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Task 2 - Representative Building Site Typologies Memo

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TECHNICAL MEMORANDUM

From: Lotus Water

To: Gord Tycho (City of Vancouver)

Date: October 13, 2023

Project: Rainwater Infrastructure Building Typologies Pathway Study

Subject: **Representative Building Site Typologies Memo**

1. Introduction

A building site typology is a generic description of a building as defined by the combination of its various physical characteristics including building footprint, building height, current and allowable use, and parcel size, along with pervious and impervious coverages. The goal of this task is to identify representative building site typologies that can be used in subsequent tasks to analyze potential compliance pathways to meet the City of Vancouver's (City) Rain City requirements. To identify representative building site typologies, available relevant data sources were collected, evaluated, and aggregated to provide a comprehensive picture of the existing conditions and future development in the City. Table 1 below provides a list of the primary data sources used in this analysis and the following sections describe the data in more detail.

Table 1 – Primary Data Sources for Building Site Typology Analysis

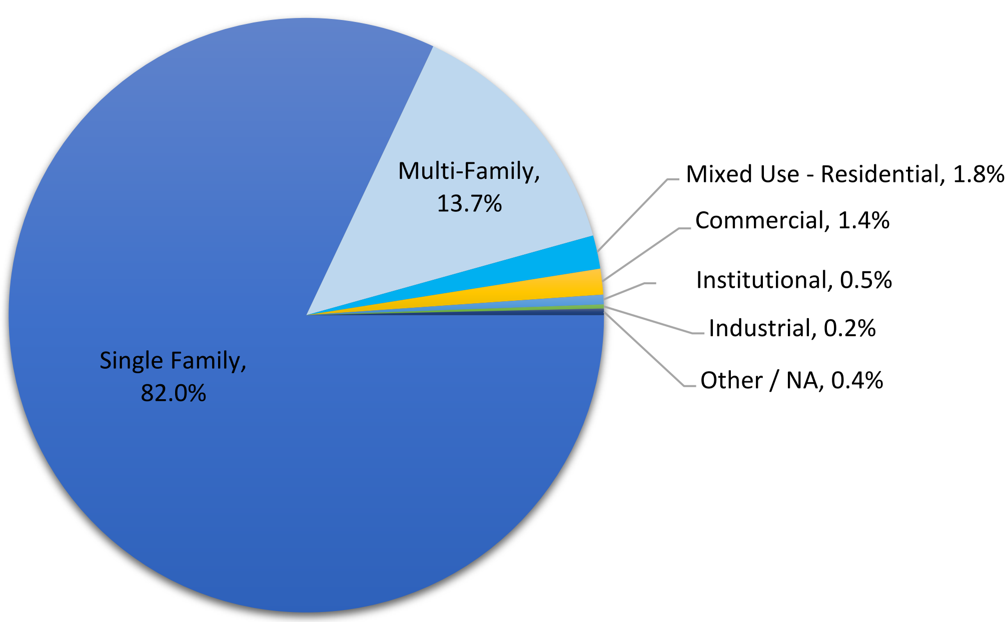
Database	Source	Pertinent Fields
Property Parcels	Vancouver OpenData (updated 2021)	Tax ID, Street Address, Parcel Size
Building Footprints 2009	Vancouver OpenData (updated 2009)	Roof Area, Roof Type, Building Height
Zoning Districts & Labels	Vancouver OpenData (updated 2021)	Zoning
Issued Building Permits	Vancouver OpenData (updated 2021)	Street Address, Construction Type, Building Description from 2017-2021
Land Use Typology	Unknown, no metadata provided	Zoning by Parcel, Land Use by Parcel
Impervious Surface Area	Golder Associates Image Classification (2014)	Impervious Area by Parcel, Impervious % by Parcel, Zoning by Parcel, Land Use by Parcel
Rainwater Management Plan (RWMP) Submissions for Development Applications	City of Vancouver, Development Water Resources Management (2021)	New Development Characteristics from 2018-2021

2. Building Permit Database

The "Issued Building Permits" database consists of over 25,000 entries for building permits issued by the City from January 2017 through July 2021. This includes permits issued for new construction, but also for additions/alterations, demolition, salvage and abatement, temporary buildings, and outdoor uses without structures. For this analysis, only those permits for new construction are relevant, of which there are 5,890 permits that were issued during this period. These 5,890 permits were grouped into 120 sub-categories based on the specific use category field and then further distilled into 8 new building use types based on the description of the specific use and property use. For example, "Infill One-Family Dwelling" specific use category is assigned a building use type of Single Family Residential while "General Office, Retail Store" is assigned a building use type of Commercial. As the estimated project value was available for most of the permits, the project value was used to double check the use type assumption and adjust or regroup, as necessary. The average project value and standard deviation of the project value were computed for each building use type and then the project description of the outliers was read and used to determine proper categorization.

As shown in Figure 1, the issuance of building permits over the past four and a half years has been dominated by single family residential. However, parcel size for single family residential is typically smaller than other land use types (Table 2) and the maximum allowable percent impervious area is 70% compared to up to 100% for other land use types, so the distribution of building permits by land use type is not directly proportionate to the impact on stormwater runoff.

Figure 1 - New Construction Permits by Building Use Type (1/2017 to 7/2021)



The following are the definitions of the various use types shown in the figure above. These definitions are used consistently throughout the document to classify both building and land uses except where otherwise noted. Additional building or land use types that from other data sources used in this evaluation have been translated over to fit these use types. These use type categories are further broken down by lot size and building height in subsequent sections of this memorandum.

- **Single Family Residential (SFR)** – Small parcel, single family homes, dwelling units, duplexes, and laneway homes
- **Multi-Family Residential (MFR)** – Small-to-mid scale, multi-family residential, typically less than or equal to 6 stories above ground, such as townhomes and apartment buildings.
- **Mixed-Use Residential (MUR)** – Large scale, multi-family residential, typically greater than 6 stories above ground, with a commercial or institutional use type included. Comprehensive Development building use types are included in this category.
- **Commercial (COM**) – Commercial buildings of all scales that typically contain office space and also house businesses such as retail or restaurants
- **Institutional (INST)** – Schools, Hospitals, Community Care Facilities, etc.
- **Industrial (IND)** – Industrial, Manufacturing
- **Other (OTHER)** – Not Stated, Public Utilities, Parks, Marinas, etc.

3. Impervious Surface Area Database

The Impervious Surface Area database was created in 2014 for the City of Vancouver by team of consultants as part of a previous effort. This database served as the primary data source for the existing conditions of the building and land use in the City. The Impervious Surface Area database contains data on all parcels for the entire city, over 103,000 parcels, including tax ID number, address, zoning, total parcel area, and a breakdown of total impervious area and percent impervious area per parcel. The Impervious Surface Area database was created using image classification of impervious areas such as roads and buildings and pervious areas such as grass lawns. The image classification could not differentiate non-infiltration pervious surfaces and from infiltrative pervious surfaces, but the percentage of pervious surfaces that are non-infiltrative is assumed to be very small for the full citywide analysis. The first step in the analysis was to cross-check the entries in the Impervious Surface Area database with those available in the Property Parcels, Building Footprints and Land Use Type databases. The entries were linked by Tax ID, Site ID, or street address and select entries were checked for consistency across the databases. additionally, using the "Category" and "Typology" fields, over 1,000 data entries were removed from the data set as they consisted of rights-of-way (ROW) parcel data that is not relevant to this analysis. The remaining entries were grouped into seven land use types, as shown in Table 2. The grouping of the individual zoning districts into existing land use types is documented in Appendix A.

Table 2 - Land Use Data in Impervious Surface Area Database

Existing Land Use	Number of Parcels	% of Total Parcels	Total Parcel Area (HA)	% of Total Area	Total Impervious Area (HA)	% of Total Impervious Area
Single Family Residential	69,483	67.6%	3,437	41.6%	1,493	41.8%
Multi-Family Residential	19,004	18.5%	911	11.0%	464	13.0%
Mixed-Use Residential	4,889	4.8%	927	11.2%	543	15.2%
Commercial	4,465	4.3%	277	3.3%	215	6.0%
Industrial	2,799	2.7%	617	7.5%	446	12.5%
Institutional	240	0.2%	454	5.5%	227	6.4%
Other/Park/Agriculture	1,850	1.8%	1647	19.9%	184	5.1%
Total	**102,730**	**100.0%**	**8,269**	**100.0%**	**3,572**	**100.0%**

The impervious surface area data for the first six land use types were separated into their own databases for further analysis. The seventh land use type, Other/Park/Agriculture, did not undergo any further analysis as development of these parcels would be unique and not relevant to this study. Vancouver Board of Parks and Recreation has a separate Rain City Strategy action plan for their parcels.

The six land use type databases were further refined by removing all parcels which had a total area of less than 20 square meters; it was deemed that these parcels were either included as a processing error or are too small and irregularly shaped to be considered for development. Moreover, any entries that were missing critical information were also removed. A statistical analysis was performed on each land use type databases to determine the distribution of parcel sizes, impervious area percentage, and relationship between parcel size and impervious area. Histograms showing the breakdown of size and impervious area percentage for Commercial parcels are shown in Figure 2 and Figure 3, respectively, while Table 3 lists the tabular results.

Figure 2 - Distribution of Parcel Size for Commercial Land Use Type

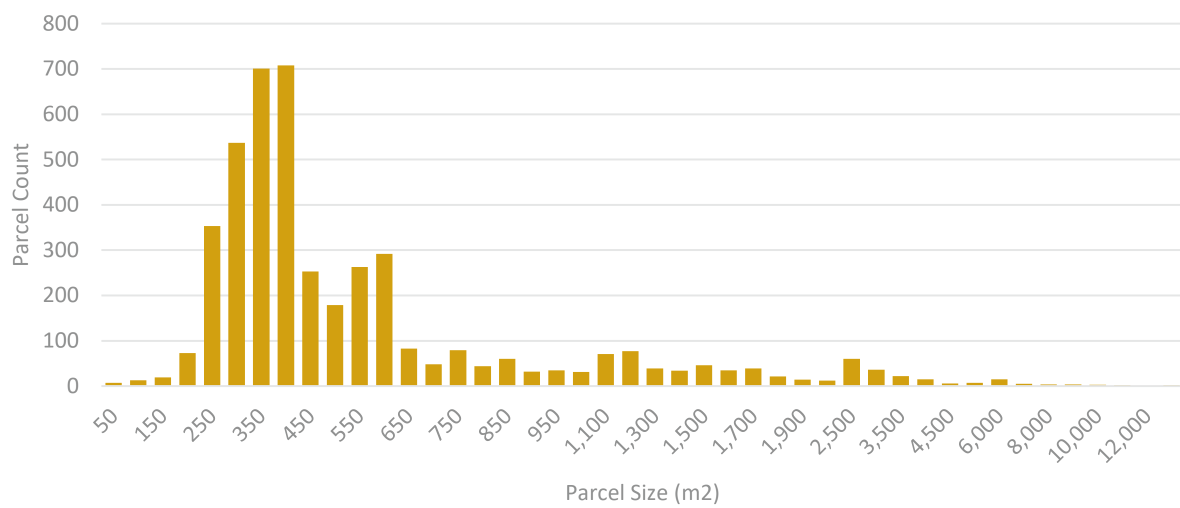


Figure 3 – Distribution of Percent Impervious Area for Commercial Land Use Type

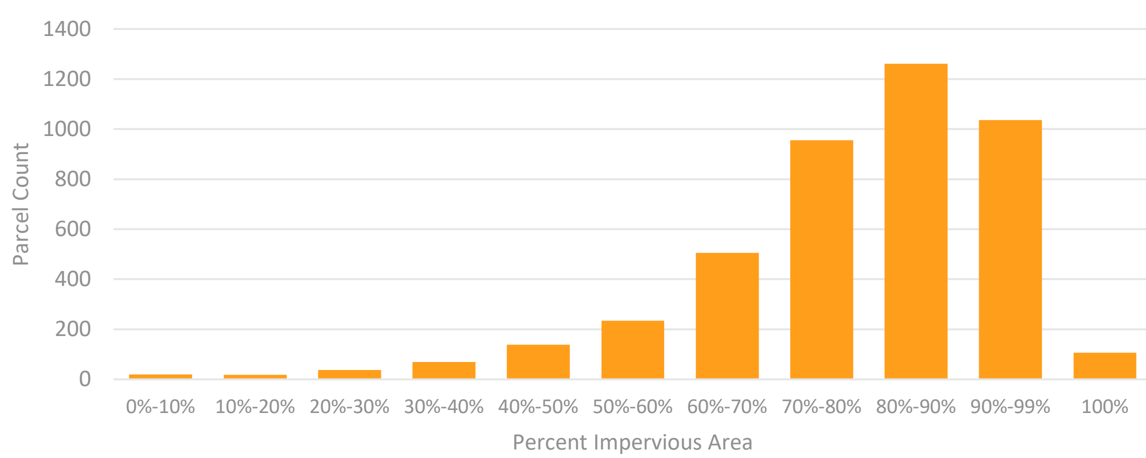


Table 3 - Analysis of Parcel Size and Percent Impervious Area for Commercial Land Use Type

Parcel Size (m^2)		Percent Impervious Area (%)	
Minimum	21	Minimum	0%
2nd Percentile	190	2nd Percentile	33%
Median	374	Median	82%
Average	630	Average	79%
98th Percentile	2,975	98th Percentile	100%
Maximum	12,899	Maximum	100%

This same analysis was also performed on the other five land use type databases. Use of this data to inform the existing typologies (Table 5) is discussed in section 5.

4. Building Footprint Database

The Building Footprints 2009 database contains over 125,000 entries with fields for area, type, and height of the roofs in the City in 2009. As this database was created from aerial imagery, it can be assumed that for this analysis the building footprint and roof area are the same. To make this data more useful, GIS software was used to spatially join the Building Footprints 2009 database with the Property Parcels database, which allowed for the roof data to become associated with a tax ID. These tax IDs were then referenced against the Land Use Typology database to associate building footprint / roof areas with zoning categories and land use typology. The resulting Building Footprints database contains nearly 88,000 unique data entries for roofs in the City. This data was broken out into the same six land use types as the Impervious Area Database (not including Other/Park/Agriculture) and analyzed. The resulting statistics for roof area as a percent of parcel area is presented in Table 4.

Table 4 – Roof Area as a Percent of Parcel Area per Land Use Type

Land Use Type	Count	Roof Area as % of Parcel Area				
		Min.	*2nd percentile*	*Mean*	*98th percentile*	*Max.*
Single Family Residential	65,279	0.2%	9.7%	26.4%	48.0%	99.3%
Multi-Family Residential	15,548	1.4%	11.1%	31.9%	76.7%	99.8%
Mixed-Use Residential	2,605	0.3%	1.8%	27.8%	91.3%	99.5%
Commercial	2,242	5.8%	8.2%	49.9%	97.1%	99.8%
Industrial	1,148	0.2%	1.1%	41.7%	96.6%	99.6%
Institutional	165	0.7%	1.6%	27.4%	85.3%	86.5%

5. Existing Building Site Typologies

The various data and analysis discussed above was compiled and distilled to create an existing building site typologies table using the six land use types (Table 5).

Table 5 – Existing Building Site Typologies

Building Use	Existing Properties					
	% Existing Parcels	*Size (m²)*		*% Imp Area*		% Roof Area
Single Family Residential	67.9%	Small	375	Average	49%	26%
				Dense	72%	48%
		Large	1,100	Average	42%	26%
				Dense	67%	48%
Multi-Family Residential	18.5%	Small	200	Average	49%	32%
				Dense	82%	77%
		Medium	600	Average	50%	32%
				Dense	78%	77%
		Large	2,500	Average	54%	32%
				Dense	83%	77%
Mixed-Use Residential	4.8%	Small	300	Average	80%	28%
				Dense	100%	91%
		Medium	2,500	Average	60%	28%
				Dense	100%	91%
		Large	15,000	Average	57%	28%
				Dense	96%	91%
Commercial	4.3%	Small	300	Average	80%	50%
				Dense	100%	97%
		Medium	600	Average	77%	50%
				Dense	99%	97%
		Large	2,500	Average	78%	50%
				Dense	99%	97%
Industrial	2.7%	Small	300	Average	75%	42%
				Dense	100%	97%
		Medium	600	Average	78%	42%
				Dense	100%	97%
		Large	2,500	Average	72%	42%
				Dense	98%	97%
Institutional	0.2%	Small	2,500	Average	54%	27%
				Dense	97%	85%
		Medium	12,500	Average	59%	27%
				Dense	85%	85%
		Large	25,000	Average	50%	27%
				Dense	81%	85%

The percentage of existing parcels, parcel size, and impervious area percentage are based on the analysis of the Impervious Surface Area database for each land use type. Existing parcels were broken into thirds based on the distribution of their total area. The "small" parcel size is roughly the average of the smallest third of the parcel sizes but adjusted with respect to the peaks of the parcel size histogram. The "medium" parcel size is approximately the average size of the middle third but is also adjusted with respect to the peaks of the parcel size histogram. The "large" parcel size is approximately the 98^{th} percentile of the parcel size data.

Parcels were further grouped into Light, Average, or Dense based on existing impervious area percentages. Light was excluded from further analysis because parcels with a significant percentage of pervious area should be able to comply with all stormwater requirements. "Average" is roughly the average impervious area with for each corresponding third of the parcel sizes. "Dense" percent impervious area is approximately the 98^{th} percentile of the percent impervious area for each corresponding third of the parcel sizes. The existing roof area as a percentage of parcel area is based on the analysis of the Building Footprints database.

6. Rainwater Management Plan (RWMP) Database

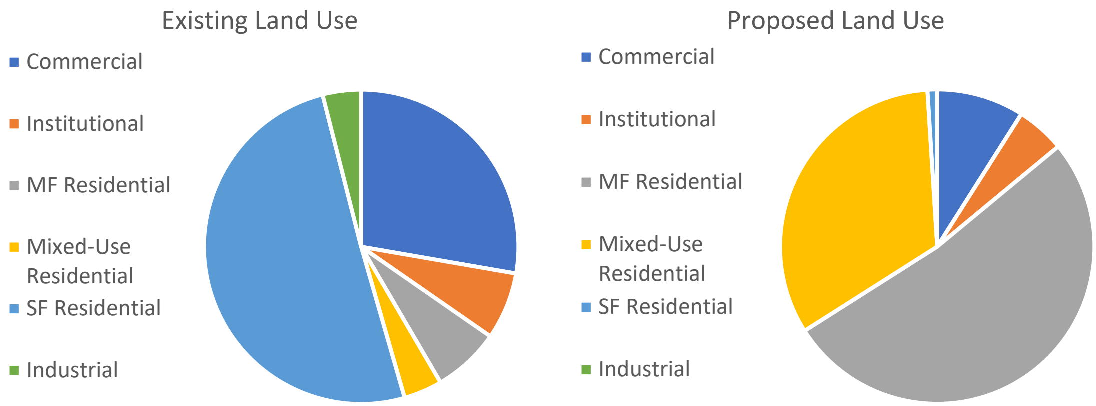
Rainwater Management Plans (RWMP) are the submittals to the City that document the size, location, and configuration of proposed Green Rainwater Infrastructure (GRI) that will be utilized to meet the rainwater management requirements. Since 2018, developers must submit RWMPs to the City for approval either when applying for a rezoning permit or a development permit.

The City passed along 298 RWMPs in July 2021. Roughly a third of those, 101 in total, were selected to be reviewed in detail and analyzed. Of the 101 chosen entries, 94 are complete entries while the remaining 7 are only partially complete and may not be useful for certain evaluations. A RWMP database was created by reviewing the select documents and extracting relevant project information including, but not limited to address, existing land use, proposed land use, building height in stories, lot size, existing impervious area, proposed impervious area, pre- and post-project runoff peak flow, require rainwater management volume, and the number and type of GRI facilities proposed at the site.

Existing impervious areas for the proposed projects were taken directly from the RWMP and typically consisted of an existing building footprints plus other impervious areas such as sidewalks, driveways, and parking lots. This is consistent with the image classification process used to create the Impervious Surface Area database described in Section 3. Proposed impervious areas included traditional impervious areas from the RWMPs but also included all non-infiltrative area such as green roofs, landscape on slab, and planter boxes within the building footprint. These are typically classified as green rainwater infrastructure (GRI) in the RWMPs and help meet rainwater compliance. However, one major goal of this study is to determine the area available for infiltration for each representative building site typology and thus the non-infiltrative areas were included as impervious for the following analysis.

It should be noted that most of the RWMP were submitted for projects that are still in the planning or permit stages of the development process, and the site configuration and rainwater management is very likely to change. However, the RWMP database that was created does provide good insight into how land use and parcel use is changing in the City. **Figure 4** shows how the land use is being rezoned in the RWMP database, particularly from Commercial and Single-Family Residential land uses to Multi-Family Residential and Mixed-Use Residential.

Figure 4 – Land Use Changes due to Rezoning in the RWMP Database



For additional analysis, the projects in the RWMP database were separated by proposed land use into seven groups. Two of the groups, Single-Family Residential and Mixed-Use District, only had a single applicable RWMP and therefore were not analyzed. The minimum, maximum, and average parcel size for the five remaining land use groups along with the pre- and post-project average impervious areas are presented below.

Table 6 – Average RWMP Parcel Sizes and Percent Impervious Areas per Proposed Land Use

Proposed Land Use	# RWMP	Parcel Size (m^2)				Avg. % Imp Area		Avg Change % Imp Area
		Minimum	*Median*	*Average*	*Maximum*	*Pre*	*Post*	
Commercial	9	580	2,404	3,774	12,991	95%	100%	5%
Institutional	5	4,000	26,695	26,493	57,087	19%	77%	58%
MF Residential	52	558	1,997	2,248	6,273	49%	89%	40%
Mixed-Use Residential	33	621	1,743	3,209	44,300	79%	93%	14%

As shown above, an increase in impervious area has been proposed for all land use types in the RWMP submitted. Notably, there is a proposed large increase in percent impervious area for the Multi-Family Residential land use, which is likely due to the rezoning of low-density single-family residential land use with private yard space to mid-density multi-family residential land use with communal outdoor space. It should be noted that the sizes of the RWMP projects are larger than the average existing parcel sizes because rezoning and development permits which require RWMP submittals typically occur on larger parcel sizes. The average non-park parcel size in the City of Vancouver is roughly 650 square meters while the average parcel size of the RWMPs reviewed is just under 4,000 square meters. Unfortunately, this means that there is limited data available from the RWMP Database on Single-Family Residential land use type, which accounts for roughly 2/3 of the parcels in the City and over 4/5 of the new construction building permits issued since 2017.

The proposed projects in the RWMP were also classified as low-rise, mid-rise, and high-rise building heights and then subjected to a similar analysis as above. Table 7 presents the results of that analysis.

Table 7 – Average RWMP Parcel Sizes and Percent Impervious Areas per Building Type

Stories	Building Height	# RWMP	Parcel Size (m²)				Avg. % Imp Area		Avg Change % Imp Area
			Minimum	*Median*	*Average*	*Maximum*	*Pre*	*Post*	
1-3	Low-Rise	24	621	2,642	5,173	57,087	47%	84%	37%
4-6	Mid-Rise	49	583	1,873	3,316	44,300	63%	92%	29%
7+	High-Rise	26	558	1,842	4,199	33,100	74%	96%	23%

The largest increase in impervious area is being proposed for low-rise buildings, which push towards denser development without expanding vertically. RWMP for high-rise building types are proposing the smallest increase in impervious area, but both existing and proposed scenarios have the highest total percentage of impervious area.

One final analysis was performed on the RWMP Database to support creation of building site typologies, which was to combine the proposed land use type and building height to determine if there is a correlation between land use type, parcel size, and building height (Table 8).

Table 8 – Average RWMP Parcel Size per Land Use Type and Building Height

Proposed Land Use	Building Height	# RWMP	Avg. Parcel Size (m²)
Multi-Family Residential	Low-Rise	19	2,718
	Mid-Rise	27	1,986
	High-Rise	4	1,306
Mixed-Use Residential	Low-Rise	2	1,315
	Mid-Rise	18	4,059
	High-Rise	13	2,323
Commercial	Low-Rise	1	1,208
	Mid-Rise	1	2,404
	High-Rise	7	4,336
Institutional	Low-Rise	2	34,335
	Mid-Rise	2	15,348
	High-Rise	1	33,100

There does not appear to be a consistent correlation between building height and parcel size across the land use types. RWMP for Multi-Family Residential show a trend for low-rise buildings on large parcels and high-rise buildings on smaller parcels, while RWMP for Commercial land use show the opposite.

7. New Development Building Site Typologies

The various data and analysis discussed for the RWMP database was compiled and distilled to create a new development building site typologies table shown below using the same six land use types that were used for existing building site typologies. However, Single-Family Residential only has a few applicable RWMP and Industrial does not have any, so those have been omitted.

Table 9 – New Development Building Site Typologies

Building Use	New Development							
	% New Development	*Size (m2)*		*% Imp Area*		*Story AG*	*Story BG*	*Roof Area (% of Parcel)*
Multi-Family Residential	13.7%	Small	600	Average	84%	18	3	50%
				Dense	100%			
		Medium	2,100	Average	91%	6	2	50%
				Dense	100%			
		Large	4,500	Average	91%	3	1	50%
				Dense	100%			
Mixed-Use Residential	1.8%	Small	600	Average	87%	3	1	85%
				Dense	100%			
		Medium	1,800	Average	97%	23	3	75%
				Dense	100%			
		Large	4,500	Average	93%	6	2	80%
				Dense	100%			
Commercial	1.4%	Small	600	Average	100%	3	1	90%
				Dense	100%			
		Medium	2,200	Average	100%	6	2	65%
				Dense	100%			
		Large	8,000	Average	100%	14	4	70%
				Dense	100%			
Institutional	0.5%	Small	4,000	Average	85%	4	1	15%
				Dense	100%			
		Medium	25,000	Average	73%	11	4	40%
				Dense	98%			
		Large	40,000	Average	83%	2	0	60%
				Dense	100%			

The size and impervious area percentage for the new development building site typologies were broken out in the same manner as those for existing building site typologies, though data from the RWMP Database was used. To determine the representative parcel sizes and percent impervious areas, new development parcel sizes were broken into thirds based on the distribution of the parcel sizes. The "small" parcel size is roughly the average of the smallest third of the parcel sizes but adjusted to be near the minimum development size of approximately 550 square meters. The "medium" parcel size is approximately the average size of the middle third and is also roughly equivalent to the average of the entire data set. The "large" parcel size is approximately the average of the largest third but was also based on the overall distribution of parcel sizes as most sets had one or two very large projects that skewed the average of this third.

"Average" percent impervious area is the average impervious area of the corresponding third based on parcel size. "Dense" percent impervious area is approximately the 98th percentile of the percent impervious area for each corresponding third of the parcel sizes. Building heights in stories above and parkade below ground are based on data gathered from the RWMP and the Vancouver Building Permits database. The number of stories in low-rise and mid-rise buildings is consistent across land uses, based on the new development data and the definition of building typology, while the number of stories in the high-rises varies based on the data collected. New development percent roof area is based on the roof area or building footprint of the projects in the RWMP database. The percentages shown are based on total parcel area.

8. Representative Building Site Typologies

All the data and analysis presented above, particularly in the summary tables for existing and new development building site typologies, was combined to create the following seven representative building site typologies that will be used in subsequent tasks to analyze potential compliance pathways to meet the City's rainwater management requirements. Illustrative example graphics for each typology are included in Appendix B.

Table 10 – Representative Building Site Typologies for the City of Vancouver

Building Site Typology	*Representative Value*				
	Total Parcel Area (m^2)	Total Impervious Area [1] (% of parcel)	Roof Area [2] (% of parcel)	Story AG [3]	Parkade [4]
Small Lot Residential – Low Massing	375	45%	30%	2	0
Small Lot Residential – High Massing	375	70%	50%	2	0
Low-Rise Residential & Mixed-Use	2,500	90%	40%	3	1
Mid-Rise Residential & Mixed-Use	3,000	95%	65%	6	2
High-Rise Residential & Mixed-Use	1,200	90%	70%	20	3
Low/Mid-Rise Non-Residential	2,500	100%	40%	3	1
High-Rise Non-Residential	8,000	100%	55%	14	4

Notes:

1. Impervious Area represents the area onsite that will not be available for infiltration into the subgrade. This includes the roof area, all surface level impervious surfaces (e.g. paved parking, pathways, etc), and also subsurface structures (such as a parkade, which may extend nearly lot line to lot line) that could have planting above it.
2. Roof area is the elevated portion of the building, what might be considered the building footprint. Roof Area is a subset of the Total Impervious Area (e.g. surface/subsurface impervious area on the parcel is the difference between the Total Impervious Area and the Roof Area).
3. Story AG is the number of building levels above ground
4. Parkade is the number of building levels below-ground.

Typology Descriptions:

- **Small Lot Residential – Low Massing** primarily covers single family residential development with one building on the parcel, representative of the character of much of the historic existing residential lots.
- **Small Lot Residential – High Massing** covers lower density residential more likely to be built now, typically with multiple buildings, such as a single-family home with laneway house, duplex, or rowhouse. This also covers smaller multi-unit development such as character 4- and 6-unit buildings.

- **Low-Rise Residential & Mixed-Use** covers medium density development such as a stacked townhouse or low-rise apartment building, including those with a commercial component.
- **Mid-Rise Residential & Mixed-Use** covers medium density development such as mid-rise apartment buildings.
- **High-Rise Residential & Mixed-Use** covers larger high-rise apartment buildings and similar.
- **Low/Mid-Rise Non-Residential** covers lower density commercial and industrial buildings.
- **High-Rise Non-Residential** covers higher density commercial and industrial buildings.

Table 11 – Typical Ranges for Building Site Typologies for the City of Vancouver

Building Site Typology	*Typical Range of Value*				
	Total Parcel Area (m^2)	Total Impervious Area (% of parcel)	Roof Area (% of parcel)	Story AG	Parkade
Small Lot Residential – Low Massing	250 to 1,100	40% to 50%	30% to 50%	1 to 3	0
Small Lot Residential – High Massing	250 to 1,100	60% to 70%	30% to 50%	1 to 3	0
Low-Rise Residential & Mixed-Use	600 to 4,500	85% to 100%	30% to 50%	1 to 3	0 to 1
Mid-Rise Residential & Mixed-Use	2,000 to 4,500	90% to 100%	40% to 60%	4 to 6	1 to 2
High-Rise Residential & Mixed-Use	600 to 1,800	85% to 100%	40% to 80%	7 to 30	2 to 3
Low/Mid-Rise Non-Residential	600 to 4,000	85% to 100%	30% to 50%	4 to 6	1 to 2
High-Rise Non-Residential	4,000 to 12,000	100%	50% to 60%	7 to 17	1 to 5

9. Green Roof Area

The green roof area as a percent of the total parcel size was also analyzed for the new development RWMP database. The intent was to determine typical ranges for green roof areas that could be included as part of the representative building-site typologies. A total of 37 of the projects in the RWMP database propose Tier 1 green roofs as GRI. This data was analyzed to determine green roof as a percent of total project area. However, as can be seen below, the proposed green roof areas are very low compared to the overall roof area and total parcel size.

Table 12 - Typical Ranges for Green Roofs in the City of Vancouver

Building Site Typology	***Typical Ranges***			
	Parcel Size (m^2)	**Roof Area (% of Parcel)**	**Green Roof Area (% of Parcel**	**Green Roof Area (% of Roof)**
Single Family Residential	250 to 1,100	30% to 50%	*NA*	*NA*
Low-Rise Residential	600 to 4,500	30% to 50%	1% to 20%	2% to 50%
Mid-Rise Residential	2,000 to 4,500	40% to 60%	15% to 40%	15% to 75%
High-Rise Residential	600 to 1,800	40% to 80%	5% to 15%	2% to 60%
Low/Mid-Rise Non-Residential	600 to 4,000	30% to 50%	*NA*	*NA*
High-Rise Non-Residential	4,000 to 12,000	50% to 60%	5% to 60%	10% to 90%

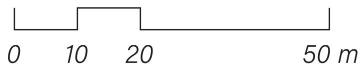
The reason is that the green roofs proposed in the RWMP are not maximized but rather are typically reduced to the smallest extent possible while maintaining minimum runoff reduction for compliance. Green roofs have additional design considerations such as structural support that are not as relevant to other GRI. Additionally, green roofs often compete with other programming requirements or constraints like mechanical equipment or outdoor amenity space that reduce the available area.

APPENDIX A – LAND USE TYPE CLASSIFICATION FOR CITY OF VANCOUVER ZONING DISTRICTS

ZONING CATEGORY	*One Family Dwelling*	*Two Family Dwelling*	*Multiple Family Dwelling*	*Comprehensive Development*	*Light Industrial Mixed Use*	*Historic Area*	*Commercial*	*Industrial*	*Light Industrial*	*Institutional*	*Park*	*Limited Agricultural*	*<Null>*
ZONING DISTRICT	RS-1	RT-1	FM-1	BCPED	M-1A	HA-1	C-1	M-1	I-1	All	PARK	RA-1	N/A
	RS-1A	RT-10	RM-1	CD-1	MC-1	HA-1A	C-2	M-1B	I-2				
	RS-1B	RT-10N	RM-1N	CWD	MC-2	HA-2	C-2B	M-2	I-3				
	RS-2	RT-11	RM-2	DD		HA-3	C-2C		IC-1	(Classified based on typology rather than zone name)			
	RS-3	RT-11N	RM-3	DEOD			C-2C1		IC-2				
	RS-3A	RT-2	RM-3A	FCCDD			C-3A		IC-3				
	RS-4	RT-3	RM-4	FSD			C-5						
	RS-5	RT-4	RM-4N				C-6						
	RS-6	RT-4A	RM-5				C-7						
	RS-7	RT-4AN	RM-5A				C-8						
		RT-4N	RM-5B				FC-1						
		RT-5	RM-5C										
		RT-5A	RM-6										
		RT-5AN	RM-7										
		RT-5N	RM-7N										
		RT-6											
		RT-7											
		RT-8											
		RT-9											
LAND USE TYPE	**Single Family Residential**	**Multi-Family Residential**		**Mixed-Use Residential**			**Commercial**	**Industrial**		**Institutional**	**Other/Park/Agriculture**		

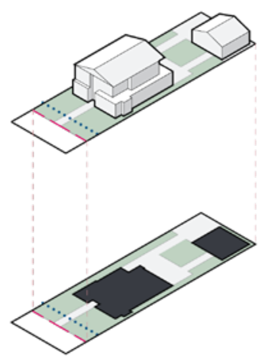
APPENDIX B

REPRESENTATIVE BUILDING SITE TYPOLOGIES GRAPHICS



LEGEND

- Landscape Area
- Hardscape Area
- Parkade Footprint
- Parcel Boundary
- 5m Building Offset



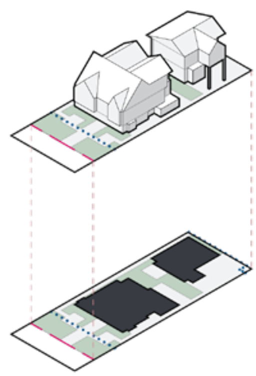
Typology Representative Characteristics

Total Parcel Area	375 m²	**Building Roof Area**	113 m²	**Parkade Area**	0
Total Impervious Area	45% of parcel	**Building Roof Area**	30% of parcel	**Parkade Levels**	0
Gross Floor Area	225 m²	**Building Stories**	2		

SMALL LOT RESIDENTIAL (LOW MASSING)

LEGEND

- Landscape Area
- Hardscape Area
- Parkade Footprint
- Parcel Boundary
- 5m Building Offset



Typology Representative Characteristics

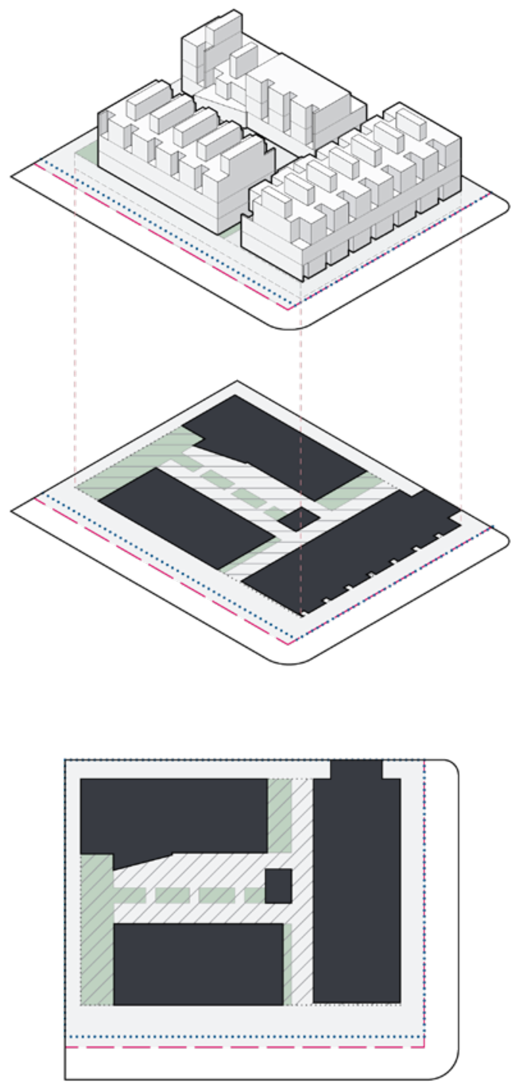
Total Parcel Area	375 m²	**Building Roof Area**	188 m²	**Parkade Area**	0
Total Impervious Area	70% of parcel	**Building Roof Area**	50% of parcel	**Parkade Levels**	0
Gross Floor Area	375 m²	**Building Stories**	2		

SMALL LOT RESIDENTIAL (HIGH MASSING)

0 10 20 50 m

LEGEND

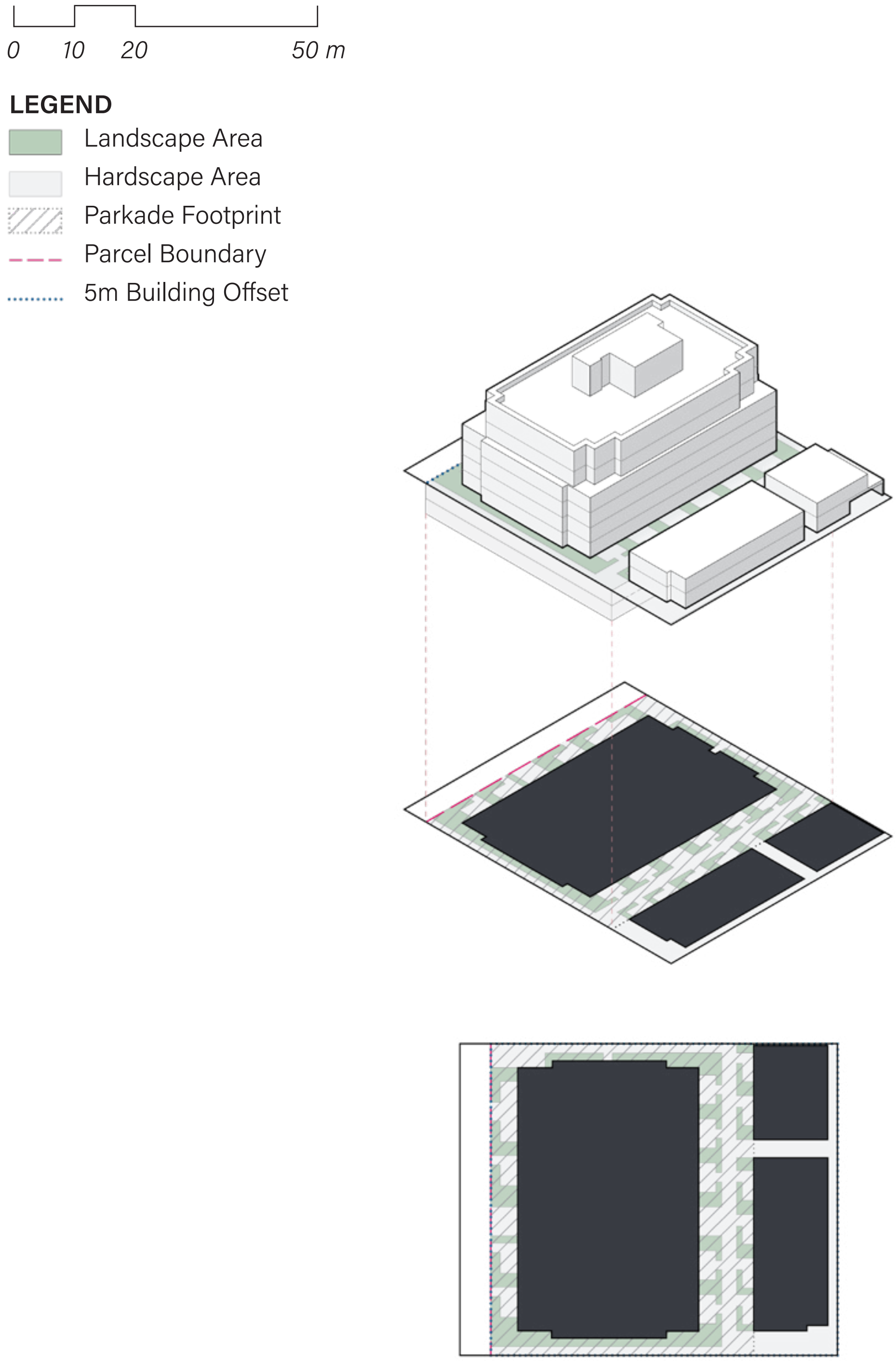
- Landscape Area
- Hardscape Area
- Parkade Footprint
- Parcel Boundary
- 5m Building Offset



<u>**Typology Representative Characteristics**</u>

Total Parcel Area	2,500 m²	**Building Roof Area**	1,000 m²	**Parkade Area**	90% of parcel
Total Impervious Area	90% of parcel	**Building Roof Area**	40% of parcel	**Parkade Levels**	1
Gross Floor Area	3,000 m²	**Building Stories**	3		

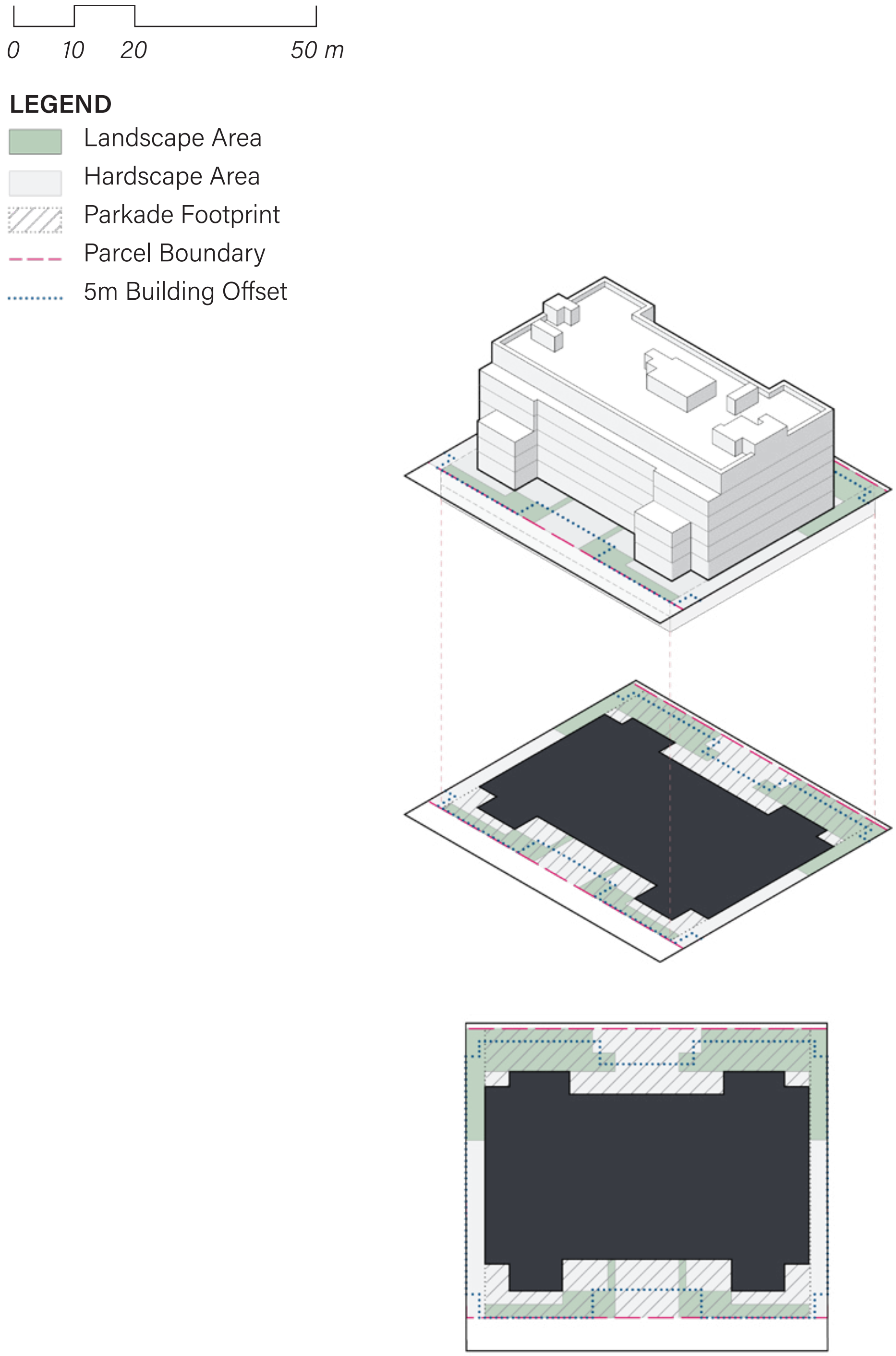
LOW-RISE RESIDENTIAL & MIXED-USE



Typology Representative Characteristics

Total Parcel Area	3,000 m²	**Building Roof Area**	1,950 m²	**Parkade Area**	95% of parcel
Total Impervious Area	95% of parcel	**Building Roof Area**	65% of parcel	**Parkade Levels**	2
Gross Floor Area	11,700 m²	**Building Stories**	6		

MID-RISE RESIDENTIAL & MIXED-USE (VERSION A)



Typology Representative Characteristics

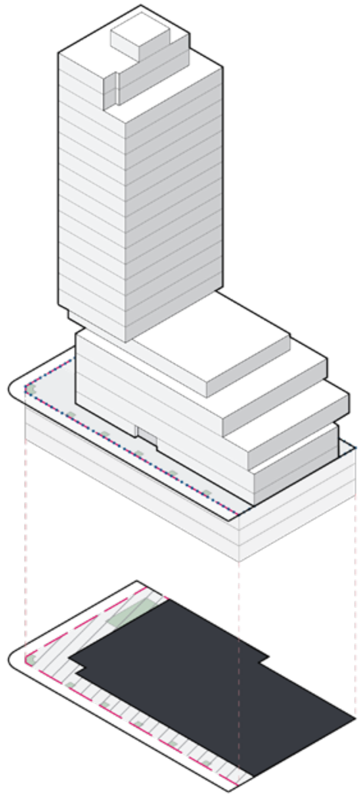
Total Parcel Area	3,000 m²	**Building Roof Area**	1,950 m²	**Parkade Area**	95% of parcel
Total Impervious Area	95% of parcel	**Building Roof Area**	65% of parcel	**Parkade Levels**	2
Gross Floor Area	11,700 m²	**Building Stories**	6		

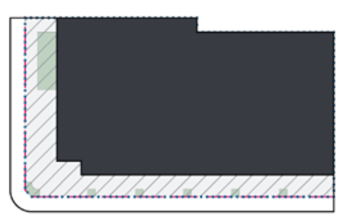
MID-RISE RESIDENTIAL & MIXED-USE (VERSION B)

0 10 20 50 m

LEGEND

- Landscape Area
- Hardscape Area
- Parkade Footprint
- Parcel Boundary
- 5m Building Offset

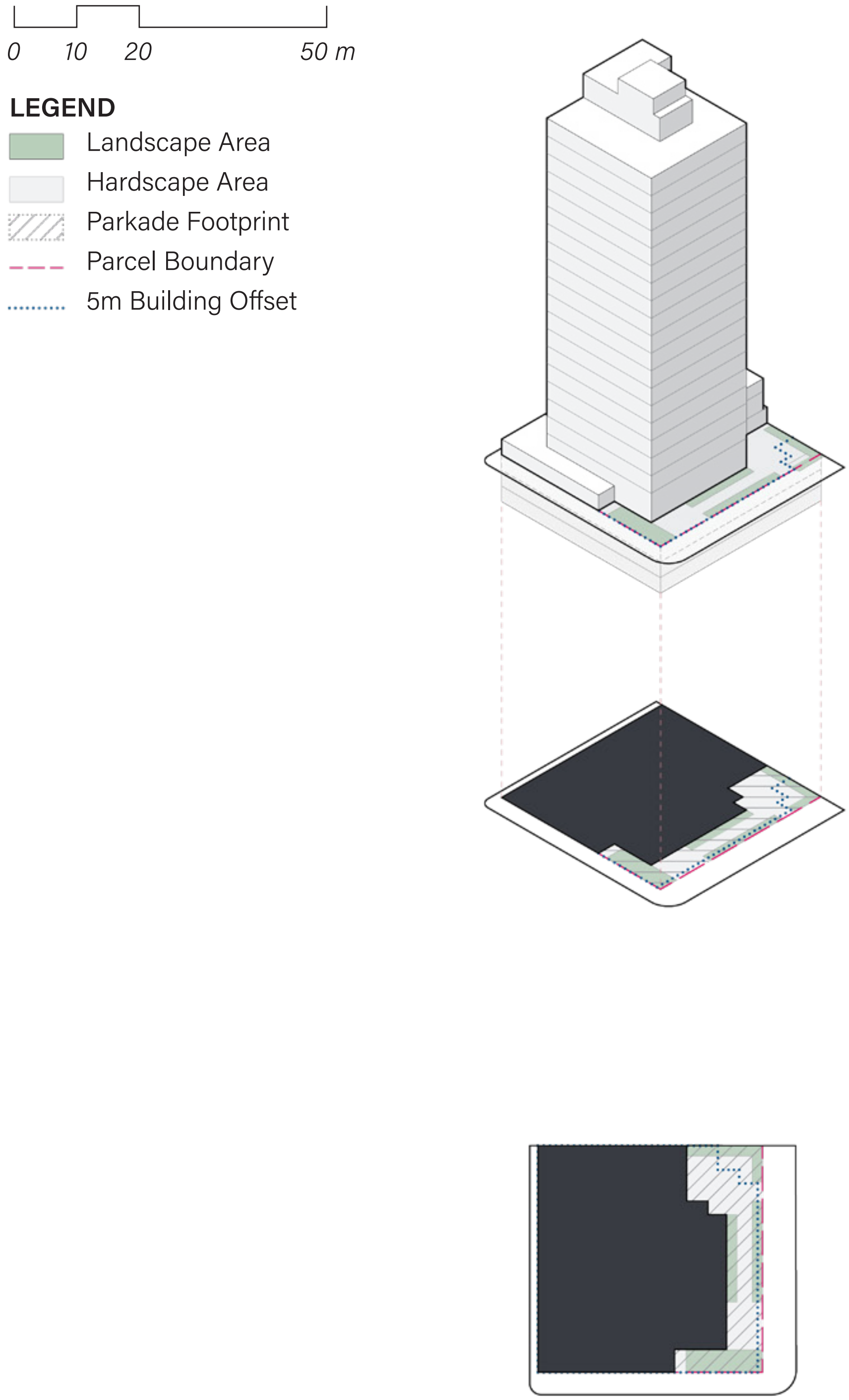




Typology Representative Characteristics

Total Parcel Area	1,200 m^2	**Building Roof Area**	840 m^2	**Parkade Area**	90% of parcel
Total Impervious Area	90% of parcel	**Building Roof Area**	70% of parcel	**Parkade Levels**	3
Gross Floor Area	16,800 m^2	**Building Stories**	20		

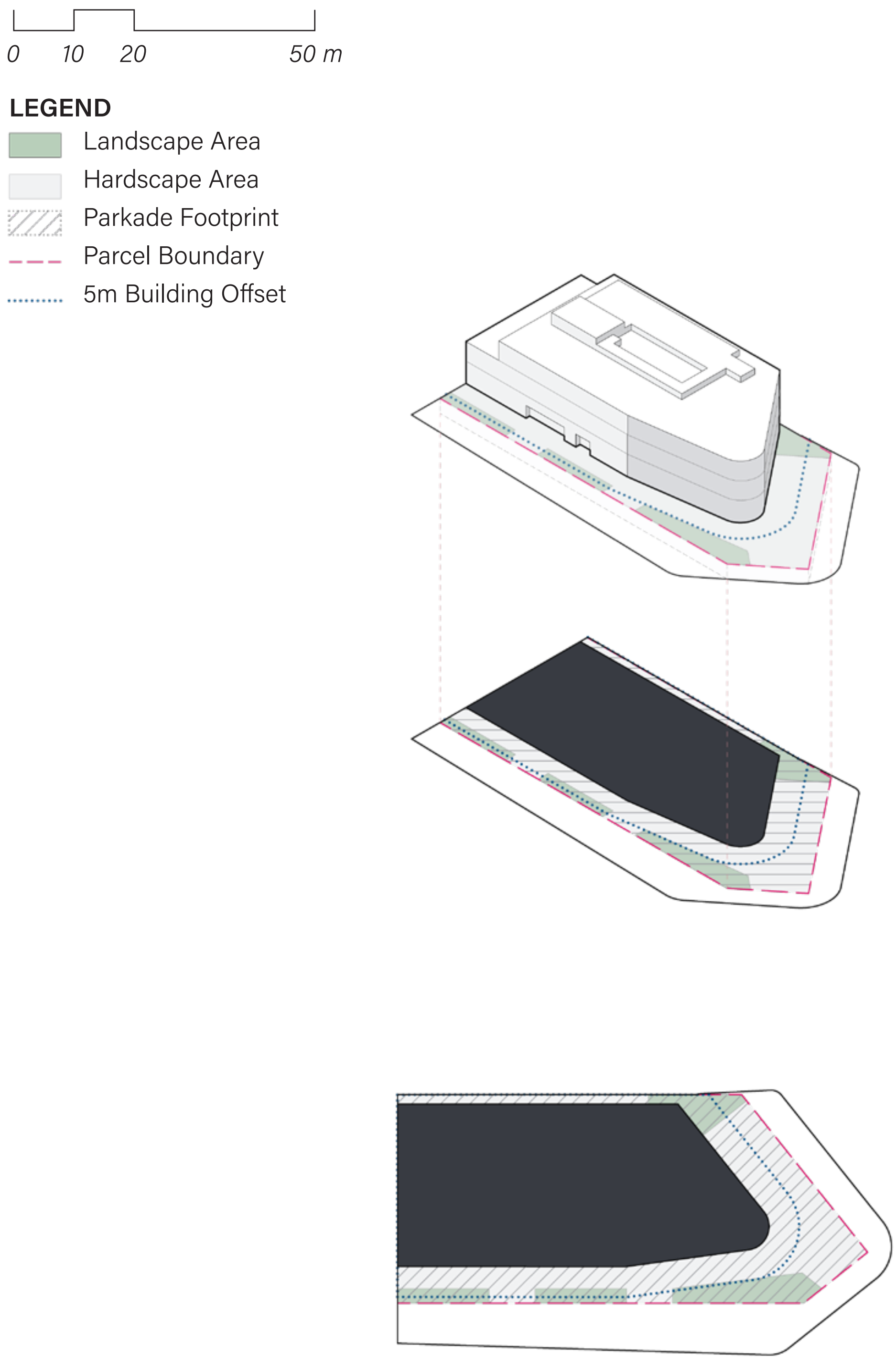
HIGH-RISE RESIDENTIAL & MIXED-USE (ON PODIUM)



Typology Representative Characteristics

Total Parcel Area	1,200 m²	**Building Roof Area**	840 m²	**Parkade Area**	90% of parcel
Total Impervious Area	90% of parcel	**Building Roof Area**	70% of parcel	**Parkade Levels**	3
Gross Floor Area	16,800 m²	**Building Stories**	20		

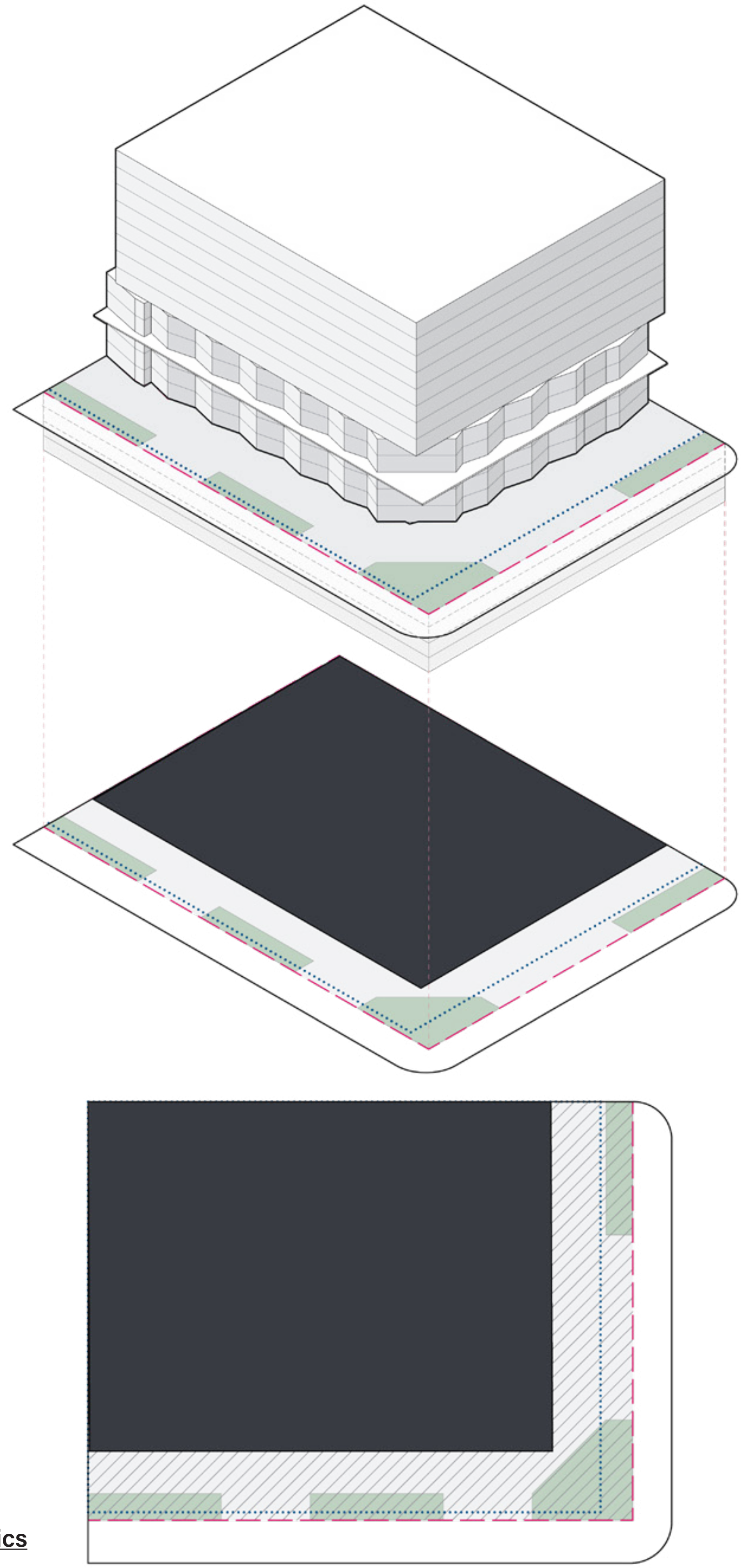
HIGH-RISE RESIDENTIAL & MIXED-USE



Typology Representative Characteristics

Total Parcel Area	2,500 m²	**Building Roof Area**	1,000 m²	**Parkade Area**	100% of parcel
Total Impervious Area	100% of parcel	**Building Roof Area**	40% of parcel	**Parkade Levels**	1
Gross Floor Area	3,000 m²	**Building Stories**	3		

LOW/MID-RISE NON-RESIDENTIAL



Typology Representative Characteristics

Total Parcel Area	8,000 m²	**Building Roof Area**	4,400 m²	**Parkade Area**	100% of parcel
Total Impervious Area	100% of parcel	**Building Roof Area**	55% of parcel	**Parkade Levels**	4
Gross Floor Area	61,600 m²	**Building Stories**	14		

HIGH-RISE NON-RESIDENTIAL

Task 3 – Rainwater Management Tools Memo

MEMORANDUM

Date: October 13, 2023

To: Gord Tycho *(City of Vancouver, BC)*

From: Brian Busiek, Julianne Chechanover, and Meghan Feller *(Herrera)*

Cc: Bryce Wilson and Eric Zickler (*Lotus Water*)

Project: Rainwater Infrastructure Building Typologies Pathway Study

Subject: Task 3 – Representative Rainwater Management Tools

INTRODUCTION

The Lotus Water team is working with the City of Vancouver, BC (City) to develop and test site-level rainwater management compliance pathways for a suite of building-site typologies. These compliance pathways represent different combinations of rainwater management tools that can be deployed to meet the City's rainwater management design standards (capture and clean 48 mm of rainfall) and help achieve the City's Rain City Strategy goals.

An early task in this study focuses on defining the set of potential rainwater management tools, including both green rainwater infrastructure (GRI) tools and grey (non-GRI) tools, that could be used by developers to meet the City's rainwater management design standards. These tools will be the basis for compliance pathway development and will be analyzed further in subsequent tasks to determine performance, costs, and co-benefits.

This memorandum summarizes the methods and information used to initially define and develop the rainwater management tools for future analysis.

RAINWATER MANAGEMENT TOOL LIST

Since there are many types of GRI and non-GRI tools available, the first step was to establish the proposed list of rainwater management tools to be included in this study. This list was developed based on existing City guidance, review of recent Rainwater Management Plans submitted to the City, practical design experience, and City input. Proposed tools were selected due to their ability to be:

- collectively applied across a range of hydraulic and hydrologic processes;
- applicable for the range of building-site typologies; and

- tested across the anticipated range of benefits, costs, and barriers likely to be encountered during implementation by developers.

Starting with tools identified in the project charter, an initial tool list was developed and presented to City staff members during a meeting on August 10, 2021. Based on feedback provided at the meeting, a refined tool list was developed. This list of tools includes primary types (e.g., permeable pavement) as well as sub-types (e.g., permeable pavers, pervious concrete, and pervious asphalt) that may provide different siting applications, performance, cost, and/or co-benefits. This list of tool types and sub-types is presented in Table 1.

Table 1. Rainwater Management Tool List

Tool Type	Tool Sub-type
Green Rainwater Infrastructure (GRI) Tools	
Resilient roofs [1]	Extensive (<150 mm soil depth) green roofs
	Intensive (≥150 mm soil depth) green roofs
	Blue-green roofs
Bioretention [1]	Sloped-side bioretention (w/ and wo/ underdrains)
	Full-walled bioretention (planter) (w/ and wo/ underdrains)
	Partial-walled bioretention (w/ and wo/ underdrains)
Absorbent landscapes [1]	Over native soils
	Over slab
Tree trenches	Structural soils
	Soil cells
Permeable pavement	Permeable pavers
	Pervious concrete
	Pervious asphalt
Subsurface infiltration [1]	Small-scale near-surface infiltration (e.g., drywells)
	Large-scale near-surface infiltration (e.g., infiltration chambers)
	Deep infiltration (e.g., drill drains)
Offsite green facilities	Centralized green facilities
	Localized green facilities (e.g., green street)
Non-potable water systems [1]	Rainwater harvesting systems (rooftop runoff)
	Groundwater + rooftop rainwater harvesting systems (rooftop runoff)
	Rainwater harvesting systems (all impervious runoff)

Table 1. Rainwater Management Tool List	
Tool Type	**Tool Sub-type**
Grey Rainwater Infrastructure (Non-GRI) Tools	
Detention tanks (without reuse) [1]	Surface detention tanks
	Subsurface detention tanks/vaults
	Blue roofs
Proprietary water quality devices [1]	Pre-treatment devices
	Basic treatment (50-80% Total Suspended Solids (TSS) removal)

[1] Tool required to be included per the project charter.

Rainwater Management Tool Definitions

Detailed definitions of rainwater management tools must be established to facilitate development of compliance pathways in future tasks. The tool definitions must effectively support development of concept designs of the rainwater management solution at each of the building-site typologies evaluated in the study. As such, the definitions must include sufficient detail to site, size, and evaluate performance of each of the rainwater management tools being considered.

The Lotus Water team reviewed the key design resources for the City of Vancouver, including the City's "2019 Vancouver Building Bylaw," "Integrated Resource Management Plan (IRMP) - Volume II," and "Rain City Strategy," as well as Metro Vancouver's "Stormwater Source Control Design Guidelines." Definitions and key siting and design information for each tool type were primarily compiled from these resources. As necessary, definitions were supplemented with information from guidance documents from U.S. West Coast cities (i.e., Seattle, Portland, San Francisco) as well as practical design experience.

Two primary categories of information were compiled for each tool: siting considerations and design parameters. Siting considerations included applicable building-site typologies, maximum contributing drainage areas, minimum soil infiltration rates, minimum groundwater separation, and other setback criteria. Design parameters compiled included minimum and maximum dimensions, component characteristics, outlet and discharge requirements, and other design considerations.

Narrative definitions for each of the tools is presented in Table 2 below. A matrix of compiled siting and design data is presented in Attachment 1.

Table 2. Rainwater Management Tool Definitions

Tool Type	Tool Sub-type	Narrative Tool Definition
GRI Tools		
Resilient roofs	Extensive (<150 mm soil depth) green roofs	Resilient roofs are rooftop facilities that can be designed to manage rainwater. Examples of resilient roofs include green roofs (extensive or intensive) and blue-green roofs. Green roofs use vegetation and soils to absorb and filter rainwater. Intensive green roofs support larger plants with a thick layer of soil and are typically accessible to building users, whereas extensive green roofs support smaller plants with a thin layer of soil and are generally not accessible. Blue roofs are designed to temporarily store rainwater on an unvegetated roof surface before releasing it to the sewer system. When blue roofs are designed with vegetation, they are called blue-green roofs. The additional water storage in a blue-green roof can help irrigate the roof vegetation *(Source: Modified from Rain City Strategy)*
	Intensive (≥150 mm soil depth) green roofs	
	Blue-green roofs	
Bioretention	Sloped-side bioretention (w/ and wo/ underdrains)	Bioretention or infiltration rain gardens capture and treat rainwater in a shallow earthen depression or at-grade vertical walled boxes using a designed soil mix and plants adapted to the local climate and soil moisture conditions. Rainwater is stored as surface ponding before it filters through the underlying bioretention soil. Rainwater that exceeds the surface storage capacity overflows to an adjacent drainage system. Treated water is either infiltrated into the underlying soil or collected by an elevated underdrain and discharged to the drainage system. In some cases, a drain rock reservoir is used below the soil media to provide additional storage. For this study, three types of bioretention are considered: sloped-side, full-walled (planter), and partial-walled bioretention. *(Source: Modified from IRMP and Rain City Strategy)*
	Full-walled bioretention (planter) (w/ and wo/ underdrains)	
	Partial-walled bioretention (w/ and wo/ underdrains)	
Absorbent landscapes	Over native soils	Absorbent landscapes are vegetated areas designed to absorb and retain larger amounts of rainfall than conventional compacted landscapes. The practice can be as simple as providing an increased uncompacted topsoil depth or including other design features that can capture and retain water. Examples include large evergreen trees to intercept rainwater; plentiful surface vegetation to absorb water, prevent erosion, and encourage evapotranspiration; and healthy soil with the right sand and organic matter content, which balances permeability and water holding capacity. *(Source: Modified from Rain City Strategy)*
	Over slab	

Table 2. Rainwater Management Tool Definitions

Tool Type	Tool Sub-type	Narrative Tool Definition
Tree trenches	Soil cells Structural soils	Tree trenches are multifunctional GRI practices that provide both storage for rainwater and support to street trees. This type of GRI practice, typically located in dense urban environments, directs urban rainwater runoff from adjacent impermeable areas such as streets, parking lots, sidewalks, plazas and rooftops into underground trenches for treatment and then infiltration or uptake by street trees. There are two types of tree trenches considered in this study: soil cells and structural soil. Soil cells consists of plastic frames that are strong enough to bear the weight of surfaces like sidewalks. Soil fills the void left in the plastic frame, leaving space for tree roots. Structural soil uses a mix of large, crushed stone and soil. The stone bears the weight of the surface while the soil and the space between the stone allows tree root growth. *(Source: Modified from Rain City Strategy)*
Permeable pavement	Permeable pavers Pervious concrete Pervious asphalt	Permeable pavement comes in a variety of forms similar to the various types of conventional paving materials. All permeable pavement types allow rainfall to soak into an underlying reservoir base where it is either infiltrated or removed by a subsurface drain. Rainwater is partially filtered and cleaned through the different aggregate layers and the underlying subsoil layer. Permeable pavement provides a hard, usable surface for cars, bikes, or pedestrians, while reducing runoff volume and improving water quality. For this study, three types of permeable pavement are considered: permeable pavers, pervious concrete, and pervious asphalt. *(Source: Modified from Rain City Strategy)*
Subsurface infiltration	Small-scale near-surface infiltration (e.g., drywells) Large-scale near-surface infiltration (e.g., infiltration chambers) Deep infiltration (e.g., drill drains)	Subsurface infiltration practices collect and convey rainwater to areas where it can be stored and infiltrated. Rainwater is partially filtered and cleaned through the different aggregate layers and the underlying subsoil layer. For this study, both near-surface infiltration and deep infiltration facilities are considered. For near-surface applications, large aggregate materials with void spaces and/or modular crates and arches are used to create storage space below the ground surface. Rainwater is temporarily stored in these practices, giving it a chance to soak back into the ground. Near-surface infiltration practices have been further differentiated into small-scale facilities (e.g., dry wells) and large-scale facilities (e.g., chambers and modular systems). Deep infiltration is typically achieved via injection wells to direct stormwater past surface soil layers that have lower infiltration rates and into well-draining soil at depth. All subsurface infiltration practices will likely need additional pre-treatment prior to discharging to groundwater. *(Source: Modified from Rain City Strategy)*

Table 2. Rainwater Management Tool Definitions		
Tool Type	**Tool Sub-type**	**Narrative Tool Definition**
Offsite green facilities	Centralized green facilities	A centralized green facility provides storage and water quality treatment for a large drainage area. The facility uses vegetation and treatment media to provide treatment to large developments or potentially to multiple adjacent properties. These facilities are highly customizable and can incorporate similar mechanisms as bioretention, constructed wetlands, and large-scale infiltration ponds. They can be installed in unutilized open space or integrated into urban landscapes as a multifunctional design element. Localized green facilities also manage runoff offsite but do so at a smaller scale in areas closer to the development. An example of a localized offsite green facility would be a green street (i.e., bioretention, permeable pavement, and tree trenches) fronting the development. *(Source: Developed from Cambie Corridor Integrated Water Management Plan)*
	Localized green facilities (e.g., green streets)	
Non-potable water systems	Rainwater harvesting systems (rooftop runoff)	Non-potable water systems capture and route on-site source water to a storage cistern, treatment system, and pumping and distribution system to allow the collected water to be used for various non-potable purposes, including onsite toilet flushing, laundry, irrigation, and make-up water for boilers and cooling towers. For this study, three types of source water for non-potable water systems are considered: rainwater harvesting system (rooftop runoff). groundwater + rainwater harvesting system (rooftop runoff). and rainwater harvesting system (all impervious area). Rooftop rainwater systems target cleaner runoff predominantly from rooftops but could also include other select clean hardscapes. A rooftop rainwater system can also be supplemented with groundwater to allow for a more reliable water supply during dry months. A rainwater harvesting system could also include runoff from all impervious surfaces including those with greater pollution generating capacity (e.g., roads and parking lots). Treatment requirements for rainwater harvesting systems managing ground level impervious surfaces could be substantially greater than those needed for rooftop systems. *(Source: Developed from multiple sources)*
	Groundwater + rainwater harvesting systems (rooftop runoff)	
	Rainwater harvesting systems (all impervious runoff)	
Non-GRI Tools		
Detention tanks (without reuse)	Surface detention tanks	Detention tanks collect and store rainwater during storm events. The rainwater is released to a downstream drainage system at a controlled rate, which helps alleviate peak discharges during storm events. Detention tanks can be located either above or below ground. *(Source: Modified from IRMP)* Blue roofs are designed to temporarily store rainwater on an unvegetated roof surface before releasing it to the sewer system. *(Source: Modified from Rain City Strategy)*
	Subsurface detention tanks/vaults	
	Blue roofs	

<table>
<tr><th colspan="3">Table 2. Rainwater Management Tool Definitions</th></tr>
<tr><th>Tool Type</th><th>Tool Sub-type</th><th>Narrative Tool Definition</th></tr>
<tr><td rowspan="2">Proprietary water quality devices</td><td>Pre-treatment devices</td><td rowspan="2">Proprietary water quality devices are underground devices manufactured to treat a variety of pollutants and improve water quality. Pre-treatment devices (e.g., hydrodynamic separators) remove trash, oils, coarse sediments, and associated pollutants before the rainwater typically flows to another rainwater management tool. Basic treatment devices (e.g., Filterra) are typically comprised of one or more structures that house rechargeable, media-filled cartridges that trap particulates and adsorb pollutants from stormwater runoff. These devices are often used in ultra-urban settings typically provide at least 50-80% removal TSS. (Source: Modified from IRMP)</td></tr>
<tr><td>Basic treatment (50-80% Total Suspended Solids (TSS) removal)</td></tr>
</table>

ATTACHMENT 1

Tool Data Matrix

RAINWATER INFRASTRUCTURE BUILDING TYPOLOGIES PATHWAY STUDY

Rainwater Management Tool Data Repository

Version 3
October 13, 2023

Purpose

Data and information was compiled for each rainwater management tool to be considered during development and analysis of compliance pathways for the study building typologies. Data and information was compiled from multiple data sources and organized as noted below.

Organization

Tabs	Description
Overview	Includes summary overview of information matrix, sources, and general assumptions
Siting	Includes building site typologies, contributing drainage area, and setback information
Design and Performance	Includes design parameters and sizing considerations

Reference Key

Data Sources
2019 Vancouver Building Bylaw
Metro Vancouver Stormwater Source Control Design Guidelines
City of Vancouver Integrated Resource Management Plan - Volume II
City of Vancouver Draft GI Design Guidance
Cambie Integrated Water Management Plan
King County, Washington
Seattle, Washington
San Francisco, California
Best Professional Judgement

RAINWATER INFRASTRUCTURE BUILDING TYPOLOGIES PATHWAY STUDY
Rainwater Management Tool Data Repository

Rainwater Management Tool	Applicable Building Site Typologies							Siting Criteria			
	Single Family Home, with and without Laneway	Low-Rise Residential	Mid-Rise Residential	High-Rise Residential	Low/Mid-Rise Commercial/Industrial	High-Rise Commercial/ Industrial	Institutional	Maximum Contributing Drainage Area	Minimum Native Soil Design Infiltration Rate	Minimum Separation from Groundwater/ Hydraulically Restrictive Layer	Setbacks
GRI TOOLS											
Resilient roofs	✓	✓	✓	✓	✓	✓	✓	Self-mitigating (with maximum 2:1 ratio)	N/A	N/A	N/A
Extensive (<150 mm soil depth) green roofs											
Intensive (≥150 mm soil depth) green roofs											
Blue-green roofs											
Bioretention	✓	✓	✓	✓	✓	✓	✓	35:1	7.5 mm/hr (without underdrain)	0.6 m	* Minimum of 30 m from wells, minimum of 3 m downslope of building foundations, and only in areas where foundations have footing drains
Sloped-side bioretention (w/ and wo/ underdrains)											
Full-walled bioretention (planter) (w/ and wo/ underdrains)											
Partial-walled bioretention (w/ and wo/ underdrains)											
Absorbent landscapes	✓	✓	✓	✓	✓	✓	✓	Max 2:1 ratio of impervious area to absorbent landscape	N/A	N/A	N/A
Over native soils											
Over slab											
Tree trenches		✓	✓	✓	✓	✓	✓	30:1	N/A	0.6 m	* Excavate the trench according to the dimensions necessary to install the desired tree well system. Allow 12" (30 cm) additional space along all edges
Soil cells											
Structural soils											
Permeable pavement	✓	✓	✓	✓	✓	✓	✓	2:1 impervious to pervious area (up to 50:1 ratio for roof runoff to pervious area)	13 mm/hr	0.6 m	* Suitable for low traffic areas (e.g., driveways, parking areas, storage yards, bike paths, walkways, RV pads, service roads, and fire lanes) * Grid pavers with soil and grass should be restricted to areas with evening parking (i.e. residential) or periodic day parking to allow sunshine to reach grass. * Permeable interlocking concrete pavers with wide joints should not be used for disabled persons parking stalls or pedestrian ramps at street crossing. * Minimum of 30 m from wells * The pavement should be downslope from building foundations, and the foundations should have piped drainage at the footing * Avoid utility or other crossings of the pervious pavement area. Where utility trenches must be constructed crossing below the reservoir, install trench dams at exits to avoid infiltration water following the utility trench.
Permeable pavers											
Pervious concrete											
Pervious asphalt											
Subsurface infiltration	✓	✓	✓	✓	✓	✓	✓	N/A			* Minimum of 30 m from wells * If steep slopes or drinking water wells exist within 200 m horizontally from the proposed surface infiltration (drywell), provide a hydro-geotechnical report to analyze site specific risks and determine setbacks. * Guidelines for setbacks to steep slopes are 60 m from the tops of slopes more than 3 m high and steeper than 2h:1v. * Provide a sedimentation manhole, and a maximum of two drywells in series, unless otherwise approved. Minimum distance between drywells shall be 8 m.
Small-scale near-surface infiltration (e.g., drywells)									0.6 mm/hr	0.6 m	
Large-scale near-surface infiltration (e.g., infiltration chambers)											
Deep infiltration (e.g., drill drains)									Varies	1.5 m	
Offsite/centralized green facilities	✓	✓	✓	✓	✓	✓	✓	160 ha	N/A	0.6 m	* Minimum of 30 m from wells and 60 m from the tops of steep slopes more than 3 m high and steeper than 2h:1v.
Non-potable water systems	✓	✓	✓	✓	✓	✓	✓	N/A	N/A	N/A	N/A
Rainwater harvesting systems (rooftop runoff)											
Groundwater + rainwater harvesting systems (rooftop runoff)											
Rainwater harvesting systems (all impervious runoff)											
NON-GRI TOOLS											
Detention tanks (without reuse)		✓	✓	✓	✓	✓	✓	N/A	N/A	N/A	N/A
Surface detention tanks											
Subsurface detention tanks/vaults											
Blue roofs											
Proprietary water quality devices	✓	✓	✓	✓	✓	✓	✓	Varies	Varies	Varies	Varies
Pre-treatment devices											
Basic treatment (50-80% Total Suspended Solids (TSS) removal)											

RAINWATER INFRASTRUCTURE BUILDING TYPOLOGIES PATHWAY STUDY

Rainwater Management Tool Data Repository

Rainwater Management Tool	Dimensions				Surface Storage			Media			Subsurface			Outlets and Discharge					Other Design Considerations
	Bottom Width (mm)	Top Area Footprint (m^2)	Lineal Dimensions (L:W)	Side Slopes	Max Ponding Depth (mm)	Max Ponding Time (days)	Freeboard (mm)	Media Depth (mm)	Media Porosity (%)	Media Design Infiltration Rate (mm/hr)	Aggregate Depth (mm)	Aggregate Porosity (%)	Time to Drain (hrs)	Underdrain Diameter (mm)	Overflow/Outlet	Weir Height (mm)	Slope	Drawdown Time (hrs)	
GRI TOOLS																			
Resilient roofs	Varies with roof size	Varies with roof size	Varies with roof size	Vertical	Varies	Varies	N/A	Varies	25%	N/A	N/A	N/A	N/A	N/A	Valve on downspouts or riser pipe on roof drains	N/A	Up to 20% slope	N/A	* Inverted or traditional flat roofing systems * Fire breaks of non-combustible material, such as gravel or concrete pavers, 50 cm wide, should be located every 40 m in all directions, and at all roof perimeter and roof penetrations. * Waterproof membrane extends to 100 mm above finished grade. * Roof access, structural design, and irrigation should all be considered during design. * Resilient roofs can vary in soil, drainage profile and detention design.
Extensive (<150 mm soil depth) green roofs					N/A	N/A		Up to 150 mm (typically 100 mm)											
Intensive (≥150 mm soil depth) green roofs								Up to 1,200 mm											
Blue-green roofs					100 mm	1 day		Up to 300 mm											
Bioretention	600 mm (min) 3,000 mm (desirable)	10-20% of upstream impervious area	2:1 (bottom)	Up to 2:1 (4:1 preferred for maintenance)	150-300 mm (200 mm is common)	1 day	100 mm	450 mm (min)	30%	70 mm/hr (50 mm/hr min)	N/A	N/A	N/A	150 mm (min)	Catch basin with 10 mm pipe outlet for up to 0.46 ha tributary area	See ponding depth	2% max longitudinal slope	48 hrs preferred (72 hrs max)	* Transition slope or edge be covered with rock or study mulch instead of grass. * A non-erodible outlet or spillway must be established to discharge overflow to the storm sewer system. * Sediment accumulation allowance of 3 mm/yr or more.
Sloped-side bioretention (w/ and wo/ underdrains)																			
Full-walled bioretention (planter) (w/ and wo/ underdrains)																			
Partial-walled bioretention (w/ and wo/ underdrains)																			
Absorbent landscapes	Varies with application	Varies with application	Varies with application	N/A	No or almost no ponding	2 days	N/A	Min depths of growing medium (150 mm lawn, 300 mm ground covers, 450 mm shrubs, and 600 mm trees	25%	70 mm/hr (50 mm/hr min)	N/A	N/A	N/A	N/A	N/A	N/A	Gently sloping (2%) or slightly dished (concave)	Same as max ponding time	
Over native soils																			
Over slab																			
Tree trenches	Varies	2-5% of upstream impervious area	Varies	Vertical	N/A	N/A	N/A	Varies	25%	N/A	N/A	N/A	N/A	150 mm (min)	Catch basin with 10 mm pipe outlet for up to 0.46 ha tributary area	N/A	2% max longitudinal slope	48 hrs preferred (72 hrs max)	* Consider whether cleanouts may be required.
Soil cells																			
Structural soils																			
Permeable pavement	Varies with application	Varies with application	Varies with application	N/A	N/A	N/A	N/A	N/A	N/A	N/A	50-100 mm (with 250 to 1,000 mm reservoir)	40%	96 hrs max, 72 hrs desirable	150 mm	Varies	Varies	Surface 1% to avoid ponding; bottom of reservoir 0% for full infiltration or min 0.1% slope in piped systems	96 hrs max, 72 hrs desirable.	* Min depth from base of drain rock reservoir to water table or solid bedrock 600 mm. * Provide a secondary overflow inlet and inspection chamber (catch basin or manhole) at the flow control assembly. If no secondary overflow inlet is installed, provide a non-erodible outlet or spillway to the major storm flow path. * Pavement infiltration rate: Initially >280 mm/hr, min of 28 mm/hr over pavement lifetime (usually 20 years) * Permeable paving is generally typically discouraged on top of slabs.
Permeable pavers																			
Pervious concrete																			
Pervious asphalt																			
Subsurface infiltration	Varies	Varies	N/A	Vertical	Varies	Varies	Varies	N/A	N/A	N/A	Varies	Varies	N/A	N/A	N/A	N/A	N/A	N/A	* Pre-treatment required prior to discharge to groundwater * Bottom of the surface infiltration shall be at least 600 mm above the seasonal high water table or bedrock, or as recommended by the engineer. * Pipe: PVC, DR 35, 100 mm min. dia. with cleanouts certified to CSA B182.1 as per MMCD. * Barrel shall not be perforated within 1200 mm of the cone (top section).
Small-scale near-surface infiltration (e.g., drywells)	1,200 mm	1.2 m^2			NA	NA	NA				1,800 mm	40%							
Large-scale near-surface infiltration (e.g., infiltration chambers)					1,800 mm	1 day	300 mm				NA	N/A							
Deep infiltration (e.g., drill drains)	200 mm	3.9 m^2			N/A	N/A	N/A				6,000 mm	40%							
Offsite/centralized green facilities	Varies	2-5% of upstream impervious area	2:1	Up to 2:1	600 mm	1 day	N/A	1,000 mm	30%	300 mm/hr	1,000 mm	40%	96 hrs max, 72 hrs desirable	300 mm	Riser pipe	See ponding depth	2% max longitudinal slope	Same as max ponding time	* Hybrid design of infiltration basin with treatment media and stormwater wetland * Highly customizable in size and cross-section with the ability to utilize hard or soft edges
Non-potable water systems	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Overflow control structure	N/A	N/A	N/A	* Design based on per-capita or gross building area approximations of potable water demand (0.368 L/day/m2 office; 0.338 L/day/m2 retail; 8.602 L/day/m2 restaurant; 1.014 L/day/m2 gen commercial; 117.58 L/day/capita residential; 7483 L/day/ha industrial) * Calculations for stormwater capture based on long-term continuous simulation
Rainwater harvesting systems (rooftop runoff)																			
Groundwater + rainwater harvesting systems (rooftop runoff)																			
Rainwater harvesting systems (all impervious runoff)																			
NON-GRI TOOLS																			
Detention tanks (without reuse)	Varies	Varies	Varies	Vertical	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Overflow control structure	N/A	N/A	N/A	* All underground tanks should have an air space equal to 20% of the max depth, connected to the atmosphere by a vent. * The max depth is a function of safety and convenience of users. A depth of over 2 meters is not recommended. * Underground tanks must have a min of 0.5 meters of cover and must be capable of handing the loads from the surface above.
Surface detention tanks																			
Subsurface detention tanks/vaults																			
Blue roofs					100 mm	1 day													
Proprietary water quality devices	Varies	Varies	Varies	Vertical	Varies	Varies	N/A	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Pipe	N/A	N/A	N/A	
Pre-treatment devices								N/A	N/A	N/A	N/A	N/A	N/A	N/A					
Basic treatment (50-80% Total Suspended Solids (TSS) removal)	1.2 m	1.5 m^2			50 mm	1 day		500 mm	40%	2,500 mm/hr	150 mm	40%	24 hours	100 mm					

Task 4 – GRI Design Methodology Memo

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TECHNICAL MEMORANDUM

From: Lotus Water

To: Gord Tycho, City of Vancouver

Date: October 13, 2023

Project: Rainwater Infrastructure Building Typologies Pathway Study

Subject: Task 4 – GRI Design Methodology [1]

1. Introduction

The City of Vancouver (City) has introduced new rainwater management requirements for privately-owned redevelopment sites. As a result, several questions have come up for how the nascent regulatory program is implemented. Developers, proponents, and City staff have also identified data gaps and the need for guidance regarding the interpretation of the City's rainwater management design standard and target requirements, where they apply, and how green rainwater infrastructure (GRI) can be designed to meet those requirements. Questions have also been raised regarding what measures the City can take to simplify the rainwater management requirements and streamline the compliance process.

To answer many of these questions and mitigate the uncertainty with how the program may be implemented, the City of Vancouver has initiated the Rainwater Infrastructure Building Typologies Pathway Study (Pathways Study). The Pathways Study will explore the different pathways for the development community to meet the intent of the Rain City Strategy for different land uses through the development of technical guidance and policy recommendations to facilitate a balance between the intent of the larger policy and the realities of managing rainwater onsite.

The Pathways Study includes nine tasks organized to progressively identify the problem statement, fill data gaps, and provide recommendations. The purpose of this memorandum is to document the work completed as part of Task 4 *GRI Design Methodology*, where the consultant team is tasked with closing data gaps and answering important questions for the City, developers, and the design community in Vancouver. The goals of Task 4 are to:

- Establish a clear GRI design methodology to help standardize and inform the design process.
- Develop recommendations for revisions or modifications to City rainwater management regulations, policy, and guidance that would simplify the compliance process and enable private sites to meet the City's requirements in a more streamlined fashion.

[1] This Technical Memo updates and combines material included in draft Technical Memo #1 (Current State Assessment, Needs Assessment, & Jurisdictional Scan Methodology) and draft Technical Memo #2 (Jurisdictional Scan and Technical Analysis of Proposed GRI Design Methodology) with additional information covering the GRI Design Tool and preliminary recommendations.

- Create a GRI sizing tool to identify and size appropriate compliance pathways for the representative building typologies.

The resulting standardized sizing process and supporting tool and guidance are intended to establish consistency and reliability for the design and development community. This will include recognition that standard compliance may not be attainable at highly constrained sites, and a pathway for modified or alternative compliance may be necessary for certain land uses and building types.

This technical memorandum documents the methods, analysis, and recommendation of the GRI Design Methodology task. The Current State Assessment describes the current compliance process, an analysis of Rainwater Management Plans (RWMPs) where GRI is being installed, and a summary of existing challenges, barriers, and opportunities to creating a simplified, more streamlined process. The Needs Assessment summarized the barriers and gaps identified in the Current State Assessment and integrated the Task 8 Barriers Assessment into six categories that the team used to conduct a jurisdictional scan that will inform subsequent work as part of the larger project. The Jurisdictional Scan presents a brief examination of municipalities that provide clear instruction and direction with regards to GRI design and methodology for meeting rainwater management requirements. This is followed by a summary of the technical analysis and recommendations for GRI design methodology and an overview of the GRI Design Tool created to model and evaluate rainwater management compliance pathways for the representative building site typologies.

2. Current State Assessment[2]

The purpose of this section is to summarize the current state of the overall regulatory environment, applicability, and GRI design requirements related to successful submittal of a RWMP. The current state assessment includes review and summaries of key, relevant sections of the Vancouver Building By-Law, Zoning & Development By-Law, the Engineering Design Manual, and the Rainwater Management Bulletin. It should be noted that the Sewer and Watercourse Bylaw, which set requirements for sewer connection permits and sewer capacity review, was not included in this assessment. However, it is related to and, in some cases, part of the RWMP process.

Additional policies or bylaws that may arise when designing and implementing GRI under various conditions are also not covered in depth, for example policies related to groundwater, urban forestry, and streets and traffic. Once feasible GRI pathways are defined in subsequent tasks, a more detailed review of barriers and policy considerations specific to those typologies and pathways may be needed.

The project team has also reviewed a sample of 100 submitted RWMPs to support their understanding of the current compliance approach. This task has informed Task 8 – Rainwater Management Barriers; however, no detailed discussion of the barriers is included within this document. This task will also provide inputs on the Needs Assessment and highlight specific areas of concern when developing the tools and recommendations for streamlining and process improvements.

[2] This memo was prepared in mid 2022 and the regulatory summary documents the status at that time.

2.1 Key Documents Governing Rainwater Management

Rain City Strategy (2019) and the Integrated Rainwater Management Plan (IRMP) are high level visionary documents that provide the policy and strategy for Vancouver's approach to rainwater management. While these policies provide the guidance and purpose of the RWMPs and expected outcomes, they are not the regulatory instrument for compliance. The following section outlines some of the bylaws, codes, manuals, and bulletins necessary for rainwater management in Vancouver.

2.2 Relevant Bylaws and Requirements for GRI Design

The project team examined the various by-laws, rules, bulletins, and design guides, and found the following documents and sections to be most relevant to GRI design and rainwater management, which are summarized below. These represent the necessary and typical requirements to be considered when seeking approval for a typical development or redevelopment project, depending on type and scale. Additional documents and bylaws likely impact rainwater management and GRI design, depending on the specific site conditions.

The Rainwater Management Bulletin is the current guidance document used by the City of Vancouver to review and approve RWMPs. The Bulletin has no actual legal power and instead references/describes related submission processes and the City's preferred tier system – but authority is from the Zoning and Development Bylaw (Section 4). Technically, the City can require RWMPs anywhere in the city at the DP stage. There is a detailed review of the Bulletin at the end of this section, along with an analysis of 101 of the RWMPs provided by the City to the project team for review.

2.3 Vancouver Building By-law (2019)

The City states that construction projects[3] and any change of land use or occupancy on private property will require a building permit. Projects must comply with the Vancouver Building By-law (VBBL) to meet life safety, livability, accessibility, and sustainability requirements. A building permit is the tool the City uses to achieve these requirements.

The following sections provide key language related to stormwater and drainage. Periodically, bulletins will be published to compliment the VBBL.

VBBL Book II, Division B, Part 2 Plumbing Systems, Section 2.1. General

This section includes the public service connection requirements for buildings.

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[3] The B.C. Building Code regulates building in two main categories: simple buildings and complex buildings, commonly called Part 9 and Part 3 buildings. Part 9 buildings are typically under three storeys in height and with a footprint less than 600 square meters; a single-family home is a good example. Part 3 buildings are typically over three storeys or over 600 square meters in footprint; an office building, apartment building, or shopping mall would all be examples. Building requirements for each type of building are based on the differences in their size and use.

Section 2.1.2.2. Storm Drainage Systems

1) Except as provided in Subsection 2.7., every storm drainage system shall be connected to a public storm sewer, a public combined sewer or a designated storm water disposal location.

Section 2.1.2.4 Separate Services

1) Piping in any building connected to the public services shall be connected separately from piping of any other building, except that an ancillary building on the same property may be served by the same service.

Book II, Division B, Part 2 Plumbing Systems, Section 2.4. Drainage Systems

This section includes requirements on connection for rainwater tanks and drainage systems.

2.4.2.2. Connection of Overflows from Rainwater Tanks

1) An overflow from a rainwater tank shall not be directly connected to a drainage system.

2.4.2.4. Connections to Storm Drainage Systems

1) Except as provided in Sentence (2), all roof and paved areas shall drain to a storm drainage system.
2) Building and site drainage need not connect to a storm drainage system if on-site rainwater or storm water management practices are employed and a) rainwater or storm water does not create a hazardous condition or discharge upon or impact other lands or sites, and b) overflow is drained to a storm drainage system. (See Sentence 2.4.2.2.(1).)

VBBL Book II, Division B, Part 2 Plumbing Systems, Section 2.7. Non-Potable Water Systems

This section specifies the allowable sources (including which types of surface runoff are permitted for reuse) and uses (both mandatory and optional) for onsite non-potable water systems, along with treatment requirements and other relevant information.

Currently, a non-potable water system shall not collect perimeter drainage water, groundwater, storm water, greywater, or blackwater. Policy development work (by DBL/CBO and Vancouver Coastal Health Authority) is underway to add "storm water" (as defined by the VBBL) as a source water for non-potable water systems. Pending Council approval, this is targeted for the VBBL in 2023.

2.7.1.2. Non-Potable Water Sources

1) A non-potable water system shall collect only a) rainwater from roof surfaces or similar areas: i) that do not allow the passage of vehicular traffic, ii) that are above grade, and iii) where hydrocarbon-based fuels, hazardous materials, or fertilizers are not stored or used on such surfaces, or b) clear-water waste, or c) both.
2) A non-potable water system shall not collect perimeter drainage water, groundwater, storm water, greywater, or blackwater.

2.7.1.3. Non-Potable Water Uses

1) Except as provided in Sentence (2), a non-potable water system may use treated non-potable water for any of the uses set out in Columns A *[Water closets, urinals and trap primers]* or B *[Irrigation of non-food purpose plants, clothes washers, vehicle wash facilities, make-up water for hydronic systems, make-up water for cooling towers, adiabatic cooling systems, and tempering of discharge]* of Table 2.7.1.3.
2) An alternate water source system shall use treated non-potable water in lieu of potable water for all of the uses set out in Column A of Table 2.7.1.3.
3) Non-potable water shall not be used in lieu of potable water for any other uses.

VBBL Book I, Division B, Part 3 Fire Protection, Occupant Safety and Accessibility, Section 3.1 - General

This section contains information concerning permittable applications for green roofs.

3.1.14.4. Green Roof Assemblies

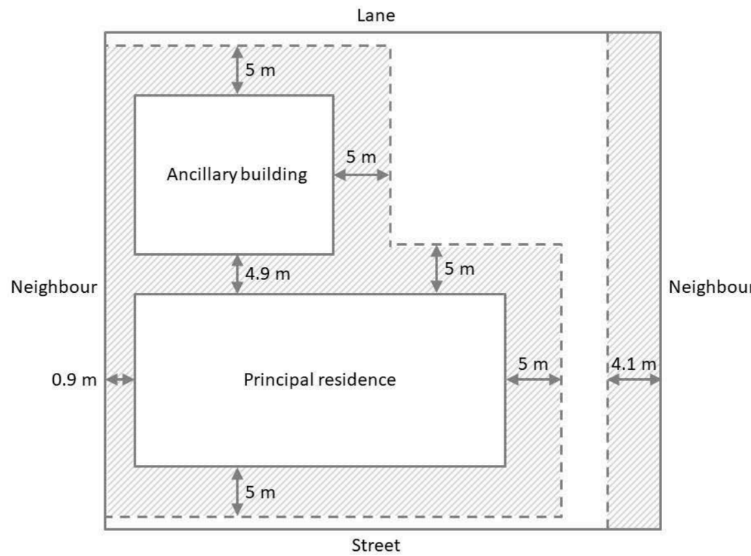
1) A green roof assembly is permitted in combustible and noncombustible construction if a) the green roof assembly is designed and constructed in conformance with ANSI/SPRI VF-1 "External Fire Design Standard for Vegetative Roofs", Rev. 12715 Division B Consolidated changes to June 01, 2021 Vancouver Building By-law 2019 Part 3 – Fire Protection, Occupant Safety and Accessibility Division B: Acceptable Solutions b) gravity loads on the building structure are determined by ASTM E2397-11 "Standard Practice for Determination of Dead Loads and Live Loads Associated with Vegetative (Green) Roof Systems", c) the green roof assembly is designed and constructed with a root barrier, d) the green roof assembly is designed and constructed with water retention materials to support vegetative growth, and e) the drainage layer of the green roof assembly is designed to accommodate rainwater harvesting and conforms to ASTM E2398-11 "Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Vegetative (Green) Roof Systems".
2) In addition to the requirements in Sentence (1), the roof assembly which supports a green roof assembly shall conform with Subsection 3.1.15., except for Part 9 buildings.
3) In addition to the requirements in Sentence (1), the roof assembly which supports a green roof assembly shall conform with Part 5.

VBBL Book I, Division B, Part 9 – Housing and Small Buildings, Section 9.14. Drainage

This section deals directly with drainage and provides some information on elements such as Foundation Drainage, Drainage Tile and Pipe, Granular Drainage Layer, Drainage Disposal and Surface Drainage. Article 9.14.5.3. deals with the location of dry wells, setting a condition that they must be a minimum of 5m from a building. This condition is further developed by the Siting Requirements for On-Site Infiltration Systems Bulletin.

Bulletin 2019-008-PL - Siting Requirements for On-Site Infiltration Systems

This Bulletin further clarifies the intent of VBBL Book I, Division B, Article 9.14.5.3.(2), which is to limit harm to persons and damage to buildings from excessive moisture loading on foundation walls, basement floors and the soil immediately beneath footings. The following figure illustrates the information contained within the bulletin.



The setbacks are applicable to stormwater management systems (such as bioretention planters or infiltration trenches) to which site runoff is directed for infiltration. The setbacks do not apply to site landscaping; however, it is not clear if some run-on to the landscaping would be acceptable. The bulletin notes that setbacks from the street, lane, and utilities infrastructure are at the discretion of the City Engineer. This document also suggests that while other pertinent minimum separations are shown, this bulletin is not a comprehensive summary of all potentially applicable setback regulations.Theses infiltration setbacks also need not be applied for specific structures (detached garages and carports that serve no more than one dwelling unit, are less than 55 m2 floor area, not more than 1 storey in height, and are not of masonry or masonry veneer construction).

The sections referenced above offer limited pieces of requirements affecting the feasibility and installation of some GRI practice types. While the VBBL does not provide designers with all required information for a functional rainwater management system, these requirements must be met in all applicable projects.

2.4 Zoning & Development By-law (2021)

The Vancouver Zoning & Development By-law consists of a variety of constraints and factors to be considered in the early stages of a project such as building heights, number of storeys, setbacks, building lines, densities, and provision of open spaces to provide light and air.

2.4.1 Development Permit

According to the City’s website, development is defined as "any change in the use of any land or building or the carrying out of any construction, engineering, or other operation in, on, over, or under land or land covered by water". Large-scale projects, and/or where zoning relaxations or particular types of land uses are proposed, require a separate development permit before a building permit application can be submitted. Development applies to both construction/renovation and changing the use of a building or part of a building and is regulated by the Zoning and Development By-law.

The development permit in some cases[4] requires a RWMP and compliance with groundwater management requirements. However, in the By-law language, the determination for whether a RWMP is required is left to the discretion Director of Planning or the Development Permit Board (see Sections 4.3.4-4.3.6). Determination of inadequacy of drainage may require a RWMP and a GWMP. Adequate drainage is defined in the Zoning and Development By-law. If it is determined that a RWMP is required, the Director or Board may withhold the permit until a rainwater and groundwater agreement is signed. The owner will maintain the systems, ensure performance, and give the City "statutory right of way and equitable charge."

Other site coverage/space requirements in this By-law will have an additional impact on rainwater management as usable space often conflicts with a site's capacity for GRI practices. For example, the schedules for different zoning districts provided within this By-law. Each of these schedules outlines various conditions to be met by different development sites in each of these zones. Section 4 of these schedules contains regulations relevant to rainwater management, with section 4.8 containing information related to site coverage. The site coverage conditions are linked to the implementation of effective rainwater management as one of the key barriers to successful GRI implementation is lack of space.

2.5 Other Rezoning Policies

Vancouver allows for site specific rezonings to be proposed by property owners and developers and has a rezoning application process. As part of that process, applicants are directed to the Development Rezoning Enquiry Guidance Document for Sewers, which states that rainwater management requirements apply to all rezonings and refers to the Rainwater Management Bulletin.

The City also has a variety of rezoning policies in addition to the Zoning & Development By-law. These policies include supplementary information specific to certain zones and/or development types. Some of these policies are city-wide, some are area-specific, while others are relevant only for projects with certain characteristics. The two most relevant rezoning policies to the current state assessment are the Green Building Policy for Rezoning and the Rezoning Policy for Sustainable Large Developments. These policies are put into practice by additional bulletins.

2.5.1 Green Building Policy for Rezonings (2018)

The Green Building Policy for Rezonings outlines the requirements to be met for all rezonings for projects with Green Buildings. There is also a bulletin for this policy: Green Building Policy for Rezonings – Process and Requirements (2019). It contains most of the detailed instructions on rainwater management requirements and content. There are two pathways by which a development can comply with these requirements: Net Zero Emissions or Low Emissions. For Net Zero Emissions rezoning, there are various

[4] Per Checklists on City website the following require a RWMP: Major Applications (except if RWMP submitted in a rezoning enactment); Cambie Corridor Only – Commercial or Industrial Buildings, Mixed-Use Buildings and Multiple Dwelling Buildings (all zones) and RT Zones (all building types)

requirements involving materials and energy, but no rainwater management or green rainwater infrastructure requirements. There still may be release rate controls required for a subset of these proposed developments due to unknown or sewer capacity concerns evaluated by others at the City. If so, a "limited" RWMP for release rate control only would still be necessary. However, Low Emissions Green Buildings must manage rainfall onsite in a manner consistent with the IRMP. However, as noted above, if all rezoning must submit a RWMP per the Development Rezoning Enquiry Guidance Document for Sewers, then this distinction is irrelevant and could cause confusion for rezoning applicants.

This policy was intended to promote sustainable practices for developments on a large scale. However, Vancouver is moving closer to implementing more sustainable practices at all levels, with part of the Greenest City Action Plan targeting a requirement for all new buildings from 2020 to be carbon neutral in operations. Metro Vancouver also released it's Climate 2050 Roadmap for Buildings – A Pathway to Zero Emissions and Resilient Buildings in October 2021, which includes strategies specific to water reuse in buildings.

If a project which intends to be environmentally sustainable neglects to manage rainwater efficiently, it will likely put more pressure on public infrastructure. This could potentially result in larger loads on both public sewers and water treatment plants, triggering sewer back ups, flooding, or other related infrastructure capacity issues.

2.5.2 Rezoning Policy for Sustainable Large Developments (July 2021)

The Rezoning Policy for Sustainable Large Developments outlines requirements set out for development projects which consist of land parcels having a total size of 8,000m^2 or projects that contain 45,000m^2 of new development floor area. This policy was written to ensure large developments are leaders in advancing sustainability and contribute to meeting the objectives of the Urban Forest Strategy, the Biodiversity Strategy, and the Rain City Strategy, among others. This policy reiterates the rainwater management requirements of 24 mm retention and treatment, though ideally these requirements would be codified elsewhere and only the requirements that are particular to large sites would be in this policy. As the implementation of the Rain City Strategy was still in development when the large site policy was updated in 2018, creating requirements specific to large sites was not possible.

- Section A3.2 states that developments must maximize opportunities for a variety of open spaces that are contiguous. These would include rooftops, courtyards, and ground-level spaces. This section suggests that these spaces should include extensive green roofs, solar panels, and water storage if they are inaccessible, and if they are accessible should consist of common use areas with intensive green roofs.
- Section A3.3 outlines setbacks to some underground parking structures to retain existing trees, conserve soil, plant trees and other vegetation, and retain soil volumes for rainwater management. A consideration to relax these requirements may be provided to highly urbanized sites or those with unique conditions.
- Sections A3.5, A3.6 and, A3.7 briefly touch on the requirement to protect, retain, and plant healthy trees where possible.

- Section A3.9 describes a requirement for a dog relief area on any residential building (excluding townhouse developments). This is to protect natural and planted areas.
- Section D3 details the Integrated Water Management Approach, in which applicable developments are expected to produce a Water Balance for any buildings in the development. These will be used to track water use in these developments and to ensure these projects meet the requirements of this policy. The requirements are a minimum 20% reduction in indoor potable water use through conservation, efficient use and/or onsite non-potable water reuse. An additional requirement of a minimum 50% reduction in outdoor potable water is to be achieved using the same methods.
- Section E3 outlines requirements to manage any groundwater being intercepted as it must be managed onsite and cannot enter the public sewers and covers the flow control and water quality requirements as set forth in the RWM Bulletin.
- These sections of the Rezoning Policy for Sustainable Large Developments can be crucial in defining the overall layout of a development. Many of the requirements listed above, and in similar policies, dictate how certain parts of a site can be used and create requirements for setbacks, tree retention, and a variety of other factors. There is an opportunity to coordinate this Rezoning Policy with other redevelopment requirements to balance creative approaches to stormwater design and maximizing GRI implementation.

2.5.3 Sustainable Large Developments (2020)

The Sustainable Large Developments Bulletin is intended to provide supplemental information to applicants seeking to comply with the Rezoning Policy for Sustainable Large Developments. As such, this bulletin and its parent policy apply to the same types of projects. The relevant sections are summarized below.

- Section 1 discusses sustainable site design. The introduction to this section outlines how large site developments should follow principles of sustainable site design to increase the quality of life in neighbourhoods. In addition to the health aspect of design, this bulletin also notes how retaining or mimicking natural processes and modelling healthy living systems should be done wherever possible.
  - This section also mentions how sustainable site design, in addition to meeting the requirements of this bulletin, should consider that the RWMP must be coordinated with the open space plan, site plan, and landscape plan. The grading and landscape plans must demonstrate water conservation and rainwater management through employing landscape grading techniques and hardscape design strategies such as using permeable materials and implementing infiltrative systems and other treatment train strategies. On top of the requirements mentioned above, structural design should anticipate slab strength and modifications to ensure sufficient soil volumes are provided for trees.
  - Finally, this section briefly discusses some additional information required, referring to the Protection of Trees By-law, No. 9958, section 7.2 and the Urban Forestry Strategy

for the requirements surrounding the protection and enhancement of Vancouver's urban forest.

- Section 2 discusses sustainable food systems including things like community gardens, shared garden plots, urban farms, and other food system assets. The information here does not currently inform rainwater management but is worth mentioning as future solutions such as rainwater harvesting, and infiltrative systems could be implemented to great success in developments like these.
- Section 4 instructs designers on potable water management. This section gives additional details on the Water Balance mentioned in the Rezoning Policy for Sustainable Large Developments, providing a method for developing both indoor and outdoor potable water use baselines.
- Section 5 references the Groundwater Management Bulletin, which provides information to applicants seeking a rezoning and development permit and requires a hydrogeological study. This Bulletin addresses concerns related to this project including flooding, subsidence and erosion, and sewer capacity (discharging of pumped groundwater).
- Section 7 sets out requirements for affordable housing in these developments. While this does not directly impact rainwater management, financial factors are a critical consideration when looking at future rainwater management solutions.
- Section 8 discusses the importance of resilience in design. This does not currently specify rainwater management design guides but, like section 7, will be of utmost importance when implementing GRI solutions as these can assist a property in achieving the resilience desired.

2.6 Engineering Design Manual (2019)

The Vancouver Engineering Design Manual (2019) was developed as a comprehensive guide that documents the typical design processes and criteria to be used for projects conducted by and for the City of Vancouver. This manual includes foundational background, goals and objectives, and guidance for a multitude of engineering disciplines. It consolidates the city of Vancouver's design preferences, and is to be used in conjunction with the Vancouver Standard Detail Drawings. The manual has been written to design for current and future resilience and refers to the following nine documents as having "goals that influence engineering design", including the IRMP and the City's climate strategy. The Manual is currently being updated and will include a substantial GRI design section along with updated IDF curves and updated design storm distributions.

This manual provides most of the information required for the design of effective servicing systems and streets. The additional information contained in the VBBL and additional by-laws and policies for Vancouver cover specific scenarios and general requirements such as accepted materials, fittings, and methods of connection. Where possible, the criteria set out in this manual must be met, but it is understood that use of accepted industry standards and specifications will still likely be required.

The following briefly outlines some of the key guidance provided relative to the existing management of rainwater infrastructure in Vancouver.

- Chapter 1 states that developing and maintaining reliable and resilient sewer and drainage infrastructure throughout Vancouver is a key strategy to help fulfill the City's mission, values, and objectives, which are as follows:
    - Protect Vancouver's waterways and the environment.
    - Fully separate the sanitary and storm sewer systems.
    - Eliminate combined sewer overflows by 2050.
    - Reduce the City of Vancouver's carbon footprint.
    - Ensure the City is prepared for the impacts of climate change, and emergencies, including major disasters.

  This chapter also describes green rainwater infrastructure and how various types of GRI can improve water quality, improve resilience to rain and heat events, and support biodiversity and recreational water use. The manual goes on to discuss how GRI development will help meeting the City's goals, values, and objectives of:

    - Improve and protect Vancouver's water quality.
    - Increase Vancouver's resilience through sustainable water management.
    - Enhance Vancouver's livability by improving natural and urban ecosystems.
    - Capture and treat 90% of Vancouver's annual average rainfall on both public and private property.
- Chapter 2 provides a design development matrix in the form of table 2-4. This matrix provides details on required drawings, design briefs and associated reports/documents to be submitted at various design levels. This information is important when considering the impacts that the implementation of GRI may have on the design and approval processes. The remainder of section 2.5 provides additional information on each submission type's requirements. Further to this, section 2.6 discusses the Development Design Review Process in detail.
- Chapter 3 contains important design information for Water Systems in Vancouver. However, there is limited useful information with respect to rainwater management, and the lack of guidance on rainwater harvesting and reuse has been identified here by the project team.
- Chapter 4 deals with the Sanitary Sewer System. This does not provide information directly relevant to rainwater management, but the information on service connections contained in section 4.6 may be relevant, particularly location requirements.
- Chapter 5 contains almost all information currently required for the design of a functional stormwater management system as part of development and in the public realm. This includes design flow information, methods of calculation, runoff coefficients, rainfall data, component design guides, service connections and more. All this information is given to assist in the development of a rainwater management system for any type of project which can meet the targets set out by the city.
- It should be noted that VBBL Book II (Plumbing Systems) supersedes the Engineering Design Manual for designs within the private realm if there is conflicting information between the two documents (e.g., Maintenance Holes).

- Table 5-18 from the Manual, included below, summarises the performance standard, consistent with the RWM Bulletin.

Table 5-18: Green Infrastructure Design Targets

Objective	Target	Standard
Volume Reduction	Retain the first 24mm of rainfall (50% of the 6 month - 24-hour return period storm, 70% of the average annual rainfall volume)	Infiltrate, evapotranspire, and reuse rainwater to the greatest extent practicable.
Water Quality	Treat the first 48mm of rainfall (6 month - 24-hour return period storm, 90% of the average annual rainfall volume)	Remove 80% of Total Suspended Solids for particles > 50microns(1); the total concentration of sediment can be no more than 75mg/L(2)

Notes:
(1) Criteria comes from the Dept. of Fisheries and Oceans Land Development Guidelines
(2) Criteria comes from the City of Vancouver Sewer & Watercourse Stormwater Discharge

- The Manual refers the designer to The Metro Vancouver Stormwater Source Control Guidelines for the design of GRI including:
    - Absorbent Landscapes
    - Infiltration Swale System
    - Infiltration Rain Garden
    - Pervious Paving
    - Green Roofs
    - Infiltration Trench and Soakaway Manholes
- Other chapters may impact usable space or additional setbacks as follows:
    - Chapter 7 relates to third party utilities that may impact the space remaining for implementation of rainwater management systems.
    - Chapter 8 relates to road classifications and design. Specific sections contain information that does not currently inform rainwater management design but may in the future provide opportunity for a more holistic approach to how rainwater is managed both on and off private properties. For example, section 8.4.6 contains information relating to boulevards. This information is currently not of use to rainwater design but could be used for GRI implementation.
    - Chapter 9 relates to streetscape and urban forest design and is taken from The City of Vancouver Street Tree By-law No. 5985, which could affect the availability of space for rainwater management facilities. This also has an impact on the available location of City sewer connections. Depending on the tree type and size, sewer connections often cannot encroach the drip line which may inadvertently impact the already limited space for rainwater management.
    - Chapter 10 relates to street lighting and traffic signals and can also be important when assessing the needs and availability of space for the implementation of rainwater management systems in the right-of-way in conjunction with development.

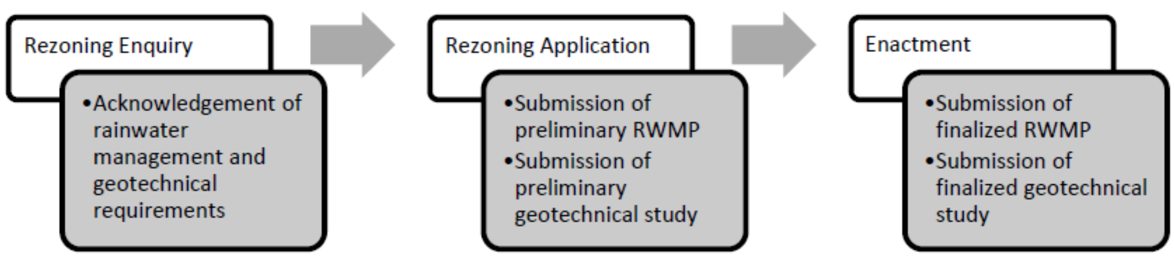
Overall, the Chapters relating to GRI are short and their usefulness for RWMP submissions are limited because the manual was written for a broader audience and not specific to meeting rainwater performance targets. The Rainwater Management Bulletin, discussed below, was intended to provide that direction although there is an opportunity to provide better guidance for developers and designers in how to comply with the VBBL and rainwater management policies.

Note that the 2019 Engineering Design Manual and the Rain City Strategy (RCS) were published around the same time. While the RCS proposed to set a single 48mm performance target for the capture and clean of rainwater, the Engineering Design Manual did not incorporate the 48mm proposal at that time and included the language from the 2018 Rainwater Management Bulletin. As noted above, the Engineering Design Manual is currently being updated.

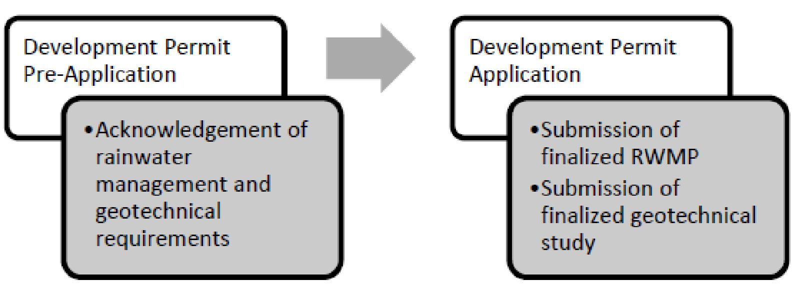
2.7 Rainwater Management Bulletin (2018)

Though the authoritative requirements for rainwater management are contained in the Zoning and Development Bylaw Section 4, the current guiding document for RWMP submissions is the Rainwater Management Bulletin (effective July 11, 2018). The purpose of this section is to examine which requirements currently set the baseline for submissions under this policy. The bulletin states that applications to rezone a development site must include a preliminary RWMP. The process for different application types is laid out in a set of flow diagrams, as shown below. The bulletin also clarifies that large developments (total site size of 8,000 m^2 or more, or containing 45,000 m^2 or more of new development floor area) should follow the requirements within the Rezoning Policy for Sustainable Large Developments.

1. Rezoning Applications



2. Direct Development Permit Applications (major applications, e.g., Cambie Corridor, Broadway Plan)



3. Outright Development (Typical Vancouver)
   Outright uses are permitted "as of right" under the existing zoning and the applicant is typically not required to submit a preliminary RWMP in advance of the development permit submission.

2.7.1 Volume Reduction

This bulletin defines three tiers of methods to achieve the volume reduction target of 24mm. The definitions of the tiers from the Rainwater Management Bulletin are defined as follows:

- Tier 1: Use volume reducing green infrastructure practices. Acceptable practices include but are not limited to: infiltration into in-situ soil, rainwater harvesting and re-use, and green roofs.
- Tier 2: Use non-infiltrating landscapes. For example, rainwater can be directed to absorbent landscape on slab, closed-bottom planter boxes, and lined bioretention systems.
- Tier 3: Use detention in combination with a water quality treatment practice as a last resort. Includes instruction for determining the allowable release rate.

The applicant is to prioritize use of Tier 1 and manage any remainder volume of rainwater using Tier 2 and 3 methods. Justification is to be provided as to why Tier 1 methods were not employed and for each Tier 2 and Tier 3 method selected. A general list of exemptions in the Bulletin are as follows:

- Low infiltration capacity (e.g., less than 1.5mm/hr);
- Limited available space for engineered infiltration systems due to on-site conditions;
- Seasonally high groundwater table or bedrock within 0.6 m of the bottom of the practice;
- Contamination concerns; and
- Slope stability concerns (as supported by a preliminary geotechnical study, see submission requirements below).

Clear instructions for the information needed to justify using Tier 2 or 3 would be beneficial to the applicant. The above is not considered to be an exhaustive list of exemptions.

2.7.2 Release Rate

The Rainwater Management Bulletin provides guidance on how to comply with the requirement for an acceptable rainwater release rate. Intensity-Duration-Frequency (IDF) curves are included within the bulletin. These IDF curves are based on 2014 and a climate adjusted 2100 curve. The pre-development rate is to be defined by the 2014 IDF curve and the post-development intensity is to be defined by the 2100 IDF curve. The release rate is to be limited to the pre-development flow. The bulletin considers pre-development to be the existing condition immediately prior to development.

2.7.3 Water Quality

The water quality target is to treat the first 24mm from all surfaces, pervious and impervious, to remove 80% of total suspended solids. For impervious surfaces with high pollutant loads, the first 48mm of rainfall must be treated. Vegetated practices or absorbent landscapes that can infiltrate or filter the appropriate water quality volume through a minimum of 450mm of growing media are considered to meet the water quality requirement.

Proprietary treatment devices need to meet the above treatment standard and be certified by either the Washington State Department of Ecology's Technology Assessment Protocol – Ecology Program (TAPE) or Environment Technology Verification (ETV) Canada.

2.8 Review of Rainwater Management Plans

2.8.1 Rainwater Management Plan Overview

To understand how applicants are complying with the RWM Bulletin requirements, the project team was provided Rainwater Management Plans (RWMP) prepared by a range of consultants and reviewed by the City of Vancouver. The City initially provided 100 RWMPs, which were reviewed in detail and information was extracted to create a project database for analysis. The City subsequently provided another 192 RWMPs, which were used to validate the findings from analysis of the original 100. Note this assessment does not represent final accepted RWMPs; rather, they were reviewed in various stages of submittal and acceptance for this exercise.

2.8.2 RWMP Data Analysis

The information below is a summary of the RWMP analysis, providing an overview of the current state, potential concerns, and whether the objectives presented in the Rainwater Management Bulletin were achieved. This assessment depicts the on-site component of GRI usage only.

To meet the volume reduction criteria provided in the Rainwater Management Bulletin, a proposed development must manage 24mm of rainfall, ideally through retention-based Tier 1 GRI practices (e.g., infiltrating bioretention, green roofs, or rainwater reuse). If a project meets acceptable exemptions for using Tier 1, they may then pursue either Tier 2 GRI (e.g., non-infiltrating bioretention, absorbent landscape on slab), which will provide some limited retention along with detention, or the Tier 3 practice of detention with treatment. The table below outlines the percentage of projects in the sample that achieved some or all of the 24mm volume reduction requirement through retention, using either Tier 1 or Tier 2 GRI practices.

Table 2-1: Rainfall Retention Thresholds

Retention Depth Achieved	Projects Retaining Runoff with			
	Only Tier 1 Methods	Only Tier 2 Methods	Both Tier 1 and Tier 2 Methods	Total
24+ mm	2%	4%	7%	13%
18 to <24 mm	2%	1%	9%	12%
12 to <18 mm	0%	1%	14%	15%
6 to <12 mm	3%	2%	19%	24%
<6 mm	2%	15%	13%	30%
Any Retention	9%	23%	62%	94%

The above data highlights that only 13% of the proposed projects analyzed met the rainwater management criteria using retention-based practices, and only 2% using only the preferred Tier 1 methods. Though 94% of project met at least some portion of rainwater management with retention in either a Tier 1 or Tier 2 practice, over half of the projects were not able to provide retention for even half of the depth requirements (i.e., 30% retained less than 6mm and an additional 24% retained between 6 and 12 mm). For all of these projects, the remainder of the volume capture requirement is met with Tier 3 detention practices (e.g., 9% of projects had some combination of Tier 1 and Tier 3, and 62% of projects had some combination of Tier 1, Tier 2, and Tier 3).

In addition to documenting what facilities were used to meet the design targets, the team looked at the range, and average, performance achieved for retention-based practices. This is shown in the following table.

Table 2-2: Rainfall Retention Ranges

Retention Method	Runoff Retained		
	Min.	Avg	Max
Tier 1 Only	2.9 mm	17 mm	>24 mm
Tier 2 Only	1.4 mm	13 mm	>24 mm
Both Tier 1 & 2	0.7 mm	18.5 mm	>24 mm

Though some projects are achieving high levels of retention, and others almost none, the average depth retained is about 71% of the standard for projects using only Tier 1 methods (17 mm), 54% for projects using only Tier 2 methods (13 mm), and 77% for projects using both Tier 1 and 2 methods (18.5 mm). The remainder of the 24 mm capture target is being addressed by Tier 3 detention facilities.

2.8.3 Tier 1 Methods

Out of the 100 RWMPs examined, 74 proposed some form of Tier 1 management and 47 proposed a higher performing tool other than absorbent landscaping. Multiple methods for Tier 1 may be proposed within a single RWMP. The below table summarizes the total number of GRI practice types that were proposed.

Table 2-3: Tier 1 Methods Used

GRI Method	Number of Occurrences
Absorbent Landscape	47
Green Roof	37
Subsurface Infiltration	7
Permeable Pavement	5
Bioretention	4
Rainwater Harvesting & Reuse	2
Tree Trench	1

2.8.4 Tier 2 Method

Out of the 100 RWMPs examined, 90 proposed some form of Tier 2 management, and 51 had a tool other than landscaping on slab. Multiple methods for Tier 2 may be proposed within a single RWMP. The below table summarizes the total number of GRI practice types that were proposed:

Table 2-4: Tier 2 Methods Used

GRI Methodology	Number of Occurrences
Absorbent Landscape on Slab	64
Planter Boxes	42
Permeable Pavement on Slab	10
Passive Irrigation System (Permavoid)	4

2.8.5 Tier 3 Methods

Out of the 100 RWMPs examined, 99 proposed some form of Tier 3 management, 53 proposed only non-infiltrating or low performing (e.g., absorbent landscaping) Tier 1 or 2 tools along with Tier 3, and 15 proposed only absorbent landscaping along with Tier 3 tools. Multiple methods for Tier 3 may be proposed within a single RWMP. The below table summarizes the total number of rainwater management types that were proposed:

Table 2-5: Tier 3 Methodology Usage

GRI Methodology	Number of Occurrences
Detention Tank	90
Proprietary Water Quality Device (includes Jellyfish, Stormceptor, CDS)	82
Blue Roof	3
Detention Pond	1

2.8.6 Key Observations

- The most frequently proposed Tier 1 GRI tool was absorbent landscaping, which is often just the natural landscape areas included around the edges of properties where the parkade is located. Absorbent landscaping often represents a small portion of the site and typically does not manage significant impervious runoff.
- Green roofs were the next most common Tier 1 tool type found. Green roofs were often encouraged by the City during the review process. Higher performing infiltrating Tier 1 GRI

methods, such as bioretention, infiltration galleries, or permeable pavement, were much less common and found primarily on large sites with institutional land uses.

- Rainwater harvesting and reuse was also not commonly used, with only two instances of proposed.
- Tier 2 GRI methods primarily consist of absorbent landscaping on slab and lined planter boxes. Rainwater is infrequently directed towards these GRI and their performance is limited.
- Tier 3 practices, primarily detention tanks and proprietary treatment devices, were by far the most common method of managing rainwater with nearly all projects (93%) utilizing a detention facility of some kind.

In reviewing the City's response comments to the RWMPs, justification for lack of Tier 1 methods is typically requested and the review comments usually strongly encourage a higher proportion of Tier 1 approaches. Infiltration is commonly rejected by the applicant as a viable methodby citing the On-site Infiltration Systems Bulletin (described above). Suggestions to utilize a green roof on a project are often countered with a letter from a structural engineer citing that it would be structurally infeasible, for instance due to a wood frame structure.

2.9 Current State Assessment Conclusions

The project team reviewed the key codes, by-laws, policies, and bulletins written to assist developers and designers in developments that contribute towards meeting the goals and strategies to improve rainwater management and overall sustainability. The project team noted the following conclusions:

1) Applicability for when rainwater management in redevelopment is required is not explicitly stated. The by-laws state that RWMP requirements are discretionary, per drainage analysis, and/or case by case (i.e., Cambie Corridor and Broadway Plans). There is no citywide standard (or threshold) for rainwater management applicability and performance.

2) Overlaps exist between different rainwater policies. For example, some policies have conflicting instructions such as the City of Vancouver Engineering Design Manual, the Integrated Rainwater Management Plan, and the Rain City Strategy.

3) Multiple locations for drainage and rainwater management information and requirements. The VBBL provides basic information on some specific elements of design and all codes necessary for plumbing and drainage. However, this by-law provides only a portion of information needed by designers for rainwater management, which can result in wide range of design approaches. Subsequent bulletins seek to clarify parts of the VBBL and provide addition resources but fail to provide a detailed rainwater management methodology or to consolidate most of the required information for successful RWMPs.

4) The Engineering Design Manual is a robust document that provides information covering a variety of engineering design issues, particularly servicing and streetscape design. While it provides the technical information needed for these designs, as well as methodology for a variety of calculations, it does not provide a comprehensive summary of all the key information

to be considered when designing a rainwater management system specific to a redevelopment scenario.

5) The RWM Bulletin provides much of the required performance criteria to be met for rainwater management but only briefly touches on elements of GRI design. This document, together with the Engineering Design Manual, could provide most information needed for the design of a rainwater management system. However, the Manual is general and does not provide specific guidance on how to integrate GRI into site and development plans. The Team recommends a standalone and comprehensive manual for meeting stormwater management requirements that clarifies applicability, performance standards, and design guidance.

6) The by-laws and policies reviewed above successfully provide most of the information required for design but lack the needed consolidation and completeness for successful implementation of all policies. Various policies and bulletins serve as appendices to many of the by-laws, and designers are expected to evaluate all these documents to obtain the required information. This can be quite time consuming as some of these by-laws, policies and bulletins can be difficult to find from the cities website if a designer is not aware they are relevant.

7) Performance requirements are unclear. The RCS is an aspirational document that proposed the capture and treatment of the first 48mm of rainfall during a rainfall event; however, most of the documents reviewed, containing similar information, require the capture and treatment of the first 24mm of rainfall during a rainfall event. If the goal of these documents is to assist in the fulfillment of these strategic goals, that needs to be reflected in the documents themselves through more stringent requirements.

8) Broader policy goals justifying the rainwater management requirements are unclear. The benefits to the drainage system and receiving waters from scaled implementation for the 48mm requirement have not yet been quantified. Completing this analysis would give the City's policies grounding and direction to align with the Vancouver Plan and Healthy Waters Plan as redevelopment occurs over the next 30 years.

Overall, the project team recommends that the City of Vancouver revise and consolidate the codes, by-laws and bulletins behind a clear policy goal, and then translate that goal to rainwater management at the project-scale through a single guidance manual that is easy to navigate and use for both developers and city staff.

3. Needs Assessment

The Needs Assessment categories and themes below were developed based on identified questions, opportunities, barriers, and gaps that have been gathered thus far. Priority items (focused on a limited number) will be addressed through the ensuing Jurisdiction Scan and technical analysis. Other needs will be addressed in the Task 9 policy section or will be documented for resolution by the City in subsequent efforts.

The City provided an initial list of questions to be considered for the Needs Assessment. Those were combined with the observations from the Current State Assessment and the Task 8 - Barriers analysis to create the seven themes listed below.

1. **Applicability and Project Scale**
   Under this theme, this assessment will establish clear minimum and maximum thresholds for determining applicability and compliance with the Rainwater Management Bulletin or other policies for large development projects, specifically discuss applicability for single family residential projects, and articulate how applicability aligns with related ongoing drainage planning and land use/growth planning efforts. This discussion would also consider the type of drainage system fronting the project (and any planned drainage infrastructure upgrades in the project area).
2. **GRI Design Parameters**
   The questions and recommendations related to GRI design parameters will establish the technical metrics applying to all GRI types, such as runoff coefficients, infiltration rates and drawdown times, underdrains, and flow control devices, and establishing consistent terms, definitions, and descriptions associated with GRI design.
3. **Performance Standard and Sizing GRI Practices**
   This assessment will establish clearer performance standards, sizing methods, site-scale modeling parameters, and determine the tools needed to properly size GRI within a site.
4. **Water Quality and Treatment**
   This assessment will clarify and streamline the requirements for water quality treatment including discussions of various surfaces, uses, and level of treatment required.
5. **Site Peak Flows and Release Rates**
   These recommendations will streamline and standardize the current approach by clarifying release rate and treatment requirements for rainwater that is not retained by GRI (also see #4), and at which scales to evaluate release of excess water (not infiltrated).
6. **Guidance Documents**
   This peer review assessment will identify design guidance provided by sister agencies that address barriers and gaps in the context of rainwater management for redevelopment in Vancouver. The jurisdictional scan will note which municipalities/utilities have published design and process guidance written specifically for redevelopment applicants to streamline submittals and approvals for rainwater management requirements and key content included in those documents.
7. **Regulatory Recommendations**
   This assessment will include a detailed code and bylaw review and suggest revisions to allow for recommended GRI design methods, where required.

4. Jurisdictional Scan

4.1 Jurisdictional Scan Methodology

The jurisdictional scan used the Needs Assessment categories and the lenses listed below as the framework to collect key information on municipalities with relevant rainwater management policies, recommended design methodology, and successful mechanisms for achieving compliance.

The scan covered the following municipalities:

1. Toronto, Ontario
2. North Vancouver, British Columbia
3. Portland, Oregon
4. Seattle, Washington
5. San Francisco, California
6. Philadelphia, Pennsylvania
7. Washington, D.C.

In addition to the Needs Assessment themes, the scan reviewed for key information on several relevant regulatory examples and "best practices" from North American jurisdictions such as:

- Integration of green roofs as an acceptable GRI tool for stormwater compliance as well as noting overlapping policies for green roofs
- Success and maturation of the policies and programs for stormwater compliance
- Distinguish the various drivers for each jurisdiction's policies and requirements
- Strengths and weaknesses as they relate to the GRI Pathways goals

The team also reviewed published reports that analyzed North Vancouver, BC, Portland, OR, and Washington, D.C. Other source documents were the publicly available rules, guidelines, codes and/or plans for each jurisdiction. The data collection focused on the categories/themes listed above in the Needs Assessment and specific relevant examples for Vancouver. The team collected consistent data points across each municipality so the scan will produce comparable results, to the extent possible. Each jurisdiction also included a description of key findings, best practices, and innovative ideas.

4.2 Jurisdictional Scan Summary

The scan focused on municipalities with both separate and combined drainage systems, except for North Vancouver which has only a separate storm drainage and sanitary sewer system. It highlighted the goals and drivers for the respective stormwater management regulations as well as the specific standards established.

In addition to this summary, Exhibit A provides a comprehensive and detailed description of these programs, including links directly to the legal authority and codes/bylaws enabling each jurisdiction to enforce the stormwater regulations in new and redevelopment.

The scan found that all jurisdictions had clear standards for where and how the stormwater regulations were applied. It also found that all jurisdictions had some form of alternative or modified compliance or variance built into its codes and manuals.

All jurisdictions had guidance manuals specifically written for stormwater compliance in new and redevelopment projects that meet the stated thresholds or applicability. While these vary in quality and comprehensiveness, the manuals lay out the background and purpose, design criteria and standards, submittal requirements, exceptions, and other critical details to ease the compliance process for the applicant and the regulating agency. The scan also noted where site-scale modeling is required and if sizing tools are provided by the jurisdiction for the applicants. As much as possible, the scan noted how long the stormwater management regulations for new development have been in place.

In the relevant findings for each jurisdiction, the scan includes additional programmatic efforts by the jurisdiction to encourage or require green roof installation, either as an optional tool to meet the stormwater regulations or for other sustainable building/urban greening goals. It also notes other city-sponsored programmatic efforts to retrofit existing buildings and residential properties using GRI. Links are provided throughout the jurisdictional scan attached as Exhibit A for reference whenever available.

For the US jurisdictions, there are clear similarities driven by the Clean Water Act, as summarized below.

- Stormwater codes for development were primarily enacted as result of federal and state requirements pursuant to the Clean Water Act. While the CWA regulates combined systems and separate (MS4) systems differently, the MS4 permits specifically require "post-construction" compliance for regulated sites. Due to this:
    - Applicability of the requirement is standard and clearly defined in all US jurisdictions and often dictated by the MS4 permit language (e.g., disturbance area thresholds), however some jurisdictions choose to broaden applicability to achieve greater benefits beyond MS4 minimum requirements.
    - Detailed guidance manuals specific to meeting the stormwater management requirements in development are ubiquitous in the US jurisdictions, as are local codes establishing authority, permitting, and enforcement of the requirements.
    - The technical tools and requirement for sizing and designing the stormwater management practice vary, but the manuals all provide detailed instructions and expectations for how to complete the calculations and often provide design standards. Often these are provided by the state stormwater manual.
- In recent years, some jurisdictions with both types of drainage systems have decided to regulate their whole service area under the same rules and providing benefits for both CSO and separately sewered areas.

For the two Canadian jurisdictions, the respective provinces directed the jurisdictions to produce either a liquid waste management plan or a wet weather management plan, which resulted in rainwater management requirement for new development. Like the US cities, these plans are driven by watershed health and receiving water quality as well as drainage and flooding. There does not appear to be a standardized permitting and reporting process similar to the one the US EPA administers and it's unclear how that influences the Canadian Provinces and smaller jurisdictions in pushing them to achieve highest outcomes. However, Toronto's example of the Toronto Green Standard achieves the integration of high standards for green building and climate goals, including stormwater and reuse, as a cohesive policy. This implementation strategy allows the city to avoid the siloed processes and requirements that many US cities struggle with in complying with the CWA.

5. Current GRI Design Methods

Current GRI design methodology is outlined in the City of Vancouver's Engineering Design Manual, which is discussed in detail in Section 2.6 above. The manual was developed as a comprehensive guide that documents the typical design processes and criteria to be used for projects constructed in the City of Vancouver. Chapter 5 of the manual contains the information currently required for the design of a functional stormwater management system, including GRI, as part of a development. This includes design flow information, methods of calculation, runoff coefficients, rainfall data, and component design guides. Current GRI design follows the design information and procedures outlined in the manual to meet the design standards and performance targets. That criteria and a more detailed discussion of the methods are presented below.

5.1 Current Design Standards

There are three elements of the onsite rainwater management requirements for GRI: volume reduction, water quality treatment, and release rate. The following are direct excerpts from the City of Vancouver's 2018 Rainwater Management Bulletin (RMB) that was created to provide developers and designers guidance on meeting the City's onsite rainwater management requirements as defined by the Zoning and Development Bylaw, Section 4 Development Permits, Paragraph 4.3.6.

Volume Reduction

> *Capture 24mm of rainfall in 24-hours from all areas, including rooftops, paved areas, and landscape and infiltrate, evaporation, or reuse it.*

Water Quality

> *The first 24mm of rainfall from all pervious and impervious surfaces shall be treated to remove 80% Total Suspended Solids (TSS) by mass prior to discharge from the site. For impervious surfaces with high pollutant loads, including roads, driveways, and parking lots, the rainfall to be treated increases to the first 48mm of rainfall. Treatment can be provided either by a single green infrastructure practice or structural Best Management Practice (BMP), or by means of a treatment train comprised of multiple green infrastructure practices or structural BMPs in sequence that can be demonstrated to meet the 80% TSS reduction target.*

Release Rate

> *The rainwater management system for the building(s) and site shall be designed such that the peak flow rate discharged to the sewer under post development conditions is not greater than the peak pre-development flow rate for the return period specified in the City of Vancouver's Intensity Duration Frequency curve (IDF curve). The City of Vancouver's 2014 IDF curve is utilized for pre-development design flow calculations, and the City's 2100 IDF curve, which takes into account the effects of climate change, is utilized for post-development design flow calculations. Pre-development, in this context, means the site's immediate use preceding development.*

The rainfall depths listed for volume reduction and water quality are design standards, and roughly equal to 50% of the 6-month, 24-hour storm (24mm) and the full 6-month, 24-hour storm (48mm). Based on rainfall analysis performed for the City of Vancouver, these design standard rainfall depths capture roughly to 70% and 90%, respectively, of the annual rain events experienced in Vancouver. The performance targets and design standards are described in further detail in Volume 1 of the Citywide Integrated Rainwater Management Plan (IRMP) and are based on guidelines from the federal Department of Fisheries and Oceans. The following sections will discuss GRI design methods in terms of the design standards, as they are used by developers and written into the City's Zoning and Development Bylaws.

5.2 Current Runoff Calculation and GRI Design Practices

Based on the above criteria and the process outlined in the Engineering Design Manual, the runoff is calculated and GRI designed for proposed developments using the following generalized methods. These generalizations are based on the guidelines in the Engineering Design Manual and a review of over 100 submitted RWMPs.

5.2.1 Volume Reduction

In the context of volume reduction, there is no mention in any of the City's guidance as to the use of volume-based runoff coefficients, Curve Numbers, or initial abstraction of rainfall, all of which are commonly used when calculating rainfall-runoff volume. Thus, the total runoff volume required to be captured (i.e., retained onsite) for each project is simply equal to the project area multiplied by the 24mm rainfall depth. This results in an over estimation of runoff volume, which makes it difficult for developments to retain this volume onsite. Rainfall that falls onto pervious areas, such as natural landscape or GRI, is typically subtracted from the total runoff volume - provided there is sufficient storage in the soil or media of those features based on the area, depth, and assumed porosity. If there is additional storage after the direct rainfall is stored in the pervious areas, runoff from impervious areas can be directed to the natural landscape or GRI for further reduction of the total site's runoff volume. Of the RWMP's reviewed for this study, only 13% of the developments proposed sufficient natural landscape and GRI to capture the full 24mm of rainfall from project site. The remaining 87% of those projects meet the GRI performance criteria by detaining and treating some or all of the runoff prior to discharge.

5.2.2 Water Quality

The water quality treatment volume is calculated using the same method as the volume reduction volume, as it is typically the same volume minus the amount that is retained by the natural landscape and GRI as described above. There is additional water quality treatment volume from "high pollutant" areas, primarily on-parcel driveways and parking lots, but these features are not common in high-density developments where parking is often provided in below-ground parkades. Therefore, for most of the projects, the water quality treatment volume is simply the project area multiplied by 24mm rainfall depth minus the runoff captured by natural landscape and GRI. This water quality treatment volume is typically used as the size of the detention tank required for storage, provided that the detention required to meet the release rate requirement is not larger. Typically, detained runoff is released at a rate not to exceed the pre-development release rate as calculated below and treated using proprietary treatment devices prior to discharge. Since the release rate is dependent upon the brief yet intense 5- or 10-year storm events, contingent on land use, the result is that there is little detention of runoff from less intense, longer duration storm events.

5.2.3 Release Rate

The Engineering Design Manual provides two options for designing on-site storm systems and calculating release rate: the rational method for sites less than 20 hectares (ha) and the hydrograph method for sites larger than 20 ha (no specific hydrograph method is mentioned, though it is noted that the modeling approach must be approved by the City). Given that 20 ha (200,000 square meters) is an especially large project site and not typical of developments in Vancouver, the release rate for most projects is calculated using the rational method.

Using the rational method, the current pre-development peak flow (Qpre) and future post-development peak flow (Qpost) for the appropriate design storm is calculated using the equation Q = C x I x A, where:

(A) is project area

(C) is the weighted runoff coefficient based on the coefficients in Tables 5-1 or 5-2 of the Engineering Design Manual and the proportional area of each surface type for both existing and proposed conditions

(I) is the rainfall intensity determined using the IDF curves for the appropriate year (2014 for pre-development and 2100 for post-development) based on the assumed Time of Concentration (ToC), which is typically 5 or 10 minutes given the relatively small and highly developed sites, and design storm event return period (5-year for residential projects, 10-year for commercial, industrial, and downtown core projects).

The peak release rate for the post-development scenario must be at or below the pre-development peak flow. Given the intensity of the short duration 5- and 10-year storms, the pre-development or design release rate is high, with an average of around 40 liters per second (L/s) or 130 liters per second per hectare (L/s/ha) for the RWMPs reviewed as part of Task 2.

The required storage volume to meet the design release rate is commonly determined through the rational hydrograph method, which involves calculating the pre- and post-development peak flow using the rational method for multiple storm durations, starting at 5 minutes, and increasing in either 1-minute or 5-minute intervals. The difference in the pre- and post-development peak flows for each storm duration is then multiplied by the storm duration to determine the required storage volume for each. The required detention storage volume is either the largest of these calculated storage volumes or, as is more commonly the case, the water quality treatment volume determined above.

The City has recently changed the RWMP review process in an attempt to optimize the requirements for release rate. Under this process, if the detention required from the water quality treatment volume above is larger than the detention necessary to meet the release rate requirement, the release rate is reduced from its pre-development peak flow rate until it reaches a release rate that requires the same storage volume as the water quality treatment volume. The result of this change is an improved detention design that has a lower release rate and higher utilization of the detention storage volume. However, since the release rate is still based upon a short duration, 5-year or 10-year storm event, there is likely not much impact to the rainwater runoff release rate from lower intensity, longer duration storm events.

5.3 Evaluation of Current GRI Design Methods

There are several areas where the current approach to rainfall-runoff calculations and GRI design methods based on the current methodology can be improved. A few of them are identified below.

- There is no conversion of rainfall to runoff for volume calculations. Current methodology assumes 100% of the 24mm of rainfall becomes runoff, which is an overly conservative approach and makes compliance more difficult.
- The criteria and guidance state that a proposed project must manage the 24mm rainfall in 24 hours, but this time component is not included in the design process. Volume reduction and water quality treatment volumes are determined based on a static rainfall depth rather than a dynamic rainfall pattern. By not distributing the rainfall depth across a full storm duration or using variable rainfall intensities, the rainwater runoff patterns are over-simplified and resulting GRI designs are often oversized.
- The current methodology uses basic storage calculations, such as media volume times media porosity, for natural landscapes and other, retention-based GRI. This is a good starting point but does not allow for time-variable accounting of dynamic processes such as infiltration into the media, infiltration into the subsurface, temporary ponding of GRI due to peak runoff, or release from detention to the sewers during the storm event. The result is either oversized GRI or, more typically, the opportunity for applicants to justify the use of detention-based GRI to meet the onsite rainwater management requirements.
- Though not common in current development projects, driveways and parking lots are considered “high-pollutant” areas and have an additional 24mm of water quality treatment volume associated with them. Inconsistent rainwater management requirements across a single project complicates the design process, and the majority of pollutants will be captured by the smaller and more frequent rainfall events which produce the first 24 mm of runoff, reducing the value and effectiveness of this additional treatment volume.
- Volume reduction and water quality treatment use simplified, time-independent methods of single rainfall depth while release rate is determined using various design storms and time-dependent calculations. This results in a more complicated evaluation of compliance and ensures that the results are not directly comparable.
- Release rate of water quality treatment volume is initially set at the design release rate based on an intense, short duration, 5-year storm event, then adjusted down to use the required storage volume more efficiently. This results in a high release rate that tends to produce limited peak discharge reduction for longer duration or less intense storms, such as those with 24mm to 48mm of rainfall, where GRI can be more impactful.
- There is little discussion or consideration of standard orifice sizes when setting the design release rate. Proper orifice sizing using standard sizes could potentially lead to larger storage volumes. Additionally, as mentioned in Section 5.2 above, the City is now requiring optimization of orifice size to increase detention for longer duration or less intense storms occurs during the design review process. However, this optimization should be built into the GRI design process from the start to allow for clarity, consistency, and overall better design.

6. GRI Design Methodology

Based on the list of questions provided by the City in the RFP, the needs assessment themes identified, and the evaluation of current methods as described above, an updated GRI design methodology is recommended. The recommended methodology would be a single design storm, distributed over 24 hours, with a unit hydrograph approach to routing that allows for the evaluation of GRI performance in terms of rainwater runoff volume and peak discharge rate. The method proposed is consistent with industry standards and approved methods at other municipalities and will result in a simplified and streamlined GRI design process to meet rainwater management requirements.

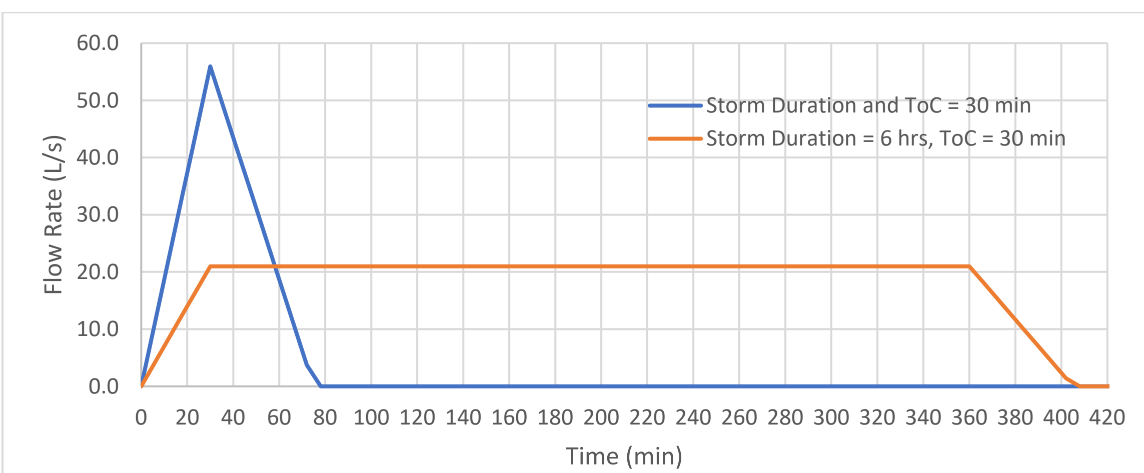
6.1 Rainfall-to-Runoff Methodology

The following sections discuss various methodologies for converting rainfall to runoff using hydrographs to allow for time-variable accounting of dynamic processes in GRI design.

6.1.1 Rational Hydrograph Method

The Rational Method is currently the primary method of calculating rainwater runoff for proposed projects in Vancouver. However, as the Rational Method is only calculating peak flow from a storm of given intensity, and not total runoff volume from a storm event, the volume reduction component of GRI design has been reduced to an overly simplistic calculation as described in Section 5.2. The inputs used in the Rational Method described in Section 5.2 can be used to calculate total runoff volume by using the Modified Rational Method, also known as the Rational Hydrograph Method. In this method, the flow rate calculated using the Rational Method is consistent for the duration of the storm after the ToC. For storm durations equal to a project's ToC, the hydrograph is a triangle with a peak discharge rate at the ToC. For storm durations longer than a project's ToC, the hydrograph is a trapezoid with a constant discharge rate after the ToC based on the intensity of the storm duration. The difference in hydrograph shapes described above can be easily understood graphically as shown in Figure 6-1 below.

Figure 6-1 - Rational Hydrograph Method for Different Storm Durations



In the example hydrographs above, the project's ToC is 30 minutes while the two storm durations are 30 minutes and 6 hours. The shorter storm results in a higher peak flow rate of 56 L/s compared to 21 L/s for the longer-duration storm. But the total runoff for the longer duration storm is 463 m^3 while the total runoff volume for the shorter duration storm is around a quarter of that at 126 m^3. However, as can be seen in Figure 6-1 above, these are both simplistic hydrographs and not necessarily representative of true rainfall conditions. The Rational Method is a universally accepted method for calculating peak flow rates and sizing conveyance structures. The allowance of the Rational Hydrograph Method for sizing GRI varies across jurisdictions but, where allowed, it is only for small, simple project sites with a single GRI.

6.1.2 Santa Barbara Unit Hydrograph (SBUH) Method

The most common method for calculating rainwater runoff volume generating hydrographs across all jurisdictions in the United States is the Soil Conservation Service (SCS) Runoff Curve Number (CN) Method and corresponding SCS Unit Hydrograph Method. The SCS Runoff CN Method assigns a CN, between 30 and 98, to the site based on the properties of the underlying soil along with the type and amount of cover on that soil. The CN is used to calculate initial abstraction, which is the amount of rainwater that can land on a surface before runoff is generated, and then the depth of the runoff is calculated based on the depth of precipitation compared to that initial abstraction. To allow for the inclusion and evaluation of time dependent properties of GRI such as ponding, infiltration, and discharge, runoff is generated based on precipitation in each time-step using the SCS Unit Hydrograph Method. However, as the SCS Unit Hydrograph Method can be difficult to use in spreadsheet-based calculations, a modified version of this called the Santa Barbara Unit Hydrograph (SBUH) Method is recommended. The SBUH Method is based on the SCS Runoff CN Method but is easier to implement in a spreadsheet calculation because it computes the runoff hydrograph directly without going through the intermediate steps of generating unit hydrographs. The SBUH Method uses the SCS Runoff CN Method equations, for computing initial abstraction and precipitation excess, to generate incremental runoff depths for a given drainage area and design storm. The incremental runoff depths from the drainage basin are converted into instantaneous hydrographs that are then routed through a theoretical reservoir with a time delay equal to the drainage area's time of concentration. The corresponding outflows from each drainage area are then summed to determine the site's overall runoff hydrograph. The SBUH Method is an approved and recommended method to calculate rainwater runoff generation in major cities in the U.S. including San Francisco, Portland, Philadelphia, and Washington DC.

6.1.3 Example Runoff Hydrographs and GRI Design

The following examples have been created to demonstrate the differences in the various rainwater runoff hydrograph methods and the corresponding impact on GRI design for a 24mm and 48mm rainfall event. The SBUH Method uses a distribution of the total rainfall depths across a specified duration. The rainfall distribution used is the SCS Type IA, which is the rainfall distribution specified in the Engineering Design Manual for 24 hours, to match the volume reduction criteria as discussed in Section 5.1. For the Rational Hydrograph Method, the IDF tables were referenced to find a storm that has close to 24mm and 48mm depths. Using the updated 2100 IDF tables for Zone 5, the 2-year, 2-hour storm and the 10-year, 1-hour storms have a total storm depth closest to 24mm. As the volume reduction criteria says to capture 24mm of rainfall in 24-hours, the longer duration 2-year storm is used for the 24mm storm. The storms from the 2100 IDF Zone 5 table that most closely match the 48mm depth are the 2-year, 6-hour and 200-year, 2-hour storms. To be consistent and to avoid using such a low annual exceedance probability storm as a 200-year event, the 2-year, 6-hour storm is used. Additionally, to match the City's onsite rainwater management criteria, a 24-hour storm duration for the Rational Hydrograph Method is also used.

6.1.3.1 Runoff Hydrographs from a Fully Impervious Site

The first example involves a 500 square meter (0.05 ha) site that is 100% impervious. For the runoff hydrographs below, it is assumed that a C of 0.85 and CN of 98 are assigned for the Rational Method and the SCS Runoff CN Method, respectively. The time of concentration of the site is set at 10 min while the storm durations for the Rational Hydrograph and SBUH methods are as described above.

Figure 6-2 - Comparison of the SBUH and Rational Hydrograph methods (100% Imp., 24mm Rain)

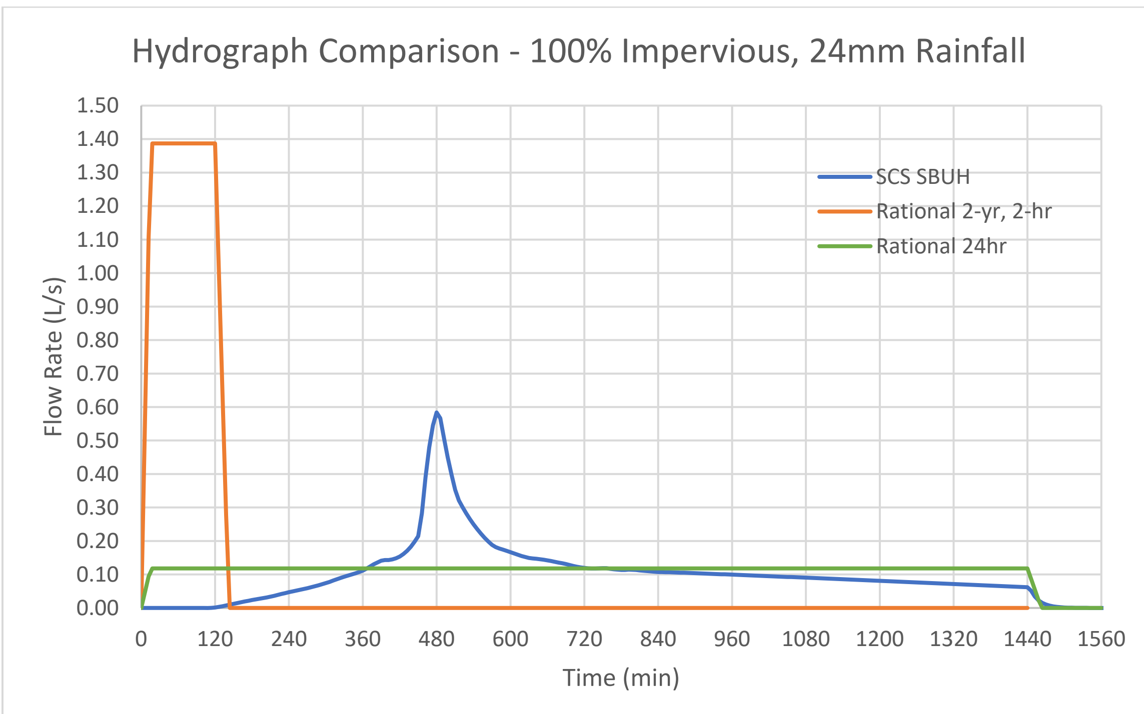


Table 6-1: Comparison of Peak Flow and Total Runoff from a 24mm Storm at 100% Impervious Site

Metric	SCS SBUH		Rational 2-yr, 2-hr		Rational 24hr	
Peak Flow Rate	0.58	L/s	1.39	L/s	0.12	L/s
Total Runoff	9	m^3	10	m^3	10	m^3

Figure 6-3: Comparison of the SBUH and Rational Hydrograph methods (100% Imp., 48mm Rain)

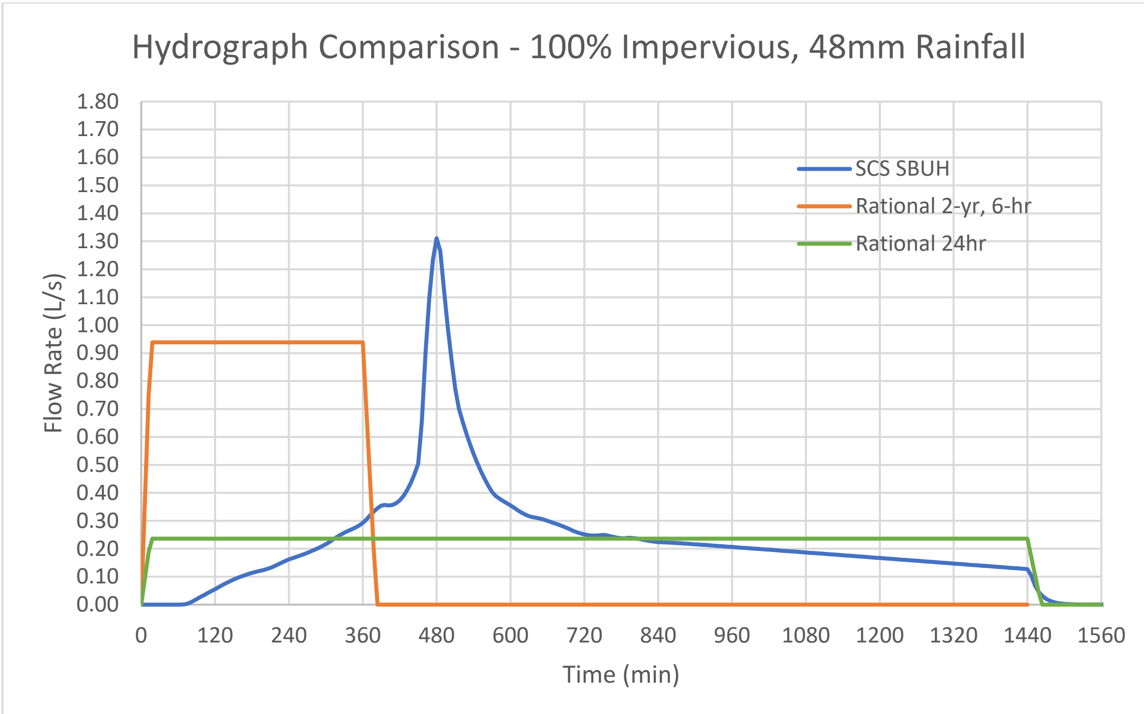


Table 6-2: Comparison of Peak Flow and Total Runoff from a 48mm Storm at 100% Impervious Site

Metric	SCS SBUH		Rational 2-yr, 6-hr		Rational 24hr	
Peak Flow Rate	1.31	L/s	0.94	L/s	0.24	L/s
Total Runoff	21	m^3	20	m^3	20	m^3

The total runoff from the two hydrograph methods is consistent for both storm depths, as the volume from the SBUH Method is within approximately 1 cubic meter (m^3) of the volume from the Rational Hydrograph Method for both storm depths. The total volume increased by 12 m^3 from the small to the large storm event for the SBUH Method while it increased only 10 m^3 for the Rational Hydrograph Methods. For the SBUH Method, the initial abstraction of the impervious surface is used up by a small depth of rainfall, roughly 1.04mm, at the front end of the storm, so the additional rainfall depth is converted nearly entirely to runoff. A 12 m^3 increase in total runoff is equivalent to the 24mm increase in rainfall depth across the 500 square meter site. As the Rational Method does not use initial abstraction but rather assumes a constant rate of conversion between rainfall and runoff, a 10 m^3 increase in runoff is expected as that is equal to 85% of the 24mm increase in rainfall depth across the 500 square meter site.

Unlike the total runoff volume, the peak flow rate varies substantially between the runoff calculation methods and the storm depths. The highest peak flow is seen for the Rational Hydrograph Method using the 2-year, 2-hour storm. This peak flow is a result of consistent rainfall intensity which is simply the total depth of 24mm divided by the storm duration of 2 hours, or roughly 12mm per hour. The peak flow rate from the larger, 48mm storm for the Rational Hydrograph Method is roughly 33% less than the peak flow from the smaller, 24mm storm event. Though this seems counter-intuitive, it is due to the longer, 6-hour duration of the 48mm storm used in the Rational Hydrograph Method which results in an overall smaller consistent rainfall intensity. Unlike the total runoff volumes, the peak flow rates using the Rational Hydrograph Method are not directly proportional between different storm depths unless the storm duration is held constant. This can be seen in the results from the 24-hour storm using the Rational Hydrograph Method where the peak flow rate doubles from 0.12 L/s to 0.24 L/s as the storm depth is doubled.

The SBUH Method uses a rainfall distribution, meaning that a set percentage of the total rainfall will fall within a given timestep, rather than assuming a consistent rainfall intensity across the full storm duration like the Rational Hydrograph Method. This means that the storm duration is fixed and the flow rates are proportional across various storm depths. Thus, using the SBUH Method resulted in the lowest peak flow rate of 0.58 L/s for the 24mm storm depth and the second highest peak flow rate of 1.31 L/s for the 48mm storm depth. These peak flows are not directly proportional due the routing of the runoff through the theoretical reservoir as discussed in Section 6.1.2 above. The Rational Hydrograph Method peak flow rates were 40% higher than those of the SBUH Method for the 24mm storm but 30% less than the SBUH Method peak flow rates for the 48mm storm.

6.1.3.2 Comparison of GRI Design

The hydrographs presented in Figure 6-2 and Figure 6-3 were used to evaluate potential GRI design in Vancouver. In addition, to evaluate potential infiltration-based GRI, hydrographs were created for the two methods and two design storm depths for an example 500 square meter site that is 80% impervious and 20% pervious. The pervious areas of the site were assigned a CN of 74, for grass cover in soil group C, and a C of 0.18, from Table 5-2 of Vancouver's Engineering Design Manual, for the two runoff hydrograph methods while those for impervious areas remained the same at CN of 98 and C of 0.85. These hydrographs from the 80% impervious site are not presented as figures in this report because they do not differ substantially from the figures for the 100% impervious site presented above. The total runoff volume and peak flow rates from the hydrographs, however, are shown in Table 6-5 and Table 6-6 below.

Detention Tanks at a 100% Impervious Site

As the first example was for a 100% impervious site, a detention tank was used for the representative rainwater management facility as that is likely what would be proposed for such a development. Though the simplest way to size a detention tank is to have its volume equal the total unmanaged runoff volume, as is done in the current approach, more nuanced design would also factor in the discharge that occurs during the storm event. As the peak flow rates from the two hydrograph methods differ, the discharge rate was set at 25% of the peak flow rate (75% reduction) to allow for more comparable results. The design discharge rates and required retention volumes are shown in the tables below for the two design storm depths. The peak flow and design discharge rates for the current approach are included, but these are based on the 5-year, 15-minute storm events as discussed in Section 5.2.

Table 6-3: Comparison of Discharge Rate and Required Detention Volume for the 24mm Storm

Metric	SCS SBUH	Rational 2-yr, 2-hr	Rational 24-hr	Current Approach
Peak Flow Rate	0.58 L/s	1.39 L/s	0.12 L/s	5.11 L/s
Total Runoff Volume	9 m^3	10 m^3	11 m^3	12 m^3
Peak Flow Reduction	75%			27% (Var.)
Design Discharge Rate	0.15 L/s	0.35 L/s	0.03 L/s	3.75 L/s
Required Detention Volume	1.7 m^3	7.6 m^3	7.7 m^3	12 m^3

Table 6-4: Comparison of Discharge Rate and Required Detention Volume for the 48mm Storm

Metric	SCS SBUH	Rational 2-yr, 6-hr	Rational 24-hr	Current Approach
Peak Flow Rate	1.31 L/s	0.94 L/s	0.24 L/s	5.11 L/s
Total Runoff Volume	21 m^3	20 m^3	20 m^3	24 m^3
Peak Flow Reduction	75%			27% (Var.)
Design Discharge Rate	0.33 L/s	0.24 L/s	0.06 L/s	3.75 L/s
Required Detention Volume	3.8 m^3	15.3 m^3	15.3 m^3	24 m^3

The current approach results in the largest required detention volume for both storm depths as the site is 100% impervious and therefore it is assumed that 100% of the rainfall becomes unmanaged runoff. For the more detailed, time-dependent design methods, the detention volumes required using the Rational Hydrograph Method for runoff generation are roughly 4 to 4.5 times the required detention volumes using the SBUH Method for both storm depths, even when the SBUH Method results in a higher peak flow rate. The reason is that the SBUH Method uses a rainfall distribution which assumes only a moment of peak rainfall intensity while the Rational Hydrograph Method assumes a consistent rainfall intensity across the full duration of the storm.

<u>*Bioretention at an 80% Impervious Site*</u>

A second example was developed assuming an 80% impervious site where retention and infiltration of rainwater runoff is feasible. To evaluate the impact of the two runoff methods on this type of GRI, a generic bioretention facility was used assuming standard bioretention design parameters as discussed in the Task 3 Representative Rainwater Management Tools memorandum. Filtration rate into the bioretention media was not considered as part of this analysis but infiltration into the subsurface was set at 20mm/hr. The required area of bioretention necessary to retain 100% of the 24mm and 48mm runoff volumes are shown in the tables below, along with the impervious drainage area to bioretention area sizing ratio.

Table 6-5: Comparison of Required Bioretention Area for the 24mm Storm

Metric	SCS SBUH	Rational 2-yr, 2-hr	Rational 24-hr	Current Approach
Peak Flow Rate	0.47 L/s	1.17 L/s	0.10 L/s	4.31 L/s
Total Runoff Volume	8 m^3	9 m^3	9 m^3	8.6 m^3
Retention Target	100%			
Required Bioretention Area	10.1 m^2	22.9 m^2	10.6 m^2	25.6 m^2
Bioretention Sizing Ratio	2.5%	5.7%	2.7%	6.4%

Table 6-6: Comparison of Required Bioretention Area for the 48mm Storm

Metric	SCS SBUH	Rational 2-yr, 6-hr	Rational 24-hr	Current Approach
Peak Flow Rate	1.05 L/s	0.79 L/s	0.20 L/s	4.31 L/s
Total Runoff Volume	18 m^3	17 m^3	17 m^3	17.2 m^3
Retention Target	100%			
Required Bioretention Area	23.1 m^2	37.7 m^2	21.1 m^2	51.2 m^2
Bioretention Sizing Ratio	5.8%	9.4%	5.3%	12.8%

As with the detention tank example above, the current approach results in the largest required GRI as it is time-independent and no subtraction from the runoff volume from infiltration occurs. Between the two hydrograph approaches, the Rational Hydrograph Method using the 2-year storms again results in the larger required GRI compared to that designed using the SBUH Method, even when the SBUH Method results in the higher peak flow rate. However, the required bioretention area for the Rational Hydrograph Method using the 24-hour storm distribution is nearly half the size using the 2-year, 6-hour storm and approximately equal to that using the SBUH Method. This is because both the SBUH and 24-hour Rational Method storms distribute the same amount of rainfall over the same duration of time, even if the SBUH Method using the SCS Type IA distribution produces a brief period of intense rainfall that is not matched by the 24-hour Rational Hydrograph Method distribution.

6.1.4 Recommendation for Rainfall-Runoff Methodology

The Rational Hydrograph Method is an acceptable method for calculating rainwater runoff from a study area and allows for time-variable account of dynamic processes in GRI design. It is also similar to the current approach used by developers in Vancouver and therefore likely to be used by the development and engineering community on future projects. However, the Rational Hydrograph Method is a simplistic approach to runoff calculations that is only appropriate for small sites, typically less than 0.5 ha, with simple approaches to GRI design and compliance. Also, the Rational Hydrograph Method is based on the Rational Method, which was developed to determine peak flow rates rather than total rainwater runoff from storm events. To evaluate runoff volume, a storm duration must be determined and a rainfall intensity calculated. The result is a peak flow rate that is both consistent across, and highly dependent upon, the chosen storm duration. This could potentially lead to GRI design and rainwater management compliance that is inconsistent across projects.

One of the overall purposes of this study is to evaluate and develop potential pathways that proposed projects can use to comply with the City's onsite rainwater management requirements. Additionally, the stated goal of this task is to simplify and streamline rainwater management criteria and the GRI design process. The SBUH Method is standard industry practice for runoff calculations and GRI design and has been used in multiple jurisdictions for decades. Coupled with an appropriate rainfall distribution, the SBUH Method allows for the evaluation of both peak flow rate and total runoff volume from rainfall patterns that mimic real-world conditions. Additionally, as shown in Section 6.1.3.2 above, the SBUH Method results in better design, as the rainfall distribution typically allows for higher efficiency GRI by minimizing area or volume while still capturing the required runoff and peak flows. Therefore, it is recommended that the Pathways Study use the SBUH Method with a fixed rainfall distribution that will allow for a simple, but not simplistic, evaluation of rainwater runoff and GRI design.

6.2 Design Storms and Performance Targets

One of the stated goals of the overall project is to "simplify and streamline the City's rainwater management requirements to simplify and streamline the GRI design process." As described in Section 5.1, there are currently two design standards for volume reduction and water quality, that are based on 70% and 90% annual rainfall capture depths. Using two different rainfall depths at the same project site based on ill-defined surface types can cause confusion and complications. Additionally, though the intent of the two different rainfall depths is to capture and treat more runoff from the high-pollutant surfaces, it is generally understood that the highest pollutant loading in rainwater runoff occurs during the first inch (or 25.4mm) of rainfall, which includes the "first flush" of build-up/wash-off constituents in the urban environment. Therefore, the additional water quality treatment volume associated with the high-pollutant surfaces likely provides only incidental reductions in the total pollutant load to receiving water bodies. It is recommended that a single design storm be applied uniformly across the site for rainwater runoff and GRI design purposes.

This Study assumes that the 24mm and 48mm design standards are the performance targets and appropriate depths to capture 70% and 90% of the average annual rainfall. However, our team's understanding is that the City is currently undertaking a separate study to examine rainfall patterns and depths across the city. At the conclusion of that rainfall study, the assumptions that a 6-month, 24-hour storm has a total depth of roughly 48mm and that 48mm depth is equal to the capture of 90% of the average annual storms should be confirmed. The results of the modeling undertaken in Task 5 - Performance Modeling of this Pathways Study will provide guidance as to how much retention and treatment is possible at developments with varying building and site characteristics. Based on these results, and the results of the rainfall study, a retention depth design standard that differs from either 24mm or 48mm should be considered.

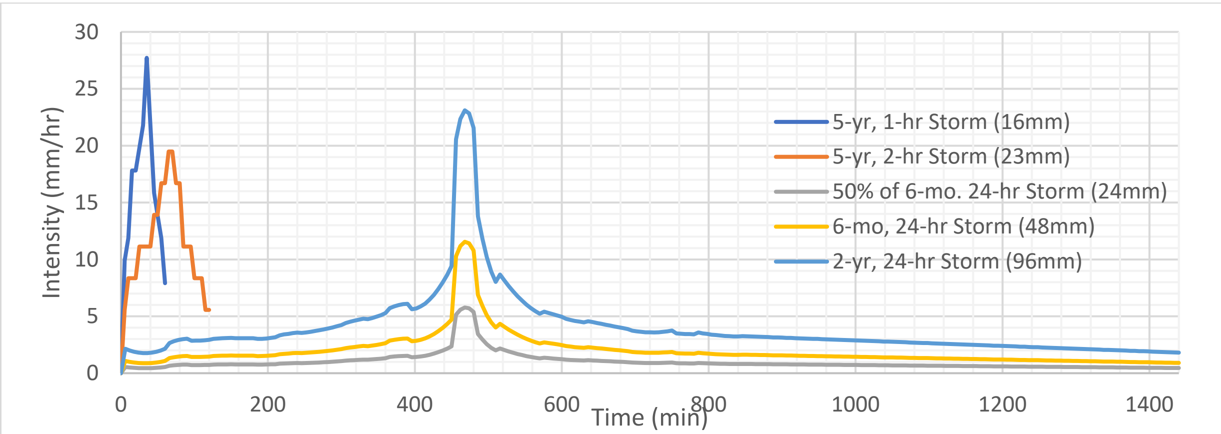
Unlike the volume reduction and water quality treatment depths, the required release rate from a project is not based on the targets established in Volume 1 of the IRMP. The IRMP does include a release rate target but specifically states that it is only for "large scale developments" that are defined by the City as sites greater than 8,000 square meters. For those developments, the post-development release rate must be at or below the pre-development release rate for the 2-year, 24-hour storm event. For smaller developments, there is no mention of a release rate target listed in the IRMP. This release rate target is not reflected in the Rezoning Policy for Sustainable Large Development, which aligns with the Zoning and Development Bylaw, or the Sustainable Large Development Bulletin, which references the Rainwater Management Bulleting. The performance standard for release rates from these documents, as stated above in Section 5.1, is the same target as traditional development using gray infrastructure, which is typically not suitable for GRI design since the goals of gray and green infrastructure differ. The short duration and high intensity of the 5-year or 10-year, 5- or 10-minute storm used for release rate calculations results in a high pre-development release rate target which, in effect, means that systems with orifices sized to that standard produce no attenuation of peak discharge during smaller or less intense storms. Additionally, the difference between the pre-development 2018 intensity and the post-development 2100 intensity means that the size of the detention tank is large even if the post-development site maintains a pre-development level of impervious surfaces. As shown in Table 6-7 below, even in scenarios where there is no change in runoff coefficient between the pre-development and post-development conditions, the increase between the 2018 and 2100 depths based on the IDF curves is substantial.

Table 6-7: Typical Rainfall Intensities Used for Release Rate Calculations

Design Storm	Storm Depth	Peak Intensity	Difference
	(mm)	(mm/hr)	(mm/hr)
2018 5-year, 10-min	6.4	38.4	13.9
2100 5-year, 10-min	8.7	52.3	
2018 10-year, 5-min	5.4	65.1	23.2
2100 10-year, 5-min	7.4	88.3	

The design storms that have been discussed for use in GRI design based on review of the City's documents and discussion with City personnel are: the 5-year 1-hour storm (16mm), the 5-year 2-hour storm (23mm), 50% of the 6-month 24-hour storm (24mm), the 6-month 24-hour storm (48mm), and the 2-year 24-hour storm (96mm). The hyetographs for these design storms are shown in Figure 6-4 below.

Figure 6-4: Comparison of Potential Distributed Design Storms for GRI Design



A longer duration design storm matching the high rainfall intensities from the 5-year, 5-min or 10-min storms would require a much larger distributed storm event than has previously been proposed. Table 6-8 below shows the 2100 IDF design storm return periods and depths that have an equivalent peak rainfall intensity to the 5-year, 5-min and 10-min storms when using various rainfall distributions.

Table 6-8: Distributed Storm Events with Equivalent Peak Rainfall Intensity (2100 IDF Curve)

Release Rate Design Storm	Peak Intensity	AES 1 Hour		AES 2 Hour		SCS Type IA 24 Hour	
	(mm/hr)	Approx. Return Period	Req. Storm Depth	Approx. Return Period	Req. Storm Depth	Approx. Return Period	Req. Storm Depth
2021 5-year 5-min	53.2	50-Year	32 mm	200-Year	64 mm	200-Year	221 mm
2100 5-year 5-min	72.3	200-year	43 mm	>200-Year	86 mm	>200-Year	300 mm
2021 5-year 10-min	38.4	10-year	23 mm	25-Year	46 mm	25-Year	160 mm
2100 5-year 10-min	52.3	50-year	32 mm	200-Year	63 mm	200-Year	217 mm

To have a peak rainfall intensity equal to the 2021 5-year, 5-min storm of 53.2 mm/hr, the SCS Type IA 24-hour rainfall distribution would require a design storm depth of over 220mm, which is approximately the depth of the 200-year return frequency (0.5% annual exceedance probability) storm event. An AES 1 Hour rainfall distribution would require a design storm depth of 32mm to match that same peak intensity, which is approximately the depth of the 50-year return frequency (2% annual exceedance probability) storm event.

Though the goal is to choose a single 24-hour design storm for GRI design, none of the design storms listed in Table 6-8 above approach the peak intensities currently used for detention and release rate calculations are appropriate design storms for GRI. Storms with 50- to 200-year return frequency are typically used to model flood scenarios for public safety and not to design private drainage infrastructure, particularly smaller distributed facilities like GRI.

The design storms shown in the Figure 6-4 above do not approach the peak intensities of Table 6-7. However, the 5-year 1-hour, 5-year 2-hour, and 2-year 24-hour all experience peak rainfall intensities at or above 20mm per hour which is substantial. As the 2-year, 24-hour design storm has a peak rainfall roughly equivalent to the 5-year storms and a total depth that is easily compared to the 24mm and 48mm design standards, this design storm could potentially be used to model both runoff volume and peak discharge. For example, a capture of 25% of the runoff volume would be equivalent to 100% capture of the 24mm storm and 50% runoff capture be equivalent to 100% capture of the 48mm storm. Alternatively, a synthetic 24-hour storm distribution that distributes 48mm of rainfall across 24 hours while also having a brief peak intensity that more closely mimics the 5-year, 5- or 10-minute peak intensity could be developed for use in GRI design. Synthetic storm generation is a fairly common practice though outside the scope of the current task.

6.3 Project Scale

The minimum size threshold for which rainwater compliance is required typically varies by jurisdiction and can be chosen based on any number of physical and regulatory factors that support the ultimate goals for the receiving waters and drainage systems. A few typical examples are a minimum earth disturbance area threshold, a minimum area of impervious added or modified, and/or minimum total parcel size. These thresholds (or triggers) standardize the applicability of the rainwater compliance and allow the jurisdiction to adjust or expand over time, if necessary. For instance, a jurisdiction may establish a new, standard threshold at 4,000 square meters and annually reduce that to 300 square meters citywide or reduce it only in more sensitive or challenging areas as needed.

One potential minimum size for rainwater compliance applicability is total parcel area. Based on existing parcel data collected as part of Task 2, 95% of parcels in the City are larger than 275 square meters. This 5th percentile threshold for total project area would capture the vast majority of development in the City, including parcels zoned as single-family residential. The other option is a minimum impervious area created or disturbed. The smallest average parcels in the City are single-family residential. Ninety-five percent (95%) of those parcels are less than 300 square meters and new guidelines allow for up to 60% to 70% of the area of a single-family residential plot to be impervious after construction. Thus, a minimum impervious area created or disturbed of 150 square meters would be large enough to remove unnecessary or inefficient GRI from developments while still capturing the new single-family residential construction.

Most jurisdictions require computer-based modeling for larger projects rather than using the simplified methods or excel-based tools. Vancouver's Engineering Design Manual currently sets that threshold at 20 hectares (ha), which is a very large site and not typical of the sizes of developments proposed in the City. It is recommended that the threshold for advanced, computer-based stormwater modeling be lowered to something in the range of 1 ha (10,000 square meters). While this would increase the number of advanced rainwater models, only 7% of the RWMPs reviewed as part of Task 2 were larger than 1 ha while less than 1% of the total parcels in the City are greater than 1 ha. It is therefore not likely to increase the number of computer-based models substantially while ensuring proper, detailed design for the larger and more complicated projects.

7. GRI Design Tool

The GRI Design Tool is an excel-based calculator that can be used to evaluate potential onsite rainwater management compliance pathways using different types of GRI along with the methodology and design storms discussed above. Modeling of various compliance pathways for the representative building site typologies (developed as part of Task 2) using this GRI Design Tool will be completed in Task 5. The performance modeling approach and scenario development is documented in the Task 5 memo.

7.1 Description of GRI Design Tool

The GRI Design Tool is fully contained within an excel workbook, but it spread over many worksheets. Some of the worksheets are merely informative, such as those providing tabular and graphic views of design storm distribution. Two of the worksheets are provided for input while the remaining majority include the models and calculations used to evaluate rainfall runoff and GRI performance. The following table lists the various component worksheets of the GRI Design Tool and briefly describes their purpose.

Table 7-1: Description of GRI Design Tool Worksheets

WORKSHEET	DESCRIPTION
GRI Sizing Calculator	Primary user interface for the GRI Design Tool. Project details, site characteristics, drainage area distribution, and proposed GRI properties are all entered here for use in the subsequent calculations. The output from the calculations is also shown and compared to the design criteria to shown if compliance is met. Many cells in this worksheet are currently auto-populated based on the chosen Building Site Typology, but these properties would be entered by the user in a public-facing design tool. Additionally, several GRI properties are set as constants for the Task 5 effort to reduce modeling variables and make the results comparable. For a public-facing tool, these properties would be provided a recommended default but could be varied by the user per the proposed design.
RWH Simulation	Secondary user interface for the GRI Design Tool. When rainwater reuse is proposed, the cistern volume, annual rainfall data, evapotranspiration data, and rainwater reuse demands are entered. A year-long simulation of rainwater runoff, capture, and reuse is performed using a daily water balance based on volume captured, reused, and stored. The results of the simulation are displayed graphically, and a total rainwater capture percentage is displayed.
Typology Data	Stores the representative Building Site Typology data from Task 2 along with other assumed typology properties used to populate the site characteristic input boxes of the GRI Sizing Calculator. This worksheet is only for Task 5 modeling and would not be included in a public-facing design tool.
24_hr_Design_Storms	Presentation in tabular and graphic format of the SCS Type IA rainfall distribution for 24mm and 48mm storm depths used the GRI Design Tool hydrograph calculations. This worksheet is included to provide clarity on the design storms used for design and also to allow for the extraction of the design storms so that they can be used in more advanced rainwater runoff modeling, if desired.

ToC_Calc	Calculates the existing and proposed times-of-concentration (ToC) per the site characteristics provided in the GRI Sizing Calculator worksheet. The ToC are used in the SBUH calculations to determine runoff lag and in the peak flow rate calculations to determine rainfall intensity for the pre- and post-development conditions.
lists	Contains constants such as evapotranspiration rate and lists used in drop-down menus in the GRI Sizing Calculator worksheet.
results	Calculates and displays the results of the SBUH and water balance calculations for all GRI. Worksheet is used as source for the performance table shown at the bottom of the GRI Sizing Calculator worksheet.
SBUH_24mm / 48mm	Worksheets where the SBUH Calculations are conducted for the pre- and post-development land use conditions.
GRI_X	Series of worksheets where runoff calculated in the SBUH worksheets is routed through the GRI using water balance calculations. GRI performance including inflow, outflow, overflow, infiltration, evapotranspiration, and volume remaining in various storage layers is calculated for each timestep.
Peak_Flow_Rates	Calculates the design release rate using land cover types, project areas, the ToC, and the 2018 and 2100 IDF curves for either the 5-year or 10-year storm event. The peak flow rate for existing and proposed conditions (pre- and post-development) are routed through GRI using the Rational Hydrograph Method. Additional details on the hydrograph water balance calculations and peak flow rates and provided below.
RWH_Eval	Calculates performance of the RWH cistern given the properties entered and the year-long simulation performed in the RWH Simulation worksheet. The most important statistic calculated is the average volume available in the cistern prior to a rain event, which is determined by averaging the volume of the cistern that is empty in the day prior to rain based on the chosen rainfall data set. This calculated average volume available, rather than the total cistern volume, is used to evaluate cistern performance in the SBUH calculation worksheets.
CoolingDemand	Provides baseline inputs for calculating cooling makeup water demand. Non-potable use for cooling demands is only part of the expanded "Reuse Scenario 2" variable for modeling. As there was no local cooling data available, estimates for this demand used cooling makeup water data from San Francisco and were adjusted to the Vancouver climate based on relative monthly temperatures.
IndoorDemand	Calculates the indoor demands (i.e. flushing and laundry). This tab is set up to calculate all indoor demand (including potable) but the only values currently used are the identified nonpotable demands (flushing for "Reuse Scenario 1" and flushing + laundry for "Reuse Scenario 2"). Most of the inputs (flow rate, duration, etc) are from the Sustainable Large Development Bulletin. The non-potable demand is calculated on a unit per capita basis on this tab (i.e., liters per day per employee or resident) for use on other tabs.
Annual_Rainfall	Contains 5 different synthetic annual rainfall data sets, in daily totals, obtained from the City of Vancouver in tabular formation. This daily rainfall data is used in the cistern performance evaluation in the RWH Simulation worksheet.

7.2 Summary of GRI Design Tool Methods

The representative building site typologies developed in Task 2 of this study are included in the GRI Design Tool and used to populate site characteristics of the *GRI Sizing Calculator* worksheet. These typologies include proposed conditions that impact GRI design and compliance pathways such as parcel area, impervious area, roof area, building height, and building use type. The typologies from Task 2 are presented again Table 7-2 below.

Table 7-2: Representative Building Site Typologies from Task 2

Building Site Typology	*Representative Value*				
	Total Parcel Area (m^2)	Total Impervious Area (% of parcel)	Roof Area (% of parcel)	Story AG	Parkade
Single Family Residential – Low Density	375	45%	30%	2	0
Single Family Residential – High Density	375	70%	50%	2	0
Low-Rise Residential	2,500	90%	40%	3	1
Mid-Rise Residential	3,000	95%	65%	6	2
High-Rise Residential	1,200	90%	70%	20	3
Low/Mid-Rise Non-Residential	2,500	100%	40%	3	1
High-Rise Non-Residential	8,000	100%	55%	14	4

Other, site-specific parameters input into the *GRI Sizing Calculator* worksheet including subsurface infiltration rate, routing of rainwater runoff, and existing conditions will be varied as part of the modeling process. To allow for comparable results and limit the number of model iterations, most of the physical properties used in sizing GRI, like ponding depth, media depth, media porosity, media conductivity, storage layer depth, storage layer porosity, and drain offset height, are set as constants based on the tables developed in Task 3 of this study and guidance provided by the City. All of the constants and variables used in the modeling process will be documented along with the results as part of Task 5.

The GRI Design Tool uses site characteristics and rainfall depths to determine rainwater runoff and then uses the drainage managed areas (DMA) and GRI properties to route rainwater runoff through the post-development site to determine if the design standards of the performance targets are met. The design storm rainfall depths of 24mm and 48mm are distributed across a 24-hour storm duration using the SCS Type IA rainfall distribution, which is consistent with the 24-hour rainfall distribution presented in the Engineering Design Manual. The only difference is that the rainfall distribution, and subsequent runoff and routing calculations using the SBUH method, occur in 6-minute intervals (0.1 hours) over 24 hours, rather than the 20-minute intervals presented in the manual. As most of the projects are relatively small, high-density developments, this brings the time step closer to the assumed time of concentration of the sites and allow for additional refinement of GRI design.

The rainwater runoff per timestep is routed through proposed GRI based on the DMA of each GRI entered in the primary *GRI Sizing Calculator* worksheet. Water balance calculations are performed for each GRI at every timestep to determine the fate of the runoff. Exact water balance calculations vary per GRI but can generally be summarized as:

$$Q_{out} = Q_{in} + V_{(t-1)} - (Q_{extract} + V_t)$$

(Flow Out = Flow In + Volume Remaining in Storage from Pervious Timestep – (Extractions + Volume Remaining in Storage)

The main extraction used in the SBUH calculations is infiltration into the subsurface, but evapotranspiration is included for vegetated GRI and rainwater reuse is included for cisterns. Volume remaining in storage includes the total runoff volume captured in the storage layer, the media layer, and the ponding layer of the GRI, where appropriate. Flow out from the GRI includes flow from both the underdrain, where proposed, and overflow. Overflow can occur due to completely full storage volume, or due to inflow at a particular timestep that exceeds both the media filtration capabilities and the available storage in ponding for that timestep. Flow out from a GRI can flow directly offsite or to the detention tank then offsite. Future iterations of the tool may allow for outflow from Tier I GRI to enter other Tier I or Tier II GRI in the form of a treatment train.

Though the SBUH calculations described above provide a peak outflow from the 24mm and 48mm design storms, the design release rate calculated by the GRI Design Tool uses the methodology described in the Engineering Design Manual. Existing and proposed land cover types, project areas, and ToC are used along with the 2018 and 2100 IDF curves for the 5-year and 10-year storm events to calculate the peak flow rates for existing (pre-development) and proposed (post-development) conditions. The calculated peak flow rate for each condition is input into a hydrograph using the Rational Hydrograph Method where the peak flow rate is assumed to occur at the timestep closest to the calculated ToC with a straight-line increase and decrease on either side of the ToC down to zero. The resulting hydrograph is used to route the runoff from the calculated peak flow rate from the proposed condition through the GR. Water balance calculations equal to those described above are performed for each GRI for each time timestep to determine the fate of the runoff. Flow out from the GRI flows directly to the detention tank and then off site.

Total outflow from the SBUH calculations is used to determine if the proposed site can meet the 24mm and 48mm design standards of the performance targets for volume reduction and water quality. For design release rate criteria, peak flow rate from proposed conditions is compared to the peak flow rate from the existing condition. If the proposed peak flow rates through GRI are above existing peak flow rates, then a detention tank with orifice control is needed to reduce the peak flow to match pre-development conditions.

8. Preliminary Recommendations

Based on the work completed in Task 4, the team has the following preliminary recommendations for the City to consider. These will be carried forward for further discussion and consideration in the policy implications and recommendations that will be developed in Task 9.

Preliminary Conclusions from Regulatory Review

- Refer to Section 2.9 "Current State Assessment Conclusions".

Preliminary Recommendations for Improving Current GRI Design Methods

- Refer to section 5.3 "Evaluation of Current GRI Design Methods".

Preliminary Recommendations for Additional Technical Analyses

- Quantify benefits of the performance targets and design standards compared to the broader water quality goals for the City's receiving waters.
- Quantify benefits of potential changes to the rainwater management requirements for combined sewer overflow and drainage capacity issues during wet weather.
- Quantify benefits of potential changes to the rainwater requirements on total loadings discharged to receiving waters in areas with separate storm drainage.
- Assess impacts of existing stormwater collection infrastructure draining the property as it relates to various release rates, as well as local watershed constraints that should be considered in GRI design.
- Develop a standard maximum peak flow discharge rate (L/S/hectare) based on the above analyses.
- Verify that 24/48mm volume retention is equivalent to 70-90% of annual runoff
- Develop a synthetic storm to capture 24/48mm depth (or other design standard depth) PLUS the 5- or 10-year peaks (or other peak rate)

Preliminary Observations for RWM Framework and/or Policy

- Design methodology could be a single design storm, distributed over 24 hours, with a unit hydrograph approach to routing that allows for the evaluation of GRI performance in terms of rainwater runoff volume and peak discharge rate.
- Clarify the standard terms, simplify language, and explain how the volume reduction and water quality standards are related.
- Align the RWM standard with the broader water quality goals and consider stronger standards for areas already substantially separated or that have highest likelihood of being separated in the next 10 years or so.

- Apply the RWM Bulletin standard beyond rezonings or large developments in a simple clear way, i.e., "All redevelopment disturbing 1000 square meters or greater, or adding 500 sq meters of impervious area, shall submit a RWMP." Many other jurisdictions apply similar thresholds or other triggers to achieve broader drainage and water quality goals more quickly.
- Strengthen detention requirements for Tier 3, thereby making Tiers 1 and 2 tools more comparable and in theory will drive a more considered design approach.
- Once GRI pathways are more defined and focused, a deeper dive on barriers and policy conflicts may be warranted.
- If the City finds that a specific jurisdiction (e.g., Portland, Oregon) has an approach to regulating redevelopment that is particularly appealing and/or suitable for Vancouver, a deeper dive into the governance structure and administrative process would be useful and instructive in developing policy considerations in subsequent tasks.

Exhibit A – Jurisdictional Scan Findings

TORONTO, ONTARIO	
Drainage System Type Combined/Separate/Both	Both
Key Drivers for Stormwater Policy/Requirements	The Toronto City Council adopted a Wet Weather Flow Management Policy (WWFMP) in September 2003 to manage wet weather flow on a watershed basis, and requires all developments in the city to comply with the policy. The policy was accompanied by the implementation of an overall Wet Weather Flow Master Plan and Guidelines, that aim to protect the environment and water quality in the water bodies surrounding Toronto. In 2010, the Toronto Green Standard (TGS), a series of green building and climate action bylaws, became mandatory as part of the Site Plan Control applications, which requires a Stormwater Management Report. The TGS implements the climate mitigation, climate adaptation, resilience, and stainability policies of the City of Toronto Official Plan. The TSG is also aligned with the Ontario Building Code and the National Building Code (2021). Version 4 of the TSG goes into effect May 1, 2022.
Stormwater Design Standard	Three WWFMP targets are to control water runoff volume, water quality and water quantity. The primary objective within the water runoff volume target is to capture and manage annual rainfall within the development site. • The amount of rainwater retained on site shall be as required to achieve the same annual volume of overland runoff as the pre-development conditions. This volume (calculated as a percentage of total annual rainfall) is determined based on the imperviousness of the proposed development and the soil type on site. • If the allowable annual runoff volume from post-development conditions is less than the pre-development conditions, then whichever runoff volume requirement is more stringent becomes the governing target for the development site. • The minimum on-site runoff retention requires the development to be able to retain all runoff from a small design rainfall event of typically 5mm. Storms with 24-hour volumes of 5mm or less and 20mm or less contribute about 50% and 90% of the total average rainfall volumes, respectively. The WWFMP key target of water quantity is met through peak flow and runoff volume controls. The required peak flow control from a development site that contributes to a specific watercourse is determined by following the Toronto and Region Conservation Authority (TRCA) Flood Flow Criteria (FFC) Map. The FFC map specifies the amount of flow control that is required, ranging from no post and pre-control to over-control; e.g. post-development flows being restricted to less than pre-development. For development sites <2 ha, rational methods combined with IDF curves can be used to compute peak flows. When the % imperviousness of a

	development site under pre-development condition is higher than 50%, the maximum value of C (Runoff Coefficient) used in calculating the pre-development peak runoff rate is limited to 0.5. Version 4 of the TGS layers on water balance requirements for Mid to High-rise Residential & Non-Residential; Low-Rise and City Agency, Corporation & Divisions Owned Facilities Standards as follows: • Tier 1 - retain or reuse 5mm • Tier 2 - retain or reuse 10mm, or ensure that the total landscaped site area at or above grade include at least one of the following: green roof at 80% coverage, pollinator species on 50% of green roof area, 25% of lot area planted with native plants, bioretention to capture/control 75% of runoff from hardscape, or reforestation of a portion of the site. • Tier 3 - retain or reuse 25mm • Water quality requirement is to remove 80% of TSS from all runoff leaving the site, based on post-development condition.
Application of the Standard	The TSG outlines requirements for various types of developments, all of which reference the WWFMP for new development including areas of infill development are required to follow the guidelines set out in the WWFMP guidelines. The goals is to achieve the Provincial Water Quality Objectives over the long term, as well as the City's water quality and climate action goals.
Alternative Compliance Options	Cash-in-lieu for water balance requirements is not permitted. It appears that the water quality requirements may allow it as an alternative option where implementing controls at the source is not feasible.
Legal Authority for Enforcement	The Toronto Green Standard is the umbrella set of bylaws and policies enforcing green building requirements. Specifically, the authority to require the Stormwater Management Reports as part of the Site Plan Control applications is provided by the Planning Act, the Provincial Policy Statement, the Official Plan, the Wet Weather Flow Management Policy and Chapter 681 of the Municipal Code – Sewer.
Entity Approving and/or Issuing Permits	City of Toronto Planning Division
Design Manual Provided	Wet Weather Flow Management Guidelines 2006 (WWFMG) City of Toronto Development Guide
Hydrologic Calculation Methods for Sizing GRI	• Water balance requirements, for which GRI (referred to as Low Impact Development) is encouraged, and water quality requirements are to follow guidance in the WWFMG and may be supported with "well-documented" computer modeling programs. • Curve Number hydrologic modeling is suggested for Low Impact Development in Appendix F of the WWFMG. • For development sites < 2 ha, a simplified approach such as the Rational Method may be used to compute peak flows.
Sizing Tool Available	No

Year Implemented	The Wet Weather Flow Master Plan and Wet Weather Flow Master Policy were adopted by the Toronto City Council in 2003. The latest WWFM Guidelines were published in November 2006.

Additional Noteworthy and Relevant Findings:

Watershed-based Management

- Wet weather flow within the Toronto jurisdiction is managed on a watershed basis, where developments contributing to specific watersheds may be required to meet specific restrictions.
- For example, if a development site is located within the Highland Creek watershed, the post-development peak flows are to be controlled to predevelopment levels for all storms up to and including the 100-year storm. Alternatively, the Humber River watershed post-development peak flows are required to be controlled to unit flow rates, as per calculations found in Appendix C in the WWFM guidelines. These calculations output a unit flow rate based on the area of the site in hectares.

Estimated Annual Runoff Requirements

- The water balance targets used in the WWFMP guidelines are based off the pre-development imperviousness percentages and existing soil types of each lot.
- Table 3 (pg. 16/117) and Figure 2 (pg.17/117) within the guidelines show the percentage of estimated allowable annual runoff that is required to be retained to achieve the same level of annual runoff under pre-development conditions, considering ground imperviousness and soil types.
- This approach of calculating the amount of rainfall retention required based off impervious area and soil conditions is somewhat unique in comparison to strategies employed by other municipalities.

Green Roof Program Development

- Pre-2006, the City commissioned a study that indicated widespread implementation of green roofs would provide significant benefit, particularly in stormwater management and reducing urban heat island.
- The City held stakeholder workshops to define criteria for to devise a green roof strategy that would include: a pilot incentive program, installation of green roofs on City/ABC buildings, use of the development approval process to encourage green roofs, and public outreach. The City Council adopted this green roof strategy in 2006 called “Making Green Roofs Happen".
- The Pilot Incentive Program was funded by Toronto Water and offered \$10/m^2 for green roof installation by the private sector. The program was successful at awarding 16 applicants and later became the EcoRoof Incentive Program.
- New buildings constructed by the City and its agencies, boards, and commissions were required to install green roofing on at least 50% of available roof space.
- Zoning by-law amendments were made to encourage and allow for green roofs to be approved as part of site control plan applications so they could be implemented through the new development planning process.
- The City created a green roof web page and held 2 technical workshops/staff trainings to increase knowledge and awareness.
- New Development Requirements:

- In 2009, Toronto became the first city in North America to adopt a bylaw requiring green roofs for new developments or additions over certain square-foot thresholds and established construction standards for them.
    - Amendments made by the Province of Ontario to Section 108 of the City of Toronto Act (COTA) provided the City Council with the authority to pass a by-law that would require green roofs, making an exception to the Building Code Act.
    - Green roofs became required on new commercial, institutional, and residential development with a minimum gross floor area of 2,000 m^2
    - Developers can apply for an exemption and build a smaller green roof than required along with a cash-in-lieu payment (\$200/m^2). The funds collected from the cash-in-lieu are directed to fund the Eco-Roof Incentive Program.
- Design/Construction Requirements:
    - All green roof projects must be designed and built-in conformance with the Toronto Green Roof Construction Standard, and a Green Roof Building Permit is required.
    - Green roofs are required to cover a minimum percentage of the building's available roof space based on the building's gross floor area. 4,999 m^2 : 20%; 5,000 - 9,999 m^2 : 30%; 10,000 – 14,999 m^2 : 40%; 15,000 – 19,999 m^2 : 50%; 20,000 m^2 or greater: 60%.
- EcoRoof Incentive Program (Grant Program):
    - Green roof incentives: \$100/m^2 installed and up to \$1,000 for structural assessment.
    - Cool roof incentives: \$5/m^2 for cool roof with a new membrane and \$2/m^2 for a cool roof coating over an existing roof.
        - A cool roof is a roof with an exterior surface that reflects sunlight to reduce urban heat island.
    - Funding requests can be up to \$100,000.

Mandatory Downspout Disconnection Program (WWFMP 2017 Update)

The following describes the City's assessment of the downspout disconnect program as of 2017:

The Mandatory Downspout Disconnection Program (MDDP) is one of the City's most important source control initiatives. In 2008, City Council adopted amendments to the Toronto's Municipal Code, Chapter 681, Sewers, to require the City-wide disconnection of downspouts from buildings directly or indirectly to the City's sewer system, unless an exemption has been granted by the General Manager of Toronto Water (e.g., in situations where disconnection would create a hazardous condition or is not technically feasible). The by-law requirements came into effect across the city in three phases, as follows:

- Phase 1: Approximately 200,000 properties in the area of the city served by combined sewers - November 20, 2011
- Phase 2: Approximately 90,000 properties in study areas identified as basement flooding-prone - December 3, 2013
- Phase 3: Approximately 216,000 properties in the remaining areas of the city - December 3, 2016

Based on computer simulation modelling, it has been estimated that at least 70%of the houses in a given sewershed must be disconnected from the storm sewer system for a significant reduction in sewer surcharging to be achieved.

The MDDP has been highly successful in achieving a high rate of disconnection (79%) by employing education and outreach efforts, and without enhanced enforcement. In order to further increase the disconnection rate and achieve the maximum potential disconnection rate, Toronto Water will continue to employ the multi-year enhanced education, communication, and outreach strategy that was utilized during the implementation of the MDDP. Toronto Water will also undertake focused field studies in wards with low disconnection rates, reduced disconnection rates, or as required for other program considerations.

NORTH VANCOUVER, BRITISH COLUMBIA	
Drainage System Type Combined/Separate/Both	Separate
Key Drivers for Stormwater Policy/Requirements	The City of North Vancouver (CNV) is a municipal member of the Greater Vancouver Sewerage and Drainage District (GVS&DD), and as such is required to implement municipal action as set out in the Metro Vancouver Integrated Liquid Waste and Resource Management Plan (ILWRMP). This action includes developing and implementing a liquid waste management plan, which in the CNV's case is their Integrated Stormwater Management Plan (ISMP). These liquid waste management plans are authorized and regulated through the BC Environmental Management Act. The corresponding SWMPs are intended to protect watershed values as development and redevelopment affects the landscape. Examples of watershed values include the abundance and diversity of aquatic and terrestrial animals and the density and health of forest areas. Watershed values also include social elements, such as public safety, health and traditional uses, and values of indigenous citizens.
Stormwater Design Standard	For three-unit developments or larger, runoff originating from new impervious surfaces must be managed with source controls. Stormwater source controls must retain 56mm of rain over a 24-hour period from all impervious building surfaces. Building runoff is recommended to be managed with blue or green roofs and all surrounding/ additional impervious areas must be directed to pervious vegetated areas or a source control for treatment and attenuation. For stormwater detention, the target release rate is 0.25 l/s/ha. For single family and duplex developments a more prescriptive approach is provided. CNV recommends the use of infiltration chambers, rainwater tanks with infiltration chambers, or rainwater tanks with slow-release valves. Additional tools that they recommend should these not be sufficient are absorbent landscapes, rain gardens, and green/blue roofs. CNV provides a tool sheet for property owners to calculate the area of the infiltration chamber required using the property's infiltration rate and total roof area. For rainwater tanks with infiltration a minimum tank size of 6,500 liters 9 mm slow-release outlet is required. Rainwater tanks without infiltration are required to be a minimum of 9,500 liters with a 9 mm slow-release outlet.

Application of the Standard	All new developments including single family, duplexes, triplexes and any larger developments (including commercial, industrial or institutional land uses) must prepare a stormwater management plan. A stormwater plan is not required for infill accessory developments such as coach houses or garages if the primary residence will not be impacted.
Alternative Compliance Option	For single family homes, the CNV stipulates that a fee in lieu of the stormwater management works can be paid and will be put towards SWM on public property. This option will only be considered when no other viable options exist. For three-unit developments or larger, if source controls are unable to be provided on site, the City will work with the developers to meet equivalent impervious area mitigation requirements elsewhere in the City, or to contribute an equivalent fee (based on volume of water) to City projects.
Legal Authority for Enforcement	SWMPs are required as part of the City's Subdivision and Development Control Bylaw. As a municipal member of the GVS&DD, the CNV is also required to report to Metro Vancouver annually regarding their progress on the ISMP implementation. This information is then passed on to the Ministry of Environment.
Entity Approving and/or Issuing Permits	The City of North Vancouver
Design Manual Provided	Metro Vancouver Stormwater Source Control Design Guidelines (2012) for 3-unit or larger projects, and Stormwater Management Tool Sheets for 1- and 2-unit projects
Hydrologic Calculation Methods for Sizing GRI	• Simplified Sizing Approach (for single GRI facility) • Water Balance Model Powered by QUALHYMO • EPA SWMM computer model
Sizing Tool Available	Stormwater Management Tool Sheets for 1- and 2-unit projects
Year Implemented	The CNV ISMP is dated November 2016

Additional Noteworthy and Relevant Findings:

Infiltration Chamber Sizing Worksheet for Single Family and Duplex Residential Lots

- The CNV's top recommended tool for meeting Stormwater Management Plan requirements on private properties is the implementation of below-ground infiltration systems.
- The CNV has a sophisticated yet simple tool on their website that is intended to be used by homeowners to calculate the area of infiltration chamber required. The calculation tool has its own set of limitations, including the assumption of a default infiltration rate of 10mm/hour.
- However, overall, we find this tool to be quite informative and even if not all-encompassing is a great starting point in terms of a resource for the general population. An infiltration chamber sizing tool or something similar is a concept to be considered implementing in Vancouver.

Green Roof Sizing Tool

- CNV refers to the green roof sizing tool provided in the Stormwater and Source Control Design Guidelines from Metro Vancouver, and referenced in the SWMP from the City of North Vancouver.
- Two sizing approaches presented: sizing for depth capture criteria and sizing for % capture of average annual rainfall.

- Sizing for soil depth uses the following formula, where the answer Ds corresponds to the depth of soil required. Standard depth range is between 150-600mm, which accounts for a rainfall capture depth of between 30-120mm. If the calculated depth exceeds 600mm, overflow from the roof can be directed to an infiltration rock trench or other facility.
- The average annual rainfall is determined from an isohyetol drawing found in the appendix. From there, the following chart is used and based off the target capture percentage the soil depth is chosen. If the target capture percentage does not intersect on the graph with an annual rainfall amount, the overflow from the green roof is to be directed to an infiltration facility.
- Some limitations to this approach are exemplified by the site scenario depicted in the guide.
- This scenario is highly infeasible for several reasons. For new large developments, parking is overwhelmingly located underground beneath the building, and in order to maximize profit site buildings are likely to cover a much larger percentage of the property area. As such, a more realistic site example would be for this roof area to extend to the extents of the parking lot shown, if not further. While this gives the developer a larger roof area to turn into a green roof, there is little to no space left to infiltrate excess rainwater, especially once the 5m setback from the building is considered. As such, this method becomes infeasible to implement on larger scale projects.
- These green roof calculations also assume that the entirety of the roof will become green which is likely not to be the case.

PORTLAND, OREGON BUREAU OF ENVIRONMENTAL SERVICES	
Drainage System Type Combined/Separate/Both	Both
Key Drivers for Stormwater Policy/Requirements	NPDES permit for stormwater and separated collection system (MS4), managed by the City's Bureau of Environmental Services (BES), established a comprehensive stormwater management program that includes controls on post-dev stormwater runoff, and the SWMM which focuses on LID, stormwater management facilities, and conveyance features. NPDES permit for the wastewater treatment plant and combined sewer system CSO Program completed in 2011. Ongoing management of CSS guided by NPDES wastewater discharge permit for Columbia Boulevard Wastewater Treatment Plant and CSS. Regs include requirements for Capacity, Management, O&M, and incorporate the EPA's CSO policy regarding the "Nine Minimum Controls". A water pollution control facility permit (WPCF) under the federal Safe Drinking Water Act for underground injection controls to protect groundwater quality was issued in 2005 and regulates stormwater discharges for all City-owned and City-operated underground injection controls (UICs). The City has over 9K public UICs that infiltrate stormwater runoff from the ROW and City-owned property.
Stormwater Design Standard	Level 1: Full onsite[1] infiltration of 10 yr., 24 hr. storm (3.4 in) is required to max extent practicable for sites with infiltration rates of 2 in/hr. or more, unless site constraints prevent infiltration or the site qualifies for the ecoroof exception. UICs in the ROW must infiltrate the peak flow rate from the 10 yr. storm (2.86 in/hr. for 5-min) with a safety factor of 2. Parcel based UICs must infiltrate the 10 yr./ 24 hr. storm (3.4 in). UICs with no overland escape route (e.g. under-buildings) must infiltrate the 100 yr., 24 hr. storm (4.4 in). New impervious area can be managed by existing UICs only if the UIC meets the current design standards and has sufficient capacity to accept the additional runoff and still meet the performance requirements. Level 2: For offsite discharge to an MS4, pollution reduction and flow control are required to prevent hydromodification. Water quality treatment is required to achieve 70% TSS removal from 90% of average annual rainfall runoff (1.61 in over 24 hr., or 0.19 in/hr. for 5-min) as

[1] Portland's 2020 Stormwater Management Design defines the term "onsite" as "the limits of the project site and is not a distinction between property and the right-of-way. For example, a residential development proposal could manage the runoff from the building onsite (on private property) via drywells and the runoff from the frontage improvements onsite (in the public-right-of-way) through a vegetated planter. While development proposals on property may be bound by the parcel or tax lot geometry, the term "onsite" can be used to describe meeting the Infiltration and Discharge Hierarchy for any type of project."

	well as compliance with any Total Maximum Daily Loads (TMDLs)[2] based on watershed. For discharge to small water bodies directly or indirectly (via piped system), limit post-dev peak runoff rate to pre-development rate for ½ of the 2 yr. event, and for the 5, 10, and 25 yr. events. For discharge to large water bodies including the Willamette, Columbia Slough, and Columbia River when there is a system need, limit the post-dev peak runoff rate to pre-dev rate for the 2, 5, and 10 yr. events. There is a flow control exemption available if the MS4 discharging to a large water body has sufficient available capacity. Level 3: Applies to areas served by combined sewer system. BES requires SW management onsite to infiltrate to the maximum extent practicable and to provide some infiltration even if infiltration of the 10 yr. storm is not feasible. For offsite discharge to the combined system, flow control measures are required to limit the 25 yr. post-dev peak runoff rate to the 10 yr. pre-dev rate and pre-development conditions are based on the undeveloped site (Lewis and Clark era). • Onsite SW management is required to max extent feasible unless SW management is provided by regional facility. • SW management approach prioritizes vegetation and infiltration over underground injection control system (UIC). UICs must be registered with DEQ or BES. • For projects in public ROW where full onsite infiltration is not feasible within the development area and that propose discharge to the combines sewer system, lined stormwater facilities and/or piped overflows should only be used where there are capacity problems and where flow control and other benefits of lined systems have been identified. • If there are no capacity problems, the applicant must maximize the use of **Tree Credit** and then request to pay an **Offsite Stormwater Management Fee** through the **Special Circumstances Process**.
Application of the Standard	New development and redevelopment activities that create or replace **500 sq ft** or more of impervious area.
Alternative Compliance Option	Yes - "Special circumstances on a proposed site may make it impractical to meet stormwater management requirements to the standards specified in this manual. A project designer can request to pay an Offsite Stormwater Management Fee instead of building a stormwater management facility for some or all of the stormwater management requirements for the project by submitting a Special Circumstances Request. The Offsite Stormwater Management Fee charged for a project is calculated per square foot of unmanaged impervious area."
Legal Authority for Enforcement	The City's Stormwater and Water Quality Management Requirements are located in the City's Code 17.38.040.

[2] Total Maximum Daily Load is defined by the US Environmental Protection Agency (EPA) as "the calculation of the maximum amount of a pollutant allowed to enter a waterbody so that the waterbody will meet and continue to meet water quality standards for that particular pollutant."

	The SWMM is adopted by the Director of BES following a public review process and filed with the City Auditor as required by Portland City Code Chapter 1.07. In 1999, City Council adopted code changes to Portland City Code Chapter 17.38 to authorize the Director of Environmental Services to adopt rules, procedures, and forms and to maintain a SWMM (Ordinance #173330). In 2000, in conjunction with a City Code update, City Council confirmed the authority of the Director of BES to update the SWMM (Ordinance #174745).
Entity Approving and/or Issuing Permits	The Bureau of Environmental Services (BES)
Design Manual Provided	2020 Stormwater Management Manual
Hydrologic Calculation Methods for Sizing GRI	• **Simplified Approach**: Based on standard stormwater facility designs and simple sizing ratios; does not require design professional. Only allowable for projects on parcels with up to 10,000 sq ft (930 m^2) of impervious area (intended for small-scale residential). • **Presumptive Approach**: A City-provided sizing calculator that uses the Santa Barbara Unit Hydrograph (SBUH) Method; for planters and basins. • **Performance Approach:** Requires either SBUH Method, SCS Runoff Curve Number Method, HEC-HMS, or SWMM; for projects with unique circumstances that need analysis beyond the Simplified or Presumptive Approaches.
Sizing tool Available	Y - Link here
Year Implemented	First SWMM in 1999, first manual in 2014 and most recently updated in 2020

Additional Noteworthy and Relevant Findings:

Division of O&M Responsibilities

- Developers of private projects may deliver GRI in public ROW during construction, and these GRI facilities ultimately become city-owned assets.
- Private sites are responsible for O&M of GRI assets in private realm. Sites are required to submit an O&M form that details maintenance activities and the responsible party for carrying them out.
- Private sites are responsible for O&M of GRI assets delivered in public realm until the City accepts and assumes O&M after first 2-years (warranty period).

Ecoroof Policy

- The City's Ecoroof Policy is embedded as zoning code for the central city and requires 60% of roof area on new buildings to be an Ecoroof. Ecoroof sites must still meet all relevant flow control requirements.
- Incentive program from 2008-2012: offered property owners incentive of $5/SF for ecoroof construction. Granted almost $2 million to help fund over 130 projects that managed about 4.4 million gallons of SW annually.
- An ecoroof counts as an impervious area reduction technique and therefore reduces the amount of onsite stormwater management required.

Alternative Compliance Mechanism: Apply for Special Circumstances

- Special Circumstance process is outlined in the Stormwater Manual.
- Applicants must demonstrate technical infeasibility and that the onsite management implemented is to maximum extent practicable.
- In application, the project designer may propose meeting a portion of their onsite stormwater management requirements with facilities located in the public ROW or elsewhere offsite.
- Fee amount assessed per square foot of unmanaged impervious area.
- Fee-in-lieu money goes to The % for Green Program, which funds a grant program and other stormwater improvements such as stormwater projects in the ROW.
- A very small percentage of projects comply with their stormwater requirements by paying the fee-in-lieu.
- A main programmatic challenge is that the fee is too low so there is not enough money collected per project to implement targeted mitigation strategies.
- A programmatic update was implemented to help streamline the review process for Special Circumstance requests so that there is a staff level review rather than a full committee review and a $100 application fee was added.
- Staff attitude towards Special Circumstances is that it should be used more, but the fee is too low. It is not very easy to apply for special circumstances.
- An annual inflationary increase to the fee should have been coded into the program when it was initiated.

SEATTLE, WASHINGTON SEATTLE PUBLIC UTILITIES	
Drainage System Type Combined/Separate/Both	Both
Key Drivers for Stormwater Policy/Requirements	Washington State Department of Ecology (DOE) 2019-2024 NPDES Phase I Permit and State Waste Discharge General Permit for Discharge from Large and Medium MS4 systems, effective Aug 2019 (MS4 Permit). Permit requires City to adopt local programs to prevent and control impacts of SW runoff from new development, redevelopment and construction activities. This is accomplished largely through the Seattle Stormwater Code and the Directors' Rule (the manual) which the DOE determined to meet the permit requirements with reference to the Stormwater Management Manual for Western Washington.
Stormwater Design Standard	Depending upon the project type, receiving water, downstream conveyance conditions, new plus replaced hard surface* area, new plus replaced pollution generating hard surface* area, existing land cover condition, area of vegetation converted, and land disturbance area (see Chapter 4) , one or more of the following standards may be triggered: • **Soil Amendment**: Retain or protect undisturbed soil in areas not being developed and amend all new, replaced and disturbed topsoil with organize matter. • **On-site Stormwater Management**: "On-site stormwater" practices (e.g., rain gardens, permeable pavement, dispersion) must be installed to either meet a performance standard or meet the "On-site List" which includes on-site practices that must be applied, as feasible, in a preferred order. The hierarchy generally prioritizes BMP is the following order: infiltration-based BMPs and rainwater harvesting, partial dispersion, lined bioretention and vegetated roofs, trees. • **Flow Control**: Depending upon the project type, size and discharge location one or more of the following performance standards may be triggered: - Wetland Protection Standard: Complex standard protecting functions and values of wetland - Pre-developed Forest Standard: Match flow durations (from half 2-year to 50-year) to pre-developed forest condition - Pre-developed Pasture Standard: Match flow durations (from half 2-year to 2-year) to pre-developed pasture condition - Existing Conditions Standard: Match flow durations (from half 2-year to 25-year) to the existing condition - Peak Control Standard: Limit peak flows such that 2-year ≤ 0.07 cfs/acre, 5-year ≤ 0.10 cfs/acre, and 25-year ≤ 0.4 cfs/acre • **Water Quality Treatment**: Depending upon project characteristics, one or more of these standards may be triggered: - Basic Treatment: Basic Treatment BMPs are designed to achieve 80 percent removal of TSS for influent concentrations greater than 100 mg/l, but less than 200 mg/l.

	- Oil Control Treatment: Required for "high-use sites" or those that have NPDES permits that require oil control - Phosphorus Treatment: Required for projects discharging stormwater to or infiltrating within 1/4 mile of a nutrient-critical receiving water or a tributary to that water - Enhanced Treatment: Targets removal of dissolved metals (BMPs without compost are designed to remove greater than 30 percent dissolved copper and greater than 60 percent dissolved zinc). *"**Hard surface**" means impervious surface, permeable pavement, or vegetated roof.
Application of the Standard	• Single Family Residential Project: Project that constructs one Single-family dwelling unit and any accessory dwelling unit on land classified as Single-family Residential. If the total new plus replaced hard surface exceeds 5,000 SF, the project is considered a parcel-based project. • Sidewalk Project: Creation or replacement of a sidewalk. If the total new plus replaced hard surface in the roadway exceeds 10,000 SF, the project is considered a roadway project. • Trail Project: Creation or replacement of a trail. • Roadway Project: Project located in public ROW that creates new or replaces existing roadway or alley. If the project includes any development in addition to the roadway then considered parcel-based project. • Parcel-Based Projects. Any project not meeting other project definitions (e.g., projects crossing the right-of-way line, multifamily developments, parks, projects exceeding the area thresholds listed above). Some pollution-generating activities are also classified as parcel-based projects and require drainage review (e.g., fueling stations, vehicle maintenance yards). Requirements also vary by receiving water and downstream conveyance conditions: wetlands, creek basin, listed creek basin, public combined sewer, small lake basins, designated receiving waters, capacity, and/or constrained conveyance system.
Alternative Compliance Option	Yes, at the discretion of the SPU Director, flow control, water quality treatment, on-site stormwater management, or wetland protection requirements can be met at an alternative location if the developer voluntarily contributes funds towards the construction of, or constructs, one or more drainage control facilities at an alternative location. Link here.
Legal Authority for Enforcement	The City's Stormwater Code is contained in the Seattle Municipal Code chapters 22.800-22.808.

Entity Approving and/or Issuing Permits	Seattle Public Utilities (SPU) and Seattle Department of Construction and Inspections (SDCI) jointly developed the requirements, code, and the manual. SPU has authority over work in the public ROW. SDCI has authority over private development.
Design Manual Provided	City of Seattle Stormwater Manual (2021)
Hydrologic Calculation Methods for Sizing GRI	• Most sites must be modeled using an HSPF-based continuous simulation model (i.e., WWHM or MGSFlood). • "Pre-sizing" is available for the most commonly triggered performance standards and may be used for smaller sites with less than 10,000 sf (930 m^2) of new and replaced hard surface. • Single-event rainfall-runoff modeling (e.g., NRCS TR-55, SBUH, SWMM) and rational method are only allowed for conveyance sizing.
Sizing Tool Available	Yes. The manual includes pre-sizing tables (sizing factors or equations). Excel sizing tools are also available for flow control and the on-site stormwater management list. Link for flow control calculator
Year Implemented	2016; most recently updated in 2021

Additional Noteworthy and Relevant Findings:

Alternative Compliance Mechanisms

- Integrated Drainage Plan: Specific to one or more sites such that the cumulative effect on the discharge from the site(s) to the same receiving water is the same or better than that which would be achieved by a less integrated, site-by-site implementation of BMPs.
- Projects that do not discharge to the combined sewer system: Flow control, water quality treatment, on-site stormwater management, or wetland protection requirements can be met at an alternative location if specific conditions are met.
- Projects that discharge to the combined sewer system: Flow control or on-site stormwater management requirements can be met at an alternative location if the developer voluntarily contributes funds towards the construction of, or constructs, one or more drainage control facilities at an alternative location.
- Landscape management plan (LMP): Alternative to the requirement to formally treat runoff from pollution generating pervious surfaces. City approved plan defines the layout and long-term maintenance of landscaping features to minimize the use of pesticides and fertilizers and reduce the discharge of TSS and other pollutants. LMPs do not apply to artificial turf fields.

Incentives (especially for Green Roofs)

- RainWise Program: Rebate program that helps property owners manage stormwater by installing cisterns and/or rain gardens on private property (Link)
- RainCity Partnership: Community-based public private partnership to expand voluntary, community-identified GSI improvements in specific areas throughout the City. Pilot starting soon. (Link)
- Drainage Fee Credit Program: Seattle's Stormwater Facility Credit program offers drainage fee credits to property owners for managing stormwater on-site. (Link)

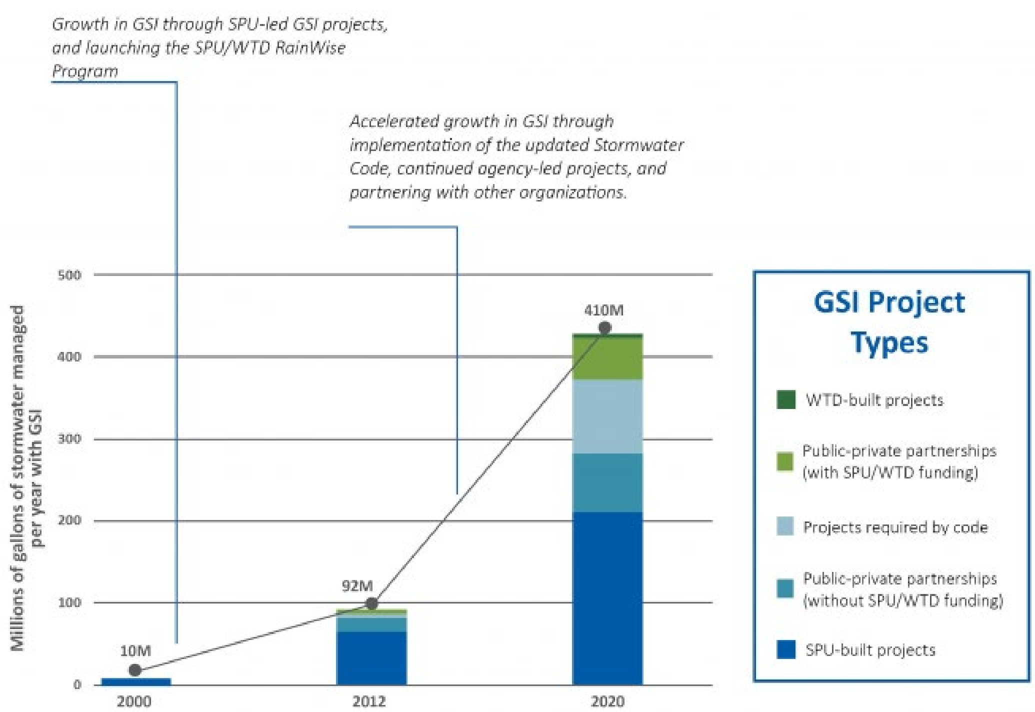
O&M Responsibilities

- The owner and other responsible parties shall inspect and maintain permanent drainage control facilities, temporary drainage control facilities, source control BMPs, and implement LMPs to keep these facilities in continuous working order. More frequent inspections and/or maintenance may be ordered by the City to ensure functioning at design capacity.

- Owner(s) shall inform future purchasers and other successors and assignees to the property of the existence of the drainage control facilities and the elements of the drainage control plan, the limitations of the drainage control facilities, and the requirements for continued inspection and maintenance of the drainage control facilities and for implementation of LMPs, if applicable. SPU requires a "memorandum of drainage control" as a condition precedent to the issuance of any permit or approval for which a drainage control plan is required. See page 61 of the 2021 SW Code for more on the memo. Also see page 64 which describes the code enforcement.

Other Noteworthy Elements

- 700 million gallons goal: goal is to use GSI to manage 700 million gallons of polluted runoff each year by 2025 (Link). 2020 Progress report is here. As the graph below shows, development and redevelopment projects are part of a suite of GSI solutions to achieve this goal (see “GSI projects required by code”, light blue bar).



PHILADELPHIA, PENNSYLVANIA PHILADELPHIA WATER DEPARTMENT	
Drainage System Type Combined/Separate/Both	Both
Key Drivers for Stormwater Policy/Requirements	Compliance with MS4 Permit and CSO Consent Order. Post-Construction Stormwater Management (PCSM) Requirements regulate how stormwater runoff leaves a project site in the built or post-development condition. PCSM Requirements have four components: Water Quality, Channel Protection, Flood Control, and Public Health and Safety Release Rate requirements. The goal is "to improve the health and vitality of Philadelphia's waterways along with the City's own sizable clean water investments."
Stormwater Design Standard	**The Channel Protection requirement** stipulates the detention and release of runoff from the one-year, 24-hour Natural Resources Conservation Service Type II design storm event for all DCIA within the limits of earth disturbance at a maximum rate of 0.24 cfs per acre of associated DCIA in no more than 72 hours. **The Flood Control requirement** stipulates that a development project meet or reduce peak rates of runoff, as determined by its Flood Management District, from predevelopment to post-development conditions during certain storm events. Sites located in certain combined sewer areas of the Delaware Direct and Lower Schuylkill River Watersheds where known flooding has occurred due to constraints in the sewer network are required to comply with a **Public Health and Safety maximum release rate** (cfs per acre) for the one-year through ten-year storm events. This rate is determined by PWD based upon analysis of available pipe capacity for the project within the sewershed and will differ depending on the location of the project's sewer connection(s).
Application of the Standard	Citywide for development with earth disturbance of 15,000 SF (1,400 m^2) or more, except in certain watersheds its 5,000 SF.
Alternative Compliance Option	Yes, if site constraints or existing conditions will prevent a development project from complying fully, or if placement of an SMP could result in a potential environmental or safety hazard, the designer may consider Stormwater Management Banking and Trading. Proposals to use banking and trading methods are considered by PWD on a case-by-case basis.
Legal Authority for Enforcement	The Philadelphia Water Department (PWD) Stormwater Regulations (Stormwater Regulations), presented in Appendix C, have been developed in accordance with Philadelphia Code §14-704(3), and they consist of four major Post-Construction Stormwater Management Requirements: Water Quality, Channel Protection, Flood Control, and Public Health and Safety Release Rate.
Entity Approving and/or Issuing Permits	Private Development Services is a program within the PWD Green Stormwater Infrastructure (GSI) Implementation Unit. Private Development Services is responsible for administering the

	Department's Stormwater Regulations through the review, construction inspection, and maintenance inspection of development sites. Within Private Development Services are two programs: Stormwater Plan Review and Stormwater Inspections.
Design Manual Provided	Stormwater Management Guidance Manual (2020)
Hydrologic Calculation Methods for Sizing GRI	• SCS Runoff Curve Number Method is recommended approach. • Additional methods or modeling software may be used with approval from City. • Rational Method is acceptable for designing storm sewers, but is not allowed for stormwater management practice design, outlet control design, or detention routing.
Sizing Tool Available	Yes, sizing tables are provided
Year Implemented	Stormwater Management regulations were revised in 2006, 2015, and 2018. Latest Stormwater Management Guidance Manual is from 2020.

Additional Noteworthy and Relevant Findings:

- The 15,000 SF (1,400 m^2) threshold effectively eliminates the compliance and review of smaller sites and most single family residential, but regulates smaller projects (5,000 SF) in critical or sensitive watersheds.
- PWD's stormwater regulations are implemented in a similar framework as Vancouver's current RWM Bulletin with a tiered approach – retention and WQ targets, and a detention requirement third.
- The notable difference is that the detention requirement is standard across the board and is not based on prior use. This detention/flow rate is aligned with and supports the PWD's citywide water quality and flooding goals.
- Sizing and flow routing is not reliant on a custom tool or specific models. Several calculations and equations are acceptable depending on the development type.
- Chapter 3 of the manual specifically addresses site design and integration of stormwater management.
- Provides construction guidance to ensure proper installation.
- O&M Agreements are required. Maintenance is expected in perpetuity with notification requirement for changes over time. Periodic inspections are required and part of the agreement. Failure to maintain may result in enforcement actions.
- If the developer proposes a non-structural design, disconnected impervious area, and bioinfiltration/bioretention for compliance, they may be eligible for expedited review. This is a concept to consider in Vancouver.
- Development incentives are also available in the form of grants and zoning bonuses, which encourage developers to exceed the requirements for stormwater management.
- PWD Grant funding is available for projects that:
    - Direct ROW drainage into the new development's stormwater practices
    - Purchase of assets, where PWD allows a developer to construct and maintain a planned GSI asset in the ROW as part of the development work related to sidewalks, street trees, accessibility ramps, etc.
- Zoning Bonuses encourage green roofs through:
    - Green Roof Density Bonus for qualifying green roofs that cover at least 60% of roof area for low density multi-family and neighborhood commercial corridors.

    - Height Bonuses in certain areas of the city for mixed-use projects if the development can manage ROW drainage within the property, management of additional on-site drainage, or use of vegetated systems.

Inclusion of green roofs and related standards, requirements, or incentives

- Green roofs are included as a GRI practice that can be used to meet the stormwater requirements. Design and sizing guidelines are provided in the manual.
- The Guidance Manual is a comprehensive design and process manual written specifically for redevelopment applicants to streamline and ease submittals, compliance, and approvals for rainwater management requirements and key content included in those documents.
- Philadelphia also offers the following green roof incentives for new and existing buildings:
- A Green Roof Tax Credit against the Business Income and Receipts Tas (BIRT) for 50% of all costs incurred to construct the green roof, not to exceed $100,000.
- Two grants offered by the city, GARP and SMIP, fund retrofits to existing property, including green roof projects.
- Stormwater Credits may be granted for compliant green roofs toward a property's stormwater charge (based on impervious cover).

Related GSI Initiatives

- PWD offers a Rain Check Program to residential property owners to disconnect downspouts, install raingardens, permeable pavers, and rain barrels.

<table>
<tr><th colspan="2">SAN FRANCISCO, CALIFORNIA
SAN FRANCISCO PUBLIC UTILITIES COMMISSION</th></tr>
<tr><td>Drainage System Type Combined/Separate/Both</td><td>Both</td></tr>
<tr><td>Key Drivers for Stormwater Policy/Requirements</td><td>Water quality protection and reduced stormwater volume in the City's sewer system are the fundamental drivers behind the stormwater management requirements. These requirements are administered in accordance with the federal Clean Water Act and State of California National Pollutant Discharge Elimination System (NPDES) permit. The NPDES permit requires a program to reduce pollutants in stormwater runoff from new and redevelopment projects, referred to as a post-construction stormwater control program.</td></tr>
<tr><td>Stormwater Design Standard</td><td>
Combined Sewer Areas:
For sites with existing imperviousness of greater than 50%, stormwater runoff rate and volume must be reduced by 25% relative to pre-development conditions for the 2-year, 24 hour design storm. For sites with existing imperviousness of less than 50%, stormwater runoff rate and volume shall not exceed pre-development conditions for the 1- and 2-year, 24 hour design storms.
Separate Sewer Areas:
Projects over 5,000 SF in SFPUC jurisdiction, SW req is to implement source controls and BMPs to capture and treat the rainfall from the 90th percentile, 24 hr. storm of 0.75 in with intensity of 0.24 in/hr (for limited area within Port of SF jurisdiction, the treatment requirement is reduced to the 85% percentile, 24 hr. storm of 0.63 in with intensity of 0.2 in/hr). If project increases imperviousness by more than 50%, the stormwater requirement applies to the entire site. If imperviousness of site is increased by less than 50%, the requirement applies to new/replaced impervious area only.
Projects with new or replaced impervious area between 2,500-5,000 SF must implement at least one Site Design Measure to reduce runoff.
Utilizes BMP hierarchy. Must use preferred BMPs to the max extent practicable before considering remaining BMPs. The hierarchy prioritizes infiltration-based BMPs, rainwater harvesting, and green-roofs followed by lined bioretention.
In 2014, SFPUC initiated a Modified Compliance Program for combined sewer area to allow projects with proven site challenges to comply with the SMR via modified SW control performance requirements or the use of BMPs in adjacent public sidewalks to meet standard performance requirements. Eligible projects may decrease volume reduction performance to a minimum of 10% if they increase peak rate reduction by a 1:1 ratio to a max of 40%.
Pre-development conditions are the existing conditions before the proposed development.
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Application of the Standard	New and redevelopment that creates and/or replaces 5,000 SF or more of impervious area. Less stringent requirements for projects in separated sewer areas that create or replace between 2,500 and 5,000 sf of impervious area.
Alternative Compliance Option	Yes, an active modified compliance program and an fee-in-lieu program developed (currently in the approval process) and an offsite compliance framework, currently in development. Both the fee-in-lieu and offsite compliance frameworks have been created with the potential for a stormwater credit trading program in mind for the future. See details below.
Legal Authority for Enforcement	Stormwater control requirements for development and redevelopment projects are contained in the Stormwater Management Ordinance (SMO). The SMO provides the City with the legal authority to implement the postconstruction program outlined in the Stormwater Management Requirements and Design Guidelines (SMR). The San Francisco Green Building Code requires projects to meet the requirements outlined in the SMR.
Entity Approving and/or Issuing Permits	The San Francisco Public Utilities Commission (SFPUC) (and, for limited portions of the city, the Port of San Francisco) administers the stormwater management program. The SFPUC reviews and approves a Stormwater Control Plan (SCP) as a requirement for projects receiving their Certificate of Final Completion from the Department of Building Inspection.
Design Manual Provided	Stormwater Management Requirements and Design Guidelines (2016)

Hydrologic Calculation Methods for Sizing GRI	• City-provided sizing calculator that uses the Santa Barbara Unit Hydrograph (SBUH) Method; for sites < 20,000 m^2 (and individual GRI drainage areas no larger than 8,000 m^2).
	• Single-event hydrologic modeling software or continuous simulation modeling software (e.g. EPA SWMM, or equal) allowed for all project sites.
	• Only for projects with simple BMP systems:
	  ○ An industry-standard engineering method for generating runoff hydrographs (e.g., the SCS Runoff Curve Number Method or the Santa Barbara Urban Hydrograph Method).
	  ○ For small sites (< 0.25 acre): Rational Method for peak flow and Simple Method for volume.

Sizing Tool Available	Combined Sewer Area Sizing Calculator Separate Sewer Area Sizing Calculator
Year Implemented	First implemented in 2010. Latest set of Stormwater Management Requirements updated in 2016.

Additional Noteworthy and Relevant Findings:

Modified Compliance Program

- In 2014, the San Francisco Public Utilities Commission (SFPUC) initiated a Modified Compliance Program for the combined sewer area to allow projects with proven site challenges to comply with the City's Stormwater Management Requirements (SMR) via modified stormwater control performance requirements or the use of stormwater facilities located in adjacent public sidewalks to meet standard performance requirements. The Modified Compliance Program was developed based on research and modeling by the SFPUC along with feedback and coordination from the development and design community. Eligibility and compliance options of the Modified Compliance Program are as follows:

- Applies only to projects with existing imperviousness of greater than 50% and located within the combined sewer system
- Requires evaluation of site constraints, including high groundwater, shallow depth to bedrock, poorly infiltrating soils, contamination, and presence of zero lot line conditions (buildings that extend to the property lines)
- Requires evaluation of project potential for rainwater harvesting
- Requires the submittal of a Modified Compliance Application

- Eligible projects may meet stormwater requirements via either:
    - Modification of performance requirements: Allowed decrease in volume reduction requirements (to a minimum of 10%) and required increase in peak rate reduction requirements at a 1:1 ratio (to a maximum of 40%). For example, if the volume reduction requirement is decreased from 25% to 20%, the required peak flow reduction increases from 25% to 30%.
        - OR
    - Stormwater facilities in adjacent public sidewalk: The use of stormwater facilities in the adjacent public right-of-way (i.e. sidewalks) to comply with standard Combined Sewer Area performance requirements.

Fee-in-Lieu Compliance Program

Status: Currently developed program under review for approval and implementation

The development of the primary fee-in-lieu framework components – eligibility, fee basis, and application of revenue – consisted of a precedent study of 18 stormwater agencies nationwide, followed by evaluation of how various criteria and program functions would operate in the context of San Francisco meeting its specific stormwater management goals. Potential site eligibility criteria were assessed for defensibility, fairness, and simplicity, as well as the consequences of various participation rates. In general site eligibility for fee-in-lieu consideration was developed in order to provide flexibility to both the developer and the SFPUC in arriving at an optimal compliance solution, but not to supersede the intent of the SMO to require redevelopment projects to manage stormwater onsite.

This SFPUC has created a detailed fee-in-lieu program The SFPUC will need to further develop certain aspects of the fee-in-lieu program prior to rollout, however recommendations regarding the fundamental basis for project eligibility, fee, and applicability of the revenue are listed below.

- Eligibility: fee-in-lieu eligibility criteria is based on Modified Compliance criteria. The SFPUC may also choose to grant eligibility for sites that are constrained due to land-use type or site programming on a case-by-case basis.
- Fee basis and magnitude: The in-lieu fee is based on the estimated SMO unit compliance costs per impervious acre for Modified Compliance sites: $766,000 base cost + $154,000 life cycle costs = $920,000 total fee per acre impervious surface.

- Applicability: fee-in-lieu revenue will be used for the construction of equivalent or better performing projects that are strategically located either through an existing SFPUC capital program or via an existing or new grant program.

Offsite Compliance Program

Status: Currently in development

The proposed offsite compliance program would be available to both MS4 and CSS projects. Due to different stormwater management goals of the different sewer system areas, namely runoff treatment in MS4 versus peak flow and volume reduction in CSS, the program framework will be somewhat different in each sewer system area. While the SFPUC will need to further develop certain aspects of the offsite compliance program prior to rollout, Tables 1 and 2 below provide a summary of eligibility, project requirement, and approval process recommendations by sewer system type.

TABLE 1. SUMMARY OF OFFSITE COMPLIANCE FRAMEWORK RECOMMENDATIONS: ELIGIBILITY

	MS4	CSS
BMP FEASIBLITY		
Modified Compliance criteria as basis for eligibility?	YES – with modification that A and B soils are infiltrative, C and D soils are non-infiltrative	YES – identical to Modified Compliance criteria
Eligibility for partial site after maximum feasible onsite management using 1st priority BMPs?	YES – eligible portion of WQv_{reg} dependent on site infiltration area percentage and total impervious area project size	NO – full WQv_{reg} must be managed through offsite compliance if selected
POLLUTANT LOADING		
Restrictions based on pollutant loading?	YES – Sites with known or suspected SF Bay TMDL pollutants (Mercury, PCBs, Fecal-Indicator Bacteria) ineligible. No exclusions based on non-TMDL pollutants.	NO – no water quality requirements in CSS
LOCATION		
Specific areas to be excluded?	YES – SFPUC discretion to exclude sites on case-by-case basis that drain to sensitive receiving waters (e.g., dead end sloughs) and beaches with bacteria TMDLs.	YES – Mariposa and Sea Cliff pump station sub watersheds excluded based on beneficial impacts of runoff reduction on CSD reduction in these areas. SFPUC discretion to exclude sites on case-by-case basis where onsite stormwater BMPs could have beneficial effects on downstream localized flood risk or could eliminate the need for pipe or infrastructure upsizing.

Acronyms:

- BMP: Stormwater Best Management Practice
- WQv_{reg}: Regulated site Water Quality Volume
- TMDL: Total Maximum Daily Load
- PCBs: Polychlorinated Biphenyls
- CSD: Combined Sewer Discharge

TABLE 2. SUMMARY OF OFFSITE COMPLIANCE FRAMEWORK RECOMMENDATIONS: PROJECT REQUIREMENTS

	MS4	CSS

REGULATED SITE REQUIREMENTS		
Onsite management using 1st priority BMPs to maximum extent feasible?	YES	NO – full WQv_{reg} must be managed through offsite compliance if selected
"Treatment only" of remaining unmanaged runoff in addition to offsite compliance?	YES – to minimize untreated runoff to receiving waters	NO – no treatment requirement for CSS
OFFSITE BMP TYPE		
BMP type restriction?	YES – 1st and 2nd priority BMPs only	NO – all approved BMPs (or YES – 1st and 2nd priority BMPs only?)
OFFSITE SITING		
Same city?	YES – San Francisco only	YES – San Francisco only
Same sewer system type?	YES – MS4 only	YES – CSS only
Same watershed?	YES – Bay, Ocean, Lake Merced	YES – same basin (Bayside vs Westside)
Same jurisdiction?	NO – SFPUC / Port reciprocity, must be within San Francisco	N/A – all CSS area in SFPUC jurisdiction, must be within San Francisco
Land use type restriction?	NO	NO
Post-entitlement and redevelopment sites?	YES for "same runoff" (1), NO for "different runoff" (2)	YES for "same runoff", YES for "different runoff" (3)
OFFSITE SIZING		
Offsite performance requirement	Manage WQv_{reg} if offsite BMP is 1st priority	Reduce peak flow and volume equal to 25% flow and volume reduction of regulated site
NOBMP type trading ratio?	YES – 1.3*WQv_{reg} if offsite BMP is 2nd priority	NO – requirements are rate and volume reductions, BMP hierarchy not explicitly required
Pollutant loading trading ratio?	YES – 1.7*WQv_{reg} if regulated site is industrial and offsite is residential or commercial	NO – pollutant reduction not part of CSS requirements
OFFSITE TIMING		
Offsite implementation deadline?	Offsite compliance final SCP must be approved prior to regulated site receiving certificate of final completion. A penalty based on the proposed in-lieu fee shall be imposed for non-compliance.	Offsite compliance final SCP must be approved prior to regulated site receiving certificate of final completion. A penalty based on the proposed in-lieu fee shall be imposed for non-compliance.

Notes:

(1) "Same runoff": Offsite compliance scenarios in which the regulated site runoff is managed at an offsite location

(2) "Different runoff": Offsite compliance scenarios in which regulated site runoff remains unmanaged and offsite runoff is managed by offsite BMPs

(3) Post-entitlement and redevelopment sites may be "different runoff" offsite compliance projects only if offsite location generates enough runoff so that stormwater management features could eventually be constructed which meet its own flow and volume reduction requirements as well as the flow and volume reduction requirements of the regulated site development.

Stormwater Control Sizing Calculators

- After selecting and locating stormwater controls that are appropriate for site conditions, design teams must size the stormwater facilities to achieve the required stormwater performance results. Projects that are five acres (2 ha) or less, or with subwatershed areas that are two acres (0.8 ha) or less, can use Excel-based sizing calculator tools that were developed by the SFPUC. Larger, more complex development projects can use the sizing calculators as planning tools but must use modeling to prove compliance with the SMR. If using the calculators, all performance requirements are built into the spreadsheets, which, upon entry of site information, automatically provide runoff reduction estimates and indicate whether the site design passes (meets requirements) or fails (does not meet requirements). The BMP Sizing Calculator results allow design teams to iteratively complete a stormwater management plan for the site, showing proposed land uses, sub-watershed areas and drainage management areas, and specific BMP designs.

- The two calculator spreadsheets, one for combined sewer area projects and one for separate sewer area projects, are available on the SFPUC website along with additional guidance on facility sizing, information about the calculator approach (Santa Barbara Urban Hydrograph Method), and design parameters for each BMP.

Better Roofs Ordinance

- Effective January 1st, 2017, San Francisco became the first U.S. city to mandate solar and green roofs on most new construction. With the passage of this legislation, between 15% and 30% of roof space on most new construction projects will incorporate solar, green roofs, or a combination of both.
- The Better Roofs requirements apply to new construction that meet the following:
    - are non-residential with a gross floor area of 2,000 square feet or more, or are residential of any size; and
    - has 10 or fewer occupied floors
- The City analyzed the cost-effectiveness of meeting the Better Roofs requirement entirely with a green roof instead of solar, considering San Francisco's Mediterranean climate. The analysis was conducted with a green roof that uses 6 inches of lightweight media with native and adapted plants and two building types of similar size that are good candidates for green roofs: medium commercial and small multi-family. The costs and benefits of the living roof were compared to the costs and benefits of a baseline membrane roof with cool with coating that is a requirement for compliance with California Title 24. The analysis found that a green roof provides net financial benefit to the building owner, while providing significant additional benefit to the tenants, and the broader community. The largest cost of a green roof – the one-time installation cost – is largely offset by the avoided one-time stormwater management equipment costs that would be incurred with the baseline roof. The largest potential benefits is added real estate value, which also accrues to the building owner.

Onsite Water Reuse Program

The Onsite Water Reuse Program allows for the collection, treatment, and use of alternate water sources for non-potable applications in individual buildings and at the district-scale. In 2012, the City adopted the Onsite Water Reuse for Commercial, Multi-family, and Mixed-Use Development Ordinance. Commonly known as the Non-potable Water Ordinance (NPO), it added Article 12C to the San Francisco Health Code, allowing the collection, treatment, and use of alternate water sources for non-potable uses such as toilet flushing and irrigation. Since its adoption, the NPO has been amended to allow for district-scale projects, where two or more parcels can share alternate water sources, and in 2022 reduced the compliance threshold for requiring new development projects to install and operate an onsite non-potable water system to 100,000 square feet (9,290 square meters) or more of gross floor area.

The required alternate water sources and required non-potable uses are based on development project type. For commercial buildings, the project must meet its toilet and urinal flushing through the collection, treatment, and use of available blackwater and condensate. For residential and mixed-use buildings, the project must meet its toilet and urinal flushing, irrigation, and clothes washing demands through the collection, treatment, and use of available graywater and condensate. The requirements apply to both development projects consisting of a single building or multiple buildings.

New development projects of 40,000 gross square feet (3,720 square meters) or more are required to submit water budget calculations assessing the supply available from the required alternate water sources and the demand from required non-potable uses but are not required to install and operate an onsite water reuse system.

Customers with onsite non-potable water systems may receive an adjusted water and wastewater capacity charge that accurately reflects the reduced demand placed on SFPUC water and wastewater systems. Additionally, the SFPUC is currently implementing a Water Use Allocation Program and excess use charges for new development projects. Projects that are required to have an onsite reuse system will be assigned monthly water use allocations based on the project's approved Water Budget Application. Any amount of potable water used in excess of the monthly allocation is subject to excess use charges and will be billed at a rate equal to 300% (3x) the applicable water and wastewater rates.

The SFPUC provide a Water Use Calculator that must be completed and submitted for approval. This calculator provides a consistent and recommended methodology for computing the total and required water supplies and demands for the project (either single site or multi-building district scale). The calculator has flexibility to allow users to adjust inputs and assumptions, however all changes from default value must be justified.

The policy driver for the NPO is to diversify the City's water portfolio. While the City still prefers that projects utilize all available alternative water sources to meet all potential non-potable water demand, rainwater reuse is no longer a required supply. In 2022 the NPO was amended to no longer require that either rainwater (rooftop) or stormwater (at-grade) supplies be collected and treated for reuse. This change was in part driven by needs of the Water Use Allocation Program, as it was determined to be infeasible to calculate a monthly water use allocation that included a dynamic environmentally influenced input such as rainfall. With this change, the capture and reuse of rainwater to satisfy the City's stormwater management requirements was not allowed for NPO compliant projects, except for any portion of demand that exceeded the supply from required alternative water sources.

WASHINGTON, DC DC WATER AND DEPARTMENT OF ENERGY AND ENVIRONMENT	
Drainage System Type Combined/Separate/Both	Both
Key Drivers for Stormwater Policy/Requirements	MS4 Permit compliance, CSO, water quality (Chesapeake Bay Total Maximum Daily Load (TMDL) - pollution diet) DC has a NPDES MS4 Permit, which covers approximately 2/3 of the District. The Stormwater Management Division of the Natural Resources Division within the DOEE is responsible for managing the NPDES Permit. DOEE assumed responsibility for DC's stormwater management in 2007. DC also has a combined sewer system, which covers approximately 1/3 of the District. DC Water is the regional authority that manages the combined sewer system and the waste water treatment operations. DC Water has a Consent Decree with EPA and the Department of Justice to control CSOs through large-scale tunnel storage and green infrastructure.

Stormwater Design Standard	**Stormwater Retention Volume (SWRv)**
	• Major land disturbing activities must retain the first 30 mm/1.2" of rain from a storm event (90th percentile storm).
	• Major substantial improvement activities must retain the first 20 mm/0.8" of rain from a storm event.
	• Regulated projects have the option to meet a portion of their retention requirement offsite:
	    ○ Up to 100% off-site compliance in CSO areas
	    ○ Max 50% offsite compliance in MS4 areas
	
	Water Quality Treatment Volume (WQTv)
	• In addition to SWRv requirements, sites in the Anacostia Waterfront Development Zone (AWDZ) that are publicly owned or financed shall employ BMPs and post-dev land cover necessary to achieve a WQTv equal to the difference between the post-dev runoff from the 95th percentile rainfall event (1.7") measured for a 24 hr. rainfall event with a 72 hr. antecedent dry period, and the SWRv.
	• A site in the AWDZ that is governed by the Anacostia Waterfront Environmental Standards Amendment Act of 2012 may achieve on-site treatment for WQTv with on-site treatment to remove 80% TSS, on-site retention, or direct conveyance to an approved shared BMP with sufficient available capacity.
	
	2-yr Storm Control
	Projects are required to provide onsite detention to ensure post-project peak discharge rate from 2-yr, 24-hr storm is reduced to the pre-dev peak discharge rate. Detention can be provided underground or surface storage, or by increasing size of BMPs used to meet SWRv requirements. Exemption for major substantial improvement projects, reconstruction projects in existing public ROW, and projects with SW

	runoff through MS4 to tidal Potomac or Anacostia Rivers, Washington Channel, or Chesapeake and Ohio Canal as long as it doesn't flow through above ground tributary and will not cause erosion. **15-yr Storm Control** Projects are required to provide onsite detention to ensure post-project peak discharge rate from the 15-yr, 24-hr storm is reduced to the pre-project peak discharge rate, unless project is in public ROW or if it is a major substantial improvement project. **100-yr Storm Control** Project sites are required to maintain post-project peak discharge rate from the 100-yr storm event controlled to the pre-project peak discharge rate if the site increases the size of a Special Flood Hazard Area, or does not discharge into the sewer system, or has a post-dev peak discharge rate for the 100-yr storm event that will cause building flooding. Pre-dev conditions are defined hydrologically as "meadow in good condition".
Application of the Standard	• *Major Land disturbing activity*: Project disturbs over 5,000 SF and site has pre-project natural land cover or over 2,500 of post-project impervious area. • *Major substantial improvement activities* such as renovation or addition to a structure that exceeds the following cost and size thresholds: ○ Cost of project is greater than 50% of pre-project assed value of structure. ○ Combined footprint of structure(s) exceeding cost threshold and any land disturbance is greater than 5,000 SF. • No post-construction SW management req: If project doesn't include land disturbance of over 5,000 SF or if it does but there was no pre-project natural cover and less than 2,500 SF of post-project impervious area, and there is no renovation or addition that qualifies as Major Substantial Improvement Activity.
Alternative Compliance Option	Yes - Developments that cannot meet the on-site stormwater management requirement can pay an In-Lieu Fee or purchase credits on the Stormwater Retention Credit (SRC) marketplace.
Legal Authority for Enforcement	DC Municipal Regulations (Chapter 21-5, Water Quality and Pollution)
Entity Approving and/or Issuing Permits	DOEE
Design Manual Provided	Stormwater Management Guidbook (2020)
Hydrologic Calculation Methods for Sizing GRI	Recommended methods: • SCS Runoff Curve Number Method • EPA SWMM computer model Other acceptable methods:

	• Storage-Indication Routing • HEC-HMS, WinTR-55, and TR-20 Computer Models • Rational Method (limited to smaller sites and not recommended because it cannot account for the detention benefits of smaller retention BMPs applied on a site)
Sizing Tool Available	Y - Link here
Year Implemented	Most recently updated in 2020

Additional Noteworthy and Relevant Findings:

- Washington, DC's MS4 permit, DC Water's CSO control consent decree, and the Chesapeake Bay TMDL are all drivers for requiring GI installation.
- In DC, post-construction requirements for development are key mechanisms for meeting stormwater and green infrastructure objectives.
- DC's requirements for stormwater management go beyond what is required by its MS4 permit.
- DC's 2013 Stormwater Rule is the largest driver towards achieving GI implementation across the District, which requires the installation of GI on major development projects to meet a retention standard.
- Those developments that cannot meet the on-site stormwater management requirement can pay an In-Lieu Fee or purchase credits on the Stormwater Retention Credit (SRC) marketplace. The marketplace is supplied by developments that go beyond code or those property owners that voluntarily install retrofits on their property. This program is called the SRC Trading Program.
- Stakeholder engagement was crucial for the development of the SRC Trading Program, which took over 2 years.

Stormwater Retention Credit Trading Program

- Impetus: When DC was trying to roll-out stormwater regulatory requirements for private development there was a lot of push-back from development community, so SRC program was developed to provide flexibility for regulatory compliance while incentivizing private landowners throughout the District to build GI.
- Allows sites to meet up to a certain % of their on-site retention requirement by purchasing SRCs generated by projects that voluntarily provide retention (above and beyond regulatory requirement).
- Projects in combined sewer system area that drain to large storage tunnels may meet 100% of their retention requirement offsite, while projects in MS4 area may meet up to 50% of their retention requirement by purchasing SRCs or paying the In-Lieu Fee.
- Credits may be purchased from projects located anywhere in the District (no sub-watershed or catchment trading boundaries).
- Prices for SRCs are negotiated between buyers and sellers and fluctuate with supply and demand.
- All SRCs are registered and posted by the DOEE to the online SRC Registry. SRC sales and trades are tracked by the DOEE through its Stormwater Database.
- Each SRC represents 1 gallon of GI retention capacity for 1 yr, and DOEE will certify up to 3 years' worth of SRCs at one time.
- Through the SRC price lock program, SRC generators have the option to sell their SRCs to the DOEE at fixed prices to offer revenue certainty. And the Fee-In-Lieu acts as a price ceiling for the SRC trading market because developers would opt to pay the Fee-In-Lieu if the only available SRCs were priced more highly.

Operation and Maintenance

- Regulated projects and projects that want to generate and certify SRCs must submit a Stormwater Management Plan to District plan reviewers. Once the plan is approved and construction begins, inspectors make periodic inspections along with a final inspection once construction is complete.
- There is a legal obligation for sites to maintain their stormwater facilities in perpetuity established through a legal covenant applied to the land on which GI was installed which is binding for current and future property owners.

Related GSI Initiatives

- The **RiverSmart Program** is an umbrella program for a number of rebates, grants, and discounts:
- RiverSmart Rewards provides sites with voluntarily installed GI a discount on the DOEE Stormwater Fee and DC Water's Impervious Area Charge to encourage uptake of GI practices.
- RiverSmart Homes, RiverSmart Communities, RiverSmart Schools, and RiverSmart Rebates offer installation of certain GI practices (i.e., rain barrels, rain gardens, bayscaping, permeable pavers, and shade trees) for a minor co-payment or direct rebate.
- RiverSmart Rooftops offers a green roof installation rebate (up to $15/square ft).

Task 5 – Performance Modeling and Pathway Development Memo

MEMORANDUM

Date: October 13, 2023

To: Gord Tycho *(City of Vancouver, BC)*

From: Brian Busiek, Neil Schaner, and Meghan Mullen *(Herrera)*

Cc: Bryce Wilson and Eric Zickler (*Lotus Water*)

Project: Rainwater Infrastructure Building Typologies Pathway Study

Subject: Task 5 - Performance Modeling and Pathway Development

INTRODUCTION

The Lotus Water team is working with the City of Vancouver, BC (City) to develop and test site-level rainwater management compliance pathways for a suite of building-site typologies. These compliance pathways represent different combinations of rainwater management tools that can be deployed to meet the City's rainwater management design standards (capture and clean 48 mm of rainfall) and help achieve the City's Rain City Strategy goals. Earlier tasks in this study focused on:

- defining a hypothetical set of building-site typologies to be tested (Task 2),
- defining the potential rainwater management tools, including green rainwater infrastructure (GRI) tools and grey (non-GRI) tools, that could be used by developers to meet the City's rainwater management design standards (Task 3),
- developing the design methodology and the model to test various compliance pathways (Task 4), and
- identifying barriers and constraints to broader adoption of GRI tools (Task 8).

The next step in the project is to assemble and test a set of potential compliance pathways for each building-site typology using the rainwater management tools and the model developed under previous tasks. This work represents Task 5 of the project scope. The purpose of this memorandum is to document the modeling variables, the overall modeling approach, modeling results and observations, and recommendations for further pathway development.

Modeling Variables

The primary purposes of the performance modeling task (Task 5) are to determine the viability of various rainwater management tools and compliance pathways for the building-site typologies developed in Task 2, which represent the range of representative development types to be tested. The rainwater management tools to be used to build compliance pathways for each typology were defined in Task 3. The design standards, site conditions, and development conditions represent additional modeling variables that were developed in consultation with the City over a series of working group meetings in Task 5. All these variables are discussed further in subsections that follow and are summarized in Table 3 at the end of this section.

Building-Site Typologies

Seven building-site typologies were created in Task 2 based on review and analysis of existing development patterns and recent rezoning applications, and consultation with the City. These represent a range of building and land-use types expected to be encountered as the City densifies and redevelops in the future.

The *Representative Building Site Typologies Technical Memo* developed during Task 2 presents a summary of the analysis used to create the typologies, along with representative characteristic values as summarized in Table 1 below.

Table 1. Representative Building Site Typologies

Building Site Typology	*Representative Value*				
	Total Parcel Area (m^2)	Total Impervious Area [1] (% of parcel)	Roof Area [2] (% of parcel)	Story AG [3]	Parkade [4]
Small Lot Residential – Low Massing	375	45%	30%	2	0
Small Lot Residential – High Massing	375	70%	50%	2	0
Low-Rise Residential & Mixed-Use	2,500	90%	40%	3	1
Mid-Rise Residential & Mixed-Use	3,000	95%	65%	6	2
High-Rise Residential & Mixed-Use	1,200	90%	70%	20	3
Low/Mid-Rise Non-Residential	2,500	100%	40%	3	1
High-Rise Non-Residential	8,000	100%	55%	14	4

Notes:

1. Total Impervious Area represents the area onsite that will not be available for infiltration into the subgrade. This includes the roof area, all surface level impervious surfaces (e.g., paved parking, pathways, etc.), and also subsurface structures (such as a parkade, which may extend nearly lot line to lot line) that could have planting above it.
2. Roof area is the elevated portion of the building, what might be considered the building footprint. Roof Area is a subset of the Total Impervious Area (e.g., surface/subsurface impervious area on the parcel is the difference between the Total Impervious Area and the Roof Area).
3. Story AG is the number of building levels above ground
4. Parkade is the number of building levels below-ground.

For the purposes of advancing the compliance pathway development, three characteristic values were added to further define the land cover and occupancy characteristics of each building-site typology. Each of these additional defining characteristics helped in pairing the appropriate rainwater management tools with site elements as part of the compliance pathway development, which include:

- pedestrian and vehicular portions of ground-level impervious area, which differentiates pollutant generating impervious surfaces (PGIS) from non-pollutant generating surfaces;
- building occupancy populations, which informs demand for non-potable water systems; and
- at-grade area available for infiltration given different setback requirements.

Table 2. Representative Building Site Typologies Expanded Characteristics

Building Site Typology	Total Parcel Area (m^2)	Building Roof Area (m^2)	Total Ground-Level Imperv. (m^2)	PGIS (m^2)	Ground-Level Pervious (m^2)	Number of Building Occupants		
						Resident	Employee	Visitor
Small Lot Residential – Low Massing	375	113	56	28	206	4	0	0
Small Lot Residential – High Massing	375	188	75	38	113	7	0	0
Low-Rise Residential & Mixed-Use	2,500	1,000	1,250	250	250	86	0	0
Mid-Rise Residential & Mixed-Use	3,000	1,950	900	180	150	301	51	23
High-Rise Residential & Mixed-Use	1,200	840	240	48	120	432	73	33
Low/Mid-Rise Non-Residential	2,500	1,000	1,500	150	0	0	130	60
High-Rise Non-Residential	8,000	4,400	3,600	360	0	0	2,678	1,228

Compliance Standards

The City is seeking to test two different compliance design standards for rainwater management in the City under this study. The first represents the City's existing standard defined in the *Zoning and Development By-law* with further guidance provided in the *2018 Rainwater Management Bulletin* and the *2019 Engineering Design Manual*. This standard requires prioritizing retention and allows detention and treatment when full retention is not possible. The second compliance standard represents the aspirational goals defined in the *2019 Rain City Strategy*.

Compliance Standards

- *Existing Standard* - 24-mm retention OR treatment/detention with pre/post-construction peak flow matching + additional 24-mm treatment for PGIS
- *Rain City Strategy Standard* - 48-mm retention with pre/post-construction peak flow matching

Rainwater Management Tools

A set of GRI and non-GRI tools are defined in the *Representative Rainwater Management Tools Technical Memorandum* (completed under Task 3). These tools can be assembled in a potential multitude of ways for each building-site typology to meet the two compliance design standards to be tested. These tools were developed based on existing City guidance, review of recent Rainwater Management Plans submitted to the City, practical design experience, and City input.

Two primary categories of information were compiled for each tool: siting considerations and design parameters.

1. Siting considerations included applicable building-site typologies, maximum contributing drainage areas, minimum soil infiltration rates, minimum groundwater separation, and other setback criteria.

2. Design parameters compiled included minimum and maximum dimensions, component characteristics, outlet and discharge requirements, and other design considerations.

Through the *Rainwater Management Bulletin*, the City defines three tiers of tools to achieve the existing compliance standard (24-mm). These tiers represent a hierarchy of methods and associated tools to be considered when designing rainwater management compliance pathways. These tiers include:

- **Tier 1:** Use volume reducing GRI, which include but are not limited to infiltrating tools, rainwater harvesting systems, and resilient roofs.

- **Tier 2:** Use non-infiltrating GRI, which includes absorbent landscapes on slab and lined or closed bottom GRI tools.

- **Tier 3**: Use grey non-GRI tools, which includes various forms of detention in combination with a water quality treatment device.

The City's policy dictates that Tier 1 tools are to be prioritized, with any remaining volume of rainwater to be managed using Tier 2 and 3 methods. A full listing of the rainwater management tools (and assigned tiers) is provided in Table 3 below.

Table 3. Rainwater Management Tool List	
Primary Tool Type	**Tool Sub-type**
Tier 1 Tools	
Resilient roofs	Extensive (<150 mm soil depth) green roofs Intensive (≥150 mm soil depth) green roofs Blue-green roofs
Bioretention (unlined)	Sloped-side bioretention (unlined wo/ underdrains) Full-walled bioretention (planter) (unlined wo/ underdrains) Partial-walled bioretention (unlined wo/ underdrains)
Absorbent landscapes	Over native soils
Tree trenches	Structural soils Soil cells
Permeable pavement	Permeable pavers Pervious concrete Pervious asphalt
Subsurface infiltration	Small-scale near-surface infiltration (e.g., drywells) Large-scale near-surface infiltration (e.g., infiltration chambers) Deep infiltration (e.g., drill drains)
Rainwater harvesting systems	Rainwater harvesting systems (rooftop runoff) Rainwater harvesting systems (all impervious runoff)
Tier 2 Tools	
Bioretention (lined)	Sloped-side bioretention (lined w/ underdrains) Full-walled bioretention (planter) (lined w/ underdrains) Partial-walled bioretention (lined w/ underdrains)
Absorbent landscapes	Over slab
Permeable pavement	Permeable pavers (lined w/ underdrains) Pervious concrete (lined w/ underdrains) Pervious asphalt (lined w/ underdrains)
Tier 3 Tools	
Detention tanks (without reuse)	Surface detention tanks Subsurface detention tanks/vaults Blue roofs
Proprietary water quality devices	Pre-treatment devices (50% Total Suspended Solids (TSS) removal) Basic treatment (80% Total Suspended Solids (TSS) removal)
Offsite Tools	
Offsite green facilities	Centralized green facilities Localized green facilities (e.g., green street)

Site Conditions

Two separate variables representing site conditions were determined to be critical for evaluating performance of compliance pathways. These were pre-development conditions and existing soil conditions. A third potential variable that represents downstream context was also considered but was not included in the proposed set of site condition variables. Each of these three variables are described further below.

Site Conditions

Pre-Development Conditions

- No pre-development (0% impervious)
- Less than post-development (50% of post-construction impervious)
- Equivalent to post-development (100% of post-construction impervious)

Soil Conditions

- High Infiltration (50 mm/hr)
- Moderate Infiltration (20 mm/hr)
- Low Infiltration (5 mm/hr)
- No infiltration (0 mm/hr)

Pre-Development Conditions

The two compliance standards to be tested include a release rate component. Compliance with the release rate standard requires that post-construction peak flow rates not exceed the pre-construction peak flows (using specified intensity-duration-frequency (IDF) curves). Determination of pre-construction flows requires an evaluation of pre-development conditions. Since the typologies are hypothetical sites without an established pre-development state, a set of three pre-development conditions were initially proposed to represent the range of potential values encountered in a real-world development scenario, ranging from 0% impervious to 100% impervious. The pre-development condition values include the two extremes (0% and 100% of post-development impervious area) as well as a middle value (50% of post-development impervious area).

Soil Conditions

Soil conditions are a key variable to determine selection and performance of rainwater management tools for a particular site. One of the primary considerations for soil condition is infiltration capacity, which has a direct bearing on the performance of infiltrating GRI tools (Tier 1). A range of infiltration rates were proposed to reflect potential real-world conditions—ranging from high (50 mm/hr) to moderate (20 mm/hr) to low infiltration (5 mm/hr). A no infiltration (0 mm/hr) value was also included to represent very poor infiltration conditions, as well as other site conditions where runoff infiltration is not possible or not recommended. These other site conditions could include high groundwater, steep sloped areas, and areas with soil or groundwater contamination.

Upstream and Downstream Context

For this study, upstream and downstream context could include a number of conditions, including large developments and/or upzonings, increased impervious cover upstream in the watershed, the presence of ecologically sensitive zones downstream, a combined sewer or otherwise capacity constrained pipe, or floodplain with potential for backwatered conditions.

While these are all important contexts, assessment of these conditions would require watershed-scale modeling, which is not part of this study. However, the team highly recommends carrying out watershed-scale modeling based on Task 9 policy recommendations to assess its aggregated impact on the broader conveyance system over a specific timeframe (e.g., aligned with the Healthy Waters Plan's and Vancouver Plan's planning horizon). This would allow the City to quantify the potential system benefits from those policy recommendations, and course correct as needed.

Development and Policy Conditions

Three development-specific conditions that are reflective of decisions made by the developer or influenced by City policy were identified as potential variables of interest. These were roof area managed by rainwater management tools, infiltration area available at ground level as a result of setback requirements and parkade extent, and degree of non-potable reuse. Each of these three variables is described further below.

Roof Area Managed by Roof GRI

Several rainwater management tools (i.e., resilient roofs and blue roofs) require sufficient flat or mildly-sloped roof area to meet or contribute to meeting the standards. The availability of roof area for resilient roofs or blue roofs is highly varied amongst developments given the competition for roof space for bulkheads, egress, and mechanical equipment. Note that roof area programed for public access and amenities space or play areas can be integrated into resilient roof systems and designs and can be included in the managed roof area. These are not mutually exclusive uses.

Therefore, while "roof area available" (i.e., within which the actual resilient roof system managing rainfall would be located) is the primary variable impacted by space constraints, for modeling purposes, "roof area managed" was the variable used to simplify the analysis (acknowledging that a resilient roof system can be designed to manage runoff from adjacent roof area). To capture a range of areas that might be available in a real-world application, a range of values for roof area managed was used from 0% of total roof area up to 100%.

Infiltration Area Available

The availability of space for siting infiltrating GRI tools determines the extent to which these Tier 1 tools are utilized to meet the performance standards. For many of the denser building-site typologies, there is very little, if any, ground-level non-impervious surface available. Even when some ground-level pervious area is available, the ability to site infiltrating GRI tools can be limited by City policies including parking and infiltration setback requirements and by developer decisions around site layout. The available infiltration area considers these two factors:

- Setback Requirements
- Parkade Extent

While these are not the sole limiting factors of infiltration area availability, the values considered for each variable do reflect the potential outcome of a range of future policies and development decisions, which is an increase in available infiltration area.

Development and Policy Conditions

Roof Area Managed by Roof GRI

- No roof GRI (0%)
- Low (25%)
- Medium (50%)
- High (75%)
- All roof area managed by roof GRI (100%)

Setback Requirements

- Existing Setbacks (5 meters)
- Modified Setbacks (3 meters)
- No Setbacks (0 meters)

Parkade Extent

- Full Extent of Impervious Area
- Full Building Footprint

Non-Potable Reuse

- Typical non-potable demands of flushing + irrigation
- Expanded non-potable demands including clothes washing and cooling makeup

Setback Requirements

The Vancouver Building By-law (VBBL) requires a 5 meter setback from building foundation for any infiltration system.[1] In addition to this existing requirement, the setback assumption variable used in the modeling includes two additional setback assumptions: a modified setback exemption (3-meter setback) achieved via the Alternatives Solutions submission, and a no setback assumption (0-meter setback). The impact of the setback variable on the at-grade areas on the site was calculated using representative building footprints for parcels of each typology considered.

- First, representative parcels were identified for each typology as well as assumptions about the location of buildings on adjacent parcels, alleys, and streets.
- Next, the setback options (5 m, 3 m, and 0 m) were added to the parcels based on the proposed building footprints and assumed building locations on neighboring parcels.
- Lastly, the at-grade area outside of each setback option was measured. The results of this analysis are shown in Table 4 below.

[1] Additional setbacks from streets, lanes, and utilities may be required at the discretion of the City Engineer and other authorities such as Vancouver Coastal Health which enforces setbacks from potable water services.

Table 4. Infiltration Area Availability due to Setback Requirements			
Building Site Typology	**Current Setbacks (5 m)**	**Modified Setbacks (3 m)**	**No Setback (0 m)**
Small Lot Residential – Low Massing	15%	35%	100%
Small Lot Residential – High Massing	3%	15%	100%
Low-Rise Residential & Mixed-Use	28%	49%	100%
Mid-Rise Residential & Mixed-Use	15%	44%	100%
High-Rise Residential & Mixed-Use	25%	51%	100%
Low/Mid-Rise Non-Residential	69%	80%	100%
High-Rise Non-Residential	78%	86%	100%

These percentages were applied proportionally to the amount of at-grade pervious and impervious area present at each site typology. The resulting areas represent the amount of area available for infiltration at each site typology based on setback allowances. It should be noted that the amount of at-grade area varies greatly between the site typologies. See again Table 2.

Parkade Extent

The parkade extent variable includes two extremes which represent the range of impacts expected due to parkade structures located beneath the parcels:

a) **Full Impervious Footprint Parkade:** suggests that the parkade extends to the full limit of the defined impervious area for a typology (i.e., the parkade is much larger than the building footprint, occupying 90-100% of the parcel). This is the maximum value, resulting in the greatest reduction to site area available for an infiltrating GRI footprint. This is the standard development practice assumed in the representative site typologies characteristics.

b) **Building Footprint Parkade:** suggests that the parkade does not extend beyond the defined building footprint for a typology. This is the minimum value, resulting in the parkade having no impact on the site area available for infiltrating GRI footprint.

Parkade structures are not included in the two small lot residential typologies, so infiltration setbacks are applied only from the building, equivalent to option (b).

Non-Potable Reuse

The VBBL, Book II, Plumbing Systems contains the current requirements for non-potable water systems and onsite reuse. The VBBL Section 2.7.1.3 Non-Potable Water Uses dictates the allowable uses for non-potable water as toilet/urinal flushing, trap priming, irrigation (of non-food purposes plants), clothes washing, and makeup water for heating/cooling systems.

Section 2.7.1.2 Non-Potable Water Sources of the VBBL only permits the collection of rainwater from non-vehicular above grade (e.g., rooftop) surfaces as well as clear-water waste (e.g., condensate from heating/cooling systems) for onsite reuse, with stormwater[2] as well as groundwater, perimeter drainage, graywater, and blackwater all prohibited. Differing approaches to permitted water sources were explored with the rainwater management tools variable, through the rainwater harvesting system subtypes. The first sub-type, "rainwater harvesting systems (rooftop runoff)" represents the currently permitted policy, while "rainwater harvesting systems (all impervious runoff)" represent the additional inclusion of rainwater runoff from other impervious surfaces (i.e., including ground-level stormwater).

With non-potable water supply variables covered by the different rainwater management reuse tools being considered, the non-potable reuse variable focused on different levels of non-potable demand. The reuse variable included two values: typical non-potable demands (flushing and irrigation) and expanded non-potable demands (typical demands plus clothes washing and cooling makeup). While both fall under currently permitted uses, they represent two ends of plausible reuse scenarios. More ambitious non-potable demands or even potable demands were considered during modeling approach development but were deemed to be highly unlikely to be encountered frequently in real-world scenarios.

[2] It is our understanding that the City is in the process of amending the VBBL to allow the collection of ground-level stormwater in addition to above-grade rainwater.

Table 5. Summary of Proposed Modeling Variables								
Modeling Variable	**Typology**	**Compliance Standards**	**Rainwater Management Tools**	**Site Conditions**		**Development and Policy Conditions**		
				Pre-Development Conditions	**Soil Conditions**	**Roof Area Managed by Roof GRI**	**Infiltration Area Available**	**Non-Potable Reuse**
Variable Values	• Small Lot Residential – Low Massing • Small Lot Residential – High Massing • Low-Rise Residential & Mixed-Use • Mid-Rise Residential & Mixed-Use • High-Rise Residential & Mixed-Use • Low/Mid-Rise Non-Residential • High-Rise Non-Residential	• Existing Standard - 24-mm retention OR treatment/ detention with pre/post-construction peak flow matching + additional 24-mm treatment for PGIS • Rain City Strategy Standard - 48-mm retention with pre/post-construction peak flow matching	• All, paired with appropriate standard	• No pre-development (0% impervious) • Less than post-development (50% of post-construction impervious) • Equivalent to post-development (100% of post-construction impervious)	• High Infiltration (50 mm/hr) • Medium Infiltration (20 mm/hr) • Low Infiltration (5 mm/hr) • No infiltration (0 mm/hr)	• No roof GRI (0%) • Low (25%) • Medium (50%) • High (75%) • Entire roof area managed by roof GRI (100%)	**Setback Requirements** • Existing setback (5 m) • Modified setback (3 m) • No setback (0 m) AND **Parkade Extent[1]** • Parkade extends to building footprint only • Parkade extends past building to impervious extent	• Typical non-potable demands of flushing + irrigation • Expanded non-potable demands including clothes washing and cooling makeup

1. Note that parkade extent does not impact Small Lot Residential typologies.

Overall Modeling Approach

Testing and development of compliance pathways for each of the typologies and design standards being considered were performed using the spreadsheet-based GRI Design Sizer developed in Task 4. The modeling process involved the creation of different modeling scenarios that represent distinct combinations of typologies, compliance standards, rainwater management tools, and all the other site, development, and policy condition variables discussed in the previous section.

The most complicated component of this modeling analysis is pairing the many rainwater management tools with the many typologies and additional variables that influence tool siting and performance. This is compounded by the hypothetical nature of this exercise, where true site conditions and context are not known. To navigate these complexities, the modeling approach will require modeling in multiple phases.

In Phase 1, as described below, the high-level viability and scale testing was performed to isolate each primary rainwater management tool type to help determine its performance and viability towards meeting overall typology compliance. The collective results of Phase 1 modeling facilitated the identification of tools and variables that were critical for pathway compliance and informed the recommended pathways shown in Table 10.

Phase 2 of the modeling will occur during Task 9 where the tools' performance, cost (Task 6), and co-benefits (Task 7) will be brought together to develop pathway tool sets for each typology.

Phase 1 Modeling Approach

As noted above, the intent of Phase 1 of the pathway modeling effort was to isolate rainwater management tool performance and determine their viability towards meeting overall typology compliance. The compliance standards being tested in this study include multiple modes of management (i.e., retention, detention, and treatment) and a hierarchy that prioritizes retention first and then allows for detention and treatment when full retention is not possible. Given this complexity and the fact that meeting the retention standard is the most challenging mode of rainwater management, the Phase 1 modeling was focused primarily on determining viability of pathways that achieve the 24-mm and 48-mm volume reduction requirements through retention. This limited the rainwater management tools considered in Phase 1 modeling to Tier 1 tools (Tier 2 tools can provide treatment, but only limited retention). The other modes of rainwater management and the associated tools will be considered further in Task 9.

To develop modeling scenarios, each building-site typology was broken into distinct relevant land covers: roof area and ground area (Figure 1). These land covers were then paired with logical sets of associated Tier 1 tools to create the Phase 1 set of tool variables for testing.

Pairing of these tools with the associated land covers is shown in Table 6 and is also graphically depicted in Figure 2, which shows those tools that are sited on the land cover that they manage (i.e., self-managing) as well as those tools that manage one land cover while sited on another.

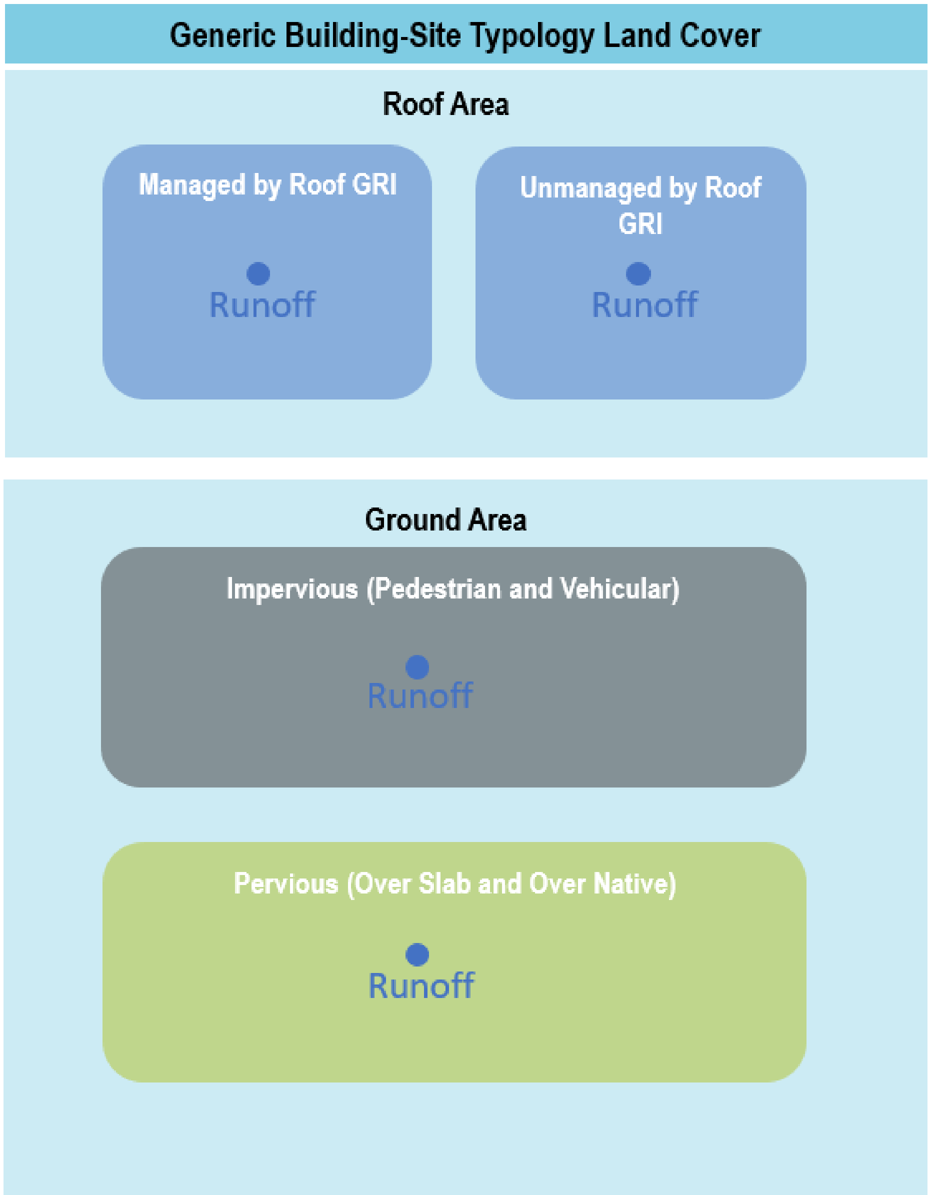


Figure 1. Generic Typology Land Covers

Table 6. Tier 1 Rainwater Management Tools and Eligible Land Covers Managed								
Land Cover Category	**Land Cover Subcategory**	**Resilient Roof**	**Rainwater Harvesting System**	**Bioretention (Unlined)**	**Absorbent Landscapes**	**Tree Trenches**	**Permeable Pavement (Unlined)**	**Subsurface Infiltration**
Impervious – Roof	Managed by Roof GRI	✓		✓	✓		✓	✓
	Unmanaged by Roof GRI		✓	✓	✓		✓	✓
Impervious – Ground	Pedestrian Impervious		✓	✓	✓	✓	✓	✓
	Vehicular Impervious		✓	✓	✓	✓	✓	✓
Pervious – Ground	Over Slab			✓	✓			✓
	Over Native			✓	✓			✓

These paired rainwater management tools are then modeled individually for all seven building-site typologies, both compliance retention design standards, and all the relevant site, development, and policy condition variable values. This resulted in over 73,000 distinct scenarios that were modeled in Phase 1. Each scenario was modeled with the GRI Design Sizer to evaluate the rainwater management tool viability and performance.

The modeling accounted for siting considerations (e.g., maximum contributing drainage areas, setback criteria) and design parameters (e.g., average dimensions, component characteristics) for each Tier 1 rainwater management tool. Because of the significant complexity of sizing each tool to exactly manage the required retention volume given the set of site variables, each tool was tested with the maximum footprint based on the available space on the land cover on which it was sited and the drainage area to footprint ratio established for each tool in Task 3. In this way, the modeling results represent the full potential for a particular tool to manage runoff. While this may be unrealistic in real world applications, it is helpful to understand the viability of a particular tool and site context. More precise sizing will be completed during Task 9 with a smaller subset of defined pathways.

Scripting with Visual Basic and R was used to create and loop through an input matrix of each scenario variable combination and to report out the results from the GRI Design Sizer. Results and observations of the Phase 1 modeling are shown in the next sections.

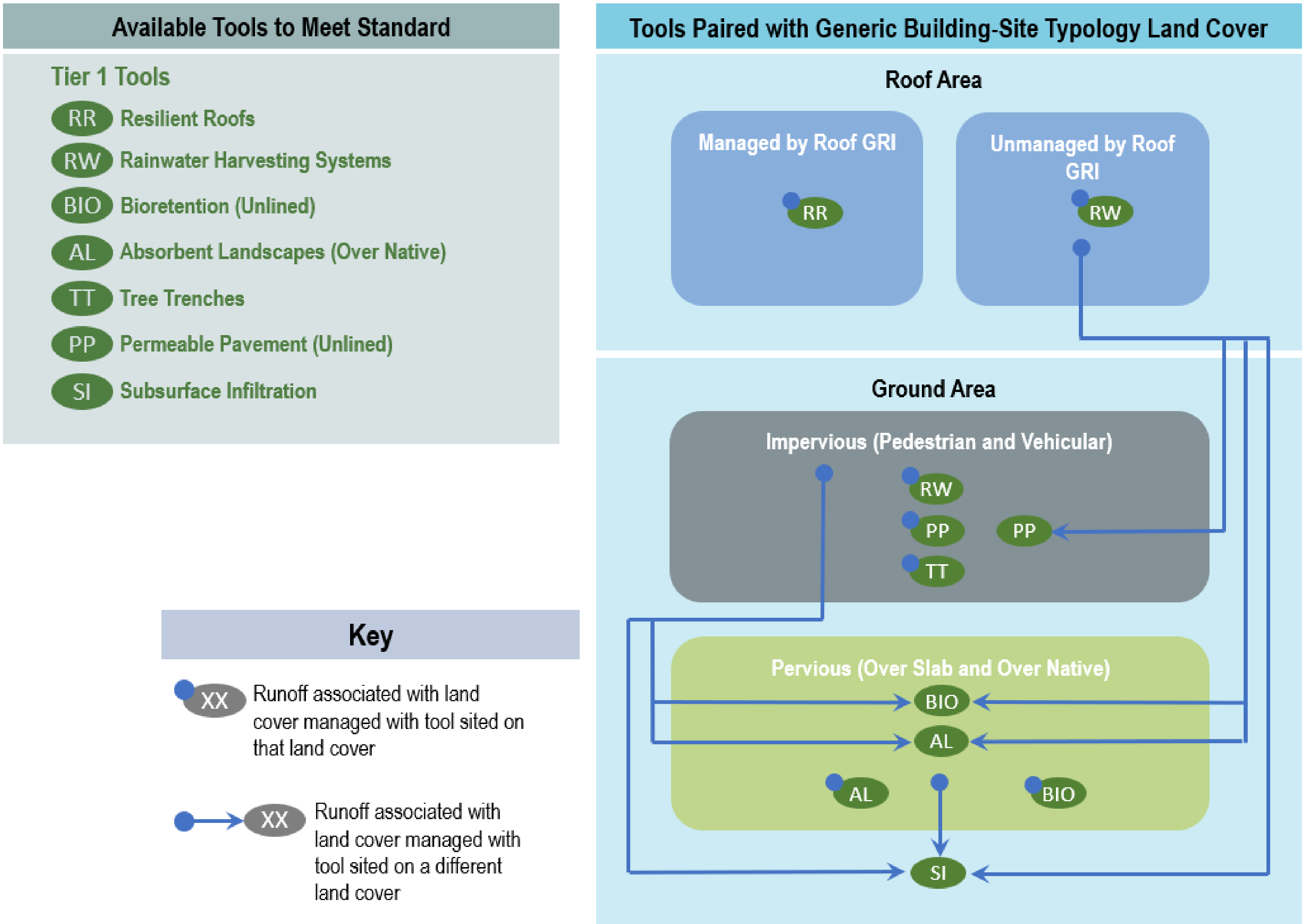


Figure 2. Phase 1 Tools Paired with Generic Typology Land Covers

Modeling Results

The output from the Phase 1 modeling yielded a significant amount of data, including a full water balance of how much design storm runoff volume was generated from each surface, directed to each rainwater management tool, and processed in each tool (i.e., infiltrated, evapotranspired, stored, reused, and bypassed). Since the focus of the Phase 1 modeling was on retention, the results of interest represented the percentage of the runoff that was retained within each tool. The following equation was used to represent percent retention:

$$\textbf{\textit{Retention Percentage}} = \frac{\textbf{\textit{Volume Retained}}}{\textbf{\textit{Volume Generated}}}$$

Where:

Volume Retained = Total runoff volume from the design event directed to each rainwater management tool that is infiltrated, evapotranspired, stored in media with means to infiltrate/ evapotranspire after the event, and/or reused.

Volume Generated = Total runoff from the full contributing land cover plus rainfall incident to (i.e., falling on) the tool footprint (if the tool is self-mitigating)

An example calculation is shown in Figure 3 below.

From the modeling, the retention percentage was calculated for each of the over 73,000 scenarios that represent different rainwater tools paired with typology land covers and the range of associated site, development, and policy variables. Because of the significant amount of data to review and report, the data was further simplified and a dashboard was created for viewing results. To simplify the viewing of results, several rainwater management tools were omitted from the reporting:

- **Absorbent landscaping** was omitted because it provides less retention than bioretention and competes for the same pervious space in the site-typologies.
- **Tree trenches** were omitted because they provide less retention than permeable pavement and compete for the same impervious space in the site-typologies
- **Resilient roofs** were represented by "roof area managed." Since roof area managed is a site development variable, it was considered redundant to show both. Roof area managed served as a surrogate in the reporting for resilient roofs.

With the simplified set of tools, the results could be more easily viewed across a range of scenario variable values. A high-level summary of results and key observations is provided in the section below. The dashboard set up and full dashboards for each typology and the important variables are shown in Appendix A.

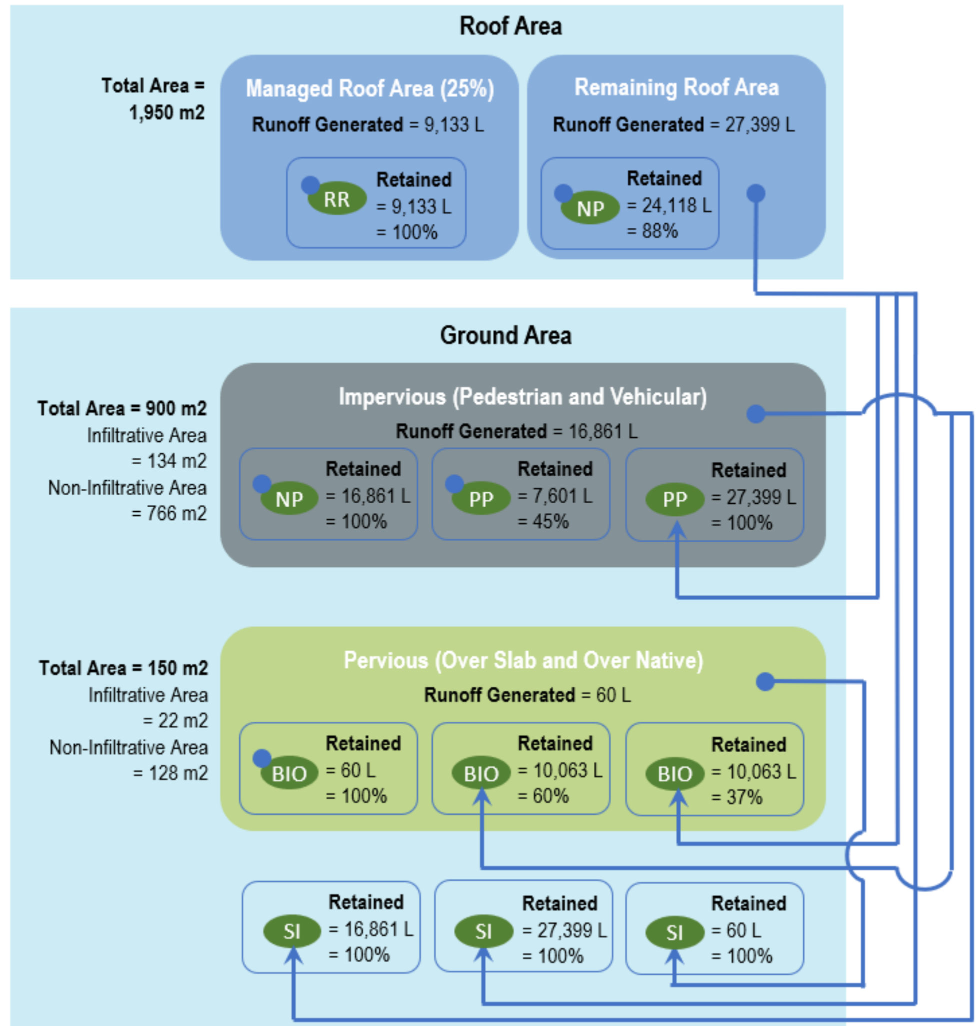
Example Calculation

Scenario Variables

Typology	Mid-Rise Residential & Mixed-Use
Standard	24 mm Retention
Rooftop Managed	25%
Soil Conditions	Low Infiltration
Parkade Extent	Full Building Footprint
Setback Policy	Existing Setback (5m)
Reuse Policy	Basic Non-potable Uses

Performance Results

Surface Type	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
Impervious - Roof	88%	100%	37%	100%
Impervious - Ground	100%	45%	60%	100%
Pervious			100%	100%



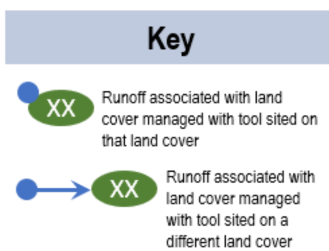


Figure 3. Example Retention Calculation

KEY OBSERVATIONS

Reviewing modeling results through the dashboards illuminated a number of key general observations on pathway compliance. While compliance with the 24-mm and 48-mm retention standards was possible for many of the scenarios tested, especially those representing more favorable site conditions (e.g., less impervious area, higher infiltration potential), the focus of the observations below is related to non-compliance and the factors that contribute to it.

With few exceptions, most site-typologies have at least some conditions where compliance is not feasible for the 24-mm and/or 48-mm retention standards. There are two general conditions that were found to have the greatest influence on the potential for available tools to meet the retention standard at a particular site-typology:

- **Site Conditions** – These are the factors that are inherent in the geography of the site. The most important site-related feasibility factor is the "soil conditions" variable and associated infiltration capacity, which has a direct bearing on the performance of ground-level Tier 1 tools. Slope and other geologic and hydrologic conditions also frequently affect infiltration feasibility. (These are also discussed in the Task 8 *Barriers and Solutions Technical Memorandum* under "Physical Constraints and Barriers.")

- **Current Development and Policy Conditions** – These are the factors that dictate the resulting character of the development. Some are influenced by City policy and some are influenced by the purpose and economics of a particular development. The most important of these factors are the impervious extent of the development, which is hard-coded into the typology definition, and the "infiltration area available" variable, which includes infiltration setbacks set by City policy and the extent of the subsurface parkade dictated by developer decisions. Like the soil conditions variable, the infiltration area available variable has a direct bearing on the feasibility and performance of ground-level Tier 1 tools. (These are also discussed in the Task 8 *Barriers and Solutions Technical Memorandum* under "Regulatory Barriers.")

Site Conditions

The following observations were made about the influence of the soil conditions variable:

- The "no infiltration" condition is the most common variable that limits compliance potential. Four typologies (Low-Rise Residential & Mixed-Use, Mid-Rise Residential & Mixed-Use, Low/Mid-Rise Non-Residential, and High-Rise Non-Residential) cannot achieve 48-mm retention in the "no infiltration" condition. Two typologies (Low-Rise Residential & Mixed-Use and Low/Mid-Rise Non-Residential) cannot achieve even 24-mm retention in the "no infiltration" condition.

- While rainwater harvesting and resilient roofs are critical tools in these "no infiltration" scenarios to achieve some rainwater retention, they are often not able to facilitate compliance on their own and when they are, they must be deployed at very high levels to achieve compliance. See Table 7 below to review the compliance potential and the most important tools for achieving compliance for "no infiltration" scenarios.

- While increasing infiltration potential (from "low infiltration" to "high infiltration") intuitively aligns with a greater potential to meet retention standards, there are three typologies (Mid-Rise Residential & Mixed-Use, Low/Mid-Rise Non-Residential and High-Rise Non-Residential) where it is very difficult or impossible to meet 48-mm retention under existing development and policy conditions with even the "high infiltration" condition due to the parkade and infiltration setback resulting in little to no space for infiltrating tools.

Current Development and Policy Conditions
The following observations were made about the influence of the development and policy conditions variables:

- Assuming the infiltration setbacks (5 meters), impervious extents, and the existing practice of extending parkades past the building footprint, two typologies (Low-Rise Residential & Mixed-Use and Mid-Rise Residential & Mixed-Use) have very limited pathways to 48-mm and even 24-mm compliance, while two other typologies (Low/Mid-Rise Non-Residential, High-Rise Non-Residential) had no compliant pathways.

- Changing the infiltration setback to 3 meters and/or reducing the parkade extent provided enough space for infiltration for all typologies to meet the 48-mm standard in all but the least favorable "no infiltration" conditions. It should be noted that changing the infiltration setback to 0 meters offered limited to no improvement in terms of compliance potential. See Table 8 and Table 9 to review how improvements to compliance potential are achieved with these development and policy modifications.

- Changing the infiltration setback and/or reducing the parkade extent reduced the dependency on rainwater harvesting and resilient roofs for compliance by improving the viability of ground-level infiltrating tools (e.g., bioretention, permeable pavement).

- No amount of modification to infiltration setbacks or parkade extents helps achieve retention compliance at typologies subject to the "no infiltration" condition.

Based on the observations above, it is apparent that pathways with lower retention requirements will be an important consideration for sites with no or limited infiltration potential. Likewise, exceptions to infiltration setbacks in certain situations and consideration for reducing site impervious area and parkade extents will also be important. Each of these will be reflected and explored more in the pathway set development in Task 9.

Table 7. Performance Modeling Results Summary – Phase 1 "No Infiltration" Scenarios												
Typology	24-mm Retention Standard; Existing Policy and Development Practice						48-mm Retention Standard; Existing Policy and Development Practice					
	Compliant Scenarios Possible	GRI Tool Performance and Importance for Compliance					Compliant Scenarios Possible	GRI Tool Performance and Importance for Compliance				
		Resilient Roof (RR)	Rainwater Harvesting (RWH)	Permeable Pavement (PP)	Bioretention (Bio)	Subsurface Infiltration (SI)		Resilient Roof (RR)	Rainwater Harvesting (RWH)	Permeable Pavement (PP)	Bioretention (Bio)	Subsurface Infiltration (SI)
Small Lot Residential – Low Massing	Yes	Optional	***Critical***	Not viable	Optional	Not viable	Yes	Optional	***Critical***	Not viable	Optional	Not viable
Small Lot Residential – High Massing	Yes	***Critical***	***Critical***	Not viable	Optional	Not viable	Yes	***Critical***	***Critical***	Not viable	Optional	Not viable
Low-Rise Residential & Mixed-Use	No						No					
Mid-Rise Residential & Mixed-Use	Yes	***Critical***	***Critical***	Not viable	Optional	Not viable	No					
High-Rise Residential & Mixed-Use	Yes	Optional	***Critical***	Not viable	Optional	Not viable	Yes	Optional	***Critical***	Not viable	Optional	Not viable
Low/Mid-Rise Non-Residential	No						No					
High-Rise Non-Residential	Yes	***Critical***	***Critical***	Not viable	Not viable	Not viable	No					

KEY: Color-coding indicates the relative retention performance of the tool for all typology scenarios modeled:

- (green) tool could potentially manage a large percentage of site runoff (>75%)
- (yellow) tool could potentially manage between 25% and 75% of the site runoff but would need to be paired with other tools to manage all runoff from the site
- (pink) tool could potentially manage a limited percentage of site runoff (<25%)

Tools are noted to be "Critical" if they must be used to achieve the associated retention standard, "Optional" if they could be part of a compliant pathway but are not required to be, and "Not Viable" if they cannot be used based on site characteristics.

Table 8. Performance Modeling Results Summary – Phase 1 "Low Infiltration" Scenario – 24-mm Retention Standard

Typology	Existing Policy and Development Practice						Modified Policy and/or Development Practice					
	Compliant Scenarios Possible	GRI Tool Performance and Importance for Compliance					Compliant Scenarios Possible with Modified Practice/ Policy	GRI Tool Performance and Importance for Compliance				
		Resilient Roof (RR)	Rainwater Harvesting (RWH)	Permeable Pavement (PP)	Bioretention (Bio)	Subsurface Infiltration (SI)		Resilient Roof (RR)	Rainwater Harvesting (RWH)	Permeable Pavement (PP)	Bioretention (Bio)	Subsurface Infiltration (SI)
Small Lot Residential – Low Massing	Yes	Optional	Optional	Optional	Optional	Optional	Yes, with 3 m setback	Optional	Optional	Optional	Optional	Optional
Small Lot Residential – High Massing	Yes	Optional	Optional	Optional	Optional	Optional	Yes, with 3 m setback	Optional	Optional	Optional	Optional	Optional
Low-Rise Residential & Mixed-Use	Yes	***Critical***	Optional	Not viable	Optional	Optional	Yes, with Reduced parkade	Optional	Optional	Optional	Optional	Optional
Mid-Rise Residential & Mixed-Use	Yes	***Critical***	Optional	Not viable	Optional	Optional	Yes, with Reduced parkade	Optional	Optional	Optional	Optional	Optional
High-Rise Residential & Mixed-Use	Yes	Optional	Optional	Not viable	Optional	Optional	Yes, with 3 m setback	Optional	Optional	Not viable	Optional	Optional
Low/Mid-Rise Non-Residential	No						Yes, with Reduced parkade	Optional	Optional	Optional	Not viable	Optional
High-Rise Non-Residential	Yes	***Critical***	***Critical***	Not viable	Not viable	Not viable	Yes, with Reduced parkade	Optional	Optional	Optional	Not viable	Optional

KEY: Color-coding indicates the relative retention performance of the tool for all typology scenarios modeled:

- tool could potentially manage a large percentage of site runoff (>75%)
- tool could potentially manage between 25% and 75% of the site runoff but would need to be paired with other tools to manage all runoff from the site
- tool could potentially manage a limited percentage of site runoff (<25%)

Tools are noted to be "Critical" if they must be used to achieve the associated retention standard, "Optional" if they could be part of a compliant pathway but are not required to be, and "Not Viable" if they cannot be used based on site characteristics.

Table 9. Performance Modeling Results Summary – Phase 1 "Low Infiltration" Scenario – 48-mm Retention Standard

Typology	Existing Policy and Development Practice						Modified Policy and/or Development Practice					
	Compliant Scenarios Possible	GRI Tool Performance and Importance for Compliance					Compliant Scenarios Possible with Modified Practice/ Policy	GRI Tool Performance and Importance for Compliance				
		Resilient Roof (RR)	Rainwater Harvesting (RWH)	Permeable Pavement (PP)	Bioretention (Bio)	Subsurface Infiltration (SI)		Resilient Roof (RR)	Rainwater Harvesting (RWH)	Permeable Pavement (PP)	Bioretention (Bio)	Subsurface Infiltration (SI)
Small Lot Residential – Low Massing	Yes	Optional	Optional	Optional	Optional	Optional	Yes, with 3 m setback	Optional	Optional	Optional	Optional	Optional
Small Lot Residential – High Massing	Yes	***Critical***	Optional	Optional	Optional	Optional	Yes, with 3 m setback	Optional	Optional	Optional	Optional	Optional
Low-Rise Residential & Mixed-Use	No						Yes, with Reduced parkade	Optional	Optional	Optional	Optional	Optional
Mid-Rise Residential & Mixed-Use	No						Yes, with 3 m setback + Reduced parkade	Optional	Optional	Optional	Optional	Optional
High-Rise Residential & Mixed-Use	Yes	Optional	Optional	Not viable	Optional	Optional	Yes, with 3 m setback	Optional	Optional	Not viable	Optional	Optional
Low/Mid-Rise Non-Residential	No						Yes, with Reduced parkade	Optional	Optional	Optional	Not viable	Optional
High-Rise Non-Residential	No						Yes, with Reduced parkade	Optional	Optional	Optional	Not viable	Optional

KEY: Color-coding indicates the relative retention performance of the tool for all typology scenarios modeled:

- (green) tool could potentially manage a large percentage of site runoff (>75%)
- (yellow) tool could potentially manage between 25% and 75% of the site runoff but would need to be paired with other tools to manage all runoff from the site
- (pink) tool could potentially manage a limited percentage of site runoff (<25%)

Tools are noted to be "Critical" if they must be used to achieve the associated retention standard, "Optional" if they could be part of a compliant pathway but are not required to be, and "Not Viable" if they cannot be used based on site characteristics

PATHWAY FRAMEWORK RECOMMENDATIONS

As noted in the previous section, there are numerous pathways to compliance with both the 24-mm and 48-mm retention standards depending on the chosen typology, site conditions, and development conditions. There are also numerous site and development constraints that contribute to non-compliance with these retention standards, which suggests the need for revised or clarified standards, policy exceptions, and alternative development approaches. These will be considered and discussed in Task 9 and form the basis for the study recommendations.

It is expected that the pathway set in Task 9 will follow and support the study recommendations developed during that task. The proposed framework for the pathway set includes three broad categories of compliance. The first two categories mirror the retention standards tested in Phase 1 of the performance modeling:

- **24-mm Compliance** – this category follows the City's existing standard defined in the *Zoning and Development By-law*, which calls for 24-mm retention plus 24 mm of additional treatment of PGIS. Note that detention is not considered an alternative to retention in this compliance category.

- **48-mm Compliance** – this category follows the City's aspirational Rain City Strategy standard, which calls for 48-mm retention. Note again that detention is not considered an alternative to retention in this compliance category.

For those typologies where 24-mm and 48-mm retention compliance is possible, pathways will be assembled based on Phase 1 modeling results. These recommended pathways are shown in Table 10.

The third category represents an alternative compliance mechanism or mechanisms that will be proposed and discussed further in Task 9. This compliance category would include pathways to compliance for those constrained typologies that cannot meet either the 24-mm or 48-mm retention standard:

- **Alternative Compliance** – this category will reflect Task 9 study recommendations that could include, a reduced retention requirement, consideration of detention instead of retention, off-site compliance options, and/or fee in lieu programs, among others.

For all three compliance categories, pathways will be developed using rainwater management tools that are sized and modeled during the Phase 2 modeling. Costs from Task 6 and co-benefits from Task 7 will be layered on to each pathway to allow for comparison of trade-offs related to constructability, costs, and co-benefits. This will help support and hone the potential policy, program, and approach recommendations that come out of this study.

Table 10. Recommended Pathways for 24 mm and 48 mm Retention					
Retention:	**24 mm**			**48 mm**	**Alternative Compliance (Detention + Treatment)**
Treatment:	**24 mm (48 mm from PGIS)**			**48 mm**	**48 mm**
Release Rate:	**Post-development peak ≤ pre-development peak**			**Post ≤ pre**	**Post ≤ pre**
Soil Condition Variable:	**No Infiltration**	**Low Infiltration**	**Low Infiltration**	**Low Infiltration**	**NA**
Setback/Parkade Variable:	**Existing**	**Existing**	**Modified**	**Modified**	**NA**
Pathway:	**1**	**2**	**3**	**4**	**5**
Small Lot Residential – Low Massing	None available	Bioretention	Bioretention	Bioretention	Detention + treatment device
Small Lot Residential – High Massing	None available	Bioretention + permeable pavement + resilient roof	Bioretention	Subsurface infiltration + resilient roof	Detention + treatment device
Low-Rise Residential & Mixed-Use	None available	Bioretention + resilient roof	Bioretention	Bioretention + permeable pavement	Detention + treatment device
Mid-Rise Residential & Mixed-Use	Rainwater harvesting + resilient roof	Bioretention + rainwater harvesting + resilient roof	Bioretention + permeable pavement	Subsurface infiltration + resilient roof	Detention + treatment device
High-Rise Residential & Mixed-Use	Rainwater harvesting	Bioretention + resilient roof	Bioretention	Bioretention + permeable pavement	Detention + treatment device
Low/Mid-Rise Non-Residential	None available	None available	Bioretention + permeable pavement	Bioretention + permeable pavement + resilient roof	Detention + treatment device
High-Rise Non-Residential	Rainwater harvesting + resilient roof	None available	Bioretention + permeable pavement	Bioretention + permeable pavement + resilient roof	Detention + treatment device

NOTE: Pathways 1, 2, and 3 may also include Tier 2 or 3 tools for extra treatment of PGIS as needed

APPENDIX A

Typology Modeling Result Dashboards

Overview

The output from the Phase 1 modeling yielded a significant amount of data, including a full water balance of how much design storm runoff volume was generated from each surface, directed to each rainwater management tool, and processed in each tool (i.e., infiltrated, evapotranspired, stored, reused, and bypassed). Since the focus of the Phase 1 modeling was on retention, the results of interest represented the percentage of the runoff that was retained within each tool. The following equation was used to represent percent retention:

$$\textbf{\textit{Retention Percentage}} = \frac{\textbf{\textit{Volume Retained}}}{\textbf{\textit{Volume Generated}}}$$

Where:

Volume Retained = Total runoff volume from the design event directed to each rainwater management tool that is infiltrated, evapotranspired, stored in media with means to infiltrate/ evapotranspire after the event, and/or reused.

Volume Generated = Total runoff from the full contributing land cover plus rainfall incident to the tool footprint (if the tool is self-mitigating)

From the modeling, the retention percentage was calculated for each of the over 73,000 scenarios that represent different rainwater tools paired with typology land covers and the range of associated site, development, and policy variables. Because of the significant amount of data to review and report, a dashboard was created for reviewing results. The dashboard set up is described in Figure A below. Full dashboards for each typology and key sets of variables are provided on the following pages.

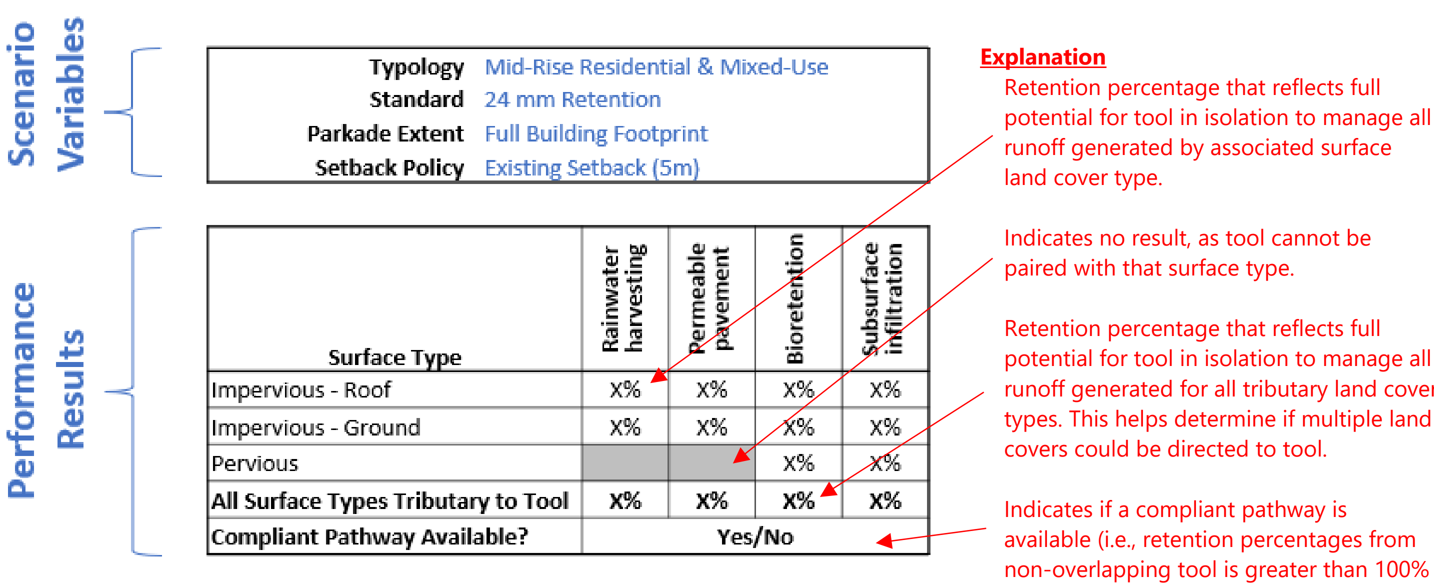
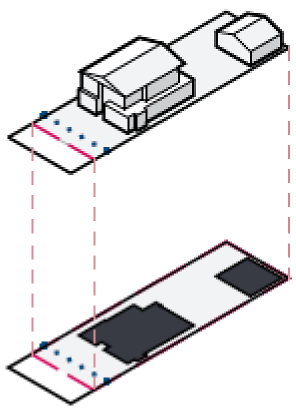
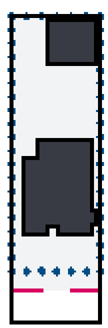


Figure A. Explanation of Dashboard Result Reviewer

Small Lot Residential – Low Massing

Summary Overview





Typology Summary

Parcel Size (m^2)	% Imperv-ious	% Roof Area	Total Imperv-ious Area (m^2)	Roof Area (m^2)	At-grade Pedestrian Impervious Area (m^2)	At-grade Vehicular Impervious Area (m^2)	Pervious Area (m^2)	No. of Storeys (above ground)	No. of Parkade Levels (below ground)
375	45%	30%	169	113	28	28	206	2	0

Setback Summary

	Current setbacks (5 m)	Modified setback (3 m)	No setback (0 m)
Total Impervious Roof (m^2)	**113**	**113**	**113**
Total Impervious Ground (m^2)	**56**	**56**	**56**
Infiltration Area (m^2)	8	20	56
Non-Infiltration Area (m^2)	48	36	0
Total Pervious (m^2)	**206**	**206**	**206**
Infiltration Area (m^2)	31	73	206
Non-Infiltration Area (m^2)	176	134	0

Performance Modeling Conclusions (Low Infiltration)

Standard	Compliant Scenarios Possible (Policy/Practice)	GRI Tool Performance and Importance				
		Resilient Roof	Rainwater Harvesting	Permeable Pavement	Bioretention	Subsurface Infiltration
24-mm Retention	Yes (Existing)	Optional	Optional	Optional	Optional	Optional
	Yes (3 m setback)	Optional	Optional	Optional	Optional	Optional
48-mm Retention	Yes (Existing)	Optional	Optional	Optional	Optional	Optional
	Yes (3 m setback)	Optional	Optional	Optional	Optional	Optional

HERRERA

Small Lot Residential – Low Massing

Performance Modeling Summary (24 mm)

Typology	Small Lot Residential – Low Massing
Standard	24 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Existing Setback (5m)

Scenarios with compliant pathways 20/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

Infiltration Scenario	Surface Type	Existing Area (m2)	*0% Managed with Resilient Roof*				*25% Managed with Resilient Roof*				*50% Managed with Resilient Roof*				*75% Managed with Resilient Roof*				*100% Managed with Resilient Roof*			
			Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	113	100%	0%	8%	0%	100%	0%	11%	0%	100%	0%	17%	0%	100%	0%	33%	0%	NA	NA	NA	NA
	Impervious - Ground	56	100%	0%	17%	0%	100%	0%	17%	0%	100%	0%	17%	0%	100%	0%	17%	0%	100%	0%	17%	0%
	Pervious	206			17%	0%			17%	0%			17%	0%			17%	0%			17%	0%
	All Surface Types Tributary to GRI		**100%**	**0%**	**4%**	**0%**	**100%**	**0%**	**5%**	**0%**	**100%**	**0%**	**6%**	**0%**	**100%**	**0%**	**7%**	**0%**	**100%**	**0%**	**8%**	**0%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Low Infiltration	Impervious - Roof	113	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	56	100%	47%	100%	100%	100%	47%	100%	100%	100%	47%	100%	100%	100%	47%	100%	100%	100%	47%	100%	100%
	Pervious	206			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**100%**	**82%**	**100%**	**100%**	**100%**	**78%**	**100%**	**100%**	**100%**	**73%**	**100%**	**100%**	**100%**	**64%**	**100%**	**100%**	**100%**	**47%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Moderate Infiltration	Impervious - Roof	113	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	56	100%	47%	100%	100%	100%	47%	100%	100%	100%	47%	100%	100%	100%	47%	100%	100%	100%	47%	100%	100%
	Pervious	206			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**100%**	**82%**	**100%**	**100%**	**100%**	**78%**	**100%**	**100%**	**100%**	**73%**	**100%**	**100%**	**100%**	**64%**	**100%**	**100%**	**100%**	**47%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
High Infiltration	Impervious - Roof	113	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	56	100%	47%	100%	100%	100%	47%	100%	100%	100%	47%	100%	100%	100%	47%	100%	100%	100%	47%	100%	100%
	Pervious	206			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**100%**	**82%**	**100%**	**100%**	**100%**	**78%**	**100%**	**100%**	**100%**	**73%**	**100%**	**100%**	**100%**	**64%**	**100%**	**100%**	**100%**	**47%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			

Small Lot Residential – Low Massing

Performance Modeling Summary (48 mm)

Typology	Small Lot Residential – Low Massing
Standard	48 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Existing Setback (5m)

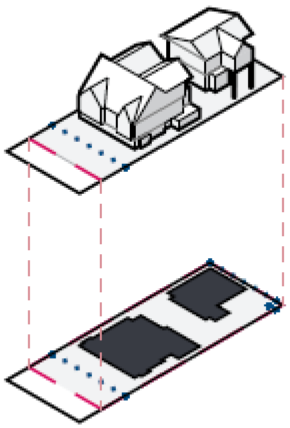
Scenarios with compliant pathways	20/20

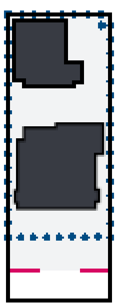
Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

			0% Managed with Resilient Roof				*25% Managed with Resilient Roof*				*50% Managed with Resilient Roof*				*75% Managed with Resilient Roof*				*100% Managed with Resilient Roof*			
Infiltration Scenario	**Surface Type**	**Existing Area (m2)**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**
No Infiltration	Impervious - Roof	113	100%	0%	4%	0%	100%	0%	5%	0%	100%	0%	7%	0%	100%	0%	15%	0%	NA	NA	NA	NA
	Impervious - Ground	56	100%	0%	7%	0%	100%	0%	7%	0%	100%	0%	7%	0%	100%	0%	7%	0%	100%	0%	7%	0%
	Pervious	206			5%	0%			5%	0%			5%	0%			5%	0%			5%	0%
	All Surface Types Tributary to GRI		**100%**	**0%**	**2%**	**0%**	**100%**	**0%**	**2%**	**0%**	**100%**	**0%**	**2%**	**0%**	**100%**	**0%**	**2%**	**0%**	**100%**	**0%**	**3%**	**0%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Low Infiltration	Impervious - Roof	113	100%	61%	100%	100%	100%	81%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	56	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%
	Pervious	206			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**100%**	**40%**	**100%**	**100%**	**100%**	**48%**	**100%**	**100%**	**100%**	**60%**	**100%**	**100%**	**100%**	**63%**	**100%**	**100%**	**100%**	**46%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Moderate Infiltration	Impervious - Roof	113	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	56	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%
	Pervious	206			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**100%**	**76%**	**100%**	**100%**	**100%**	**78%**	**100%**	**100%**	**100%**	**73%**	**100%**	**100%**	**100%**	**63%**	**100%**	**100%**	**100%**	**46%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
High Infiltration	Impervious - Roof	113	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	56	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%
	Pervious	206			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**100%**	**81%**	**100%**	**100%**	**100%**	**78%**	**100%**	**100%**	**100%**	**73%**	**100%**	**100%**	**100%**	**63%**	**100%**	**100%**	**100%**	**46%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			

Small Lot Residential – High Massing

Summary Overview





Typology Summary

Parcel Size (m²)	% Imperv-ious	% Roof Area	Total Imperv-ious Area (m²)	Roof Area (m²)	At-grade Pedestrian Impervious Area (m²)	At-grade Vehicular Impervious Area (m²)	Pervious Area (m²)	No. of Storeys (above ground)	No. of Parkade Levels (below ground)
375	70%	50%	263	188	38	38	113	2	0

Setback Summary

	Current setbacks (5 m)	Modified setback (3 m)	No setback (0 m)
Total Impervious Roof (m²)	**188**	**188**	**188**
Total Impervious Ground (m²)	**75**	**75**	**75**
Infiltration Area (m²)	3	11	75
Non-Infiltration Area (m²)	72	64	0
Total Pervious (m²)	**113**	**113**	**113**
Infiltration Area (m²)	4	17	113
Non-Infiltration Area (m²)	109	96	0

Performance Modeling Conclusions (Low Infiltration)

Standard	Compliant Scenarios Possible (Policy/Practice)	GRI Tool Performance and Importance				
		Resilient Roof	Rainwater Harvesting	Permeable Pavement	Bioretention	Subsurface Infiltration
24-mm Retention	Yes (Existing)	Optional	Optional	Optional	Optional	Optional
	Yes (3 m setback)	Optional	Optional	Optional	Optional	Optional
48-mm Retention	Yes (Existing)	***Critical***	Optional	Optional	Optional	Optional
	Yes (3 m setback)	Optional	Optional	Optional	Optional	Optional

Small Lot Residential – High Massing

Performance Modeling Summary (24 mm)

Typology	Small Lot Residential – High Massing
Standard	24 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Existing Setback (5m)

Scenarios with compliant pathways	19/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

Infiltration Scenario	Surface Type	Existing Area (m2)	*0% Managed with Resilient Roof*				*25% Managed with Resilient Roof*				*50% Managed with Resilient Roof*				*75% Managed with Resilient Roof*				*100% Managed with Resilient Roof*			
			Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	188	100%	0%	1%	0%	100%	0%	1%	0%	100%	0%	1%	0%	100%	0%	3%	0%	NA	NA	NA	NA
	Impervious - Ground	75	100%	0%	2%	0%	100%	0%	2%	0%	100%	0%	2%	0%	100%	0%	2%	0%	100%	0%	2%	0%
	Pervious	113			8%	0%			8%	0%			8%	0%			8%	0%			8%	0%
	All Surface Types Tributary to GRI		**91%**	**0%**	**0%**	**0%**	**100%**	**0%**	**1%**	**0%**	**100%**	**0%**	**1%**	**0%**	**100%**	**0%**	**1%**	**0%**	**100%**	**0%**	**1%**	**0%**
	Compliant Pathway Available?		No				Yes				Yes				Yes				Yes			
Low Infiltration	Impervious - Roof	188	100%	25%	46%	67%	100%	33%	62%	89%	100%	50%	93%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	75	100%	11%	100%	100%	100%	11%	100%	100%	100%	11%	100%	100%	100%	11%	100%	100%	100%	11%	100%	100%
	Pervious	113			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**91%**	**18%**	**32%**	**47%**	**100%**	**22%**	**39%**	**57%**	**100%**	**28%**	**49%**	**73%**	**100%**	**38%**	**67%**	**100%**	**100%**	**11%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Moderate Infiltration	Impervious - Roof	188	100%	48%	81%	91%	100%	64%	100%	100%	100%	94%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	75	100%	11%	100%	100%	100%	11%	100%	100%	100%	11%	100%	100%	100%	11%	100%	100%	100%	11%	100%	100%
	Pervious	113			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**91%**	**34%**	**57%**	**65%**	**100%**	**42%**	**69%**	**78%**	**100%**	**52%**	**86%**	**100%**	**100%**	**45%**	**100%**	**100%**	**100%**	**11%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
High Infiltration	Impervious - Roof	188	100%	70%	100%	100%	100%	94%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	75	100%	11%	100%	100%	100%	11%	100%	100%	100%	11%	100%	100%	100%	11%	100%	100%	100%	11%	100%	100%
	Pervious	113			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**91%**	**50%**	**95%**	**96%**	**100%**	**61%**	**100%**	**100%**	**100%**	**60%**	**100%**	**100%**	**100%**	**45%**	**100%**	**100%**	**100%**	**11%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			

Small Lot Residential – High Massing

Performance Modeling Summary (48 mm)

Typology	Small Lot Residential – High Massing
Standard	48 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Existing Setback (5m)

Scenarios with compliant pathways	11/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

0% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	188	57%	0%	0%	0%
	Impervious - Ground	75	100%	0%	1%	0%
	Pervious	113			1%	0%
	All Surface Types Tributary to GRI		**41%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	188	57%	11%	21%	30%
	Impervious - Ground	75	100%	11%	52%	74%
	Pervious	113			100%	100%
	All Surface Types Tributary to GRI		**41%**	**8%**	**14%**	**20%**
	Compliant Pathway Available?		No			
Moderate Infiltration	Impervious - Roof	188	57%	22%	37%	41%
	Impervious - Ground	75	100%	11%	91%	100%
	Pervious	113			100%	100%
	All Surface Types Tributary to GRI		**41%**	**16%**	**26%**	**29%**
	Compliant Pathway Available?		No			
High Infiltration	Impervious - Roof	188	57%	43%	69%	63%
	Impervious - Ground	75	100%	11%	100%	100%
	Pervious	113			100%	NA
	All Surface Types Tributary to GRI		**41%**	**31%**	**49%**	**45%**
	Compliant Pathway Available?		Yes			

25% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	188	76%	0%	0%	0%
	Impervious - Ground	75	100%	0%	1%	0%
	Pervious	113			1%	0%
	All Surface Types Tributary to GRI		**49%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	188	76%	15%	28%	40%
	Impervious - Ground	75	100%	11%	52%	74%
	Pervious	113			100%	100%
	All Surface Types Tributary to GRI		**49%**	**10%**	**16%**	**24%**
	Compliant Pathway Available?		No			
Moderate Infiltration	Impervious - Roof	188	76%	30%	50%	54%
	Impervious - Ground	75	100%	11%	91%	100%
	Pervious	113			100%	100%
	All Surface Types Tributary to GRI		**49%**	**19%**	**31%**	**35%**
	Compliant Pathway Available?		No			
High Infiltration	Impervious - Roof	188	76%	58%	92%	83%
	Impervious - Ground	75	100%	11%	100%	100%
	Pervious	113			100%	NA
	All Surface Types Tributary to GRI		**49%**	**38%**	**59%**	**54%**
	Compliant Pathway Available?		Yes			

50% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	188	100%	0%	1%	0%
	Impervious - Ground	75	100%	0%	1%	0%
	Pervious	113			1%	0%
	All Surface Types Tributary to GRI		**63%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	188	100%	23%	42%	59%
	Impervious - Ground	75	100%	11%	52%	74%
	Pervious	113			100%	100%
	All Surface Types Tributary to GRI		**63%**	**12%**	**20%**	**30%**
	Compliant Pathway Available?		No			
Moderate Infiltration	Impervious - Roof	188	100%	44%	74%	82%
	Impervious - Ground	75	100%	11%	91%	100%
	Pervious	113			100%	100%
	All Surface Types Tributary to GRI		**63%**	**25%**	**40%**	**44%**
	Compliant Pathway Available?		Yes			
High Infiltration	Impervious - Roof	188	100%	83%	100%	100%
	Impervious - Ground	75	100%	11%	100%	100%
	Pervious	113			100%	NA
	All Surface Types Tributary to GRI		**63%**	**46%**	**73%**	**69%**
	Compliant Pathway Available?		Yes			

75% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	188	100%	0%	1%	0%
	Impervious - Ground	75	100%	0%	1%	0%
	Pervious	113			1%	0%
	All Surface Types Tributary to GRI		**87%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	188	100%	45%	83%	100%
	Impervious - Ground	75	100%	11%	52%	74%
	Pervious	113			100%	100%
	All Surface Types Tributary to GRI		**87%**	**17%**	**27%**	**39%**
	Compliant Pathway Available?		Yes			
Moderate Infiltration	Impervious - Roof	188	100%	87%	100%	100%
	Impervious - Ground	75	100%	11%	91%	100%
	Pervious	113			100%	100%
	All Surface Types Tributary to GRI		**87%**	**33%**	**54%**	**61%**
	Compliant Pathway Available?		Yes			
High Infiltration	Impervious - Roof	188	100%	100%	100%	100%
	Impervious - Ground	75	100%	11%	100%	100%
	Pervious	113			100%	NA
	All Surface Types Tributary to GRI		**87%**	**44%**	**92%**	**94%**
	Compliant Pathway Available?		Yes			

100% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	188	NA	NA	NA	NA
	Impervious - Ground	75	100%	0%	1%	0%
	Pervious	113			1%	0%
	All Surface Types Tributary to GRI		**100%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		Yes			
Low Infiltration	Impervious - Roof	188	NA	NA	NA	NA
	Impervious - Ground	75	100%	11%	52%	74%
	Pervious	113			100%	100%
	All Surface Types Tributary to GRI		**100%**	**11%**	**39%**	**58%**
	Compliant Pathway Available?		Yes			
Moderate Infiltration	Impervious - Roof	188	NA	NA	NA	NA
	Impervious - Ground	75	100%	11%	91%	100%
	Pervious	113			100%	100%
	All Surface Types Tributary to GRI		**100%**	**11%**	**83%**	**97%**
	Compliant Pathway Available?		Yes			
High Infiltration	Impervious - Roof	188	NA	NA	NA	NA
	Impervious - Ground	75	100%	11%	100%	100%
	Pervious	113			100%	NA
	All Surface Types Tributary to GRI		**100%**	**11%**	**100%**	**100%**
	Compliant Pathway Available?		Yes			

Small Lot Residential – High Massing

Performance Modeling Summary (48 mm, Modified Setback)

Typology	Small Lot Residential – High Massing
Standard	48 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Modified Setback (3m)

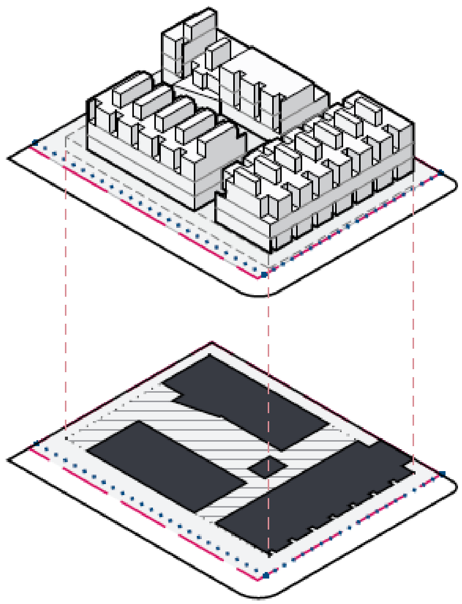
Scenarios with compliant pathways	16/20

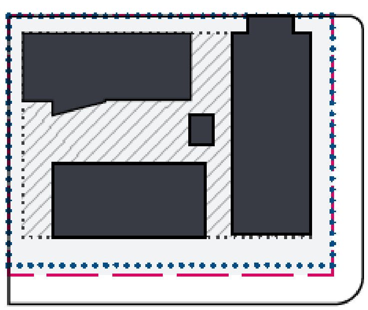
Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

Infiltration Scenario	Surface Type	Existing Area (m2)	*0% Managed with Resilient Roof*				*25% Managed with Resilient Roof*				*50% Managed with Resilient Roof*				*75% Managed with Resilient Roof*				*100% Managed with Resilient Roof*			
			Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	188	57%	0%	1%	0%	76%	0%	2%	0%	100%	0%	2%	0%	100%	0%	5%	0%	NA	NA	NA	NA
	Impervious - Ground	75	100%	0%	3%	0%	100%	0%	3%	0%	100%	0%	3%	0%	100%	0%	3%	0%	100%	0%	3%	0%
	Pervious	113			5%	0%			5%	0%			5%	0%			5%	0%			5%	0%
	All Surface Types Tributary to GRI		**41%**	**0%**	**1%**	**0%**	**49%**	**0%**	**1%**	**0%**	**63%**	**0%**	**1%**	**0%**	**87%**	**0%**	**1%**	**0%**	**100%**	**0%**	**2%**	**0%**
	Compliant Pathway Available?		No				No				No				No				Yes			
Low Infiltration	Impervious - Roof	188	57%	49%	90%	100%	76%	65%	100%	100%	100%	97%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	75	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%
	Pervious	113			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**41%**	**35%**	**57%**	**86%**	**49%**	**42%**	**67%**	**100%**	**63%**	**54%**	**82%**	**100%**	**87%**	**66%**	**100%**	**100%**	**100%**	**46%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Moderate Infiltration	Impervious - Roof	188	57%	95%	100%	100%	76%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	75	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%
	Pervious	113			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**41%**	**67%**	**100%**	**100%**	**49%**	**79%**	**100%**	**100%**	**63%**	**76%**	**100%**	**100%**	**87%**	**66%**	**100%**	**100%**	**100%**	**46%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
High Infiltration	Impervious - Roof	188	57%	100%	100%	100%	76%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	75	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%	100%	46%	100%	100%
	Pervious	113			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**41%**	**83%**	**100%**	**100%**	**49%**	**81%**	**100%**	**100%**	**63%**	**76%**	**100%**	**100%**	**87%**	**66%**	**100%**	**100%**	**100%**	**46%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			

Low-Rise Residential & Mixed-Use

Summary Overview





Typology Summary

Parcel Size (m²)	% Imperv-ious	% Roof Area	Total Imperv-ious Area (m²)	Roof Area (m²)	At-grade Pedestrian Impervious Area (m²)	At-grade Vehicular Impervious Area (m²)	Pervious Area (m²)	No. of Storeys (above ground)	No. of Parkade Levels (below ground)
2,500	90%	40%	2,250	1,000	1,000	250	250	3	1

Setback Summary

	Parkade Full Extent of Impervious Area			Parkade Full Extent of Building Footprint		
	Current setbacks (5 m)	Modified setback (3 m)	No setback (0 m)	Current setbacks (5 m)	Modified setback (3 m)	No setback (0 m)
Total Impervious Roof (m²)	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**
Total Impervious Ground (m²)	**1,250**	**1,250**	**1,250**	**1,250**	**1,250**	**1,250**
Infiltration Area (m²)	0	0	0	346	606	1,250
Non-Infiltration Area (m²)	1,250	1,250	1,250	904	644	0
Total Pervious (m²)	**250**	**250**	**250**	**250**	**250**	**250**
Infiltration Area (m²)	69	121	250	69	121	250
Non-Infiltration Area (m²)	181	129	0	181	129	0

Performance Modeling Conclusions (Low Infiltration)

Standard	Compliant Scenarios Possible (Policy/Practice)	GRI Tool Performance and Importance				
		Resilient Roof	Rainwater Harvesting	Permeable Pavement	Bioretention	Subsurface Infiltration
24-mm Retention	Yes (Existing)	***Critical***	Optional	Not viable	Optional	Optional
	Yes (Reduced parkade)	Optional	Optional	Optional	Optional	Optional
48-mm Retention	No (Existing)					
	Yes (Reduced parkade)	Optional	Optional	Optional	Optional	Optional

Low-Rise Residential & Mixed-Use

Performance Modeling Summary (24 mm)

Typology	Low-Rise Residential & Mixed-Use
Standard	24 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Existing Setback (5m)

Scenarios with compliant pathways	13/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

0% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,000	33%	0%	2%	0%
	Impervious - Ground	1,250	27%	0%	2%	0%
	Pervious	250			20%	0%
	All Surface Types Tributary to GRI		**15%**	**0%**	**1%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	1,000	33%	0%	100%	100%
	Impervious - Ground	1,250	27%	0%	100%	100%
	Pervious	250			100%	100%
	All Surface Types Tributary to GRI		**15%**	**0%**	**66%**	**60%**
	Compliant Pathway Available?		No			
Moderate Infiltration	Impervious - Roof	1,000	33%	0%	100%	100%
	Impervious - Ground	1,250	27%	0%	100%	100%
	Pervious	250			100%	NA
	All Surface Types Tributary to GRI		**15%**	**0%**	**100%**	**81%**
	Compliant Pathway Available?		Yes			
High Infiltration	Impervious - Roof	1,000	33%	0%	100%	100%
	Impervious - Ground	1,250	27%	0%	100%	100%
	Pervious	250			100%	NA
	All Surface Types Tributary to GRI		**15%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes			

25% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,000	44%	0%	3%	0%
	Impervious - Ground	1,250	27%	0%	2%	0%
	Pervious	250			20%	0%
	All Surface Types Tributary to GRI		**17%**	**0%**	**1%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	1,000	44%	0%	100%	100%
	Impervious - Ground	1,250	27%	0%	100%	100%
	Pervious	250			100%	100%
	All Surface Types Tributary to GRI		**17%**	**0%**	**74%**	**67%**
	Compliant Pathway Available?		No			
Moderate Infiltration	Impervious - Roof	1,000	44%	0%	100%	100%
	Impervious - Ground	1,250	27%	0%	100%	100%
	Pervious	250			100%	NA
	All Surface Types Tributary to GRI		**17%**	**0%**	**100%**	**91%**
	Compliant Pathway Available?		Yes			
High Infiltration	Impervious - Roof	1,000	44%	0%	100%	100%
	Impervious - Ground	1,250	27%	0%	100%	100%
	Pervious	250			100%	NA
	All Surface Types Tributary to GRI		**17%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes			

50% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,000	67%	0%	4%	0%
	Impervious - Ground	1,250	27%	0%	2%	0%
	Pervious	250			20%	0%
	All Surface Types Tributary to GRI		**19%**	**0%**	**1%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	1,000	67%	0%	100%	100%
	Impervious - Ground	1,250	27%	0%	100%	100%
	Pervious	250			100%	100%
	All Surface Types Tributary to GRI		**19%**	**0%**	**84%**	**77%**
	Compliant Pathway Available?		Yes			
Moderate Infiltration	Impervious - Roof	1,000	67%	0%	100%	100%
	Impervious - Ground	1,250	27%	0%	100%	100%
	Pervious	250			100%	NA
	All Surface Types Tributary to GRI		**19%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes			
High Infiltration	Impervious - Roof	1,000	67%	0%	100%	100%
	Impervious - Ground	1,250	27%	0%	100%	100%
	Pervious	250			100%	NA
	All Surface Types Tributary to GRI		**19%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes			

75% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,000	100%	0%	8%	0%
	Impervious - Ground	1,250	27%	0%	2%	0%
	Pervious	250			20%	0%
	All Surface Types Tributary to GRI		**22%**	**0%**	**1%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	1,000	100%	0%	100%	100%
	Impervious - Ground	1,250	27%	0%	100%	100%
	Pervious	250			100%	100%
	All Surface Types Tributary to GRI		**22%**	**0%**	**97%**	**90%**
	Compliant Pathway Available?		Yes			
Moderate Infiltration	Impervious - Roof	1,000	100%	0%	100%	100%
	Impervious - Ground	1,250	27%	0%	100%	100%
	Pervious	250			100%	NA
	All Surface Types Tributary to GRI		**22%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes			
High Infiltration	Impervious - Roof	1,000	100%	0%	100%	100%
	Impervious - Ground	1,250	27%	0%	100%	100%
	Pervious	250			100%	NA
	All Surface Types Tributary to GRI		**22%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes			

100% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,000	NA	NA	NA	NA
	Impervious - Ground	1,250	27%	0%	2%	0%
	Pervious	250			20%	0%
	All Surface Types Tributary to GRI		**27%**	**0%**	**2%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	1,000	NA	NA	NA	NA
	Impervious - Ground	1,250	27%	0%	100%	100%
	Pervious	250			100%	100%
	All Surface Types Tributary to GRI		**27%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes			
Moderate Infiltration	Impervious - Roof	1,000	NA	NA	NA	NA
	Impervious - Ground	1,250	27%	0%	100%	100%
	Pervious	250			100%	NA
	All Surface Types Tributary to GRI		**27%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes			
High Infiltration	Impervious - Roof	1,000	NA	NA	NA	NA
	Impervious - Ground	1,250	27%	0%	100%	100%
	Pervious	250			100%	NA
	All Surface Types Tributary to GRI		**27%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes			

Low-Rise Residential & Mixed-Use

Performance Modeling Summary (48 mm)

Typology	Low-Rise Residential & Mixed-Use
Standard	48 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Existing Setback (5m)

Scenarios with compliant pathways	5/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

Infiltration Scenario	Surface Type	Existing Area (m2)	*0% Managed with Resilient Roof*				*25% Managed with Resilient Roof*				*50% Managed with Resilient Roof*				*75% Managed with Resilient Roof*				*100% Managed with Resilient Roof*			
			Rainwater harvesting	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**
No Infiltration	Impervious - Roof	1,000	15%	0%	1%	0%	20%	0%	1%	0%	30%	0%	2%	0%	60%	0%	4%	0%	NA	NA	NA	NA
	Impervious - Ground	1,250	12%	0%	1%	0%	12%	0%	1%	0%	12%	0%	1%	0%	12%	0%	1%	0%	12%	0%	1%	0%
	Pervious	250			7%	0%			7%	0%			7%	0%			7%	0%			7%	0%
	All Surface Types Tributary to GRI		**7%**	**0%**	**0%**	**0%**	**7%**	**0%**	**0%**	**0%**	**9%**	**0%**	**0%**	**0%**	**10%**	**0%**	**1%**	**0%**	**12%**	**0%**	**1%**	**0%**
	Compliant Pathway Available?		No				No				No				No				No			
Low Infiltration	Impervious - Roof	1,000	15%	0%	70%	60%	20%	0%	93%	80%	30%	0%	100%	100%	60%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	1,250	12%	0%	56%	48%	12%	0%	56%	48%	12%	0%	56%	48%	12%	0%	56%	48%	12%	0%	56%	48%
	Pervious	250			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**7%**	**0%**	**30%**	**26%**	**7%**	**0%**	**33%**	**29%**	**9%**	**0%**	**37%**	**33%**	**10%**	**0%**	**43%**	**39%**	**12%**	**0%**	**51%**	**46%**
	Compliant Pathway Available?		No				No				No				No				No			
Moderate Infiltration	Impervious - Roof	1,000	15%	0%	100%	82%	20%	0%	100%	100%	30%	0%	100%	100%	60%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	1,250	12%	0%	98%	66%	12%	0%	98%	66%	12%	0%	98%	66%	12%	0%	98%	66%	12%	0%	98%	66%
	Pervious	250			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**7%**	**0%**	**53%**	**37%**	**7%**	**0%**	**60%**	**41%**	**9%**	**0%**	**68%**	**47%**	**10%**	**0%**	**78%**	**55%**	**12%**	**0%**	**92%**	**65%**
	Compliant Pathway Available?		No				No				No				No				Yes			
High Infiltration	Impervious - Roof	1,000	15%	0%	100%	100%	20%	0%	100%	100%	30%	0%	100%	100%	60%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	1,250	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	98%
	Pervious	250			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**7%**	**0%**	**91%**	**56%**	**7%**	**0%**	**97%**	**63%**	**9%**	**0%**	**100%**	**72%**	**10%**	**0%**	**100%**	**83%**	**12%**	**0%**	**100%**	**98%**
	Compliant Pathway Available?		No				Yes				Yes				Yes				Yes			

Low-Rise Residential & Mixed-Use

Performance Modeling Summary (48 mm, Modified Setback)

Typology	Low-Rise Residential & Mixed-Use
Standard	48 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Modified Setback (3m)

Scenarios with compliant pathways	9/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

			0% Managed with Resilient Roof				*25% Managed with Resilient Roof*				*50% Managed with Resilient Roof*				*75% Managed with Resilient Roof*				*100% Managed with Resilient Roof*			
Infiltration Scenario	**Surface Type**	**Existing Area (m2)**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**
No Infiltration	Impervious - Roof	1,000	15%	0%	2%	0%	20%	0%	2%	0%	30%	0%	3%	0%	60%	0%	7%	0%	NA	NA	NA	NA
	Impervious - Ground	1,250	12%	0%	1%	0%	12%	0%	1%	0%	12%	0%	1%	0%	12%	0%	1%	0%	12%	0%	1%	0%
	Pervious	250			9%	0%			9%	0%			9%	0%			9%	0%			9%	0%
	All Surface Types Tributary to GRI		**7%**	**0%**	**1%**	**0%**	**7%**	**0%**	**1%**	**0%**	**9%**	**0%**	**1%**	**0%**	**10%**	**0%**	**1%**	**0%**	**12%**	**0%**	**1%**	**0%**
	Compliant Pathway Available?		No				No				No				No				No			
Low Infiltration	Impervious - Roof	1,000	15%	0%	100%	100%	20%	0%	100%	100%	30%	0%	100%	100%	60%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	1,250	12%	0%	97%	84%	12%	0%	97%	84%	12%	0%	97%	84%	12%	0%	97%	84%	12%	0%	97%	84%
	Pervious	250			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**7%**	**0%**	**51%**	**46%**	**7%**	**0%**	**56%**	**51%**	**9%**	**0%**	**64%**	**59%**	**10%**	**0%**	**73%**	**68%**	**12%**	**0%**	**86%**	**81%**
	Compliant Pathway Available?		No				No				No				No				No			
Moderate Infiltration	Impervious - Roof	1,000	15%	0%	100%	100%	20%	0%	100%	100%	30%	0%	100%	100%	60%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	1,250	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	100%
	Pervious	250			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**7%**	**0%**	**90%**	**64%**	**7%**	**0%**	**99%**	**72%**	**9%**	**0%**	**100%**	**82%**	**10%**	**0%**	**100%**	**95%**	**12%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		No				Yes				Yes				Yes				Yes			
High Infiltration	Impervious - Roof	1,000	15%	0%	100%	100%	20%	0%	100%	100%	30%	0%	100%	100%	60%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	1,250	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	100%
	Pervious	250			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**7%**	**0%**	**100%**	**96%**	**7%**	**0%**	**100%**	**100%**	**9%**	**0%**	**100%**	**100%**	**10%**	**0%**	**100%**	**100%**	**12%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			

Low-Rise Residential & Mixed-Use

Performance Modeling Summary (48 mm, Zero Setback)

Typology	Low-Rise Residential & Mixed-Use
Standard	48 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	No Setbacks (0m)

Scenarios with compliant pathways	**15/20**

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

Infiltration Scenario	**Surface Type**	**Existing Area (m2)**	***0% Managed with Resilient Roof***				***25% Managed with Resilient Roof***				***50% Managed with Resilient Roof***				***75% Managed with Resilient Roof***				***100% Managed with Resilient Roof***			
			Rainwater harvesting	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**
No Infiltration	Impervious - Roof	1,000	15%	0%	3%	0%	20%	0%	4%	0%	30%	0%	7%	0%	60%	0%	13%	0%	NA	NA	NA	NA
	Impervious - Ground	1,250	12%	0%	3%	0%	12%	0%	3%	0%	12%	0%	3%	0%	12%	0%	3%	0%	12%	0%	3%	0%
	Pervious	250			12%	0%			12%	0%			12%	0%			12%	0%			12%	0%
	All Surface Types Tributary to GRI		**7%**	**0%**	**1%**	**0%**	**7%**	**0%**	**1%**	**0%**	**9%**	**0%**	**2%**	**0%**	**10%**	**0%**	**2%**	**0%**	**12%**	**0%**	**2%**	**0%**
	Compliant Pathway Available?		No				No				No				No				No			
Low Infiltration	Impervious - Roof	1,000	15%	0%	100%	100%	20%	0%	100%	100%	30%	0%	100%	100%	60%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	1,250	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	100%
	Pervious	250			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**7%**	**0%**	**99%**	**94%**	**7%**	**0%**	**100%**	**100%**	**9%**	**0%**	**100%**	**100%**	**10%**	**0%**	**100%**	**100%**	**12%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Moderate Infiltration	Impervious - Roof	1,000	15%	0%	100%	100%	20%	0%	100%	100%	30%	0%	100%	100%	60%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	1,250	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	100%
	Pervious	250			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**7%**	**0%**	**100%**	**100%**	**7%**	**0%**	**100%**	**100%**	**9%**	**0%**	**100%**	**100%**	**10%**	**0%**	**100%**	**100%**	**12%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
High Infiltration	Impervious - Roof	1,000	15%	0%	100%	100%	20%	0%	100%	100%	30%	0%	100%	100%	60%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	1,250	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	100%	12%	0%	100%	100%
	Pervious	250			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**7%**	**0%**	**100%**	**100%**	**7%**	**0%**	**100%**	**100%**	**9%**	**0%**	**100%**	**100%**	**10%**	**0%**	**100%**	**100%**	**12%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			

HERRERA

Low-Rise Residential & Mixed-Use

Performance Modeling Summary (48 mm, Reduced Parkade)

Typology	Low-Rise Residential & Mixed-Use
Standard	48 mm Retention
Parkade Extent	Full Building Footprint or NA
Setback Policy	Existing Setback (5m)

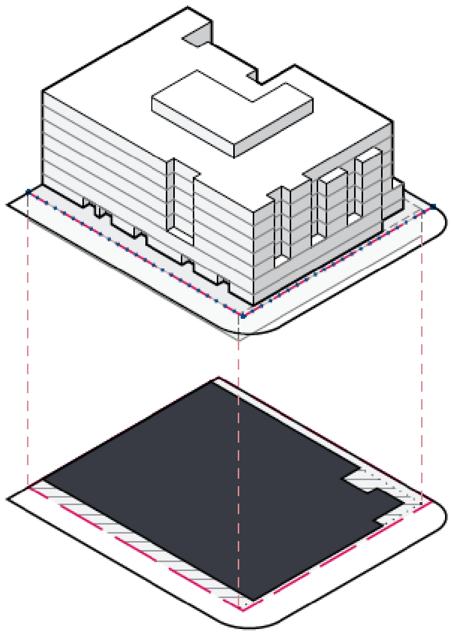
Scenarios with compliant pathways	15/20

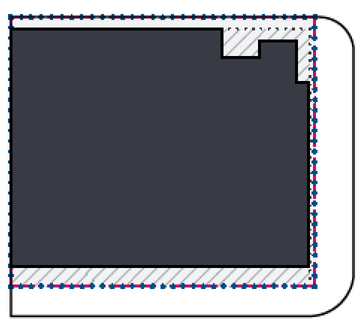
Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

			0% Managed with Resilient Roof				*25% Managed with Resilient Roof*				*50% Managed with Resilient Roof*				*75% Managed with Resilient Roof*				*100% Managed with Resilient Roof*			
Infiltration Scenario	**Surface Type**	**Existing Area (m2)**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**
No Infiltration	Impervious - Roof	1,000	15%	0%	1%	0%	20%	0%	1%	0%	30%	0%	2%	0%	60%	0%	4%	0%	NA	NA	NA	NA
	Impervious - Ground	1,250	12%	0%	1%	0%	12%	0%	1%	0%	12%	0%	1%	0%	12%	0%	1%	0%	12%	0%	1%	0%
	Pervious	250			7%	0%			7%	0%			7%	0%			7%	0%			7%	0%
	All Surface Types Tributary to GRI		**7%**	**0%**	**0%**	**0%**	**7%**	**0%**	**0%**	**0%**	**9%**	**0%**	**0%**	**0%**	**10%**	**0%**	**1%**	**0%**	**12%**	**0%**	**1%**	**0%**
	Compliant Pathway Available?		No				No				No				No				No			
Low Infiltration	Impervious - Roof	1,000	15%	100%	70%	100%	20%	100%	93%	100%	30%	100%	100%	100%	60%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	1,250	12%	84%	56%	100%	12%	84%	56%	100%	12%	84%	56%	100%	12%	84%	56%	100%	12%	84%	56%	100%
	Pervious	250			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**7%**	**91%**	**30%**	**100%**	**7%**	**90%**	**33%**	**100%**	**9%**	**88%**	**37%**	**100%**	**10%**	**86%**	**43%**	**100%**	**12%**	**84%**	**51%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Moderate Infiltration	Impervious - Roof	1,000	15%	100%	100%	100%	20%	100%	100%	100%	30%	100%	100%	100%	60%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	1,250	12%	84%	98%	100%	12%	84%	98%	100%	12%	84%	98%	100%	12%	84%	98%	100%	12%	84%	98%	100%
	Pervious	250			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**7%**	**91%**	**53%**	**100%**	**7%**	**90%**	**60%**	**100%**	**9%**	**88%**	**68%**	**100%**	**10%**	**86%**	**78%**	**100%**	**12%**	**84%**	**92%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
High Infiltration	Impervious - Roof	1,000	15%	100%	100%	100%	20%	100%	100%	100%	30%	100%	100%	100%	60%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	1,250	12%	84%	100%	100%	12%	84%	100%	100%	12%	84%	100%	100%	12%	84%	100%	100%	12%	84%	100%	100%
	Pervious	250			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**7%**	**91%**	**91%**	**100%**	**7%**	**90%**	**97%**	**100%**	**9%**	**88%**	**100%**	**100%**	**10%**	**86%**	**100%**	**100%**	**12%**	**84%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			

Mid-Rise Residential & Mixed-Use

Summary Overview





Typology Summary

Parcel Size (m^2)	% Imperv-ious	% Roof Area	Total Imperv-ious Area (m^2)	Roof Area (m^2)	At-grade Pedestrian Impervious Area (m^2)	At-grade Vehicular Impervious Area (m^2)	Pervious Area (m^2)	No. of Storeys (above ground)	No. of Parkade Levels (below ground)
3,000	95%	65%	2,850	1,950	720	180	150	6	2

Setback Summary

	Parkade Full Extent of Impervious Area			Parkade Full Extent of Building Footprint		
	Current setbacks (5 m)	Modified setback (3 m)	No setback (0 m)	Current setbacks (5 m)	Modified setback (3 m)	No setback (0 m)
Total Impervious Roof (m^2)	**1,950**	**1,950**	**1,950**	**1,950**	**1,950**	**1,950**
Total Impervious Ground (m^2)	**900**	**900**	**900**	**900**	**900**	**900**
Infiltration Area (m^2)	0	0	0	134	393	900
Non-Infiltration Area (m^2)	900	900	900	766	507	0
Total Pervious (m^2)	**150**	**150**	**150**	**150**	**150**	**150**
Infiltration Area (m^2)	22	66	150	22	66	150
Non-Infiltration Area (m^2)	128	84	0	128	84	0

Performance Modeling Conclusions (Low Infiltration)

Standard	Compliant Scenarios Possible (Policy/Practice)	GRI Tool Performance and Importance				
		Resilient Roof	Rainwater Harvesting	Permeable Pavement	Bioretention	Subsurface Infiltration
24-mm Retention	Yes (Existing)	***Critical***	Optional	Not viable	Optional	Optional
	Yes (Reduced parkade)	Optional	Optional	Optional	Optional	Optional
48-mm Retention	No (Existing)					
	Yes (3m setback + Reduced parkade)	Optional	Optional	Optional	Optional	Optional

Mid-Rise Residential & Mixed-Use

Performance Modeling Summary (24 mm)

Typology	Mid-Rise Residential & Mixed-Use
Standard	24 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Existing Setback (5m)

Scenarios with compliant pathways	11/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

			0% Managed with Resilient Roof				*25% Managed with Resilient Roof*				*50% Managed with Resilient Roof*				*75% Managed with Resilient Roof*				*100% Managed with Resilient Roof*			
Infiltration Scenario	**Surface Type**	**Existing Area (m2)**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**
No Infiltration	Impervious - Roof	1,950	66%	0%	0%	0%	88%	0%	0%	0%	100%	0%	1%	0%	100%	0%	1%	0%	NA	NA	NA	NA
	Impervious - Ground	900	100%	0%	1%	0%	100%	0%	1%	0%	100%	0%	1%	0%	100%	0%	1%	0%	100%	0%	1%	0%
	Pervious	150			17%	0%			17%	0%			17%	0%			17%	0%			17%	0%
	All Surface Types Tributary to GRI		**45%**	**0%**	**0%**	**0%**	**54%**	**0%**	**0%**	**0%**	**69%**	**0%**	**0%**	**0%**	**93%**	**0%**	**0%**	**0%**	**100%**	**0%**	**1%**	**0%**
	Compliant Pathway Available?		No				No				No				No				Yes			
Low Infiltration	Impervious - Roof	1,950	66%	0%	26%	22%	88%	0%	34%	30%	100%	0%	52%	45%	100%	0%	100%	89%	NA	NA	NA	NA
	Impervious - Ground	900	100%	0%	56%	48%	100%	0%	56%	48%	100%	0%	56%	48%	100%	0%	56%	48%	100%	0%	56%	48%
	Pervious	150			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**45%**	**0%**	**18%**	**15%**	**54%**	**0%**	**21%**	**18%**	**69%**	**0%**	**26%**	**23%**	**93%**	**0%**	**35%**	**31%**	**100%**	**0%**	**54%**	**48%**
	Compliant Pathway Available?		No				No				No				Yes				Yes			
Moderate Infiltration	Impervious - Roof	1,950	66%	0%	46%	31%	88%	0%	61%	41%	100%	0%	91%	61%	100%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	900	100%	0%	96%	66%	100%	0%	96%	66%	100%	0%	96%	66%	100%	0%	96%	66%	100%	0%	96%	65%
	Pervious	150			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**45%**	**0%**	**31%**	**21%**	**54%**	**0%**	**37%**	**25%**	**69%**	**0%**	**47%**	**32%**	**93%**	**0%**	**62%**	**43%**	**100%**	**0%**	**93%**	**65%**
	Compliant Pathway Available?		No				No				Yes				Yes				Yes			
High Infiltration	Impervious - Roof	1,950	66%	0%	83%	46%	88%	0%	100%	62%	100%	0%	100%	92%	100%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	900	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	99%	100%	0%	100%	97%
	Pervious	150			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**45%**	**0%**	**57%**	**32%**	**54%**	**0%**	**67%**	**38%**	**69%**	**0%**	**82%**	**48%**	**93%**	**0%**	**100%**	**64%**	**100%**	**0%**	**100%**	**97%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			

HERRERA

Mid-Rise Residential & Mixed-Use

Performance Modeling Summary (48 mm)

Typology	Mid-Rise Residential & Mixed-Use
Standard	48 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Existing Setback (5m)

Scenarios with compliant pathways	2/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,950	30%	0%	0%	0%	40%	0%	0%	0%	59%	0%	0%	0%	100%	0%	1%	0%	NA	NA	NA	NA
	Impervious - Ground	900	64%	0%	0%	0%	64%	0%	0%	0%	64%	0%	0%	0%	64%	0%	0%	0%	64%	0%	0%	0%
	Pervious	150			5%	0%			5%	0%			5%	0%			5%	0%			5%	0%
	All Surface Types Tributary to GRI		**20%**	**0%**	**0%**	**0%**	**24%**	**0%**	**0%**	**0%**	**31%**	**0%**	**0%**	**0%**	**42%**	**0%**	**0%**	**0%**	**64%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No				No				No				No				No			
Low Infiltration	Impervious - Roof	1,950	30%	0%	12%	10%	40%	0%	15%	13%	59%	0%	23%	20%	100%	0%	46%	40%	NA	NA	NA	NA
	Impervious - Ground	900	64%	0%	25%	22%	64%	0%	25%	22%	64%	0%	25%	22%	64%	0%	25%	22%	64%	0%	25%	22%
	Pervious	150			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**20%**	**0%**	**8%**	**7%**	**24%**	**0%**	**9%**	**8%**	**31%**	**0%**	**12%**	**10%**	**42%**	**0%**	**16%**	**14%**	**64%**	**0%**	**24%**	**21%**
	Compliant Pathway Available?		No				No				No				No				No			
Moderate Infiltration	Impervious - Roof	1,950	30%	0%	21%	14%	40%	0%	28%	18%	59%	0%	42%	27%	100%	0%	83%	55%	NA	NA	NA	NA
	Impervious - Ground	900	64%	0%	45%	30%	64%	0%	45%	30%	64%	0%	45%	30%	64%	0%	45%	30%	64%	0%	45%	30%
	Pervious	150			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**20%**	**0%**	**14%**	**9%**	**24%**	**0%**	**17%**	**11%**	**31%**	**0%**	**21%**	**14%**	**42%**	**0%**	**29%**	**19%**	**64%**	**0%**	**43%**	**29%**
	Compliant Pathway Available?		No				No				No				No				Yes			
High Infiltration	Impervious - Roof	1,950	30%	0%	39%	21%	40%	0%	52%	28%	59%	0%	78%	42%	100%	0%	100%	84%	NA	NA	NA	NA
	Impervious - Ground	900	64%	0%	80%	46%	64%	0%	80%	46%	64%	0%	80%	46%	64%	0%	80%	46%	64%	0%	80%	45%
	Pervious	150			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**20%**	**0%**	**27%**	**14%**	**24%**	**0%**	**32%**	**17%**	**31%**	**0%**	**40%**	**22%**	**42%**	**0%**	**53%**	**30%**	**64%**	**0%**	**78%**	**45%**
	Compliant Pathway Available?		No				No				No				No				Yes			
			0% Managed with Resilient Roof				***25% Managed with Resilient Roof***				***50% Managed with Resilient Roof***				***75% Managed with Resilient Roof***				***100% Managed with Resilient Roof***			

Mid-Rise Residential & Mixed-Use

Performance Modeling Summary (48 mm, Modified Setback)

Typology	Mid-Rise Residential & Mixed-Use
Standard	48 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Modified Setback (3m)

Scenarios with compliant pathways 7/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

0% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,950	30%	0%	0%	0%
	Impervious - Ground	900	64%	0%	1%	0%
	Pervious	150			9%	0%
	All Surface Types Tributary to GRI		**20%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	1,950	30%	0%	34%	29%
	Impervious - Ground	900	64%	0%	73%	63%
	Pervious	150			100%	100%
	All Surface Types Tributary to GRI		**20%**	**0%**	**22%**	**20%**
	Compliant Pathway Available?		No			
Moderate Infiltration	Impervious - Roof	1,950	30%	0%	61%	40%
	Impervious - Ground	900	64%	0%	100%	87%
	Pervious	150			100%	100%
	All Surface Types Tributary to GRI		**20%**	**0%**	**40%**	**27%**
	Compliant Pathway Available?		No			
High Infiltration	Impervious - Roof	1,950	30%	0%	100%	61%
	Impervious - Ground	900	64%	0%	100%	100%
	Pervious	150			100%	NA
	All Surface Types Tributary to GRI		**20%**	**0%**	**73%**	**42%**
	Compliant Pathway Available?		No			

25% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,950	40%	0%	1%	0%
	Impervious - Ground	900	64%	0%	1%	0%
	Pervious	150			9%	0%
	All Surface Types Tributary to GRI		**24%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	1,950	40%	0%	45%	39%
	Impervious - Ground	900	64%	0%	73%	63%
	Pervious	150			100%	100%
	All Surface Types Tributary to GRI		**24%**	**0%**	**27%**	**24%**
	Compliant Pathway Available?		No			
Moderate Infiltration	Impervious - Roof	1,950	40%	0%	81%	53%
	Impervious - Ground	900	64%	0%	100%	87%
	Pervious	150			100%	100%
	All Surface Types Tributary to GRI		**24%**	**0%**	**48%**	**33%**
	Compliant Pathway Available?		No			
High Infiltration	Impervious - Roof	1,950	40%	0%	100%	82%
	Impervious - Ground	900	64%	0%	100%	100%
	Pervious	150			100%	NA
	All Surface Types Tributary to GRI		**24%**	**0%**	**85%**	**50%**
	Compliant Pathway Available?		Yes			

50% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,950	59%	0%	1%	0%
	Impervious - Ground	900	64%	0%	1%	0%
	Pervious	150			9%	0%
	All Surface Types Tributary to GRI		**31%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	1,950	59%	0%	68%	58%
	Impervious - Ground	900	64%	0%	73%	63%
	Pervious	150			100%	100%
	All Surface Types Tributary to GRI		**31%**	**0%**	**34%**	**30%**
	Compliant Pathway Available?		No			
Moderate Infiltration	Impervious - Roof	1,950	59%	0%	100%	80%
	Impervious - Ground	900	64%	0%	100%	87%
	Pervious	150			100%	100%
	All Surface Types Tributary to GRI		**31%**	**0%**	**60%**	**41%**
	Compliant Pathway Available?		No			
High Infiltration	Impervious - Roof	1,950	59%	0%	100%	100%
	Impervious - Ground	900	64%	0%	100%	100%
	Pervious	150			100%	NA
	All Surface Types Tributary to GRI		**31%**	**0%**	**98%**	**63%**
	Compliant Pathway Available?		Yes			

75% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,950	100%	0%	2%	0%
	Impervious - Ground	900	64%	0%	1%	0%
	Pervious	150			9%	0%
	All Surface Types Tributary to GRI		**42%**	**0%**	**1%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	1,950	100%	0%	100%	100%
	Impervious - Ground	900	64%	0%	73%	63%
	Pervious	150			100%	100%
	All Surface Types Tributary to GRI		**42%**	**0%**	**45%**	**40%**
	Compliant Pathway Available?		No			
Moderate Infiltration	Impervious - Roof	1,950	100%	0%	100%	100%
	Impervious - Ground	900	64%	0%	100%	86%
	Pervious	150			100%	100%
	All Surface Types Tributary to GRI		**42%**	**0%**	**80%**	**56%**
	Compliant Pathway Available?		Yes			
High Infiltration	Impervious - Roof	1,950	100%	0%	100%	100%
	Impervious - Ground	900	64%	0%	100%	100%
	Pervious	150			100%	NA
	All Surface Types Tributary to GRI		**42%**	**0%**	**100%**	**85%**
	Compliant Pathway Available?		Yes			

100% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,950	NA	NA	NA	NA
	Impervious - Ground	900	64%	0%	1%	0%
	Pervious	150			9%	0%
	All Surface Types Tributary to GRI		**64%**	**0%**	**1%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	1,950	NA	NA	NA	NA
	Impervious - Ground	900	64%	0%	73%	63%
	Pervious	150			100%	100%
	All Surface Types Tributary to GRI		**64%**	**0%**	**67%**	**61%**
	Compliant Pathway Available?		Yes			
Moderate Infiltration	Impervious - Roof	1,950	NA	NA	NA	NA
	Impervious - Ground	900	64%	0%	100%	86%
	Pervious	150			100%	100%
	All Surface Types Tributary to GRI		**64%**	**0%**	**100%**	**86%**
	Compliant Pathway Available?		Yes			
High Infiltration	Impervious - Roof	1,950	NA	NA	NA	NA
	Impervious - Ground	900	64%	0%	100%	100%
	Pervious	150			100%	NA
	All Surface Types Tributary to GRI		**64%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes			

Mid-Rise Residential & Mixed-Use

Performance Modeling Summary (48 mm, Reduced Parkade)

Typology	Mid-Rise Residential & Mixed-Use
Standard	48 mm Retention
Parkade Extent	Full Building Footprint or NA
Setback Policy	Existing Setback (5m)

Scenarios with compliant pathways	13/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

Infiltration Scenario	Surface Type	Existing Area (m2)	*0% Managed with Resilient Roof*				*25% Managed with Resilient Roof*				*50% Managed with Resilient Roof*				*75% Managed with Resilient Roof*				*100% Managed with Resilient Roof*			
			Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,950	30%	0%	0%	0%	40%	0%	0%	0%	59%	0%	0%	0%	100%	0%	1%	0%	NA	NA	NA	NA
	Impervious - Ground	900	64%	0%	0%	0%	64%	0%	0%	0%	64%	0%	0%	0%	64%	0%	0%	0%	64%	0%	0%	0%
	Pervious	150			5%	0%			5%	0%			5%	0%			5%	0%			5%	0%
	All Surface Types Tributary to GRI		**20%**	**0%**	**0%**	**0%**	**24%**	**0%**	**0%**	**0%**	**31%**	**0%**	**0%**	**0%**	**42%**	**0%**	**0%**	**0%**	**64%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No				No				No				No				No			
Low Infiltration	Impervious - Roof	1,950	30%	56%	12%	70%	40%	75%	15%	93%	59%	100%	23%	100%	100%	100%	46%	100%	NA	NA	NA	NA
	Impervious - Ground	900	64%	46%	25%	100%	64%	46%	25%	100%	64%	46%	25%	100%	64%	46%	25%	100%	64%	46%	25%	100%
	Pervious	150			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**20%**	**38%**	**8%**	**47%**	**24%**	**46%**	**9%**	**57%**	**31%**	**58%**	**12%**	**71%**	**42%**	**65%**	**16%**	**96%**	**64%**	**46%**	**24%**	**100%**
	Compliant Pathway Available?		No				No				Yes				Yes				Yes			
Moderate Infiltration	Impervious - Roof	1,950	30%	100%	21%	95%	40%	100%	28%	100%	59%	100%	42%	100%	100%	100%	83%	100%	NA	NA	NA	NA
	Impervious - Ground	900	64%	46%	45%	100%	64%	46%	45%	100%	64%	46%	45%	100%	64%	46%	45%	100%	64%	46%	45%	100%
	Pervious	150			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**20%**	**73%**	**14%**	**65%**	**24%**	**79%**	**17%**	**78%**	**31%**	**74%**	**21%**	**98%**	**42%**	**65%**	**29%**	**100%**	**64%**	**46%**	**43%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
High Infiltration	Impervious - Roof	1,950	30%	100%	39%	100%	40%	100%	52%	100%	59%	100%	78%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	900	64%	46%	80%	100%	64%	46%	80%	100%	64%	46%	80%	100%	64%	46%	80%	100%	64%	46%	80%	100%
	Pervious	150			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**20%**	**82%**	**27%**	**97%**	**24%**	**79%**	**32%**	**100%**	**31%**	**74%**	**40%**	**100%**	**42%**	**65%**	**53%**	**100%**	**64%**	**46%**	**78%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			

Mid-Rise Residential & Mixed-Use

Performance Modeling Summary (48 mm, Modified Setback + Reduced Parkade)

Typology	Mid-Rise Residential & Mixed-Use
Standard	48 mm Retention
Parkade Extent	Full Building Footprint or NA
Setback Policy	Modified Setback (3m)

Scenarios with compliant pathways	15/20

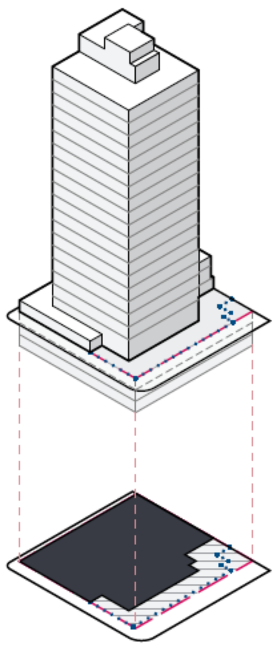
Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

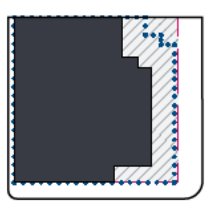
Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,950	30%	0%	0%	0%	40%	0%	1%	0%	59%	0%	1%	0%	100%	0%	2%	0%	NA	NA	NA	NA
	Impervious - Ground	900	64%	0%	1%	0%	64%	0%	1%	0%	64%	0%	1%	0%	64%	0%	1%	0%	64%	0%	1%	0%
	Pervious	150			9%	0%			9%	0%			9%	0%			9%	0%			9%	0%
	All Surface Types Tributary to GRI		**20%**	**0%**	**0%**	**0%**	**24%**	**0%**	**0%**	**0%**	**31%**	**0%**	**0%**	**0%**	**42%**	**0%**	**1%**	**0%**	**64%**	**0%**	**1%**	**0%**
	Compliant Pathway Available?		No				No				No				No				No			
Low Infiltration	Impervious - Roof	1,950	30%	100%	34%	100%	40%	100%	45%	100%	59%	100%	68%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	900	64%	100%	73%	100%	64%	100%	73%	100%	64%	100%	73%	100%	64%	100%	73%	100%	64%	100%	73%	100%
	Pervious	150			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**20%**	**100%**	**22%**	**100%**	**24%**	**100%**	**27%**	**100%**	**31%**	**100%**	**34%**	**100%**	**42%**	**100%**	**45%**	**100%**	**64%**	**100%**	**67%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Moderate Infiltration	Impervious - Roof	1,950	30%	100%	61%	100%	40%	100%	81%	100%	59%	100%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	900	64%	100%	100%	100%	64%	100%	100%	100%	64%	100%	100%	100%	64%	100%	100%	100%	64%	100%	100%	100%
	Pervious	150			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**20%**	**100%**	**40%**	**100%**	**24%**	**100%**	**48%**	**100%**	**31%**	**100%**	**60%**	**100%**	**42%**	**100%**	**80%**	**100%**	**64%**	**100%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
High Infiltration	Impervious - Roof	1,950	30%	100%	100%	100%	40%	100%	100%	100%	59%	100%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	900	64%	100%	100%	100%	64%	100%	100%	100%	64%	100%	100%	100%	64%	100%	100%	100%	64%	100%	100%	100%
	Pervious	150			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**20%**	**100%**	**73%**	**100%**	**24%**	**100%**	**85%**	**100%**	**31%**	**100%**	**98%**	**100%**	**42%**	**100%**	**100%**	**100%**	**64%**	**100%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
			0% Managed with Resilient Roof				***25% Managed with Resilient Roof***				***50% Managed with Resilient Roof***				***75% Managed with Resilient Roof***				***100% Managed with Resilient Roof***			

HERRERA

High-Rise Residential & Mixed-Use

Summary Overview





Typology Summary

Parcel Size (m²)	% Imperv-ious	% Roof Area	Total Imperv-ious Area (m²)	Roof Area (m²)	At-grade Pedestrian Impervious Area (m²)	At-grade Vehicular Impervious Area (m²)	Pervious Area (m²)	No. of Storeys (above ground)	No. of Parkade Levels (below ground)
1,200	90%	70%	1,080	840	192	48	120	20	3

Setback Summary

	Parkade Full Extent of Impervious Area			Parkade Full Extent of Building Footprint		
	Current setbacks (5 m)	Modified setback (3 m)	No setback (0 m)	Current setbacks (5 m)	Modified setback (3 m)	No setback (0 m)
Total Impervious Roof (m²)	**840**	**840**	**840**	**840**	**840**	**840**
Total Impervious Ground (m²)	**240**	**240**	**240**	**240**	**240**	**240**
Infiltration Area (m²)	0	0	0	59	123	240
Non-Infiltration Area (m²)	240	240	240	181	117	0
Total Pervious (m²)	**120**	**120**	**120**	**120**	**120**	**120**
Infiltration Area (m²)	30	62	120	30	62	120
Non-Infiltration Area (m²)	90	58	0	90	58	0

Performance Modeling Conclusions (Low Infiltration)

Standard	Compliant Scenarios Possible (Policy/Practice)	GRI Tool Performance and Importance				
		Resilient Roof	Rainwater Harvesting	Permeable Pavement	Bioretention	Subsurface Infiltration
24-mm Retention	Yes (Existing)	Optional	Optional	Not viable	Optional	Optional
	Yes (3 m setback)	Optional	Optional	Not viable	Optional	Optional
48-mm Retention	Yes (Existing)	Optional	Optional	Not viable	Optional	Optional
	Yes (3m setback)	Optional	Optional	Not viable	Optional	Optional

HERRERA

High-Rise Residential & Mixed-Use

Performance Modeling Summary (24 mm)

Typology	High-Rise Residential & Mixed-Use
Standard	24 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Existing Setback (5m)

Scenarios with compliant pathways	20/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

			0% Managed with Resilient Roof				*25% Managed with Resilient Roof*				*50% Managed with Resilient Roof*				*75% Managed with Resilient Roof*				*100% Managed with Resilient Roof*			
Infiltration Scenario	**Surface Type**	**Existing Area (m2)**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**
No Infiltration	Impervious - Roof	840	100%	0%	1%	0%	100%	0%	1%	0%	100%	0%	2%	0%	100%	0%	4%	0%	NA	NA	NA	NA
	Impervious - Ground	240	100%	0%	4%	0%	100%	0%	4%	0%	100%	0%	4%	0%	100%	0%	4%	0%	100%	0%	4%	0%
	Pervious	120			20%	0%			20%	0%			20%	0%			20%	0%			20%	0%
	All Surface Types Tributary to GRI		**100%**	**0%**	**1%**	**0%**	**100%**	**0%**	**1%**	**0%**	**100%**	**0%**	**1%**	**0%**	**100%**	**0%**	**2%**	**0%**	**100%**	**0%**	**3%**	**0%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Low Infiltration	Impervious - Roof	840	100%	0%	79%	68%	100%	0%	100%	91%	100%	0%	100%	100%	100%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	240	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%
	Pervious	120			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**100%**	**0%**	**59%**	**53%**	**100%**	**0%**	**73%**	**66%**	**100%**	**0%**	**95%**	**87%**	**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Moderate Infiltration	Impervious - Roof	840	100%	0%	100%	93%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	240	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%
	Pervious	120			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**100%**	**0%**	**100%**	**72%**	**100%**	**0%**	**100%**	**89%**	**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
High Infiltration	Impervious - Roof	840	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	240	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%
	Pervious	120			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			

High-Rise Residential & Mixed-Use

Performance Modeling Summary (48 mm)

Typology	High-Rise Residential & Mixed-Use
Standard	48 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Existing Setback (5m)

Scenarios with compliant pathways	20/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

			0% Managed with Resilient Roof				*25% Managed with Resilient Roof*				*50% Managed with Resilient Roof*				*75% Managed with Resilient Roof*				*100% Managed with Resilient Roof*			
Infiltration Scenario	**Surface Type**	**Existing Area (m2)**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**
No Infiltration	Impervious - Roof	840	100%	0%	0%	0%	100%	0%	1%	0%	100%	0%	1%	0%	100%	0%	2%	0%	NA	NA	NA	NA
	Impervious - Ground	240	100%	0%	2%	0%	100%	0%	2%	0%	100%	0%	2%	0%	100%	0%	2%	0%	100%	0%	2%	0%
	Pervious	120			7%	0%			7%	0%			7%	0%			7%	0%			7%	0%
	All Surface Types Tributary to GRI		**100%**	**0%**	**0%**	**0%**	**100%**	**0%**	**0%**	**0%**	**100%**	**0%**	**1%**	**0%**	**100%**	**0%**	**1%**	**0%**	**100%**	**0%**	**1%**	**0%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Low Infiltration	Impervious - Roof	840	100%	0%	35%	30%	100%	0%	47%	41%	100%	0%	71%	61%	100%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	240	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%
	Pervious	120			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**100%**	**0%**	**26%**	**23%**	**100%**	**0%**	**32%**	**29%**	**100%**	**0%**	**42%**	**38%**	**100%**	**0%**	**59%**	**54%**	**100%**	**0%**	**100%**	**98%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Moderate Infiltration	Impervious - Roof	840	100%	0%	63%	42%	100%	0%	84%	56%	100%	0%	100%	83%	100%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	240	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%
	Pervious	120			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**100%**	**0%**	**48%**	**32%**	**100%**	**0%**	**59%**	**40%**	**100%**	**0%**	**76%**	**53%**	**100%**	**0%**	**100%**	**77%**	**100%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
High Infiltration	Impervious - Roof	840	100%	0%	100%	64%	100%	0%	100%	85%	100%	0%	100%	100%	100%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	240	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%
	Pervious	120			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**100%**	**0%**	**84%**	**50%**	**100%**	**0%**	**96%**	**62%**	**100%**	**0%**	**100%**	**81%**	**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			

High-Rise Residential & Mixed-Use

Performance Modeling Summary (48 mm, Modified Setback)

Typology	High-Rise Residential & Mixed-Use
Standard	48 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Modified Setback (3m)

Scenarios with compliant pathways	20/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

			0% Managed with Resilient Roof				*25% Managed with Resilient Roof*				*50% Managed with Resilient Roof*				*75% Managed with Resilient Roof*				*100% Managed with Resilient Roof*			
Infiltration Scenario	**Surface Type**	**Existing Area (m2)**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**
No Infiltration	Impervious - Roof	840	100%	0%	1%	0%	100%	0%	1%	0%	100%	0%	2%	0%	100%	0%	4%	0%	NA	NA	NA	NA
	Impervious - Ground	240	100%	0%	3%	0%	100%	0%	3%	0%	100%	0%	3%	0%	100%	0%	3%	0%	100%	0%	3%	0%
	Pervious	120			10%	0%			10%	0%			10%	0%			10%	0%			10%	0%
	All Surface Types Tributary to GRI		**100%**	**0%**	**1%**	**0%**	**100%**	**0%**	**1%**	**0%**	**100%**	**0%**	**1%**	**0%**	**100%**	**0%**	**2%**	**0%**	**100%**	**0%**	**3%**	**0%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Low Infiltration	Impervious - Roof	840	100%	0%	74%	64%	100%	0%	98%	85%	100%	0%	100%	100%	100%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	240	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%
	Pervious	120			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**100%**	**0%**	**53%**	**48%**	**100%**	**0%**	**65%**	**60%**	**100%**	**0%**	**84%**	**78%**	**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Moderate Infiltration	Impervious - Roof	840	100%	0%	100%	87%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	240	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%
	Pervious	120			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**100%**	**0%**	**94%**	**67%**	**100%**	**0%**	**100%**	**83%**	**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
High Infiltration	Impervious - Roof	840	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	240	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%
	Pervious	120			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**100%**	**100%**	**100%**	**0%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			

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High-Rise Residential & Mixed-Use

Performance Modeling Summary (48 mm, Reduced Parkade)

Typology	High-Rise Residential & Mixed-Use
Standard	48 mm Retention
Parkade Extent	Full Building Footprint or NA
Setback Policy	Existing Setback (5m)

Scenarios with compliant pathways	20/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

			0% Managed with Resilient Roof				*25% Managed with Resilient Roof*				*50% Managed with Resilient Roof*				*75% Managed with Resilient Roof*				*100% Managed with Resilient Roof*			
Infiltration Scenario	**Surface Type**	**Existing Area (m2)**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**
No Infiltration	Impervious - Roof	840	100%	0%	0%	0%	100%	0%	1%	0%	100%	0%	1%	0%	100%	0%	2%	0%	NA	NA	NA	NA
	Impervious - Ground	240	100%	0%	2%	0%	100%	0%	2%	0%	100%	0%	2%	0%	100%	0%	2%	0%	100%	0%	2%	0%
	Pervious	120			7%	0%			7%	0%			7%	0%			7%	0%			7%	0%
	All Surface Types Tributary to GRI		**100%**	**0%**	**0%**	**0%**	**100%**	**0%**	**0%**	**0%**	**100%**	**0%**	**1%**	**0%**	**100%**	**0%**	**1%**	**0%**	**100%**	**0%**	**1%**	**0%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Low Infiltration	Impervious - Roof	840	100%	58%	35%	91%	100%	77%	47%	100%	100%	100%	71%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	240	100%	75%	100%	100%	100%	75%	100%	100%	100%	75%	100%	100%	100%	75%	100%	100%	100%	75%	100%	100%
	Pervious	120			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**100%**	**44%**	**26%**	**70%**	**100%**	**55%**	**32%**	**86%**	**100%**	**72%**	**42%**	**100%**	**100%**	**86%**	**59%**	**100%**	**100%**	**75%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Moderate Infiltration	Impervious - Roof	840	100%	100%	63%	100%	100%	100%	84%	100%	100%	100%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	240	100%	75%	100%	100%	100%	75%	100%	100%	100%	75%	100%	100%	100%	75%	100%	100%	100%	75%	100%	100%
	Pervious	120			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**100%**	**85%**	**48%**	**96%**	**100%**	**93%**	**59%**	**100%**	**100%**	**91%**	**76%**	**100%**	**100%**	**86%**	**100%**	**100%**	**100%**	**75%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
High Infiltration	Impervious - Roof	840	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	240	100%	75%	100%	100%	100%	75%	100%	100%	100%	75%	100%	100%	100%	75%	100%	100%	100%	75%	100%	100%
	Pervious	120			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**100%**	**93%**	**84%**	**100%**	**100%**	**93%**	**96%**	**100%**	**100%**	**91%**	**100%**	**100%**	**100%**	**86%**	**100%**	**100%**	**100%**	**75%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			

High-Rise Residential & Mixed-Use

Performance Modeling Summary (48 mm, Modified Setback + Reduced Parkade)

Typology	High-Rise Residential & Mixed-Use
Standard	48 mm Retention
Parkade Extent	Full Building Footprint or NA
Setback Policy	Modified Setback (3m)

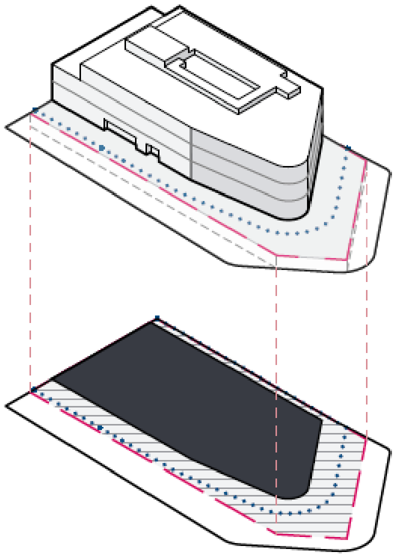
Scenarios with compliant pathways	20/20

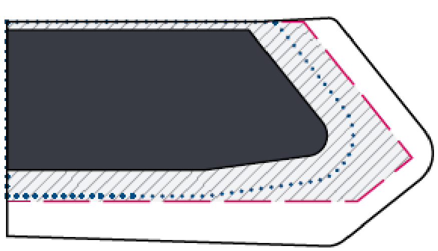
Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

Infiltration Scenario	Surface Type	Existing Area (m2)	*0% Managed with Resilient Roof*				*25% Managed with Resilient Roof*				*50% Managed with Resilient Roof*				*75% Managed with Resilient Roof*				*100% Managed with Resilient Roof*			
			Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	840	100%	0%	1%	0%	100%	0%	1%	0%	100%	0%	2%	0%	100%	0%	4%	0%	NA	NA	NA	NA
	Impervious - Ground	240	100%	0%	3%	0%	100%	0%	3%	0%	100%	0%	3%	0%	100%	0%	3%	0%	100%	0%	3%	0%
	Pervious	120			10%	0%			10%	0%			10%	0%			10%	0%			10%	0%
	All Surface Types Tributary to GRI		**100%**	**0%**	**1%**	**0%**	**100%**	**0%**	**1%**	**0%**	**100%**	**0%**	**1%**	**0%**	**100%**	**0%**	**2%**	**0%**	**100%**	**0%**	**3%**	**0%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Low Infiltration	Impervious - Roof	840	100%	100%	74%	100%	100%	100%	98%	100%	100%	100%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	240	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Pervious	120			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**100%**	**92%**	**53%**	**100%**	**100%**	**100%**	**65%**	**100%**	**100%**	**100%**	**84%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Moderate Infiltration	Impervious - Roof	840	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	240	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Pervious	120			100%	100%			100%	100%			100%	100%			100%	100%			100%	100%
	All Surface Types Tributary to GRI		**100%**	**100%**	**94%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
High Infiltration	Impervious - Roof	840	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	NA	NA	NA	NA
	Impervious - Ground	240	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Pervious	120			100%	NA			100%	NA			100%	NA			100%	NA			100%	NA
	All Surface Types Tributary to GRI		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			

Low/Mid-Rise Non-Residential

Summary Overview





Typology Summary

Parcel Size (m^2)	% Imperv-ious	% Roof Area	Total Imperv-ious Area (m^2)	Roof Area (m^2)	At-grade Pedestrian Impervious Area (m^2)	At-grade Vehicular Impervious Area (m^2)	Pervious Area (m^2)	No. of Storeys (above ground)	No. of Parkade Levels (below ground)
2,500	100%	40%	2,500	1,000	1,350	150	0	3	1

Setback Summary

	Parkade Full Extent of Impervious Area			Parkade Full Extent of Building Footprint		
	Current setbacks (5 m)	Modified setback (3 m)	No setback (0 m)	Current setbacks (5 m)	Modified setback (3 m)	No setback (0 m)
Total Impervious Roof (m^2)	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**
Total Impervious Ground (m^2)	**1,500**	**1,500**	**1,500**	**1,500**	**1,500**	**1,500**
Infiltration Area (m^2)	0	0	0	1,039	1,204	1,500
Non-Infiltration Area (m^2)	1,500	1,500	1,500	461	296	0
Total Pervious (m^2)	**0**	**0**	**0**	**0**	**0**	**0**
Infiltration Area (m^2)	0	0	0	0	0	0
Non-Infiltration Area (m^2)	0	0	0	0	0	0

Performance Modeling Conclusions (Low Infiltration)

Standard	Compliant Scenarios Possible (Policy/Practice)	GRI Tool Performance and Importance				
		Resilient Roof	Rainwater Harvesting	Permeable Pavement	Bioretention	Subsurface Infiltration
24-mm Retention	No (Existing)					
	Yes (Reduced parkade)	Optional	Optional	Optional	Not viable	Optional
48-mm Retention	No (Existing)					
	Yes (Reduced parkade)	Optional	Optional	Optional	Not viable	Optional

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Low/Mid-Rise Non-Residential

Performance Modeling Summary (24 mm)

Typology	Low/Mid-Rise Non-Residential
Standard	24 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Existing Setback (5m)

Scenarios with compliant pathways	0/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

			0% Managed with Resilient Roof				*25% Managed with Resilient Roof*				*50% Managed with Resilient Roof*				*75% Managed with Resilient Roof*				*100% Managed with Resilient Roof*			
Infiltration Scenario	**Surface Type**	**Existing Area (m2)**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**
No Infiltration	Impervious - Roof	1,000	15%	0%	0%	0%	20%	0%	0%	0%	30%	0%	0%	0%	61%	0%	0%	0%	NA	NA	NA	NA
	Impervious - Ground	1,500	10%	0%	0%	0%	10%	0%	0%	0%	10%	0%	0%	0%	10%	0%	0%	0%	10%	0%	0%	0%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**6%**	**0%**	**0%**	**0%**	**7%**	**0%**	**0%**	**0%**	**8%**	**0%**	**0%**	**0%**	**9%**	**0%**	**0%**	**0%**	**10%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		**No**				**No**				**No**				**No**				**No**			
Low Infiltration	Impervious - Roof	1,000	15%	0%	0%	0%	20%	0%	0%	0%	30%	0%	0%	0%	61%	0%	0%	0%	NA	NA	NA	NA
	Impervious - Ground	1,500	10%	0%	0%	0%	10%	0%	0%	0%	10%	0%	0%	0%	10%	0%	0%	0%	10%	0%	0%	0%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**6%**	**0%**	**0%**	**0%**	**7%**	**0%**	**0%**	**0%**	**8%**	**0%**	**0%**	**0%**	**9%**	**0%**	**0%**	**0%**	**10%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		**No**				**No**				**No**				**No**				**No**			
Moderate Infiltration	Impervious - Roof	1,000	15%	0%	0%	0%	20%	0%	0%	0%	30%	0%	0%	0%	61%	0%	0%	0%	NA	NA	NA	NA
	Impervious - Ground	1,500	10%	0%	0%	0%	10%	0%	0%	0%	10%	0%	0%	0%	10%	0%	0%	0%	10%	0%	0%	0%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**6%**	**0%**	**0%**	**0%**	**7%**	**0%**	**0%**	**0%**	**8%**	**0%**	**0%**	**0%**	**9%**	**0%**	**0%**	**0%**	**10%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		**No**				**No**				**No**				**No**				**No**			
High Infiltration	Impervious - Roof	1,000	15%	0%	0%	0%	20%	0%	0%	0%	30%	0%	0%	0%	61%	0%	0%	0%	NA	NA	NA	NA
	Impervious - Ground	1,500	10%	0%	0%	0%	10%	0%	0%	0%	10%	0%	0%	0%	10%	0%	0%	0%	10%	0%	0%	0%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**6%**	**0%**	**0%**	**0%**	**7%**	**0%**	**0%**	**0%**	**8%**	**0%**	**0%**	**0%**	**9%**	**0%**	**0%**	**0%**	**10%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		**No**				**No**				**No**				**No**				**No**			

Low/Mid-Rise Non-Residential

Performance Modeling Summary (48 mm)

Typology	Low/Mid-Rise Non-Residential
Standard	48 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Existing Setback (5m)

Scenarios with compliant pathways	0/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

0% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,000	7%	0%	0%	0%
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**3%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	1,000	7%	0%	0%	0%
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**3%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
Moderate Infiltration	Impervious - Roof	1,000	7%	0%	0%	0%
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**3%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
High Infiltration	Impervious - Roof	1,000	7%	0%	0%	0%
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**3%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			

25% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,000	9%	0%	0%	0%
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**3%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	1,000	9%	0%	0%	0%
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**3%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
Moderate Infiltration	Impervious - Roof	1,000	9%	0%	0%	0%
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**3%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
High Infiltration	Impervious - Roof	1,000	9%	0%	0%	0%
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**3%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			

50% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,000	14%	0%	0%	0%
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**3%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	1,000	14%	0%	0%	0%
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**3%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
Moderate Infiltration	Impervious - Roof	1,000	14%	0%	0%	0%
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**3%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
High Infiltration	Impervious - Roof	1,000	14%	0%	0%	0%
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**3%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			

75% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,000	27%	0%	0%	0%
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**4%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	1,000	27%	0%	0%	0%
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**4%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
Moderate Infiltration	Impervious - Roof	1,000	27%	0%	0%	0%
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**4%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
High Infiltration	Impervious - Roof	1,000	27%	0%	0%	0%
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**4%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			

100% Managed with Resilient Roof

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	1,000	NA	NA	NA	NA
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**5%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
Low Infiltration	Impervious - Roof	1,000	NA	NA	NA	NA
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**5%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
Moderate Infiltration	Impervious - Roof	1,000	NA	NA	NA	NA
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**5%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			
High Infiltration	Impervious - Roof	1,000	NA	NA	NA	NA
	Impervious - Ground	1,500	5%	0%	0%	0%
	Pervious	0			NA	NA
	All Surface Types Tributary to GRI		**5%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No			

HERRERA

Low/Mid-Rise Non-Residential

Performance Modeling Summary (48 mm, Reduced Parkade)

Typology	Low/Mid-Rise Non-Residential
Standard	48 mm Retention
Parkade Extent	Full Building Footprint or NA
Setback Policy	Existing Setback (5m)

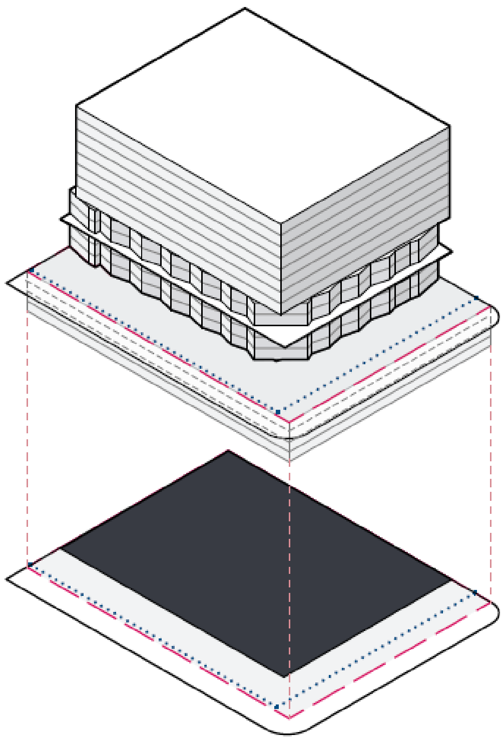
Scenarios with compliant pathways	15/20

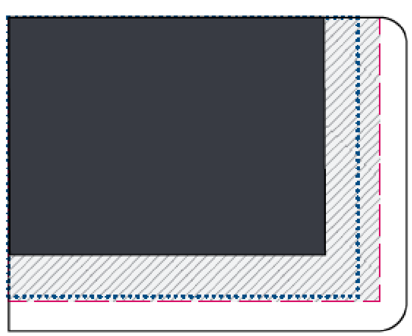
Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

			0% Managed with Resilient Roof				*25% Managed with Resilient Roof*				*50% Managed with Resilient Roof*				*75% Managed with Resilient Roof*				*100% Managed with Resilient Roof*			
Infiltration Scenario	**Surface Type**	**Existing Area (m2)**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**
No Infiltration	Impervious - Roof	1,000	7%	0%	0%	0%	9%	0%	0%	0%	14%	0%	0%	0%	27%	0%	0%	0%	NA	NA	NA	NA
	Impervious - Ground	1,500	5%	0%	0%	0%	5%	0%	0%	0%	5%	0%	0%	0%	5%	0%	0%	0%	5%	0%	0%	0%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**3%**	**0%**	**0%**	**0%**	**3%**	**0%**	**0%**	**0%**	**3%**	**0%**	**0%**	**0%**	**4%**	**0%**	**0%**	**0%**	**5%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No				No				No				No				No			
Low Infiltration	Impervious - Roof	1,000	7%	100%	0%	100%	9%	100%	0%	100%	14%	100%	0%	100%	27%	100%	0%	100%	NA	NA	NA	NA
	Impervious - Ground	1,500	5%	100%	0%	100%	5%	100%	0%	100%	5%	100%	0%	100%	5%	100%	0%	100%	5%	100%	0%	100%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**3%**	**100%**	**0%**	**100%**	**3%**	**100%**	**0%**	**100%**	**3%**	**100%**	**0%**	**100%**	**4%**	**100%**	**0%**	**100%**	**5%**	**100%**	**0%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Moderate Infiltration	Impervious - Roof	1,000	7%	100%	0%	100%	9%	100%	0%	100%	14%	100%	0%	100%	27%	100%	0%	100%	NA	NA	NA	NA
	Impervious - Ground	1,500	5%	100%	0%	100%	5%	100%	0%	100%	5%	100%	0%	100%	5%	100%	0%	100%	5%	100%	0%	100%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**3%**	**100%**	**0%**	**100%**	**3%**	**100%**	**0%**	**100%**	**3%**	**100%**	**0%**	**100%**	**4%**	**100%**	**0%**	**100%**	**5%**	**100%**	**0%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
High Infiltration	Impervious - Roof	1,000	7%	100%	0%	100%	9%	100%	0%	100%	14%	100%	0%	100%	27%	100%	0%	100%	NA	NA	NA	NA
	Impervious - Ground	1,500	5%	100%	0%	100%	5%	100%	0%	100%	5%	100%	0%	100%	5%	100%	0%	100%	5%	100%	0%	100%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**3%**	**100%**	**0%**	**100%**	**3%**	**100%**	**0%**	**100%**	**3%**	**100%**	**0%**	**100%**	**4%**	**100%**	**0%**	**100%**	**5%**	**100%**	**0%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			

High-Rise Non-Residential

Summary Overview





Typology Summary

Parcel Size (m²)	% Imperv-ious	% Roof Area	Total Imperv-ious Area (m²)	Roof Area (m²)	At-grade Pedestrian Impervious Area (m²)	At-grade Vehicular Impervious Area (m²)	Pervious Area (m²)	No. of Storeys (above ground)	No. of Parkade Levels (below ground)
8,000	100%	55%	8,000	4,400	3,240	360	0	14	4

Setback Summary

	Parkade Full Extent of Impervious Area			Parkade Full Extent of Building Footprint		
	Current setbacks (5 m)	Modified setback (3 m)	No setback (0 m)	Current setbacks (5 m)	Modified setback (3 m)	No setback (0 m)
Total Impervious Roof (m²)	**4,400**	**4,400**	**4,400**	**4,400**	**4,400**	**4,400**
Total Impervious Ground (m²)	**3,600**	**3,600**	**3,600**	**3,600**	**3,600**	**3,600**
Infiltration Area (m²)	0	0	0	2,811	3,099	3,600
Non-Infiltration Area (m²)	3,600	3,600	3,600	789	501	0
Total Pervious (m²)	**0**	**0**	**0**	**0**	**0**	**0**
Infiltration Area (m²)	0	0	0	0	0	0
Non-Infiltration Area (m²)	0	0	0	0	0	0

Performance Modeling Conclusions (Low Infiltration)

Standard	Compliant Scenarios Possible (Policy/Practice)	GRI Tool Performance and Importance				
		Resilient Roof	Rainwater Harvesting	Permeable Pavement	Bioretention	Subsurface Infiltration
24-mm Retention	Yes (Existing)	***Critical***	***Critical***			
	Yes (Reduced parkade)	Optional	Optional	Optional	Not viable	Optional
48-mm Retention	No (Existing)					
	Yes (Reduced parkade)	Optional	Optional	Optional	Not viable	Optional

HERRERA

High-Rise Non-Residential

Performance Modeling Summary (24 mm)

Typology	High-Rise Non-Residential
Standard	24 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Existing Setback (5m)

Scenarios with compliant pathways	4/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	4,400	82%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	NA	NA	NA	NA
	Impervious - Ground	3,600	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**45%**	**0%**	**0%**	**0%**	**52%**	**0%**	**0%**	**0%**	**62%**	**0%**	**0%**	**0%**	**77%**	**0%**	**0%**	**0%**	**100%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No				No				No				No				Yes			
Low Infiltration	Impervious - Roof	4,400	82%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	NA	NA	NA	NA
	Impervious - Ground	3,600	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**45%**	**0%**	**0%**	**0%**	**52%**	**0%**	**0%**	**0%**	**62%**	**0%**	**0%**	**0%**	**77%**	**0%**	**0%**	**0%**	**100%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No				No				No				No				Yes			
Moderate Infiltration	Impervious - Roof	4,400	82%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	NA	NA	NA	NA
	Impervious - Ground	3,600	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**45%**	**0%**	**0%**	**0%**	**52%**	**0%**	**0%**	**0%**	**62%**	**0%**	**0%**	**0%**	**77%**	**0%**	**0%**	**0%**	**100%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No				No				No				No				Yes			
High Infiltration	Impervious - Roof	4,400	82%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	NA	NA	NA	NA
	Impervious - Ground	3,600	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**45%**	**0%**	**0%**	**0%**	**52%**	**0%**	**0%**	**0%**	**62%**	**0%**	**0%**	**0%**	**77%**	**0%**	**0%**	**0%**	**100%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No				No				No				No				Yes			
			0% Managed with Resilient Roof				***25% Managed with Resilient Roof***				***50% Managed with Resilient Roof***				***75% Managed with Resilient Roof***				***100% Managed with Resilient Roof***			

High-Rise Non-Residential

Performance Modeling Summary (48 mm, Reduced Parkade)

Typology	High-Rise Non-Residential
Standard	48 mm Retention
Parkade Extent	Full Extent of Impervious Area
Setback Policy	Existing Setback (5m)

Scenarios with compliant pathways	0/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

Infiltration Scenario	Surface Type	Existing Area (m2)	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration	Rainwater harvesting	Permeable pavement	Bioretention	Subsurface infiltration
No Infiltration	Impervious - Roof	4,400	37%	0%	0%	0%	49%	0%	0%	0%	74%	0%	0%	0%	100%	0%	0%	0%	NA	NA	NA	NA
	Impervious - Ground	3,600	45%	0%	0%	0%	45%	0%	0%	0%	45%	0%	0%	0%	45%	0%	0%	0%	45%	0%	0%	0%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**20%**	**0%**	**0%**	**0%**	**23%**	**0%**	**0%**	**0%**	**28%**	**0%**	**0%**	**0%**	**34%**	**0%**	**0%**	**0%**	**45%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No				No				No				No				No			
Low Infiltration	Impervious - Roof	4,400	37%	0%	0%	0%	49%	0%	0%	0%	74%	0%	0%	0%	100%	0%	0%	0%	NA	NA	NA	NA
	Impervious - Ground	3,600	45%	0%	0%	0%	45%	0%	0%	0%	45%	0%	0%	0%	45%	0%	0%	0%	45%	0%	0%	0%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**20%**	**0%**	**0%**	**0%**	**23%**	**0%**	**0%**	**0%**	**28%**	**0%**	**0%**	**0%**	**34%**	**0%**	**0%**	**0%**	**45%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No				No				No				No				No			
Moderate Infiltration	Impervious - Roof	4,400	37%	0%	0%	0%	49%	0%	0%	0%	74%	0%	0%	0%	100%	0%	0%	0%	NA	NA	NA	NA
	Impervious - Ground	3,600	45%	0%	0%	0%	45%	0%	0%	0%	45%	0%	0%	0%	45%	0%	0%	0%	45%	0%	0%	0%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**20%**	**0%**	**0%**	**0%**	**23%**	**0%**	**0%**	**0%**	**28%**	**0%**	**0%**	**0%**	**34%**	**0%**	**0%**	**0%**	**45%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No				No				No				No				No			
High Infiltration	Impervious - Roof	4,400	37%	0%	0%	0%	49%	0%	0%	0%	74%	0%	0%	0%	100%	0%	0%	0%	NA	NA	NA	NA
	Impervious - Ground	3,600	45%	0%	0%	0%	45%	0%	0%	0%	45%	0%	0%	0%	45%	0%	0%	0%	45%	0%	0%	0%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**20%**	**0%**	**0%**	**0%**	**23%**	**0%**	**0%**	**0%**	**28%**	**0%**	**0%**	**0%**	**34%**	**0%**	**0%**	**0%**	**45%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No				No				No				No				No			
			0% Managed with Resilient Roof				***25% Managed with Resilient Roof***				***50% Managed with Resilient Roof***				***75% Managed with Resilient Roof***				***100% Managed with Resilient Roof***			

High-Rise Non-Residential

Performance Modeling Summary (48 mm, Reduced Parkade)

Typology	High-Rise Non-Residential
Standard	48 mm Retention
Parkade Extent	Full Building Footprint or NA
Setback Policy	Existing Setback (5m)

Scenarios with compliant pathways 15/20

Percent of Total Surface Type Runoff Volume Managed by Tool in Isolation

			0% Managed with Resilient Roof				*25% Managed with Resilient Roof*				*50% Managed with Resilient Roof*				*75% Managed with Resilient Roof*				*100% Managed with Resilient Roof*			
Infiltration Scenario	**Surface Type**	**Existing Area (m2)**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**	**Rainwater harvesting**	**Permeable pavement**	**Bioretention**	**Subsurface infiltration**
No Infiltration	Impervious - Roof	4,400	37%	0%	0%	0%	49%	0%	0%	0%	74%	0%	0%	0%	100%	0%	0%	0%	NA	NA	NA	NA
	Impervious - Ground	3,600	45%	0%	0%	0%	45%	0%	0%	0%	45%	0%	0%	0%	45%	0%	0%	0%	45%	0%	0%	0%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**20%**	**0%**	**0%**	**0%**	**23%**	**0%**	**0%**	**0%**	**28%**	**0%**	**0%**	**0%**	**34%**	**0%**	**0%**	**0%**	**45%**	**0%**	**0%**	**0%**
	Compliant Pathway Available?		No				No				No				No				No			
Low Infiltration	Impervious - Roof	4,400	37%	100%	0%	100%	49%	100%	0%	100%	74%	100%	0%	100%	100%	100%	0%	100%	NA	NA	NA	NA
	Impervious - Ground	3,600	45%	100%	0%	100%	45%	100%	0%	100%	45%	100%	0%	100%	45%	100%	0%	100%	45%	100%	0%	100%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**20%**	**100%**	**0%**	**100%**	**23%**	**100%**	**0%**	**100%**	**28%**	**100%**	**0%**	**100%**	**34%**	**100%**	**0%**	**100%**	**45%**	**100%**	**0%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
Moderate Infiltration	Impervious - Roof	4,400	37%	100%	0%	100%	49%	100%	0%	100%	74%	100%	0%	100%	100%	100%	0%	100%	NA	NA	NA	NA
	Impervious - Ground	3,600	45%	100%	0%	100%	45%	100%	0%	100%	45%	100%	0%	100%	45%	100%	0%	100%	45%	100%	0%	100%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**20%**	**100%**	**0%**	**100%**	**23%**	**100%**	**0%**	**100%**	**28%**	**100%**	**0%**	**100%**	**34%**	**100%**	**0%**	**100%**	**45%**	**100%**	**0%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			
High Infiltration	Impervious - Roof	4,400	37%	100%	0%	100%	49%	100%	0%	100%	74%	100%	0%	100%	100%	100%	0%	100%	NA	NA	NA	NA
	Impervious - Ground	3,600	45%	100%	0%	100%	45%	100%	0%	100%	45%	100%	0%	100%	45%	100%	0%	100%	45%	100%	0%	100%
	Pervious	0			NA	NA			NA	NA			NA	NA			NA	NA			NA	NA
	All Surface Types Tributary to GRI		**20%**	**100%**	**0%**	**100%**	**23%**	**100%**	**0%**	**100%**	**28%**	**100%**	**0%**	**100%**	**34%**	**100%**	**0%**	**100%**	**45%**	**100%**	**0%**	**100%**
	Compliant Pathway Available?		Yes				Yes				Yes				Yes				Yes			

Task 6 – Costing Summary Memo

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San Francisco, CA 94105
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TECHNICAL MEMORANDUM

From:	Lotus Water
To:	Gord Tycho (City of Vancouver)
Date:	October 13, 2023
Project:	Rainwater Infrastructure Building Typologies Pathway Study
Subject:	Task 6 - Costing Summary Memo

1. Introduction

The City of Vancouver is advancing the Rainwater Infrastructure Pathways Study (Study) to better understand what green rainwater infrastructure (GRI) tool combinations (compliance pathways) can be used to meet the City's rainwater management design standards for a range of building-site 'typologies'. Typologies range from single family homes to large dense developments. As part of this work, we are also seeking to better understand the cost of these GRI compliance pathways. This work will inform the development of improved rainwater management policies that seek to achieve the goals of the Rain City Strategy in a fair and consistent manner. The goals of Task 6 - Costing are to:

- Develop planning-level unit capital costs, appropriate for construction in the City of Vancouver, for the green rainwater infrastructure (GRI) and non-GRI tools,
- Calculate planning-level total capital cost estimates for the compliance pathways identified for each building-site typology,
- Estimate total capital costs for each pathway as a percentage of the overall building construction cost, and
- Provide a qualitative evaluation of the operation and maintenance (O&M) cost for each pathway.

Capital costs (including the materials and labor for construction as well as the soft costs associated with planning, design, and delivery) are a challenge to estimate, and especially so in the highly theoretical context of these representative typologies and pathways. The first step in this task was to gather available rainwater management tool costing data, standardize the data to currency and year, and establish a set of unit costs for the tools used in this Study. These unit costs were then applied to the modeled size of each compliance pathway rainwater management tool to calculate pathway construction cost estimates. The following sections document this task.

2. Unit Costs - Rainwater Management Tools

2.1 Cost Data Sources

Costing data for rainwater infrastructure tools were gathered from many sources including capital planning and project costs from the City of Vancouver, capital planning and project costs from other municipalities, private sector planning and project costs, vendor pricing, previous costing studies, and cost estimating tools used by other agencies. The following is a list of costing sources compiled in the costing database and used to establish the unit costs for this study. All cost data used for this study is compiled in Appendix A (unit construction costs adjusted to 2022 Canadian dollars) and Appendix B (all unit cost data gathered from original data sources).

Vancouver City Agencies

- City of Vancouver - Engineering Services
- City of Vancouver– GI Sizing Cost Estimator
- Cambie Integrated Water Management Plan (IWMP) – Cost Basis

Other Municipalities

- King County, Washington – Water Quality Benefits Evaluation (WQBE) Life-Cycle Cost Assessment (LCCA)
- San Francisco (California) Public Utilities Commission (SFPUC) – Green Infrastructure Unit Cost and Performance Study
- SFPUC - Evaluation of Rainwater Harvesting Requirements in CSS Areas (2015)
- SFPUC - Water Reuse System Cost Study (2019)
- New York City (NYC) Environmental Protection - Stormwater Management Program Plan (SWMPP) - Post-Construction Capital and O&M Unit Costs
- Los Angeles Flood Control District (LAFCD) – Watershed Management Modeling System (WMMS2.0) - Regional and Distributed BMP Capital and O&M Unit Costs

Studies with GRI Costing Data

- ARUP. San Francisco Living Roof Cost-Benefit Study. Summary Report. June 8, 2016.
- Bureau of Environmental Services (BES), Portland, Oregon. *Cost Benefit Evaluation of Ecoroofs*. 2008.
- Canadian Nursery Landscape Association. Life Cycle Cost Analysis of Natural On-Site Stormwater Management Methods.
- Center for Neighborhood Technologies (CNT). The Green Values® Stormwater Management Calculator Methods. 2019.
- General Service Administration (GSA). *The Benefits and Challenges of Green Roofs on Public and Commercial Buildings*. Government of the United States. May 2011.
- Green Infrastructure Foundation (GIF). Green Infrastructure in Mississauga, Richmond Hill, and Toronto. A Visualization and Cost-Benefit Analysis. 2017.
- GIF. Green Infrastructure for Climate Adaptation. Visualization, Economic Analysis, and Recommendations for Six Ontario Communities. 2019.

- Green Roofs for Healthy Cities (GRHC), GIF. Making Informed Decisions: A Green Roof Cost and Benefit Study for Denver. October 13, 2017.
- Kerr Wood Leidal (KWL). Rainwater Analysis for Multiplex Development, Final Report. January 23, 2023.
- KWL. Tier 3 Rainwater Management Options for Multiplex Sites. March 3, 2023.

Project Costs

- City of Coquitlam – Centennial Synthetic Sports Field Project
- City of Coquitlam – Cottonwood Park Project
- City of Richmond – Olympic Oval Plaza Project
- Vancouver Affordable Housing Agency Projects

A/E Design or Construction Firms

- Low & Bonar
- R.F. Binnie & Associates
- Van Der Zalm & Associates
- Wilco Civil, Inc.

Vendors/Distributors

- Architek
- ACO Canada
- BC Brick
- Columbia Green
- Contech ES
- Deeproot
- Imbrium Systems
- Langley Concrete Group
- New Stone Group
- Next Level Stormwater Management
- Romex
- Veratec Engineered Soils

2.2 Standardization of Cost Data

The cost data gathered from the sources listed above came in a variety of formats that required standardization so that the costs could be compared and unit costs for rainwater infrastructure established. The first step in the standardization process was to verify that each cost was a unit cost (e.g., cost per square meter of bioretention planter) rather than a total cost (e.g., total cost for a bioretention planter of a specific size) and to convert from total to unit costs when possible. If total cost was provided but the quantity of units was unknown, this data was not included in the summary database. As the data sources are from both the United States and Canada, there was a wide variety of units assigned to length, area, or volume for the GRI. Thus, the second standardization step involved converting all the unit costs to meters for length, square meters for area, and cubic meters for volume.

The most involved steps of the standardization process were those needed to convert the unit costs to 2022 Canadian dollars (CAD). Some of the unit costs were already in CAD while many more were in United States dollars (USD). Additionally, unit cost sources were from various previous years, so they needed to be adjusted to equivalent 2022 values. For unit costs in USD, the historical exchange rate for the year of the unit cost was used to convert USD to CAD. The historical exchange rates were obtained from the Bank of Canada website. The Bank of Canada only had historical exchange rates dating back to 2017, so the CanadianForex (OFX) website was used to obtain historical exchange rates back to 2004. The 2017-2022 exchange rates from OFX were compared to those of the Bank of Canada to verify the accuracy of these rates.

Once all unit costs were in CAD for their specific cost year, the unit costs were multiplied by the Building Construction Price Index (BCPI) for Vancouver to convert to 2022 CAD. The BPCI was obtained from the Statistics Canada website - though, like the historical exchange rate, a complete dataset was not available. BCPI for residential building type prior to 2017 could not be found. But rather than use the lower non-residential BCPI for the full dataset conversion, the non-residential BPCI was used for pre-2017 price increases and the residential BCPI was used for post-2017 price increases. This was considered appropriate as most of the cost data comes from after 2017 and the majority of new development in Vancouver is for residential buildings. Archived Table 18-10-0049-01 "Non-residential building construction price index, by class of structure, quarterly" for Vancouver, British Columbia was used to obtain BCPI for the years 2002 to 2017. Table 18-10-0135-01 "Building construction price indexes, by type of building" for residential buildings in Vancouver metropolitan area was used to obtain BCPI for the years 2017 to 2022.

Due to the wide variety and sources of cost data, many unit costs underwent three calculations to be standardized to metric units in 2022 CAD. An example is the "intensive green roof" cost from the 2017 Green Roofs for Healthy Cities study for Denver, Colorado. That cost-benefit study provided a total construction unit cost of $35 per square foot of green roof in 2017 USD. That is equal to $377 per square meter ($m^2$) in 2017 USD, $489 / m^2 in 2017 CAD, and $684 / m^2 in 2022 CAD.

2.3 Rainwater Management Tool Construction Unit Costs

The standardized construction unit costs for each rainwater management tool were then evaluated to identify a baseline construction unit cost for use in this study. Due to the large spread in unit costs in the database, the median value was chosen for the baseline. These unit costs and subsequent cost estimates are of a conceptual pre-planning level, equivalent to a Class 5 Estimate by AACE Estimate Classification standards. Class 5 estimates are based on very limited information, with project definition from 0 to 2%, and subsequently have a wide accuracy range of -20% to -30% on the lower end and +30 to +50% on the higher end. Considering the building typologies and associated rainwater infrastructure are entirely conceptual and representative in nature, the outer bounds of the accuracy range are appropriate for these estimates, and a range of costs is provided based on those expectations (i.e., -30% and +50% of the baseline). The baseline and range of capital unit cost to be used for the Study is shown in Table 1 below. Table 2 summarizes the number of data points, full unit cost range, and variability in source data for each tool type.

Table 1. Baseline and Range of Construction Unit Costs

Rainwater Management Tool		Unit	Baseline Construction Unit Cost ($ per unit)		Const. Unit Cost Range ($ per unit)	
					Low	High
Resilient Roof	Green roof - Extensive (<150mm soil depth)	$ / Area	$220	per sq. m.	$154	$330
	Green roof - Intensive (≥150 mm soil depth)	$ / Area	$430	per sq. m.	$301	$645
	Blue-green roof	$ / Area	$340	per sq. m.	$238	$510
Bioretention	Raingarden (simplest bioretention)	$ / Area	$160	per sq. m.	$112	$240
	Sloped-side bioretention (w/o underdrain)	$ / Area	$1,500	per sq. m.	$1,050	$2,250
	Sloped-side bioretention (w/ underdrain)	$ / Area	$2,000	per sq. m.	$1,400	$3,000
	Full-walled bioretention (w/o underdrain)	$ / Area	$2,100	per sq. m.	$1,470	$3,150
	Full-walled bioretention (w/ underdrain)	$ / Area	$2,600	per sq. m.	$1,820	$3,900
Tree Trench	Soil cells	$ / Area	$400	per sq. m.	$280	$600
	Structural soils	$ / Area	$900	per sq. m.	$630	$1,350
Permeable Pavement		$ / Area	$250	per sq. m.	$175	$375
Subsurface Infiltration		$ / Volume	$2,200	per cu. m.	$1,540	$3,300
Absorbent Landscape		$ / Area	$17	per sq. m.	$12	$26
Non-GRI	Detention tank	$ / Volume	$900	per cu. m.	$630	$1,350
	Blue roof (rooftop detention)	*Insufficient data*				
	Proprietary water quality treatment device	$ / Flow Rate	$34,000 + $1,900	per Lps	-30%	50%

Some additional notes on the data and development of recommended costs for use in the study are below.

- Unit costs for "raingardens" are significantly lower than other bioretention as they are assumed to be for a very simple depressed landscape feature that might be installed in a single-family residential setting, and would not include any piping, overflow structure, connection to downstream collection system, drain rock reservoir, liner or similar.
- There was insufficient data to identify separate costs for different types of permeable pavement (and most data points were general) so all data was combined for a single representative baseline cost.
- There was insufficient data available to identify unit costs for different types of subsurface infiltration systems, so a single subsurface infiltration cost was identified.
- There was insufficient data available to identify a unit cost for blue roofs.

Table 2. Construction Unit Cost Database Summary

Rainwater Management Tool		Source Count	Unit	Construction Unit Cost Database					
				Min	Max	Median	Mean	Range from Median Low	Range from Median High
Resilient Roof	Green roof - Extensive (<150mm soil depth)	13	$/sq. m.	$89	$504	$220	$240	-60%	129%
	Green roof - Intensive (≥150 mm soil depth)	9	$/sq. m.	$233	$738	$430	$460	-46%	72%
	Blue-green roof	3	$/sq. m.	$215	$338	$340	$300	-37%	-1%
Bioretention	Raingarden (simplest bioretention)	6	$/sq. m.	$97	$226	$160	$160	-39%	41%
	Sloped-side bioretention (w/o underdrain)	7	$/sq. m.	$1,073	$2,903	$1,500	$1,700	-28%	94%
	Sloped-side bioretention (w/ underdrain)	4	$/sq. m.	$1,527	$3,014	$2,000	$2,100	-24%	51%
	Full-walled bioretention (w/o underdrain)	4	$/sq. m.	$765	$4,608	$2,100	$2,400	-64%	119%
	Full-walled bioretention (w/ underdrain)	3	$/sq. m.	$1,753	$4,713	$2,600	$3,000	-33%	81%
Tree Trench	Soil cells	3	$/sq. m.	$279	$513	$400	$400	-30%	28%
	Structural soils	3	$/sq. m.	$718	$1,201	$900	$900	-20%	33%
Permeable Pavement		25	$/sq. m.	$89	$2,659	$250	$540	-65%	964%
Subsurface Infiltration		9	$/cu. m.	$303	$9,398	$2,200	$3,500	-86%	327%
Absorbent Landscape		9	$/sq. m.	$2	$178	$17	$50	-86%	947%
Non-GRI	Detention tank	10	$/cu. m.	$350	$7,555	$900	$2,600	-61%	739%
	Blue roof (rooftop detention)	1	$/sq. m.	$117	$117	$117	$117	0%	0%
	Proprietary water quality treatment device	19	each	$32,500	$250,000	$77,400	$95,400	-58%	223%

2.4 Rainwater Harvesting System Construction Unit Costs

Developing unit cost estimates for rainwater harvesting systems was approached a bit differently than the other GRI tools. To estimate the total pathways cost for most tools, the total cost estimate will be determined based on the size of the facility (i.e., the footprint area in square meters or the volume in cubic meters) multiplied by the unit cost. Rainwater harvesting systems are more complex infrastructure with components integrated into a building. As a result, it is necessary to estimate the total cost of each primary component separately and using an appropriate measurement to normalize the costs (e.g., gallons of storage, gross floor area of building, or daily design capacity of reuse system). Of the data sources gathered for use in this costing analysis, three contained useful cost data for rainwater harvesting systems (data summarized in Appendix B):

- SFPUC - Evaluation of Rainwater Harvesting Requirements in CSS Areas
- SFPUC - Water Reuse System Cost Study
- Cambie Integrated Water Management Plan (IWMP) – Cost Basis

Data was summarized for the major system components for a rainwater harvesting system:

- Storage and Collection – The tank or cistern, typically within the lower levels of a building, to hold raw rainwater prior to treatment and distribution. This also includes any additional collection piping to carry flow to the tank, pre-filters and first-flush diverts to provide preliminary treatment prior to storage, overflow connections from the tank, and accounts for some added cost and complexity of integrating storage into a building for reuse rather than as a simple detention tank.
- Treatment and Pump – The treatment equipment that improves captured water to a level of quality acceptable for indoor use (for rainwater reuse this typically includes filtration and UV/chlorine disinfection), the distribution equipment that pumps rainwater into the non-potable piping network (typically includes one or more pumps, buffer/pressure tank(s), and a treated water tank), and associated electrical components and controls.
- Non-potable Plumbing – The non-potable piping network inside the building that delivers treated non-potable water to end uses and fixtures, separate from the standard potable water piping.

Table 3. Rainwater Harvesting System Construction Unit Costs

Component	Unit Cost based on	Baseline Unit Construction Cost	Low Range	High Range
Storage	per m^3 of rainwater tank	$1,300	$910	$1,950
Treatment and Pump	per m^2 of gross floor area (GFA) of building	$22	$15	$33
Non-potable Plumbing	per m^2 of gross floor area (GFA) of building	$14	$10	$21

2.5 Non-Construction Cost Component

The total capital cost for a project includes both the construction costs (including materials and labor for installation, sometimes referred to as "hard costs") as well as non-construction costs (including costs for planning, design, permitting/fees, construction management, and commissioning, sometimes referred to as "soft costs"). Data sources typically provided cost data in terms of the construction (hard) cost portion only. However, there were several sources that provided a total capital cost in addition to the construction cost, most notably the following:

- Cambie Integrated Water Management Plan (IWMP) – Cost Basis
- SFPUC – Green Infrastructure Unit Cost and Performance Study
- NYC Environmental Protection - SWMPP - Post-Construction Capital and O&M Unit Costs

To estimate the non-construction (soft) costs associated with rainwater management implementation, which combined with the construction costs would represent the total capital cost for these facilities, the team analyzed data from the available sources to determine a recommended non-construction cost multiplier. The following is a summary of the construction cost as a percentage of total capital cost:

- Data Count 21
- Minimum 53.5%
- Maximum 62.6%
- Median 56.0%
- Average 57.1%
- Std Deviation 2.6%

Based on this data, a standard construction cost being 57% of total capital cost will be used for all cost estimates (and thus non-construction soft costs will represent 43% of the total capital cost).

3. Overall Building Construction Cost

Limited data was available to estimate the costs to construct the full building and parkade structures and non-GRI sitework for each typology (i.e., everything else that would comprise the typology development project other than the rainwater management tools). Data was used from a "Canadian Cost Guide" prepared by the Altus Group that had construction cost data for the Vancouver area for a variety of residential and commercial building types (see Appendix C). Costs for the total building project can thus be calculated by multiplying these unit costs by the square footage of building structure for each typology.

Table 4. Building Structure and Generic Sitework Construction Unit Costs

Typology or Component	*Category from Altus Canadian Cost Guide*	Construction Unit Costs ($ per sq. m.)		
		Median	*Low*	*High*
Small Lot Residential – Low Massing	*Single Family Residential w/ Unf. Basement*	$2,691	*$1,991*	*$3,391*
Small Lot Residential – High Massing	*Row Townhouse with Unfinished Basement*	$2,530	*$1,938*	*$3,122*
Low-Rise Residential & Mixed-Use	*3 Storey Stacked Townhouse*	$2,772	*$2,314*	*$3,229*
Mid-Rise Residential & Mixed-Use	*Up to 6 Storey Wood Framed Condo*	$3,202	*$2,637*	*$3,767*
High-Rise Residential & Mixed-Use	*Condominiums/Apartments 13-39 Storeys*	$3,929	*$3,552*	*$4,306*
Low/Mid-Rise Non-Residential	*Office Building Under 5 Storeys (Class B)*	$3,579	*$3,122*	*$4,037*
High-Rise Non-Residential	*Office Building 5 - 30 Storeys (Class A)*	$3,633	*$3,175*	*$4,090*
Parkade	*Underground Parking Garages*	$1,884	*$1,292*	*$2,476*
Site Hardscape/Paving	*Surface Parking*	$188	*$108*	*$269*

4. Cost Estimates for Rainwater Management Pathways

The construction unit costs were applied to the modeled size of each compliance pathway rainwater management tool, as well as the overall building typology characteristics, to create construction cost estimates for each pathway.

Table 5 below summarizes the tools that comprise the compliance pathways for each building typology. As described in the Performance Modeling TM, each typology has up to five pathways, each aligned with a pathway "type" associated with distinct variable conditions as follows:

- Pathway 1 assumes that the site soils have no infiltration capacity (i.e., due to clayey soil characteristics, presence of soil contamination, high groundwater, or other).
- Pathway 2 assumes that the site soils do have a low infiltration capacity (5 mm/hr), that the building foundation infiltration setback is per current requirements (i.e., 5 meters), and that the footprint extent of the parkade is according to the typology definition (i.e., equivalent to the defined impervious area percentage).
- Pathway 3 assumes that additional area onsite can be made available for infiltration through a reduced foundation setback and/or reduced footprint extent of the parkade.
- Pathway 4 assumes that the compliance standard for retention is 48 mm.
- Pathway 5 is a "gray" or Tier 3 pathway, using only detention and a water quality treatment device. This pathway does not meet the compliance requirements and is included mainly as a basis of comparison for the GRI pathways.

More information on the pathway categories and variables is available in the Performance Modeling TM.

To aid in identification, each pathway is assigned a unique code. This code is based on the initials of the building typology (e.g., Small Lot Residential – Low Massing = SLRLM) and the pathways type (e.g., Pathway 1 for Small Lot Residential – Low Massing has a pathway code of SLRLM1).

The following Table 6 summarizes the pathway and total project costs for each representative building typology. An expanded construction cost estimate for each pathway is included in Appendix D. These estimates include the characteristics of the building typologies (type, size, and parkade), the characteristics of the rainwater management tools (type, size, and unit cost), and an indication of the range of potential costs.

Table 5. Compliance Pathways

Pathway Type		**Compliance Pathway Rainwater Management Tools, per Building Typology**						
#	**Variable Parameters**	**Small Lot Residential – Low Massing**	**Small Lot Residential – High Massing**	**Low-rise Residential & Mixed-Use**	**Mid-rise Residential & Mixed-Use**	**High-rise Residential & Mixed-Use**	**Low/Mid-rise Non-Residential**	**High-rise Non-Residential**
	Typology Code:	**SLRLM**	**SLRHM**	**LRMU**	**MRMU**	**RRMU**	**LMNR**	**HNR**
1	Retention Standard = 24 mm Infiltration Capacity of Soils = No Infiltration Infiltration Setback = n/a Parkade Footprint = n/a	No compliant pathway	No compliant pathway	No compliant pathway	Green Roof Rainwater Harvesting	Rainwater Harvesting	No compliant pathway	Green Roof Rainwater Harvesting
2	Retention Standard = 24 mm Infiltration Capacity of Soils = Low (5 mm/hr) Infiltration Setback = Typical (5m) Parkade Footprint = Typical	Bioretention *or* Subsurface Infiltration	Green Roof Bioretention Permeable Pavement	Green Roof Bioretention	Green Roof Rainwater Harvesting Bioretention	Green Roof Bioretention	No compliant pathway	No compliant pathway
3	Retention Standard = 24 mm Infiltration Capacity of Soils = Low (5 mm/hr) Infiltration Setback = Reduced (<5m) AND/OR Parkade Footprint = Reduced	*Same as #2*	Bioretention	Bioretention	Bioretention Permeable Pavement	Bioretention	Bioretention Permeable Pavement	Bioretention Permeable Pavement
4	Retention Standard = 48 mm Infiltration Capacity of Soils = Low (5 mm/hr) Infiltration Setback = Reduced (<5m) AND/OR Parkade Footprint = Reduced	Bioretention	Green Roof Subsurface Infiltration	Bioretention Permeable Pavement	Green Roof Subsurface Infiltration	Bioretention Permeable Pavement	Green Roof Bioretention Permeable Pavement	Green Roof Bioretention Permeable Pavement
5	Retention Standard = n/a (non-compliant, detention) Infiltration Capacity of Soils = n/a Infiltration Setback = n/a Parkade Footprint = n/a	Detention + Treatment Device						

Table 6. Pathway Initial Capital Cost Estimates

Building Typology	Small Lot Residential – Low Massing									
Pathway	SLRLM1		SLRLM2		SLRLM2ALT		SLRLM4		SLRLM5	
	Cost	%	Cost	%	Cost	%	Cost	%	Cost	%
Rainwater Infrastructure Subtotal	n/a		**$16,900**	*1.5%*	**$26,000**	*2.3%*	**$47,000**	*4.1%*	**$67,500**	*5.8%*
GRI Tools Const. Cost			$9,900		$15,000		$27,000		-	
Non-GRI Tools Const. Cost			-		-		-		$38,500	
Soft Cost Allowance			$7,000		$11,000		$20,000		$29,000	
Building and Parkade Subtotal			**$1,096,500**	*98.5%*	**$1,092,300**	*97.7%*	**$1,093,200**	*95.9%*	**$1,094,500**	*94.2%*
Construction Cost			$623,500		$623,300		$623,200		$623,500	
Soft Cost Allowance			$473,000		$469,000		$470,000		$471,000	
Total Capital Cost			**$1,113,400**		**$1,118,300**		**$1,140,200**		**$1,162,000**	

Building Typology	Small Lot Residential – High Massing									
Pathway	SLRHM1		SLRHM2		SLRHM3		SLRHM4		SLRHM5	
	Cost	%	Cost	%	Cost	%	Cost	%	Cost	%
Rainwater Infrastructure Subtotal	n/a		**$125,700**	*6.9%*	**$55,500**	*3.2%*	**$102,900**	*5.7%*	**$71,800**	*4.1%*
GRI Tools Const. Cost			$71,700		$31,500		$58,900		-	
Non-GRI Tools Const. Cost			-		-		-		$40,800	
Soft Cost Allowance			$54,000		$24,000		$44,000		$31,000	
Building and Parkade Subtotal			**$1,687,800**	*93.1%*	**$1,677,700**	*96.8%*	**$1,687,900**	*94.3%*	**$1,680,900**	*95.9%*
Construction Cost			$961,800		$961,700		$961,900		$961,900	
Soft Cost Allowance			$726,000		$716,000		$726,000		$719,000	
Total Capital Cost			**$1,813,500**		**$1,733,200**		**$1,790,800**		**$1,752,700**	

Table 6. Pathway Initial Capital Cost Estimates (continued)

Building Typology	Low-Rise Residential & Mixed-Use									
Pathway	LRMU1		LRMU2		LRMU3		LRMU4		LRMU5	
	Cost	%	Cost	%	Cost	%	Cost	%	Cost	%
Rainwater Infrastructure Subtotal	n/a		**$721,500**	*3.1%*	**$341,000**	*1.5%*	**$494,500**	*2.2%*	**$156,300**	*0.7%*
GRI Tools Const. Cost			$412,500		$195,000		$282,500		-	
Non-GRI Tools Const. Cost			-		-		-		$89,300	
Soft Cost Allowance			$309,000		$146,000		$212,000		$67,000	
Building and Parkade Subtotal			**$22,385,100**	*96.9%*	**$22,386,900**	*98.5%*	**$22,260,900**	*97.8%*	**$22,388,100**	*99.3%*
Construction Cost			$12,794,100		$12,792,900		$12,722,900		$12,795,100	
Soft Cost Allowance			$9,591,000		$9,594,000		$9,538,000		$9,593,000	
Total Capital Cost			**$23,106,600**		**$22,727,900**		**$22,755,400**		**$22,544,400**	

Building Typology	Mid-Rise Residential & Mixed-Use									
Pathway	MRMU1		MRMU2		MRMU3		MRMU4		MRMU5	
	Cost	%	Cost	%	Cost	%	Cost	%	Cost	%
Rainwater Infrastructure Subtotal	**$1,415,700**	*1.6%*	**$1,262,700**	*1.5%*	**$425,000**	*0.5%*	**$1,064,500**	*1.2%*	**$181,900**	*0.2%*
GRI Tools Const. Cost	$808,700		$721,700		$243,000		$608,500		-	
Non-GRI Tools Const. Cost	-		-		-		-		$103,900	
Soft Cost Allowance	$607,000		$541,000		$182,000		$456,000		$78,000	
Building and Parkade Subtotal	**$84,665,700**	*98.4%*	**$84,671,300**	*98.5%*	**$84,559,300**	*99.5%*	**$84,666,700**	*98.8%*	**$84,664,700**	*99.8%*
Construction Cost	$48,382,700		$48,382,300		$48,321,300		$48,382,700		$48,382,700	
Soft Cost Allowance	$36,283,000		$36,289,000		$36,238,000		$36,284,000		$36,282,000	
Total Capital Cost	**$86,081,400**		**$85,934,000**		**$84,984,300**		**$85,731,200**		**$84,846,600**	

Table 6. Pathway Initial Capital Cost Estimates (continued)

Building Typology	High-Rise Residential & Mixed-Use									
Pathway	HRMU1		HRMU2		HRMU3		HRMU4		HRMU5	
	Cost	**%**	**Cost**	**%**	**Cost**	**%**	**Cost**	**%**	**Cost**	**%**
Rainwater Infrastructure Subtotal	**$1,092,300**	*0.9%*	**$408,100**	*0.3%*	**$202,500**	*0.2%*	**$389,500**	*0.3%*	**$109,400**	*0.1%*
GRI Tools Const. Cost	$624,300		$233,100		$115,500		$222,500		-	
Non-GRI Tools Const. Cost	-		-		-		-		$62,400	
Soft Cost Allowance	$468,000		$175,000		$87,000		$167,000		$47,000	
Building and Parkade Subtotal	**$126,264,000**	*99.1%*	**$126,266,600**	*99.7%*	**$126,264,100**	*99.8%*	**$126,243,300**	*99.7%*	**$126,265,000**	*99.9%*
Construction Cost	$72,152,000		$72,151,600		$72,151,100		$72,140,300		$72,152,000	
Soft Cost Allowance	$54,112,000		$54,115,000		$54,113,000		$54,103,000		$54,113,000	
Total Capital Cost	**$127,356,300**		**$126,674,700**		**$126,466,600**		**$126,632,800**		**$126,374,400**	

Building Typology	Low/Mid-Rise Non-Residential									
Pathway	LMNR1		LMNR2		LMNR3		LMNR4		LMNR5	
	Cost	**%**	**Cost**	**%**	**Cost**	**%**	**Cost**	**%**	**Cost**	**%**
Rainwater Infrastructure Subtotal	n/a		n/a		**$359,000**	*1.3%*	**$735,000**	*2.6%*	**$160,600**	*0.6%*
GRI Tools Const. Cost					$205,000		$420,000		-	
Non-GRI Tools Const. Cost					-		-		$91,600	
Soft Cost Allowance					$154,000		$315,000		$69,000	
Building and Parkade Subtotal					**$27,318,600**	*98.7%*	**$27,317,600**	*97.4%*	**$27,464,800**	*99.4%*
Construction Cost					$15,612,600		$15,612,600		$15,693,800	
Soft Cost Allowance					$11,706,000		$11,705,000		$11,771,000	
Total Capital Cost					**$27,677,600**		**$28,052,600**		**$27,625,400**	

Table 6. Pathway Initial Capital Cost Estimates (continued)

Building Typology	High-Rise Non-Residential									
Pathway	HNR1		HNR2		HNR3		HNR4		HNR5	
	Cost	%	Cost	%	Cost	%	Cost	%	Cost	%
Rainwater Infrastructure Subtotal	**$6,171,100**	*1.2%*	n/a		**$1,085,000**	*0.2%*	**$3,079,500**	*0.6%*	**$366,700**	*0.1%*
GRI Tools Const. Cost	$3,526,100				$620,000		$1,759,500		-	
Non-GRI Tools Const. Cost	-				-		-		$209,700	
Soft Cost Allowance	$2,645,000				$465,000		$1,320,000		$157,000	
Building and Parkade Subtotal	**$498,134,200**	*98.8%*			**$497,870,800**	*99.8%*	**$497,865,800**	*99.4%*	**$498,132,200**	*99.9%*
Construction Cost	$284,649,200				$284,495,800		$284,495,800		$284,649,200	
Soft Cost Allowance	$213,485,000				$213,375,000		$213,370,000		$213,483,000	
Total Capital Cost	**$504,305,300**				**$498,955,800**		**$500,945,300**		**$498,498,900**	

5. Operation & Maintenance Cost Evaluation

The data available for quantifying potential annual operations and maintenance costs was limited and highly variable. All data points are included in the cost database tables in Appendix A and B and summarized in the tables below. The range of annual O&M costs per size of tool (e.g., square meter or cubic meter) are shown in Table7. A qualitative indicator (low/medium/high) of the annual O&M cost is provided for each rainwater management tool in Table 8. This was based on a comparison of annual O&M cost per unit of drainage area managed (DMA), using the O&M unit cost data below and the sizing of tools from the pathways, as well as the professional judgement and experience of our team. Each pathway was then assigned a qualitative indicator based on the size of each tool (Table 9).

Table 7. O&M Cost Data for Rainwater Management Tools

Rainwater Management Tool		Source Count	Unit	**Annual O&M Unit Cost**		
				Minimum	Maximum	Median
Resilient Roof	Green roof - Extensive (<150mm)	7	$/sq. m.	$0.42	$13.24	$4.08
	Green roof - Intensive (≥150 mm)	5	$/sq. m.	$7.00	$54.53	$17.26
Bioretention	Raingarden (simple bioretention)	4	$/sq. m.	$3.90	$8.35	$7.52
	Bioretention (typical)	4	$/sq. m.	$61.15	$274.60	$160.96
Tree trench		2	$/sq. m.	$37.08	$200.55	$118.82
Permeable pavement		6	$/sq. m.	$0.29	$5.48	$0.50
Subsurface infiltration		2	$/cu. m.	$175.01	$381.16	$278.08
Rainwater harvesting and reuse		3	varies	varies	varies	varies
Absorbent landscape		5	$/sq. m.	$0.50	$1.54	$1.34
Non-GRI	Detention tank	4	$/cu. m.	$61.25	$240.63	$69.64
	Water quality treatment device	5	each	$1,500	$20,000	$4,000

Table 8. O&M Cost Evaluation for Rainwater Management Tools

Rainwater Management Tool		**Median Annual O&M Unit Cost per Area Managed by Tool ($ / sq. m. DMA)**	**Qualitative Evaluation of O&M Cost**
Resilient Roof	Green roof - Extensive (<150mm soil depth)	$4.08	**Medium**
	Green roof - Intensive (≥150 mm soil depth)	$17.26	**High**
Bioretention	Raingarden (simplest bioretention)	$0.45	**Low**
	Bioretention	$9.66	**Medium**
Tree trench		$7.13	**Medium**
Permeable pavement		$0.17	**Low**
Subsurface infiltration		$16.69	**High**
Rainwater harvesting and reuse		varies	**High**
Absorbent landscape		$1.34	**Low**
Non-GRI	Detention tank	$1.70	**Low**
	Proprietary water quality treatment device	$1.74	**Low**

Table 9. O&M Cost Evaluation for Pathways

Pathway	1	2	3	4	5
Retention Target (mm)	*24*			*48*	*0*
Soil Infiltration	*None*	*Low Infiltration (5 mm/hr)*			*n/a*
Setback/Parkade Conditions	*n/a*	*Typical*	*Reduced*		*n/a*
Small Lot Residential – Low Massing	n/a	Medium	Medium	Medium	Low
Small Lot Residential – High Massing	n/a	Medium/High	Medium	High	Low
Low-Rise Residential & Mixed-Use	n/a	Medium/High	Medium	Low / Medium	Low
Mid-Rise Residential & Mixed-Use	High	High	Medium	High	Low
High-Rise Residential & Mixed-Use	High	Medium/High	Medium	Medium	Low
Low/Mid-Rise Non- Residential	n/a	n/a	Low / Medium	Low / Medium	Low
High-Rise Non-Residential	High	n/a	Medium	Low / Medium	Low

Appendix A

Rainwater Management Tool Cost Database - Adjusted

(standardized to 2022 CAD $)

Rainwater Management Tool	Source	Source Year	Source Currency	ORIGINAL COST DATA (source year & currency) Construction Cost $ per unit	O&M (Average) $ per unit	Conversion Factor to 2022 CAD	STANDARDIZED COST DATA (2022 CAD) Construction Cost $ per unit	O&M (Average) $ per unit
GRI TOOLS								
Resilient roofs								
Extensive (<150mm soil depth) green roofs								
Extensive Green Roof (Aggregate)	*GRHC/GIF*	2017	USD	$269 /sq. m.	$2.05 /sq.m./yr	1.82	$489 /sq. m.	$3.71 /sq.m./yr
EcoRoof	*Portland BES*	2008	USD	$62 /sq. m.	$0.27 /sq.m./yr	1.58	$98 /sq. m.	$0.42 /sq.m./yr
Green Roof (Nationwide)	*U.S. GSA*	2011	USD	$167 /sq. m.	$2.91 /sq.m./yr	1.66	$277 /sq. m.	$4.83 /sq.m./yr
Green Roof (DC)	*U.S. GSA*	2011	USD	$154 /sq. m.	$3.88 /sq.m./yr	1.66	$256 /sq. m.	$6.44 /sq.m./yr
"Basic Extensive"	*Architek (DB Firm)*	2022	CAD	$194 /sq. m.		1.00	$194 /sq. m.	
"Extensive Water Retention"	*Architek (DB Firm)*	2022	CAD	$215 /sq. m.		1.00	$215 /sq. m.	
Green Roof	*CNT Green Values SWM Calculator*	2013	USD	$129 /sq. m.	$8.07 /sq.m./yr	1.64	$211 /sq. m.	$13.24 /sq.m./yr
Vegetated Roof Extensive	*SFPUC*	2017	USD	$277 /sq. m.		1.82	$504 /sq. m.	
Extensive Green Roof	*GIF 2017 Toronto Area*	2017	CAD	$201 /sq. m.	$1.96 /sq.m./yr	1.40	$281 /sq. m.	$2.74 /sq.m./yr
Extensive Green Roof	*GIF 2019 Ontario Cities*	2019	CAD	$187 /sq. m.	$3.27 /sq.m./yr	1.25	$233 /sq. m.	$4.08 /sq.m./yr
"Lite N Less" Soilless System	*Next Level Stormwater Management*	2022	CAD	$89 /sq. m.		1.00	$89 /sq. m.	
"Stormcap II" System	*Next Level Stormwater Management*	2022	CAD	$178 /sq. m.		1.00	$178 /sq. m.	
"Growing Medium" System	*Next Level Stormwater Management*	2022	CAD	$133 /sq. m.		1.00	$133 /sq. m.	
Intensive (≥150 mm soil depth) green roofs								
Living Roof	*ARUP*	2016	USD	$216 /sq. m.	$4.95 /sq.m./yr	1.97	$426 /sq. m.	$9.74 /sq.m./yr
Intensive Green Roof (Specific)	*GRHC/GIF*	2017	USD	$377 /sq. m.	$13.89 /sq.m./yr	1.82	$684 /sq. m.	$25.21 /sq.m./yr
Intensive Green Roof (Aggregate)	*GRHC/GIF*	2017	USD	$323 /sq. m.	$30.03 /sq.m./yr	1.82	$586 /sq. m.	$54.53 /sq.m./yr
Green Roof (6" Trays)	*NYC SWMPP*	2018	USD	$164 /sq. m.		1.72	$283 /sq. m.	
"Intensive"	*Architek (DB Firm)*	2022	CAD	$269 /sq. m.		1.00	$269 /sq. m.	
Vegetated Roof Intensive	*SFPUC*	2017	USD	$407 /sq. m.		1.82	$738 /sq. m.	
Intensive Green Roof	*GIF 2017 Toronto Area*	2017	CAD	$300 /sq. m.	$5.00 /sq.m./yr	1.40	$420 /sq. m.	$7.00 /sq.m./yr
Intensive Green Roof	*GIF 2019 Ontario Cities*	2019	CAD	$372 /sq. m.	$13.83 /sq.m./yr	1.25	$464 /sq. m.	$17.26 /sq.m./yr
"Flora Garden 8" Rooftop Oasis" System	*Next Level Stormwater Management*	2022	CAD	$233 /sq. m.		1.00	$233 /sq. m.	
Blue-green roofs								
Blue-Green Roofs	*Cambie IWMP*	2020	CAD	$276 /sq. m.	$6.93 /sq.m./yr	1.22	$337 /sq. m.	$8.45 /sq.m./yr
"Blue-Green Roof"	*Architek (DB Firm)*	2022	CAD	$338 /sq. m.		1.00	$338 /sq. m.	
"Blue-Green Roof"	*Columbia Green*	2022	CAD	$215 /sq. m.		1.00	$215 /sq. m.	
Other Roof Types								
"EcoSedum Trays"	*Architek (DB Firm)*	2022	CAD	$269 /sq. m.		1.00	$269 /sq. m.	
"Engineered Sloped Green Roof System"	*Architek (DB Firm)*	2022	CAD	$323 /sq. m.		1.00	$323 /sq. m.	
"Planted-in-Place" Tray Green Roof System	*Columbia Green*	2022	CAD	$140 /sq. m.		1.00	$140 /sq. m.	
"BioBerm"	*Columbia Green*	2022	CAD	$385 /sq. m.		1.00	$385 /sq. m.	

Rainwater Management Tool	Source	Source Year	Source Currency	ORIGINAL COST DATA (source year & currency)		Conversion Factor to 2022 CAD	STANDARDIZED COST DATA (2022 CAD)	
				Construction Cost	O&M (Average)		Construction Cost	O&M (Average)
				$ per unit	*$ per unit*		*$ per unit*	*$ per unit*
Bioretention								
Raingarden (simple bioretention)								
Rain Garden	*CNT Green Values SWM Calculator*	2009	USD	$65 /sq. m.	$4.41 /sq.m./yr	1.86	$121 /sq. m.	$8.20 /sq.m./yr
Planter Box	*CNT Green Values SWM Calculator*	2010	USD	$104 /sq. m.		1.80	$187 /sq. m.	
Bioretention	*Canadian Nursey Landscape Association*	2017	CAD	$70 /sq. m.	$2.79 /sq.m./yr	1.40	$97 /sq. m.	$3.90 /sq.m./yr
Rain Garden	*GIF 2017 Toronto Area*	2017	CAD	$122 /sq. m.	$4.90 /sq.m./yr	1.40	$171 /sq. m.	$6.85 /sq.m./yr
Rain Garden	*GIF 2019 Ontario Cities*	2019	CAD	$124 /sq. m.	$6.69 /sq.m./yr	1.25	$154 /sq. m.	$8.35 /sq.m./yr
Slope-Sided Bioretention	*VDZ-A*	2022	CAD	$226 /sq. m.		1.00	$226 /sq. m.	
Sloped-side bioretention (w/o underdrains)								
Bioretention	*NYC SWMPP*	2018	USD	$909 /sq. m.		1.72	$1,565 /sq. m.	
Bioretention Garden Parcel	*SFPUC*	2017	USD	$850 /sq. m.		1.82	$1,544 /sq. m.	
Parcel Bioretention Sloped Sides	*Cambie IWMP*	2020	CAD	$1,223 /sq. m.	$50.13 /sq.m./yr	1.22	$1,492 /sq. m.	$61.15 /sq.m./yr
Bioretention No Underdrain on Proptery	*KC WQBE*	2019	USD	$1,753 /sq. m.		1.66	$2,903 /sq. m.	
Bioretention Full Infiltration (24mm)	*CoV GRI Sizing Cost Estimator*	2017	CAD	$895 /sq. m.		1.40	$1,251 /sq. m.	
Bioretention Full Infiltration (48mm)	*CoV GRI Sizing Cost Estimator*	2017	CAD	$767 /sq. m.		1.40	$1,073 /sq. m.	
Bioretention	*LA WMMS 2.0*	2020	USD	$1,270 /sq. m.	$157.15 /sq.m./yr	1.64	$2,077 /sq. m.	$257.00 /sq.m./yr
Sloped-side bioretention (w/ underdrains)								
Bioretention UD	*NYC SWMPP*	2018	USD	$887 /sq. m.		1.72	$1,527 /sq. m.	
Flow Thru Planter Parcel	*SFPUC*	2017	USD	$980 /sq. m.		1.82	$1,778 /sq. m.	
Bioretention No Underdrain on Proptery	*KC WQBE*	2019	USD	$1,820 /sq. m.		1.66	$3,014 /sq. m.	
Bioretention w/ Underdrain	*LA WMMS 2.0*	2020	USD	$1,380 /sq. m.	$167.92 /sq.m./yr	1.64	$2,258 /sq. m.	$274.60 /sq.m./yr
Full-walled bioretention (planter) (w/o underdrains)								
Bioretention Planter ROW	*SFPUC*	2017	USD	$1,292 /sq. m.		1.82	$2,345 /sq. m.	
Streetside Bioretention Double-Walled	*Cambie IWMP*	2020	CAD	$1,551 /sq. m.	$53.23 /sq.m./yr	1.22	$1,892 /sq. m.	$64.93 /sq.m./yr
Bioretention No Underdrain in ROW	*KC WQBE*	2019	USD	$2,782 /sq. m.		1.66	$4,608 /sq. m.	
Full Walled Bioretention	*VDZ-A*	2022	CAD	$765 /sq. m.		1.00	$765 /sq. m.	
Full-walled bioretention (planter) (w/ underdrains)								
Flow Thru Planter ROW	*SFPUC*	2017	USD	$1,432 /sq. m.		1.82	$2,599 /sq. m.	
Bioretention Underdrain in ROW	*KC WQBE*	2019	USD	$2,845 /sq. m.		1.66	$4,713 /sq. m.	
Partial-walled bioretention (w/o underdrains)								
Streetside Bioretention Single-Walled	*Cambie IWMP*	2020	CAD	$1,437 /sq. m.	$53.23 /sq.m./yr	1.22	$1,753 /sq. m.	$64.93 /sq.m./yr
Tree trenches								
Soil cells								
Tree	*CNT Green Values SWM Calculator*	2019	USD	$168 /sq. m.	$121.09 /sq.m./yr	1.66	$279 /sq. m.	$200.55 /sq.m./yr
Silva Cell (1m deep)	*deeproot*	2022	CAD	$399 /sq. m.		1.00	$399 /sq. m.	
Silva Cell (>1m deep)	*deeproot*	2022	CAD	$513 /sq. m.		1.00	$513 /sq. m.	
Structural soils								
Structural Soil Tree Trenches	*Cambie IWMP*	2020	CAD	$716 /sq. m.	$30.40 /sq.m./yr	1.22	$873 /sq. m.	$37.08 /sq.m./yr
Tree Trench Full Infiltration (24mm)	*CoV GRI Sizing Cost Estimator*	2017	CAD	$858 /sq. m.		1.40	$1,201 /sq. m.	
Tree Trench Full Infiltration (48mm)	*CoV GRI Sizing Cost Estimator*	2017	CAD	$513 /sq. m.		1.40	$718 /sq. m.	

Rainwater Management Tool	Source	Source Year	Source Currency	ORIGINAL COST DATA (source year & currency) Construction Cost	O&M (Average)	Conversion Factor to 2022 CAD	STANDARDIZED COST DATA (2022 CAD) Construction Cost	O&M (Average)
				$ per unit	$ per unit		$ per unit	$ per unit
Permeable pavement								
Permeable Pavement								
Permeable Pavement	*CNT Green Values SWM Calculator*	2011	USD	$93 /sq. m.	$0.22 /sq.m./yr	1.66	$155 /sq. m.	$0.36 /sq.m./yr
Permeable Paving Parcel w/o Underdrain	*SFPUC*	2017	USD	$291 /sq. m.		1.82	$528 /sq. m.	
Permeable Paving Parcel w Underdrain	*SFPUC*	2017	USD	$355 /sq. m.		1.82	$645 /sq. m.	
Permeable Pavement on Parcel	*Cambie IWMP*	2020	CAD	$419 /sq. m.	$3.29 /sq.m./yr	1.22	$511 /sq. m.	$4.01 /sq.m./yr
Permeable Pavement	*GIF 2017 Toronto Area*	2017	CAD	$76 /sq. m.	$0.21 /sq.m./yr	1.40	$106 /sq. m.	$0.29 /sq.m./yr
Permeable Pavement	*GIF 2019 Ontario Cities*	2019	CAD	$114 /sq. m.	$0.48 /sq.m./yr	1.25	$143 /sq. m.	$0.60 /sq.m./yr
Permeable Pavement	*GIF 2019 Ontario Cities*	2019	CAD	$74 /sq. m.	$0.31 /sq.m./yr	1.25	$93 /sq. m.	$0.39 /sq.m./yr
Permeable Pavement Full Infiltration (24mm)	*CoV GRI Sizing Cost Estimator*	2017	CAD	$645 /sq. m.		1.40	$903 /sq. m.	
Permeable Pavement Full Infiltration (48mm)	*CoV GRI Sizing Cost Estimator*	2017	CAD	$652 /sq. m.		1.40	$912 /sq. m.	
Porous Pavement	*LA WMMS 2.0*	2020	USD	$1,552 /sq. m.	$54.90 /sq.m./yr	1.64	$2,538 /sq. m.	
Porous Pavement w/ Underdrain	*LA WMMS 2.0*	2020	USD	$1,626 /sq. m.	$54.90 /sq.m./yr	1.64	$2,659 /sq. m.	
"Profi-Deko" Pedestrian	*Romex / VDZ-A*	2022	CAD	$253 /sq. m.		1.00	$253 /sq. m.	
"Profi-Deko" Heavy Vehicular	*Romex / VDZ-A*	2022	CAD	$382 /sq. m.		1.00	$382 /sq. m.	
Permeable pavers								
Wilco Pavers	*ROO Sport and Event Plaza (Project)*	2022	CAD	$311 /sq. m.		1.00	$311 /sq. m.	
Permeable Pavers	*CNT Green Values SWM Calculator*	2017	USD	$83 /sq. m.	$3.02 /sq.m./yr	1.82	$151 /sq. m.	$5.48 /sq.m./yr
Porous Pavers	*NYC SWMPP*	2018	USD	$753 /sq. m.	$0.00 /sq.m./yr	1.72	$1,296 /sq. m.	
Permeable Pavers w/ Sand Layer	*KC WQBE*	2019	USD	$117 /sq. m.		1.66	$194 /sq. m.	
Permeable Pavers w/o Sand Layer	*KC WQBE*	2019	USD	$101 /sq. m.		1.66	$167 /sq. m.	
"Eco-Priora"	*BC Brick / VDZ-A*	2022	CAD	$89 /sq. m.		1.00	$89 /sq. m.	
"Aquapave" - Standard	*BC Brick / VDZ-A*	2022	CAD	$115 /sq. m.		1.00	$115 /sq. m.	
"Aquapave" - Venetian Cobble	*BC Brick / VDZ-A*	2022	CAD	$120 /sq. m.		1.00	$120 /sq. m.	
"GrassCrete - Dorado Drain Pavers" w/ Soil	*New Stone Group / VDZ-A*	2022	CAD	$100 /sq. m.		1.00	$100 /sq. m.	
"GrassCrete - Dorado Drain Pavers" w/ Aggregate	*New Stone Group / VDZ-A*	2022	CAD	$365 /sq. m.		1.00	$365 /sq. m.	
Pervious concrete								
Pervious Concrete Sidewalk w/o Sand Layer	*KC WQBE*	2019	USD	$339 /sq. m.		1.66	$562 /sq. m.	
Pervious asphalt								
Porous Asphalt w/ Sand Layer	*KC WQBE*	2019	USD	$136 /sq. m.		1.66	$224 /sq. m.	
Subsurface infiltration								
Small-scale near-surface infiltration (e.g., drywells)								
Drywell	*CNT Green Values SWM Calculator*	2019	USD	$1,321 /cu. m.	$105.67 /cu. m./yr	1.66	$2,188 /cu. m.	$175.01 /cu. m./yr
Drywell	*Langley Concrete*	2022	CAD	$850 /cu. m.		1.00	$850 /cu. m.	
Drywell on Property 6' deep x 4' dia	*KC WQBE*	2019	USD	$3,701 /cu. m.		1.66	$6,130 /cu. m.	
Infiltration Gallery	*KWL Multiplex Study*	2022	CAD	$303 /cu. m.		1.00	$303 /cu. m.	
Large-scale near-surface infiltration (e.g., infiltration chambers)								
Stormbrixx SD	*ACO (Vendor)*	2022	CAD	$350 /cu. m.		1.00	$350 /cu. m.	
Stormbrixx HD	*ACO (Vendor)*	2022	CAD	$450 /cu. m.		1.00	$450 /cu. m.	
Infiltration Vault in Till Soil on Property	*KC WQBE*	2019	USD	$5,675 /cu. m.		1.66	$9,398 /cu. m.	
Infiltration Trench Full Infiltration (24mm)	*CoV GRI Sizing Cost Estimator*	2017	CAD	$5,012 /cu. m.		1.40	$7,012 /cu. m.	
Infiltration Trench Full Infiltration (48mm)	*CoV GRI Sizing Cost Estimator*	2017	CAD	$3,420 /cu. m.		1.40	$4,784 /cu. m.	
Deep infiltration (e.g., drill drains)								
Deep UIC Well on Property 20' deep x 8" dia	*KC WQBE*	2019	USD	$3,802 /m		1.66	$6,296 /m	
Infiltration Well	*LA WMMS 2.0*	2020	USD	$2,637 /cu. m.	$233.08 /cu. m./yr	1.64	$4,312 /cu. m.	$381.16 /cu. m./yr

Rainwater Management Tool	Source	Source Year	Source Currency	ORIGINAL COST DATA (source year & currency)		Conversion Factor to 2022 CAD	STANDARDIZED COST DATA (2022 CAD)	
				Construction Cost	**O&M (Average)**		**Construction Cost**	**O&M (Average)**
				$ per unit	*$ per unit*		*$ per unit*	*$ per unit*
Rainwater harvesting and reuse systems								
Storage and Collection								
Storage Tank	*SFPUC Evaluation of RWH*	2015	USD	$678 /cu. m.		1.94	$1,317 /cu. m.	
Treatment and Distribution System								
Pump System - Baseline	*SFPUC Evaluation of RWH*	2015	USD	$113 /cu. m.		1.94	$220 /cu. m.	
Pump System - High End	*SFPUC Evaluation of RWH*	2015	USD	$527 /cu. m.		1.94	$1,025 /cu. m.	
Baseline Treatment System	*SFPUC Evaluation of RWH*	2015	USD	$339 /cu. m.		1.94	$659 /cu. m.	
High End Treatment System	*SFPUC Evaluation of RWH*	2015	USD	$903 /cu. m.		1.94	$1,757 /cu. m.	
Avg Rain + Gray Treatment & Pumps	*SFPUC Water Reuse Cost Study*	2019	USD	$13 /sq. m. GFA		1.66	$22 /sq. m. GFA	
Avg Rain + Gray Treatment & Pumps	*SFPUC Water Reuse Cost Study*	2019	USD	$25 /L/day		1.66	$41 /L/day	
Non-potable Indoor Plumbing								
Indoor Dual Plumbing - Office	*SFPUC Evaluation of RWH*	2015	USD	$7 /sq. m. GFA		1.94	$14 /sq. m. GFA	
Indoor Dual Plumbing - Residential	*SFPUC Evaluation of RWH*	2015	USD	$15 /sq. m. GFA		1.94	$30 /sq. m. GFA	
Indoor Dual Plumbing	*SFPUC Water Reuse Cost Study*	2019	USD	$5 /sq. m. GFA		1.66	$8 /sq. m. GFA	
Overall System								
Operations & Maintenance	*SFPUC Water Reuse Cost Study*	2019	USD		$50,000 ea / yr	1.66		$82,809 ea / yr
Rainwater Reuse System	*Cambie IWMP*	2020	CAD	$2,718 /cu. m.	$60.12 /cu. m./yr	1.22	$3,315 /cu. m.	$73.33 /cu. m./yr
Rainwater and Greywater Reuse System	*Cambie IWMP*	2021	CAD	$4,441 /cu. m.	$624.12 /cu. m./yr	1.16	$5,130 /cu. m.	$721.01 /cu. m./yr
Absorbent landscapes								
150mm Turf	*ROO Sport and Event Plaza (Project)*	2022	CAD	$29 /sq. m.		1.00	$29 /sq. m.	
450mm Shrub Bed	*ROO Sport and Event Plaza (Project)*	2022	CAD	$31 /sq. m.		1.00	$31 /sq. m.	
Native Vegetation	*CNT Green Values SWM Calculator*	2004	USD	$2 /sq. m.	$0.54 /sq.m./yr	2.81	$6 /sq. m.	$1.51 /sq.m./yr
Planting Bed	*GIF 2017 Toronto Area*	2017	CAD	$120 /sq. m.	$5.78 /sq.m./yr	1.40	$167 /sq. m.	
Planting Bed	*GIF 2019 Ontario Cities*	2019	CAD	$143 /sq. m.	$7.19 /sq.m./yr	1.25	$178 /sq. m.	
Turf (Natural)	*GIF 2017 Toronto Area*	2017	CAD	$2 /sq. m.	$0.36 /sq.m./yr	1.40	$2 /sq. m.	$0.50 /sq.m./yr
Turf/Lawn	*GIF 2019 Ontario Cities*	2019	CAD	$13 /sq. m.	$1.23 /sq.m./yr	1.25	$17 /sq. m.	$1.54 /sq.m./yr
Meadow/Grassland	*GIF 2019 Ontario Cities*	2019	CAD	$2 /sq. m.	$0.60 /sq.m./yr	1.25	$2 /sq. m.	$0.75 /sq.m./yr
Turf (Active)	*GIF 2017 Toronto Area*	2017	CAD	$12 /sq. m.	$0.96 /sq.m./yr	1.40	$16 /sq. m.	$1.34 /sq.m./yr

Rainwater Management Tool	Source	Source Year	Source Currency	ORIGINAL COST DATA (source year & currency)		Conversion Factor to 2022 CAD	STANDARDIZED COST DATA (2022 CAD)	
				Construction Cost	O&M (Average)		Construction Cost	O&M (Average)
				$ per unit	*$ per unit*		*$ per unit*	*$ per unit*
NON-GRI TOOLS								
Detention tanks (without reuse)								
Surface detention tanks								
Rain Barrel	*CNT Green Values SWM Calculator*	2019	USD	$528 /cu. m.	$145.29 /cu. m./yr	1.66	$875 /cu. m.	$240.63 /cu. m./yr
Cistern	*KC WQBE*	2019	USD	$4,562 /cu. m.		1.66	$7,555 /cu. m.	
Cistern Galvanized Steel	*LA WMMS 2.0*	2020	USD	$452 /cu. m.		1.64	$739 /cu. m.	
Subsurface detention tanks/vaults								
Cistern	*CNT Green Values SWM Calculator*	2019	USD	$362 /cu. m.	$36.98 /cu. m./yr	1.66	$599 /cu. m.	$61.25 /cu. m./yr
Stormbrixx SD	*ACO (Vendor)*	2022	CAD	$350 /cu. m.		1.00	$350 /cu. m.	
Stormbrixx HD	*ACO (Vendor)*	2022	CAD	$450 /cu. m.		1.00	$450 /cu. m.	
Detention Vault	*NYC SWMPP*	2018	USD	$2,361 /cu. m.	$38.40 /cu. m./yr	1.72	$4,064 /cu. m.	$66.10 /cu. m./yr
Gray Storage	*Cambie IWMP*	2020	CAD	$820 /cu. m.	$60.00 /cu. m./yr	1.22	$1,000 /cu. m.	$73.18 /cu. m./yr
Detention Vault on Property	*KC WQBE*	2019	USD	$4,395 /cu. m.		1.66	$7,279 /cu. m.	
Rainwater Detention System (average)	*KWL Multiplex Study*	2022	CAD	$3,398 /cu. m.		1.00	$3,398 /cu. m.	
Blue roofs								
Blue Roof	*SFPUC*	2017	USD	$65 /sq. m.		1.82	$117 /sq. m.	
Water quality devices								
Proprietary Treatment devices								
JF CONCR 1200MM 1HF 1DD	*Langley Concrete*	2021	CAD	$34,000		1.16	$39,278 ea	
JF CONCR 1200MM 2HF 1DD	*Langley Concrete*	2021	CAD	$38,000		1.16	$43,899 ea	
JF CONCR 1800MM 3HF 1DD	*Langley Concrete*	2021	CAD	$55,000		1.16	$63,538 ea	
JF CONCR 1800MM 4HF 1DD	*Langley Concrete*	2021	CAD	$59,000		1.16	$68,159 ea	
JF CONCR 1800MM 5HF 1DD	*Langley Concrete*	2021	CAD	$63,000		1.16	$72,780 ea	
JF CONCR 1800MM 6HF 1DD	*Langley Concrete*	2021	CAD	$67,000		1.16	$77,401 ea	
JF CONCR 2400MM 6HF 2DD	*Langley Concrete*	2021	CAD	$105,000		1.16	$121,301 ea	
JF CONCR 2400MM 7HF 2DD	*Langley Concrete*	2021	CAD	$107,000		1.16	$123,611 ea	
JF CONCR 2400MM 8HF 2DD	*Langley Concrete*	2021	CAD	$111,000		1.16	$128,232 ea	
JF CONCR 2400MM 9HF 2DD	*Langley Concrete*	2021	CAD	$115,000		1.16	$132,853 ea	
JF CONCR 2400MM 10HF 2DD	*Langley Concrete*	2021	CAD	$119,000		1.16	$137,474 ea	
Manuf. Stormwater Treatment System - 1 L/s	*Contech ES*	2022	CAD	$32,500	$1,500 ea / yr	1.00	$32,500 ea	$1,500 ea / yr
Manuf. Stormwater Treatment System - 2 L/s	*Contech ES*	2022	CAD	$37,500	$1,500 ea / yr	1.00	$37,500 ea	$1,500 ea / yr
Manuf. Stormwater Treatment System - 7 L/s	*Contech ES*	2022	CAD	$55,000	$4,000 ea / yr	1.00	$55,000 ea	$4,000 ea / yr
Manuf. Stormwater Treatment System - 17 L/s	*Contech ES*	2022	CAD	$115,000	$7,500 ea / yr	1.00	$115,000 ea	$7,500 ea / yr
Manuf. Stormwater Treatment System - 50 L/s	*Contech ES*	2022	CAD	$250,000	$20,000 ea / yr	1.00	$250,000 ea	$20,000 ea / yr
Filterra 4x4 in Urban ROW with PCC Surface	*KC WQBE*	2019	USD	$83,248		1.66	$137,874 ea	
Filterra 4x4 in Urban ROW with HMA Surface	*KC WQBE*	2019	USD	$59,952		1.66	$99,291 ea	
Filterra 4x4 on Property	*KC WQBE*	2019	USD	$46,230		1.66	$76,565 ea	

Appendix B

Rainwater Management Tool Cost Database - Source

(original from data sources)

Rainwater Management Tool	Source	Source Year	Source Currency	Capital Cost Data				Multiplier			Operations and Maintenance Cost Data			
				Construction Cost	Non-Construction Cost *(Design, Permitting, CM)*	Total Capital Cost	Full or Incremental Cost?	Const. Cost as % of Tot. Capital Cost	Total Cost Mult.	Soft Cost as % of Const. Cost	Vegetated Facility O&M (Years 1-3)	Vegetated Facility O&M (Years 4+)	Vegetated Facility O&M (Year X - media / plant	O&M (Average)
				$ per unit	*$ per unit*	*$ per unit*		*%*		*%*	*$ per unit*	*$ per unit*	*$ per unit*	*$ per unit*
GRI TOOLS														
Resilient roofs														
Extensive (<150mm soil depth) green roofs														
Extensive Green Roof (Aggregate)	*GRHC/GIF*	2017	USD	$269 /sq. m.			Incremental							$2.05 /sq.m./yr
EcoRoof	*Portland BES*	2008	USD	$62 /sq. m.			Incremental							$0.27 /sq.m./yr
Green Roof (Nationwide)	*U.S. GSA*	2011	USD	$167 /sq. m.			Incremental							$2.91 /sq.m./yr
Green Roof (DC)	*U.S. GSA*	2011	USD	$154 /sq. m.			Incremental							$3.88 /sq.m./yr
"Basic Extensive"	*Architek (DB Firm)*	2022	CAD	$194 /sq. m.			Incremental							
"Extensive Water Retention"	*Architek (DB Firm)*	2022	CAD	$215 /sq. m.			Incremental							
Green Roof	*CNT Green Values SWM Calculator*	2013	USD	$129 /sq. m.			Incremental							$8.07 /sq.m./yr
Vegetated Roof Extensive	*SFPUC*	2017	USD	$388 /sq. m.	$312 /sq. m.	$700 /sq. m.	Full	55.4%	1.81	80.6%				
Extensive Green Roof	*GIF 2017 Toronto Area*	2017	CAD	$201 /sq. m.			Incremental							$1.96 /sq.m./yr
Extensive Green Roof	*GIF 2019 Ontario Cities*	2019	CAD	$187 /sq. m.			Incremental							$3.27 /sq.m./yr
"Lite N Less" Soilless System	*Next Level Stormwater Management*	2022	CAD	$289 /sq. m.			Full							
"Stormcap II" System	*Next Level Stormwater Management*	2022	CAD	$378 /sq. m.			Full							
"Growing Medium" System	*Next Level Stormwater Management*	2022	CAD	$333 /sq. m.			Full							
Intensive (≥150 mm soil depth) green roofs														
Living Roof	*ARUP*	2016	USD	$216 /sq. m.			Incremental							$4.95 /sq.m./yr
Intensive Green Roof (Specific)	*GRHC/GIF*	2017	USD	$377 /sq. m.			Incremental							$13.89 /sq.m./yr
Intensive Green Roof (Aggregate)	*GRHC/GIF*	2017	USD	$323 /sq. m.			Incremental							$30.03 /sq.m./yr
Green Roof (6" Trays)	*NYC SWMPP*	2018	USD	$164 /sq. m.	$98 /sq. m.	$262 /sq. m.	Incremental	62.6%	1.60	59.7%	$13.54 /sq.m./yr	$3.87 /sq.m./yr	$164.15 /sq.m.	$4.84 /sq.m./yr
"Intensive"	*Architek (DB Firm)*	2022	CAD	$269 /sq. m.			Incremental							
Vegetated Roof Intensive	*SFPUC*	2017	USD	$517 /sq. m.	$420 /sq. m.	$936 /sq. m.	Full	55.2%	1.81	81.3%				
Intensive Green Roof	*GIF 2017 Toronto Area*	2017	CAD	$300 /sq. m.			Incremental							$5.00 /sq.m./yr
Intensive Green Roof	*GIF 2019 Ontario Cities*	2019	CAD	$372 /sq. m.			Incremental							$13.83 /sq.m./yr
"Flora Garden 8" Rooftop Oasis" System	*Next Level Stormwater Management*	2022	CAD	$433 /sq. m.			Full							
Blue-green roofs														
Blue-Green Roofs	*Cambie IWMP*	2020	CAD	$440 /sq. m.	$296 /sq. m.	$736 /sq. m.	Full	59.8%	1.67	67.3%				$6.93 /sq.m./yr
"Blue-Green Roof"	*Architek (DB Firm)*	2022	CAD	$538 /sq. m.			Full							
"Blue-Green Roof"	*Columbia Green*	2022	CAD	$215 /sq. m.			Incremental							
Other Roof Types														
"EcoSedum Trays"	*Architek (DB Firm)*	2022	CAD	$269 /sq. m.			Incremental							
"Engineered Sloped Green Roof System"	*Architek (DB Firm)*	2022	CAD	$323 /sq. m.			Incremental							
"Planted-in-Place" Tray Green Roof System	*Columbia Green*	2022	CAD	$140 /sq. m.			Incremental							
"BioBerm"	*Columbia Green*	2022	CAD	$385 /sq. m.			Incremental							

Rainwater Management Tool	Source	Source Year	Source Currency	Capital Cost Data				Multiplier			Operations and Maintenance Cost Data			
				Construction Cost	**Non-Construction Cost** *(Design, Permitting, CM)*	**Total Capital Cost**	Full or Incremental Cost?	**Const. Cost as % of Tot. Capital Cost**	**Total Cost Mult.**	**Soft Cost as % of Const. Cost**	**Vegetated Facility O&M (Years 1-3)**	**Vegetated Facility O&M (Years 4+)**	**Vegetated Facility O&M (Year X - media / plant**	**O&M (Average)**
				$ per unit	*$ per unit*	*$ per unit*		*%*		*%*	*$ per unit*	*$ per unit*	*$ per unit*	*$ per unit*
Bioretention														
Raingarden (simple bioretention)														
Rain Garden	*CNT Green Values SWM Calculator*	2009	USD	$65 /sq. m.			n/a							$4.41 /sq.m./yr
Planter Box	*CNT Green Values SWM Calculator*	2010	USD	$104 /sq. m.			n/a							$12.70 /sq.m./yr
Bioretention	*Canadian Nursey Landscape Association*	2017	CAD	$70 /sq. m.			n/a							$2.79 /sq.m./yr
Rain Garden	*GIF 2017 Toronto Area*	2017	CAD	$122 /sq. m.			n/a							$4.90 /sq.m./yr
Rain Garden	*GIF 2019 Ontario Cities*	2019	CAD	$124 /sq. m.			n/a							$6.69 /sq.m./yr
Slope-Sided Bioretention	*VDZ-A*	2022	CAD	$226 /sq. m.			n/a							
Sloped-side bioretention (w/o underdrains)														
Bioretention	*NYC SWMPP*	2018	USD	$909 /sq. m.	$775 /sq. m.	$1,700 /sq. m.	n/a	53.5%	1.87	85.2%	$154.46 /sq.m./yr	$54.52 /sq.m./yr	$170.23 /sq.m.	$64.51 /sq.m./yr
Bioretention Garden Parcel	*SFPUC*	2017	USD	$850 /sq. m.	$667 /sq. m.	$1,518 /sq. m.	n/a	56.0%	1.78	78.5%				
Parcel Bioretention Sloped Sides	*Cambie IWMP*	2020	CAD	$1,223 /sq. m.	$819 /sq. m.	$2,042 /sq. m.	n/a	59.9%	1.67	67.0%	$63.00 /sq.m./yr	$42.00 /sq.m./yr	$223.00 /sq.m.	$50.13 /sq.m./yr
Bioretention No Underdrain on Proptery	*KC WQBE*	2019	USD	$1,753 /sq. m.			n/a							
Bioretention Full Infiltration (24mm)	*CoV GRI Sizing Cost Estimator*	2017	CAD	$895 /sq. m.			n/a							
Bioretention Full Infiltration (48mm)	*CoV GRI Sizing Cost Estimator*	2017	CAD	$767 /sq. m.			n/a							
Bioretention	*LA WMMS 2.0*	2020	USD			$2,228 /sq. m.	n/a							$157.15 /sq.m./yr
Sloped-side bioretention (w/ underdrains)														
Bioretention UD	*NYC SWMPP*	2018	USD	$887 /sq. m.	$742 /sq. m.	$1,629 /sq. m.	n/a	54.4%	1.84	83.7%	$154.46 /sq.m./yr	$54.52 /sq.m./yr	$170.23 /sq.m.	$64.51 /sq.m./yr
Flow Thru Planter Parcel	*SFPUC*	2017	USD	$980 /sq. m.	$764 /sq. m.	$1,744 /sq. m.	n/a	56.2%	1.78	78.0%				
Bioretention No Underdrain on Proptery	*KC WQBE*	2019	USD	$1,820 /sq. m.			n/a							
Bioretention w/ Underdrain	*LA WMMS 2.0*	2020	USD			$2,422 /sq. m.	n/a							$167.92 /sq.m./yr
Full-walled bioretention (planter) (w/o underdrains)														
Bioretention Planter ROW	*SFPUC*	2017	USD	$1,292 /sq. m.	$1,012 /sq. m.	$2,303 /sq. m.	n/a	56.1%	1.78	78.3%				
Streetside Bioretention Double-Walled	*Cambie IWMP*	2020	CAD	$1,551 /sq. m.	$1,039 /sq. m.	$2,590 /sq. m.	n/a	59.9%	1.67	67.0%	$68.00 /sq.m./yr	$45.00 /sq.m./yr	$223.00 /sq.m.	$53.23 /sq.m./yr
Bioretention No Underdrain in ROW	*KC WQBE*	2019	USD	$2,782 /sq. m.			n/a							
Full Walled Bioretention	*VDZ-A*	2022	CAD	$765 /sq. m.			n/a							
Full-walled bioretention (planter) (w/ underdrains)														
Flow Thru Planter ROW	*SFPUC*	2017	USD	$1,432 /sq. m.	$1,130 /sq. m.	$2,562 /sq. m.	n/a	55.9%	1.79	78.9%				
Bioretention Underdrain in ROW	*KC WQBE*	2019	USD	$2,845 /sq. m.			n/a							
Partial-walled bioretention (w/o underdrains)														
Streetside Bioretention Single-Walled	*Cambie IWMP*	2020	CAD	$1,437 /sq. m.	$962 /sq. m.	$2,399 /sq. m.	n/a	59.9%	1.67	66.9%	$68.00 /sq.m./yr	$45.00 /sq.m./yr	$223.00 /sq.m.	$53.23 /sq.m./yr
Tree trenches														
Soil cells														
Tree	*CNT Green Values SWM Calculator*	2019	USD	$168 /sq. m.			n/a							$121.09 /sq.m./yr
Silva Cell (1m deep)	*deeproot*	2022	CAD			$700 /sq. m.	n/a							
Silva Cell (>1m deep)	*deeproot*	2022	CAD			$900 /sq. m.	n/a							
Structural soils														
Structural Soil Tree Trenches	*Cambie IWMP*	2020	CAD	$716 /sq. m.	$480 /sq. m.	$1,196 /sq. m.	n/a	59.9%	1.67	67.0%	$43.00 /sq.m./yr	$29.00 /sq.m./yr	$0.00 /sq.m.	$30.40 /sq.m./yr
Tree Trench Full Infiltration (24mm)	*CoV GRI Sizing Cost Estimator*	2017	CAD	$858 /sq. m.			n/a							
Tree Trench Full Infiltration (48mm)	*CoV GRI Sizing Cost Estimator*	2017	CAD	$513 /sq. m.			n/a							

Rainwater Management Tool	Source	Source Year	Source Currency	Capital Cost Data				Multiplier			Operations and Maintenance Cost Data			
				Construction Cost	Non-Construction Cost *(Design, Permitting, CM)*	Total Capital Cost	Full or Incremental Cost?	Const. Cost as % of Tot. Capital Cost	Total Cost Mult.	Soft Cost as % of Const. Cost	Vegetated Facility O&M (Years 1-3)	Vegetated Facility O&M (Years 4+)	Vegetated Facility O&M (Year X - media / plant	O&M (Average)
				$ per unit	*$ per unit*	*$ per unit*		*%*		*%*	*$ per unit*	*$ per unit*	*$ per unit*	*$ per unit*
Permeable pavement														
Permeable Pavement														
Permeable Pavement	*CNT Green Values SWM Calculator*	2011	USD	$93 /sq. m.			n/a							$0.22 /sq.m./yr
Permeable Paving Parcel w/o Underdrain	*SFPUC*	2017	USD	$291 /sq. m.	$237 /sq. m.	$527 /sq. m.	n/a	55.1%	1.81	81.5%				
Permeable Paving Parcel w Underdrain	*SFPUC*	2017	USD	$355 /sq. m.	$280 /sq. m.	$635 /sq. m.	n/a	55.9%	1.79	78.8%				
Permeable Pavement on Parcel	*Cambie IWMP*	2020	CAD	$419 /sq. m.	$221 /sq. m.	$700 /sq. m.	n/a	59.9%	1.67	52.7%				$3.29 /sq.m./yr
Permeable Pavement	*GIF 2017 Toronto Area*	2017	CAD	$76 /sq. m.			n/a							$0.21 /sq.m./yr
Permeable Pavement	*GIF 2019 Ontario Cities*	2019	CAD	$114 /sq. m.			n/a							$0.48 /sq.m./yr
Permeable Pavement	*GIF 2019 Ontario Cities*	2019	CAD	$74 /sq. m.			n/a							$0.31 /sq.m./yr
Permeable Pavement Full Infiltration (24mm)	*CoV GRI Sizing Cost Estimator*	2017	CAD	$645 /sq. m.			n/a							
Permeable Pavement Full Infiltration (48mm)	*CoV GRI Sizing Cost Estimator*	2017	CAD	$652 /sq. m.			n/a							
Porous Pavement	*LA WMMS 2.0*	2020	USD			$2,723 /sq. m.	n/a							$54.90 /sq.m./yr
Porous Pavement w/ Underdrain	*LA WMMS 2.0*	2020	USD			$2,852 /sq. m.	n/a							$54.90 /sq.m./yr
"Profi-Deko" Pedestrian	*Romex / VDZ-A*	2022	CAD	$253 /sq. m.			n/a							
"Profi-Deko" Heavy Vehicular	*Romex / VDZ-A*	2022	CAD	$382 /sq. m.			n/a							
Permeable pavers														
Wilco Pavers	*ROO Sport and Event Plaza (Project)*	2022	CAD	$311 /sq. m.			n/a							
Permeable Pavers	*CNT Green Values SWM Calculator*	2017	USD	$83 /sq. m.			n/a							$3.02 /sq.m./yr
Porous Pavers	*NYC SWMPP*	2018	USD	$753 /sq. m.	$631 /sq. m.	$1,384 /sq. m.	n/a	54.4%	1.84	83.9%				
Permeable Pavers w/ Sand Layer	*KC WQBE*	2019	USD	$117 /sq. m.			n/a							
Permeable Pavers w/o Sand Layer	*KC WQBE*	2019	USD	$101 /sq. m.			n/a							
"Eco-Priora"	*BC Brick / VDZ-A*	2022	CAD	$89 /sq. m.			n/a							
"Aquapave" - Standard	*BC Brick / VDZ-A*	2022	CAD	$115 /sq. m.			n/a							
"Aquapave" - Venetian Cobble	*BC Brick / VDZ-A*	2022	CAD	$120 /sq. m.			n/a							
"GrassCrete - Dorado Drain Pavers" w/ Soil	*New Stone Group / VDZ-A*	2022	CAD	$100 /sq. m.			n/a							
"GrassCrete - Dorado Drain Pavers" w/ Aggregate	*New Stone Group / VDZ-A*	2022	CAD	$365 /sq. m.			n/a							
Pervious concrete														
Pervious Concrete Sidewalk w/o Sand Layer	*KC WQBE*	2019	USD	$339 /sq. m.			n/a							
Pervious asphalt														
Porous Asphalt w/ Sand Layer	*KC WQBE*	2019	USD	$136 /sq. m.			n/a							
Subsurface infiltration														
Small-scale near-surface infiltration (e.g., drywells)														
Drywell	*CNT Green Values SWM Calculator*	2019	USD	$1,321 /cu. m.			n/a							$105.67 /cu. m./yr
Drywell	*Langley Concrete*	2022	CAD	$850 /cu. m.			n/a							
Drywell on Property 6' deep x 4' dia	*KC WQBE*	2019	USD	$3,701 /cu. m.			n/a							
Infiltration Gallery	*KWL Multiplex Study*	2022	CAD	$303 /cu. m.										
Large-scale near-surface infiltration (e.g., infiltration chambers)														
Stormbrixx SD	*ACO (Vendor)*	2022	CAD	$350 /cu. m.			n/a							
Stormbrixx HD	*ACO (Vendor)*	2022	CAD	$450 /cu. m.			n/a							
Infiltration Vault in Till Soil on Property	*KC WQBE*	2019	USD	$5,675 /cu. m.			n/a							
Infiltration Trench Full Infiltration (24mm)	*CoV GRI Sizing Cost Estimator*	2017	CAD	$5,012 /cu. m.			n/a							
Infiltration Trench Full Infiltration (48mm)	*CoV GRI Sizing Cost Estimator*	2017	CAD	$3,420 /cu. m.			n/a							
Deep infiltration (e.g., drill drains)														
Deep UIC Well on Property 20' deep x 8" dia	*KC WQBE*	2019	USD	$3,802 m			n/a							
Infiltration Well	*LA WMMS 2.0*	2020	USD			$4,626 /cu. m.	n/a							$233.08 /cu. m./yr

Rainwater Management Tool	Source	Source Year	Source Currency	Capital Cost Data				Multiplier			Operations and Maintenance Cost Data			
				Construction Cost	Non-Construction Cost (Design, Permitting, CM)	Total Capital Cost	Full or Incremental Cost?	Const. Cost as % of Tot. Capital Cost	Total Cost Mult.	Soft Cost as % of Const. Cost	Vegetated Facility O&M (Years 1-3)	Vegetated Facility O&M (Years 4+)	Vegetated Facility O&M (Year X - media / plant	O&M (Average)
				$ per unit	$ per unit	$ per unit		%		%	$ per unit	$ per unit	$ per unit	$ per unit
Rainwater harvesting and reuse systems														
Storage and Collection														
Storage Tank	*SFPUC Evaluation of RWH*	2015	USD			$1,189 /cu. m.								
Treatment and Distribution System														
Pump System - Baseline	*SFPUC Evaluation of RWH*	2015	USD			$198 /cu. m.								
Pump System - High End	*SFPUC Evaluation of RWH*	2015	USD			$925 /cu. m.								
Baseline Treatment System	*SFPUC Evaluation of RWH*	2015	USD			$594 /cu. m.								
High End Treatment System	*SFPUC Evaluation of RWH*	2015	USD			$1,585 /cu. m.								
Avg Rain + Gray Treatment & Pumps	*SFPUC Water Reuse Cost Study*	2019	USD			$23 /sq. m. GFA								
Avg Rain + Gray Treatment & Pumps	*SFPUC Water Reuse Cost Study*	2019	USD			$44 L/day								
Non-potable Indoor Plumbing														
Indoor Dual Plumbing - Office	*SFPUC Evaluation of RWH*	2015	USD			$12 /sq. m. GFA								
Indoor Dual Plumbing - Residential	*SFPUC Evaluation of RWH*	2015	USD			$27 /sq. m. GFA								
Indoor Dual Plumbing	*SFPUC Water Reuse Cost Study*	2019	USD			$9 /sq. m. GFA								
Overall System														
Operations & Maintenance	*SFPUC Water Reuse Cost Study*	2019	USD											$50,000 each
Rainwater Reuse System	*Cambie IWMP*	2020	CAD	$2,718 /cu. m.										$60.12 /cu. m.
Rainwater and Greywater Reuse System	*Cambie IWMP*	2021	CAD	$4,441 /cu. m.										$624.12 /cu. m.
Absorbent landscapes														
150mm Turf	*ROO Sport and Event Plaza (Project)*	2022	CAD	$29 /sq. m.			n/a							
450mm Shrub Bed	*ROO Sport and Event Plaza (Project)*	2022	CAD	$31 /sq. m.			n/a							
Native Vegetation	*CNT Green Values SWM Calculator*	2004	USD	$2 /sq. m.			n/a							$0.54 /sq.m./yr
Planting Bed	*GIF 2017 Toronto Area*	2017	CAD	$120 /sq. m.			n/a							$5.78 /sq.m./yr
Planting Bed	*GIF 2019 Ontario Cities*	2019	CAD	$143 /sq. m.			n/a							$7.19 /sq.m./yr
Turf (Natural)	*GIF 2017 Toronto Area*	2017	CAD	$2 /sq. m.			n/a							$0.36 /sq.m./yr
Turf/Lawn	*GIF 2019 Ontario Cities*	2019	CAD	$13 /sq. m.			n/a							$1.23 /sq.m./yr
Meadow/Grassland	*GIF 2019 Ontario Cities*	2019	CAD	$2 /sq. m.			n/a							$0.60 /sq.m./yr
Turf (Active)	*GIF 2017 Toronto Area*	2017	CAD	$12 /sq. m.			n/a							$0.96 /sq.m./yr
NON-GRI TOOLS														
Detention tanks (without reuse)														
Surface detention tanks														
Rain Barrel	*CNT Green Values SWM Calculator*	2019	USD	$528 /cu. m.			n/a							$145.29 /cu. m./yr
Cistern	*KC WQBE*	2019	USD	$4,562 /cu. m.			n/a							
Cistern Galvanized Steel	*LA WMMS 2.0*	2020	USD			$793 /cu. m.	n/a							
Subsurface detention tanks/vaults														
Cistern	*CNT Green Values SWM Calculator*	2019	USD	$362 /cu. m.			n/a							$36.98 /cu. m./yr
Stormbrixx SD	*ACO (Vendor)*	2022	CAD	$350 /cu. m.			n/a							
Stormbrixx HD	*ACO (Vendor)*	2022	CAD	$450 /cu. m.			n/a							
Detention Vault	*NYC SWMPP*	2018	USD	$2,361 /cu. m.	$1,976 /cu. m.	$4,337 /cu. m.	n/a	54.4%	1.84	83.7%				$38.40 /cu. m./yr
Gray Storage	*Cambie IWMP*	2020	CAD	$820 /cu. m.	$550 /cu. m.	$1,370 /cu. m.	n/a	59.9%	1.67	67.1%				$60.00 /cu. m./yr
Detention Vault on Property	*KC WQBE*	2019	USD	$4,395 /cu. m.			n/a							
Rainwater Detention System (average)	*KWL Multiplex Study*	2022	CAD	$3,398 /cu. m.										
Blue roofs														
Blue Roof	*SFPUC*	2017	USD	$65 /sq. m.	$54 /sq. m.	$118 /sq. m.	n/a	54.5%	1.83	83.3%				
Water quality devices														
Proprietary Treatment devices														
Costs developed separately.														

Study Title: **SFPUC - Evaluation of Rainwater Harvesting Requirements in CSS Areas**
Date: **2015**

Component	Cost Unit	Total Capital Cost
Indoor Dual Plumbing - Office	$ / gross square footage (GSF) of building	$1.15
Indoor Dual Plumbing - Residential	$ / GSF of building	$2.50
Storage Tank	$ / gal of storage	$4.50
Pump System - Baseline	$ / gal of storage	$0.75
Pump System - High End	$ / gal of storage	$3.50
Treatment System - Baseline	$ / gal of storage	$2.25
Treatment System - High End	$ / gal of storage	$6.00

1. High end pump system includes additional booster pump, buffer/day tank, and overflow connections.

2. Baseline treatment includes filtration, UV disinfection system, and labor costs for electricians and plumbers.

3. High-end treatment includes filtration, chlorination system, control panel, commissioning, labor costs for electricians and plumbers.

Study Title: **SFPUC - Water Reuse System Cost Study**
Date: **2019**

		Construction Cost		
Component	**Cost Unit**	**Average**	**Median**	**Range**
Indoor Dual Plumbing	$ / GSF of building	$0.81	$0.88	$0.31 - $1.29
Treatment System	$ / GSF of building	$2.14	$2.02	$1.03 - $3.18
	$ / gpd of system capacity	$165.57	$143.31	$81 - $355
O&M	$ / year per system	$50,000	$50,000	-

Study Title: **Cambie IWMP - Cost Basis**
Date: **2020**

System	Cost Unit	Construction Cost	O&M (Average)	Lifecycle Period (years)
Rainwater Reuse System	$ / m^3 of storage	$2,718	$60	30
Rainwater and Greywater Reuse System	$ / m^3 of storage	$4,441	$624	30

Source: Langley Concrete Group (Jim Boon, Sales Manager)
Date: 5/27/2021
Does not include installation.

JELLYFISH FILTER UNIT *Does not include installation. Unit Price does not include any hatches, frames, or covers.*								**LOTUS ADJUSTMENTS TO TOTAL INSTALLED COST**		
								Hatches, frames, covers	Installation & Contingencies	**Total Construction Cost**
DESCRIPTION		**Treatment Flow Rate (L/s)**	**Unit Price**	**Freight**	**Tax**	**Total Unit Cost**		5%	10%	
JF CONCR 1200MM 1HF 1DD	JF4-1-1	7.6	$ 27,300	$ 500	$ 1,946	**$ 29,746**		$ 1,500	$ 3,000	$ 34,000
JF CONCR 1200MM 2HF 1DD	JF4-2-1	12.6	$ 30,520	$ 500	$ 2,171	**$ 33,191**		$ 1,700	$ 3,300	$ 38,000
JF CONCR 1800MM 3HF 1DD	JF6-3-1	17.7	$ 43,945	$ 650	$ 3,122	**$ 47,717**		$ 2,400	$ 4,800	$ 55,000
JF CONCR 1800MM 4HF 1DD	JF6-4-1	22.7	$ 47,085	$ 650	$ 3,341	**$ 51,076**		$ 2,600	$ 5,100	$ 59,000
JF CONCR 1800MM 5HF 1DD	JF6-5-1	27.8	$ 50,230	$ 650	$ 3,562	**$ 54,442**		$ 2,700	$ 5,400	$ 63,000
JF CONCR 1800MM 6HF 1DD	JF6-6-1	32.8	$ 53,375	$ 650	$ 3,782	**$ 57,807**		$ 2,900	$ 5,800	$ 67,000
JF CONCR 2400MM 6HF 2DD	JF8-6-2	35.3	$ 84,625	$ 775	$ 5,978	**$ 91,378**		$ 4,600	$ 9,100	$ 105,000
JF CONCR 2400MM 7HF 2DD	JF8-7-2	40.4	$ 85,835	$ 775	$ 6,063	**$ 92,673**		$ 4,600	$ 9,300	$ 107,000
JF CONCR 2400MM 8HF 2DD	JF8-8-2	45.4	$ 89,225	$ 775	$ 6,300	**$ 96,300**		$ 4,800	$ 9,600	$ 111,000
JF CONCR 2400MM 9HF 2DD	JF8-9-2	50.5	$ 92,680	$ 775	$ 6,542	**$ 99,997**		$ 5,000	$ 10,000	$ 115,000
JF CONCR 2400MM 10HF 2DD	JF8-10-2	55.5	$ 96,105	$ 775	$ 6,782	**$ 103,662**		$ 5,200	$ 10,400	$ 119,000
JF CONCR 3000MM 11HF 3DD	JF10-11-3	63.1	$ 135,088	$ 1,700	$ 9,575	**$ 146,363**		$ 7,300	$ 14,600	$ 168,000
JF CONCR 3000MM 12HF 3DD	JF10-12-3	68.1	$ 138,332	$ 1,700	$ 9,802	**$ 149,834**		$ 7,500	$ 15,000	$ 172,000
JF CONCR 3000MM 12HF 4DD	JF10-12-4	70.7	$ 141,576	$ 1,700	$ 10,029	**$ 153,305**		$ 7,700	$ 15,300	$ 176,000
JF CONCR 3000MM 13HF 4DD	JF10-13-4	75.7	$ 144,822	$ 1,700	$ 10,257	**$ 156,778**		$ 7,800	$ 15,700	$ 180,000
JF CONCR 3000MM 14HF 4DD	JF10-14-4	80.8	$ 148,068	$ 1,700	$ 10,484	**$ 160,251**		$ 8,000	$ 16,000	$ 184,000
JF CONCR 3000MM 15HF 4DD	JF10-15-4	85.8	$ 151,315	$ 1,700	$ 10,711	**$ 163,726**		$ 8,200	$ 16,400	$ 188,000
JF CONCR 3000MM 16HF 4DD	JF10-16-4	90.8	$ 154,562	$ 1,700	$ 10,938	**$ 167,200**		$ 8,400	$ 16,700	$ 192,000
JF CONCR 3000MM 17HF 4DD	JF10-17-4	95.9	$ 154,562	$ 1,700	$ 10,938	**$ 167,200**		$ 8,400	$ 16,700	$ 192,000
JF CONCR 3000MM 18HF 4DD	JF10-18-4	100.9	$ 161,061	$ 1,700	$ 11,393	**$ 174,154**		$ 8,700	$ 17,400	$ 200,000
JF CONCR 3000MM 19HF 4DD	JF10-19-4	108.5	$ 164,310	$ 1,700	$ 11,621	**$ 177,631**		$ 8,900	$ 17,800	$ 204,000

Source: Contech ES (Doug Miller - Area Manager)
Date: 4/12/2023
Construction costs include estimated installation cost and the estimated maintenance costs are averaged per year and assume normal sediment loading.

	Construction Cost		**Maintenance Cost**	
DESCRIPTION	**Low**	**High**	**Low**	**High**
Manuf. Stormwater Treatment System - 1 L/s	$ 25,000	$ 40,000	$ 1,000	$ 2,000
Manuf. Stormwater Treatment System - 2 L/s	$ 30,000	$ 45,000	$ 1,000	$ 2,000
Manuf. Stormwater Treatment System - 7 L/s	$ 50,000	$ 60,000	$ 3,000	$ 5,000
Manuf. Stormwater Treatment System - 17 L/s	$ 100,000	$ 130,000	$ 5,000	$ 10,000
Manuf. Stormwater Treatment System - 50 L/s	$ 225,000	$ 275,000	$ 15,000	$ 25,000

Source: Imbrium (Ben Farrell - Area Manager)
Date: 4/20/2023

		Construction Cost	**Maintenance Cost**	
DESCRIPTION			**Low**	**High**
JFVLAN-1A-2-1-15C	2 L/s	$ 30,000	$ 1,000	$ 2,000
JFVLAN-1A-3-1-27C	7 L/s	$ 35,000	$ 1,000	$ 2,000
JFVLAN-II-6-2-27C	17 L/s	$ 45,000	$ 1,000	$ 2,000
JFVLAN-III-9-2-54C	50 L/s	$ 80,000	$ 1,000	$ 2,000
Filterra FT0606	2 L/s	$ 20,000	$ 250	$ 450
Filterra FT1206	7 L/s	$ 40,000	$ 250	$ 450
Filterra 2xFT1206	17 L/s	$ 80,000	$ 250	$ 450
Filterra 4xFT1206	50 L/s	$ 160,000	$ 250	$ 450

Appendix C

Building Construction Cost Data

BUILDING CONSTRUCTION COST DATA

Source: Altus Group Canadian Cost Guide 2023 (Vancouver market)

	Building Type	Unit Construction Cost				
		$/ft^2		$/m^2		
		Low	High	Low	High	Average
RESIDENTIAL	**Condominiums/Apartments**					
	Up to 12 Storeys	$310	$380	$3,337	$4,090	**$3,714**
	13-39 Storeys	$330	$400	$3,552	$4,306	**$3,929**
	40-60 Storeys	$340	$420	$3,660	$4,521	**$4,090**
	60+ Storeys	$365	$460	$3,929	$4,951	**$4,440**
	Premium for High Quality	up to	$245	up to	$2,637	**$2,637**
	Wood Framed Residential					
	Row Townhouse with Unfinished Basement	$180	$290	$1,938	$3,122	**$2,530**
	Single Family Residential with Unfinished Basement	$185	$315	$1,991	$3,391	**$2,691**
	3 Storey Stacked Townhouse	$215	$300	$2,314	$3,229	**$2,772**
	Up to 6 Storey Wood Framed Condo	$245	$350	$2,637	$3,767	**$3,202**
COMMERCIAL	**Office Building**					
	Under 5 Storeys (Class B)	$290	$375	$3,122	$4,037	**$3,579**
	5 - 30 Storeys (Class B)	$290	$370	$3,122	$3,983	**$3,552**
	5 - 30 Storeys (Class A)	$295	$380	$3,175	$4,090	**$3,633**
	31 - 60 Storeys (Class A)	$320	$450	$3,444	$4,844	**$4,144**
	Interior Fitout (Class B)	$85	$150	$915	$1,615	**$1,265**
	Interior Fitout (Class A)	$130	$250	$1,399	$2,691	**$2,045**
	Hotel					
	Budget	$210	$270	$2,260	$2,906	**$2,583**
	Suite Hotel	$335	$405	$3,606	$4,359	**$3,983**
	4 Star Full Service	$355	$470	$3,821	$5,059	**$4,440**
	Premium for Luxury	up to	$200	up to	$2,153	**$2,153**
	Parking					
	Surface Parking	$10	$25	$108	$269	**$188**
	Freestanding Parking Garages (above grade)	$120	$200	$1,292	$2,153	**$1,722**
	Underground Parking Garages	$120	$230	$1,292	$2,476	**$1,884**
	Underground Parking Garages - Premium for Unusual Circumstances	up to	$205	up to	$2,207	**$2,207**

Altus Group

2023

Canadian Cost Guide

Introduction

Your guide to better understanding Canadian real estate development and infrastructure construction costs

The Canadian construction and development industry hit major turbulence in 2022. The combination of widespread supply chain disruptions, sustained cost escalation, and rapidly rising interest rates strained the budgets of builders, developers, and governments alike.

Nevertheless, there is reason for cautious optimism. Underpinned by high immigration, increased immigration targets and a large backlog of projects underway, demand is likely to remain strong in the year ahead, even with a mild recession. In addition, supply chain snarls and inflation appear to be at, or nearing, an inflection point; potentially opening the door to less construction cost volatility in the year ahead.

Even so, let's not forget the hard-won lessons of the past few years. The best laid plans can be stymied by abrupt reversals in myriad factors - pandemic, geopolitical relations, and run-away inflation to name a few. Take these lessons to heart and ensure your budgets and pro formas are living documents, up-to-date with the latest available information. Having a current and accurate understanding of construction costs is imperative to help manage development risk and navigate turbulent times.

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About the 2023 construction cost data

Construction costs are impacted by global and local economic conditions, market trends, and advances in building materials, practices, and approaches. We have considered all these factors when producing our annual guide, to provide you with a budget range of construction hard costs across all asset classes in the Canadian marketplace.

Our proprietary project cost database includes data from over 900 engagements in 2022 alone.

This guide is designed to be an accessible tool for initial budgeting or to benchmark an estimate, however we strongly advise that you seek independent professional advice to produce a precise estimate and pro forma figures that reflect the specific conditions and details of your unique development and infrastructure undertakings.

Data based on

Residential	$148 BILLION	2,317 PROJECTS	836M+ SQUARE FEET
ICI	$90 BILLION	2,362 PROJECTS	410M+ SQUARE FEET
Infrastructure	$120 BILLION	390 PROJECTS	
Total	$358 BILLION	5,069 PROJECTS	1,246M+ SQUARE FEET

Private sector (cost per square foot)

BUILDING TYPE	Vancouver			Calgary			Edmonton			Winnipeg			GTA			Ottawa/Gatineau			Montreal			Halifax			St. John's		
	Low		High	Low		High	Low		High	Low		High	Low		High	Low		High	Low		High	Low		High	Low		High
RESIDENTIAL																											
CONDOMINIUMS/APARTMENTS																											
Up to 12 Storeys	310	to	380	260	to	320	260	to	320	260	to	320	275	to	380	275	to	355	225	to	295	180	to	255	185	to	260
13-39 Storeys	330	to	400	275	to	325	275	to	325	275	to	320	285	to	370	315	to	345	230	to	300	190	to	265	n/a	to	n/a
40-60 Storeys	340	to	420	280	to	330	280	to	330	280	to	325	320	to	400	320	to	375	240	to	325	n/a	to	n/a	n/a	to	n/a
60+ Storeys	365	to	460	n/a	to	n/a	n/a	to	n/a	n/a	to	n/a	345	to	450	360	to	425	n/a	to	n/a	n/a	to	n/a	n/a	to	n/a
Premium for High Quality	up to		245	up to		240	up to		240	up to		235	up to		245	up to		200	up to		200	up to		185	up to		190
WOOD FRAMED RESIDENTIAL (DIMENSIONAL LUMBER)																											
Row Townhouse with Unfinished Basement	180	to	290	160	to	220	160	to	220	160	to	220	200	to	245	130	to	180	130	to	185	110	to	150	130	to	170
Single Family Residential with Unfinished Basement	185	to	315	150	to	240	150	to	240	145	to	230	205	to	280	140	to	225	140	to	205	105	to	165	130	to	165
3 Storey Stacked Townhouse	215	to	300	170	to	230	170	to	230	165	to	230	235	to	270	170	to	205	150	to	205	140	to	180	155	to	190
Up to 6 Storey Wood Framed Condo	245	to	350	195	to	265	195	to	265	190	to	265	240	to	325	180	to	255	160	to	235	150	to	185	160	to	195
Custom Built Single Family Residential	485	to	1,225	450	to	995	450	to	995	450	to	975	515	to	1,130	500	to	1,055	430	to	860	275	to	555	320	to	670
SENIORS HOUSING																											
Independent / Supportive Living Residences	250	to	355	195	to	300	195	to	300	190	to	295	290	to	390	305	to	355	195	to	300	190	to	265	195	to	275
Assisted Living Residences	275	to	410	230	to	310	230	to	310	225	to	305	310	to	410	330	to	380	235	to	315	210	to	285	215	to	295
Complex Care Residences	330	to	435	295	to	425	295	to	425	290	to	420	355	to	450	355	to	405	285	to	345	235	to	335	255	to	350
COMMERCIAL																											
OFFICE BUILDINGS																											
Under 5 Storeys (Class B)	290	to	375	215	to	295	215	to	295	210	to	290	265	to	360	215	to	280	195	to	270	180	to	235	185	to	240
5 - 30 Storeys (Class B)	290	to	370	215	to	300	215	to	300	210	to	295	275	to	385	225	to	310	200	to	280	185	to	260	190	to	270
5 - 30 Storeys (Class A)	295	to	380	245	to	340	245	to	340	240	to	335	310	to	455	265	to	355	215	to	305	205	to	290	210	to	300
31 - 60 Storeys (Class A)	320	to	450	280	to	390	280	to	390	275	to	385	360	to	515	n/a	to	n/a	275	to	405	n/a	to	n/a	n/a	to	n/a
Interior Fitout (Class B)	85	to	150	70	to	110	70	to	110	65	to	105	100	to	150	80	to	125	85	to	125	60	to	95	60	to	100
Interior Fitout (Class A)	130	to	250	105	to	185	105	to	185	100	to	180	140	to	265	115	to	185	130	to	195	95	to	160	95	to	170
RETAIL																											
Strip Plaza	200	to	275	205	to	265	205	to	265	200	to	260	225	to	285	145	to	220	140	to	210	120	to	170	130	to	175
Supermarket	210	to	265	190	to	230	190	to	230	185	to	225	175	to	260	180	to	255	170	to	235	150	to	210	155	to	205
Big Box Store	200	to	265	185	to	230	185	to	230	180	to	225	165	to	240	175	to	225	160	to	225	155	to	205	155	to	205
Enclosed Mall	300	to	405	240	to	365	240	to	365	235	to	360	275	to	480	245	to	310	245	to	330	205	to	290	220	to	270
HOTELS																											
Budget	210	to	270	190	to	255	190	to	255	185	to	250	240	to	320	220	to	280	185	to	250	190	to	240	190	to	235
Suite Hotel	335	to	405	275	to	375	275	to	375	270	to	370	345	to	420	285	to	380	240	to	315	220	to	310	225	to	295
4 Star Full Service	355	to	470	290	to	390	290	to	390	285	to	385	365	to	550	315	to	440	265	to	340	240	to	325	250	to	320
Premium for Luxury	up to		200	up to	to	180	up to	to	180	up to	to	175	up to		305	up to		155	110	to	175	up to	to	110	up to		115
PARKING																											
Surface Parking	10	to	25	7	to	23	7	to	23	7	to	23	12	to	28	10	to	21	8	to	22	6	to	17	6	to	17
Freestanding Parking Garages (above grade)	120	to	200	105	to	145	105	to	145	100	to	140	140	to	210	115	to	145	100	to	135	100	to	130	110	to	145
Underground Parking Garages	120	to	230	145	to	210	145	to	210	140	to	205	195	to	270	210	to	275	125	to	165	125	to	175	140	to	170
Underground Parking Garages - Premium for Unusual Circumstances	up to		205	up to		140	up to		140	up to		135	up to		220	up to		205	up to	to	175	up to		165	up to		165
INDUSTRIAL FACILITIES																											
Warehouse & Distribution Facility	115	to	185	105	to	155	105	to	155	100	to	150	95	to	180	120	to	170	110	to	170	100	to	145	100	to	155
Urban Storage Facility	115	to	160	105	to	150	105	to	150	100	to	145	95	to	125	105	to	130	n/a	to	n/a	n/a	to	n/a	n/a	to	n/a

Public sector (cost per square foot)

BUILDING TYPE	Vancouver			Calgary			Edmonton			Winnipeg			GTA			Ottawa/Gatineau			Montreal			Halifax			St. John's		
	Low		High	Low		High	Low		High	Low		High	Low		High	Low		High	Low		High	Low		High	Low		High
INSTITUTIONAL																											
EDUCATIONAL BUILDINGS																											
Elementary School	350	to	420	280	to	365	280	to	365	275	to	360	370	to	455	350	to	430	330	to	450	285	to	360	300	to	440
Secondary School	370	to	440	310	to	395	310	to	395	305	to	390	400	to	480	370	to	450	350	to	475	330	to	385	320	to	460
Universities & Colleges - Teaching and Lecture Hall Building	620	to	950	525	to	770	525	to	770	520	to	765	850	to	1,100	650	to	975	540	to	800	540	to	650	525	to	730
Universities & Colleges - Laboratories (Level 1 and 2)	850	to	1,200	665	to	950	665	to	950	660	to	945	1,050	to	1,400	900	to	1,200	650	to	900	650	to	850	660	to	955
Universities & Colleges - Student Residence	350	to	420	280	to	360	280	to	360	275	to	355	350	to	450	350	to	450	250	to	350	275	to	350	260	to	340
HEALTH CARE																											
General Hospital/Acute Care	825	to	1,300	640	to	995	640	to	995	635	to	990	950	to	1,500	920	to	1,400	650	to	1,000	650	to	1,000	670	to	950
Medical Clinic/Treatment Centre	405	to	570	335	to	585	335	to	585	330	to	580	410	to	580	390	to	560	340	to	510	350	to	500	350	to	515
CIVIC																											
TRANSPORTATION BUILDINGS																											
Regional Airport Terminal	415	to	520	455	to	570	455	to	570	450	to	565	485	to	580	380	to	480	375	to	470	375	to	465	350	to	485
International Airport Terminal	795	to	1,030	685	to	935	685	to	935	680	to	930	805	to	1,065	770	to	950	750	to	900	725	to	885	725	to	885
Bus Terminal/Garage	350	to	450	330	to	385	330	to	385	325	to	380	420	to	700	330	to	415	310	to	375	305	to	395	270	to	365
GOVERNMENT BUILDINGS																											
Fire/EMS Station	500	to	850	500	to	645	500	to	645	495	to	640	510	to	735	500	to	650	430	to	500	370	to	425	375	to	455
Police Station - Local Detachment	530	to	580	390	to	475	390	to	475	385	to	470	550	to	600	520	to	580	480	to	550	400	to	450	400	to	460
Police Station - Regional Headquarters	460	to	600	415	to	495	415	to	495	410	to	490	485	to	580	450	to	550	440	to	525	350	to	440	340	to	435
Court House	495	to	680	470	to	650	470	to	650	465	to	645	590	to	755	510	to	680	485	to	645	460	to	520	465	to	505
Facilities Maintenance Building	400	to	500	285	to	415	285	to	415	280	to	410	500	to	590	450	to	520	315	to	410	275	to	335	280	to	330
Penitentiary	485	to	645	465	to	585	465	to	585	460	to	580	580	to	700	440	to	570	420	to	540	415	to	575	465	to	575
Municipal Office (including fit-up)	400	to	520	370	to	415	370	to	415	365	to	410	405	to	540	360	to	450	345	to	430	325	to	375	300	to	365
Library	430	to	725	390	to	600	390	to	600	385	to	595	460	to	850	450	to	800	385	to	590	400	to	650	370	to	575
RECREATION/ENTERTAINMENT BUILDINGS																											
Ice Arena	345	to	465	330	to	420	330	to	420	325	to	415	345	to	435	330	to	430	315	to	400	325	to	375	330	to	385
Community Aquatic Facility	525	to	915	450	to	600	450	to	600	445	to	595	590	to	915	550	to	750	515	to	675	500	to	550	400	to	550
Multi-Use Recreational Centre	505	to	900	400	to	540	400	to	540	395	to	535	650	to	1,125	520	to	635	400	to	550	400	to	600	350	to	470
Performing Arts Building	875	to	1,200	575	to	910	575	to	910	570	to	905	915	to	1,235	595	to	940	495	to	815	475	to	615	470	to	600
Museum / Gallery	525	to	865	510	to	880	510	to	880	505	to	875	590	to	880	585	to	725	465	to	700	455	to	595	430	to	600

Infrastructure (cost per unit)

	British Columbia			Alberta			Ontario (GTA Region)			Ontario (Ottawa Region)		
	Low		High	Low		High	Low		High	Low		High
LIGHT RAIL TRANSIT												
Guideway - Underground (Tunnel) (per km)	84,520,000	to	200,760,000	74,030,000	to	175,880,000	81,430,000	to	193,640,000	76,910,000	to	182,870,000
Guideway - Underground (Cut and Cover) (per km)	38,520,000	to	372,060,000	33,690,000	to	325,830,000	37,170,000	to	358,630,000	35,090,000	to	338,670,000
Guideway - At Grade (per km)	2,490,000	to	72,400,000	2,150,000	to	28,510,000	2,370,000	to	31,370,000	2,240,000	to	29,650,000
Guideway - Elevated (per km)	3,290,000	to	77,260,000	2,820,000	to	59,150,000	3,080,000	to	65,100,000	2,960,000	to	61,550,000
Stops - At Grade (per unit)	1,310,000	to	6,910,000	1,140,000	to	5,730,000	1,260,000	to	6,310,000	1,180,000	to	5,960,000
Stations - Underground (per unit)	51,210,000	to	240,510,000	44,840,000	to	184,100,000	49,360,000	to	202,630,000	46,670,000	to	191,370,000
Stations - At Grade (per unit)	5,670,000	to	46,400,000	4,960,000	to	39,330,000	5,450,000	to	43,320,000	5,200,000	to	40,870,000
Stations - Elevated (per unit)	28,780,000	to	82,220,000	25,240,000	to	74,810,000	27,700,000	to	82,380,000	26,220,000	to	77,730,000
Operations and Maintenance Facility (per square feet)	225	to	1,705	200	to	1,150	215	to	1,270	210	to	1,205
Systems (per km)	5,890,000	to	76,390,000	5,080,000	to	24,000,000	5,680,000	to	26,390,000	5,320,000	to	24,930,000
HIGHWAYS												
Multi-Lane Highways (per lane km)	2,260,000	to	3,170,000	1,940,000	to	2,830,000	2,170,000	to	4,210,000	2,050,000	to	3,160,000

Note: All building costs include the above grade scope of work only; complete with foundations. To calculate the total construction cost you need to also include the below grade scope of work (see the Parking section of the cost tables).

Here is how the calculation is applied separately for above and below grade:

40-storey office building in Toronto | 800,000 square feet above grade | 200,000 square feet below grade

Above grade 800,000 square feet x $440/square foot = $352 million

Below grade 200,000 square feet x $230/square foot = $46 million

Total $398 million

Frequently asked questions

Q. If I am budgeting a building that has no underground parking area, can I use just the applicable rate for the above grade without adding any underground parking cost?

Yes, the above grade costs include the cost of a slab on grade and associated footings.

Q. In the Parking section, when would the Underground Parking Garages – Premium for Unusual Circumstances apply and what would it include?

Underground parking garage costs can vary significantly depending on their site specifics, location, soil conditions, ground water conditions, shape, and depth. Examples where additional costs may be incurred, include:

- Non-typical foundations due to poor soil stability
- Bath tubbing the underground due to groundwater or municipal regulations
- Soil conditions that increase excavation costs and/or shoring costs
- Unusually constricted site conditions (e.g., proximity to adjacent structures)
- Footprint shapes that increase the ratio of exterior wall area relative to floor area
- Non-typical floor heights and/or specifications
- Remediation of contaminated soils or groundwater

Q. Why does the cost of the same asset type differ so much between cities in some cases?

The Cost Guide numbers reflect the probable costs of the identified type of building as it would typically be defined in that market. Not only do the costs of labour and materials differ between markets, the standards/specification of each building type may differ as well.

For example, the specification of a mid-quality condominium in Vancouver will typically be a higher specification than what is provided for a mid-quality condominium in Halifax. In addition, there are climatic & code variances between cities. For instance, the HVAC system required in Calgary will be different than the HVAC system required in Vancouver.

These differences are also reflected in the numbers. The difference in the Cost Guide numbers is a composite of both the differences in labour and material cost and the differences in design.

Q. In the Condominiums/Apartments section, what is the Premium for High Quality item, what does it include, and when does it apply?

The Cost Guide numbers are representative of the level of finishes and design that would be considered "typical" of a mid-quality condominium/apartment in that city. If aspects of your building's design are beyond what would be considered typical, you should be adding this premium. The delineation of what is and is not premium differs from market to market, but could include such things as: premium quality floor finishes, kitchen cabinetry, appliances, luxury building amenities, upgrades to exterior enclosure, etc.

Q. What is the methodology used to determine the Cost Guide numbers?

The Cost Guide numbers are determined through a combination of our historical data for each asset class in each city, overlaid with expert opinion and knowledge provided by the senior managers in each of our offices across the country.

Q. Can Cost Guide numbers be used for insurance purposes and estimating replacement costs?

A replacement cost estimate should be prepared by a qualified cost professional and with respect to your unique asset, especially when it comes to unique properties with a greater level of design. Relying on generic estimates, untailored to your needs, can leave you exposed.

Q. I want to measure cost escalation from year to year. Will comparing the current Cost Guide numbers to previous Cost Guide numbers provide me a useful measure of annual cost escalation?

We do not recommend using the Cost Guide to measure cost escalation. It is meant to be used as a tool for clients who are considering an appropriate conceptual budget for a building type in a specific market at a particular point in time. Its methodology thus allows all variables (design, costs, etc.) to vary from year to year and location to location to constantly reflect what is 'typical' of each market each year. What is typical of one city may not be typical of another city. Similarly, what is typical of a building type today, may not have been typical of the same building type 5 years ago.

To provide an accurate measure of cost escalation – and isolate only the changes due to escalation of costs – all other variables would need to remain static.

Q. Can I apply the zoning floor areas calculated by my Architect to the unit rates in the Cost Guide?

Using zoning floor areas to calculate costs is a common and potentially costly error. The Cost Guide rates are calculated using the Canadian Institute of Quantity Surveyors' definition of floor area, whereas zoning floor area definitions differ from municipality to municipality and often exclude significant areas of the building from the calculation. Thus, using the floor area measured per zoning definitions can result in underestimating costs by as much as 12%. If you do not have floor plans for your building when preparing your budget, you will need to "gross up" the zoning floor areas to account for the variance in definition. If you do have floor plans for your building, we strongly recommend having the floor areas properly measured in accordance with the Canadian Institute of Quantity Surveyors', Method of Measurement of Construction Works.

Q. Previous Cost Guides (pre-2020) included the Canadian Cost Index, which compared the relative costs between cities. Why is this no longer included?

We no longer produce this index for a couple reasons. First, no single index number is universally applicable to all building types. In a single city, some building types may be a premium versus the benchmark city, while other building types are a discount versus the benchmark city. For example, the cost of a 30-storey residential tower could be higher than the benchmark city, while the cost of a wood frame townhouse project is less expensive.

Second, in many cases the design of the building in the indexed city will be significantly different than that of the benchmark city. Consider the scenario of indexing the cost of a building in Iqaluit to that of Toronto. A building built in Iqaluit will have substantive differences in design compared to a similar building built in Toronto (due to environmental considerations, site, code, local design standards, etc.). Although this is an extreme example for the purpose of illustrating a point, the same issue applies to some degree when indexing construction costs of any city to those of another.

For these reasons, we recommend that you consult a professional who can consider the complexities on a case-by-case basis, rather than relying upon an index.

Notes on correct use of data

Guide only

The construction cost data contained herein are of a general nature only and subject to confirmation with respect to specific circumstances.

The unit rates for the building types described are an average range exclusively for that particular type of building. The unit rates assume that a level, open site exists with no restrictions from adjoining properties. It is assumed that stable soil conditions prevail. Average-quality finishes (unless otherwise stated), both to the exterior and interior are also assumed.

Judgement factors must be applied within the average range to allow for:

- Quality
- Schedule
- Extent of site works
- Location
- Site restrictions
- Design method
- Type of contract
- Building shape, size and height
- Market conditions
- User requirements
- Topography and soil conditions
- Procurement advantage of developer/contractor

Correct measurement & use of square foot

In preparing a “cost per square foot” guide, we must outline how we define the area used as the denominator to calculate this value. We have adopted the Canadian Institute of Quantity Surveyors’ definition which dictates:

1. Measure each floor to the outer face of the external walls.
2. No deductions for opening at stairs, elevators or vertical ducts are made.
3. A deduction is made for a non-service vertical protrusion, e.g., atrium space.
4. Mezzanine floors are generally included.
5. Balconies are excluded; enclosed solariums in residential condominiums are included.
6. Sloping and stepped floors (auditoriums/movie theatres) are measured flat.
7. External covered walkways are excluded.

If the building includes underground parking areas, these costs need to be added based on the “Underground Parking Garage” rate in the guide.

Hard construction costs only

The unit costs outlined herein cover construction costs only. In all commercial developments the project budget must also include development or “soft” costs. These would include some or all the following:

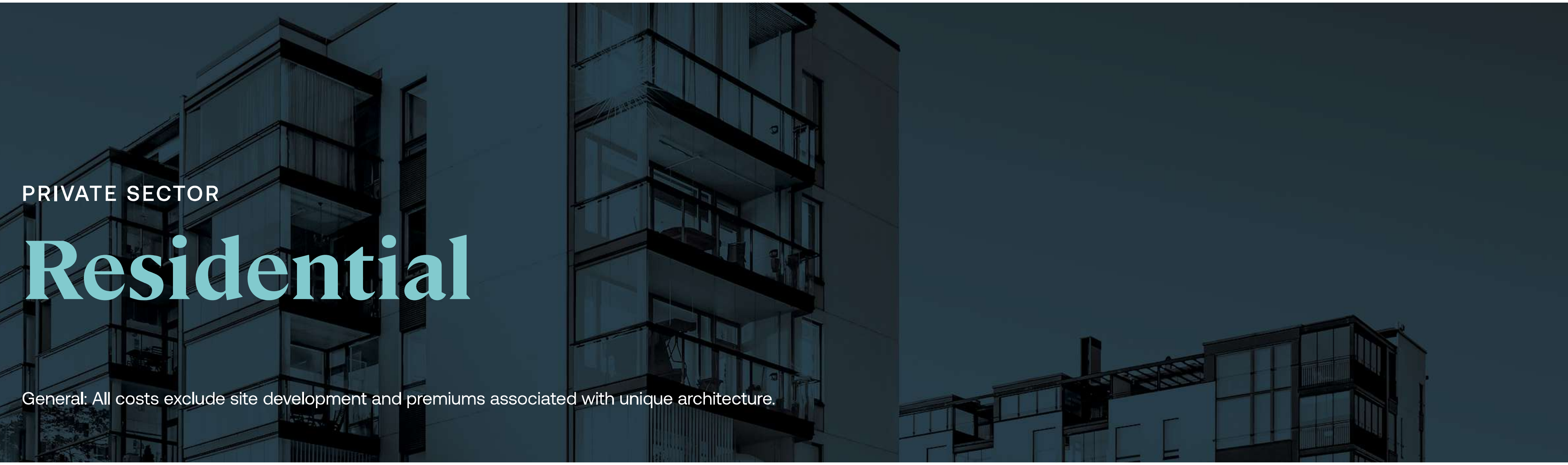
- Land and related costs
- Legal fees
- Site services outside the property
- Tenant incentives
- Soil and environmental tests
- Contingencies
- Architectural and engineering fees
- Special design consultants
- Interest charges and lenders’ fees
- Permits and development charges
- Land surveys
- Government registered programs
- Special equipment and furnishings
- Marketing and advertising
- Purchaser upgrades
- Property taxes
- Other municipal fees
- Insurance and bond costs
- Management costs
- Levies
- Appraisals
- Broker commissions
- Developer profit
- Rezoning costs

Federal & provincial sales tax

The unit costs provided exclude Value Added Taxes (GST, HST and QST), but include Provincial Sales Tax (PST) where applicable at the time of the release of this guide.

Appendix

Building type descriptions



PRIVATE SECTOR

Residential

General: All costs exclude site development and premiums associated with unique architecture.

Condominiums and apartments

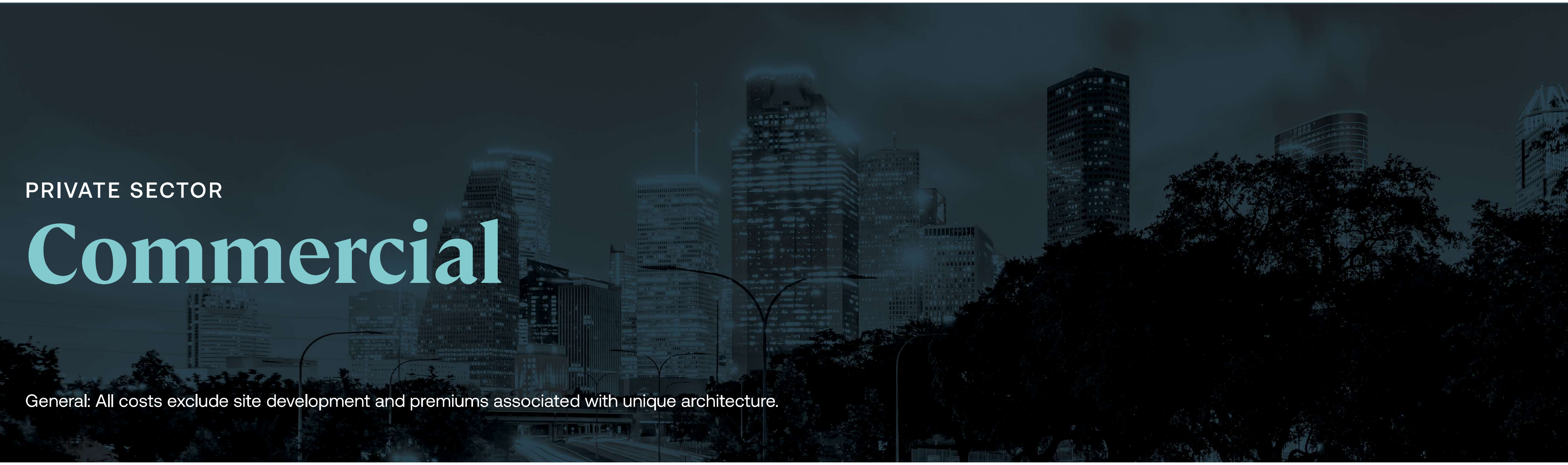
- Assumed cast-in-place concrete structure unless otherwise indicated.
- The premium for high-quality can be applied to any of the condominium/apartment categories.
- Parking is excluded from all unit rates and should be added accordingly.

Wood-framed

- The floor area of the unfinished basement and garage should be excluded from the area used with the unit rate provided.
- Parking is excluded from all unit rates and should be added accordingly.

Seniors housing

- Costs can fluctuate depending on the level of care, services provided to the residents, and whether the facility is for-profit or community-based.



PRIVATE SECTOR

Commercial

General: All costs exclude site development and premiums associated with unique architecture.

Office buildings

- Assumed base building construction only, including mechanical and electrical services, washrooms, and finishing of ground floor entrance lobby.
- Tenant partitioning and finishes (with the exception of ceiling and column finishes) are excluded. The cost of finishing this space can fluctuate depending on the density of partitioning and the quality of the finishes.
- Costs assume standalone buildings and are not representative of a component within a mixed-use building.
- Parking is excluded from all unit rates and should be added accordingly.

Retail

- Assumed single-storey buildings with the exception of enclosed malls.
- The CRU space is considered shell.
- Public spaces within an enclosed mall are finished.
- Costs assume standalone buildings and are not representative of a component within a mixed-use building.

Hotels

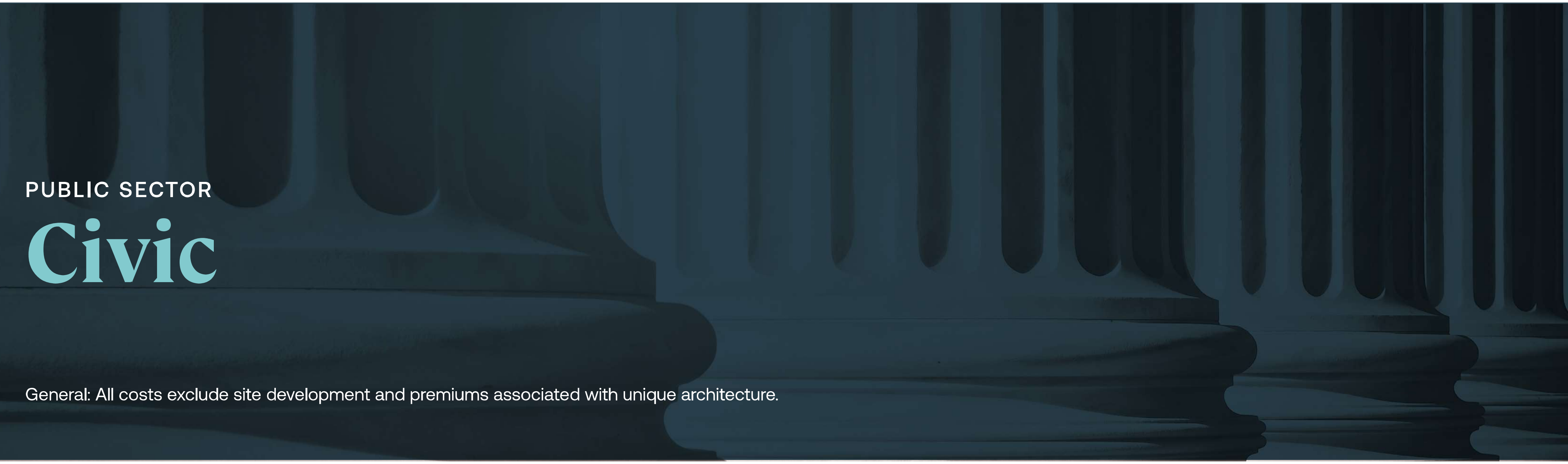
- FF&E allowances are excluded, as each operator has its own definition, and the costs can vary significantly.
- Budget hotel assumes no restaurant or bar facilities and minimal meeting/conference areas.
- Suite hotels assumed to include a kitchenette.
- Four-star full-service hotels include dining and conference facilities and special-use lounges. Premiums for luxury should only be applied to the four-star full-service hotel.

Parking

- On-grade parking assumes an asphalt paved surface lot, including necessary curbs, line painting, storm servicing, and pole lighting.
- Freestanding (above grade) parking assumes an open-air structure.
- Underground parking assumes that there are no extraordinary conditions or unusual circumstances.
- Premium for unusual circumstances could be applied to account for issues such as but not limited to poor soil conditions, excessive groundwater, environmental contamination, restricted site conditions, small or non-standard footprint shape, and non-typical floor to floor heights.
- The “efficiency” of garages (parking area/stall) is also an important cost variable.
- All parking unit rates should be applied to the area of parking required and not the associated building area.

Industrial

- Warehouse space is based on heated shell space, excluding mezzanine areas. A finished office component is included.
- Urban storage facilities are based on multi-level facilities which have site constraints.



PUBLIC SECTOR

Civic

General: All costs exclude site development and premiums associated with unique architecture.

Transportation buildings

- Regional airport terminals are typically single-storey facilities that have smaller gate and circulation capacity for local domestic flights and minimal amenities.
- International airport terminals are multilevel facilities with extensive amenity space for restaurants, retail stores, and have larger circulation space and gate capacity. Also included are spaces for customs and immigration control. Costs for any parking, airside infrastructure, or equipment are excluded.
- Bus garages are slab-on-grade, single-storey, long-span steel structures including vehicle maintenance facilities and a small administration area. FF&E including vehicle lifts are excluded.
- All buildings are based on suburban facilities with no site constraints. Any associated site work or parking is excluded from the unit costs.
- Costs assume a design standard equivalent to LEED Silver. Premiums associated with actual certification or Gold/Platinum design are excluded.

Government buildings

- Fire/EMS Stations exclude any costs associated with training buildings.
- Local Police Detachments include offices and facilities for police and civilian members with minimal interview rooms and holding cells.
- Regional Police Headquarters include the same scope as a Local Police Detachment, plus additional interview rooms, holding cells, training space, and administration.
- Courthouses include judicial chambers, administrative offices, holding cells, and courtrooms.
- Facilities Maintenance Building costs are based on the main facility only, including maintenance, storage, and administrative areas. Any outbuildings would be an additional cost.
- The range of costs for penitentiaries vary depending on the level of security and size of the facility.
- Municipal Offices include administrative space for all municipal departments, meeting and conference rooms, council chambers, cafeteria, daycare facility, and significant atrium space.
- Library costs vary depending on size and whether the building is standalone or part of a multi-use facility

Recreation / Entertainment Buildings

- Ice arenas include single to four-pad facilities with spectator seating; unit costs are based on steel structures.
- Community aquatic facilities include single or multiple pools, minimal spectator seating, change room facilities, and fitness areas. Unit costs are based on conventionally framed structures for most of the building.
- Multi-use recreation centres could include any combination of fitness, gymnasium, daycare, community room, and administrative space. Facilities with arena, pool, and multi-purpose areas should be based on the costs for each component combined.
- Performing arts buildings unit costs vary depending on the size and function of the facility. Acoustical treatment, theatre lighting, stage, and seating requirements would all impact the cost.
- Museum and gallery costs vary depending on the purpose of the space; humidity and temperature control, redundant systems, and fire prevention all impact the costs.

PUBLIC SECTOR

Institutional & Infrastructure

General: All costs exclude site development and premiums associated with unique architecture.

Institutional

- Educational buildings exclude allowances for FF&E.
- Health care buildings: With more than 40 subcategories of space types available in hospitals, the mix of costs fluctuate depending on the type of facility being constructed, the mix of beds, clinics, and surgical suites, as well as the building configuration. Parking and FF&E are excluded.

Infrastructure

Light Rail

- Assumes average project conditions and does not account for unusual circumstances such as but not limited to poor soil conditions, excessive groundwater, or environmental contamination.
- Does not include structures such as bridges and interchanges
- Does not include utility works
- Based on direct construction costs only
- Stops - at Grade – Assumes an average size of 5,000 square feet
- Stations - Underground - Assumes an average size of 100,000 square feet
- Stations - at Grade – Assumes an average size of 30,000 square feet
- Stations - Elevated - Assumes an average size of 30,000 square feet
- Operations and Maintenance Facility - Inclusive of storages, light maintenance facilities and heavy maintenance facilities

Highways

- Rates allow for underground storm, sewer, lighting, earthworks, curbs, and asphalt roadways. Items such as berms, retaining walls, noise barrier fences, entrance features, storm ponds, landscaping, and external services are excluded.
- Assumes average project conditions and does not account for unusual circumstances such as but not limited to poor soil conditions, excessive groundwater, or environmental contamination.
- Based on direct construction costs only.
- Does not include structures such as bridges and interchanges.
- Through-city highways are excluded.

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Appendix D

Pathway Cost Estimates

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Small Lot Residential – Low Massing**	
Pathway Code	**SLRLM2**	*Retention: 24 mm*
Total Parcel Area	375 sq. m.	
Building Roof/Footprint Area	113 sq. m.	
Building (above-grade) Gross Floor Area	225 sq. m.	*Stories: 2*
Parkade (below-grade) Gross Floor Area	0 sq. m.	*Levels: 0*

Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*AACE Class 5 Cost Range* *Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	0	sq. m.	$ 1,500	$ -	$ -	$ -
Bioretention with Underdrain	0	sq. m.	$ 2,000	$ -	$ -	$ -
Permeable Pavement	0	sq. m.	$ 250	$ -	$ -	$ -
Subsurface Infiltration	5	cu. m.	$ 2,200	$ 9,900	$ 6,900	$ 14,900
Resilient Roof - Intensive (450mm)	0	sq. m.	$ 430	$ -	$ -	$ -
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	$ -	$ -
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	$ -	$ -
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	$ -	$ -
Subtotal				**$ 9,900**	***$ 6,900***	***$ 14,900***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	$ -	$ -
Proprietary WQ Treatment Device	0	each	$ -	$ -	$ -	$ -
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	225	sq. m.	$ 2,691	$ 610,000	$ 450,000	$ 760,000
Parkade Structure (below-grade)	0	sq. m.	$ -	$ -	$ -	$ -
At-grade Landscaping	206	sq. m.	$ 17	$ 3,500	$ 2,500	$ 5,300
At-grade Paving	56	sq. m.	$ 188	$ 10,000	$ 10,000	$ 20,000
Subtotal				**$ 623,500**	***$ 462,500***	***$ 785,300***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 633,400**	***$ 469,400***	***$ 800,200***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 480,000	$ 350,000	$ 600,000
Total Capital Cost				**$ 1,113,400**	***$ 819,400***	***$ 1,400,200***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Small Lot Residential – Low Massing**
Pathway Code	**SLRLM2ALT** *Retention: 24 mm*
Total Parcel Area	375 sq. m.
Building Roof/Footprint Area	113 sq. m.
Building (above-grade) Gross Floor Area	225 sq. m. *Stories: 2*
Parkade (below-grade) Gross Floor Area	0 sq. m. *Levels: 0*

Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*AACE Class 5 Cost Range* *Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	10	sq. m.	$ 1,500	$ 15,000	*$ 10,500*	*$ 22,500*
Bioretention with Underdrain	0	sq. m.	$ 2,000	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	0	sq. m.	$ 430	$ -	*$ -*	*$ -*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ 15,000**	***$ 10,500***	***$ 22,500***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	225	sq. m.	$ 2,691	$ 610,000	*$ 450,000*	*$ 760,000*
Parkade Structure (below-grade)	0	sq. m.	$ -	$ -	*$ -*	*$ -*
At-grade Landscaping	196	sq. m.	$ 17	$ 3,300	*$ 2,300*	*$ 5,000*
At-grade Paving	56	sq. m.	$ 188	$ 10,000	*$ 10,000*	*$ 20,000*
Subtotal				**$ 623,300**	***$ 462,300***	***$ 785,000***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 638,300**	***$ 472,800***	***$ 807,500***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 480,000	*$ 350,000*	*$ 610,000*
Total Capital Cost				**$ 1,118,300**	***$ 822,800***	***$ 1,417,500***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Small Lot Residential – Low Massing**	
Pathway Code	**SLRLM4**	*Retention: 48 mm*
Total Parcel Area	375 sq. m.	
Building Roof/Footprint Area	113 sq. m.	
Building (above-grade) Gross Floor Area	225 sq. m.	*Stories: 2*
Parkade (below-grade) Gross Floor Area	0 sq. m.	*Levels: 0*

Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*AACE Class 5 Cost Range* *Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	18	sq. m.	$ 1,500	$ 27,000	*$ 18,900*	*$ 40,500*
Bioretention with Underdrain	0	sq. m.	$ 2,000	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	0	sq. m.	$ 430	$ -	*$ -*	*$ -*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ 27,000**	***$ 18,900***	***$ 40,500***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	225	sq. m.	$ 2,691	$ 610,000	*$ 450,000*	*$ 760,000*
Parkade Structure (below-grade)	0	sq. m.	$ -	$ -	*$ -*	*$ -*
At-grade Landscaping	188	sq. m.	$ 17	$ 3,200	*$ 2,200*	*$ 4,800*
At-grade Paving	56	sq. m.	$ 188	$ 10,000	*$ 10,000*	*$ 20,000*
Subtotal				**$ 623,200**	***$ 462,200***	***$ 784,800***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 650,200**	***$ 481,100***	***$ 825,300***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 490,000	*$ 360,000*	*$ 620,000*
Total Capital Cost				**$ 1,140,200**	***$ 841,100***	***$ 1,445,300***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Small Lot Residential – Low Massing**
Pathway Code	**SLRLM5** *Retention: 0 mm*
Total Parcel Area	375 sq. m.
Building Roof/Footprint Area	113 sq. m.
Building (above-grade) Gross Floor Area	225 sq. m. *Stories: 2*
Parkade (below-grade) Gross Floor Area	0 sq. m. *Levels: 0*

Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*AACE Class 5 Cost Range* *Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	0	sq. m.	$ 2,100	$ -	*$ -*	*$ -*
Bioretention with Underdrain	0	sq. m.	$ 2,600	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	0	sq. m.	$ 430	$ -	*$ -*	*$ -*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Tier 3 Rainwater Management						
Detention Tank	4.1	cu. m.	$ 900	$ 3,700	*$ 2,600*	*$ 5,500*
Proprietary WQ Treatment Device	1	each	$ 34,800	$ 34,800	*$ 26,000*	*$ 44,000*
Subtotal				**$ 38,500**	***$ 28,600***	***$ 49,500***
Other Project Components						
Building Structure (above-grade)	225	sq. m.	$ 2,691	$ 610,000	*$ 450,000*	*$ 760,000*
Parkade Structure (below-grade)	0	sq. m.	$ -	$ -	*$ -*	*$ -*
At-grade Landscaping	206	sq. m.	$ 17	$ 3,500	*$ 2,500*	*$ 5,300*
At-grade Paving	56	sq. m.	$ 188	$ 10,000	*$ 10,000*	*$ 20,000*
Subtotal				**$ 623,500**	***$ 462,500***	***$ 785,300***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 662,000**	***$ 491,100***	***$ 834,800***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 500,000	*$ 370,000*	*$ 630,000*
Total Capital Cost				**$ 1,162,000**	***$ 861,100***	***$ 1,464,800***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Small Lot Residential – High Massing**
Pathway Code	**SLRHM2** *Retention: 24 mm*
Total Parcel Area	375 sq. m.
Building Roof/Footprint Area	188 sq. m.
Building (above-grade) Gross Floor Area	375 sq. m. *Stories: 2*
Parkade (below-grade) Gross Floor Area	0 sq. m. *Levels: 0*

Description	Quantity	Unit	Baseline Unit Cost	Total	*AACE Class 5 Cost Range* Low	*AACE Class 5 Cost Range* High
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	5	sq. m.	$ 2,100	$ 10,500	*$ 7,400*	*$ 15,800*
Bioretention with Underdrain	0	sq. m.	$ 2,600	$ -	*$ -*	*$ -*
Permeable Pavement	4	sq. m.	$ 250	$ 1,000	*$ 700*	*$ 1,500*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	140	sq. m.	$ 430	$ 60,200	*$ 42,100*	*$ 90,300*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ 71,700**	***$ 50,200***	***$ 107,600***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	375	sq. m.	$ 2,530	$ 950,000	*$ 730,000*	*$ 1,170,000*
Parkade Structure (below-grade)	0	sq. m.	$ -	$ -	*$ -*	*$ -*
At-grade Landscaping	108	sq. m.	$ 17	$ 1,800	*$ 1,300*	*$ 2,700*
At-grade Paving	71	sq. m.	$ 188	$ 10,000	*$ 10,000*	*$ 20,000*
Subtotal				**$ 961,800**	***$ 741,300***	***$ 1,192,700***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 1,033,500**	***$ 791,500***	***$ 1,300,300***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 780,000	*$ 590,000*	*$ 980,000*
Total Capital Cost				**$ 1,813,500**	***$ 1,381,500***	***$ 2,280,300***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Small Lot Residential – High Massing**
Pathway Code	**SLRHM3** *Retention: 24 mm*
Total Parcel Area	375 sq. m.
Building Roof/Footprint Area	188 sq. m.
Building (above-grade) Gross Floor Area	375 sq. m. *Stories: 2*
Parkade (below-grade) Gross Floor Area	0 sq. m. *Levels: 0*

Description	Quantity	Unit	Baseline Unit Cost	Total	*AACE Class 5 Cost Range Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	15	sq. m.	$ 2,100	$ 31,500	*$ 22,100*	*$ 47,300*
Bioretention with Underdrain	0	sq. m.	$ 2,600	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	0	sq. m.	$ 430	$ -	*$ -*	*$ -*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ 31,500**	***$ 22,100***	***$ 47,300***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	375	sq. m.	$ 2,530	$ 950,000	*$ 730,000*	*$ 1,170,000*
Parkade Structure (below-grade)	0	sq. m.	$ -	$ -	*$ -*	*$ -*
At-grade Landscaping	98	sq. m.	$ 17	$ 1,700	*$ 1,200*	*$ 2,500*
At-grade Paving	75	sq. m.	$ 188	$ 10,000	*$ 10,000*	*$ 20,000*
Subtotal				**$ 961,700**	***$ 741,200***	***$ 1,192,500***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 993,200**	***$ 763,300***	***$ 1,239,800***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 740,000	*$ 570,000*	*$ 930,000*
Total Capital Cost				**$ 1,733,200**	***$ 1,333,300***	***$ 2,169,800***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Small Lot Residential – High Massing**
Pathway Code	**SLRHM4** *Retention: 48 mm*
Total Parcel Area	375 sq. m.
Building Roof/Footprint Area	188 sq. m.
Building (above-grade) Gross Floor Area	375 sq. m. *Stories: 2*
Parkade (below-grade) Gross Floor Area	0 sq. m. *Levels: 0*

Description	**Quantity**	**Unit**		**Baseline Unit Cost**		**Total**	*AACE Class 5 Cost Range*	*Low*		*High*
Tier 1 & 2 Rainwater Management (GRI)										
Bioretention	0	sq. m.	$	2,100	$	-	*$*	*-*	*$*	*-*
Bioretention with Underdrain	0	sq. m.	$	2,600	$	-	*$*	*-*	*$*	*-*
Permeable Pavement	0	sq. m.	$	250	$	-	*$*	*-*	*$*	*-*
Subsurface Infiltration	8	cu. m.	$	2,200	$	18,500	*$*	*12,900*	*$*	*27,700*
Resilient Roof - Intensive (450mm)	94	sq. m.	$	430	$	40,400	*$*	*28,300*	*$*	*60,600*
Resilient Roof - Extensive (100mm)	0	sq. m.	$	220	$	-	*$*	*-*	*$*	*-*
Rainwater Harvesting - Storage Tank	0	cu. m.	$	1,300	$	-	*$*	*-*	*$*	*-*
RWH - Treatment & Plumbing	0	sq. m.	$	36	$	-	*$*	*-*	*$*	*-*
Subtotal					**$**	**58,900**	***$***	***41,200***	***$***	***88,300***
Tier 3 Rainwater Management										
Detention Tank	0	cu. m.	$	900	$	-	*$*	*-*	*$*	*-*
Proprietary WQ Treatment Device	0	each	$	-	$	-	*$*	*-*	*$*	*-*
Subtotal					**$**	**-**	***$***	***-***	***$***	***-***
Other Project Components										
Building Structure (above-grade)	375	sq. m.	$	2,530	$	950,000	*$*	*730,000*	*$*	*1,170,000*
Parkade Structure (below-grade)	0	sq. m.	$	-	$	-	*$*	*-*	*$*	*-*
At-grade Landscaping	113	sq. m.	$	17	$	1,900	*$*	*1,300*	*$*	*2,900*
At-grade Paving	75	sq. m.	$	188	$	10,000	*$*	*10,000*	*$*	*20,000*
Subtotal					**$**	**961,900**	***$***	***741,300***	***$***	***1,192,900***
Total Construction Cost	*(57% of Total Capital Cost)*				**$**	**1,020,800**	***$***	***782,500***	***$***	***1,281,200***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*				$	770,000	*$*	*590,000*	*$*	*960,000*
Total Capital Cost					**$**	**1,790,800**	***$***	***1,372,500***	***$***	***2,241,200***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Small Lot Residential – High Massing**
Pathway Code	**SLRHM5** *Retention: 0 mm*
Total Parcel Area	375 sq. m.
Building Roof/Footprint Area	188 sq. m.
Building (above-grade) Gross Floor Area	375 sq. m. *Stories: 2*
Parkade (below-grade) Gross Floor Area	0 sq. m. *Levels: 0*

Description	Quantity	Unit	Baseline Unit Cost		Total	*AACE Class 5 Cost Range Low*		*High*	
Tier 1 & 2 Rainwater Management (GRI)									
Bioretention	0	sq. m.	$	2,100	$ -	*$*	*-*	*$*	*-*
Bioretention with Underdrain	0	sq. m.	$	2,600	$ -	*$*	*-*	*$*	*-*
Permeable Pavement	0	sq. m.	$	250	$ -	*$*	*-*	*$*	*-*
Subsurface Infiltration	0	cu. m.	$	2,200	$ -	*$*	*-*	*$*	*-*
Resilient Roof - Intensive (450mm)	0	sq. m.	$	430	$ -	*$*	*-*	*$*	*-*
Resilient Roof - Extensive (100mm)	0	sq. m.	$	220	$ -	*$*	*-*	*$*	*-*
Rainwater Harvesting - Storage Tank	0	cu. m.	$	1,300	$ -	*$*	*-*	*$*	*-*
RWH - Treatment & Plumbing	0	sq. m.	$	36	$ -	*$*	*-*	*$*	*-*
Subtotal					**$ -**	***$***	***-***	***$***	***-***
Tier 3 Rainwater Management									
Detention Tank	6.3	cu. m.	$	900	$ 5,700	*$*	*4,000*	*$*	*8,500*
Proprietary WQ Treatment Device	1	each	$	35,100	$ 35,100	*$*	*26,000*	*$*	*44,000*
Subtotal					**$ 40,800**	***$***	***30,000***	***$***	***52,500***
Other Project Components									
Building Structure (above-grade)	375	sq. m.	$	2,530	$ 950,000	*$*	*730,000*	*$*	*1,170,000*
Parkade Structure (below-grade)	0	sq. m.	$	-	$ -	*$*	*-*	*$*	*-*
At-grade Landscaping	113	sq. m.	$	17	$ 1,900	*$*	*1,300*	*$*	*2,900*
At-grade Paving	75	sq. m.	$	188	$ 10,000	*$*	*10,000*	*$*	*20,000*
Subtotal					**$ 961,900**	***$***	***741,300***	***$***	***1,192,900***
Total Construction Cost	*(57% of Total Capital Cost)*				**$ 1,002,700**	***$***	***771,300***	***$***	***1,245,400***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*				$ 750,000	*$*	*580,000*	*$*	*930,000*
Total Capital Cost					**$ 1,752,700**	***$***	***1,351,300***	***$***	***2,175,400***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Low-Rise Residential & Mixed-Use**	
Pathway Code	**LRMU2**	*Retention: 24 mm*
Total Parcel Area	2,500 sq. m.	
Building Roof/Footprint Area	1,000 sq. m.	
Building (above-grade) Gross Floor Area	3,000 sq. m.	*Stories: 3*
Parkade (below-grade) Gross Floor Area	2,250 sq. m.	*Levels: 1*

Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*AACE Class 5 Cost Range* *Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	60	sq. m.	$ 1,500	$ 90,000	*$ 63,000*	*$ 135,000*
Bioretention with Underdrain	0	sq. m.	$ 2,000	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	750	sq. m.	$ 430	$ 322,500	*$ 225,800*	*$ 483,800*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ 412,500**	***$ 288,800***	***$ 618,800***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	3,000	sq. m.	$ 2,772	$ 8,320,000	*$ 6,940,000*	*$ 9,690,000*
Parkade Structure (below-grade)	2,250	sq. m.	$ 1,884	$ 4,240,000	*$ 2,910,000*	*$ 5,570,000*
At-grade Landscaping	240	sq. m.	$ 17	$ 4,100	*$ 2,900*	*$ 6,100*
At-grade Paving	1,200	sq. m.	$ 188	$ 230,000	*$ 130,000*	*$ 320,000*
Subtotal				**$ 12,794,100**	***$ 9,982,900***	***$ 15,586,100***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 13,206,600**	***$ 10,271,700***	***$ 16,204,900***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 9,900,000	*$ 7,700,000*	*$ 12,150,000*
Total Capital Cost				**$ 23,106,600**	***$ 17,971,700***	***$ 28,354,900***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Low-Rise Residential & Mixed-Use**
Pathway Code	**LRMU3** *Retention: 24 mm*
Total Parcel Area	2,500 sq. m.
Building Roof/Footprint Area	1,000 sq. m.
Building (above-grade) Gross Floor Area	3,000 sq. m. *Stories: 3*
Parkade (below-grade) Gross Floor Area	2,250 sq. m. *Levels: 1*

Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*AACE Class 5 Cost Range* *Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	130	sq. m.	$ 1,500	$ 195,000	*$ 136,500*	*$ 292,500*
Bioretention with Underdrain	0	sq. m.	$ 2,000	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	0	sq. m.	$ 430	$ -	*$ -*	*$ -*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ 195,000**	***$ 136,500***	***$ 292,500***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	3,000	sq. m.	$ 2,772	$ 8,320,000	*$ 6,940,000*	*$ 9,690,000*
Parkade Structure (below-grade)	2,250	sq. m.	$ 1,884	$ 4,240,000	*$ 2,910,000*	*$ 5,570,000*
At-grade Landscaping	170	sq. m.	$ 17	$ 2,900	*$ 2,000*	*$ 4,300*
At-grade Paving	1,200	sq. m.	$ 188	$ 230,000	*$ 130,000*	*$ 320,000*
Subtotal				**$ 12,792,900**	***$ 9,982,000***	***$ 15,584,300***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 12,987,900**	***$ 10,118,500***	***$ 15,876,800***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 9,740,000	*$ 7,590,000*	*$ 11,910,000*
Total Capital Cost				**$ 22,727,900**	***$ 17,708,500***	***$ 27,786,800***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Low-Rise Residential & Mixed-Use**	
Pathway Code	**LRMU4**	*Retention: 48 mm*
Total Parcel Area	2,500 sq. m.	
Building Roof/Footprint Area	1,000 sq. m.	
Building (above-grade) Gross Floor Area	3,000 sq. m.	*Stories: 3*
Parkade (below-grade) Gross Floor Area	2,250 sq. m.	*Levels: 1*

Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*AACE Class 5 Cost Range Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	130	sq. m.	$ 1,500	$ 195,000	*$ 136,500*	*$ 292,500*
Bioretention with Underdrain	0	sq. m.	$ 2,000	$ -	*$ -*	*$ -*
Permeable Pavement	350	sq. m.	$ 250	$ 87,500	*$ 61,300*	*$ 131,300*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	0	sq. m.	$ 430	$ -	*$ -*	*$ -*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ 282,500**	***$ 197,800***	***$ 423,800***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	3,000	sq. m.	$ 2,772	$ 8,320,000	*$ 6,940,000*	*$ 9,690,000*
Parkade Structure (below-grade)	2,250	sq. m.	$ 1,884	$ 4,240,000	*$ 2,910,000*	*$ 5,570,000*
At-grade Landscaping	170	sq. m.	$ 17	$ 2,900	*$ 2,000*	*$ 4,300*
At-grade Paving	850	sq. m.	$ 188	$ 160,000	*$ 90,000*	*$ 230,000*
Subtotal				**$ 12,722,900**	***$ 9,942,000***	***$ 15,494,300***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 13,005,400**	***$ 10,139,800***	***$ 15,918,100***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 9,750,000	*$ 7,600,000*	*$ 11,940,000*
Total Capital Cost				**$ 22,755,400**	***$ 17,739,800***	***$ 27,858,100***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Low-Rise Residential & Mixed-Use**
Pathway Code	**LRMU5** *Retention: 0 mm*
Total Parcel Area	2,500 sq. m.
Building Roof/Footprint Area	1,000 sq. m.
Building (above-grade) Gross Floor Area	3,000 sq. m. *Stories: 3*
Parkade (below-grade) Gross Floor Area	2,250 sq. m. *Levels: 1*

Description	Quantity	Unit	Baseline Unit Cost	Total	*AACE Class 5 Cost Range* Low	High
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	0	sq. m.	$ 1,500	$ -	*$ -*	*$ -*
Bioretention with Underdrain	0	sq. m.	$ 2,000	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	0	sq. m.	$ 430	$ -	*$ -*	*$ -*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Tier 3 Rainwater Management						
Detention Tank	53	cu. m.	$ 900	$ 47,700	*$ 33,400*	*$ 71,600*
Proprietary WQ Treatment Device	1	each	$ 41,600	$ 41,600	*$ 31,000*	*$ 52,000*
Subtotal				**$ 89,300**	***$ 64,400***	***$ 123,600***
Other Project Components						
Building Structure (above-grade)	3,000	sq. m.	$ 2,772	$ 8,320,000	*$ 6,940,000*	*$ 9,690,000*
Parkade Structure (below-grade)	2,250	sq. m.	$ 1,884	$ 4,240,000	*$ 2,910,000*	*$ 5,570,000*
At-grade Landscaping	300	sq. m.	$ 17	$ 5,100	*$ 3,600*	*$ 7,700*
At-grade Paving	1,200	sq. m.	$ 188	$ 230,000	*$ 130,000*	*$ 320,000*
Subtotal				**$ 12,795,100**	***$ 9,983,600***	***$ 15,587,700***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 12,884,400**	***$ 10,048,000***	***$ 15,711,300***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 9,660,000	*$ 7,540,000*	*$ 11,780,000*
Total Capital Cost				**$ 22,544,400**	***$ 17,588,000***	***$ 27,491,300***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Mid-Rise Residential & Mixed-Use**	
Pathway Code	**MRMU1**	*Retention: 24 mm*
Total Parcel Area	3,000 sq. m.	
Building Roof/Footprint Area	1,950 sq. m.	
Building (above-grade) Gross Floor Area	11,700 sq. m.	*Stories: 6*
Parkade (below-grade) Gross Floor Area	5,700 sq. m.	*Levels: 2*

Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*AACE Class 5 Cost Range Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	0	sq. m.	$ 2,100	$ -	*$ -*	*$ -*
Bioretention with Underdrain	0	sq. m.	$ 2,600	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	750	sq. m.	$ 430	$ 322,500	*$ 225,800*	*$ 483,800*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	50	cu. m.	$ 1,300	$ 65,000	*$ 45,500*	*$ 97,500*
RWH - Treatment & Plumbing	11,700	sq. m.	$ 36	$ 421,200	*$ 180,200*	*$ 386,100*
Subtotal				**$ 808,700**	***$ 451,500***	***$ 967,400***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	11,700	sq. m.	$ 3,202	$ 37,470,000	*$ 30,860,000*	*$ 44,080,000*
Parkade Structure (below-grade)	5,700	sq. m.	$ 1,884	$ 10,740,000	*$ 7,360,000*	*$ 14,110,000*
At-grade Landscaping	158	sq. m.	$ 17	$ 2,700	*$ 1,900*	*$ 4,000*
At-grade Paving	893	sq. m.	$ 188	$ 170,000	*$ 100,000*	*$ 240,000*
Subtotal				**$ 48,382,700**	***$ 38,321,900***	***$ 58,434,000***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 49,191,400**	***$ 38,773,400***	***$ 59,401,400***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 36,890,000	*$ 29,080,000*	*$ 44,550,000*
Total Capital Cost				**$ 86,081,400**	***$ 67,853,400***	***$ 103,951,400***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Mid-Rise Residential & Mixed-Use**
Pathway Code	**MRMU2** *Retention: 24 mm*
Total Parcel Area	3,000 sq. m.
Building Roof/Footprint Area	1,950 sq. m.
Building (above-grade) Gross Floor Area	11,700 sq. m. *Stories: 6*
Parkade (below-grade) Gross Floor Area	5,700 sq. m. *Levels: 2*

Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*AACE Class 5 Cost Range* *Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	20	sq. m.	$ 2,100	$ 42,000	*$ 29,400*	*$ 63,000*
Bioretention with Underdrain	0	sq. m.	$ 2,600	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	450	sq. m.	$ 430	$ 193,500	*$ 135,500*	*$ 290,300*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	50	cu. m.	$ 1,300	$ 65,000	*$ 45,500*	*$ 97,500*
RWH - Treatment & Plumbing	11,700	sq. m.	$ 36	$ 421,200	*$ 180,200*	*$ 386,100*
Subtotal				**$ 721,700**	***$ 390,600***	***$ 836,900***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	11,700	sq. m.	$ 3,202	$ 37,470,000	*$ 30,860,000*	*$ 44,080,000*
Parkade Structure (below-grade)	5,700	sq. m.	$ 1,884	$ 10,740,000	*$ 7,360,000*	*$ 14,110,000*
At-grade Landscaping	138	sq. m.	$ 17	$ 2,300	*$ 1,600*	*$ 3,500*
At-grade Paving	893	sq. m.	$ 188	$ 170,000	*$ 100,000*	*$ 240,000*
Subtotal				**$ 48,382,300**	***$ 38,321,600***	***$ 58,433,500***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 49,104,000**	***$ 38,712,200***	***$ 59,270,400***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 36,830,000	*$ 29,030,000*	*$ 44,450,000*
Total Capital Cost				**$ 85,934,000**	***$ 67,742,200***	***$ 103,720,400***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Mid-Rise Residential & Mixed-Use**
Pathway Code	**MRMU3** *Retention: 24 mm*
Total Parcel Area	3,000 sq. m.
Building Roof/Footprint Area	1,950 sq. m.
Building (above-grade) Gross Floor Area	11,700 sq. m. *Stories: 6*
Parkade (below-grade) Gross Floor Area	5,700 sq. m. *Levels: 2*

Description	Quantity	Unit		Baseline Unit Cost		Total		*AACE Class 5 Cost Range* *Low*		*High*
Tier 1 & 2 Rainwater Management (GRI)										
Bioretention	80	sq. m.	$	2,100	$	168,000	*$*	*117,600*	*$*	*252,000*
Bioretention with Underdrain	0	sq. m.	$	2,600	$	-	*$*	*-*	*$*	*-*
Permeable Pavement	300	sq. m.	$	250	$	75,000	*$*	*52,500*	*$*	*112,500*
Subsurface Infiltration	0	cu. m.	$	2,200	$	-	*$*	*-*	*$*	*-*
Resilient Roof - Intensive (450mm)	0	sq. m.	$	430	$	-	*$*	*-*	*$*	*-*
Resilient Roof - Extensive (100mm)	0	sq. m.	$	220	$	-	*$*	*-*	*$*	*-*
Rainwater Harvesting - Storage Tank	0	cu. m.	$	1,300	$	-	*$*	*-*	*$*	*-*
RWH - Treatment & Plumbing	0	sq. m.	$	36	$	-	*$*	*-*	*$*	*-*
Subtotal					**$**	**243,000**	***$***	***170,100***	***$***	***364,500***
Tier 3 Rainwater Management										
Detention Tank	0	cu. m.	$	900	$	-	*$*	*-*	*$*	*-*
Proprietary WQ Treatment Device	0	each	$	-	$	-	*$*	*-*	*$*	*-*
Subtotal					**$**	**-**	***$***	***-***	***$***	***-***
Other Project Components										
Building Structure (above-grade)	11,700	sq. m.	$	3,202	$	37,470,000	*$*	*30,860,000*	*$*	*44,080,000*
Parkade Structure (below-grade)	5,700	sq. m.	$	1,884	$	10,740,000	*$*	*7,360,000*	*$*	*14,110,000*
At-grade Landscaping	78	sq. m.	$	17	$	1,300	*$*	*900*	*$*	*2,000*
At-grade Paving	593	sq. m.	$	188	$	110,000	*$*	*60,000*	*$*	*160,000*
Subtotal					**$**	**48,321,300**	***$***	***38,280,900***	***$***	***58,352,000***
Total Construction Cost	*(57% of Total Capital Cost)*				**$**	**48,564,300**	***$***	***38,451,000***	***$***	***58,716,500***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*				$	36,420,000	*$*	*28,840,000*	*$*	*44,040,000*
Total Capital Cost					**$**	**84,984,300**	***$***	***67,291,000***	***$***	***102,756,500***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Mid-Rise Residential & Mixed-Use**	
Pathway Code	**MRMU4**	*Retention: 48 mm*
Total Parcel Area	3,000 sq. m.	
Building Roof/Footprint Area	1,950 sq. m.	
Building (above-grade) Gross Floor Area	11,700 sq. m.	*Stories: 6*
Parkade (below-grade) Gross Floor Area	5,700 sq. m.	*Levels: 2*

Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*AACE Class 5 Cost Range* *Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	0	sq. m.	$ 2,100	$ -	*$ -*	*$ -*
Bioretention with Underdrain	0	sq. m.	$ 2,600	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	86	cu. m.	$ 2,200	$ 189,200	*$ 132,400*	*$ 283,800*
Resilient Roof - Intensive (450mm)	975	sq. m.	$ 430	$ 419,300	*$ 293,500*	*$ 628,900*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ 608,500**	***$ 425,900***	***$ 912,700***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	11,700	sq. m.	$ 3,202	$ 37,470,000	*$ 30,860,000*	*$ 44,080,000*
Parkade Structure (below-grade)	5,700	sq. m.	$ 1,884	$ 10,740,000	*$ 7,360,000*	*$ 14,110,000*
At-grade Landscaping	158	sq. m.	$ 17	$ 2,700	*$ 1,900*	*$ 4,000*
At-grade Paving	893	sq. m.	$ 188	$ 170,000	*$ 100,000*	*$ 240,000*
Subtotal				**$ 48,382,700**	***$ 38,321,900***	***$ 58,434,000***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 48,991,200**	***$ 38,747,800***	***$ 59,346,700***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 36,740,000	*$ 29,060,000*	*$ 44,510,000*
Total Capital Cost				**$ 85,731,200**	***$ 67,807,800***	***$ 103,856,700***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Mid-Rise Residential & Mixed-Use**
Pathway Code	**MRMU5** *Retention: 0 mm*
Total Parcel Area	3,000 sq. m.
Building Roof/Footprint Area	1,950 sq. m.
Building (above-grade) Gross Floor Area	11,700 sq. m. *Stories: 6*
Parkade (below-grade) Gross Floor Area	5,700 sq. m. *Levels: 2*

Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*AACE Class 5 Cost Range* *Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	0	sq. m.	$ 2,100	$ -	*$ -*	*$ -*
Bioretention with Underdrain	0	sq. m.	$ 2,600	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	0	sq. m.	$ 430	$ -	*$ -*	*$ -*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Tier 3 Rainwater Management						
Detention Tank	68	cu. m.	$ 900	$ 61,200	*$ 42,800*	*$ 91,800*
Proprietary WQ Treatment Device	1	each	$ 42,700	$ 42,700	*$ 32,000*	*$ 53,000*
Subtotal				**$ 103,900**	***$ 74,800***	***$ 144,800***
Other Project Components						
Building Structure (above-grade)	11,700	sq. m.	$ 3,202	$ 37,470,000	*$ 30,860,000*	*$ 44,080,000*
Parkade Structure (below-grade)	5,700	sq. m.	$ 1,884	$ 10,740,000	*$ 7,360,000*	*$ 14,110,000*
At-grade Landscaping	158	sq. m.	$ 17	$ 2,700	*$ 1,900*	*$ 4,000*
At-grade Paving	893	sq. m.	$ 188	$ 170,000	*$ 100,000*	*$ 240,000*
Subtotal				**$ 48,382,700**	***$ 38,321,900***	***$ 58,434,000***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 48,486,600**	***$ 38,396,700***	***$ 58,578,800***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 36,360,000	*$ 28,800,000*	*$ 43,930,000*
Total Capital Cost				**$ 84,846,600**	***$ 67,196,700***	***$ 102,508,800***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**High-Rise Residential & Mixed-Use**	
Pathway Code	**HRMU1**	*Retention: 24 mm*
Total Parcel Area	1,200 sq. m.	
Building Roof/Footprint Area	840 sq. m.	
Building (above-grade) Gross Floor Area	16,800 sq. m.	*Stories: 20*
Parkade (below-grade) Gross Floor Area	3,240 sq. m.	*Levels: 3*

Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*AACE Class 5 Cost Range* *Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	0	sq. m.	$ 2,100	$ -	*$ -*	*$ -*
Bioretention with Underdrain	0	sq. m.	$ 2,600	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	0	sq. m.	$ 430	$ -	*$ -*	*$ -*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	15	cu. m.	$ 1,300	$ 19,500	*$ 13,700*	*$ 29,300*
RWH - Treatment & Plumbing	16,800	sq. m.	$ 36	$ 604,800	*$ 258,700*	*$ 554,400*
Subtotal				**$ 624,300**	***$ 272,400***	***$ 583,700***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	16,800	sq. m.	$ 3,929	$ 66,000,000	*$ 59,680,000*	*$ 72,330,000*
Parkade Structure (below-grade)	3,240	sq. m.	$ 1,884	$ 6,100,000	*$ 4,190,000*	*$ 8,020,000*
At-grade Landscaping	120	sq. m.	$ 17	$ 2,000	*$ 1,400*	*$ 3,100*
At-grade Paving	240	sq. m.	$ 188	$ 50,000	*$ 30,000*	*$ 60,000*
Subtotal				**$ 72,152,000**	***$ 63,901,400***	***$ 80,413,100***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 72,776,300**	***$ 64,173,800***	***$ 80,996,800***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 54,580,000	*$ 48,130,000*	*$ 60,750,000*
Total Capital Cost				**$ 127,356,300**	***$ 112,303,800***	***$ 141,746,800***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**High-Rise Residential & Mixed-Use**	
Pathway Code	**HRMU2**	*Retention: 24 mm*
Total Parcel Area	1,200 sq. m.	
Building Roof/Footprint Area	840 sq. m.	
Building (above-grade) Gross Floor Area	16,800 sq. m.	*Stories: 20*
Parkade (below-grade) Gross Floor Area	3,240 sq. m.	*Levels: 3*

					AACE Class 5 Cost Range	
Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	25	sq. m.	$ 2,100	$ 52,500	*$ 36,800*	*$ 78,800*
Bioretention with Underdrain	0	sq. m.	$ 2,600	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	420	sq. m.	$ 430	$ 180,600	*$ 126,400*	*$ 270,900*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ 233,100**	***$ 163,200***	***$ 349,700***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	16,800	sq. m.	$ 3,929	$ 66,000,000	*$ 59,680,000*	*$ 72,330,000*
Parkade Structure (below-grade)	3,240	sq. m.	$ 1,884	$ 6,100,000	*$ 4,190,000*	*$ 8,020,000*
At-grade Landscaping	95	sq. m.	$ 17	$ 1,600	*$ 1,100*	*$ 2,400*
At-grade Paving	240	sq. m.	$ 188	$ 50,000	*$ 30,000*	*$ 60,000*
Subtotal				**$ 72,151,600**	***$ 63,901,100***	***$ 80,412,400***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 72,384,700**	***$ 64,064,300***	***$ 80,762,100***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 54,290,000	*$ 48,050,000*	*$ 60,570,000*
Total Capital Cost				**$ 126,674,700**	***$ 112,114,300***	***$ 141,332,100***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**High-Rise Residential & Mixed-Use**	
Pathway Code	**HRMU3**	*Retention: 24 mm*
Total Parcel Area	1,200 sq. m.	
Building Roof/Footprint Area	840 sq. m.	
Building (above-grade) Gross Floor Area	16,800 sq. m.	*Stories: 20*
Parkade (below-grade) Gross Floor Area	3,240 sq. m.	*Levels: 3*

Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*AACE Class 5 Cost Range* *Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	55	sq. m.	$ 2,100	$ 115,500	*$ 80,900*	*$ 173,300*
Bioretention with Underdrain	0	sq. m.	$ 2,600	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	0	sq. m.	$ 430	$ -	*$ -*	*$ -*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ 115,500**	***$ 80,900***	***$ 173,300***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	16,800	sq. m.	$ 3,929	$ 66,000,000	*$ 59,680,000*	*$ 72,330,000*
Parkade Structure (below-grade)	3,240	sq. m.	$ 1,884	$ 6,100,000	*$ 4,190,000*	*$ 8,020,000*
At-grade Landscaping	65	sq. m.	$ 17	$ 1,100	*$ 800*	*$ 1,700*
At-grade Paving	240	sq. m.	$ 188	$ 50,000	*$ 30,000*	*$ 60,000*
Subtotal				**$ 72,151,100**	***$ 63,900,800***	***$ 80,411,700***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 72,266,600**	***$ 63,981,700***	***$ 80,585,000***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 54,200,000	*$ 47,990,000*	*$ 60,440,000*
Total Capital Cost				**$ 126,466,600**	***$ 111,971,700***	***$ 141,025,000***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**High-Rise Residential & Mixed-Use**
Pathway Code	**HRMU4** *Retention: 48 mm*
Total Parcel Area	1,200 sq. m.
Building Roof/Footprint Area	840 sq. m.
Building (above-grade) Gross Floor Area	16,800 sq. m. *Stories: 20*
Parkade (below-grade) Gross Floor Area	3,240 sq. m. *Levels: 3*

Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*AACE Class 5 Cost Range* *Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	100	sq. m.	$ 2,100	$ 210,000	*$ 147,000*	*$ 315,000*
Bioretention with Underdrain	0	sq. m.	$ 2,600	$ -	*$ -*	*$ -*
Permeable Pavement	50	sq. m.	$ 250	$ 12,500	*$ 8,800*	*$ 18,800*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	0	sq. m.	$ 430	$ -	*$ -*	*$ -*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ 222,500**	***$ 155,800***	***$ 333,800***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	16,800	sq. m.	$ 3,929	$ 66,000,000	*$ 59,680,000*	*$ 72,330,000*
Parkade Structure (below-grade)	3,240	sq. m.	$ 1,884	$ 6,100,000	*$ 4,190,000*	*$ 8,020,000*
At-grade Landscaping	20	sq. m.	$ 17	$ 300	*$ 200*	*$ 500*
At-grade Paving	190	sq. m.	$ 188	$ 40,000	*$ 20,000*	*$ 50,000*
Subtotal				**$ 72,140,300**	***$ 63,890,200***	***$ 80,400,500***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 72,362,800**	***$ 64,046,000***	***$ 80,734,300***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 54,270,000	*$ 48,030,000*	*$ 60,550,000*
Total Capital Cost				**$ 126,632,800**	***$ 112,076,000***	***$ 141,284,300***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**High-Rise Residential & Mixed-Use**
Pathway Code	**HRMU5** *Retention: 0 mm*
Total Parcel Area	1,200 sq. m.
Building Roof/Footprint Area	840 sq. m.
Building (above-grade) Gross Floor Area	16,800 sq. m. *Stories: 20*
Parkade (below-grade) Gross Floor Area	3,240 sq. m. *Levels: 3*

Description	Quantity	Unit	Baseline Unit Cost	Total	*AACE Class 5 Cost Range* Low	High
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	0	sq. m.	$ 2,100	$ -	*$ -*	*$ -*
Bioretention with Underdrain	0	sq. m.	$ 2,600	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	0	sq. m.	$ 430	$ -	*$ -*	*$ -*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Tier 3 Rainwater Management						
Detention Tank	26	cu. m.	$ 900	$ 23,400	*$ 16,400*	*$ 35,100*
Proprietary WQ Treatment Device	1	each	$ 39,000	$ 39,000	*$ 29,000*	*$ 49,000*
Subtotal				**$ 62,400**	***$ 45,400***	***$ 84,100***
Other Project Components						
Building Structure (above-grade)	16,800	sq. m.	$ 3,929	$ 66,000,000	*$ 59,680,000*	*$ 72,330,000*
Parkade Structure (below-grade)	3,240	sq. m.	$ 1,884	$ 6,100,000	*$ 4,190,000*	*$ 8,020,000*
At-grade Landscaping	120	sq. m.	$ 17	$ 2,000	*$ 1,400*	*$ 3,100*
At-grade Paving	240	sq. m.	$ 188	$ 50,000	*$ 30,000*	*$ 60,000*
Subtotal				**$ 72,152,000**	***$ 63,901,400***	***$ 80,413,100***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 72,214,400**	***$ 63,946,800***	***$ 80,497,200***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 54,160,000	*$ 47,960,000*	*$ 60,370,000*
Total Capital Cost				**$ 126,374,400**	***$ 111,906,800***	***$ 140,867,200***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Low/Mid-Rise Non-Residential**	
Pathway Code	**LMNR3**	*Retention: 24 mm*
Total Parcel Area	2,500 sq. m.	
Building Roof/Footprint Area	1,000 sq. m.	
Building (above-grade) Gross Floor Area	3,000 sq. m.	*Stories: 3*
Parkade (below-grade) Gross Floor Area	2,500 sq. m.	*Levels: 1*

Description	Quantity	Unit	Baseline Unit Cost	Total	*AACE Class 5 Cost Range Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	70	sq. m.	$ 1,500	$ 105,000	*$ 73,500*	*$ 157,500*
Bioretention with Underdrain	0	sq. m.	$ 2,000	$ -	*$ -*	*$ -*
Permeable Pavement	400	sq. m.	$ 250	$ 100,000	*$ 70,000*	*$ 150,000*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	0	sq. m.	$ 430	$ -	*$ -*	*$ -*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ 205,000**	***$ 143,500***	***$ 307,500***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	3,000	sq. m.	$ 3,579	$ 10,740,000	*$ 9,360,000*	*$ 12,110,000*
Parkade Structure (below-grade)	2,500	sq. m.	$ 1,884	$ 4,710,000	*$ 3,230,000*	*$ 6,190,000*
At-grade Landscaping	155	sq. m.	$ 17	$ 2,600	*$ 1,800*	*$ 4,000*
At-grade Paving	875	sq. m.	$ 188	$ 160,000	*$ 90,000*	*$ 240,000*
Subtotal				**$ 15,612,600**	***$ 12,681,800***	***$ 18,544,000***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 15,817,600**	***$ 12,825,300***	***$ 18,851,500***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 11,860,000	*$ 9,620,000*	*$ 14,140,000*
Total Capital Cost				**$ 27,677,600**	***$ 22,445,300***	***$ 32,991,500***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Low/Mid-Rise Non-Residential**
Pathway Code	**LMNR4** *Retention: 48 mm*
Total Parcel Area	2,500 sq. m.
Building Roof/Footprint Area	1,000 sq. m.
Building (above-grade) Gross Floor Area	3,000 sq. m. *Stories: 3*
Parkade (below-grade) Gross Floor Area	2,500 sq. m. *Levels: 1*

				Baseline			*AACE Class 5 Cost Range*			
Description	**Quantity**	**Unit**		**Unit Cost**		**Total**		*Low*		*High*
Tier 1 & 2 Rainwater Management (GRI)										
Bioretention	70	sq. m.	$	1,500	$	105,000	*$*	*73,500*	*$*	*157,500*
Bioretention with Underdrain	0	sq. m.	$	2,000	$	-	*$*	*-*	*$*	*-*
Permeable Pavement	400	sq. m.	$	250	$	100,000	*$*	*70,000*	*$*	*150,000*
Subsurface Infiltration	0	cu. m.	$	2,200	$	-	*$*	*-*	*$*	*-*
Resilient Roof - Intensive (450mm)	500	sq. m.	$	430	$	215,000	*$*	*150,500*	*$*	*322,500*
Resilient Roof - Extensive (100mm)	0	sq. m.	$	220	$	-	*$*	*-*	*$*	*-*
Rainwater Harvesting - Storage Tank	0	cu. m.	$	1,300	$	-	*$*	*-*	*$*	*-*
RWH - Treatment & Plumbing	0	sq. m.	$	36	$	-	*$*	*-*	*$*	*-*
Subtotal					**$**	**420,000**	***$***	***294,000***	***$***	***630,000***
Tier 3 Rainwater Management										
Detention Tank	0	cu. m.	$	900	$	-	*$*	*-*	*$*	*-*
Proprietary WQ Treatment Device	0	each	$	-	$	-	*$*	*-*	*$*	*-*
Subtotal					**$**	**-**	***$***	***-***	***$***	***-***
Other Project Components										
Building Structure (above-grade)	3,000	sq. m.	$	3,579	$	10,740,000	*$*	*9,360,000*	*$*	*12,110,000*
Parkade Structure (below-grade)	2,500	sq. m.	$	1,884	$	4,710,000	*$*	*3,230,000*	*$*	*6,190,000*
At-grade Landscaping	155	sq. m.	$	17	$	2,600	*$*	*1,800*	*$*	*4,000*
At-grade Paving	875	sq. m.	$	188	$	160,000	*$*	*90,000*	*$*	*240,000*
Subtotal					**$**	**15,612,600**	***$***	***12,681,800***	***$***	***18,544,000***
Total Construction Cost	*(57% of Total Capital Cost)*				**$**	**16,032,600**	***$***	***12,975,800***	***$***	***19,174,000***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*				$	12,020,000	*$*	*9,730,000*	*$*	*14,380,000*
Total Capital Cost					**$**	**28,052,600**	***$***	***22,705,800***	***$***	***33,554,000***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**Low/Mid-Rise Non-Residential**
Pathway Code	**LMNR5** *Retention: 0 mm*
Total Parcel Area	2,500 sq. m.
Building Roof/Footprint Area	1,000 sq. m.
Building (above-grade) Gross Floor Area	3,000 sq. m. *Stories: 3*
Parkade (below-grade) Gross Floor Area	2,500 sq. m. *Levels: 1*

Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*AACE Class 5 Cost Range* *Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	0	sq. m.	$ 1,500	$ -	*$ -*	*$ -*
Bioretention with Underdrain	0	sq. m.	$ 2,000	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	0	sq. m.	$ 430	$ -	*$ -*	*$ -*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Tier 3 Rainwater Management						
Detention Tank	55	cu. m.	$ 900	$ 49,500	*$ 34,700*	*$ 74,300*
Proprietary WQ Treatment Device	1	each	$ 42,100	$ 42,100	*$ 32,000*	*$ 53,000*
Subtotal				**$ 91,600**	***$ 66,700***	***$ 127,300***
Other Project Components						
Building Structure (above-grade)	3,000	sq. m.	$ 3,579	$ 10,740,000	*$ 9,360,000*	*$ 12,110,000*
Parkade Structure (below-grade)	2,500	sq. m.	$ 1,884	$ 4,710,000	*$ 3,230,000*	*$ 6,190,000*
At-grade Landscaping	225	sq. m.	$ 17	$ 3,800	*$ 2,700*	*$ 5,700*
At-grade Paving	1,275	sq. m.	$ 188	$ 240,000	*$ 140,000*	*$ 340,000*
Subtotal				**$ 15,693,800**	***$ 12,732,700***	***$ 18,645,700***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 15,785,400**	***$ 12,799,400***	***$ 18,773,000***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 11,840,000	*$ 9,600,000*	*$ 14,080,000*
Total Capital Cost				**$ 27,625,400**	***$ 22,399,400***	***$ 32,853,000***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**High-Rise Non-Residential**	
Pathway Code	**HNR1**	*Retention: 24 mm*
Total Parcel Area	8,000 sq. m.	
Building Roof/Footprint Area	4,400 sq. m.	
Building (above-grade) Gross Floor Area	61,600 sq. m.	*Stories: 14*
Parkade (below-grade) Gross Floor Area	32,000 sq. m.	*Levels: 4*

Description	Quantity	Unit	Baseline Unit Cost	Total	*AACE Class 5 Cost Range Low*	*AACE Class 5 Cost Range High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	0	sq. m.	$ 2,100	$ -	*$ -*	*$ -*
Bioretention with Underdrain	0	sq. m.	$ 2,600	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	2,650	sq. m.	$ 430	$ 1,139,500	*$ 797,700*	*$ 1,709,300*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	130	cu. m.	$ 1,300	$ 169,000	*$ 118,300*	*$ 253,500*
RWH - Treatment & Plumbing	61,600	sq. m.	$ 36	$ 2,217,600	*$ 948,600*	*$ 2,032,800*
Subtotal				**$ 3,526,100**	***$ 1,864,600***	***$ 3,995,600***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	61,600	sq. m.	$ 3,633	$ 223,780,000	*$ 195,600,000*	*$ 251,960,000*
Parkade Structure (below-grade)	32,000	sq. m.	$ 1,884	$ 60,280,000	*$ 41,330,000*	*$ 79,220,000*
At-grade Landscaping	540	sq. m.	$ 17	$ 9,200	*$ 6,400*	*$ 13,800*
At-grade Paving	3,060	sq. m.	$ 188	$ 580,000	*$ 330,000*	*$ 820,000*
Subtotal				**$ 284,649,200**	***$ 237,266,400***	***$ 332,013,800***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 288,175,300**	***$ 239,131,000***	***$ 336,009,400***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 216,130,000	*$ 179,350,000*	*$ 252,010,000*
Total Capital Cost				**$ 504,305,300**	***$ 418,481,000***	***$ 588,019,400***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**High-Rise Non-Residential**	
Pathway Code	**HNR3**	*Retention: 24 mm*
Total Parcel Area	8,000 sq. m.	
Building Roof/Footprint Area	4,400 sq. m.	
Building (above-grade) Gross Floor Area	61,600 sq. m.	*Stories: 14*
Parkade (below-grade) Gross Floor Area	32,000 sq. m.	*Levels: 4*

Description	Quantity	Unit	Baseline Unit Cost	Total	*AACE Class 5 Cost Range* Low	High
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	200	sq. m.	$ 2,100	$ 420,000	*$ 294,000*	*$ 630,000*
Bioretention with Underdrain	0	sq. m.	$ 2,600	$ -	*$ -*	*$ -*
Permeable Pavement	800	sq. m.	$ 250	$ 200,000	*$ 140,000*	*$ 300,000*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	0	sq. m.	$ 430	$ -	*$ -*	*$ -*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ 620,000**	***$ 434,000***	***$ 930,000***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	61,600	sq. m.	$ 3,633	$ 223,780,000	*$ 195,600,000*	*$ 251,960,000*
Parkade Structure (below-grade)	32,000	sq. m.	$ 1,884	$ 60,280,000	*$ 41,330,000*	*$ 79,220,000*
At-grade Landscaping	340	sq. m.	$ 17	$ 5,800	*$ 4,000*	*$ 8,700*
At-grade Paving	2,260	sq. m.	$ 188	$ 430,000	*$ 240,000*	*$ 610,000*
Subtotal				**$ 284,495,800**	***$ 237,174,000***	***$ 331,798,700***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 285,115,800**	***$ 237,608,000***	***$ 332,728,700***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 213,840,000	*$ 178,210,000*	*$ 249,550,000*
Total Capital Cost				**$ 498,955,800**	***$ 415,818,000***	***$ 582,278,700***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**High-Rise Non-Residential**
Pathway Code	**HNR4** *Retention: 48 mm*
Total Parcel Area	8,000 sq. m.
Building Roof/Footprint Area	4,400 sq. m.
Building (above-grade) Gross Floor Area	61,600 sq. m. *Stories: 14*
Parkade (below-grade) Gross Floor Area	32,000 sq. m. *Levels: 4*

Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*AACE Class 5 Cost Range* *Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	200	sq. m.	$ 2,100	$ 420,000	*$ 294,000*	*$ 630,000*
Bioretention with Underdrain	0	sq. m.	$ 2,600	$ -	*$ -*	*$ -*
Permeable Pavement	800	sq. m.	$ 250	$ 200,000	*$ 140,000*	*$ 300,000*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	2,650	sq. m.	$ 430	$ 1,139,500	*$ 797,700*	*$ 1,709,300*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ 1,759,500**	***$ 1,231,700***	***$ 2,639,300***
Tier 3 Rainwater Management						
Detention Tank	0	cu. m.	$ 900	$ -	*$ -*	*$ -*
Proprietary WQ Treatment Device	0	each	$ -	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Other Project Components						
Building Structure (above-grade)	61,600	sq. m.	$ 3,633	$ 223,780,000	*$ 195,600,000*	*$ 251,960,000*
Parkade Structure (below-grade)	32,000	sq. m.	$ 1,884	$ 60,280,000	*$ 41,330,000*	*$ 79,220,000*
At-grade Landscaping	340	sq. m.	$ 17	$ 5,800	*$ 4,000*	*$ 8,700*
At-grade Paving	2,260	sq. m.	$ 188	$ 430,000	*$ 240,000*	*$ 610,000*
Subtotal				**$ 284,495,800**	***$ 237,174,000***	***$ 331,798,700***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 286,255,300**	***$ 238,405,700***	***$ 334,438,000***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 214,690,000	*$ 178,800,000*	*$ 250,830,000*
Total Capital Cost				**$ 500,945,300**	***$ 417,205,700***	***$ 585,268,000***

Task 6 - Pathway Capital Cost Estimate

Building Site Typology	**High-Rise Non-Residential**	
Pathway Code	**HNR5**	*Retention: 0 mm*
Total Parcel Area	8,000 sq. m.	
Building Roof/Footprint Area	4,400 sq. m.	
Building (above-grade) Gross Floor Area	61,600 sq. m.	*Stories: 14*
Parkade (below-grade) Gross Floor Area	32,000 sq. m.	*Levels: 4*

Description	**Quantity**	**Unit**	**Baseline Unit Cost**	**Total**	*AACE Class 5 Cost Range Low*	*High*
Tier 1 & 2 Rainwater Management (GRI)						
Bioretention	0	sq. m.	$ 2,100	$ -	*$ -*	*$ -*
Bioretention with Underdrain	0	sq. m.	$ 2,600	$ -	*$ -*	*$ -*
Permeable Pavement	0	sq. m.	$ 250	$ -	*$ -*	*$ -*
Subsurface Infiltration	0	cu. m.	$ 2,200	$ -	*$ -*	*$ -*
Resilient Roof - Intensive (450mm)	0	sq. m.	$ 430	$ -	*$ -*	*$ -*
Resilient Roof - Extensive (100mm)	0	sq. m.	$ 220	$ -	*$ -*	*$ -*
Rainwater Harvesting - Storage Tank	0	cu. m.	$ 1,300	$ -	*$ -*	*$ -*
RWH - Treatment & Plumbing	0	sq. m.	$ 36	$ -	*$ -*	*$ -*
Subtotal				**$ -**	***$ -***	***$ -***
Tier 3 Rainwater Management						
Detention Tank	179	cu. m.	$ 900	$ 161,100	*$ 112,800*	*$ 241,700*
Proprietary WQ Treatment Device	1	each	$ 48,600	$ 48,600	*$ 36,000*	*$ 61,000*
Subtotal				**$ 209,700**	***$ 148,800***	***$ 302,700***
Other Project Components						
Building Structure (above-grade)	61,600	sq. m.	$ 3,633	$ 223,780,000	*$ 195,600,000*	*$ 251,960,000*
Parkade Structure (below-grade)	32,000	sq. m.	$ 1,884	$ 60,280,000	*$ 41,330,000*	*$ 79,220,000*
At-grade Landscaping	540	sq. m.	$ 17	$ 9,200	*$ 6,400*	*$ 13,800*
At-grade Paving	3,060	sq. m.	$ 188	$ 580,000	*$ 330,000*	*$ 820,000*
Subtotal				**$ 284,649,200**	***$ 237,266,400***	***$ 332,013,800***
Total Construction Cost	*(57% of Total Capital Cost)*			**$ 284,858,900**	***$ 237,415,200***	***$ 332,316,500***
Project Soft Costs/Delivery Cost Allowance	*(43% of Total Capital Cost)*			$ 213,640,000	*$ 178,060,000*	*$ 249,240,000*
Total Capital Cost				**$ 498,498,900**	***$ 415,475,200***	***$ 581,556,500***

Task 7 – Rainwater Management Value and Co-Benefits Memo

MEMORANDUM

Date: October 13, 2023

To: Gord Tycho *(City of Vancouver, BC)*

From: Olivia Wright and Brian Busiek *(Herrera)*

Cc: Bryce Wilson, Margot Walker, and Eric Zickler (*Lotus Water*)

Project: Rainwater Infrastructure Building Typologies Pathway Study

Subject: Task 7 – Rainwater Management Value and Co-Benefits

INTRODUCTION

The Lotus Water team is working with the City of Vancouver, BC (City) to develop and test site-level rainwater management compliance pathways for a suite of building-site typologies. These compliance pathways represent different combinations of rainwater management tools that can be deployed to meet the City's rainwater management design standards (capture and clean 48 mm of rainfall) and help achieve the City's Rain City Strategy goals. Earlier tasks in this project focused on:

- defining a hypothetical set of building-site typologies to be tested (Task 2),
- defining the potential rainwater management tools, including green rainwater infrastructure (GRI) tools and grey (non-GRI) tools, that could be used by developers to meet the City's rainwater management design standards (Task 3),
- developing the design methodology and model and performing modeling to test and develop various compliance pathways for each building-site typology (Tasks 4 and 5),
- developing unit costs for various rainwater management tools to help compare compliance pathways (Task 6), and
- identifying barriers and constraints to broader adoption of GRI tools (Task 8).

The next step in the project is to develop a framework and methodology for evaluating and measuring the other ancillary value and co-benefits provided by the rainwater management tools that comprise each compliance pathway. This work will be combined with the performance modeling results and the cost analysis to allow for a robust comparison of the compliance pathways. This work represents Task 7 of the project scope. The purpose of this memorandum is to document the process the project team will use to evaluate the values and co-benefits for the rainwater management tools and the compliance pathways.

Definitions

The framework for this analysis uses two related, but subtly distinct terms ("value" and "co-benefit") to describe the additional advantages gained and services provided by the utilization of rainwater management tools. These advantages and services are intended to go beyond fulfillment of the primary objectives associated with the City's rainwater quality, quantity, and peak flow rate design standards.

The term "value" refers to an intrinsic characteristic of a rainwater management tool that provides a particular advantage over another tool. Examples of values include increased reliability, implementability, feasibility, and resiliency. Values are not typically thought of as co-benefits but are nonetheless important considerations when weighing the performance of a tool against its cost. This is especially critical in the absence of a full life-cycle cost analysis that is beyond the scope of this project.

The term "co-benefit" refers to an additional benefit beyond the prime water management objectives that is generated by utilizing a rainwater management tool. A co-benefit may be received by individual or multiple parties, including the tenant, property owner, developer, and/or the broader public. Co-benefits typically refer to economic, social, and other environmental benefits. It should be noted that water quality and quantity performance and capital costs were not considered in the co-benefits since these components are considered separately in the comparison of compliance pathways.

Approach

The approach for developing a framework includes the following key steps explained further below: identification and development of criteria and metrics that will be used to represent key values and co-benefits, development of a scoring and weighting scheme to evaluate individual rainwater management tools, and development of a scoring scheme for full compliance pathways.

Criteria and Metric Development

An initial list of value and co-benefit criteria and metrics were compiled from the project charter and from other projects in the region that consisted of rigorous internal review processes. The project team specifically leveraged the results from the Cambie Corridor Integrated Water Management Plan (Herrera, 2019), or "Cambie Project", to augment the criteria. The Cambie Project was specifically leveraged because the value and co-benefit criteria and metrics for that project were developed iteratively with multiple City stakeholders through a series of workshops to ensure they were aligned with the City's values and broader water management objectives.

The initial list of criteria and metrics was refined to ensure applicability and that information was available to perform a qualitative assessment for the rainwater management tools used in the

Pathway study. The rainwater management tool types considered for this project are general and developed for broad application. Therefore, the value and co-benefit criteria and metrics needed to be general enough to be applied to conceptual tools and scenarios and have measurable characteristics that allow for qualitative scoring. The team intentionally avoided criteria and metrics that depended on spatial location and also avoided including too many specific interests in separate metrics, which can result in non-differentiating results.

The proposed criteria and metrics are organized into four value and co-benefit categories: Economic, Environmental, Community, and Resiliency. These overarching categories consist of 11 individual criteria and 14 qualitative metrics that will be used in the value and co-benefit evaluation. See Table 1.

Table 1. Proposed Value and Co-Benefit Criteria and Metrics

Category	Criteria	Metric	Definition	Origin
Economic	Life Cycle Considerations	Ease of O&M	Evaluates the ease of maintenance including frequency and resource requirements (i.e., staff, equipment, programs/policies).	A
		Replacement frequency	Evaluates the life span and periodic need and frequency of renewal or replacement (e.g., new vegetation or filter media).	A
	Property Values	Property value uplift	Evaluates uplift in property / rental value to developer and/or strata associated with amenities provided by tools.	B
	Energy Efficiency	Energy savings	Evaluates savings from reduced building heating/ cooling loads due to deployment of tools.	B
	Other Cost Implications	Other costs	Evaluates other potential costs (e.g., higher insurance premiums) and savings (e.g., allied incentives) associated with tools.	A
Environmental	Ecosystem Health	Biodiversity and habitat enhancement	Evaluates degree of potential ecological benefit defined by improving biodiversity and enhancing pollinator and wildlife habitat.	B & C
	Water Preservation	Potable water savings	Evaluates degree of potential reduction in potable water use through the offset of municipal supplied water.	C
	Water Resource Restoration	Groundwater recharge	Evaluates potential to recharge groundwater via infiltration or direct discharge to groundwater.	B
	Climate	Carbon sequestration	Evaluates potential for tool to store and sequester atmospheric carbon.	B
Community	Community Health	Air quality improvement	Evaluates potential to enhance community health by improving local air quality.	B & C
		Urban heat island mitigation	Evaluates potential to enhance community health by reducing local heat-island impacts.	B & C
		Provides or enhances access to nature	Evaluates potential to improve access to green/ open space and improve mental health and community cohesion.	B & C
Resiliency	Long-Term Stresses (e.g., Climate Change)	Adaptability	Evaluates the ability to mitigate or reduce risk associated with impacts from long-term stresses like climate change (e.g., drought, flooding, sea-level rise) or changing environmental needs or regulatory requirements.	C
	Short-Term Stresses & Shocks (e.g., Earthquake and Other Disasters)	Service disruption potential	Evaluates the ability to maintain service during a short-term shock or to recover quickly following the event.	C

NOTES: Origin: (A) Added to allow for evaluation of relative life-cycle costs of tools, (B) Inclusion suggested by the City (project review team and/or project charter), (C) From Cambie Project

Metric Scoring and Weighting for Rainwater Management Tools

For each rainwater management tool, a value and co-benefit score was developed for each metric on a measurement scale of 0 to 5, with 0 representing no to low value or benefit and 5 representing the highest value or benefit. To combine metric scores and calculate a composite "total value and co-benefit score" for each tool, each metric was weighted to reflect its relative overall importance to the City. Preliminary metric weighting was assigned based on a similar exercise completed with City stakeholders across multiple departments for the Cambie Project. That project included a slightly different set of metrics, tools, and overall objectives, so further refinement of the metric weighting was completed by City staff during review of the draft version of this memorandum. The value and co-benefit scoring definitions and considerations are presented in Table 2, along with the metric weighting.

Metric scoring for each tool was initially completed based on the average scores assigned by four members of the Lotus Water team based on best professional judgement and experience planning, designing, constructing, and maintaining each tool. These scores were further adjusted by City staff following review of the draft version of this memorandum. The metric scores for each rainwater management tool are presented in Table 3.

Based on the individual metric scoring and the weighting, a composite "total value and co-benefit score" was calculated for each rainwater management tool using the following equation:

$$S_{tool} = \sum_{i=1}^{n} S_{metric(i)} \times W_{metric(i)}$$

Where:

S_{tool} = *Total value and co-benefit score for a rainwater management tool*

$S_{metric(i)}$ = *Individual value and co-benefit score for the i^{th} metric*

$W_{metric(i)}$ = *Weighted contribution (%) of the i^{th} metric towards the total score*

The total value and co-benefit score for each tool is also presented in Table 3.

Table 2. Value and Co-Benefit Scoring and Weighting Scheme

Benefit Category	Criteria	Metric	Metric Weight	Value and Co-Benefit Scoring		
				0	**3**	**5**
Economic	Life Cycle Considerations	Ease of O&M	8%	High ongoing O&M costs	Moderate ongoing O&M costs	Minimal ongoing O&M costs
		Replacement frequency	8%	High replacement frequency; every 15 years	Moderate replacement frequency; every 30 years	Low replacement frequency; every 30+ years
	Property Values	Property value uplift	4%	Provides no uplift in property/rental value; provides no amenity value	Provides moderate uplift in property/rental value; provides moderate amenity value (typically GRI tool with some vegetation)	Provides significant uplift in property/rental value; provides significant amenity value (typically GRI tool with dense/ diverse vegetation)
	Energy Efficiency	Energy savings	4%	Provides no savings from reducing building heating/cooling loads	Provides moderate savings from reducing building heating/cooling loads; has ground level vegetation	Provides significant savings from reducing building heating/cooling loads; has roof level vegetation
	Other Cost Implications	Other costs	4%	Increases costs	Costs stay the same	Decrease costs
Environmental	Ecosystem Health	Biodiversity and habitat enhancement	7%	Removes or provides no habitat (pollinator or wildlife) and provides no diversity; 0 plant species	Provides moderate habitat (pollinator or wildlife) with moderate vegetation diversity; 1-5 different plant species	Provides substantive and high-quality habitat (pollinator or wildlife) with significant vegetation diversity; 5+ plant species
	Water Preservation	Potable water savings	7%	Increases municipal supplied water use; irrigation typically needed	Does not offset municipal supplied water use; irrigation typically needed only for establishment	Offsets municipal supplied water use; rainwater harvesting system
	Water Resource Restoration	Groundwater recharge	7%	Does not facilitate groundwater recharge	Facilitation of a moderate amount of groundwater recharge	Facilitation of a significant amount of groundwater recharge

Table 2. Value and Co-Benefit Scoring and Weighting Scheme						
Benefit Category	**Criteria**	**Metric**	**Metric Weight**	**Value and Co-Benefit Scoring**		
				0	**3**	**5**
	Climate	Carbon sequestration potential	7%	Does not sequester carbon	Moderate carbon sequestration in soil media and/or vegetation	Significant carbon sequestration in soil media and/or vegetation
Community	Community Health	Air quality improvement	8%	Non-vegetated with no benefit to air quality	Moderate air quality improvement; has small amount of vegetation	Significant air quality improvement; has significant amount of ground level vegetation
		Urban heat island mitigation	10%	Non- vegetated with no relative benefit to urban heat-island impacts	Moderate relative contribution to urban heat-island reduction; has small amount of vegetation	Significant relative contribution to urban heat-island reduction; has significant amount of vegetation
		Provides or enhances access to nature	10%	No permanent change to green spaces	Creates or enhances private green space; has some vegetation but is typically not accessible to the community	Creates or enhances community green space; has vegetation and is typically accessible to the broader community
Resiliency	Long-Term Stresses (e.g., Climate Change)	Adaptability	10%	Cannot be modified; no ability to expand/adapt to meet potential future stresses or demands; below ground and/or no additional space to expand available	Can be modified; limited ability to expand/adapt to meet potential future stresses or demands; above ground with some additional space to expand available	Can be easily modified; maximizes ability to expand/adapt to meet potential future stresses or demands; above ground with significant space to expand available

Table 2. Value and Co-Benefit Scoring and Weighting Scheme						
Benefit Category	**Criteria**	**Metric**	**Metric Weight**	**Value and Co-Benefit Scoring**		
				0	**3**	**5**
	Short-Term Stresses & Shocks (e.g., Earthquake and Other Disasters)	Service disruption potential	6%	More likely to be significantly damaged during an earthquake or other short-term disaster and likely to be out of service greater than 3 months after a disaster	May/may not be damaged during an earthquake or other short-term disaster and services are likely to be delivered within 1-2 weeks after a disaster	Less likely to be damaged during an earthquake or other short-term disaster and services are likely to be delivered immediately (within 4 hours) after a disaster

Table 3. Preliminary Value and Co-Benefit Score Results

Benefit Category	**Economic**					**Environmental**				**Community**			**Resiliency**		**Total Value and Co-Benefit Score (0 -5 scale)**
Category Weight	**28%**					**28%**				**28%**			**16%**		
Metric	**Lifecycle Considerations -- Ease of O&M**	**Lifecycle Considerations -- Replacement Frequency**	**Property Values -- Property Value Uplift**	**Energy Efficiency -- Energy Savings**	**Other Cost Implications -- Other Costs**	**Ecosystem Health -- Biodiversity and Habitat**	**Water Preservation -- Potable Water Savings**	**Water Resource Restoration – Groundwater Recharge**	**Climate -- Carbon Sequestration**	**Community Health -- Air Quality Improvement**	**Community Health -- Urban Heat Island Mitigation**	**Social Equity & Community -- Nature Access**	**Long-Term Stresses -- Adaptability**	**Short-Term Stresses -- Service Disruption**	
Metric Weight	8%	8%	4%	4%	4%	7%	7%	7%	7%	8%	10%	10%	10%	6%	
Green Rainwater Infrastructure (GRI) Tools															
Resilient roofs	2	3	4	4	0	3	0	0	3	3	4	3	0	3	2.3
Bioretention	3	3	4	2	3	4	3	5	4	4	3	4	3	4	3.5
Tree trenches	4	4	3	3	3	3	3	4	4	4	3	4	1	3	3.3
Permeable pavement	4	4	0	0	3	0	2	3	0	0	0	0	2	3	1.5
Subsurface infiltration	5	5	0	0	3	0	3	5	0	0	0	0	3	3	2.0
Non-potable water systems	1	4	1	0	4	0	5	0	0	0	0	0	4	0	1.4
Grey Rainwater Infrastructure (Non-GRI) Tools															
Detention tanks (w/o reuse)	3	5	0	0	3	0	2	0	0	0	0	0	2	2	1.2
Proprietary treatment devices	3	2	0	0	3	0	2	0	0	0	0	0	2	2	1.0

HERRERA

Overall Scoring for Compliance Pathways

As full compliance pathways are developed in Task 9, additional analyses of values and co-benefits will be completed for each pathway. Each pathway will be comprised of one or more rainwater management tools necessary to meet the City's rainwater quality, quantity, and peak flow rate design standards. The value and co-benefit score for a compliance pathway will be calculated based on the proportion of rainwater managed by each tool. This is reflected in the following equation:

$$S_{pathway} = \sum_{i=1}^{n} S_{tool(i)} \times P_{tool(i)}$$

Where:

$S_{pathway}$ = *Total value and co-benefit score for a compliance pathway*

$S_{tool(i)}$ = *Total value and co-benefit score for the i^{th} rainwater management tool*

$P_{tool(i)}$ = *Proportion of target rainwater volume managed (%) by the i^{th} tool*

The total value and co-benefit score for each pathway will be calculated in Task 9.

References

Herrera. 2019. Cambie Corridor Integrated Water Management Plan, Phase 1. Assessment Approach and Decision Support Tool (Task 3).

Task 8 – Rainwater Management Barriers and Solutions Memo

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TECHNICAL MEMORANDUM

From:	Lotus Water
To:	Gord Tycho, City of Vancouver
Date:	2/26/2024
Project:	Rainwater Infrastructure Building Typologies Pathway Study
Subject:	Task 8 - Rainwater Management Barriers & Solutions Memo – Revised Final

1. Introduction

The purpose of Task 8 is to identify, describe, and assess the key barriers for implementing green rainwater infrastructure (GRI) in new development under current policies and regulations in the City of Vancouver. Additionally, Task 8 began to explore potential solutions for wider adoption of GRI to meet the Rain City Strategy goals. These solutions will be further developed in Task 9 as policy recommendations, as appropriate.

This work builds on the previous effort in Task 8 that focused on identifying and sorting the barriers for GRI implementation into five key categories: Physical, Regulatory, Economic, Procedural, and Cultural. Following this barrier identification, the team completed a Current State Assessment and Jurisdictional Scan as part of Task 4 and held two public workshops to gain input from external stakeholders. The observations, analysis, and feedback from these efforts were synthesized to narrow down the extensive initial list of barriers into a more focused list to highlight the issues most frequently faced when determining if and how to implement GRI on a specific site.

The following table lists the barrier categories, with their corresponding barriers and solutions. These are all discussed in more detail in the subsequent sections.

A note on the memo organization:

Table 1 provides a summary of each of the barriers and solutions assessed as part of Task 8 and further in Task 9. The subsequent tables corresponding to each barrier category below are lists and descriptions of each barrier in that category and are also included in the barrier matrix attached.

Each barrier category section includes subsections that describe and summarize the solution corresponding to Table 1. It should be noted that there is not a direct correlation between each constraint/barrier and a solution. The solutions are grouped and can be repeated as they can collectively address a whole category of barriers.

Table 1. Barriers & Solutions Summary

Barrier Category	Barriers	Solutions
Physical	• Steep Topography • Soil or Groundwater Contamination • High Groundwater or Bedrock • Low or Zero Infiltration Capacity • Existing Trees (Root Protection Zones) • Inadequate or Shallow Municipal Service Connection	• GRI Design Standards and Manual • Alternative Compliance Program
Regulatory	• Rooftop Space Constraints and Competition • Building Envelope Certification and Building Insurance • Maximizing Development within Zoning By-law, Parking, and Other Policies • Building Integrity Concerns • Challenges with Managing Runoff Across Property Lines • Rainwater Harvesting Feasibility and Cost Effectiveness • Limited GRI Design Standards to Support Current Regulation and Policy	• GRI Design Standards and Manual • Align By-Laws, Bulletins, and Other Policy and Guidance Documents • Resilient Roofs Policy • GRI Design Standards and Manual • Expanding Green Building Policy for Rezonings • Expand Alternative Water Sources Allowed for Onsite Reuse • Alternative Compliance Program
Procedural	• Lack of Departmental Coordination • Unclear RWMP Submission Process • Lack of GRI Maintenance Plan Enforcement	• GRI Design Guidance Coordination • GRI Maintenance Standards and Enforcement
Economic	• Added Incremental Costs • Affordability of Housing	• GRI Design Standards and Manual • Alternative Compliance Program
Cultural	• Limited Local GRI Design Expertise • Insufficient GRI Construction Standards and Expertise • Limited Understanding of Benefits and Costs • Perception of Higher Risk	• GRI Engagement and Training • Providing Leadership

2. Physical Barriers

2.1 Physical Barriers Summary

At the site scale, physical site characteristics require the design professional to make a set of decisions in order to achieve desired and/or required goals. Depending on the type of constraint, a solution can often be found through the site assessment and design process and then by selecting the appropriate GRI type to achieve the goal (e.g., compliance with rainwater management targets).

Physical constraints range in severity from high groundwater to challenging site topography and poor soils. Some physical constraints can be prohibitive to overcome, especially for infiltrative GRI tools, which would lead the designer to choose more traditional gray/detention solutions instead of GRI solutions. Table 2 lists commonly encountered physical site constraints, and typical solutions.

Regulatory barriers that result in physical constraints (such as minimal space to implement GRI solutions at grade or competition for rooftop GRI) are discussed in the Regulatory section below.

Table 2. Physical Site Constraints

Common Site Constraints	Description
Steep Topography	Using GRI on steep sites presents challenges related to velocity and erosion.
Soil or Groundwater Contamination	Managing rainwater above or near soil or groundwater contamination may require an impermeable liner in the GRI asset or remediating the contamination during construction.
High Groundwater or Bedrock	No infiltration should occur in these conditions due to water quality concerns. Very high groundwater would also risk diverting groundwater into underdrains and into the storm sewer.
Low or Zero Infiltration Capacity	Little to no infiltration can occur in these conditions.
Existing Trees (Root Protection Zones)	Depending on the extent of the root protection zone, this limits space to excavate for ground-level GRI.
Inadequate or Shallow Municipal Service Connection	This constraint can arise where the depth of the GRI or subsurface infiltration system is lower than the adjacent municipal service connection.

2.2 Physical Barrier Solutions

With the complexity and variety of site conditions, it would be impractical to have a one-solution-fits-all approach for GRI design and sizing. A specific guideline or manual, with a set of standard details and specifications, to assist developers in implementing GRI is recommended as a solution for meeting rainwater management goals despite a site's physical constraints.

2.2.1 GRI Design Standards and Manual

This document should provide specific guidance for each category of site constraints including site assessment standards. Once site assessments are completed, a design approach can be developed. The manual should illustrate design approaches for commonly encountered site constraints and provide guidance on how to overcome or integrate them into the site. In Task 9, the team will include a recommendation for design standards and tools for assisting design professionals in assessing site conditions, determining feasibility, and siting and sizing the appropriate GRI asset type.

Task 4's Jurisdictional Scan provided several examples of North America's leading practices for stormwater design standards and their accompanying manuals. Specifically, refer to Portland, OR; Seattle, WA; Philadelphia, PA; San Francisco, CA; Washington, D.C. Each of these jurisdictions have very clearly documented the stormwater design standards using a manual or guidelines documents that Vancouver could use a model.

2.2.2 Alternative Compliance Program

In some cases, there may be valid constraints on the use of Tier 1 facilities to justify the reliance on Tier 3 facilities (i.e., detention tanks and treatment devices) to comply with the requirements of the Rainwater Management Bulletin. Current policy does not include any specific options for alternative (e.g., offsite) or modified (e.g., adjusted capture/treat/flow targets) compliance approaches for highly constrained sites to pursue. The City provides an Alternative Solutions process to allow for flexibility in design or "to employ design methods that are different from the prescriptive Building Bylaw requirements" however there is no guidance on acceptable alternative approaches specific to stormwater management. Developing a more formalized program, with clear guidance and submittal requirements, around potential alternative or modified compliance options (e.g., offsite compliance, fee-in-lieu, adjusted performance targets) may create incentive and opportunity for constrained sites and the City to meet the intent of the Rain City Strategy (RCS).

3. Regulatory Barriers

3.1 Regulatory Barriers Summary

Regulatory barriers arise when potential GRI tools are determined to be unfeasible due to constraints or conflicts that emerge from existing regulations or policies. The solutions to these barriers would be revisions to existing regulations and guidance, and/or the creation of new regulations and guidance documents.

The regulatory barriers fall into two general categories, the first being those that are related to the at-grade configuration of the new development including setbacks, building over slab construction, integration with the public realm, private-to-private rainwater management, and so on. The second category is related to the building itself such as internal plumbing and reuse, and rooftop uses, loading, programming, and the quality of the building envelope.

Table 3. Regulatory Barriers

Barrier	Description of Barrier
Rooftop Space Constraints and Competition	Depending on the building type (residential or commercial), size, and zoning, available space for GRI on rooftops may be limited by City requirements, programming needs, or building infrastructure. For example, policies contain requirements for rooftops amenity space (such as the Guideline: High Density Housing for Families with Children, which describes minimum outdoor play areas) and which the planning department and design panels often request be in areas with access to sunlight. Other policies may impact where mechanical equipment is placed (such as condensers/heat pumps) that is installed to meet the City's Sustainability objectives.
Building Envelope Certification and Building Insurance	Based on information provided by the City, Technical Working Group participants, and those participating in Workshop #2, insuring buildings with green roofs has been challenging due to the building envelope requirements resulting from past "leaky condo" problems.[1] While there are green roofs being successfully installed in the City at this time, there is a broader concern that there is a disincentive to install green roofs due to unclear requirements and guidance between the building envelope certification and the insurers'.[2] Anecdotally, the team heard that many developers are foregoing a green roof in anticipation of being denied insurance for the building.[3] See Appendix B for more detailed discussion of green roof barriers in Vancouver and Toronto's successes with their program.
Maximizing Development within Zoning By-law, Parking, and Other Policies	Zoning By-laws set the building form requirements within areas of the City. Due to the value of the land and cost of development, developers often maximize all buildable area within a site resulting in zero lot line development.

[1] BC Housing Presentation at Workshop #2.

[2] Roofing Contractors Association of BC Presentation at Workshop #2.

[3] Roofing Contractors Association of BC Presentation at Workshop #2.

	The zoning approvals in their various forms can result in space constraints with the Zoning & Development by-law, Rezoning approvals, and CD-1 by-laws determining structure setbacks from the property line. The parking requirements in the Parking By-Law often result in projects constructing large parkades under buildings to provide the required parking spaces. These subsurface parkades will regularly extend to property lines, reducing opportunity for Tier 1 GRI at ground level.
Building Integrity Concerns	The VBBL contains 5-meter setback requirements for building from infiltrative facilities that are intended to limit harm to people, damage to buildings from excessive moisture loading on foundations and footings and short-circuiting that could occur by infiltrating water adjacent to a structure (which could enter the foundation drains that lead to the sewer). Setback distance from the street, lane, and utilities are at the discretion of the City.
Challenges with Managing Runoff Across Property Lines	Currently, there is a regulatory mechanism for a private property rainwater to be managed in an adjacent public property if a public storm connection is provided to the private property for its storm drainage system and the rainwater cannot be managed within the site. The circumstances leading to this solution are likely unique and infrequent. For private-to-private rainwater management, another regulatory mechanism is needed, which could be beneficial if the City were to pursue regional or district-scale GRI solutions. Changes to the Sewer and Watercourse By-law, which requires that every separate parcel of land must connect to the public sewer system (where available) via an individual connection, would likely be needed. The VBBL states that storm water cannot discharge upon or impact other properties. Routing private rainwater to another private site would require non-standard exceptions and agreements.
Rainwater Harvesting Feasibility and Cost Effectiveness	The VBBL, Book II, Section 2.7 only allows onsite reuse systems to use rainwater from roofs and prohibits the reuse of groundwater, graywater, and blackwater (stormwater is also not currently allowed, though that is likely subject to change). Without these additional alternative sources, the seasonal nature of rainwater supply (and thus need for large storage tanks or long periods of supplemental potable water) will make cost-effective non-potable reuse systems a challenge.
Limited GRI Design Standards to Support Current Regulation and Policy	There is a lack of guidance from the City for how to identify an acceptable and compliant GRI approach and how to design the GRI facilities, outside of what's provided in the Rainwater Management Bulletin, the Zoning By-law, and the VBBL. This issue is compounded by an existing knowledge gap within the local consultant community. There are design resources regionally, such as the Metro Vancouver – Source Control Guidelines, however these are often tailored towards lower density development and provide a framework that does not meet the dense urban requirements in Vancouver.

3.2 Regulatory Barrier Solutions

The key regulatory solutions are focused on coordination across different strategies, policies, and departments to meet both site level and city-wide rainwater management goals. Other solutions address a need for new collaboration between developers/owners and the City whereby rainwater can be managed collaboratively and more efficiently across property lines or within offsite GRI facilities.

3.2.1 Align By-Laws, Bulletins, and Other Policy and Guidance Documents

Ideally, revisions to existing by-laws, bulletins, and policy documents would be part of an overarching policy framework for rainwater management in new development to achieve both site-level and system-wide benefits. Once that was clearly articulated the precise language changes would be developed and guidance documents could be drafted.

This effort would focus on language revisions through the lens of the above barriers but also consider the original intent of the respective by-law, policies, and guidance documents. A strategic approach for incremental changes over a set timeline could also be developed. Also see Task 4's Jurisdictional Scan.

Task 9 intends to propose recommendations for that overarching policy framework, that would highlight which regulatory changes would support both site-level GRI hierarchy as well as broader RCS goals.

3.2.2 Resilient Roofs Policy

Based on the preliminary pathways modeling and analysis, it has become clear that resilient roofs on new development will be critical to successful GRI implementation in Vancouver. While the solutions to the related barriers would be covered in the regulatory revisions described above, it is important to note that resilient roof policy could proceed forward on its own track and could allow for earlier adoption, especially in multi-family residential scale or larger buildings.

Intensive green roofs are typically sold as systems and mostly modular to install. This allows a jurisdiction to set basic standards and/or performance metrics and allow the designer to specify which system to procure for a project.

The rollout of standards, guidance, or performance metrics around resilient roofs could help alleviate the issue of space constraints at ground-level. Also see Toronto example included in Task 4's Jurisdictional Scan. New guidance could also clarify and show examples of resilient roofs incorporated into amenity space while not significantly impacting space for bulkheads, egress, and mechanical equipment. Other regulatory changes, such as allowing mechanical floors to be excluded from the maximum floor space ratio calculation could also be explored.

Insurance barriers related to green roofs and the building envelope certification were discussed at the Green Roof Workshop. A review of the insurance laws and the City's building envelope certifications will need further review to determine how the City's regulations or policies would need to be revised. This would be done in coordination with green roof professionals, building envelope professionals, and insurance representatives.

3.2.3 GRI Design Standards and Manual

At present the project team have identified several documents including by-laws, policies, bulletins, and the engineering design manual that all contribute to the design of rainwater management systems in Vancouver. Navigating these documents presents designers with a complex and time-consuming task.

Currently the rainwater management regulations are within the Zoning and Development By-Law but are slated to be moved into the Vancouver Building By-Law. With this change, a solution could be to use minimal, concise language within the by-law and reference a manual for compliance. This is common practice among North American jurisdictions. The outcome would be a single document that contains all the regulatory requirements, related procedures, standard details, and any of the sizing tools. It could be updated as needed without revisions to the by-law itself.

This manual should also clearly describe the basis for the standard infiltration setbacks and provide guidance on the process of requesting a reduced setback. This would include standard siting and design requirements, conditional reduced setbacks with clear criteria and design/submittal requirements (e.g., waterproofing, professional certification), and infiltration testing requirements. Also see Task 4's Jurisdictional Scan.

3.2.4 Expanding Green Building Policy for Rezonings

The *Green Buildings Policy for Rezonings (2022)* places high importance on energy use in a building and less emphasis on rainwater management and reuse. Green buildings that are also rezonings must submit a Rainwater Management Plan per the latest Rainwater Management Bulletin, however there is a missed opportunity to require a higher rainwater management standard under green building policies where the developers are already trying to reach a higher design and building performance standard.

3.2.5 Expand Alternative Water Sources Allowed for Onsite Reuse

As noted, the seasonality of rainwater supply can challenge the cost effectiveness of an onsite non-potable reuse system. Allowing additional sources that have a more consistent year-round supply, such as graywater, could allow a much greater level of potable water offset (and associated long term cost savings) with relatively little additional initial capital expense. This would require that the City develop additional standards and requirements around the design, approval, commissioning, and ongoing testing/operation of systems that use these additional sources.

3.2.6 Alternative Compliance Program

As noted above, a more formalized alternative compliance program, with accompanying guidance, would create opportunities for constrained sites to implement GRI. Also see Task 4's Jurisdictional Scan.

4. Procedural Barriers

4.1 Procedural Barriers Summary

Procedural barriers include challenges involved in the progression of a project from early concept design to building permit, including the development and submittal of the Rainwater Management Plan (RWMP). These types of barriers can have a substantial impact on a project timeline and therefore the cost of the project. Barriers to the inspection and maintenance of GRI systems have the potential to render them ineffective.

The procedural barriers are listed in Table 4. Note, there is a strong correlation between regulatory and procedural barriers as procedural guidelines are usually laid out in regulatory or guidance documents.

Table 4. Procedural Barriers

Barrier	Description of Barrier
Lack of Departmental Coordination	The City is a complex organization with many different departments involved in rainwater management and their various regulations can affect GRI implementation both directly and indirectly. Coordination and alignment across disciplines can be challenging for some types of development, and there are often multiple departmental signoffs. Comments or requirements can come from these departments at various points in the design process, which adds time and potential need for costly redesign. In addition, some City departments have competing priorities that add complexity to the development process and restrict the ability to implement GRI. For instance, there are competing priorities with climate readiness, affordable housing, parking, and rainwater management.
Unclear RWMP Submission Process	Upon reviewing the RWMP submittals, it appears that the report portion is well standardized, however the supporting information is inconsistent. Many reports are missing information necessary for approval when they are submitted to the City. Additionally, it is common for these reports to suggest multiple forms of GRI at early stages that are later either deemed infeasible or removed prior to building permit. Feasibility assessments are not required prior to submitting the RWMP.
Lack of GRI Maintenance Plan Enforcement *(beyond the 2-yr post-occupancy period)*	At present, a required RWM Agreement includes the Owner's responsibility to submit Statutory Declaration after a 2-yr period following Occupancy Permit issuance. This is required to ensure onsite rainwater management systems are maintained, repaired and/or cleaned in accordance with the O&M manual to keep intended performance post-occupancy within the 2-yr period. Beyond the 2-yr period, there is no enforcement currently established at this time. The exception is the Operating Permit for rainwater harvesting systems. The RWM Agreement does not provide guidelines or requirements to ensure that the GRI facilities are maintained and remain functional post-construction after the 2-year term of the agreement. Landscape Plans (and the associated GRI) are not easy to enforce with current legal tools. The Vancouver Charter prohibits the City to collect landscape installation deposits/ LOC's. The City does not use subject matter experts to inspect landscape installations or related GRI's. The Board of Variance can quash development permit conditions imposed by the Director of Planning, which can weaken the City's position in enforcement of landscape treatment and materials.

4.2 Procedural Barrier Solutions

The solutions to the procedural barriers will largely rely on the regulatory solutions discussed above. In general, the alignment of rainwater management regulations and policies should streamline much of the RWMP submittal, design, and permitting process and provide a simpler method for City plan reviewers. Addressing the issue of enforcement of existing maintenance & inspection to ensure the longevity of GRI is critical to programmatic success, but also necessitates a broader discussion around staffing resources or third-party options and costs.

4.2.1 GRI Design Guidance Coordination

As discussed above, the consolidation of rainwater management design requirements is a solution to procedural challenges. This includes the coordination across City departments and their respective policies and guidelines, as well as the development of a manual. New design guidance and standards should also clearly define the applicability for RWMP submittal, the pathway for compliance and permit approval as well as clear minimum performance requirements instead of aspirational targets. Also see Task 4's Jurisdictional Scan.

4.2.2 GRI Maintenance Standards and Enforcement

Successful GRI policy and programs depend on adequate inspection and maintenance of these systems. The City currently has a team of maintenance staff who are responsible for the upkeep of GRI in the public realm. Currently, there are limited requirements for inspection and maintenance for GRI and water reuse systems in the City.

To combat any deficient maintenance operations by Strata or other property or building management, new inspection and maintenance requirements should be included with the updated rainwater management regulations and procedures. This should allow City staff, or third parties on behalf of the City, to inspect GRI on private sites and request maintenance and repairs as required. A financial analysis would be required to assess the effort needed to meet the City's expectations for maintenance of private GRI.

There are many variables to consider on this topic. In the US, many of the on-site GRI implemented as part of new or redevelopment is required to be inspected and an annual reported submitted per Municipal Separate Storm Sewer System (MS4) Permits. While these inspections may not be perfect, it has forced jurisdictions into some frequency of inspection cycle, self-reporting or self-certification, or other systems. The frequency and level of inspection depends on the amount of assets, parcels, and resources. Enforcement tools such as random inspections, fines, and liens can also be effective tools for this purpose. Routine building inspections are not a new challenge however and there are likely several models that would fit the scale and needs for the City to consider.

5. Economic Barriers

5.1 Economic Barriers Summary

For the purposes of Task 8, the economic barriers will be described from the perspective of the developer in terms of cost to design and implement the GRI as part of a new development. This section will discuss them as the "economic factors" that relate directly to individual projects. It should be noted that rainwater management is generally a small percentage of total development soft and hard costs, particularly in the context of large residential, commercial, or mixed-use developments.

Assuming that the majority of projects required to submit a RWMP are privately funded, profitability will typically remain a developer's key concern as well as ensuring the viability of the project overall. Single-family homes and co-ops will have far less financial backing than big developers, increasing the importance of keeping costs down for residents and workers.

Table 5. Economic Barriers

Barrier	Description of Barrier
Added Incremental Costs	If co-benefits are not valued, there is minimal economic payback for the incremental costs to design, permit, and install GRI compared to conventional site landscaping and gray infrastructure. As a result, GRI tools are often the first items to be removed in a value-engineering process if they are not a requirement.
Affordability of Housing	The incremental costs associated with design, permitting, and construction of GRI, or the associated loss of developable area, may challenge the affordability of some residential affordable housing projects. For projects such as temporary housing and below-market housing, that are submitted on provincial and sometimes federal budgets, the fixed budgets may not be sufficient for a large investment in GRI. This is especially true if the building has maximized floor area to be economically feasible, leaving more expensive building systems such as green roofs or rainwater harvesting as the only available GRI practices.

5.2 Economic Barrier Solutions

The current economic factors affecting the widespread application of GRI in new development are related to the aspirational goals of the Rainwater Management Bulletin and the less costly pre-development release rate policy. Under typical circumstances, economic forces will push developers to build the least expensive solution, including cost for design and permitting.

Assuming regulatory changes are enacted, the City would work with stakeholders to review the changes, the potential incremental costs, and work to educate residents on the benefits of GRI to their properties and for the City's system. In addition, engagement with the design and engineering community about procedural changes to reduce time and costs for permitting should be highlighted and promoted.

5.2.1 GRI Design Standards and Manual

As mentioned above, there are many benefits to a dedicated manual, design standards, and clear policy and procedures. In this case, these standards would provide more predictability with what is acceptable and how to implement it, creating a more efficient process and more confidence in the costs prior to their implementation. While each site has unique characteristics, the pathways will provide a framework from which a developer or homeowner can assume potential costs. In addition, having standard design solutions allows the local market to design and supply these features with greater repetition, leading to a reduction in costs as solutions become less custom as they are adopted. Also see Task 4's Jurisdictional Scan.

5.2.2 Alternative Compliance Program

An alternative compliance program would provide projects with additional approaches to meet rainwater management requirements, and this added flexibility and opportunity could allow for more cost-effective implementation. Also see Task 4's Jurisdictional Scan.

6. Cultural Barriers

6.1 Cultural Barriers Summary

In this context, cultural barriers are a reluctance to accept changes to conventional rainwater management approaches unless it is absolutely required. Cultural barriers can be based on direct experience but are often based on anecdotal evidence. These barriers are perpetuated by those with limited experience in the design, construction, review, and maintenance of GRI. The table below lists the cultural barriers that were derived from stakeholder input, the team, and the City's current experience in GRI implementation.

Table 5. Cultural Barriers

Barrier	Description of Barrier
Limited Local GRI Design Expertise	There is an existing knowledge gap within the local consultant community around the planning and design of GRI. Rainwater management strategies are also often thought of a secondary concern and are developed and incorporated too late in the design process, which can impact their feasibility or cost effectiveness. This issue is compounded by limited guidance provided by the City that can cause confusion and perpetuate misconceptions about design and installation of GRI.
Insufficient GRI Construction Standards and Expertise	Correct installation of GRI is imperative to its success. There is currently a lack of local industry expertise and experience in constructing, maintaining, and monitoring the performance of GRI. In addition, the city does not provide any contractor training or guidance specific to GRI construction, except for rainwater harvesting. This lack of construction knowledge may lead to longer development timelines, increased costs, and poor implementation.
Limited Understanding of Benefits and Costs	There is an industry perception that GRI is more expensive to build and to maintain than traditional gray solutions for stormwater management, with little return on any additional investment. This is often a product of limited experience, a poor understanding of the benefits of GRI to the site and the City, or an incomplete accounting of the life-cycles costs.
Perception of Higher Risk	The implementation of GRI is relatively new for many designers and developers and a lack of past experience may increase the perceived risk associated with functionality, costs, and/or maintenance of GRI facilities for owners or the liability for designers.

6.2 Cultural Barrier Solutions

The solutions to cultural barriers are intended to address misconceptions around various forms of GRI and educate the various stakeholder groups on the rainwater management benefits and co-benefits of GRI implementation. Solutions for the advancement of the design community should involve training programs to address gaps in knowledge, skills, and experience that currently exist.

It is also critical for the City to provide leadership in this area to get ahead of misconceptions, reduce regulatory and procedural barriers, and lead by example. This would likely have the greatest impact on cultural barriers.

6.2.1 GRI Engagement and Training

The correct design, installation, and maintenance of GRI systems is necessary for performance. With any new regulation change, the City should provide training courses for designers, contractors, and maintenance crews to ensure correct design, installation, and longevity of these systems. Once current contractors and maintenance workers are trained, the knowledge will be passed on to newer staff as GRI becomes commonplace around the city.

6.2.2 Providing Leadership

City leadership for GRI and innovative rainwater management would help shape public opinion and minimize cultural barriers. City-led changes to regulations and procedures would reflect the seriousness and commitment to GRI as well as broader drainage and water quality issues facing the City. Again, an overarching policy framework would show continuity with the RCS and Healthy Waters Plan goals and ground the new regulations in clear outcomes.

Appendix A

Barriers Matrix

#	Barrier	Description	Tool Applicability	Key Party	Project Phase
Physical Barriers (i.e., Site Characteristics Constraints)			Tool Applicability	Key Party	Project Phase
1	Steep Topography	Using GRI on steep sites presents challenges related to velocity and erosion.	Infiltrative facilities	Consultants	Design
2	Soil or Groundwater Contamination	Managing rainwater above or near soil or groundwater contamination may require an impermeable liner in the GRI asset or remediating the contamination during construction.	Infiltrative facilities	Consultants	Design
3	High Groundwater or Bedrock	No infiltration should occur in these conditions due to water quality concerns. Very high groundwater would also risk diverting groundwater into underdrains and into the storm sewer.	Infiltrative facilities	Consultants	Design
4	Low or Zero Infiltration Capacity	Little to no infiltration can occur in these conditions.	Infiltrative facilities	Consultants	Design
5	Existing Trees	Depending on the extent of the root protection zone, this limits space to excavate for ground-level GRI.	Infiltrative facilities	Consultants	Design
6	Inadequate or Shallow Municipal Service Connection	This constraint can arise where the depth of the GRI or subsurface infiltration system is lower than the adjacent municipal service connection.	Infiltrative facilities	Consultants	Design
Regulatory Barriers			Tool Applicability	Key Party	Project Phase
7	Rooftop Space Constraints and Competition	Depending on the building type (residential or commercial), size, and zoning, available space for GRI on rooftops may be limited by City requirements, programming needs, or building infrastructure. For example, policies contain requirements for rooftops amenity space (such as the Guideline: High Density Housing for Families with Children, which describes minimum outdoor play areas) and which the planning department and design panels often request be in areas with access to sunlight. Other policies may impact where mechanical equipment is placed (such as condensers/heat pumps) that is installed to meet the City's Sustainability objectives.	Resilient roofs	City	Design
8	Building Envelope Certification and Building Insurance	Insuring buildings with green roofs has been challenging due to the building envelope requirements resulting from past "leaky condo" problems. While there are green roofs being installed in the City at this time, there is a broader concern that there is a disincentive to install green roofs due to unclear requirements and guidance between the building envelope certification and the insurers'. Anecdotally, the team heard that many developers are foregoing a green roof in anticipation of being denied insurance for the building.	Resilient roofs	City	Design
9	Maximizing Development within Zoning By-law, Parking, and Other Policies	Zoning By-laws set the building form requirements within areas of the City. Due to the value of the land and cost of development, developers often maximize all buildable area within a site resulting in zero lot line development. The zoning approvals in their various forms can result in space constraints with the Zoning & Development by-law, Rezoning approvals, and CD-1 by-laws determining structure setbacks from the property line. The parking requirements in the Parking By-Law often result in projects constructing large parkades under buildings to provide the required parking spaces. These subsurface parkades will regularly extend to property lines, reducing opportunity for Tier 1 GRI at ground level. Another example is the Urban Forest Strategy, which outlines the importance of trees in the urban environment and sets out targets for tree planting that require existing and future tree canopy to be prioritized.	Infiltrative facilities	City	Design
10	Building Integrity Concerns	The VBBL contains 5-meter setback requirements for building from infiltrative facilities that are intended to limit harm to people, damage to buildings from excessive moisture loading on foundations and footings and short-circuiting that could occur by infiltrating water adjacent to a structure (which could enter the foundation drains that lead to the sewer). Setback distance from the street, lane, and utilities are at the discretion of the City.	Infiltrative facilities	City	Design
11	Challenges with Managing Runoff Across Property Lines	Currently, there is a regulatory mechanism for a private property rainwater to be managed in an adjacent public property if a public storm connection is provided to the private property for its storm drainage system and the rainwater cannot be managed within the site. The circumstances leading to this solution are likely unique and infrequent. For private-to-private rainwater management, another regulatory mechanism is needed, which could be beneficial if the City were to pursue regional or district-scale GRI solutions. Changes to the Sewer and Watercourse By-law, which requires that every separate parcel of land must connect to the public sewer system (where available) via an individual connection, would likely be needed. The VBBL states that storm water cannot discharge upon or impact other properties. Routing private rainwater to another private site would require non-standard exceptions and agreements.	Offsite/centralized green facilities	City	Design
12	Rainwater Harvesting Feasibility and Cost Effectiveness	The VBBL, Book II, Section 2.7 only allows onsite reuse systems to use rainwater from roofs and prohibits the reuse of groundwater, graywater, and blackwater (stormwater is also not currently allowed, though that is likely subject to change). Without these additional alternative sources, the seasonal nature of rainwater supply (and thus need for large storage tanks or long periods of supplemental potable water) will make cost-effective non-potable reuse systems a challenge.	Non-potable water systems	City	Design
13	Limited GRI Design Standards to Support Current Regulation and Policy	There is a lack of guidance from the City for how to identify an acceptable and compliant GRI approach and how to design the GRI facilities, outside of what's provided in the Rainwater Management Bulletin, the Zoning By-law, and the VBBL. This issue is compounded by an existing knowledge gap within the local consultant community. There are design resources regionally, such as the Metro Vancouver – Source Control Guidelines, however these are often tailored towards lower density development and provide a framework that does not meet the dense urban requirements in Vancouver.	GRI tools (all)	City	Design

#	Barrier	Description	Tool Applicability	Key Party	Project Phase
Procedural Barriers			Tool Applicability	Key Party	Project Phase
14	Lack of Departmental Coordination	The City is a complex organization with many different departments involved in rainwater management and their various regulations can affect GRI implementation both directly and indirectly. Coordination and alignment across disciplines can be challenging for some types of development, and there are often multiple departmental signoffs. Comments or requirements can come from these departments at various points in the design process, which adds time and potential need for costly redesign. In addition, some City departments have competing priorities that add complexity to the development process and restrict the ability to implement GRI. For instance, there are competing priorities with climate readiness, affordable housing, parking, and rainwater management.	GRI tools (all)	City	Design
15	Unclear RWMP Submission Process	Upon reviewing the RWMP submittals, it appears that the report portion is well standardized, however the supporting information is inconsistent. Many reports are missing information necessary for approval when they are submitted to the City. Additionally, it is common for these reports to suggest multiple forms of GRI at early stages that are later either deemed infeasible or removed prior to building permit. Feasibility assessments are not required prior to submitting the RWMP.	All tools	Consultants	Design
16	Lack of GRI Maintenance Plan Enforcement *(beyond the 2-yr post-occupancy period)*	At present, a required RWM Agreement includes the Owner's responsibility to submit Statutory Declaration after a 2-yr period following Occupancy Permit issuance. This is required to ensure onsite rainwater management systems are maintained, repaired and/or cleaned in accordance with the O&M manual to keep intended performance post-occupancy within the 2-yr period. Beyond the 2-yr period, there is no enforcement currently established at this time. The exception is the Operating Permit for rainwater harvesting systems. The RWM Agreement does not provide guidelines or requirements to ensure that the GRI facilities are maintained and remain functional post-construction after the 2-year term of the agreement. Landscape Plans (and the associated GRI) are not easy to enforce with current legal tools. The Vancouver Charter prohibits the City to collect landscape installation deposits/ LOC's. The City does not use subject matter experts to inspect landscape installations or related GRI's. The Board of Variance can quash development permit conditions imposed by the Director of Planning, which can weaken the City's position in enforcement of landscape treatment and materials.	GRI tools (all)	Developer / Owner	Post-Occupancy
Economic Barriers			Tool Applicability	Key Party	Project Phase
17	Added Incremental Costs	If co-benefits are not valued, there is minimal economic payback for the incremental costs to design, permit, and install GRI compared to conventional site landscaping and gray infrastructure. As a result, GRI tools are often the first items to be removed in a value-engineering process if they are not a requirement.	GRI tools (all)	Developer / Owner	Design
18	Affordability of Housing	The incremental costs associated with design, permitting, and construction of GRI, or the associated loss of developable area, may challenge the affordability of some residential affordable housing projects. For projects such as temporary housing and below-market housing, that are submitted on provincial and sometimes federal budgets, the fixed budgets may not be sufficient for a large investment in GRI. This is especially true if the building has maximized floor area to be economically feasible, leaving more expensive building systems such as green roofs or rainwater harvesting as the only available GRI practices.	All tools	Developer / Owner	Design
Cultural Barriers			Tool Applicability	Key Party	Project Phase
19	Limited Local GRI Design Expertise	There is an existing knowledge gap within the local consultant community around the planning and design of GRI. Rainwater management strategies are also often thought of a secondary concern and are developed and incorporated too late in the design process, which can impact their feasibility or cost effectiveness. This issue is compounded by limited guidance provided by the City that can cause confusion and perpetuate misconceptions about design and installation of GRI.	GRI tools (all)	Developer / Owner	Design
20	Insufficient GRI Construction Standards and Expertise	Correct installation of GRI is imperative to its success. There is currently a lack of local industry expertise and experience in constructing, maintaining, and monitoring the performance of GRI. In addition, the city does not provide any contractor training or guidance specific to GRI construction, except for rainwater harvesting. This lack of construction knowledge may lead to longer development timelines, increased costs, and poor implementation.	GRI tools (all)	Consultants	Construction
21	Limited Understanding of Benefits and Costs	There is an industry perception that GRI is more expensive to build and to maintain than traditional gray solutions for stormwater management, with little return on any additional investment. This is often a product of limited experience, a poor understanding of the benefits of GRI to the site and the City, or an incomplete accounting of the life-cycles costs.	GRI tools (all)	Developer / Owner	Design
22	Perception of Higher Risk	The implementation of GRI is relatively new for many designers and developers and a lack of past experience may increase the perceived risk associated with functionality, costs, and/or maintenance of GRI facilities for owners or the liability for designers.	GRI tools (all)	Developer / Owner	Design

Task 9 – Policy Considerations Memo

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TECHNICAL MEMORANDUM

From:	Lotus Water
To:	Gord Tycho, City of Vancouver
Date:	6/10/2024
Project:	Rainwater Infrastructure Building Typologies Pathway Study
Subject:	Task 9 - Rainwater Management Policy Considerations – Revised Final

Introduction

The Lotus Water team (Lotus) has prepared the following technical memorandum per Task 9 described in the work plan. The objectives of this task are to develop a prioritized pathway tool set, provide policy recommendations to support the identified pathways, and make recommendations for general policy development. The policy considerations presented in this technical memorandum are presented in the current context of the recent changes to City of Vancouver (City) Building Bylaw (VBBL) for rainwater management in new development and the advancement of the Healthy Waters Plan (HWP) analyses, both of which were either unknown or undeveloped at the time the Rainwater Infrastructure Building Typologies Pathways Study (the "GRI Pathways Study") was initiated in 2021.

In summary and given the above, this deliverable provides:

- insights and information concerning the feasibility for certain private developments to meet either the 24mm or 48mm retention[1] design standard (i.e., a set of compliance pathways),
- general recommendations for policies, guidance, and tools that the City could develop to support the implementation of green rainwater infrastructure (GRI) and overcome barriers, and
- general recommendations for streamlining and simplifying the design, submission, review, and approval of rainwater management plans.

This memo addresses the RFP requirements in the following ways:

Recommended Pathways

- The pathways are summarized in Section 9.1 (with tables in the appendices documenting all characteristics of each pathway, e.g., performance, costs, benefits summary, etc).
- It is not possible to identify a single "recommended pathway" for each typology considering the feasibility and opportunities for different GRI tools is dependent on the assumed site characteristics and other modeling variables. Thus, each pathway is effectively the "recommended pathway" for that particular set of characteristics (i.e., for that pathway category).

[1] For the purposes of the GRI Pathways Study, "retain/retention" is defined as captured runoff permanently removed through evapotranspiration, reuse, or infiltration (reduces peak flow and volumes) and "detain/detention" is defined as runoff that is captured and drains slowly back to combined sewer or stormwater collection system (reduces peak flows). (HWP Options Catalogue, 2023).

Policy Development

- Policy Type: Prescriptive or Performance Based: Primarily discussed in Section 2.2 - Determine Performance-Based Design Standard.
- Conflicting City Policy and Policy Prioritization: Recommendations on how existing City policy can be amended are primarily included in Section 2.2.1 - Recommendations to Strengthen Current ZDBL Requirements, Section 2.2.2 - Recommendation for Release Rate Reduction, and Section 3.1 - Recommendations for Specific GRI Types
- GRI Costs and 'Target Not Achieved' Options: Discussed in Section 3.2.3 - Develop Alternative Compliance Options.

Policy Implementation (Rollout/Phasing)

- Policy rollout and framework processes are discussed in the introduction to Section 2 – Policy Options and Recommendations, Section 2.1 - Alignment with Healthy Waters Plan Performance Measures, and Section 3.2.1 - Finalize HWP Performance Measures and Complete Performance-Based Modeling Analysis.

Standards, Toolkits, and Capacity Building

- Recommendations are discussed in Section 3.2.2 - GRI Design Manual and Technical Resources, Section 3.2.4 – Facilitate GRI Engagement and Training, and Section 3.2.5 - GRI Maintenance Standards and Enforcement.

Policy Recommendations Overview

As a result of the GRI Pathways Study, the policy recommendations fall under two key sequential steps:

First, articulate the city-wide watershed management and water quality objectives (or targets) so that new private property development requirements can be linked to and compatible with those objectives.

The City is encouraged to advance the HWP, specifically for drainage system and receiving water benefits resulting from updated new development rainwater management bylaws, and build upon this work to develop:

- a quantifiable understanding of the city-wide system benefits of the current or future rainwater management regulations (e.g., 24 mm detention[1], 24 mm retention, 48 mm retention),
- a defensible technical basis for a 48 mm (or 24 mm) retention standard, which would require a more thorough analysis of potential drainage system and receiving water benefits (e.g., reduced flow to drainage systems with capacity challenges, reduction in pollutant levels discharged to receiving bodies, reduction in CSO events),
- an evaluation of the costs and benefits of changing regulations, outside of site-level criteria such as GRI tool feasibility and construction cost comparisons for representative projects, or
- a numerical recommendation for the City's VBBL Phase 2 design standards (i.e., retention depth, flow rate reduction) that links back to the City's water quality goals.

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Second, based on the city-wide objectives and the GRI Pathways Study work, establish an administrative process for new development that provides clear and specific technical resources, and certainty and predictability for the professional design and development communities. Both would decrease time and costs for rainwater management compliance and increase the likelihood of the City achieving its goals for parcel-based GRI.

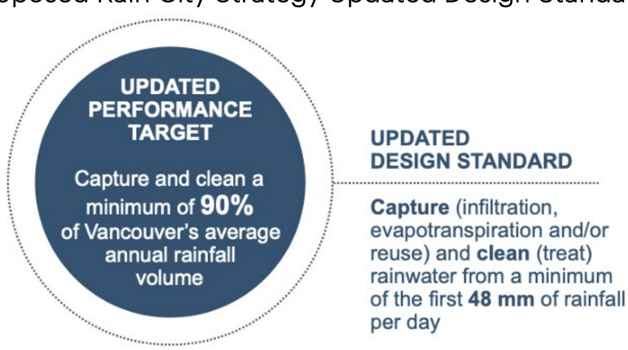
The GRI Pathways Study highlighted many elements of this process, and these are discussed in more detail below. In summary they include the following recommendations:

- Provide a performance-based design standard.[2]
- Evaluate and modify parkade and set-back requirements.
- Clarify green roof design standards aligned with Building Envelope Inspection process and certifications.
- Provide a dedicated design manual and technical resources, such as sizing tools, to assist applicants and standardize submittal format and information presentation.
- Create a "prescriptive" or standard process and steps to allow developers to estimate the time and effort for rainwater management planning and implementation more accurately.
- Develop a simple alternative compliance hierarchy for challenging site conditions and/or to incentivize certain outcomes.

Background

The GRI Pathways Study was conceived as a response to the 2019 Rain City Strategy (RCS) – a visionary rainwater management strategy with goals focused on improving water quality in the City's receiving waters, and increased climate resilience and livability. The objective of the Study is to identify feasible site-level approaches to meeting the City's current design standard (capture and retain 24 mm rainfall) and proposed RCS standard (capture and retain 48 mm rainfall) using green rainwater infrastructure (GRI) tools (Figure 1).

Figure 1 - Proposed Rain City Strategy Updated Design Standards (2019)



[2] Performance-based design standard requires all sites that must comply with a rainwater management requirement to meet a "site-wide" performance, i.e. manage 90% of the 5-year storm, and show drawings, calculations, and/or models to verify that performance will be met. A prescriptive-based design standard would, in theory, require specific rainwater management typologies be installed according to the various redevelopment types and ask for variances if those typologies were not feasible or not compatible with the future uses of the site. The former provides more flexibility for developers, engineers, and architects during the design and redevelopment process and is typically more time efficient and cost effective.

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It's important to understand that at the time the RCS was published, the drainage system and receiving water benefits of the proposed 48 mm design standard were not quantified or considered in conjunction with other City rainwater management initiatives. The lack of a robust technical basis for the 48 mm design standard has been noted by Lotus and City teams throughout the GRI Pathways Study work to date. However, the GRI Pathways Study scope was not developed with the intent to confirm, assess, or model the cumulative benefits of the 24 mm or 48 mm design standard at any scale larger than example parcels and building typologies.

In spring of 2022, the team notified the City that questions received about the broader cumulative benefits of the design standard will be more challenging to respond to as the team worked to advance solutions and policy recommendations that are not tied to a larger citywide runoff reduction or pollutant load reduction goal. It was made clear that the team risked producing deliverables that did not meet the goals of the City or provide the City with adequate justification for existing or future design standards, and the likely possibility that the City and technical working group would find the deliverables lacking or incomplete in supporting the implementation of the Rain City Strategy. In response, the team was directed to continue to follow the original scope of work as described in the RFP and the approved Work Plan. The memos and additional service submittals describing this risk are attached as Appendix A.

In the fall of 2022, the City informed Lotus that the rainwater management requirements, at the time enforced under the Zoning and Development Bylaw (ZDBL), would be modified and moved into the VBBL. The purpose of this change was to streamline and more efficiently enforce the rainwater management requirements in various development types. There were a series of meetings and coordination activities between the City and Lotus in the winter of 2022/2023 to coordinate the proposed bylaw changes with the GRI Pathways Study, and it was determined that Lotus should hold on progressing the GRI Pathways Study until there was clear direction from the City on the best way to accommodate this change.

Table 1 below summarizes and compares the rainwater management requirements previously within the ZDBL and recently implemented in the VBBL. The new VBBL rainwater management policy has key differences, mainly that it modifies the requirements for both capture and water quality treatment.

Simultaneously, the Healthy Waters Plan (HWP) analyses, specifically the development of the Mass Balance Model (MBM), had begun in early 2023, and has the potential to be a critical tool in terms of target setting and preferred pathway development within Phase 2 of the HWP planning process. The MBM will eventually be able to quantify drainage system benefits for multiple potential design standards (such as 24 mm or 48 mm retention) applied to private parcels at various scales within a basin. This modeling can be used to establish the technical basis for basin and/or city-wide targets. These basin and city-wide targets will help the City with downstream analyses, such as those necessary to support the HWP Phases 2 and 3 and the VBBL Phase 2 rainwater policy work.[3]

[3] The VBBL transition and resulting bylaw should undergo a thorough review as it relates to GRI adoption, in our opinion. Each policy recommendation should be assumed flagged for this purpose.

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Table 1 - Rainwater Management Policy Summary

<table>
<tr><th>Standard</th><th>Previous Policy (ZDBL)</th><th>Current Policy (VBBL)</th></tr>
<tr><td>Volume Reduction (Capture)</td><td>Retain the first 24 mm of rainfall across the site (though in practice detention is allowed per Rainwater Management Bulletin guidance)</td><td>Provide detention volume equal to 24 mm multiplied by site area, minus the volume retained over 24 hours in landscape features, green roofs, and rainwater harvesting systems</td></tr>
<tr><td rowspan="2">Flow Control (Release Rate)</td><td colspan="2">Post-development peak flow rate discharged to the sewer shall not be greater than the pre-development peak flow discharged to the sewer, calculated with the Rational Method and using:</td></tr>
<tr><td>IDF Curve:
Pre-development: 2014
Post-development: 2100
Return Period:[4]
5-year for residential projects
10-year for commercial projects
Minimum Inlet Time:
5-year storm: 10 minutes
10-year storm: 5 minutes</td><td>IDF Curve:
Pre-development: 2014 [5]
Post-development: 2100
Return Period:
Pre-development: 5-year
Post-development: 10-year
Minimum Inlet Time: [6]
5-year storm: 10 minutes
10-year storm: 5 minutes</td></tr>
<tr><td>Water Quality</td><td>Per Sewer & Watercourse By-law.
and
Treat runoff to remove 80% of total suspended solids; treat the first 24 mm from all surfaces, except treat the first 48 mm from impervious surfaces with high pollutant load.</td><td>Per Sewer & Watercourse By-law.</td></tr>
</table>

[4] The return period is based on the land use of the site and/or the upstream catchment area and are established through a Sewers review of the local drainage area.

[5] The VBBL IDF Curve is set to be "existing conditions IDF curve as per the Engineering Design Manual" which is currently 2014 IDF but soon will be 2018 and will be periodically updated as needed.[6] VBBL wording references "the inlet time specified in the City of Vancouver Engineering Design Manual" (these times are not directly specified in the by-law in case they change in the future).

[6] VBBL wording references "the inlet time specified in the City of Vancouver Engineering Design Manual" (these times are not directly specified in the by-law in case they change in the future).

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SECTION 1 – Pathway Solution Sets and Release Rate Analysis

The final output from pathway set development and the release rate analysis are presented below (and included in Appendices A through C). A contextual discussion of those results is integrated into the *Policy Options and Recommendations* section that follows.

An important aspect of the modeling analysis and pathways sizing for compliance that was completed for this study and documented in this memo is that it was based on the ZDBL rainwater management requirements that were in place at the outset of this study. Though these requirements changed with the incorporation of rainwater management requirements into the VBBL, it is understood that future changes to the rainwater management requirements (i.e., a subsequent "VBBL Phase 2") may return aspects of the requirements previously in place (e.g., such as a 24-mm retention standard or a more robust water quality standard) and this analysis will be informative for the development of those future requirements. More context on these changing regulations is included in the Background section above.

1.1 Pathway Methodology and Purpose

The primary purpose of the performance modeling task (Task 5) was to determine the viability of various rainwater management tools and compliance pathways for the building-site typologies developed in Task 2, which represent the range of representative development types to be tested. The rainwater management tools to be used to build compliance pathways for each typology were defined in Task 3 (Tools). The design standards, site conditions, and development conditions represent additional modeling variables that were developed in consultation with the City over a series of working group meetings in Task 5 (Modeling).

The initial testing and development of compliance pathways for each of the typologies and design standards being considered were performed in Task 5 (Modeling) using the spreadsheet-based GRI Design Sizer tool developed in Task 4 (GRI Design Methodology); see Task 4 technical memo for more detail on the sizer tool. The modeling process involved the creation of different modeling scenarios that represent distinct combinations of typologies, compliance standards, rainwater management tools, and all the other site, development, and policy condition variables. The most critical variables to pathway development were the compliance standard (level of retention achieved), infiltration rate of existing site soils (which directly informs the feasibility of infiltration-based GRI tools), assumed setback from building foundation for infiltration systems, and size of subsurface parkade (both of which directly inform the potential for location infiltration-based GRI tools on the site).

A summary of the variables used is included in Table 2 below.

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Table 2 - Pathway Modeling Variables

Retention Compliance Standard	Site Conditions		Infiltrative Area Available	
	Pre-Development Condition	Soil Infiltration Rate	Foundation Infiltration Setback	Parkade Extents
24 mm / day 48 mm / day	No pre-development (Natural conditions, 0% impervious) Less than post-development (50% of typology impervious) Equivalent to post-development (100% of typology impervious)	High (50 mm/hr) Medium (20 mm/hr) Low (5 mm/hr) None (0 mm/hr)	Typical (5 m) Reduced (3 m) No setback (0 m)	Parkade minimum - occupies only the building footprint Parkade maximum – occupies portion of parcel equal to total impervious area (i.e., 90-100% of parcel)

This first phase of pathway identification completed in Task 5 (Modeling) was high-level feasibility and scale testing, performed to isolate each primary rainwater management tool type to help determine its performance and viability towards meeting the compliance standard for each typology. The collective results of this modeling facilitated the identification of tools and variables that were critical for pathway compliance and informed the recommended pathways for each typology. It is important to note that the pathways included in this memo (see Section 1.2 Pathway Solution Set) are only a small subset of all theoretical pathways for each typology, chosen for further analysis based on implementation feasibility and alignment with the identified pathway categories.

The identified pathways are organized into five categories. These pathway categories are characterized by specific modeling variable values used for the pathways in each. These pathway categories, and their associated variable values, are summarized in Table 3. Pathway categories 1, 2, and 3 are differentiated by the infiltration potential assumed for the building site; category 1 assumes no infiltration is possible, category 2 assumes the soils have a low infiltration potential, but typical foundation infiltration setbacks and large parkades limit the available space on site, and category 3 assumes that the setbacks and/or parkades are reduced to create some space for infiltrating GRI. Also, all pathways assumed a pre-development condition of "less than post-development" impervious coverage which in discussion with City staff was determined to be an appropriate baseline condition.

- Pathway categories 1, 2, and 3 meet the previous ZDBL 24-mm retention standard (along with the flow rate and water quality standards).
- Pathway category 4 meets the aspirational Rain City Strategy standard of 48-mm retention.
- Pathway category 5 is a detention-only approach (i.e., a gray infrastructure "Tier 3" detention tank and water quality treatment device) that is included to provide a basis of comparison with the various GRI pathways.

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Table 3 - Pathway Category Characteristics

Pathway Category	Retention Standard	Soil Condition	Foundation Infiltration Setback	Parkade Extents
Category 1	24 mm	No infiltration (0 mm/hr)	n/a	n/a
Category 2	24 mm	Low infiltration (5 mm/hr)	Typical setback (5 m)	Full parkade extents (90-100% of parcel)
Category 3	24 mm	Low infiltration (5 mm/hr)	Reduced setback as necessary (<5 m)	Reduced parkade extents as necessary
Category 4	48 mm	Low infiltration (5 mm/hr)	Reduced setback as necessary (<5 m)	Reduced parkade extents as necessary
Category 5	n/a (Tier 3)	n/a	n/a	n/a

As documented in the Task 5 (Modeling) memo, to develop a discrete set of pathways (e.g., 3-5 per typology) for further evaluation it was necessary to limit the pathway categories to specific modeling variable conditions (e.g., pre-development impervious cover less than post-development, no and low infiltration rate soils). A discussion on the impact and influence (e.g., on tool selection and sizing) of some of the modeling variables not included in the identified pathways (e.g., higher soil infiltration rates, lower or higher pre-development impervious coverage) is included below in Section 1.4 Site Condition Variable Sensitivity.

Some key takeaways from the pathway modeling exercise include:

- In the most restrictive "no infiltration" soil condition:
    - Larger building typologies met the 24-mm retention standard (through a combination of green roofs and rainwater harvesting for reuse)
    - In the other typologies, incorporating lined non-infiltrating bioretention in addition to green roofs still achieved approximately half of this retention standard.
- With at least "low infiltration" site soils:
    - Nearly all typologies met the 24-mm retention standard.
    - Small Lot and High-Rise Residential typologies met the 48-mm retention standard.
    - Three typologies (Mid-Rise Residential and both the Non-Residential) are defined with parkades that occupy nearly the entire site, eliminating any infiltration potential.
- Changing the foundation infiltration setback to 3 meters and/or reducing the parkade extent:
    - All typologies met both the 24-mm and 48-mm retention standards.
    - By creating additional opportunity for ground-level infiltrating tools (e.g., bioretention, permeable pavement) the dependency on rainwater harvesting and green roofs for compliance was reduced.

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1.2 Pathway Solution Set

The pathway tool sets that were identified with the Task 5 (Modeling) analysis were evaluated individually using the GRI Design Sizer to confirm their viability and to size each GRI tool component to manage the total site rainfall. These pathways are summarized in Table 4 below. Additional information on performance, co-benefits, and costs is included in the detailed Pathway Solution Set tables in Appendix A (pathways organized by category) and Appendix B (pathways organized by typology). There is also information on GRI tool sizes and sizing ratios in Appendix C.

Table 4 – Pathway Solution Set Summary Table

Pathway Category:	**1**	**2**	**3**	**4**	**5**
Retention Standard:	*24 mm*			*48 mm*	*n/a (Tier 3)*
Soil Conditions:	*No Infiltration*	*Low Infiltration (5 mm/hr)*			*n/a*
Setback/Parkade:	*n/a*	*Typical (Full)*	*Reduced*		*n/a*
Small Lot Residential – Low Massing *Stories: 2* *GFA: 225 m²*	*No viable pathway*	Bioretention	Bioretention	Bioretention	Detention & Treatment device
Small Lot Residential – High Massing *Stories: 2* *GFA: 375 m²*	*No viable pathway*	Green roof Bioretention Permeable pavement	Bioretention	Green roof Subsurface infiltration	Detention & Treatment device
Low-Rise Residential & Mixed-Use *Stories: 3* *GFA: 3,000 m²*	*No viable pathway*	Green Roof Bioretention	Bioretention	Bioretention Permeable pavement	Detention & Treatment device
Mid-Rise Residential & Mixed-Use *Stories: 6* *GFA: 11,700 m²*	Green roof Rainwater harvesting	Green roof Rainwater harvesting Bioretention	Bioretention Permeable pavement	Green roof Subsurface infiltration	Detention & Treatment device
High-Rise Residential & Mixed-Use *Stories: 20* *GFA: 16,800 m²*	Rainwater harvesting	Green Roof Bioretention	Bioretention	Bioretention Permeable pavement	Detention & Treatment device
Low/Mid-Rise Non-Residential *Stories: 3* *GFA: 3,000 m²*	*No viable pathway*	*Not applicable (parkade occupies entire site)*	Bioretention Permeable pavement	Green roof Bioretention Permeable pavement	Detention & Treatment device
High-Rise Non-Residential *Stories: 14* *GFA: 61,600 m²*	Green roof Rainwater harvesting	*Not applicable (parkade occupies entire site)*	Bioretention Permeable pavement	Green roof Bioretention Permeable pavement	Detention & Treatment device

GFA = Gross Floor Area

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Retention Compliance Summary

Retention Standard = 24 mm

- Category 1 – With no infiltration soils, compliance was only possible for the large dense typologies (GFA>10,000 m2) with pathways composed entirely of building-based rainwater management tools (i.e., rainwater harvesting and green roofs).
- Category 2 - With low infiltration soils, compliance was possible for all typologies with pathways composed of a combination of building-based tools and ground-level infiltration tools (e.g., bioretention planters).[7]

For both Categories 1 and 2, the project capital costs increased by 1-3% using the GRI tool pathway compared to the conventional approach of a detention tank and water quality treatment device.

- Category 3 - With infiltrative soils and reduced foundation infiltration setback and/or parkade condition, compliance was possible for all typologies with pathways composed of infiltration tools only.

For Category 3, the project capital costs increased by less than 1% over the conventional approach. [8]

Retention Standard = 48-mm[9]

- With either non-infiltrative soils or low infiltrative soils (and a standard foundation infiltration setback/parkade) compliance with a 48 mm retention standard was typically not feasible (and thus there is no category for this condition).
- Category 4 - With low infiltration soils and a reduced foundation infiltration setback and/or parkade condition, compliance was possible for all typologies with a combination of building-based tools (green roofs and rainwater harvesting) and infiltration tools.

For Category 4, the project capital costs increased by 1-3% over the conventional approach.

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[7] Though only low infiltration soils were used for the selected pathways, in situations where soil infiltration rates are medium or high the reliance on building-based tools could expect to be reduced or eliminated.

[8] The cost increase with reduced foundation infiltration setbacks assumed that the building design is able to account for the reduced setback without requiring additional waterproofing/structural costs.

[9] Though only low infiltration soils were used for the selected pathways, in situations where soil infiltration rates are medium or high then it typically is feasible for most typologies to achieve a 48 mm retention standard using a combination of building-based and infiltration tools.

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1.3 Observations by Pathway Category

The following are key observations and comments for the pathways and each category. Additional information on performance, co-benefits, and costs for each Pathways is included in the detailed Pathway Solution Set tables in Appendix A (pathways organized by category) and Appendix B (pathways organized by typology).

Category 1 - 24 mm retention, no infiltration soils

- With at-grade infiltrative facilities not feasible, there are only viable compliance pathways for the three denser typologies. All of them rely on rainwater harvesting (including capturing ground-level impervious) and most have green roofs.
- These GRI pathways typically increase initial capital costs for total building construction by 1-2% over the typical Tier 3 approach (i.e., using a detention tank and water quality treatment device).10
- There is no compliant pathway for Small-Lot Residential, Low-Rise Residential, or Low/Mid-rise Non-Residential primarily because of the technical infeasibility of rainwater harvesting (RWH) for these typologies – essentially there is not enough non-potable demand in these buildings for a RWH system to achieve a 24 mm retention standard (or 70% annual retention).
- Typologies that do not incorporate RWH but instead use green roofs and/or bioretention with an underdrain can still provide some retention, meeting on average around 50% of the 24 mm requirement, while also meeting the release rate and water quality requirements. Additional discussion and examples of GRI approaches and performance for this "non-compliant" condition (as far as meeting the 24 mm retention standard) are provided in Section 1.6 below. The Pathways Solution Set tables in the Appendix include a non-compliant (i.e., not meeting the 24 mm standard) tool set approach for each of the typologies to show what could be achieved with a GRI approach.

Category 2 - 24 mm retention, low infiltration soils, standard infiltration setback/parkade

- For the two Non-Residential typologies (Low/Mid-Rise and High-Rise) this pathway category is identical to Pathway Category 1 (i.e., there is no Category 2 for those typologies) because the parkade and foundation infiltration setback occupies the entire parcel, leaving no opportunity for any infiltrative tools.
- The Small Lot Residential – Low Massing typology has sufficient space to incorporate ground-level GRI tools (subsurface infiltration gallery or bioretention) which provides much greater performance (retention and release rate) and a lower initial capital cost for total building construction (about 4% lower) than the Tier 3 approach.
- The four other Residential typologies all have much less available space for ground-level infiltrative facilities and as a result all require green roofs in addition to the small amount of bioretention or permeable pavement that can be fit into the margins of the site. The GRI pathways for these provide

[10] The costing exercise in this study was focused on capital and O&M costs. It did not include impact on revenue or return on investment, in part because those aspects are too dependent on the individual building design and marketing to be able to provide a general planning-level estimate.

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greater performance but at a higher initial capital cost for total building construction (between 0.2% and 3.1% higher) than the Tier 3 approach.

Category 3 - 24 mm retention, low infiltration soils, reduced infiltration setback/parkade

- Since Small Lot Residential – Low Massing has sufficient space even with a standard foundation infiltration setback, there's no need for a reduced foundation infiltration setback and no difference between Category 2 for that typology.
- Creating some space on site for ground-level infiltration allows pathways for all typologies that use bioretention and/or permeable pavement. These pathways provide much higher performance (full 24 mm retention and significantly greater peak release rate reduction) than the Tier 2 approach with only a minor increase in initial capital cost for total building construction (less than 1%) over the "baseline" Tier 3 detention approach.
- For each typology, the Category 3 pathway also typically has lower O&M costs and a higher co-benefit score than Category 2.

Category 4 - 48 mm retention, low infiltration soils, reduced infiltration setback/parkade

- There is a compliant pathway to reach 48 mm retention for each typology, but all use infiltrative tools and thus require at least low infiltrating soils and (other than Small Lot Residential) more space onsite to infiltrative by reducing the size of parkade and/or foundation infiltration setback.
- Pathways for all typologies include at least two and sometimes three GRI tools, in order to maximize opportunities for rainwater capture needed to hit the 48 mm retention target.
- Initial capital costs for total building construction with these pathways are higher than Tier 3 approach, but only around 1-2% higher since they utilize more cost-effective bioretention and permeable pavement (compared to Category 2, where rainwater harvesting and lots of green roof is needed).

Category 5 - Baseline detention-only approach

- This approach allows for a reduction in peak release rates (via detention in a storage tank with an orifice-controlled outlet) and treatment (via a proprietary water quality treatment device) but has no mechanism for reducing stormwater volume and thus provides no retention. Further, the above retention-based approaches, that remove 24-48mm of rainfall, typically result in little to no site discharge at all during the release rate design storm (i.e., 90-100% release rate reduction from the pre-development condition) whereas a detention-only approach designed to meet the release rate requirement will only provide around a 40-60% reduction in peak flow from the pre-development condition. As discussed further in Section 2, further study would be necessary to determine what volume reduction and flow rate reduction design standards are necessary to achieve long-term City goals and the corresponding appropriateness of detention- versus retention-based rainwater management approaches.
- The costs (initial capital cost and ongoing O&M) are low for all typologies, however for sites with amendable conditions (e.g., infiltrative soils and a project designed to incorporate at-grade GRI) they are only marginally lower than a GRI retention-based approach.
- The co-benefits of a detention-only approach are lower than most GRI pathways, providing limited benefit in longevity and low replacement frequency.

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1.4 Site Condition Variable Sensitivity

As noted in Section 1.1 Pathway Methodology and Purpose, the modeling effort evaluated a range of values for five variables: Retention Compliance Standard, Site Conditions (Pre-development Condition, Soil Infiltration Rate), and Infiltration Area Available (Foundation Setback, Parkade Extent).For the pathway development, to limit the number of pathways and to allow a more equivalent comparison between pathways, the two site condition variables were kept constant at "less than post-development (50% of typology imperviousness)" for the pre-development condition and either "no infiltration" or "low infiltration (5 mm/ hr)" for the soil condition. It is informative, however, to see the influence of changing these variables. As discussed below, the pre-development condition has little influence on pathway selection or sizing, but the soil infiltration rate condition can have a significant influence with higher infiltration rate soils resulting in reduced size of tools (and thus lower cost and more likelihood of GRI being feasible to meet retention targets).

Pre-development Condition

This variable has little influence on the GRI pathways (Categories 1-4) because if the pathway is sized to provide 24 mm or more of retention then it far exceeds the peak flow release rate target for the 5- or 10-year storm, in all cases achieving zero discharge (or close to that).

The detention pathways (Category 5) however would not meet the release rate targets with the standard sizing approach (i.e., 24 mm multiplied by impervious site area, and a 50 mm orifice) for the "No pre-development (Natural conditions, 0% impervious)" condition. To meet the target for this condition, either the tank would have to get much larger or (more likely) the discharge orifice would have to be reduced to further attenuate the outflow.

Soil Infiltration Rate Condition [11]

This variable is one of the primary influences on pathway viability, tool selection, and tool sizing. For purposes of pathway development, the Category 1 pathways were defined as having no infiltration in the subgrade soils and the Category 2-4 pathways were defined as having only low (5 mm/hr) infiltration into the soil. If soil infiltration rates are greater than this, however, then infiltration facilities can achieve a higher level of performance (i.e., either manage more drainage area in the same GRI tool footprint or shrink the GRI tool footprint and manage the same drainage area). The impact of this is illustrated with two examples in the following table for pathways LMRU2 and MRMU2. Both pathways include green roofs in addition to bioretention and/or rainwater harvesting. If the soil infiltration capacity is increased to moderate (20 mm/hr) then the green roof can be reduced in size (or eliminated in the case of MRMU2) with that additional area

[11] The values used for the infiltration rate variable (i.e. 0, 5, 20, 50 mm/hr) were established in coordination with the City during the Task 5 Modeling process, in order to reflect a range of potential conditions that could be encountered. The most conservative two infiltration variables (no infiltration and low infiltration) were chosen for pathway development as these provide information on opportunities for the most constrained sites; this is further discussed in the Task 5 Modeling memo. No spatial analysis or assessment of expected soil infiltration rates throughout the City was included in the scope, however our understanding is that infiltration rates around the City are highly variable. Preliminary infiltration assessments from the Green Infrastructure Branch have demonstrated that past infiltration rate estimations for the City may have been highly conservative, and moderate/high infiltration conditions may be more common than previously anticipated.

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routed into the bioretention planter and adequately managed. This maintains equivalent performance with a significant reduction in cost and complexity of the stormwater management system.

Table 5 - Comparison of Selected Pathways with Low and Moderate Infiltration[12]

Typology	Site Variable - Soil Conditions	Pathway (Tool Combination)		Performance Summary		Pathway Construction Cost	
		Code	Rainwater Management Tools	Retention (mm)	Release Rate - Peak Flow Reduction	Total	Impact on Building Const. Cost
Low-Rise Residential & Mixed-Use	Low infiltration (5 mm/hr)	LRMU2	Green Roof (750 sq. m.) Bioretention (60 sq. m.)	24 mm	99%	$412,500	Increase 2.5%
	Moderate infiltration (20 mm/hr)	**LRMU2 variant**	**Green Roof (200 sq. m.)** Bioretention (60 sq. m.)	24 mm	97%	$176,000	Increase 0.7%
Mid-Rise Residential & Mixed-Use	Low infiltration (5 mm/hr)	MRMU2	Green Roof (450 sq. m.) Bioretention (20 sq. m.) Rainwater Harvesting	24 mm	100%	$721,700	Increase 1.3%
	Moderate infiltration (20 mm/hr)	**MRMU2 variant**	~~**Green Roof (0 sq. m.)**~~ Bioretention (20 sq. m.) Rainwater Harvesting	24 mm	94%	$528,200	Increase 0.9%

1.5 Release Rate Sensitivity & Zero Discharge Analysis

The City is interested in the feasibility of achieving enhanced release rate targets (i.e., limiting post development flows even further than currently required) including the potential for zero discharge under the 5-year (residential typologies) and 10-year (commercial typologies) design storms. This evaluation was undertaken as a component of the modeling effort.

The current release rate standard is that the post-development peak flow rates discharged to the sewer from a parcel must be equal or less than the pre-development peak flow rates. There are specific IDF curves, return periods, and minimum inlet times used to calculate these flow rates (see Table 1).

For each typology, the peak release rate was calculated for each of the three pre-development condition variables (no development, less than post-development, equivalent to post-development)[13] as well as for the post-development condition assuming no rainwater management tools are implemented. These rates are included in the table below.

[12] This table documents a limited analysis to show two examples of the tools that would be needed for compliance if soil infiltration rates were higher than the "low infiltration" used for the selected pathways. It is not intended to document the full range of typologies, soil conditions, or retention standards.

[13] See Task 5 Modeling memo for more detail on the pre-development condition variables.

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Table 6 - Peak Release Rates for Pre- and Post- Development (with no management)

Building Site Typology	**Design Storm Return Period**	**Peak Release Rate (L/s/ha)** **Pre-Development Condition (2014 IDF)**			**Post-Development Condition (2100 IDF)**
		No development (Natural conditions, 0% impervious)	**Less than post-development** (50% of typology impervious)	**Equivalent to post-development** (100% of typology impervious)	**No rainwater management**
Small Lot Residential – Low Massing	5-year	24	39	54	73
Small Lot Residential – High Massing	5-year	24	47	70	96
Low-Rise Residential & Mixed-Use	5-year	21	53	81	111
Mid-Rise Residential & Mixed-Use	5-year	20	55	86	117
High-Rise Residential & Mixed-Use	5-year	22	54	83	113
Low/Mid-Rise Non-Residential	10-year	25	69	148	202
High-Rise Non-Residential	10-year	21	61	130	176

Table 7 - Peak Release Rate Increase for Post-Development (with no management)

Building Site Typology	**Design Storm Return Period**	**Increase in Post-Development Peak Release Rate (2100 IDF) Compared to Pre-Development Peak Release Rate (2014 IDF) with No Rainwater Management assuming Pre-Development Condition of:**		
		No development (Natural conditions, 0% impervious)	**Less than post-development** (50% of typology impervious)	**Equivalent to post-development** (100% of typology impervious)
Small Lot Residential – Low Massing	5-year	204%	87%	35%
Small Lot Residential – High Massing	5-year	300%	104%	37%
Low-Rise Residential & Mixed-Use	5-year	429%	109%	37%
Mid-Rise Residential & Mixed-Use	5-year	485%	113%	36%
High-Rise Residential & Mixed-Use	5-year	414%	109%	36%
Low/Mid-Rise Non-Residential	10-year	708%	193%	36%
High-Rise Non-Residential	10-year	738%	189%	35%

As shown in Table 8, typologies with GRI pathways (Categories 1-4) that achieve 24-48 mm of retention are all able to significantly reduce the post-development flow for the design storms, to even lower than the pre-development natural condition. Note how all compliant pathways essentially achieve zero discharge (and thus far exceed even pre-development forested conditions) for the 5- and 10-year design storms.

The rational method was used determine peak release rates, which is dependent on storm intensity and area, and essentially independent of the methods used to calculate retention of the 24mm and 48mm rainfall depths. For calculation of the release rates in the tables below (using the GRI Design Tool Sizer), the storm duration used to calculate the post-development storm intensity (using 2100 Moderate IDF Curve - Zone 5 equation) is equal to the time-of-concentration of the project site. In all circumstances analyzed, this

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was 10 minutes or less, which results in a much higher intensity than a 1-hour duration storm event. The modeling results show that the implementation of GRI to capture the 24mm and 48mm storm events (Categories 1-4) result in no flow from these short duration 5-year or 10-year rainfall events used to calculate peak flow rates from the project site. All GRI facilities are assumed empty at the beginning of the calculation, so a GRI management approach with 24mm (or more) retention capacity would have no outflow for the peak storm. Category 5 detention tanks were sized to capture the 24mm runoff (see Task 4 memo GRI Design Methodology, Section 5.2.2 Water Quality), and a 50mm diameter orifice was included on each tank. The peak release rate for detention tanks shown in this table was calculated using the methods described above.

The detention tank pathways (sized to capture 24 mm of runoff from the site impervious area and using a 50 mm orifice) typically achieve release rates close to but above the pre-development forested condition. The detention tank volume was sized to capture 24 mm of runoff across the typology impervious area. The 50 mm orifice size was used as a default minimum size as this was the smallest orifice allowed by VBBL detention specifications without incorporating anti-clogging measures. At this size, the rate of flow is below the pre-development condition requirement and the flow out (of the detention tank) through a water quality device is minimized to reduce the size and cost of the WQ device without adding additional complexity and maintenance cost that a very small orifice may require. While it is not possible for a detention approach to achieve zero discharge, the incorporation of additional detention capacity and/or a smaller orifice could meet or exceed the undeveloped peak release rate.

For more detailed discussion of the calculation methodology and modeling approach, see Task 4 - GRI Design Methodology memo, especially Section 5. Current GRI Design Methods and Section 6. GRI Design Methodology.

Table 8 - Peak Release Rates with Rainwater Management

Building Site Typology	**Design Storm Return Period**	**Peak Release Rate (L/s/ha)**		
		Pre-Development Condition (2014 IDF)	**Post-Development Condition (2100 IDF)**	
		No development (Natural conditions, 0% impervious)	**Pathway Category 1-4 (24-48 mm Retention)**	**Pathway Category 5 (Detention only)**
Small Lot Residential – Low Massing	5-year	24	0	25
Small Lot Residential – High Massing	5-year	24	0	29
Low-Rise Residential & Mixed-Use	5-year	21	0	26
Mid-Rise Residential & Mixed-Use	5-year	20	0	23
High-Rise Residential & Mixed-Use	5-year	22	0	44
Low/Mid-Rise Non-Residential	10-year	25	0	27
High-Rise Non-Residential	10-year	21	0	10

1.6 Non-compliant Pathways

Important to note also is that even the Category 1 "non-compliant" pathways, that were only able to meet a portion of the 24 mm retention requirement, are still able to achieve a significantly lower peak release rate

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than the "no development" pre-development condition. These tool combinations, which included green roofs and non-infiltrating bioretention that treats and detains (rather than infiltrating bioretention that treats and retains), result in a peak release rate around 5 L/s/ha from each parcel compared to the 20-25 L/s/ha for historically undeveloped parcels. This is equivalent to a peak release rate reduction of around 80% from the no development condition and a reduction of around 90% from the "less development" condition (which was the baseline used for pathway development).

Table 9 – Retention and Peak Release Rates for Non-compliance Pathways

Building Site Typology	Pathway Code	Retention Achieved	Peak Release Rate (L/s/ha)
Small Lot Residential – Low Massing	SLRLM1	13 mm	5 L/s/ha
Small Lot Residential – High Massing	SLRHM1	16 mm	4 L/s/ha
Low-Rise Residential & Mixed-Use	LRMU1	12 mm	5 L/s/ha
Low/Mid-Rise Non-Residential	LMNR1	7 mm	5 L/s/ha
High-Rise Non-Residential	HNR1ALT	10 mm	5 L/s/ha

1.7 Key Observations

Based on the analysis and results from the pathway development, Lotus has the following observations with policy implications:

1. The typologies with the most potential to meet the retention requirements are the larger residential buildings, mid-rise residential and high-rise residential. These three typologies can achieve compliance under all categories (most critically, Category 1 with no infiltration and Category 2 with low infiltration but no reduced setbacks). This is because they:
    - have enough non-potable demand to utilize rainwater harvesting as a retention method (critical if infiltration is not possible),
    - were defined with a parkade that did not occupy the entire site (90% vs 100% for the larger commercial typologies) therefore when infiltration is possible there is space onsite to incorporate at-grade infiltrative facilities (and the space can be increased with a reduced foundation infiltration setback alone, rather than a reduced parkade size), and
    - have a larger proportion of the site occupied by the building (65-70% versus 40-55% for the larger commercial typologies) therefore green roofs are able to manage more of the overall site runoff (flexibility if at-grade GRI tools are challenging to incorporate).

    The other typologies (Small Lot Residential and Low/Mid-Rise Non-residential) cannot meet the retention target under Category 1 because they do not have sufficient non-potable demand to utilize rainwater harvesting.

2. The development/policy practice that would most facilitate implementation of cost-effective GRI and thus an increased feasibility of meeting retention targets would be allowing a reduction in the foundation infiltration setback requirement (e.g., 3 m, with additional criteria established to further reduce in certain situations) and/or policy that would facilitate a reduction in the parkade extents (e.g., reducing parking

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requirements). The effect of either of these is simply to create more space on site to locate infiltrative GRI facilities. It is worth noting that currently a special case can be made to reduce the current 5m foundation infiltration setback requirements (i.e., through the Alternative Solutions process), however the potential uncertainty of an approval encourages developers toward Tier 3 detention instead of designing for Tier 1 without a certain outcome. There may also be additional costs for a developer to achieve an Alternative Solution for reducing the foundation infiltration setback, in order to provide mitigation to the building foundation (for example, partial sealing of building foundation).

3. Meeting retention targets is most challenging and expensive if a site does not have the ability to infiltrate because rainwater harvesting would be required (a green roof can manage above-ground runoff but can not manage the runoff from at-grade impervious area, so retaining this requires capturing it in a rainwater harvesting system if there is no place to infiltrate it). Only larger/denser buildings (mid-rise residential, high-rise residential, and high-rise non-residential) have sufficient daily indoor non-potable demand to make rainwater harvesting a feasible tool to meet a 24 mm retention requirement. Note that the Pathways tables in Appendix A and B do show the benefit provided for other typologies if GRI is used that doesn't meet the retention target (as discussed in Section 1.6 above).

4. Pre-development release rates for all of the typologies are around 20-25 L/s/HA assuming the site has no existing development (i.e., no imperious surfaces) and up to 150 L/s/HA if the site had an equivalent amount of development (i.e., the same impervious surface coverage)[14]. The City's release rate standard requires that projects do not exceed that pre-development rate (i.e., post-development rate be equal or less than the pre-development rate). Said another way, the release rate requirement is that a project must achieve a post-development peak flow reduction of 0% or greater (less than 0% would be a peak rate increase). Projects that meet the 24mm (or higher) retention standard achieve a significantly higher rate reduction than 0%, i.e., for all GRI retention pathways the release rate reduction is at least 95% (as discussed previously, this is due to the retention tools typically eliminating all discharge during the release rate design storm). Even typology categories that can't meet the retention requirement, such as in Category 1 pathways, can use non-infiltrating GRI (e.g., bioretention with an impermeable liner and an underdrain) to achieve a release rate reduction of around 90% for the short duration release rate design storm. This is in comparison to the standard Tier 3 detention tank approach (sizing a tank based on 24 mm rainfall depth and a minimum orifice of 50 mm) that typically only results in a release rate reduction of 50% or less.

5. Green roofs are typically necessary to achieve the retention targets when there are space or site (infiltration) constraints at-grade. Green roofs are a component of all Category 1 pathways (24 mm retention with no infiltration) and nearly all Category 2 pathways (24 mm retention with standard foundation infiltration setback/parkade). They are also a component of about half of the Category 4 (48 mm retention) pathways. However, no green roofs are included in any of the Category 3 pathways (24 mm retention with reduced foundation infiltration setback/parkade) since there is more space onsite to located at-grade infiltration facilities as a result of the reduced setback/parkade. The Task 5 Modeling memo, and specifically the "Performance Modeling Results Summary" tables, can provide the City with

[14] Variation in pre-development release rates across typologies given the same pre-development condition (e.g., no impervious surface) are due to slight differences in time of concentration for different sized sites, along with the use of 5-yr storm for residential and 10-yr storm for commercial sites.

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more detailed guidance concerning where the modeling analysis observed that green roofs were critical for meeting the retention standard and where they were optional. It should also be noted that Vancouver's asynchronous peaks of evapotranspiration and rainfall have implications for green roofs in meeting retention targets. The single-event modeling for this study (i.e., performance in meeting the 24-hour retention target or design storm release rate target) assumed that all rainwater management facilities were empty and dry at the start of a storm event. However, for rainfall on a green roof with saturated soil (i.e., during periods of frequent rainfall) there will be little to no available storage capacity in the soil and the rainwater retention benefits would be greatly decreased. On an annual basis, it is still likely that these systems will meet the retention performance basis of 70% annual rainfall removed. However, to provide peak flow attenuation in the "saturated" condition a green roof would need to be designed with a detention component that slowly drains through an orifice (e.g., ponding on the surface or a storage layer below the soil media).

6. In terms of influence on overall building construction cost, if infiltration is not feasible (or if setbacks/parkade are not reduced) the impact on initial capital cost to implement GRI to retain 24 mm of rainfall (compared to a traditional Tier 3 detention tank approach) is likely around a 1-3% increase in total project construction costs. If infiltration is feasible and foundation infiltration setbacks/parkades are reduced then the incremental cost increase is only around 1% or less for 24 mm retention, or up to 2% for 48 mm retention.[15] More detail on all pathway costs and impact on overall project cost can be found in the Task 6 Costing memo and the detail Pathway tables in Appendix A and B.
7. Our observation from reviewing Rainwater Management Plans and discussion with staff is that most developments have complied with the ZDBL rainwater management requirements via Tier 3 detention rather than Tier 1 retention. Our opinion is that this is because the RWMB allows detention and implementing traditional Tier 3 approach is more familiar to developers and designers, is likely estimated and bid as a much more affordable option compared to GRI due to this familiarity and common deployment, and due to lack of local design and construction the Tier 3 approach is perceived as a more straightforward design and implementation step compared to implementing GRI. A more detailed assessment of how building design and rainwater management has been approached on existing sites (and specifically why retention practices have been employed so infrequently and if there were practical opportunities to achieve a higher level of retention) would be a worthwhile exercise, however this was beyond the scope of the study. Such work would be a critical prerequisite to policy and regulatory development and would inform next steps. We'd speculate (based on the outcomes of the modeling work and our experience in other similar jurisdictions) that in many cases the level of retention achieved on these projects could feasibly have been much higher, and the use of GRI may have been more prevalent if the regulations (or enforcement) required it.

[15] As noted previously, the cost increase with reduced foundation infiltration setbacks assumed that the building design is able to account for the reduced setback without requiring additional waterproofing/structural costs. Also, the costing exercise in this study was focused on capital and O&M costs. It did not include impact on revenue or return on investment, in part because those aspects are too dependent on the individual building design and marketing to be able to provide a general planning-level estimate.

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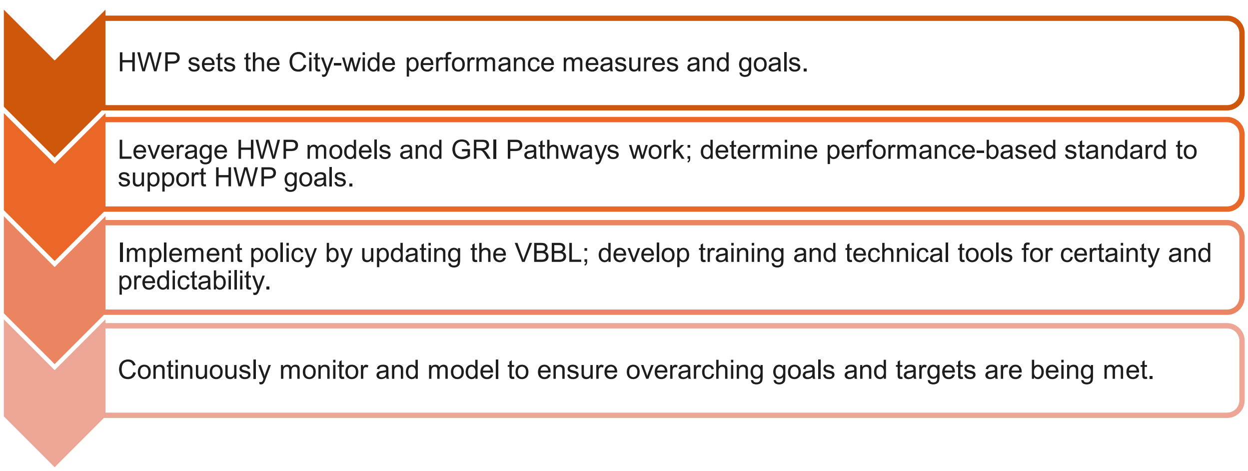
SECTION 2 – Policy Options and Recommendations

As mentioned above, the policy recommendations fall under two key sequential steps:

- First, articulate the city-wide watershed management and water quality objectives (or targets) so that new private property development requirements can be linked to and compatible with those objectives.
- Second, based on the city-wide objectives <u>and</u> the GRI Pathways Study work, establish an administrative process for new development that provides clear and specific technical resources, and certainty and predictability for the professional design and development communities. Both would decrease time and costs for rainwater management compliance and increase the likelihood of the City achieving its goals for parcel-based GRI.

Figure 2 outlines the steps that would establish a framework and the technical basis for private development rainwater management bylaws and initiatives going forward, therefore ensuring consistency across departments in the City's stated purpose for advancing drainage and rainwater policies, and ultimately receiving water quality.

Figure 2 - Example General Policy Framework Process for GRI Pathways



In Lotus' experience, and as documented in the Jurisdictional Scan (Task 4 - GRI Design Methodology), a jurisdiction will typically determine the system- or city-wide performance goal or criteria first and then develop the appropriate development standards, policies, and procedures to support that goal. In many cases the performance goal is a regulatory requirement imposed by a provincial or federal entity. For the City, the standards were set in the Rainwater Management Bulletin (RWMB) in the absence of an overall performance standard or water quality based regulatory requirement. The considerations and recommendations below provide the City a list of next steps to mitigate the potential that the GRI Pathways Study is divorced from any broader system or citywide initiatives or benefits, therefore conflicting with or undermining its purpose.

As noted above, the link between basin-scale or city-scale benefits for the broader drainage system resulting from GRI pathways retaining 24 mm and 48 mm have not been fully quantified. The implications of this are that the GRI Pathways Study, per the current scope, can not provide grounded conclusions for which to base related city-wide policy recommendations or considerations.

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However, there are several findings that do provide useful direction in next steps for establishing a policy that meets the City's HWP goals and provide predictably and certainty for the private development community.

- Using the MBM and other modeling tools used in the HWP effort, it may be possible to estimate outcomes of different standards applied at scale, and over time, so that the City can begin to draw conclusions about the appropriate rainwater management intervention to achieve broader City goals for water quality, climate, and public health.
- Once defensible justification for system-wide benefits is gained, the City can provide the appropriate technical resources for the development community to reduce complexity and confusion and provide predictability and certainty to the City's redevelopment process which may reduce the time and cost to complete the development approval process.
- While the goal for the GRI Pathways Study is to prioritize retention (as required by the ZDBL) and identify feasible approaches to achieve this GRI, stronger detention standards could provide an acceptable benefit to the City, with smaller-scale GRI providing treatment and/or a more achievable level of retention in certain geographies or site conditions.
- The City is a good candidate for an alternative compliance program in the future. Alternative compliance provides the development community flexibility and allows the City to target or direct resources to areas of greatest need. Alternative compliance formats may include allowing detention instead of retention with a stricter release rate or the creation of a cash-in-lieu option. For these types of programs to be implemented, a transparent and defensible justification that shows an equivalent or better water quality benefit in the basin or as part of an overall city-wide water quality goal would be needed.

Current and Developing Policy

The Rain City Strategy and Healthy Waters Plan will set the overarching city-wide goals for rainwater management and improving receiving waterways. Private redevelopment design standards are foundational to achieving those goals because the cumulative benefits increase as redevelopment occurs. Conversely, delayed deployment of redevelopment design standards that reflect current and future climate conditions could put the City at further risk of capacity issues and water quality concerns.

Table 10 - Rain City Strategy Performance Measures

Objectives	Performance Measures
Remove pollutants from water and air	Design GRI systems to capture (infiltrate, evapotranspire, and/or reuse) and clean (treat) a minimum of 90% of Vancouver's average annual rainfall volume (long term)
Increase impermeable area managed by GRI	Manage urban rainwater runoff from 40% of impervious areas in the city with GRI by 2050
Mitigate urban heat island effect	
Increase total green area	
Reduce volume of rainwater entering the pipe system	Capture and clean 48mm of rainfall on public and private property
Harvest and reuse water	TBD

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Table 11 - HWP Draft Goals, Objectives, Performance Measures

Objective	Performance Measure
Goal 1: Healthy Waterways	
Objective 1.1. Eliminate pollution of waterways due to sewage (combined sewer overflows [CSO] and sanitary sewer overflows [SSO])	Reduction in sewer overflows
Objective 1.2. Eliminate pollution of waterways due to urban runoff	Improvement in rainwater cleaned
Objective 1.1. Eliminate pollution of waterways due to sewage (CSOs and SSOs) Objective 1.2 Eliminate pollution of waterways due to urban runoff	Removal of pollutants
Objective 1.3. Eliminate pollution of waterways due to groundwater	Groundwater kept out of system
Objective 1.4. Prevent pollution from entering the sewage and drainage system	Pollution stopped at its source
Goal 2: Healthy and Livable Watersheds	
Objective 2.1. Restore the retention and absorption of rainwater close to where it falls	Infiltration of rainwater
Objective 2.2. Restore the amount of natural area within the sewer and rainwater management system	Restoration of natural areas & reduction of urban heat
	Change in hardscaped surfaces
Objective 2.3. Increase the availability of non-potable water	Re-use of rainwater
Objective 2.4. Restore quality of natural area within the sewer and management system.	Connectivity to natural drainage systems
	Improvement in streamside habitat quality
Goal 3: Adapt to Risk and Uncertainty	
Objective 3.2. Minimize overland flooding risk to people, critical infrastructure, and property	Reduction in flooding
Objective 3.3. Minimize sea level rise flooding risk to people, critical infrastructure, and property	Reduction in sea level rise impacts
Objective 3.4. Minimize seismic risk to sewage and drainage services	Improvement to seismic resilience
Objective 3.5. Minimize capacity risk due to growth and development	Impact in sewer and drainage capacity
Goal 4: Affordable and Optimal Service Delivery	
Objective 4.1. Minimize public investment requirement	Total cost
Objective 4.2. Minimize private investment requirement Objective 4.3. Fairly balance the distribution of costs over time and across public and private sectors	Public vs. private costs
Objective 4.1. -Minimize the overall investment	Total overall costs
Objective 4.2. Minimize public investment requirement	Total public cost
Objective 4.3. Minimize private investment requirement	Total private costs
Objective 4.4 Maximize the adaptability of investments to manage future uncertainties	Costing of 4.1-4.3 under different scenarios (e.g., differing growth forecasts or accelerated climate change)

2.1 Alignment with Healthy Waters Plan Performance Measures

The Healthy Waters Plan has defined draft objectives and performance measures for healthy waterways, healthy watersheds, adaptation to risk, and affordability (Table 11). It has also identified specific options, or tools, that the City can utilize to achieve these performance measures over time. One of those tools is a policy option for new development, based on the current and proposed Rain City Strategy performance standards of 24 mm and 48 mm rainwater capture, respectively. The GRI Pathways Study outlines clear

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methods and conditions for meeting the on-site rainwater management goals outlined in the Healthy Waters Plan.

The HWP goals and objectives will become the foundation for the overarching city-wide policy for rainwater management and specifically on parcels and in redevelopment. Once finalized, several of the options will be combined and optimized leading to HWP Phase 3 implementation planning. Given the high proportion of land area and impervious cover within the realm of private parcels and the potential for low costs and high benefits to the City over time, its highly likely that the option related to rainwater management in redevelopment will be included in HWP Phase 3.

As revealed in the pathway costing evaluation, the portion of total development costs for retaining 24 mm or 48 mm depending on the typology did not exceed 3% (see Appendix A). Therefore, it is likely that streamlining and strengthening the rainwater management requirement itself will not result in negative impacts to private redevelopment. However, the opportunity to streamline the administrative process (e.g., timeline for submittals, reviews, approvals, and/or clear alternative compliance mechanisms) could have material benefits for private redevelopment in terms of time and cost savings. Clear technical design guidance in the form of standard drawings and sizing procedures would also assist in simplifying the delivery of GRI solutions.

When linking overarching city policy with specific requirements or incentives, a jurisdiction will need to revise and iterate scenarios until they achieve the right balance of supporting city objectives, meeting regulatory expectations, and ensuring that the requirement is reasonable and technically feasible. This is where the HWP and the GRI Pathways Study intersect.

This memo will not cover the scope of the HWP and its modeling and performance analysis, but once the HWP quantifies the outcomes needed to meet these goals and objectives, the City will be able to define the specific goals for rainwater management across several land use types and/or within the various basins. Then HWP Phase 3 and the list of specific options to be implemented can be applied toward that numeric goal. Using the output developed from the HWP (i.e., the Mass Balance Model) and the GRI Pathways Study, the City will have the tools to begin a performance analysis for the redevelopment policy options.

Even at its early development stage, using the results of the MBM analyses (see introductory Background section for further detail on the Mass Balance Model) can provide some context at the basin-scale and an initial direction for near term policy decisions. The combined results of the MBM and the GRI Pathways Study can provide the City with a basis for initial reasonable expectations for site-level retention or detention that are feasible and can be used in the implementation of the VBBL Phase 2 effort.

2.2 Determine Performance-Based Design Standard

The City is interested in recommendations as to whether some specific building-site typologies should have "prescriptive" or "performance-based" policies, Lotus does not recommend typology specific "prescriptive" policies for rainwater management in redevelopment in Vancouver. Instead, Lotus recommends a "performance-based" compliance policy.

Given the City's current challenges with capacity, variation in submittals, permit approval timelines, and uneven application of the ZDBL rainwater management requirements, a performance-based standard would better support the City's goals to streamline the permit submittal and approval process and to accommodate modified or alternative compliance frameworks where compliance is not feasible.

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Benefits of Performance Based-Design Standard

Both approaches have a similar goal of creating certainty and predictability in the submittal and approval process. However, the benefits of a performance-based standard are preferred for the following reasons:

- Technical resources and submittal templates developed to support a performance-based standard can be standardized for all typologies or developed in tiers for large categories of buildings (e.g., Part 3 and Part 9).
- Demonstrating compliance can be a straightforward process where submissions utilize the same calculations, modeling tools, standard details, etc. reducing the variation from submission to submission. As reviewers become familiar with the calculations and performance outputs, they would presumably spend less time getting to an approval.[16]
  - See the example of Portland, OR in the Jurisdictional Scan (Task 4 GRI Design Methodology memo) for a tiered submittal process, which established a tiered administrative process with the degree of complexity of the redevelopment site and project. This example allows for a simplified process for routine permit applications, but also allows for more extensive reviews for larger sites as well.
  - Another example are "professional-certification" processes, such as the NYC Department of Buildings, which allows simple, routine permits to be approved in one business day without a plan review and with only a professional stamp (professional engineer or architect).
- Developers, with their professional design team, will have the flexibility and leeway to integrate the rainwater requirements into their site plan most efficiently, which can reduce compliance costs and timelines.
- Integrating alternative or modified compliance frameworks within a performance-based standard is a more straightforward process because compliance is tied to a performance metric that can be assigned a unit cost for a fee in-lieu, can be met with an equivalent off-site project, or be integrated into a credit trading system. The performance metric can be used as a common currency to provide transparency to the development community and public, as well as to ensure that an equivalent water quality benefit is being achieved.
- Updates and revisions to bylaws and design manuals can be more efficient to adapt and be less time consuming to update, as opposed to the multiple details that are required to be changed or revised with a prescriptive approach.
- Performance-based standards can be modeled at scale, across watersheds or basin-wide, to help predict potential system-wide benefits such as discharge volumes, flooding analyses, and other spatial assessments of costs and benefits of various rainwater management efforts.

Ideally, the HWP modeling and analysis will determine an initial minimum design standard that can be applied to all redevelopment and extrapolated over time to assess the cumulative benefits. Once the standard is determined, it would be applied universally to all parcels over a fixed area (e.g., parcels of 0.25 hectares or larger). Basing rainwater management compliance on building mass (e.g., total floor area)

[16] Forthcoming VBBL process will have standard forms, calculations, details, etc. that align with this recommendation.

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is not recommended for a rainwater management requirement as one of the main inputs for all the calculations for runoff volumes are surface areas and types. The amount of runoff that a new development project is going to create and discharge offsite (absent any rainwater management interventions) is directly associated with the amount of impervious surface on that site. In our experience, jurisdictional requirements for rainwater management are essentially always tied to this metric as opposed to building massing. Building mass, if considered along with building type (e.g., commercial or residential), can be a reasonable proxy for onsite non-potable water demand and thus be indicative of the potential to implement a rainwater harvesting system.

A "performance-based" standard relies on clear standards for how to successfully meet the performance goals. As mentioned, developers will need step-by-step guidance to design and size the GRI systems. The proposed standards below would seek to address the issue of uneven applications in the requirements, which impacts the permit submittal and approvals, and would result in higher quality submissions from developers. The below bullets are two proposals for a viable approach to a performance-based standard.

In the absence of the HWP modeling, we can see in the results of the GRI Pathways Study that a true retention standard provides greater than 90% reduction in the release rate for all typologies. That is significant and is a clear basis for two options of performance-based standards:

- Maintaining but clarifying and strengthening the requirements in the most recent RWMB (August 2022), or
- Creating a 90% release rate reduction requirement from the current pre-/post-, to mimic and achieve benefits similar to the retention standard without a prescriptive bylaw. (Also see Section 2.2.2)

The following two sections review two unique approaches to transitioning to a performance-based design standard that would encourage and prioritize GRI approaches: strengthening the ZDBL or implementing a significant reduction in the maximum release rate.

2.2.1 Recommendations to Strengthen ZDBL Requirements[17]

There are several areas where the current approach to rainfall-runoff calculations and GRI design methods based on the current methodology can be strengthened and improved including:

1) Clearly define the application of the standard.
    - Apply the ZDBL rainwater management standard beyond rezonings or large developments in a simple clear way, e.g., "All redevelopment disturbing 1000 square meters or greater, or adding 500 square meters of impervious area, shall submit a Rainwater Management Plan (RWMP)." Lot size or disturbance thresholds are commonly used by jurisdictions to achieve broader drainage and water quality goals more quickly.
2) Use a dynamic storm event basis for the minimum design standard.

[17] While this approach is not likely given VBBL updates, it's included here to satisfy the original intent of the scope outlined in the work plan.

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- Current methodology assumes 100% of the 24mm of rainfall becomes runoff, which is overly conservative and can make compliance more difficult.
- The criteria and guidance state that a proposed project must manage the 24mm rainfall in 24 hours, but this time component is not included in the design process. Volume reduction and water quality treatment volumes are determined based on a static rainfall depth rather than a dynamic rainfall pattern. By not distributing the rainfall depth across a full storm duration or using variable rainfall intensities, the rainwater runoff patterns are over-simplified and resulting GRI designs are often oversized.
- Volume reduction and water quality treatment use simplified, time-independent methods of single rainfall depth while release rate is determined using various design storms and time-dependent calculations. This results in a more complicated evaluation of compliance and ensures that the results are not directly comparable.
- The current methodology uses basic storage calculations, such as media volume times media porosity, for natural landscapes and other, retention based GRI. This is a good starting point but does not allow for time-variable accounting of dynamic processes such as infiltration into the media, infiltration into the subsurface, temporary ponding of GRI due to peak runoff, or release from detention to the sewers during the storm event. The result is either oversized GRI or, more typically, the opportunity for applicants to justify the use of detention based GRI to meet the onsite rainwater management requirements.

3) Combine retention and water quality volume requirements.
   - Though not common in current development projects, driveways and parking lots are considered "high-pollutant" areas and have an additional 24mm of water quality treatment volume associated with them. Inconsistent rainwater management requirements across a single project complicates the design process, and most pollutants will be captured by the smaller and more frequent rainfall events which produce the first 24 mm of runoff, reducing the value and effectiveness of this additional treatment volume.

4) Standardize orifice size and release rates.
   - Release rate of capture volume is initially set at the design release rate based on an intense, short duration, 5-year storm event, then adjusted down to use the required storage volume more efficiently. This results in a high release rate that tends to produce limited peak discharge reduction for longer duration or less intense storms, such as a 24-hour storm with 24mm to 48mm of rainfall, where GRI can be more impactful.
   - There is little discussion or consideration of standard orifice sizes when setting the design release rate. Proper orifice sizing using standard sizes could potentially lead to larger storage volumes. Additionally, the City is now requiring optimization of orifice size to increase detention for longer duration or less intense storms occur during the design review process. However, this optimization should be built into the GRI design process from the start to allow for clarity, consistency, and overall better design.

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2.2.2 Recommendation for Release Rate Reduction

The original scope for the GRI Pathways Study did not anticipate the VBBL changes the City has implemented, as described above. However, the results of the release rate analysis did show a strong argument for the benefits of substantial reduction in the release rates for a detention-based design standard and requirement to achieve close equivalent benefits as compared to the retention-based design standard and requirement. A post-development peak flow rate of no more than 10% of the pre-development peak flow rate is recommended.

A significant release rate reduction would align efficiently with the recent Phase I VBBL changes for the following reasons:

- It's a detention-based standard that allows retention; therefore, a dramatic increase in the total detention volume would incentivize more retention where feasible in order to reduce the detention volume because large grey tanks can cost more than bioretention.
- A maximum release rate would allow developers to determine the scale of the retention and detention features within the site based on the site plan, programing, parkades, and other factors.
- The detention-based standard can be refined over time as the City develops more modeling tools for system-wide benefits of redevelopment requirements.
- Once the HWP modeling is complete, it will be possible for the City to transition to a standard maximum release rate L/s/ha that would be applied to all redevelopment parcels exceeding a certain size or impervious cover threshold.

Without the modeling to confirm which categories of buildings would be subject to this new maximum release rate, the City can set an initial reduction ratio based on the result of this study, which showed that all retention pathways reduced release rates by over 90%. Example VBBL language is shown in the table below as compared to the current and upcoming policies:

Table 12 - Example of Revised VBBL Language

<table>
<tr><th>Standard</th><th>Previous Policy (ZDBL)</th><th>Current Policy (VBBL)</th><th>Example VBBL Language</th></tr>
<tr><td rowspan="2">Flow Control (Release Rate)</td><td colspan="2">Post-development peak flow rate discharged to the sewer shall not be greater than the pre-development peak flow discharged to the sewer, based on:</td><td>Post-development peak flow rate discharged to the sewer shall not be greater than 10% of the pre-development peak flow discharged to the sewer, based on:</td></tr>
<tr><td>IDF Curve:
Pre-development: 2014
Post-development: 2100
Return Period:
5-year for residential projects
10-year for commercial projects
Minimum Inlet Time:
5-year storm: 10 minutes
10-year storm: 5 minutes</td><td colspan="2">IDF Curve:
Pre-development: 2014
Post-development: 2100
Return Period:
Pre-development: 5-year
Post-development: 10-year
Minimum Inlet Time:
10 minutes</td></tr>
</table>

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SECTION 3 - Recommended Implementation Steps

There are two sets of recommendations presented in this section: the recommended steps for increasing the use of specific GRI Types, and recommendations for broader policy to advance the Pathways Study purpose and align this work with related City initiatives and policies.

3.1 Recommendations for Specific GRI Types

The GRI Pathways Study looked at various constraints and limitations to GRI implementation in Task 8 (Barriers and Solutions). Regulatory constraints arise when potential GRI tools are determined to be infeasible due to real and perceived conflicts that emerge from existing regulations or policies. The solutions to these constraints are policy recommendations to revise existing regulations and guidance, and/or the creation of new regulations and guidance documents.

3.1.1 Develop Resilient Roofs Policy

Based on the Pathways Solution Sets modeling and analysis, it's clear that resilient roofs in redevelopment will be critical to successful GRI implementation in Vancouver. While the solutions to the related constraints would be covered in the regulatory revisions described above, it is important to note that resilient roof policy could proceed forward on its own track and could allow for earlier adoption, especially in multi-family residential scale or larger buildings.

Intensive green roofs are typically sold as systems and mostly modular to install. This allows a jurisdiction to set basic standards and/or performance metrics and allow the designer to specify which system to procure for a project.

The rollout of standards, guidance, or performance metrics around resilient roofs for rainwater management would help alleviate the issue of space constraints at ground-level. New guidance could also clarify and show examples of resilient roofs incorporated into amenity space while not significantly impacting space for bulkheads, egress, and mechanical equipment. Other regulatory changes, such as allowing mechanical floors to be excluded from the maximum floor space ratio calculation could also be explored.

Insurance barriers related to green roofs and the building envelope certification were discussed at the Green Roof Workshop. A review of the insurance challenges (e.g., concerns with leaking or maintenance) and the City's building envelope certifications will need further attention to determine how the City's regulations or policies would need to be revised. This would be done in coordination with green roof professionals, building envelope professionals, and insurance representatives.

3.1.2 Expand Alternative Water Sources Allowed for Onsite Reuse

The VBBL (Book II, Section 2.7) only allows onsite reuse systems to use rainwater and stormwater and prohibits the reuse of groundwater, greywater, and blackwater. Without these additional alternative sources (which are allowed in many jurisdictions with onsite reuse policies), the seasonal nature of rainwater supply often means that a system either incorporates large storage tanks to capture enough rainfall during the rainy season that the system can continue to operate into the dry season (this is exacerbated by the relative lack of irrigation demand during the rainy season for systems that supply non-potable water to irrigation) or that, without the large tanks, the system ends up offsetting a relatively low portion of potable demand and has a

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long period of supplemental potable water purchases throughout the dry season. Either of these approaches can challenge the cost effectiveness of constructing and operating an onsite non-potable reuse system.

Allowing additional sources that have a more consistent year-round supply, such as greywater, often provides the opportunity for an onsite reuse system to achieve a much greater level of potable water offset. For some projects, particularly larger residential typologies, the long-term avoided costs (i.e., reduced municipal utility fees) resulting from a much higher level of onsite non-potable reuse can balance out the increased initial construction and ongoing operation costs associated with treating the additional alternative water sources and benefit the overall cost-effectiveness (in addition to greatly enhanced potable water savings, if that is a City goal).[18]

Lotus recommends that the City develop additional standards and requirements around the design, treatment, approval, commissioning, and ongoing testing/operation of systems that use these additional sources (greywater and/or blackwater) to provide additional opportunities and flexibility for projects that wish to implement more ambitious onsite reuse systems.

3.1.3 Increase Retention Opportunities within Parcels

Zoning by-laws set the building form requirements within areas of the City. Meeting all of the zoning requirements can result in limited space specifically in determining structure setbacks from the property line.

The parking requirements in the Parking By-Law often result in projects constructing large parkades under buildings to provide the required parking spaces. These subsurface parkades regularly extend to property lines, reducing opportunity for GRI at ground level.

The VBBL contains 5-meter setback requirements from building foundations for infiltrating GRI, that are intended to limit harm to people and damage to buildings from excessive moisture loading on foundations and footings. The foundation infiltration setbacks are intended to avoid any short-circuiting that could occur by infiltrating water adjacent to a structure (which could enter the foundation drains that lead to the sewer). It should be noted that the model National Building Code contains a 5 m setback, reaffirmed in the 2020 edition in Division B, Sentence 9.14.5.3.(2). The Province has reaffirmed this requirement in the 2024 BC Building Code, and this will be carried through into the next edition of the Vancouver Building By-law. Should there be appropriate technical documentation supporting a reduction of this setback, staff in Development, Buildings & Licensing would submit a formal "Code Change Request" to the Canadian Board for Harmonized Construction Codes. Setback distance from the street, lane, and utilities are at the discretion of the City.

[18] In our experience, diversifying the available alternative water supplies (e.g., using greywater in addition to rainwater) will increase the initial capital and operating costs of an onsite reuse system, but the economies of scale that can be gained from a larger system can sometimes provide a better overall life-cycle cost (resulting from a significant increase in annual potable water savings). However, this is very dependent on local requirements around treatment and testing/monitoring, as well as the size and function of the building.

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As described in Section 1, the foundation infiltration setback and parkade requirements are key limitations for expanding the application of GRI and retention in redevelopment. Lotus recommends addressing those requirements to allow for more opportunities onsite to incorporate at-grade/infiltrating GRI. Specifically:

- Remove or drastically reduce parking requirements for buildings near public transit, for example handicap parking and building service areas only.
- Reduce the minimum foundation infiltration setback requirement for retention GRI from buildings (e.g., to three meters). Provide design standards for below-grade structure sealing and waterproofing, along with structural soils, and other resources. Additional engineering analysis and evaluation would be necessary to determine an appropriate lowered standard setback.[19]
- Create clear guidance for foundation infiltration setbacks from streets, lanes, and utilities for GRI retention to eliminate or drastically reduce discretionary approvals. Develop reasonable, allowable minimums and allow for variances upon request and review. In addition, the City can create standard design details to protect streets and lanes adjacent to retention facilities and share them with the professional design community for redevelopment projects.

3.2 Recommendations for Implementation of Policy

Looking ahead to the VBBL Phase 2 revisions and future HWP performance measures coordination, Lotus has developed the following key steps for new policy implementation to achieve the larger policy goals of healthy waters, increased retention and drainage management with parcels, and increased certainty for developers in the rainwater management approval process.

The City's leadership and advocacy for GRI and innovative rainwater management provides an overarching tone as these policies are implemented. City-led changes to regulations and procedures would reflect the commitment to GRI as well as broader drainage and water quality issues facing the City. Having a clear overarching policy framework from the HWP will show continuity with the RCS and ground the new regulations in clear outcomes.

3.2.1 Finalize HWP Performance Measures and Complete Performance-Based Modeling Analysis

As stated above, confirming the city-scale performance measures with numeric targets is on the critical path for creating a beneficial redevelopment policy. As part of that effort, the modeling analysis to confirm the performance-based design standards at the parcel level can also begin. The City can then use those modeling outputs for both city-scale or basin-scale and parcel-scale to develop the VBBL Phase 2 rainwater requirements while simultaneously developing a design manual and accessible technical resources to link the city-wide policy and the redevelopment policy.

Completing this modeling will provide the City with the opportunity to perform a cost/benefit analysis to present to the development community, i.e., showing where potential costs for compliance and co-benefits

[19] The modeling leading to this recommendation for the reduced foundation infiltration setback was done as a sensitivity analysis step, and any actual policy change to the foundation infiltration setback will require additional study/discussion by the City.

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can vary depending on the proportion of retention and detention systems and, if applicable, alternative compliance options.

3.2.2 Rainwater Management Design Manual and Technical Resources

Regardless of the ultimate details for the performance-based design standard and specific requirements, Lotus recommends a dedicated design manual and accompanying technical resources (e.g., sizing calculator) be developed specifically for rainwater management in redevelopment and new development scenarios, including GRI. Ensuring certainty and predictability will equate to lower costs and less time in developing rainwater management submittals and will streamline the approval process. The more ambiguity surrounding rainwater management requirements, submittals, and approvals, the more likely the development community will take the path of least resistance (which currently is resulting in more tanks and less GRI).

Several of the recommendations made for the GRI design methodology fall under the umbrella of creating certainty and predictability. For example:

- Standardizing the land use application of the rainwater management requirement for redevelopment parcels is key.
- Providing clear design and sizing guidance with examples for how to meet the priority goals, including what will not be approved.
- Communicating that an alternative compliance option is available, or will be developed.
- Creating enhanced engagement with stakeholders, professionals, and developers, including regularly scheduled workshops covering the manual and sizing tool, and "open hours" with City staff for questions and problem solving.

Creating the recommended specific guidance and technical resources will build capacity and help manage risk within the development community. These resources allow for all participants from the professional design community, developers, reviewers, and contractors as well as City management to be aligned about requirements and reduce the need for special exceptions or discretionary reviews and approvals.

With the complexity and variety of site conditions demonstrated through the pathways development, prescriptive pathways are not recommended for GRI design and sizing. A specific guideline or manual, with a set of standard details and specifications, to assist developers in implementing GRI is recommended as a solution for meeting rainwater management goals despite a site's physical constraints.

The rainwater management standards and manual should provide stepwise guidance for each category of site constraints including site assessment requirements. Once site assessments are completed, a design approach can be developed. The manual should illustrate design approaches for commonly encountered site constraints and provide guidance on how to overcome or integrate them into the site.

Over the course of the GRI Pathways Study, Lotus identified several sources and documents including by-laws, policies, bulletins, and the engineering design manual that all contribute to the design of rainwater management systems in Vancouver. Navigating these documents individually presents designers with a complex and time-consuming task to align with multiple resources that may lack consistency. A single design manual that considers all of these inputs and creates a simplified and common language and set of

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units will support a more efficient design process. During the majority of this study the rainwater management regulations were within the ZDBL, but then were moved into the VBBL. With this change, a period of transition will take place with the City engaging heavily with applicants, responding to questions, and clarifying expectations. Especially during policy transitions, manuals and technical resources (such as sizing tools) are fundamental to providing consistency, leadership, risk management, capacity building, and reinforcing certainty and predictability.

It is recommended that the City draft concise language within the new by-law and reference a detailed manual for stepwise guidance for compliance. This is common practice among North American jurisdictions. The outcome would be a single document that contains all the regulatory requirements, related procedures, standard details, and any of the sizing tools. It could be updated as needed without revisions to the by-law itself.

This manual should describe the following topics at a minimum:

- Applicability: Applicability for when rainwater management in redevelopment is required should be very clear and based on a total parcel area, total proposed impervious area, and/or disturbance area. Lotus recommends a standalone and comprehensive manual for meeting stormwater management requirements that clarifies applicability, performance standards, and design guidance. The manual would provide a single location for rainwater management compliance information and all requirements.
- Precise Audience: The Engineering Design Manual is a robust document that provides information covering a variety of engineering design issues, particularly servicing and streetscape design. While it provides most of the technical information needed for these designs, as well as the methodology for a variety of calculations, it does not provide a comprehensive summary of all the key information to be considered when designing a rainwater management system specific to a redevelopment scenario.
- Sole Technical Resource: The ZDBL, and related RWM Bulletin, provides much of the required performance criteria to be met for rainwater management but only briefly touches on elements of GRI design. This document, together with the Engineering Design Manual, could provide most information needed for the design of a rainwater management system. However, the Engineering Design Manual is general and does not provide specific guidance on how to integrate GRI into site and development plans.
- Clear, Predictable Standards: The RCS is an aspirational document that proposed the capture and treatment of the first 48mm of rainfall during a rainfall event; however, most of the documents reviewed, containing similar information, require the capture and treatment of the first 24mm of rainfall during a rainfall event. The manual recommended here would clarify these two documents and statements and give guidance on exactly which performance standard must be met.

The Jurisdictional Scan completed in Task 4 (GRI Design Methodology) provides several leading examples of manuals and the underlying performance standards they achieve.

3.2.3 Develop Alternative Compliance Options

Based on this study, it's clear that not all sites will be able to retain 24 mm (or 48 mm) of rainfall given real physical constraints. In these cases, the allowance for detention facilities (i.e., detention tanks and treatment devices) provides a pathway for compliance with the intent of the rainwater management requirements.

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The current policy does not include any specific options for alternative (i.e., offsite, fee-in-lieu, credit trading) or modified (i.e., adjusted capture/treat/flow targets) compliance approaches for highly constrained sites.

The City does provide an Alternative Solutions process to allow for flexibility in design or "to employ design methods that are different from the prescriptive Building Bylaw requirements" however there is no guidance on acceptable alternative approaches specific to stormwater management (i.e., no certainty and predictability). Developing a more formalized program around potential alternative or modified compliance options, with clear guidance and submittal requirements, may create incentive and opportunity for constrained sites and the City to meet the intent of the RCS.

Given the shift in the VBBL Phase 1 approach (see Table 1) toward only requiring detention facilities, the City may not necessarily need an alternative compliance option in the near term. However, if the VBBL Phase 2 requirements look to reinstate a compliance hierarchy with retention as the priority, then an alternative compliance option may be a detention system with a significantly reduced release rate to attain almost similar performance.

Once the final performance-based design standard is determined, alternative compliance options can be developed. There are several general approaches to alternative compliance including:

- Fee-In-Lieu options can be a last resort and per discretion only, or broadly utilized to create a new revenue stream for the jurisdiction to use in the funding of capital projects toward Healthy Waters Plan goals. Examples of these projects include building large green facilities, tree planting, urban greening and watershed health initiatives, or distributed GRI assets within the public right-of-way – all within the same basin as the proposed development. Fee-in-lieu programs can be shaped to fit the specific needs and goals of the jurisdiction and can be tailored to meet the City's goals using the magnitude of the fee and eligibility criteria to drive participation accordingly.
- Credit Trading options create a buyer/seller marketplace for GRI credits as public and private parcel-based projects are developed. The jurisdiction regulates a market-based unit price per credit and develops the software and reporting to facilitate the trading system of rainwater credits when needed. Some projects can sell GRI credits where they have more space and can build a larger GRI facility, and other projects are very constrained and need to purchase credits for compliance. The most well-established stormwater credit trading program is in Washington, D.C. and was covered in the Task 4 (GRI Design Methodology) Jurisdictional Scan.
- Off-Site Compliance options typically require the developer to build an equivalent GRI facility somewhere else within the watershed or subcatchment. Often these off-site projects can be banked, or consolidated, to install more meaningful projects that are targeted in areas of a higher need. Off-site compliance could be combined with credit trading programs.
- Due to the difficulty of meeting retention targets using green infrastructure systems on some building typologies, the City may want to consider incentivizing "green" detention systems such as non-infiltrating bioretention planters that could be incorporated into site landscaping plans, could provide many of the co-benefits of green retention systems, and could offset the size of on-site detention tanks.

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3.2.4 Facilitate GRI Engagement and Training

The correct design, installation, and maintenance of GRI systems is necessary for long-term performance. With any new regulation change, the City should provide training courses for designers, contractors, and maintenance crews to ensure correct design, installation, and longevity of these systems. Once current contractors and maintenance workers are trained, the knowledge will be passed on to newer staff as GRI becomes commonplace around the City.

In general, the alignment of HWP and rainwater management requirements should streamline much of the submittal, design, and permitting process and provide a simpler method for City plan reviewers. Addressing the issue of enforcement of existing maintenance & inspection to ensure the longevity of GRI is critical to programmatic success, but also necessitates a broader discussion around staffing resources or third-party options and costs.

The development of a design manual is also a solution to administrative and training challenges, as well as serving as an engagement tool. The manual would support coordination across City departments and their respective policies and guidelines and provide a single document for all policies related to rainwater management in redevelopment as a training resource.

3.2.5 GRI Maintenance Standards and Enforcement

Successful GRI policy and programs depend on adequate inspection and maintenance of these systems. The City currently has a team of maintenance staff who are responsible for the upkeep of GRI in the public realm. Currently, there are limited requirements for inspection and maintenance for most GRI in the City.

To combat any deficient maintenance operations by Strata or other property or building management, new inspection and maintenance requirements should be included with the updated rainwater management regulations and procedures. This should allow City staff, or third parties on behalf of the City, to inspect GRI on private sites and request maintenance and repairs as required. A financial analysis would be required to assess the effort needed to meet the City's expectations for maintenance of private GRI.

There are many variables to consider on this topic. In the US, many of the on-site GRI implemented as part of new or redevelopment is required to be inspected and an annual reported submitted per Municipal Separate Storm Sewer System (MS4) Permits. While these inspections may not be perfect, it has forced jurisdictions into some frequency of inspection cycle, self-reporting or self-certification, or other systems. The frequency and level of inspection depends on the amount of assets, parcels, and resources. Enforcement tools such as random inspections, fines, and liens can also be effective tools for this purpose. Routine building inspections are not a new challenge however and there are likely several models that would fit the scale and needs for the City to consider.

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3.3 Interim Steps To Consider

At this time, the VBBL updates are being implemented and the HWP is ongoing. If the City wanted to advance any of the recommendations from the Pathways Study, there are some interim steps that may be taken. These were also presented to the City on March 7, 2024.

- Advance the expansion of policy for specific GRI types (City and Provincial Level)
- Start alignment of City-wide policies and goals (HWP Performance Measures)
    a. Using the MBM and VSA modeling analyses can provide an initial direction for near term policy decisions at the basin-scale.
    b. Combined results of modeling and GRI Pathways Study can provide the City with a basis for initial reasonable expectations for site-level retention or detention that are feasible and can be used in the implementation of the VBBL Phase 2 effort.
    c. Release an RFP or change order for HWP to further refine appropriate city-wide performance standard that meets HWP goals.
- Create resources to support GRI on private sites and simplify review process for City staff
- Provide an interim performance-based standard
    a. Modify Release Rate Reduction in VBBL Revisions, Phase 2
    b. Can be updated/revised after further study

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