COMPARING INVESTMENTS DECISIONS USING DIFFERENT SYSTEM PERFORMANCE ASSESSMENT METHODS FOR WASTEWATER NETWORKS

A. Lindgren & B. Robinson, Aurecon New Zealand Limited

ABSTRACT

Target levels of service for the performance of reticulated wastewater networks under wet weather flows vary widely throughout the country, as does the approach for assessing whether these target levels of service are likely to be met. Generally target levels of service will require flows resulting from a wet weather event of certain magnitude to be passed without overflow, or restrict the frequency of overflows to a specified frequency.

Calibrated hydraulic models provide a powerful tool for assessing the likely performance of a wastewater network under a range of wet weather events and future growth scenarios. But more importantly, these models enable of a number of network upgrade options to be investigated to provide the desired level of service, and the cost of providing this level of service to be quantified.

A number of options are available to a wastewater modeller for assessing the system performance of a wastewater network, including the use of synthetic design storms, historical storms, a typical year rainfall time-series or a long rainfall time-series rainfall

This paper compares and analyses the system performance results from a number of wastewater models using different methods. It also compares the costs of network upgrades required to provide a given level of service using different system performance assessment methods, and explores the different investment decisions which might be made on the back of using one of these methods over another.

The results presented are based on actual wastewater modelling projects undertaken throughout New Zealand and Australia, and involve wastewater networks encompassing a wide range of current system performance standards and target levels of service.

KEY WORDS

Wastewater modelling, level of service, system performance assessment, investment decisions.

INTRODUCTION

Target Levels of Service (LOS) for the performance of reticulated wastewater networks under wet weather flows vary widely throughout New Zealand. Generally target LOS will require flows resulting from a wet weather event of certain magnitude to be passed without overflow, or restrict the frequency of overflows to a specified frequency. For example, a LOS may be in the form of:

- ‘sewers should contain a 1 in 5 year Average Recurrence Interval (ARI) rainfall event without overflow’ or
- ‘the network should overflow no more than twice in 10 years on average’

Often, no target LOS exists in terms of the overflow containment standard provided by a wastewater network, and the decision is made on the basis of what is considered affordable, resulting in wildly varying LOS through the country.

There are a variety of methods commonly used to assess wastewater network performance, including the use of

- synthetic design storms,
- historical storms,
- a typical year rainfall time-series, or
- a long rainfall time-series rainfall.

Calibrated hydraulic models provide a powerful tool for assessing the likely performance of a wastewater network under a range of wet weather events and future growth scenarios. But more importantly, these models enable of a number of network upgrade options to be investigated to provide a given LOS, and the cost of providing this LOS to be quantified.

This aim of this paper is to compare the costs of network upgrades required to provide a given LOS using different system performance assessment methods. An assessment is also made of the different investment decisions which might be made on the back of using one of these methods over another.

The results presented are derived from calibrated hydraulic models of three wastewater networks throughout New Zealand and Australia, which cover a wide range of current system performance standards and target LOS.

OBJECTIVE

The objective of this paper is to make a comparison between the network upgrades that might be recommended using a design storm approach and a long time series approach.

STUDY CATCHMENTS

No two wastewater networks are the same, with distinct differences in a number of factors common, including

- Age and condition
- Pump station/rising main or gravity dominated
- Time of concentration
- Degree and variation of groundwater infiltration
- Degree and variation of fast response inflow
- Degree and variation of slow response infiltration
- Ability to accommodate projected growth

Three study catchments with distinctly different characteristics which cover a range of current system performance standards have been used to enable the subtle differences between analysis methods for different networks to be explored. The characteristics of the study catchments are summarised below.

Parameter	Study Catchment		
	A (NZ)	B (NZ)	C (Australia)
Age	1980's	Oldest parts - 1920's	1980's
Population	10,000	4,000	2,000
Manholes	1,500	550	800
Pump Stations	13 total (2 major)	5 total (1 major)	3 (all minor)
Target LOS	None	None	5 yr ARI storm
Critical Duration Storm	12 hrs	48 hrs	6 hrs
Wet weather peaking factor in critical duration 1 yr ARI storm	4.8	8.3	7.0
Current Performance	Generally good Terminal P/S capacity < 1 yr ARI Limited surcharge in 5 yr ARI Rest of Network > 10 yr ARI	Poor Significant and widespread overflows in 6 month ARI event	Good One location overflows in 2 yr ARI Rest of network > 5 yr ARI
Projected growth	High	Low	Medium
Model used	Future (2061)	Existing	Future (2050)

Table 1: Catchment Characteristics

It can be seen that the all three study catchments are relatively small, but cover a wide range of critical duration storms, wet weather peaking factors and current system performance. No target LOS exists in relation to conveyance capacity for catchment A and B, with documented LOS relating to repairs and maintenance. Catchment C, which is located in Australia, has a target LOS of no overflows in a 5 year ARI design storm.

METHODOLOGY

Calibrated hydraulic models had been previously developed for each catchment using Infoworks CS software. Future models were used for catchment A and catchment C due to the significant growth forecast within these catchments which will likely drive future network improvements. This study utilised two commonly used methods for assessing system performance of wastewater networks; synthetic design storms and historical time series rainfall. The process used for each method is outlined below

SYNTHETIC DESIGN STORM APPROACH

Synthetic design storms offer an efficient way to assess the performance of a wastewater network under a range of wet weather conditions. The generation of synthetic design storms utilises the relationship between rainfall intensity, duration and frequency. For a specified duration and frequency, the corresponding amount of rainfall is distributed in a pre defined manner throughout the duration of the storm.

Design rainfall data was obtained from HIRDS (High Intensity Rainfall Design Storms) for catchments A and B. No allowance was made for climate change to enable comparison with historical rainfall records.

Infoworks CS has a number of design storm generators in-built into the software. For this study the UK rainfall generator was used which enables a number of synthetic design storms of varying durations and return periods to be quickly generated from the 5 yr 60 minute rainfall depth, and a ratio of 60 minute to 48 hr rainfall depth. Rainfall depths for the generated rainfall events were checked against HIRDS rainfall data to ensure they were appropriate for this study, and were found to be generally within 5% agreement. ‘Average’ initial catchment wetness conditions were assessed from a ‘typical’ year’s rainfall data.

Design storms for catchment C were developed in accordance with the Australian Bureau of Meteorology ‘Rainfall and Runoff’ charts and imported into Infoworks.

Each hydraulic model was then used to simulate 5 year rainfall events ranging from 60 minutes to 48 hour duration. Simulation start times were selected so that sanitary and wet weather peak flows occurred simultaneously to provide a worse case scenario to enable a fair comparison between different duration storms. Flooding and overflow volumes were analysed for each duration storm to determine the critical duration storm for each catchment (i.e. the one that results in the most widespread flooding and overflows). The critical duration storm was then used in the development of upgrade options for each catchment.

HISTORICAL TIME SERIES RAINFALL

Utilising historical rainfall records to simulate a long time series rainfall scenario enables the performance of the network to be assessed under a more realistic set of actual rainfall events, of varying durations, intensities and magnitudes. It also enables the likelihood of wet weather events coinciding with peak sanitary flows to be accounted for more realistically. This approach has the added advantage of enabling varying antecedent catchment wetness to be represented between rainfall events, and the likelihood of back to back events to be represented. The obvious drawback is much longer model simulation times.

Permanent rainfall gauges which recorded rainfall in hourly increments or less were identified in the vicinity of each catchment, and at least 10 years of historic rainfall records obtained from the relevant source. Data was inspected to identify any missing or anomalous data, and gaps filled with data from nearby rain gauges where necessary. A continuous 10 year historical rainfall record was then imported into Infoworks for each catchment. Due to the small size of each of the study area, no spatial variation of rainfall was considered.

The model was then used to simulate runoff and flows from the continuous 10 year rainfall record for each catchment. A statistics template was set up in Infoworks to identify independent spill/overflow events, and events ranked in terms of

a) overflow volume (for each area of deficiency and for the network as a whole)
b) number of incidents.

Using the results of this analysis, spill events were then ranked and the specific events identified which were considered to be equivalent to a 6 month, 1 year, 2 year and 5 year ARI event to be used in the options analysis. This ranking was undertaking both for the network as a whole, and for each individual area of network deficiency.

For example, if the target LOS was a no overflows in a 2 year ARI storm, then it can be inferred that on average five events equivalent to or larger than a 2 year ARI storm could be expected in a 10 year period. Therefore if network improvements are identified such that the fifth largest event can be conveyed without overflow, then it is likely that the target LOS will be met. The full set of rainfall events should be run through the model to verify this.

The individual rainfall events selected as being equivalent to a 6 month, 1 year, 2 year and 5 year ARI event were then used (with an appropriate ‘run-in’ period to adequately represent catchment wetness and rainfall induced infiltration from preceding events.) in the development of upgrade solutions. Where individual locations showed a markedly different spill frequency and severity to the selected rainfall event, upgrade solutions were checked with the relevant event to ensure the appropriate level of service was being achieved.

UPGRADE OPTIONS

This study has not sought to optimise solutions for each catchment, but has investigated a set of three basic upgrade options to enable comparison of the upgrade solutions achieved using different analysis methods. The three upgrade options investigated were:

a) Network amplifications without storage.

   This option assumed the capacity of network constraints (gravity sewers, pump stations, rising mains) resulting in flooding/overflows would be increased to match expected peak flows from the design event so that expected flows could be conveyed without surcharge.

b) Storage without network amplifications.

   This option assumed that in areas predicted to flood/overflow, overflows to underground storage would be constructed. This was modelled by including weirs at a level 100mm above pipe soffit level, connecting to an arbitrary storage node to enable the required storage volume to be determined to alleviate overflows/flooding from the network. Connections back into the network were included so that the storage may empty when capacity allows.

c) Combination of network amplification and storage.

   This option aimed to strike a balance between widespread network upgrade and large storage volumes by providing a degree of attenuation through storage to reduce the extent of downstream network upgrades. It assumed that at the areas of deficiency, approximately 70 **-** 80% of the unconstricted peak flow would be passed forward for the given design event, with the balance directed to storage.

RESULTS

The results of the modelling and the investigation of upgrade options are discussed below for each catchment.

Catchment A

The estimated cost of required network upgrades to achieve each LOS for each of the three upgrade options are tabulated below for catchment A. The lowest cost solution is highlighted.

Time Series Approach - upgrade costs ($M)				
ARI	**6 month**	**1 yr**	**2 yr**	**5 yr**
Option 1 - Network Amplification	5.0	5.7	5.7	8.0
Option 2 - Storage	4.6	5.7	7.0	8.2
Option 3 - Amplification + Storage	4.6	4.8	6.5	6.7
Best Cost Solution - Time Series Approach	**4.6**	**4.8**	**5.7**	**6.7**

Design Storm Approach - upgrade costs ($M)				
ARI	**6 month**	**1 yr**	**2 yr**	**5 yr**
Option 1 - Network Amplification	6.3	7.4	7.6	7.9
Option 2 - Storage	7.1	8.4	9.8	11.7
Option 3 - Amplification + Storage	7.4	7.1	7.5	7.8
Best Cost Solution - Design Storm Approach	**6.3**	**7.1**	**7.5**	**7.8**

Table 2: Upgrade Costs – Catchment A

It can be seen from the above results that the time series approach provides lower upgrade costs than the design storm approach for almost all scenarios. This is likely to be influenced to a large degree by the conservative assumption that sanitary peaks and wet weather peaks will occur simultaneously for the design storm approach.

The limitation of the existing terminal pump station is such that major upgrades are required even for the 6 month ARI event. Whilst there is no clear pattern as to the nature of the lowest cost upgrade option across all return period events, the storage option (Option 2) is generally the most expensive.

A lower degree of confidence can be placed in the appropriateness of larger return period rainfall events (i.e. 5yr) when using the time series approach with 10 years of rainfall data. This is because it is quite possible a 5 year event (or larger) could actually occur 3 or more times within a 10 year period, or similarly could not occur at all.

It is worth noting that a comparison of depth and duration for individual rainfall events within the 10 year rainfall record used did not identify any events that corresponded to a 5 year ARI or larger. Therefore the upgrade options developed using the time series approach for the larger return period events may be underestimated, resulting in a lower LOS than anticipated.

Upgrade costs for each scenario are plotted against return period below.

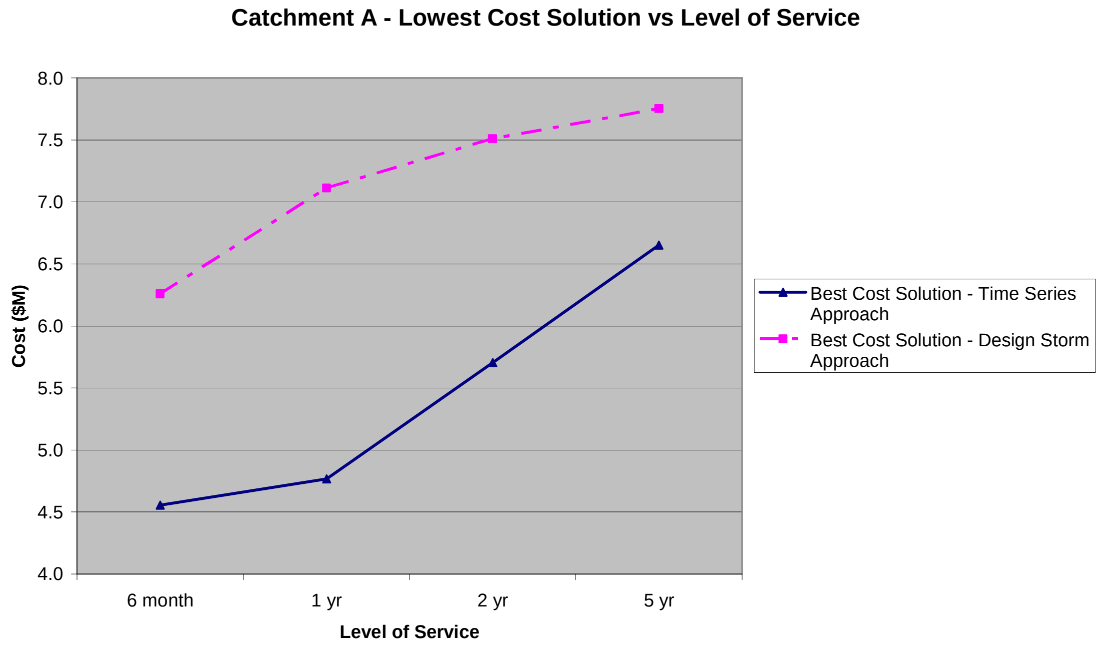

Figure 1: Upgrade Cost versus LOS – Catchment A

Once again it is clearly demonstrated that the time series approach results in lower cost solutions for a given return period event for catchment A. Given that no target LOS for this network exists in terms of overflow containment, an assessment of the likely benefit for a given cost can quickly be made from the above graph.

It could be concluded that if a time series approach was used, then a 1 year LOS would be expected to provide the best 'value for money' set of solutions. This corresponds to a network amplification + storage upgrade with an estimated cost of $4.8M.

Conversely, if a design storm approach was adopted, given the relatively small incremental increase in cost for achieving a higher LOS, an argument could be put forward for providing a 2 yr or 5 yr LOS. However given the comparatively high cost associated with the 6 month LOS for what is a relatively small town with a limited pool of ratepayers, it is considered more likely that a 6 month LOS would be adopted. This corresponds to a straight network amplification upgrade with an estimated cost of $6.3M.

Catchment B

The estimated cost of required network upgrades to achieve each LOS for each of the three upgrade options are tabulated below for catchment B. The lowest cost solution is highlighted.

Time Series Approach - upgrade costs ($M)				
ARI	**6 month**	**1 yr**	**2 yr**	**5 yr**
Option 1 - Network Amplification	0.8	6.1	7.0	9.8
Option 2 - Storage	2.2	8.4	15.6	36.5
Option 3 - Amplification + Storage	1.7	9.6	13.0	22.0
Best Cost Solution - Time Series Approach	**0.8**	**6.1**	**7.0**	**9.8**

Design Storm Approach - upgrade costs ($M)				
ARI	**6 month**	**1 yr**	**2 yr**	**5 yr**
Option 1 - Network Amplification	2.7	4.5	5.6	8.1
Option 2 - Storage	6.9	13.3	18.3	26.8
Option 3 - Amplification + Storage	5.4	12.7	11.5	14.1
Best Cost Solution - Design Storm Approach	**2.7**	**4.5**	**5.6**	**8.1**

Table 3: Upgrade Costs – Catchment B

It can be seen from the above results that the network amplification option provides the lowest cost upgrade for each scenario. This is heavily influenced by the poor condition of the network, and the significant and prolonged rainfall induced inflow and infiltration (I/I) evident. Without widespread network upgrades, very large storage volumes are required to contain expected flows.

With the exception of the 6 month ARI event, the design storm approach provides lower network amplification upgrade costs than the time series approach. This is contrary to the observations for catchment A where the time series approach provided lower cost solutions. This is due in part to the much higher I/I associated with catchment B, meaning the sanitary flow is a much smaller proportion of flows, and the assumption that sanitary peaks and wet weather peaks coincide has less of an impact. It is also likely to be influenced by the long lag associated with I/I following rainfall, meaning a twin peaked actual rainfall event (as often occurs in reality) may have more of an impact than a synthetic design storm which assumes a single peak in rainfall.

For the options with storage, the time series approach provides lower cost upgrades for the 6 month and 1 year LOS, but higher costs for the 2 yr and 5 yr events.

It is worth noting that a comparison of depth and duration for individual rainfall events within the 10 year rainfall record identified four rainfall events equating to a 5 year ARI or higher (including one event assessed as being approximately 20 yr ARI and one at approximately 50yr ARI). Therefore the upgrade options developed using the time series approach for the larger return period events are likely to be overestimated, resulting in a higher LOS than anticipated...

Upgrade costs for each scenario are plotted against return period below.

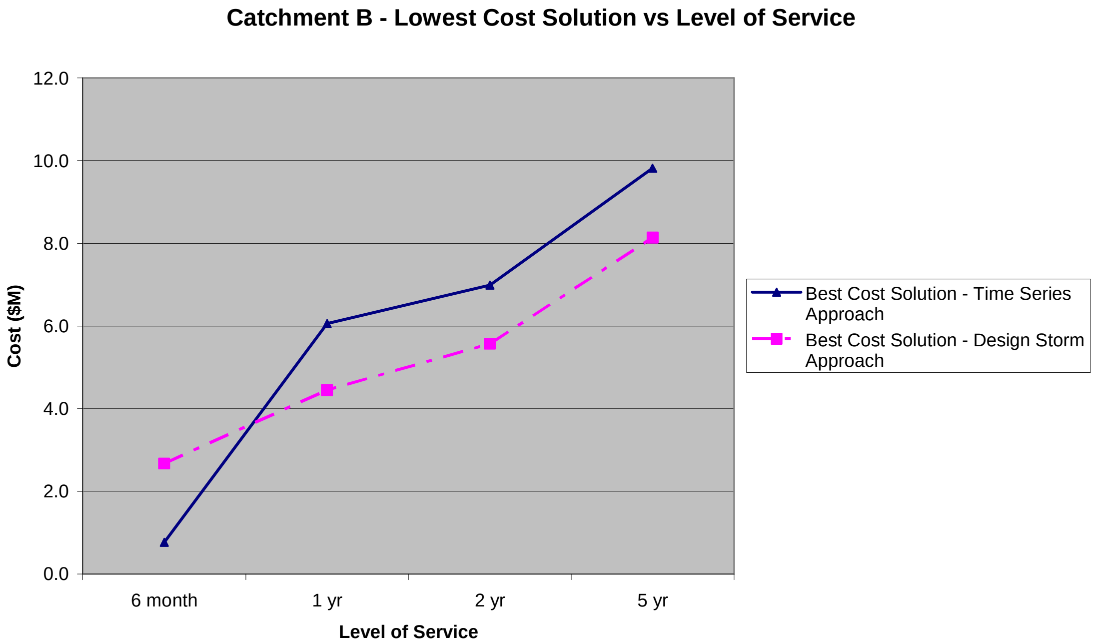

Figure 2: Upgrade Cost for each LOS – Catchment B

It is clearly demonstrated that the design storm approach results in lower cost solutions for all return period events except a 6 month LOS. Given that no target LOS for this network exists in terms of overflow containment, an assessment of the likely benefit for a given cost can quickly be made from the above graph.

It could be concluded that if a time series approach was used, then a 6 month LOS would be expected to provide the best 'value for money' set of solutions. This corresponds to a network amplification upgrade with an estimated cost of $0.8M.

Similarly, if a design storm approach was adopted, given the relatively large incremental increase in cost for achieving a higher LOS, and the limited pool of ratepayers, it is considered most likely that a 6 month LOS would also be adopted. This also corresponds to a network amplification upgrade with an estimated cost of $2.7M.

Catchment C

The estimated cost of required network upgrades to achieve each LOS for each of the three upgrade options are tabulated below for catchment C. The lowest cost solution is highlighted.

Time Series Approach - upgrade costs ($M)					
ARI	**6 month**	**1 yr**	**2 yr**	**5 yr**	**10 yr**
Option 1 - Network Amplification	0.3	0.3	1.0	1.7	4.9
Option 2 - Storage	0.1	0.3	0.5	0.6	1.5
Option 3 - Amplification + Storage	0.3	0.3	1.0	1.7	4.9
Best Cost Solution - Time Series Approach	**0.1**	**0.3**	**0.5**	**0.6**	**1.5**

Design Storm Approach - upgrade costs ($M)					
ARI	**6 month**	**1 yr**	**2 yr**	**5 yr**	**10 yr**
Option 1 - Network Amplification	0.3	1.0	1.0	1.2	1.7
Option 2 - Storage	0.2	0.4	0.5	0.9	1.2
Option 3 - Amplification + Storage	0.3	1.0	1.0	1.2	1.7
Best Cost Solution - Design Storm Approach	**0.2**	**0.4**	**0.5**	**0.9**	**1.2**

Table 4: Upgrade Costs – Catchment C

It can be seen from the above results that the storage option provides the lowest cost upgrade for each scenario. Due to the relatively minor network amplifications required for this network (generally an increase of just one pipe diameter), the network amplification with storage option did not enable any different solutions to be adopted

With the exception of the 10 year ARI event, the time series approach provides lower storage upgrade costs than the time series approach. As for catchment A, this is likely to be influenced to a large degree by the conservative assumption that sanitary peaks and wet weather peaks will occur simultaneously for the design approach.

For the network amplification upgrades, the time series approach provides lower or equal cost upgrades for the 6 month, 1 year and 2 year LOS, but higher costs for the 5 yr and 10 yr events.

It is worth noting that a comparison of depth and duration for individual rainfall events within the 10 year rainfall record identified four rainfall events equating to a 5 year ARI or higher. Therefore the upgrade options developed using the time series approach for the larger return period events may be overestimated, resulting in a higher LOS than anticipated..

Upgrade costs for each scenario are plotted against return period below.

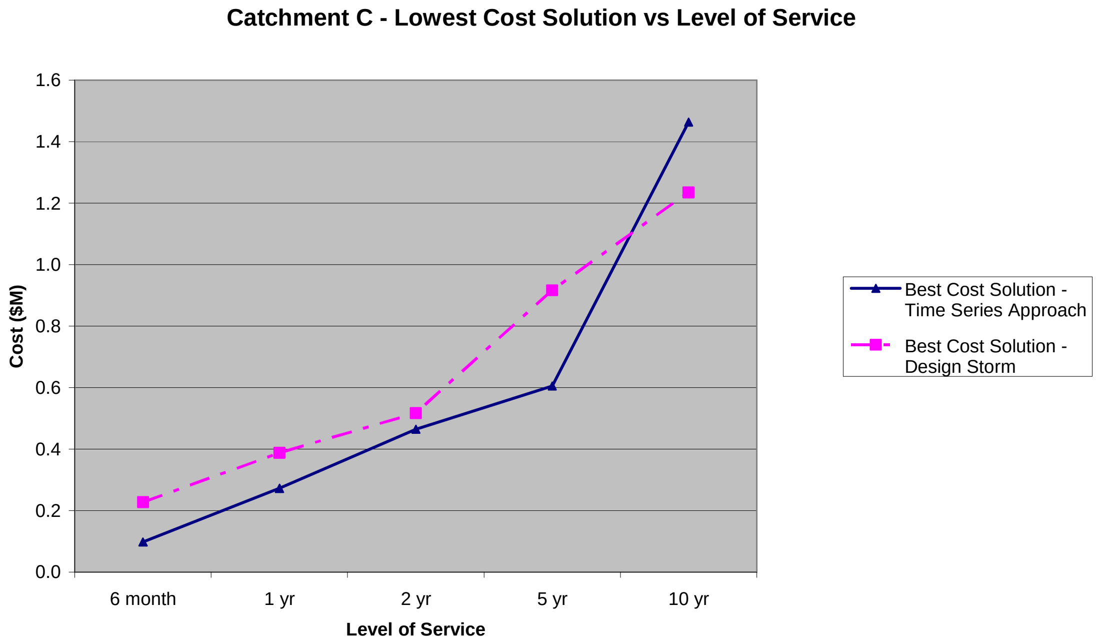

Figure 3: Upgrade Cost for each LOS – Catchment C

It can be seen from the above graph that the time series approach results in lower cost solutions for all return period events except a 6 month LOS. The target LOS for this network is a 5 year containment standard (i.e. no overflows or flooding in a 1 in 5 year storm).

If a time series approach was used, this would result in programme of network upgrades involving storage, at a cost of $0.6M for the 5 year LOS. This LOS would coincidentally appear to give the best value for money for the time series approach.

If a design storm approach was used, this would also result in programme of network upgrades involving storage, at a cost of $0.9M for the 5 year LOS. If there was no target LOS for this network, then there would be a reasonable argument for adopting a 2 year LOS (based on the design storm approach). It is worth noting that this would result in a very similar upgrade program and cost to the upgrades required for a 5 year LOS if a time series approach was used.

DISCUSSION

The sensitivity of different networks to the method for assessing system performance is very dependent on the nature of the network. No two wastewater networks are the same, and it is not possible to draw any conclusions from this study that apply to all three networks. However a number of observations have been made, and a number of lessons learnt, which are discussed in more detail below

A summary of the recommended LOS and upgrade options is given below for all three catchments.

	Time Series Approach			Design Storm Approach		
	Recommended LOS	Cost	Nature of Upgrade	Recommended LOS	Cost	Nature of Upgrade
Catchment A	1 Year	$4.8M	Amplifications + Storage	6 month	$6.3M	Network Amplifications
Catchment B	6 month	$0.8M	Network Amplifications	6 month	$2.7M	Network Amplifications
Catchment C	5 year	$0.6M	Storage	5 year	$0.9M	Storage

Table 5: Summary of recommended LOS and Upgrades

It can be seen that the design storm approach results in higher upgrade costs to achieve the recommended LOS for all catchments. For two of the three catchments (catchments A and C), the design storm approach generally results in higher upgrade costs to achieve each LOS considered. This is most likely due to the conservative assumption that wet weather peaks resulting from the design storm will coincide with sanitary peaks, when in actual fact rainfall events could occur at any time. This impact is more pronounced in networks with relatively low I/I (indicated by lower wet weather peaking factors), as the sanitary flow component is proportionally higher. It will also be influenced to a degree by the assumed distribution of rainfall throughout the specified storm duration.

By contrast, the design storm approach generally results in lower upgrade costs to achieve a given level of service for Catchment B, with the exception of the 6 month LOS recommended. It is noted that catchment B is subject to high I/I and groundwater infiltration and has a wet weather peak factor of over 8 in a 48 hr (critical duration) 1 yr ARI rainfall event. As a result the, the conservatism associated with matching of sanitary and wet weather peaks is negated to a certain degree. It is considered the long lag associated with the infiltration from much of the Catchment B network may result in an underestimate of flows from a single peak design storm compared to actual rainfall events where the rainfall is distributed more randomly throughout the storm.

The design storm approach is generally less favourable to storage as an upgrade option due to the conservatism associated with the assumption of matching sanitary and wet weather peaks, and the fact that the specified amount of rainfall is generally distributed in a single peaked storm.

By contrast the time series approach means rainfall could fall any time throughout the day, and could be distributed in a twin or multi peaked storm, potentially allowing storage to drain down in between peaks. It is recommended that if storage is considered likely to form part of an upgrade solution, that the time series approach is adopted to validate the amount of storage required. An alternative is to utilise an independent historical rainfall event (with appropriate run-in time) assessed as being of the appropriate order of magnitude to represent the desired level of service.

A lower degree of confidence can be placed in the appropriateness of larger return period rainfall events (i.e. 5yr) when using the time series approach with 10 years of rainfall data, as the likelihood of two events of such magnitude within a 10 year period is a lot less certain. It is recommended that if a high LOS is being adopted (i.e. 5 yr ARI or higher), then an appropriate length of rainfall records is utilised to remove this uncertainty. It is recommended that the length of rainfall record should be 4 to 5 times the ARI of the event to be utilised in assessing compliance with the target LOS.

Whichever method of assessing system performance of a wastewater network, a sensitivity analysis is recommended to enable the modeller to gain a thorough understanding of how the network performs under a range of scenarios.

CONCLUSIONS

The following conclusions can be drawn from this study

- No two wastewater networks are the same – variations in time of concentration, severity and nature of I/I, and existing network constraints can have a significant impact on the most appropriate method of assessing system performance.

- A modeller needs to have a thorough understanding of the system being analysed before deciding on the most appropriate method for assessing compliance with a given LOS.

- Design storms provide a quick and efficient way of assessing system performance under a range of rainfall events.

- Design storms generally over estimate required storage volumes

- The historical time series rainfall approach is time consuming but enables a more realistic representation of likely flow regimes to be developed.

- Utilising historical time series rainfall can enable lower cost upgrade solutions to meet a given LOS to be identified.

- The historical rainfall record used should be at least 4 to 5 times the frequency of the rainfall event corresponding to the target LOS.