LOW IMPACT DESIGN APPROACH FOR A HYPOTHETICAL SUBDIVISION DEVELOPMENT AT SHAKESPEAR REGIONAL PARK.

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ABSTRACT

Low Impact Design (LID) is an integrated set of principles to minimise the effects of development on the environment through stormwater management and landuse planning techniques.

The Auckland Council sponsored LID student competition presents a medium for final year University of Auckland engineering students to apply these methods into designing a fictional subdivision. This paper describes the winning design as judged by the Auckland Council and IPENZ, and the design methodology.

The design criteria was to provide a hypothetical high density housing (500 dwelling units) development within a 26.2 hectare section of Shakespear Regional Park while maintaining predevelopment hydrology and providing water quality treatment through the implementation of LID principles.

Urban design principles integrated within the development provided central communal areas, maintained harbour views, maximised daylight, preserved natural channels and vegetation, and incorporated street amenities to improve efficiency of Council services and resident safety. LID principles within the design included clustered dwellings, large shared public spaces, and LID treatment trains combining permeable pavements, grassed swales and rain gardens. Modelling and calculations determined the development successfully exceeded minimum council requirements for peak flow while reducing total runoff volume to predevelopment conditions for a range of design storms, and provided a high level of surface water treatment.

KEYWORDS

Low Impact Design, Stormwater, Student, Subdivision, Urban, Landscape

AUTHOR PROFILES

Karen, Kevin and Jason completed their studies towards a BE (Hons) in Civil and Environmental Engineering at the University of Auckland in 2011, and are now easing into the working environment. Among them they have a broad interest in all aspects of Civil and Environmental Engineering.

1 INTRODUCTION

Photograph 1: Study site at Shakespear Regional Park

1.1 AUCKLAND LID STUDENT COMPETITION

This paper outlines the winning design of the Auckland Council 2011 Low Impact Design (LID) competition run through the Urban Stormwater Management course at the University of Auckland's Faculty of Engineering. The competition brief was to design a hypothetical subdivision at a section of Shakespear Regional Park to accommodate 500 dwelling units (150 villa dwelling units, 250 terrace dwelling units, and 100 apartment dwelling units) based on LID principles as well as achieve above and beyond the Auckland Council stormwater management requirements. Current council guidelines require that peak flow rates for a development are maintained at pre-development levels for the 2 year and 10 year average recurrence interval (ARI) storm events. In addition to this the competition objectives were to maintain peak flow rates at pre-development levels for the $^1/_3$ 2 year ARI event, and to maintain total volume discharge for all three design storms at pre-development levels.

1.2 LOW IMPACT DESIGN

Traditionally council requirements for managing the hydrology of new developments have been met using 'end-of-pipe' approaches which can be costly and are increasingly becoming unsustainable (Coffman, 2002). The new sustainable way of improving hydrologic outcomes are low impact philosophies for design. However the adoption of LID approaches is often met with barriers such as perceived additional costs and lack of awareness (Coffman, 2002; Olorunkiya et al., 2010).

The increase in impermeable area due to development and the resulting increase in runoff is one of the primary causes of degradation of receiving watercourses. LID is a design philosophy that aims to minimise the hydrological impacts of urban development on the existing environment through stormwater management and landuse planning techniques. This way of designing can limit the effect development has on downstream environments where it can cause erosion, lower water quality and decrease habitat ecosystems (Ferguson, 2005), and this design philosophy helps to improve the aesthetic qualities and liveability of the site. (ARC, 2003; USEPA, 1999).

The overall site layout design of the hypothetical development aimed to meet the stormwater management objectives and to eliminate many of the perceived negative aspects of LID development from the point of view of both developers and residents. The layout of roads and positioning of dwelling lots, amenities and green spaces all contribute to the effectiveness of a design and effect the value of the properties, and were therefore planned early in the design process.

1.3 THE STUDY SITE

Shakespear Regional Park is located at the end of the Whangaparoa Peninsula in the Rodney District, about 40 minutes north of Auckland. The study site area is 26.2 ha and is naturally divided by several small gullies that drain to three different outlet points. Currently the 26.2 ha study site is predominantly grazed farm land. Mature trees provide a natural division between the grazed paddocks. The ground slopes at an average of 5 to 10 degrees towards the three outlet points. Two unsealed roads service several farm dwellings and buildings at the south eastern area of the site. An existing road, Bruce Harvey Drive, runs along the eastern boundary of the study site (but is not within the boundary of the study site) and provides public access to Te Haruhi Bay to the south.

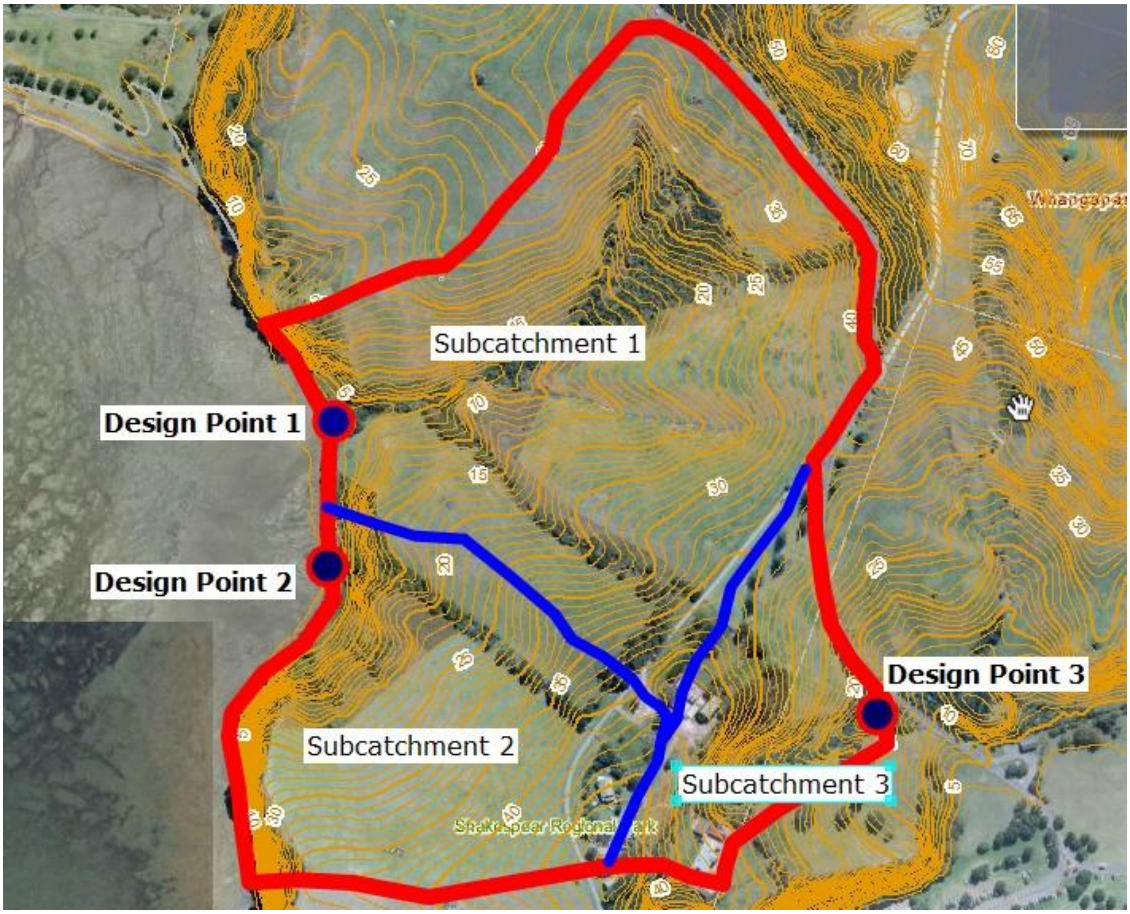

Figure 1: Delineation of catchment and design outlet points. Source: Auckland Council GIS Viewer

The study site was delineated into three sub-catchments and corresponding design points as shown in Figure 1. The entire catchment was then modelled using the HEC-HMS software for the three conditions of pre-development, the post-development design and post-development design without LID devices. This was to determine if the design could meet the competition objectives and what effect the implementation of the LID devices had on the site hydrology. The five LID devices used in the design (rain gardens, grass swales, permeable pavements, green roofs and rainwater tanks) were either modelled and calibrated using a set of observed data from existing devices or modelled using a theoretical approach. The Auckland Regional Council's Contaminant Load Model spreadsheet (ARC, 2006) was employed to determine the difference in contaminant loading between pre and post-development conditions and to try to reduce the impact of the development on the contaminant loading potential.

2 DISCUSSION

2.1 DESIGN LAYOUT

2.1.1 LAND USE CONSTRAINTS

In order to protect and utilise the existing natural hydrology of the site, the land areas available for development were restricted. All watercourses were identified and a 5m buffer zone was placed around them. The design proposes that these areas be amended with a layer of filter medium and vegetated to create a healthy riparian zone. This will help stabilise the watercourses as well as provide additional water quality benefits (USEPA, 2005).

To minimise earthworks, development was also restricted to ground with a slope not exceeding 15 degrees. These areas were instead allocated to public green space. However land that was considered too steep will be vegetated. Furthermore, all existing trees were marked to be preserved with the exception of the south eastern area of the site due to space limitations. This will take advantage of their stormwater runoff reduction benefits (Xiao et al., 2000) and add to the aesthetic value of the development while new trees mature.

2.1.2 LOT AND ROAD LAYOUT

The clustering of lots was an important concept in the development layout design. By clustering lots shorter lengths of road were required to serve the dwellings and more public green space was able to be provided. The areas of development were generally kept to the higher elevations of the sub-catchments. This was to allow the remaining undeveloped green space to act as an additional buffer zone to help treat and remove pollutants and reduce flow rates of stormwater runoff flowing from the developed areas to receiving water bodies. The volume of stormwater flowing through the developed areas and picking up contaminants from lawns and road surfaces was also reduced as a result of this approach.

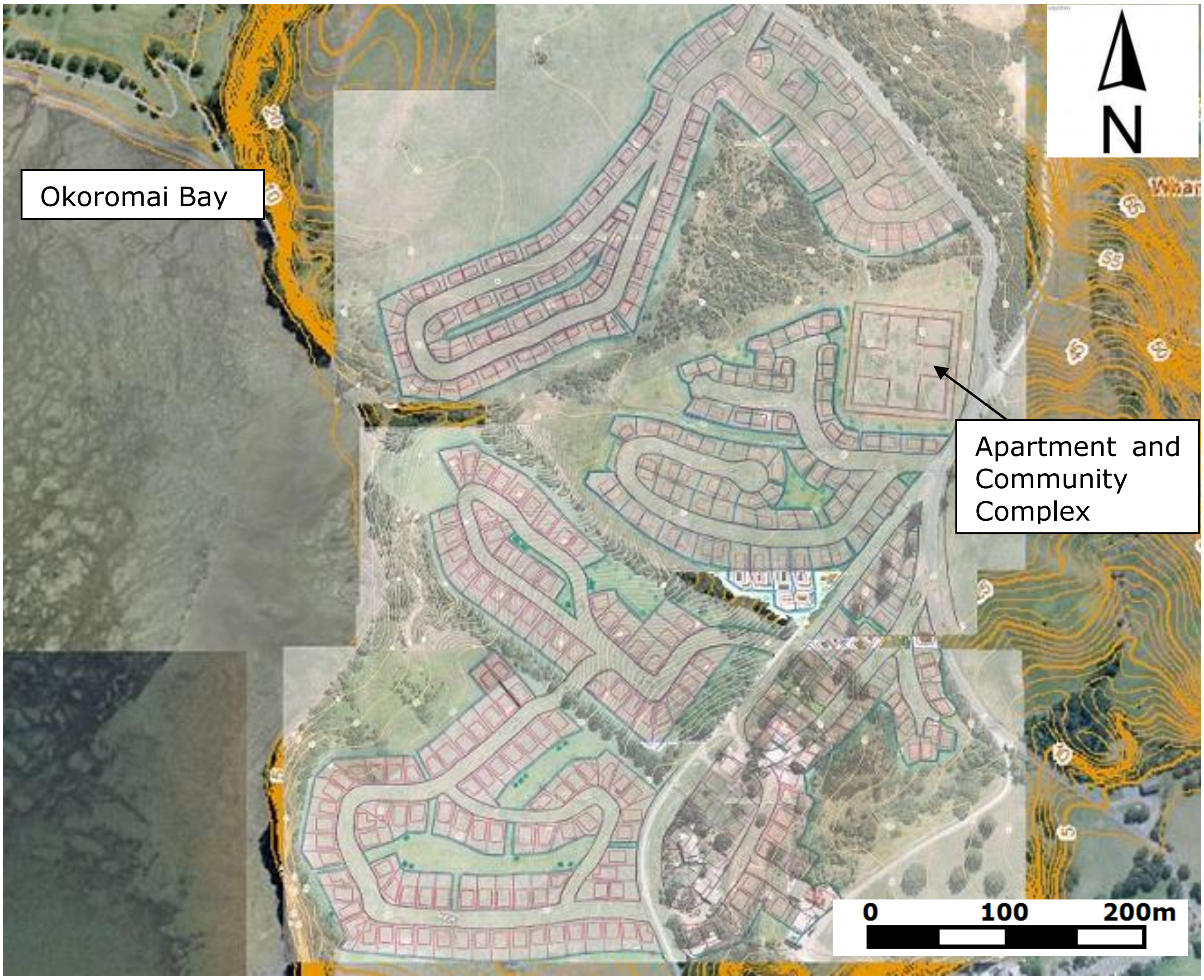

Figure 2: Layout of road network and dwelling lots.

Terrace lots were primarily positioned on the northern sections of the site and the villa lots were positioned around the southern sections (Figure 2). Views and sunlight were competing considerations for lot and dwelling positioning but were both able to be achieved for the majority of dwelling units.

The natural topography of the land, the watercourses and existing vegetation provided a challenge to the road network layout. In order to minimise the total length of road required to serve the lots, a ‘loop and lollipop’ layout was adopted where the topography and area dimensions allowed for it.

2.1.3 GREEN SPACE

Shared green spaces have been provided throughout the development with the aim of every household being within a 2 minute walk of shared open green space. Most dwellings share property boundaries with public green space areas, providing both direct physical and visual access to the neighbouring green space. The idea behind this was to create a feeling of ownership by the residents due to the easy green space access and use. With clustered dwellings, lot sizes and therefore private gardens are much smaller and so this was deemed important to add value and liveability to the properties. Clear sightlines from private property to areas of public space also provide security through natural surveillance (City of Virginia Beach, 2000). Roads however are generally not visible from the green space areas which are instead surrounded by trees and houses.

The public spaces also create a more pedestrian friendly environment, encourage walking and reduce road traffic by providing a more direct route for pedestrians to reach other areas of the development including the central community area. Additionally an area at the western end of the development was reserved for public green space to ensure easy access for residents to an access way down to Okoromai Bay.

2.1.4 COMMUNITY

Creating a community was an important aspect of the design to add value to the properties in the area. The apartment complex was designed to be part of a community hub that includes eateries, a retail centre and local amenities. It was therefore necessary to locate the complex in a centralised location within walking distance of every dwelling. However it was equally important to ensure that there was no significant increase in traffic volumes of non-residents on the local road network, as this would require wider roads and impede on the pedestrian friendly concept. As seen in Figure 2, the community complex was positioned directly off Bruce Harvey Drive and within a 650 meter walk of the furthest dwelling.

2.2 ROADS

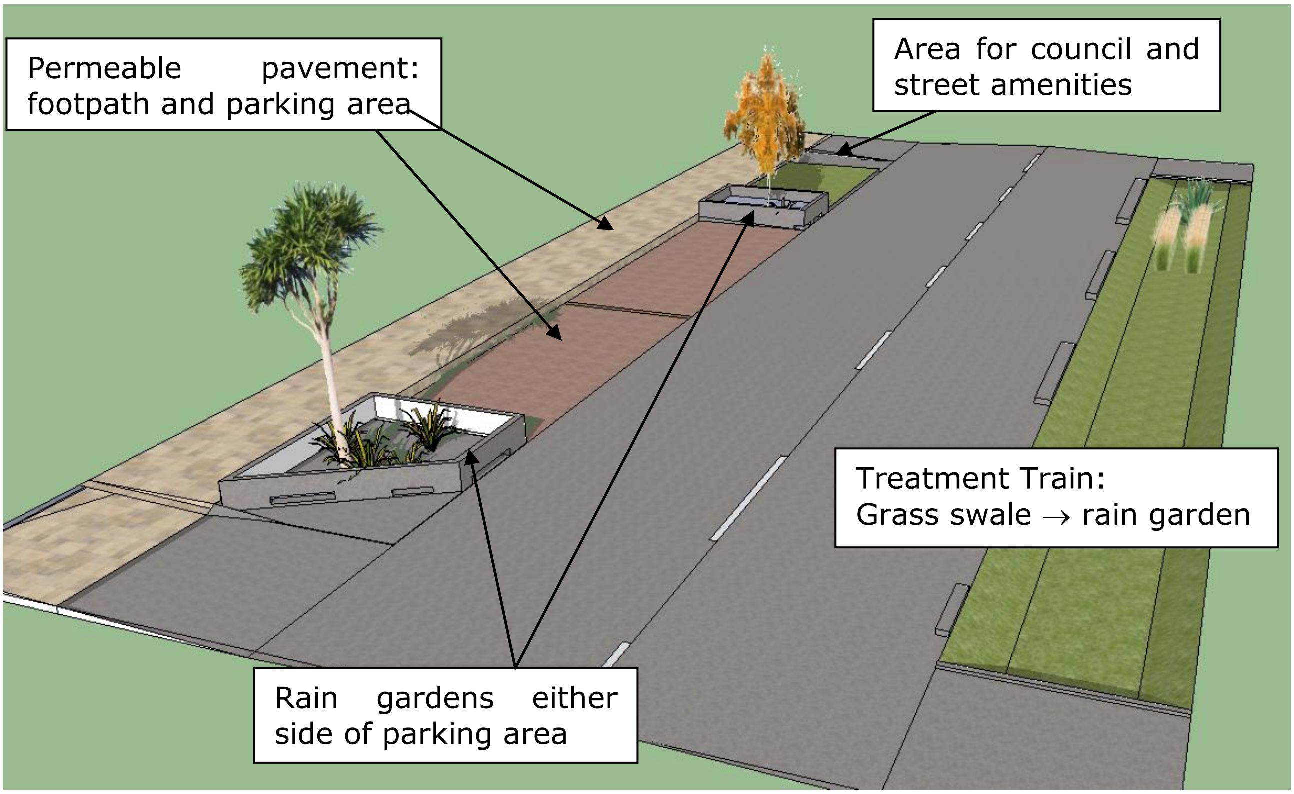

Figure 3: 3D model of the two-way road design

Pavements and roads are one of the most influential features in the urban environment and occupy more than twice the area of buildings. Roads produce around two thirds of the excess runoff generated from a catchment and most hydrocarbon pollutants are discharged from pavement runoff.

The subdivision road design and layout at Shakespear Regional Park incorporates different road designs to make use of as much space as possible and reduce impervious area. The road network is made up of a main road, two-way roads, one-way roads, cul-de-sacs and y-turning areas (Table 1). One-way roads make up 41% of the total road network and reduce impervious area by 45% when compared to two-way roads. Y-turning areas have been used frequently as they have a reduced impervious area when compared with cul-de-sacs (Wellington City Council, 1992). These types of roadways were used in the design to reduce impervious area and therefore reduce the amount of stormwater runoff that needed to be captured and treated.

Stormwater runoff from one side of the roadway for all road types flows into either of the two rain garden areas that surround the permeable parking bay (Figure 3). For the two-way road, runoff from the other side of the road flows through a treatment train: down a grass swale underneath one shared driveway and into a rain garden placed at the end of the swale.

Permeable pavement has been used for the parking bays and footpaths to reduce impervious area and treat heavy metals and other contaminants from vehicles. There is much evidence in the literature to support the significance of heavy metal concentration reduction by permeable pavement systems (Brattebo & Booth, 2003; Dierkes, et al., 2002; Fassman & Blackbourn, 2011). Over time the pavement's contaminant removal capability will degrade and regular maintenance is advised to reduce the potential for clogging and creating an impervious pavement. If clogging does occur, any surface flow from the permeable pavement is still able to flow into the rain garden downstream where pollutants will be removed through filtration and runoff volume and flow rate will still be reduced. The rain garden can also treat runoff from the permeable pavement during higher intensity events as an alternative treatment device if the surface infiltration rate of the pavement is lower than the rate of rainfall. Permeable pavements were only used on low loading sites as the sub base of the pavement structure will not have to be very deep. The rain gardens either side of the permeable parking bay act to discourage heavy vehicles from driving over the permeable surface, as these vehicles can weaken the structure significantly (Waitakere City Council, 2004).

Downstream of the rain garden there is a green area that can be used for street lamps or street signs. There is a concreted area just before the next shared driveway that has been designed for four household rubbish bins to fit. It is designed for the four houses on both sides of the road to use every week. This area can reduce the stopping and starting time for the rubbish truck on its route as well as reduce the inconvenience that may be caused for the truck by the one-way roads.

Table 1: Different aspects in the width of road types

	One-way Road	Two-way Road / No-exit Road	Main Road
Footpath	2m	2m	2m
Parking and Amenities	2.5m	2.5m	2.5m
LHS Road from Fig 4	3.7m	3.7m	3.7m
Median Strip	N/A	N/A	3m
RHS Road from Fig 4	N/A	3m	3m
Grass Swale	N/A	2.4m	2.4m
Grassed Area	2.5m	N/A	N/A
Total Width	10.7m	13.6m	16.6m

2.3 VILLA AND TERRACE LOTS

LID devices have been employed to manage the additional runoff from the increase in impermeable area within the villa and terrace lots. However by limiting the amount of impermeable area to begin with, fewer and smaller treatment devices were required allowing for both a cost and space saving.

The average villa lot covers an area of 352m^2, and has a building footprint of 120m^2. The average terrace lot covers an area of 205m^2, and has a building footprint of 88m^2. Double garages are provided for all villas and 150 of the 250 terrace dwellings. The remaining 100 terrace units have a single garage. All garages have been incorporated into the ground floor of the dwellings to limit the net impervious area within each lot. Additionally, the buildings have been set back from the right-of-way a distance of only 3.5m. This provides just enough length for an extra parking space for a small car and significantly reduces the impervious cover area of the lot and the sub-catchment as a whole, as well as providing a larger private back yard for residents. When compared to a common setback of 6.5m with a driveway the full width of the garage, the reduced setbacks result in a saving of 660m^3 of concrete and a direct construction cost saving of approximately $460,000 over all of the subdivision lots. Furthermore the reduced impervious area is equivalent to the footprint of 48 additional villa lots and equates to a 312m^2 reduction in the required total rain garden area to treat the additional runoff from the development.

Table 2: Stormwater treatment devices used within villa and terrace lots

Lot Type	Impermeable Area	1st Control Device	2nd Control Device
Villa	135m^2	4500L Rainwater Tank	6.5m^2 Rain garden
Terrace (Single Garage)	100m^2	8.2m^2 Rain garden	
Terrace (Double Garage)	103m^2	8.4m^2 Rain garden	

Two LID stormwater control devices are used to treat and manage the additional runoff within each villa lot from the roof and driveway areas. These are rainwater tanks and rain gardens (Table 2). The average four person household uses 430L of water per day for laundry, gardening, and toilet flushing (ARC, 2003). However not all activities require potable water from the piped reticulation system. Hence rainwater tanks have been placed within each villa lot to collect runoff from the roof and store it for non-potable water uses. The rainwater tanks were sized for water quality credit volumes in accordance with Auckland Regional Council’s TP10 (ARC, 2003) only and not for peak flow attenuation as this would require a size of tank that may be deemed unsightly. Using the tables provided in ARC’s TP10, the designed size of 4500L for the rainwater tanks allows a 50% reduction in equivalent roof area for runoff treatment calculations and provides up to 70% of the annual household non-potable water requirements. This would result in an average annual cost saving of $143 per household (Watercare Services Limited, 2011). Because of the small building footprint of the terrace dwellings, the economic benefits provided by a rainwater tank are limited and so they were not incorporated into the design of the terrace lots.

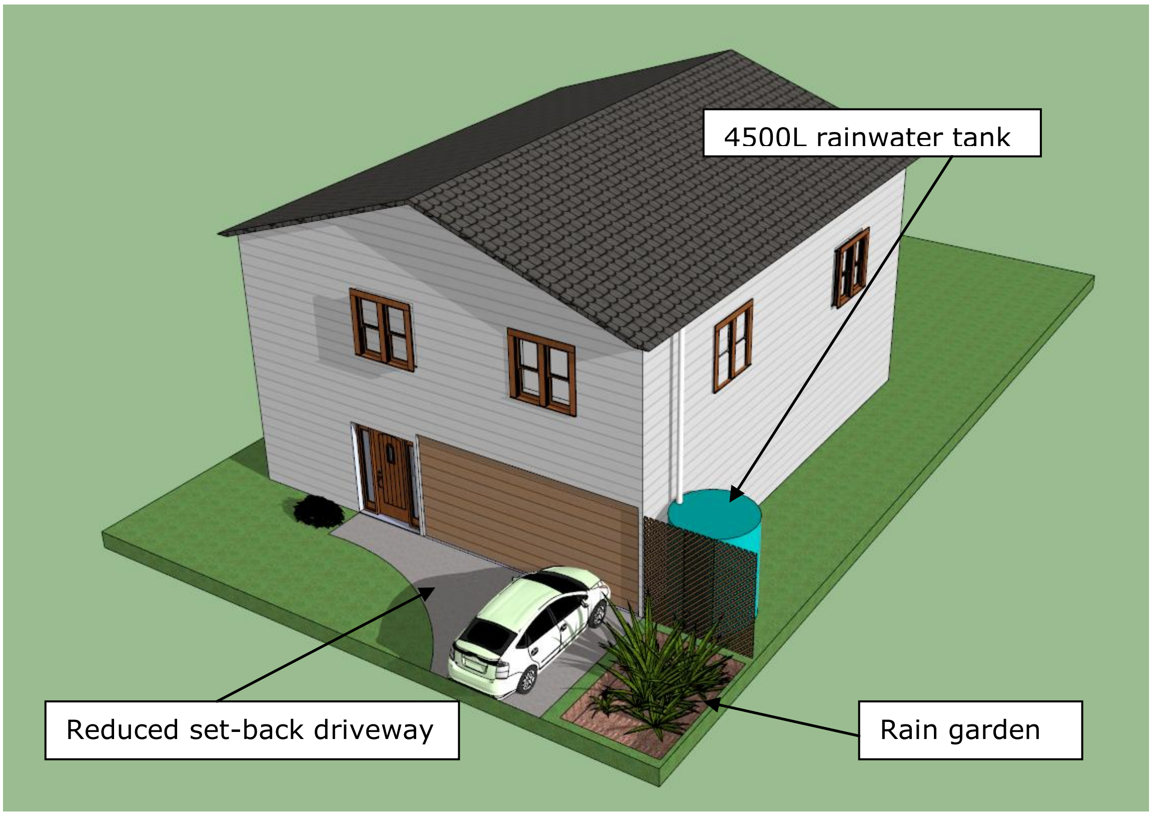

Figure 4: 3D model of a typical villa lot layout

Because the rainwater tanks were only designed for water quality credit volume their peak flow reduction benefits are limited as there is no additional volume for storage and controlled release of the Extended Detention Volume (EDV), and the 2 year and 10 year event roof runoffs. Additionally because roof contaminants can often be discharged in dissolved form (e.g., zinc) the pollutant removal benefits would be minimal. Hence a second control device was required to treat the overflow from the rainwater tanks and retain peak flow rates at pre-development levels. Overflow from the rainwater tanks along with driveway runoff is directed to a rain garden located at the front of each property as can be seen in Figure 4. Rain gardens have been chosen because of their consistent ability to reduce peak flow rates and total discharge volumes (Debusk & Wynn, 2011; Li & Davis, 2009), and remove heavy metals and hydrocarbons by filtration, sedimentation and adsorption (Li & Davis, 2008; Li et al., 2009; Diblasi et al., 2009); the main pollutants of concern from residential roofs and driveways.

As the rain gardens are within private property, it will ultimately be the responsibility of the residents to keep them maintained and operational. Rain gardens will need to be cleared of any debris and weeds on a regular basis, and the soil will need to be replaced after significant sediment and contaminant build up (NZWERF, 2004). One of the factors affecting the likelihood of proper maintenance is the size of the rain garden, and so keeping the rain gardens to a manageable size was important. Rain gardens were designed for the Water Quality (WQ) event storm. The use of rainwater tanks on villa lots reduced the required rain garden area to treat the WQ storm by 6m^2, resulting in a required rain garden area of 6.5m^2 for the villa lots as opposed to 8.2m^2 and 8.4m^2 for the single and double garage terrace lots respectively. Rain gardens were positioned to the front of the dwellings so that they were visible from the street. This not only adds an aesthetic appeal and character to the area, but also encourages proper maintenance of the rain gardens by residents. Additionally, one option that is utilised in some overseas locations is that the maintenance obligations for the rain gardens on private property may be incorporated into the legal structure adopted to manage the maintenance of public green space areas, roads and the swales and rain gardens serving the roads such as a Bodies Corporate or Trust.

2.4 APARTMENT COMPLEX

The apartment complex contains 100 dwelling units and is situated towards the centre of the proposed development. The building is a central area of the subdivision and the ground floor of the complex was reserved for shops and amenities for the public. Four apartment towers at each corner of the complex consist of five dwelling units per floor and 25 units per tower. The large area on the first floor roof of the apartment complex has been designed as a public rooftop courtyard, adding to the communal atmosphere that was desirable for the design. A 3D model of the apartment complex is shown in Figure 5. The courtyard space between the towers allows sunlight to reach each apartment tower throughout the day and ensures different parts of the courtyard can enjoy the sun during the day. As the complex was situated at one of the higher elevation points of the site, the courtyard area and apartment dwellings will provide good views of the surrounding area.

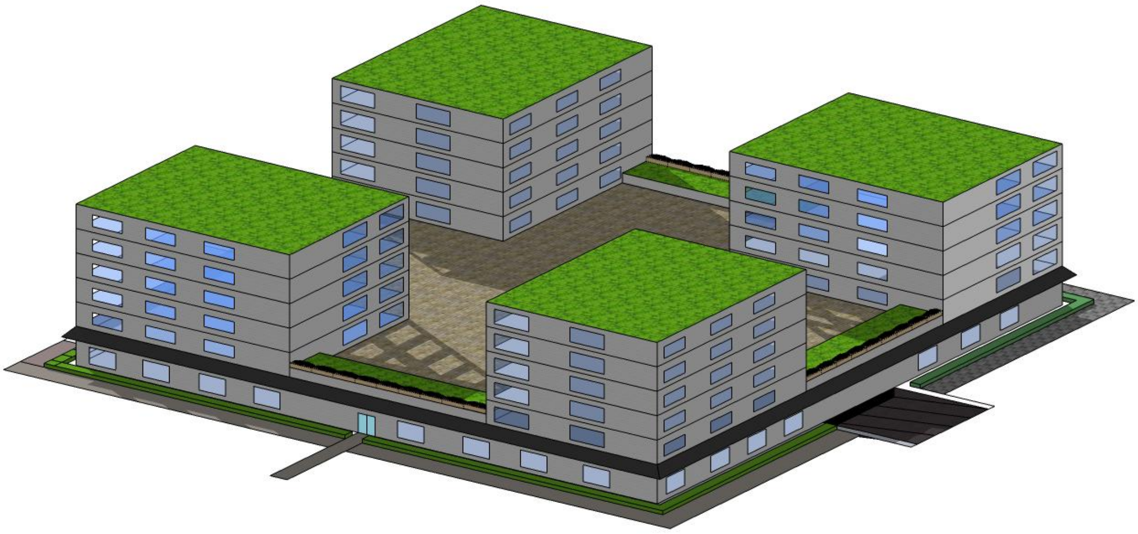

Figure 5: 3D model of the apartment and community complex

Hydrology of the apartment complex is controlled first with multiple living roofs situated on the top of the four corner towers. As they will be out of sight, extensive living roofs can be employed allowing for both a construction and maintenance cost saving. Living roofs are also positioned around the perimeter of the courtyard to provide extra distance to the edge of the building for safety purposes. Rain garden areas have been placed around the perimeter of the entire building on the ground floor to treat runoff from the courtyard area. The rain gardens were sized based on the WQ event storm and are 1.2m wide.

As a community area, high traffic volumes would be expected, and so an underground carpark is located below the apartment complex. Two levels of car park will provide space for around 300 cars, with access directly from Bruce Harvey Drive. To encourage walking, pedestrian access to the building has been maximised with doors and paths on each side of the building.

2.5 MODELLING WITH HEC-HMS

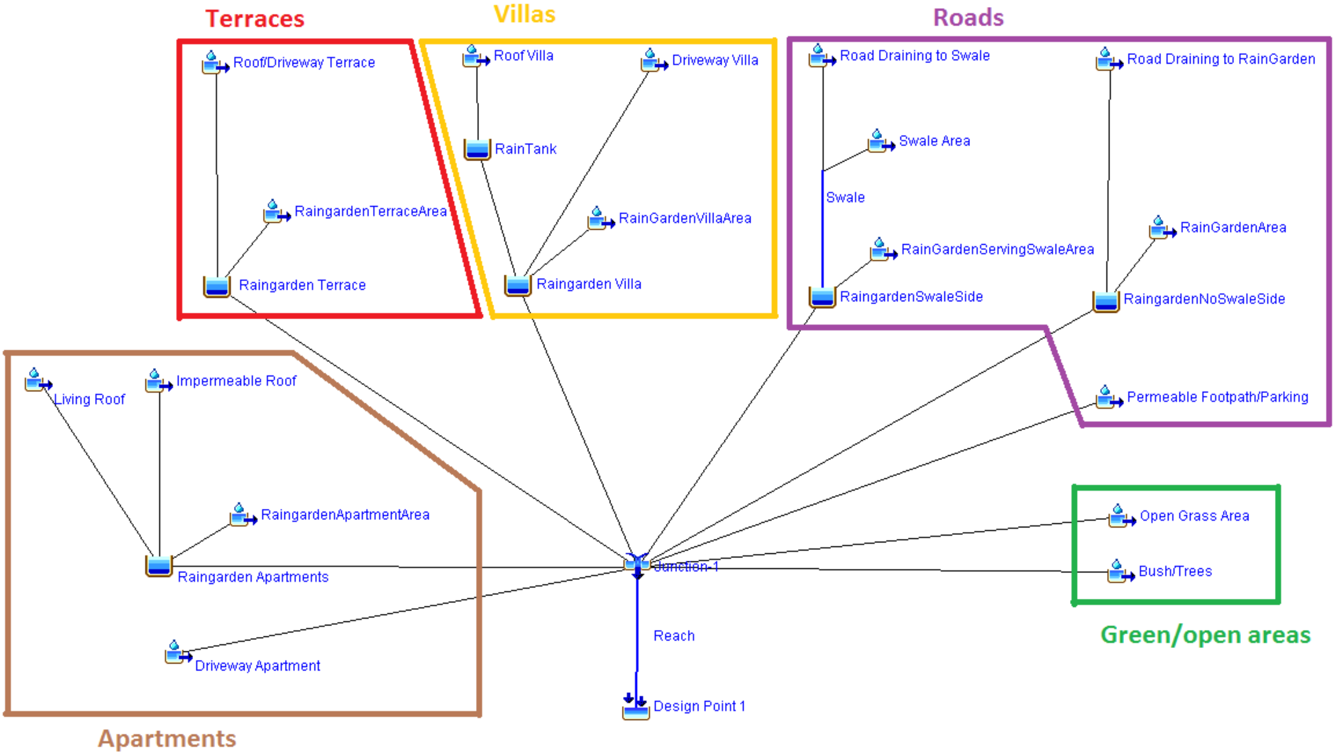

Figure 6: HEC-HMS model layout of Sub-catchment 1

The hydrology of the pre and post-development conditions were modelled separately for each sub-catchment using HEC-HMS and in accordance with Auckland Regional Council's TP108 (ARC, 1999). Figure 6 shows the layout of the HEC-HMS model for one of the sub-catchments. Each of the five LID devices used in our design were either modelled by calibration and verification against a set of data collected from a study site, or by using a theoretical approach as was the case with rainwater tanks and rain gardens.

The living roofs on the apartment complex were modelled using a 'sub-basin' that was calibrated against data sets collected from the living roof atop the engineering building at the University of Auckland. Rainfall events ranged from 21mm to 55mm. The resulting model was then validated against a different set of data collected from the same living roof. The living roof model was shown to be accurate to within 17% of observed values.

The HEC-HMS model to represent permeable pavement behaviour was developed from observed data recorded at a permeable pavement site on Birkdale Road on Auckland's North Shore. It was modelled as a sub-basin with a corresponding curve number and initial abstraction number as permeable pavements act to reduce peak flow and volume much like a vegetated surface. The pavement was modelled differently for peak flow and volume control as a single model was unable to be accurately calibrated against both data sets.

The rainwater tanks were modelled in HEC-HMS as a simple reservoir. The outflow curve was based on a storage-discharge function. As the tanks were designed only for water quality volume credit and not peak flow attenuation there were no orifices to restrict outflow rate and instead there was only a single 'overflow' outlet modelled at the top end of each tank (above 4500L of storage). The water level within the tank at the beginning of any rainfall event varies from event to event. For the purpose of the HEC-HMS model it was assumed that the tanks would be 75% full at the beginning of a rainfall event. The same model was used in both the HEC-HMS calculations for peak flow attenuation and total volume attenuation. Note however that the rainwater tanks will serve no benefit in peak flow attenuations (except for very small rainfall events) as the tanks are likely to already be at capacity during the peak intensity period of the design storm.

Like rainwater tanks, the rain gardens were also modelled using a theoretical approach, as a simple reservoir with an outflow curved based on a storage-discharge function. By using the default structure of the rain garden as per Auckland Regional Council’s TP10 (ARC, 2003), the outflow rate could be calculated by manipulating the sizing equation. The volume of storage before outflow occurs was based on the field capacity of the filter media, which was assumed to be 10% (w/w) to cover for antecedent moisture. The density of the filter media then needed to be defined as well, and this was assumed to be 1800kg/m^3. A table of depth against storage volume and flow rate was constructed with these parameters for each rain garden size.

The grass swales were modelled in HEC-HMS as a reach using the kinematic wave method. They were modelled using a Manning's equation constant as per Auckland Council's TP10 (ARC, 2003), derived from the design length and slope from the site where they were used. Amended soil will be used for the swale as the soil at the site does not provide the desired soil specification in terms of permeability.

3 NUMERICAL RESULTS

3.1 HYDROLOGY

Without the implementation of LID stormwater management devices, the development would have substantially increased the peak flow and total volume of runoff due to the increase in impermeable area (Table 4). The implementation of LID devices and treatment trains using rainwater tanks, living roofs, rain gardens, permeable pavement and swales successfully reduced peak flow down to pre-development conditions for all sub-catchments and design storms with the exception of sub-catchment one and the 10 year ARI design storm. This could be due to the high intensity of the storm and the slower infiltration potential that will occur in LID devices. One solution to this could be the construction of a wetland at the bottom of the sub-catchment. The clustering and layout of dwellings units within the road network has preserved space for this to be implemented. The competition objective of maintaining the total volume of runoff at pre-development conditions was also met with the inclusion of the LID devices. This shows that current council requirements can be achieved and exceeded without requiring the use of costly end-of-pipe structures.

Table 3: Comparison of pre and post-development hydrology with and without LID devices modelled using HEC-HMS.

		WQ Event (27.3mm)		2Year ARI Event (82mm)		10Year ARI Event (140mm)	
Design Outlet Point	Development Condition	Peak Discharge (m^3/s)	Total Discharge ($1000m^3$)	Peak Discharge (m^3/s)	Total Discharge ($1000m^3$)	Peak Discharge (m^3/s)	Total Discharge ($1000m^3$)
One	Pre	0.11	0.68	0.92	5.28	2.13	12.04
	No LID Devices	0.28	1.55	1.35	7.41	2.62	14.91
	LID Devices	0.07	0.64	0.75	4.81	2.54	12.05
Two	Pre	0.06	0.37	0.54	2.89	1.24	6.55
	No LID Devices	0.17	0.93	0.77	4.23	1.52	8.36
	LID Devices	0.04	0.33	0.41	2.44	1.06	6.41
Three	Pre	0.04	0.20	0.26	1.26	0.57	2.74
	No LID Devices	0.06	0.35	0.30	1.67	0.61	3.35
	LID Devices	0.02	0.16	0.16	1.13	0.57	2.75

3.2 CONTAMINANT LOADING

The Auckland Regional Council's Contaminant Load Model spreadsheet (ARC, 2006) was used to calculate the zinc, copper, total suspended solids (TSS), and total petroleum hydrocarbon (TPH) contaminant loading of the pre and post-development conditions (Table 5). The results showed that contaminant loading was successfully maintained at pre-development levels for zinc, copper and TSS, but TPH loading was higher for the post development condition. This was expected from the large increase in vehicle loadings on a site that previously contained only two short lengths of road serving farm dwellings. TSS loading was reduced substantially to well beyond the 75% reduction required by Auckland Regional Council. From this analysis the LID devices that have been implemented in the design are actively working to reduce contaminants that would otherwise be discharged into receiving water bodies.

Table 4: Contaminant loading results for pre and post-development

		Bottom of site out-fall Loads (kg a^{-1})			
Design Point	Condition	TSS	Zn	Cu	TPH
One	Pre	5906.4	1.0	0.0	0.1
	Post	405.0	0.7	0.0	0.6
Two	Pre	7477.0	0.9	0.1	0.1
	Post	237.9	0.3	0.0	1.0
Three	Pre	3014.2	0.3	0.0	0.1
	Post	499.5	0.3	0.0	0.1

4 CONCLUSIONS

A 500 dwelling subdivision development was successfully achieved using LID principles. Clustering of dwellings, minimising road widths and reducing dwelling set-backs all contributed to limiting the increase in impermeable area as a result of the development. This resulted in less stormwater runoff and therefore smaller and fewer required treatment devices, giving a cost and space saving. This extra area was instead used for additional green spaces. The inclusion of public green space throughout the development and the integration of a central community complex resulted in a highly liveable development with aesthetic appeal and a community atmosphere.

HEC-HMS modelling showed that without LID treatment devices the increase in impermeable area would result in significant increases in peak flow rate and volume of runoff reaching the three design outlet points. However with the implementation of LID treatment devices such as rainwater tanks, living roofs, rain gardens, permeable pavement and swales, the hydrology of the site was able to be maintained at pre-development conditions for all design storms with the exception of peak flow for the 10 year ARI storm for Sub-catchment one. This included the additional competition objectives of maintaining peak flow for the one third of the 2 year ARI storm at pre-development levels and maintaining total discharge volume at pre-development levels for all design storms. Contaminant out-fall loads for zinc, copper and TSS were also able to be maintained at pre-development levels, showing that implementation of LID treatment trains can effectively treat development runoff.

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