times 4050 + 0.075 \times 2070}{1490}$$

$$= \underline{512 \text{ mm}}$$

Reaction force R_2 must be greater than 2.37 kN which was the calculated value from the unmodified pump.

$$\therefore L_{MIN} = \frac{0.15 \times 2370 + 0.075 \times 2070}{1490}$$
$$= 342 \text{ mm}$$

This value is less then the distance on the standard pump outlet

Therefore to prevent overloading of modified auto couple L must be less then 512 mm. The extra pressure developed by pumping in series will not cause the auto couples to leak.

$$\therefore 345 \geq L \geq 512 \text{ mm}$$

Appendix D Prototype Drawings

All design drawings were reproduced with permission from Citiwater a business unit of Townsville City Council. All drawing completed by the Citiwater drafts person Kevin McGrath under the direction of the author.

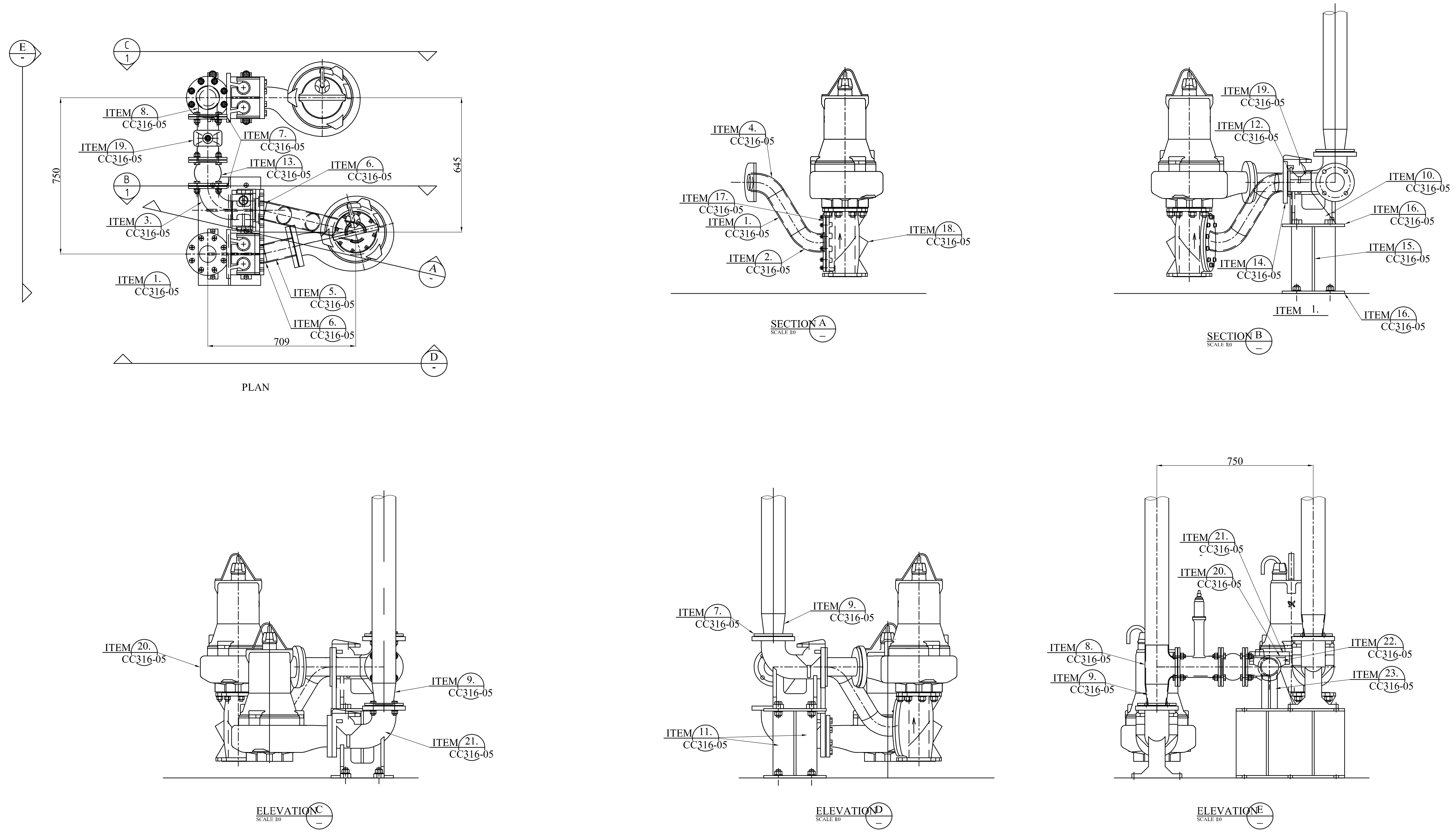
Appendix D1; Drawing No. CC316-01; Sewage – Garbutt Pump Station A11B Series Pump Trial, General Arrangement

Appendix D2; Drawing No. CC316-02; Sewage – Garbutt Pump Station A11B Series Pump Trial, Support Frame

Appendix D3; Drawing No. CC316-03; Sewage – Garbutt Pump Station A11B Series Pump Trial, Manifold Details

Appendix D4; Drawing No. CC316-04; Sewage – Garbutt Pump Station A11B Series Pump Trial, Discharge Manifold Details

Appendix D5; Drawing No. CC316-05; Sewage – Garbutt Pump Station A11B Series Pump Trial, Items



ZONE	REF.	REVISIONS	BY	CKD.	DATE

FOR INFORMATION ONLY.

LOGO'S CT_Main_BW.jpg

ASSOCIATED DRAWINGS	
CC316-02	
CC316-05	
LEVEL DATUM	CAD INDEX NO.
A.H.D.	CC316
ERGON	TELSTRA

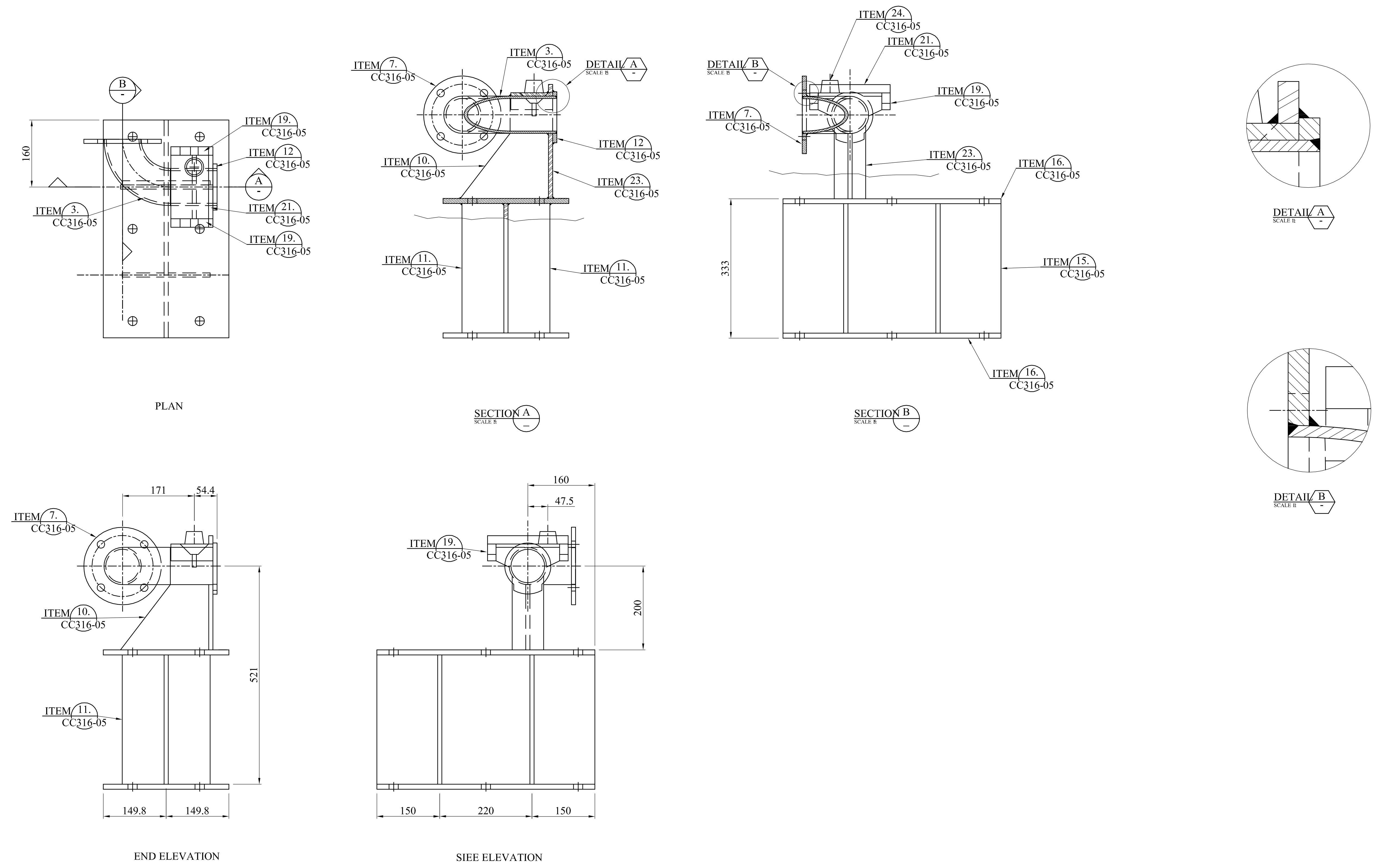
CITIWATER TOWNSVILLE

APPROVED	DES.	
RPEQ 4693	DRN.	KDM
MANAGER	SD.	
RPEQ 6010 TECHNICAL SERVICES ENGINEER	S/ENG.	

SEWAGE - GARBUTT PUMP STATION A11B SERIES PUMP TRIAL GENERAL ARRANGEMENT

1 of 5

DATE	M/FILM	SCALE	DRAWING NO.	
04/03/07		1 : 10	CC316-01	A1



ZONE	REF.	REVISIONS	BY	CKD.	DATE

FOR INFORMATION ONLY.

ASSOCIATED DRAWINGS	
CC316-01	
CC316-05	
LEVEL DATUM	CAD INDEX NO.
A.H.D.	CC316
ERGON	TELSTRA

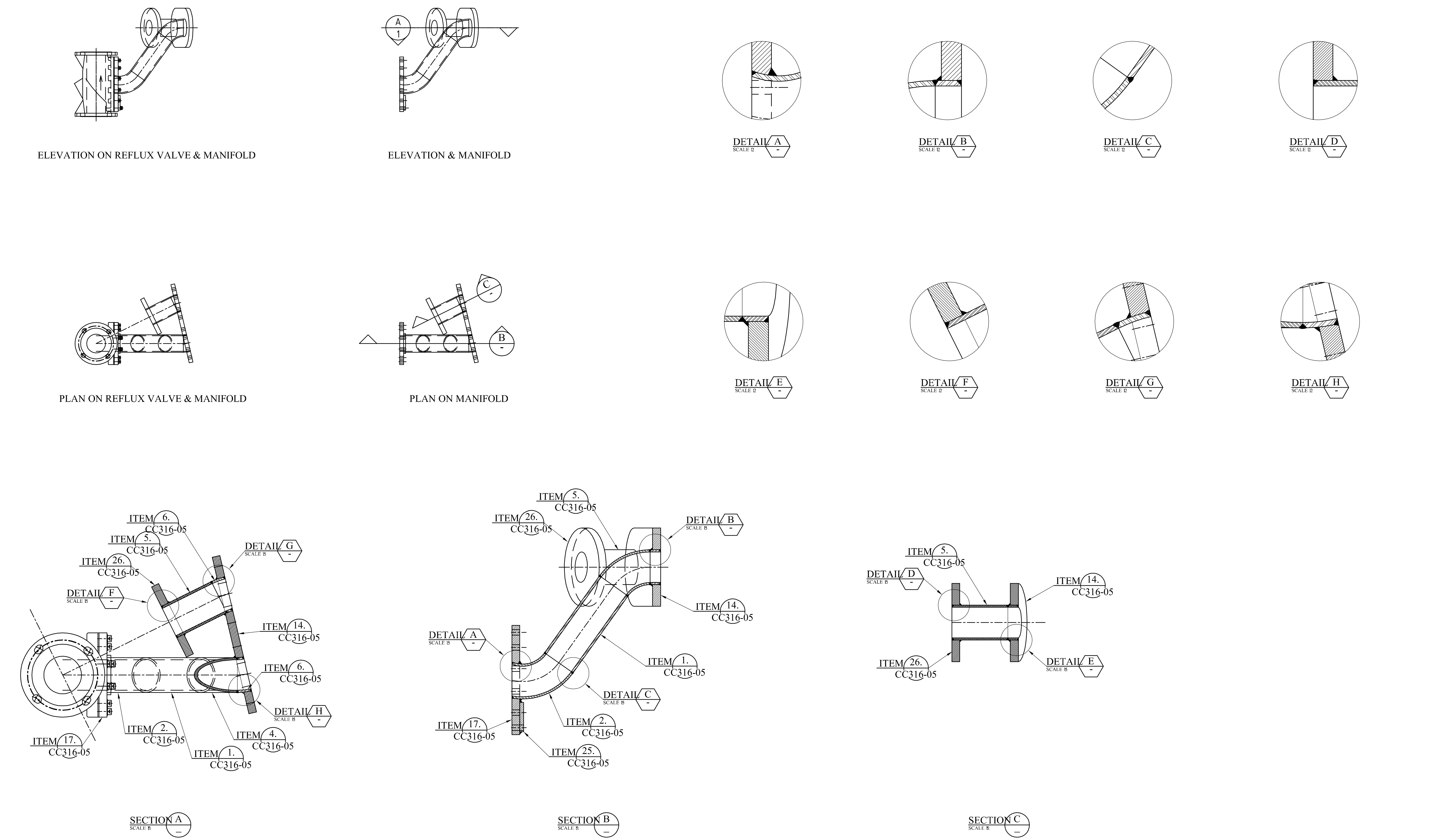
CITIWATER TOWNSVILLE

APPROVED	DES.	
RPEQ 4693	DRN.	KDM
MANAGER	SD.	
RPEQ 6010	S/ENG.	
TECHNICAL SERVICES ENGINEER		

SEWAGE - GARBUTT
PUMP STATION A11B
SERIES PUMP TRIAL
SUPPORT FRAME

2 of 5

DATE	M/FILM	SCALE	DRAWING NO.	
04/03/07		1 : 10 & 1 : 2	CC316-02	A1



ZONE	REF.	REVISIONS	BY	CKD.	DATE

FOR INFORMATION ONLY.

ASSOCIATED DRAWINGS	
CC316-01	
CC316-05	
LEVEL DATUM	CAD INDEX NO.
A.H.D.	
ERGON	TELSTRA

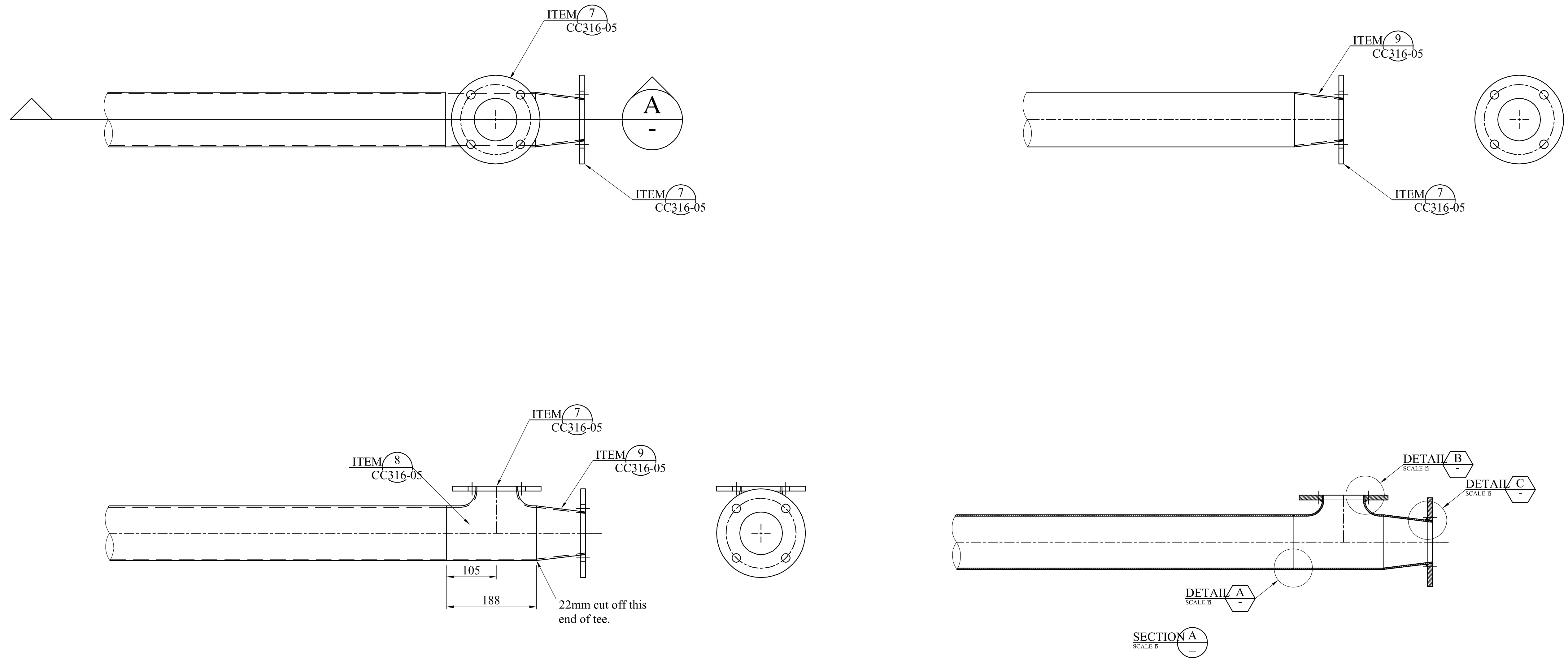
CITIWATER TOWNSVILLE

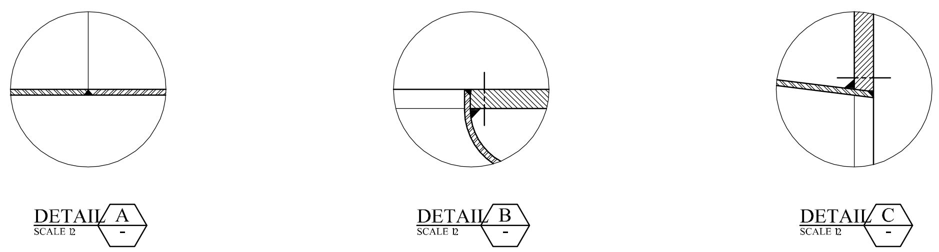
APPROVED	DES.
RPEQ 4693	DRN. KDM
MANAGER	SD. C316
RPEQ 6010	S/ENG.
TECHNICAL SERVICES ENGINEER	

SEWAGE - GARBUTT
PUMP STATION A11B
SERIES PUMP TRIAL
MANIFOLD DETAILS

3 of 5

DATE	M/FILM	SCALE	DRAWING NO.	
02/04/07		as shown	CC316-03	A1





GENERAL NOTES:

1. ALL PIPE WORK AND FITTINGS TO BE "SCHEDULE 40" STAINLESS STEEL GRADE 316, U.N.O.
2. ALL FLANGES TO BE "TABLE D" U.N.O., TO AS2129.
3. ELECTRODES TO BE IN ACCORDANCE WITH AS/NZS1553.3 OR AS2717.3, UNO.
4. ALL WELDS SHALL BE 6mm CONTINUOUS FILLET IN ACCORDANCE WITH AS1554.6 - CATEGORY 2A, UNO.
5. ALL BUTT WELDS TO BE COMPLETE PENETRATION IN ACCORDANCE WITH AS1554.6 - CATEGORY 2A, UNO.
6. REMOVE ALL SHARP EDGES AND CORNERS.
7. ALL BURRS, SLAG AND WELD SPLATTER TO BE REMOVED ON COMPLETION OF FABRICATION.
8. SURFACE FINISH OF WELDS TO BE GRADE II, IN ACCORDANCE WITH AS1554.6
9. ALL BOLTS TO BE M16 STAINLESS STEEL GRADE 316/L, U.N.O.
10. ALL PASSIVATION & PICKLING TO BE CARRIED IN ACCORDANCE WITH ASTM A380, UNO.
11. PICKLING SHOULD PREFERABLY BE CARRIED OUT ON FULLY ANNEALED STAINLESS STEEL DUE TO RISK OF GRAIN BOUNDARY ATTACK. THIS PROBLEM IS ESPECIALLY RELEVANT TO STEELS SENSITISED IN WELDING.

ZONE	REF.	REVISIONS	BY	CKD.	DATE

FOR INFORMATION ONLY.

LOGO\CT_Main_BW.jpg

ASSOCIATED DRAWINGS	
CC316-01	
CC316-05	
LEVEL DATUM	CAD INDEX NO.
A.H.D.	CC316
ERGON	TELSTRA

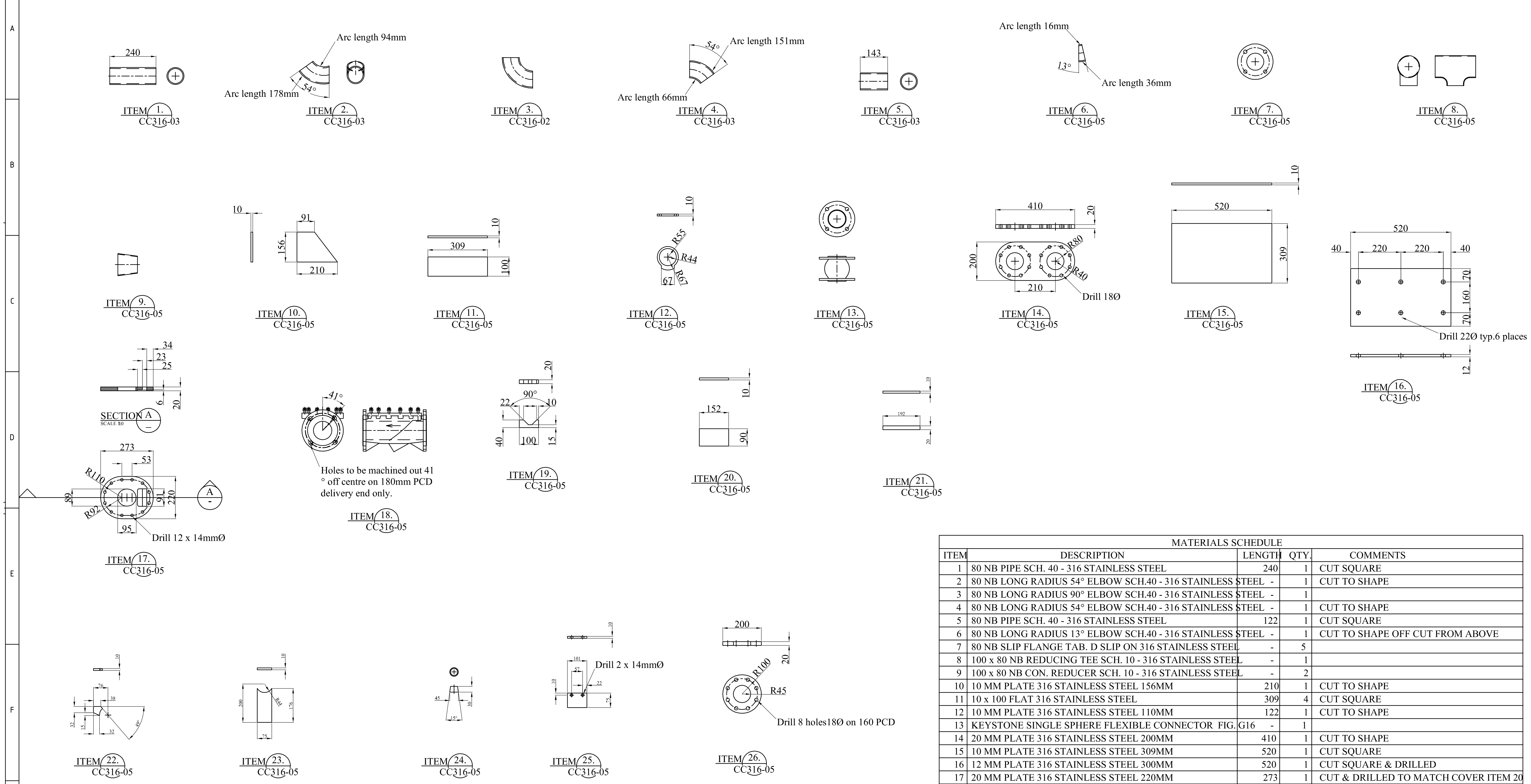
CITIWATER TOWNSVILLE

APPROVED	DES.	
RPEQ 4693	DRN.	KDM
MANAGER	SD.	
RPEQ 6010 TECHNICAL SERVICES ENGINEER	S/ENG.	

SEWAGE - GARBUTT
PUMP STATION A11B
SERIES PUMP TRIAL
DISCHARGE MANIFOLD DETAILS

4 of 5

DATE	M/FILM	SCALE	DRAWING NO.	
02/04/07		as shown	CC316-04	A1



MATERIALS SCHEDULE

ITEM	DESCRIPTION	LENGTH	QTY.	COMMENTS
1	80 NB PIPE SCH. 40 - 316 STAINLESS STEEL	240	1	CUT SQUARE
2	80 NB LONG RADIUS 54° ELBOW SCH.40 - 316 STAINLESS STEEL	-	1	CUT TO SHAPE
3	80 NB LONG RADIUS 90° ELBOW SCH.40 - 316 STAINLESS STEEL	-	1	
4	80 NB LONG RADIUS 54° ELBOW SCH.40 - 316 STAINLESS STEEL	-	1	CUT TO SHAPE
5	80 NB PIPE SCH. 40 - 316 STAINLESS STEEL	122	1	CUT SQUARE
6	80 NB LONG RADIUS 13° ELBOW SCH.40 - 316 STAINLESS STEEL	-	1	CUT TO SHAPE OFF CUT FROM ABOVE
7	80 NB SLIP FLANGE TAB. D SLIP ON 316 STAINLESS STEEL	-	5	
8	100 x 80 NB REDUCING TEE SCH. 10 - 316 STAINLESS STEEL	-	1	
9	100 x 80 NB CON. REDUCER SCH. 10 - 316 STAINLESS STEEL	-	2	
10	10 MM PLATE 316 STAINLESS STEEL 156MM	210	1	CUT TO SHAPE
11	10 x 100 FLAT 316 STAINLESS STEEL	309	4	CUT SQUARE
12	10 MM PLATE 316 STAINLESS STEEL 110MM	122	1	CUT TO SHAPE
13	KEYSTONE SINGLE SPHERE FLEXIBLE CONNECTOR FIG. G16	-	1	
14	20 MM PLATE 316 STAINLESS STEEL 200MM	410	1	CUT TO SHAPE
15	10 MM PLATE 316 STAINLESS STEEL 309MM	520	1	CUT SQUARE
16	12 MM PLATE 316 STAINLESS STEEL 300MM	520	1	CUT SQUARE & DRILLED
17	20 MM PLATE 316 STAINLESS STEEL 220MM	273	1	CUT & DRILLED TO MATCH COVER ITEM 20
18	100 NB REFLUX VALVE (NORCAST)	-	1	
19	20 x 40 FLAT 316 STAINLESS STEEL	100	2	CUT TO SHAPE
20	10 x 90 FLAT 316 STAINLESS STEEL	152	1	CUT SQUARE
21	10 x 20 FLAT 316 STAINLESS STEEL	192	1	CUT SQUARE
22	10MM PLATE 316 STAINLESS STEEL 50MM	47	2	CUT TO SHAPE
23	10 x 75 FLAT 316 STAINLESS STEEL	176	1	CUT TO SHAPE
24	45MM ROUND 316 STAINLESS STEEL	30	1	MACHINED
25	10 x 75 FLAT 316 STAINLESS STEEL	101	1	CUT SQUARE & DRILLED
26	20 MM PLATE 316 STAINLESS STEEL 200MM	200	1	
TOTAL				

ZONE	REF.	REVISIONS	BY	CKD.	DATE

FOR INFORMATION ONLY.

ASSOCIATED DRAWINGS
CC316-01
CC316-04

LEVEL DATUM	CAD INDEX NO.
A.H.D.	CC316
ERGON	TELSTRA

CITIWATER TOWNSVILLE

APPROVED	DES.	
RPEQ 4693	DRN.	KDM
MANAGER	SD.	
RPEQ 6010 TECHNICAL SERVICES ENGINEER	S/ENG.	

SEWAGE - GARBUTT PUMP STATION A11B SERIES PUMP TRIAL ITEMS

5 of 5

DATE	M/FILM	SCALE	DRAWING NO.	
04/03/07		1 : 10	CC316-05	A1

Appendix E, Manufacturer's Specifications

Appendix E 1; Grundfos SV034DHU50 pump specifications

Reproduced with permission from Grundfos Australia, sourced from
Grundfos, 2007, *Webcaps – Online pump selection*,
Accessed at <http://www.grundfos.com/web/homeau.nsf>on Friday the 6th of April 2007.

Appendix E 2; AVK FLEXI CHECK VALVE PN 16, brochure

Reproduced with permission from AVK Australia, sourced from
AVK, 2007, *Series 741/50 Flexi Check resilient seated non return valve,* brochure, Accessed at < http://www.avkvalves.com.au/>on Friday the 6th of April 2007

Appendix E 3; Rubber Expansion Joints – Type FSF, brochure

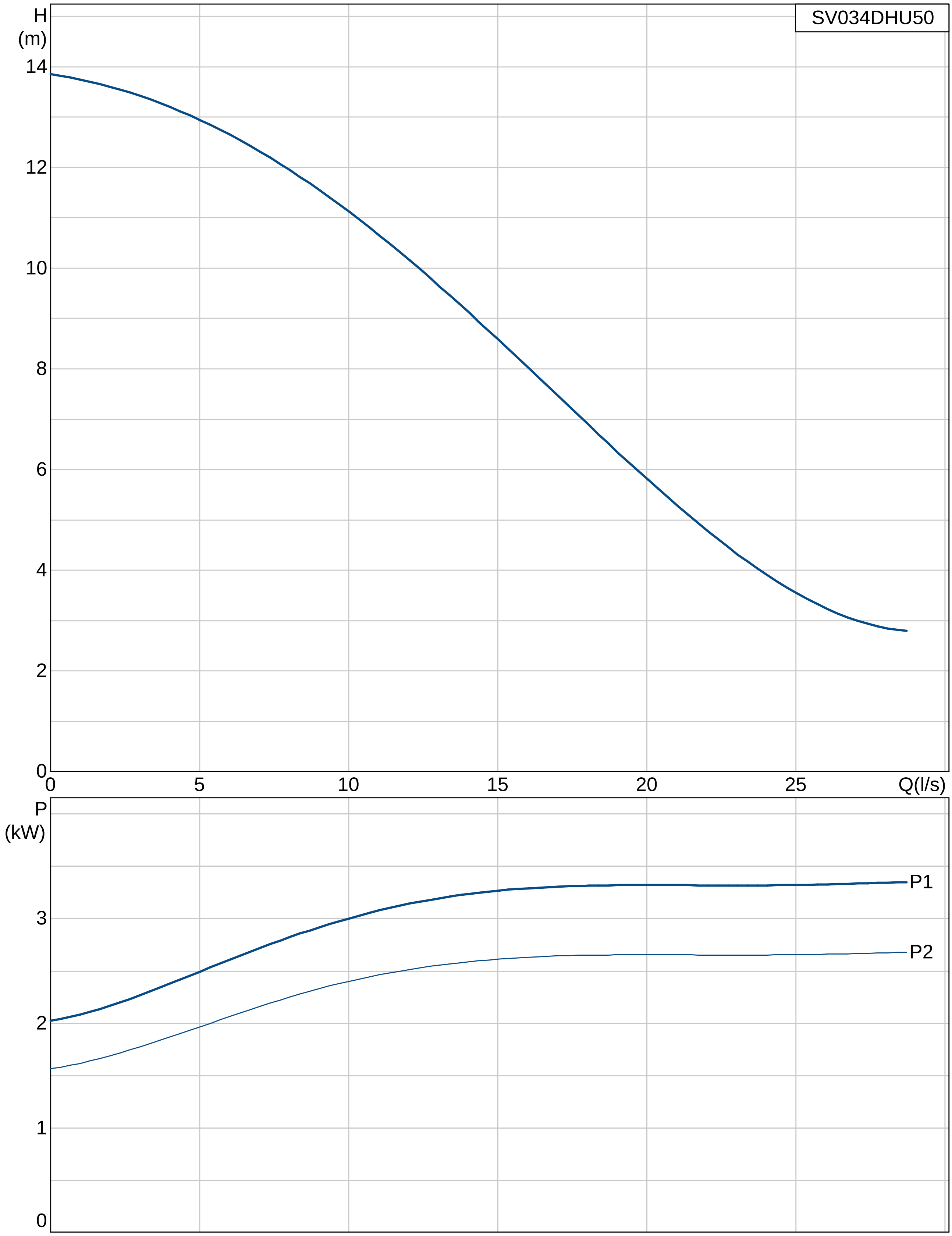
Reproduced with permission from Tyco Pacific, sourced from
Tyco Flow Control, 2007, *Rubber Expansion Joints – Type FSF, Sizes 32 – 600 mm,* brochure, Accessed at <http://www.tycovalves-pc.com/products.asp>on Friday the 6th of April 2007

Appendix E 4; Resilient Seated gate Valves – Figure 500, brochure

Reproduced with permission from Tyco Water, sourced from
Tyco Water, 2007, *Resilient Seated gate Valves – Figure 500, Dn80 - DN600* brochure, Accessed at
<http://www.tycowater.com/pipeline_components2/Products/>on Friday the 6th of April 2007

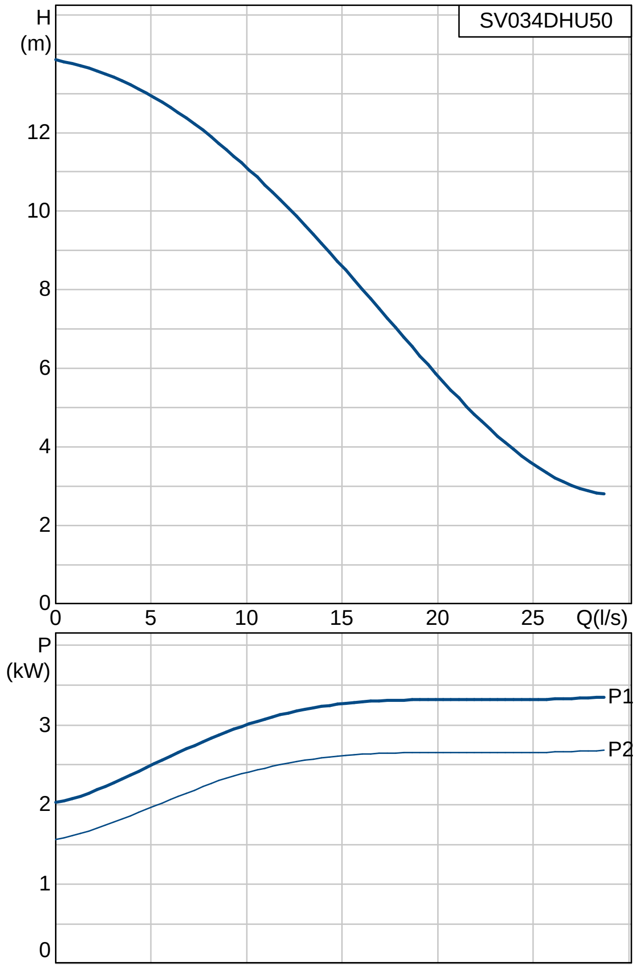
Company name: -
Created by: -
Phone: -
Fax: -
Date: -

96253903 SV034DHU50



Company name: -
Created by: -
Phone: -
Fax: -
Date: -

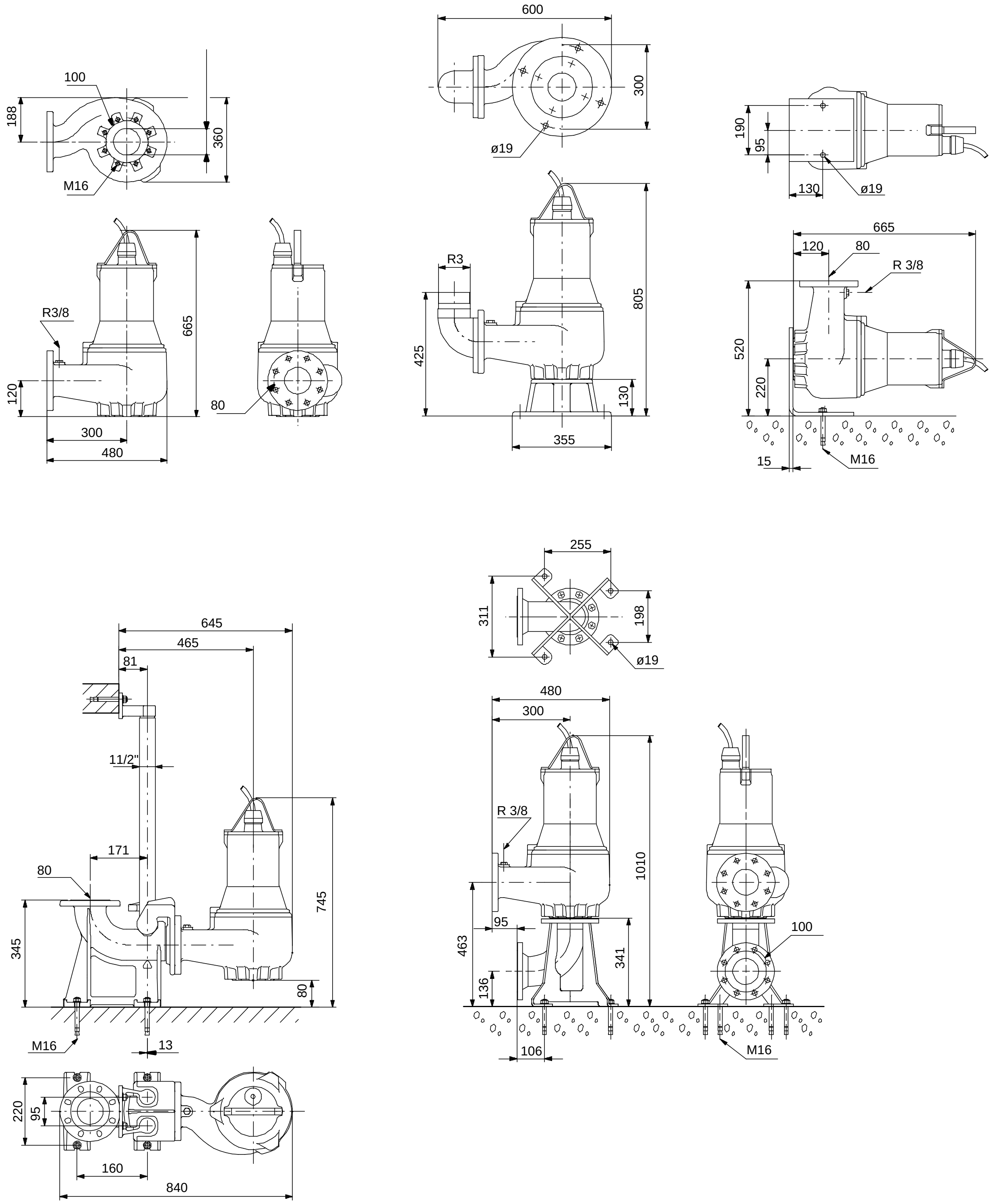
Description	Value
Product name:	SV034DHU50
Product No:	96253903
EAN number:	5700830408711
Technical:	
Max flow:	101 m³/h
Head max:	14 m
Type of impeller:	SUPERVORTEX
Maximum particle size:	80 mm
Primary shaft seal:	SIC-SIC
Secondary shaft seal:	SIC-CARBON
Curve tolerance:	ISO 9906 Annex A
Cooling jacket:	without cooling jacket
Materials:	
Pump housing:	Cast iron
	EN-JL1040 DIN W.-Nr.
	A48 30 AISI
Impeller:	Ductile cast iron
	EN-JS1050 DIN W.-Nr.
	80-55-06 AISI
Motor:	Cast iron
	EN-JL1040 DIN W.-Nr.
	A48 30 AISI
Installation:	
Range of ambient temperature:	-20 .. 40 °C
Flange standard:	DIN
Pump inlet:	DN 100
Pump outlet:	DN 80
Pressure stage:	PN 10
Maximum installation depth:	20 m
Installation:	S
Inst dry/wet:	S
Installation:	horizontal
Auto-coupling:	Y
Frame range:	42
Liquid:	
Maximum liquid temperature:	40 °C
Electrical data:	
Number of poles:	4
Power input - P1:	3.6 kW
Rated power - P2:	2.9 kW
Mains frequency:	50 Hz
Rated voltage:	3 x 400-415 V
Voltage tolerance:	+5/-10 %
Start. method:	direct-on-line
Max starts per. hour:	25
I MAX:	- / 7 A
Starting current:	49 A
Rated current at no load:	4.2 A
Cos phi - power factor:	0,73
Cos phi - p.f. at 3/4 load:	0,64
Cos phi - p.f. at 1/2 load:	0,53
Rated speed:	1461 rpm
Motor efficiency at full load:	0,8 %
Motor efficiency at 3/4 load:	0,78 %
Motor efficiency at 1/2 load:	0,75 %
Enclosure class (IEC 34-5):	IP68
Insulation class (IEC 85):	F
Explosion proof:	no
Motor protec:	KLIXON
Length of cable:	15 m
Cable type:	H07RN-F AT



Description	Value
Cable size:	1X7X1,5MM2
Controls:	
Moisture sensor:	with moisture sensors
Water-in-oil sensor:	without water-in-oil sensor
Others:	
Net weight:	120 kg

Company name: -
Created by: -
Phone: -
Fax: -
Date: -

96253903 SV034DHU50



Note! All units are in [mm] unless others are stated.

AVK FLEXI CHECK VALVE PN 16 741/50

Flexi Check resilient seated non return valve
AS 3578 dimensional compliance
Flanged, drilled to AS 4087 figure B5

Use:

For potable water and sewage to max. 60°C

Tests:

Hydrostatic test to AS 4794

Seat: 16 bar
Body: 24 bar

Optional extras:

Bonnet plug

Materials:

Body and bonnet	Ductile iron, Gr. 400/12 to AS 1831
Resilient seated disc	EPDM with ductile iron core
Gasket	EPDM rubber
Coating	Fusion bonded epoxy resin to AS 4158 - Internally and externally
Bolts and washers	Stainless steel 316

The designs, materials and specifications shown are subject to change without notice due to our continuing program of product development.

AVK Australia Pty Ltd
559A Grand Junction Road, Wingfield, SA 5013 Australia
Tel: +61 8 8368 0900
Fax: +61 8 8368 0970
e-mail: info@avkvalves.com.au
www.avkvalves.com.au

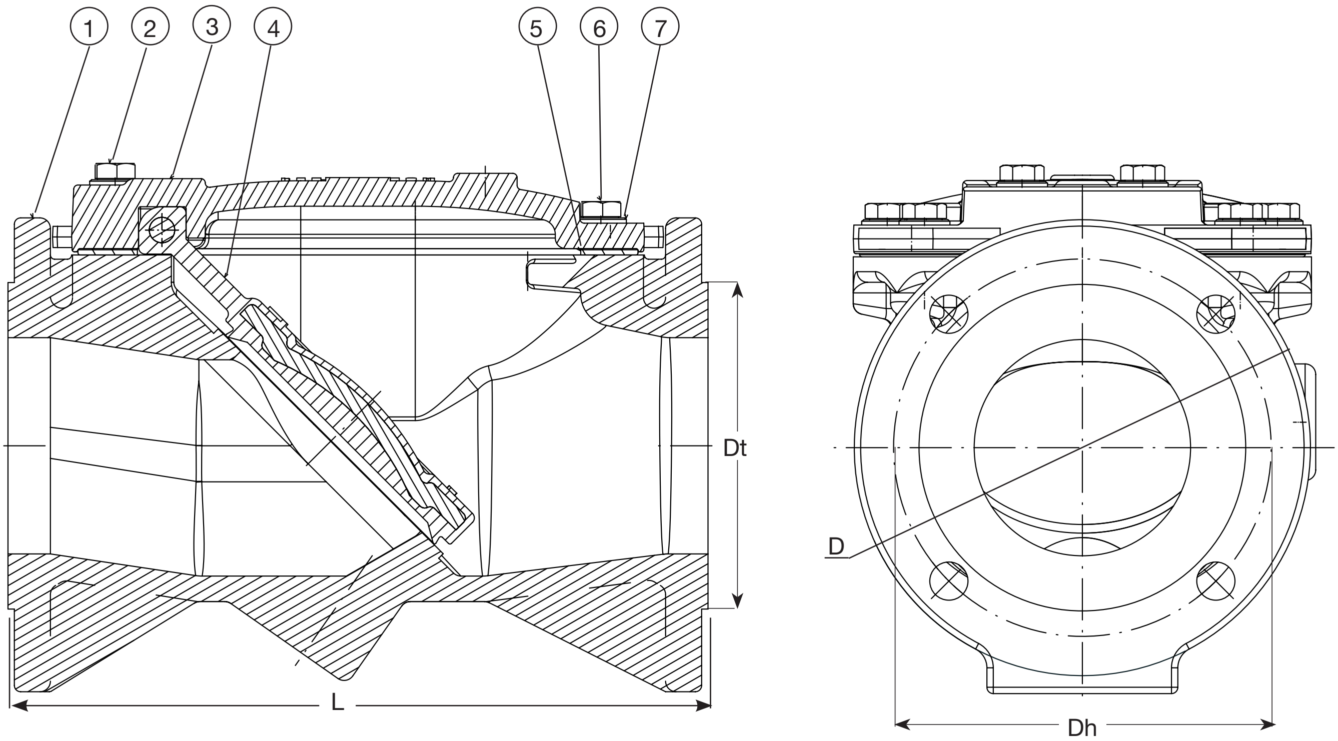
3N74150AQ
April 2005

AVK FLEXI CHECK VALVE PN 16 741/50

Flexi Check resilient seated non return valve
AS 3578 dimensional compliance
Flanged, drilled to AS 4087 figure B5

Component list

1. Body
2. Hexagon bolt
3. Bonnet
4. Disc
5. Bonnet gasket
6. Hexagon bolt
7. Washer



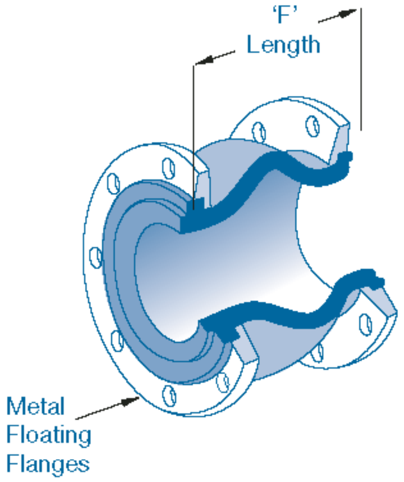
Ref. nos. Epoxy internally	DN	L mm	Dt mm	Dh mm	D mm	Holes	Weight kilos
741-0080-505012	80	260	122	146	185	4	22
741-0100-505012	100	330	154	178	215	4	32
741-0150-505012	150	410	209	235	280	8	65
741-0200-505012	200	540	264	292	335	8	124

AVK

tyco
Flow Control

Single Sphere expansion joint with Flanges. Constructed of a rubber inner liner & outer cover with embedded nylon cord reinforcement and wire reinforced collars.

Flexible Piping Systems



Available Materials

Material Code	Cover Elastomer	Tube Elastomer	Maximum Operating Temp (ºC)
EE	EPDM	EPDM	100
BB	Chloro Butyl	Chloro Butyl	100
HH	Neoprene	Neoprene	100
NP	Neoprene	Nitrile (Buna)	100

Temperature/Pressure Factors

Temperature (ºC)	Working Pressure Factor
50	x 1.00
70	x 0.75
100	x 0.50

Type FSF - Single Sphere Connectors with Flanges

Nominal Dia.		'F' installed length mm		Travel mm	Allowable Movements from Neutral				Pressure		Weight kg	
mm	inch	Neutral Length	Max Installed	Min Compr. Extended	Total Compr. mm	Axial Ext. mm	Axial Defl. mm	Lateral Angular Defl.	Positive MPa	Vacuum mm	Joint & Flanges	Control Unit Sets
32	1¼"	95	89-97	87-99	8	4	8	15º	1.55	660	2.10	1.40
40	1½"	95	89-97	87-99	8	4	8	15º	1.55	660	2.45	1.99
50	2"	105	99-107	99-110	8	5	8	15º	1.55	660	3.86	2.86
65	2½"	115	107-118	103-121	8	6	10	15º	1.55	660	5.60	3.36
80	3"	130	122-133	118-113	12	6	10	15º	1.55	660	6.40	3.68
100	4"	135	122-140	117-145	18	10	12	15º	1.55	660	7.80	3.27
125	5"	170	156-175	152-180	18	10	12	15º	1.55	660	10.70	3.86
150	6"	180	167-185	162-190	18	10	12	15º	1.55	660	13.20	4.82
200	8"	205	186-212	180-220	25	14	22	15º	1.55	660	18.80	6.36
250	10"	240	221-247	215-254	25	14	22	15º	1.55	660	26.60	10.00
300	12"	260	241-267	235-274	25	14	22	15º	1.55	660	37.70	12.73
350	14"	265	246-273	240-281	25	14	22	15º	1.03	660	54.50	13.41
400	16"	265	246-273	240-281	25	14	22	15º	0.86	660	76.40	12.63
450	18"	265	246-273	240-281	25	14	22	15º	0.86	660	77.30	15.04
500	20"	265	246-273	240-281	25	14	22	15º	0.86	660	79.50	15.50
550	22"	254	235-262	229-270	25	16	19	15º	0.79	660	95.50	15.68
600	24"	254	235-262	229-270	25	16	19	15º	0.76	660	116.00	20.90

Note:

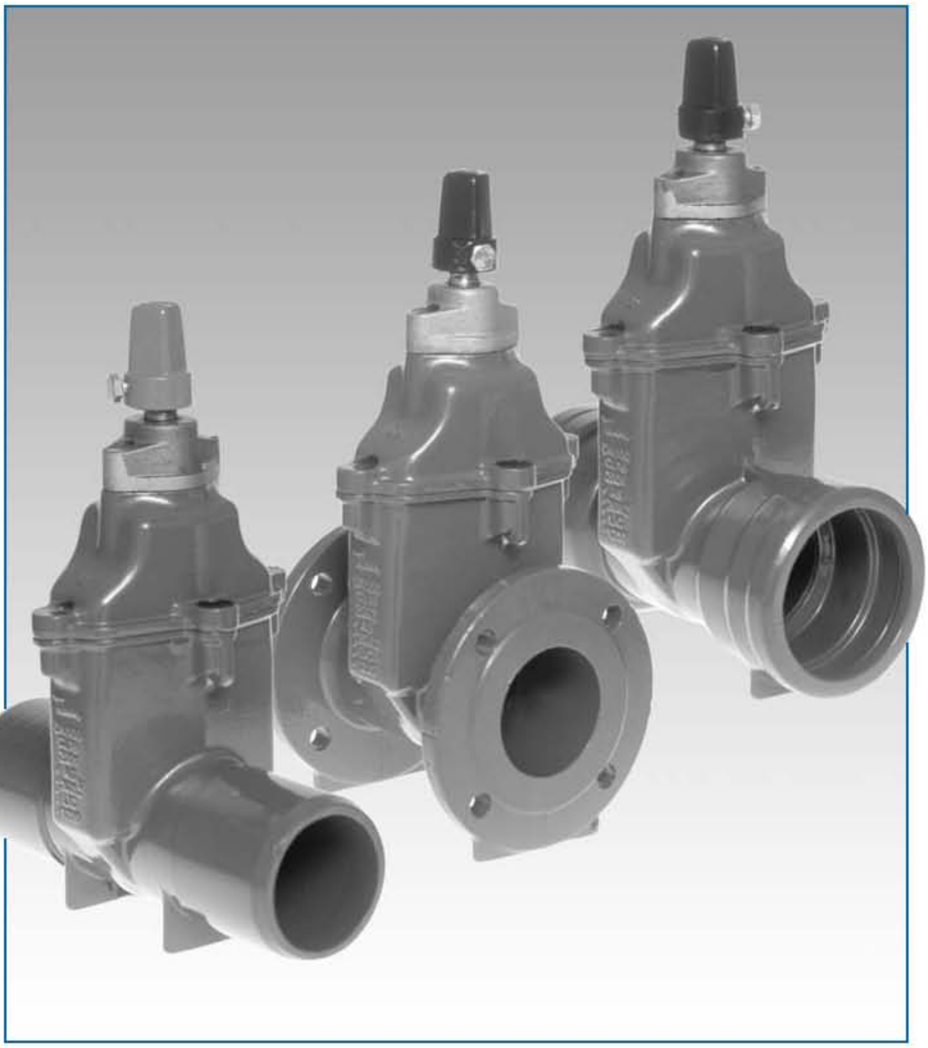
1. *Pressure shown are recommended "operating". Test pressure is 1.5 times "operating". Burst pressure is approximate 4 times "operating".*
2. *Vacuum rating is based on neutral installed length, without external load. Products should not be installed "extended" on vacuum applications.*
3. *All expansion joints are furnished complete with retaining flanges. Control units are available on special order.*

A.B.N. 83 000 922 690

Figure 500 resilient seated gate valves are designed and manufactured to AS 2638.2

Features

- Ductile Iron body and bonnet for high strength and impact resistance.
- Ductile Iron gate fully encapsulated in EPDM rubber to ensure drop tight sealing.
- Grade 431 Stainless Steel spindle for high strength and corrosion resistance.
- Gunmetal dezincification resistant top casting incorporating dual O-ring seals and wiper ring for long life operation.
- Back seal facility to allow for replacement of seals under full operating pressure.
- Thermally bonded polymeric coating for long life corrosion protection.
- Straight through full bore to avoid debris traps.
- Isolated fasteners for corrosion protection.
- Anti-friction thrust washer for low operating torques.
- Integral cast in feet for safe and easy storage.
- Integral lifting lugs for installation convenience.
- Anticlockwise closing or clockwise closing available.
- Key, hand wheel or gearbox operation available.



General Application

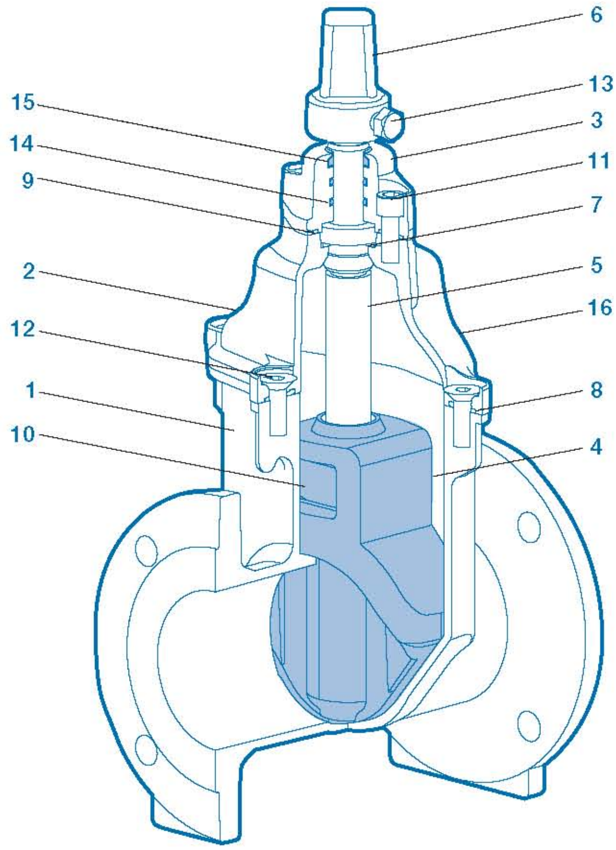
Figure 500 resilient seated gate valves are suitable for use with drinking water and waste water, in below or above ground applications. Used for the isolation of sections and branches in pipelines.

Technical Data

Size Range: DN80-DN600
Allowable Operating Pressure:
1600 or 2500 kPa.
Maximum Temperature: 40°C
End Connections:
Flanged to AS 4087 Fig B5 or B6
TYTON® Socket
Spigot to AS/NZS 2280
Flange – TYTON Socket
Certifications:
WSAA Appraisal No. 98/21
ISC AS 2638 Certified Product License No. PRD/R61/0412/2
Certified to AS 4020 - suitable for contact with drinking water.

A.B.N. 75 087 415 745

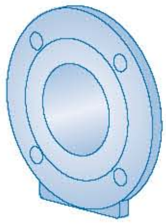
Resilient Seated Gate Valves - Figure 500
DN80 - DN600



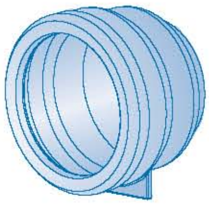
Parts List

No	Description	Material	Standard
1	Body	Ductile Iron	AS 1831 400-15
2	Bonnet	Ductile Iron	AS 1831 400-15
3	Seal Retainer	Gunmetal	AS 1565 C83600
4	Gate	Ductile Iron (EPDM Encapsulated)	AS 1831 400-15
5	Spindle	Stainless Steel	ASTM A 276 431
6	Spindle Cap	Ductile Iron	AS 1831 400-15
7	Thrust Washer	Acetal	-
8	Body Gasket	EPDM	AS 1646
9	Bonnet Gasket	EPDM	AS 1646
10	Gate Nut	Gunmetal	AS 1565 C83600
11	Socket Head Screws	High Tensile Alloy Steel	-
12	Countersunk Screws	High Tensile Alloy Steel	-
13	Hex Head Screw	Stainless Steel	ASTM A276 316
14	O-Rings	Nitrile Rubber	AS 1646
15	Wiper Ring	Nitrile Rubber	AS 1646
16	Polymeric Coating	-	AS/NZS 4158

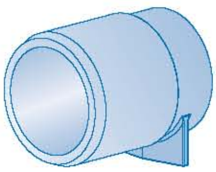
End Connections



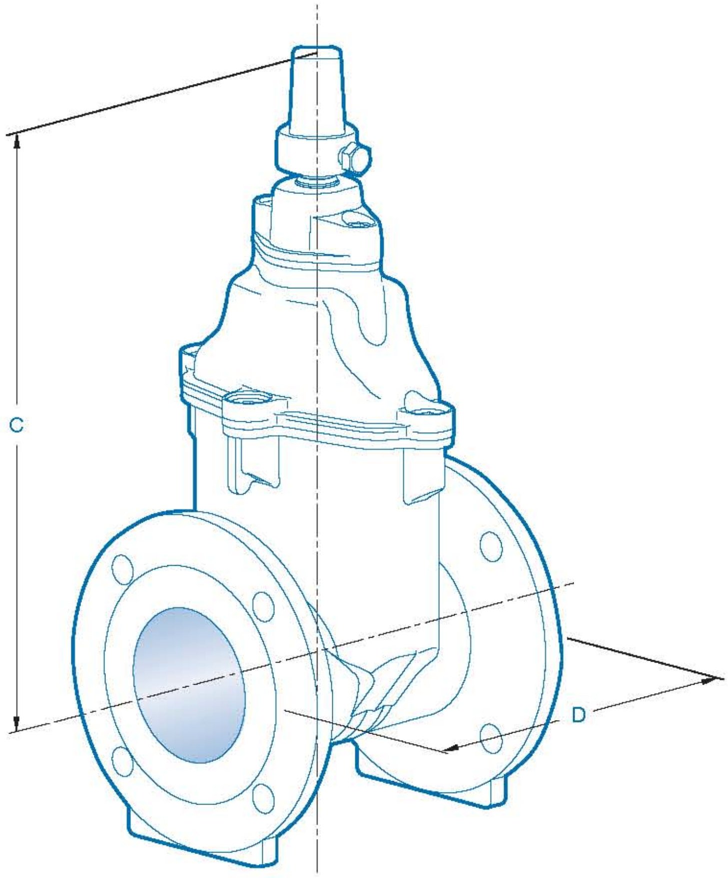
Flange



Socket



Spigot



Dimensions (mm)

		D					
			PN 16		PN 25		
Valve Size	C	TYTON Socket	Flange AS4087 Fig B5	Spigot	Flange AS4087 Fig B6	Turns to Close	Approx. Mass kg
80*	367	-	203	305	-	20	18
100†	402	150	229	365	229	23	24
150†	502	170	267	380	267	26	43
200†	610	195	292	410	-	34	75
225†	649	205	305	420	-	38	85
250†	723	235	330	435	-	42	110
300	810	245	356	450	-	50	160
375	960	275	381	-	-	62	340
450	1145	-	432	-	-	76	560
500	1290	-	457	-	-	82	710
600	1467	-	508	-	-	98	940

Note:
For compatability with Series 1 PVC (white) pipe, PLASTYT gaskets may be used in TYTON sockets.
** Flange to Polydex socket available.*
† Flange to TYTON socket available.

Resilient Seated Gate Valves - Figure 500

DN80 - DN600

Available Range

DN	Resilient Seated Gate Valves Inside Screw PN 16 FI-FI	Sc-Sc	Sp-Sp	FI-Sc	PN 25 FI-FI
80	✓		✓	✓	
100	✓	✓	✓	✓	✓
150	✓	✓	✓	✓	✓
200	✓	✓	✓	✓	
225	✓	✓	✓	✓	
250	✓	✓	✓	✓	
300	✓	✓	✓	✓	
375	✓	✓			
450	✓				
500	✓				
600	✓				
Fig No.	500	500	500	500	500
Coating					
Polymeric Coating	✓	✓	✓	✓	✓
Options					
Anticlockwise Closing	✓	✓	✓	✓	✓
Clockwise Closing	✓	✓	✓	✓	✓
Gear Actuator	✓				✓
Flange Drilling Fig B5 (TC)	✓			✓	Fig B6 (HP)

Recommended Specification

- Gate valves shall be resilient seated conforming to AS2638.2.
- The allowable operating pressure shall be 1600/2500 kPa.
- Operation shall be by means of a key/handwheel.
- The direction of closing shall be anticlockwise/clockwise.
- The valve body and bonnet shall be cast in Ductile Iron and coated with a thermally applied polymeric coating to AS/NZS 4158.
- The gate shall be cast in Ductile Iron and fully encapsulated in EPDM rubber - partially coated wedges are not acceptable.
- The spindle shall be Grade 431 Stainless Steel incorporating a failsafe thrust collar.
- The spindle seal retainer shall be manufactured from a dezincification resistant copper alloy to AS1565.
- The spindle seal shall be affected by a minimum of two O-rings, which can be replaced under full operating pressure.
- Fasteners shall be completely isolated from the external environment.
- Valves shall be manufactured under a product certification scheme and each valve marked in accordance with the certification body's requirements.

Appendix F Friction Loss Calculations

Values of k from Chart 14 from AS-2200:2006

Pump No.1		
Fitting	No.	k
Tee (through)	1	0.6
	Total	**0.6**

Pump No.2		
Fitting	No.	k
Swing check valve	1	1.3
	Total	**1.3**

Pumps 1 and 2 connected in series		
Fitting	No.	k
Tee (branch)	1	1.78
Gate valve (fully open)	1	0.6
90° elbow	1	0.4
45° elbow	2	0.2
slightly rounded inlet	1	0.22
	Total	**3.4**

Constants used	
Check valve diameter	0.1 m
Connecting pipe length	0.5 m
Connecting pipe diameter	0.08 m
Pipe roughness e	0.045 mm
e/d	0.0005625
Kinematic viscosity at 25° C	8.96×10^{-7} m^2/s
Acceleration due to gravity	9.81 m/s^2

Pump No.1				
Unmodified pump		V (m/s) 100 mm pipe	Minor head loss	H (m) modified pump
Q (l/s)	H (m)			
0.3	13.8	0.0	0.0	13.8
5.1	12.9	0.6	0.0	12.9
10.1	11.1	1.3	0.1	11.0
15.1	8.55	1.9	0.1	8.4
20.1	5.77	2.6	0.2	5.6
25.1	3.53	3.2	0.3	3.2

Pump No.2				
Unmodified pump		V (m/s) 100 mm pipe	Minor head loss	H (m) modified pump
Q (l/s)	H (m)			
0.3	13.8	0.0	0.0	13.8
5.1	12.9	0.6	0.0	12.9
10.1	11.1	1.3	0.1	11.0
15.1	8.55	1.9	0.2	8.3
20.1	5.77	2.6	0.4	5.3
25.1	3.53	3.2	0.7	2.9

Pumps 1 and 2 connected in series							
Unmodified pumps		V (m/s) 80 mm pipe	Fittings head loss	Reynold's number	*f*	Pipe fiction loss	H (m) modified pump
Q (l/s)	H (m)						
0.3	27.6	0.1	0.001	5.33×10^3	0.037	0.001	27.6
5.1	25.8	1.0	0.178	9.06×10^4	0.021	0.007	25.6
10.1	22.2	2.0	0.700	1.79×10^5	0.019	0.012	21.5
15.1	17.1	3.0	1.564	2.68×10^5	0.019	0.018	15.5
20.1	11.54	4.0	2.771	3.57×10^5	0.018	0.023	8.7
25.1	7.06	5.0	4.321	4.46×10^5	0.018	0.029	2.7