PRESSURE SEWER APPLICATIONS IN COMMERCIAL DEVELOPMENTS

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ABSTRACT

The application of pressure sewer technology has been increasingly used in Christchurch following the earthquakes of 2010/11. In general, these applications have been limited to residential applications, through the rebuild of damaged infrastructure in highly liquefaction prone areas or the replacement of septic tanks in small communities on Banks Peninsula. Pattle Delamore Partners (PDP) were engaged by a large commercial land developer to investigate options for servicing of approximately 40 Ha of industrially zoned land in south west Christchurch. The investigation incorporated developing concept designs for gravity reticulation and pressure sewer reticulation options. A significant challenge associate with pressure sewer was the requirement that the proposed network would be able to service the maximum permissible density of development under the City Plan zone rules. This was approximately 6 times the density of development envisaged by the developer at completion of the development. A flexible pressure sewer design concept was devised by PDP which would meet the require design parameters for both the minimum and maximum possible design density scenarios. This was achieve which still meeting the key criteria with respect to self-cleansing velocities and residence times in the reticulation network for moth the maximum and minimum development scenarios. The proposed concept was a "win-win" for both Christchurch City Council (CCC) and the developer. CCC would save considerable annual operation and maintenance costs associated with the operation of a conventional wastewater network for the development, while the developer saved approximately $1 million in capital construction costs.

KEYWORDS

Pressure Sewer, Commercial Development.

1 INTRODUCTION

PDP were engaged by a large commercial land developer to investigate options for servicing of approximately 40 Ha of industrially zoned land in south west Christchurch. The zoning of the land restricted future activities to those of a "dry industry" nature only, and placed severe restrictions on the production of any trade waste. The local CCC wastewater infrastructure was also relatively constrained with respect to available capacity. Resolving this constraint required that a conventional wastewater network, designed in accordance with Councils Infrastructure Design Standards (IDS), needed to pump a significant distance to by-pass the local constriction or, alternatively, a significant upgrade of the local infrastructure was required.

This paper will focus on the options investigation approach taken by PDP to develop and recommend a solution which was essentially a "win-win" scenario for both the developer and CCC. This was achieved through the mimimisation of up-front construction costs to the developer and also on-going operational and maintenance costs incurred by CCC through the lifecycle of the infrastructure to be adopted.

Pressure Sewer technology has been used increasingly in New Zealand over the last 10 years with a number of systems installed within rural residential communities to replace ageing and failing septic tank systems. Higher densities of development can impact on the cost effectiveness of pressure sewer system, as the supply of the individual pump units are a significant component of the capital cost of such a system and these costs increase linearly with increasing number of lots serviced.

Following the earthquake events of 2010/11 in Canterbury, much effort has been expended by Christchurch City Council (CCC) and the Stronger Christchurch Infrastructure Rebuild Team (SCIRT) into the investigation of resilient infrastructure for the conveyance of wastewater. One of the technologies approved for use in the most liquefaction prone areas of Christchurch has been pressure sewer systems, with plans for some 6000 residential installations having been approved by CCC. The small diameter welded PE pipelines are particularly resistant to damage as a result of land deformation. The area of the subject site is located over shallow gravels with deep groundwater, hence liquefaction risk is very low and pressure sewer would not normally meet the necessary criteria for approval under the IDS.

2 OPTIONS INVESTIGATION

2.1 SUBJECT SITE

The site in question was a 40 ha block of business zoned land in south west Christchurch. A significant portion of the block, approximately 6.5 ha, was designated as part of the future Southern Motorway corridor and would not be developed for commercial purposes. The zoning allowed for general business type activities within the development area; however there were site specific rules which restrict the production of trade waste from the development. Essentially, the development was restricted to less than half the equivalent residential wastewater flow allowance for an equivalent area.

The trade waste rule reflected a known restriction on capacity in the downstream network at the time of the Plan Change. During the Plan Change process, the available capacity in the immediate downstream wastewater network was estimated to be approximately 6 l/s. This was based on an IDS calculation of the zoned area contributing to the existing local sewer network, relative to the total conveyance capacity of the pipeline. The inclusion of the restrictive trade waste rule in the Plan Change was agreed, between the hearing commissioner, Christchurch City Council (CCC) and the developer, as a tool to enable the development of the land with a very low level of wastewater production, but with sufficient triggers to require an upgrade of the downstream infrastructure should the land develop in a more intensive manner.

In order to develop the site, the developer had to ensure that the 6 l/s flow restriction was not exceeded. Alternatively, to permit greater discharge allowance, the immediate restriction would have to be by-passed with new infrastructure, or the restricted infrastructure upgraded. PDP was engaged to investigate the infrastructure options available to allow for a less restricted wastewater connection.

Figure 1: Site location with location of sewer restrictions

2.2 SERVICING OPTIONS AVAILABLE

The earthquakes, and their after effects, have not only caused significant damage to the wastewater network in Christchurch, they have also forced CCC to take a serious look at alternative methods of providing wastewater reticulation, which may be more resilient than the traditional approaches that have been prevalent in the city. In the past, Christchurch has been serviced by conventional wastewater reticulation systems. This has involved the laying of gravity collection pipelines at relatively flat grades to regional pump stations which, in turn, pump the wastewater to larger trunk pipelines that convey the wastewater to Bromley. These gravity pipelines were typically laid at depths of 1.5 to 4m below ground level, before discharging to a pump station. This type of wastewater reticulation has proven to be particularly difficult and expensive to repair, following earthquake damage, due to the depths of many of the pipelines and the high levels of groundwater that pre-dominate the region. In response to this, CCC has been investigating alternative reticulation methods for repair of the existing wastewater network, and for construction of new reticulation in rebuild areas and greenfield developments.

These alternative methods can be split into three options:

- Enhanced Gravity Reticulation
- Pressure Sewer Reticulation
- Vacuum Reticulation.

Enhanced gravity reticulation involves the laying of gravity pipes at depths of no greater than 3m deep, and having lateral connections from properties at depths of no greater than 2.5m. This will result in a significantly larger number of pump stations to service an area, in comparison to the traditional method of gravity reticulation. CCC has adopted the use of “Lift Stations” to reduce the financial implications of the additional pump stations. These lift stations are essentially enlarged manholes with a pump located in the invert which lifts the flow up to higher gravity sewer exiting the chamber. This exiting sewer also acts as an internal overflow in the event of pump failure.

Pressure sewer reticulation involves the location of a small pressure pump chamber, within the private property, with a short length of gravity lateral from the building to the pump chamber. Wastewater is then pumped into a network of small diameter, shallow, polyethylene (PE) pressure pipelines to a discharge point in the Council trunk wastewater network. Pressure sewer reticulation is generally suited to residential or commercial applications where the composition of the flow is of a domestic nature i.e. toilets and washbasins. They are particularly suited to areas where there is a relatively low level of flow being produced over quite a large area, such as a rural-residential or a "dry industry" area where the flows and number of pumps are relatively low and the catchment area is relatively large.

Vacuum sewer reticulation involves wastewater gravitating from approximately 4 lots to a common collection pit located in the road berm. From here it transitions, via an actuating valve, into a network of shallow pipes which are laid in a "sawtooth" profile and operate under a vacuum pressure. The movement of air through the pipes carries the wastewater over a series of "sawtooth" lifts to a central vacuum station. From here it is pumped to the trunk sewer system. Vacuum reticulation is generally considered more economically viable where there are a relatively large number of connections to offset the high costs associated with the vacuum pump stations. It was therefore not considered suitable for this development due to the relative small number of connections.

2.3 SERVICING OPTIONS INVESTIGATED

Two options were selected for detailed investigation. These were an enhanced gravity sewer option, which was the CCC preferred solution for the development, and a pressure sewer option. The pressure sewer option would present significant challenges due to the CCC requirements to allow for potential future intensification within the development, while also allowing for acceptable operation of the relatively low number of connections from large site footprints expected on completion of the development.

2.3.1 ENHANCED GRAVITY SEWER OPTION

The enhanced gravity option for the subject site involved a reticulation network of 225mm gravity sewers draining to a pump station located at the north eastern end of the site. The minimum Infrastructure Design Standard (IDS) requirement for gravity sewers in a business zoned area, at the time of the investigation, was 225mm diameter.

The rules of the Plan Change required that, the flow form the development to the immediate CCC sewer network needed to be restricted to 6 l/s to match the available capacity in the sewer. The rule also allowed for the downstream network to be upgraded or for a connection to by-pass the existing restriction and discharge further downstream. If this option was taken, then an increased wastewater allowance of 0.09 l/s/ha from the proposed development area would be acceptable. Based on an IDS calculation, and assuming an average sewer flow of 0.09 l/s/Ha, the pump station would therefore need to be designed to pump a maximum design flow of 13 l/s. This would require a proposed DN125 PE100 pressure main which would need to discharge to the existing 300mm diameter gravity sewer, a distance of approximately 1000m downstream of the subject site. This route involved crossing at least two private sites, and a railway line, to gain access to the connection point. The proposed site reticulation layout for this option is shown in Figure 2.

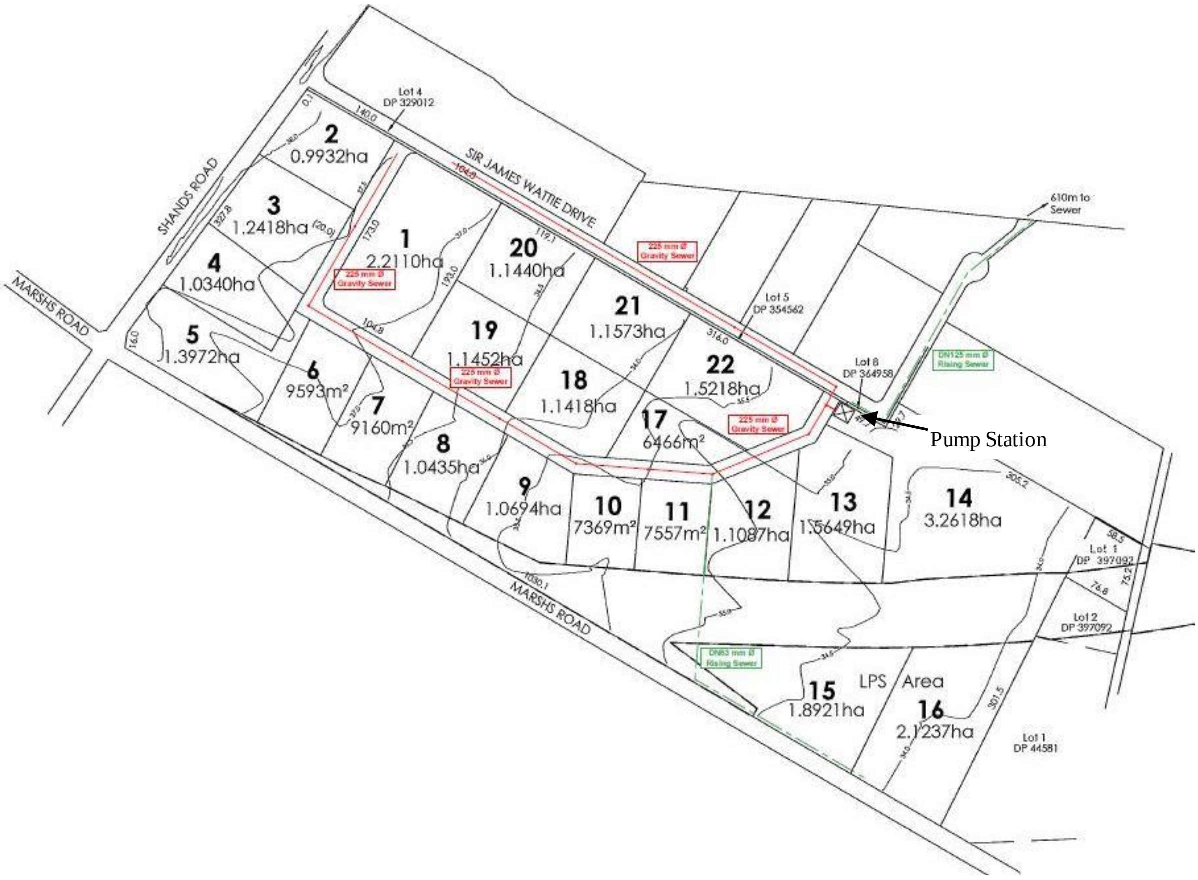

Figure 2: Enhanced Gravity Concept Design

2.3.2 PRESSURE SEWER OPTION

An alternative to the installation of an enhanced gravity sewer system within the subject site was to install a pressure sewer system. There are a number of advantages to a pressure sewer system, in that the pipes are typically small diameter, and laid in shallow trenches or directionally drilled. The design principles of a pressure sewer system are quite different to those of a gravity sewer system, as the pipelines are sized according to the probability of a maximum number of pumps operating at any one time. There are key criteria that need to be met with respect to maximum and minimum flow velocities, system head and residence times within the pipelines. This would provide significant challenges to this proposed site, as the development plan envisaged a relatively small number of large (1 to 4 ha) sites. While this would normally be quite easy to design, CCC also required that the proposed network would be able to service the maximum permissible density of development under the City Plan zone rules. This meant that the proposed network would have to achieve the required performance for network velocity and residence times while servicing anywhere from 22 to 60 industrial lots.

In response to this challenge, PDP created a concept design of a pressure sewer solution for the Sir James Wattie Drive site. This concept generally used a DN63mm PE pipeline to convey the flow from the lots through to the CCC sewer at Canada Crescent, with a dual DN63mm main used along the main spine pipeline of the development in order to cater for potential future changes of use. It was anticipated that only one of these pipelines will be operational once the development is completed. If further subdivisions, or significant changes of use, were to occur, then the twin mains would be made operational as required by the simple operation of a single valve for each. To test the proposed concept design and ensure that would meet the requirement of CCC with respect to potential future intensification; a number of development scenarios were tested. A key design parameter of each of these scenarios was that the peak flow from the development was not to exceed 6 l/s.

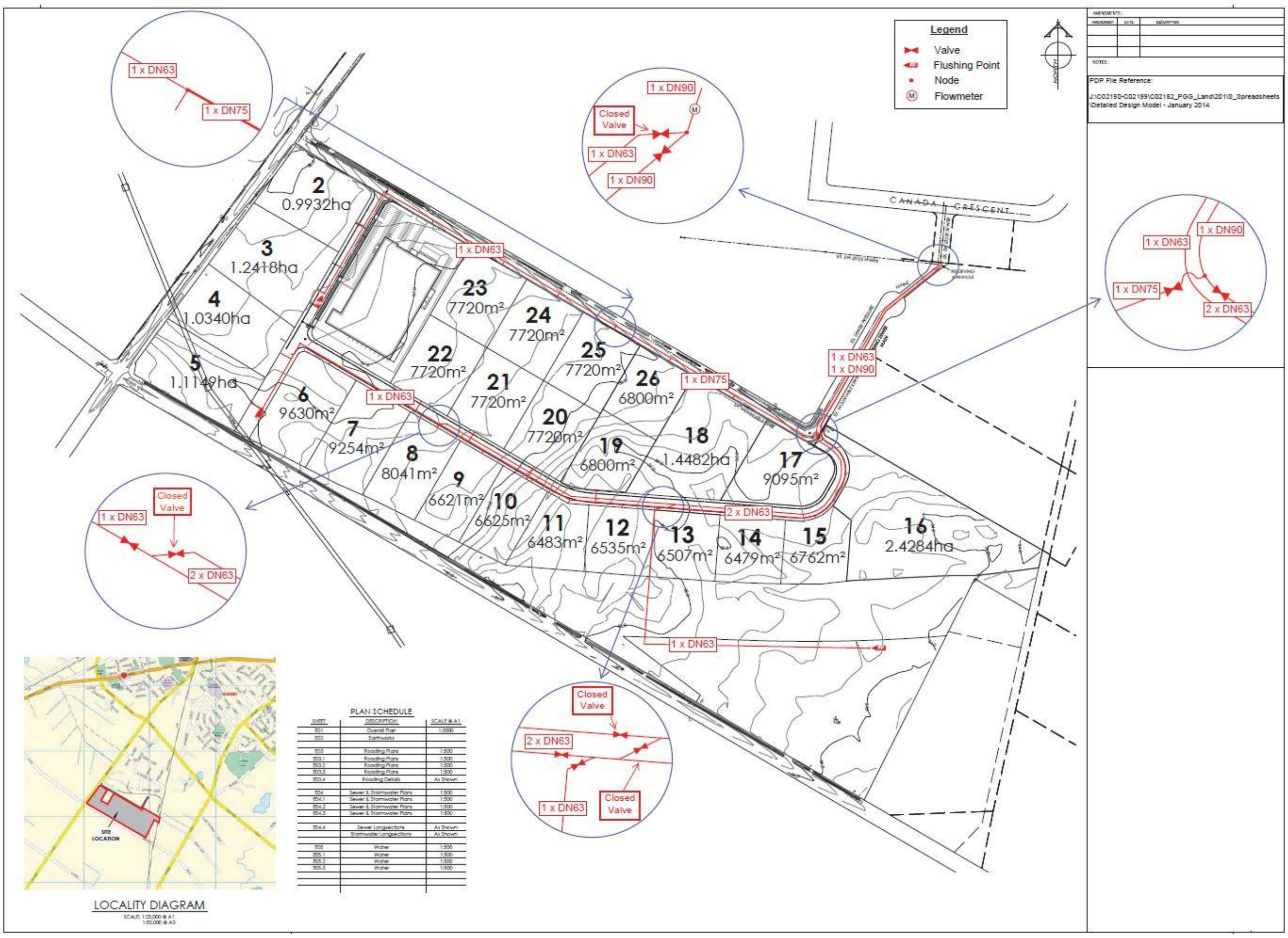

Figure 3: Pressure Sewer Concept Design

2.4 DEVELOPMENT SCENARIOS TESTED AGAINST PRESSUER SEWER CONCEPT

The first scenario was a low density development of approximately 22 lots, ranging in size from 1 ha to 3.9 ha. This scenario was the completed development envisaged by the developer and assumed that each developed lot was serviced by a single simplex pump unit. This scenario would represent the anticipated density of development within the block, where the businesses are typically very large scale warehouse and distribution activities and have a relatively low employee to area density.

The second scenario looked at a much higher density of development, which could conceivably occur under the zoning rules, but would not typically be the type of subdivision that the developer would seek to carry out. This scenario assumed that each of the 22 lots in Scenario 1 further subdivide into approximately 5000m^2 lots. The scenario created a total of 63 lots within the development. It allowed for more of a mix of development occurring with some "dry" manufacturing businesses, which would not require as much area per lot as the businesses in Scenario 1.

The third scenario looked at a possible ultimate development scenario, which could be catered for by the proposed concept reticulation design. This development scenario essentially applied a scaling factor to scenario 2 to look at the maximum number of pump units which could be serviced by the proposed reticulation, while still remaining within the critical design standards outlined above. This scenario assumed that up to 135 pump units were located within the development either as simplex units via duplex pump units.

The concept design would need to meet the key criteria of minimum self-cleansing velocity, and residence time for all scenarios in order to be acceptable. Residence time was important as excessive residence times can result in septicity occurring in the wastewater. This results in the production of Hydrogen Sulphide which produces odour issues and can lead to harmful acid attack within the downstream gravity network.

2.4.1 DESIGN PARAMETERS USED

A spreadsheet was designed for each scenario to calculate flow, velocity, head loss, accumulative head loss and average residence time for each pipeline section within the network based on the maximum number of pumps in operation. Many New Zealand applications for pressure sewer, including SCIRT installations in Christchurch, have been designed based on the E-One design software. Using this system, the maximum number of pumps operating simultaneously is calculated using the E-One design manual which tabulates a correlation between the number of pumps present in a system and the maximum number of those pumps that are likely to be operational at any time. This relationship is displayed below in Table 1. This table is the basis of the E-One design philosophy, and is currently being used by SCIRT to size pressure sewer systems for residential and commercial areas. The table is based on analysis of approximately 58,000 pump operations over a 307 day period in a pressure sewer system in Albany, New York. It was extrapolated out for larger systems using the probability method and its reliability has been proven through the operation of hundreds of large and small pressure sewer systems over the last 20 years (E-One, 2008). Network modelling could also be used, however as this particular investigation involved looking at a broad range of operating scenarios, rather than a specific scenario, it was felt that modelling would have limited benefits.

Number of Grinder Pump Cores Connected	Maximum Daily Number of Grinder Pump Cores Operating Simultaneously
1	1
2–3	2
4–9	3
10–18	4
19–30	5
31–50	6
51–80	7
81–113	8
114–146	9
147–179	10

Table 1: Maximum number of grinder pumps operating daily

The area analysed in Albany was predominantly a residential area, so some further analysis was required to ensure that the design principles outlined above, would be appropriate for use in the dry industry application proposed at the subject site. In a residential area, this flow would occur in a diurnal pattern with a high morning peak and another evening peak. Hence, it is during either this morning or evening peak that the likelihood of simultaneous pump operations is highest. Figures 4 and 5 represent typical residential and 10-hour commercial water use over an average day (without irrigation). Figure 5 is sourced from the CCC North West zone water supply model and Figure 4 is sourced from the CCC water supply modelling specification. While these graphs are representative of flows in the water supply network, they are considered to be an accurate representation of typical wastewater profiles for residential or commercial connections, as they represent an instantaneous water supply flow measurement at the connection point. The graphs represent scaling factors which would be applied to average flows over a 24 hour period to calculate flow rates over that period. It can be seen that the maximum scaling factor for residential demand is approximately 2.0 and occurs for a very short time during the morning peak. The maximum scaling factor for commercial demand is 2.25, and this occurs over a prolonged period during the business day. This would suggest that there is a higher probability of pumps operating during the business hours in a commercial setting than during the relatively short morning peak in a residential setting. It is therefore considered that, for an equivalent daily volume of wastewater, the values in Table 4 would under-predict the maximum number of pumps operating when applied to a commercial setting.

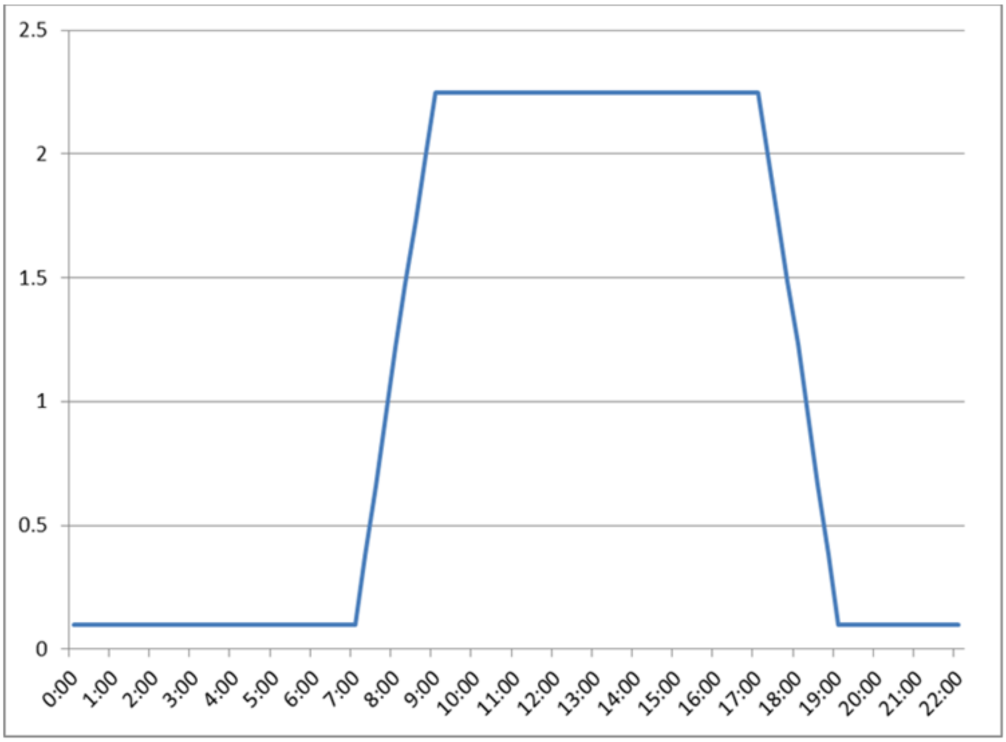

Figure 4: Typical 10-Hour Commercial water use profile

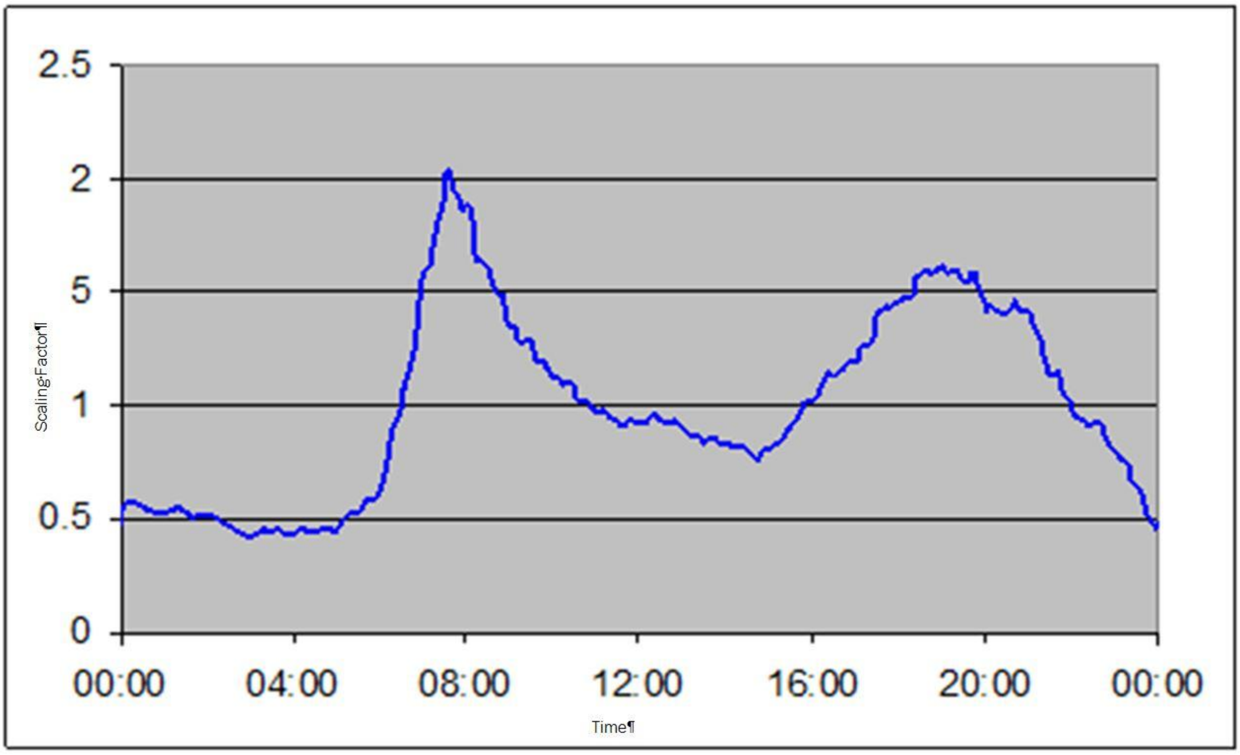

Figure 5: Typical Residential water use profile

It was felt that a factor of safety needed to be introduced to the figures in Table 1 to be more representative of a commercial setting. To achieve this, 25% and 50% reduction factors were applied to the Table 1 figures to give a more conservative range of values to represent the maximum number of pumps operating at any one time. Table 2 below shows the three sets of pump operating figures that were tested against Scenario 3 outlined above to give a suitably conservative ultimate design horizon. This ultimate number of pumps, capable of being serviced by the proposed pressure sewer design, was calculated to be 135 pumps based on a 50% reduction in the E-One design figures.

Maximum Daily Number of Grinder Pump Cores Operating Simultaneously	Number of Grinder Pump Cores Connected E-One Design Manual	Number of Grinder Pump Cores Connected E-One Design Manual -25%	Number of Grinder Pump Cores Connected E-One Design Manual -50%
1	1	1	1
2	2–3	2-3	2-3
3	4–9	4-7	4-5
4	10–18	8-14	6-9
5	19–30	15-23	10-15
6	31–50	24-38	16-25
7	51–80	39-60	26-40
8	81–113	61-85	41-57
9	114–146	86-110	58-73
10	147–179	111-134	74-90
11	180-212	135-159	91-106
12	213-245	160-184	107-123
13	246-278	185-209	124-139

Table 1: Revised maximum number of grinder pumps operating daily

As a further check of the conservatism of the above approach, another approach was also tested was tested. The statistical method used is referenced in the British/European standard BS EN 1671:1 1997 for design of pressure sewer systems. This method uses a Poisson distribution equation to estimate the probability for a certain number of pumps running simultaneously. The equation is outlined below.

$$P = \frac{N!}{R!\,(N-R)!}\left(1-\frac{q_{in}}{q_p}\right)^{N-R}\left(\frac{q_{in}}{q_p}\right)^{R}$$

Where:

P = Probability that a certain number of pumps are running simultaneously.

R = Number of pumps for which P is estimated.

N = Total number of pumps.

q_{in} = Inflow to the pump station.

q_p = Pump flow.

The British/European Standard BS EN1671 requires that, for this statistical method, pressure sewer reticulation systems should be designed for the conditions relative to a 10% probability for the number of pumps running simultaneously. That number of pumps is therefore inferred from the 10% probability value in the right-hand side of the distribution curve. The statistical method was tested for a number of pump ranges and the results suggested that it aligned quite closely with the figures in the E-One design manual, which are detailed in Table 1.

Hence, the approach taken by PDP with respect to estimating of the maximum extent of development which the design could cater for, based on 135 pumps and a 50% reduction on the Table 1 figures, was shown to be suitably conservative. This represented a density of development approximately six times greater than that anticipated by the developer. In this scenario, the maximum flow from the development was expected to exceed 6 l/s infrequently. Based on the statistical method above, the estimated probability of a flow discharging to Canada Crescent which is greater than 6.0 l/s for the ultimate design projection was approximately 9%. It should be noted, however, that the above probability represents the occurrence of a pump run which only has a very short duration. Therefore if a flow of 6 l/s was exceeded, it would only be for very short durations, would be unlikely to coincide with a peak flow downstream, and would be anticipated to have negligible effect on the hydraulic grade of the downstream sewer. In addition, the development density in Scenario 3 was some six times the density anticipated by the developer at the completion of the development, and was not considered likely to occur at any time in the future.

3 COMPARATIVE CONSTRUCTION COSTS

For comparative purposes the capital construction costs of both the pressure sewer installation and the construction of the enhanced gravity reticulation and pump station were estimated. The capital cost associated with the pressure sewer system incorporated the supply and installation of the pump units required for the envisaged development, along with the 50mm and 63mm outer diameter pressure main pipework associated with the reticulation. The capital cost of the enhanced gravity sewer option incorporated construction of the gravity pipelines, at greenfield rates, required to internally service the development to the proposed pump station. The costs of the pump station construction were incorporated, along with the construction of a 1 km long pressure main from the proposed pump station to the existing sewer at a point downstream of the existing restriction. This cost also incorporated costs associated with laying pipes in the public road and crossing of a main trunk railway line.

Of the three servicing options examined, the pressure sewer option was significantly less expensive to construct than the gravity sewer option. Indeed, the construction cost of the pressure sewer system for Scenario 1, which was anticipated to be the most likely density of development, was approximately 27% of the cost of constructing the equivalent gravity sewer system with standard pump station. This represented a saving of approximately $1 million on construction costs.

4 OWNERSHIP MODEL AND OPERATING COSTS

It was intended that the pressure sewer pump units would be owned by the businesses occupying each lot, and therefore CCC would not be responsible for the on-going operation and maintenance costs associated with the pumps. It was assumed that CCC would own and maintain the boundary kits, in a similar fashion to water supply meters. This is a similar ownership model for pressure sewer systems practiced by a number of local authorities around New Zealand for residential pressure sewer systems. This approach also relieved CCC of future responsibility with respect to future changes in use of a property, whereby the new proposed activity required an increase in the volume of storage required to meet the 24 hours emergency storage criteria. For the gravity sewer system options, it was anticipated that CCC would adopt the reticulation and the pump station, as per a normal subdivision, and would therefore be responsible for all associated on-going operation and maintenance costs.

A plot of lifecycle operation and maintenance costs, which would be incurred by CCC, is outlined in Figure 6 below. The operational costs to CCC only involved the replacement of the boundary kits at 25 year intervals, the pump operation and maintenance costs would be incurred by the business owners. The costs associated with the enhanced gravity network predominantly reflected the annual operation and maintenance cost associated with the pump station along with periodic renewal of various pump station components. It can clearly be see that the pressure sewer system would have a relatively negligible ongoing cost to CCC when compared to the equivalent costs associated with the proposed pressure sewer network.

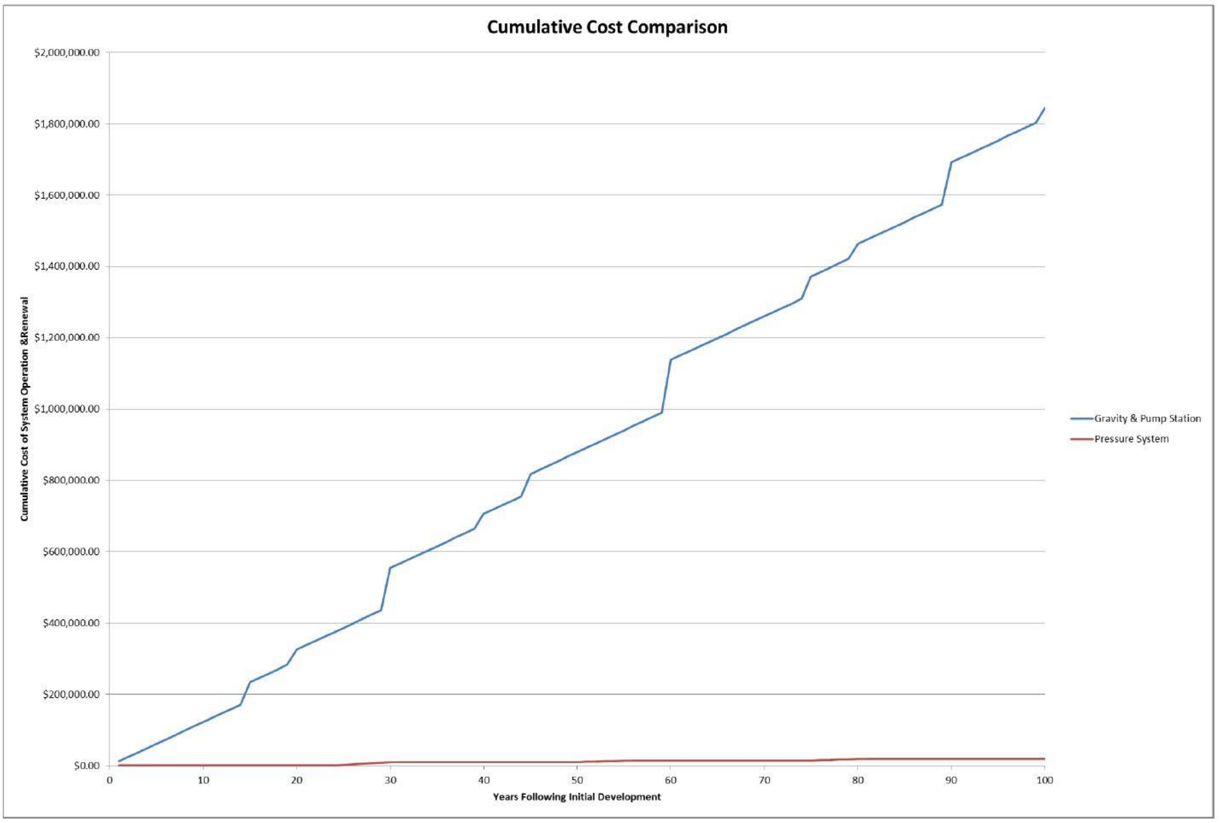

Figure 6: Comparison of ongoing costs to CCC for each option

5 CONCLUSIONS

The options investigation resulted in the recommendation, and acceptance by CCC, of a pressure sewer reticulation system to service the proposed commercial development. The use of pressure sewer for this area was something that CCC did not normally permit under their IDS, however the results of the investigation displayed how use of the technology would be a win-win for both Council and developer. CCC would save considerable annual operation and maintenance costs associated with the operation of a conventional wastewater network for the development, while the developer saved approximately $1 million in capital construction costs. It would also result in better management of wastewater flows as development proceeded. The approach highlighted the cost effectiveness of pressure sewer applications in dray industry applications where relatively low densities of development occur over relatively large areas.

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