19 ON SITE DETENTION

19.1 INTRODUCTION

This chapter provides guidelines for the design of the on-site stormwater detention (OSD) facilities outlined in Chapter 18. The designer is advised to read the general principles for detention storage provided in Chapter 18 before proceeding with detailed analysis and design.

19.2 SITE SELECTION

For undeveloped sites, the decision of whether or not to include OSD to control site discharges should be made as early as possible in the concept planning stage for developing the site. It is far easier to integrate OSD facilities into a site arrangement as part of the total development concept than to attempt to retrofit them after the form and extent of buildings, driveways, and landscaping have been designed or constructed. This approach will give the designer the most flexibility for design and will generally allow opportunities for developing innovative and/or more cost-effective design solutions.

For developed sites, the location and level of existing structures and services can severely restrict opportunities for providing satisfactory OSD systems. It may not be practical, due to factors such as cost or public safety, to provide the amount of storage necessary to limit post-development peak flows to the amounts required. In such cases, consideration should be given to increasing the limit on post-development peak flows to match the maximum amount of storage available.

19.3 FLOW CONTROL REQUIREMENTS

19.3.1 Design Storm

The design storm for discharge from an OSD storage, termed the *discharge design storm*, shall be the minor system design ARI of the municipal drainage system to which the storage is connected (refer Table 4.1). The design storm for calculating the required storage volume, termed the *storage design storm*, shall be 10 year ARI.

19.3.2 Permissible Site Discharge (PSD)

The PSD is the maximum allowable post-development discharge from a site for the selected discharge design storm and is estimated on the basis that flows within the downstream stormwater drainage system will not be increased. Phillips (1983) describes the PSD as being dependent on the following criteria:

- the time of concentration of the catchment to its outlet, or a point of concern either within or downstream of the catchment
- the position of the site, time-wise from the uppermost reach of the catchment
- the original or adopted ARI of the public drainage system within the catchment and rainfall data
- the area of the development site
- the proportion of impervious area of the development site
- the type of OSD storage facility
- the extent of development or redevelopment within the catchment
- local and/or regional drainage policies

19.3.3 Site Storage Requirement (SSR)

The SSR is the total amount of storage required to ensure that the required PSD is not exceeded and the OSD facility does not overflow during the storage design storm ARI.

19.3.4 Site Coverage

Where possible, the site drainage system and grading should be designed to direct runoff from the entire site to the OSD system. Sometimes this will not be feasible due to ground levels, the level of the receiving drainage system, or other circumstances. In these cases, as much runoff from impervious areas as possible should be drained to the OSD system.

19.3.5 Frequency Staged Storage

Generally the most challenging task in designing OSD systems is locating and distributing the storage(s) in the face of the following competing demands:

- making sure the system costs no more than necessary
- creating storages that are aesthetically pleasing and complementary to the architectural design
- avoiding unnecessary maintenance problems for future property owners
- minimising any personal inconvenience for property owners or residents

These demands can be balanced by providing storage in accordance with a frequency staged storage approach. Under this approach, a proportion of the required storage for a given ARI is provided as below-ground storage, whilst the remainder of the required storage, up to the design storm ARI, is provided as above-ground storage. The depth of inundation and extent of area inundated in the above-ground storage is thus limited such that the greatest inconvenience to property owners or occupiers occurs very infrequently. The approach recognises that people are generally prepared to accept flooding which causes inconvenience, provided it does not cause any damage and does not happen too often. Conversely, the lesser the degree of personal inconvenience, the more frequently the inundation can be tolerated.

Recommended storage proportions for designing a composite above and below-ground storage system using a frequency staged storage approach are provided in Table 19.1. A typical composite storage system is illustrated in Figure 19.1. Refer to Table 19.2 for recommended maximum ponding depths in the above-ground storage component.

Table 19.1 Relative Proportions for Composite Storage Systems

Storage Area	Proportion of Total Storage (%)	
	Below-Ground Storage Component	Above-Ground Storage Component
Pedestrian areas	60	40
Private Courtyards	60	40
Parking areas and driveways	50	50
Landscaped areas	25	75
Paved outdoor recreation areas	15	85

19.3.6 Bypass Flows

An OSD storage is generally designed only to deal with stormwater runoff from the site under consideration. If runoff from outside the site enters the storage, it will fill more quickly, causing a greater nuisance to occupiers and it will become ineffective in terms of reducing stormwater runoff leaving the site.

Unless the storage is sized to detain runoff from the entire upstream catchment, an overland flow path or a floodway must be provided through the site to ensure that all external flows bypass the OSD storage.

Overland Flow Paths: These are small surface drainage systems, such as dish drains and swales, which are designed to collect relatively minor sheet flow from upstream properties and convey it around the storage, or allow it to pass across the site without interference.

Floodways: These are larger surface drainage systems, such as natural gullies and grassed floodways, which are designed to convey relatively major concentrated surface or surcharge flows from an upstream catchment around the storages.

The surface area of an overland flow path or a floodway is excluded from the site area for the purpose of calculating the site storage requirements. Such areas must be protected from future development within the site by an appropriate covenant or drainage reserve.

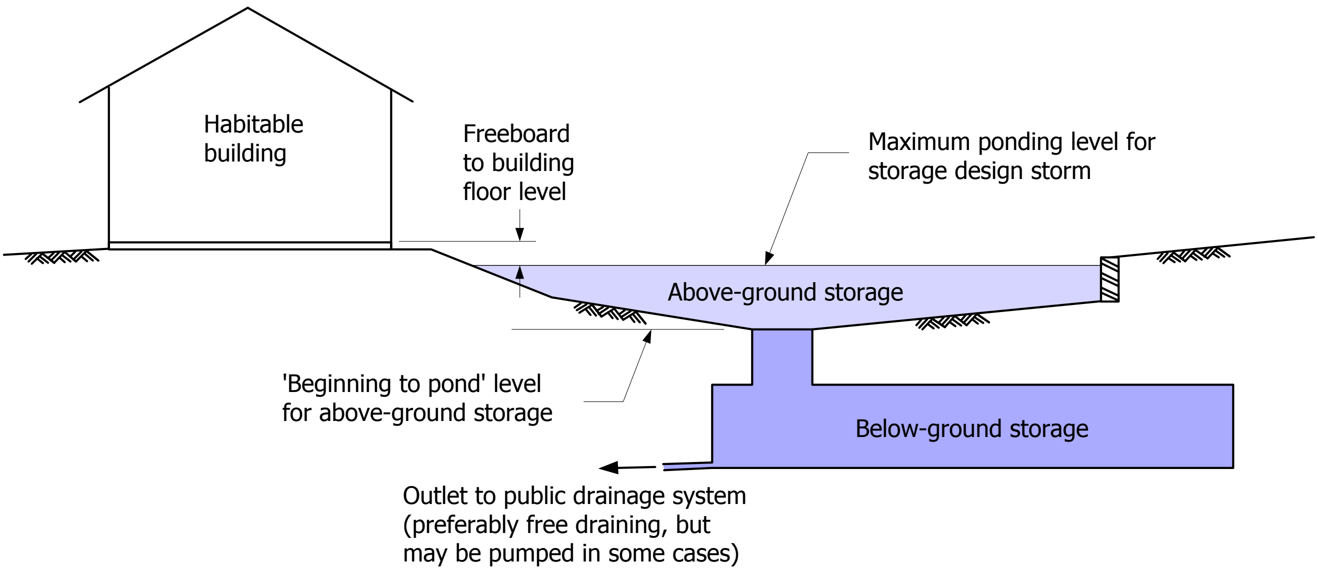


Figure 19.1 Illustration of a Composite Storage System

19.4 DETERMINATION OF PSD AND SSR

19.4.1 OSD Sizing Method

The recommended method for estimating PSD and SSR is the Swinburne Method, developed at the Swinburne University of Technology in Melbourne, Australia. Although the method is essentially site-based, some allowance is made for the position of the site within the catchment. The peak flow time of concentration from the top of the catchment to the development site, t_{cs}, is compared to the total time of concentration for the catchment, t_c. The PSD varies with this ratio and may be less than or greater than the peak pre-development site discharge depending on the position of the site within the catchment. Figure 19.2 illustrates the relationship between t_c and t_{cs}.

The method uses the Rational Method (refer Chapter 14) to calculate site flows, and utilises a non-dimensional triangular site hydrograph based on the triangular design storm method of Yen and Chow (1983) as illustrated in Figure 19.3. The site discharges are calculated using the total catchment time of concentration t_c (not the time of concentration to the development site) for the design storm ARI under consideration (see Figure 19.2).

(i) PSD

As stated in Section 19.3.1 the discharge design storm for estimating the PSD is the minor system design ARI of the municipal stormwater system to which the site is or will be connected. The following general equation is used to calculate the PSD for the site in litres per second. The factors a and b are different for above-ground and below-ground storages due to differences in storage geometry and outflow characteristics.

$$PSD = \frac{a - \sqrt{a^2 - 4\,b}}{2} \tag{19.1}$$

For above-ground storage :

$$a = \left(4\,\frac{Q_a}{t_c}\right)\left(0.333\ t_c\,\frac{Q_p}{Q_a} + 0.75\,t_c + 0.25\,t_{cs}\right) \tag{19.1a}$$

$$b = 4\ Q_a\,Q_p \tag{19.1b}$$

For below-ground storage :

$$a = \left(8.548\,\frac{Q_a}{t_c}\right)\left(0.333\ t_c\,\frac{Q_p}{Q_a} + 0.35\,t_c + 0.65\,t_{cs}\right) \tag{19.1c}$$

$$b = 8.548\ Q_a\,Q_p \tag{19.1d}$$

Where,

t_c = peak flow time of concentration from the top of the catchment to a designated outlet or point of concern (minutes)

t_{cs} = peak flow time of concentration from the top of the catchment to the development site (minutes)

Q_a = the peak post-development flow from the site for the discharge design storm with a duration equal to t_c (l/s)

Q_p = the peak pre-development flow from the site for the discharge design storm with a duration equal to t_c (l/s)

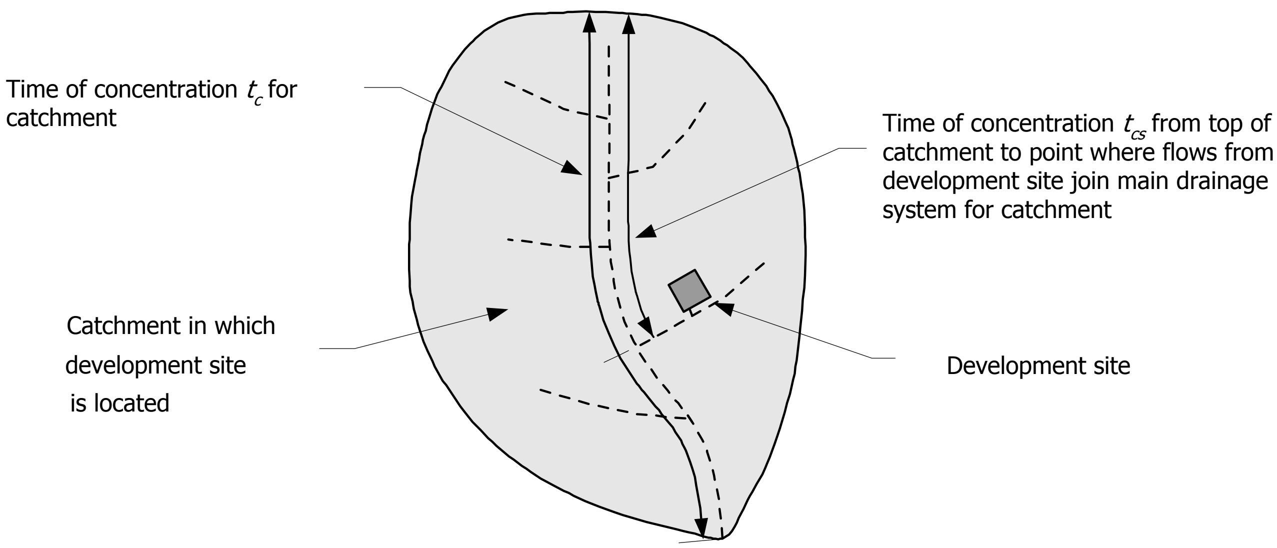


Figure 19.2 Relationship Between t_c and t_{cs} for the Swinburne Method

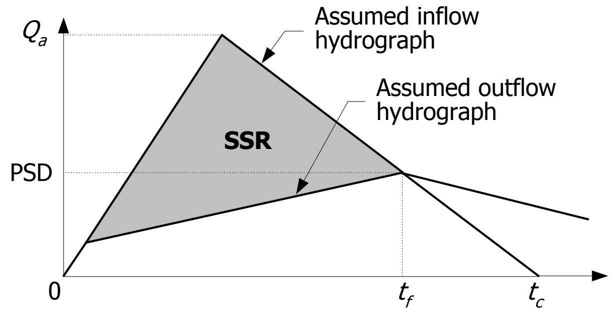


Figure 19.3 Swinburne Method Assumptions
t_f = time for storage to fill

(ii) SSR

As stated in Section 19.3.1, the *storage design storm* for estimating the SSR is 10 year ARI. In sizing the volume of the storage facility, the method assumes a triangular inflow hydrograph and an outflow hydrograph shape related to the type of storage adopted. These simplifications are acceptable providing the site catchment is small.

Typically, the critical storm duration that produces the largest required storage volume is different from the time of concentration used for peak flow estimation. Therefore, storage volumes must be determined for a range of storm durations to find the maximum storage required as indicated in Figure 19.4.

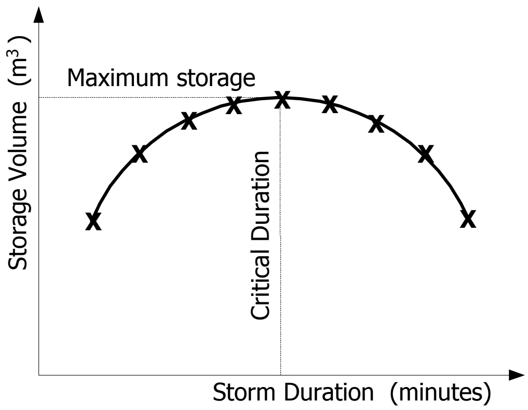


Figure 19.4 Typical Relationship of Storage Volume to Storm Duration

The following general equation is used to calculate the SSR for the site in cubic metres. Different factors for *c* and *d* are applied for above-ground and below-ground storages to account for differences in storage geometry and outflow characteristics.

$$SSR = 0.06\ t_d \left(Q_d - c - d \right) \tag{19.2}$$

For above-ground storage :

$$c = 0.875\ PSD \left(1 - 0.459\ \frac{PSD}{Q_d} \right) \tag{19.2a}$$

$$d = 0.214\ \frac{PSD^2}{Q_d} \tag{19.2b}$$

For below-ground storage :

$$c = 0.675\ PSD \left(1 - 0.392\ \frac{PSD}{Q_d} \right) \tag{19.2c}$$

$$d = 0.117\ \frac{PSD^2}{Q_d} \tag{19.2d}$$

Where,

t_d = selected storm duration (minutes)
Q_d = the peak post-development flow from the site for a storm duration equal to t_d (l/s)

19.4.2 OSD Sizing Procedure

A simplified design procedure for determining the required volume of detention storage is as follows:

1. Select storage type(s) to be used within the site, i.e. separate above and/or below-ground storage(s), or a composite above and below-ground storage.
2. Determine the area of the site that will be drained to the OSD storage system. As much of the site as possible should drain to the storage system.
3. Determine the amount of impervious and pervious areas draining to the OSD storage system.
4. Determine the times of concentration, t_c and t_{cs}.
5. Calculate the pre and post-development flows, Q_p and Q_a, for the area draining to the storage for the discharge design storm with time of concentration t_c.
6. Determine the required PSD for the site using Equation 19.1 for the discharge design storm.
7. Determine the required SSR for the site using Equation 19.2 for the storage design storm over a range of durations to determine the maximum value. For composite storages, apportion the required SSR in accordance with Table 19.1.

Note: For composite storages, use the PSD and SSR equation factors relating to the largest storage component. If these are equal, use the above-ground storage factors.

19.5 GENERAL CONSIDERATIONS

19.5.1 Drainage System

The stormwater drainage system (including gutters, pipes, open drains, and overland flow paths) for the site must:

- be able to convey all runoff to the OSD storage, up to and including the storage design storm, with time of concentration t_c
- ensure that the OSD storage is bypassed by all runoff from neighbouring properties and any part of the site not being directed to the OSD storage facility

The outlet from the OSD facility must be designed to ensure that outflow discharges:

- do not cause adverse effects on downstream properties by concentrating flow
- can be achieved with low maintenance

The OSD outlet should be designed to be independent of downstream flow conditions under all design circumstances wherever possible (i.e. not outlet controlled). If this is not possible, the outlet should be sized to account for drowned or partly drowned outlet conditions (refer Section 19.3.1).

19.5.2 Multiple Storages

In terms of construction and recurrent maintenance costs, it is preferable to provide fewer larger storages than a larger number of smaller storages. Multiple storages should be carefully treated when preparing a detailed design. The storages need to be designed separately with the catchment draining to each storage defined. When establishing the catchments draining to each storage, it is important to remember that flows, up to and including the storage design storm ARI, need to be directed to the storage. This will mean that, in addition to the property drainage system, surface gradings will need to be checked to ensure that surface flows and overflows from roof gutters, pipes, and open drains are directed to the appropriate storage.

The outlet pipe from a storage needs to be connected downstream of the primary outlet structure of any other storage, i.e. storages should act independently of each other and not be connected in series.

19.5.3 Site Grading

Sites should be graded according to the following general guidelines:

- grade the site for surface drainage such that no serious consequences will occur if the property drainage system fails. The surface flows in many sites are so small that there is no need for any property drainage other than the roof drainage system
- avoid filling the site with stormwater inlets that are not needed. Inlets rarely get any maintenance. As well, increased pit head loss through the drainage system can cause drainage failure due to blockage
- direct as much of the site as possible to the OSD storage. A frequent failing of storage systems is that the driveways either discharge directly to the street or a grated drain on the boundary. These drains rarely perform adequately. A better approach is to introduce a speed hump or threshold, which will more effectively divert surface flows to a storage or contain flows when the driveway forms part of the OSD storage system

19.5.4 Floor Levels

The site drainage system must ensure that:

- all habitable floor levels for new and existing dwellings are a minimum 200 mm above the storage maximum water surface level for the storage design storm ARI
- garage floor levels are a minimum 100 mm above the storage design storm ARI maximum water surface level

A similar freeboard should be provided for flowpaths adjacent to habitable buildings and garages.

19.5.5 Aesthetics

The designer should try to ensure that OSD storages and discharge control structures blend in with and enhance the overall site design concept by applying the following general guidelines:

- when OSD storage is provided in a garden area, avoid placing the discharge control structure in the centre where it will be an eyesore. Where possible, grade the floor of the storage such that the discharge control structure is located unobtrusively, e.g. in a corner next to shrubbery or some garden furniture
- If space permits, try to retain some informality in garden areas used for storage. Rectangular steep-sided basins unbroken by any features maximise the volume, but may detract from the appearance of the landscaping

19.5.6 Construction Tolerances

Because of the importance of OSD systems in protecting downstream areas from flooding, every effort should be made to avoid, or at least minimise, construction errors. Whilst an OSD system with slightly less than the specified storage volume will mitigate flooding in most storm events, it will not be fully effective in the storage design storm. For this reason, the design should allow for the potential reduction in the storage volume due to common post-construction activities such as landscaping, top dressing and garden furniture.

Notwithstanding this, it is recognised that achieving precise levels and dimensions may not always be possible in practice. It is therefore considered that an OSD system will meet the design intent where the:

- storage volume is at least 95% of the specified volume
- design outflow is within plus or minus 5% of the PSD

19.5.7 Signs

It is essential that current and future property owners are aware of the purpose of the OSD facilities provided. A permanent advisory sign for each OSD storage facility provided should be securely fixed at a pertinent and clearly visible location stating the intent of the facility. An example of an advisory sign is shown in Figure 19.5.

Colours:	
Triangle and "WARNING"	Red
Water	Blue
Figure and other lettering	Black

Figure 19.5 Typical OSD Advisory Sign (UPRCT, 1999)

19.6 ABOVE-GROUND STORAGE

There are few absolute requirements when designing an above-ground storage. The following guidelines allow the designer maximum flexibility when integrating the storage into the site layout.

19.6.1 Maximum Storage Depths

Maximum storage depths in above-ground storages should not exceed the values provided in Table 19.2.

Table 19.2 Recommended Maximum Storage Depths for Different Classes of Above-Ground Storage

Storage Classes	Maximum Storage Depth
Pedestrian areas	50 mm
Parking areas and driveways	150 mm
Landscaped areas	600 mm
Private courtyards	600 mm
Flat roofs	300 mm
Paved outdoor recreation areas	100 mm

19.6.2 Landscaped Areas

Landscaped areas offer a wide range of possibilities for providing above-ground storage and can enhance the aesthetics of a site. The minimum design requirements for storage systems provided in landscaped areas are:

- maximum ponding depths shall not exceed the limits recommended in Table 19.2 under design conditions
- calculated storage volumes shall be increased by 20% to compensate for construction inaccuracies and the inevitable loss of storage due to the build up of vegetation growth over time
- the minimum ground surface slope shall be 2% to promote free surface drainage and minimise the possibility of pools of water remaining after the area has drained
- side slopes should be a maximum 1(V):4(H) where possible. If steep or vertical sides (e.g. retaining walls) are unavoidable, due consideration should be given to safety aspects, such as the need for fencing, both when the storage is full and empty
- subsoil drainage around the outlet should be provided to prevent the ground becoming saturated during prolonged wet weather
- where the storage is to be located in an area where frequent ponding could create maintenance problems or inconvenience to property owners, a frequency staged storage approach should be adopted as recommended in Table 19.1. If this is not practicable, the first 10-20% of the storage should be provided in an area able to tolerate frequent inundation, e.g. a paved outdoor entertainment area, a permanent water feature, or a rock garden
- landscaping should be designed such that loose materials such as mulch and bark etc. will not wash into and block storage outlets
- retaining walls shall be designed to be structurally adequate for the hydrostatic loads caused by a full storage

19.6.3 Impervious Areas

Car parks, driveways, paved storage yards, and other paved surfaces may be used for stormwater detention.

Car park detention shares the same surface area with parked vehicles. If the detention is designed without regard for the primary use of the car park in mind, considerable inconvenience and damage to parked vehicles can occur when it rains. First and foremost, for the car park detention to be acceptable to its owners, it is necessary to ensure that the lot does not pond water frequently. Also, when the lot detains stormwater, it should be inundated for only a short period of time. Thus, it is important to recognise the limitations in ponding depths and the frequency of ponding. Failure to do so can lead to owners taking action to eliminate this nuisance after experiencing flooding on their property.

The minimum design requirements for storage systems provided in impervious areas shall be as follows:

- to avoid damage to vehicles, depths of ponding on driveways and car parks shall not exceed the limits recommended in Table 19.2 under design conditions
- transverse paving slopes within storages areas shall not be less than 0.7%
- if the storage is to be provided in a commonly used area where ponding will cause inconvenience (e.g. a car park or pedestrian area), a frequency staged storage approach should be adopted as recommended in Table 19.1. If this is not practical, the first 10-20% of the storage should be provided in a non-sensitive area on the site

19.6.4 Flat Roofs

Rooftop storage may be provided on buildings with flat roofs. Stormwater can be detained up to the maximum depth recommended in Table 19.2 by installing flow restrictors on roof drains. Their design are covered in Section 19.8.

Flat roofs used for detention will have a substantial live load component. It is therefore essential that the structural design of the roof is adequate to sustain increased loadings from ponded stormwater. The latest structural codes and standards should be checked before finalising plans. Roofs must also be sealed to prevent leakage.

A typical flow restrictor on a roof drain is shown in Figure 19.6. As can be seen, the outlet has a strainer that is surrounded by a flow restricting ring. The degree of flow control is determined by the size and number of holes in the ring. When the water depth reaches the top of the ring, it then spills freely into the roof drain with virtually no further restriction. Water ponding depth is thereby controlled to the permissible depth while providing a controlled release rate for a measured storage volume.

The most common problem with rooftop detention is lack of proper inspection and maintenance. The flow control ring can clog with debris, such as leaves, and cause the water to pond for prolonged periods. Building owners have been known to remove these flow restrictors to eliminate the nuisance of ponded water on the roof, often not realising that the control ring is an integral part of the site drainage system. This happens frequently after a roof develops a leak.

Roof detention systems should be regularly inspected to ensure that all roof restrictors are working as designed. A municipal enforcement program is also necessary to minimise the loss of roof detention through the deliberate or inadvertent removal of roof restrictors by property owners or occupiers.

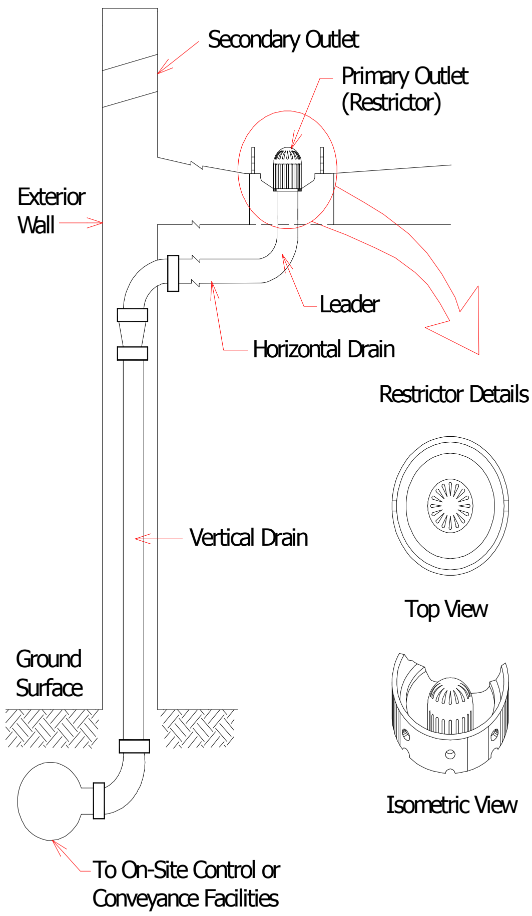


Figure 19.6 Typical Roof Storage Flow Restrictor

19.6.5 Surface Tanks

Surface tanks are normally provided on residential lots for rainwater harvesting. These tanks collect rainwater from the rooftops of buildings and store it for later domestic use. Surface tanks may also be used solely for on-site detention, or utilised in combination with storage provided for rainwater harvesting as illustrated in Figure 19.7.

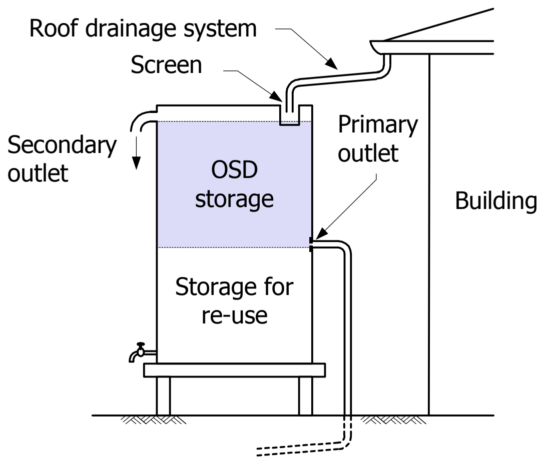


Figure 19.7 Typical Multi-Purpose Surface Tank

If a combined system is provided, the rainwater harvesting storage volume cannot be relied upon for detention purposes as this portion may be full or partly full at the onset of rain and therefore ineffective for detention. The storage volume that is required for on-site detention must therefore be in addition to the storage volume provided for rainwater harvesting.

Since surface tanks will only provide detention volume for rooftops of buildings, other forms of detention storage (such as landscaped storage or pipe packages) must also be provided if flows from the whole site are to be reduced.

19.7 BELOW-GROUND STORAGE

Providing a small proportion of the required storage volume underground can often enhance a development by limiting the frequency of inundation of an above-ground storage area. In difficult topography, the only feasible solution may be to provide all or most of the required storage volume below-ground. However, it should be recognised that below-ground storages:

- are more expensive to construct than above-ground storage systems
- are difficult to inspect for silt and debris accumulation
- can be difficult to maintain
- can be dangerous to work in and may be unsafe for property owners to maintain

When preparing a design for below-ground storage, designers should be aware of any statutory requirements for working in confined spaces. Where practicable, the design should minimise the need for personnel to enter the storage space for routine inspection and maintenance.

19.7.1 Underground Tanks

(a) Basic Configuration

Typical below-ground storage tanks are either circular or rectangular in plan and/or cross-section (see Figure 19.8) but, due to their structural nature, can be configured into almost any geometrical plan shape. The main advantages of tanks are they are out of sight and stored water will not cause inconvenience to property owners or occupiers under normal operation. The main disadvantages of tanks include high construction cost and maintenance safety hazards.

Storage tanks can be connected both 'in-line' and 'off-line' to the stormwater conveyance system. How they are used depends on the design objectives.

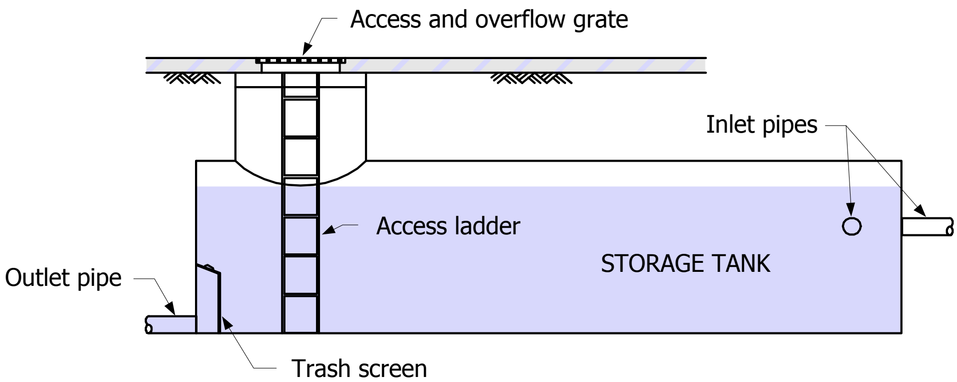


Figure 19.8 Typical Below-ground Storage Tank

The configuration of a below-ground storage tank is largely determined by site conditions. For instance, the vertical fall in the stormwater system will determine if the storage can be drained by gravity or if pumping will be required (refer to Chapter 47 for guidelines on pumping systems).

(b) Structural Adequacy

Storage tanks must be structurally sound and be constructed from durable materials that are not subject to deterioration by corrosion or aggressive soil conditions. Tanks must be designed to withstand the expected live and dead loads on the structure, including external and internal hydrostatic loadings. Buoyancy should also be checked, especially for lightweight tanks, to ensure that the tank will not lift under high groundwater conditions.

(c) Horizontal Plan

Site geometry will dictate how the installation is configured in plan. Obviously, the area that the storage facility will occupy will depend, among other things, on height and width limitations on the site. This can be especially critical in high-density developments where available site space may be very limited.

A rectangular shape offers certain cost and maintenance advantages, but space availability will sometimes dictate a variation from a standard rectangular plan. It may be necessary on some site to design irregularly shaped tanks. In such cases, construction and maintenance costs will normally be higher.

(d) Bottom Slope

To permit easy access to all parts of the storage for maintenance, the floor slope of the tank should not be greater than 10%. The lower limit for this slope is 2%, which is needed for good drainage of the tank floor.

(e) Ventilation

It is very important to provide ventilation for below-ground storage systems to minimise odour problems. Ventilation may be provided through the tank access opening(s) or by separate ventilation pipe risers. Although the inflow and outflow pipes can provide some ventilation of the storage tank, their contribution is unreliable and should not be considered in the design. Also, the ventilation openings should be designed to prevent air from being trapped between the roof of the storage and the water surface.

(f) Overflow Provision

An overflow system must be provided to allow the tank to surcharge in a controlled manner if the capacity of the tank is exceeded due to a blockage of the outlet pipe or a storm larger than the storage design ARI. As illustrated in Figure 19.8, an overflow can be provided by installing a grated access cover on the tank.

(g) Access Openings

Below-ground storage tanks should be provided with openings to allow access by maintenance personnel and equipment. An access opening should be located directly above the outlet for cleaning when the storage tank is full and the outlet is clogged. A permanently installed ladder or step iron arrangement must be provided below each access opening if the tank is deeper than 1200 mm.

In addition to maintenance access and overflow provision, access openings can also be used for ventilation and to admit daylight into the tank.

19.7.2 Pipe Packages

(a) Basic Configuration

A *pipe package* is a below-ground storage consisting of one or more parallel rows of buried pipes connected by a common inlet and outlet chamber.

The size of a pipe package is determined by the storage volume requirements and the physical availability of space on the site. A pipe package does not need to be installed in a straight line along its entire length, it can change direction anywhere along its length to fit any site space limitations. A typical pipe package, shown in Figure 19.9, is equipped with a flow regulator installed in the outlet chamber and an overflow spillway located at either the inlet or outlet chamber.

(b) Minimum Pipe Size and Longitudinal Grade

To facilitate inspection and cleaning, the minimum pipe size shall be 900 mm diameter.

Pipes should be laid at a minimum longitudinal grade of 2% to avoid standing pockets of water which can occur due to lack of precision during construction.

(c) Low Flow Provision

Although sediment will settle out inside pipe packages, the extent of deposition can be reduced by installing one of the pipes lower than the others as shown in Figure 19.9. To keep the other pipes from filling during low flows, the difference in level between the low flow pipe and other pipes needs to be sufficient to keep the low flows confined wholly within the low flow pipe. Confining low flows to one pipe will help the system to become self-cleansing.

(d) Inlet Chamber

The site drainage system is connected to the pipe package through an inlet chamber at the upstream end. The chamber must be large enough to permit easy access to all of the pipes by maintenance personnel and equipment.

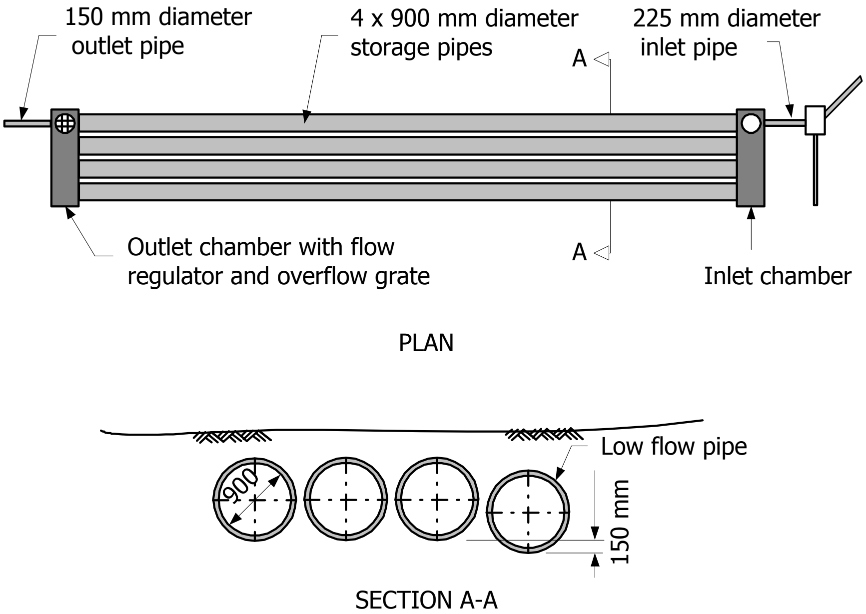


Figure 19.9 Basic Layout of a Pipe Package Storage (Stahre and Urbonas, 1990)

(e) Outlet Chamber

At the downstream end, the pipe package is connected to the municipal stormwater drainage system through an outlet chamber. The chamber must also be large enough for maintenance access. Flow through the outlet chamber may be controlled by one of the primary outlet devices discussed in Section 19.8.

(f) Overflow Provision

To prevent water from surcharging at stormwater inlets or manholes upstream during storms larger than the storage design storm or if the primary outlet becomes blocked, a secondary outlet overflow system must be installed at either the inlet or outlet chamber (refer to Section 19.9).

On steep sites or for long pipe lengths, the overflow should preferably be located at the inlet chamber as illustrated in Figure 19.10(a). In this type of arrangement, the outlet chamber may need to be sealed to allow the water to back up into the inlet chamber before the overflow operates. As a result, the storage capacity in the pipe package is fully utilised. It is essential to check that backwater effects will not cause damage or other problems upstream.

Figure 19.10(b) illustrates an overflow located at the outlet chamber. Although there is less risk of causing upstream flooding, it is possible that the storage capacity may not be fully utilised in the above-mentioned cases. Also, there is a greater risk with this configuration that the bottom deposits in the pipe will be resuspended and deposited downstream.

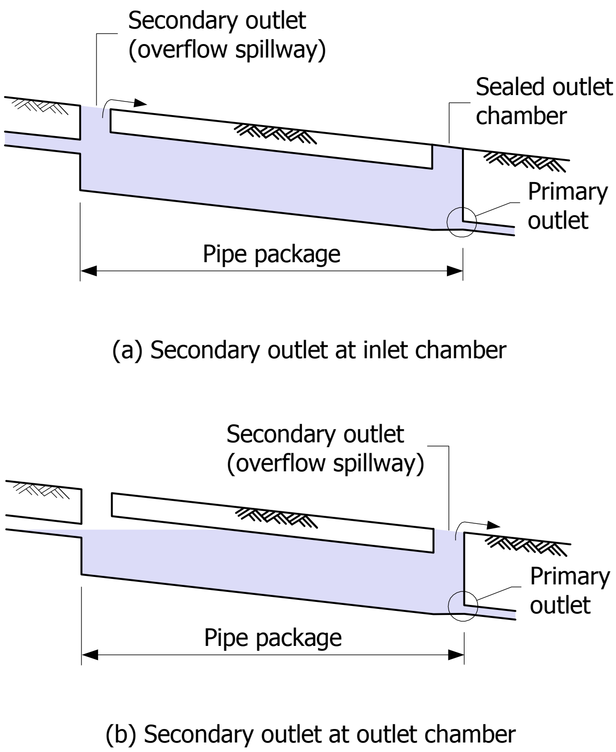


Figure 19.10 Pipe Package Secondary Outlet (After ATV, 1978)

(g) Access Openings

Access openings are required at both chambers to facilitate normal cleaning and maintenance of a pipe package. Such openings provide access for personnel and cleaning equipment, and ventilation and lighting.

If more than three parallel pipes are used, two openings should be installed in each chamber. The maximum distance between access openings shall not exceed 30 m. Therefore, on long pipe packages, additional access openings along each of the pipes may be required.

19.8 PRIMARY OUTLETS

19.8.1 General Design Considerations

(a) Flow Regulation

Flow detention is provided by a storage volume that is released by some types of flow regulating device. It is the flow regulator that determines how efficiently the storage volume will be utilised. Obviously, the flow regulator has to be in balance with the available storage volume for the range of runoff events it is designed to control.

Flow regulating devices are often called upon to perform what may appear to be conflicting tasks, such as limiting flow rates, be free of clogging, and be relatively maintenance free.

The Swinburne Method requires variable discharge from OSD storages to ensure that the timing of flow peaks from sites at different locations within a catchment do not coincide with the flow peak for the total catchment at the catchment outlet. Therefore, below-ground storages must be configured for variable discharge and under no circumstances should a high early discharge configuration be used. Some degree of high early discharge is inevitable with above-ground storages, but this situation has been accounted for in the equations provided for PSD and SSR.

(b) Location of the Flow Regulator

Flow regulating devices for above-ground storages are typically housed in an outlet structure, called a discharge control pit (DCP), which is an important component of the storage facility. It not only controls the release rate, but also determines the maximum depth and volume within the storage.

Flow regulating devices for below-ground storages are typically located within the storage facility. In this type of arrangement, the flow regulator should be located at, or near, the bottom of the storage facility. In some cases, where the topography does not permit emptying of the storage facility by gravity, pumping will be required to regulate the flow rate.

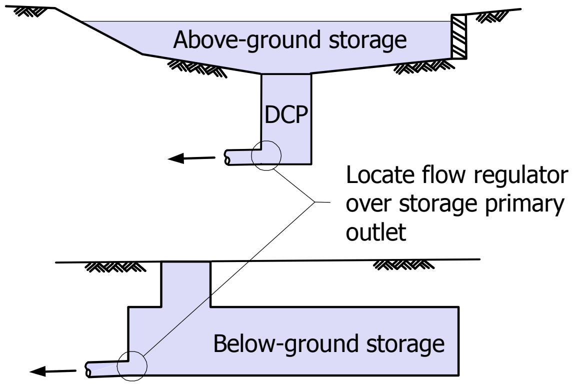


Figure 19.11 Primary Outlet Flow Regulator

Figure 19.11 shows the indicative location of the primary outlet flow regulator in a typical above and below-ground storage.

(c) Protection from Blockage

For most OSD applications, the size of the primary outlet required to produce the desired reduction in site discharge is relatively small and can therefore be highly susceptible to blockage by debris. It is essential that all OSD storages are protected from potential blockage by installing trash screens around the primary outlet (refer to Section 19.8.6).

19.8.2 Orifice

The simplest flow regulating device is an orifice. When the outlet is small in comparison to the depth of water, the discharge through the orifice can be calculated using the orifice equation:

$$Q = C_d A_o \sqrt{2g H_o} \tag{19.3}$$

where,

Q = the orifice flow rate (m^3/s)

C_d = orifice discharge coefficient (use 0.60 for orifice diameter D_o < 50 mm, 0.62 for $D_o \geq$ 50 mm)

A_o = area of orifice (m^2)

H_o = effective head on the orifice measured from the centroid of the opening (m)

g = acceleration due to gravity (9.81 m/s^2)

The orifice equation assumes that there is no back pressure from the downstream drainage system (i.e. the outlet is not submerged). To ensure that free discharge is maintained, the outlet needs to be well ventilated and the outlet pipe needs to be large enough to prevent submergence. The outlet pipe from the storage has a just-full capacity of at least twice the PSD.

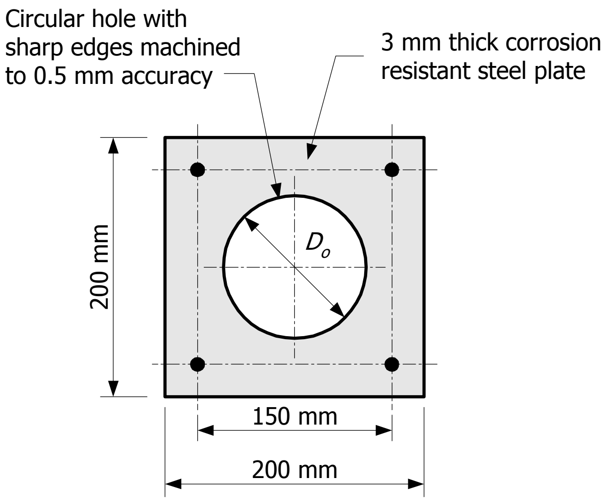


Figure 19.12 Typical Orifice Plate Details (UPRCT,1999)

However, if the outlet is submerged, the orifice equation can still be used. The effective head H_o in Equation 19.3 becomes the difference in elevation between the water surface level in the storage and the HGL in the outlet pipe on the downstream side of the orifice.

The orifice shall be cut into a plate and then securely fixed over the outlet pipe by at least four bolts or similar (one at each corner) such that it can be readily removed for maintenance or replacement. The orifice plate shall be a minimum 200 mm by 200 mm flat stainless steel plate, 3 mm thick (refer to Figure 19.12). The orifice must be tooled to the exact dimensions as calculated, with the edges smooth and sharp (not rounded), to ensure that the completed facility will operate as designed.

The minimum orifice diameter shall be 25 mm to minimise the potential for blockage.

It is sometimes necessary to estimate the time it takes to drain a known stored volume through an orifice. The following equation may be used to check that the storage does not take too long to empty after the storm ends:

$$t = -\frac{1}{C_d\, A_o \sqrt{2g}} \int_{H_1}^{H_2} \left(\frac{A_s}{\sqrt{y}} \right) dy \qquad (19.4)$$

where,

- t = time to empty (seconds)
- y = depth of water in the storage (m)
- A_s = storage water surface area at depth y (m^2)
- $H_{1,2}$ = effective heads on the orifice measured from the centroid of the opening (m)

Where the water surface area is constant (i.e. vertical walls), Equation 19.4 reduces to:

$$t = \frac{2\, A_s}{C_d\, A_o \sqrt{2g}} \cdot \left(\sqrt{y_1} - \sqrt{y_2} \right) \qquad (19.5)$$

19.8.3 Flow Restricting Pipe

The main advantage of using a flow restricting pipe as a storage outlet is that it is difficult to modify the hydraulic capacity of the pipe, unlike an orifice which can be easily removed. As illustrated in Figure 19.13, the net flow restricting effect of the pipe is mostly a function of the pipe length and pipe roughness characteristics.

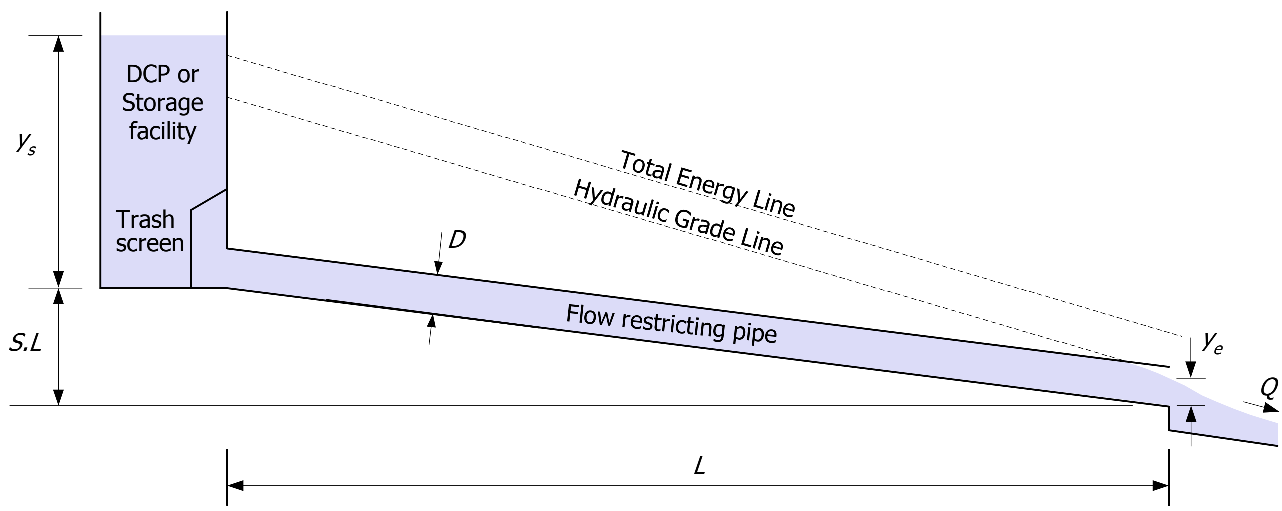


Figure 19.13 Flow Regulation with an Outlet Pipe (Stahre and Urbonas, 1990)

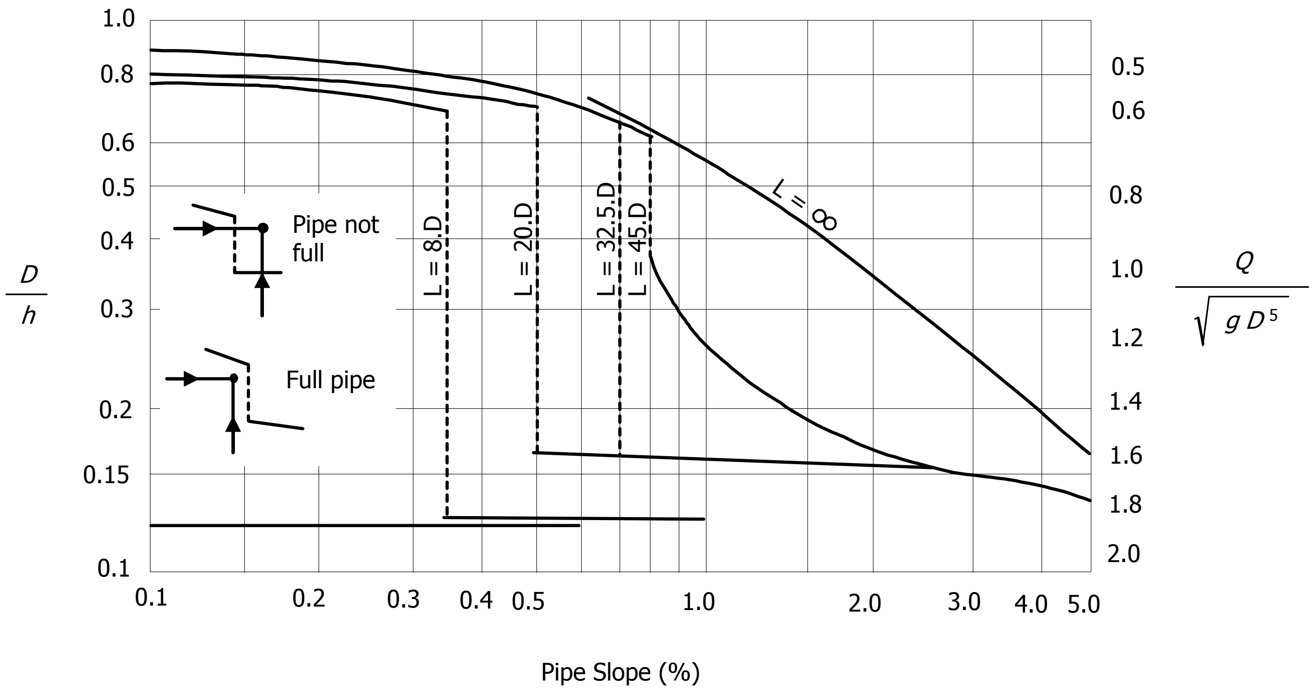


Figure 19.14 Length Upstream of Outlet Needed to Assure Full Pipe Flow (After Li and Patterson, 1956)

Another advantage is that the required flow reduction may be achieved using a larger diameter opening than an orifice, which considerably reduces the possibility of blockage of the outlet. The pipe must be set at a slope less than the hydraulic friction slope, but steep enough to maintain a minimum velocity of 1.0 m/s in the pipe in order to keep any silt carried by the water from settling out within the pipe.

If the pipe is assumed to be flowing full, the outlet capacity can be calculated from Equation 19.6 which is based on the continuity equation. This equation is applicable to all outlet conditions, i.e. free outfall as well as submergence.

$$Q = A \cdot \sqrt{2g \cdot \frac{y_s + S.L - y_e}{K_L}} \quad (19.6)$$

where,

Q = pipe capacity (m^3/s)

A = cross-sectional area of the pipe (m^2)

g = acceleration due to gravity (9.81 m/s^2)

y_s = water depth at the upstream invert of the pipe (m)

y_e = water depth at the downstream invert of the pipe (m)

S = pipe longitudinal slope (m/m)

L = pipe length (m)

K_L = sum of loss factors for the pipe system

Figure 19.14, developed by Li and Patterson (1956), can be used to determine if the pipe is, in fact, entirely full. Although this figure is based on model tests using plastic pipe, it should provide a reasonable basis for checking the flow condition in other pipe types.

The sum of the loss factors will depend on the characteristics of the outlet. For example, it may contain:

$$K_L = K_t + K_e + K_f + K_b + K_o \quad (19.7)$$

where,

K_t = trash screen loss factor

K_e = entrance loss factor

K_f = friction loss factor

K_b = bend loss factor

K_o = outlet loss factor

Trash Screen Loss Factor: According to Creager and Justin (1950), the average loss factor of a trash screen can be approximated using the following equation:

$$K_t = 1.45 - 0.45\left(\frac{A_n}{A_g}\right) - \left(\frac{A_n}{A_g}\right)^2 \quad (19.8)$$

where,

A_n = net open area between the screen bars (m^2)

A_g = gross area of the screen and supports (m^2)

When estimating the maximum potential losses at the screen, assume that 50% of the screen area is blocked. However, the maximum outlet capacity should be calculated assuming no blockage. Minimum and maximum outlet capacities should be calculated to ensure that the installation will function adequately under both possible operating scenarios.

Entrance Loss Factor : Assuming orifice conditions at the pipe entrance, the pipe entrance loss factor may be expressed as:

$$K_e = \frac{1}{C_d^2} - 1 \quad (19.9)$$

where, C_d = orifice discharge coefficient

Friction Loss Factor : The pipe friction loss factor for a pipe flowing full is expressed as:

$$K_f = f\frac{L}{D} \quad (19.10)$$

where,

f = Darcy-Weisbach friction loss coefficient

D = pipe diameter (m)

The Darcy-Weisbach friction loss co efficient, under certain simplifying assumptions, can be expressed as a function of Manning's n, namely:

$$f = 125\frac{n^2}{D^{1/3}} \quad (19.11)$$

Bend Loss Factor : Bend losses in a closed conduit are a function of bend radius, pipe diameter, and the deflection angle at the bend. For 90° bends having a radius at least twice the pipe diameter, a value of K_{90} = 0.2 may be adopted. For bends having other than 90°, the bend loss factor can be calculated using the following equation:

$$K_b = F_b \cdot K_{90} \quad (19.12)$$

where,

F_b = adjustment factor provided in Table 19.3

K_{90} = loss factor for 90° bend

Outlet Loss Factor : Virtually no recovery of velocity head occurs where the pipe outlet freely discharges into the atmosphere or is submerged under water. Therefore, unless a specially shaped flared outlet is provided, assume that K_o = 1.0. If the pipe outlet is submerged, assume K_o = 0.5.

Table 19.3 Adjustment Factors for other than 90° Bends

Angle of Bend (in degrees)	Adjustment Factor F_b
0	0.00
20	0.37
40	0.63
60	0.82
80	0.90
90	1.00

After US Bureau of Reclamation, 1973

19.8.4 Proprietary Products

The following products are used in some overseas countries as alternative flow regulating devices to orifices and flow restricting pipes. These may not be readily available in Malaysia and may need to be imported.

(i) Hydrobrake

In the 1960s, a flow regulator called the 'hydrobrake' was developed in Denmark. This is a self-regulating device that is suited to both above-ground and below-ground storage systems. The rate of discharge through the hydrobrake is, in part, a function of the pressure head upstream of the device. The hydrobrake consists of an eccentric cylinder housing with an inlet opening located on the side. As depicted in Figure 19.15, the flow enters the hydrobrake tangentially to the outlet pipe. An outlet pipe is installed normal to the housing cylinder. This pipe is inserted into the outlet structure using a standard 0-ring to seal the annular space between the structure and the outlet pipe. Normally, no additional anchoring is needed to hold this device in place.

The discharge characteristics of a standard Hydrobrake are indicated in Figure 19.16.

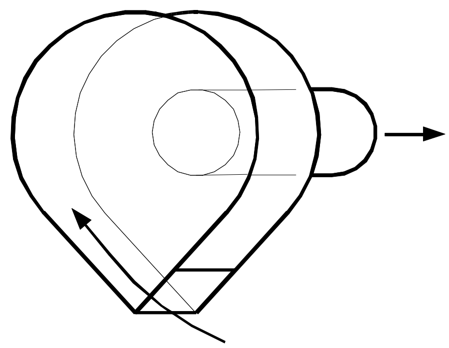


Figure 19.15 Illustration of a Hydrobrake (After Hydro-Brake Systems Inc., Portland, Maine)

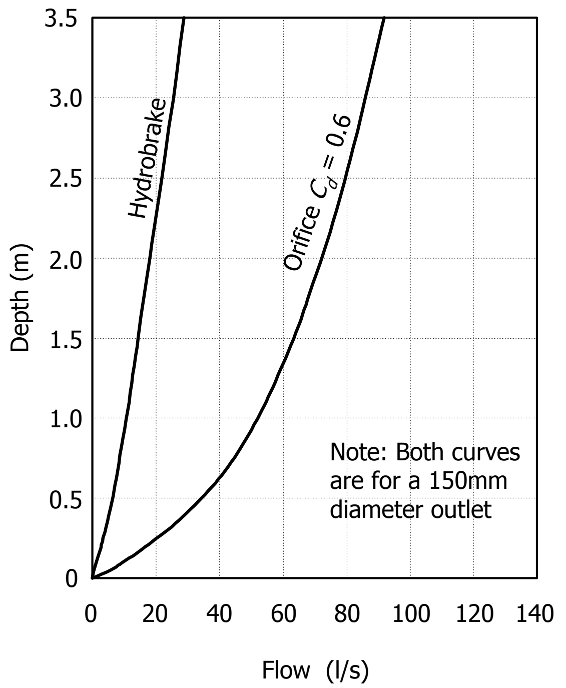


Figure 19.16 Discharge Characteristics of a Standard Hydrobrake and an Orifice with the Same Opening (After Hydro-Brake Systems Inc., Portland, Maine)

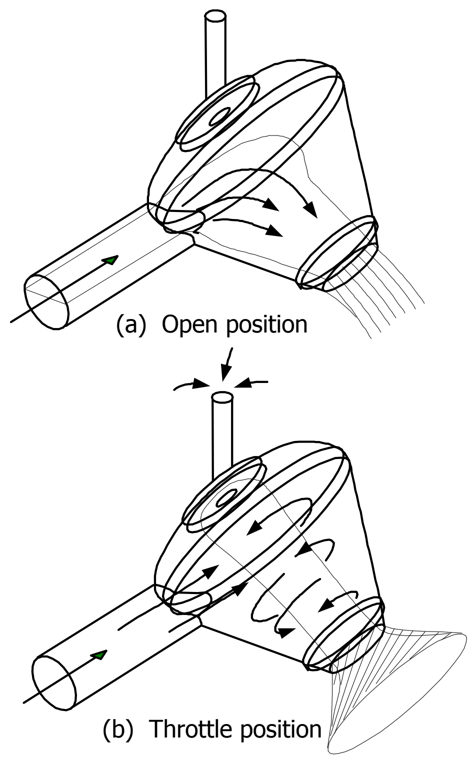


Figure 19.17 Illustration of the Wirbeldrossel (After Brombach, Umwelt and Fluidtechnik)

(ii) Wirbeldrossel

The 'wirbeldrossel' (vortex throttle) was developed at the University of Stuttgart in West Germany in the mid 1970s and has many similarities to the hydrobrake.

The wirbeldrossel has a symmetrical cylinder housing with an inlet pipe connecting tangentially to the cylinder. The outlet is a circular opening in the bottom surface of the cylinder. The opening of the outlet can be adjusted using manufactured rings of various sizes. On the opposite side from the outlet is an air supply pipe (see Figure 19.17).

The device may be installed with the outlet at any desired angle (normally horizontal), and should be located to enable easy access for inspection and maintenance. The discharge characteristics of a standard Wirbeldrossel are indicated in Figure 19.18.

(iii) Phillips Multi-cell

The Phillips Multi-cell was developed at the Swinburne Institute of Technology in Australia in the early 1990s. The Multi-cell is a compact rectangular precast concrete unit divided into 5 cells by diaphragms. Each diaphragm has a rectangular orifice along the bottom edge.

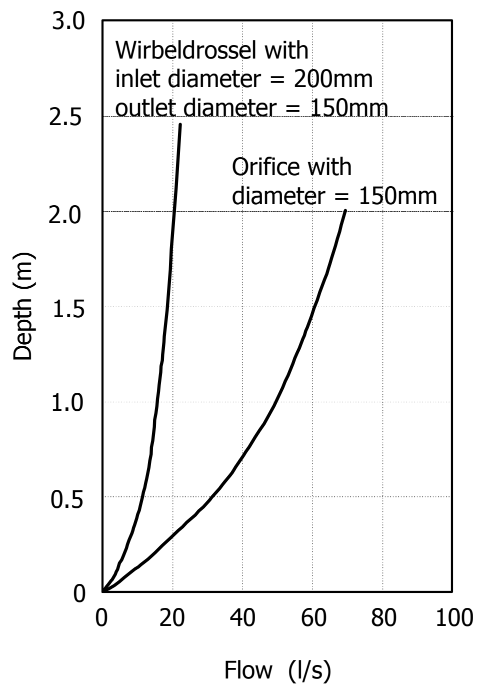


Figure 19.18 Discharge Characteristics of the Wirbeldrossel and an Orifice with the Same Opening (After Quadt and Brombach, 1978)

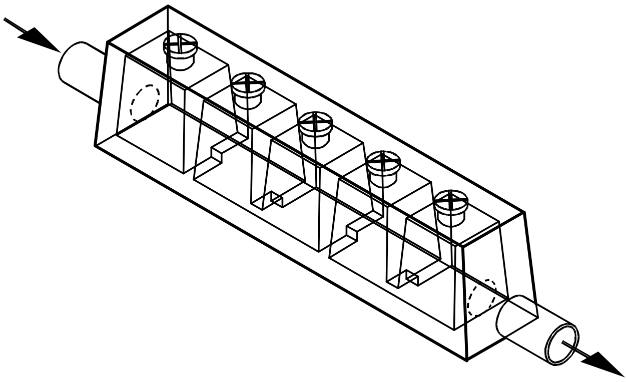


Figure 19.19 Illustration of the Phillips Multi-Cell (Phillips, 1993)

As depicted in Figure 19.19, flow enters the unit and is progressively throttled through each cell until the required amount of flow reduction is achieved at the outlet. The rectangular orifices are staggered to ensure that flows will circulate in each cell and keep debris and sediment suspended. The units have been designed to be blockage free and it is claimed that no regular maintenance is required.

19.8.5 Discharge Control Pit (DCP)

As previously stated, a DCP (see Figure 19.20) is typically used to house a flow regulator for an above-ground storage. All of the previously described flow control devices, except for the Phillips Multi-cell, may be housed within a DCP. The DCP provides a link between the storage and the connection to the municipal stormwater drainage system.

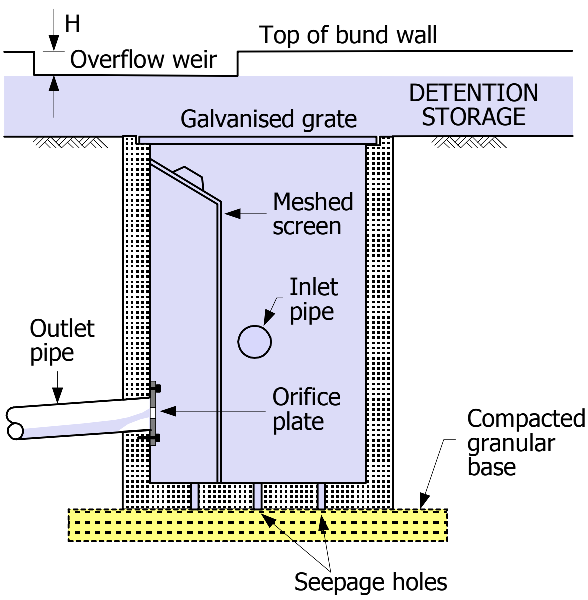


Figure 19.20 Typical DCP (After UPRCT,1999)

To facilitate access and ease of maintenance, the minimum internal dimensions (width and breadth) of a DCP shall be as follows. These dimensions can be increased to allow greater screen sizes or improve access.

- up to 600 mm deep: 600 mm x 600 mm
- greater than 600 mm deep: 900 mm x 900 mm

The following minimum dimensions will achieve predictable hydraulic characteristics:

- minimum design head = 2 D_o (from centre of orifice to top of overflow)
- minimum screen clearance = 1.5 D_o (from orifice to upstream face of screen)
- minimum floor clearance = 1.5 D_o (from centreline of orifice to bottom of pit)

Note : D_o is the diameter of the orifice

19.8.6 Trash Screens

All primary outlets must be protected by an internal screen. The screen is required to:

- protect the outlet from blockage
- create static conditions around an outlet which helps to achieve predictable discharge coefficients
- retain litter and debris which would otherwise degrade downstream waterways

(i) Screen Type

A small aperture-expanded steel mesh, such as Maximesh Rh3030, is recommended for primary outlets less than 150 mm in diameter. This type of screen retains relatively fine material (e.g. cigarette butts and grass clippings) while maintaining the performance of the orifice under heavy debris loading.

For primary outlets larger than 150 mm, the screen area necessary for a fine mesh screen can make it difficult to fit to an outlet, particularly in a DCP. A grid mesh, such as Weldlok F40/203, may be used for these larger outlets. If the grid mesh is used in areas likely to collect litter or debris, a fine mesh screen should be installed upstream of the outlet.

(ii) Screen Area

The minimum recommended area (including blocked area) for an internal screen is:

- 50 times the primary outlet cross-sectional area where a fine mesh screen is used (e.g. Maximesh Rh3030)
- 20 times the cross-sectional area where a grid mesh is used (e.g. Weldlok F40/203).

(iii) Screen Orientation

In a DCP, the inlet pipe should direct inflows parallel (or at a small angle) to the screen. Perpendicular inflows drive debris into a mesh screen making it difficult to dislodge. When inflows are directed parallel to the screen, the debris is layered on the screen but is blown off when the inflow exceeds approximately two to three times the PSD. This arrangement is illustrated in Figure 19.21. The performance of the outlet and screen is influenced by the orientation of the screen.

To assist in shedding debris, the screen should be positioned as close to vertical as possible. This allows debris to fall off once the water level in the storage or DCP drops. In DCPs up to 600 mm deep where debris build-up can be easily seen, the screen should be placed no less than 45° to the horizontal. In deeper DCPs, the angle of the screen should be increased to a minimum of 60°.

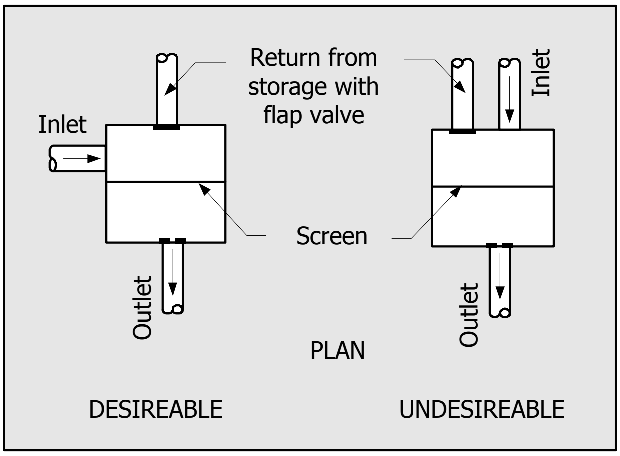


Figure 19.21 Screen Orientation in a DCP (UPRCT,1999)

(iv) General Considerations

To prevent blockages, Maximesh screens must be positioned so that the long axis of the oval shaped holes are horizontal, with the protruding lip angled upwards and facing downstream. Blockages can occur if the screen is accidentally place upside down. Fitting a handle to the screen not only reduces the chance of incorrect placement, but also makes removal for cleaning easier.

After being cut to size, Maximesh screens should be 'hot dipped' galvanised to prevent corrosion.

All mesh screens deflect under high inflows and heavy debris loading and should be braced to stop debris being carried around the screen.

19.8.7 Drowned Outlets

Even when care has been taken to ensure that the outlet pipe from a storage is large enough, the assumption of free discharge may not be valid if the outlet is drowned by the downstream drainage system.

An OSD system is designed to control flows in all storms up to and including the storage design storm ARI, while the downstream drainage system is often only able to cater for smaller storms (typically 2 year to 5 year ARI) without surcharging. The effects of this surcharging on the storage outlet are shown in Figure 19.22.

Figure 19.22(a) shows a drainage system where the storage outlet is above the downstream water level. The outlet will discharge freely, even in a severe storm event. This outlet arrangement gives the designer the most certain form of discharge control.

Figure 19.22(b) shows a system where, due to site drainage constraints, it is not possible to locate the storage outlet above the surcharged water level downstream and the outlet is submerged. In this case, it will be necessary to assess whether the submergence is significant.

When the outlet is submerged, the effective head becomes less and the discharge from the storage is reduced, causing the storage to fill more quickly. OSD storages are designed to fill in longer storm events than will generally cause the street drainage system to surcharge. Therefore the additional storage in these shorter events may not cause the OSD system to overflow. However, if overflow will occur which will cause unacceptable inconvenience or damage to property, the storage volume should be increased (using the reduced discharge as the PSD) to compensate for the effects of the outlet submergence.

Figure 19.22(c) shows a storage located below the downstream water level. The outlet from the storage is highly dependent on the water level in the downstream drainage system and the discharge is likely to vary over a wide range of storm events. In the more severe events, there is a possibility that flows from the street drainage system will enter the OSD storage. Consideration should be given to raising the storage and outlet or using a tailwater discharge compensator. The purpose of a compensator is to allow drainage from a storage to a receiving stream or pipe with an invert below the storage invert and a potential water surface level between the storage invert and water surface level. The device should not be used in the case of trivial outlet submergence. However on projects with more difficult downstream drainage conditions, it may be worth considering. Alternatively, the storage volume may be adjusted (using the reduced discharge as the PSD) to compensate for the effects of outlet submergence.

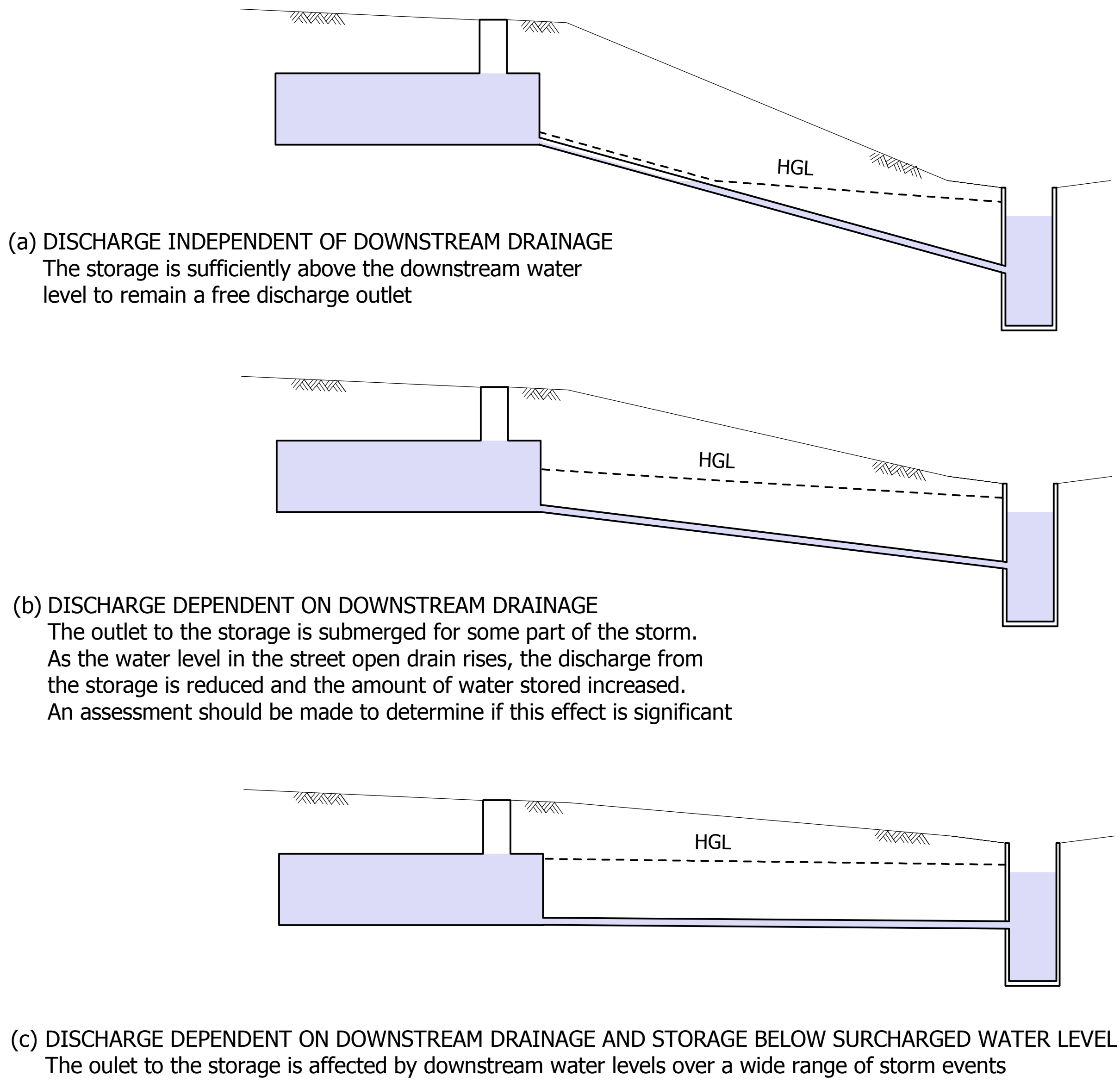


Figure 19.22 Effects of Downstream Drainage on a Storage Outlet (After UPRCT, 1999)

19.9 SECONDARY OUTLETS

A suitable overflow arrangement must be provided to cater for rarer storms than the OSD facilities were designed for, or in the event of a blockage anywhere in the site drainage system.

The most commonly used arrangement for an above-ground storage is a broad-crested weir which, with most storages, can be designed to pass the entire overflow discharge with only a few centimetres depth of water over the weir. This is particularly desirable for car park storages to minimise the potential for water damage to parked vehicles. Refer to Chapter 20 for details on the hydraulic design of weirs.

The overflow weir must be constructed from durable, non-erodible materials to ensure the discharge capacity of the overflow is maintained and not changed over time. The most commonly used materials are concrete, pavers or brickwork.

For a below-ground storage, it is common for the access chamber or manhole to be designed as the overflow system. If this is not practicable, an overflow pipe may be provided at the top of the storage to discharge to a safe point downstream.

It is essential that the access opening or overflow pipe has sufficient capacity to pass the storage design storm flow. An access point must be sized for the dimensions required to pass this flow or the dimensions required for ease of access, whichever is larger. A grating is normally placed on the access chamber to allow the storage to overflow. The grating can also serve as a ventilation point to reduce the likelihood of odours in the storage.

As far as possible, all overflows shall be directed away from buildings and adjacent properties. Overflows should be directed to a flow path through the site and conveyed to a suitable point downstream where they can be combined with any uncontrolled discharge from the site.

If the site drainage system becomes blocked, any resulting overflow from an OSD storage should cause flooding in a noticeable location so that the malfunction is likely to be investigated and remedied.

Some typical examples of secondary outlets for above and below-ground storages are illustrated in Figure 19.23.

19.10 OPERATION AND MAINTENANCE

19.10.1 General

OSD systems are intended to regulate flows over the entire life of the development. This cannot be achieved without some regular periodical maintenance to ensure OSD facilities are kept in good working order and operate as designed. The designer's task is to minimise the frequency of maintenance and make the job as simple as possible. The following considerations will assist in this regard, however, they will not always be feasible due to site constraints:

- locate access points to below-ground storages away from heavily trafficked areas and use light duty covers that can be easily lifted by one person. Manholes in the entrance driveway to a large development can discourage property owners from regularly inspecting and maintaining the system

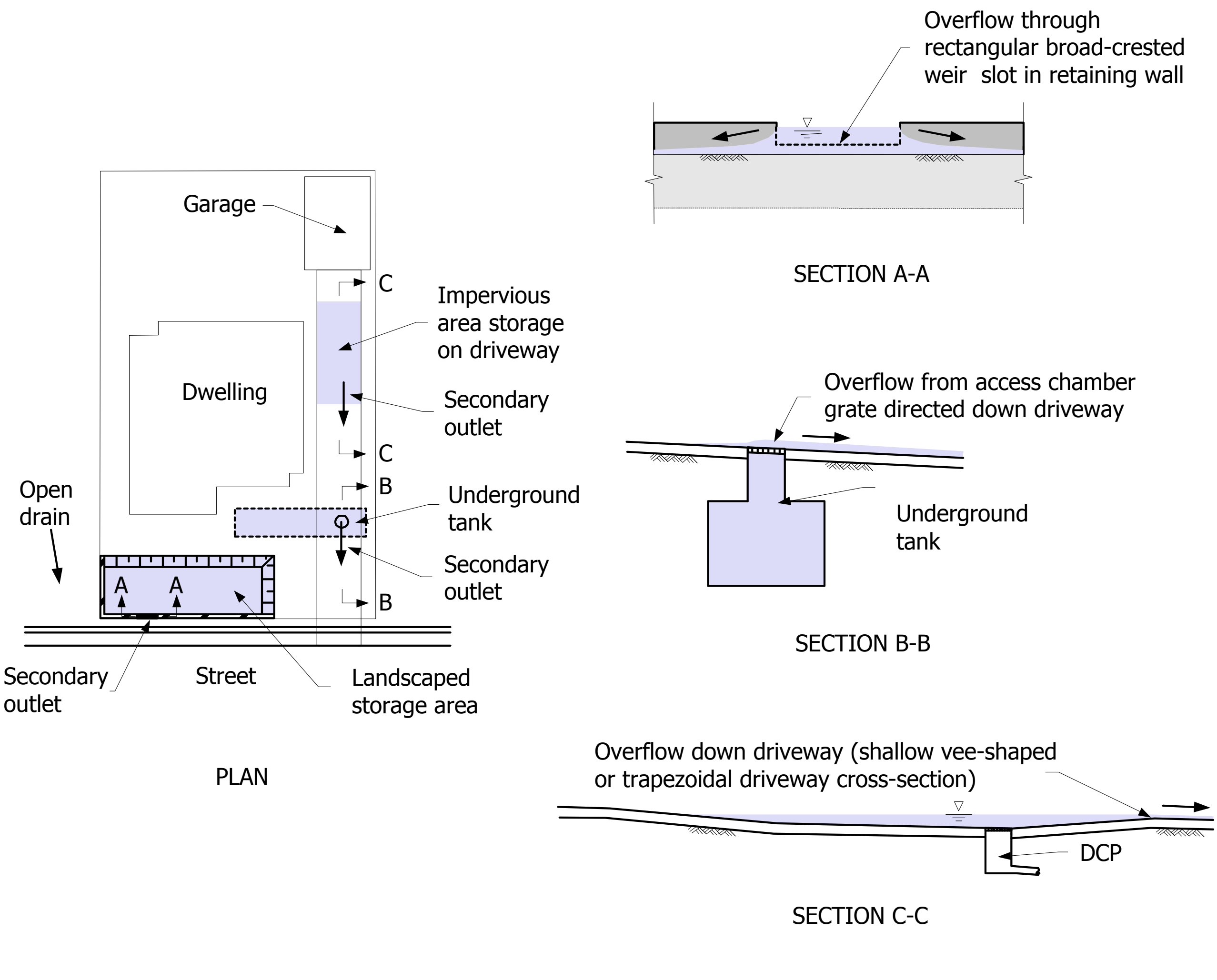


Figure 19.23 Examples of Secondary Outlets

- locate the DCP for an above-ground storage in an accessible location. A slight regrading of an above-ground storage floor will often allow a DCP to be moved from a private courtyard into a common open space area. Common areas are more readily accessible for inspection and maintenance
- all DCPs and manholes throughout the site should be fitted with a standard lifting/keying system. This should assist future property owners to replace missing keys
- use circular lids for access openings in pits and manholes wherever possible as they are often easier to remove and will not drop into the storage when being removed or replaced
- use a guide channel inside a storage or DCP to fix the screen in place and put a handle on the screen to assist removal. The guide channel prevents debris from being forced between the wall of the pit and the screen and allows the screen to be easily removed and replaced in the correct position

For safety, all maintenance access to storages must conform to any statutory requirements for working in confined spaces.

Step irons or access ladders shall be installed where the depth of a below-ground storage or DCP is 1200 mm or greater.

All inlet pits and manholes shall be fitted with removable covers and/or grates to permit maintenance, having regard to the need to prevent the covers or grates being removed by children. Grates should have openings that restrict the entry of debris likely to cause blockages.

To minimise the risk of debris blocking grates or outlets, inlet pits should be located on driveways, walkways, or other impervious areas wherever possible.

For below-ground storages, it is advisable to make provisions for fresh water to wash down the walls of the storage and flush out accumulated sediment and other deposits.

The optimal solution will generally be a system where the property owner, bodycorporate, or responsible authority is able to carry out routine maintenance. Where the property owner or occupier cannot maintain the structure, this must be clearly identified in the maintenance schedule.

19.10.2 Maintenance Schedule

A maintenance schedule should be prepared and included in the detailed design submission. The schedule is a set of operating instructions for future property owners and/or occupiers. It should be clearly and simply set out and include the following type of information.

Who should do the maintenance?

The majority of small OSD systems, particularly those where a large proportion of the storage is located above-ground, will be able to be maintained by property owners, residents, or handymen. Larger below-ground systems, particularly those with limited access and/or substantial depth, may require the owner to engage commercial cleaning companies with specialised equipment.

What must be done?

The type of routine maintenance necessary to keep OSD facilities in good working order must be clearly and simply specified. Some of the issues that need to be addressed are:

- where the storages are located
- which parts of the system need to be accessed for cleaning and how access is obtained
- a description of any equipment needed (such as key and lifting devices) and where they can be obtained
- the location of screens and how they can be removed for cleaning

How often should it be done?

The owner should be provided with advice on how frequently the system needs to be inspected and approximately how often it will require cleaning. The frequencies of both inspections and maintenance will be highly dependant on the nature of the development, location of the storage, and the occurrence of major storms. Suggested frequencies are provided in Table 19.4.

When inspecting OSD facilities, if any of following items are noticed, cleaning and/or repair should be undertaken:

- clogged outlet and obstructed inlets
- excessive deposits
- corrosion of metal parts
- deterioration of concrete
- any other damage or visible problems

Table 19.4 Suggested Frequencies for Inspection and Maintenance

Residential lots	• inspect system every 3 months and after heavy rainfall • clean system as required, generally at least every 6 months
Commercial and Industrial lots	• inspect system every 2 months and after heavy rainfall • clean system as required, generally at least every 4 months

19.11 DESIGN PROCEDURES

General procedures for both the preliminary and detailed design of OSD storage systems are provided in Figures 19.24 and 19.25 respectively.

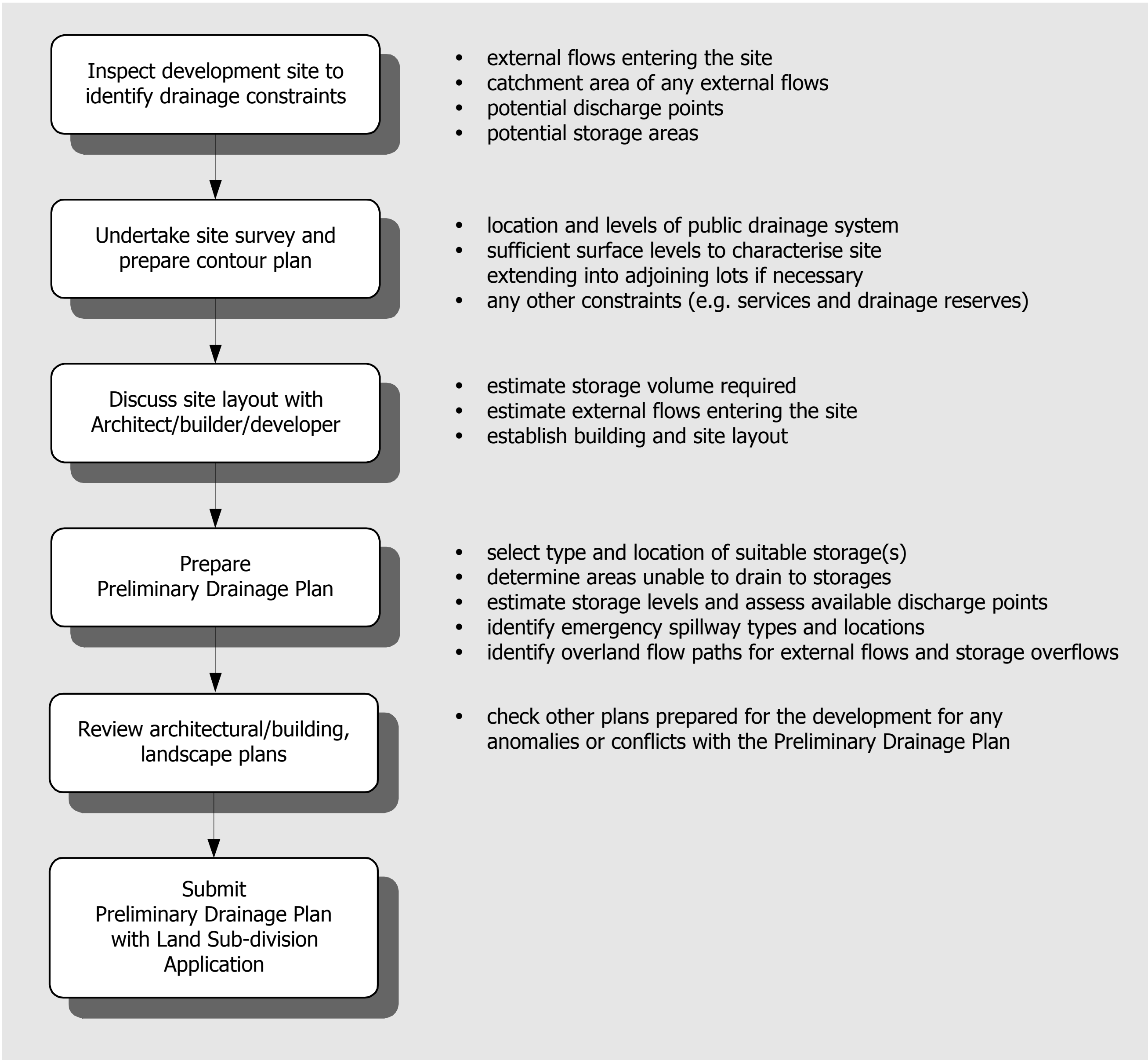


Figure 19.24 Preliminary Design Procedure for OSD Storage Systems

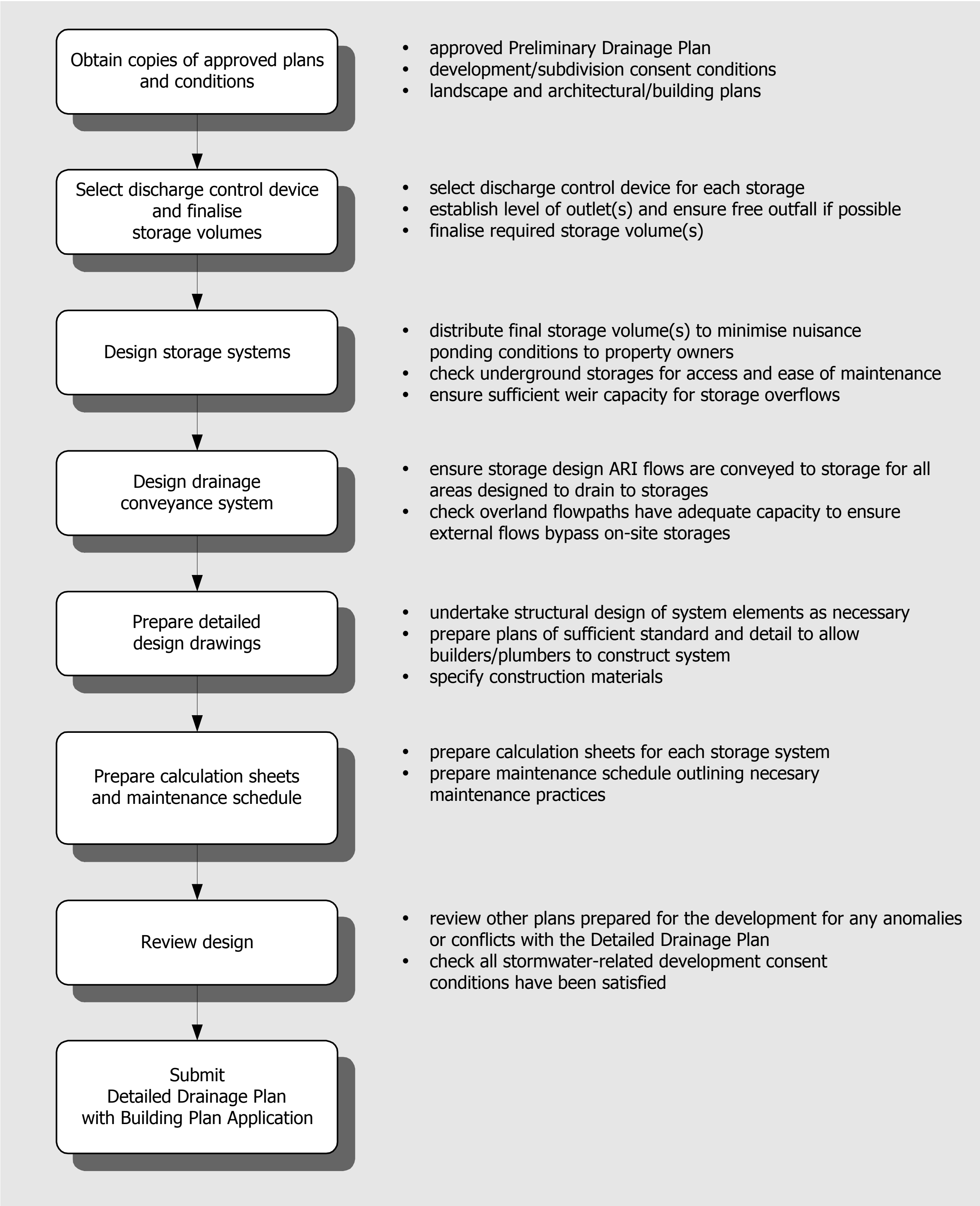


Figure 19.25 Detailed Design Procedure for OSD Storage Systems

APPENDIX 19.A WORKED EXAMPLE

19.A.1 Designing an Above-Ground Storage System

Problem: Determine the size of an above-ground storage for the proposed residential development in Kuala Lumpur shown in Figure 19.A1. The area of the site is 600 m^2.

Solution:

Step (1) Determine Storage Volume Required (refer Section 19.4.2)

1. Select storage type to be used within the site.

   As shown in Figure 19.A1, an above-ground OSD storage is to be provided in the lawn area at the front of the site. The storage will be excavated into the lawn and a brick retaining wall constructed along the front and side boundary of the site to maximise the storage volume within the space available. The primary outlet will be an orifice housed in a DCP which will discharge to the open drain in the street. The secondary outlet (emergency overflow) will be via a broad-crested weir slot in the retaining wall.

2. Determine the area of the site that will be directed to the OSD storage system.

   The house and garage, part of the concrete driveway, and the backyard will be drained to the DCP in the OSD storage via a pipe drainage system. A swale drain is to be provided along the edge of the concrete driveway to prevent runoff from the adjacent lot draining to the OSD storage.

   Of the total site area of 600 m^2, 547 m^2 will drain to the OSD storage.

3. Determine the amount of impervious and pervious areas draining to the OSD storagesystem.

   Impervious area:

Dwelling	=	115.7 m^2
Garage	=	30.2 m^2
Driveway	=	40.6 m^2
Surface paving and paths	=	49.5 m^2
TOTAL	=	236 m^2

   Pervious area:

Lawns and Gardens	=	311 m^2

   The site condition before development was park lawn.

4. Determine times of concentration, t_c and t_{cs}.

   To determine the catchment times of concentration, an analysis of the catchment drainage system will need to be undertaken. For this example, it is assumed that:

   t_{cs} = 20 minutes
   t_c = 30 minutes

5. Calculate the pre and post-development flows for the area draining to the OSD storage.

   The minor drainage system that the OSD storage will discharge into has been designed for a 2 year ARI capacity. The rainfall intensity is estimated using Equation 13.2 ($t_c \geq$ 30 minutes) and Table 13.A1 for t_c:

   $$\ln({}^{2}I_{30}) = 4.775 + 0.598\ \ln(30) + (-0.231)(\ln(30))^2 + 0.012\ (\ln(30))^3 \ = \ 4.601$$

   $${}^{2}I_{30} = 100 \text{ mm/hr}$$

Using the Rational Method, the pre and post-development flows are calculated as follows:

Development Status	I (mm/hr)	Impervious Area		Pervious Area		ΣCA	Q (l/s)
		C	A (m^2)	C	A (m^2)		
Pre-development	100	-	-	0.43	547	235.2	6.5 (Q_p)
Post-development	100	0.9	236	0.43	311	346.1	9.6 (Q_a)

6. Determine the required PSD.

Using Equation 19.1 with Equations 19.1a and 19.1b for above-ground storage:

$$a = \left(4 \text{ x } \frac{9.6}{30}\right)\left(0.333 \text{ x } 30 \text{ x } \frac{6.5}{9.6} + 0.75 \text{ x } 30 + 0.25 \text{ x } 20\right) = 43.86$$

$$b = 4 \text{ x } 6.5 \text{ x } 9.6 = 249.60$$

$$PSD = \frac{43.86 - \sqrt{43.86^2 - 4 \, x \, 249.60}}{2} = 6.7 \text{ l/s}$$

7. Determine the required SSR.

Using Equation 19.2 with Equations 19.2a and 19.2b for above-ground storage, the site discharge for the storage design storm (10 year ARI) and the corresponding SSR is calculated for a range of storm durations to determine the maximum SSR. These calculations are summarised in the following two tables.

NOTE: There are two different methods for estimating the rainfall intensity depending on whether the storm duration t_d is less than or greater than 30 minutes (refer to Section 13.2 for details).

t_d (mins)	I (mm/hr)	Impervious Area		Pervious Area		ΣCA	Q_d (l/s)
		C	A (m^2)	C	A (m^2)		
5	347	0.9	236	0.75	311	445.7	43.0
10	252	0.9	236	0.70	311	430.1	30.1
15	199	0.9	236	0.63	311	408.3	22.6
20	165	0.9	236	0.58	311	392.8	18.0
30	126	0.9	236	0.49	311	364.8	12.8
35	114	0.9	236	0.46	311	355.5	11.3

t_d (mins)	Q_d (l/s)	PSD (l/s)	c	d	SSR (m^3)
5	43.0	6.7	5.46	0.22	11.2
10	30.1	6.7	5.28	0.32	14.7
15	**22.6**	**6.7**	**5.08**	**0.43**	**15.4**
20	18.0	6.7	4.87	0.54	15.1
30	12.8	6.7	4.46	0.76	13.6
35	11.3	6.7	4.28	0.86	13.0

From the previous table, a maximum SSR of 15.4 m^3 occurs at a duration of 15 minutes. However, for a landscaped storage, an additional 20% is added to the volume to account for inaccuracies in construction and future loss of storage due to the build-up of the lawn surface. Therefore:

Required SSR = 15.4 x 1.2 = 18.5 m^3

Step (2) Size Primary Outlet

The primary outlet orifice is sized to discharge the PSD assuming free outlet conditions when the storage is full. Using a 600 mm deep DCP and a maximum storage depth of 300 mm, adopt a maximum head to the centreline of the orifice of 0.8 m. The required orifice size under free outlet conditions is calculated by rearranging Equation 19.3:

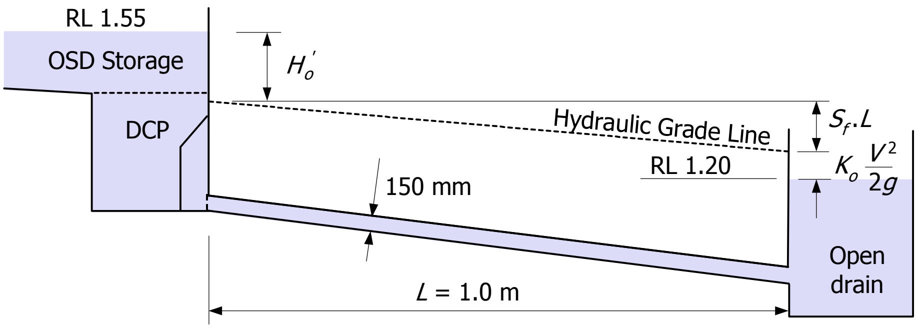
$$A_o = \frac{PSD}{C_d \sqrt{2g\,H_o}} = \frac{6.7 \times 10^{-3}}{0.62\sqrt{2 \times 9.81 \times 0.8}} = 0.0027 \text{ m}^2$$

$$D_o = \sqrt{\frac{4A_o}{\pi}} = \sqrt{\frac{4 \times 0.0043}{\pi}} = 0.0589 \text{ m} = 58.9 \text{ mm} \qquad \text{(say, 59 mm)}$$

However, a flow analysis of the open drain indicates that the orifice will become submerged during a 10 year ARI event when the storage is full (see Section A-A in Figure 19.A1). As the orifice has been sized for free outlet conditions, the submergence will reduce the discharge and the storage will overflow in the storage design storm. If this is undesirable, the storage volume should be increased to compensate for the reduced discharge.

Step (3) Increase Storage Volume (if required)

If the storage capacity needs to be increased to compensate for outlet submergence, the reduced head on the orifice needs to be estimated to calculate the reduced outflow. The reduced head will be the difference between the maximum water level in the storage and the HGL elevation at the upstream end of the outlet pipe. This HGL elevation is estimated by adding the outlet head loss and the friction head loss in the pipe to the flow elevation in the open drain at the time the storage becomes full.



It is estimated that the open drain will be running full when the storage is full. Given that the storage and open drain water levels are 1.55 m and 1.2 m respectively measured from the base of the open drain, the reduced head on the orifice is:

$$H_o' = 1.55 - 1.20 - K_o.\frac{V^2}{2g} - S_f.L$$

Adopting a 1.0 m long 150 mm UPVC outflow pipe and an outlet loss factor K_o = 0.5, the reduced outflow Q can be estimated from Equation 19.3 by trial and error. Trial and error calculations are summarised in the following table (pipe velocity $V = Q/A$ and pipe friction slope S_f is obtained from Figure 25.B1).

Trial Q (l/s)	Pipe V (m/s)	$K_o \frac{V^2}{2g}$ (m x 10^{-3})	$S_f.L$ (m x 10^{-3})	H_o' (m)	Estimated Q (l/s)
3.0	0.170	0.73	2.60	0.347	4.27
4.3	0.243	1.51	4.70	0.344	4.25

Reduced outflow Q is estimated to be 4.3 l/s.

Repeat 7 in step (1) to obtain the revised SSR:

t_d (mins)	Q_d (l/s)	*PSD* (l/s)	*c*	*d*	*SSR* (m^3)
5	43.0	4.3	3.59	0.09	11.8
10	30.1	4.3	3.52	0.13	15.9
15	22.6	4.3	3.43	0.18	17.1
20	**18.0**	**4.3**	**3.35**	**0.22**	**17.3**
30	12.8	4.3	3.18	0.31	16.8
35	11.3	4.3	3.11	0.35	16.5

The revised SSR is 17.3 x 1.2 = 20.8 m^3.

Step (4) Determine Storage Dimensions

The maximum allowable depth for a landscaped storage area is 600 mm. However, to reduce the height of the brick retaining wall, a maximum storage depth of 300 mm has been adopted.

The minimum recommended floor slope is 2% graded toward the DCP. Assuming the average depth in the storage is 260 mm, the adopted dimensions of the revised storage volume are:

16.0 m (length) x 5.0 m (width) x 0.26 m (average depth) = 20.8 m^3 (OK)

If overflow due to outlet submergence is acceptable and an increase in storage volume is not required, the adopted dimensions of the initial storage volume estimate would be:

15.8 m (length) x 4.5 m (width) x 0.26 m (average depth) = 18.5 m^3 (OK)

Step (5) Size Secondary Outlet

The secondary outlet is a broad-crested weir slotted into the retaining wall along the front boundary. The weir should be sized for the estimated major system ARI flow from the site for time t_{cs} (20 minutes). The major drainage system in the catchment has been designed for 50 year ARI.

The 20 minute, 50 year ARI rainfall intensity for Kuala Lumpur is estimated using Equation 13.3:

$$^{50}P_{20} = 77.4 - 0.47 \text{ x } (99.4 - 77.4) = 67.1 \text{ mm}$$

$$^{50}I_{20} = \frac{^{50}P_{20}}{d} = \frac{67.1}{\left(\frac{20}{60}\right)} = 201 \text{ mm/hr}$$

Using the Rational Method, the major system flow is calculated as follows:

I (mm/hr)	Impervious Area		Pervious Area		ΣCA	*Q* (l/s)
	C	*A* (m^2)	*C*	*A* (m^2)		
201	0.9	236	0.63	311	408.3	21.9

Assuming the head over the weir is limited to 50 mm and C_{BCW} = 1.70, rearranging Equation 20.5 gives:

$$B = \frac{Q_d}{C_{BCW}\ H^{1.5}} = \frac{21.9 \text{ x } 10^{-3}}{1.70 \text{ x } 0.05^{1.5}} = 1.15 \text{ m}$$

Allowing 50 mm freeboard, the dimensions of the secondary outlet weir are:

1150 mm (wide) x 100 mm (high)

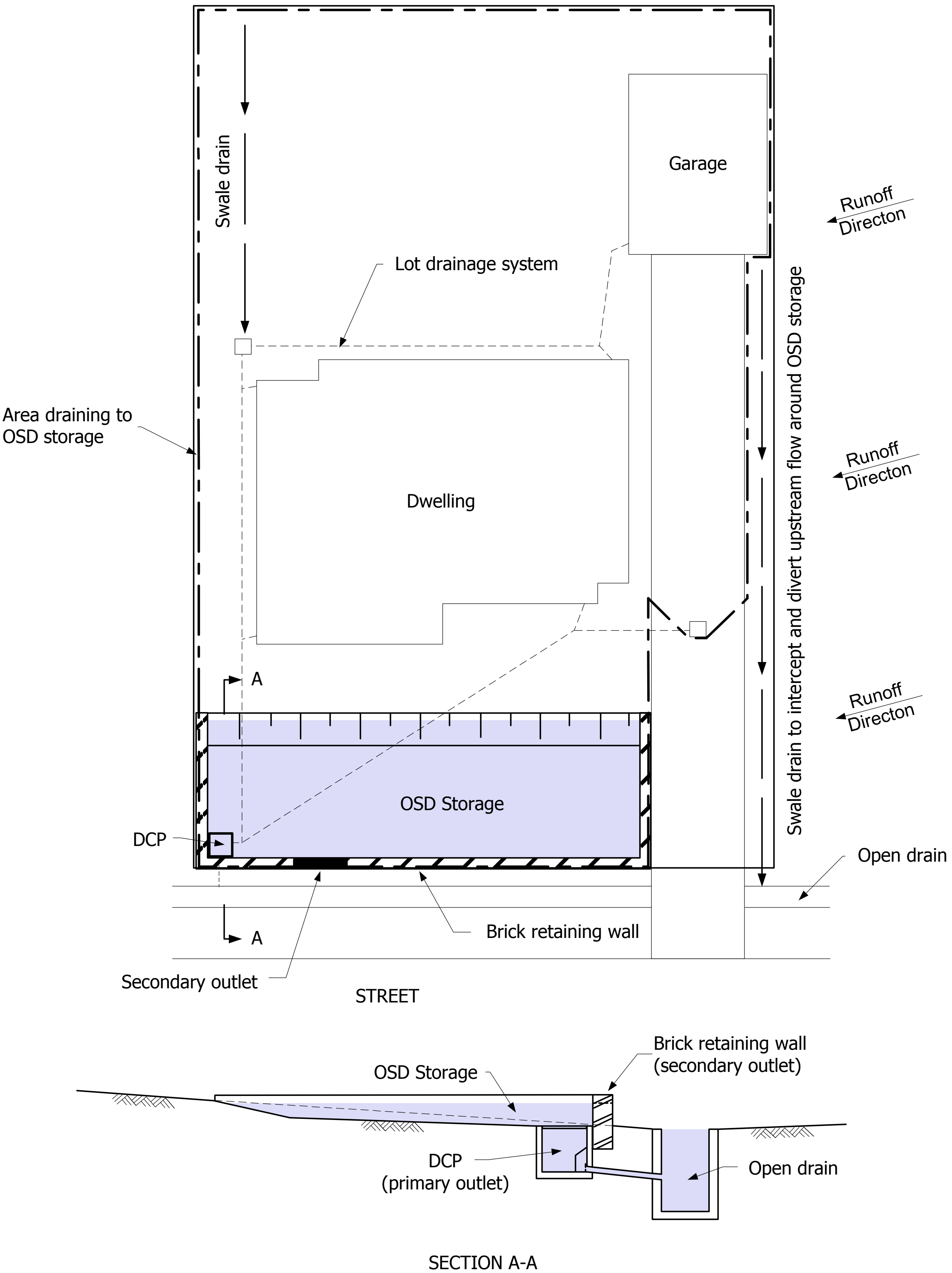


Figure 19.A1 Example 19.A.1 Above-Ground Storage System

19.A.2 Designing a Composite Above and Below-Ground Storage System

Problem: Determine the size of a composite above and below-ground storage for the proposed office redevelopment in Kuala Lumpur shown in Figure 19.A1. The area of the site is 1828 m^2.

Solution:

Step (1) Determine Storage Volume Required (refer Section 19.4.2)

1. Select storage type to be used within the site.

   As shown in Figure 19.A2, a composite above and below-ground storage is to be provided at the rear of the site. Above-ground storage will be provided on the car park surface and below-ground storage in a pipe package underneath. The primary outlet will be a UPVC flow restricting pipe from the pipe package outlet chamber which will discharge to the municipal pipe system. Overflows will pass over the car park kerbing along the rear boundary of the site (secondary outlet) and flow through the adjoining lot to the next street. Care must be taken to ensure that overflows will not cause any damage to the adjacent property or inconvenience to the owners.

2. Determine the area of the site that will be directed to the OSD storage system.

   The whole area of the site will drain to the OSD storage.

3. Determine the amount of impervious and pervious areas draining to the OSD storage system.

   Impervious area:

Office building	=	580.0 m^2
Car parking and access	=	780.3 m^2
Surface paving and paths	=	467.7 m^2
TOTAL	=	1828.0 m^2

   There is no pervious area draining to the storage.

   The site before development was a temporary car park surfaced with gravel and grass (impervious area of 1120 m^2 and pervious area of 708 m^2).

4. Determine times of concentration, t_c and t_{cs}.

   To determine the catchment times of concentration, an analysis of the catchment drainage system will need to be undertaken. For this example, it is assumed that:

   t_{cs} = 15 minutes
   t_c = 60 minutes

5. Calculate the pre and post-development flows for the area of the site draining to the OSD storage.

   The minor drainage system that the OSD storage will discharge to has been designed for a 5 year ARI capacity. The rainfall intensity is estimated using Equation 13.2 ($t_c \geq 30$ minutes) and Table 13.A1 for t_c:

   $$\ln({}^5I_{60}) = 5.029 + 0.564\ln(60) + (-0.231)(\ln(60))^2 + 0.012\,(\ln(60))^3 = 4.289$$

   $${}^5I_{60} = 73 \text{ mm/hr}$$

   Using the Rational Method, the pre and post-development flows are calculated as follows:

Development Status	Impervious Area		Pervious Area		ΣCA	I (mm/hr)	Q (l/s)
	C	A (m^2)	C	A (m^2)			
Pre-development	0.9	1120.0	0.43	708.0	1312.4	73.0	26.6 (Q_p)
Post-development	0.9	1828.0	-	-	1645.2	73.0	33.4 (Q_a)

6. Determine the required PSD.

For a composite storage system in a car park, the above and below-ground storage components recommended in Table 19.1 are each 50% of the total required storage volume. The form of Equation 19.2 relating to the largest storage component should be used for calculating PSD (this also applies to selecting the equations for calculating SSR) As the storage volumes are equal in this case, either form could be used.

Using Equation 19.1 with Equations 19.1a and 19.1b for above-ground storage:

$$a = \left(4 \text{ x } \frac{33.4}{60}\right)\left(0.333 \text{ x } 60 \text{ x } \frac{26.6}{33.4} + 0.75 \text{ x } 60 + 0.25 \text{ x } 15\right) = 143.98$$

$$b = 4 \text{ x } 33.4 \text{ x } 26.6 = 3553.76$$

$$PSD = \frac{143.98 - \sqrt{143.98^2 - 4 \, x \, 3553.76}}{2} = 31.6 \text{ l/s}$$

7. Determine the required SSR.

The site discharge for the 10 year ARI and the corresponding SSR (using the above-ground form of Equation 19.2) is calculated for a range of storm durations to determine the maximum SSR for the total storage. These calculations are summarised in the following two tables.

NOTE: There are two different methods for estimating the rainfall intensity depending on whether the storm duration is less than or greater than 30 minutes (refer to Section 13.2 for details).

t_d (mins)	I (mm/hr)	Impervious Area		Pervious Area		ΣCA	Q_d (l/s)
		C	A (m^2)	C	A (m^2)		
5	347	0.9	1828	-	-	1645.2	158.6
10	252	0.9	1828	-	-	1645.2	115.2
15	199	0.9	1828	-	-	1645.2	90.9
20	165	0.9	1828	-	-	1645.2	75.4
30	126	0.9	1828	-	-	1645.2	57.6
35	114	0.9	1828	-	-	1645.2	52.1
40	105	0.9	1828	-	-	1645.2	48.0

t_d (mins)	Q_d (l/s)	PSD (l/s)	c	d	SSR (m^3)
5	158.6	31.6	25.14	1.35	39.6
10	115.2	31.6	24.19	1.86	53.5
15	90.9	31.6	23.26	2.36	58.8
20	**75.4**	**31.6**	**22.35**	**2.84**	**60.4**
30	57.6	31.6	20.70	3.72	59.7
35	52.1	31.6	19.96	4.11	58.9
40	48.0	31.6	19.31	4.46	58.2

From the previous table, the maximum SSR occurs for a duration of 20 minutes. The required volume for the total storage is 60.4 m^3 and the required composite storage volumes are:

Pipe package = 30.2 m^3
Car park surface = 30.2 m^3

Step (2) Size Primary Outlet

The primary outlet flow restricting pipe is to be sized to discharge 31.6 l/s when the car park storage is full. The required pipe diameter is found by rearranging Equation 19.6 and using trial and error:

$$A_p = \frac{PSD}{\sqrt{2g \cdot \frac{y_s + S.L - y_e}{K_L}}} \quad \text{and} \quad D_p = \sqrt{\frac{4A_p}{\pi}} \quad \text{where} \quad K_L = K_t + K_e + K_f + K_o$$

Using the downstream end of the outlet pipe as the height datum, Y_s = 2.4 m and Y_e = 0.6 m

The outlet pipe slope S = 10% and length L = 7.0 m

For the trash rack, $\frac{A_n}{A_g}$ = 0.75

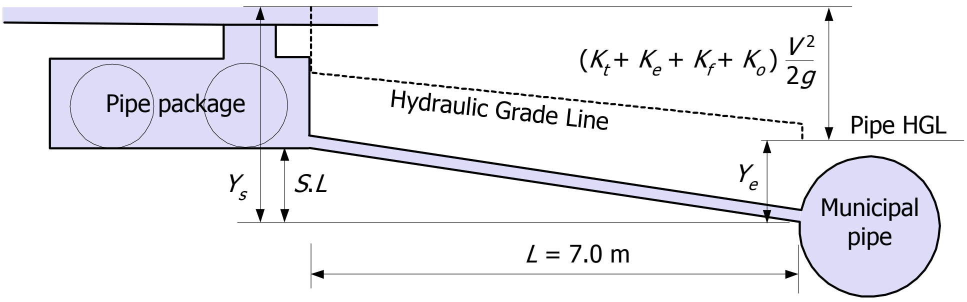
From equation 19.8, trash loss factor, $K_t = 1.45 - 0.45\,(0.75) - (0.75)^2$ = 0.55

From equation 19.9, entrance loss factor, $K_e = \frac{1}{0.6^2} - 1$ = 2.78

From equations 19.10 & 19.11, friction loss factor, $K_f = 125 \times \frac{0.009^2}{D^{1/3}} \times \frac{7.0}{D} = 0.071\, D^{-4/3}$

Adopt outlet loss factor, K_o = 0.5

$$K_L = 0.55 + 2.78 + 0.071\, D^{-4/3} + 0.5 \quad = \quad 3.83 + 0.071\, D^{-4/3}$$



Adopting an initial trial diameter of 150 mm, the trial and error calculations are summarised in the following table.

Trial D (mm)	K_L	Area A_p (m^2)	Estimated D (mm)
150.0	4.721	0.0098	111.7
120.0	5.030	0.0101	113.5
114.0	5.114	0.0102	114.0

A pipe diameter of 115 mm is adopted. This will give an outflow of 32.2 l/s which is acceptable (less than 5% greater than the PSD).

Step (3) Determine Storage Dimensions

(a) Pipe package

Adopting 2 x 900 mm diameter pipes, the volume of the inlet and outlet chambers is:

$$2 \text{ x } 1.2 \text{ (height) x } 2.7 \text{ (width) x } 1.0 \text{ (breadth)} = 6.5 \text{ m}^3$$

The total length of pipe required is found by dividing the residual volume by the pipe cross-sectional area:

$$\text{Length} = \frac{30.2 - 6.5}{2 \text{ x} \left(\dfrac{\pi \text{ x } 0.9^2}{4} \right)} = 18.6 \text{ m}$$

(b) Car park

Using a maximum allowable ponding depth in a car park area is 150 mm (Table 19.2) and a minimum surface slope of 0.7%, the storage volume is calculated to cover the area shown in Figure 19.A2.

Step (4) Size Secondary Outlet

The kerbing along the rear boundary of the site is designed to act as a broad-crested weir to discharge overflows through the adjoining property. The weir should be sized for the estimated major system ARI flow from the site for time t_{cs} (15 minutes). The major drainage system in the catchment has been designed for 50 year ARI.

The 15 minute, 50 year ARI rainfall intensity for Kuala Lumpur is estimated using Equation 13.3:

$$^{50}P_{15} = 77.4 - 0.80 \text{ x } (99.4 - 77.4) = 59.8 \text{ mm}$$

$$^{50}I_{15} = \frac{^{50}P_{20}}{d} = \frac{59.8}{\left(\dfrac{15}{60} \right)} = 239 \text{ mm/hr}$$

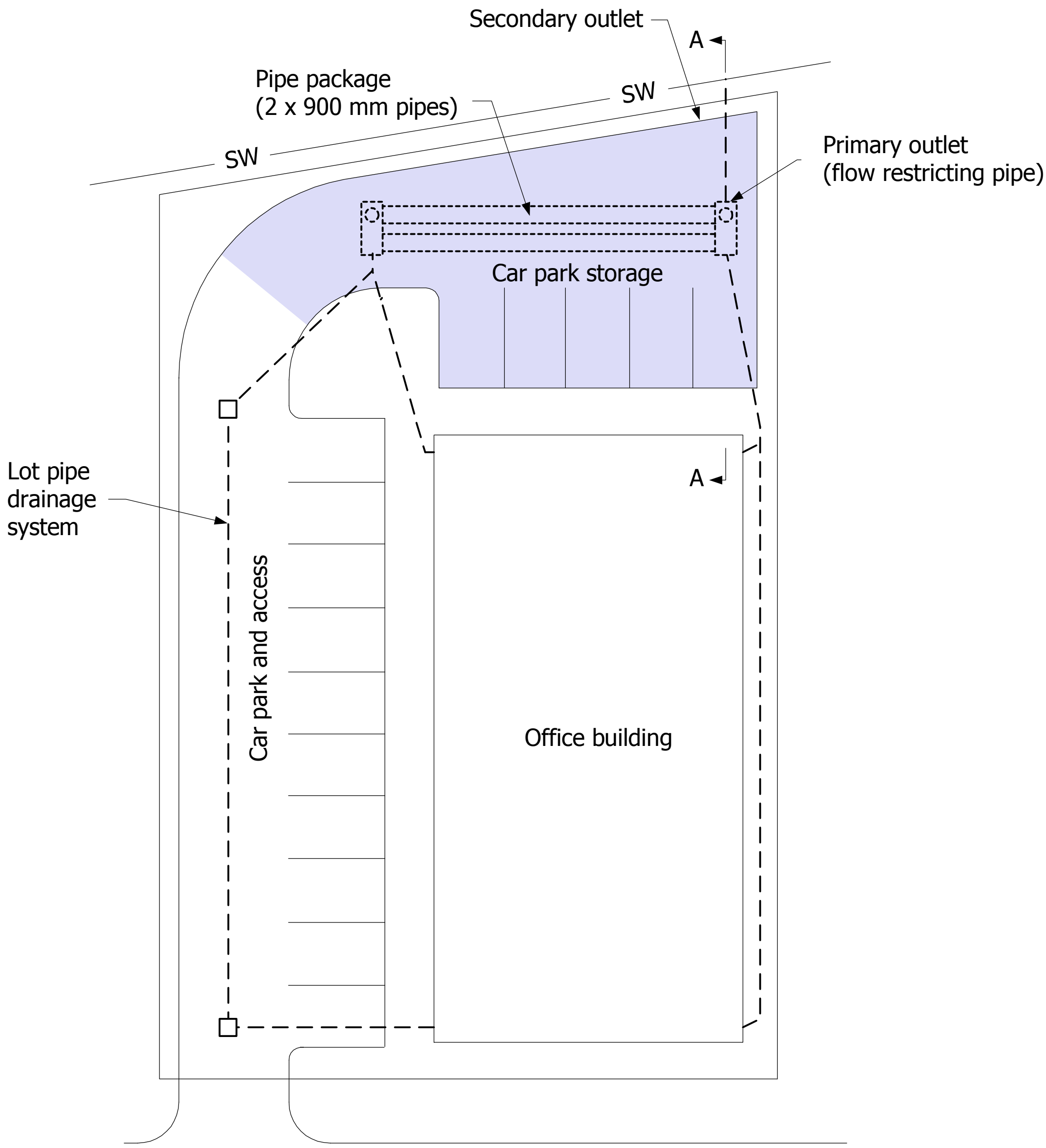
Using the Rational Method, the major system flow is calculated as follows:

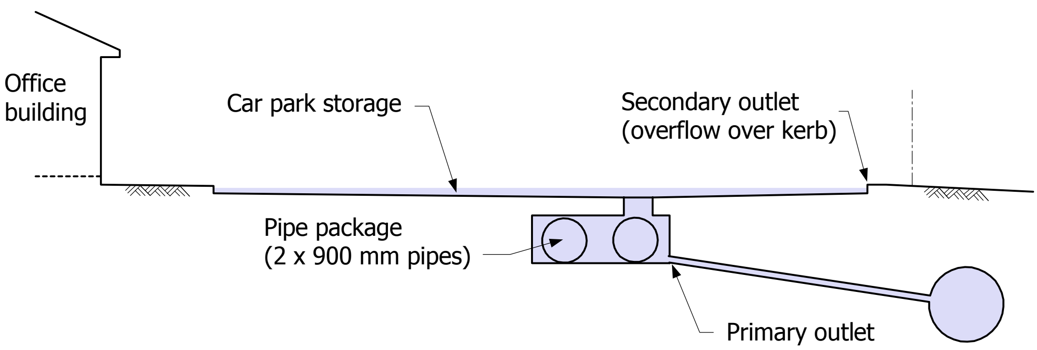
Impervious Area		Pervious Area		ΣCA	I (mm/hr)	Q (l/s)
C	A (m²)	C	A (m²)			
0.9	1828.0	-	-	1645.2	239	109.2

Assuming the head over the kerb is limited to 50 mm and C_{BCW} = 1.70, rearranging Equation 20.5 gives:

$$B = \frac{Q_d}{C_{BCW} \ H^{1.5}} = \frac{109.2 \text{ x } 10^{-3}}{1.70 \text{ x } 0.05^{1.5}} = 5.75 \text{ m}$$

A freeboard of 25 – 50 mm could be included depending on the height of kerbing provided.





SECTION A-A

Figure 19.A2 Example 19.A.2 Composite Storage System