Cost Optimal Wastewater System Improvements – 2009/2010 North Shore City Wastewater Optimisation Project

J.I. Wilson – Optimatics

N.Z. Brown – North Shore City Council

ABSTRACT

This paper presents the methodology and results of the North Shore City Wastewater Optimisation project completed during 2009 and 2010. The project showcases innovative planning techniques and smart technology which enabled North Shore City Council (NSCC) to determine least-cost solutions to achieve complex planning objectives.

Like many cities and councils, NSCC endeavour to provide their customers with a wastewater system which minimises social, cultural and environmental impacts while doing so at the least cost to the community. Cost-optimisation has been an integral part of the NSCC Project CARE master plan programme over the past ten years. Advances in technology have allowed NSCC to transition from a traditional trial-and-error options analysis approach to linear-programming optimisation in 2001 and then to genetic algorithm (GA) optimisation in 2008.

To meet the needs of the 2009/2010 city-wide optimisation project, substantial advances were made in the optimisation technology originally used by NSCC in 2008. These innovative technology enhancements achieved robust and repeatable results for the city-wide optimisation project. The solutions achieved were more practical from an engineering standpoint, and the usability of the technology was dramatically improved. At the time the project was commenced there had been no larger scale application of the optimisation technology in New Zealand, Australia, or the Unites States.

North Shore City Council has a wastewater network strategic improvement programme of $300 Million to be implemented by 2021. Cost savings on such a large programme are very significant.

The results presented in this Paper will demonstrate how the technology and engineering processes used in the North Shore City Optimisation project provide a robust method for evaluation of options to deliver least-cost solutions; allows the cost of different level of service (LOS) and other planning objectives to be quantified; and, by definition, saves money.

KEYWORDS

Wastewater Master Planning, Optimisation, Innovation, Inflow and Infiltration Reduction

1 INTRODUCTION

From 2009 to 2010 North Shore City Council (NSCC) performed a detailed options analysis for the City's wastewater collection system. The project involved identifying feasible improvement alternatives, developing unit cost rate estimates for each improvement option, identifying the design storm event which achieves the City's target overflow frequency and conducting a series of optimisation runs using Optimizer WCS (genetic algorithm optimisation software).

The improvement options identified for the NSCC collection system included parallel sewer augmentations, new flow path alternatives, pump station upgrades, inflow and infiltration (I/I) reduction, flow control storage facilities and wastewater treatment plant (WWTP) upgrades. In a single optimisation analysis Optimizer WCS evaluates many thousands of possible option configurations and assesses both total solution cost and hydraulic performance simultaneously. Ultimately the optimisation analysis determines those combinations of improvement options which meet the specified design and performance criteria at least cost.

The 2009/2010 North Shore City Wastewater Optimisation case study presented in this paper demonstrates 1) the optimisation process, 2) the least cost master plan solution which was identified, and 3) the cost savings achieved when compared with the previous solution developed using an alternative linear-programming optimisation technique.

1.1 PROJECT BACKGROUND

ProjectCARE was developed between 1998 and 2002 as a master planning tool to reduce the frequency of wastewater wet weather overflows to the environment. The target containment standard for ProjectCARE is an average of no more than two wastewater overflows per annum by 2021, as assessed by computer modelling. The output of the ProjectCARE study was a containment standard and the Wastewater Network Strategic Improvement Progamme (WNSIP) which details the capital works programme and recommended timing of improvements.

Part of ProjectCARE was a least-cost linear optimisation process to develop the least- cost capital works programme to achieve the target containment standard. As a consent condition NSCC must review ProjectCARE to ensure that the programme is on track every six years. The reason for the review is to check that the original input assumptions are still valid and that the completed capital works programmes are achieving what was intended.

As part of the first review NSCC built, calibrated and calculated system performance and used the resultant model to assess the effectiveness of the completed infrastructure. The same model was used to forecast whether the remaining WNSIP programme was capable of achieving the required containment standard. The review found the programme would not meet the target containment standard. A manual assessment exercise was then undertaken to evaluate and update the WNSIP. It was determined that some projects were no longer needed, others projects were too large or too small, and some new projects were required. The total change to the WNSIP cost was less than 7% (after escalation was taken into account).

The largest variation in overall cost between 2000 and 2008 was not due to changes in projects but due to escalation. ProjectCARE assumed escalation of 4% per annum; actual escalation was 8% per annum. Costs for different solution options varied with regard to each other, e.g., rehabilitation costs remained relatively static while pipe costs increased at >8% per annum.

NSCC decided to undertake optimisation as part of the review to evaluate whether there was any cost saving or operational benefit in re-optimising a system which had previously been optimised.

Optimizer WCS was chosen as the optimisation tool to use for the re-optimisation process. The original optimisation tool used was SEWCOM/SEEKER which was developed by Sydney Water. SEWCOM is unsupported and not commercially available. Optimizer WCS is a commercially available least-cost optimisation tool developed by Optimatics Pty Ltd. The tool was tested on a pilot project within North Shore City prior to using the product at a citywide master planning scale for this study.

2 PROJECT METHODOLOGY

The NSCC wastewater optimisation project involved the following key tasks:

- Options identification workshop
- Unit cost rate development
- Design storm selection
- Preparing the hydraulic model
- Defining the design and performance criteria
- Formulating the optimisation model and performing optimisation runs

2.1 OPTIONS IDENTIFICATION WORKSHOP

Workshops were held to identify the possible improvement options for each area. The focus of the workshops was to identify alternate alignments and pump station locations from those which currently exist. Duplication of pipes along existing alignments was allowed for every pipe in the system. Inflow and Infiltration (I/I) rehabilitation was allowed for every catchment except when the catchment had already been extensively rehabilitated or where low confidence was held in the calculated I/I rates (subtract catchments). Reticulation amplification was allowed for all catchments if necessary. All manholes were allowed to be selected as storage locations for the initial runs and then actual site locations were identified within the vicinity of the locations selected in the initial runs. Expansion of the existing WWTP capacity was allowed. The allowable improvement options resulting from the workshop are presented in Figure 1.

Once the options to be considered were identified for the network a degree of difficulty was applied to each route using local knowledge. Items considered for degree of difficulty were:

- Ground condition
- Construction methodology (trenched, trenchless)
- Disruption to residents
- Alignment along roads/easements versus under houses and along the foreshore

The degree of difficulty was assigned to each option as a cost multiplier on the standard unit rates.

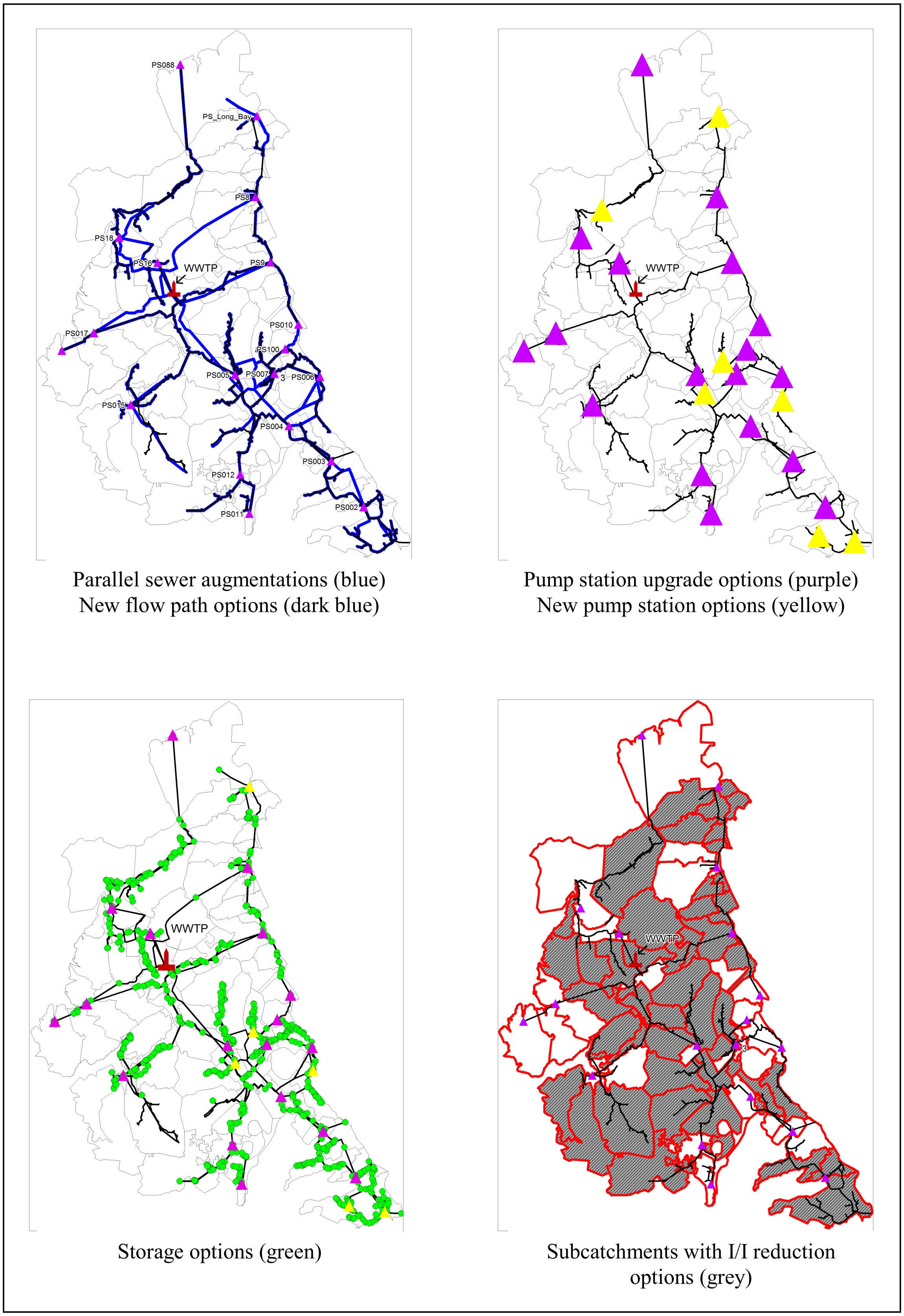

Figure 1: System Improvement Options

2.2 UNIT COST RATE DEVELOPMENT

NSCC commissioned Sinclair Knight Merz to produce the cost data and generic cost curves to be used in the optimisation analysis of the NSCC wastewater network. The cost data and cost curves were developed for the following:

- Trunk sewer augmentation
- Rising mains
- New and upgraded pump stations
- Storage tanks
- Wastewater treatment plant (WWTP) upgrades
- I/I reduction and reticulation amplification (prepared separately by NSCC)

For comparative costing and optimisation, cost data was prepared for the life cycle cost of the assets, including:

- Land acquisition
- Engineering and project management
- Consent costs
- Construction costs
- Operating and maintenance costs
- Depreciation of assets within the 50-year evaluation period.

Level of Difficulty (LoD) cost multiplication factors were developed for each individual improvement option. The cost multiplier range of 0.7 to 1.4 times the “average” cost was applied depending on whether the specific project was deemed to be “low” or “high” risk, respectively.

The asset lives shown in Table 1 were used for calculation of life cycle costs. A discount rate of 8% has been used to bring future expenditure back to a net present value. Future costs for operation, maintenance and renewal have been escalated by 3% per annum. Table 2 shows the operation and maintenance considerations included for each asset type.

Table 1: Asset Life used for Calculation of Life Cycle Costs

Asset	Lifespan (Years)
Gravity Sewers	80
Manholes	80
Rising mains	50
Pumps	20
I/I Rehabilitation	25
Above-ground pipe work, fittings and valves (pump stations and WWTP)	40
Electrical equipment	20
Controls and instrumentation	15
Concrete structures (pump station wet wells and storage tanks)	50
Storage Tank – Buckets	10
WWTP – UV Equipment	15
WWTP – Chemical Scrubber	15

Table 2: Operations and Maintenance Inclusions

Asset	O&M Cost Allowances
Pipe Lines	CCTV inspections on a 10-year cycle until the pipe line is 30 years old and then on a 5-year cycle. Jet washing once pipe lines are 35 years old and then on a 5-year cycle.
Storage Tanks	Routine and reactive maintenance, energy costs and depreciation.
Pump Stations	Routine and reactive maintenance, energy costs and depreciation. For the purposes of assessing annual energy costs it has been assessed that the average flow of the pump station will be 20 % of its total rated capacity.
WWTP	No operating and maintenance costs have been included as an additional plant is expected to have very limited impact on the overall annual cost for maintenance of the Rosedale plant.

The unit rates were developed from actual project costs of projects carried out in North Shore City between 2002 and 2008. The rates were supplemented with data from the greater Auckland region where limited information was available from North Shore City projects. The rates are the key determinate in the selection of the mix of solutions which are the outcome from this study. If the unit rates are incorrect the least-cost solution could change.

2.3 DESIGN STORM SELECTION

A design storm event was required for the optimisation process. The design storm represents the containment standard required. Use of a design storms allows options to be built into the hydraulic model and evaluated with each run taking less than 5 minutes. Running the long time series to test each option would take 200 times as long as using a design event.

A single synthetic rainfall event was generated which is equivalent to the required containment standard. For NSCC the required containment standard is on average two overflows per annum. A 17-year rainfall time series was simulated through the ProjectCARE hydraulic model, and the 34th overflow event from each release point was assessed. The 34th overflow event was chosen as it represents the event which occurs twice per annum.

The rainfall events causing overflow events between the 28th and 40th ranked events (surrounding the 34th event) were assessed to see which historic rainfall events were common for different parts of the wastewater system. An individual rainfall event for each geographic area was selected as being representative as all the overflows which failed the containment standard in that area had the same historic rainfall event ranked between the 28th and 40th events triggering an overflow.

North Shore City was assessed and was found to have five unique geographic areas each with a different representative historic rainfall pattern equivalent to the desired containment standard. The synthetic design rainfall was created by combining five historical events into one synthetic rainfall event.

The synthetic design rainfall event was run through the ProjectCARE model to check that the statistics produced by the design rainfall were similar to the statistics produced by the long-term time series model output. The design event was further refined by scaling the rainfall in areas where the statistics between the design event and the long-term time series did not align.

The optimisation solutions developed during initial runs were evaluated using the long-term time series rainfall data and, where necessary, refinements were made to the synthetic design rainfall event to achieve the target overflow containment standard. Unlike a manual trial and error design approach, changing the design storm event did not cause significant set-backs as it was relatively easy to update the optimisation model inputs and rerun the optimisation.

2.4 PREPARING THE HYDRAULIC MODEL

New improvement options to be evaluated in the optimisation analyses must first be included in the hydraulic model. Parallel pipe options and new flow path alignments must be available in the hydraulic model to be called on in the optimisation model. It is the engineer, not the computer, who defines the allowable flow path alignments. Once the engineering team has decided on which pipe options need to be considered the next step is to include them in the hydraulic model. Only the horizontal alignment and vertical alignment of the new pipe options needs to be modelled; the optimisation routine then determines optimal pipe sizes and locations. Any pipe segments or new alignments which are not required in the optimal solution will be given a zero diameter.

The NSCC collection system is modelled using the MOUSE hydraulic modelling program. The wastewater optimisation model (Optimizer WCS) uses SWMM Version 5.0 for completing hydraulic model simulations of various option configurations. The primary reason Optimizer WCS uses SWMM is that the open source code enables hundreds of simulations to be completed simultaneously using distributed computing without requiring hundreds of expensive software licenses. In a single optimisation run, over 100,000 model simulations are completed so the advantage of distributed computing amounts to months of time savings when compared to processing runs on a single machine.

For the optimisation task, the MOUSE model of the NSCC collection system was converted for use in the EPA SWMM hydraulic modelling program. Wastewater flow rates and wet weather events were replicated by exporting the inflow hydrographs from the MOUSE model, then importing them to SWMM as time series boundary conditions at individual node points within the system.

The SWMM model was validated by comparing flow values and depths with those obtained using the MOUSE model at key locations in the system. Minor discrepancies between the SWMM model and the MOUSE model were observed; however, these discrepancies did not affect the optimisation outcomes.

2.5 DESIGN AND PERFORMANCE CRITERIA SUMMARY

The design and performance criteria applied in the optimisation analyses are summarised in Table 3.

Table 3: Design and Performance Criteria Summary

Facility Planning Design and Performance Criteria Category	**Performance Criteria**
Design Storm Event(s)	Composite (synthetic) rainfall event which represents the target performance of the network
Solution Validation Rain Event(s) (for checking optimisation solutions)	17-year Long Time Series for the 2056 planning horizon used to check the design event was representative for all locations and the solution is valid
Surcharge Criteria	No overflows to occur during the selected design storm event
Minimum Velocity in Rising Mains	1.2 meters per second (m/s)
Maximum Velocity in Rising Mains	2.5 m/s
Pipe Manning's Roughness for New Gravity Sewers	0.015
Minimum pipe cover	900 mm or existing cover where less than 900 mm
Soffit matching	All upgrade and new works match soffit to soffit not invert to invert (affects minimum cover and capacities).

2.6 FORMULATION THE OPTIMISATION MODEL AND PERFORMING OPTIMISATION RUNS

Figure 2 shows an overview of the options analysis process using Optimizer WCS. This figure can be described as follows (note that the solution presented in Figure 2 is for the North Shore City, Albany catchment which was evaluated during a pilot optimisation project in 2008):

1. The top left quadrant represents the input data which are gathered in preparation for the optimisation study.

2. The optimisation model is then formulated by importing the hydraulic model, defining the allowable improvement options, importing the unit cost rates, defining the design and performance criteria, and referencing model elements to the relevant option tables, cost tables and performance criteria.

3. Once formulated the optimisation model is ready to run. In a single optimisation analysis tens of thousands of complete hydraulic model simulations are completed. Each trial solution is evaluated with respect to hydraulic performance and total project cost. The optimisation progress plot, in the bottom right quadrant, shows the best solution cost in each set of 200 trial solutions (each

"generation") and shows how the optimisation converges towards the least-cost solutions after approximately 30,000 trial solutions. The optimisation run typically takes from twelve hours to two days depending on the size of the hydraulic model.

4. The optimised solution selected from a number of least-cost, hydraulically-viable solutions is presented in the bottom left. This is compared with the "Baseline Solution" which was developed by NSCC prior to the optimisation study using a linear programming optimisation technique (SEWCOM/SEEKER).

5. To perform scenario evaluations or sensitivity analysis, or to rerun the optimisation with revised input data, the relevant component of the optimisation model is adjusted and the optimisation rerun.

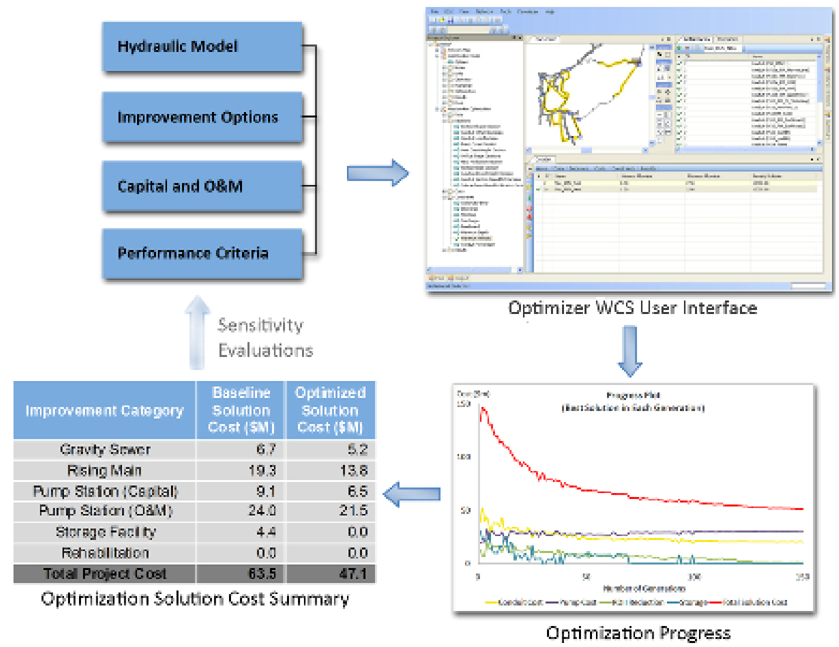

Figure 2: Overview of the Options Analysis Process using Optimizer WCS

3 OPTIMISED MASTER PLAN SOLUTION

The Optimised Solution for the 2056 design storm presented in Figure 3 consists of the following:

- 36 km of gravity sewer improvements (not including reticulation sewers)
- 8 ML of additional storage capacity
- I/I reduction in five catchments
- Reticulation amplification in local catchments
- WWTP upgrade to a total capacity of 4000 L/s
- Capacity upgrades for three existing pump stations
- Eight new pump stations
- Seven new flow path alignments / pump station flow diversions

A summary of the estimated project costs for this solution is shown in Table 4. The $316 M total estimated capital cost is comprised of $156 M for new sewers mains (gravity sewers, rising mains and reticulations sewers), $92 M for new and expanded pump stations, $24 M for new storage facilities, $35 M for I/I reduction, and $9 M for WWTP capacity expansion.

The solution is characterised by conveyance with only a few storage locations and limited I/I rehabilitation suggested. The overall concept for the wastewater network will be as presented in the Figure 3 however factors such as operational flexibility, on site factors and risk will be assessed and the concept solution will be refined to come up with the revised programme to replace the existing WNSIP.

Table 4: Optimised Solution Cost Summary

Cost Item	**Capital Cost ($M)**	**O&M ($M)**	**Total Cost ($M)**
Gravity Sewer	80	23	102
Rising Main	18	5	23
Pump Station	92	50	142
Storage	24	20	44
I/I Reduction	35		35
Reticulation Sewer	58		58
WWTP	9		9
TOTAL ($M)	**316**	**98**	**413**

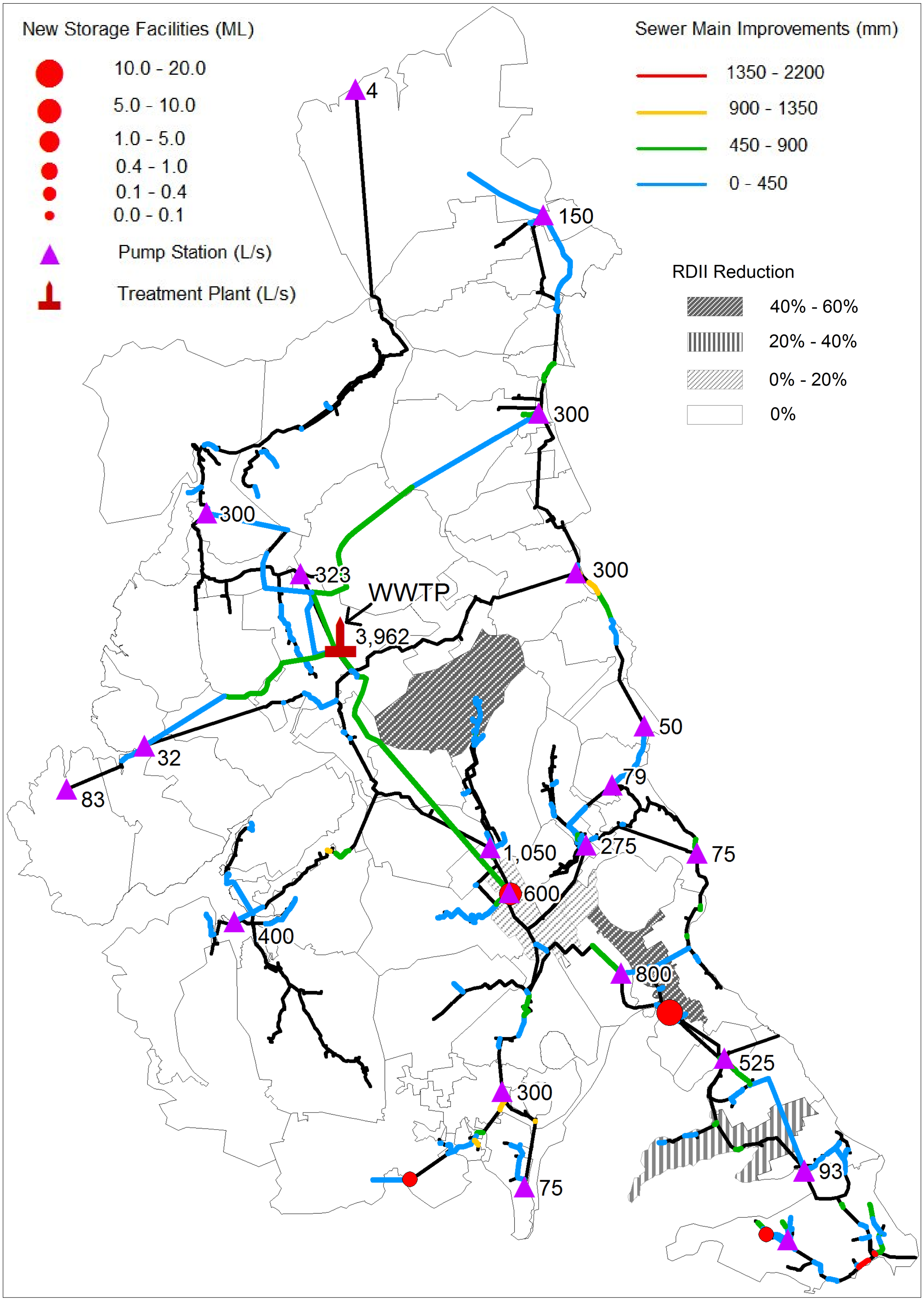

Figure 3: Optimised Solution

4 COMPARISON WITH PAST PROJECT CARE SOLUTION

The previous Project CARE WNSIP was updated in 2008 for costs of solutions to be built prior to 2021. The 2009/2010 Project CARE solution is based on 2056 projected design flows. To provide an apples-with-apples comparison an optimisation scenario for the 2021 projected design flows is currently being undertaken. The solution from this scenario will demonstrate the cost savings achieved using the Optimizer WCS (genetic algorithm optimisation) approach compared with the SEWCOM/SEEEKER (linear programming optimisation) approach used in the 2002 study.

In the interim period to the 2021 optimisation solution being developed a comparison between the 2056 solution developed using Optimizer WCS and the 2021 costs developed using SEWCOM/SEEKER can be made for indicative purposes. The SEWCOM/SEEKER solution had a total capital cost of approximately $305 M for the 2021 planning horizon. This compares with a total capital cost of approximately $316 M identified for the 2056 planning horizon using Optimizer WCS. This provides an early indication that Optimizer WCS has achieved significant cost savings when compared to a capital works programme which had previously been optimised.

5 CONCLUSIONS

If the optimisation project were not undertaken the Wastewater Network Strategic Improvement Programme would not represent the least cost solution for the system and for the ratepayers of North Shore City. Undertaking an optimisation exercise has resulted in significant cost savings for North Shore City Council and residents, much higher than that represented by manual refinements of the WNSIP programme.

Optimisation is more than just the Optimizer software it is a process of thinking about system improvement options and a tool to inform the debate around the best options for the network. The process focused attention on parts of the network which are not as well understood by throwing up solutions for problems which had to be considered and understood.

Re-optimising the system had benefits even though the original optimisation was undertaken only 8 years previously, mainly due to the changes in input variables such as growth and unit rates.

The optimisation process itself allows insights into the network and how different options can operate together to give a near optimal solution. A number of optimisation runs are required prior to the final result to remedy any issues with input data, hydraulics and allowable options, every run adds to the knowledge of the network and engineers feel for the network. The final optimisation solution will always contain an element of manual refinement.

The tool has far more potential than was used in this project with regard to sensitivity of the process to input variables and development of milestone solutions to stage the capital works programme through time.

Using the Optimizer software gives an auditable trail of inputs and outputs should a regulator be interested in the process followed and the outcomes achieved.

Key inputs, namely the hydraulic model, unit cost rates, population growth forecast, infrastructure condition deterioration and I/I effectiveness have a significant bearing on the optimisation results. When using optimisation software it is important to utilise the best available data and apply sensitivity analyses to identify how assumptions influence the solution. Ultimately, optimisation software needs to be used as a planning tool to support engineering judgment and develop planning strategies which are not only low cost but have sufficient flexibility to allow for adaptations to be made as system knowledge improves.