ON-SITE STORMWATER DETENTION TANK SYSTEMS

TECHNICAL GUIDE
(REVISION 3: AUG 2024)

ON-SITE STORMWATER

DETENTION TANK SYSTEM

TECHNICAL GUIDE

Revision 3 – Aug 2024

S/No.	Section/Pages	Revision
1	Section 6.2 – Development Control (DC) Stage / Page 24	"all industrial, commercial, institutional and residential developments…" *removed and replaced with* "all developments…"
2	Section 6.3 – Building Plan (BP) Stage / Page 24	"all industrial, commercial, institutional and residential developments…" *removed and replaced with* "all developments…"
3	Section 6.4 – Temporary Occupation Permit (TOP) Stage / Page 24	"all industrial, commercial, institutional and residential developments…" *removed and replaced with* "all developments…"
4	Section 6.5 – Certificate of Statutory Completion (CSC) Stage / Page 25	"all industrial, commercial, institutional and residential developments…" *removed and replaced with* "all developments…"

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Contents

Appendices

Appendix A	-	Design Calculations Template A, Site Analysis
Appendix B	-	Design Calculations Template B, Modified Rational Method Gravity Discharge
Appendix C	-	Design Calculations Template C, Modified Rational Method Pumped Discharge
Appendix D	-	Design Calculations Template D, Full Detention of Runoff Method
Appendix E	-	Design Calculations Template E, Hydrological and Hydraulic Modelling
Appendix F	-	Sample of Operations & Maintenance Checklist for On-site Stormwater Detention Systems

Symbols

Symbol	Definition
A	Catchment area
A_t	Bottom area of detention tank
C	Runoff coefficient
$C_{0.55}$	Runoff coefficient of 0.55
C_o	Orifice discharge coefficient
C_{post}	Post development runoff coefficient
d	Water depth in detention tank
d_o	Orifice diameter
d_s	Pump start depth
d_t	Effective depth of detention tank
f_{ic}	Fraction of site to apply full detention
g	Acceleration due to gravity
H_o	Maximum head to the centres of the orifice
I	Inflow
i	Average rainfall intensity
i_{10}	Average rainfall intensity of 10-year return period storm
i_z	Average rainfall intensity for critical storm event
K_1	Constant used in the direct solution for the Modified Rational Method
K_2	Constant used in the direct solution for the Modified Rational Method
K_3	Constant used in the direct solution for the Modified Rational Method
Q	Outflow
$Q_{allowable}$	Maximum allowable peak discharge rate
Q_{inflow}	Inflow rate
Q_o	Orifice discharge rate
Q_p	Pump capacity
Q_{post}	Post-development peak runoff at the point of design
Q_r	Peak runoff at the point of design
Q_{target}	Target peak discharge rate
Q_z	Peak inflow rate for critical storm event
t_c	Time of concentration
t_d	Rainfall duration
t_x	Rainfall duration minus time of concentration
$t_{xcritical}$	t_x which results in the estimated required storage volume required using the Modified Rational Method
t_{xlimit}	t_x which corresponds to the inflow hydrograph with a peak discharge equals to Q_{target} using the Modified Rational Method
t_{xmax}	t_x which results in the mathematical maximum storage volume required using the Modified Rational Method
t_z	Critical rainfall duration
V	Volume of water in detention tank
V_t	Required detention volume
Δt	Time interval used in storage routing
ΔV	Change in volume

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1 Introduction

1.1 Background

PUB adopts a holistic "Source-Pathway-Receptor" approach to stormwater management, where measures are taken right from the source where runoff is generated (e.g. through on-site detention), to the pathways through which runoff is conveyed (e.g. through widening and deepening drains and canals), as well as in areas where floodwaters may end up (e.g. through specifying platform levels to protect developments from floods) (Figure 1.1.1). Implementing measures at the source, pathways and receptors builds flexibility and adaptability into the drainage system to cope with increasing weather uncertainties and future climate change impacts.

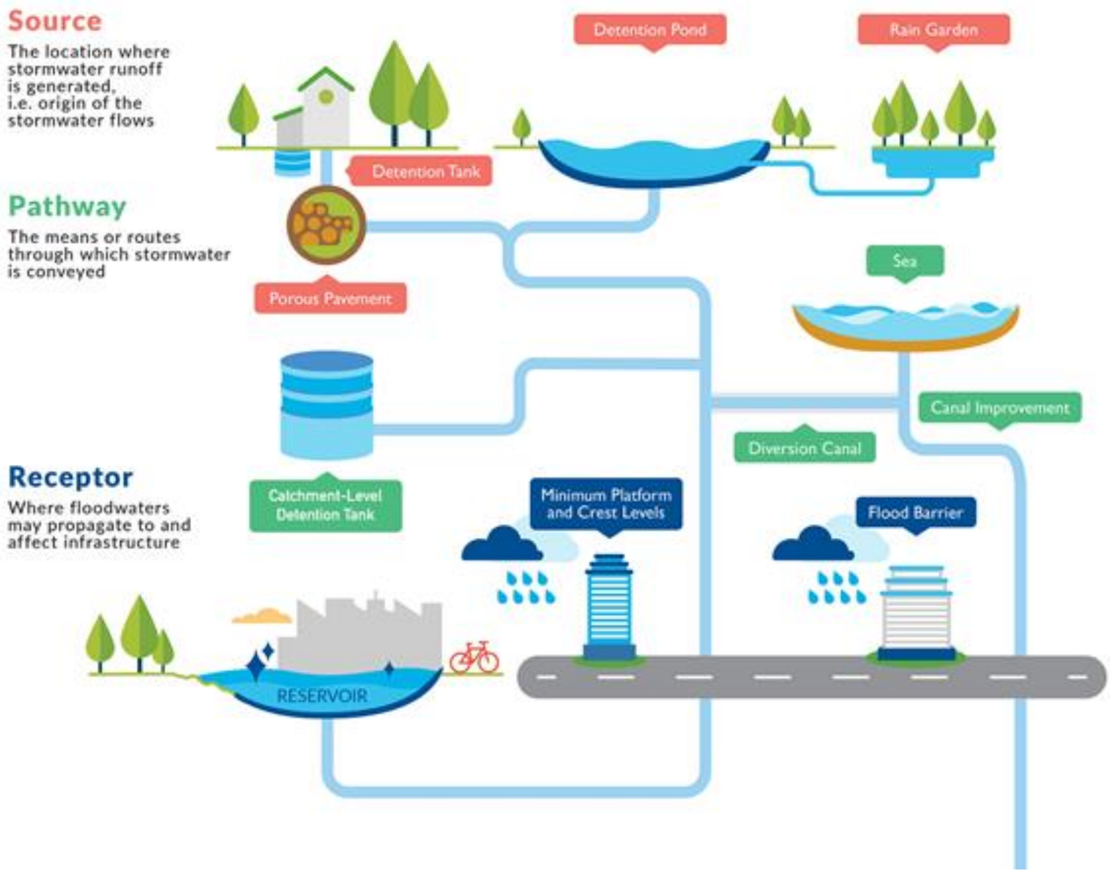


Figure 1.1.1 Examples of Source, Pathway and Receptor solutions (Source: PUB website – https://www.pub.gov.sg/drainage)

1.2 Requirements for Managing Peak Runoff at Source

Clause 7.1.5 of the Code of Practice (COP) on Surface Water Drainage (Seventh Edition – Dec 2018 with amendments under Addendum No.1 – Apr 2021) stipulates the following requirement for the maximum allowable peak runoff to be discharged from development sites to the public drains:

Industrial, commercial, institutional and residential developments greater than or equal to 0.2 hectares (ha) in size are required to control the peak runoff discharged from their sites. The maximum allowable peak runoff to be discharged to the public drains will be calculated based on a *runoff coefficient of 0.55, for design storms with a return period of 10 years and for various storm durations of up to 4 hours (inclusive).*

1.3 On-site Detention and Retention Features

Peak runoff reduction can be achieved through the implementation of on-site ABC Waters design features and structural detention and retention features, such as:

- Detention tanks
- Retention ponds/Sedimentation basins
- Larger perimeter drains
- Wetlands
- Planter boxes
- Bioretention swales
- Porous pavements
- Bioretention basins or rain gardens, etc.

ABC Waters design features can help to reduce runoff volumes and discharge rates while still performing active, beautiful and clean functions. Features such as bioretention basins, and gravel trenches may be designed to hold stormwater runoff in porous subsoil voids or at the surface by allowing for temporary surface ponding. These features may be incorporated with the architectural design of the developments to create aesthetically pleasing and functional storage systems.

Figure 1.3.1 Rain Garden at Balam Estate

Figure 1.3.2 Retention Pond adjoining Khoo Teck Puat Hospital

Besides ABC Waters design features, effective reduction of peak runoff can also be achieved by on-site detention tank systems, which will be the focus of this Technical Guide.

Reduction in peak runoff of a site can be achieved by using one or a combination of detention/retention measures, depending on the availability of space, intended functions of the stormwater management system, and costs. These detention systems may be used in conjunction with rainwater harvesting and reuse systems. However, to ensure the detention volume is available for the next storm event, the storage volume for the rainwater harvesting and reuse system would have to be catered for separately from the detention volume. See Section 2.4 for details.

As part of the requirements in the COP, QPs are required to submit details (calculations and/or hydraulic model results) showing how the proposed system meets the required peak runoff rates.

1.4 Objective of Quick Start Technical Guide

This Technical Guide aims to provide general guidelines to developers, property owners and Qualified Persons (QPs) on the implementation strategies, design considerations and submittal guidance for on-site detention tank systems.

2 Detention Tank Systems

2.1 Introduction to Stormwater Detention Tank Systems

Detention tanks collect and store stormwater runoff during a storm event, then release it at controlled rates to the downstream drainage system, thereby attenuating peak discharge rates from the site. With such systems in place, the drainage system as a whole can cater for higher intensity storms brought about by increasing uncertainties due to climate change. Detention tanks may be located on ground levels and even underground. Figure 2.1.1 below shows an example of an on-site detention tank system.

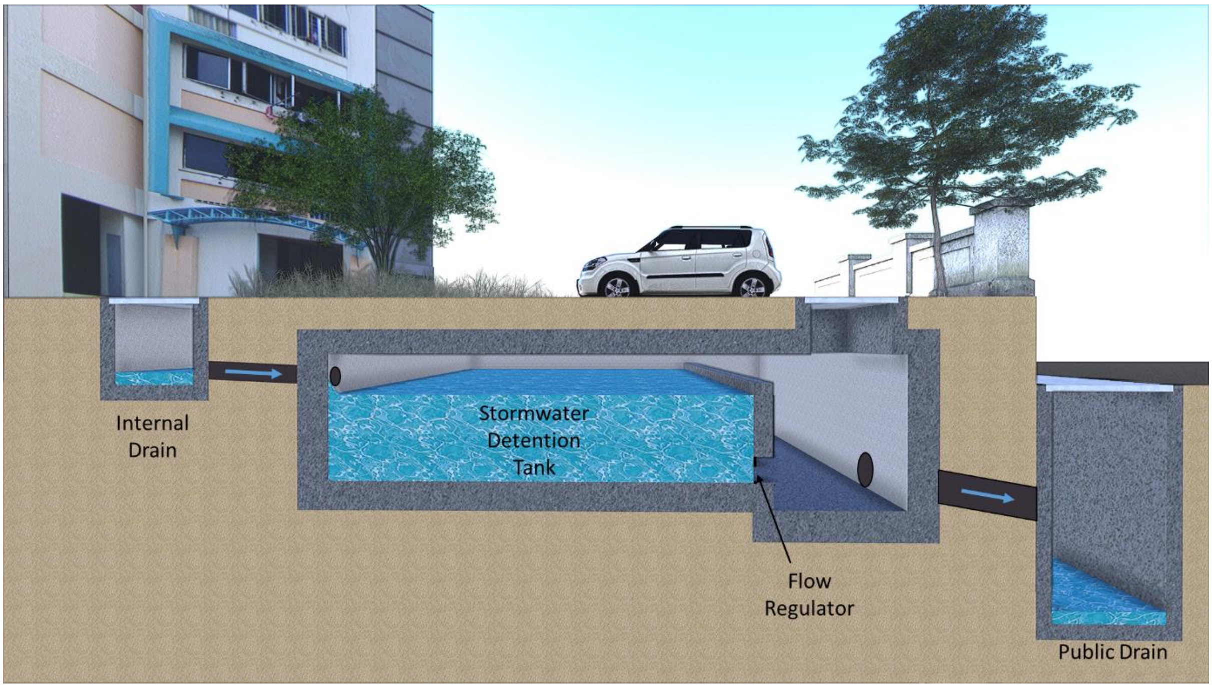


Figure 2.1.1 Schematic diagram of an underground detention tank

2.2 Tank Configurations

Stormwater detention tank systems can be configured as online or offline systems (Figure 2.2.1 and Figure 2.2.2).

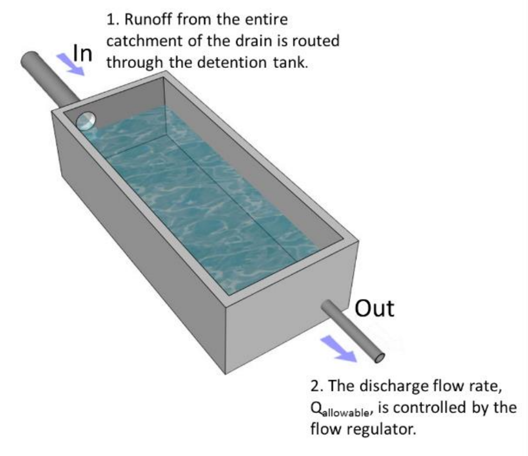


Figure 2.2.1 Online detention system

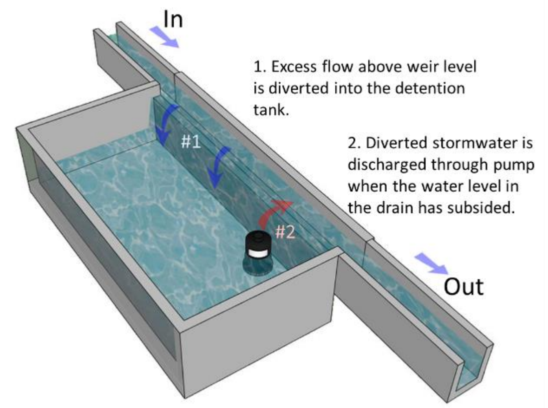


Figure 2.2.2 Offline detention system

For online detention systems, runoff from the entire catchment of the drain is routed through the detention tank via an inlet.

Offline detention systems are located separately from, or in parallel to the drain through which runoff from the catchment flows. Hence, only a portion of the flow in the drain is conveyed into the detention tank. When the water level in the drain exceeds a certain level, determined by the flow diversion structure such as a side flow weir, the excess flow above the weir level will be diverted into the detention tank. Although the detention volumes required by offline detention systems are smaller as compared with online detention systems, offline detention systems are generally more complex to design due to the sensitivity of the weir levels in relation to the water levels in the diversion structure.

2.3 Discharge Methods

Stormwater in the detention tank may be discharged either by gravity or through pumping. In order to ensure that detention volume is available for the next storm event, discharge systems shall be designed to empty the tank within 4 hours after a storm event.

A gravity discharge system utilises the head difference between the water in the detention tank and the receiving drain to discharge the water collected in the detention tank. Hence, the elevation of the site with respect to the receiving drain will determine the maximum effective depth of the detention tank. As no pumping is required, gravity discharge systems generally incur lower operations and maintenance costs as compared with pumped discharge systems. Where gravity discharge of the stormwater is not feasible due to site constraints, pumped discharge systems may be used.

Discharge of stormwater in the detention tank can take place during or after the storm event, as long as the total peak runoff discharged from the development site is in compliance with the maximum allowable peak discharge requirement. Systems that are designed to release the water after the storm event are recommended to have a control system to activate the discharge so as to ensure reliable operations. Instrumentation and control systems, such as an automated valve linked to a rain-sensor or water level sensor in the drain to which the tank discharges to, may be used to automate the activation of the discharge when the storm has ceased or when the water level in the drain has subsided.

2.4 Combined Detention-Rainwater Harvesting Systems

Developers may wish to implement rainwater harvesting systems for their developments to supplement their non-potable water use. Rainwater can be collected for non-potable use within their own premises and will have to satisfy a set of PUB conditions listed in the Guidance Notes for the Application of Rainwater Collection Systems.
(https://www.pub.gov.sg/Documents/GuidanceNotes.pdf).

Developers should note that Clause 7.1.5 in the COP is imposed so that peak runoff discharged from the development site is controlled. As detention systems implemented to comply with COP Clause 7.1.5 serve different purpose from rainwater harvesting systems, the required detention volume shall be independent of the volume of proposed rainwater collection.

2.4.1 Requirements and Possible Configurations

A combined detention-rainwater harvesting system can be considered, subject to the following conditions:

- The required detention volume is independent of the rainwater harvesting volume i.e. the required detention volume shall always be available; and
- In the event of storm, the required detention volume shall be restored within 4 hours after the storm

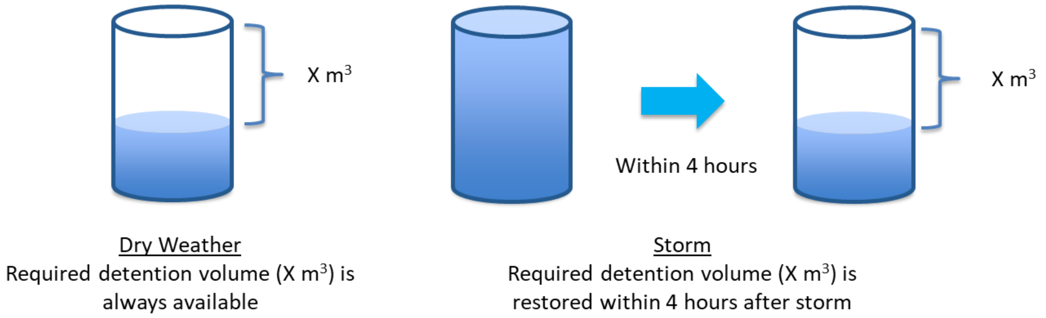


Figure 2.4.1 Schematic diagram on requirements for combined detention-rainwater harvesting systems

Developers may wish to utilise the water stored in the detention system for non-potable uses using the following methods, provided that the conditions stated above are fulfilled:

- pumping and storing the water in a separate secondary tank; or
- designing a larger tank to cater for both detention and rainwater harvesting purposes, provided that the required volume for each purpose is catered for separately

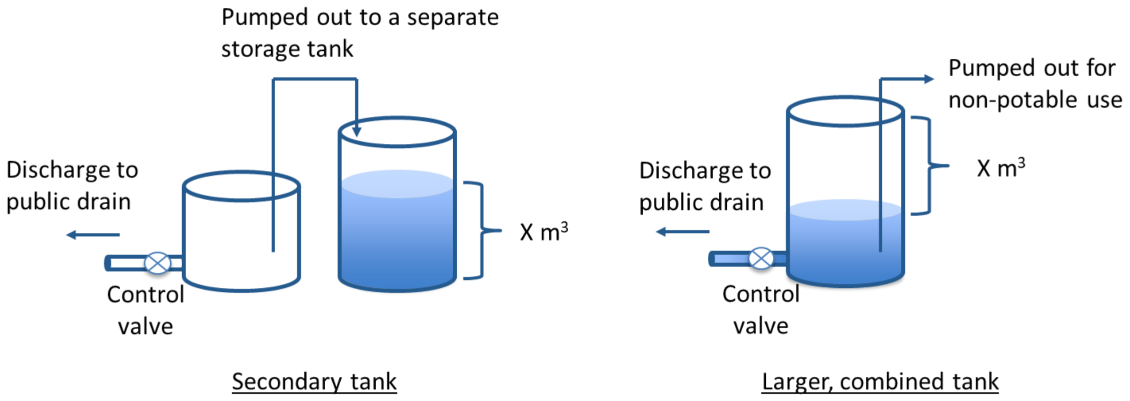


Figure 2.4.2 Possible configurations of combined detention-rainwater harvesting systems

3 Design of Detention Tank Systems

To determine if detention tank systems are required for the development, QPs shall calculate the post-development peak runoff and the maximum allowable peak discharge for the site as described in Section 3.1. If the post development peak runoff exceeds the maximum allowable peak discharge, on-site detention/retention shall be required.

QPs may carry out a site analysis to determine if a single catchment or multiple sub-catchments approach will be adopted for the detention system(s), as outlined in Section 3.2, to meet the peak discharge requirement.

Various detention systems may be used to control the peak runoff discharged from the sites. Some common detention systems are described in Section 3.3. Based on the site characteristics and approach, QPs may select one detention system for each sub-catchment (or catchment).

Whilst there are many methods that can be used to size the detention system, the technical guide provides details for some common methods in Section 3.4. Design calculations templates for the common detention tank systems are included in the Appendices of this Technical Guide. In each template, a suitable design method and calculation is adopted for each system. These templates may be adapted for development consultation submissions.

The discharge system selected for the detention tank shall be adequately designed as described in Section 3.5. Other design considerations for the detention tank are covered in Chapter 4 and operations and maintenance considerations are covered in Chapter 5.

As stated in Clause 7.1.5 of the COP, QPs shall be required to submit details, in the form of calculations and/or hydraulic modelling results showing how the proposed system meets the required peak runoff rates. The submission guidelines can be found in Chapter 6 of this technical guide.

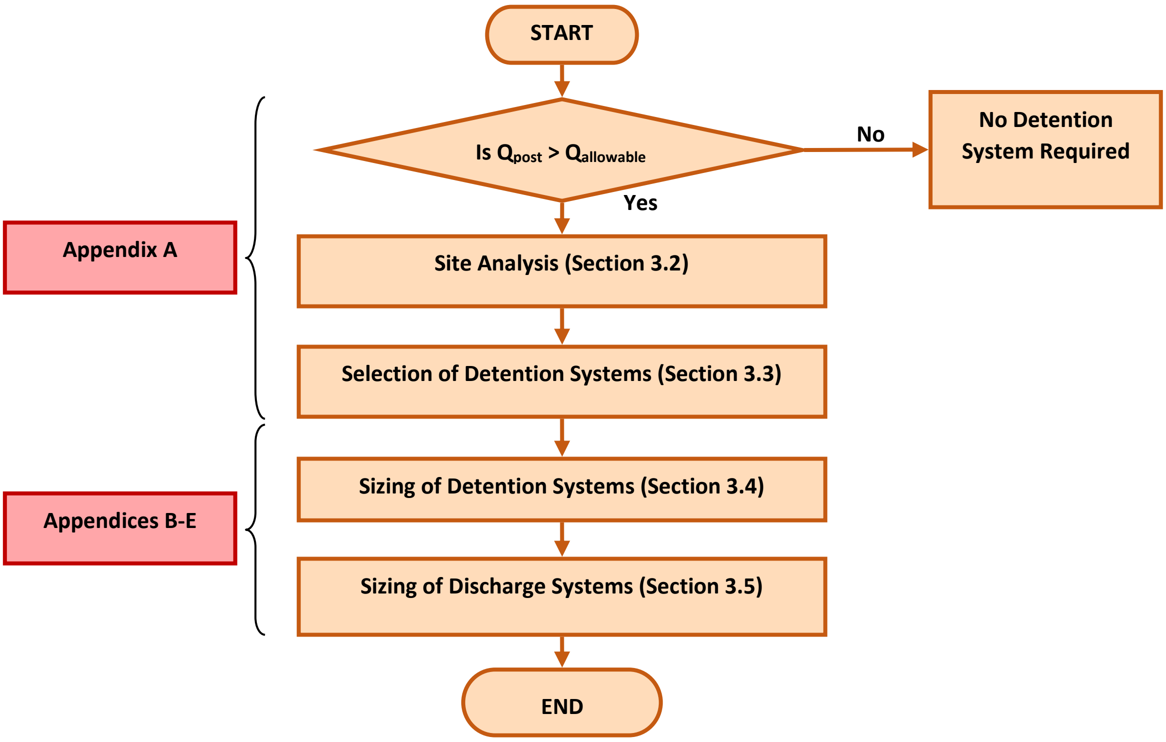


Figure 3.1: Design of Detention Tank Flow Chart

3.1 Determining Maximum Allowable Peak Discharge

The maximum allowable peak discharge shall be computed at the downstream end of the internal drainage system of the development prior to its connection to the public drain. For developments with multiple sub-catchments, each sub-catchment should discharge into the internal drains before discharge to the public drainage system. The total discharge from the site into the public drainage system shall not exceed the maximum allowable peak discharge.

3.1.1 Rational Formula

QPs shall determine the maximum allowable peak discharge for the proposed development using the Rational Formula:

$$Q_r = \frac{1}{360} CiA \qquad \textbf{(Equation 3.1.1)}$$

Where Q_r = Peak runoff at the point of design [m^3/s]
C = Runoff coefficient
i = Average rainfall intensity [mm/hr]
A = Catchment area [ha]

3.1.1.1 Runoff Coefficient

The runoff coefficient (C) of a site depends on its land uses or surface characteristics. Pervious areas that allow water to infiltrate into the ground, such as grass or landscaped areas located on true ground, may assume a C value of 0.45 while impervious areas like roads, buildings and pavement may assume a C value of 1. The runoff coefficient of the site shall be calculated based on a weighted C value as represented by the following Equation 3.1.2:

$$\text{Weighted } C = \frac{\sum_{i=1}^{n} (A_i \times C_i)}{\sum_{i=1}^{n} (A_i)} \qquad \textbf{(Equation 3.1.2)}$$

Where A_i = Area of sub-area
C_i = Runoff coefficient of sub-area
n = Total number of sub-areas

3.1.1.2 Rainfall Intensity

For a storm of return period of T years, the rainfall intensity (i) is the average rate of rainfall from a storm having a duration equal to the time of concentration (t_c) of the catchment. The average rainfall intensity (i) can be obtained from the Intensity-Duration-Frequency (IDF) curves (shown in Appendix 4 of the COP) by estimating the duration of rainfall equivalent to the time of concentration of the catchment and selecting the required return period of T years. The rainfall intensity curve for a design storm with a 10-year return period can be represented by the following formula:

$$i_{10} = \frac{8913}{t_c+36} \qquad \textbf{(Equation 3.1.3)}$$

Where i_{10} = Average rainfall intensity of 10-year return period storm [mm/hr]
t_c = Time of concentration [min]

3.1.1.3 Time of Concentration

According to the Rational Method, the peak runoff (Q_r) occurs when all parts of the catchment receiving a steady, uniform rainfall intensity are contributing to the outflow. This condition is met when the duration of rainfall equals the time of concentration (t_c). The time of concentration (t_c) consists of the overland flow time (t_o) plus the drain flow time from the most remote drainage inlet to the point of design (t_d), viz. $t_c=t_o+t_d$. Table 3.1.1 below provides a guide of the times of concentration for sites of different areas.

Table 3.1.1 Typical time of concentration for various site areas

Site Area (ha)	Time of Concentration, t_c (min)
0.2 - 2.0	5
2.0 - 6.0	10
6.0 - 10.0	15
≥10	15*

*QPs to substantiate with hydraulic calculations if $t_c > 15$min is used.

3.1.2 Maximum Allowable Peak Discharge

Based on the Rational Formula, the post-development peak runoff from a development site with no runoff controls can be defined as:

$$Q_{post} = \frac{1}{360} C_{post} i_{10} A \qquad \textbf{(Equation 3.1.4)}$$

Where Q_{post} = Post development peak runoff at the point of design [m^3/s]
C_{post} = Post development weighted runoff coefficient of site
i_{10} = Average rainfall intensity of 10-year return period storm [mm/hr]
A = Catchment area [ha]

Using the same average rainfall intensity, i_{10}, and site area, A, the maximum allowable peak runoff to be discharged from the development site is calculated based on a runoff coefficient of 0.55:

$$Q_{allowable} = \frac{1}{360} C_{0.55} i_{10} A \qquad \textbf{(Equation 3.1.5)}$$

Where $Q_{allowable}$= Maximum allowable peak discharge [m^3/s]
$C_{0.55}$ = Runoff coefficient of 0.55
i_{10} = Average rainfall intensity of 10-year return period storm [mm/hr]
A = Catchment area [ha]

3.2 Site Analysis (Appendix A)

For small sites, it may be possible to have one detention system to serve the entire site. However, for larger sites, it may not be viable to have one detention system to serve the entire catchment as it means a large detention volume would be needed and the system would have to be placed at the most downstream end of the internal drainage network. Thus, a site may be analysed and split into various sub-catchments, adopting a distributed catchment approach. Sub-catchment specific detention systems can be designed for each sub-catchment as long as the sum of the target discharge rates, Q_{target}, for each sub-catchment is less than or equal to the $Q_{allowable}$ of the entire site. With this approach, the runoff from some sub-catchments where detention systems may be difficult to employ may remain uncontrolled. Other sub-catchments may employ a more stringent Q_{target} to enable the site to meet the discharge requirements. Appendix A provides a guide on how to analyse a site and determine the various Q_{target} for each sub-catchment. Worked Example 7.3 shows how a distributed catchment approach may be employed.

$$\sum_{i=1}^{n} Q_{target\ i} \leq Q_{allowable} \qquad \textbf{(Equation 3.2.1)}$$

Where Q_{target} = Target peak discharge of sub-catchment [m^3/s]
$Q_{allowable}$ = Maximum allowable peak discharge [m^3/s]

3.3 Selection of Detention Systems

Developers may employ various detention systems to control the peak runoff discharged from their sites. Selection of these systems would depend on multiple considerations, such as space availability, site topography, as well operations and maintenance. Larger sites have greater flexibility of implementing one or more types of detention systems. Table 3.3.1 provides a comparison of the common types of detention systems and the associated benefits and limitations of each system. Table 3.3.1 serves as a starting point for developers or designers to identify an appropriate system for their site and directs QPs to design calculations templates (in the appendices) to assist them in consultation submissions.

Table 3.3.1 Comparison of common detention systems

Type of System	**Online**			**Offline**
Time of Discharge	**During Storm**		**After Storm**	**After Storm**
Discharge Mechanism	**Gravity**	**Pumped**	**Gravity or Pumped**	**Gravity or Pumped**
Description	This detention system receives all the runoff from the catchment of the drain. The discharge rate from this system is regulated by a flow control device such as an orifice.	This detention system receives all the runoff from the catchment of the drain. The discharge rate from this system is regulated by a pump.	This detention system receives all the runoff from the catchment of the drain. The discharge rate from the site is regulated by limiting the area that contributes to the runoff discharge from the site during a storm event.	This detention system receives only a portion of the flow from the drain. The discharge rate from the site is regulated by diversion of runoff that exceeds the maximum allowable peak runoff, through a flow diversion structure such as a side flow weir, into the detention system.
Mechanical, Electrical, Instrumentation & Control Systems	• None required	• Pumps • Water level sensors (in tank)	• Actuated valves or pumps • Rain/Water level sensors	• Actuated valves or pumps • Rain/Water level sensors
Benefits	• No mechanical and electrical components	• Suitable for most sites	• Runoff from the remainder of the site may be left uncontrolled	• Requires smaller detention volume • Discharge systems operate only after significant storm events (O&M savings)
Limitations	• Sufficient elevation difference between the proposed system inlet and the outlet point is necessary (greater than 1m) for this system to be effective	• Pumping required for every storm event	• Requires large detention volume	• Mechanical and electrical systems will need to be serviced on a regular basis to ensure operability during storm events.
Design Method and Design Calculations Templates (in appendices)	• Modified Rational Method with Gravity Discharge (Appendix B) • Hydrological and Hydraulic Modelling (Appendix E)	• Modified Rational Method with Pumped Discharge (Appendix C) • Hydrological and Hydraulic Modelling (Appendix E)	• Full Detention of Runoff Method (Appendix D)	• Hydrological and Hydraulic Modelling (Appendix E)

3.4 Sizing of Detention Tanks

This section describes the common methods that can be used in the sizing of detention tank systems. It should be noted that these calculation methods are intended for planning purposes and it is the responsibility of the QP to determine and develop the necessary hydraulic calculations for the detailed design.

3.4.1 Modified Rational Method with Gravity Discharge (Appendix B)

The Modified Rational Method (MRM) is a variation of the Rational Method and is primarily used for preliminary sizing of detention facilities in urban areas. This method would give a conservative detention system design and may only be applied for detention tank systems which serve a catchment area less than 8ha. Should designers require an optimised detention system design, hydrological and hydraulic modelling described in Section 3.4.4 may be adopted.

This method, in particular, can be used to size online detention systems which discharge the detained volume by gravity during the storm event. It assumes that all runoff from the catchment of the drain is conveyed into the online detention tank system and discharged via an orifice outlet structure. The design calculations template for this method can be found in Appendix B.

3.4.1.1 Determining Detention Volume

While the Rational Method assumes a triangular runoff hydrograph, the MRM considers a family of trapezoidal runoff hydrographs. Figure 3.4.1 below shows a family of runoff inflow hydrographs of various storm durations that are considered for the sizing of a detention tank with a storm return period of T years.

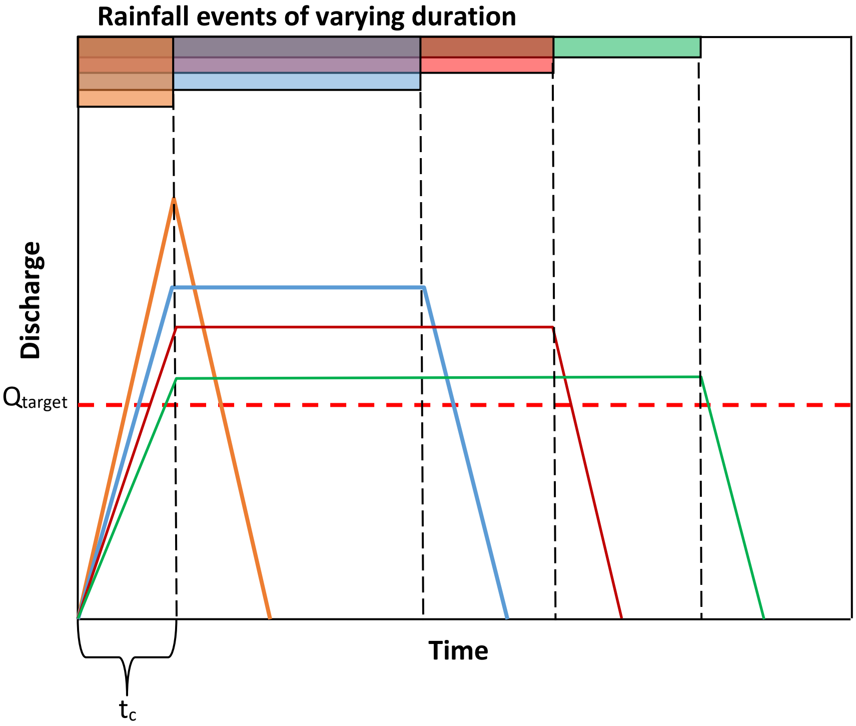


Figure 3.4.1 Family of MRM runoff hydrographs for storms of varying durations with return period of T years

The first triangular hydrograph represents the rainfall event with duration that is equal to the time of concentration (t_c). The subsequent hydrographs are trapezoidal, all of which peak at the same time of concentration (t_c) and continue for the duration of the storm. Once the rain has ceased, the time it takes for the discharge to return to zero is assumed to be equal to t_c. The peak discharge rate for each hydrograph can be calculated using the Rational Formula, $Q=\frac{1}{360}CiA$ with $i=\frac{8913}{t_d+36}$ (where t_d = rainfall duration). Storm durations that are shorter than the time of concentration t_c, or result in peak discharge below the maximum target peak discharge Q_{target} need not be considered.

The outflow hydrograph for online gravity discharge detention systems is approximated by a straight line as shown in Figure 3.4.2.

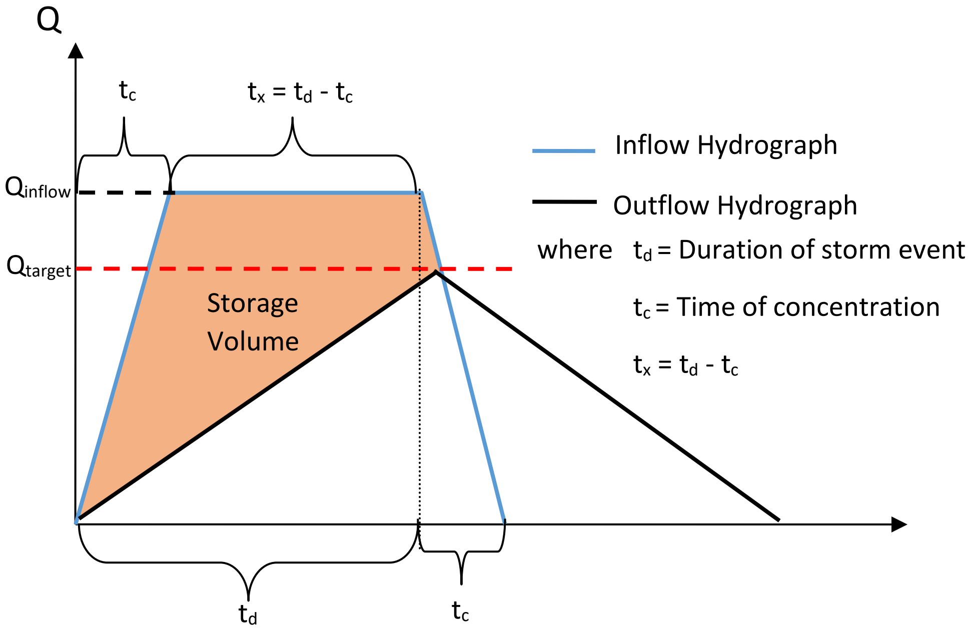


Figure 3.4.2 Example of inflow and outflow hydrographs for online gravity-controlled detention system

The storage volume required for a particular storm duration is represented by the shaded area between the inflow and outflow hydrographs as shown in Figure 3.4.2 and expressed by the following Equation 3.4.1:

Storage Volume, $$V_t=Q_{inflow}(t_c+t_x)-\frac{1}{2}Q_{target}(2t_c+t_x)\ [m^3] \qquad \textbf{(Equation 3.4.1)}$$

Where, $$Q_{inflow}=\frac{1}{360}C_{post}\left(\frac{8913}{t_d+36}\right)A$$

$$Q_{target}=\frac{1}{360}C_{target}\left(\frac{8913}{t_c+36}\right)A$$

The MRM involves iterative calculation steps to determine the various storage volumes for different storm durations up to 4 hours. The maximum storage volume obtained from the iterative computations is the estimated size of the detention system required.

3.4.1.2 Direct Solution for Modified Rational Method

Alternatively, a direct mathematical solution can be used to derive the maximum storage volume required by using the first principle of derivatives. By taking the first derivative of the volume function and equating it to zero, the storm duration resulting in the maximum storage volume required can be determined. A condition, however, is that the inflow hydrograph for the considered storm duration should not lie below Q_{target}. The following steps outline the calculations to determine the estimated volume of storage required via a direct solution using the MRM for orifice-controlled gravity discharge system for online detention tank. A worked example for the MRM calculation of a detention tank with gravity discharge is illustrated in Section 7.1.

Determining Critical Storm Duration:

Taking $dV_t/dt_x = 0$, the maximum t_x duration that results in the estimated maximum storage volume required via first derivative can be derived by the following expression:

$$t_{xmax} = K_3 \pm \sqrt{\frac{36\,K_1\,K_3}{K_2}} \quad \text{[min]} \qquad \textbf{(Equation 3.4.2)}$$

$$\text{Where } K_1 = \frac{8913 C_{post} A}{6}$$

$$K_2 = \frac{8913 C_{target} A}{12}$$

$$K_3 = t_c + 36$$

The inflow hydrograph corresponding to t_{xmax} may lie below the target peak discharge, Q_{target}. Thus, the t_{xlimit} that corresponds to the inflow hydrograph with a peak discharge equals to Q_{target} must be determined through the flowing expression:

$$t_{xlimit} = \frac{(C_{post} - C_{target})(t_c + 36)}{C_{target}} \quad \text{[min]} \qquad \textbf{(Equation 3.4.3)}$$

The smaller of the 2 values, t_{xmax} and t_{xlimit} would be taken as the critical t_x, $t_{xcritical}$.

If $t_{xmax} < t_{xlimit}$, maximum storage volume occurs when $t_{xcritical} = t_{xmax}$

If $t_{xlimit} < t_{xmax}$, maximum storage volume occurs when $t_{xcritical} = t_{xlimit}$

Note: For sites where $t_{xcritical} = t_{xlimit}$, the peak Q_{inflow} would be equal to Q_{target}. This is the mathematical solution for the detention volume required even if it may seem like a detention system is not necessary since the peak Q_{inflow} is already equal to the Q_{target}.

The associated t_x value is substituted into the following Equation 3.4.4 to determine the estimated storage volume of the detention tank.

$$V_t = \frac{K_1\left(t_c + t_{xcritical}\right)}{\left(K_3 + t_{xcritical}\right)} - \frac{K_2\left(2t_c + t_{xcritical}\right)}{K_3} \quad [m^3] \qquad \textbf{(Equation 3.4.4)}$$

3.4.2 Modified Rational Method with Pumped Discharge (Appendix C)

The Modified Rational Method may be adapted to size online detention systems which discharge the detained volume by pumps during the storm event. The design calculations template for this method can be found in Appendix C. Similar to Section 3.4.1, this method would give a conservative detention system design and may only be applied for detention tank systems which serve a catchment area less than 8ha. Should designers require an optimised detention system design, hydrological and hydraulic modelling described in Section 3.4.4 may be adopted.

In order to ascertain the critical rainfall duration that results in the largest detention volume, it can first be assumed that the critical rainfall duration and the outflow hydrograph for the pumped discharge detention system would be similar to that with an orifice discharge. Hence, all the steps in Section 3.4.1 may be followed. However, since the outflow hydrographs for an orifice-controlled gravity discharge system and pumped discharge system may be different, confirmation of the design calculations by storage routing would be necessary. After the critical rainfall duration is determined, the corresponding trapezoidal inflow hydrograph may be developed, and the storage routing based on the actual pump discharge rates and pump start levels will be carried out.

The storage routing Equation 3.4.5 is based on the conservation of mass. The change in storage volume in a tank is equal to the inflow minus the outflow.

$$I - Q = \frac{\Delta S}{\Delta t} \qquad \textbf{(Equation 3.4.5)}$$

Where I = Inflow
Q = Outflow
S = Storage

Using a spreadsheet, iterations can be performed to determine the outflow at every time step. With this, the adequacy of the detention volume and pump capacity and operations can be verified. A worked example for the MRM calculation of a detention tank with pumped discharge is illustrated in Section 7.2.

3.4.3 Full Detention of Runoff Method (Appendix D)

In this method, the peak discharge from a site is managed by reducing the area of the catchment that contributes to the stormwater runoff. All the runoff from a portion of the impervious area is detained throughout the duration of the storm while runoff from the other parts of the catchment can remain uncontrolled and is allowed to flow directly into the drains. The total runoff from part of the impervious area of the site to be detained should be calculated based on a 10-year return period storm event of 4-hour duration. This is equivalent to a total rainfall depth of 130mm (based on the IDF curves published in Appendix 4 of the COP). The design calculations template for this method can be found in Appendix D.

Determining the Fraction of Site to Employ Full Detention and Sizing the Detention Volume

The fraction of the total site area where full detention would need to be employed to ensure that the discharge from the site is equal to the $Q_{allowable}$ can be calculated based on the C_{post} of the entire site using the following Equation 3.4.6. Equation 3.4.6 assumes that the full detention is only be applied to impervious areas. The detained runoff volume shall be discharged only after the storm.

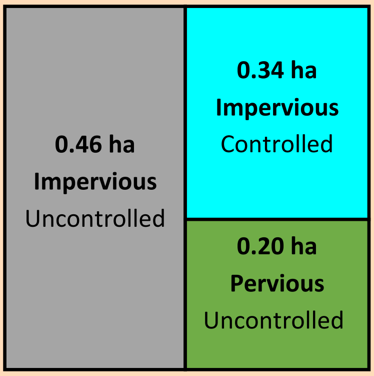
Fraction of site area to be controlled = C_{post} - C_{target} (Equation 3.4.6)

The corresponding detention volume required per total site area can be calculated using the following Equation 3.4.7.

Detention volume per total site area=1300(C_{post} - C_{target}) [m^3/ha] (Equation 3.4.7)

Example

For a 1.0ha site with a C_{post} of 0.89 (0.2ha pervious and 0.8ha impervious), according to Equation 3.4.6 (0.89 – 0.55 = 0.34), runoff from 0.34ha of the impervious area would have to be detained through the entire storm in order to meet the $Q_{allowable}$. The runoff from the remaining 0.66ha can remain uncontrolled and discharge directly into the drainage system. According to Equation 3.4.7 [(1300x0.89)-(1300x0.55)]x1.0 = 442m^3], a total of 442m^3 of detention volume would be required.



3.4.4 Hydrological and Hydraulic Modelling (Appendix E)

This method is applicable for sizing online or offline detention systems, including detention systems for larger developments (greater than 8ha) or developments with more complex drainage systems. Developers may choose appropriate hydrological and hydraulic models such as U.S. EPA SWMM, MIKE 11, etc. to size or verify the adequacy of the proposed detention system. The design calculations template for this method can be found in Appendix E.

3.5 Design of Discharge Systems

3.5.1 Orifice Discharge System

For an orifice discharge system, the orifice will serve as the flow regulator for the detention tank. The effective detention tank depth can be determined by considering the system configuration such as the inlet drain invert level and the discharge invert level. Once the effective tank depth is determined, the orifice size can be calculated based on Equation 3.5.1. Note that Equation 3.5.1 applies to free flow discharge orifice conditions, thus, the downstream sump or pipe would need to satisfy this condition to use Equation 3.5.1.

$$Q_o = C_o A_o \sqrt{2gH_o} \qquad \textbf{(Equation 3.5.1)}$$

Where Q_o = Orifice discharge rate [m^3/s] (i.e., Q_{target})
C_o = Discharge coefficient [m^2]
A_o = Area of orifice [m^2]
g = Acceleration due to gravity [9.81 m/s^2]
H_o = Maximum head to the centre of the orifice [m]

Figure 3.5.1: Diagram on orifice discharge parameters

Figure 3.5.1 above depicts the various parameters of the orifice Equation 3.5.1. The orifice Equation 3.5.1 may be applied for free-flowing discharge from the detention tank. The discharge from the detention tank shall be channelled to internal drains before discharge to the public drainage system.

3.5.2 Pumped Discharge Systems

The minimum pumping capacity shall be sufficient to empty the tank within 4 hours, after the end of a storm event. The maximum operating pumping capacity shall be less than the maximum allowable discharge.

Figure 3.5.2 below shows an example of a detention tank with pumped discharge system.

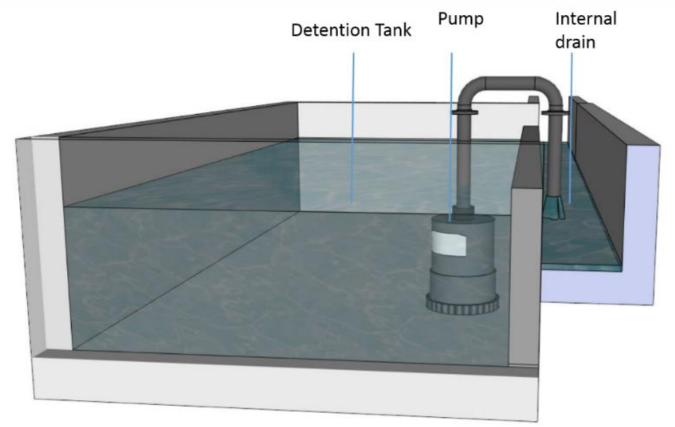


Figure 3.5.2: Example of a pumped discharge system

All pumped discharged systems shall be designed for automated operation of the pumping system, with an option for manual control to override the automated system when required.

The system shall be designed to ensure backflow does not occur by implementing gooseneck pipes where required. These shall be installed such that the invert level of such pipes are at least 150mm above the minimum platform level for general developments as specified in Clause 2.1.1(a) of the COP, or at least 300mm above the minimum platform level for commercial/multi-unit residential developments with basements or special facilities and developments with linkages to special underground facilities as specified in Clause 2.1.1(b) and (c) of the COP. The pumped discharge system shall discharge stormwater from the detention tank into the internal drainage system of the development. Direct pumping into the public drains is not permissible.

The pumped drainage system required for the drainage of underground building facilities (e.g. basements), as stipulated in Clause 4.10 of the COP, shall not be combined with the pumped discharge system for the detention tank.

4 Design Considerations

4.1 Siting of Detention Tank System

The site characteristics shall be assessed in terms of space availability, topography and elevations of internal and external drain levels. The detention tank system may be located above ground on buildings, on ground level or underground. The location of the detention tank will determine its operation and effectiveness. For example, above ground detention systems can typically be discharged by gravity and therefore generally incur lower operating costs. However, they may only capture runoff from a smaller catchment area. Such trade-offs should be assessed in the siting of the detention tank system.

4.2 Location of Discharge Outlets

The location of the discharge outlet should be designed taking into account the downstream water level in the drain to enable free discharge as much as possible, and to prevent backflow of water from the drain into the detention tank system.

4.3 Design of Pumps

For detention tank systems using pumped discharge mechanisms, it is good practice to consider a 2+1 pump system (with 2 duty pumps and 1 standby pump having a capacity of 0.5Q each), which allows for both redundancy and rotation. This may not apply under spatial constraints, whereby at least one standby pump is required.

The sizing of the generator set for the development should also cater for the additional pumping associated with the detention tank system. A standby generator set is recommended for additional reliability.

4.4 Overflow Structure

An overflow structure shall be required for an online detention tank system to allow drainage of the site in the event that the detention tank system malfunctions (e.g. the orifice clogs or a power outage disables the pumps) or is completely full. The overflow structure shall be sized for a maximum allowable peak discharge based on a runoff coefficient of 0.55.

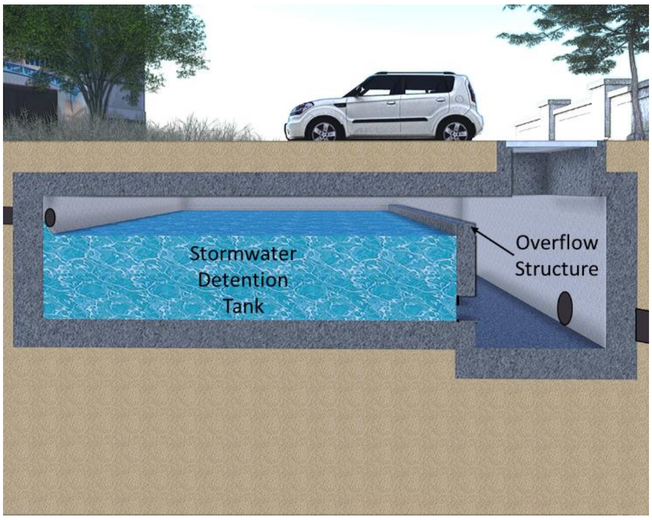


Figure 4.4.1: Overflow structure for an underground detention tank

4.5 Grading of Detention Tank

The detention tanks shall be graded towards the outlet or the discharge sump to prevent stagnation of water. If a pumped discharge system is proposed, the pumps shall be located within a small sump pit which should be deeper than the pump sump so that there will be no stagnant water in the pump /discharge sump at all times. The gradient used shall direct flow towards the outlet while allowing easy accessibility during maintenance.

4.6 Access Requirements

The detention tank system shall be designed to allow personnel and equipment access to various parts of the tank which would require maintenance. These areas include the base of the tank as well as the inlet and outlet structures. Where necessary, ladders shall be provided below openings to the tank.

4.7 Trash Screen/Rack Requirements

To protect the inlet and outlet structures of the tank from debris clogging, trash screens may be provided upstream of stormwater detention systems and flow diversion structures.

4.8 Mosquito Control Considerations

In the construction and maintenance of the detention tank system, measures must be put in place to comply with the National Environment Agency's (NEA) requirements for the prevention of mosquito breeding. The tank shall be designed to allow the tank to be completely drained after storm events. Regular inspection and proper maintenance of the detention tank system to prevent water stagnation would also ensure that they do not become potential mosquito breeding grounds.

The NEA's guidelines on the prevention of mosquito breeding are available on the following website, https://www.nea.gov.sg/corporate-functions/resources/practices-and-guidelines/guidelines, which provides information for property maintenance officers, managing agents and operational managers on measures to prevent or treat mosquito breeding.

4.9 Instrumentation and Control Considerations

Detention tank systems that discharge through pumping or actuated valve installations should be designed with the necessary instrumentation and control features such as pump controls, rain sensors and water level sensors to automate the discharge of the tank systems. CCTVs, flow meters or water level sensors such as electrode sensors may also be installed to monitor tank operations and verify the performance of the pumping system.

5 Operations and Maintenance Considerations

5.1 Operations and Maintenance Plan

Regular inspections and maintenance can help to ensure that the detention tank system is able to perform as required during a storm event. The owner/Management Corporation Strata Title (MCST)/Managing Agent (MA)/Town Council should understand the importance of regular and proper upkeep of the detention tank system to ensure smooth operations of the system as part of stormwater management. An operations and maintenance plan can be developed to provide guidance on these aspects. The plan should also include the personnel in charge of the tasks as well as the frequency and method of maintenance.

A log recording the dates and description of the inspection and maintenance activities performed as well as the findings from the inspection shall be maintained. Water level or flow logs and pump operation logs may also be kept. A sample of an operations and maintenance checklist for an on-site stormwater detention system can be found in Appendix F. This checklist should serve as a general guide for the operation and maintenance regime.

5.2 Inspections

Inspections should be carried out at least once per month and after significant storm events. The detention tank systems should be inspected for the physical condition of the tank (including structural damage), stagnant water, clogging at trash racks or inlet and outlet structures, sedimentation, condition of ancillary fittings and equipment such as pumps, valves and generator sets, and clear access of pathways and openings. Immediate rectification works should be carried out if the detention system is found not to be in order.

5.3 Maintenance

General maintenance and servicing of mechanical and electrical equipment should be carried out at least quarterly. Where applicable, maintenance works should include desilting/cleaning the detention tank, cleaning trash screens, servicing/testing the pumps, pump starters and the instrumentation and control systems and servicing both the duty and standby generator sets. A desilting pump may be needed to remove silt and sediments from the detention system.

If the pump house is located away from the control room, it should be outfitted with a pressure gauge so that it can be monitored remotely to ensure that the pumps are working. The owner/MCST/MA/Town Council should refer to the maintenance regime specified by their respective pump/equipment manufacturers or suppliers for proper maintenance of their systems.

For developments constructed with pumped detention tank systems, the owner/MCST/MA/Town Council shall keep the following documents and submit to PUB via PUB website – Qualified Persons Portal on an annual basis:

a. Annual electrical installation license issued by EMA;
b. Quarterly maintenance records of pumps;
c. Quarterly maintenance records of level control system; and
d. Quarterly cleaning and desilting records of tank and pump sump.

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6 Submission Requirements for Proposed Detention Tank Systems

6.1 Submission Requirements Flowchart

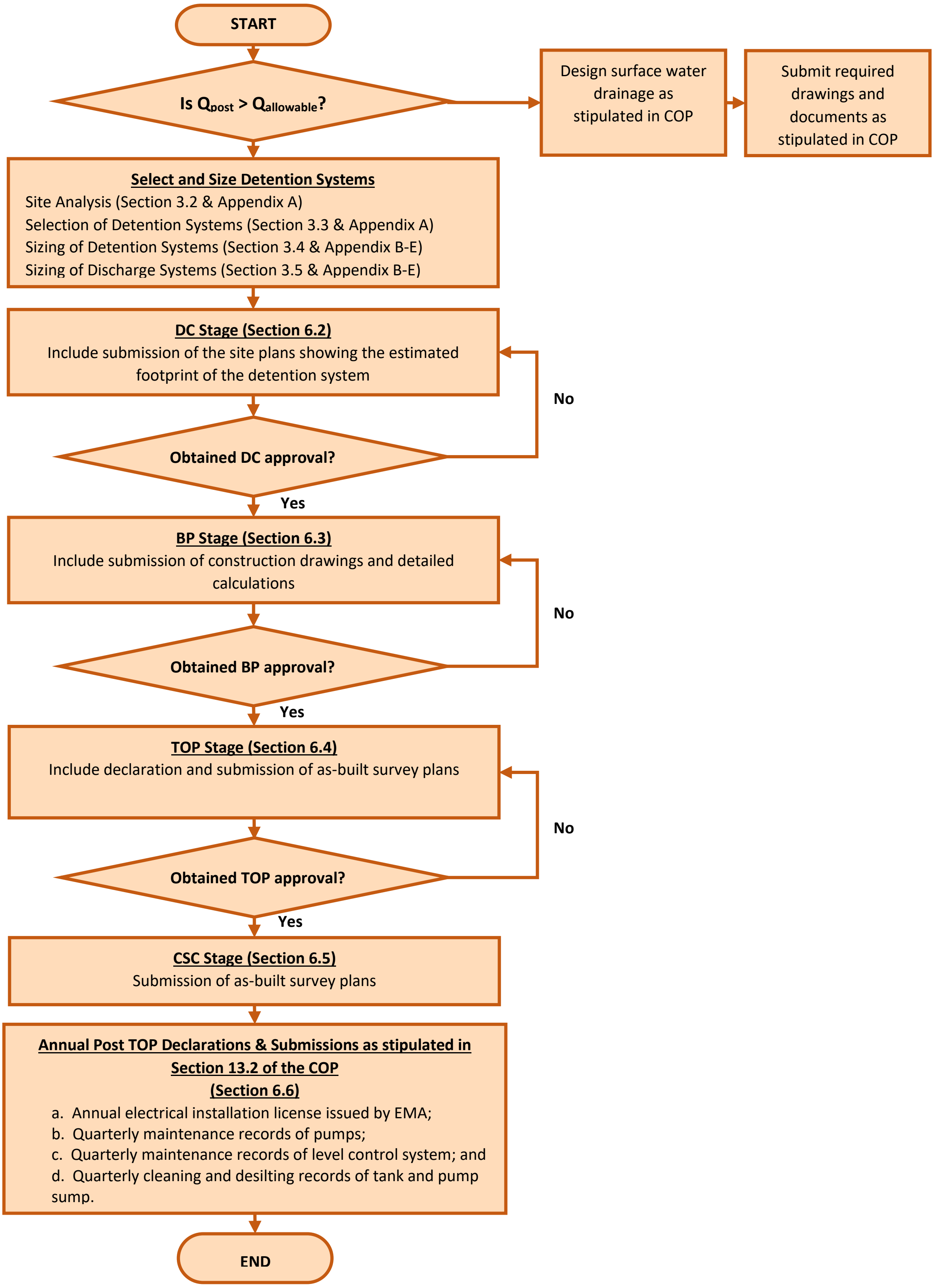

Figure 6.1.1: Submission Requirements Flow Chart

6.2 Development Control (DC) Stage

For all developments greater than or equal to 0.2ha with detention tank systems, the following documents, endorsed by a QP, shall be submitted:

i) Proposed drainage plans indicating catchment and sub-catchment boundaries. If more than one detention tank is required, the plans should indicate clearly the specific sub-catchment(s) of each tank including the outlet discharge point of the internal drainage system to the public drain.
ii) Proposed site plan with runoff coefficients and area of development with varying characteristics of catchment/sub-catchment clearly indicated.
iii) Proposed site plan with features, and catchment/sub-catchment area of each feature, to attenuate stormwater runoff to comply with COP requirements clearly indicated.
iv) Proposed site layout plans indicating the location and footprint of the detention tank(s), pumping facilities (if applicable), the effective depth of the detention tank(s) and the connection point to the internal drainage system. For a detention tank that is located in the basement and is operated with a pumped drainage system, the gooseneck pipe (showing the crest level) of the pumped drainage discharge structure.

6.3 Building Plan (BP) Stage

For all developments greater than or equal to 0.2ha with detention tank systems, the following documents, endorsed by a QP, shall be submitted:

i) Construction drawings plans and sections, of the detention system, if applicable, clearly indicating the inlet and outlet configuration and levels, connections to upstream drainage network and downstream internal and external drains.
ii) Design calculations or modelling results as per the design calculations templates or equivalent.
iii) Details of the proposed pump system (pump capacity, crest level of discharge, power requirements), if applicable.
iv) Details of the Standard Operating Procedure (SOP) on the operation and maintenance of the detention system (including pumped discharge system, if applicable).

6.4 Temporary Occupation Permit (TOP) stage

For all developments greater than or equal to 0.2ha with detention tank systems, the following documents, endorsed by a QP, shall be submitted:

i) QPs are required to declare that the maximum stormwater discharge from the development is in compliance with the maximum allowable peak runoff stipulated in the COP and constructed according to approved plans when applying for Temporary Occupation Permit (TOP) clearance.
ii) QPs are required to confirm that they have liaised with the Developer/Owner (Developer/Owner to countersign acknowledgement) to ensure that a Maintenance/Managing Agent has been established to undertake the SOP of the maintenance, operation and monitoring of the detention tank system, when applying for TOP clearance.
iii) The declaration shall consist of the application for TOP clearance and be supported by as-built survey plans indicating the crest levels, platform levels and flood protection levels (based on the approved flood protection measures), detention systems (including final design

calculations) where applicable, and any other relevant information as required by the Board, prepared and endorsed by a registered surveyor. PUB will only issue TOP clearance to the developer/ owner when the declaration and all necessary supporting documents are submitted and assessed to be in compliance with the requirements of approved plans and the COP.

6.5 Certificate of Statutory Completion (CSC) stage

For all developments greater than or equal to 0.2ha with detention tank systems, the following documents, endorsed by a QP, shall be submitted:

i) As-built survey plans indicating that the drainage facilities were constructed in accordance with the approved plans.

6.6 Maintaining the Integrity of Stormwater Drainage System including Flood Protection Measures

Upon obtaining the Temporary Occupation Permit (TOP), the Owner/MCST/MA/Town Council of premises with pumped detention tank systems shall make annual declarations and submissions of the following documents to PUB as stipulated in Section 13.2 of the COP:

a. Annual electrical installation license issued by EMA;
b. Quarterly maintenance records of pumps;
c. Quarterly maintenance records of level control system; and
d. Quarterly cleaning and desilting records of tank and pump sump.

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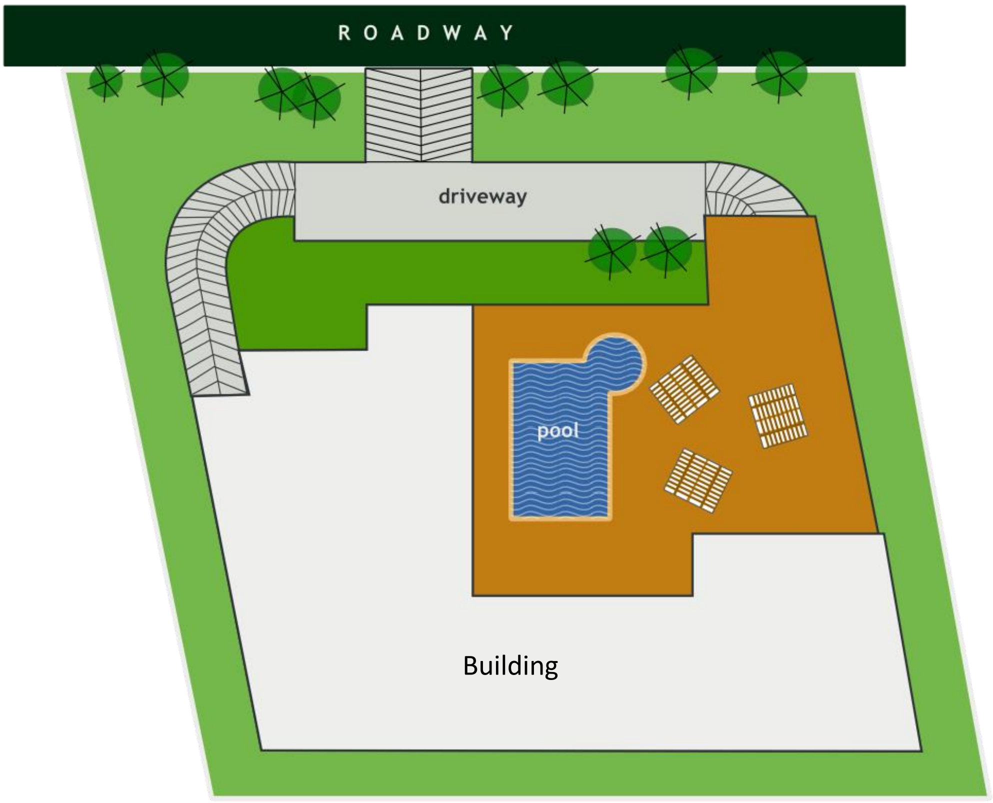
7 Worked Examples for Stormwater Detention Tank Systems

7.1 Online Gravity Discharge Detention Tank for Entire Site

7.1.1 Introduction

A new residential development is proposed for a 0.3ha site. The proposed site layout is shown in Figure 7.1.1. A detention tank is required to control the peak discharge of the site to ensure it complies with the maximum allowable peak discharge requirement specified in the COP.



Not to Scale

Figure 7.1.1 Site Layout

Catchment Description

The site consists of the following land use:

Table 7.1.1 Catchment Description

Land Use	Percentage of Site Area	Area	Runoff Coefficient
Impervious Surfaces (rooftops, roads, walkways, swimming pool)	85%	2550m^2	1.0
Pervious Surfaces (grass, landscaping)	15%	450m^2	0.45

Site Analysis

The development site is relatively small and is situated on a significantly higher elevation (at least 1m) than the adjoining public roads and drainage networks. As such, an online gravity discharge detention tank to serve the entire site would be most suitable.

Description	Symbol		Sub-catchment 1	Remarks
Sub-catchment area	A (ha)	=	0.3ha	
Weighted runoff coefficient	C_{post}	= =	(0.85×1)+(0.15×0.45) 0.92	Equation 3.1.2
Time of concentration	t_c (min)	=	5min	Table 3.1.1
Average rainfall intensity for 10yr storm event	i_{10} (mm/hr)	= = =	$\frac{8913}{t_c+36}$ $\frac{8913}{5+36}$ 217mm/hr	Equation 3.1.3
Peak discharge from sub-catchment	Q_{post} (m^3/s)	= = =	$\frac{C_{post} i_{10} A}{360}$ $\frac{0.92 \times 217mm/hr \times 0.3ha}{360}$ $0.166m^3/s$	Equation 3.1.4
Maximum allowable peak discharge for entire site	$Q_{allowable}$	= = =	$\frac{C_{0.55} i_{10} A}{360}$ $\frac{0.55 \times 217mm/hr \times 0.3ha}{360}$ $0.099m^3/s$	Equation 3.1.5
Target runoff coefficient	C_{target}	=	0.55	
Target peak discharge for sub-catchment	Q_{target} (m^3/s)	= = =	$\frac{C_{target} i_{10} A}{360}$ $\frac{0.55 \times 217mm/hr \times 0.3ha}{360}$ $0.099m^3/s$	
Check $\sum Q_{target} \leq Q_{allowable}$	-	=	yes	Equation 3.2.1
Type of detention system to employ	-	=	Online, during storm, gravity discharge detention system	Table 3.3.1
Design calculations template	-	=	Template B	

7.1.2 Calculation Steps

The design of an online gravity discharge detention system can be developed by the following calculation steps.

Step 1: Identify peak discharge from site and maximum allowable peak discharge

Step 2: Determine required detention volume

Step 3: Determine detention system configuration

Step 4: Sizing of detention system discharge control

Details for each calculation step are provided below.

Step 1: Identify peak discharge from site and maximum allowable peak discharge

Step	Description	Equation			Remarks
1a	Site area	A (ha)	=	0.3ha	From Site Analysis in Section 7.1.1
1b	Weighted runoff coefficient of site	C_{post}	=	0.92	From Site Analysis in Section 7.1.1
1c	Time of concentration	t_c (min)	=	5min	From Site Analysis in Section 7.1.1
1d	Average rainfall intensity for 10yr storm event	i_{10} (mm/hr)	=	217mm/hr	From Site Analysis in Section 7.1.1
1e	Peak discharge from site	Q_{post} (m^3/s)	=	$0.166m^3/s$	From Site Analysis in Section 7.1.1
1f	Target runoff coefficient	C_{target}	=	0.55	From Site Analysis in Section 7.1.1
1g	Target peak discharge	Q_{target} (m^3/s)	=	$0.099m^3/s$	From Site Analysis in Section 7.1.1

Step 2: Determine required detention volume

Step	Description	Equation			Remarks
2a	Calculate K_1	K_1	= = =	$\frac{8913\times C_{post}\times A}{6}$ $\frac{8913 \times 0.92 \times 0.3}{6}$ 410	Equation 3.4.2
2b	Calculate K_2	K_2	= = =	$\frac{8913\times C_{target}\times A}{12}$ $\frac{8913\times 0.55\times 0.3}{12}$ 123	Equation 3.4.2
2c	Calculate K_3	K_3	= = =	t_c+36 5+36 41	Equation 3.4.2
2d	Calculate t_{xmax}	t_{xmax} (min)	= = =	$-K_3+\sqrt{\frac{36K_1K_3}{K_2}}$ $-41+\sqrt{\frac{36 \times 410 \times 41}{123}}$ 29.1min	Equation 3.4.2
2e	Calculate t_{xlimit}	t_{xlimit} (min)	= = =	$\frac{(C_{post}-C_{target})(t_c+36)}{C_{target}}$ $\frac{(0.92-0.55)(5+36)}{0.55}$ 27.6min	Equation 3.4.3
2f	Select $t_{xcritical}$	$t_{xcritical}$ (min)	=	27.6 min*	Compare t_{xmax} and t_{xlimit} and select smaller of the values
2g	Required detention volume	V_t (m^3)	= = =	$\frac{K_1(t_c+t_{xcritical})}{(K_3+t_{xcritical})}-\frac{K_2(2t_c+t_{xcritical})}{K_3}$ $\frac{410(5+27.6)}{(41+27.6)}-\frac{123(2\times5+27.6)}{41}$ $82.0m^3$	Equation 3.4.4

*Note: For sites where $t_{xcritical} = t_{xlimit}$, the peak Q_{inflow} would be equal to Q_{target}. This is the mathematical solution for the detention volume required even if it may seem like a detention system is not necessary since the peak Q_{inflow} is already equal to the Q_{target}.

Step 3: Determine detention tank configuration

Step	Description	Equation			Remarks
3a	Effective tank depth	d_t (m)	=	1.0m	Check site boundary conditions. Effective tank depth is the depth between the invert of inlet drain and discharge orifice. The tank, orifice and discharge pipe/drain inverts shall allow free flow discharge into the public drain.
3b	Tank bottom area	A_t (m^2)	= = =	$V_t \div d_t$ $82.0 \div 1.0$ $82.0m^2$	

Based on the site layout a good location to site the detention tank would be underground below the driveway, since there is sufficient elevation difference between the ground level of the development and the discharge point to the public drain, as shown in the Figure 7.1.2.

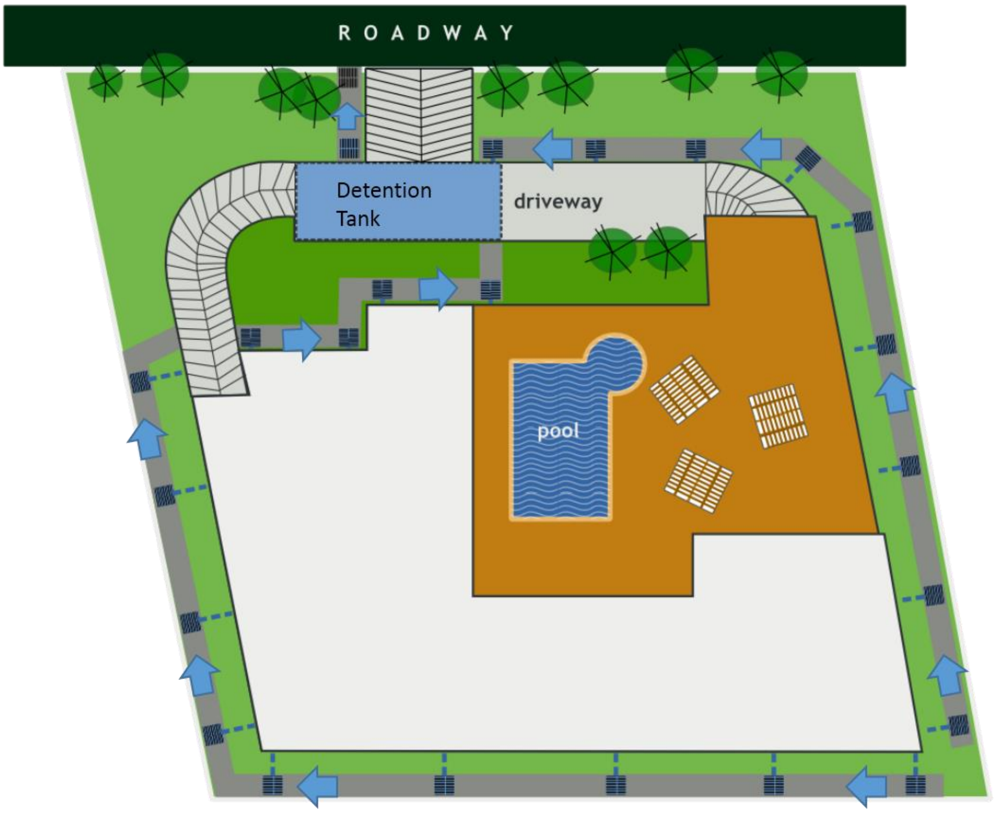


Figure 7.1.2: Location of Detention Tank

Step 4: Sizing of detention tank discharge control

Step	Description	Equation			Remarks
4a	Orifice discharge	Q_o (m^3/s)	=	$C_oA_o\sqrt{2gH_o}$ Where, Q_o = Orifice discharge rate (m^3/s) C_o: Orifice discharge coefficient, use 0.6 A_o: Area of Orifice(m^2) g: Acceleration due to gravity ($9.81m/s^2$) H_o: Maximum head to centre of orifice (m)	Equation 3.5.1
	$Q_o=Q_{target}$	$0.099m^3/s$	=	$0.6\times\frac{\pi d_o^2}{4}\sqrt{2\times9.81\times(1.0-\frac{d_o}{2})}$ Where, d_o = Orifice Diameter (m)	For circular orifice
	Solve for orifice diameter	d_o (m^3/s)	=	0.22m	Use orifice of 0.22m diameter

7.1.3 Detention Tank Schematic Plan and Sectional View

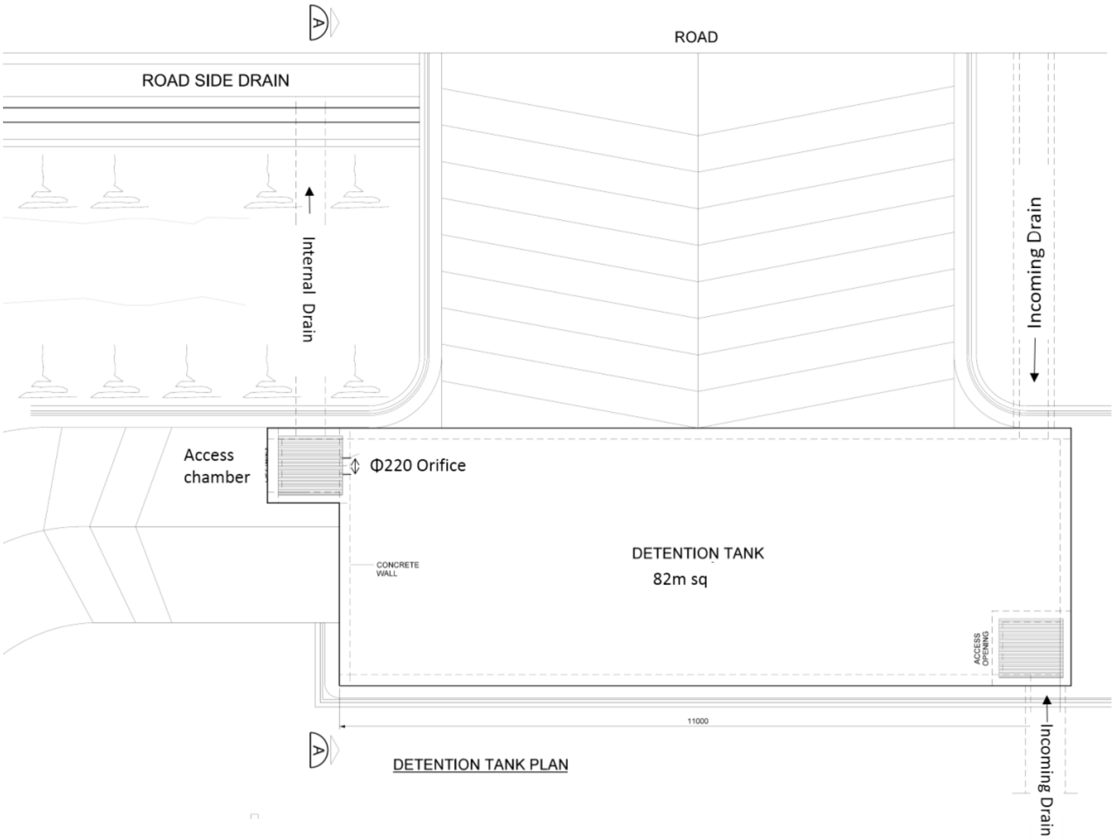


Figure 7.1.3: Detention Tank Schematic Plan

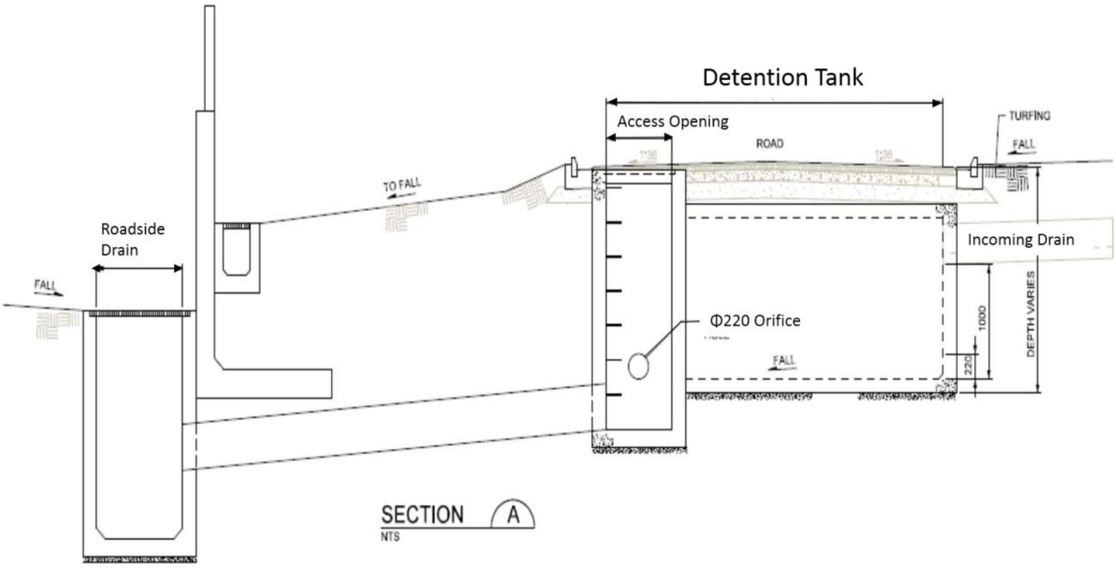


Figure 7.1.4: Detention Tank Schematic Section

7.2 Online Pumped Discharge Detention Tank for Entire Site

7.2.1 Introduction

This example would be based on the same site as Section 7.1, however, instead of using a gravity discharge system, a pumped discharge system would be selected.

7.2.2 Calculation Steps

The design of an online pumped discharge detention system can be developed by the following calculation steps.

Step 1: Identify peak discharge from site and target peak discharge

Step 2: Determine inflow hydrograph

Step 3: Determine detention system configuration

Step 4: Specify pump operations

Step 5: Develop routing spreadsheet

Details for each calculation step are provided below.

Step 1: Identify peak discharge from site and target peak discharge

Step	Description	Equation			Remarks
1a	Site area	A (ha)	=	0.3ha	From Site Analysis in Section 7.1.1
1b	Weighted runoff coefficient of site	C_{post}	=	0.92	From Site Analysis in Section 7.1.1
1c	Time of concentration	t_c (min)	=	5min	From Site Analysis in Section 7.1.1
1d	Average rainfall intensity for 10yr storm event	i_{10} (mm/hr)	=	217mm/hr	From Site Analysis in Section 7.1.1
1e	Peak discharge from site	Q_{post} (m^3/s)	=	$0.166m^3/s$	From Site Analysis in Section 7.1.1
1f	Target runoff coefficient	C_{target}	=	0.55	From Site Analysis in Section 7.1.1
1g	Target peak discharge	Q_{target} (m^3/s)	=	$0.099m^3/s$	From Site Analysis in Section 7.1.1

Step 2: Determine inflow hydrograph

Step	Description	Equation			Remarks
2a	Calculate K_1	K_1	= = =	$\frac{8913 \times C_{post} \times A}{6}$ $\frac{8913 \times 0.92 \times 0.3}{6}$ 410	Equation 3.4.2
2b	Calculate K_2	K_2	= = =	$\frac{8913 \times C_{target} \times A}{12}$ $\frac{8913 \times 0.55 \times 0.3}{12}$ 123	Equation 3.4.2
2c	Calculate K_3	K_3	= = =	t_c+36 5+36 41	Equation 3.4.2
2d	Calculate t_{xmax}	t_{xmax} (min)	= = =	$-K_3+\sqrt{\frac{36K_1K_3}{K_2}}$ $-41+\sqrt{\frac{36 \times 410 \times 41}{123}}$ 29.1min	Equation 3.4.2
2e	Calculate t_{xlimit}	t_{xlimit} (min)	= = =	$\frac{(C_{post}-C_{target})(t_c+36)}{C_{target}}$ $\frac{(0.92-0.55)(5+36)}{0.55}$ 27.6min	Equation 3.4.3
2f	Select $t_{xcritical}$	$t_{xcritical}$ (min)	=	27.6 min*	Compare t_{xmax} and t_{xlimit} and select smaller of the values
2g	Critical rainfall duration	t_z	= = =	$t_{xcritical} + t_c$ 27.6 + 5 32.6min	
2h	Average rainfall intensity for critical storm event	i_z (mm/hr)	= = =	$\frac{8913}{t_z+36}$ $\frac{8913}{32.6+36}$ 130mm/hr	
2i	Peak inflow rate for critical storm event	Q_z (m^3/s)	= = =	$\frac{C_{post} i_z A}{360}$ $\frac{0.92 \times 130mm/hr \times 0.3ha}{360}$ $0.100m^3/s$	

*Note: For sites where $t_{xcritical} = t_{xlimit}$, the peak Q_{inflow} would be equal to Q_{target}. This is the mathematical solution for the detention volume required even if it may seem like a detention system is not necessary since the peak Q_{inflow} is already equal to the Q_{target}.

Step 3: Determine detention system configuration

Step	Description	Equation			Remarks
3a	Detention tank volume	V_t (m^3)	= = =	$\frac{K_1(t_c+t_{xcritical})}{(K_3+t_x\text{critical})} - \frac{K_2(2t_c+t_{xcritical})}{K_3}$ $\frac{410(5+27.6)}{(41+27.6)} - \frac{123(2\times5+27.6)}{41}$ $82.0m^3$	Equation 3.4.4
3b	Tank depth	d_t (m)	=	1.5m	Take tank depth of 1.5m
3c	Tank bottom area	A_t (m^2)	= = =	$V_t \div d_t$ $82.0 \div 1.5$ $54.7m^2$	Applies to vertical walled tank.

Step 4: Specify pump operations

Step	Description	Equation			Remarks
4a	Pump 1: Pump capacity	Q_{p1} (m^3/s)	=	$0.045m^3/s$	
4b	Pump 1: Pump start depth	d_{s1} (m)	=	0.75m	
4c	Pump 2: Pump capacity	Q_{p2} (m3/s)	=	$0.045m^3/s$	
4d	Pump 2: Pump start depth	d_{s2} (m)	=	1.00m	

Step 5: Develop routing spreadsheet

Time (min)	I (m^3/s)	Q (m^3/s)	ΔV (m^3)	V (m^3)	d (m)
0	0.000	0.000	0.0	0.0	0.000
1	0.020	0.000	1.2	1.2	0.022
2	0.040	0.000	2.4	3.6	0.066
3	0.060	0.000	3.6	7.2	0.132
4	0.080	0.000	4.8	12.0	0.220
5	0.100	0.000	6.0	18.0	0.329
6	0.100	0.000	6.0	24.0	0.439
7	0.100	0.000	6.0	30.0	0.549
8	0.100	0.000	6.0	36.0	0.659
9	0.100	0.000	6.0	42.0	0.768
10	0.100	0.045	3.3	45.3	0.829
11	0.100	0.045	3.3	48.6	0.889
12	0.100	0.045	3.3	51.9	0.949
13	0.100	0.045	3.3	55.2	1.010
14	0.100	0.090	0.6	55.8	1.021
15	0.100	0.090	0.6	56.4	1.032
16	0.100	0.090	0.6	57.0	1.043
17	0.100	0.090	0.6	57.6	1.054
18	0.100	0.090	0.6	58.2	1.065
19	0.100	0.090	0.6	58.8	1.076
20	0.100	0.090	0.6	59.4	1.087
21	0.100	0.090	0.6	60.0	1.098
22	0.100	0.090	0.6	60.6	1.109
23	0.100	0.090	0.6	61.2	1.120
24	0.100	0.090	0.6	61.8	1.130
25	0.100	0.090	0.6	62.4	1.141
26	0.100	0.090	0.6	63.0	1.152
27	0.100	0.090	0.6	63.6	1.163
28	0.100	0.090	0.6	64.2	1.174
29	0.100	0.090	0.6	64.8	1.185
30	0.100	0.090	0.6	65.4	1.196
31	0.100	0.090	0.6	66.0	1.207
32	0.100	0.090	0.6	66.6	1.218
33	0.100	0.090	0.6	67.2	1.229
34	0.080	0.090	-0.6	66.6	1.218
35	0.060	0.090	-1.8	64.8	1.185
36	0.040	0.090	-3.0	61.8	1.130
37	0.020	0.090	-4.2	57.6	1.054
38	0.000	0.090	-5.4	52.2	0.955
39	0.000	0.090	-5.4	46.8	0.856
40	0.000	0.090	-5.4	41.4	0.757
21	0.100	0.090	0.6	60.0	1.098

It may be noted that pump 1 starts at t=10min when the depth in the tank at t=9min exceeds d_{s1} which was proposed at 0.75m. Pump 2 starts at t=14min when the depth in the tank at t=13min exceeds d_{s2} which was proposed at 1.00m.

The maximum outflow is 0.090m^3/s which is less than the Q_{target} of 0.099m^3/s. The maximum water depth in the tank is 1.223m which is less than the tank depth of 1.5m. Thus, the detention tank configuration in Step 3, with a detention volume of 82.0m^3 and pump operations in Step 4 are suitable and would be used to for the detention tank design.

The inflow and outflow hydrographs are shown in Figure 7.2.1.

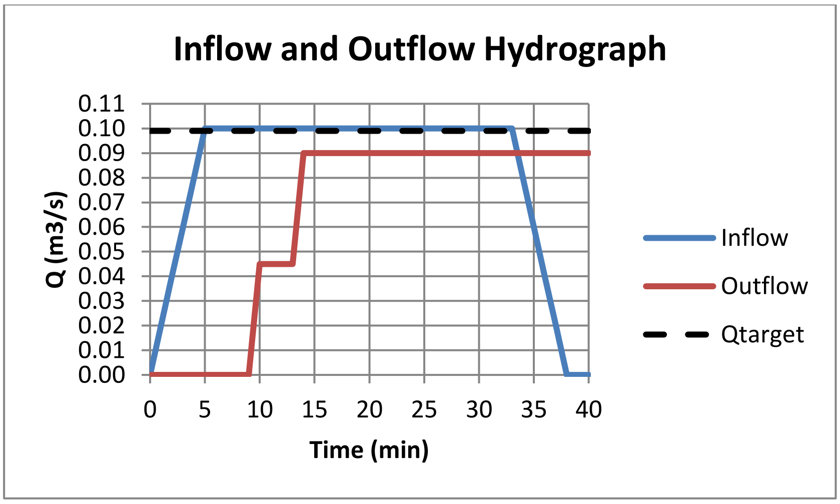


Figure 7.2.1: Inflow and Outflow Hydrographs

Note: For sites where $t_{xcritical} = t_{xlimit}$, the peak Q_{inflow} would be equal to Q_{target}. This is the mathematical solution for the detention volume required even if it may seem like a detention system is not necessary since the peak Q_{inflow} is already equal to the Q_{target}.

7.2.3 Detention Tank Schematic Plan and Sectional View

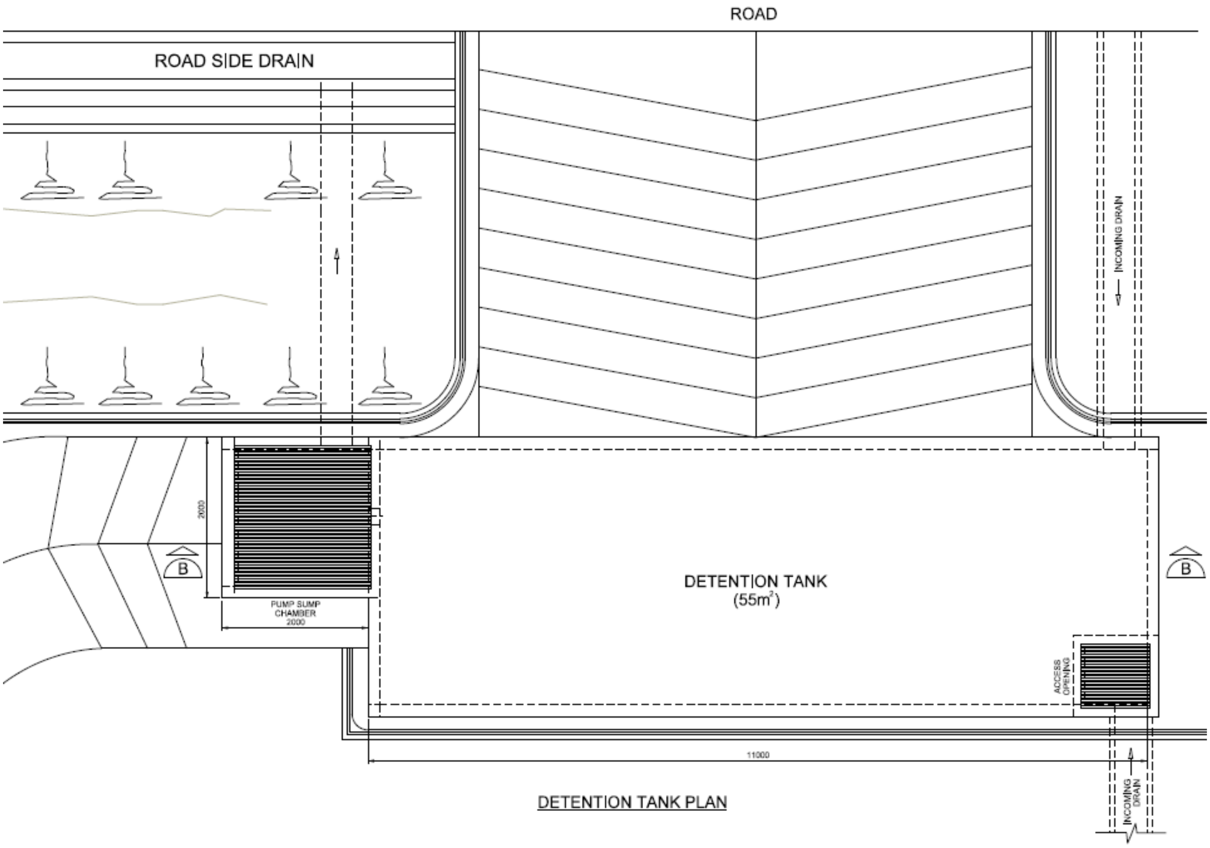


Figure 7.2.2: Detention Tank Schematic Plan

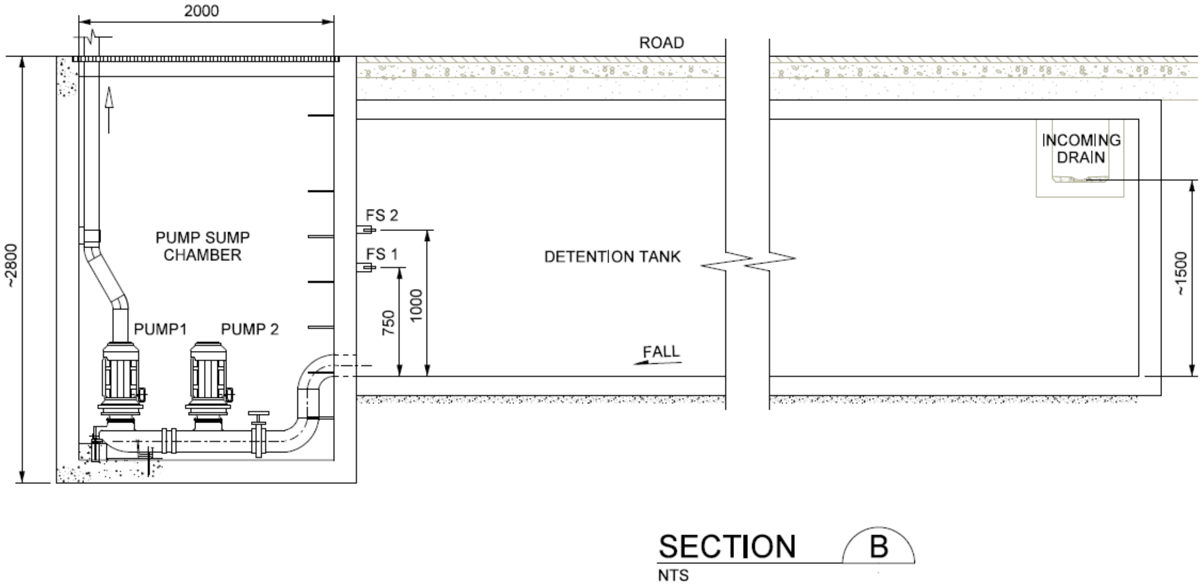


Figure 7.2.3: Detention Tank Schematic Section

7.3 Distributed Catchment Approach

7.3.1 Introduction

A new mixed used development is proposed for a 1.0ha site. The plot consists of residential and commercial buildings with a pocket park with a large rain garden within the development. The proposed site layout is shown in Figure 7.3.1.

Not to Scale

Figure 7.3.1: Site Layout

Catchment Description

The site consists of the following land use:

Table 7.3.1 Catchment Description

	Block A	Block B	Block C	Block D	Other
Percentage of Site Area	30%	25%	10%	10%	25%
Area	3000m^2	2500m^2	1000m^2	1000m^2	2500m^2
Runoff Coefficient	1.0	1.0	1.0	1.0	0.615 Where, Road (C=1) – 750m^2 Grass (C=0.45) – 750m^2 Rain Garden (C=0.45) – 1000m^2

Site Analysis

The development is fragmented with multiple buildings and land uses. A single detention tank to serve the entire catchment would be rather large and elevations may not be ideal for a gravity discharge detention system. A distributed catchment approach with multiple detention systems would be more suited to this type of development. The site will be broken down into sub-areas and detention systems will be designed to serve each sub-area. In this example, 4 different detention systems are proposed. It is assumed that there is only one discharge point to the public drainage network for this site.

In order to meet the $Q_{allowable}$, the strategy is to allow runoff from the “other” sub-area to remain uncontrolled while detention systems are applied to the building sub-areas. Due to the smaller building footprint of Blocks C and D and therefore smaller volumes of runoff generated, an online post-storm discharge detention system consisting of a rooftop detention system and a rain garden was selected for Block C and D respectively. Block A will employ a gravity discharge online detention tank while Block B will employ a pumped detention system.

7.3.2 Site Analysis

Description	**Symbol**	**Block A**	**Block B**	**Block C**	**Block D**	**Other**
Sub-catchment area	A (ha)	0.3ha	0.25ha	0.1ha	0.1ha	0.25ha
Weighted runoff coefficient	C_{post}	1.0	1.0	1.0	1.0	0.615
Time of concentration	t_c (min)	5min	5min	5min	5min	5min
Average rainfall intensity for 10yr storm event	i_{10} (mm/hr)	$\frac{8913}{t_c+36}$ = 217mm/hr	$\frac{8913}{t_c+36}$ = 217mm/hr	$\frac{8913}{t_c+36}$ = 217mm/hr	$\frac{8913}{t_c+36}$ = 217mm/hr	$\frac{8913}{t_c+36}$ = 217mm/hr
Peak discharge from sub-catchment	Q_{post} (m^3/s)	$\frac{C_{post} i_{10} A}{360}$=0.181$m^3/s$	$\frac{C_{post} i_{10} A}{360}$=0.151$m^3/s$	$\frac{C_{post} i_{10} A}{360}$=0.060$m^3/s$	$\frac{C_{post} i_{10} A}{360}$=0.060$m^3/s$	$\frac{C_{post} i_{10} A}{360}$=0.093$m^3/s$
Maximum allowable peak discharge for entire site	$Q_{allowable}$	$\frac{C_{0.55} i_{10} A}{360} = \frac{0.55 \times 217 \times 1.0}{360}$ = 0.332m^3/s				
Target runoff coefficient	C_{target}	0.55	0.93	0	0	0.615
Target peak discharge for sub-catchment	Q_{target} (m^3/s)	$\frac{C_{target} i_{10} A}{360}$=0.099$m^3/s$	$\frac{C_{target} i_{10} A}{360}$=0.140$m^3/s$	0m^3/s	0m^3/s	0.093m^3/s
Check $\sum Q_{target} \leq Q_{allowable}$	-	0.099+0.140+0+0+0.093=0.332m^3/s (yes, $\sum Q_{target} \leq Q_{allowable}$)				
Type of detention system to employ	-	Online, during storm, gravity discharge detention system	Online, during storm, pumped discharge detention system	Online, after storm, gravity discharge detention system	Online, after storm, gravity discharge detention system	None
Design calculations template	-	Appendix B	Appendix C	Appendix D	Appendix D	None

The above example illustrates one strategy to control the peak discharge from a site with multiple sub-catchments which complies with the COP requirements. Other strategies which achieve the same results may also be employed. It is the QP's responsibility to develop and design site-specific strategies that will comply with the PUB's requirements and meet other development objectives where applicable.

7.3.3 Location of Detention Systems

The locations of the different detention systems are shown in Figure 7.3.2.

Not to Scale

Figure 7.3.2: Locations of Detention Systems

Appendix A

Design Calculations Template A
Site Analysis

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Appendix A: Design Calculations Template A

Site Analysis

A site can be broken into one or more sub-catchments. Sub-catchment specific detention systems can be designed for each sub-catchment as long as the sum of the target discharge rates, Q_{target}, for each sub-catchment is less than or equal to the $Q_{allowable}$ of the entire site. With this approach, the runoff from some sub-catchments where detention systems may be difficult to employ may remain uncontrolled. Other sub-catchments may employ a more stringent Q_{target}.to meet the discharge requirements.

Description	Symbol	Sub-catchment 1	Sub-catchment 2	Sub-catchment 3	Sub-catchment n	Remarks
Sub-catchment area	A (ha)					
Weighted runoff coefficient	C_{post}					Equation 3.1.2
Time of concentration	t_c (min)					Table 3.1.1
Average rainfall intensity for 10yr storm event	i_{10} (mm/hr)	$\frac{8913}{t_c+36}$	$\frac{8913}{t_c+36}$	$\frac{8913}{t_c+36}$	$\frac{8913}{t_c+36}$	Equation 3.1.3
Peak discharge from sub-catchment	Q_{post} (m^3/s)	$\frac{C_{post} i_{10} A}{360}$	$\frac{C_{post} i_{10} A}{360}$	$\frac{C_{post} i_{10} A}{360}$	$\frac{C_{post} i_{10} A}{360}$	Equation 3.1.4
Maximum allowable peak discharge for entire site	$Q_{allowable}$	$\frac{C_{0.55} i_{10} A}{360}$ (Equation 3.1.5)				Where i_{10} is the largest i_{10} of the sub-catchments and A is the entire site area
Target runoff coefficient	C_{target}					If runoff is to remain uncontrolled, $C_{target}=C_{post}$, thus $Q_{target}=Q_{post}$
Target peak discharge for sub-catchment	Q_{target} (m^3/s)	$\frac{C_{target} i_{10} A}{360}$	$\frac{C_{target} i_{10} A}{360}$	$\frac{C_{target} i_{10} A}{360}$	$\frac{C_{target} i_{10} A}{360}$	
Check $\sum Q_{target} \leq Q_{allowable}$	-	(yes/no) If no, lower C_{target} for one or more sub-catchments until $\sum Q_{target} \leq Q_{allowable}$				Equation 3.2.1
Type of detention system to employ	-					Table 3.3.1
Design calculations template	-					Choose from Appendix B-E

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Appendix B

Design Calculations Template B
Modified Rational Method Gravity Discharge

Appendix B: Design Calculations Template B

Modified Rational Method Gravity Discharge

Step 1: Identify peak discharge from site and target peak discharge

Step	Description	Equation			Remarks
1a	Catchment area	A (ha)	=		From Template A
1b	Weighted runoff coefficient of site	C_{post}	=		From Template A
1c	Time of concentration	t_c (min)	=		From Template A
1d	Average rainfall intensity for 10yr storm event	i_{10} (mm/hr)	= =	$\frac{8913}{t_c+36}$	From Template A
1e	Peak discharge from site	Q_{post} (m^3/s)	= =	$\frac{C_{post} i_{10} A}{360}$	From Template A
1f	Target runoff coefficient	C_{target}	=		From Template A
1g	Target peak discharge	Q_{target} (m^3/s)	= =	$\frac{C_{target} i_{10} A}{360}$	From Template A

Step 2: Determine required detention volume

Step	Description	Equation			Remarks
2a	Calculate K_1	K_1	= =	$\frac{8913 \times C_{post} \times A}{6}$	Equation 3.4.2
2b	Calculate K_2	K_2	= =	$\frac{8913 \times C_{target} \times A}{12}$	Equation 3.4.2
2c	Calculate K_3	K_3	= =	t_c+36	Equation 3.4.2
2d	Calculate t_{xmax}	t_{xmax} (min)	= =	$-K_3+\sqrt{\frac{36K_1K_3}{K_2}}$	Equation 3.4.2
2e	Calculate t_{xlimit}	t_{xlimit} (min)	= =	$\frac{(C_{post}-C_{target})(t_c+36)}{C_{target}}$	Equation 3.4.3
2f	Select $t_{xcritical}$	$t_{xcritical}$ (min)	=	*	Compare t_{xmax} and t_{xlimit} and select smaller of the values
2g	Required detention volume	V_t (m^3)	= =	$\frac{K_1(t_c+t_{xcritical})}{(K_3+t_{xcritical})}-\frac{K_2(2t_c+t_{xcritical})}{K_3}$	Equation 3.4.4

*Note: For sites where $t_{xcritical} = t_{xlimit}$, the peak Q_{inflow} would be equal to Q_{target}. This is the mathematical solution for the detention volume required even if it may seem like a detention system is not necessary since the peak Q_{inflow} is already equal to the Q_{target}.

Step 3: Determine detention system configuration

Step	Description	Equation			Remarks
3a	Effective tank depth	d_t (m)	=		Check site boundary conditions. Effective tank depth is the depth between the invert of inlet drain and discharge orifice. The tank, orifice and discharge pipe/drain inverts shall allow free flow discharge into the public drain.
3b	Tank bottom area	A_t (m^2)	= =	$V_t \div d_t$	

Step 4: Sizing of detention system discharge control

Step	Description	Equation			Remarks
4a	Orifice discharge	Q_o (m^3/s)	=	$C_o A_o \sqrt{2gH_o}$ Where, Q_o = Orifice discharge rate (m^3/s) C_o: Orifice discharge coefficient A_o: Area of Orifice(m^2) g: Acceleration due to gravity ($9.81 m/s^2$) H_o: Maximum head to centre of orifice (m)	Equation 3.5.1
	$Q_o = Q_{target}$	Q_{target} (m^3/s)	=	$C_o \frac{\pi d_o^2}{4} \sqrt{2gH_o}$ Where, d_o = Orifice Diameter (m)	Using a circular orifice.
	Solve for orifice diameter	d_o (m)	=		

Step 5: Design of overflow structure

An overflow structure shall be required for online detention systems to allow a secondary means of discharge for extreme storm events. An overflow sump or equivalent may be incorporated into the design of the detention system; however, it should not be counted towards the detention volume. The overflow structure shall be sized for a maximum allowable peak discharge based on a runoff coefficient of 0.55.

Appendix C

Design Calculations Template C
Modified Rational Method Pumped Discharge

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Appendix C: Design Calculations Template C

Modified Rational Method Pumped Discharge

Step 1: Identify peak discharge from site and target peak discharge

Step	Description	Equation			Remarks
1a	Catchment area	A (ha)	=		From Template A
1b	Weighted runoff coefficient of site	C_{post}	=		From Template A
1c	Time of concentration	t_c (min)	=		From Template A
1d	Average rainfall intensity for 10yr storm event	i_{10} (mm/hr)	= =	$\frac{8913}{t_c+36}$	From Template A
1e	Peak discharge from site	Q_{post} (m^3/s)	= =	$\frac{C_{post} i_{10} A}{360}$	From Template A
1f	Target runoff coefficient	C_{target}	=		From Template A
1g	Target peak discharge	Q_{target} (m^3/s)	= =	$\frac{C_{target} i_{10} A}{360}$	From Template A

Step 2: Determine inflow hydrograph

The Modified Rational Method is used to determine the inflow hydrograph. The inflow hydrograph to be adopted corresponds with the hydrograph for the critical storm duration that results in the largest detention volume. The outflow hydrograph for the pumped discharge system is assumed to be triangular (similar to orifice discharge) in this step. However, the actual outflow hydrograph would be confirmed in the later steps through storage routing.

Step	Description	Equation			Remarks
2a	Calculate K_1	K_1	= =	$\frac{8913\times C_{post}\times A}{6}$	Equation 3.4.2
2b	Calculate K_2	K_2	= =	$\frac{8913\times C_{target}\times A}{12}$	Equation 3.4.2
2c	Calculate K_3	K_3	= =	t_c+36	Equation 3.4.2
2d	Calculate t_{xmax}	t_{xmax} (min)	= =	$-K_3+\sqrt{\frac{36K_1K_3}{K_2}}$	Equation 3.4.2
2e	Calculate t_{xlimit}	t_{xlimit} (min)	= =	$\frac{(C_{post}-C_{target})(t_c+36)}{C_{target}}$	Equation 3.4.3
2f	Select $t_{xcritical}$	$t_{xcritical}$ (min)	=	*	Compare t_{xmaxl} and t_{xlimit} and select smaller of the values
2g	Critical rainfall duration	t_z	= =	$t_{xcritical} + t_c$	
2h	Average rainfall intensity for critical storm event	i_z (mm/hr)	= =	$\frac{8913}{t_z+36}$	
2i	Peak inflow rate for critical storm event	Q_z (m^3/s)	= =	$\frac{C_{post}i_zA}{360}$	

*Note: For sites where $t_{xcritical} = t_{xlimit}$, the peak Q_{inflow} would be equal to Q_{target}. This is the mathematical solution for the detention volume required even if it may seem like a detention system is not necessary since the peak Q_{inflow} is already equal to the Q_{target}.

The inflow hydrograph is assumed to be trapezoidal with the peak inflow, Q_{inflow}, occurring at the time of concentration, t_c. The inflow rate remains at Q_{inflow} up to the end of the rainfall duration when it returns to zero. The inflow hydrograph is illustrated below.

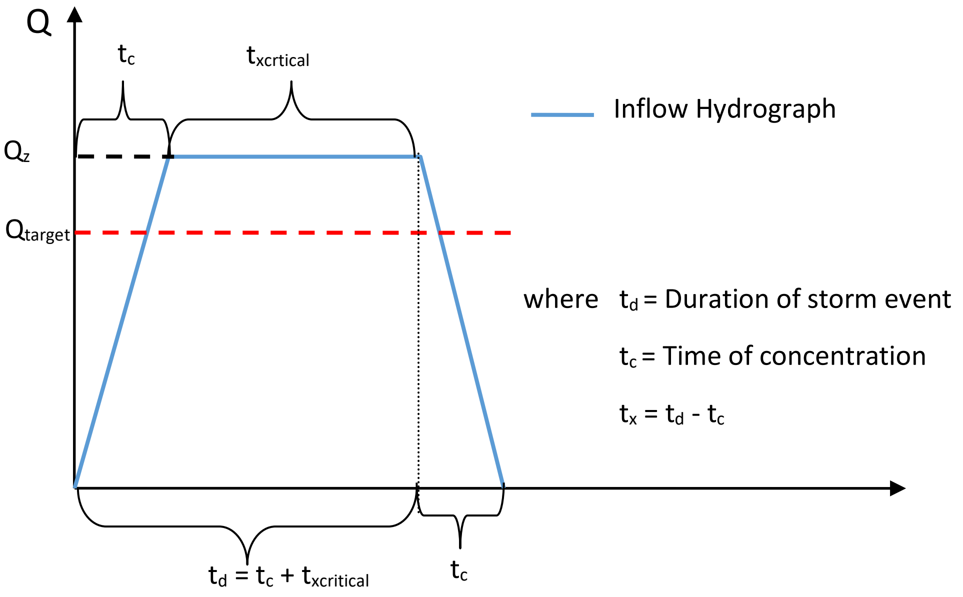

Figure C13: Inflow hydrograph

Step 3: Determine detention system configuration

Step	Description	Equation			Remarks
3a	Detention tank volume	V_t (m^3)	=	$\frac{K_1(t_c+t_{xcritical})}{(K_3+t_{xcritical})} - \frac{K_2(2t_c+t_{xcritical})}{K_3}$	Equation 3.4.4
3b	Tank depth	d_t (m)	=		Choose a suitable tank depth
3c	Tank bottom area	A_t (m^2)	=	$V_t \div d_t$	Applies to vertical walled tank.

Step 4: Specify pump operations

One or more pumps may be selected for discharge. Multiple pumps with varying capacities and pump start depths would lead to smoother operations of the system as it would minimise the occurrence of the pump(s) starting and stopping frequently during operations. The sum of the pump capacities should not exceed Q_{target}.

Step	Description	Equation			Remarks
4a	Pump 1: Pump capacity	Q_{p1} (m^3/s)	=		
4b	Pump 1: Pump start depth	d_{s1} (m)	=		Pump 1 to begin pumping when water level in the tank reaches d_{s1}.

Step	Description	Equation			Remarks
4c	Pump 2: Pump capacity	Q_{p2} (m3/s)	=		A second pump is optional but recommended.
4d	Pump 2: Pump start depth	d_{s2} (m)	=		Pump 2 to begin pumping when water level in the tank reaches d_{s2}.

Step 5: Develop routing spreadsheet

The routing table can be developed based on the following simplified routing equation:

$$I\text{-}Q=\frac{\Delta V}{\Delta t} \qquad \text{(Equation 3.4.5)}$$

Where I = Inflow
Q = Outflow
S = Storage

The "time" column of the table can be input based on an appropriate time interval of not more than 1min. The "inflow" column is input based on the inflow hydrograph of the critical storm event.

The following steps may be used to complete the table:

i) Fill in the "Inflow" column base on the inflow hydrograph developed in Step 2.
ii) Set all the values in the "Outflow" column to zero for the moment.
iii) Calculate the change in volume, $\Delta V=\Delta t(I\text{-}Q)$ for each time step. Δt is the time interval (seconds) between time steps.
iv) Calculate the volume in the tank, V, which is the cumulative sum of ΔV at each time step.
v) Calculate the water depth in the detention tank, $d=V/A_t$ for each time step. A_t is the tank bottom area.
vi) Fill in the "Outflow" column based on the proposed pump operations in Step 4.

Time Step	**Time (min)**	**I (m^3/s)**	**Q (m^3/s)**	**ΔV (m^3)**	**V (m^3)**	**d (m)**
1	0	I_1	Q_1	$\Delta V_1=\Delta t(I_1\text{-}Q_1)$	$V_1=0+\Delta V_1$	$d_1=V_1/A_t$
2	t	I_2	Q_2	$\Delta V_2=\Delta t(I_2\text{-}Q_2)$	$V_2=V_1+\Delta V_2$	$d_2=V_2/A_t$
3	2t	I_3	.	.	.	.
4	3t	I_4	.	.	.	.
. . .	. . .	. . .	. . .	. . .	. . .	. . .

To confirm that the detention tank volume determined in Step 3, the following conditions must be true,

i) The outflow from the tank, Q, is always less than or equal to Q_{target}.
ii) The water depth in the detention tank, d, is always less than the tank depth, d_t.

If the conditions are not met, the tank dimensions or the pump operations should be revised and Step 5 be repeated again with the revised figures.

If these conditions are met, the detention tank configuration in Step 3 and the pump operations selected in Step 4 are deemed suitable. The detention tank configuration and pump operations should not be further optimised based on the routing spreadsheet in Step 5. This approach will result in a conservative design. Further optimisation through modelling methods may be adopted.

The inflow and outflow hydrographs according to the routing spreadsheet may now be graphed.

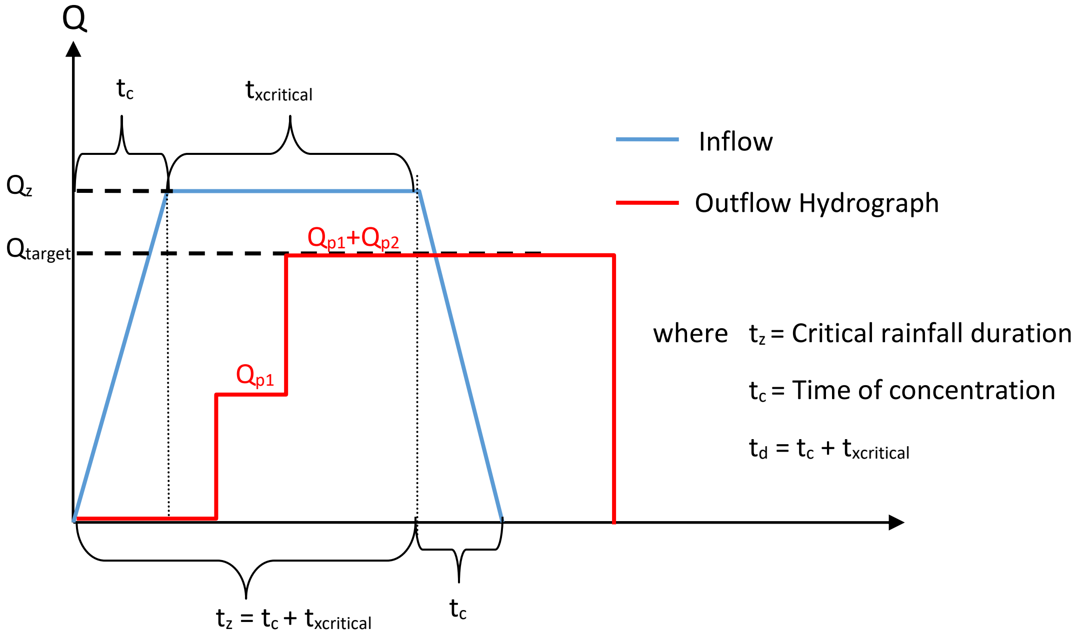

Figure C14: Inflow and outflow hydrographs

Step 6: Design of overflow structure

An overflow structure shall be required for online detention systems to allow a secondary means of discharge for extreme storm events. An overflow sump or equivalent may be incorporated into the design of the detention system, however, it should not be counted towards the detention volume. The overflow structure shall be sized for a maximum allowable peak discharge based on a runoff coefficient of 0.55.

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Appendix D

Design Calculations Template D
Full Detention of Runoff Method

Appendix D: Design Calculations Template D

Full Detention of Runoff Method

Step 1: Identify peak discharge from site and target peak discharge

Step	Description	Equation			Remarks
1a	Catchment area	A (ha)	=		From Template A
1b	Weighted runoff coefficient of site	C_{post}	=		From Template A
1c	Time of concentration	t_c (min)	=		From Template A
1d	Average rainfall intensity for 10yr storm event	i_{10} (mm/hr)	= =	$\frac{8913}{t_c+36}$	From Template A
1e	Peak discharge from site	Q_{post} (m^3/s)	= =	$\frac{C_{post} i_{10} A}{360}$	From Template A
1f	Target runoff coefficient	C_{target}	=		From Template A
1g	Target peak discharge	Q_{target} (m^3/s)	= =	$\frac{C_{target} i_{10} A}{360}$	From Template A

Step 2: Determine detention volume

Step	Description	Equation			Remarks
2a	Determine fraction of site to apply full detention	f_{ic}	= =	C_{post} - C_{target}	Equation 3.4.6 Full detention should be applied to impervious areas of the site only.
2b	Detention volume	V_t (m^3)	= =	$1300(C_{post}-C_{target})\times A$	Equation 3.4.7

Step 3: Sizing of detention system discharge control

The detention volume should be discharged after the storm event. The detention volume should be discharged within 4 hours and the discharge rate should not exceed Q_{target}.

Step	Description	Equation			Remarks
3a	Minimum discharge rate Note: Discharge rate should not exceed Q_{target}.	Q_o (m^3/s)	= =	$V_t \div 14400$	Detention system should empty within 4 hour. Appropriate discharge mechanisms (i.e. pumps, valves) to be selected.

If infiltration is used as the method of discharge, show that the infiltration rates allow the detention volume to be drained within 4hr.

Step 4: Describe instrumentation and control systems

The detained runoff can be released into the receiving drains after the storm event has ceased or the water levels in the receiving drains have subsided. Rain or water level sensors may be installed to activate the discharge system. Location and operations of such systems shall be described in this step.

Step 5: Design of overflow structure

An overflow structure shall be required for online detention systems to allow a secondary means of discharge for extreme storm events. An overflow sump or equivalent may be incorporated into the design of the detention system, however, it should not be counted towards the detention volume. The overflow structure shall be sized for a maximum allowable peak discharge based on a runoff coefficient of 0.55.

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Appendix E

Design Calculations Template E
Hydrological and Hydraulic Modelling

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Appendix E: Design Calculations Template E

Hydrological and Hydraulic Modelling

Step 1: Identify peak discharge from site and target peak discharge

Step	Description	Equation			Remarks
1a	Catchment area	A (ha)	=		From Template A
1b	Weighted runoff coefficient of site	C_{post}	=		From Template A
1c	Time of concentration	t_c (min)	=		From Template A
1d	Average rainfall intensity for 10yr storm event	i_{10} (mm/hr)	= =	$\frac{8913}{t_c+36}$	From Template A
1e	Peak discharge from site	Q_{post} (m^3/s)	= =	$\frac{C_{post} i_{10} A}{360}$	From Template A
1f	Target runoff coefficient	C_{target}	=		From Template A
1g	Target peak discharge	Q_{target} (m^3/s)	= =	$\frac{C_{target} i_{10} A}{360}$	From Template A

Step 2: Model setup

Develop 3 separate models. The first would represent the post-development catchment with the internal drainage network and the detention system. The second would be identical to the first except without the detention system. The third would be exactly the same as the second except that the catchment runoff coefficient would be set to C_{target}. Show the graphical representation of the model and state the hydrological and hydraulic model used.

Example:

In this illustration, the hydrological/hydraulic model was setup using USEPA SWMM.

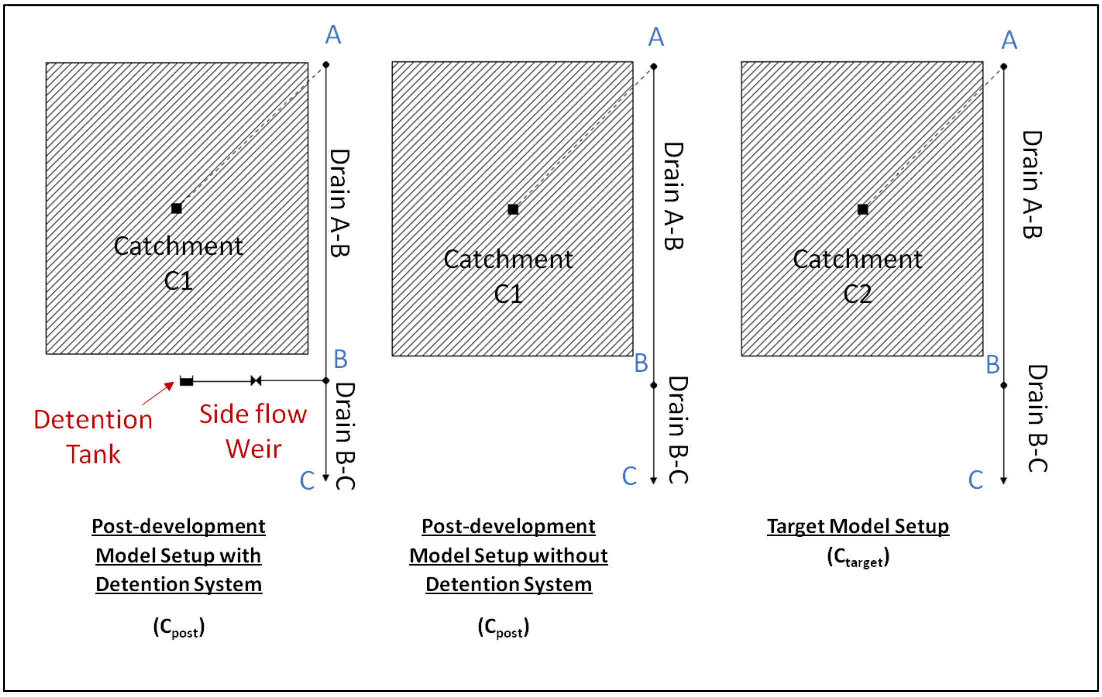

Figure E15: Example of hydrological/hydraulic model setups

Step 3: Describe catchment set up and hydrological model used

Explain how the site characteristics are modelled. Define the parameters used for the set up. Rainfall input for the model should follow the 10yr return period, 4hour duration synthetic rainfall shown in Table E4.

Table E4: 10yr return period, 4hour synthetic rainfall

Time (h:mm:ss)	Rainfall Depth (mm)	Time (h:mm:ss)	Rainfall Depth (mm)	Time (h:mm:ss)	Rainfall Depth (mm)	Time (h:mm:ss)	Rainfall Depth (mm)
0:02:30	0.179	1:02:30	0.568	2:02:30	9.058	3:02:30	0.532
0:05:00	0.185	1:05:00	0.606	2:05:00	7.089	3:05:00	0.500
0:07:30	0.193	1:07:30	0.649	2:07:30	5.699	3:07:30	0.471
0:10:00	0.200	1:10:00	0.697	2:10:00	4.681	3:10:00	0.444
0:12:30	0.208	1:12:30	0.750	2:12:30	3.914	3:12:30	0.420
0:15:00	0.217	1:15:00	0.810	2:15:00	3.321	3:15:00	0.397
0:17:30	0.226	1:17:30	0.877	2:17:30	2.853	3:17:30	0.376
0:20:00	0.235	1:20:00	0.953	2:20:00	2.478	3:20:00	0.357
0:22:30	0.245	1:22:30	1.038	2:22:30	2.172	3:22:30	0.339
0:25:00	0.256	1:25:00	1.136	2:25:00	1.919	3:25:00	0.323
0:27:30	0.268	1:27:30	1.249	2:27:30	1.708	3:27:30	0.308
0:30:00	0.280	1:30:00	1.379	2:30:00	1.530	3:30:00	0.293
0:32:30	0.293	1:32:30	1.530	2:32:30	1.379	3:32:30	0.280
0:35:00	0.308	1:35:00	1.708	2:35:00	1.249	3:35:00	0.268
0:37:30	0.323	1:37:30	1.919	2:37:30	1.136	3:37:30	0.256
0:40:00	0.339	1:40:00	2.172	2:40:00	1.038	3:40:00	0.245
0:42:30	0.357	1:42:30	2.478	2:42:30	0.953	3:42:30	0.235
0:45:00	0.376	1:45:00	2.853	2:45:00	0.877	3:45:00	0.226
0:47:30	0.397	1:47:30	3.321	2:47:30	0.810	3:47:30	0.217
0:50:00	0.420	1:50:00	3.914	2:50:00	0.750	3:50:00	0.208
0:52:30	0.444	1:52:30	4.681	2:52:30	0.697	3:52:30	0.200
0:55:00	0.471	1:55:00	5.699	2:55:00	0.649	3:55:00	0.193
0:57:30	0.500	1:57:30	7.089	2:57:30	0.606	3:57:30	0.185
1:00:00	0.532	2:00:00	9.058	3:00:00	0.568	4:00:00	0.179

Example:

Table E5: Example of modelled catchment parameter inputs

Parameter	***Post-development Setup with Detention Tank System***	***Target Model Setup***
Area	*1.0ha*	*1.0ha*
Width of catchment	*100m*	*100m*
Slope	*1%*	*1%*
Runoff Coefficient	*0.89*	*0.55*
. . .	. . .	. . .

Step 4: Describe the internal drainage network setup

Define the various drain shapes, invert levels and slopes. Explain how the runoff is routed to the internal drainage network.

Example:

Table E6: Example of internal drainage network modelled inputs

Drain	***Invert Start (m)***	***Invert End (m)***	***Length (m)***	***Slope (m/m)***	***Manning's n***	***Drain Shape***	***Remarks***
A-B	*110.55*	*110.05*	*100*	*0.005*	*0.015*	*Rectangular 1m wide by 1m deep*	*Catchment runoff is linked to Node A*
B-C	*110.05*	*110.00*	*10*	*0.005*	*0.015*	*Rectangular 1m wide by 1m deep*	*Outlet C is assumed to be a free flow discharge outlet.*
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .

Step 4a: Describe flow diversion structure (for offline detention systems only)

Show the location of the proposed flow diversion structure in relation to the internal drainage network. Define how flow diversion structure operates and all model input parameters associated with it.

Example:

Flow diversion structure is modelled as a rectangular sharp-crested side flow weir at Node B in Figure C13. Weir level is at 110.28m, weir length is 5.0m. Discharge coefficient assumed is 1.7.

Step 4b: Describe detention system discharge controls (for online detention systems only)

Describe discharge control system and all model input parameters associated with it.

Example:

Discharge control is modelled as a circular orifice located at the bottom of the detention system. Orifice diameter is 0.25m. Discharge coefficient assumed is 0.6.

Step 5: Describe detention tank setup

Show the location of the proposed detention system in relation to the internal drainage network. Explain the tank configuration/dimensions and how it is connected to the flow diversion structure (offline systems) or internal drainage network (online systems).

Example:

Detention tank is modelled as a vertical walled tank as indicated in Figure C13. The bottom area is 100m^2 and the tank depth is 2m.

Step 6: Generate outflow hydrograph

Generate the outflow hydrographs for the,

- Post-development with detention tank setup
- Post-development without detention tank setup
- Target model setup

Check that,

- The peak discharge for the post-development without detention tank setup is comparable with Q_{post} calculated in Step 1e.
- The peak discharge for the post-development with detention tank setup is less than or equal to Q_{target} (calculated in Step 1f) OR the peak discharge for the target model setup.
- Check that the water level in the detention tank is not greater than the tank depth. Provide a graph that shows how the water level in the tank varies with time.

Example:

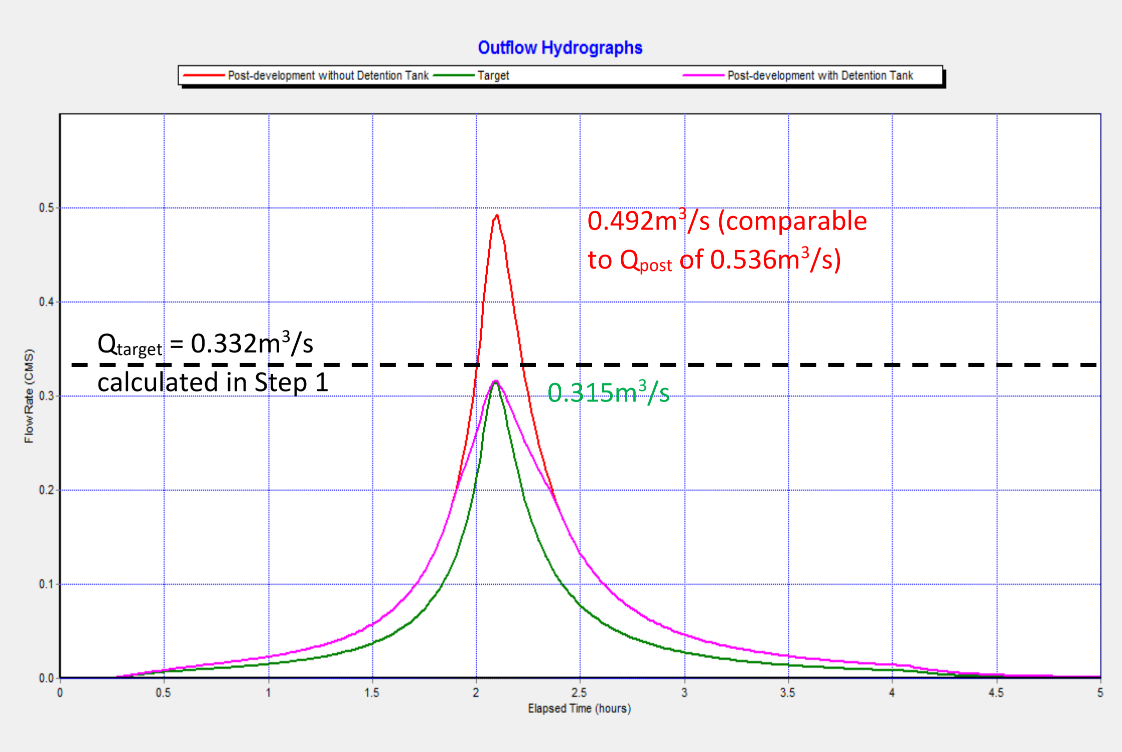

Figure E16: Example of modelled outflow hydrographs

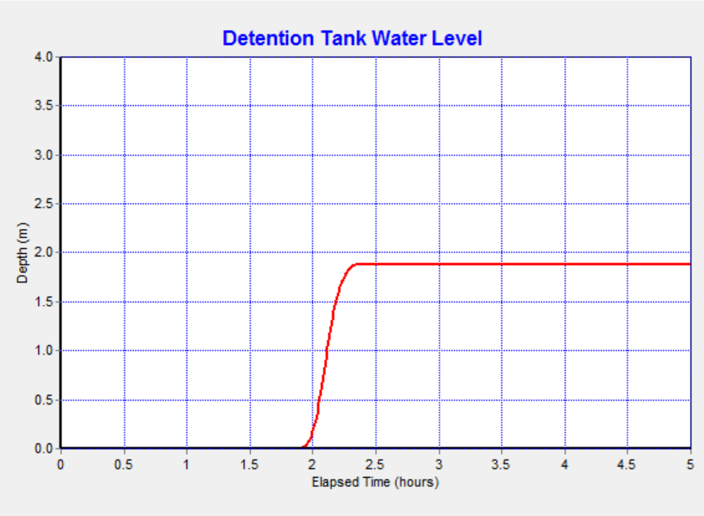

Figure E17: Example of modelled water level in the detention tank

Step 7a: Sizing of detention system discharge control (for offline detention systems only)

The detention volume should be discharged after the storm event. The detention volume should be discharged within 4 hours and the discharge rate should not exceed Q_{target}. The discharge control may be simulated in the model. The model input parameters for the discharge control are to be described. The graphs illustrating how the discharge and tank depth varies with time shall be provided.

Alternatively, the following manual method would suffice.

Step	Description	Equation			Remarks
7a	Minimum discharge rate Note: Discharge rate should not exceed Q_{target}.	Q_o (m^3/s)	= =	V_t÷14400s	Detention system should empty within 4hr. Appropriate discharge mechanisms (i.e. pumps, valves) to be selected.

Step 7b: Design of overflow structure (for online detention systems only)

An overflow structure shall be required for online detention systems to allow a secondary means of discharge for extreme storm events. An overflow sump or equivalent may be incorporated into the design of the detention system, however, it should not be counted towards the detention volume. The overflow structure shall be sized for a maximum allowable peak discharge based on a runoff coefficient of 0.55.

Appendix F

Sample of Operations & Maintenance Checklist for On-site Stormwater Detention Systems

OPERATIONS AND MAINTENANCE CHECKLIST FOR ON-SITE STORMWATER DETENTION SYSTEMS

Devt Address & MCST no.:	
Location of Detention Tank:	

	**(at least monthly, and after significant storm events)*	***FINDINGS / OBSERVATIONS***			
	Date of Inspection*:				
1	**Detention Tanks**				
a	Is access into the detention tank system secure (out of bounds to public and unauthorised personnel)?				
b	Any obstruction of maintenance access/openings?				
c	Is the structural integrity of tank and features compromised (check for cracks/leaks)?				
d	Any stagnant water in tank?				
e	Any residual water at inlet/outlet structures?				
f	Any mosquito breeding?				
g	Any pest infestation within the system?				
h	Any clogging at inlet/outlet structures/trash racks?				
i	Any excessive sediment build-up in tanks?				
2	**Equipment**				
a	Number of pumps that are available (in service)				
b	Number of pumps that can operate manually				
c	Level control successfully activates pump/valve when *<conditions are met>*				
3	**Conclusion**				
a	Other Remarks/Findings				
b	Inspection by (name)				
c	Sign-off				

OPERATIONS AND MAINTENANCE CHECKLIST
FOR ON-SITE STORMWATER DETENTION SYSTEMS

Devt Address & MCST no.:	
Location of Detention Tank:	

^Servicing scope of works is specific to each equipment and manufacturer

Overview of Maintenance Work
(Each conducted quarterly)

1. **Electrical Installation License**

License Number	
Expires on	
Renewed on	
New expiry date	

2. **LEW Inspection / Electrical Servicing^**

Date	Job Reference no.	Remarks

3. **Standby Generator Servicing^ / Testing**

Date	Job Reference no.	Remarks

4. **Pump set Servicing^**

Date	Job Reference no.	Remarks

5. **De-silting of Detention Tank, Clearing of Screens**

Date	Job Reference no.	Remarks

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