LESSONS LEARNT FROM RETROFITTING EXISTING WASTEWATER CATCHMENTS WITH VACUUM SEWER SYSTEMS POST-EARTHQUAKE

Pete Dawson BEng (Hons), MEngNZ (Beca ltd.) and Victor Wong (Christchurch City Council)

ABSTRACT

During the infrastructure rebuild after the Christchurch earthquakes in 2010 and 2011 as part of the Stronger Christchurch Infrastructure Rebuild Team (SCIRT) alternative wastewater systems were considered as a resilient alternative to replace the existing gravity systems in areas that were badly damaged by the earthquake.

During the concept stage of design, Vacuum Sewer Systems (VSS) were considered along with Pressure Sewer Systems as a resilient alternative to conventional gravity systems to replace the badly damaged existing gravity systems. Two existing gravity wastewater catchments in Shirley and Aranui servicing approximately 700 properties and 3000 properties respectively, were recommended to be replaced with a VSS due to their lowest whole of life cost, which included an indicative cost for the expected resilience of the systems against expected future earthquakes.

Pre-Christchurch earthquake there was limited industry knowledge of VSS in New Zealand, with only one VSS existing in Kawakawa Bay, south of Auckland, and no known international experience of retrofitting an existing gravity system that has been badly damaged by an earthquake with a VSS. As such, many lessons have been learnt during the design, construction, commissioning and operation stages that can be applied to future projects where considering utilising VSS. This paper looks at the lessons learnt during these stages.

KEYWORDS

Earthquake, resilience, wastewater, retrofit, vacuum sewer system, lessons learnt, SCIRT

PRESENTER PROFILE

Peter worked as a designer and Project Lead on wastewater projects during SCIRT. He was instrumental in implementing the VSS at SCIRT, developing new design/construction standards, agreeing technical requirements, liaising with vacuum suppliers to understand system limitations and has had technical involvement in the commissioning and operation.

1 INTRODUCTION

1.1 STRONGER CHRISTCHURCH INFRASTRUCTURE REBUILD TEAM (SCIRT)

The Stronger Christchurch Infrastructure Rebuild Team (SCIRT) was created after the 2011 February earthquake as an alliance to manage and deliver recovery works. SCIRT was formed with the Christchurch City Council (CCC), the New Zealand Transport Authority (NZTA) and CERA and five head contractors (City Care, Fulton Hogan, Downers, Fletchers and MacDow) and various consultants seconded.

The main aim of SCIRT was to get the cities civil infrastructure back on its feet and provide security and confidence to the people of Christchurch.

1.2 WHY VACUUM SEWER SYSTEMS WERE CONSIDERED

Vacuum Sewer Systems (VSS) are typically used in large catchments that are very flat, with high groundwater and poor ground conditions where there is an economic basis to keep the infrastructure as shallow as possible.

The Infrastructure Recovery Technical Standards and Guideline's (IRTSG) was created after the February 2011 earthquake to return the infrastructure networks to a pre earthquake condition and where possible a more resilient network. The IRTSG identified that alternative wastewater systems were to be considered as a resilient alternative.

Vacuum Sewer Systems and Pressure Sewer Systems were identified in the CCC Infrastructure Design Standards (IDS) to be considered in the concept stage in areas where liquefaction was observed, as they offered a resilient alternative solution.

Existing wastewater catchments were assessed for damage during the concept design stage and where the damage to the existing wastewater catchments were significant (typically in the East of the City), alternative systems were considered.

During the concept design stage where existing wastewater catchments were being evaluated and options being considered a member of the design team was chosen as the VSS technical lead and tasked to better understand the technical requirements to ensure that in the concept stage the system could be evaluated sufficiently.

The VSS technical lead agreed on acceptable standards with input from CCC and their maintenance and operations contractor as well as deviations to the standards to meet local conditions, selection of vacuum suppliers, better understanding of maintenance and operational requirements, contacting existing VSS asset owners, and providing technical guidance during concept design.

1.3 VACUUM SEWER SYSTEMS IN NZ AND RETROFITTING EXPERIENCE

There are no known examples of retrofitting existing gravity catchments with a vacuum sewer system post-earthquake, as typically they are installed on green field sites or retrofitting septic tank systems. Additionally there is no public documentation that highlights the risks in doing this.

While VSS exist all over the world, prior to the earthquake there was only one VSS in New Zealand, located in Kawakawa Bay, South of Auckland. This VSS was a retrofitting of septic tanks as the existing network did not meet environmental regulations. At the time of design the catchment served around a population of 630 with the expected future population to be around 3000.

1.4 VACUUM SEWER SYSTEM CATCHMENTS

Two existing gravity wastewater catchments were recommended and accepted to be retrofitted with Vacuum Sewer Systems at SCIRT based on a whole of life cost evaluation in line with the IRTSG and CCC IDS requirements. An overview of each catchment can be seen below:

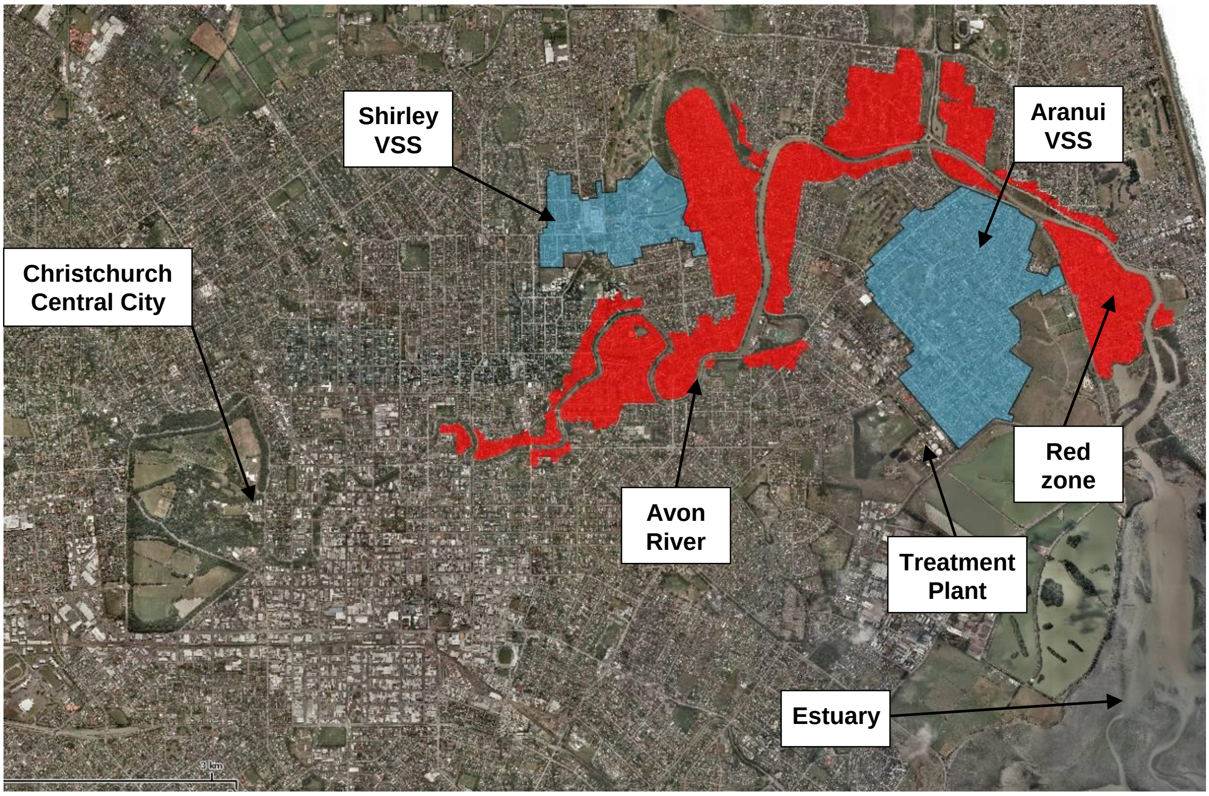

Figure 1 Vacuum Sewer System Catchment Overview

Aranui VSS Catchment Overview

The Aranui VSS catchment is located in close proximity to the red zone along the River Avon. The ground is predominately running sands with groundwater ranging from 0 m to 2 m below the ground level. The VSS serves just under 3000 dwellings with small numbers of commercial buildings. The system was designed with a maximum flow of 120 l/s and approx. 800 collection chambers.

Shirley VSS Catchment Overview

The Shirley VSS catchment borders the red zone to the East. The ground is predominately running sands with groundwater ranging from 0 m to 2 m below the ground level. The VSS serves 700 dwellings with a large number of commercial buildings including a mall, 2 schools, a petrol station and multiple smaller businesses. The system was designed with a maximum flow of 34 l/s and has approx. 200 collection chambers.

1.5 HOW A VACUUM SEWER SYSTEM WORKS

A VSS operates by vacuum pumps within a centralised vacuum pump station generating a constant vacuum typically within a range of -55 to -70 kPa into a vacuum vessel (like a wet well) and around the vacuum mains and vacuum laterals to the vacuum valves within collection chambers. See below for a typical layout of a vacuum pump station:

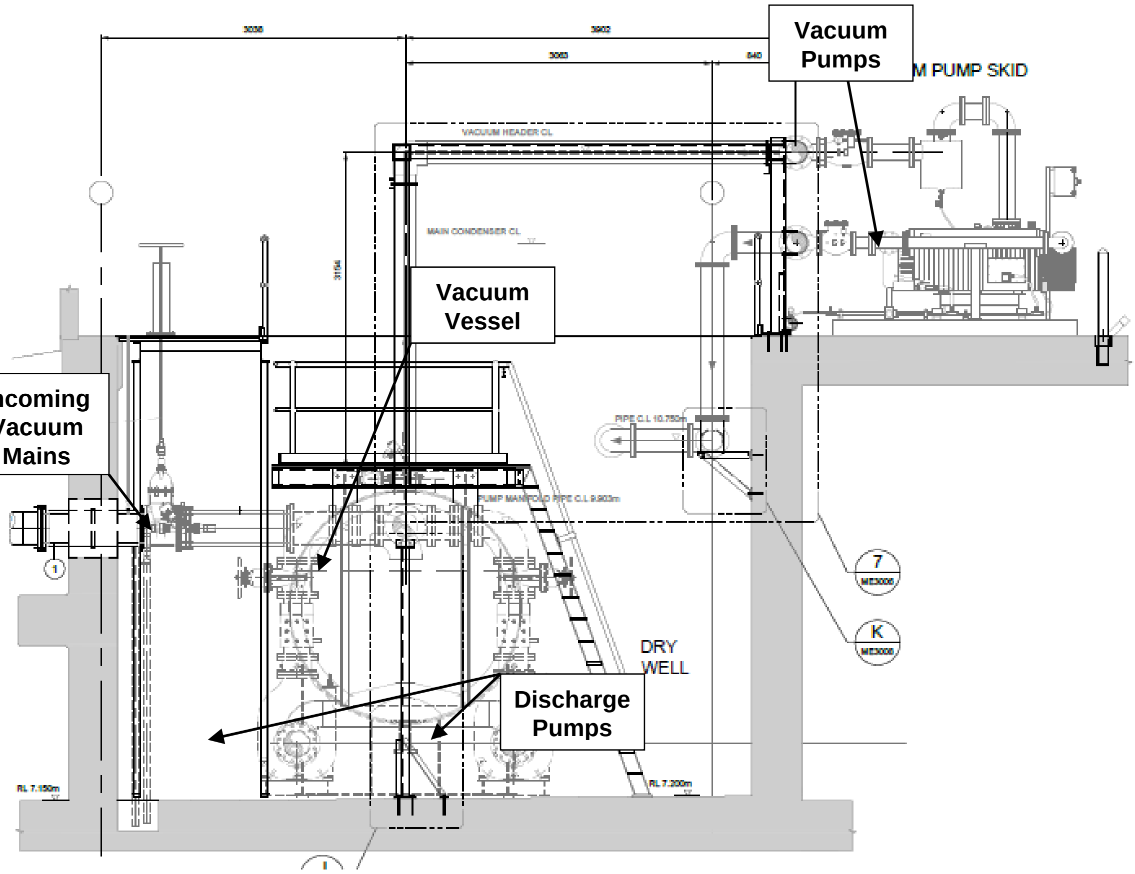

Figure 2 Typical Cross Section of a Vacuum Pump Station

Wastewater is collected in a collection chamber (typically 3-4 house connections to ensure consistent air to liquid ratio) via gravity laterals. A vacuum valve is located in the top of the collection chamber, and when approx. 40 liters of wastewater enters the collection chamber the valve opens (for approximately 10 seconds) and the differential pressure evacuates the wastewater (along with air behind) into the vacuum mains towards the vacuum station. The vacuum valve operates using the vacuum in the main therefore no power is required to operate the valves. The vacuum mains rely on a mixture of vacuum pressure and gravity, and the vacuum mains are laid with a saw tooth profile using “lifts” as shown below.

Figure 3 Vacuum Main and Lift Installation

Figure 4 Collection Chamber and Vacuum Valve Installation

Once a vacuum valve closes the wastewater within the vacuum main will gravitate to the nearest lift and when another valve opens the wastewater will pass through the lift and on to the next lift until it reaches the vacuum pump station. As a series of lifts can be used the vacuum mains can be designed to be shallow (typically 1-1.5m). As the vacuum pressure lifts the wastewater at each lift a maximum of 4m of lifts can be used on each vacuum main. 4m is used as a maximum amount of lifts required as this is the lowest operating vacuum pressure minus the vacuum required to open a valve i.e. -55kPa – 15kPa = -40kPa = 4m, therefore in the worst case if the system is drowned there is enough vacuum for all vacuum valves to operate at the lowest operating range.

It is important to note that there is no overflow point at the Vacuum Pump Station which is different to a typical pump station, therefore in the event of the vacuum pump station going down (vacuum pump/transfer pump failure) the overflow will be at the private property gully trap or the collection chamber.

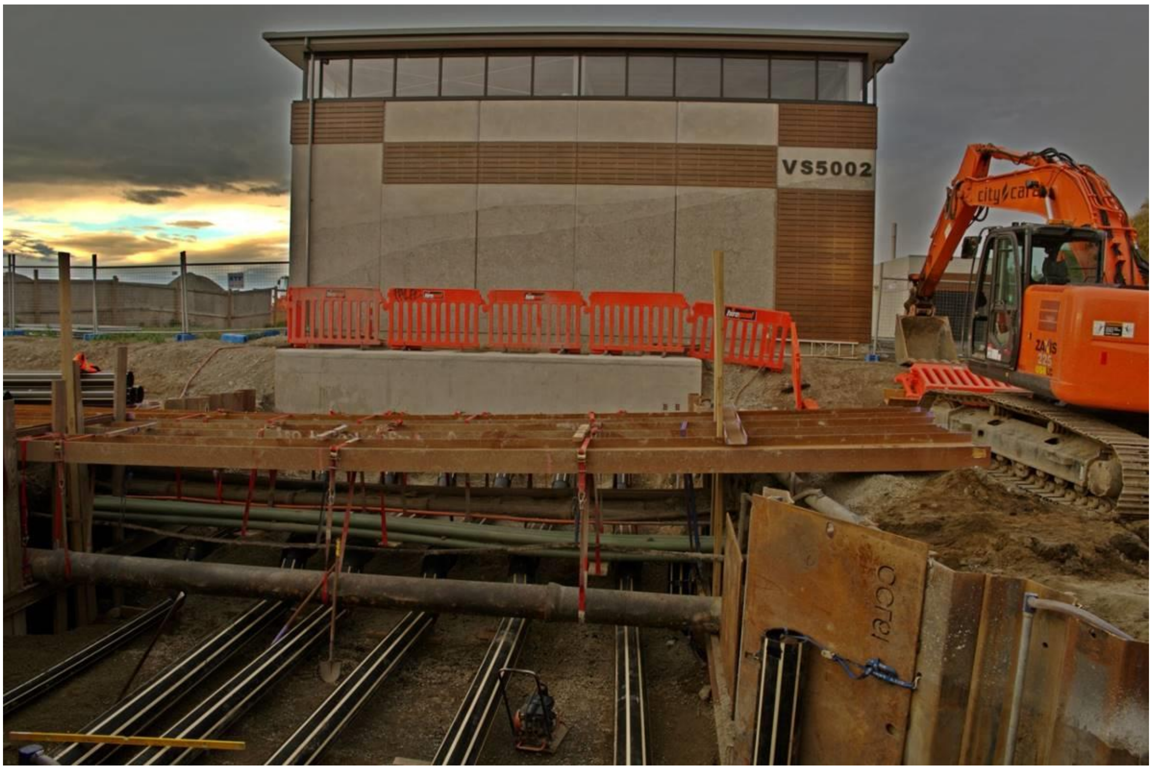

Figure 5 Vacuum Pump Station and Incoming Vacuum Mains

1.6 VACUUM SEWER SYSTEM SUPPLIERS

As the system is proprietary and there is limited industry knowledge it is critical that the vacuum supplier is involved at the earliest stage of a project. The suppliers offer a range of services such as design, design review, commissioning procedures and sign off etc. that are essential to the success of a project.

During the initial evaluation of the standards etc. two vacuum suppliers were selected as they had the appropriate experience.

2 VSS DESIGN

2.1 DESIGN STANDARDS

The following design standards were used in the design and construction of the VSS:

- Water Services Association of Australia WSA-06 – Vacuum Sewerage Code of Australia and Christchurch City Council Approved Addendum

- Airvac Design Manual (2012)
- Water Environment Federation (WEF), Alternative Sewer Systems, Second Edition

Although these standards cover most of the requirements for designing, constructing and commissioning a VSS, the vacuum suppliers provide additional guidance that is critical to the success of the system.

2.2 CONCEPT DESIGN

Following the requirements in the IRTSG, in the concept design stage a whole of life Net Present Value (NPV) assessment was completed for extensively damaged wastewater catchments comparing the following wastewater options:

- Like for like (replacing the damaged infrastructure as is)
- Enhanced gravity (tractive force theory) with lift and pump stations
- Pressure Sewer Systems (PSS)
- Vacuum Sewer Systems (VSS)

The whole of life Net Present Value (NPV) included an indicative cost for the resilience of each system in terms of cost to repair post-earthquake. PSS were seen to be the most resilient due to the pipework being shallow and not affected by changes of grade. VSS were considered to be less resilient to PSS as the vacuum mains require a minimum grade and with ground movement may require repair, although the vacuum mains are typically shallow (depth of 1.5 to 1m). Enhanced gravity was less resilient than PSS and VSS as the pipes require a grade, with deep pipes and would typically require lift and pump stations. The resilience of each system was estimated in the NPV assuming that aftershocks would occur in the future and that each system would require some cost to repair.

Initial communication was held with the vacuum suppliers to confirm that the catchments were appropriate for VSS i.e. length of vacuum mains, vacuum main diameters, vacuum station pumps, vessel size, lifts, flow rates, etc.

Typically VSS become more economical against PSS in large catchments due to the high capital cost of a vacuum pump station.

The operational and maintenance expectations are well defined in the WEF for typical VSS installations and were used to estimate the cost of maintenance and operational expenditure for the whole of life NPV.

2.3 DETAILED DESIGN

At the beginning of detailed design a VSS supplier was selected, as each supplier provides different componentry that need to be allowed for in the design and they provide a review of the design, as well as guidance on risks and deviations to the design standards. The VSS componentry and some functionality is proprietary therefore it is critical to have supplier involvement at the earliest stage.

As there were no existing CCC details for VSS a proportion of the design time was spent working through technical details and gaining acceptance from the Asset Owner Representative and the CCC Technical Representative.

The vacuum pump station location was determined first as this needs to be located centrally to ensure that the vacuum mains do not exceed the maximum of 4m lift.

2.3.1 FLOWRATES

During initial investigations into the use of VSS it was agreed with the Asset Owner Representative and CCC Technical Representative to use the CCC Infrastructure Design Standards (IDS) for design flow rates and peaking factors.

The design flow rates were calculated using the methods outlined in the IDS using the CCC Living Zone requirements (zoning requirements current at time of design in 2012) with no reduction in the wet weather flow allowances. Where properties have the potential to subdivide under the Living Zone requirements the additional flows were accounted for in the design.

It was expected that as the system is shallow and sealed that the inflow and infiltration (I&I) effect would be less than in a gravity system, therefore using the IDS peaking factors is a conservative approach. The damaged private laterals that connect to the VSS were identified to be outside of SCIRT's scope to remediate and were highlighted as an inflow and infiltration risk in the design stage. To better understand the risk to the system CCTV was undertaken to identify damaged laterals that are likely susceptible to inflow and infiltration, with CCC following up with the home owner to remediate.

2.3.2 AIR TO LIQUID RATIO

The air-to-liquid ratio is described in the WSA Code and the Airvac Design Manual and is used in the equation to initially size the vacuum pumps. The air-to-liquid ratio used in the sizing equation has been empirically derived by Airvac (a VSS supplier) and is based on the length of the longest vacuum main within the catchment:

Vacuum Generator Capacity, Q_{vp} (m^3/hour) = 3.6 x Air-to-liquid Ratio x Maximum Flow (l/s)

The air-to-liquid ratio is critical to ensure efficient runtimes of the vacuum pumps and consistent vacuum throughout the system. Too much air can result in long runtimes of the vacuum pumps and loss of vacuum (in the worst case), whereas too little air results in waterlogging of the system which causes loss of vacuum and sluggish performance of the system.

The vacuum pipework size and saw tooth profile have been empirically developed (see Airvac Design Manual) to ensure that within the vacuum pipework there is an open passage for air between the vacuum station and each vacuum valve when operating at the design flows. This enables consistent vacuum and service throughout the catchment, see below:

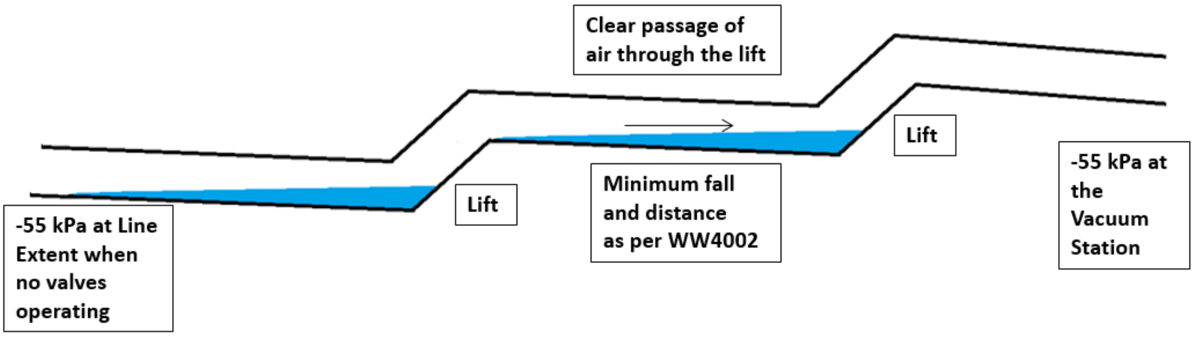

Figure 6 Vacuum Main Lift Principal

The amount of air entering the system is dependent on the wastewater flow entering into the chamber and the vacuum valve opening time. When approximately 40 litres of wastewater enters the chamber the vacuum valve opens and once the wastewater has been evacuated the valve closes. During the closing phase, air enters into the system. The valve close time can be adjusted on the valve controller to suit. Typically the controllers on valves closer to the vacuum station are adjusted to have a shorter close times due to the expected higher vacuum at the sites and a subsequent higher air inflow rate.

In operation the air-to-liquid ratio can be calculated by using the formula below:

$$\text{Air/Liquid} = \frac{m^3/\text{hr of air}}{m^3/\text{hr of wastewater}}$$

2.3.3 EMERGENCY STORAGE AND MAINTENANCE RISERS

As the vacuum pump station has no high level overflow, emergency storage is required within the collection chamber and gravity laterals, therefore if the system shuts down there is enough time for the operators and maintenance team to respond. 12 hours dry weather flow emergency storage was provided at each collection chamber.

To help with the recovery of the system during an emergency, access points to the vacuum mains called maintenance risers were designed and placed around the catchment in strategic locations. The maintenance risers were designed for a standard vacuum truck to connect to the system and evacuate the wastewater.

2.3.4 COLLECTION CHAMBERS

The VSS suppliers offer a pre-fabricated plastic collection chamber that have been designed to house the vacuum valve and associated componentry. These were selected to be used in the majority of situations as they reduce the need for bespoke chambers and additional design. The chambers were specified using the Water Services Association of Australia WSA-129, Industry Standard for Plastic Collection Tanks for Pressure and Vacuum Sewers. Each VSS supplier's collection chambers and associate componentry are different and these were considered during the design.

The collection chambers were supplied with cut outs for the gravity laterals and hole saws were provided to ensure that any connections into the collection chambers were watertight.

Bespoke concrete lids were designed to be placed on the top of the collection chamber to make the chamber trafficable with the lids bearing on the backfill therefore not loading directly onto the plastic collection chamber.

As the VSS catchments are in areas of poor ground conditions, high ground water and susceptible to liquefaction, the backfill around the collection chambers were designed to resist additional liquefaction uplift forces in an earthquake. The backfill around the collection chambers were designed to have high void backfill, therefore during an earthquake the additional pore water pressures from the liquefied ground would be able to be released through the high void backfill and into the top of the collection chamber and to reduce the risk of floatation.

2.3.5 COLLECTION CHAMBER MONITORING SYSTEM

A monitoring system was considered for each individual collection chamber which includes a high level float switch and valve open/close sensor. This was discounted due to the high capital cost and limited operational benefit as concluded in a whole of life cost NPV analysis. The NPV analysis used conservative maintenance frequencies as identified in the Water Environment Federation, Alternative Sewer Systems, Second Edition.

The vacuum valves have been designed to fail open therefore in the event of failure loss of vacuum will be noted at the vacuum pump station via an alarm (due to long vacuum pump runtime). To find the failed vacuum valve takes the operator time by systematically isolating division valves around the catchment and reading the vacuum pressure until the vacuum valve is located and fixed. The main benefit of a monitoring system is the reduced operational time to locate the failed vacuum valve.

2.4 CONSTRUCTION

The construction teams were responsible for the construction and construction monitoring of the projects at SCIRT, with the design team providing design assistance for requests for information, scope changes, non-conformances, technical guidance etc.

At the beginning of construction the design team coordinated with the construction team to pass over the experience learnt during the design stage and to identify key construction requirements.

During construction of the VSSs the land zoning changed as part of the wider recovery strategy for Christchurch, which allowed for intensification around parts of the city including the two VSS catchments. As such the Asset Owner Representative requested that a hydraulic performance assessment be undertaken once the system was completely connected to ascertain the spare capacity in each system. A masterplan was also created to help CCC identify areas of spare capacity and keep track of development in the VSS catchments.

2.5 COMMISSIONING

Typically VSS are commissioned (house laterals and valves connected) in stages as houses are developed. As the VSS replaced an existing gravity catchment it was commissioned as soon as vacuum arms (sub catchments) were installed. The existing gravity system was badly damaged and required significant operational and maintenance tasks to keep running while the VSS was being constructed, therefore the VSS was commissioned as soon as practicable.

3 CHALLENGES AND LESSONS LEARNT

There are no examples of retrofitting existing gravity wastewater catchments with a VSS post-earthquake, as typically they are installed on green field sites or retrofitting septic tanks where there is evidence that environmental regulations are not being met. Additionally there is no documented papers etc. that highlight the risks in doing this.

While risks were highlighted in the design stage some risks that were not apparent became reality.

A description of the key challenges and lessons learnt can be seen below.

3.1 INSTALLATION OF VACUUM MAINS AND LATERALS

During the handover stage some vacuum mains were identified to have been designed and installed incorrectly. Pressure transducers were placed around the catchment and the data was analysed by the vacuum supplier to better understand the risk to the system. As a result there was a loss of vacuum due to pipes having a negative grade and wastewater ponding in the pipe creating a loss of vacuum. As such vacuum mains were replaced and installed to the required grades. Additionally some vacuum laterals were installed in a similar manner causing local loss of vacuum at the collection chamber with some valves losing vacuum.

It is critical that vacuum mains and vacuum laterals are designed and installed to the grades as per the design standards. As the minimum grade is 1:500 care is required in installing the vacuum mains to this grade. It is also critical that before a lift there is 15 m of 1:500 grade pipe directly upstream, unless a sequence of lifts is designed. This is to ensure that vacuum pressure is distributed throughout the catchment as the vacuum main size and lifts have been empirically sized to ensure an air gap exists (as can be seen in Figure 6).

3.2 COLLECTION CHAMBERS

Both VSS suppliers offer a pre-fabricated plastic collection chamber that houses the vacuum valve and associated componentry and includes cut outs for gravity laterals. In some circumstances the VSS suppliers` chambers were not be the right solution due to high flows needing multiple valves or additional emergency storage required. Where a supplied chamber could not be used for practical reasons a bespoke chamber (typically a precast concrete manhole) was designed, although strict design parameters were adhered to including a review and involvement of the VSS supplier.

During the operation of the system some bespoke chambers were identified to have operational issues. On further inspection of some of these chambers it was identified that they did not follow the design parameters. The vacuum valve and associated component is made of multiple parts and it is important that they are installed in the correct way, as a small change can cause the valve to not operate as designed, which can lead to overflows.

The photo below shows a bespoke double valve chamber that did not function as specified and with significant fat build up.

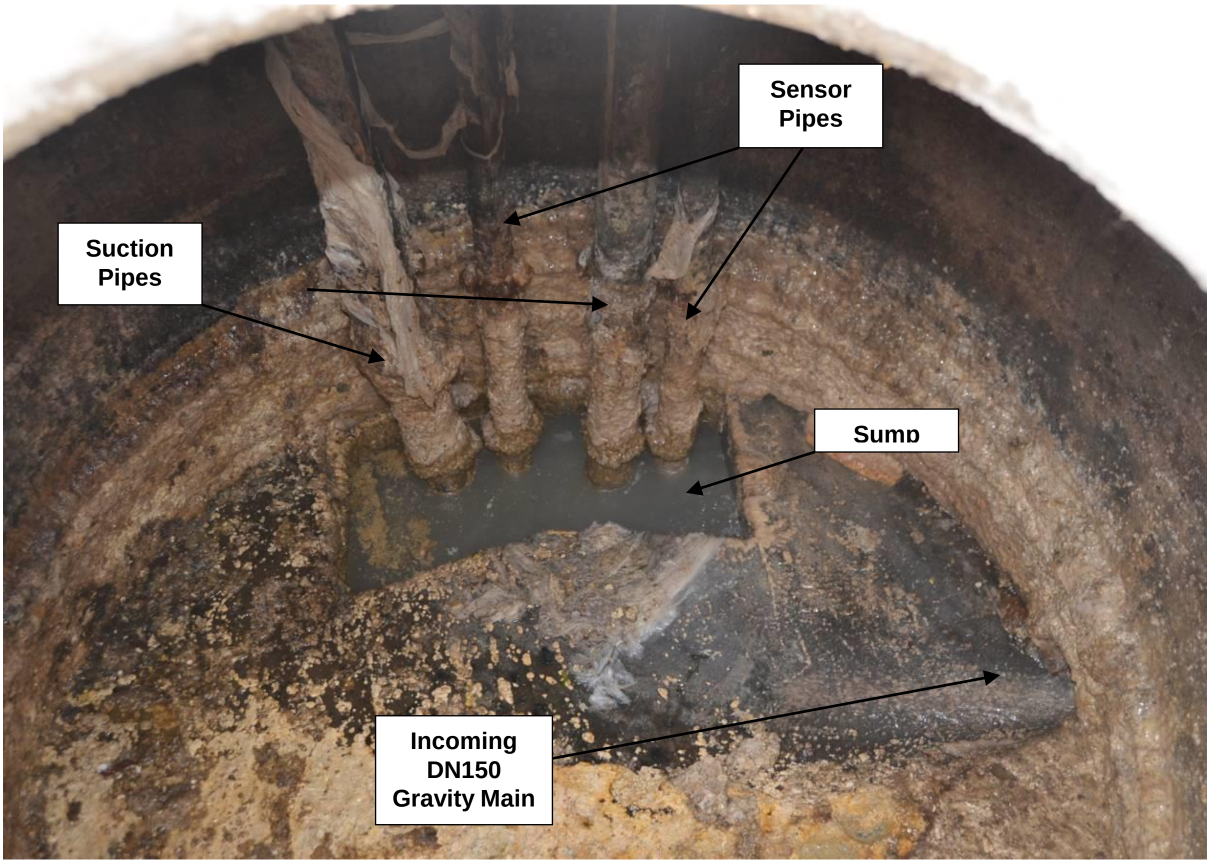

Figure 7 Bespoke Collection Chamber after Approximately 1 Year of Operation

The VSS supplier's fabricated plastic collection chambers have been designed so the vacuum valve is easily accessible from the frame and cover. During installing of the collection chambers some of the chambers were installed deeper than designed which impeded the access to the valve and would require a greater maintenance effort to access.

During the hydraulic performance assessment some chambers had been identified as having infiltration through some of the collection chambers pipe penetrations, additional inflow was identified getting into the top of the chamber through the gap between the manhole lid and collection chamber that had been designed to relieve excess pore water pressure during an earthquake. During wet weather the groundwater in parts of the catchments was at ground level and water free flowed into the top of the chamber and into the sump dramatically reducing the performance of the system.

It is critical that all connections into the collection chambers are sealed to prevent infiltration through the chamber and into the system as these flows can significantly reduce the performance of the system.

Figure 8 Infiltration Through a Duct into the top of the VSS Collection Chamber

3.3 EXISTING SERVICES

Collection chambers were indicatively located in the berm during design with the construction team to confirm on site during construction. The collection chambers and valves are recommended by the supplier to be inspected once a year and potentially may need to be accessed by an operator more frequently, therefore the collection chambers were indicatively located within the berm to provide safe access. There were multiple existing services throughout the berms therefore in some circumstances due to economic reasons some chambers were located in the road. Some examples of existing services can be seen in Figures 9 and 10 below.

Figure 9 Existing Services in the Berm Potholed Prior to Location of a Collection Chamber

Figure 10 Vacuum Mains Installation in Close Proximity to Existing Services

3.4 INFLOW AND INFILTRATION

The vacuum sewer system is a sealed system from the collection chamber to the vacuum station although the gravity laterals from the house to the collection chamber in Christchurch made up approx. 80% of the reticulation length. The private property laterals make up approximately 65% of the reticulation length. The risk of inflow and infiltration through damaged private property laterals was highlighted during detailed design and all the private property lateral where CCTVed to identify damaged laterals.

During the tuning of the system (reducing the air flow at each collection chamber to match expected air-to-liquid ratio) the flowrates from the Vacuum Stations were reviewed during wet weather to better understand spare capacity. At this stage it was identified that there was significant inflow and infiltration, further investigation identified that at some collection chambers a flowrate of 1 l/s was observed, while a peak wet weather flow of 0.14 l/s was allowed for in design.

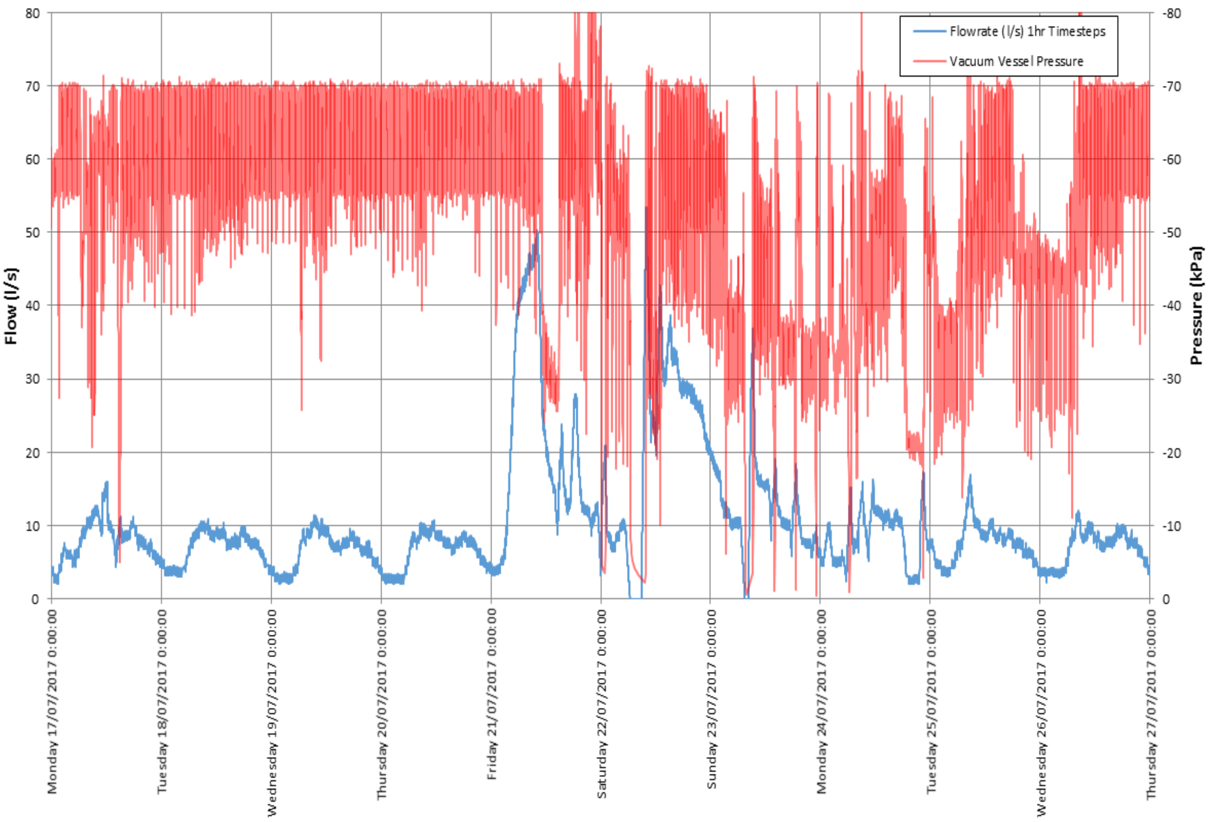

Figure 11 Graph Showing the Flowrate and Vacuum Pressure at the Vacuum Pump Station VS5001 During Wet Weather

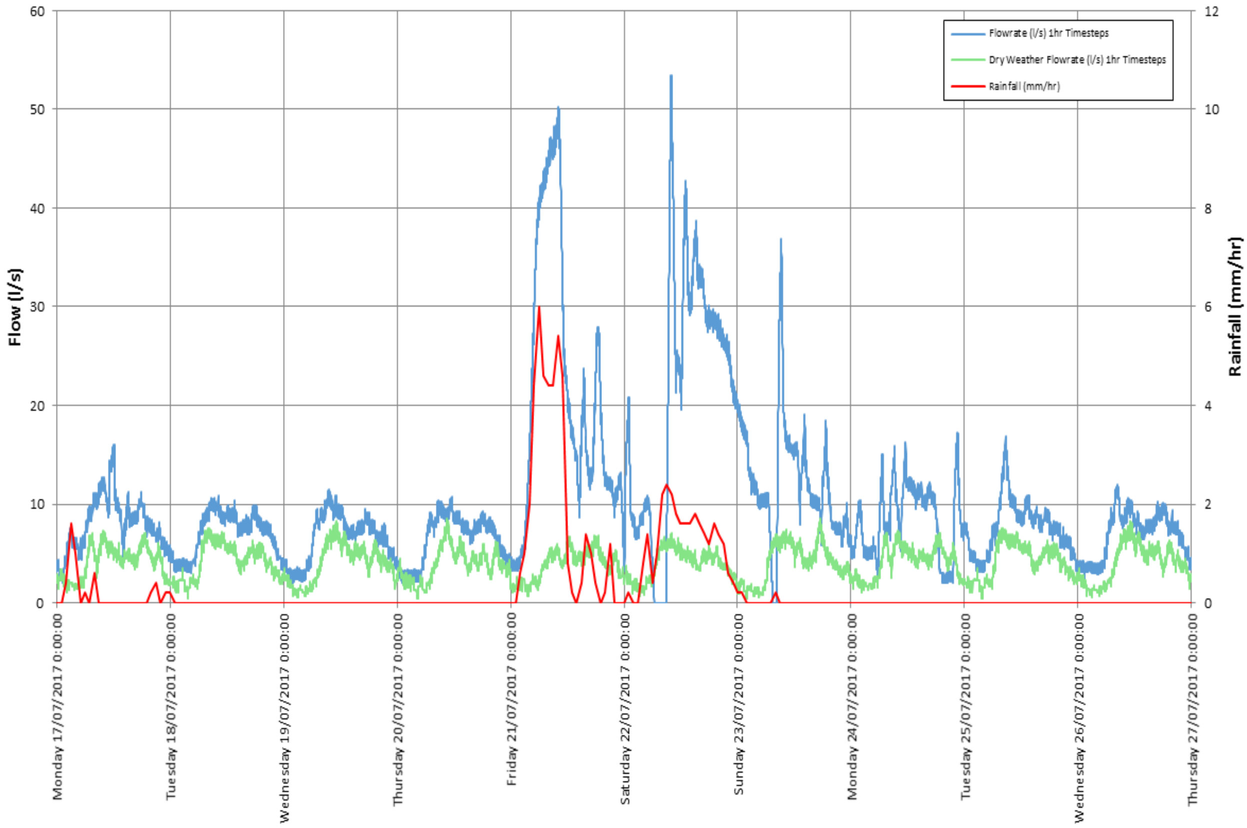

Figure 12 Graph Showing the Flowrate at the Vacuum Pump Station VS5001 and Rainfall during Wet Weather

As can be seen in Figure 11 and 12 it is evident that the additional wet weather flow is predominately inflow. As identified in Section 3.2 the inflow was predominately through high groundwater getting into the system over the top of the collection chambers. Additionally as identified in the hydraulic performance assessments of the VSS groundwater does infiltrate into the system through the damaged laterals and can have an impact on the systems performance.

Where flows into the collection chambers and through the vacuum valves exceed the design allowance there are risks to the system. These risks can be seen below:

- Waterlogging of the vacuum mains causing reducing vacuum pressure in the network
- Potential loss of service to parts of the catchment
- Higher vacuum pump runtimes
- Irregular air to liquid ratio
- Sluggish system performance
- Rapidly reduce the storage time within the chamber and laterals if the valve fails closed or the system goes down and increases the risk of overflow

As the system is dynamic these risks are dependent on many factors, the main one being the amount of inflow and infiltration flow into individual collection chambers.

Where waterlogging of the vacuum mains occurs there is currently no way an operator can be alerted to the waterlogging and loss of service at the line extents.

Additionally as inflow and infiltration was entering the system in specific areas the system could go down in certain areas and be fine in others and at the vacuum pump station still appear to be within the designed limit.

As identified in Section 3.2 it is critical that during the design stage areas where inflow and infiltration can get into the system need to be considered, as these flows can significantly reduce the performance of the system.

3.5 AIR TO LIQUID RATIO OBSERVATIONS

Figure 13 shows the air-to-liquid ratio during wet weather flow. The 'solid' green line is the air-to-liquid ratio and the 'solid` blue line is the flow.

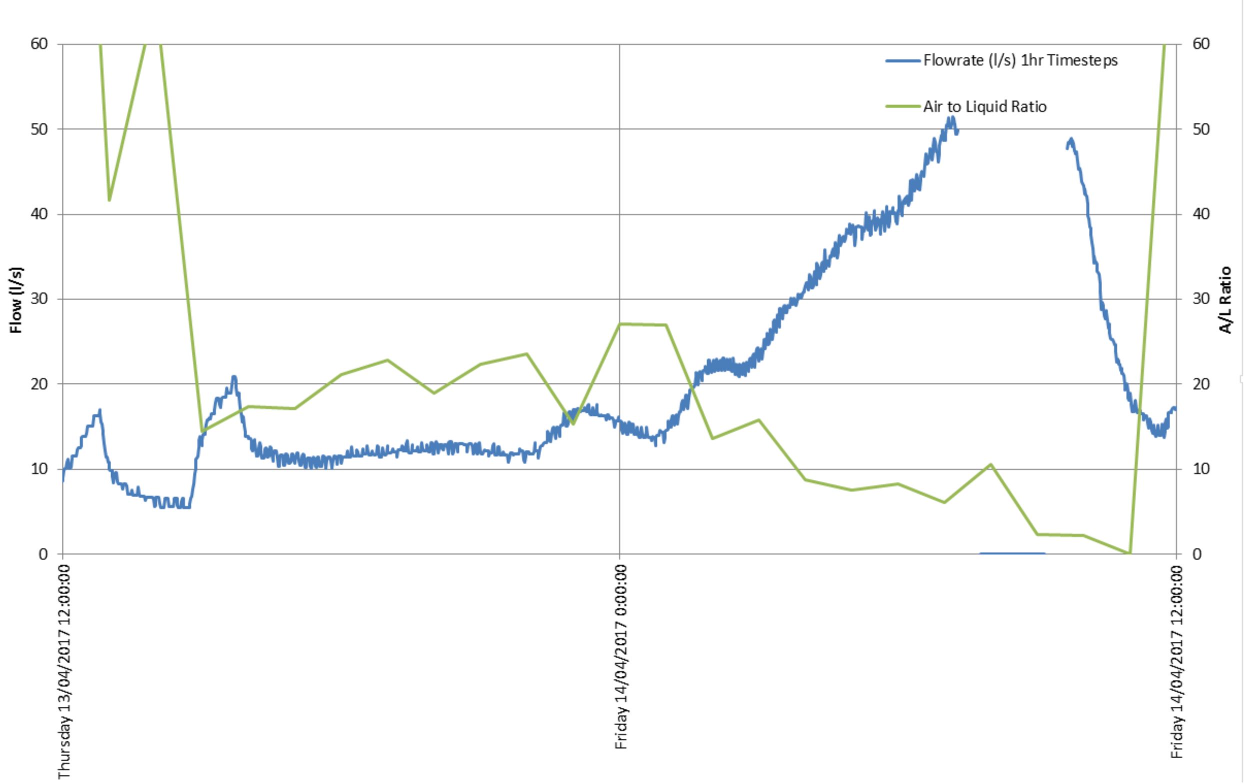

Figure 13 Air to Liquid Ratio and Flowrate at the Vacuum Pump Station VS5001 during Wet Weather Flow

What has become apparent through observations of the system is that:

- The air-to-liquid ratio changes with flowrate (and is variable based on flowrate into the collection chambers)
- Typically the air-to-liquid ratio will reduce as the wastewater flowrate increases and increase as the wastewater flow reduces
- When the wastewater flow is at or above the design maximum flow the air-to-liquid ration is reduced to approximately the design air-to-liquid ratio
- The air-to-liquid ratio described in the WSA-06 should be for the maximum wastewater inflow to ensure system operation throughout the catchment, and

therefore during dry weather flow the air-to-liquid ratio will be higher than the design value

- The air-to-liquid ratio is only an indicator of the system's performance. Because it is calculated at the Vacuum Station, it does not take into account areas where higher than the designed inflows enter the system and the local air-to-liquid ratio could be significantly lower

During concept design an assumed air to liquid ratio was used to calculate the vacuum pump runtimes and the subsequent power consumption which was included in the whole of life NPV. The actual air-to-liquid ratio may be higher than the air-to-liquid ratio used to size the vacuum pumps and this should be allowed for in the whole of life NPV.

3.6 AUTOMATIC AIR ADMITANCE SYSTEMS (AAASS)

Both vacuum suppliers offer an AAAS that can detect low vacuum within a vacuum main when for example flows higher than designed enter the system, and allows additional air to be introduced into the system to reduce the risks noted in the section above.

The AAAS comprises of pressure transducers located at the end of every vacuum arm and at the vacuum station and special vacuum valve controllers that can operate a valve when low vacuum is detected (typically two per arm). The system uses wireless repeaters to link the pressure transducer and vacuum valve controllers back to the Vacuum Station.

While an AAAS will reduce the risks to the system during wet weather flow the introduction of additional air may reduce the vacuum pumps ability to handle the maximum flow although this risk is higher without an AAAS installed.

After the hydraulic performance assessment it was recommended that both systems require an AAAS to reduce the risks to the system from inflow and infiltration. It was agreed that the AAAS would be designed and installed in each VSS catchment by CCC.

3.7 SPARE CAPACITY

Before the system was connected it was expected that as the system is sealed that there would be spare capacity as about half of the flow was assigned to wet weather flow.

Once the system was completely connected the hydraulic performance assessment identified that there was limited spare capacity during wet weather flow and that the wet weather flow was predominately from infiltration through damaged private gravity laterals.

Spare capacity should be allowed for in the system for future development and the actual flowrates (including dry weather and wet weather flow) should be confirmed once the system is fully commissioned to quantify spare capacity for future developments.

3.8 OPERATION

Anecdotal evidence as provided by the operational and maintenance contractor can be seen below:

- Higher call outs for valves failing open
- Fats build up in collection chambers (see Figure 7)
- Fats blinding the air water separators (between the vacuum pumps and vessel)

- Long vacuum pump runtimes
- Inflow and Infiltration
- Failed controllers

It is generally accepted that when a system is first commissioned that a higher frequency of calls outs is expected, therefore to understand the true cost of operating and maintaining the system an assessment needs to be undertaken once the system has been in operation for a couple of years.

3.9 COLLECTION CHAMBER MONITORING SYSTEMS

Monitoring of each individual chamber was not recommended during design based on a NPV and using the conservative information in the WEF to estimate operational and maintenance frequency and operational requirements (power consumption, renewals, etc.).

During operation the increased frequency of call outs experienced by the maintenance contractor along with the risks of infiltration and areas of operational concern (areas with fats getting into the system) potentially would better warrant a monitoring system to be installed, to reduce the risk of overflows.

While the collection chamber monitoring system was not recommended during design at SCIRT, CCC are installing a monitoring system in each VSS catchment to reduce the risks to the system that are identified in this paper.

4 CONCLUSIONS

It is concluded that:

- Further work is required to evaluate the design and construction cost benefit of VSS in comparison to other standard and alternative systems in a retrofit situation and to evaluate the actual operation and maintenance efforts
- Vacuum supplier input is critical to the success of a VSS project and reviews should take place throughout the design and construction phases. Additionally a high level of construction monitoring is necessary as the system componentry and requirements are complex and requires careful construction
- The air-to-liquid ratio described in the WSA-06 should be for the maximum wastewater inflow to ensure system operation throughout the catchment and as the air to liquid ratio changes with flowrate, during dry weather flow the air-to-liquid ratio will be higher than the design value
- Infiltration and inflow through damaged laterals and collection chambers (including pipe penetrations) can have a significant detrimental effect on the system. Inflow and infiltration will not be spread evenly throughout a catchment. Where high inflow and infiltration exceeds the design allowance the following risks have been noted:
    - Potential loss of service to parts of the catchment
    - Higher vacuum pump runtimes
    - Irregular air to liquid ratio

- Sluggish system performance
- Rapidly reduce the storage time within the chamber and laterals if the valve fails closed or the system goes down and increases the risk of overflow

Automatic Air Admittance Systems (ASSS) can be incorporated into the VSS as a tool to reduce the risks identified above.

ACKNOWLEDGEMENTS

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REFERENCES

Airvac Design Manual (2012)

Christchurch City Council, Infrastructure Recovery Technical Standards and Guidelines (IRTSG)

Christchurch City Council, Infrastructure Design Standards (https://www.ccc.govt.nz/consents-and-licences/construction-requirements/infrastructure-design-standards)

Heiler, D, and Cameron R (2014) Practitioners Guide to Building Resilience into Infrastructure Networks, Water New Zealand Conference, 2014

Pedersen, G.W. and Tse, N.K (2011) 'NZ's First Vacuum Systems - Selection and Operation' Water New Zealand Conference, 2011

Water Environment Federation (WEF), Alternative Sewer Systems, Second Edition

Water New Zealand, Infiltration and Inflow Control Manual Volumes 1 & 2 (2015)

Water Services Association of Australia WSA-06 – Vacuum Sewerage Code of Australia and Christchurch City Council Approved Addendum