A HYBRID STORMWATER MANAGEMENT SYSTEM FOR A RESIDENTIAL DEVELOPMENT – AN EXPERIENCE

Mr Shane Sai[1], Dr Babar Mahmood[2]

[1]CTR Contractors Ltd, [2] Senior Lecturer at Unitec Institute of Technology, Mt Albert Campus, Auckland, New Zealand

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ABSTRACT

Managing stormwater runoff involves controlling the quantity and quality of runoff to mitigate adverse effects on receiving environment. Stormwater runoff can be managed by implementing stormwater management systems that can be integrated with various stormwater management devices. A project was undertaken to solve stormwater runoff problem for a residential subdivision development. The extent of impervious layers will be greatly increased (after development) and therefore the total runoff volume generated in post-development will be greater than the pre-development conditions. As a result, the capacity of existing stormwater drainage system will become inadequate. Therefore, the aim of this project was to design a feasible and effective stormwater management system for the residential development, taking environmental, social, cultural and economic factors into consideration.

Three options were evaluated in this project during the design stages; a centralised system, low impact design, and a hybrid system. Based on the option evaluation process, a stormwater management system was designed to meet regulatory objectives and design criteria to have sufficient treatment, retention and detention capacity for rainfall events in post-development condition.

To cope with the increase in runoff volume, a hybrid stormwater management system (i.e. a combination of conventional and low impact design devices) was designed, as accepted by the client. The chosen hybrid stormwater management system would be sustainable and cost-effective, and could be the most feasible system in terms of managing hydrologic impacts of stormwater runoff from post-development for the site.

KEYWORDS

Stormwater management, Runoff, Sustainable, Stormwater treatment, Hybrid stormwater management system, Low Impact Design

PRESENTER PROFILE

Shane Sai is a Civil Engineer, graduated from Unitec, and now working for CTR Consulting Ltd as a site engineer. The presenter completed this real-world project for a client (as part of his final year project) under the supervision of Dr B Mahmood.

1 Introduction

Managing stormwater runoff involves controlling the quantity and quality of runoff to mitigate adverse effects on receiving environments (Auckland Council, TP10, 2003). Stormwater runoff quantity control is required to limit runoff volume, peak flow discharges and to reduce erosive runoff flows into the waterways. Excessive runoff during a rainfall event can also cause flooding risks to downstream properties and houses. Also, it is important to control and minimise contaminants of concern, such as heavy metals and sediment, entering receiving waterways and damaging the natural ecosystems.

Stormwater runoff can be managed by implementing stormwater management systems, which can be integrated with various stormwater management devices (e.g. infiltration trenches, permeable pavements, swales, etc. as listed in Table 7). These can be designed to minimise flooding risk by reducing peak flow and runoff volume, while minimising risk of contamination on the receiving environment by removing contaminants of concern.

An increase in imperviousness due to proposed development will result in a greater quantity of stormwater runoff being generated on-site because of reduced infiltration and evapotranspiration capacity from pre-development condition. To minimise the impact of development on runoff hydrological cycle, Auckland Council (AC) Technical Publication 10 (TP10) has suggested reducing imperviousness and implementing stormwater management practices, which can mimic existing natural drainage features (Auckland Council, TP10, 2003).

This paper presents unique stormwater management solutions to address and manage runoff for a residential subdivision development, and mimic natural hydrological processes. The project was completed by a final year Civil engineering student for a client.

The specific objectives of the project were:

- To evaluate available stormwater management devices i.e. both conventional and low impact design (LID) devices.

- To identify the most feasible system based on the environmental, social, cultural and economic factors associated with the implementation of the stormwater management device(s).

- To design the preferred system to meet AC's regulatory objectives to have adequate detention and retention capacity of stormwater runoff from post-development.

2 Background

This project was undertaken for a client who was interested in subdividing their property, which was located in New Lynn, Auckland. The property was in pristine condition mostly covered with trees and bushes (Figure 1). The total pre-development land area is approximately 4600m², including approximately

700m2 impervious roof of the existing house. As indicated by the client (2016, pers. comm.), the existing property and house did not connect to public piped stormwater network. Roof runoff was discharged to ground soakage for treatment and dispersal. Overflow runoff from the roof, and ground surface, drained overland to the stream behind the property.

Proposed development is likely to consist of developing the present greenfield land into five new lots, covering 2900 m^2 area. The total extent of impervious surfaces in post-development condition is likely to be increased to 2900m² (i.e. 63% of the total area). This development was likely to create new impervious surfaces, which will minimise free draining capacity of the ground and results an increase in runoff volume.

Figure 1: An aerial view of the proposed site.

According to Auckland Unitary Plan zoning, the site currently falls under Stormwater Management Area: Flow 2 (SMAF2). SMAF is defined as geo-spatial stormwater flow management zones for the development and redevelopment of impervious areas in Auckland region (Auckland Council, AUP, 2013). As this property is located in SMAF2, assessment of flood risks was required to be able to design an effective stormwater management system to minimise flooding risk during extreme rainfall events. Several rainfall events for 2, 5, 10 and 100 ARI (Annual Recurrence Interval) events were considered to be able to design an effective on-site stormwater management system, which has sufficient retention and detention capacity to minimise peak runoff from post-development. Assessment of devices was also required to identify which stormwater management devices have potential to manage runoff quantity, quality and impacts of increased stormwater runoff from proposed development.

3 METHODOLOGY

3.1 SOIL TYPE AND SITE SLOPE

The underlying soil type of the property was identified by soil excavation with shovels and borer. Five holes were dug to a depth of 500 mm for surface soil and a further depth of 500 mm for subsurface soil determination. Samples were taken from different areas of the site to get an average representation of site's soil type.
The gradient of the slope for the proposed site was calculated using equal area method as stated Auckland Council's TP10 (2003) document. The topographical data of the site with regard to elevation differences between contour lines was used to calculate slope for this proposed site.

3.2 HYDRAULIC CONDUCTIVITY (K) TEST

Permeability of underlying soil was tested to determine hydraulic conductivity, which is the soakage ability of soil to disperse rainfall runoff. Test holes of roughly 300 mm in diameter and 500 mm in depth were bored using shovel (Figure 2). Five test holes were excavated and permeability tests were undertaken in accordance with methodology in Melbourne Water Corporation (2010) to get a general representation of infiltration rate of the underlying soil layers.

Figure 2: Excavated holes for testing hydraulic conductivity of the soil.

After test holes were dug, all loose soil at the bottom of the holes was excavated in order to prevent soil from scouring when the water was added. Water was added to a depth of 300 mm and left for approximately 6 hours before measuring it again to get the depth after soakage (Melbourne Water Corporation, 2010). The same procedures were repeated for all the test holes and the average infiltration rate was computed in millimetre per hour.

3.3 HYDROLOGICAL DATA COLLECTION (PRE AND POST-DEVELOPMENT)

The Auckland Council GIS viewer was used to define hydrology of the site which is the existence of overflow path and flood prone area on the site. Overland flow paths are low-lying natural drainage paths, which can convey rainfall runoff from a catchment. Overland flow paths are required to be reserved or kept clear from development, where runoff flow during storms can flow over them until it reaches a receiving watercourse. The tasks undertaken to collect hydrological data for pre and post-development conditions of the project included rainfall intensity; peak flow & runoff volume; and determination of site impervious area.

Rainfall Intensity - Rainfall depths of 2, 5, 10 and 100 years ARI of the site for both pre and post development were produced using NIWA's High Intensity Rainfall Design System (HiRDs). Extreme rainfalls with climate change condition were also assessed.

Peak Flow and Runoff Volume - Peak flow rates and runoff volumes for both pre and post development were calculated using "Graphical Runoff Parameters" design calculation worksheet provided in Auckland Council's TP108 (1999) or "Rational Formula" provided in New Zealand Building Code (NZBC Clause E1). The "Graphical Runoff Parameters" design calculation method (Auckland Council, 1999) was used for this study because of its simplicity to integrate with rainfall intensity data. It is a method of calculating peak flow rate where catchment area, rainfall depth and specific peak flow rate are main inputs to the chart. Peak flow rates were determined using the specify flow rate equation from TP108 (Auckland Council, TP108, 1999).

4 Results and Discussions

4.1 SITE INFORMATION

Soil type: From excavated soil, the visual representation shows that the surface soil was silty soil with high organic contents whereas the subsurface soil was silty clay with high moisture content.

K test: Infiltration rates for subsurface soil were obtained from permeability test boreholes, which ranged from 25 - 38mm/hr. Refer to Table 1 below for soil soakage data obtained from test holes and the average permeability rate of the soil.

Table 1. Hydraulic conductivity test results

Test Holes	**Hole1**	**Hole2**	**Hole3**	**Hole4**	**Hole5**
Initial Depth of Water (mm)	300	300	300	300	300
Final Depth of Water	100	80	130	150	70
Time allowed (hour)	6	6	6	6	6
Depth Loss (mm)	200	220	170	150	230
Permeability Rate	33.3	36.7	28.3	25.0	38.3
	Average Permeability Rate (mm/hour)				33

Site Slope - The gradient of the slope was found to be 28%, which has a slope ratio (H:V) of 3.6:1.

4.2 SITE IMPERVIOUSNESS

Increase in imperviousness during post-development condition in comparison to pre-development condition are given in the Table 2 below. Imperviousness of site for proposed development was calculated considering surfaces such as walkway, roof and driveway as impervious surfaces.

Table 2: Pre and post development impervious areas.

	Area (ha)	**Percentage Coverage**
Total Area	0.46	
Pre-development Impervious Area	0.07	15%
Post-development Impervious Area	0.29	63%

As this property is located in SMAF2 zone under Auckland Unitary Plan (AUP), maximum permitted impervious area is 60% of the whole site. However, imperviousness of proposed development exceeds the maximum permitted imperviousness by 3%. Thus, approaches of reducing site imperviousness for the proposed development were considered. Reduction in site imperviousness by using permeable pavements can help to reduce stormwater runoff and increase in hydraulic conductivity of the site.

4.3 HYDROLOGICAL ANALYSIS

From initial hydrological analysis of the site (using the GIS viewer), it was observed that there were designated overland flow paths and 100-year ARI flood plain in the proposed development. It was also found that there was a stream behind the property, which acts as a receiving watercourse for stormwater runoff in the catchment. Aerial view of pre-development hydrology of the site is given in Figure 3 below.

Rainfall data – Refer to Table 3 below for rainfall results produced for this site (using HIRDS). This rainfall data was used to determine peak flow rates for pre and post-development conditions. This data was also a critical component in modelling required retention or detention capacity of proposed stormwater management system for the site.

Curve Number - Curve numbers used for pre and post-development condition of the site were **39** for pervious areas and **98** for impervious area as selected from clause 3.2 “Curve numbers for Auckland Conditions” of TP108 (Auckland Council, TP108, 1999).

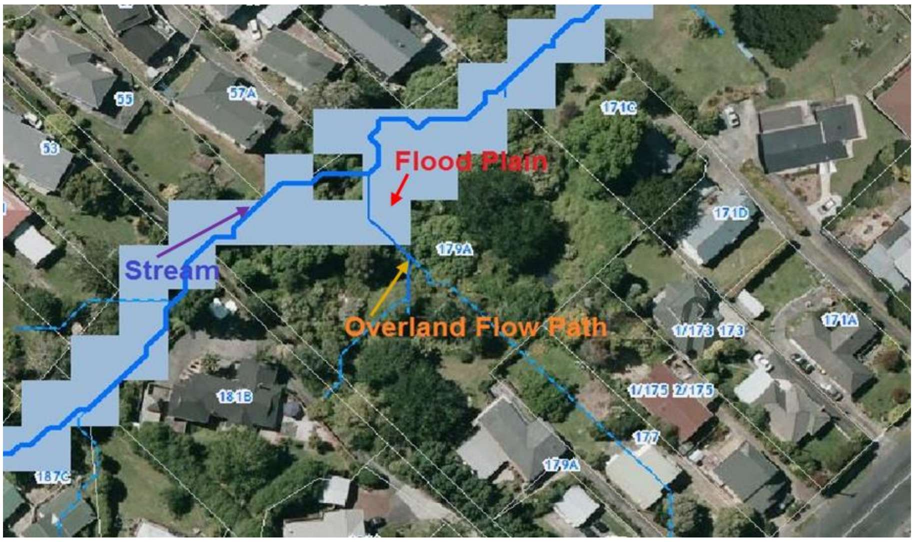

Figure 3: An aerial view of the site showing the overland flow path and the stream at the back of the site.

Table 3. Rainfall data as extracted from HIRDS.

ARI		24 hr Rainfall Depth (mm)		24 hr Rainfall Depth (mm)
2year	No Climate Change	80	With Climate Change	90.3
5year		103.1		119.8
10year		122		145.1
100year		206.3		255.8

Pre and Post Development Volume - The pre and post development flows are given below in Table 4. It compares the pre and post-development peak flow and runoff volume and calculates the differences between two development scenarios.

Table 4. Peak flows and runoff volumes for Pre and Post-Development Scenarios.

Scenarios	2 year ARI		5 year ARI		10 year ARI		100 year ARI	
	Q (m^3/s)	Vol (m^3)	Q (m^3/s)	Vol (m^3)	Q (m^3/s)	Vol (m^3)	Q (m^3/s)	Vol (m^3)
Pre- development	0.02	94	0.03	157	0.04	218	0.1	551
Post-development	0.05	214	0.07	324	0.09	424	0.18	890
Differences	0.03	120	0.04	167	0.04	206	0.08	339

5 A Brief Review of Stormwater Management Devices

Auckland Council's TP 10 (2003) and Water Sensitive Design (Lewis et al., 2015) manuals were used as guiding documents in selecting stormwater devices for the onsite stormwater management system. Lewis et al. (2015) stated that selection of potential stormwater devices for the stormwater management system is dependent on space constraint, budget available, degree of sustainability and aesthetic values to achieve.

Likewise, for this study, stormwater management devices which have potential to manage stormwater runoff from post-development conditions were evaluated based on the design requirements of quantity, quality and aquatic ecosystem protection. A list of potential devices that could be used for this site is described in Table 5 below.

Table 5. A short list of potential Stormwater Management Devices that could be used for the site.

Low Impact Design (LID) Devices	**Conventional Devices**
Wetland Vegetated Swale Rain garden Green Roof Infiltration Trench Permeable Pavement	Rainwater Tank Centralised Stormwater Drainage Lines

Low Impact Design (LID), also more commonly referred to as Water Sensitive Design (WSD), devices are decentralized 'at source' on-site stormwater management practices that aim to mimic natural systems to manage stormwater runoff through avoidance, reduction, and prevention practices as opposed to just traditional mitigation practices. The principle of LID is to recognise that stormwater is ultimately a precious resource, rather than a waste product in need of disposal (Auckland Council, 2000; Lewis et al., 2015). These devices are also described as green infrastructure, which are stormwater management devices that incorporate natural environment and engineered solutions to protect and mimic the natural hydrological water cycle (Mayhew et al., 2016; US Environmental Protection Agency, 2016).

6 Available Options for Stormwater Management Systems

Based on review of stormwater management devices undertaken for the site, the following three options (i.e. construction a new centralized drainage system, constructing a LID system, and a HSMS (hybrid stormwater management system) were considered. A brief detail of each option is given below.

6.1 OPTION 1) CONSTRUCTING A NEW CENTRALISED DRAINAGE SYSTEM

This option was to construct a new stormwater drainage system for the proposed development and connect to the council's centralised stormwater reticulation system. For drainage of water under a gravity, a suitable slope is required. As water does not flow uphill, it will require additional pump systems to convey post-development stormwater runoff to the main reticulation drainage line. The ground level of the site being proposed for the development is roughly at 45 m whilst the surface level of reticulated stormwater system is approximately at 60

m. Overall, this option was regarded as not feasible because of topography of the proposed site. Therefore, it was not considered further for options evaluation.

6.2 OPTION 2) CONSTRUCTING A LID SYSTEM

This option was to construct a LID system using devices such as infiltration trench, green roof, permeable pavement and grassed swale. These devices were favoured for option 2 because of their suitability to implement on a site with limited space availability. A thorough review of the LID devices showed that implementing LID devices could reduce site imperviousness and associated stormwater runoff, which would meet runoff water quality and quantity design criteria. All the devices that were considered in option 2 also have the ability to treat stormwater as it infiltrates through the soil and vegetated medium of the devices.

Impervious surfaces such as driveways, footpaths and parking areas from the proposed development can be built as permeable pavements, which are porous and absorbent. Therefore, there will only be limited runoff generated from these surfaces. Green roofs can be designed to minimise stormwater runoff from the roofs, whilst infiltration trench can be designed to serve overflow runoff from green roofs and pavements during heavy rainfall events. Vegetated swales can be constructed alongside driveways to convey overflow runoff from driveways and surrounding areas to infiltration trench. Vegetated swales can also be designed as overland flow paths for post-development to compensate existing overland flow paths of the proposed site. A plan view of option 2 is shown in the figure below.

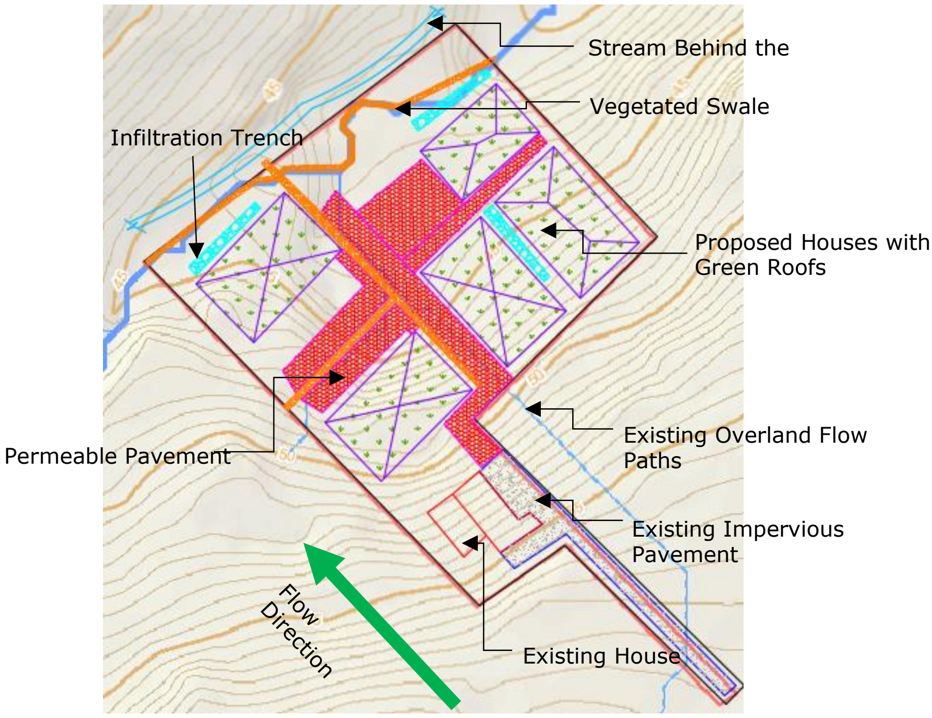

Figure 4. A plan view of the proposed LID System (Option 2).

6.3 OPTION 3) CONSTRUCTING A HYBRID STORMWATER MANAGEMENT SYSTEM

This option includes a combination of LID devices (i.e. rain garden, permeable pavement, grassed swale) and conventional device (i.e. rain tank). A thorough review of these devices (not reported here) showed that each of the device has unique advantages in managing water quantity, quality and associated hydrologic impacts (i.e. erosion and pollution) that may have on the receiving aquatic environment from runoff discharges. As different devices have different advantages on quality and quantity control of stormwater runoff, it can be advantageous to design a stormwater management system for proposed site with more than one type of device, as also recommended by Auckland Council (Auckland Council, TP10, 2003) to integrate multiple stormwater devices together to form a comprehensive stormwater management system.

Similar to option 2, impervious surfaces such as driveways, footpaths and parking areas from the proposed development can be built as permeable pavements, which will only create limited runoff from these surfaces. Vegetated/grassed swales can be constructed alongside driveways to convey overflow runoff from driveways and surrounding areas to rain gardens. Vegetated/grassed swales can also be designed as overland flow paths for post-development to compensate existing overland flow paths. Rainwater tanks can be designed to collect stormwater runoff from the roofs whilst rain garden can be designed to serve overflow runoff from the tanks and pavements during heavy rainfall events. A plan view of option 3 is shown in the figure below.

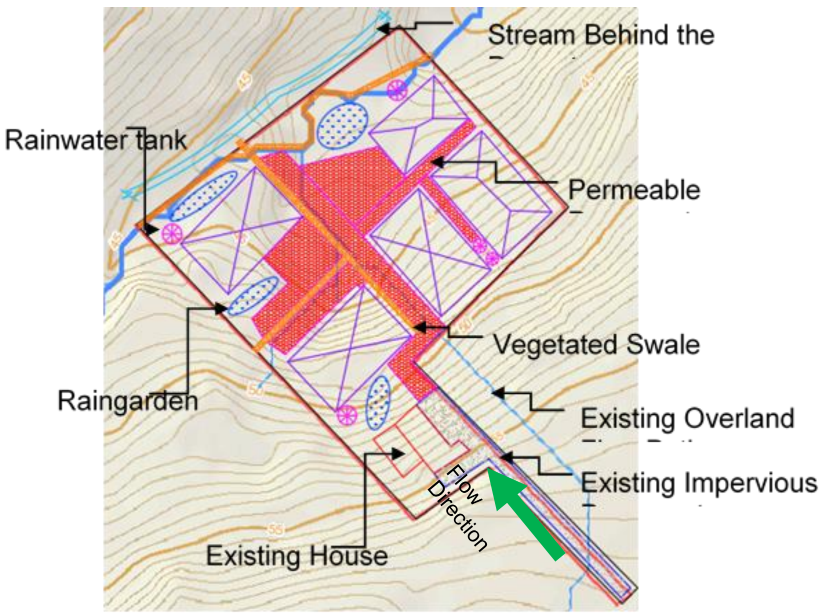

Figure 5: A plan view of the proposed HSMS (Option 3).

6.4 OPTIONS EVALUATIONS

In conformity with the Auckland Unitary Plan (Auckland Council, AUP, 2013), stormwater runoff from a site is required to be managed with regard to quality, quantity and aquatic ecosystem protection. However, the focus of this study was on quantity performance of the stormwater management system for the proposed subdivision development. Stormwater quality control of the devices were not physically tested for their efficiencies in removal of contaminants of significance (heavy metals such as Copper-Cu, Zinc-Zn, Lead-Pb, Iron-Fe, and sediments). Instead, efficiencies of the devices in removing contaminants of significance were evaluated from technical literatures for options evaluation purpose.

From reader's point of view, as an example, Good et al. (2012) established a laboratory scale rain garden experiment to evaluate the influence of substrate composition on stormwater treatment and hydraulic conductivity (K), mesocosm-scale (180 L, 0.17 m^2) laboratory rain gardens. Saturated (constant head) hydraulic conductivity was determined before and after contaminant such as Cu, Zn, Pb and nutrients removal experiments on three rain garden systems with various proportions of organic topsoil. They (Good et al., 2012) found that the system with only topsoil had the lowest saturated K (i.e. 160-164 mm/h) and poorest metal removal efficiency (Cu ≤ 69.0% and Zn ≤ 71.4%). Systems with sand and a sand-topsoil mix demonstrated good metal removal i.e. Cu up to 83.3%, Zn up to 94.5%, Pb up to 97.3% with adequate K (i.e. sand: 800-805 mm/h, sand-topsoil: 290-302 mm/h). Total metal amounts in the effluent were <50% of influent amounts for all experiments, with the exception of Cu removal in the topsoil-only system, which was negligible due to high dissolved fraction. Further, they (Good et al., 2012) reported that metal removal was greater when effluent pH was elevated (up to 7.38). Organic topsoil, a typical component in rain garden systems, influenced pH, resulting in poorer treatment due to higher dissolved metal fractions.

To select the most feasible stormwater management option for this site, a detailed options evaluation was undertaken for option 2 and 3. A weighted attribute method was used for options evaluation for this study, where scores were given for each attribute and total accumulated scores for each option were calculated. Option 3 was the preferred option, refer to below sections for more details.

6.4.1 ATTRIBUTES AND WEIGHTINGS

Efficiency in runoff quantity and quality control, environmental, social, economic and cultural factors were used as key attributes in options evaluation process for this project. Attributes and weightings for each option are presented in Table 7.

6.4.2 COST BENEFIT ANALYSIS (CBA)

A cost benefit analysis of the both options was also undertaken using a score of 1 to 10 (i.e. 1=least effective to 10=most effective). Total average weighted scores were calculated for both options (Table 6).

Table 6: A CBA of the two proposed options.

Options	Device type	Benefits	Comments
Option2	Infiltration Trench	6	High failure record
	Green Roof	10	Natural insulator, soil media acting as buffer zone, insulation and less power bills, sopace saver and more sense of garden on the roof
	Permeable Pavement	10	Permeable surface, vehical load caoacity, sense of green, sustainable structure, and high renetion capacity
	Grassed Swales	10	Additional treatment and retention capacity, green space onsite, slows peak flow and reduce runoff volume, also provides a compensation for overland flow paths after debvelopment.
	Construction cost	8	Estimated cost = $188200
	Average score	**8.8**	
Option3	Rain Garden	10	Aesthetic value, an enahnced natural system to achieve the bedt practical stormwater management outcome
	Rain Water Tank	8	Economic benefits towards energy and diverse water usage, not great in terms of water quality
	Permeable Pavement	10	Permeable surface, vehical load caoacity, sense of green, sustainable structure, and high renetion capacity
	Grassed Swales	10	Additional treatment and retention capacity, green space onsite, slows peak flow and reduce runoff volume, also provides a compensation for overland flow paths after debvelopment.
	Construction cost	10	Estimated cost = $154375
	Average score	**9.6**	

Table 7: Attributes and weightings for devices used in option 2 and 3 using a scale from 1 to 10. (1 = Least effective and 10 = Most effective)

Device type	**Parameters**							**Average score out of 10**
	Quality		**Quantity**	**Environmental**	**Social**	**Cultural**	**Operational Cost**	
	Removal efficiency (%)		Run-off volume reduction (%)	(e.g. volume reduction, enhancement of runoff quality, miminum hydrological impact from runoff, and promote aquatic life protection	(e.g. Aestheitic and amenity values, ponding , and blockage of filter, mosquito breeding)	(e.g. Cultural sensitivity, archaelogical significance, pre-treatment prior to dischartge to stream)		
	Heavy metals (%)	Total suspended solids (%)						
Infiltration Trench	51%	24%	77-97% for rainfall events < 5mm/24hr to > 15 mm/24hr	100 % as it will reduce runoff volume and enhance the runoff quality	70% as ponding can occur as a result of blockage of the filter	100 % as site is not cultural sensitive and also stormwater will be treated before it goes to the stream	100% as there is no cost to run this device	7.6
Green Roof	100%	85%	80-100% for rainfall events < 5mm/24hr to > 15 mm/24hr	100 % as it will reduce runoff volume and enhance the runoff quality	100% as no ponding and blockage. High aesthetic & amenity values.	100 % as site is not cultural sensitive and also stormwater will be treated before it goes to the stream	50% as it has high construction cost as structural support is required.	8.9
Permeable Pavement	80%	60%	96-100% for rainfall events 1 mm/hr to 45+ mm/hr	100 % as it will reduce runoff volume and enhance the runoff quality	100% as no ponding and blockage. High aesthetic & amenity values.	100 % as site is not cultural sensitive and also stormwater will be treated before it goes to the stream	100% as there is no cost to run this device	9.1
Grassed Swales	42-62%	67%	70-80%	100 % as it will reduce runoff volume and enhance the runoff quality	70% as ponding can occur as a result of blockage of the filter	100 % as site is not cultural sensitive and also stormwater will be treated before it goes to the stream	100% as there is no cost to run this device	8.1
Rain Garden	80%	75%	100% for rainfall events 1 mm/hr to 45+ mm/hr, and 50% for ranfall events of 50+ mm/hr	100 % as it will reduce runoff volume and enhance the runoff quality	100% as no ponding and blockage. High aesthetic & amenity values.	100 % as site is not cultural sensitive and also stormwater will be treated before it goes to the stream	100% as there is no cost to run this device	9.4
Rain Water Tank	100%	100%	100% for rainfall events 1 mm/hr to 50+ mm/hr	100 % as it will reduce runoff volume and enhance the runoff quality	80% as it can be visually obstructive.	100 % as site is not cultural sensitive and also stormwater will be treated before it goes to the stream	100% as there is no cost to run this device. Rain water tank has on-going operational cost but it is minimal as saving on water bills is high.	9.7
Option 2 (i.e. Infiltration trench, green roof, permrable pavement, and grasses swales)								**8.4**
Option 3 (i.e. Permeable pavement, grassed swales, rain garden and rain water tank)								**9.1**

Note: Heavy metal and total suspended solids removal efficiency data was sourced from Osullivan and Good (n.d); California Stormwater Quality Association (2003); Culligan et al., 2014); Toronto and Region Conservation Authority (2002); Collins (2007).

7 Detailed Design of Preferred Option

Option 3 (i.e. HSMS) was recommended as the most feasible stormwater management option, and the detailed design details were produced for this option. The recommended HSMS system consisted of rain garden, permeable pavement, grassed swale and rainwater tank. Every impervious layer such as walkway, roof and driveway were considered as a potential catchment area for the devices. The design details for all devices considered in the HSMS are given below.

7.1 RAINWATER TANKS DESIGN

Rainwater tanks will be installed for each proposed dwelling for this project. These will be mainly used to collet overflow water from roofs and store in them to be able to use for non-portable use onsite such as watering lawns and gardens, washing cars and flushing toilets. Roofs from each proposed dwelling has approximate catchment roof area of 300 m^2. Rainwater tanks were designed to be able to supply 90% to 100% of non-portable water usage with respect to 325 L/day consumption rate. A tank size of 16 m^3 has the capacity for long-term storage of rainwater for 325 L/d consumption rate and 1 in 10-year peak flow attenuation for each proposed dwelling as stated in the figure below.

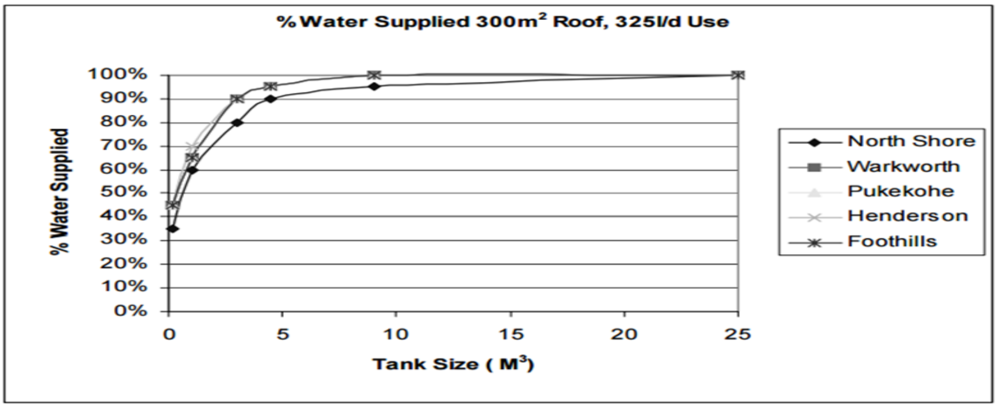

Figure 6: A graph between tank size and the %age of water supplied from roof (Sourced: Auckland Council, TP10, 2003).

Auckland Council's Water Sensitive Guideline Document (2015) requires to direct overflow from rainwater tanks to designated landscape areas. Therefore, overflow from rainwater tanks were designed to be diverted to rain gardens through 35 - 40mm orifice by means of surface flow via grassed swales. In directing overflow from rainwater tanks to rain gardens, a portion of roof catchment area is required to be included in the catchment area of downstream devices. As 10,000 litre rain tanks have enough capacity to capture 90%$^+$ runoff, 33% of roof area is required to be included in the catchment area of downstream treatment device, raingarden, as per the Table 8 (Auckland Council, TP10, 2003).

Table 8. The %age of roof area to be included in the catchment area of the downstream treatment devices (Sourced: Auckland Council, TP10, 2003).

% Roof Runoff Captured by Tank System	% Roof Area to be included in the Catchment Area of the Downstream Treatment Devices(1)
90%	33%
75%	44%
50%	63%
40%	70%
30%	78%
20%	85%
10%	93%
0%	100%

7.2 RAIN GARDEN DESIGN

Rain gardens were designed to serve overflow runoff from permeable pavements, rainwater tanks and surrounding areas. Rain garden design approach stated in Auckland Council's TP10 was used for this design calculation. To determine storage capacity of a rain garden, total runoff from ⅓ of 2 year- 24hr rainfall (water quality storm) was used in design calculation as stated in TP10. Storage capacity required for rain gardens to capture and treat runoff from associated catchments was found to be 42 m^3 whilst total surface area of rain gardens required to capture runoff was calculated as 126 m^2.

Due to space and slope constraints of the site, four raingardens were proposed to construct to meet the storage requirement of rain gardens. Surface area of each rain garden was calculated to be approximately 31.5 m^2. Storage requirement of each rain garden to capture runoff was found to be approximately 9 m^3.

With regard to Auckland Council's Rain Garden Construction Guide (Auckland Council, n.d), 1.5 m of soil is to be excavated for each rain garden. Perforated pipe of 100 mm φ are to be installed for underdrain of rain gardens and then to be backfilled with coarse aggregates to a depth of 500mm and with sand to a depth of 300 mm. Underdrain pipes will be built to drain into the stream behind the property. Rain gardens are to be backfilled with rain garden soil mix to a minimum depth of 500 mm. Then, rain gardens will be mulched to a maximum depth of 75 mm and planted with Auckland Council's recommend plants (Healy et al., 2010) such as sedges, toe toes, flaxes and so on. Recently, a study showed that vegetated rain garden provides nature-friendly space, enhances aesthetic values and increases its pollutants filtering ability (Vadheim, 2013).

7.3 PERMEABLE PAVEMENT DESIGN

Permeable pavements are LID stormwater management devices that can meet the objective of reducing runoff volume with the following advantages:

- Utilization of underlying soil's infiltration capacity.
- Filtering runoff through the layers to improve water quality.
- Maintaining the aesthetic values of the landscape with added benefits of a pavement.

Permeable pavements, which will be built for this project include carparks, driveways and footpaths. The total area of pavement for proposed development is approximately 1400m². Existing impervious areas of the property upslope and proposed pavements were included as possible catchment areas for permeable pavement design calculations. The water quality storm (WQS) depth, runoff volume, and the minimum depth of water storage allowed were estimated (as given below) in accordance with TP10.

WQS depth = ⅓ x 2 year-24hour rainfall depth = 30.1 mm (*Note: This storage depth has adequate capacity to mitigate runoff from WQS).*

Total runoff volume from WQS = 47 m^3
Minimum depth of water storage allowed = 1400 m^2 x 0.1 m = 140 m^3

With regard to Auckland Council's Permeable Pavement Construction Guide, minimum depth of 50 mm aggregate will be laid as bedding material. This designed depth will have enough capacity to capture runoff from water quality storm. Underdrain pipes are not required for these pavements as underlying soil has high infiltration capacity for soakage dispersal of stormwater runoff. Perforated pipes will be installed under the bedding where overflow runoff will be captured and directed to rain gardens through swales.

7.4 GRASSED SWALE DESIGN

Grassed swales for this project were designed to construct alongside driveways to capture overflow runoff from permeable pavements and surrounding areas to rain gardens. Grassed swales were also designed as overland flow paths for post-development to compensate existing 1 in 100 year ARI overland flow paths. Grassed swale will be enhanced by adding 100 mm aggregate bedding under the trench to increase retention capacity.

Results from graphical peak flow rate calculation of TP108 for post-development were used for grassed swale design calculations. Minimum dimension of grassed swale (0.5 m wide x 0.2 m deep) with 1H:2V side slope was found to have adequate capacity to compensate existing overland flow paths for 1 in 100-year rainfall event.

7.5 POST-DEVELOPMENT RUNOFF MITIGATION BY THE PREFERRED HSMS

Implementing these devices from option 3 can achieve the aim of to manage increased stormwater runoff from proposed development to a similar extent of runoff volume from pre-development condition. Total runoff volume from post-development was found to be lesser than pre-development as devices included in option 3 were designed to manage and mitigate stormwater runoff from (2, 5 ,10 and 100 year ARI).

Table 9. Post-development runoff volume mitigation using the HSMS.

ARI	Runoff Volume (m^3) to mitigate	Runoff Volume (m^3) Mitigated by Devices				
		Rainwater Tank	**Rain Garden**	**Permeable Pavement**	**Grassed Swale**	**Total Runoff Mitigation**
2	**120**	80	63	140	3.5	286.5
5	**167**	80	63	140	3.5	286.5
10	**206**	80	63	140	3.5	286.5
100	**339**	80	63	140	3.5	286.5

8 Conclusions

The focus of this project was to design a stormwater management system that has the capacity to manage (in terms of detention and retention capacity) increased runoff from the proposed development for the site.

As this property is located in SMAF2, assessment of flood risks was required to be able to design an effective stormwater management system to minimise flooding risk during extreme rainfall events.

Multiple options were evaluated based on environmental, social, cultural and economic factors for the site. A HSMS was selected based on a thorough review and assessment of available LID and conventional stormwater devices. The selected HSMS was most viable and feasible option for the site. The added benefits of implementing the HSMS are that it will have multifunctional capacities such as bio-retention, detention, infiltration and storage for water-recycling/reusing purposes.

The HSMS (i.e. option 3) was considered to give the best outcomes in managing stormwater runoff from post-development, minimising impervious areas on site while implementing a comprehensive stormwater management system (i.e. HSMS). This system has the capacity to limit runoff volume generated from post-development to pre-development condition and minimise hydrologic impacts on the receiving aquatic environment from stormwater runoff.

Implementation of devices (rain garden, rainwater tank, permeable pavement and grassed swale) on proposed site can mitigate increased stormwater runoff due to an increase in impervious surface for the development. According to the calculations undertaken for this project, it was found that these devices have capacity to mitigate runoff volume of 286.5 m^3, whilst runoff volumes computed for 2, 5, 10 and 100 year ARI were 120 m^3, 167 m^3, 206 m^3, 339 m^3 respectively. These devices have full retention and infiltration capacity to manage stormwater runoff from post-development for 2, 5 and 10 year ARI rainfall events (as per requirements).

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