TAURANGA SOUTHERN PIPELINE - COST MINIMISATION USING INNOVATIVE HYDRAULIC MANAGEMENT

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ABSTRACT

In 2005, Tauranga City Council embarked on the implementation of a 14.5 km 700mm to 1000 mm diameter interceptor sewer across the city (known as the Southern Pipeline). Conventional interceptor sewer design often uses short rising mains followed by longer gravity sewer systems, often in tunnels or using multiple barrel inverted siphons. Route options analysis indicated that the preferred Southern Pipeline route was to avoid unstable ground and flood plains, but this meant using main roads though residential areas with the consequential need to fully understand and manage foul air discharges. The selected design provides cost effective solutions that involve significant lengths of pressure pipelines (approximately 12.5 km total), removal of the need for multiple barrels siphons, comprehensive analysis of air management and the provision of daily flushing to minimise grit and slime build-up. Analysis of pressure transients resulted in selection of simple and robust controls using both air vessels and vacuum relief valves. The air vessels are uncommon for large sewer systems. Commissioning of the initial 5.7 km of the system was carried out successfully in early 2012.

KEYWORDS

Tauranga, Pipeline, Sewage, Hydraulics, Waterhammer, Air Vessels, Air Management

1. INTRODUCTION

As a result of significant residential development in the Tauranga region the wastewater system in the central and southern areas of the city was in need of upgrade to avoid sewage overflows into the Tauranga Harbour. A number of reports had identified that an interceptor sewer was needed crossing the city from the Southern area of Tauriko to the Te Maunga wastewater treatment plant (Te Maunga WWTP) in the east.

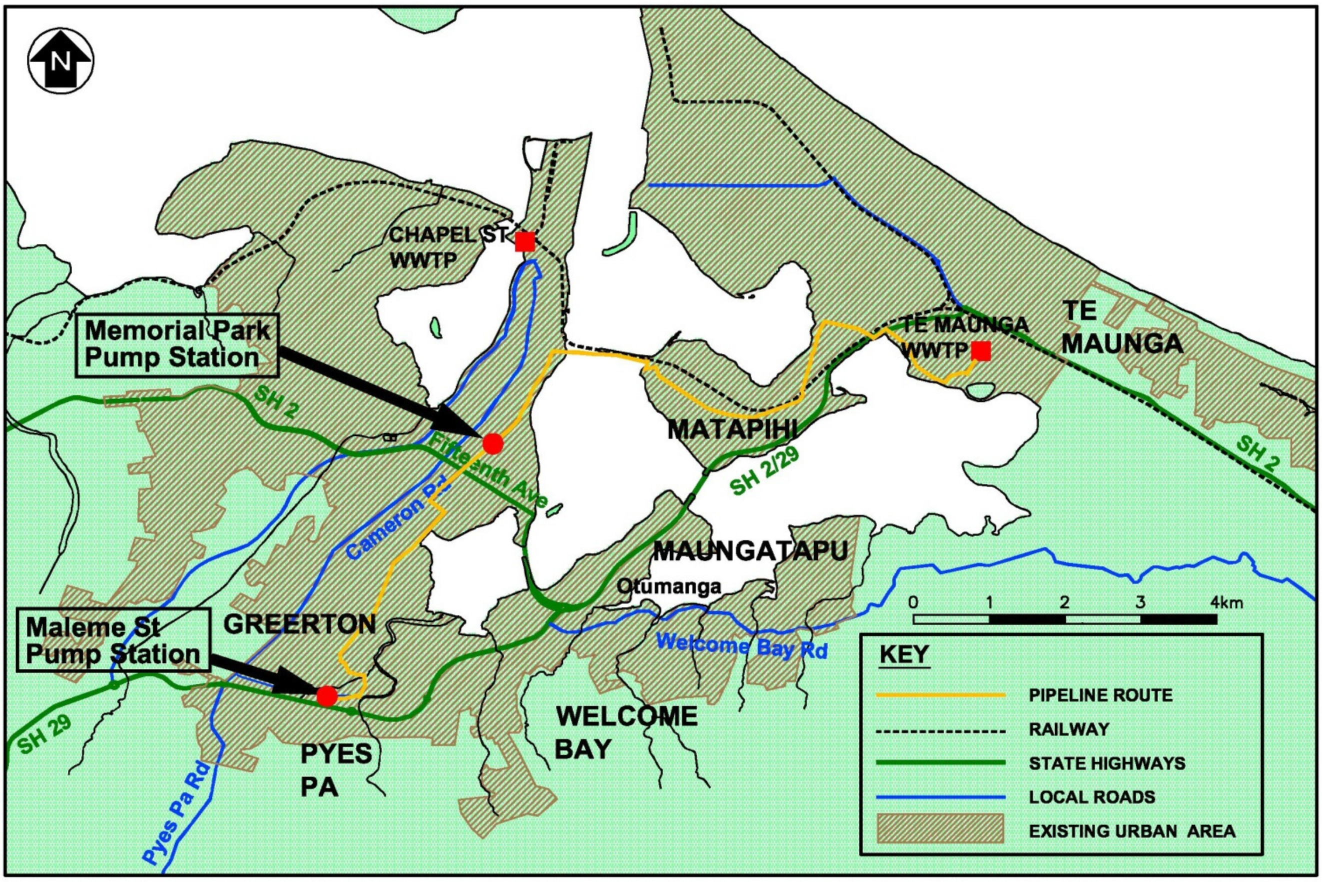
URS New Zealand Limited (URS) were engaged by Tauranga City Council (TCC) to design, obtain consents for and oversee construction of the required trunk wastewater pipeline, hereafter termed the Southern Pipeline Project (SPP). As well as providing flow capacity for the expected population growth in the southern catchments up to 2051, the SPP also has the benefit of freeing up capacity in the already restricted network in western Tauranga which currently feeds the Chapel Street WWTP.

The project is the largest non-roading infrastructure project ever undertaken by TCC. The main features of the project comprise:

- Two new large pump stations,
- Approximately 12.5 km of 710mm to 800mm diameter pressure mains, including a harbour crossing, and
- 1.8km of 800mm to 1000mm gravity sewer.

Selection of the pipeline route followed a comprehensive analysis of over 50 initial route options, with extensive investigations relating to planning, geology, archeology, harbour hydrodynamics and environmental aspects. Route options were reduced to four main and two sub-options, and then to one main route. The selected route traverses main roads through residential areas in Tauranga, crosses beneath the Tauranga Harbour, and continues through rural areas in Matapihi to the Te Maunga WWTP (refer Figure 1).

Figure 1: Southern Pipeline Overview Plan



A key characteristic of the selected pipeline route (as with the other route options) was the long conveyance time for wastewater. It was therefore essential to allow for potentially elevated hydrogen sulphide concentrations resulting from the septicity of the wastewater, to design for the control odour, corrosion, and health and safety. A further characteristic of the selected route was the presence of high points along the route which were elevated above the final discharge points. Treatment of these high points is discussed later.

Construction of Stage 2 of the SPP was carried out by Downer New Zealand Ltd, and commissioned in January 2012. Stage 2 completed a new trunk pump station and installed the pipeline section from Maleme Street to Memorial Park in Tauranga. The remaining sections of the SPP are in various stages of design and are scheduled for staged construction over the next several years.

Details for each of the SPP elements are outlined in this paper, with primary emphasis on the hydraulic challenges and solutions developed for the pipeline design.

2. ROUTE PLANNING

2.1 TOPOGRAPHY AND TERRAIN

The southern and central areas of Tauranga are undulating with elevations varying from sea level to over 40 metres. A crossing of the harbour was required and the least contentious harbour crossing options were selected. Several potential harbour route options had to be discounted for cultural reasons. In addition, pipeline route options needed to use Council roads and reserves to avoid land purchase costs.

The varying types of ash fall in Tauranga can result in ground instability and in the valleys there are considerable depths of very weak soil (over 70 metres depth in some locations). Thus the soil types presented constraints for the pipeline routes as there was a need for long term pipeline security and minimisation of liquefaction and land stability risks during earthquake events.

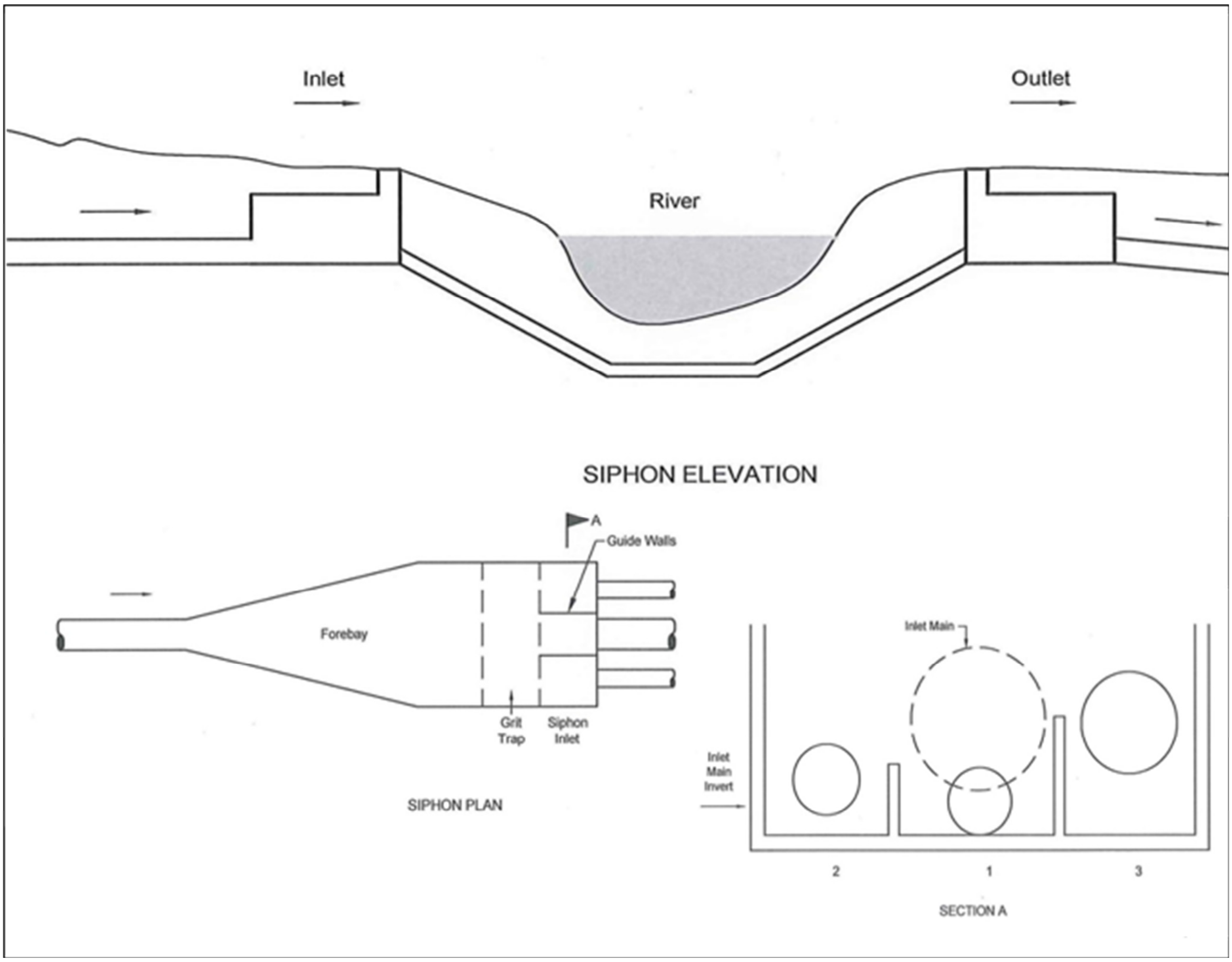
It was quickly concluded that irrespective of the route chosen the pipeline would be undulating as the cost of tunneling to maintain grades was cost prohibitive. This in turn meant that inverted siphons were inevitable.

The challenge was to develop a robust solution to ensure the interceptor pipeline could be maintained with a low hydraulic friction whilst providing flexibility of operation to ensure air and grit management was understood and accumulation of these minimized.

2.2. BACKGROUND ON CONVENTIONAL INVERTED SIPHONS

Inverted siphons are common in the wastewater industry as a means to pass under streams, through valleys, or other obstructions in an "U" shape dip and are commonly used to avoid the costs and risks associated with maintaining a falling gradient in the direction of flow. Inverted siphons have been around since Greek times with the first known one used on the island of Crete around 2000 BC. An indicative arrangement is shown in Figure 2.

Figure 2: Typical Inverted Siphon Arrangement



Inverted siphons typically require some or all of the following components.

1. A minimum of two “barrels” in parallel are required to allow for flow variations. Often several barrels are installed. This substantially increases capital and operating costs.

2. The velocities in each barrel must be typically around 0.9 m/s and preferably over 1.2 m/s to ensure that they are self-cleansing. The required velocity will be diameter dependent.

3. The horizontal alignment should be straight with no bends or fittings and no sags and preferably no high points. Namely the pipelines (all barrels) should be graded evenly.

4. The siphon inlet chamber needs to be hydraulically efficient to allow for proper distribution between the barrels, prevention of pre-swirl, and prevention of vortexing into the siphon barrels.

5. The siphon outlet chamber needs to be designed to be hydraulically efficient to allow multiple barrels to be reduced back to one pipeline.

6. The chambers also typically allow for personnel access and are commonly used for grit capture and removal and air management.

7. Ensuring that air is not trapped in the barrels is important to avoid sudden air releases and sewage surging up the chamber(s). Bypass air lines, including dedicated “air bridges” across the dips are often required and air treatment and management are a big part of overall siphon design.

8. Some systems require valving to prevent backflow down barrels not in use or to ensure reliable operation of the system.

9. Often there is a need to provide a fresh water flushing tank on the upstream side to flush barrels after use.

10. Limiting debris from entering the siphon (by screens or similar) is desirable to prevent stones, timber and other large obstacles from clogging the siphon.

11. There needs to be very good access to the chambers at all times, and because of their size this often means either significant road disruption when access is needed or for the chambers to be located on purpose purchased land adjacent to the road reserve.

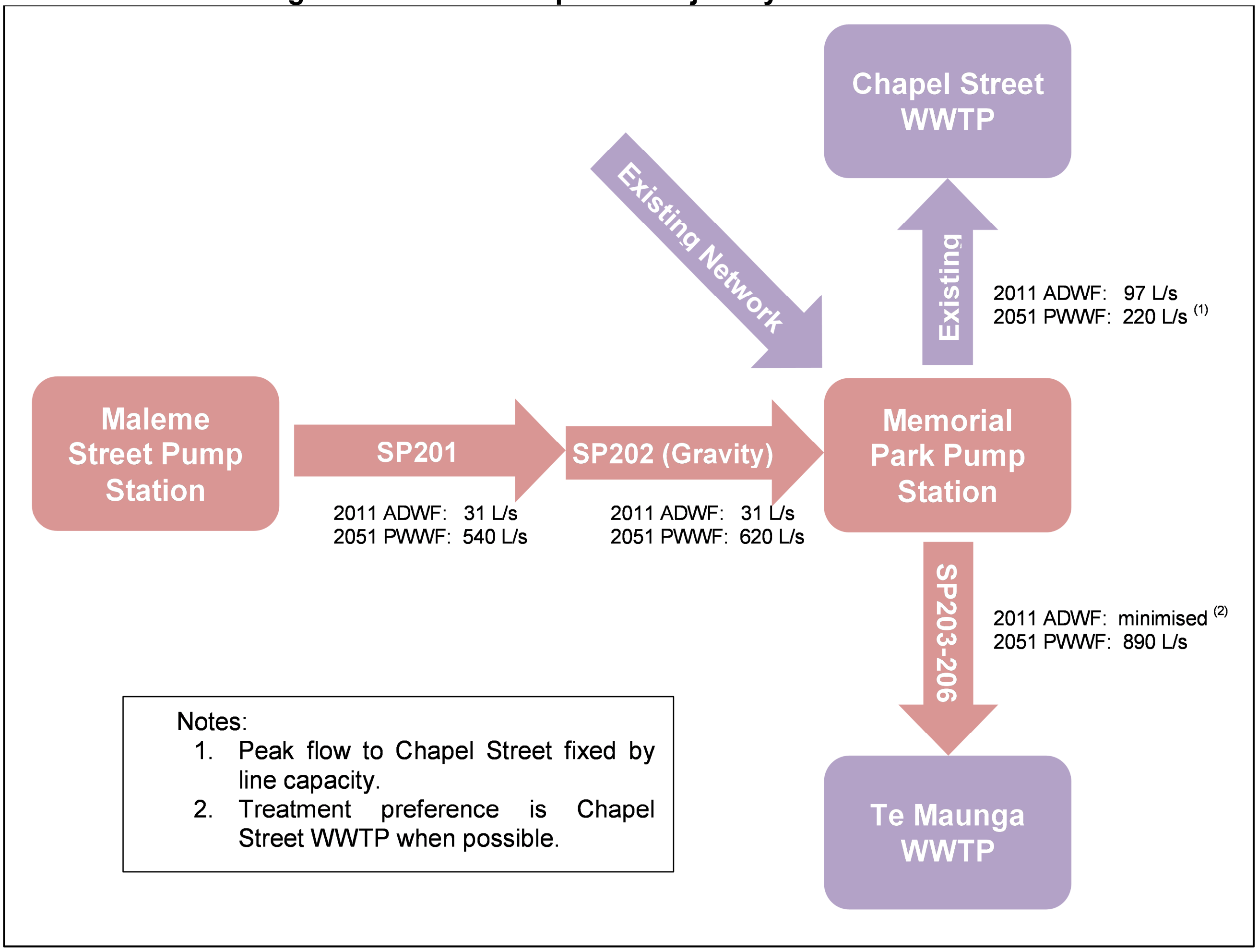
The main disadvantages of conventional inverted siphons are the need for large inlet and outlet chambers; issues over maintaining the barrels free from debris when not in use and air and odour management so that foul air can be exhausted in a controlled manner (without interference with the system). If flushing tanks are required then a large amount of potable water (or reused stormwater if available) is required for flushing in addition to space requirements for the flushing tank.

Whilst the use of inverted siphons is inevitable in some situations, with the pumped wastewater source available on the SPP the authors sought to use the pumped energy for a more cost effective and easy to maintain system.

3. SYSTEM CONFIGURATION

The core SPP infrastructure is illustrated in Figure 3 together with the current average dry weather flow (ADWF) and the year 2051 peak wet weather flow (PWWF). Peak design flows for the system are based on the year 2051 PWWF’s. As indicated on Figure 3, the SPP has been divided into sections denoted as SP201 to SP206.

Figure 3: Southern Pipeline Project system schematic



The currently commissioned sections of the SPP comprise the following elements:

- Maleme Street Pump Station – including 1350 m^3 underground storage and standby power generation.
- Pressure Pipeline SP201 – being a 3.9 km DN710mm PN8 PE100 pipeline along local main roads
- Gravity Pipeline SP202 – being a 1.8 km DN800mm / DN1000mm PE100 PKS (profiled wall) pipeline along local roads.
- Flow attenuation storage at the Memorial Park Pump Station
- Various ventilation devices, air controls, passive biofilters, and fan supplied biofilters

Flows from SP202 currently discharge into the existing Memorial Park Pump Station from where they are conveyed to the Chapel Street WWTP. This pump station will be replaced to provide increased capacity and the flexibility to split flows between the Chapel Street WWTP and the Te Maunga WWTP.

Design of the pipeline from Memorial Park to Te Maunga has been completed from Matapihi (eastern side of Tauranga Harbour) onwards. The designed pipeline section will be a continuous DN800mm PN8 PE100 pipeline over its full length, including the inverted siphon section as discussed later. Harbour crossing options to Matapihi have been consented, however final routes are yet to be confirmed and designed.

Photographs 1 to 3 show selected elements of the SPP works during construction.

Photograph 1: The new Maleme Street Pump Station (control building not in view)

Photograph 2: Part of pipeline SP201 being prepared for directionally drilled installation

Photograph 3: PKS Polyethylene manhole being installed on pipeline SP202

4. PIPELINE PROFILES AND INVERTED SIPHON DEVELOPMENT

Profiles for the two overall pipeline routes are presented as Figures 4 and 5 with associated pipeline sections and hydraulic grade line (HGL's) indicated. The profiles incorporate some substantial directional drill runs and pipe jacking in order to pass beneath hills, state highways and railways. Of note, a significant directional drill run from SP201 chainages 2200m to 2800m (approximately) was agreed with the construction contractor in order to avoid community disruption and to minimise air valve requirements.

Figure 4: Pipeline profile from Maleme Street Pump Station to Memorial Park Pump Station

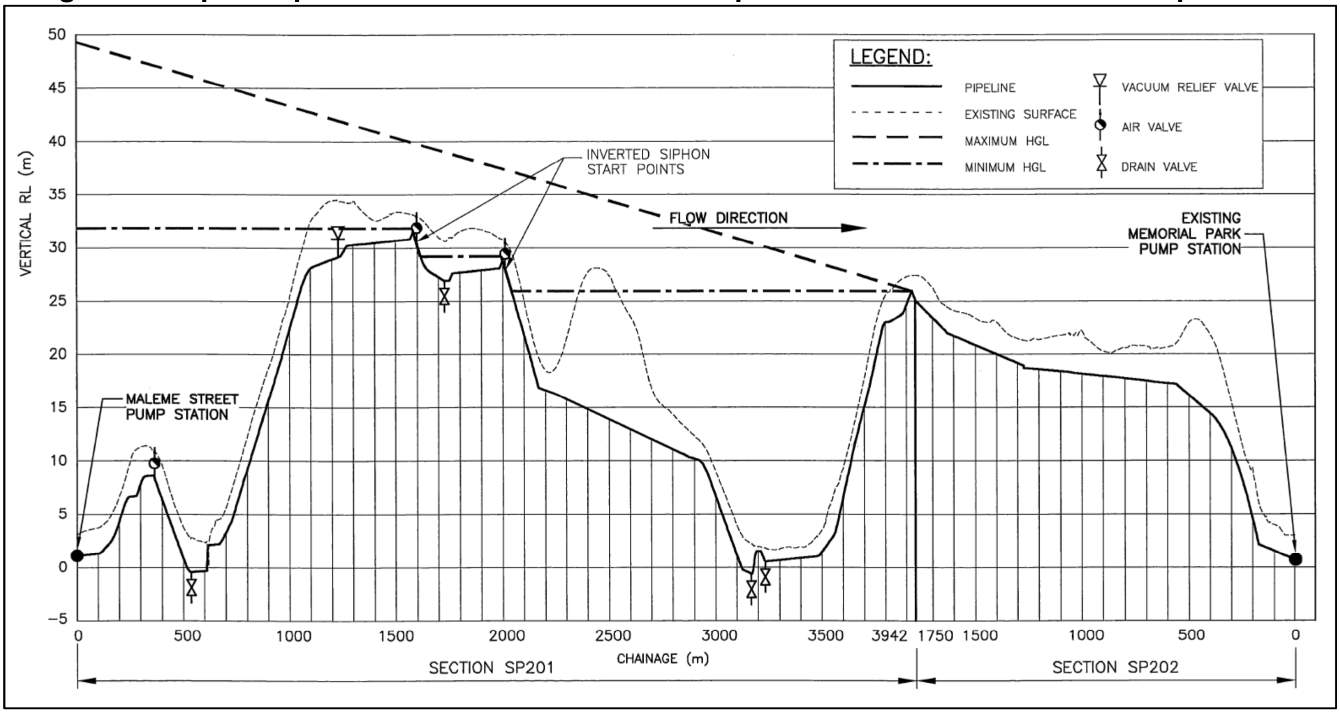
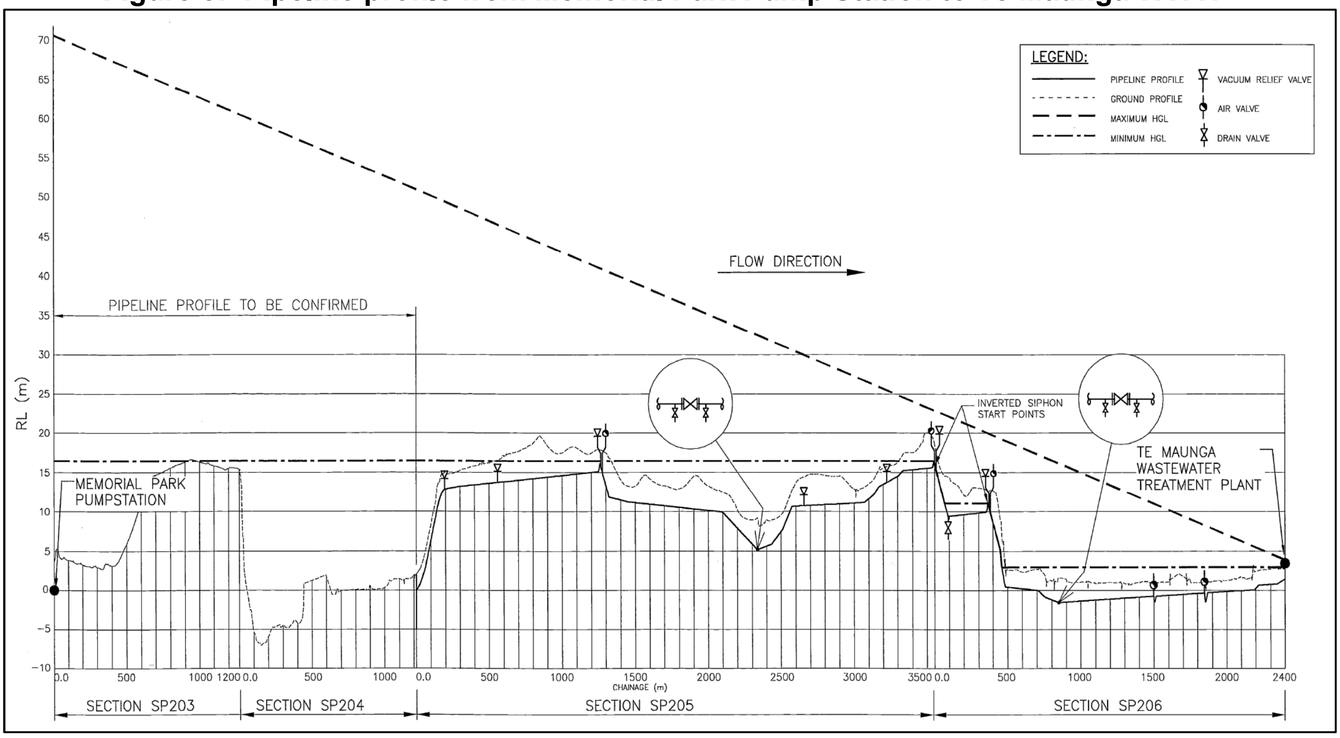


Figure 5: Pipeline profile from Memorial Park Pump Station to Te Maunga WWTP



Along each route there are unavoidable high and low points which have resulted in the need for inverted siphons. Start points for each siphon section are indicated in Figures 4 and 5.

Initially, gravity driven inverted siphons were considered for these sections using conventional multi-barrel arrangements. A number of drawbacks with such an approach were identified including:

- The cost of multiple pipelines.
- Difficulty in achieving self-cleaning velocities on some siphon sections.
- Space constraints for multiple pipelines and inlet/outlet chambers, particularly for pipeline SP201
- Requirements for careful control of level oscillation to ensure inlet and outlet chambers were not overwhelmed.

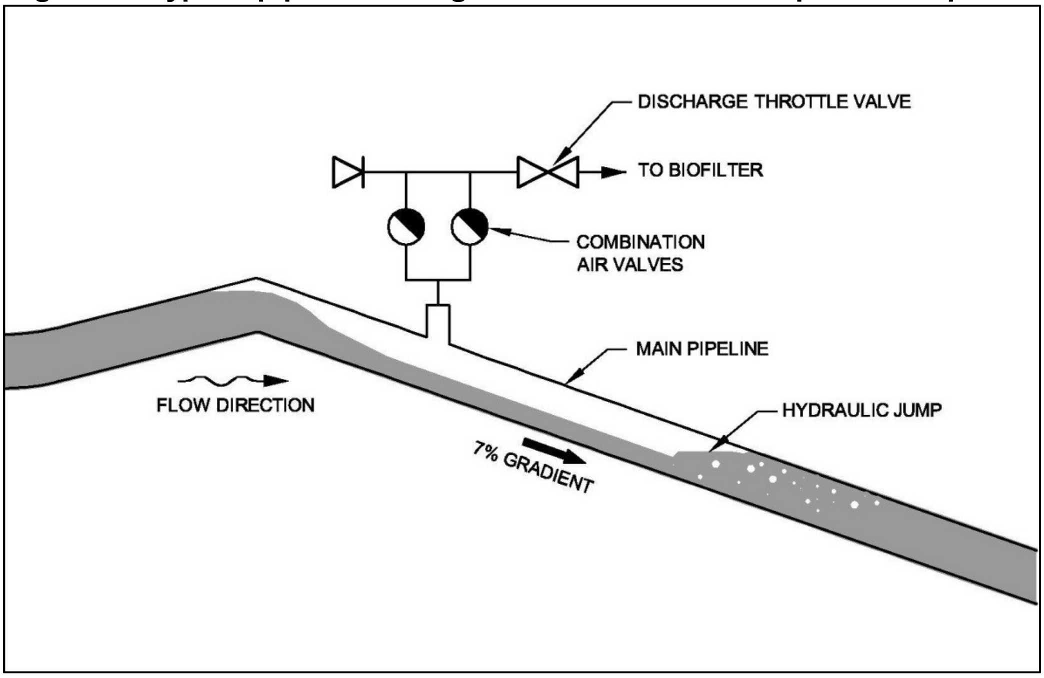
Options were explored for using single bore inverted siphons that were capable of completely filling and pressurising for peak flows and flushing purposes. Essentially then, at peak flows, each inverted siphon section would operate as a pressure pipeline contiguous with the upstream pressure section. Following detailed modelling and calculations it was decided to construct the siphons using the same pipe type and diameter as the upstream pipeline. Such a sizing ensured optimisation between hydraulic efficiency and self-cleansing velocities, consistent with the balance of the pressure pipelines. The sizing also allowed for future straight-through pigging of the pressure pipeline and inverted siphons should this ever be required.

Given the size and significance of the SPP, it was important to develop the inverted siphon design in a manner that ensured definitive control of a range of hydraulic aspects. Some of these aspects conflicted and required a careful balance to be struck. Key design considerations were as follows:

a. **Topography** – It was necessary to provide a design profile with depths that could be constructed economically (open trench construction was intended).
b. **Drain/fill volume** - The pipeline drain/fill volume needed to be minimised to allow for timely charging of the siphon, especially during routine flushing events where there is limited time to reach peak flow. Consequently a steep draining leg was preferred.
c. **Venting rate** – Given the cost of treating the foul air discharges from the siphon, the rate of discharge of displaced air needed to be limited and controlled.
d. **Fluid velocity under open channel flow** - The severity of the hydraulic jump in the inverted siphon is governed by the upstream open channel velocity, or more specifically the Froude number of this flow. This in turn impacts the air entrainment volumes, bubble size and hydrogen sulphide release. Limiting the hydraulic jump severity was therefore desirable.
e. **Fluid velocity with full siphon** – Full pipe velocity at flushing flow rates needed to be adequate for air, slime, and sediment control.
f. **Headspace** - Adequate head space needed to be maintained during open channel flow to convey air backwards to the air valves at the top of the inverted siphon.
g. **Air pocket movement** – Downstream of the hydraulic jump air bubbles will coalesce to form air pockets. It is important to ensure that air pockets do not “hang” in the pipeline, particularly during peak flow events as this would cause hydraulic inefficiencies. Analysis of air pocket movement was therefore required for different pipe slopes and at different flow rates.
h. **Flow surging** – This is initiated by changes to the flow rate such as pump starts and stops and causes oscillation in the levels of the upstream and downstream free water surfaces.

The outcome from assessment of the above aspects was to select a pipeline gradient of 7% for the draining (upstream) inverted siphon legs for both pipelines SP201 and SP206. Calculations indicated a reasonably consistent hydraulic jump Froude number of around 5 for both SP201 and SP206 over the likely range of pumped flow rates. This value is expected to result in a modest hydraulic jump for which air entrainment characteristics were assessed to be manageable based on studies by Chanson (1997) and other sources. A typical inverted siphon arrangement for the SPP is presented in Figure 6.

Figure 6: Typical pipeline arrangement at the inverted siphon start points



Air from each inverted siphon is discharged via dual air valves at the upstream end. The outlets from these air valves are manifolded and discharged to a passive biofilter at a controlled rate. Vacuum relief during siphon draining is also provided. In order to ensure adequate pipeline headspace at the air valves during open channel flow conditions, the air valves were located downstream of the high point at the start of each siphon. The position provides opportunity for flow to transition from full pipe flow to the subsequent open channel flow depth. Additional discussion on the use of air valves for the SPP is provided in section 6.

In regard to flow surging, particular care was required for the SP206 inverted siphons to ensure that:

1. Free water surfaces did not drop into flatter pipeline sections (namely, create air management issues), and

2. The receiving chamber at the Te Maunga wastewater treatment plant had sufficient capacity to accommodate surging.

Detailed modelling confirmed that the surging could be adequately managed subject to key design requirements for the receiving chamber and pipeline profile. These requirements were subsequently incorporated into the detailed design.

5. ROUTINE FLUSHING

The pressure pipelines and inverted siphons associated with the SPP are expected to be subject to relatively low peak flows during the earlier years of operation. Accordingly, there was a need to provide daily flushing flows in order to:

i. Convey solids which settle in the pipeline.

ii. Minimise the formation of slimes on the pipeline walls

iii. Flush air pockets which may periodically form in some sections of the pipeline.

Primarily the above functions are targeted at maintaining good hydraulic efficiency and avoiding the costs associated with periodic line cleaning (e.g. pigging) and increasing pumping head. The flushing is also important for the shearing of slimes from the pipe wall. These slimes include sulphide producing bacteria which can significantly contribute to the rate of hydrogen sulphide generation.

Flushing velocities were assessed using research outcomes by HR Wallingford (2000), which enable consideration of a number of parameters including pipe diameter, grit concentration and pipe slope. The methodology bases minimum self-cleansing velocities on requirements to achieve “flume traction” grit movement, namely continuous movement of all particles in individual motion. This approach is expected to yield conservative flushing velocities for the SPP owing to the sediment characteristics assumed, the continuation of some sediment movement at lower velocities, and comparisons with other studies on self-cleansing velocities in sewers. Outcomes from the assessment indicated that flushing at or near the peak design flow for each pipeline was preferred. This correlates to flushing velocities of between 1.7 m/s and 2.0 m/s for the various pipeline sections.

A 5 to 10 minute flushing time once each day was nominated for all pipeline sections based on practicable wastewater storage volume limitations. Should less or more flushing effort be found to become desirable there is flexibility to vary the frequency of flushing.

Given the limited storage at the proposed Memorial Park Pump Station, flushing was proposed as a sequential process for SP203 to SP206 using the flushing flow from the Maleme Street Pump Station. Accordingly, coordination is needed between the pump stations for the timing of flushing cycles. Given the higher flushing flow rate from the Memorial Park Pump Station (810 L/s) around 140 m^3 of additional buffer storage is required in this station for flushing.

Until the new Memorial Park Pump Station is constructed, the existing Memorial Park Pump Station is unable to receive the full flushing flow from the Maleme Street Pump Station. To accommodate this limitation, a 95 m length (approximately) of 1660 mm diameter PKS storage pipe has been included near the downstream end of SP202 to provide attenuation for pumped and flushing flows into the existing pump station. This sizing enables around 2 minutes of flushing at full flow from Maleme Street as an interim flush duration until the new Memorial Park Pump Station is constructed. The storage pipe will also be used for additional emergency storage for the existing and proposed pump stations.

6. AIR MANAGEMENT

6.1 PRESSURE PIPELINES AND INVERTED SIPHONS

Management of air in pressure pipelines and inverted siphons is an important design element, both in terms of maintaining hydraulic efficiency and controlling odours. Pipeline gradients were set to convey foul air to air valves whilst limiting the number of air valves as far as practicable due to the ongoing maintenance requirements that these create. All critical air valves were duplicated to provide redundancy during maintenance or failure of an air valve. In addition, all valves have been specified with backwash connections to facilitate regular valve flushing with the intention of improving reliability. Where discharges from air valves were expected to generate nuisance odours, odour mitigation was designed using either passive biofilters or vent stacks as appropriate.

Passive biofilters were selected to treat the large volumes of foul air which will be routinely discharged from air valves at the start of each inverted siphon. The biofilter locations were selected to minimise visual impacts. In order to limit the size of the biofilters, air flow rates from the air valves to the respective biofilter are throttled by way of an adjustable butterfly valve. This gives some flexibility in terms of balancing the timely release of air from the inverted siphons and ensuring the biofilters are not overloaded. For design purposes a target empty bed residence time of 60 seconds was used which is consistent with the range specified in NZWWA Manual for WW Odour Management (1999) and other guidelines. An example of a typical biofilter and dual air valves servicing an inverted siphon on pipeline SP201 is shown in Photographs 4 and 5 respectively. The throttle valve for controlling air flow rate is just visible in the lower right of Photograph 4.

Photograph 4: Typical air valve system at the start of an inverted siphon

Photograph 5: Typical passive biofilter servicing an inverted siphon

In addition to air release, high capacity vacuum relief valves have been included at key locations for breaking negative pressure transients and for air intake at the head of inverted siphons. Given the criticality of the vacuum relief valves, these were all duplicated. Pipeline connections for vacuum relief valves were rotated to the “2 o’clock” position on the main pipeline to limit the potential for clogging with fats and debris. Photograph 6 provides an example of a vacuum relief valve pair on pipeline SP201.

Photograph 6: Typical dual vacuum relief valves

6.2 GRAVITY PIPELINE VENTILATION

For the gravity pipeline SP202 the ventilation philosophy was developed with cognisance of the elevated hydrogen sulphide levels likely to be discharging from the upstream pressure section (SP201). Accordingly the design intent was to allow air inlet at the upstream end of SP202 and collect and treat all foul air downstream near the existing Memorial Park Pump Station. In this manner, ventilation for SP202 is effected by way of:

1. Mechanical extraction at the Memorial Park Pump Station with discharge to biofilter,
2. Induced drag from wastewater flow,
3. Changes in flow rate (namely displacement of air), and
4. Wind velocity or air pressure differences over air induct and educt points.

Light counterbalanced flap valves were used at the upstream air inlet on SP202 to prevent backflow of foul air during system start-ups. Steady-state air flow rates will be primarily determined by induced drag and were estimated at around 250 L/s and 300 L/s based on a methodology by Edwini-Bonsu and Steffler (2004). The receiving biofilter was sized to accommodate these flows in addition to other ventilation requirements for the local network.

Air to the biofilter is mechanically fed via a duty standby fan arrangement. Similarly, the biofilter has been divided into two duty/duty cells to ensure some ongoing treatment during periods when one cell is shut-down for maintenance. As used for the passive biofilter systems, a design empty bed residence time of 60 seconds was adopted. Photographs 7 shows the biofilter.

Photograph 7: Memorial Park biofilter with fan compound and existing pump station in the background

7. PRESSURE TRANSIENT MANAGEMENT

7.1 GENERAL

The long pressure pipeline lengths and elevations traversed by the pipeline have resulted in the need for relatively high head pumping and careful management of pressure transients (also referred to as water hammer or surge). Pressure transients result from changes in flow rate which can be initiated by a number of events. For the subject pipelines these events could include:

a) Pump shutdown including power failure (initial negative surge).

b) Rapid pump start up (initial positive surge).

c) Rapid air valve closure (initial positive surge).

d) Sudden pipeline breakage (initial negative surge).

e) Rapid line valve closure

Pressure transients will propagate along the pipeline at a wave speed, “c”, known as the celerity. These pressure surges reflect off boundary conditions at each end of the pipeline in addition to other pipeline discontinuities and features such as air valves, resulting in often complex patterns of positive and negative waves.

The SPP pressure pipelines were assessed as being able to withstand full cavitation pressures (approximately -100 kPa) without pipe collapse. Cavitation is however highly undesirable due to the high and typically unpredictable pressures which can result when the formed vapour cavities re-collapse. Accordingly, the design minimum pressure head was selected as -50 kPa for all pressure sections to give a design margin for model inaccuracies and variations in field conditions. Maximum design pressures were set at pipeline pressure rating of 800 kPa.

A comprehensive range of pressure transient scenarios were modeled for all pressure pipeline sections. Pressure transient controls were developed and modeled as part of this work as discussed in the following sections. Independent peer review modelling of the system and controls was carried out by an offshore firm specializing in hydraulic analysis, and the design team's approaches were supported.

Pressure transient conditions relating to pump trip events were a key element of the analyses. Where possible pressure transient control was based on the use of vacuum relief valves as these generally present the lowest cost solution. Given the increased potential for fouling of air valves in contact with wastewater, the number of critical air valves along the pipeline was minimised as far as practicable. All critical air valves were duplicated for redundancy.

7.2 MALEME STREET TO MEMORIAL PARK (PIPELINE SP201)

The use of an "air valve only" approach for controlling minimum pressures was found to be impractical for pipeline SP201. Chainages 600m to 1200m (approximately) of this pipeline lie within a narrow, steeply rising, road formation where multiple vacuum relief valves would have been necessary. Location of air valves in this section would have resulted in onerous traffic management requirements for accessing the air valves and this was considered to be unacceptable. Accordingly, the developed solution used a pressurised air vessel system in tandem with air valves, with all air valves located outside of the section between chainages 600m to 1200m. Air vessels are not common for wastewater pipelines in New Zealand and design of these vessels drew upon international experience for the key design philosophy.

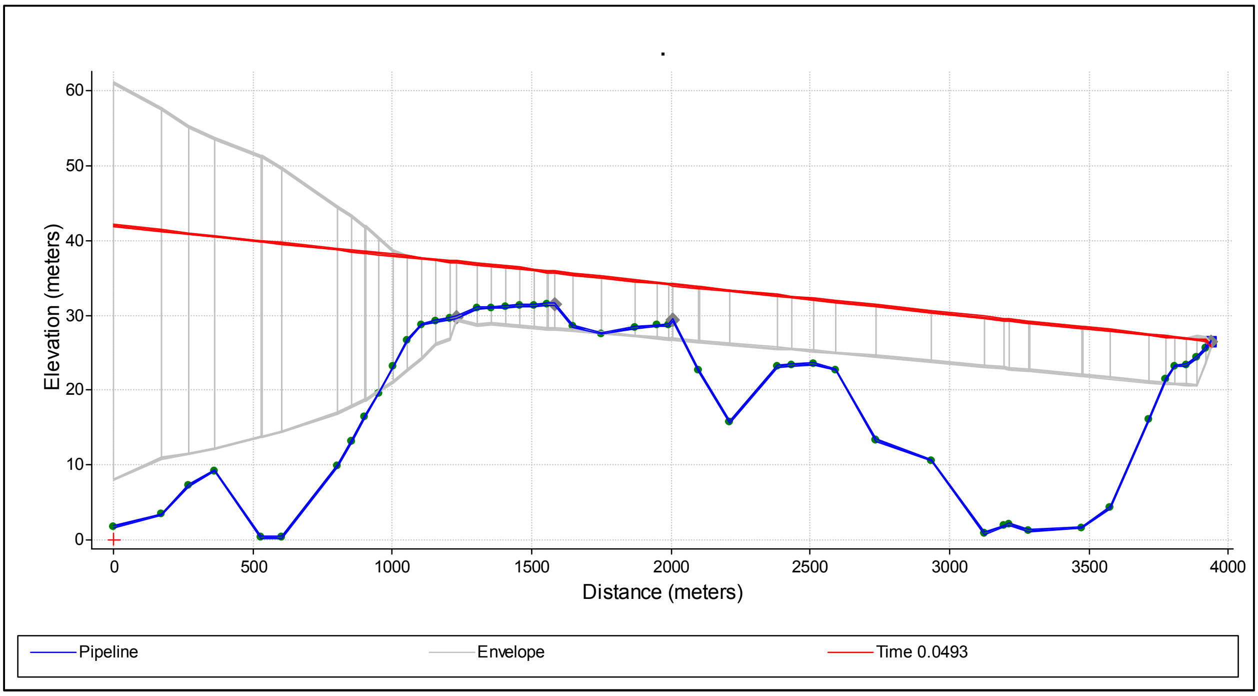
The pressurised air vessel system is located at the Maleme Street Pump Station and comprises a duty/standby vessel arrangement with a compressor for periodic air top-ups. Each vessel has a total volume of 8 m3. To reduce manual cleaning requirements, an automated pressure wash system has been included inside each vessel which operates briefly on an hourly basis. Level measurement on each vessel is via duty/standby differential pressure transducers as these are expected to provide good reliability in sewage applications when compared with other options. A view of the air vessel installation is provided in Photograph 8.

Three critical air valve locations were required (in tandem with the air vessel) to control hydraulic transients and provide air management for the inverted siphon sections. The air valve types included one vacuum relief valve system at chainage 1200m and two combination air valve systems servicing the inverted siphons. Section 6.1 provides additional information on these air valve arrangements.

Photograph 8: Maleme Street Pump Station air vessels

Model outputs for the selected pressure transient scenarios predicted compliance with the maximum and minimum pressure limits for the pipeline. An example pressure transient envelope for a peak flow pump trip event is shown in Figure 7 with the initial hydraulic grade line shown in red. These predictions were validated during commissioning tests.

Figure 7: SP201 pressure transient envelope for a pump trip event



A further aspect considered for pressure transient control was the ramp down configuration for normal pump stopping. Owing to the profile of pipeline SP201 a controlled ramp down was preferred to minimise the intake of air through the vacuum relief valves at chainage 1200m. On the basis of model outputs, the minimum time to sequentially ramp all pumps to rest was assessed to be 90 seconds. Pump switching levels in the wetwell were set with adequate volume to accommodate this ramp down time.

7.3 MEMORIAL PARK TO TE MAUNGA (PIPELINES SP203 TO SP206)

Options to control transient pressures were reviewed in detail with Tauranga City Council based on preliminary analyses. At this stage it is proposed that an air valve only solution will be used, subject to finalisation of the harbour crossing route and profile.

8. PERFORMANCE TESTING

Commissioning of the first pipeline stage from the new Maleme Street Pump Station to the existing Memorial Park Pump Station occurred in January 2012. The commissioning included routine functional testing of all key pump station and pipeline equipment. In addition, a range of both normal and pump trip events were simulated to validate the predicative modelling and enable system adjustments where required. Four high speed pressure dataloggers were used during the commission work to record pressure transients.

In addition to validation of pressure transient controls, the pressure data from commissioning was used to evaluate hydraulic performance. Peak steady state flows from SCADA recordings were around 590 L/s. Using pressure information from dataloggers at the pump station and at chainage 1200m, the operating roughness coefficient, k, was estimated to be around 0.1mm. This value is consistent with the lower bound value used in the design system curves and reflects a relatively clean pipe. It should also be noted that the pipeline internal weld beads were removed during construction and this will be having a beneficial (albeit small) impact on the hydraulic roughness.

SCADA data was again obtained from TCC after approximately six months operation to assess the ongoing effectiveness (or otherwise) of the routine pipeline flushing. Pressure and flow data from the Maleme Street Pump Station was reviewed for a three pump flush cycle on 5 July 2012. On the basis of this information, it appears that pipeline SP201 was operating with a hydraulic roughness coefficient, k, of around 0.2mm to 0.3mm. These values are well below typical values for conventional wastewater rising mains and indicate that the flushing regime is operating effectively.

Overall, the testing has demonstrated acceptable hydraulic performance of the system both in terms of steady state flows and transient pressures. Good correlation was demonstrated between the key tests performed and the predicted pressure transient model results. Some minor issues were identified during the testing and these were referred to the appropriate parties for remedying.

9. CONCLUSIONS

The Southern Pipeline Project culminates a comprehensive study of pipeline route options and development of cost effective, project specific hydraulic solutions. Of these solutions, the following aspects may be of particular value in the design of other sewage pipeline systems.

a. **Pressurising inverted siphons** – The design outlined in this paper has sought to optimise an inverted siphon arrangement that is capable of being pressurised to provide for peak flows and flushing velocities. Management of air has been shown to require careful attention to ensure that the inverted siphon will drain and fill in a manner that is both defined and controlled.

   The ability to pressurise the inverted siphons has enabled significant cost savings over earlier concepts of using multiple bore gravity inverted siphons.

b. **Pressure transient controls** – Given the inability to solely use vacuum relief valves for the initial section of the SPP, pressure transient control is assisted by way of a pressurised air vessel system. Such systems are not common for wastewater pipelines in New Zealand. The air vessel design incorporates specific measures to reduce sewage and fat fouling and has been demonstrated to operate reliably.

   Where air/vacuum valves have been used in critical locations, these have been installed with full redundancy (duplication) and provision made for regular flushing. Discharges from air valves which are likely to create odour nuisance have been conveyed to passive biofilters. The biofilters appear to be operating effectively.

c. **Routine pipeline flushing** – Pressure pipeline sections associated with the SPP will initially carry only low daily and peak flows. In order to maintain good hydraulic efficiency and reduce hydrogen sulphide production a flushing regime has been designed to maintain the pipe walls in a "clean" condition. Performance data to date for the initial pressure pipeline indicates that this flushing is effectively achieving its intended objectives.

Overall, the initial section of the SPP is performing well and attention is now focused on the successful completion of the remaining stages of the project.

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NOMENCLATURE

ADWF	Average dry weather flow.
HGL	Hydraulic grade line
m^3/s	Cubic metres per second, flow rate
PKS pipe	Profiled wall polyethylene pipe (PKS is a tradename) manufactured by PPS-Frank, Christchurch.
PWWF	Peak Wet Weather Flow: Instantaneous peak flow rate measured following a heavy rainfall event
SCADA	Supervisory control and data acquisition (control system)
SPP	Southern Pipeline Project
TCC	Tauranga City Council
URS	URS New Zealand Ltd
VSD	Variable Speed Drive, an attachment to the pump motor used to ramp the speed of the pump up or down to vary the flow output.
WWTP	Wastewater Treatment Plant