STORMWATER MANAGEMENT AND FLOOD MITIGATION IN THE MEOLA CATCHMENT, AUCKLAND

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ABSTRACT

Auckland Council established the Central Auckland Stormwater Initiative (CASI) to investigate options to alleviate flood hazards and address other stormwater management issues in central Auckland, which includes the Meola, Oakley and Epsom catchments among others. A series of CASI technical workshops resulted in the identification of probable high-level solutions to address flooding. This paper provides background on flood issues in Meola and details stormwater management and flood mitigation options.

The Meola drainage system is a complex combination of Meola Creek, wastewater pipes, stormwater pipes, combined stormwater/wastewater pipes, and public and private soakage systems. Flood issues in the Meola catchment, including habitable floor flooding are commonly associated with topographical depressions, lack of available soakage for stormwater disposal, limited drainage network capacity and contaminated flooding.

Functional requirements for flood solutions considered the influence of growth, future climate change on rainfall patterns, the extent of soakage sensitivity on flood issues, and geological conditions on construction techniques. Furthermore, geological conditions and topography in the Meola catchment play a significant role in the design and costs of the stormwater issues and options.

Stormwater management solutions considered a number of options including improved soakage systems, increased stream conveyance capacity, low impact design options, increasing stormwater storage capacity, stream daylighting and large-diameter stormwater tunnels.

KEYWORDS

Stormwater, urban, flood, drainage, catchment management, climate change

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1 INTRODUCTION

The Meola catchment in central Auckland covers 1,518 ha. It is the largest natural stormwater catchment on the Auckland Isthmus. The catchment generally slopes from the southeast from Mt Eden and Three Kings down to Meola Creek and Waitemata Harbour in the northwest (Figure 1). The base flow in Meola Creek is fed by natural freshwater springs from the underlying aquifer, particularly in the upper and middle reaches.

Figure 1: Location of Meola Catchment

The Meola Catchment is predominantly (72%) residential with a number of larger parks and open spaces (12%) and commercial/industrial areas (9%). Existing imperviousness is around 45% and is estimated to reach 60% by 2050. The total number of residential floors in the catchment is currently 24,683. This is expected to increase by 30% to over 32,000 by 2051. The total population is currently 64,000 and is expected to increase by 28% to over 82,000 by 2051.

Presently, stormwater management in Meola is achieved through a variety of methods including separated and combined stormwater/wastewater systems and public and private soakage systems. Flood issues in the Meola catchment, including habitable floor flooding are commonly associated with topographical depressions, lack of available soakage for stormwater disposal and limited drainage network capacity. Presently, 492 habitable floors are expected to be at risk of flooding due to a 100 year average recurrence interval (ARI) storm with climate change. A further 1,623 floors are within

500 mm of flooding (AECOM, 2011b). It is anticipated that climate change effects, development intensification and growth will increase flooding problems over the coming years.

Large parts of the existing drainage system are old, and as a result of development increasing beyond that originally allowed, are now insufficiently sized. Consequently, much of the system has limited capacity to drain stormwater flows from the catchment. Further, ongoing development and the effects of climate change will only serve to further exacerbate the situation. On average, combined sewer overflows currently discharge an estimated 1 million m^3 per year of combined sewage into Meola Creek and the surrounding environment.

Functional requirements for flood solutions include the influence of future climate change on rainfall patterns, the extent of soakage sensitivity on flood issues, and geological conditions on construction techniques. Geology and topography in the Meola catchment also play a significant role in the design and costs of the stormwater options.

1.1 CATCHMENT GEOLOGY

The Meola Catchment has a largely varied geology including a mixture of solid and fractured basalt, tuff and clays. Drainage in the catchment has evolved into a complex mixture of stormwater, wastewater and combined sewer networks. At present, stormwater disposal is achieved mainly by the combined sewer system and the natural soakage capability of the ground rather than through a formal piped stormwater-only network. The soakage system is a combination of publicly and privately owned soakholes that transfer surface water into the ground and ultimately into the underlying aquifer. Historically, there were several small lakes and swamps in the area.

Geology has a significant influence on flooding issues and consequently, the potential stormwater solutions in the Meola catchment. For example, the capacity of the basalt to absorb stormwater relates directly to the effectiveness of soakage solutions. Locating areas of fractured rock is unpredictable making soakage solution unreliable. The construction of tunnels through basalt is hugely more expensive than a similar tunnel through the softer underlying rock formations. Therefore, in order to understand the options for flooding solutions, one needs to first appreciate the geology of the Meola catchment.

Most of the Meola catchment consists of a base layer of sandstones (East Coast Bays Formation or ECBF). Over the last 28,500 years, a series of volcanic eruptions buried most of the ECBF in the catchment with basalt lava. The main volcanoes contributing to the lava were Mt Eden, Mt Albert and Three Kings. Recent geochemical analysis has also connected the Mt Saint John eruption to a lava flow that traversed 11 km in a narrow ribbon across the catchment to form the Meola Reef (Hayward). These overlapping lava flows have created undulations on the surface and has resulted in numerous pockets of flooding across the catchment. Cracks formed in the basalt during cooling have effectively made the rock porous. The underlying impervious sedimentary layer has contained the stormwater in the basalt layer, thus creating an aquifer system that underlies much of the catchment. It is this aquifer that provides the base flow for Meola Creek.

1.2 CLIMATE CHANGE

Rainfall increases due to climate change will also have a considerable effect on flood hazards and solutions in Meola. Due to the predicted increases in flooding, stormwater designs undertaken using today's climate scenario will likely be undersized to accommodate flows expected under the future climate change scenario. Accordingly, stormwater schemes, including long term flood mitigation scenarios should consider the effects of climate change during design.

2 DISCUSSION

This section highlights the flood issues and discusses the range of potential solutions considered for the Meola catchment.

2.1 FLOODING ISSUES

Table 1 lists the number of habitable floors predicted to flood (AECOM, 2010, 2011b). The percentage of flooded floors is based on a total of 24,683 residential habitable floors in Meola.

Table 1: Flooded Floor Counts

Flooded Floor Count	10 year ARI				50 year ARI				100 year ARI			
	Without Climate Change		With Climate Change		Without Climate Change		With Climate Change		Without Climate Change		With Climate Change	
	No. of Floors	% of Floors	No. of Floors	% of Floors	No. of Floors	% of Floors	No. of Floors	% of Floors	No. of Floors	% of Floors	No. of Floors	% of Floors
Habitable floors within 500 mm of flooding	926	3.8%	1151	4.7%	1278	5.2%	1552	6.3%	1385	5.6%	1623	6.6%
Habitable floors flooded	146	0.6%	197	0.8%	275	1.1%	407	1.6%	331	1.3%	492	2.0%

The lack of a formal reticulated stormwater network in many areas of Meola has resulted in a significant volume of stormwater entering the wastewater and combined networks. When the volume of surface flows exceeds the capacity of the combined system, contaminated flooding occurs and creates a significant public health risk.

2.2 POTENTIAL FLOODING SOLUTIONS

The development of the flood and stormwater management options has been undertaken in a systematic fashion with investigation into the feasibility and probable costs of each alternative.

Potential synergies with Watercare Services' proposed Central Interceptor were also considered. The provision of stormwater solutions in the CASI catchments, and especially in the Meola catchment, will provide opportunities to achieve improved outcomes in conjunction with the Central Interceptor. This will enable the best community outcome for the management of stormwater contaminants and the reduction of frequency and volume of combined sewer overflow spills to the receiving environments.

Stormwater management solutions considered a number of options including:

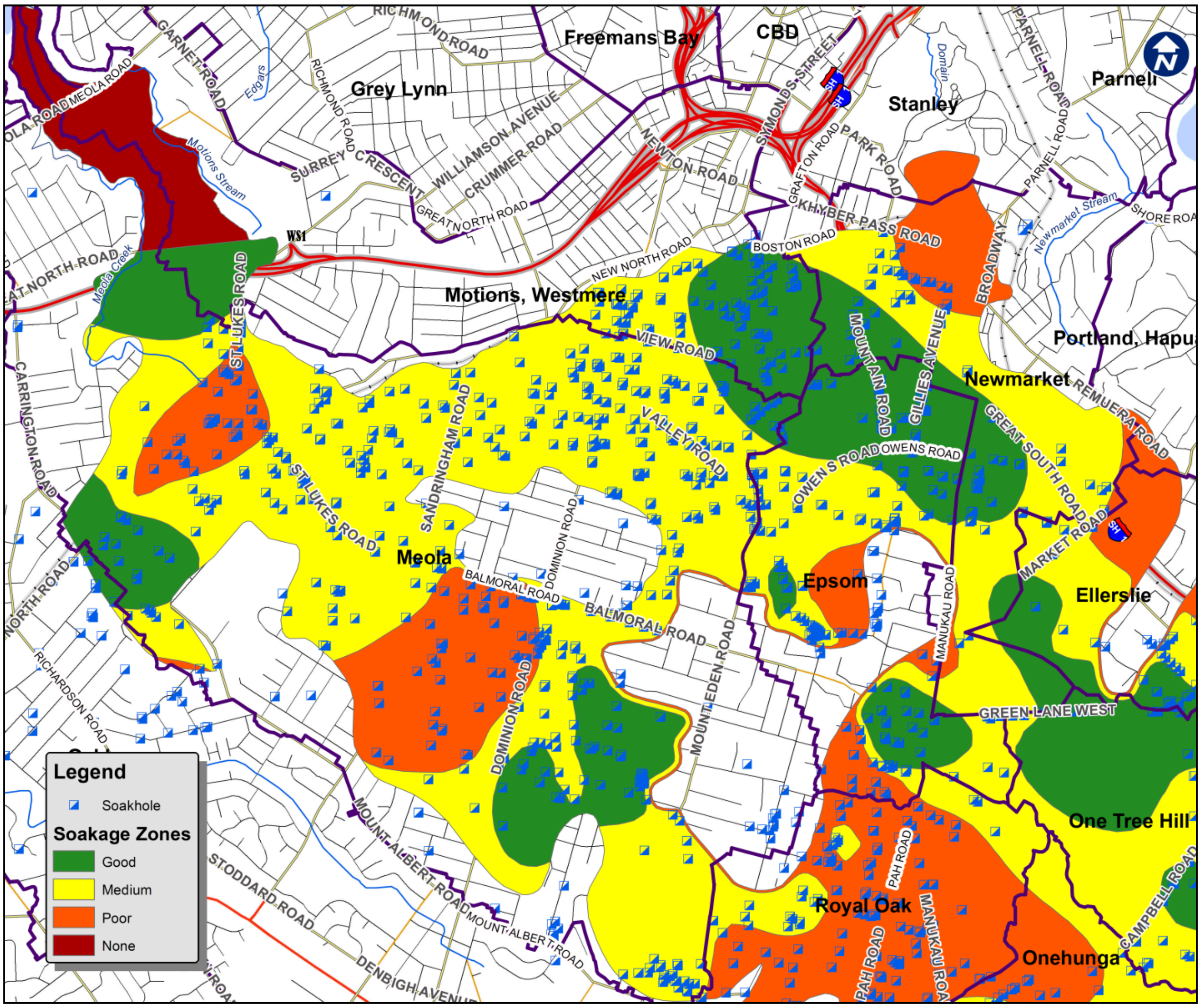
- improved soakage systems for stormwater disposal
- low impact design options
- increased stormwater storage and attenuation capacity in the catchment
- increased in-stream conveyance capacity and stream daylighting
- construction of new large-diameter stormwater tunnels

2.2.1 STORMWATER SOAKAGE

Stormwater soakage systems play a role in stormwater management in the Meola catchment. Soakage functions by discharging stormwater into the underlying cracks in the basalt lava which then feeds into the aquifer. Soakage is presently used throughout most of the Meola catchment.

Figure 2 shows the location of public soakholes (the blue squares) in the Meola catchment in relation to soakage capacity. Soakholes are generally located in areas of medium to good soakage potential with a few located in poor soakage areas. The soakhole plots are from the Auckland Council stormwater asset GIS dataset. Soakage areas generally line up with locations of underlying basalt.

Figure 2: Soakage Potential in the Meola Catchment



Data source: Auckland Council Stormwater Asset GIS Dataset.

The use of soakage as a practical means of stormwater disposal will vary from site to site. Soakage is highly dependent on local geological conditions and interference effects from soakholes located in close proximity to each other.

Records of the size and location of private soakholes are not comprehensive and private soakholes are generally not well maintained. It is thought that many property owners are not aware of the existence of soakholes on their property. There is little formal oversight of private soakholes by Council. Some private soakholes are potentially being covered over with impervious surfaces or are being filled in during site redevelopment.

The lack of control and protection of the private soakage systems will result in reduced performance as growth and intensification occurs in the area.

In contrast, records of the publicly owned soakholes are good. Regular soakhole maintenance is undertaken which has been developed historically based on experience, but due to the operational cost, it is constantly under pressure to be reduced. However, there is a risk of loss of institutional knowledge on the soakhole cleaning and maintenance regimes due to staff changes.

Although the performance of a number of public soakholes has been previously monitored, the true capacity of the existing public and private soakage systems remains largely unknown during large storms. Observations indicate that the level of service is very low in most areas. The extent of their influence on predicted flood levels has only recently been quantified by modelling (AECOM, 2011c); however, their actual performance during storm conditions needs quantification.

Prior work (Maunsell, 2008) indicates that two year ARI private soakage capacities are more realistic than the design requirement of 10 year ARI capacities. Furthermore, high flood volumes, limited inletting and aquifer uptake capacity were identified as issues during large storm events. If drainage relies on soakage, then there could potentially be significant consequences in terms of flood damage if it does not work in large storm events. Additional stormwater disposal through soakage could be investigated in some good soak zone areas, but it may not give the required results for the 100 year ARI storm event.

A sensitivity analysis of the public and private soakage in the Meola catchment was undertaken to identify the influence of soakage capacity on the number of habitable floors predicted to flood. This was done by varying the soakage capacity representations in the recently completed Meola flood hazard mapping (FHM) model (AECOM, 2010).

Nine different soakage scenarios were modelled for this sensitivity analysis. Only the public and private soakage capacities were adjusted for each model scenario. Geological and other physical limitations on soakage capacity were not taken into consideration in the sensitivity modelling. In order to gauge the effect of soakage on flood extents, it was necessary to assume that the soakholes could accommodate the flow rates assigned to them. The actual performance of soakage systems is likely to vary substantially due to geological limitations and maintenance practices as found in previous soakage investigation studies.

As expected, increasing the soakage capacity has a limited effect on reducing the flooded floor count. The general trend is that significant further increases in either public or private soakage capacity provide diminishing returns in terms of the number of flooded floors protected. Eliminating private soakage capacity restrictions in the model (i.e. unrestricted soakage) still results in flooded floors. This is due to limitations on public soakage capacity and capacity deficiencies in the existing stormwater and combined networks.

Figure 3: The Influence of Private Soakage on the 50 year ARI Flooded Floor Count

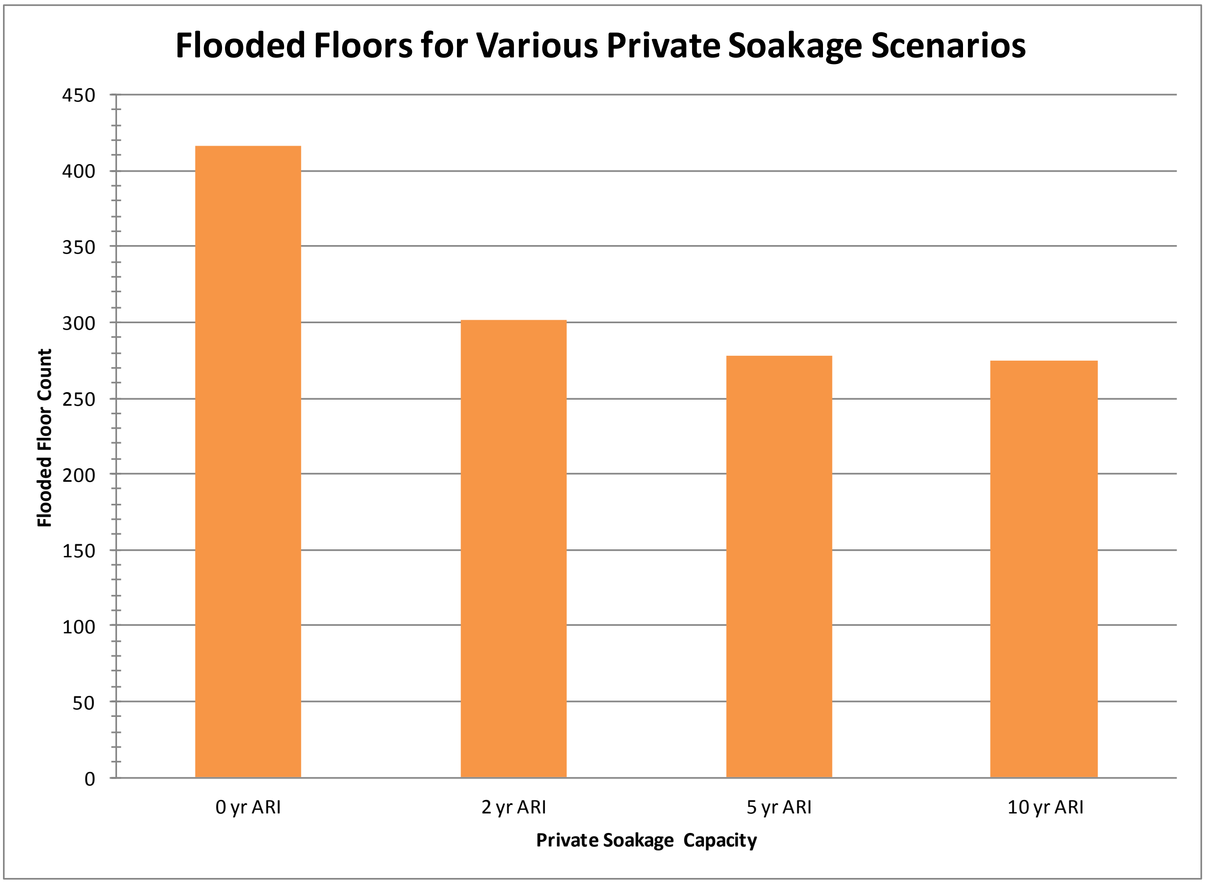


Figure 4: Volume of Stormwater to Private Soakage for the 50 year ARI Storm

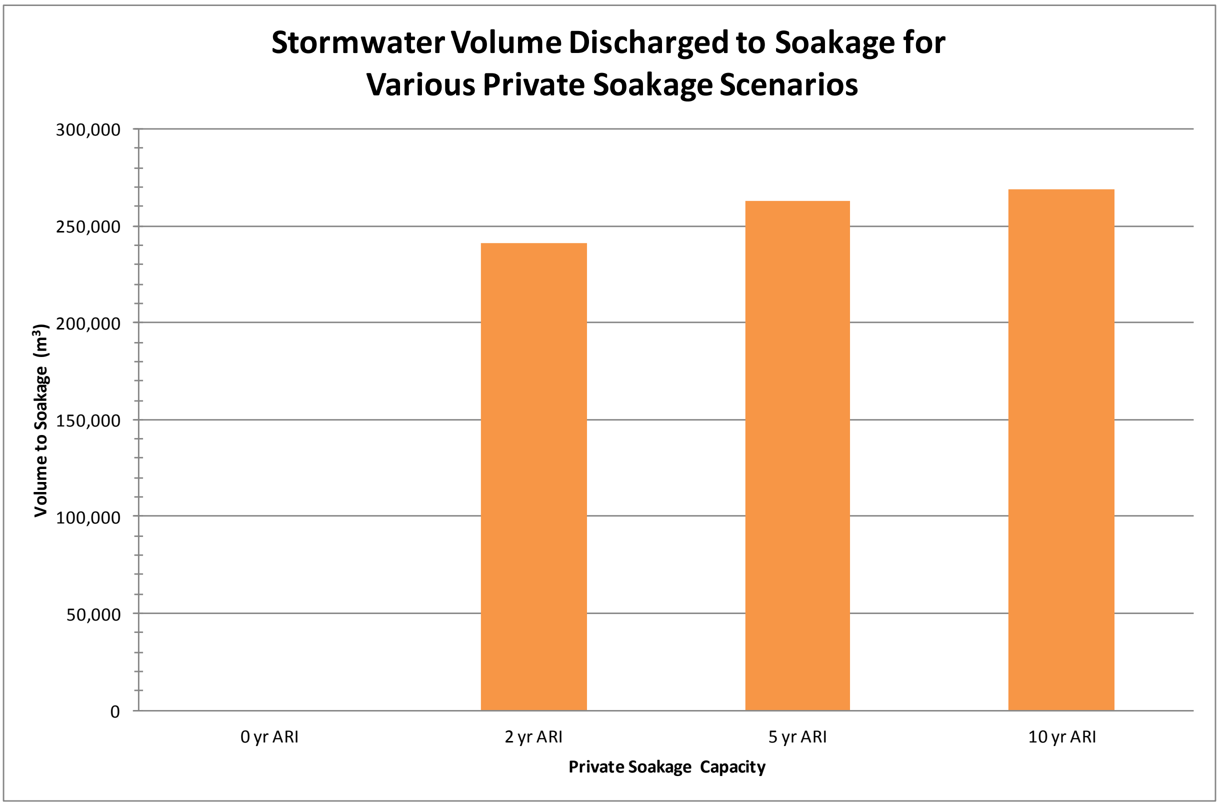


Figure 5: The Influence of Public Soakage on the 50 year ARI Flooded Floor Count

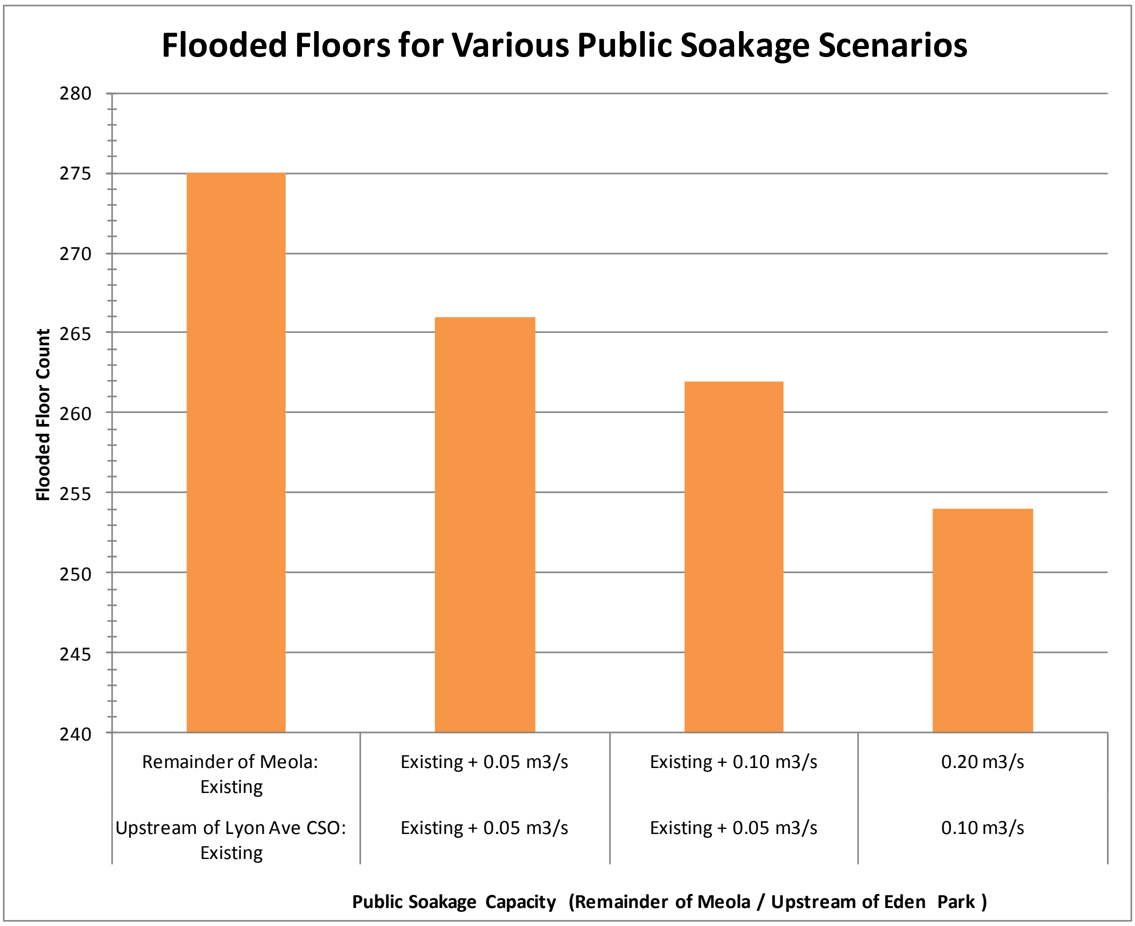
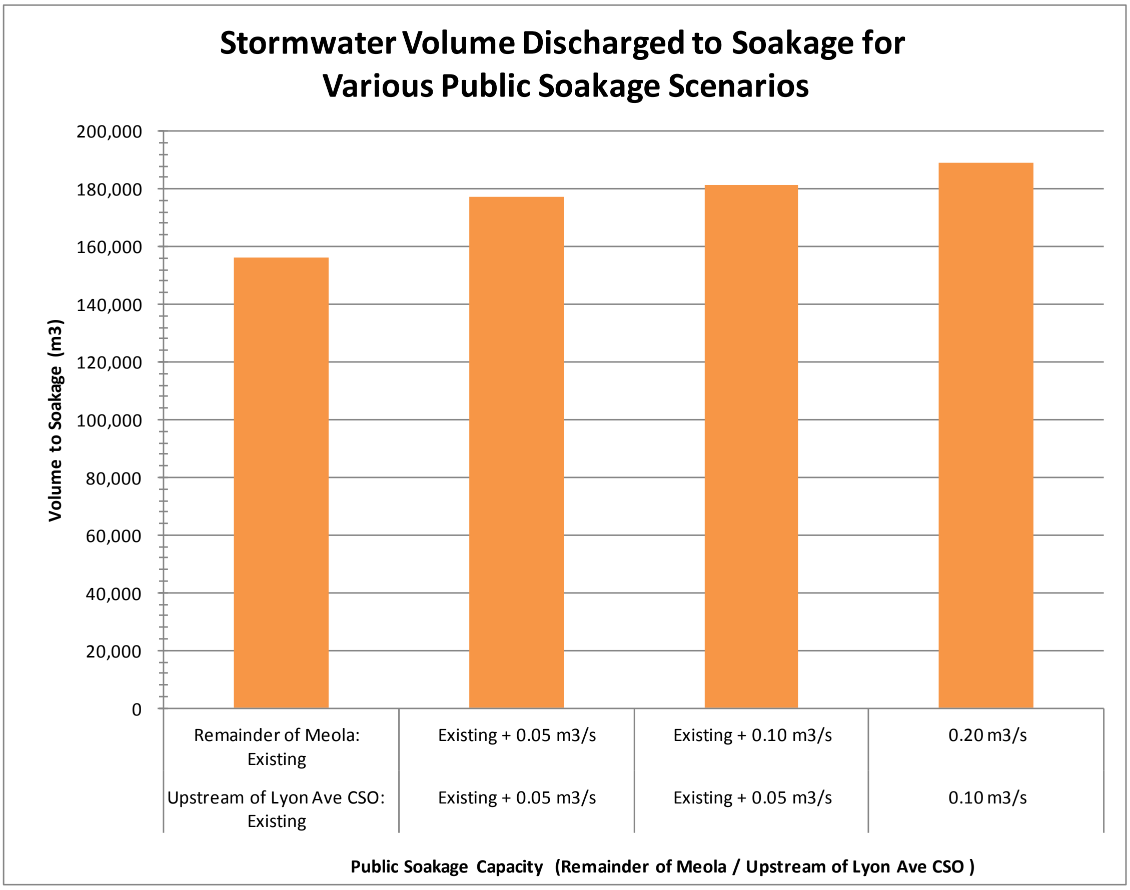


Figure 6: Volume of Stormwater to Public Soakage for the 50 year ARI Storm



Figures 3 and 5 show how the various public and private soakage flow capacities affect the flooded floor count in the Meola catchment for the modelled 50 year ARI design storm. Figures 4 and 6 show the volume of stormwater discharged to soakage for the various soakage capacities for the modelled 50 year ARI design storm. The number of flooded floors generally decreases with an increase in the volume of stormwater discharged to the modelled public and private soakage system. Increasing the capacities of either the existing public or private soakage systems can provide some benefits in terms of flooded floor protection. Modelling predicts that the private soakage systems have a greater influence on stormwater disposal than public soakage systems. The greatest benefits in terms of reductions in flooded floors can be realised by modest increases in soakage capacity (AECOM, 2011c). However, this does not appear to be attainable without significant investment into new soakage infrastructure.

It can be concluded that soakage can play an important role in flood reduction in some areas of the catchment with underlying fractured basalt. However, flood extents in other areas remain relatively unaffected by changes in soakage. Flooding in these areas is generally associated with geology or with limitations in the capacity of the existing combined and stormwater reticulation systems or topographical depressions. This results in contaminated flood areas and presents public health issues.

2.2.2 LOW IMPACT DEVELOPMENT SOLUTIONS

Possible solutions for resolving flood issues in the Meola catchment are to implement Low Impact Design (LID) solutions. Although better suited to Greenfield areas, the principle of LID in the catchment was explored. This included:

- the retrofitting of rain tanks on private properties
- the construction of detention dams and ponds
- the installation of rain gardens, swales, and overland flow paths
- the installation of permeable paving
- elevating floor above flood levels or purchasing properties which are prone to flooding

These solutions can provide advantages over conventional piped drainage solutions, including the potential for stormwater treatment, reducing peak flows and increasing base flows in streams. Other benefits may include the provision of improved wildlife habitat and improved public amenity. As the implementation of LID projects will provide incremental improvement for stormwater management, these projects can be implemented as time and funding permits.

On the other hand, LID can incur disadvantages. Some require a high level of maintenance and monitoring to work effectively. The consequence of failure due to poor maintenance can result in risk to life, property, and community disruption. Careful consideration needs to be made in terms of the ownership, maintenance and management of these devices.

Raising floor levels or purchasing properties prone to flooding are likely to be cost effective for preventing habitable floor flooding in some parts of the catchment, but do not address wider flooding issues. It is therefore concluded that this option could be an appropriate solution where other options are not cost effective.

An assessment was carried out on whether LID options would provide a viable solution to the flooding issues in the Meola catchment. This work included establishing approximate numbers, sizes and locations for the various design solutions that would be required, and preparing approximate order costs for design and implementation.

The LID options are discussed in greater detail below. The approximate comparative costs are listed in Table 2.

Table 2: Low Impact Design Options Cost Summary

LID Option	Cost Estimate
Installation of rain tanks	$247M
Construction of detention dams and ponds	$222M
Installation of rain gardens, swales, and overland flow paths	$202M
Raising floor levels or purchasing properties prone to flooding	$219M

The installation of permeable paving was considered, but it is not a viable option as it does not achieve the desired flood mitigation result.

The LID solutions available are likely to be cost effective for managing stormwater in many parts of the catchment. This is particularly the case higher up the catchment where the extent of flooding is often localised, the volumes of flood water are relatively small, and the presence of rock and distances to pass flows forward is likely to make conventional piped solutions more expensive.

It is necessary to determine the preferred whole-of-catchment solution for stormwater management in the Meola catchment. The adoption of LID solutions however will not provide an all-encompassing solution to flooding in the catchment, particularly where the availability of suitable sites for developing LID systems is limited and the cost to purchase land required to implement these solutions is prohibitive. It is therefore concluded that LID solutions could form only a part of the solution for stormwater management in the Meola catchment.

2.2.3 RAIN TANKS

The retrofitting of rain tanks to collect roof water would reduce peak stormwater volumes. They could be installed to provide storage only during extreme rain events or for the water to be utilised for non-potable purposes as well. Rain tanks would be privately owned and hence it would be the responsibility of the property owner to maintain the tank. Property owner consent would also be required.

To provide a high-level cost basis for this option, it was assumed that 50 percent of the properties in the Meola catchment would receive rain tanks. This option would add ongoing maintenance and monitoring costs that would need to be borne by the property owner. These costs may be partially offset by a reduction in potable water usage charges, but would require the property owner to re-plumb the stored water to flush toilets or for outside garden watering.

Table 3: Rain Tank Cost Estimate

Description	Cost Estimate
Rain tanks: Assume 17,300 tanks @ $10k each	$173M
Annual Opex costs = $200 p/a per tank for 10 years	$34.6M
Associated pipe network to cater for property and roads	$40M
Total costs	$247.6M

Table 4: Rain Tank Advantages and Disadvantages

Advantages	Disadvantages
Low initial costs	Privately-owned rain tanks typically only cater for roof water and not property and roads
Can be done piecemeal as budget allows	Cost uncertainty (dependent on layout of properties, gaining owners consents)
Can get early wins	High level of maintenance and monitoring required
Potential for increase in base flows in streams due to increased detention times	Large above-ground structures take space and can be unsightly, therefore community buy-in difficult to get. This can be mitigated by use of underground or slimline tanks.
Rain tanks can accommodate runoff from roofs, driveways and roads, depending on the location of the tanks and the plumbing configuration.	Underground tanks are more expensive to install due to the excavation of basalt that would likely be required.
Reduction in peak flows to streams	Community disruption
Potential for water re-use and conservation	Risk of blocking and overflowing during storm events
Can be combined with other options to optimise cost/ benefit	Short asset life (20 years) and increased renewal costs
	Potentially a short term fix that will be difficult to support as intensification occurs

2.2.4 STORMWATER DETENTION AREAS

The installation of stormwater detention dams and ponds would reduce peak stormwater flow rates and provide stormwater treatment. Properly sized detention dams can provide storage during extreme rain events, or wet ponds/wetlands can be constructed to intercept all wet weather flows, thereby potentially providing stormwater treatment, wildlife habitat and improved amenity. Detention dams and ponds installed in the upper and middle parts of the catchment that intercept overland flow or have ponding areas piped to them can maximise attenuation for downstream areas. Dams in the lower parts of the catchment have the potential to provide greater treatment with benefits to the receiving environments.

To provide a high-level cost basis for this option, it was assumed that 40 detention dams and ponds would be installed in the upper Meola Catchment. Detention dams and ponds would be Council owned and managed.

Table 5: Detention Dam/Pond Cost Estimate

Description	Cost Estimate
Dams/ponds: 40 in total @ $1M per dam/pond on average	$40M
Associated drainage modification: catchpits, stormwater pipes, overland flow paths@ $1.2M per dam on average	$48M
Purchase properties for pond sites: assume 120 (30 ponds on private property, four each on average) @ $750k per dwelling	$90M
Opex costs: 40 @ $10,000 per site for 10 years	$4M
Associated pipe network	$40M
Total costs	$222M

Table 6: Detention Dam/Pond Advantages and Disadvantages

Advantages	Disadvantages
Low initial costs	Moderate level of maintenance and monitoring required
Potential for increase in base flows in streams due to increased retention times	Cost uncertainty (high variability in site attributes requiring detailed design)
Potential for reduction in peak storm flows to Meola Creek	Risk caused by ponding water
Potential for stormwater treatment and environmental benefits	Risk of dam failure to be managed
Potential for improved community amenity	Potential for ponding of stormwater contaminated by wastewater in areas with combined sewer overflows
Can be combined with other options to optimise cost/benefit	

Due to land area requirements, detention dams would potentially reduce development potential and add ongoing maintenance costs. Detention areas could however be integrated into existing recreation or amenity reserves, and new sites could be added to the Council's reserve pool, thereby providing further public benefit.

2.2.5 STREAM NATURALISATION AND CONVEYANCE IMPROVEMENTS

Flood mitigation options that discharge to Meola Creek are partly dependant on the ability of the stream to convey additional stormwater runoff. In addition, understanding how the proposed flooding solutions affect the stream receiving environment is important to mitigating impacts. As a result, stream conveyance improvements, channel naturalisation, daylighting opportunities and other stream works required to integrate with the flood improvement options were reviewed (Morphum, 2011 and Clarke, 2012).

Several conceptual alternatives have been identified for the stream channel improvements including naturalisation, stream channel widening, daylighting and culvert upgrades. It should be noted that conveying all storm flows down the Meola was not found to be a preferred solution in the CASI optioneering. The collector system will be used to manage large storm events, which would discharge at Waterview Inlet and not into Meola Creek, thus avoiding the need for upgrades of existing undersized culverts.

Additional stream conveyance improvements will likely be necessary if additional storm flows are directed to Meola Creek. This would include upgrades to existing culverts. Specifically, the following culverts will need to be upgraded:

- Alberton Ave Culvert
- the culvert beneath the Northwestern Railway
- the culverts beneath Great North Road

Conveyance improvements can take the form of channel widening. Naturalisation can be built into the conveyance improvements through riparian planting, erosion stabilisation and daylighting of select piped stream sections. Restoration of the stream's floodplain provides other benefits such as flood attenuation, water quality and riparian habitat improvements, greater interaction with groundwater, and enhanced community and recreational amenity (Morphum, 2011).

Stream daylighting opportunities include the Haverstock Road overland flowpath, the Alberton Culvert within the War Memorial Reserve and the Armandale culvert from Asquith Ave to Norgrove Ave. Stream naturalisation and floodplain opportunities include sites at the Mount Albert Grammar School and the Chamberlain Park Golf Course, which were identified in the 1994 Auckland City Council Catchment Management Plan (CMP).

2.2.6 TRUNK STORMWATER COLLECTOR PIPES AND DISCHARGE TUNNELS

The CASI technical workshops identified probable solutions to address the lack of available soakage and limited combined sewer capacity. One of the options is to provide increased stormwater conveyance capacity through the construction of a number of new trunk stormwater collection pipes and discharge tunnels in the Meola catchment. This option also includes placement of inlets and feeder pipes in key flood areas.

The collector pipes are the backbone pipes in the upper catchment that feed into the discharge tunnel. The discharge tunnel is the main stormwater outfall that starts near the Lyon Avenue combined sewer overflow and discharges to the bottom of the catchment.

The alignments of the pipe routes considered locations of flood problem areas, geological conditions, the availability of sites for the vertical tunnel shafts and other logistical constraints such as potential service conflicts. Development of the tunnel options included an analysis of:

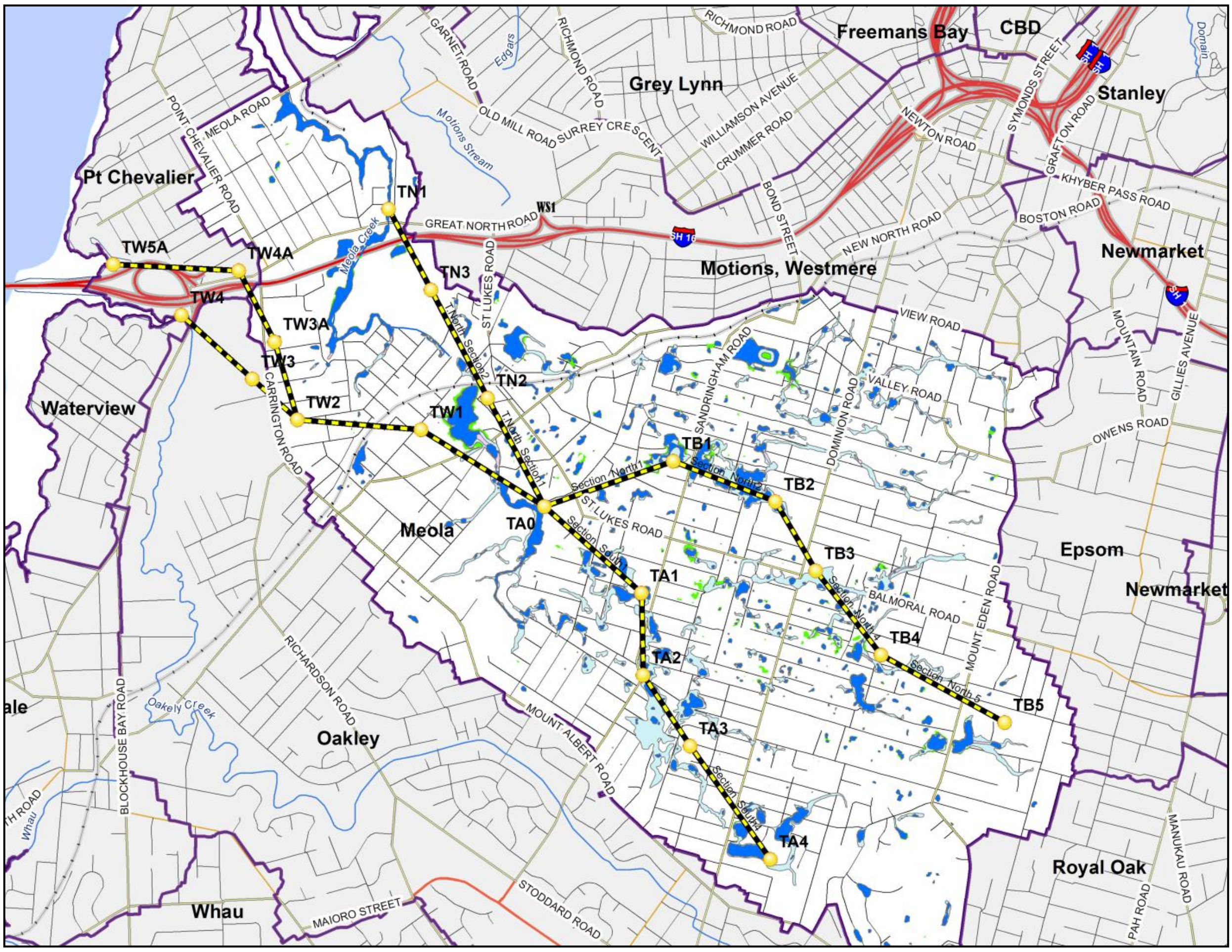
- horizontal and vertical alignments of the collector pipes and discharge tunnels
- constructability, including geological constraints
- probable costs
- known constraints
- potential service conflicts

The CASI workshop participants and others developed a number of potential stormwater pipe routes in the Meola catchment. Subsequently, the alternatives were reduced to two main collector pipe options and two main discharge pipe options (Figure 7). The collector pipe options considered several alignments including direct routes to approximately follow overland flow paths and routes that followed roads to avoid private parcels. (The under-road alignments have been omitted from Figure 7 for clarity.) The discharge tunnels options considered outlets either to lower Meola Creek or to lower Oakley Creek/Waterview Inlet.

The direct route is set up to utilise existing open spaces for the launch pits and the under-road options focus on available space near road intersections. Both route options attempt to intersect flood issue areas. One benefit of the direct route is that it can generally follow the natural overland flow paths, so piping the stormwater into the main line should be easier for the direct route than for the under-road options.

Geological conditions and topography in the Meola catchment play a significant role in the design and costs of the stormwater pipelines. Specifically, due to the number of ridges and valleys along the pipe routes, the pipelines need to be relatively deep to maintain sufficient cover over the top of the pipes.

Figure 7: Potential Stormwater Collector Pipe and Discharge Tunnel Routes



Much of the Meola catchment is covered with a basaltic lava layer that overlies a softer ECBF/alluvium layer. Drilling through basalt is an expensive proposition, approaching $19,000 per metre for a 2.5 m diameter microtunnel. Drilling the same pipe through ECBF is approximately $9,500 per metre (AECOM, 2011d). As a result, it is less expensive to install the pipe in the underlying ECBF/alluvium geology even though this dictates deep manholes and launch pits. Site specific geological conditions, including the depth of basalt would need to be better refined during the detailed design phase by using a combination of new and existing bore logs.

The collector pipes and discharge tunnels have been input into the Meola Flood Hazard Mapping model to generate long-section views of the pipe full capacity, geology layers, pipe inverts, manhole/launch pit locations, and other hydraulic and physical details. This leads into the next step of model runs to confirm and adjust pipe specifics such as slopes and diameters.

The service conflict review considered:

- power (from Vector)
- gas (from Vector)
- telecommunications (from Chorus)
- water supply (from Auckland Council and Watercare)
- wastewater (from Auckland Council and Watercare)
- stormwater (from Auckland Council)

No service conflicts are anticipated for the horizontal pipe bores due to their depth. Service conflicts can be avoided for the vertical shafts associated with the selected direct route options. In contrast, a large number of service conflicts are expected at the shaft locations for the under-road options as they are mainly located at road intersections. Furthermore, the use of intersections for vertical shaft locations poses traffic management and other logistical issues, which makes the direct route more appealing.

Costing for the options adopts the methodology and rates presented in the Meola Stormwater Tunnel Options Study (AECOM, 2011d), which focused on the feasibility and techniques of the stormwater tunnel construction.

Table 7 presents a summary of the options considered. If the direct route options are selected, then the under-road options will not be required, or vice versa. One of the discharge options presented below will be needed.

The deep collector pipe direct routes (below the bottom of the basalt layer) and the discharge to the Waterview Inlet appear to be more feasible. The 2 m and 3 m diameter collector pipe represents the best of the three options reviewed in terms of constructability and hydraulics. These are listed in Table 7 with a total cost estimate of $229 million.

The option of running the collector pipes shallower through the basalt is not considered viable due the cost, construction risks, and risk of adversely affecting the flow and level of the aquifer. This may also affect the base flow to the head of the Meola Creek. In addition to causing severe traffic disruption, tunnelling through basalt along roads is impractical.

The proposed collector pipes and discharge tunnels run approximately 14 m below creek level, so stormwater in the tunnels will not be able to be discharged to the creek. Accordingly, the flow splits between the tunnel option and soakage options need to be confirmed in order to avoid depletion of the aquifer that feeds base flows to the creek.

Costing of a discharge to upper Meola Creek near the Lyon Ave CSO was also reviewed. This alternative would need shallower launch and reception pits but would require drilling though basalt, which is significantly more expensive. Costs for this option are also listed in Table 7. Discharge of additional stormwater to upper Meola Creek would require significant in-stream capacity improvements. Costs for the in-stream improvements are not included in Table 7 as drilling a tunnel through basalt with discharge to the creek is not considered to be a practical option. In-stream options and costings are detailed in Morphum (2011) and Clarke and Sharman (2012) reports.

Table 7: Stormwater Tunnel Options Summary

	Pipe Option	Overall Length (m)	Diameter (m)	Number of Shafts	Cost Estimate (including pipes and shafts)	
					Below Basalt	**Through Basalt with Discharge to Meola Creek at Lyon Ave CSO**
COLLECTOR PIPES	Direct Route – North	3,520	2	5	$60 million (microtunnel)	Not feasible
			3	5	$81 million (microtunnel)	$160 million (segmental)
			2 and 3 (better hydraulic option)	5	$91 million (microtunnel and segmental)	Not applicable
	Direct Route – South	2,674	2	4	$51 million (microtunnel)	Not feasible
			3	4	$66 million (microtunnel)	$167 million (segmental)
			2 and 3 (better hydraulic option)	4	$63 million (microtunnel and segmental)	Not applicable
	Under-Road Option	9,590	2	23	$195 million	Not costed
DISCHARGE TUNNELS	Discharge to Lower Meola	2,650	3	4	Not feasible	Not applicable
	Discharge to Waterview Inlet	3,150	3	4	$75 million	Not applicable

The tunnel to the Waterview Inlet will need further investigation in relationship with the Waterview Connection motorway project. The alternative is to discharge to the north of the Waterview project at a cost of approximately $20 million more. All discharge options will require review of environmental and consenting issues.

The achievable grades and construction methodologies for the tunnel is highly dependent on the depth of basalt. Site specific geological conditions, including the depth of basalt would need to be better refined during the detailed design phase by using a combination of new and existing soil bore logs.

A more detailed assessment of the feeder lines (catch pit locations, leader pipes, etc) is presently underway. Costs for the feeder lines are not presently included in Table 7. The pipe options are presently being modelled together with the inlets and feeder lines in order to confirm the pipe diameters and level of service (flooded floor reductions). Several modelling iterations may be required to achieve an optimum design. Flow distributions are also presently under review to determine the optimum allocation of stormwater between the soakage system (discussed below), Meola Creek, and the stormwater collector pipes and discharge tunnel.

3 CONCLUSIONS

It is necessary to determine the preferred whole-of-catchment solution for stormwater management in the Meola catchment. The likely long-term solution of flooding problems in the catchment is likely to be a combination of stormwater management techniques based around large-diameter stormwater tunnels with some local solutions involving soakage and LID. Optimum design of inletting structures will allow a favourable split of stormwater between the soakage system (the aquifer), Meola Creek, the collector system, and the discharge tunnels. This will provide flood protection benefits for large storms while maintaining groundwater levels to augment base flows in Meola Creek and reducing combined sewer overflows. Working alongside Watercare's Central Interceptor project will also give large environmental benefits.

Low impact design solutions and soakage system improvements could form a part of the comprehensive catchment solution and are likely to be a cost-effective solution to managing stormwater in many parts of the catchment. This is particularly the case higher up the catchment, where the extent of flooding is often localised, the volumes of flood water are smaller, and the presence of basalt rock and distances to pass flows forward may make shallow piped solutions expensive. Stream channel improvements, conveyance upgrades and naturalisation can also contribute to the solution. Such solutions can be implemented in the short-term. Furthermore, the investigation of LID and soakage options for all new developments will ensure the long term viability of soakage feeding the aquifer and providing base flows to Meola Creek.

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