Options Analysis Methods for Wastewater Collection Systems

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ABSTRACT

New technologies have given the engineer additional tools with which to analyse the complexities of wastewater systems. This paper discusses the importance of the hydraulic model and the advantages it brings in wastewater system planning. At the same time, it raises questions and concerns about the accuracy of the data used to build the model, the quality of the flow survey used for calibration, and the limitations of models with respect to their ability to analyze a large number of improvement options and find the most cost-effective solutions. Options analysis techniques, such as linear programming and genetic algorithms (GA), are described as well as multi-criteria analysis, and the value of performing sensitivity analyses and scenario evaluations. Finally, a case study from the US is highlighted where GA optimisation was used to analyse a wide array of options to overcome overflow and surcharge problems, ultimately determining a hydraulically-viable, least-cost solution which incorporated multi-criteria objectives and risk-based assessment.

KEYWORDS

Wastewater planning, hydraulic model calibration, options analysis, multi-criteria analysis, linear programming, genetic algorithms, sensitivity analysis

1 INTRODUCTION

Presented with rapidly evolving technology, aging infrastructure and limited budgets, today's wastewater planning engineers are required to balance the demand for sophisticated solutions with good old-fashioned engineering judgment. Over the past 20 years the introduction of hydraulic modelling into the wastewater planning cycle of most large water utilities has caused a dramatic change in skill sets and planning techniques used by the planning team. Although today's engineers are required to overcome different, and perhaps more difficult, challenges than past generations the same basic operational requirements for a wastewater system remain. It is therefore important for our current generation of engineers to draw on the advantages of new technology without becoming overwhelmed by it and losing touch with tried and trusted traditional approaches.

Traditional wastewater planning principles applied during most of the 20th century are soundly based on empirical values for dry and wet weather flow. The engineering emphasis has been to select sewer alignments which best service the customers, minimise pumping, maintain adequate grade, and make best use of available easements while avoiding service conflicts and troublesome geography. Sizing sewer mains was merely a straightforward calculation using the empirically-based design flow and applying Manning's equation with appropriately conservative roughness coefficients.

In contrast to traditional planning, there has been a recent shift of engineering effort and particularly junior resources towards the use of hydraulic models to determine the source of existing system capacity issues and to develop capital improvement plans. In many cases, but certainly not all cases, the hydraulic model results are treated as the single source of truth. The in-situ observations reported on by the operations staff are often treated as an inconvenient ambiguity to be ignored on the basis that they are too hard to explain. The common sense design solutions which have served us so well in the past are, in some cases, being replaced by what some see as "sophisticated non-sense" solutions contrived by way of black-box, computer-generated garbage.

Millions, if not billions, of dollars are being invested each year into wastewater infrastructure, most of which stem from the results of hydraulic modeling analyses. It is essential that planning decisions are firmly based on realistic assumptions, effective analysis and real-world considerations of risk, cost and consequence to the environment. The following discussion and case study will:

- provide insight into some of the key assumptions which can significantly affect the outcome of planning studies;
- summarise advantages and disadvantages of common wastewater system improvement options;
- describe available techniques and technologies for performing wastewater options analysis;
- demonstrate the benefit of testing the planning solution's sensitivity to key assumptions; and
- suggest ways of incorporating multi-criteria analysis into a planning study.

2 WASTEWATER PLANNING ASSUMPTIONS

Properly constructed and calibrated wastewater hydraulic models provide an unprecedented ability to obtain detailed information on how the existing collection system responds during dry and wet weather operation. By first developing a model of the existing system based on asset data and then calibrating the model to flow survey data, the precise location of capacity constraints can be readily identified.

Once capacity issues have been identified the hydraulic model can be used to simulate how various improvement options help to relieve capacity constraints. The model can also be used to project future population scenarios and master planning solutions to overcome system deficiencies due to projected growth.

The key assumptions used when developing wastewater planning solutions are summarised in Table 1. The accuracy of the model calibration and flow forecast, the accuracy of infrastructure cost rates, the selection of desired standards of service and the assumed feasibility of improvement options will have significant bearing on the outcome of planning studies.

The accuracy of a hydraulic model is highly dependent on the quality of the calibration. Flow survey data is often incomplete, particularly if overflows are not gauged. Rainfall can vary significantly across the catchment during the time of the flow survey and will not be accurately represented unless sufficient rain gauges are installed. Calibration based on small rainfall events compared to the intended design event or without verification against a second wet weather event in the survey period will likely result in misleading extrapolations.

This means the water utility is not only required to invest significantly into the development and maintenance of their models but they constantly need to question the accuracy of solutions obtained from them. These realities sometimes lead to a lack of confidence in hydraulic-model based solutions and a reluctance to perform detailed options analysis studies.

Until recently the manual approach to developing planning solutions and performing options analyses has been too cumbersome to perform sufficient sensitivity and scenario evaluations. These evaluations are extremely helpful in gaining a proper understanding of how specific assumptions affect results. The application of new technology which automates the process of options analysis has demonstrated in recent projects that by performing sensitivity analysis it is possible to identify opportunities where a small amount of additional investment can be made today to achieve a much greater level of contingency in the future. It also shows which assumptions have a significant impact on short-term works projects so that utilities can focus investment into further data collection where it is important.

Table 1: Summary of Planning Assumptions

Assumption		Description / Bounds of Uncertainty
Design Flow	Calibration Accuracy	- Degree of uncertainty can usually be quantified reasonably well based on suitability of rain events during flow survey and/or success in gauging overflows
	Population Forecast	- Focused around pockets of potential high growth areas. - Can have a high degree of variability but typically possible to quantify within bounds.
	Future Rainfall Patterns	- Potential for climate change impacts or otherwise skewed historical rainfall records
Cost Rates	Cost Rates of Improvement Options	- The concern about cost rates with respect to options analysis is primarily in the accuracy of one cost relative to another cost for a different infrastructure category. (For example under-estimated storage costs and over-estimated pipe costs would skew the solution towards storage). - The most tenuous cost data are typically I/I reduction cost estimates. - Cost rates for storage, sewer mains, and treatment plants are often relatively accurate provided local site conditions are accounted for. - Future power costs for pump stations can be difficult to estimate
Desired Standards of Service	Allowable surcharge / overflow containment standard	- Overflow containment standards typically reflect community expectations and environmental regulatory requirements - By performing scenario evaluations to demonstrate the effect of criteria on planning solutions it is possible to provide information which can help define system performance expectations - Sewer main velocity and minimum cover criteria reflect operability standards which usually do not have a great deal of flexibility
Feasibility of Options	Operability / Constructability / Consentability	- During an initial high-level planning study it can be difficult to predict the actual constructability issues of certain improvement options; however, the engineering team can typically identify which options are going to be more difficult than others to construct - It is not necessary to get too bogged down in feasibility assessment of options during a first pass options analysis. The vast majority of options will be discredited in the initial options analysis. The engineering team can focus on verifying the feasibility and refining the cost rates for the limited number of promising options identified in the first round analysis. This then feeds directly into the second round analysis. - The engineering team may choose to run several scenarios with different allowable improvement options to demonstrate the cost benefit of particular options to be evaluated on a risk basis and also with other multi-criteria objectives

3 USING HYDRAULIC MODELS TO PERFORM OPTIONS ANALYSIS

One of the most significant benefits of a calibrated hydraulic model is that it enables the user to evaluate various improvement options. Depending on the individual wastewater system, there are often numerous configurations of improvement options which will achieve the desired standard of service. Each potential configuration of improvements is likely to have a different capital cost, operating cost, environmental impact, social impact, cultural impact, and level of risk associated with it. This section explores the typical range of improvement options available for wastewater systems and presents possible ways of evaluating alternatives that go beyond the traditional trial-and-error modeling approach, including multi-criteria analysis and risk-based assessment.

3.1 IMPROVEMENT OPTIONS FOR WASTEWATER SYSTEMS

Increased conveyance capacity, increased treatment plant capacity, flow equalisation and flow reduction are the four main categories of improvement options for reducing wastewater overflows in existing systems.

Conveyance capacity improvements include sewer mains and pump stations as either augmentations/upgrades to existing infrastructure or flow diversions along new route alignments. Increased treatment capacity can be provided at existing treatment plants, new plants or satellite high-rate treatment facilities (chemically enhanced clarification, biologically enhanced clarification and a UV disinfection system used to treat intermittent high wet weather wastewater flows). Flow equalisation is achieved by developing storage capacity or making use of existing storage capacity within the system. This can be done with in-pipe storage or off-line storage tanks; some cities have used vortex regulators to restrict and back up the flow in existing sewers (C. Dorsch, 2009). Flow reduction can be achieved by reducing inflow or infiltration, or by separating storm water and sanitary sewer flows in combined systems.

The advantages and disadvantages of various improvement options are presented in Table 2. From an operation, maintenance and asset data management perspective gravity sewer solutions are the most favourable options along with inflow reduction. Pressure mains can be easier to construct than gravity mains, are resistant to infiltration, and allow for shallower construction depths and greater flexibility in route alignment. However, pump stations required for pressure systems have substantial power demands as well as operations and maintenance costs, and require extensive pump station failure/shutdown safeguards to mitigate risk of dry weather overflows. Flow equalisation facilities can have significant cost-saving benefits by eliminating or delaying conveyance and treatment plant improvements but can be troublesome from an operation, maintenance and asset data management standpoint. Infiltration reduction by repairing manhole walls and sewer main cracks can be expensive and may not have a significant effect on peak wet weather flow. On the other hand, inflow reduction by repairing private lateral connections can be a cost-effective way to reduce peak system demands and eliminate trunk sewer upgrades.

The cost effectiveness of inflow and/or infiltration reduction is widely debated by wastewater planning engineers. Typically inflow and infiltration (I/I) are bundled together when discussing the effectiveness of "I/I reduction". Recent studies have demonstrated the importance of considering inflow reduction independent of infiltration reduction. For Johnson County Wastewater's pilot catchment in Kansas, US the cost to reduce peak flow is shown to be more than 10 times expensive when targetting infiltration reduction (e.g. fixing cracks in sewer mains and manholes) than targetting inflow reduction by repairing private lateral connections (V. Varghese et al., 2008). Although this pilot study result could be skewed slightly by antecedent catchment conditions and catchment specific characteristics the overall trend is clear. M. Anderson, 2006, observes a similar trend when reviewing the effectiveness of recent I/I reduction projects completed by Sydney Water, Public Utilities Board of Singapore, and Brisbane Water, stating "Rehabilitation work does not provide any consistent results in reducing groundwater infiltration. A high level of rehabilitation and associated cost is necessary to obtain a small reduction in the level of wet weather RDII getting into sewerage systems." Although the rehabilitation projects reviewed in this paper were primarily addressing infiltration reduction, inflow is still bundled in with the conclusions. It is important to recognise the potential cost benefit which can be achieved when water utilities are prepared to invest into repairing private laterals to remove improperly connected storm water. However, a range of ownership, responsibility and consenting issues can arise for water utilities when endeavouring to repair private laterals. Innovative ways to provide incentives for property owners to have private laterals repaired (targetting specific catchments where it is cost effective to do so) are currently being trialled.

Table 2: Comparison of Typical Improvement Options

Improvement Option		Advantages	Disadvantages
Conveyance	Gravity Sewer – General / Existing Sewer Replacement Upgrade	- Easy to maintain and operate - Reliable - No power consumption	- Sewer alignment must allow for sufficient grade (though inverted siphons can be used to bypass depressions)
	Gravity Sewer – Existing Sewer Parallel Augmentation	- Utilises existing system capacity	- Additional infrastructure & asset data to maintain - Wider easement required - Additional source of I/I
	Sewer Main – Trenchless	- Less disruption of traffic / disturbance of easements - Allows for greater construction depths - Directional drilling (up to 1m diameter) has similar cost to open trench	- Incongruous geology can escalate construction costs / makes cost estimation difficult
	Pump Station / Pressure Main	- More direct sewer alignments - Shallower construction depths - No infiltration	- Power consumption - Ongoing operation and maintenance - Potential for failure / risk of overflows - H_2S formulation
Flow Equalisation	Storage - General / In-Pipe Storage	- Can eliminate or delay conveyance/treatment upgrades - Opportunity to oversize new mains to provide storage at small additional cost	- Risk of sedimentation can be a limiting factor when designing in-line storage
	Storage - Off-Line Storage	- Relatively easy to stage construction / augment compared with sewer mains - Flexibility of tank or pipe/tunnel	- Site availability can be a limiting factor - Ongoing operations and maintenance - Additional infrastructure & asset data to maintain
	Flow Control Device (valves, vortex structures)	- Makes use of existing system capacity	- Accurate hydraulic model essential
Flow Reduction	Infiltration Reduction (repair MH wall, sewer main cracks, etc)	- Pipe relining increases asset life - Marginal reduction in peak flows	- Typically not very effective for reducing peak flows - Possible negative effect by reducing base flows in systems with high retention times / odour issues
	Inflow Reduction (rehabilitate MH frame/seal, private lateral repair, etc)	- Can be cost effective way of reducing peak flows and eliminating conveyance/treatment upgrades	- Private lateral repairs can be difficult to negotiate with property owners even when paid for by water utility - Difficult to estimate cost vs. flow reduction and evaluate where to target investment
	Sewer Separation (for combined systems)	- Eliminates WWTP upgrades	- Typically most expensive solution for combined systems

3.2 OPTIONS ANALYSIS AND MULTI-CRITERIA ANALYSIS

The appropriate level of detail to be applied for evaluating various possible improvement options will largely depend on the range of feasible alternatives and the water utility's policies on various improvement strategies. There is a large degree of variability from utility to utility as to what type of improvement options they are prepared to implement and the level of effort they are prepared to invest into options analysis.

Until recently a manual approach to options analysis has been the only readily available alternative. There are several commercially available automated design tools which can be used to streamline the modelling tasks but prior to the last several years there have been no specific options analysis tools which combine the hydraulic model, the cost data and the performance criteria into a single framework.

3.2.1 LINEAR PROGRAMMING OPTIONS ANALYSIS

Sydney Water first pioneered the development of a specific wastewater options analysis tool using linear programming. The in-house developed software could be programmed with a range of allowable improvement options and associated costs. When run, the tool would use peak system inflows and an assumed hydrograph profile to calculate conveyance capacity upgrade diameters (Manning's calculation for full-pipe flow) based on the flow routed through the system for a particular storage option / inflow reduction scenario.

The linear programming approach is extremely efficient because it does not use the dynamic flow model. By using only peak inflow rates and assuming a fixed unit hydrograph to determine volumes, the linear programming computation can evaluate the complete scenario evaluations more than one thousand times faster than using the hydraulic model. The inherent disadvantage of this approach is that dynamic flow routing is not correctly accounted for and the calculation of storage volumes and flow depths can have a substantial degree of error. The linear programming approach does not allow flow bifurcation options and flow path alternatives to be evaluated in a single analysis but instead requires individual runs to be completed for each possible configuration.

3.2.2 GENETIC ALGORITHM (OR SIMILAR) OPTIONS ANALYSIS

Artificial intelligence (AI) is becoming increasingly prevalent throughout the engineering industry. AI typically replicates how natural processes would occur in a controlled environment. Examples include ant colony, particle swarm, genetic algorithms and neural networks. This discussion focuses on genetic algorithms because they have been most successfully applied to wastewater options analysis to date.

Options analysis using genetic algorithms (GA) is a directed search technique used to find the best combination of options which minimises the overall value of an objective function such as total project cost. It represents a set of decision variables as a string of integers and then successively evaluates a collection of trial solutions called a "population" (Simpson et al., 1994). For each solution the GA computes a measure of worth or "fitness" based on capital cost, operating cost and hydraulic performance. Essentially, the fitness of a trial solution determines the probability of it being represented in future generations. The hydraulic model, cost rates and performance criteria provide a consistent environment through which the solutions progressively evolve until a combination is found which satisfies the objective function better than any other.

By performing a complete hydraulic model simulation for each combination of improvement options this approach enables storage, bifurcation, flow path alternatives, real-time control and inflow reduction to be evaluated accurately when compared with the linear programming approach. By applying a directed search technique specifically suited to complex non-linear problems the GA approach enables exhaustive analysis of numerous interdependent improvement options without the need to predefine or to evaluate every possible scenario.

Currently the primary limitation of GA options analysis is the need for significant computation power to execute the analysis. Fortunately recent developments in computing techniques have enabled model runs to be automatically distributed across many computers and run in parallel.

3.2.3 SENSITIVITY ANALYSIS AND SCENARIO EVALUATIONS

Regardless of whether options analysis is completed using a manual approach, linear programming or artificial intelligence, the same uncertainties in foundation data accuracy exist. The intuitive reaction is: if the foundation data accuracy is questionable then so must be the results derived from it. In no way does the following discussion dispute this proposition. However, rather than simply concluding that options analysis is futile when foundation data is unreliable, the following discussion will encourage engineers to critically assess the accuracy of data and to quantify the effect it has on the solutions derived from these data.

The rigor required to perform options analysis manually has traditionally meant that the engineer is reluctant to repeat this process many times over in order to quantify the effect assumptions may have on the solutions obtained. The recent developments in technology which now enable options analysis to be completed more efficiently and comprehensively also empower the engineer to more feasibly interrogate "what-if" scenarios. Not only does this present an unprecedented opportunity to take planning to a new level but also presents a significant challenge for engineers to shift mindsets and see beyond the mass of data and hydraulic modelling rigor which has increasingly stifled, over the past decade, their ability to make common sense, good old-fashioned engineering decisions.

Table 3 provides a detailed summary of "what-if" scenarios which can be helpful in quantifying the effect of assumptions on planning solutions and strategies. The effect of uncertainties in design flows can be quantified by performing scenario evaluations with upper flow estimates. The effect of inaccuracies in assumed cost rates can be quantified by varying the cost rate differential between different improvement option categories. Desired standards of service can be benchmarked by performing scenario evaluations to demonstrate cost vs. consequence of different overflow containment standards or permissible surcharge limits. Scenario evaluations which "lock-in" or "lock-out" particular improvement options can help to build a portfolio of least-cost solutions to be further evaluated using multi-criteria analysis.

By performing sensitivity evaluations, such as testing how the solution changes for upper estimates of design flow or upper cost estimates for I/I reduction, it is possible to demonstrate improvement projects which are required regardless of assumptions made, projects which are never selected in the analyses, and those which are highly dependent on assumptions. This provides the water utility with a clearer direction forward than a planning solution based on a single set of assumptions. Short-term projects which are independent of assumptions can be implemented with confidence and, if required, implemented with additional capacity to reflect the uppermost requirements identified in the sensitivity runs. Rather than investing into system wide data verification projects (such as additional gauging or I/I source identification) the water utility will know specifically where more information is required so that future capital projects can be confirmed.

Table 3: Useful Scenarios for Quantifying Effect of Assumptions

Assumption		"What if" Scenario	Objective
Design Flow	Calibration Accuracy	- What effect does using an upper estimate of design flow (more conservative catchment runoff parameters) have on the planning solution?	- Identify aspects of solution which are significantly affected by calibration accuracy so additional flow survey can be targeted for those areas. - Identify parts of solution which are relatively consistent and can be implemented with confidence. - Identify conservative infrastructure sizing for short-term capital works projects.
	Population Forecast	- What effect does using an upper estimate of population forecast have on the design solution?	- Determine additional cost to provide a greater level of contingency. (For example 10% additional population contingency may be achieved with only 2% additional upfront investment for improvements, whereas the overall cost to augment the system in the future may be 20% more expensive to do then rather than now.)
	Future Rainfall Patterns	- What are the effects of a higher intensity design storm on the solution?	- Determine additional cost to provide a greater level of contingency for higher than anticipated rainfall intensities.

Table 3: Useful Scenarios for Quantifying Effect of Assumptions (continued)

Assumption		"What if" Scenario	Objective
Cost Rates	Cost Rates of Improvement Options	- What effect does using upper cost estimates for I/I reduction have on the solution? - How would the planning strategy change if power costs doubled?	- Identify which sub-catchments should be targeted for I/I reduction analysis regardless of assumed cost effectivenesss of rehabilitation - Identify conservative pipe diameters which can be implemented in the interim period until pilot I/I reduction studies are completed to verify cost effectiveness of rehabilitation - Determine additional cost to provide a greater level of contingency for higher-than-anticipated power costs.
Standards of Service	Allowable surcharge / overflow containment standard	- What is the cost impact of designing for various overflow containment standards?	- Identify what is the best practicable option for each overflow location based on cost to contain compared with environmental, social and cultural impacts of overflows
Feasibility of Options	Operability / Constructability / Consentability	- What is the additional cost of avoiding high-risk least-cost improvement options? - What does the solution look like if a particular improvement option is "locked-in" or "locked-out"?	- Generate several least cost, hydraulically feasible solutions which can then be evaluated with respect to other multi-criteria objectives (operability, constructability, consentability, environmental / social / cultural impact) - Identify the additional cost to incorporate a preferred option which was not selected in the least-cost solution - Identify the additional cost to avoid an improvement option which was in the least-cost solution but is undesirable from a multi-criteria analysis perspective

3.2.4 HOW TO INCORPORATE FEASIBILITY ANALYSIS

Determining what should come first out of options feasibility analysis and options analysis can be a "chicken before the egg" conundrum. On one hand the options analysis should not be evaluating infeasible options and on the other hand the level of effort required to check the feasibility of options properly can restrict the number of options which can be verified efficiently. Discrediting options based on first-instinct simply because there is insufficient time to check their feasibility somewhat undermines the purpose of an objective options analysis; however, an intensive initial screening may be essential when using a manual options analysis approach.

If genetic algorithm (or similar) options analysis software is being used then it is effective and efficient to perform some iterations in the options feasibility screening process. The following approach helps to achieve practical solutions without over-restricting the options to be evaluated.

1. Options development and initial high-level screening. This should primarily focus on defining conceptually feasible flow path alternatives. It is also advisable to apply a first-cut cost multiplier to all sewer main improvement options and consider the most likely construction method. It is not necessary at this stage to identify potential storage locations. Feasible I/I reduction targets are typically limited by a minimum target I/I threshold.

2. Preliminary options analysis. Conduct one or more preliminary GA options analysis run, honing in on the most promising improvement options. By applying a storage-equivalent cost function to overflow volumes, the analysis will evaluate storage options at every manhole in the system. This will help to identify hydraulically-optimal, cost-effective locations for storage which can then be screened in more detail.

3. Detailed options screening. Cost multipliers and construction methods associated with individual improvement options should be reviewed and refined. Particular attention should be given to options

selected in the preliminary analysis. Storage locations identified in the preliminary analysis should be reviewed to identify feasible nearby locations for storage facilities. Sewer main upgrades should be classified as replacement upgrades or parallel augmentations at this stage in the project.

4. Interim solution options analysis. Conduct one or more options analysis GA runs using refined input from the detailed options screening.

5. Interim solution review and scenario selection. The interim solution should be reviewed and the feasibility of selected options should be verified. At this stage, the interim solution should be technically feasible, hydraulically feasible and cost effective. The solution has not yet been interrogated with respect to multi-criteria objectives. Additional scenario runs should be selected with the objective of demonstrating the cost impact of "locking-in" or "locking-out" particular options. Preferred options or options of interest which were not selected in the interim solution can be "locked-in" during a scenario run to demonstrate the additional cost to have these options in the solution. Options which were selected in the interim solution but are not preferable from an engineering perspective can be "locked-out". Staging scenarios should also be completed in the final runs to identify the net present value cost/benefit of particular planning strategies (the procedure for this analysis is beyond the intended scope of this Paper).

6. Perform final scenario runs. The final scenario runs will provide a portfolio of least-cost solutions which can be reviewed in more detail using multi-criteria analysis and reflected on later during detailed design and construction in cases where issues arise with particular works projects. Some additional scenario runs may be selected during the multi-criteria analysis project phase to further build the solution portfolio.

3.2.5 MULTI-CRITERIA ANALYSIS

Multi-criteria analysis (MCA) is an essential component of an options analysis study. The objective of the MCA should be to develop an overall solution score which accounts for capital cost, operating cost, risk of failure, construction difficulty, consent difficulty, and environmental, social and cultural impact. By developing a portfolio of least-cost, technically feasible solutions during the options analysis stage of the project there will be a solid foundation from which a focused and detailed MCA can be conducted.

The following figures demonstrate how genetic algorithm optimization runs can be used to rapidly generate solutions for a range of scenarios which meet different design objectives. In this example the option to use high-rate treatment (HRT) to eliminate system overflows is being considered, however there is uncertainty as to whether the regulatory authority will permit it.

The Cost Effective Analysis Curve shown in Figure 1 shows the additional cost required to eliminate HRT from the solution by investing into I/I removal and additional storage. This curve is developed by running several optimization scenarios with different allowable peak flows to the treatment plant. Without any storage or I/I reduction the HRT capacity needs to be 1100 L/s. The least-cost solution has some I/I reduction and storage, and the HRT capacity is at 750 L/s. The additional cost to eliminate HRT completely is approximately $110 M.

By comparing the HRT activation frequency with the Total Project Cost Curve in Figure 2 the City (in consultation with the regulatory authority) can select an acceptable HRT activation frequency based on consideration of environmental impact and cost. In this example the HRT activation frequency can be halved with an additional 5% investment or reduced to once per year with only a 20% additional investment, compared with 40% required to eliminate the HRT for the 5-year design event.

This example can be extended to any application where it is valuable to have a variety of solutions to assist the decision making framework. For example a climate change impact assessment could be completed by developing solutions for the design storm event, the design storm + 10% and the design storm +20%. The solution costs can then be compared with the cost of augmenting the system if contingency isn't built into the system upfront to mitigate the risk of climate change. For example a 10% upfront investment may provide 20% redundancy for climate change whereas augmenting the system once the 20% increased rainfall occurs may require an additional 40% net investment.

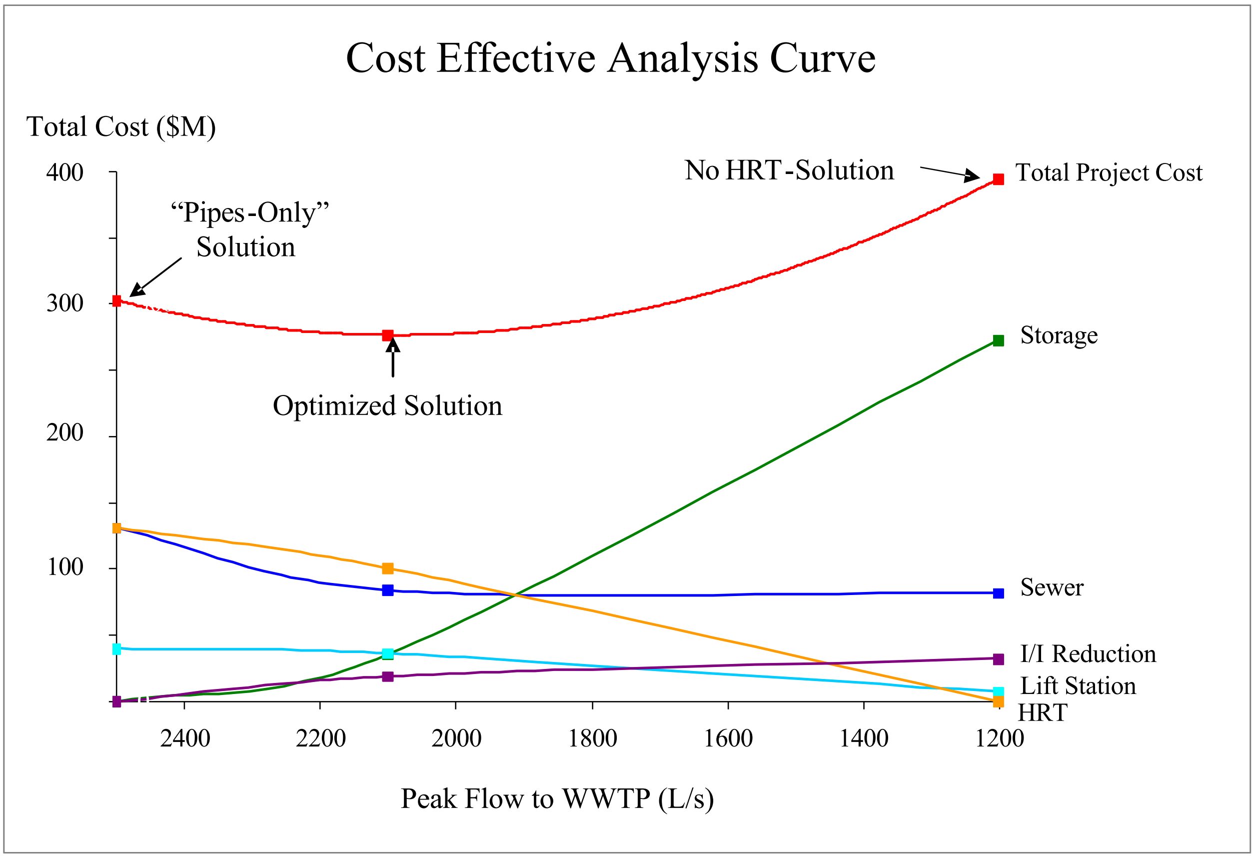

Figure 1: Example Cost Effective Analysis Curve

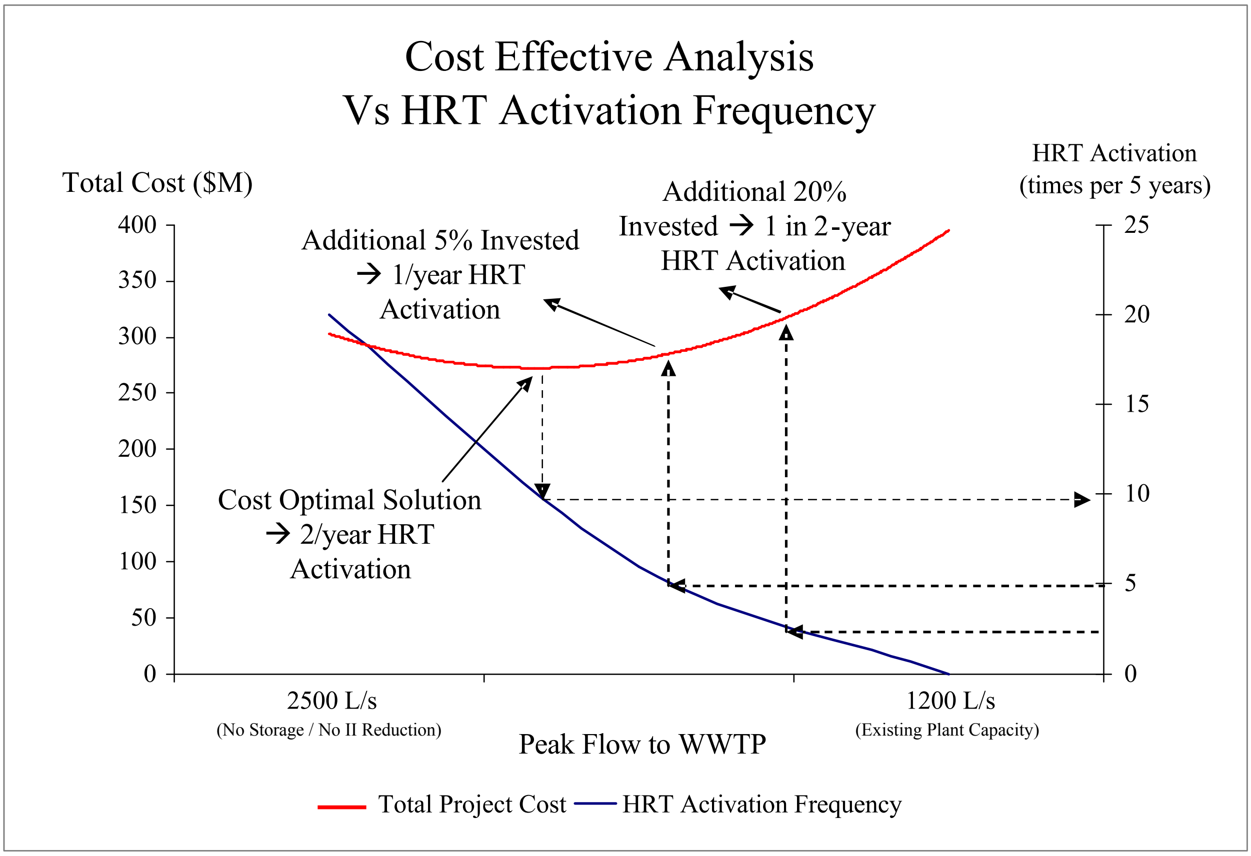

Figure 2: Multi-Criteria Analysis – Cost Vs HRT Activation

4 CASE STUDY – TURKEY CREEK SEWERSHED OPTIMISATION (US)

In 2007, Johnson County Water (JCW) in the US performed a detailed capital improvement plan options analysis for the Turkey Creek sewershed. The Turkey Creek sewershed is a 16 square mile area of mature suburban development including 240 miles of sanitary sewer. Under the 10-year design storm conditions, sections of the trunk system and the wastewater treatment plant are under capacity.

The allowable improvement options included replacement and parallel gravity sewer, in-system storage, pump station upgrades, wet-weather treatment and inflow and/or infiltration (I/I) reduction. Unit costs for each of these improvement options were developed, as well as hydraulic performance constraints such as allowable surcharge and minimum and maximum velocity.

An innovative approach to determine the most cost effective balance between I/I removal and system capacity improvements was developed for the Turkey Creek project as follows:

1. Identify current I/I rates in each of the 11 sub-basins from flow monitoring and calibration.
2. Estimate cost to identify, repair or replace leaking manholes, sewers and laterals.
3. Develop I/I reduction cost curves for each sub-basin.
4. Identify options for relief sewer, storage, pump upgrade, treatment plant upgrade and new treatment plant.
5. Develop costs for each of the allowable improvement options.
6. Review basement backup levels to determine surcharge criteria.
7. Formulate GA model with allowable improvement options, cost rates and hydraulic performance criteria.
8. Run the optimization model to produce preliminary, interim and final solutions.
9. Perform sensitivity analysis and scenario evaluations for upper I/I cost estimates

To evaluate I/I reduction options, the GA software recognizes the wet-weather inflow hydrographs from each sub-basin and adjusts them to reflect the level of I/I reduction being trialed. Capital costs to achieve specific I/I reduction levels are balanced against the cost of downstream capital improvements. The program determines the most cost-effective level of I/I reduction in each basin to reduce the overall cost of system capacity upgrades and system rehabilitation. The cost curves used for I/I reduction options comprised separate rates for different rehabilitation strategies such that the GA could select to target inflow reduction (e.g. private laterals) and/or infiltration reduction (sewer main defects). The optimisation demonstrated that it was cost effective to target inflow reduction for three of the eleven basins. Two basins with high I/I were selected for intensive inflow reduction programs aimed at achieving 50% reduction in current levels. Interestingly, one of the selected sub-basins had relatively low leakiness and high I/I removal cost, but inflow removal was determined to be cost effective because the resulting decreased flows led to substantial savings in downstream improvement costs. Repairing cracks in sewer mains and removing tree-root intrusions to reduce infiltration was not found to be cost effective in this study; however, this may still be required from an asset maintenance basis.

Figure 2 plots a cost-effective analysis curve prepared by making a series of optimisation runs for zero I/I removal and for different combinations of I/I removal that sum to an overall I/I removal level across the entire Turkey Creek sewershed. The optimised solution corresponds to the minimum cost point on the curve, with an overall I/I removal level of just under 10%.

A beneficial component of the Turkey Creek optimisation project was to incorporate a risk-based approach to address uncertainties in estimating the level of effort required to achieve I/I reduction. A scenario evaluation was completed using upper cost estimates for I/I reduction, resulting in a solution with larger, more conservative pipe sizes. With this information the JCW could then proceed with near-term I/I removal projects while at the same time verifying the cost-effectiveness of the rehabilitation work. The results from these I/I reduction projects currently being completed will provide improved input for the next round of planning for the Turkey Creek sewershed and other JCW sewersheds.

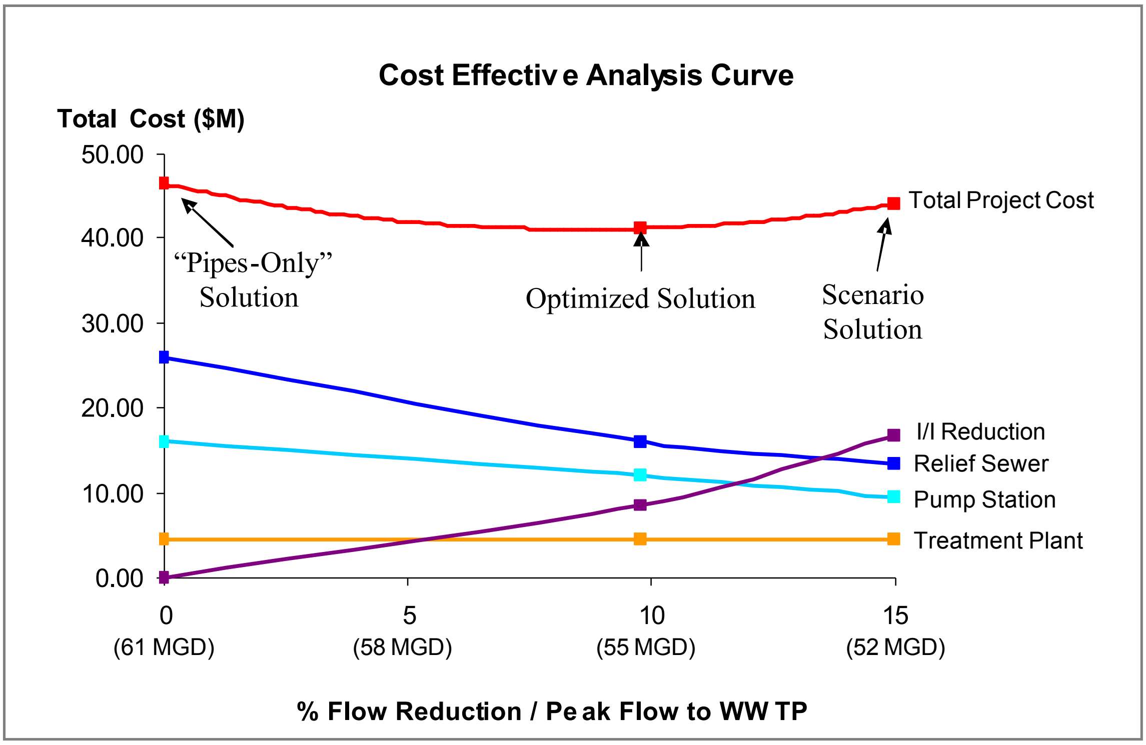

Figure 3: Cost Effective Analysis Curve from Scenario Evaluations – JCW (US)

5 CONCLUSIONS

One of the greatest challenges facing water utilities when developing wastewater planning strategies is to find solutions that are not only cost-effective in the short term, but that also provide the desired level of service for the design life of the infrastructure. Uncertainties in future population forecasts, climate change impacts, rates of system deterioration and accuracy of hydraulic model calibration can have a significant impact on planning solutions.

The approach being used for recent optimisation projects—such as that of the Johnson County Water case study—enables greater engineering input by improving the efficiency with which modelling can be completed and planning scenarios evaluated. Optimisation scenarios that demonstrate solution sensitivity to key assumptions help to: indicate aspects of solutions which have little dependence on the assumptions and can be implemented with confidence; identify opportunities where a small amount of additional investment can be made today to achieve a much greater level of contingency in the future; and show which assumptions have a significant impact on short-term works projects so that utilities can focus investment into further data collection where it is important.

The real value in optimisation is not in finding a single, absolute optimal solution but rather in having an efficient planning tool for options analysis and scenario evaluation which, when integrated with sound engineering judgment, can be used to help develop robust, cost-effective and highly defensible planning improvements and strategies. When used effectively, planning engineers have greater confidence in the output from hydraulic models and modelers have more time to participate in engineering.

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