ALL DRESSED UP AND NO PLACE TO FLOW, A $25 MILLION OUTFALL

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ABSTRACT

A major stormwater upgrade to the pipe network passing through the Ports of Auckland land was required to reduce upstream flooding and to replace aging infrastructure. Without the upgrade, drainage improvements to the upstream network (which have already been constructed) would increase downstream flood risk. Indicative capital costs of the upgrade are approximately $25 million.

Due to construction complexity and hydraulic limitations, a range of design options were considered by an Early Contractor Involvement (ECI) group that would reduce disruption to the port whilst providing improved flood resilience. A risk based approach was used to establish the costs and benefits of the options, so that a realistic hydraulic performance objective could be established by Auckland Council for the ECI group.

The risk based approach considered the effects of a range of design storms, tailwater levels, and sea level rise for the different options. The outcomes of the assessment were used to create a business case that needed to provide both value to existing ratepayers, resilience to future changes in climate and consider the effects of disruption to the Ports of Auckland.

This paper will focus on the risk based assessment and business case development that formed the recommendation to the ECI group. It will include discussion on the quantitative risk assessment including the flood damage assessment, and the economic and qualitative viewpoints encountered along the way.

KEYWORDS

Flood resilience; hydraulic performance; flood risk assessment; flood modelling; climate change impacts; cost benefit analysis; asset management planning; flood damage assessment; network design

PRESENTER PROFILE

Sarah is a Water Resources Engineer at Tonkin + Taylor and previously worked at the Waikato Regional Council. Sarah has ten years' experience and has been involved in a large number of modelling, design and optioneering projects. She is a committee member of the IPENZ Rivers Group and was lead modeller and assessor for the Stanley catchment model that is the subject of the presentation.

Richard Smedley is a Senior Stormwater Specialist within Auckland Council's Stormwater Department. He has over 20 years' experience in design and strategic planning across transport and water infrastructure. Most recently he has focussed on stormwater catchment planning in the Auckland central area championing many large scale flood mitigation projects.

1 INTRODUCTION

1.1 CATCHMENT

Auckland’s Stanley catchment is located within central Auckland and comprises a steep upstream catchment draining to a flat area of coastally reclaimed land that is used for essential transport infrastructure, commercial premises and residential development. Britomart railway station, Ports of Auckland and Vector Arena are located within the vulnerable downstream area. The catchment also drains the predominantly residential upstream suburbs of Newmarket and Parnell to the coast (refer to Figure 1).

1.2 BACKGROUND

The recently constructed trunk pipeline (shown in Figure 2) supplements an older pipeline and runs parallel to a point on the Southern side of Quay Street. Construction of the last section of the supplementary pipeline has been on hold for over a decade pending access negotiations with the Ports of Auckland Limited (POAL).

However, the completion of the last pipe section to the sea has become urgent due to increasing operational issues related to poor condition of the existing box culvert under Ports land. The project mitigates these risks and completes the pipeline so that upstream investment can be realised.

Modelling predicts only limited property damage using todays pipe reticulation, rainfall, and sea level, however, any reduction to the size of the existing outlet (e.g. by rehabilitation) will significantly increase flood risk. Increased flood risk includes shallow flooding to arterial roads, deep flooding to a large apartment complex and potential closure of Britomart rail station. Increasing sea level and rainfall will further exacerbate flood damage over time.

1.3 OBJECTIVE

Through an “Early Contractor Involvement” (ECI) arrangement to replace the infrastructure, Auckland Council’s stormwater Department (part of ECI group) developed and implemented an assessment methodology to:

- Identify an optimal outlet size and cost based on flood reduction benefits,
- Provide resilience to future changes in climate; and
- Inform a robust business case.

1.4 PAPER STRUCTURE

This paper identifies the following:

1. Challenges and Constraints;
2. The methodology development;
3. The results of the assessment and sensitivity to assumptions;
4. The conclusions of the assessment; and
5. Lessons learned.

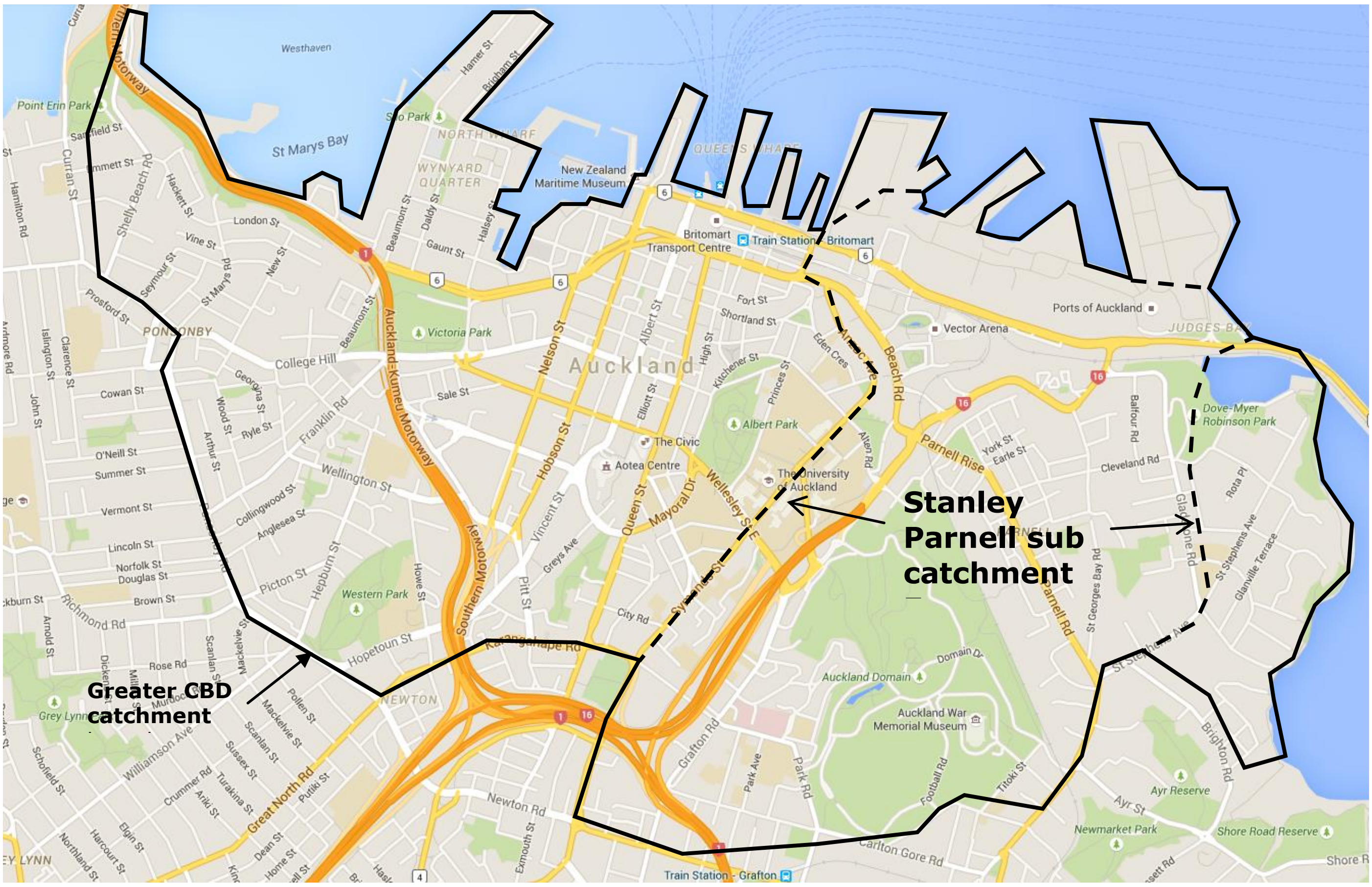


Figure 1 Stanley and greater CBD catchment boundaries

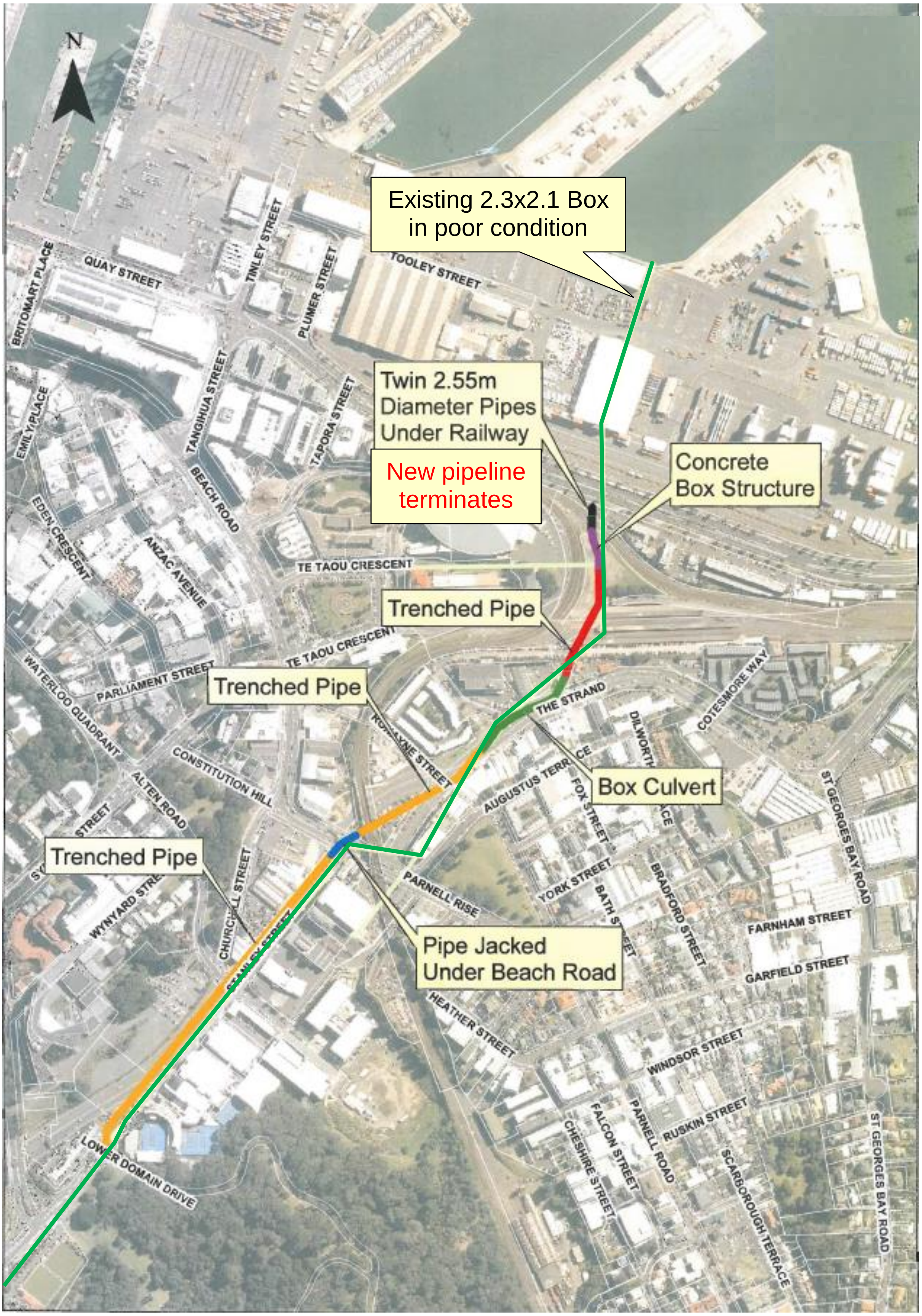


Figure 2 Supplementary trunk stormwater pipeline [Constructed 2002-2004]

2 CHALLENGES AND CONSTRAINTS

2.1 LOW LYING RECLAIMED LAND

The low lying area in the catchment which has significant flooding for the 100 year ARI future storm event is highlighted in the figure below. This area was historically reclaimed from the sea. Figure 3 shows the old coastline circa 1900 compared with the coastline at present day. The low lying land is at 3.5mRL presenting a flood mitigation challenge with limited available hydraulic grade to the sea.

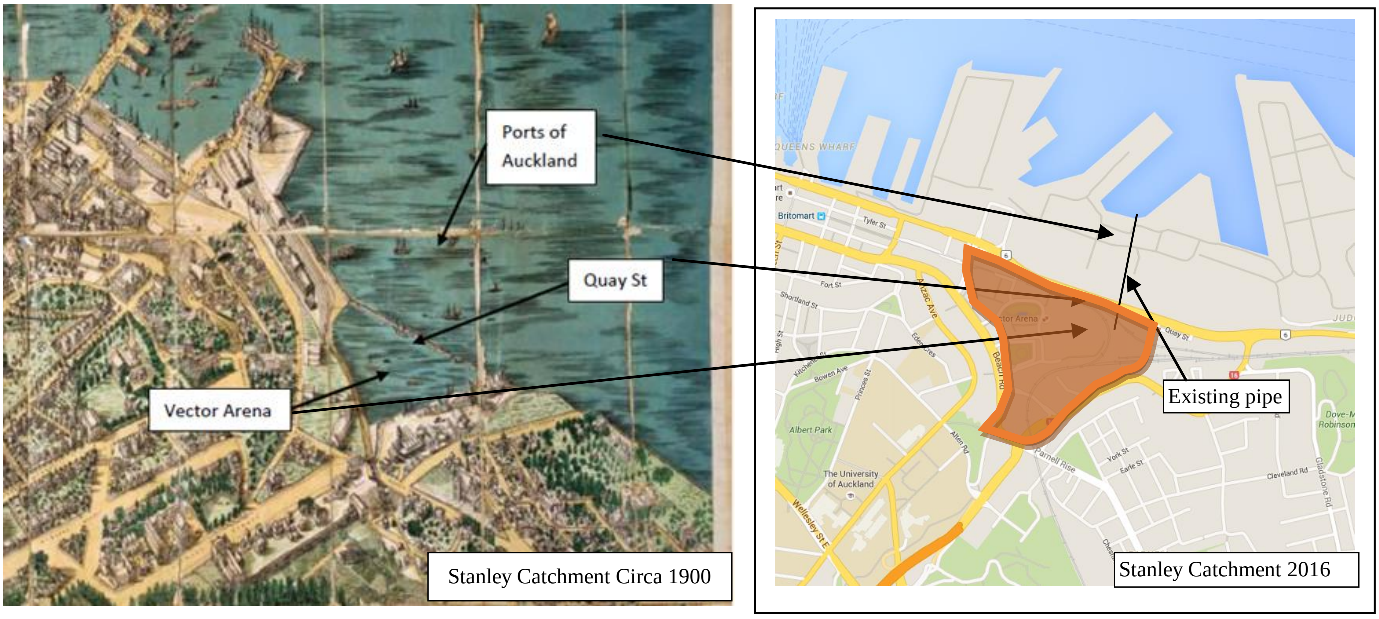


Figure 3 Stanley reclamation and flooding area (shown in brown)

2.2 PORT OPERATION

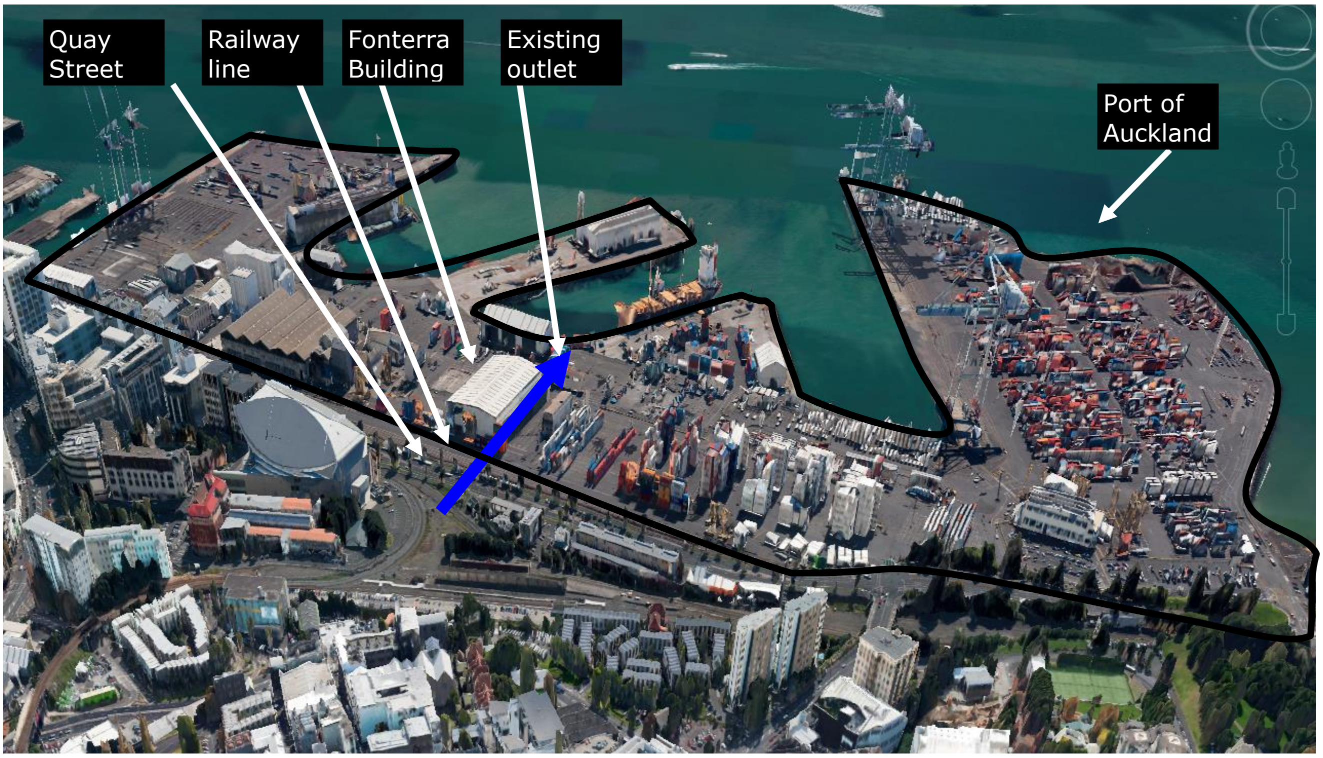
The port of Auckland operates a 24 hours a day 7 days a week operation. Nearly a third of New Zealand's sea trade passes through the ports of Auckland each year, this is summarised below:

- $27 billion worth of goods and material;
- $6.2 billion in imports;
- 20.7 billion in exports; and
- $1.25 billion of the export business is exports of dairy or dairy product;

The POAL are already short of space and actively seeking to expand port operation further into the harbour.

2.3 OTHER INFRASTRUCTURE

The new pipeline to the sea will need to cross significant infrastructure including the port operations and in particular the Fonterra building, a major arterial road (Quay Street) and railway sidings within Ports Land. This is show in the figure below.



2.4 EXISTING CULVERT

The existing box culvert is a critical asset in the Central Auckland stormwater system. It drains approximately 260 ha. It was installed in 1937 and is now an aging infrastructure with risk of collapse. Significant consequences are associated with this risk, both in terms of flooding to upstream areas and the interruption to Quay Street and ports operation.

2.5 COMPLETING THE NETWORK

The project to provide a supplementary pipeline to the sea was implemented in the early two thousands to covey increased upstream impervious area generated by the new motorway (Grafton Gulley Motorway) and address long standing flooding issues at Carlaw Park and surrounding commercial areas. For this previous investment (up to $50 million) to be fully utilized without downstream effects requires the last 350m to the sea to be completed. There are many options for completing this last section to the sea all with varying upstream benefits, costs, disruption and risk. It was important that all options be assessed to inform a robust decision given the high cost and profile of the project.

3 METHODOLOGY DEVELOPMENT

3.1 HOW TO DEMOSNTRATE VALUE AND RESLIENCE

3.1.1 UTOPIA VIEW

In an ideal world, for an options study as complex and sensitive as this, one would have an infinite amount of time and resources to develop as many options as possible and assess and analyse those options in the most detailed manner. This would be done for all annual exceedance probability (AEP) events with all possible tide levels to arrive at the optimal solution. A cost benefit analysis should be done to demonstrate which option is the best value for money.

The number of scenarios which ideally would have been required for this study is more than 1400. This is due to the range of options and hydrological and hydraulic parameters to be considered, these are listed in Table 1 below.

Table 1 Number of scenarios to be considered for this project

Scenario	**Configurations**
Downstream tidal boundary (high and low tides for existing and 2 future sea level rises)	6
ARI rainfall events (2,5,10,20,50,100)	6
Horizontal alignments	5
Vertical alignments (deep and shallow)	2
Existing pipe (no existing pipe, rehabbed smaller existing pipe and existing pipe as is)	4

3.1.2 PRACTICAL REALITIES

Although, the ideal situation is the best way to arrive at the best answer, it is rarely (or never) the case. As this is a real project in the real world, constraints apply, these are mainly related to budget and programme. Details on constraints for this project are described below.

(A) PROGRAMME – TIMELY ASSESSMENT

Due to significant operational risk associated with collapse and repair of the existing large box culvert (2.1mx2.3m) urgency was applied to completing the supplementary pipeline. Since rehabilitation of existing culvert only, was not deemed an acceptable solution, identification of the optimal supplementary pipe outlet was suddenly on the critical path for the project.

The assessment into the benefit of the various options ran in parallel with options costing performed by the design team. This provided the opportunity for each option to be examined in full at each stage. However, it also meant timely hydraulic performance assessments were critical in the process.

(B) BUDGET – FINITE MODEL RUNS

Given the time constrains above, the number of scenarios and models to be run at any one time and/or consecutively was prioritised. High priority runs were identified to meet critical design and costing time frames set by the design team. This helped clarify and limit the post processing results analysis effort and keep the modelling work highly responsive. All in all, over 100 runs were completed to inform the hydraulic input to the project. This was rationalised down from the 1400 possible runs detailed above.

The following subsection describes the steps taken to ensure an assessment with the correct level of detail while operating within the practical realities.

3.2 HOW TO PROVIDE BEST VALUE FOR MONEY

A number of steps were undertaken to ensure the important considerations such as the pipe design parameter, effect on flooding, identification of the level of service were included in the process and not lost due to the budget and programme constraints. The subsections below describe these steps.

3.2.1 FOCUS ON KEY SCENARIOS

The scenarios were divided into two groups, hydrology related scenarios and hydraulic related scenarios.

The hydrology related scenarios include upstream and downstream boundaries, such as sea levels, rainfall and AEP events.

- All models were considered at both Mean High Water Spring (MHWS) and Mean Low Water Spring (MLWS) with 0.5 m sea level rise;
- Climate change adjusted rainfall;
- 1% AEP for all options and 10% AEP for only some options;
- Some models also considered sea level rise as outlined in the latest (Ministry for the Environment (MfE) guidance document;

A range of size and vertical alignment options were identified for hydraulic scenarios with the ECI group. These comprised:

- the existing culvert as a 1.5m diameter circular pipe (rehabilitated size);
- the existing culvert (1.5m dia.) and one, two or three supplementary 2.5m circular diameter pipelines to the sea; and
- The existing culvert and one, two or three supplementary 3.0m diameter deep inverted syphons;

3.2.2 DEFINE AND REDUCE ALLIGNMENT OPTIONS

The project started with a number of possible horizontal alignments to consider for the outlet, they included the network possibly extending to twice the optimum length in order to avoid disruptions to the POAL operations. The design team used the preliminary hydraulic grade and flow results from a limited number of model runs to inform horizontal alignment. A more comprehensive set of scenarios was then applied to a single horizontal alignment to inform size decisions. Two possible vertical alignments, as outlined below were modelled:

- Shallow (at grade) alignment; and
- Deep (inverted syphon) alignment.

Reducing the number of alignment options also reduced the number of model runs, as otherwise, each alignment would need to consider different configurations of pipes (number of pipes) with different AEP events and both MHWS and MLWS.

The model was used to identify a deep option (inverted syphon) size which would achieve equivalent hydraulic performance to the shallow option. It was found that a deep twin 3m pipeline would achieve similar hydraulic performance to a shallow twin 2.5m pipeline. With this information, the modelling team decided to proceed with shallow option analysis only.

3.2.3 INCREASE MODELLING EFFICIENCIES

Model run times were approximately two to three days due to a standard requirement for very small times steps in steep 2D surface areas. The small time steps were thought to be required to keep the steep areas of 2D bathymetry stable. Reducing model extent was considered, however this was not estimated to yield the desired effects. Therefore the model extent remained the same.

Mike Urban results were unstable near the outlet for such small time steps, making results analysis and post processing very time consuming. Model time step was increased from 0.2s (causing model run times of anywhere between 52 to 36 hours) to 0.5s (reducing model run time to 12 to 15 hours) as it was assessed to have no consequences in the area of interest.

3.2.4 CONSIDERATION OF OTHER REQUIREMENTS

Other requirements from guidance documents at local, regional and national level were also considered and taken into account, these are listed below. Consideration of these requirements ensured that the options assessed provide the best solution to existing and future ratepayers and include future flood resilience. These are discussed below:

(A) AUCKLAND COUNCIL –STORWMATER FLOOD MODELLING SPECIFICATIONS (SFMS), NOVEMBER 2011

The model was built according to the Auckland Council SFMS, the main tailwater scenario is MHWS plus 0.5 included for sea level rise, this is a level of 1.89m RL. MLWS was identified as -0.6m RL inclusive of climate change. Both levels were represented as a constant water level in the model.

(B) MFE - CLIMATE CHANGE

The future sea levels proposed by the latest MfE guidelines (sea level rise of 1 m by 2115) was also assessed in some scenarios. This was done to test for appropriateness of the preferred scenario for increase in sea level as a result of future climate change. It was used to conclude that increasing sea level would not result in a larger optimal size point.

(C) REGULATORY REQUIREMENTS ON NZCPS

Guidance is also provided by the New Zealand Coastal Policy Statement (which must be considered by Local Authorities) as stated below (Policy 3):

- Adopt a precautionary approach towards proposed activities whose effects on the coastal environment are uncertain, unknown, or little understood, but potentially significantly adverse.
- In particular, adopt a precautionary approach to use and management of coastal resources potentially vulnerable to effects from climate change, so that:
    - Avoidable social and economic loss and harm to communities does not occur;
    - Natural adjustments for coastal processes, natural defences, ecosystems, habitat and species are allowed to occur; and
    - The natural character, public access, amenity and other values of the coastal environment meet the needs of future generations.

This was an important consideration as a second outlet pipeline was only required for higher tide and rainfall levels under future climate change scenarios. Analysis of Ports sea level records showed that these higher sea levels were already being experienced more often than was first thought. The model was also used to see if a larger pipeline (triple 2.5m pipes) would perform significantly better at higher sea level (2.3mRL). This work confirmed that, as expected, HGL not size limits the available upstream flood risk reduction.

3.2.5 IDENTIFY THE LEVEL OF SERVICE OBJECTIVE

Typically a design flow and associated AEP event define the parameters which the design strives to achieve. This was not the appropriate parameter to set as the effect of the tailwater conditions (sea level) were critical in the performance of the network due to the low hydraulic grade line and comparatively high tailwater level.

Therefore, the objective was to find a "best value" balance point between flood damage reduction and implementation costs (rather than prevent/eliminate all flooding).

The optimal number of flooded properties to resolve by the project was set by identifying a "knee" of the curve (point at which returns on incremental investment turn negative). The design parameters for the supplementary pipeline were then set for this optimal size/cost point.

3.2.6 CARRY OUT MODEL RUNS ENSURE ADAPTABILITY TO ECI CHANGES IN REQUIREMENTS

Model runs were carried out over a period of six months, however, they were reported on approximately bi-weekly. This was usually done through emails and face to face meetings to check in on progress and reconfirm or change priorities for model runs.

The modelling team worked iteratively with the designers and used the model to check the performance of critical designs based on static hand calculations.

The model software was DHI model with a coupled mike 21 classic grid and mike urban, the hydrology was also represented in mike urban.

4 ANALYSIS OF RESULTS

4.1 RESULTS AND SENSITIVITY

The primary scenario used to assess the options was the future 1% AEP design storm with sea level rise at high tide. Other scenarios were run to test the sensitivity of the options to tide, annual recurrence interval (ARI), sea level rise of 1m and the effects of potential bow waves from large vehicles.

Flood damage costs were estimated using a commercial stage-damage cost curve developed by Metrowater using cost data from the Whakatane Floods.

A knee curve (diminishing returns) analysis was undertaken to determine as well as visualize the optimal solution. The analysis of results was based on the flooded floor count, area of affected floor space and damage cost. Figure 4 below illustrates the construction cost vs the damage cost for each option in the 1% AEP with climate change storm event. Syphon options are not included in the graph below.

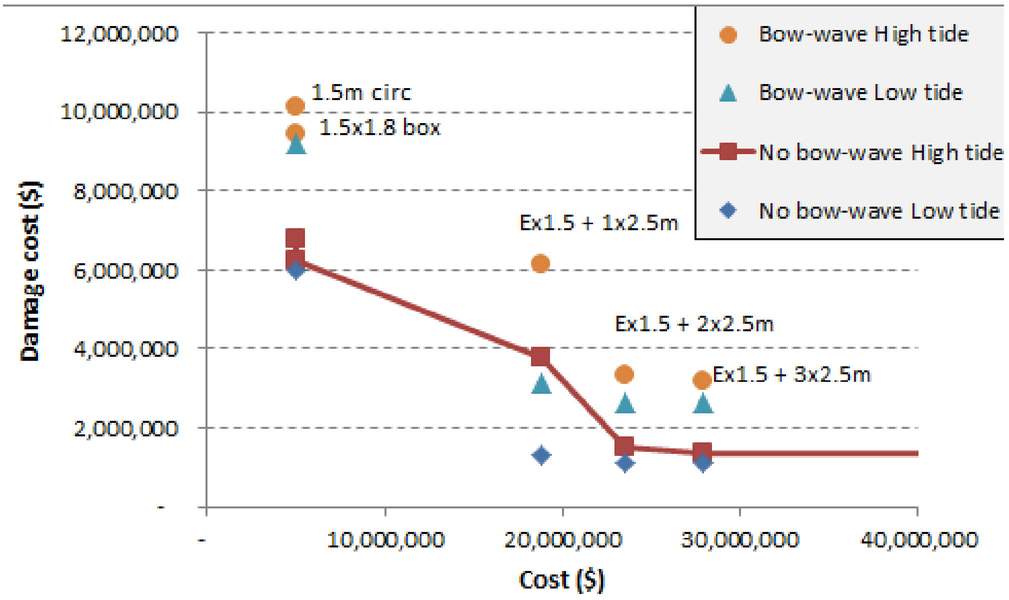


Figure 4 Flooded floor count and damage cost 100 year ARI vs construction cost

The analysis and "knee" curves were prepared for the two cases of flood ponding static water only and with flood ponded water plus a bow wave action. The chart shows a diminishing return for investment beyond $25 million.

4.2 FDA VERSUS OUTLET SIZE AND COST

A flood damage assessment (FDA) was prepared for the following scenarios at high and low tide:

1. Base (existing culvert reduced to 1.5 m diameter)
2. 1 above, plus one 2.5 m diameter supplementary pipeline
3. 1 above, plus two 2.5 m diameter supplementary pipelines.

The FDA used the model to estimate flood water levels at flooded buildings for 2, 5, 10, and 100 year ARI design storms. The results are shown below for high tide, bow wave and no bow wave scenarios to present the differential damage cost between the single and twin supplementary pipe options.

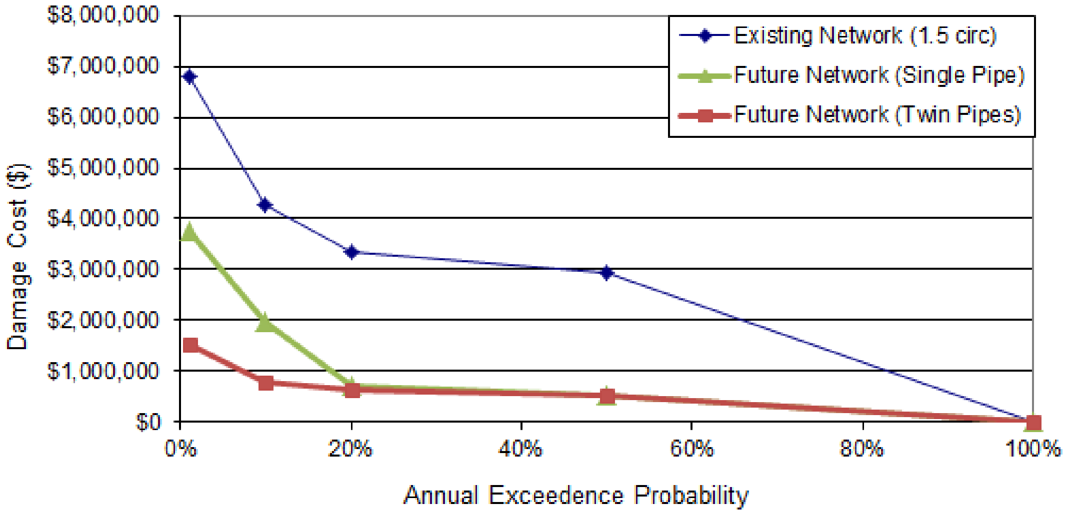


Figure 5 No Bow Wave AEP vs Damage Cost

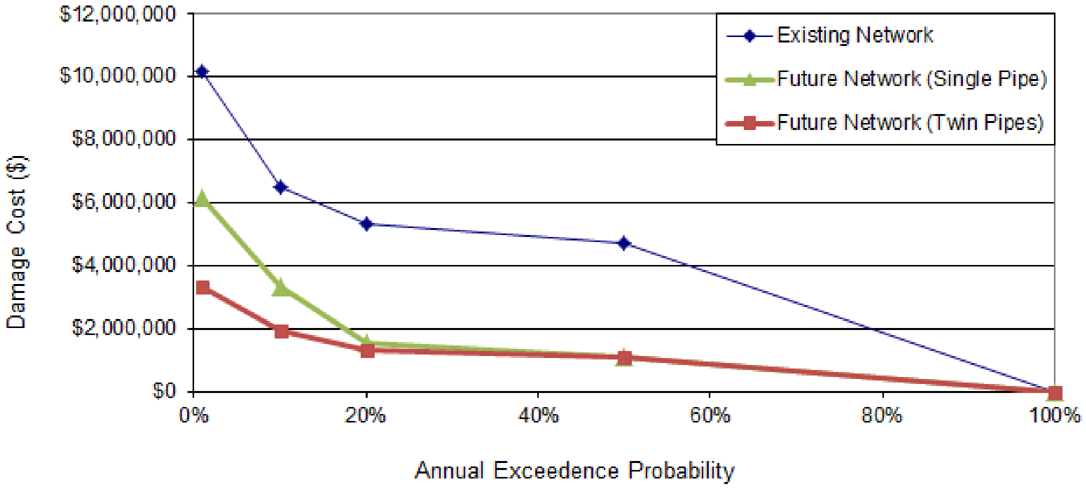


Figure 6 Bow Wave AEP vs Damage Cost

All scenarios used climate change adjusted rainfall. A period of 60 years and discount rate of 4% was used in accordance with the Auckland Council primer for economic assessment.

The FDA results show an additional $5.9 to $7.5 million of economic benefit is achieved with the twin 2.5 m supplementary bores compared with the single 2.5m supplementary bore at high tide. An FDA was not calculated for the triple 2.5m supplementary pipeline as the results already suggested there would be minimal incremental reduction in flood risk.

The low tide FDA results showed negligible differential between the single and twin supplementary pipe options. If there is equal probability of low tide during extreme rain storms, the FDA differential reduces to $3.0 to $3.8 million.

These results also indicate that at high tide, the larger outlet size starts to show additional benefit for storm events > 5 year ARI. Up to 5 year ARI the single 2.5 m supplementary pipe outlet achieves a similar FDA result as the twin 2.5 m pipelines.

4.3 PROJECT BENEFITS AND BUSINESS CASE

The total economic benefit for the project (direct damage costs only) is $55 to $76 million at high tide and $34 to $44 million at low tide. These results are plotted for the existing (1.5 m circ.) and proposed (1.5EX + 2x2.5) option to show the range of potential economic benefit of the project as seen in Figure 6.

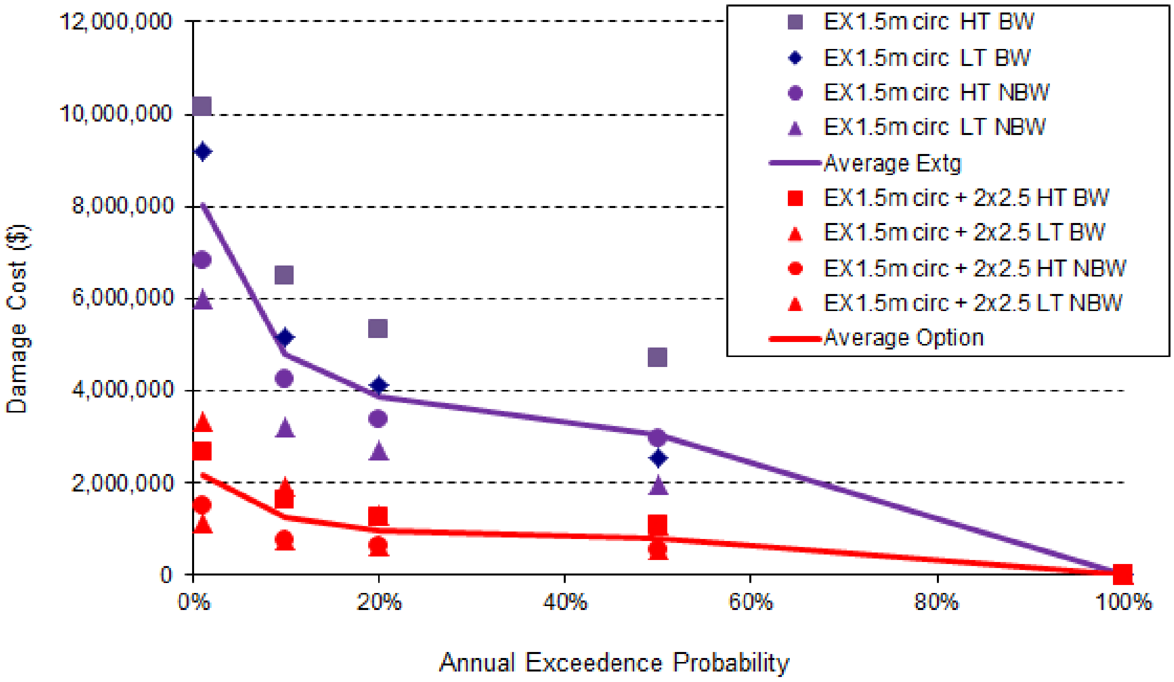


Figure 7: Existing, option, high tide, low tide bow wave, no bow wave, average

The economic benefit of the average lines over 60 years is approximately $48,000 (all at future rainfall and tide levels) as shown in table 1 below.

Table 1: No bow wave, high tide FDA results

Twin Pipe Option	AAD ($)	NPV ($)
Existing (1.5m circ)	2,633,538	59,579,500
Proposed (1.5EX + 2x2.5)	497,928	11,264,500
Economic Benefit over 60 years		**48,315,000**

Single Pipe Option	AAD ($)	NPV ($)
Existing (1.5m circ)	2,633,538	59,579,500
Proposed (1.5EX + 1x2.5)	748,793	16,940,000
Economic Benefit over 60 years		**42,639,500**

4.4 RECOMMENDATIONS TO THE ECI GROUP AND OUTCOMES

The optimal design parameters were advised to the design group as a combination of maximum water level of 2.52 mRL at the new chamber to be constructed at Quay Street and a minimum flow rate at the sea of 21m^3/s. This combination of HGL and flow rate ensures the design achieves the optimal flood reduction outcomes against cost as assessed by the modelling and FDA work.

Both the twin 2.5 m and deep 3 m diameter pipes (including the rehabilitation of the existing pipe to a 1.5 m diameter circular pipe) would meet the design criteria. An optimal range of 11m² to 12m² cross-sectional area for flow conveyance was recommended to the ECI group to allow some flexibility in the design. For example if the existing culvert was to be decommissioned instead of rehabilitated, that could be accommodated by increasing the new pipe size if HGL and flow rate criteria could still be achieved.

4.5 DEEP VERSUS SHALLOW DECISION

The focus of this paper has been to describe the process and results of an extensive modelling project to inform client's requirements for hydraulic performance of a new outlet. A key finding was a recommended size to achieve a balance between construction cost and reduction of upstream flooding risk. The analysis informed both shallow and deep size requirements given available hydraulic grade. This work informed size requirements and fed hydraulic performance into another significant body of work required to decide on vertical alignment (deep vs. shallow) which was undertaken by the designers.

To decide on deep or shallow vertical alignment, the ECI group designers prepared a wide ranging list of technical reports to input to a multi-criteria assessment (MCA). Considerations and analysis included many factors such as ease of construction, disruption to port operations in the short and long term, and feasibility and cost of future maintenance. From this analysis a decision was made to proceed to detailed design with the shallow (at grade) option. It was also recommended that the existing culvert be decommissioned and new twin pipelines increased in size.

5 CONCLUSIONS

Through an ECI arrangement to replace the infrastructure, Auckland Council's stormwater department (part of the ECI group) developed and implemented an assessment methodology to:

- Identify an optimal outlet size and cost based on flood reduction benefits;
- Provide resilience to future changes in climate; and
- Inform a robust business case.

The above objectives were met through careful rationalisation of model runs in conjunction with the ECI designers to achieve tight timeframes. Regular collaborative working between modellers and designers allowed flexibility to amend model run priorities and answer key design performance questions during the design process.

The adopted solution comprises a total outlet size of 11 to $12m^2$ total cross-sectional area and achieves a flow rate of $21m^3/s$ and maximum HGL of 2.52mRL at Quay Street. This solution provides the best balance of cost and flood risk reduction and resilience to future changes in climate. It takes into account existing and future benefits in reducing upstream flooding and ensuring an efficient stormwater network which performs in high and low tide conditions for events up to the 1% AEP.

A collaborative and iterative process of identifying key model runs and design concepts with the designer, construction contractor and Council's in-house modelling team resulted in agreement on a robust, best value for money solution. The range of information generated by this process is assisting Council to get buy-in and trust from a large range of internal and external stakeholders.

Modelling work was used to establish an optimal design criteria for a high value project which balanced reduction of flood risk and construction cost.

6 INNOVATIONS AND LESSONS LEARNED

Lessons were learned throughout the hydraulic modelling project. Some of these are summarised below:

- Establish what key drivers are for making decisions and create an assessment process to assess these things. Best value is the optimal hydraulic solution that gives the least flooding and a practical level of resilience for the least money.
- Focus on the area of interest and prepare a tool that has short run times and addresses only the key questions informing investment decisions.
- Consider how many model runs may be required and optimise run times including careful choice of time step.
- Define the base scenario early to avoid repeat work and model runs.
- Ensure all assumptions and scenario requests are recorded particularly when dealing with a large team of people to ensure consistency across the team.
- Evidence based assessment giving estimate of flooding, flood damage and construction risks leads to robust decisions.
- For coastal outfalls, carefully consider appropriate sea level and rainfall combinations to inform the sensitivity of solutions to climate change.

ACKNOWLEDGEMENTS

Auckland Council would like to thank GHD Ltd and Downer for collaborative and open working with the client.

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