ECOSENSITIVE STORMWATER SYSTEM DESIGN FOR SUB-DIVISION

Achela K. Fernando, Unitec New Zealand
Mark D. Iszard, Unitec New Zealand
Nazrul Islam, Waitakere City Council

ABSTRACT

Stormwater management is a contentious aspect of development in the 21st century. Although hydrological neutrality before and after a development is sought, it is acknowledged that any alterations to land form result in a change in the hydrological regime. Thus the goal of agencies whose responsibility it is to manage stormwater effectively is to minimise the adverse impacts of new developments on the environment. To achieve this more reasonable objective, these agencies have developed objectives and polices backed up by design criteria and requirements that developers are required to meet as part of their development proposals.

The Waitakere City Council (WCC), and the Auckland Regional Council (ARC) have worked closely together to develop a number of stormwater management manuals and design standards consistent with the Resource Management Act (1991). This paper reports the outcome of an investigation into the sustainable engineering design options satisfying the above guidelines for stormwater management for a residential sub-division in Henderson, Waitakere City using a Triple Bottom Line (TBL) assessment and a Cost Benefit Analysis (CBA).

Following the evaluation of various stormwater management devices such as shared common areas to minimise impermeable surfaces, restricted earthworks onsite, stormwater reuse and attenuation tanks, rain gardens, flow dispersion devices and swales, a detailed design was produced for two types of device: Those constructed as part of the initial development of the site and those constructed by the individual plot owners. This highlights the value of apportioning the responsibilities to relevant personnel at sub-division level as well as at individual property development level.

It is shown that it is both feasible and practical to design and construct an eco-sensitive, sustainable, low impact stormwater management system that meets the needs of the client and the requirements of the regulatory authorities.

KEYWORDS

Stormwater management, Water re-use, Flow dispersion devices

PRESENTER PROFILE

Dr. Achela Fernando received her B.Sc. (Eng) in Civil Engineering from the University of Peradeniya, Sri Lanka in 1987, M.Eng. in Environmental and Sanitary Engineering from Kyoto University, Japan in 1992, and Ph.D. from the University of Hong Kong in 1997. Since July 2003 she has been working as a lecturer in the School of Built Environment of Unitec New Zealand. Prior to that, she has worked for civil and environmental engineering consultancies in Sri Lanka, Hong Kong and New Zealand. She is a MIPENZ and holds CPEng(NZ) status.

1 INTRODUCTION

Project Twin Streams is a Waitakere City Council (WCC) led initiative to address major flooding hazards in both the Oratia and Opanuku Streams, the two biggest waterways within the council. Through this project funding was obtained from Infrastructure Auckland (I.A.) to purchase properties identified as being inundated during severe floods. One of the objectives of these property purchases was to remove the houses directly affected by flooding and restore the areas as part of natural riparian margin buffer zone.

However, as the majority of the sites are only partially affected by flooding, the remaining land area outside the extent of the 1 in 100 year flood plain has been deemed surplus to the land purchases required to meet the objectives of Project Twin Streams. To recover some the costs the WCC further investigated possible development of some of the sites.

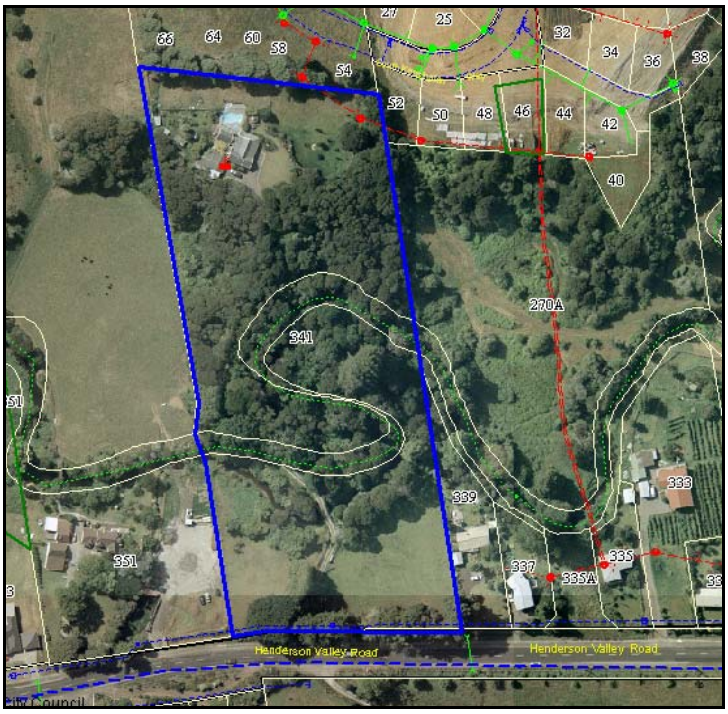

Figure 1: Schematic view of the site location

One of the sites is 349-351 Henderson Valley Rd (indicated by 341 in Figure 1) legally known as Lot 11 DP 8632. This 2.24ha (22,400m2) block of residential land is subject to flooding from the Opanuku Stream that dissects the property running west to east. Approximately 1.6Ha of this land has been calculated as being within the flood plain of the Opanuku Stream. The remaining 0.64Ha is sited above the flood plain and is suitable for further development. Figure 1 above shows a schematic view of the site location. The site is located adjacent to the flatter areas of the Opanuku Stream on the northern side of Henderson Valley Road. The site is dominated by the Opanuku Stream that meanders through the property from west to east. The majority of the site is low lying and subject to periodic inundation during storm events. Towards the rear of the site the land rises steeply (8-12°) for a short distance to a relatively flat broad plain where an existing modified 1940's bungalow is sited.

The WCC has sustainability as one of its nine key objectives and actively promotes sustainable development within the City. The aim of this paper is to present the stormwater management system designed to promote and showcase an eco-sensitive, sustainable design for the development of the aforementioned site.

2 DISCUSSION

2.1 FEASIBILITY STUDY AND PRELIMINARY OPTION INVESTIGATION

The feasibility analysis examined five possible solutions based on best management stormwater management practices for the site. Some options such as connection to an existing public system are traditional, while the other options were essentially hybrids of either a fully piped stormwater network with a discharge to Opanuku Stream, or a Low Impact Design (LID) system which manages and disposes the stormwater onsite with no adverse effects on surrounding properties. The options investigated were chosen based upon the common availability, established use, ease of maintenance and the identified site constraints.

2.1.1 Assessment Criteria

The assessment of the five possible options focused on five measurable criteria, being cost, land form (e.g. slope stability), affected neighbours, construction feasibility, and environmental effects.

(A) Cost

The cost component plays a key role in determining the final design option chosen. Costs are usually broken into construction costs, material costs, and maintenance costs. While the costs of each of these key areas can vary significantly from option to option, for the purpose of this preliminary analysis, only a ranking of the costs was made rather than a actual dollar cost estimate. The ranking system used is based on a combination of construction, material and maintenance costs. For options with a favourable cost component (low cost). high ranking would be assigned to this option (high rank). Likewise options that are expensive to construct and maintain would be ranked as high cost (low rank).

(B) Land Form

By assessing the effects that each of the possible design options have on the land form utilising a complete life cycle view, it was possible to rank the options against each other. Land constraints criteria included Geotechnical issues, Site contours, Vegetation alteration, Earthworks, and Stream alteration/modification. The objective of this criterion is to minimise land disturbance and thus the options were ranked based on their effect on the land. Options which have minimal land disturbance and will not have adverse effects on the land stability are ranked as having minimal impact (high rank - favourable) and vise versa.

(C) Affected Neighbours

This assessment criterion focused on the impact of the options on the neighbours in the immediate neighbourhood surrounding the site which may be both short and long term. Examples of short term effects such as the noise from the construction or potential land alteration that directly affects their property are easily identified. Other longer term effects that are not so easy to identify are issues such as smell from any treatment systems or amenity issues brought about by vegetation alteration or removal. Ranking can be highly subjective as the way that individuals react and feel about certain issues differs from person to person. The option rankings provided are based on tangible effects such as noise and smell. Other intangible options such as visual amenity are considered as part of this assessment, but are more subjective and therefore have been given less weighting in the final analysis.

(D) Construction Feasibility

This takes into account the possible site constraints such as site access, earthworks, timing, technical requirements and construction methodology. Systems such as a piped system require heavy machinery and prefer large open areas to work in, while other more low impact designs require a greater level of technical expertise and time from the contractors during installation. In assessing the construction feasibility of the proposed design options they have been ranked according to difficulty. This criterion has been assessed as a short term factor.

(E) Environment Effects

Assessing the environmental effects involves evaluating both the short and long term effects of the proposed system. While one of the stormwater management options may result in a temporary reduction of water quality while it is being constructed and installed, it may in fact offer the better treatment option when it is completed and commissioned. While the majority of the environmental effects will be water based, consideration was also given to other environmental effects such as air pollution from rotting organic matter in a treatment device or the effects that a land based disposal system may have on the native vegetation and fauna. At this preliminary stage, the environmental impacts assessed are based on the stormwater quality and quantity.

2.1.2 Possible Options

The preliminary options were chosen based upon the common availability, established use, ease of maintenance and the identified site constraints. The five options are described briefly below:

(A) Option 1

Option 1 is a “Fully piped system with connection to existing Public stormwater network”.

An investigation into the surrounding properties and land found that the only public stormwater system within a 500m radius was a recently constructed stormwater system located to the rear of the site within a new subdivision. This recent subdivision discharges its stormwater to a stormwater pond close to the site.

While this option presented a tidy opportunity to discharge the stormwater from this development, the site contours fall away from this system and therefore it is not feasible to gravitate the stormwater runoff from the proposed development to this system. Additionally a review of the previous consents issued for the surrounding sites indicated that the pond has not been sized to accommodate runoff from the proposed development at 349-351 Henderson Valley Rd.

(B) Option 2

Option 2 is a “Fully piped system with direct discharge to the Opanuku Stream”

Fully piped systems are common in most typical subdivisions due to their ability to convey stormwater runoff quickly and conveniently. Historically a fully piped stormwater network to serve this development would have been considered the only feasible option. The design of such a system should be undertaken in accordance with the Council’s Code of Practice for City Infrastructure and Land Development. This Code of Practice sets out the minimum engineering standards that are to be achieved to satisfy the requirements of NZS (New Zealand Standard) 4404 “Code of Practice for Urban Land Subdivision”. Piped stormwater systems generally consist of concrete or plastic pipes and inspection chamber or manholes linked together to convey stormwater runoff from source points to a suitable discharge point.

(C) Option 3

Option 3 is "Stormwater from all roofs and roads collected and piped to a common stormwater treatment device".

The use of common stormwater treatment devices can be seen in most large scale, comprehensive subdivisions where all the stormwater is piped to a common point for treatment and subsequently discharged to a stream or water body. Typical common treatment devices in these situations are stormwater ponds and wetlands as they are relatively cheap to construct and have flexibility in their location, design and shape. Other common treatment devices that could be considered suitable for this site is a 'hard' treatment option such as sand filter (ARC TP 10, 2000).

An assessment of the site quickly discounted soft engineering options such as a stormwater pond as being impractical due to no suitable land available without compromising the integrity of the development. The feasibility of a common treatment device therefore focuses on the construction of a sand filter.

(D) Option 4

Option 4 is "Roof water collected and piped to stream with road water being collected and piped to a SWQT device prior to discharging to the stream".

Studies from the Auckland Regional Council over the last five years have shown that the majority of stormwater pollutants are sourced from paved areas rather than roof areas. This is especially true in residential situations where air borne particulates are less common than in commercial and industrial areas. By allowing the roof water to bypass the quality treatment device, the reduction in size of the device is significant with a minimal increase in the possible pollutant loadings

(E) Option 5

Option 5 is a "Low Impact Design (LID) with stormwater being collected and treated on each site prior to discharge to individual stormwater dispersal devices".

In a natural situation, the stormwater that falls on to the land would lose both volume and energy by being abstracted into the soils and travelling overland. By the time it reaches a stream or water body the energy in the flow would have been dissipated over the length of the bank and has minimal velocity. A LID seeks to mimic this natural runoff pattern and maintain hydrological neutrality through incorporating the stormwater management design into the planning and design stages of the project. Approaches to site design which can reduce stormwater generation from the outset are the most effective approach to stormwater management as they can significantly reduce impermeable surfaces (ARC TP 124, 2000).

Common means of undertaking a LID approach is to firstly minimise then mitigate the stormwater runoff. Minimising stormwater runoff is achieved by reducing the widths and lengths of the driveways and paved areas as well encouraging development to go up rather than spread. However it is a fact that any impermeable surfaces created will alter the hydrological balance of the site. As it is not possible to fully minimise impermeable surfaces in a development, the answer is to mitigate the increase in impermeable surfaces using a variety of LID techniques. These commonly include stormwater tanks, bio-filtration and bio-retention methods and flow dispersal devices.

2.1.3 Feasibility matrix

Based on the assessment criteria described in 2.1 the options described in 2.2 were evaluated. While the details of evaluation of each option are not presented here, the

Table 1 summarises the ranking and the total scores that result in the final analysis. The matrix ranks the possible design options against the five assessment criteria of Cost, Land Form, Affected Neighbours, Construction feasibility and Environmental Effects. A score between 1 and 5 was given to each option for each assessment criteria. A worst score of 5 and a best score of 25 are possible under this scheme.

Option	**Criteria:** (1 = high or non-favourable; 5 = low or favourable)					Total Proceed to next stage (Y/N)
	Cost	**Land form**	**Affected neighbours**	**Construction feasibility**	**Environmental effects**	
1	High (1)	Medium (4)	High (1)	Not possible (1)	Unknown (2)	(9) No
2	High (3)	High (2)	Moderate (1)	Difficult (3)	Extreme (1)	(10) No
3	High (1)	Moderate to high (1)	Minimal (5)	Difficult (2)	Minimal (4)	(13) No
4	Moderate (4)	Moderate (3)	Minimal (3)	Easy (5)	Moderate (3)	**(18) Yes**
5	Low (5)	Minimal (5)	Potential effects (4)	Easy (4)	Minimal (5)	**(24) Yes**

Table 1: Feasibility Matrix

As can be seen from this matrix, some options such as connecting to a public stormwater system scored poorly and were easily discounted from proceeding to the next stage. Other options scored poorly in some of the assessment criteria while scoring well in others. The decision of which options to proceed with was based on the overall score. In this initial feasibility study it was assumed that each of the assessment criteria was equal in value and the scores therefore un-weighted. As can be seen in the table, the Options 4 and 5 have the highest totals (18 and 24 respectively) and thus are the appropriate candidates for the stormwater management solution.

2.2 FINAL OPION EVALUATION

Based on the preliminary investigations the two options “Low Impact Design with stormwater being collected and treated on each site prior to discharge to individual stormwater dispersal devices” which will be hereinafter called the **LID option** and “Roof water collected in tanks and piped to stream with road water being collected and piped to a SWQT device prior to discharging to the stream” which will be called the **SWQT Option** were further investigated.

A Triple Bottom Line (TBL) assessment to evaluate the two options focused on the Social, Environmental and Economic factors. Each of these factors has been further separated into the categories listed tables 2, 3 and 4. These categories have been sourced from the TBL Toolkit designed by the City of Melbourne & ICLEI (International Council for Local Environmental Initiatives) 2002 and modified to suit the project.

Categories	Key Questions
Recreational Value	Will the proposal increase the recreational value to the community?
Amenity Value (short Term)	Will the proposal affect the surrounding neighbours?
Amenity Value (Long Term)	Will the proposal enhance the amenity of public space? Will the proposal enhance and/or be, consist with the existing urban form?
Public Health and Safety	What effect will the proposal have on the safety of the public environment e.g. streets, laneways, parks and gardens?
Cultural and Heritage Values	What effect will this proposal have on the cultural heritage of Waitakere and its neighbourhood? How does the proposal support and enhance local Maori beliefs and culture?
Visual impact	Will the proposal fit into the existing visual environment?
Smell/ Air pollution	Will the proposal cause offensive smells or increase air pollution?
Community Services.	What effect will the proposal have on the community access to education, leisure, cultural and health services? Will the proposal incorporate learning experiences into the design?

Table 2: Social factors considered in the TBL analysis

Categories	Key Questions
Noise	Will the noise from the proposal have an adverse effect on the environment?
Water Quality	Will the proposal maintain or improve the water quality?
Water Quantity	Will the proposal maintain or decrease the water quantity? Will then proposal minimise scouring and erosion at the outfall?
Sedimentation	Will the proposal lead to increased sedimentation from the development to the receiving environment?
Vegetation removal/ Alteration	Will the proposal require the removal or alteration of existing, established vegetation? What effects will the proposal have on the vegetation?
Fresh water habitat	Will the proposal maintain or increase the health of the freshwater habitat? Will it lead to greater species diversity?
Land form	Will the proposal minimise disturbance to the land?
Flora and Fauna	Will the proposal manage and protect the existing native flora and fauna?

Table 3: Environmental factors considered in the TBL analysis

Categories	Key Questions
Establishment	What are the initial/capital costs? Have they been minimised?
Material costs	What are the comparisons of the cost of the materials? Are there alternatives?
Installation	Will the proposal minimise installation costs?
Loss of useable Land	Does the proposal seek to either reduce the loss of useable land or construct it in an area with low value?
Maintenance	What ongoing maintenance costs are associated with the proposal? Are the ongoing maintenance costs minimised?
Replacement cost	What will be the replacement costs at the end of the useable life of the system Will there be any decommissioning / disposal costs associated with the proposal at the end of its life?

Table 4: Economic factors considered in the TBL analysis

2.2.1 Social Factors

Criteria	Comments	Rating	
		LID Option	**SWQT Option**
Recreational Value	Neither option presents a recreational value, however it would be possible to construct a Public art work in conjunction with the SWQT outlet.	1	2
Amenity Value (short Term)	LID design is far less intrusive during the construction phase as less machinery is used. The bush area and distance to neighbours however will help mitigate any amenity issues.	3	2
Amenity Value (Long Term)	LID has the advantage of minimising structures within the Opanuku Stream, both options are non-obtrusive. As this site is at the limit of the residential zone, both options fit into the urban form.	3	2.5
Public Health and Safety	Care needs to be taken to ensure that the Pubic cannot access the sand filter as it is considered a confined space and access may result in injury or death.	3	1.5
Cultural and Heritage Values	Maori values do not favour land disposal, and require that the S/W runoff is treated to a high level.	1	3
Visual impact	As the SWQT will be buried the visual impact will be less, but as the majority of the LID will be in the bush, there is very little difference.	2	2.5
Smell/ Air pollution	Neither option should cause offensive odours, through there is a possibility of gas build up within the sand filter.	3	2.5
Community Services	LID offers good opportunities to educate the public on sustainable designs.	2	1
	Average	**2.43**	**2.14**

Table 5: Evaluation based on Social impact in the TBL analysis

The desired social impact is a positive one. As the development is proposed to have a 6m wide public cycle and walking track linking Henderson Valley Rd to the newly constructed road at the rear of the site, site interaction with the community will be an important factor. Of key concern is the health and safety of the residents and community at large. Ratings of 1,2 and 3 respectively were assigned to poor, fair and good impacts. The evaluation of the social factors resulted in the scores shown in Table 5.

2.2.2 Environmental factors

Criteria	Comments	Ratings	
		LID Option	SWQT Option
Noise	LID utilises electricity to power S/W pumps that emit noise While water reuse is only an option for SWQT.	2	3
Water Quality	Both options provide a high degree of quality treatment thus minimising the effects on the receiving environment. SWQT offers better long term treatment	2	3
Water Quantity	Both options mitigate the increased stormwater quantities, but as LID provides for S/W reuse, this will further reduce S/W volumes.	3	2
Sedimentation	Both LID and SWQT are designed to remove 75% of total suspended solids (ARC TP 10). LID also provides tertiary treatment through filtration at the dispersal outlet.	3	2
Visual	Neither option is visually obtrusive; however a constructed outfall as required for SWQT reduces the visual amenity of the site.	3	2
Vegetation removal/ alteration	The construction of a SWQT system will require the removal of vegetation and soils. LID can be deployed over ground and around existing vegetation.	3	2
Fresh water habitat	Both options reduce the suspended sediment loadings, LID maintains the water balance between infiltration, evapro-transpiration and runoff better than SWQT.	2	3
Land form	SWQT will require large scale earthworks on steep slopes as well as a stormwater outlet to the Opanuku Stream.	3	2
Flora and Fauna	SWQT will have minimal effect on the flora and fauna as it will follow the existing access-way, will require an outfall that may require the removal of a small area of vegetation. LID has potential to increase water flows over banks, which may affect existing flora and fauna.	2	2
	Average	**2.56**	**2.33**

Table 6: Evaluation based on Environmental impact in the TBL analysis

The Fourth Schedule of The Act (RMA, 1991) relates specifically to considering the effects on the environment of which most concerned are water quality, water quantity, and aquatic ecosystem protection. These three criteria are discussed in detail in the TP10 (ARC, 1999). Based on these criteria, an evaluation was made of the two options with 1 representing a poor and low value, 2 fair and of average value, and 3 good and of high value. Table 6 summarises the results of this evaluation.

2.2.3 Economic factors

Traditionally most project evaluations have very strong focus on the actual dollar cost of the project rather than assessing the proposal from a more holistic approach. A TBL approach aims to diminish the weighting of the actual dollar value by giving the environmental and social criteria an equal weighting in evaluating the options. This TBL assessment looks at both the initial costs of constructing the design as well as the long term costs such as maintenance and replacement costs.

A rating of 1 was used for expensive, 2 for moderate cost and 3 for cheap in this evaluation. Table 7 summarises the results of this evaluation.

Criteria	**Comments**	**LID Option**	**SWQT Option**
Establishment	Initial establishment costs are higher for SWQT as it requires more accurate setting out. LID offers more opportunity for cost minimisation.	1	2
Material costs	Initial construction costs favour LID as sand filters are expensive to build and install. SWQT requires additional machinery as well. Larger SWQT pipes are offset by more LID pipes.	3	1
Installation	LID has higher labour and quality assurance costs due to its detailed design.	2	3
Loss of useable Land	SWQT can be buried and minimises the loss of useable land, while LID requires areas for SW tanks and rain gardens.	2	3
Maintenance	Both options require regular maintenance to function correctly, LID is maintained by owners, while SWQT is maintained by Council, SWQT has larger pipe network and SW outfall which increase costs.	3	2
Replacement cost	The replacement of LID designs is cheaper as most of the pipe work and devices are above ground, SWQT would be very expensive to replace but has a longer expected life.	3	1
	Average	2.6	2.0

Table 7: Evaluation based on Economic impact in the TBL analysis

A summary of the totals of the TBL analysis in Table 8 indicates that LID Option has the highest score of 7.58 while the SWQT option scores a total of 6.48. Thus the preferred option is the system with stormwater being collected and treated on each site prior to discharge to individual stormwater dispersal devices.

TBL Factor	**LID Option score**	**SWQT Option**
Social	2.43	2.14
Environmental	2.56	2.33
Economic	2.6	2.0
Total	**7.58**	**6.48**

Table 8: Summary of TBL Evaluation for the two options

2.2.4 Weighted Triple Bottom Line (TBL) analysis

The TBL analysis described above in 2.2.3 ranked all of the sub-criteria as being equal in value, (all worth a maximum rating of 3). This can lead to some individual criteria that as not as critical having an equal rating to those that are.

Environmental					
Criteria	**Weighting Factor (W)**	**LID Option**		**SWQT Option**	
		Ranking (R1)	**Weighted R1 * W**	**Ranking (R2)**	**Weighted R2 * W**
Noise	0.05	2	0.1	3	0.15
Water Quality	0.2	3	0.6	2	0.4
Water Quantity	0.2	3	0.6	2	0.4
Visual	0.05	3		2	
Sedimentation	0.1	3	0.3	2	0.2
Vegetation removal/alteration	0.1	2	0.2	3	0.3
Fresh water habitat	0.1	2	0.2	3	0.3
Flora & Fauna	0.1	3	0.3	2	0.2
Land form	0.1	2	0.2	2	0.2
Average		**2.56**		**2.33**	
Total	**1**	**23**	**2.5**	**21**	**2.15**
Economic					
Criteria	**Weighting Factor /1**	**LID Option**		**SWQT Option**	
		Ranking	**Weighted**	**Ranking**	**Weighted**
Establishment	0.15	1	0.15	2	0.3
Material costs	0.2	3	0.6	1	0.2
Installation	0.2	2	0.4	3	0.6
Loss of useable Land	0.15	2	0.3	3	0.45
Maintenance	0.2	3	0.6	2	0.4
Replacement cost	0.1	3	0.3	1	0.1
			0		0
Average		**2.6**		**2**	
Total	**1**	**14**	**2.35**	**12**	**2.05**
Social					
Criteria	**Weighting Factor /1**	**LID Option**		**SWQT Option**	
		Ranking	**Weighted**	**Ranking**	**Weighted**
Recreational Value	0.1	1	0.1	2	0.2
Amenity Value (short Term)	0.05	3	0.15	2	0.1
Amenity Value (Long Term)	0.1	3	0.3	2.5	0.25
Public Health and Safety	0.25	3	0.75	1.5	0.375
Culture	0.2	1	0.2	3	0.6
Visual	0.05	2	0.1	2.5	0.125
Smell	0.1	3	0.3	2.5	0.25
Community Services	0.15	2	0.3	1	0.15
Average		**2.43**		**2.14**	
Total	**1**	**18**	**2.2**	**17**	**2.05**
Weighted TBL Scores			**7.05**		**6.25**

Table 9: Summary of weighted TBL Evaluation for the two options

To further assess and refine the TBL results, a weighted TBL matrix was developed. Each of the TBL Factors was given a total weighting of 1. The criteria that made up this TBL factor were then given a weighting factor proportional to the relative value of that criterion, e.g. the visual criteria was given a weighting factor of 0.05, or 5% of the Environmental factor. This weighting factor was then multiplied by the rating the criteria received in the TBL analysis to provide a weighted score. The use of a weighted matrix allows for a more detailed, finer evaluation of the stormwater management options chosen for further analysis.

Table 9 shows the summary of weighted analysis along with the resulting TBL scores. It should be noted that the three main TBL factors have equal contribution (one third each) with only the sub-criteria having weighting factors. As can been seen from Table 9, the rankings of the options is unchanged; however, the difference between the un-weighted and weighted Economic and Environmental factors increases while the Economic factor score remains relatively unchanged. The preferred option according to this ranking too is the LID Option.

2.2.5 Cost Benefit Analysis:

The objective of this Cost Benefit Analysis (CBA) is to consider the costs and the benefits associated with each stormwater management option. The process of understanding a cost benefit analysis for infrastructure project such as roading and other similar civil projects is well established on New Zealand. However, this is not the case for projects that focus on environmental improvement, such as integrated stormwater management systems such as Stormwater Quality Treatment and Low Impact Design.

Currently there is no common methodology in New Zealand for defining the benefits of stormwater management in terms of a purely monetary value to form input to a cost benefit analysis. Such a transition is a difficult process since many of the benefits are intangible and not easily quantified. Full definition of the benefit associated with providing integrated stormwater management including direct, indirect and passive use values would require extensive research effort.

Some of the perceived benefits are not actual benefits but rather reductions in the social and environmental effects from the development. While it is possible to argue that reduced environmental and social effects could be classed as benefits, for the purpose of this cost benefit analysis it was not appropriate to classify these reduced effects as benefits. Thus only the environmental and social factors that a real benefit could be derived from have been taken as benefits and the economic factors that can be directly related to the financial costs as the costs. The cumulative scores of the environmental and social factors were assessed directly against the Economic factors. The higher the ratio, then the more favourable the option is. The formula used for this CBA is the ratio of Benefit/Cost.

For environmental and social factors, a score of 3 represents more important while 2 is for less important and 1 is important. For economic factors, a score of 3 means more expensive and 1 means cheap. The use of a weighted matrix allows for a more detailed, finer evaluation of the stormwater management options. Table 10 summarises the benefit evaluations while Table 11 summarises the cost evaluations. Finally Table 12 presents the results of the cost benefit analysis undertaken on the stormwater management systems for this site. From this matrix it can be seen that the highest scoring stormwater management system was Option One with a ratio of 3.37. This cost benefit analysis supports the findings of the TBL assessment that Low Impact Design option is the most suitable solution for the site.

		LID Option		**SWQT Option**	
Parameter	Weight	Score	Total	Score	Total
Environment					
Water Quality	3	*3*	9	*3*	9
Water Quantity	2	*3*	6	*3*	6
Sediment Removal	3	*3*	9	*3*	9
Flora/Fauna	2	*3*	6	*2*	4
Vegetation alteration	1	*2*	2	*2*	2
Fresh water habitat	2	*3*	6	*1*	2
Social					
Aesthetics	2	*2*	4	*2*	4
Recreational	1	*1*	1	*1*	1
Culture	1	*1*	1	*1*	1
Amenity Value (Long Term)	2	*3*	6	*2*	4
Community Services	2	*2*	4	*1*	2
		Total	**54**		**44**

Table 10: Benefit scores in the Cost Benefit analysis for the two options

		LID Option		**SWQT Option**	
Parameter	Weight	Score	Total	Score	Total
Economic					
Material costs	2	3	6	3	6
Installation	2	2	4	2	4
Maintenance	3	2	6	3	9
		Total	**16**		**19**

Table 11: Cost scores in the Cost Benefit analysis for the two options

Option	**Benefit**	**Cost**	**Ratio**
LID	54	16	**3.37**
SWQT	44	19	**2.32**

Table 12: Summary of the Cost Benefit analysis for the two options

2.3 FINAL DESIGN

The site is to be sub-divided in to 9 Lots as shown in Figure 2. The areas of the Lots and the stormwater management solutions suitable for each Lot are presented in Table 13.

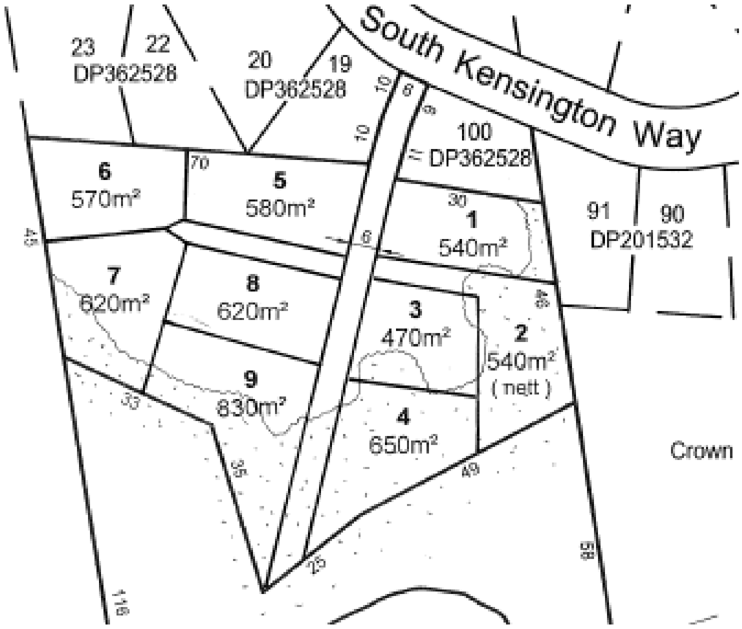

Figure 2: Proposed subdivision plan (not to scale)

Lot No.	Area (m²)	Purpose	S/W Tank	Rain Garden	Dispersion Device	Stream outlet	Swale/rain garden
1	661	Residential	✓	✓	×	✓	×
2	665	Residential	✓	✓	×	✓	×
3	862	Residential	✓	✓	✓	×	×
4	773	Residential	✓	✓	✓	×	×
5	1033	Residential	✓	✓	✓	×	×
6	942	Residential	✓	✓	✓	×	×
7	1037	Residential	✓	✓	✓	×	×
8	673	Residential	✓	✓	✓	×	×
9	180	Access-way	×	×	×	✓	✓
10	836	Access/cycle ways	×	×	×	✓	✓
Total	**7663**						

Table 13: Stormwater management solutions for the lots in the site

The following sub-sections describe the final designs of the storm water management systems for the site.

2.3.1 Guidelines

In determining the treatment options, ARC TP 124 (ARC, 2000) provides useful guidance. However, the manuals used for the design of the systems are (1) Auckland Regional Council Technical Publication 10, Stormwater Management Devices (ARC, 2003) and (2) Auckland Regional Council Technical Publication 108, Guidelines for stormwater modelling in the Auckland Region. (ARC, 1999). These provide commonly used and accepted modelling and design approaches to stormwater management aimed at providing both stormwater quantity and quality mitigation.

Other documents and Codes of Practice that relate to stormwater management referred to during the design include a number of WCC publications including: (1) Countryside and Foothills Stormwater Management Code of Practice; version 3.0 (WCC, 2005), (2) Stormwater solutions for Residential Sites; Version 1.0, (WCC, 2004), and (3) Waitakere City Council Code of Practice for City Infrastructure and Land Development (WCC, 2006).

2.3.2 Stormwater tanks

It is proposed to design stormwater tanks to be installed on each residential lot to collect the stormwater runoff from the roof areas. These tanks are to be dual purpose and provide both a water reuse (dead) volume for non-potable use as well as attenuation (live) volume detain and release the stormwater from larger (2yr and 10yr ARI) events to mitigate the effects of the development on the downstream environment.

Allowing for a minimum of 10 days' supply for non-potable uses at rates specified in Chapter 11 of TP10 (WCC, 2003) , and to provide extended detention for storm events up to and including 10% AEP, the stormwater tanks were designed to have sizes as shown in Table 14. Based on this table, the largest stormwater attenuation and reuse tank required to be installed on this development is: 7.2 m^3 (4.0m^3 for reuse + 3.2m^3 for attenuation). Drawings for a typical tank, although not produced here, were also produced.

Impermeable area		150m^2		200 m^2		250 m^2		300 m^2		350 m^2	
Storm event (ARI)		2yr	10yr	2yr	10yr	2yr	10yr	2yr	10yr	2yr	10yr
Lot 1	**f (l/s)**	0.6	0.3	1.2	0.7	1.8	1	2.4	1.3	3	1.7
661	**v (m3)**	1	0.6	1.6	0.9	2.1	1.2	2.7	1.6	3.2	1.9
m^2	**d (mm)**	22	15	32	21	39	26	50	33	50	33
	h (m)	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5
Lot 2	**f (l/s)**	0.6	0.3	1.2	0.7	1.8	1	2.4	1.3	3	1.7
665	**v (m3)**	1	0.6	1.6	0.9	2.1	1.2	2.7	1.6	3.2	1.9
m^2	**d (mm)**	22	15	32	21	39	26	45	30	50	33
	h (m)	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5
Lot 3	**f (l/s)**	0.6	0.3	1.2	0.7	1.8	1	2.4	1.3	2.9	1.6
862	**v (m3)**	1	0.6	1.6	0.9	2.1	1.2	2.7	1.6	3.2	1.9
m^2	**d (mm)**	22	15	32	21	39	26	45	30	49	32
	h (m)	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5
Lot 4	**f (l/s)**	0.6	0.3	1.2	0.7	1.8	1	2.4	1.3	3	1.7
795	**v (m3)**	1	0.6	1.6	0.9	2.1	1.2	2.7	1.6	3.2	1.9
m^2	**d (mm)**	22	15	32	21	39	26	45	30	50	33
	h (m)	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5
Lot 5	**f (l/s)**	0.6	0.3	1.2	0.7	1.8	1	2.4	1.3	3	1.7
1050	**v (m3)**	1	0.6	1.6	0.9	2.1	1.2	2.7	1.6	3.2	1.9
m^2	**d (mm)**	22	15	32	21	39	26	45	30	50	33
	h (m)	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5
Lot 6	**f (l/s)**	0.3	0.2	0.8	0.4	1.2	0.7	1.7	1	2.2	1.2
942	**v (m3)**	1	0.5	1.5	0.9	2.0	1.2	2.6	1.5	3.1	1.8
m^2	**d (mm)**	16	15	26	17	33	22	38	25	43	29
	h (m)	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5
Lot 7	**f (l/s)**	0.6	0.3	1.2	0.7	1.8	1	2.4	1.3	2.9	1.6
1073	**v (m3)**	1	0.6	1.6	0.9	2.1	1.2	2.7	1.6	3.2	1.9
m^2	**d (mm)**	22	15	32	21	39	26	45	30	50	33
	h (m)	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5
Lot 8	**f (l/s)**	0.6	0.3	1.2	0.7	1.8.	1	2.4	1.3	3	1.7
712	**v (m3)**	1	0.6	1.6	0.9	2.1	1.2	2.7	1.6	3.2	1.9
m^2	**d (mm)**	22	15	32	21	39	26	45	30	50	33
	h (m)	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5

Note: *ARI: Annual Recurrence Interval; f: Flow rate (L/s); v: Volume (m^3); d = Outlet diameter (mm), h: Height of outlet above normal water level(m).*

Table 14: Stormwater tank design result

2.3.3 Rain Gardens

The rain gardens were designed using the method described in WCC's Stormwater Solutions for Residential Sites manual. Typically rain gardens are 1.0m deep unless there are issues with a high water table in which case a reduced depth to a minimum depth of

0.6m can be considered. The size of a rain garden is determined according to the equation $A_f = \frac{WQV \cdot d_f}{k \cdot (h + d_f) \cdot t_f}$ where A_f: the surface area of the rain garden (m²); WQV: Water quality volume (m³), d_f: Planting soil depth (m); k: Coefficient of permeability (m/day); h: Average height of water (m); t_f: Time to pass WQV through depth (day). It was assumed in this design that only the paved areas drain to the rain garden.

Table 15 provides the possible design parameters for the rain gardens for two depths of choice. As none of the residential rain gardens are proposed to be constructed as part of the initial development, the different rain garden sizes provide for flexibility for the house designer when looking at impermeable surface areas on each of the residential lots. Design drawings although not presented here were also prepared for a typical garden.

Contributing catchment (m^2)	Soil depth (m)	Area (m^2)	Soil depth (m)	Area (m^2)
25	0.6	3.62	1.0	2.17
50	0.6	7.24	1.0	4.34
75	0.6	10.85	1.0	6.51
100	0.6	14.47	1.0	8.68

Table 15: Rain garden design results

2.3.4 Dispersion Devices

The design of the dispersal devices has been undertaken in accordance with section 7 of WCC's Countryside and Foothills Stormwater Management Code of Practice, version 3.0. Most appropriate dispersal device was deemed to be an above ground flow dispersal device as per figure 7-2 of the Code of Practice. As the length of the device is proportional to the area draining, dispersion device lengths were designed as shown in Table 16.

Effective catchment area drained (m^2)	Dispersal device length(m)
100	8
200	12
300	14
400	16
500	18
600	20

Table 16: Stormwater dispersion device design results

With the expectation of Lots 1 and 2, all areas shall be connected to a dispersion pipe to provide a suitable discharge point for the stormwater runoff captured within the water tank and rain garden. These will be located within the Lot boundaries that they are to serve, towards the rear of the sites and well away from any possible interference from other uses. As Lots 1 and 2 have no suitable areas to place a dispersal device, it is proposed to connect Lots 1 and 2 to the under-drain of the access-way treatment device and use this to convey the stormwater from these Lots to a safe discharge point. Drawings for the dispersion devices were also prepared.

2.3.5 Swales

The hybrid stormwater quality treatment device designed here consists of a modified rain garden in the base of the swale constructed along a sufficient length of the swale to provide the necessary treatment for the stormwater runoff. The dimensions of the modified rain gardens were determined by the length of the access-way along which the rain garden will run. Once the length had been calculated it was possible to look at different widths and depths to provide the optimal solution for the area. A summary of the final results of this exercise is provided in Table 17. Drawings, not presented here, were prepared to illustrate the configuration along with additional information on the recommendations regarding planting cover, mulch layer, planting soil, filter fabric, scoria bed, and under-drain.

Lot No.	Catchment area (m^2)	Area (m^2)	Length (m)	Depth (m)	Width (m)
9	126	17.82	29.70	0.6	0.6
10	482	40.90	58.42	1.0	0.7

Table 17: Swale design results

3 CONCLUSIONS

Of the number of stormwater management systems and techniques investigated, the Low Impact Design (LID) stormwater management system provided the most suitable means of managing the stormwater runoff from this site. Following the five basic principles in the Section 4 of ARC TP 124 , namely, (1) Achieve Multiple Objectives, (2) Integrate stormwater management and design early in the site planning (3) Prevent rather than mitigate (4) Manage stormwater as close to the point of origin as possible; minimise collection and conveyance, and (5) Rely on natural process within the soil mantle and the plant community, has permitted an eco-sensitive design that meets the needs of the client and the requirements of the regulatory authorities. By allowing for flexibility in the design parameters, there is scope for different development scenarios on these individual sites subsequently at the development stage.

ACKNOWLEDGEMENTS

Authors would like to acknowledge the financial support provided by the School of the Built Environment of Unitec to present this paper at the 5th South Pacific Stormwater Conference, Auckland, New Zealand in May 2007.

REFERENCES

Auckland Regional Council (ARC), 2003 2nd edition, Stormwater management devices: Design guideline manual, Technical Publication 10. Auckland Regional Council, Auckland, New Zealand.

Auckland Regional Council, 2000, Low Impact Design Manual for the Auckland Region, Technical Publication 124. Auckland Regional Council, Auckland, New Zealand.

Auckland Regional Council (ARC), 1999, Guidelines for Stormwater runoff modelling in the Auckland Regional, Technical Publication 108. Auckland Regional Council, Auckland, New Zealand.

Waitakere City Council (WCC), 2006, Code of Practice for City Infrastructure and Land Development. (CoP). Waitakere City Council, Waitakere City, New Zealand.

Waitakere City Council (WCC), 2005, Countryside and Foothills Stormwater Management Code of Practice; version 3.0, (CFSMCoP). Waitakere City Council, Waitakere City, New Zealand.

Waitakere City Council (WCC), 2005, Native to the West, A guide for planting and restoring the nature of Waitakere City. Waitakere City Council, Waitakere City, New Zealand.

Waitakere City Council (WCC), 2004, Stormwater Solutions for Residential Sites; Version 1.0, (SSRS). Waitakere City Council, Waitakere City, New Zealand.