OPTIMISATION OF PUMP / STORAGE TO IMPROVE CULTURAL, ENVIRONMENTAL AND ECONOMIC OUTCOMES

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ABSTRACT

Christchurch City Council is currently implementing the design and construction of new pumping, storage and pipeline infrastructure to replace existing wastewater treatment plants (WWTP's) at Lyttelton, Governor's Bay and Diamond Harbour, which will see all wastewater conveyed across to Christchurch City to the Bromley WWTP.

The flows from each of these locations are relatively small however include high levels of inflow and infiltration and reasonably significant projected population growth. Importantly they have flow records of variable quality. The existing WWTPs are alongside and discharge to the harbour coastline, such that the sites are constrained with difficult access. The conveyance distances from each of the WWTP's are significant.

This combination of factors made the determination of pump rate and storage volumes a challenge, let alone determining how they would be optimised to improve cultural, environmental and economic outcomes.

This paper outlines the technical evaluation and project decision making processes adopted to increase confidence in the input information and evaluation method used to decide upon the final size of pump rates and storage volumes. The paper highlights where emphasis was placed in the decision making process in order to achieve the cultural, environmental and economic outcomes sought.

KEYWORDS

Wastewater pump rate optimisation, wastewater overflow, wastewater storage, Lyttelton wastewater

PRESENTER PROFILE

Matthew is a Principal Water Engineer at Jacobs in New Zealand. He has 26-years experience in the water sector, with experience in the wastewater sector ranging from catchment strategy development through to detailed design and implementation, with a particular interest in pumping systems.

Mike Bourke is a senior wastewater engineer at Christchurch City Council. He has 40-years experience in the planning, design and operation of city wastewater infrastructure.

1 INTRODUCTION

Wastewater from the three catchments of Governor's Bay (GB), Diamond Harbour (DH) and Lyttelton (LT) currently flows to local wastewater treatment plants (WWTP's) for treatment prior to discharge to Lyttelton Harbour, through marine outfalls.

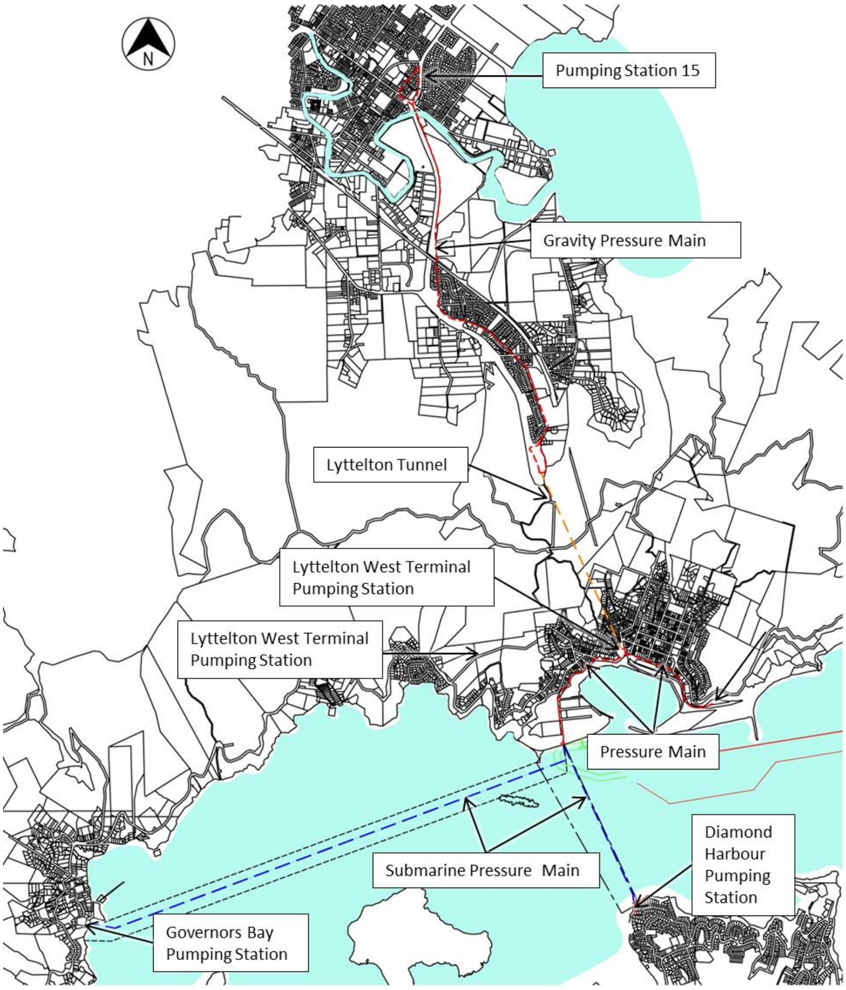
Christchurch City Council's (CCC) long term strategy for management of wastewater in the Lyttelton Harbour area aims to remove all wastewater discharges to the Harbour by collecting and conveying untreated wastewater to Pump Station PS15 in the Woolston area for onward transfer to the Bromley WWTP for treatment and disposal.

The Governor's Bay, Diamond Harbour and Lyttelton Wastewater Project was conceived to achieve this strategy and once completed will result in the construction of:

- pump station and storage facilities at each existing WWTP site
- submarine and land pressure mains connecting pump / storage facilities to a new terminal pump station in Lyttelton near the southern Lyttelton tunnel portal and onwards through the Lyttelton Road Tunnel and to Pump Station 15
- decommissioning of these WWTPs and the cessation of regular wastewater discharges to Lyttelton Harbour

The overall scheme arrangement as planned for implementation is presented in Figure 1.

Figure 1: Lyttelton Wastewater Project Scheme Arrangement



The underlying objective of the project is to remove regular wastewater discharges to the Harbour in order to improve cultural, environmental and social outcomes. An additional challenge was whether economic outcomes could also be achieved.

In order to achieve this objective the design of the scheme required:

1. Critical consideration of wastewater flows, their susceptibility to wet-weather peaking, growth projections to the 2041 design horizon and the reliability of historical flow data

2. Development of pump / storage arrangements to reduce the frequency and magnitude of environmental overflows during wet weather events and to reduce the scale and cost of built infrastructure

3. Optimisation of site designs to make the operation of the scheme 'fail safe'

4. Design-in planned upgradeability

Consultation with Harbour residents and users identified a hierarchy of sensitivity of receiving environments to wastewater discharges which resulted in an objective of providing greater conservatism in design for areas of greater sensitivity.

This paper outlines the technical evaluation and project decision making processes adopted to increase confidence in the input information and evaluation method used to decide upon the final configuration and size of pump rates and storage volumes. The paper highlights where emphasis was placed in the decision making process in order to achieve the cultural, environmental and economic outcomes sought.

A large amount of technical detail has been omitted where it does not directly relate to the objective of this paper.

2 DEVELOPMENT OF DESIGN OBJECTIVES

Critical assessment of factors identified as having the greatest potential to influence the overall scheme arrangement and performance identified the following factors and corresponding design response objectives:

a. Anecdotal evidence suggesting low confidence in wastewater flow records – *this resulted in the need to critically interrogate the flow record and apply further conservatism if uncertainty was confirmed*

b. A limit of 120 L/s that can be received at PS15, while combined peak wet weather flows for the three WWTP's is in the order of 250 L/s - *this resulted in the need for overflow storage during periods of wet weather and determination of whether this be located closer to source or in a centralised location*

c. Recognition that larger diameter and long pipelines and larger pump stations have increased cost and larger stored volume, leading to ageing sewage with increased risk of odour - *this resulted in an objective to reduce pipeline size by reducing pump rate and increasing overflow storage volume*

d. Mitigating the risk of overflow to the harbour in the event of pump station outage - *this resulted in the objective of placing storage at source rather than in a centralised facility and to seek designs that achieved fail-safe operation*

e. Sensitivity of the Governor’s Bay area to wastewater discharges due to impacts on mahinga kai - *this resulted in the objective of applying additional conservatism in the design of the pump / storage facility at Governor’s Bay if this was economically achievable*

f. Limited available space and expensive construction environment at Diamond Harbour and Governor’s Bay WWTPs - *this emphasised the value in maximizing storage, reducing footprint and construction work and optmisation of the layout of both new and existing assets at these sites.*

g. Consideration of what frequency of wastewater overflow may be acceptable from a consenting, environmental and community perspective, given the absence of formal guidelines or standards stipulating this and recognizing the likelihood of a more stringent future requirement – *This resulted in adoption of Council’s pre-existing wastewater overflow consent standard frequency of a 2-year average return interval as a minimum target, but seeking to improve on this where there was less confidence in input data, system performance or where it was cost effective to do so.*

h. Recognising that the construction of a future upgrade project to further reduce overflow frequency or accommodate catchment growth would be even more complex and difficult than the present project, specific consideration was given to how the overall scheme could be upgraded efficiently in future – *This resulted in design of all bulk infrastructure with specific future upgrade options identified*

3 DEVELOPMENT OF THE DESIGN PROCESS

The influential factors and design response objectives identified were then considered and consolidated into the following design process:

1. Review the available historical wastewater flow record for suitability for use as the basis for design and adjust as required following data verification and application of population growth to enable use as a statistical data set for scheme design sizing.

2. Develop an understanding of the maximum “sensible” storage capacity achievable at each site, taking into account site constraints, the economic sense of a “build once” philosophy for key assets and re-use of existing assets due to their remaining useful life and economic value.

3. Develop a pipe size / pump rate / storage volume optimisation model that utilises the adjusted wastewater flow record to achieve the minimum desired environmental overflow frequency whilst utilising the maximum “sensible” storage capacity at each site.

4. Develop a storage facility design that enabled (if possible) gravity flow into and out of facility and a fail safe (no overflow or operator intervention) operation in the event of power or communications failure

Site design and scheme arrangement initially focused on developing arrangements that satisfied the design steps above, then focused on modifications to achieve as many of the identified design objectives as reasonably achievable.

4 HISTORICAL WASTEWATER FLOW ASSESSMENT

10 years of flow record were available for each site and were assessed to determine their veracity, completeness and overall suitability for use as a design data set for the project. This included consideration of data continuity, flow trends, response to weather events and physical site parameters such as flow meter location and ability for flows to bypass the flow meter. The following factors were identified for further consideration:

- There was no evidence that flow meters had been calibrated except for some catchment flow records in Lyttelton, so a conservative approach was adopted when using the flow record

- There is significant inflow observed at Lyttelton and Diamond Harbour, so decisions need to be made on ability to reduce inflow over time and whether design flows assume (or should assume) inflow reduction or not

- Flows can bypass the flow meter at Lyttelton, with no way identified to determine how much flow bypasses during weather events, so additional conservatism and further flow monitoring and assessment was identified as being necessary

Overall it was concluded that given appropriate consideration of the factors identified above, the historical flow records were appropriate for use as a data set for design. It was also determined that use of the flow record provided a more representative and defendable design basis than the conventional approach of using per capita wastewater flows to projected future populations.

Development of the historical flow data set into a design data set required the following:

- Proportionate scaling of historical flows to adjust the 10-year flow record for the 2016 population (2016 adjusted flow data set)

- Scaling of 2016 adjusted flow data set for population increase to the design horizon of 2041 to get an 10-year design flow data set for the projected 2041 population (2041 design flow data set)

When developing the 2041 design flow data set for the catchments with observed high inflow (Diamond Harbour and Lyttleton), the inflow component of the 2016 adjusted flow data set was not reduced, as achieving inflow reduction could be difficult and if not achieved would result in a non-conservative design basis. This also provides Council with an opportunity to gain additional system capacity over time by targeting inflow reduction.

When developing the 2041 design flow data set for catchments with reduced confidence (Lyttelton), the 2016 adjusted flow data set was increased by 20% due to uncertainty of the extent to which peak flows bypass the flow meter at the WWTP. Additional flow monitoring within the catchment was also initiated to enable calibration of a network model to gain a better understanding of whether the 20% uncertainty allowance is appropriate. This work is ongoing and the detailed design will be reviewed once the calibrated wastewater model is available.

Due to the inherent conservatism of the 2041 design flow data set, no further allowance was made for possible climate change effects (increased rainfall and wastewater flows).

The outcome of this process was the development of 2041 design flow data set suitable for use in subsequent analysis to determine minimum pipe size / pump rate / storage volumes for each site and the overall scheme to achieve the minimum desired environmental overflow frequency.

5 MAXIMUM SENSIBLE STORAGE CAPACITY

Determination of the maximum sensible storage capacity at each site required consideration of a broad range of factors and application of engineering judgement and was different for each of the sites as discussed below.

Governor's Bay

Site features meant that construction outside of the existing WWTP footprint and site required earthworks in a hill environment, which combined with the removal of established bush, introduced visual impact and engineering risk.

Re-use of the existing treatment tank, modified to work in a pump / storage configuration was determined to achieve 200 m^3 storage. With minimal work effort and with relatively simple tank wall extensions, this could be extended to 350 m^3 of available storage. Making more storage available than this would require demolition of the existing tank or substantive engineering works.

The maximum sensible storage capacity determined for Governor's Bay was 350 m^3.

Diamond Harbour

Site features meant that construction outside of the existing WWTP footprint and site was not practically or economically feasible due to the site being cut into a rock headland.

The existing treatment tank was determined to be appropriate as foundations for a new bolted stainless steel tank, with 700 m^3 storage achievable based on the existing treatment tank diameter and a 4.5m high storage tank.

Gaining more storage than this would require demolition of the existing tank and removal of spoil offsite or modification of inlet gravity sewers and increased complexity for the pump / storage facility.

The maximum sensible storage capacity determined for Diamond Harbour was 700 m^3.

Lyttelton

Lyttelton was identified as the site with greatest potential to increase storage in future and the least sensitive in terms of overflow discharge locations. The site also receives all flows from Lyttelton and the discharge from Governor's Bay and Diamond Harbour via the town's gravity reticulation if there is a failure of the terminal pump station, reinforcing the site as a strategic location for provision of additional storage.

Site features meant that a new storage tank could be constructed outside of the existing WWTP footprint however the size was limited due to available land and risk of rock fall from adjacent cliffs. A new overflow storage tank with approximately 700 m^3 storage was considered achievable.

Reuse of the existing treatment tank was considered and would provide approximately 1,400 m^3 of storage, however gravity flow back to the pump station was not possible and the tank would be more difficult to clean after use. For these reasons this storage was considered preferable as secondary storage.

It was therefore agreed to provide a new smaller storage tank and utilize the existing treatment tank as the secondary storage tank. In this way, the overflow tank 1 which would be used more frequently could achieve gravity inflow and discharge and be easier to clean after use.

The sensible maximum storage capacity determined for Lyttelton was 700 m^3 for the primary overflow tank and 1,400 m^3 for the secondary overflow tank.

6 PUMP RATE / STORAGE VOLUME SELECTION

Optimisation of pipe size, pump rate and storage volume required development of a model that iteratively optimised these factors across the three sites to meet the installed pump capacity of 120 L/s at the Terminal Pump Station.

At each site, the 2041 design flow data set aggregated into average hourly flow rates (L/s) and the theoretical overflow rate determined for a given pipe diameter and range of pump rates for each averaged hourly flow rate over this 10-year flow data set, where:

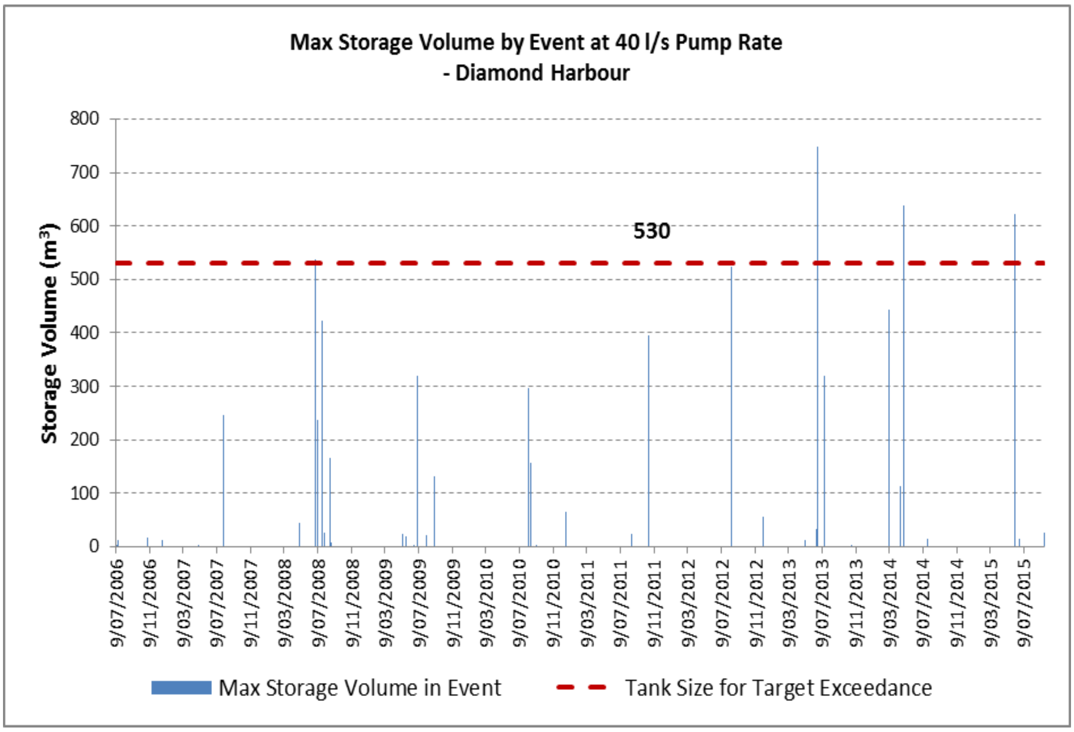
Instantaneous Overflow Rate (l/s) = Flow Rate (l/s) – Pump Rate (l/s)

The maximum storage demand was then determined for each weather event, with the total storage required increasing as inflow exceeds the pump rate, then decreasing, eventually to zero, as pump rate exceeds the inflow rate, with the maximum storage demand being the largest cumulative storage volume determined for that weather event.

The maximum storage demand for weather events across the 10-year data set were then analysed statistically to determine the storage volume with a 2-year Average Return Interval (ARI) of occurrence. This is considered the minimum storage require to provide a 2-year ARI overflow performance for the projected 2041 flows.

An example showing the cumulative storage demand assessed for Diamond Harbour using the 2041 design flow data set with a pump rate of 40 L/s is presented in Figure 2. The 2-year ARI storage volume is indicated by the dashed red line.

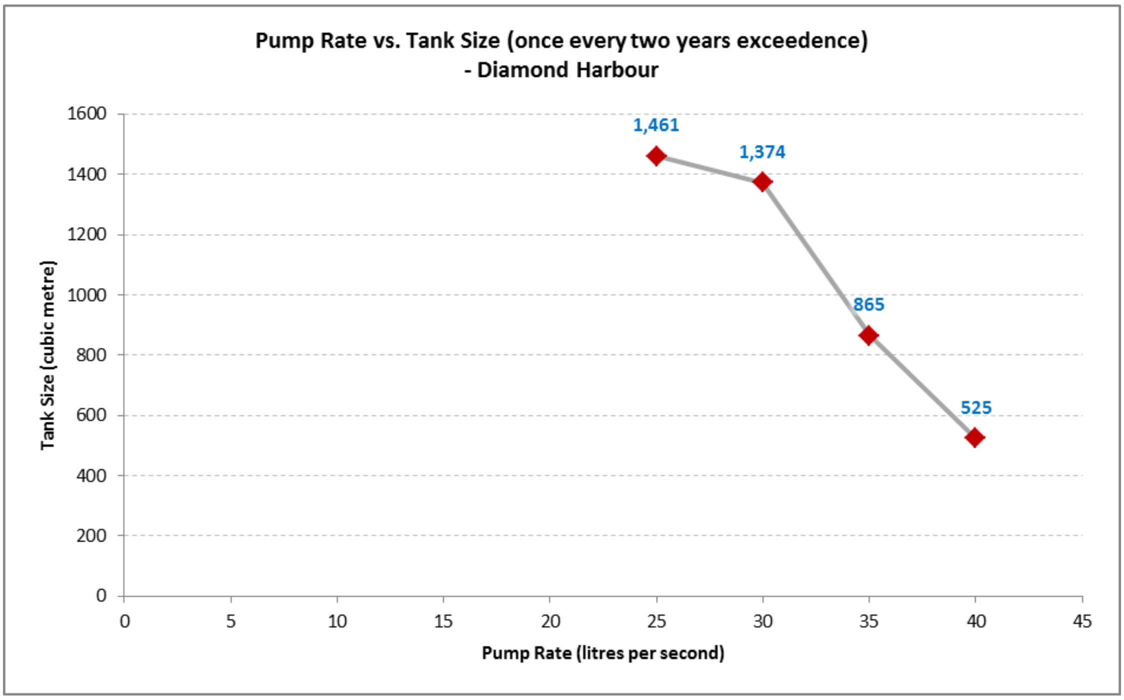
Figure 2: Storage volume required for pump rate of 40 L/s at Diamond Harbour



This process was then repeated for a range of pump flow rates to establish the 2-year ARI pump rate / storage volume relationship at each site.

An example of the 2-year ARI pump rate / storage volume relationship for Diamond Harbour is presented in Figure 3.

Figure 3 : Storage volume / tank size required relationship at Diamond Harbour to achieve a 2-ARI overflow frequency



To determine the selected pump rate and storage volume at each site, the pump rate and storage volume relationship was compared against the maximum sensible storage volume as well as:

- Uncertainty in flow and population projections;
- Uncertainty of flow values;
- Cost to increase storage capacity at Diamond Harbour and Governor's Bay in future; and
- High sensitivity of the Upper Harbour environment.

For the Diamond Harbour example above, the maximum sensible storage volume was determined to be approximately 700 m^3. By inspection with Figure 3, a minimum pump rate of 37 L/s is required with this storage amount to avoid overflows at more regular intervals than the desired 2-year ARI.

When the overall design objectives are considered in conjunction with a desire to be conservative rather than non-conservative, the selected pump rate for Diamond Harbour was increased to 40 L/s and the maximum sensible storage of 700 m^3 storage retained, providing approximately 30% more storage than the minimum determined necessary.

Using a similar assessment for each site, the pump rate and storage volumes selected for the three sites are presented in Table 1.

Table 1: Design pump rate and storage volume

Scheme Area	Pump Rate (L/s)	Storage Required (m^3)	Storage Provided (m^3)
Lyttelton	65	850	2,100
Diamond Harbour	40	525	700
Governor's Bay	15	120	350
Totals		**1,495**	**3,150**

From Table 1 it can be seen that considerably greater storage is being provided than required to reduce overflows to less than a 2-year ARI frequency, however the marginal cost to provide this conservatism was not significant due to the initial determination of maximum sensible storage volume.

7 'FAIL SAFE' OPERATION AND OPERATIONAL OPTIMISATION

The concept of 'fail safe' operation was introduced as a design objective so that specific consideration was given to how the pump / storage facilities would operate and the operational risks they were exposed to. Foreseeable risks including power failure, blockage and mechanical breakdown were considered and where possible, a 'fail safe' design was achieved such that the occurrence of these risks would not result in environmental overflows.

It is acknowledge that complete avoidance of faults that result in the pump stations being in-operable is not possible, hence 'fail safe' design aims to reduce or eliminate the adverse consequences of a range of foreseeable failures, often by changing of design approach to eliminate the components at risk of failure. Such an approach often results in simplification of processes and assets.

Due to the height of the sites above sea level, the risk exposure due to tsunami was considered low, however at Diamond Harbour, the electrical equipment was placed in an elevated located as a precautionary measure.

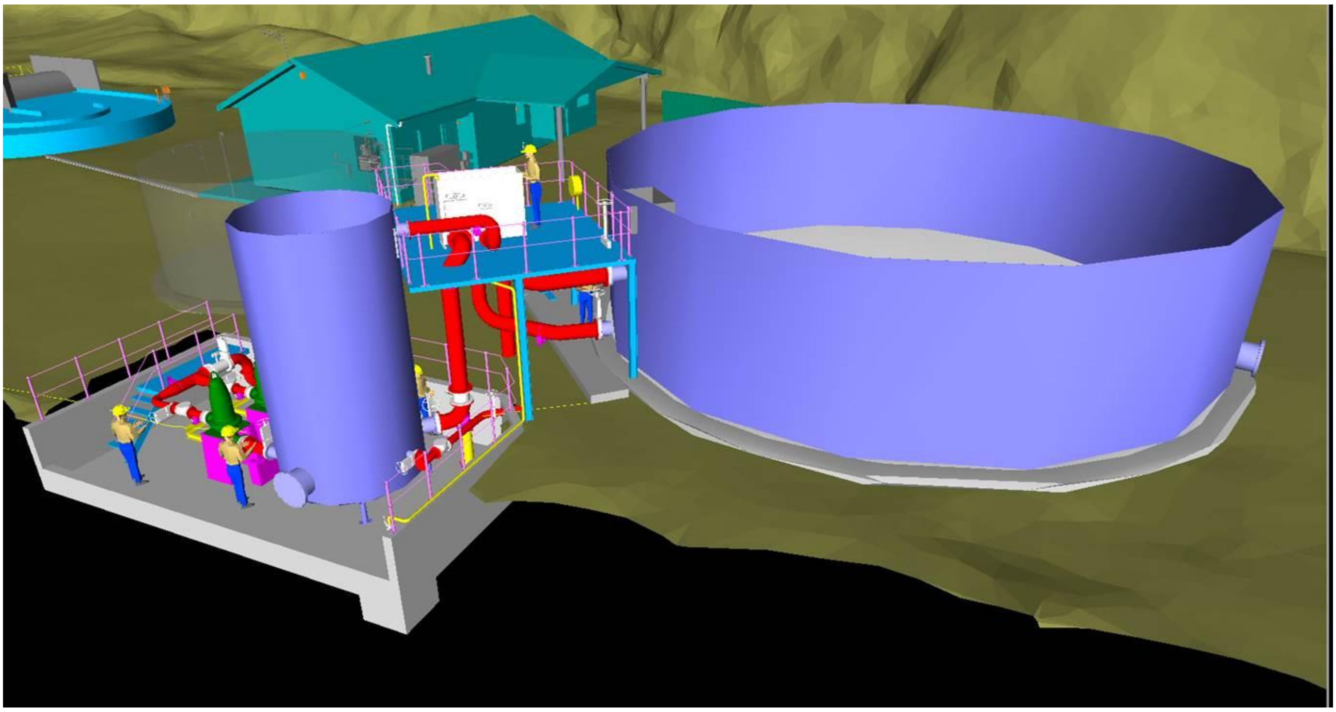
This process resulted in the development of a number of key design features that combined provided significant mitigation of effects from the identified risks including:

1. Gravity flow into and out of overflow tanks

All sites have wastewater arriving via pressure main or elevated gravity main. This allowed for adoption of an above ground wet well, 6m in height, which enabled gravity overflow into and out of the storage tank.

A 3-D perspective of the resulting general arrangement for the Lyttelton pump / storage facility is presented in Figure 4.

Figure 4 : General arrangement of the Lyttelton pump / storage facility



Additional benefits gained from this configuration include:

- 30 m³ of storage provided in the wet-well before overflow considerably reduces the frequency of use and need to clean the overflow tank

- Adoption of a bottom inlet, trapped top outlet and low vertical flow velocity enables settling of solids and trapping of floatables, eliminating the need for mechanical screening of overflows to the storage tank. This sedimentation / trapping process was repeated on the overflow tank, eliminating the need for mechanical screening all together.

2. Use of a flow splitter box

Flow splitter boxes were developed that enable the incoming flows to normally flow to the wet-well, however in the event of wet-well overflow for any reason, flows return from trapped wet-well outlet to the splitter box then pass to the storage tank. If the storage tank overflows, flows return via the splitter box to the harbor outfall.

In the event of blockage of any of these branches, flows will overtop the internal weir within the splitter box, activating the next sequential component without need for valve actuation or operator attendance.

Responses to the identified risks are as follows:

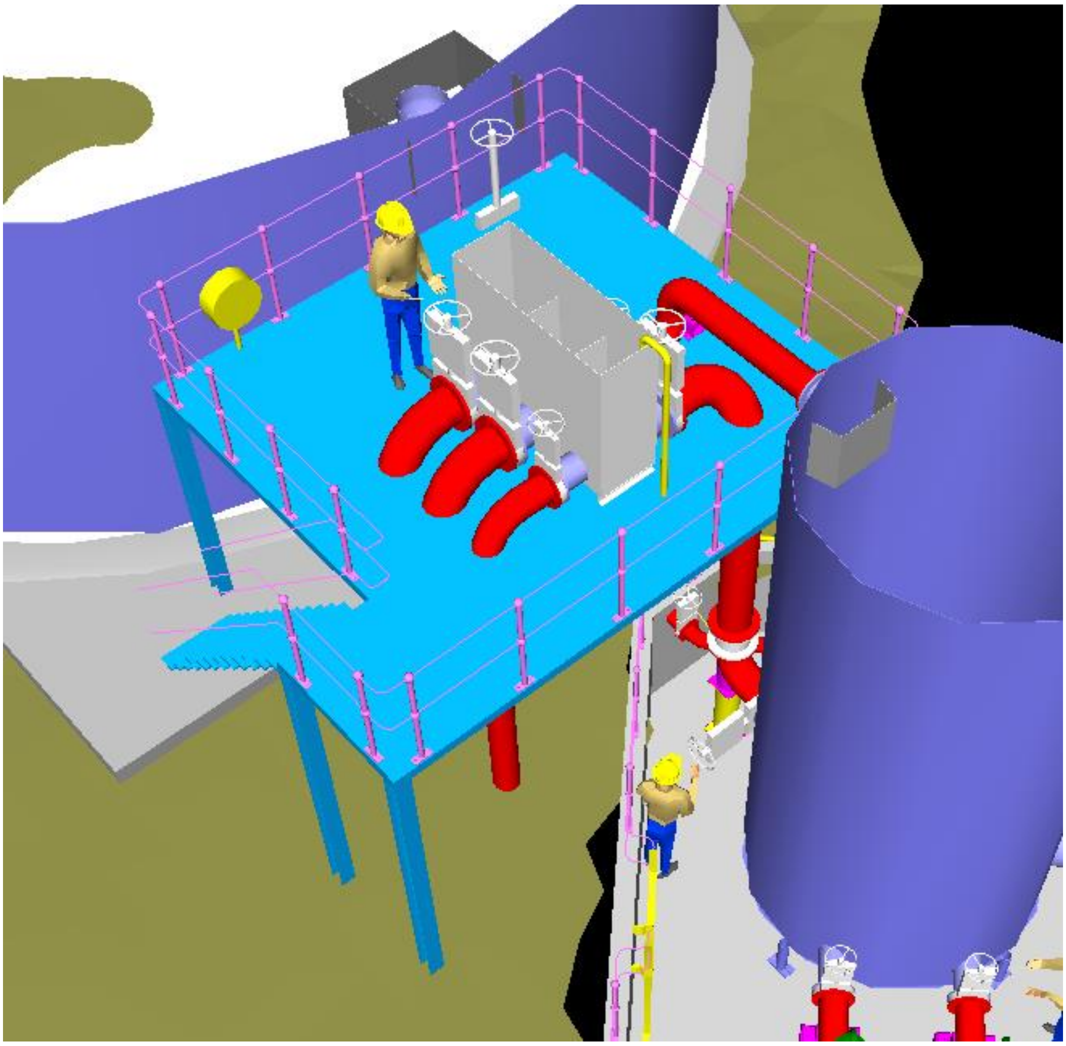
- Power outage or pump failure – flows fill wet-well, overflow via splitter box to storage tank, overflow via splitter box to harbor once all storage utilised

- Blockage to wet-well or from wet-well – flows over-top internal weir and flow to storage tank, activating built storage

Additional operational benefits include visibility of all flow routes and the ability to isolate any component of the facility.

A 3-D perspective of the resulting flow splitter arrangement is presented in Figure 5.

Figure 5 : General arrangement of the Lyttelton pump / storage facility



8 PLANNED UPGRADABILITY

Planned upgradeability has been incorporated into the design of all major infrastructure components of the project as well as the overall scheme to ensure that viable and cost effective upgrade options are possible in future, to account for growth increase, more stringent environment performance or other changes that might arise. Examples of specific upgrade provisions include:

- Design of pipelines at velocities in the order of 1.0 m/s, sufficient to reduce sedimentation risk yet enabling future velocity increase
- Oversize of pump station intake and outlet pipework to enable future velocity increase
- Placement of spool sections in pump station pipework to enable larger pump replacement
- Power supply sized for larger pump replacement or running of standby pumps in assist mode
- Utilisation of bolted stainless steel storage tanks that can be extended in future
- Provision for a 4th pump at the Simeon Quay terminal pump station

9 CONCLUSIONS

This paper provides an overview on how a complex design process with risk of not meeting environmental, cultural and economic objectives was structured to assess and manage identified risks and to provide conservatism where required or beneficial.

The use of a reviewed and adjusted historical flow record was demonstrated to provide greater confidence in the sizing of infrastructure components than use of traditional per capita flow contributions. Use of this to generate a synthetic design flow series enabled utilization of statistical methods to establish minimum pump rate / overflow storage arrangements.

The development of the concept of *maximum sensible storage volume* enabled consideration of many risks and opportunities at each of the sites when determining one of the highest cost and most difficult to upgrade components of the project.

The objective to manage cultural and environmental sensitivities enabled placement of additional conservatism in more sensitive areas, reducing the risk of non-compliance and the risks associated with that.

The focus on 'fail safe' operation lead to the development of innovative 'fail safe' designs for critical components, reducing risk of overflows to the environment and achieving greater operational reliability and ease.

Finally, the attention paid to planned upgradeability has left future asset owners with clear and cost effective upgrade pathways.

ACKNOWLEDGEMENTS

Christchurch City Council project staff including Mike Bourke, Roy Kingswood and David McLernon.

Papers reviewers including Jim Bell, Glenn McDougal, Ian Garside, David Cobby and Ben Pritchard.

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