CITY OF
VANCOUVER

Engineering Services
Green Rainwater Infrastructure Branch

GREEN INFRASTRUCTURE SIZING AND MODELLING GUIDE

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This document has been produced by the City of Vancouver Green Rainwater Infrastructure branch to provide guidance on best practices for sizing and modelling Green Rainwater Infrastructure (GI) systems and assessing the performance of GI assets relative to City of Vancouver performance targets.

This document describes the tools and strategies to assist in designing GI systems that comply with City performance targets. This guidance may be applicable to a variety of GI systems. Further information regarding sizing procedures for specific GI typologies is provided on the Green Infrastructure webpage.

Section 1 provides tools and methods for preliminary GI sizing. Section 2 provides guidance on sizing inlets to GI systems. Section 3 describes the process, principles, and equations for sizing GI systems to meet City of Vancouver volume control targets. Section 4 provides information on available resources for GI sizing. Section 5 provides detailed guidance on modelling GI systems using SWMM software.

The parameters and methods outlined in this guide may not apply to all Green Infrastructure projects. The use of this document does not guarantee the acceptance, approval, or correctness of GI system designs in the City of Vancouver. GI systems should always consider site-specific considerations, applicable design targets, and be designed and approved by a licensed engineer.

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1. Preliminary Green Infrastructure Sizing

The parameters and site characteristics influencing the acceptability and sizing of a GI system may change throughout the design process. A preliminary sizing estimate can provide an approximation of the surface area requirements of the GI system before completing a detailed design.

Green infrastructure systems on public right-of-ways (ROWs) or on private property should always be sized using the methods and tools outlined in Sections 3, 4, and 5. However, preliminary GI sizing may be a helpful first step in determining the space requirements of GI systems on a given site during the early design stages.

1.1. Feasibility Assessments

A preliminary and detailed feasibility assessment must be completed for all GI projects. A record must be kept demonstrating the results of the feasibility assessment, the information assessed, and any concerns related to the proposed site. The following information should be determined prior to completing detailed design of a Green Rainwater Infrastructure system.

- The location and depth of all utilities and structures within 5.0m of the proposed system boundaries
- Sub-surface hydraulic conductivity within the GI practice boundary at the full excavation depth of the proposed GI system
- Presence of geotechnical risk factors including but not limited to the presence of peat, other expansive soils, unstable slopes, high groundwater, contaminated soils,

For more detailed information on feasibility assessments for GI. Refer to Chapter 5.7. of the City of Vancouver Engineering Design Manual. A detailed feasibility guide is available upon request from City of Vancouver staff.

1.2. Contributing Drainage Area Delineation

The Contributing Drainage Area (CDA) is the total area that drains to the GI system during a rainfall event. GI systems in the ROW are sized to absorb a given rainfall depth (48mm) that falls over the entire contributing drainage area of the system. Determining the CDA for a given GI system is an essential first step of GI system design. The contributing drainage area should be determined using all available existing and proposed elevation data including survey points and site grading plans. The net imperviousness of the contributing drainage should also be calculated during the delineation process.

The following principles should be followed when delineating contributing drainage areas on municipal ROWs.

- The upstream boundary of the drainage area should generally be delineated from the Catch Basin (CB) upstream of the asset or the nearest upstream highpoint. For the purposes of GI sizing in the ROW, assume no drainage bypasses the upstream CB.

- The downstream end of the contributing drainage area should be defined as the most downstream inlet into the GI system area.
- CDAs should consider the crown of the road. Where roads are crowned, the contributing drainage areas should be measured from the top of the crown to the frontage of the adjacent property.
- Contributing drainage areas should include all surfaces that drain toward the GI system, including sidewalks, boulevard areas, driveways, and laneways.
- Whenever possible, drainage areas should be delineated using survey information to look for local highpoints and to align with property lines and road crowns.
- Contributing drainage areas should include the GI asset.
- Pervious and impervious areas should be delineated to determine the net imperviousness of the CDA. The imperviousness may be approximated for public ROW catchments using the imperviousness of a sample cross-section.
- Land cover should be confirmed using satellite imagery, site visits, and site plans.
- The total contributing drainage area should be delineated in CAD as a single polygon, with a label or datapoint indicating the imperviousness of the area.
- GI systems within the municipal right-of-way should assume that private property drainage is not directed to the GI area.

When sizing GI systems using the IP ratio, only the impervious contributing drainage area should be used. When sizing GI systems using SWMM software, for annual water balance, the total contributing drainage area and % imperviousness should be used.

1.3. IP Ratios

The Impervious-Pervious (IP) Ratio is a useful tool for preliminary GI sizing. The IP ratio compares the contributing *Impervious* contributing drainage area to the *Pervious* GI system area.

Example: If the GI system consists of 30 m^2 of pervious area, and 1000 m^2 of roadway (90% imperviousness), the impervious CDA is 900 m^2 and the IP ratio is 30:1.

The following table provides recommended and maximum IP ratios for functional GI sizing of different practices.

Table 1: GI Impervious to Pervious (IP) Ratios

GI System Type	Recommended IP	Maximum IP
Bioretention	20:1	35:1
Tree Trenches	20:1	30:1
Sub-surface Infiltration Systems	20:1	45:1
Permeable Pavements	0:1*	2:1

*Wherever possible, permeable pavements should be designed so that they do not receive drainage from outside the permeable pavement area.

These ratios should only be used to identify the approximate footprint requirements of GI systems and may not represent the final sizing requirements once site-specific constraints are accounted for. Detailed sizing, as outlined in Section 4 and Section 5 should be conducted for all GI systems in the City of Vancouver.

1.4. Assembling Design Resources

Drafting of GI systems and the configuration of GI components is an essential part of GI design.

Prior to detailed GI design, the CoV GI Standard Drawings should be reviewed to confirm all relevant standards and determine what system components may be relevant to the design of a given GI system. The GI Standard Drawings are available on the GI website as PDF and CAD files. Guidance on the content required in GI project drawings is included in Chapter 2 of the City of Vancouver Engineering Design Manual.

The City of Vancouver Green Rainwater Infrastructure Implementation (GRI) branch has assembled a library of useful CAD resources (the GI Block Library) that may be distributed to external designers upon request. These blocks have been designed to simplify the process of adapting standard drawings to site-specific constraints. They have been drawn to scale and include adjustable components, dimensions, and features where appropriate.

Additional resources, including information on planting design, GI planning, and past project fact sheets, may be found on the GI webpage. The GII branch will continue uploading resources to the City of Vancouver GI Webpage as they are developed.

2. Inlet and Outlet Sizing

GI inlets convey runoff from the contributing drainage area to the GI system. Runoff may be directed into GI systems in several ways, including curb cuts, trench drains, catch basins, or sheet flow from an adjacent surface. These features may also be designed as outlets for discharging flow from the GI system during major storm events when the system's capacity is full. For examples of GI inlet and outlet designs, refer to the City of Vancouver Engineering Standard Drawings GI2.1 through GI2.6.

Sizing the inlets to GI systems is essential to ensuring that the appropriate design storm volume can enter the GI system during a storm event. All GI inlets should be designed with a safety factor of 1.5 to account for potential performance reductions due to clogging from sediment and debris.

There are two standards for which inlets into GI systems may be designed:

GI Systems Inline with Municipal Drainage Infrastructure

GI systems are often designed with catch basins or other sewer connections within the boundary of the GI system, as shown in the image to the right. Throughout this guide, this is referred to as being "in-line" with the City Sewer system. For in-line GI systems, the capacity of the GI inlet must be greater than or equal to the maximum capacity of the catch basin inlet so as not to impede the flow into the sewer system during storm events.

The inlet capacity for inline GI systems with direct connection to the City sewer system should be sized to accommodate the design storm required for the underlying storm sewers as outlined in *Section 5.2.1C* of the City of Vancouver Engineering Design Manual.

GI systems should never replace or remove an existing catch basin or storm sewer connection. However, upstream CBs or sewer connections may be disconnected and relocated to within the GI system boundary to increase the contributing drainage area to the GI system.

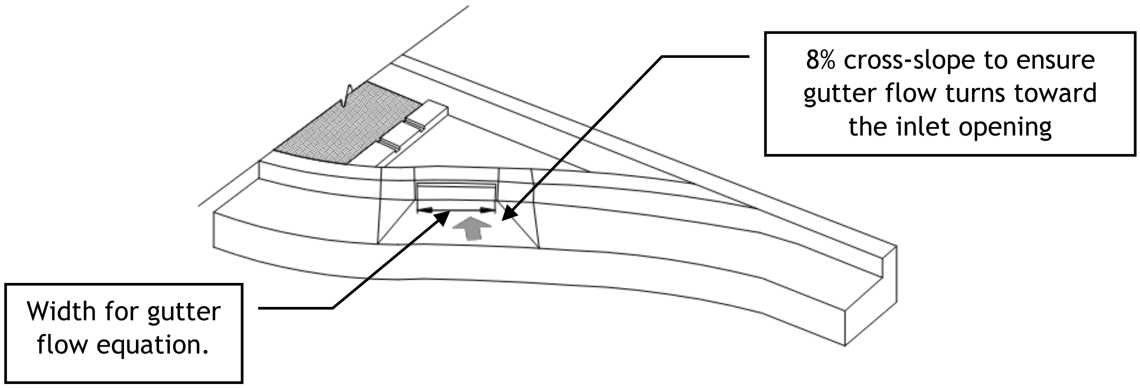
GI Systems Offline from Municipal Drainage Infrastructure

A GI system is considered "off-line" from the municipal drainage system if the nearest catch basin is NOT within the GI system boundary and is instead on the roadway downstream of the system, as shown in the image to the right.

Where GI systems are offline or disconnected from City of Vancouver sewer infrastructure, inlets shall be sized to accommodate a peak flow of at least 2.10 L/s/ha. This flow rate will accommodate the peak flow from a SCS 1A 48mm-24hr design storm with a safety factor of 1.5. However, the total major system flow capacity of the Green Infrastructure system and the immediately surrounding area must be equal to the required sewer design storm event peak flow as outlined in *Section 5.2.1* of the Engineering Design Manual.

2.1. Gutter Flow Inlet Capacity

The following equation should be used to establish the required width of GI inlets if the inlet is oriented along a roadside curb with a gutter pan depression (parallel to the direction of flow). A depressed gutter pan should be used to encourage gutter flow into the curb cut inlet.



Equation 1: Gutter Flow Inlet Capacity

$$W_T = 0.817 Q^{0.42} S_0^{0.3} \left(\frac{1}{n S_x}\right)^{0.6}$$

Where,

n = Manning's roughness (0.018 for paved roadways)
S_0 = Longitudinal slope (i.e. slope of the roadway. Typical = 0.02)
S_x = Cross-slope (i.e. slope of the gutter pan at the inlet location. Typical = 0.08)
W_T = Width of the inlet for complete capture (m)
Q = Design Flow (m^3/s)

Use the following equation to calculate the proportion of flow entering a curb cut of a specific width.

$$R_C = 1 - (1 - \frac{W}{W_T})^{1.8}$$

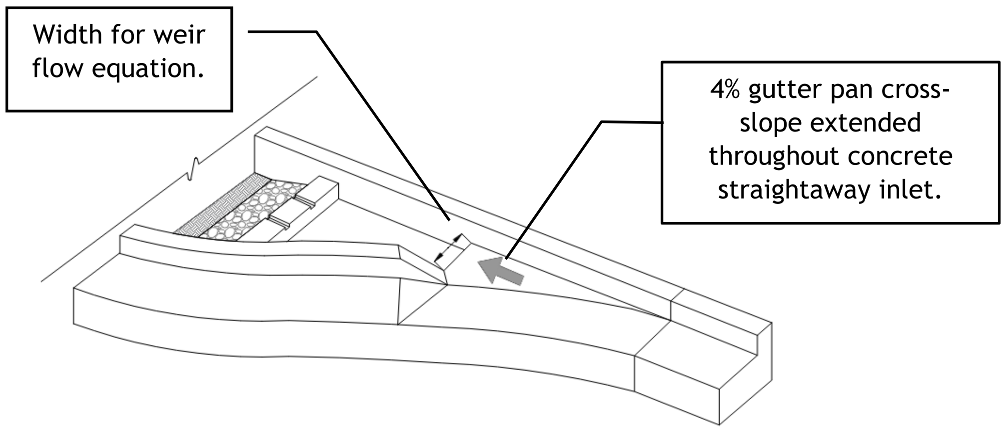
Where,

R_C = Proportion of flow entering the curb cut
W = Available Curb Cut Width
W_T = Width of the inlet for complete capture (m)

Energy dissipation measures shall be installed at each inlet location. These may consist of a concrete sediment pad, basin, or 90-120 mm round river rock stone. Energy dissipation measures should be reviewed and approved by both the engineer of record and a City engineer.

2.2. Weir Flow Inlet Capacity

When incoming runoff is perpendicular to the GI inlet, the weir equation should be used to measure the inlet capacity. Wherever possible, GI inlets should be oriented perpendicular to the direction of flow, as this orientation increases the inlet capacity compared to the gutter flow equation described in Section 3.1. The width of the inlet shall be taken to be the width that is directly perpendicular to the direction of flow.



Equation 2: Weir Flow Inlet Capacity

$$Q = \frac{2}{3} C_D W \sqrt{2g} (H)^{3/2} = 1.831 W (H)^{3/2}$$

Where,

W = Width of inlet weir
C_D = Discharge Coefficient (Typical = 0.62)
H = Max water level height at weir (Typical = 0.10m)

The Max Water Level Height at Weir (H), should be calculated as the curb height with a safety factor of 1.5.

2.3. Pretreatment (Sediment Pads and Basins)

Green Infrastructure pretreatment areas are non-vegetated components located immediately downstream of the system inlet. These areas concentrate runoff and sediment to reduce maintenance requirements and prevent trash and large debris from entering the vegetated portion of the system. The two most frequently used types of GI pretreatment are sediment pads and sediment basins.

Sediment pads are hardscape areas primarily intended to reduce erosion and scour within the GI area. The inlets upstream of a sediment ped should have contributing drainage areas less than 50m2.

Sediment basins have surrounding weir walls and are intended to capture sediment and retain sediment before it discharges and distributes within the GI system area.

The sizing of GI pretreatment areas should consider the anticipated sediment loading from the total contributing drainage area. A properly designed pretreatment area will have sufficient volume to store sediment accumulated between maintenance visits. The table below provides sediment loading guidelines for different land use types to inform pretreatment area sizing.

Table 2: Sediment Loading Rates for Pretreatment Sizing

Land Use	Sediment Accumulation Rate (m^3/ha/yr)*
Residential Road	1.3
Arterial Road	1.5
Commercial Area	2.0
Industrial Area	2.5

*The sediment accumulation rate should be increased by 0.5 m3/ha/yr for streets with a full tree canopy of deciduous trees. The sediment accumulation rate should also be increased by 0.5 m3/h/yr if long-term construction is forecasted in the contributing drainage area.

Pretreatment must be provided for all GI practices receiving drainage from public areas. The pretreatment area for GI practices maintained by the City of Vancouver should be sized to accommodate one year's worth of sediment loading. If a sufficiently sized sediment pad is not included in a GI design, this must be noted and accounted for in a GI maintenance plan.

Pretreatment feature width should not be less than 0.4m to enable easier sediment removal using a standard width shovel. Other forms of pretreatment, such as trapping hoods, sediment socks, extended sumps, or proprietary devices may be required at the request of the design engineer.

2.4. Overflow Outlets

The infiltration components of GI systems are designed to accommodate minor storm events. During larger storm events, GI systems will reach capacity and overflow. For this reason, GI systems must always be designed with an overland flow path that directs overflow to a municipal storm sewer inlet. The overflow outlet of a GI system should have a comparable capacity to a City catch basin. The overflow path for GI systems and the nearest sewer entrance should be shown on design and construction drawings. For major storm events, GI systems should overflow onto the nearest major system conveyance path, which is generally a roadway or sewer.

GI Systems Inline with Municipal Drainage Infrastructure

A GI system is considered inline with municipal drainage infrastructure if the overflow from a GI system is conveyed into a sewer-connected CB that is within the GI system boundary.

Inline Catch basins within GI systems should have an overflow grate elevation that is at least 5 cm below the elevation at which water will spill onto the roadway. This will increase runoff capture rates and reduce the chance of roadway overflow.

Catch basins within GI systems should be installed with spacers such that the rim elevation can be lowered, if necessary.

GI Systems Offline with Municipal Drainage Infrastructure

Bioretention systems may be designed to overflow onto roadways. The receiving sewer inlet should be within 5 meters of the GI system boundary and appropriate erosion and sediment control measures must be taken where runoff overflows from the GI system onto the roadway. Appropriate erosion and sediment control measures are to be outlined in design drawings and should include, at minimum, river rock or sediment socks placed around overflow outlets to a distance of 0.30 meters and to a depth of 0.20 meters from the height of the overflow.

For GI systems where vegetated debris is not a concern due to minimal to no ponding, such as infiltration trenches or rainwater tree trenches, the system may be designed to overflow onto the roadway regardless of the proximity to the nearest sewer inlet.

3. Designing for Volume Control

GI systems may be designed using one of two methods. The Static Method is a simple sizing method intended for preliminary design or for systems that meet more than 120% of the required performance criteria. Dynamic sizing is a more complex and in-depth method for confirming system performance in space-constrained areas. If a system can meet performance criteria using the static method, no additional design verification is needed. However, if the proposed GI system cannot accommodate the design target using static sizing, dynamic sizing may be used to demonstrate performance.

For the purposes of volume control, it is helpful to clarify terms that are relevant to the sizing of GI systems:

Infiltration Rate:	The rate that water is absorbed into the soil media in a GI system
Exfiltration Rate:	The rate that water leaves the GI system and enters the underlying soil beneath the GI system
Discharge Rate:	The rate water leaves the GI system through exfiltration and, if applicable, underdrain discharge
Design Storm Volume	The design storm volume is the total volume of daily rainfall that the GI system is designed to manage.

The design storm volume for ROW GI systems shall be calculated using the following equation.

Equation 3: Design Storm Volume for GI Systems

$$\begin{aligned} Design\ Storm\ Volume &= Design\ Storm\ Rainfall\ Depth\ (48mm) \\ &\times\ Contributing\ Catchment\ Area \\ &\times Contributing\ Catchment\ Imperviousness \end{aligned}$$

$$(typical\ \ roadway\ imperviousness = 90\%)$$

If the infiltration rate is greater than the discharge rate, water will accumulate and eventually cause surface ponding. If the surface ponding volume exceeds the system capacity, water will overflow into the nearest sewer inlet. In a system with no underdrain, ponding is likely whenever the infiltration rate exceeds the exfiltration rate.

3.1. Static Method

The static method requires designers to demonstrate that the total storage area of the GI system (surface storage and soil/stone pore space) is equal to the volume control target. This approach demonstrates that the GI system can accommodate the entire volume control target without any system losses. Recommendations for the porosity and depth of GI components and media in bioretention systems are provided below.

Table 3: Recommended Depth and Porosity for Green Infrastructure Systems

Bioretention Systems		
Component	**Porosity**	**Depth (m)**
Surface Ponding Area	1.00	<= 0.15
Bioretention Soil	0.35	0.45 – 1.00
Drain Rock	0.45	0.20 – 0.30
Structural Soil	0.35	0.35 – 1.00
Vegetated Tree Trenches		
Component	**Porosity**	**Depth (m)**
Surface Ponding Area	1.00	<= 0.15
Bioretention Soil	0.35	0.30 – 0.45
Structural Soil	0.35	0.35 – 0.70
Paved Tree Trenches		
Component	**Porosity**	**Depth (m)**
Structural Soil*	0.35	0.50 – 1.00
Infiltration Trenches		
Component	**Porosity**	**Depth (m)**
Drain Rock*	0.45	0.50 - 1.00

*Note that for any system which relies on distribution pipes to receive rainfall runoff, the depth of the system should be calculated as the depth from the bottom of the excavation to the invert of the sewer connection.

Using the Static Method, the total storage capacity of a GI system can be described by the following equation:

Equation 4: GI System Storage Volume

$$\begin{aligned} System\ Storage\ Volume \\ &= (Surface\ Ponding\ Volume \times Surface\ Porosity) \\ &+ (Bioretention\ and/or\ Structural\ Soil\ Volume \times Soil\ Porosity) \\ &+ (Drain\ Rock\ Volume \times Drain\ Rock\ Porosity) \end{aligned}$$

The design storm volume for a given GI system is the total volume of rainfall that the GI system should be designed to absorb within a 24-hour period. The design storm volume should be calculated using Equation 3.

Designers using the static method must demonstrate that the surface ponding volume of the system can drain over a 24-hour period. This can be demonstrated using the following equation:

Equation 5: GI System Surface Drawdown Time

$$Surface\ Drawdown\ Time = \frac{Surface\ Ponding\ Volume}{Limiting\ Exfiltration\ Rate}$$

The limiting exfiltration rate is the lower of either the subsurface infiltration rate (i.e. the rate that water infiltrates into the soil beneath the GI system) or the GI soil infiltration rate (i.e. infiltration rate of the soil within the GI system).

If the static volume calculations demonstrate that the available system storage volume exceeds the design storm volume, the limiting exfiltration rate can be considered to be the GI soil infiltration rate, even if it is higher than the subsoil infiltration rate. The design storm volume should be calculated using Equation 6.

Equation 6: GI System Design Storm Volume

$$Design\ Storm\ Volume = \ 48mm\ \times Impervious\ Contributing\ Drainage\ Area$$

A designer using the static method must also demonstrate that a saturated GI system can drain over a 72-hour period. This can be demonstrated using the following equation:

Equation 6: GI System Storage Volume

$$System\ Drawdown\ Time = \frac{System\ Storage\ Volume}{System\ Exfiltration\ Rate}$$

The system exfiltration rate is the rate that water can leave the GI system after it passes through the soil or storage medium. This may be the sum of the perforated pipe inflow capacity and subsoil infiltration rate. Additional details related to methods for calculating the system exfiltration rate are described in Section 3.2.2.

3.2. Dynamic Method

The Dynamic Method is a time-step approach that requires designers to assess the performance of a GI system throughout a theoretical 24hr, 48 mm event. The 24hr, 48 mm storm should be based on the SCS Type 1A unit hydrograph included in Section 5.2.3.2 of the City of Vancouver Engineering Design Manual. This event was selected because a system designed to capture this event will also meet the 90% annual rainfall capture target.

The dynamic method allows designers to consider the losses from the system while the storm event is occurring. Using the dynamic method, designers can subtract the volume of water that leaves the system during the 24hr drawdown period from the 48 mm storage requirement.

This method also requires designers to demonstrate that the system will not overflow during the design storm event. A water balance design sheet or SWMM model should be used to assess systems inflows and outflows at each time step to confirm that ponded water depth does not exceed the maximum ponding depth.

To demonstrate the drawdown time using the Dynamic Method, a water balance spreadsheet should be completed with 10-minute time steps. The water balance spreadsheet should use the SCS Type 1A 24hr design storm event to calculate incoming flows.

3.2.1 System Infiltration Rates

The rate at which water flows into the soil media in a green infrastructure system should use the following equation.

Equation 7: GI Soil Media Inflow Rate

$$Q_{max}(m^3/s) = \frac{K_m A_p \frac{h_{max}}{d_m}}{3.6\ x\ 10^6}$$

Where,

K_m = hydraulic conductivity of the medium (mm/hr)
A_p = area of the practice (m^2)
h_{max} = maximum head of water over the growing medium
d_m = depth of the soil media

For further instructions regarding the SWMM modeling requirements, please refer to section 5.

3.2.2 System Exfiltration Rates

GI system exfiltration rates represent the rate that water leaves a green infrastructure system. Exfiltration rates in GI systems can vary greatly depending on the saturation of the system and the ponding depth, however GI sizing calculations may assume a constant exfiltration rate based solely on system geometry and the characteristics of the underlying soil. If dynamic sizing is being used, the exfiltration rate of a system should never exceed the inflow rate at any given time step.GI system performance can vary significantly depending on the type of soil underlying the GI system. On-site infiltration tests are always the preferred method for determining infiltration rates. If only the soil type is known, the design engineer may make an estimate of the infiltration rate using the hydrologic soil group. Recommended values for the hydrologic soil group vary significantly. Estimates provided by municipalities and governmental organizations are listed in the table below.

Table 4: Infiltration Rates by Hydrologic Soil Group

Hydrologic Soil Group	Infiltration rates (mm/hr)			
	CRD	Minnesota	USDA	Metro Vancouver
A	14.4	20.3 - 41.4	10 - 40	61 - 210
B	14.4	7.6 - 11.4	4 - 40	13 - 61
C	3.61	5.1	1 - 10	6.8 – 13
D	0.36	1.5	<=1.0	0.6 – 1.2

Sources
CRD: https://www.crd.bc.ca/docs/default-source/es-watersheds-pdf/watershed-infiltration-maps-report/crdinfiltrationprojectreport-dec-2016-updated.pdf?sfvrsn=26df39ca_2
Minnesota: https://stormwater.pca.state.mn.us/index.php/Design_infiltration_rates
USDA: https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17757.wba
Metro Vancouver: http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/StormwaterSourceControlDesignGuidelines2012StormwaterSourceControlDesignGuidelines2012.pdf

3.2.3 Fully Infiltrating GI Systems

In a fully infiltrating system, water can only leave the system through infiltration into the subsoil. The discharge rate from a fully infiltrating green infrastructure system into the underlying soil can be calculated using the equation below.

Equation 8: GI Exfiltration Rate in fully infiltrating systems

$$f = \frac{K}{1000} \times (A + (P \times h_s))$$

Where,

f = exfiltration rate (m^3/hr)
A = surface area of GI system (m^2)

P = perimeter of GI system (m)
h_s = depth of subsurface storage area (loose aggregate beneath filter medium) (m)
K = design infiltration rate for underlying subsoil (mm/hr)

3.2.4 Non-infiltrating GI Systems

Non-infiltrating systems discharge water solely through a perforated pipe. The rate at which water enters the perforated pipe can be characterized using the orifice equation, where the orifice area is the sum of the area of the perforations in the pipe.

Perforated pipes, used in both partially infiltrating and non-infiltrating systems, can convey excess soil moisture out of a GI system into the municipal sewer system (underdrains) or direct runoff into a GI system (distribution pipes). Perforated distribution pipes should be laid as close to the center of the GI system as possible to ensure even moisture distribution. Underdrains should be laid such that the obvert of the pipe is at the top of the drain rock layer.

The method used to assess the maximum potential flow through a perforated pipe is the same for pipes designed to convey water into or out of a GI system. The maximum flow through a perforated pipe can be calculated using the following equation.

The maximum inflow or outflow rate of capacity of perforated pipes within GI systems (which may function as distribution pipes or underdrains) should be calculated using the following equation:

Equation 9: Perforated Pipe Inflow/Outflow Capacity

$$Q = L \times B \times A_0 \times C_D * \sqrt{2gh_{max}}$$

Where:

Q = maximum rate of water into or out of a perforated pipe (m^3/s)
L = Length of pipe (m)
B = Clogging Factor (0.5 typical)
C_d = Coefficient of discharge (0.61 for sharp edges)
A_0 = Open area of pipe perforations (m^2/m)
g = acceleration due to gravity (9.8 m/s^2)
h_{max} = distance from perforated pipe obvert to top of ponding area or overflow elevation (m)

The open area of the pipe is calculated as the open area of the perforations per linear meter of the pipe and should be received from the pipe manufacturer or drilled on-site according to designer specifications.

For non-infiltrating systems, the capacity of the perforated pipe should always be greater than the maximum flow rate through the overlying soil media. This will ensure that excessive quantities of water do not accumulate in the system. Underdrains in non-infiltrating systems should be placed at the bottom of the underlying clear crush reservoir to ensure that all water within the cell can drain through the pipe perforations.

Underdrains should be designed with a cleanout at the upstream end as shown in typical detail GI3.4. The minimum diameter of all perforated pipes used in green infrastructure systems is 100mm.

If a flow constrictor is placed on the end of a perforated pipe, the capacity of the perforated pipe shall be calculated using the following equation:

Equation 10: Flow Constrictor Capacity

$$Q = A_{orifice} * C_D * \sqrt{2gh}$$

Cd = coefficient of discharge (0.61 for sharp edges)
$A_{orifice}$ = The surface area of the orifice opening
h = The depth of water within the perforated pipe and above the orifice invert

The minimum orifice diameter for a flow constrictor shall be 15mm. Flow constrictors must be installed in a removable cap at an accessible location. The preferred location for flow constrictor installation is where the underdrain discharges to a catch basin or sewer manhole.

3.2.5 Partially Infiltrating GI Systems

If a green infrastructure system is designed to infiltrate but also has a perforated underdrain, it is referred to as a partially infiltrating GI system. Partially infiltrating systems are the most frequently used GI system because of their ability to provide infiltration and peak flow reduction in low infiltration areas and their ability to support well-drained soils. Partially infiltrating GI systems exfiltrate water through seepage into the subsoil and through the perforated underdrain. For partially infiltrating systems, the discharge rate of the cell is calculated as the lesser of the following two options:

1. The sum of the subsoil infiltration rate (per equation 8) and the perforated pipe capacity of the underdrain (per equation 9 or 10).
2. The media infiltration rate as described in Equation 7.

The subsoil infiltration rate is calculated as described above for fully infiltrating systems. The perforated pipe capacity is calculated as described in the non-infiltrating section. Option 1 is most likely to have the lesser value, but this may not be the case in areas with high infiltration rates and should be confirmed for each system.

For a partially infiltrating system, the perforated pipe should be placed at the top of the clear crush reservoir to help encourage infiltration before water discharges out of the system via the perforated underdrain.

4. SWMM Modelling

Modelling GI using SWMM software is not required to demonstrate compliance with GI system performance criteria. The design parameters within this document may also be used to inform other methods of GI sizing.

In the United States and Eastern Canada, green infrastructure systems are often referred to as LIDs (Low-Impact Developments). Some SWMM software programs also use this terminology and may be used interchangeably with GI.

The parameters and methods outlined in this section may not apply to all Green Infrastructure projects. Designers should consider the needs and constraints of the proposed GI system prior to constructing a SWMM model to assess performance. The modelling parameters used in development applications are the responsibility of the engineer of record. The use of the methods and parameters described in this section does not guarantee approval of submitted GI models.

4.1. SWMM Setup & Configuration

The following section outlines the recommended SWMM settings for modelling GI systems. These are recommendations only. Models using other parameters may still be accepted with appropriate justification.

General

Process Models

Rainfall/runoff and flow routing should always be checked. Water quality may be checked if pollutant loading parameters are added to the model. Confirm with the GI Engineer of Record whether water quality should be included in the model.

Infiltration Model:

Modified Green-Ampt is preferred. Horton, Modified Horton, Green-Ampt, and SCS Curve Number are also acceptable.

Routing Method

The Dynamic wave is preferred.

- Ensure “Allow ponding” is selected
- Groundwater does not need to be selected for GI design

Dates – Design Storm Analysis

For discrete event analysis, ensure that the model runs for 48 hours after the end of the rainfall event.

End Analysis on - Duration: Allow enough drain-out time for your storm. e.g. use 72 hrs for a 24hr storm.

If no flow is generated in your model, confirm the dates of your design storm and use the *"set simulation period from time series"* tab in the "dates" section. Make sure to add 48 hours to the duration of the storm.

- Ensure "Sync" is selected.

Dates – Synthetic Annual Analysis

A synthetic annual design storm distribution can be provided upon request to the City of Vancouver Green Infrastructure Branch.

Synthetic annual analysis may be used to assess annual volume captured by a Green Infrastructure system.

Time Steps – Design Storm Analysis

Design Storm Analysis

Table 5: Time Steps for Design Storm Analysis

Property	Time Step
Reporting	30 seconds
Runoff: Dry Weather	60 seconds
Runoff: Wet Weather	60 seconds
Routing	5 seconds

Climatology

Under Evaporation, use the table below for average monthly evaporation rates, only in continuous modelling scenarios (over 3 months). Evaporation impact on the results is negligible for design storm simulations. Select "Evaporate only during dry periods". Monthly evaporation averages provided by YVR are provided below and may be used for City of Vancouver Green Infrastructure Modelling.

Table 6: Monthly Evaporation Rates

Month	Monthly Evaporation (mm/hr)
January	0.5
February	0.8
March	1.5

April	2.5
May	2.7
June	3.7
July	3.8
August	3.2
September	2.0
October	1.0
November	0.5
December	0.4

4.2. GI Modelling Structure

GI systems can be modelled in most SWMM software using one of two methods: as a component of the contributing drainage area or as a distinct catchment area. The City of Vancouver recommends that GI systems in SWMM models be represented as discrete subcatchments. A separate catchment allows for easier performance analysis, model review, and GI parameter control.

GI SWMM models should always reflect a dual-drainage condition, characterizing surface and subsurface flows, along with any links between them such as CB inlets and underdrain connections. GI dual-drainage models should include overland flow paths (usually roadways) that will receive overflow from the GI catchment.

The table below outlines the components that should be included in a GI SWMM model, the features they should be connected to, and the corresponding model features that characterize them.

Table 7: LID Modelling Components

Dual-Drainage Model Component	Corresponding SWMM Feature
Contributing catchments to GI areas	Subcatchment
GI asset catchment	Subcatchment
Overflow Surface Ponding	Storage Node
Roadway Overflow Path	Conduit/Link
Roadway Outfall	Outfall
CB grate	Orifice

CB body	Storage Node
CB lateral	Conduit/Link
Lateral Outfall	Outfall

4.3. Model Geometry

Models of individual GI systems should consist of two catchments; the catchment represents the modelled GI system, and the catchment representing the contributing draining to the GI system.

The GI system should overflow to a catch basin, which should be modelled using three SWMM components: a storage node representing surface ponding, an orifice conduit representing the grate, and an internal storage node representing the storage volume in the CB. Overflow from the bioretention bulge is initially conveyed to a storage node that represents the available surface ponding volume above the receiving catch basin inlet. The catch basin inlet is modelled as bottom-type orifice with the capacity of City of Vancouver Grating No. 31 (City Standard S11.7). The orifice conveys flow from the overlying surface ponding node into a storage node that represents the volume within a standard catch basin (City Standard S11.4).

4.4. Model Routing

Step	Action
1	Roadway catchment routed to GI Catchment
2	GI Catchment Overflow routed to CB_Surface-Ponding Node
3	GI Underdrain directed to CB_Internal Storage
4	CB_Surface-Ponding directed through Orifice Conduit to CB_Internal-Storage. Orifice represents CB grate
5	CB_Internal-Storage directed to underdrain or lead
6	CB_Surface-Ponding overflow directed to Roadside_Overflow Conduit

4.5. Subcatchment Parameters

The following parameters should be used for catchments that represent a discrete GI system area.

Table 8: Recommended GI Subcatchment Parameters

GI Subcatchment Parameters		
Category	Properties	Min
Attributes	Width	Width of catchment
	Slope	0.5 *(confirm from grading)*

	Imperv.	0.10 *(may vary based on design - should reflect presence of weirs, sediment pads, and curbs*
	N Imperv	0.018
	N Perv	0.20
	Zero Imperv	0
	Dstore Imperv	1.25
	Dstore Perv	2.5
	Percent Routed	0.045
	Curb Length	Length of curb
Infiltration	Suction Head (mm)	166.8
	Conductivity (mm/hr)	*(determined from infiltration testing)*
	Initial deficit (fraction)	0.171
Sanitary	I&I (l/s/ha)	0.13

Table 9: Recommended Roadway Catchment Parameters

Roadway Parameters		
Category	Properties	Min
Attributes	Width	Width of catchment
	Slope	0.5 (confirm from grading)
	Imperv.	0.90
	N Imperv	0.018
	N Perv	0.20
	Zero Imperv	0
	Dstore Imperv	1.25
	Dstore Perv	2.5
	Percent Routed	0.045
	Curb Length	Length of curb
Infiltration	Suction Head (mm)	166.8
	Conductivity (mm/hr)	10
	Initial deficit (fraction)	0.171
Sanitary	I&I (l/s/ha)	0.13

4.6. Imperviousness

The following imperviousness values can be assumed for COV’s different land use types:

Table 10: Recommended Imperviousness by Land Use Type

Land Use	% Impervious	% Impervious Disconnect
Single Family Residential	55	25
Multi-Family Residential	70	25
Industrial	90	0
Commercial	90	0
Parks	5	55
Historic Development	80	0
Comprehensive	60-70	0
Roads and Paved Areas	90	0

Recommended values for "N Imperv" and "N Perv" are 0.018 and 0.15, respectively.

4.7. Depression Storage

Depression storage is the depth of rainwater stored in subcatchment depressions and below are conservative values for impervious and pervious areas recommended by CHI:

Dstore Imperv: 1.25 mm
Dstore Perv: 2.5 mm
Zero Imperv (%): 0

4.8. Subarea Routing

This option specifies the order of stormwater routing within pervious and impervious subareas of each subcatchment, along with the "Percent Routed" parameter, which determines the percentage of runoff routed between subareas. The options are "Pervious", "Impervious", and "Outlet" and below is what they mean:

Pervious: runoff from impervious area flows to pervious area. This option can be used to replicate how roof runoff would travel through the lawn before entering the piped system (for downspout disconnect houses), or how runoff from sidewalks would travel through a green strip prior to entering the pipe system.

Impervious: runoff from pervious area flows to impervious area.

Outlet: runoff from both impervious and pervious areas flows directly to the subcatchment outlet.

As an example, if the "Subarea Routing" is set to "Pervious" and the "Percent Routed" value is 100 percent, then 100 percent of the impervious area runoff goes to the pervious area.

A conservative choice (for assessing the piped system) would be "Outlet" for all land types, where all runoffs are directly routed towards the subcatchment's outlet. However, the following choices are recommended as the reasonable approach:

Table 11: Subarea Routing Percentage by Landuse Type

Land Use	Subarea Routing	% Routed
Single Family Residential	Pervious	25
Multi-Family Residential	Pervious	25
Industrial	Outlet	100
Commercial	Outlet	100
Parks	Pervious	55
Historic Development	Outlet	100
Comprehensive Development	Pervious	25
Roads and Paved Areas	Outlet	100

4.9. Infiltration Parameters

The soil group referenced in Section 3.2.2 System Exfiltration Rates, may be used to find the closest soil type and infiltration parameters for the subcatchments, unless more recent geotechnical information is available.

The preferred infiltration calculation method is "Modified Green-Ampt", which is set as the default in the COV's SWMM template. The soils within the City are divided into three distinct groups, based on infiltration potential: moderate, low, and poor. Green-Ampt parameters are provided in the soil map database and are as follows:

Table 12: Recommended Infiltration Rates

Infiltration Potential	HYDCON Saturated Hydraulic Conductivity (mm/hr)	SUCT Avg. Capillary Suction (mm)	SMDMAX Initial Moisture Deficit for Soil
Moderate	59.8	61.3	0.312
Low	10	166.8	0.171
Poor	1.0	292.2	0.092

Alternatively, the system exfiltration rates referenced in Section 3.2.2 may also be used in SWMM modelling.

4.10. GI Typology Parameters

The following sections outline the modelling parameters recommended for specific GI typologies.

Bioretention

Bioretention systems should be designed to overflow to a catch basin, which should be modelled using three SWMM components: surface ponding, an orifice conduit, and an internal storage node. Overflow from the bioretention bulge is initially conveyed to a storage node that represents the available surface ponding volume above the receiving catch basin inlet. The catch basin inlet is modelled as bottom-type orifices with the capacity of City of Vancouver Grating No. 31 (City Standard S11.7). The orifice conveys flow from the overlying surface ponding node into a storage node that represents the volume within a standard catch basin (City Standard S11.4).

Table 13: Bioretention - Recommended LID Parameters

LID Control Editor Inputs - Bioretention					
	Properties	Min	Preferred	Max	Units
Surface	Berm Height	70	150	150	mm
	Vegetation Volume Fraction	0.05	0.2	0.4	fraction
	Surface Roughness	0.12	0.24	0.30	Manning's n
	Surface Slope	0	0	2	%
Soil	Thickness	400	450	600	mm
	Porosity	0.3	0.35	0.45	
	Field Capacity	0.1	0.13	0.2	
	Wilting Point	0.045	0.08	0.1	
	Conductivity	50	70	125	mm/hr
	Conductivity Slope	5	10	20	
	Suction Head	40	60	80	mm
Storage	Thickness	150	300	400	mm
	Void Ratio	0.40	0.45	0.50	voids/solids
	Seepage Rate	0	Determined on-site	100	mm/hr
	Clogging Factor	0	0	0	-
Underdrain	Drain Coefficient*	5	15	100	mm/hr
	Drain Exponent	0.5	0.5	0.5	mm/hr
	Drain Offset Height	0	50	200	mm
	Open Level	0	0	0	mm
	Close Level	0	0	0	mm

*The drain coefficient represents the depth of rainfall that the underdrain can drawdown from the GI system area. This should be calculated based on the capacity of the orifices in the system underdrain and then converted to mm/hr based on the area of the GI system. This variable should be 0 if the system does not have an underdrain.

Note: Justification must be provided for any values that do not align with the preferred values listed above.

Table 14: Bioretention - Recommended Layer Thickness

Layer	Recommended Layer Thickness (m)	Design Infiltration Rate *(mm/hr)	Design Porosity	Specification
Mulch	0.10-0.30	N/A	0.7	*
Filter Media (GI Growing Medium/Bioretention Soil)	0.45-1.00	70	0.35	32 91 23S
Drainage Layer (Aggregate/Bedding)	0.20-0.40	1250	0.45	31 05 17 item 2.6
Non-woven Drainage Fabric	~0.01	100	N/A	31 32 20S
Impermeable Liner (Non-Infiltrating Systems Only)	~0.01	0	N/A	31 32 20S
Subsoil	N/A	TBD	N/A	
***Values may vary due to site conditions. Mulch is generally not included in SWMM models.**				

Infiltration Trench

Table 15: Infiltration Trenches - Recommended LID Parameters

LID Control Editor Inputs - Infiltration Trench					
	Properties	Min	Preferred	Max	Units
Surface	Berm Height	0	0	150	mm
	Vegetation Volume Fraction	0	0	0	fraction
	Surface Roughness	0.01	0.02	0.04	Manning's n
	Surface Slope	0	Determined on-site	0	%
Storage	Thickness	500	600	1000	mm
	Void Ratio	0.40	0.45	0.50	voids/solids
	Seepage Rate	0	Determined on-site	100	mm/hr
	Clogging Factor	0	0	0	-
Underdrain	Drain Coefficient*	0	0	100	mm/hr
	Drain Exponent	0.5	0.5	0.5	mm/hr
	Drain Offset Height	0	50	200	mm
	Open Level	0	0	0	mm
	Close Level	0	0	0	mm

*The drain coefficient represents the depth of rainfall that the underdrain can drawdown from the GI system area. This should be calculated based on the capacity of the orifices in the system underdrain and then converted to mm/hr based on the area of the GI system. This variable should be 0 if the system does not have an underdrain.

Tree Trenches

If the tree trench is designed with structural soil underlying hardscape, the tree trench should be modelled as an infiltration trench LID in SWMM software using the parameters listed below.

Table 16: Tree Trenches with Overlying Pavement - Recommended LID Parameters

LID Control Editor Inputs - Structural Soil Tree Trench					
	Properties	Min	Preferred	Max	Units
Surface	Berm Height	0	0	150	mm
	Vegetation Volume Fraction	0	0.1	0.2	fraction
	Surface Roughness	0.15	0.24	0.4	Manning's n
	Surface Slope	0	2	5	%
Storage	Thickness	500	750	1000	mm
	Void Ratio	0.35	0.40	0.45	voids/solids
	Seepage Rate	0	Determined on-site	100	mm/hr
	Clogging Factor	0	0	0	-
Underdrain	Drain Coefficient*	12	25	75	mm/hr
	Drain Exponent	0.5	0.5	0.5	mm/hr
	Drain Offset Height	0	50	200	mm
	Open Level	0	0	0	mm
	Close Level	0	0	0	mm

*The drain coefficient represents the depth of rainfall that the underdrain can drawdown from the GI system area. This should be calculated based on the capacity of the orifices in the system underdrain, and then converted to mm/hr based on the area of the GI system. This variable should be 0 if the system does not have an underdrain.

If the tree trench is constructed using growing medium with a stone sub-base, the tree trench should be modelled as a bioretention cell using the following parameters.

Table 17: Tree Trenches with Overlying Soil - Recommended LID Parameters

LID Control Editor Inputs - Growing Medium Tree Trench					
	Properties	**Min**	**Preferred**	**Max**	**Units**
Surface	Berm Height	0	150	150	mm
	Vegetation Volume Fraction	0.05	0.3	0.4	fraction
	Surface Roughness	0.12	0.24	0.30	Manning's n
	Surface Slope	0	2	5	%
Soil	Thickness	400	450	600	mm
	Porosity	0.3	0.35	0.45	
	Field Capacity	0.1	0.13	0.2	
	Wilting Point	0.045	0.1	0.12	
	Conductivity	50	70	125	mm/hr
	Conductivity Slope	5	10	20	
	Suction Head	40	60	80	mm
Storage	Thickness	150	300	400	mm
	Void Ratio	0.40	0.45	0.60	voids/solids
	Seepage Rate	0	Determined on-site	100	mm/hr
	Clogging Factor	0	0	0	-
Underdrain	Drain Coefficient*	12	25	75	mm/hr
	Drain Exponent	0.5	0.5	0.5	mm/hr
	Drain Offset Height	0	50	200	mm
	Open Level	0	0	0	mm
	Close Level	0	0	0	mm

*The drain coefficient represents the depth of rainfall that the underdrain can drawdown from the GI system area. This should be calculated based on the capacity of the orifices in the system underdrain, and then converted to mm/hr based on the area of the GI system. This variable should be 0 if the system does not have an underdrain

Where tree trenches receive drainage from either side of the trench via two separate paved surfaces (i.e. the roadway and a bike lane). Each contributing catchment should be modelling as a distinct subcatchment. This will allow for appropriate sizing of the inlets on either side of the trench along with a more accurate characterization of the overflow volume and timing on either side of the trench.

The area of the tree trench catchment should reflect the full area of the soil, structural soil, or soil cells used within the system.

If there are permeable pavers above the tree trench, the surface area of the permeable pavers should be included in the contributing roadway or bike lane catchment. If the GI system is modelled as a distinct catchment, no rainfall should be assigned to GI catchment under this scenario.

Permeable Pavement

The City of Vancouver does not yet have an established Permeable Pavement standard. Due to the variety of products and performance variables, modelling parameters for Permeable Pavement should be received from the product supplier. Correspondence should be provided as an addendum to any SWMM reports.

Permeable pavement modelling should be conducted with a 2x safety factor.

The following are draft parameters based on existing best practices in other municipalities. These values are subject to change based on the results from ongoing pilot studies and manufacturer specifications.

Table 18: Permeable Pavement - Recommended LID Parameters

LID Control Editor Inputs - Permeable Pavement			
	Properties	DRAFT	Units
Surface	Berm Height	0	mm
	Vegetation Volume Fraction	0	fraction
	Surface Roughness	0.02	Manning's n
	Surface Slope	1	%
Pavement	Thickness	100	mm
	Void Ratio	0.15	Voids/solids
	Impervious Surface Fraction	0	
	Permeability	100	
	Clogging Factor	0	mm/hr
	Regeneration Interval	0	days
	Regeneration fraction	0	
Storage	Thickness	300	mm
	Void Ratio	0.45	voids/solids
	Seepage Rate	Determined on-site	mm/hr
	Clogging Factor	0	-
Underdrain	Drain Coefficient*	15	mm/hr
	Drain Exponent	0.5	mm/hr
	Drain Offset Height	50	mm
	Open Level	0	mm
	Close Level	0	mm

*The drain coefficient represents the depth of rainfall that the underdrain can drawdown from the GI system area. This should be calculated based on the capacity of the orifices in the system underdrain and then converted to mm/hr based on the area of the GI system. This variable should be 0 if the system does not have an underdrain

Green Roofs

For Green Roof design and modelling information, please refer to the City of Vancouver Green Roof Best Practices Guide.

4.11. Displaying LID System Outputs & Time Series

Follow the steps below to display outputs from LID Control Editor feature.

1. Designate a file path for the .txt file export for the LID Control you wish to display

2. Run the model

3. Go to the "Graphs" menu and click "open"

4. Navigate to your file that you exported and open it

Notes:

- All values in mm should be multiplied by the GI system area to get the volume values

4.12. Water Quality and Pollutant Loading

As of June 2022, no guidance is available related to pollutant loading or water quality modelling using SWMM software. However, following the modelling guidance within this document and the design guidance in the GI Design Manual chapter will lead to systems that are designed for 80% TSS removal.

4.13. Continuous Modelling

Continuous modelling may be used to demonstrate 90% annual capture for large areas with multiple GI systems or for sizing individual GI systems. For continuous modelling rainfall data, contact the City of Vancouver Green Infrastructure Implementation Branch.

Appendix A: SWMM Modelling Checklist

Simulation Options	Model Compliance?	Notes
General		
Process Model = Rainfall/runoff checked	☐	
Routing Method = Dynamic Wave	☐	
Infiltration Method = Modified Green-Ampt	☐	
Miscellaneous: Allow Ponding = checked, flow units = LPS	☐	
Dates		
Minimum 3 days duration to allow for drawdown	☐	
Time Steps		
Reporting = 0:00:30, Runoff = 0:01:00, Routing = 5s	☐	
LID Control Editor		
Surface properties comply with recommended values	☐	
Soil properties comply with recommended values	☐	
Storage properties comply with recommended values	☐	
Underdrain properties comply with recommended values	☐	
LID Usages		
Area reflects actual vegetated area of system	☐	
If LID is internal to catchment: % of area captured = percent of catchment treated If LID is standalone catchment: % of area captured = 100%	☐	
If underdrain is present: Confirm “Send drain flow” is directed to the node receiving underdrain flow	☐	
Minimum one detailed report file generated for each typology?	☐	
Results		
Runoff continuity error <1%	☐	
Routing continuity error <1%	☐	
Detailed LID report file shows predictable flow routing	☐	