CHAPTER 3 QUALITY DESIGN FUNDAMENTALS

3.1 INTRODUCTION

This chapter provides fundamentals on the non-point source (NPS) pollutants from typical urban areas, estimation of annual pollutant load based on the event mean concentration (EMC) and simplified procedures required for preliminary sizing and designing stormwater quality control facilities or Best Management Practices (BMPs). The recommended approach is to adopt performance standards as set out in Chapter 1. For new development and redevelopment, a minimum overall *reduction in the average annual pollutant load* is specified (Table 1.4) compared with the load under existing condition. The targeted reduction is achievable applying the prescribed BMPs and treatment trains, as presented in the relevant design Chapters.

3.2 POLLUTANT ESTIMATION

3.2.1 Typical Runoff Pollutants

Although many different constituents can be found in urban runoff, the focus is primarily on certain pollutants that can be used as representative indicators of others. The following constituents are recommended as typical pollutants characterising urban runoff in Malaysia:-

- Gross pollutants;
- Total suspended solids (TSS);
- Biochemical oxygen demand (BOD);
- Chemical oxygen demand (COD);
- Total nitrogen (TN);
- Total phosphorus (TP);
- Copper (Cu);
- Lead (Pb);
- Zinc (Zn);
- Oil and grease (O&G); and
- Bacteria (*E. coli*).

However, in the current practice, BMPs are to be designed based on three types of selected pollutants; namely gross pollutants, total suspended solids (TSS), and nutrients (TN and TP). These stormwater pollutants are potentially generated from various landuses as given in Table 3.1.

Table 3.1: Selected Pollutants Generation Potentials (Adapted from Melbourne Water, 2005)

Landuse	Generation Potentials		
	Gross Pollutants	Total Suspended Solids (TSS)	Nutrients (TN & TP)
Roads and Highways	Low	High	Low
Residential	High	High	High
Commercial	High	Medium	Medium
Industrial	Medium	Medium	Low
Parks and Agricultural	Low	Medium	High

3.2.2 Water Quality Volume (WQV)

It is necessary to estimate runoff volumes before any assessment can be made of pollutant loads. Runoff estimation is necessary to size certain BMPs and also to design the outlet structures of the BMPs. Runoff volumes (expressed as rainfall depth multiplied by the catchment area and volumetric runoff coefficient, C_v) should be used to determine the BMPs volumes.

The required water quality volume (WQV) for BMPs can be calculated using Equation 3.1 as follows:

$$\text{WQV} = C_v.(P_d).A \tag{3.1}$$

where,

WQV = Water quality volume (m³);
C_v = Area-weighted volumetric runoff coefficient for the landuse (Table 2.5);
P_d = Rainfall depth for water quality design storm (m); and
A = Contributing drainage area (m²).

The runoff coefficient *C* for Rational Method (Chapter 2) is a function of rainfall intensity, and therefore of event ARI. In general, the value of average volumetric runoff coefficient C_v will be less than that of Rational Method runoff coefficient *C* for events of large ARI (say >2 years), and C_v will be greater than *C* for events of small ARI. However, for the simplicity and without compromising the accuracy, the values of C_v can be considered same as *C* given in Table 2.5, which would provide safe values as the BMPs are designed for small ARIs.

3.2.3 Load Estimate

Ideally, the identification of sustainable pollutant loads in receiving water should be based on the magnitude of overall catchment pollutant exports, and the reduction in pollutant loads required to achieve water quality objectives. Land activities and practices within a catchment contribute to the accumulation of pollutant loads as a result of stormwater wash off. Event mean concentrations (EMC) for different land activities are to be used to estimate pollutant loads.

Load estimation, based on the EMC method, is recommended for most practices. This is the simplest but most widely used method to estimate runoff pollutants from urban areas. However, the reliability of this method depends on the accuracy of the EMC values for the intended parameters and landuses. Recommended mean EMC values for various pollutants and landuses are set out in Table 3.2. They are related to level of housekeeping practices within the selected study areas, namely in Malacca, Damansara and Penang river catchments and Kajang Municipality.

Table 3.2: Mean EMC Values for Selected Landuses

Pollutants		Landuses			
Parameter	Unit	Residential	Commercial	Industrial	Highway
TSS	mg/L	128.00	122.00	166.00	80.00
Turbidity	NTU	122.00	96.00	147.00	69.00
TDS	mg/L	131.00	43.00	137.00	38.00
pH	-	6.46	6.77	6.66	6.57
BOD	mg/L	17.90	22.90	19.30	14.90
COD	mg/L	97.00	134.00	140.00	81.00
AN	mg/L	0.73	0.85	1.00	0.44
TKN	mg/L	2.38	2.53	4.25	1.43
TN	mg/L	4.21	4.84	5.00	2.25
TP	mg/L	0.34	0.32	0.49	0.16
O&G	mg/L	2.00	4.00	NA	3.00
Zn	mg/L	0.19	0.34	0.43	0.21
Pb	µg/L	6.00	22.00	12.00	20.00
Cu	µg/L	28.00	37.00	42.00	28.00
Cr	µg/L	4.00	32.00	31.00	11.00
Ni	µg/L	10.00	17.00	30.00	15.00
Cd	µg/L	6.00	26.00	5.00	10.00

Source: Local stormwater studies conducted by DID in Malacca, Damansara, Penang and Kajang

The load estimated by EMC method is

$$L = R . EMC . A . C_v / 100 \tag{3.2}$$

where,

L = Annual pollutant load (kg/year);
R = Mean annual rainfall-MAR (mm/year);
EMC = Event mean concentration (mg/L);
A = Catchment area (ha); and
C_v = Area-weighted volumetric runoff coefficient for the whole catchment (Table 2.5).

3.3 POLLUTANT CONTROL

Stormwater pollutants can be particulates, dissolved substances and floatables (litters and hydrocarbons). Physicochemical nature of each group of pollutants is different. Therefore, mechanism to remove them from the water is also different, which are briefly discussed below.

3.3.1 Particulate Pollutants

Particulates are the primary pollutants found in stormwater and are removed through sedimentation and filtration. Sedimentation occurs when particles have a greater density than the surrounding liquid. Under laboratory quiescent conditions, it is possible to settle out very small particles; the smallest practical settling size in the field is around 0.01 mm (Metcalf & Eddy, 1979). Sometimes, the smallest particles become electrically charged, which can further interfere with their ability to settle out. The Newton's and Stoke's laws are often used to quantify the sedimentation process. More information on sedimentation theory, including Stokes' and Newton's laws, can be found in other references (Hazen, 1904).

Particulates can also be removed by filtration through use of infiltration facilities. The mechanism is different from sedimentation process, where media is used for example sand, to increase the efficiency of the pollutant filtration process. Excellent removal of suspended solids in field bioretention systems has been reported elsewhere (Li and Davis, 2009).

3.3.2 Dissolved Pollutants

Dissolved pollutants are mainly removed through adsorption, microbial fixation, biochemical degradation and plant uptake (phytoremediation). However, the dominancy of the process mechanism depends on the type of BMPs. Soil or plant-based media is required to remove the dissolved pollutants (Metals, TN, TP, BOD, COD, pesticides, herbicides, etc.).

Two most common BMPs used to remove dissolved pollutant from stormwater are wetlands and bioretention facilities. Wetlands support various types of microphytes and macrophytes that either absorb or adsorb dissolved pollutants from the storm runoff. On the other hand removal of dissolved pollutants by bioretention facility is mainly done by media and plant uptakes. This is because due to the dry nature of the bioretention system, the number of microbial aquatic organism (e.g. algae) will be less, which plays important role in removing micronutrients of low concentrations.

3.3.3 Floatable Pollutants

Floatable pollutants in the storm runoff can be in the form of litters (refuse or trash) or oil and grease (floating hydrocarbon). The litters are floating or submerged particles large enough to be removed by screen, trash rack, nets and other mechanical devices. Opening of the litter trapping devices depend on the size of the particles to be trapped. However, fine screens pose high potential to choke or clog the drainage system. Therefore, captured floatable pollutants should be removed from the gross pollutant trap at the soonest possible time, preferably before the next storm occurs.

The removal of floating oil and grease (hydrocarbon) is based upon the rise rate velocity of oil droplet and rate of runoff. However, with the exception of stormwater from oil refineries there are no data describing the characteristics of petroleum products in urban stormwater that are relevant to design; either oil density and droplet size to calculate rise rate or direct measurement of rise rates. Further, it is known that a significant percentage of the petroleum products are attached to the fine suspended solids and therefore are removed by settling (API, 1990).

3.4 BMPs FACILITIES

This Section provides types, treatment objectives and guidance for the selection of a stormwater treatment system (BMPs). They should be carefully selected based on site-specific conditions and the overall management objectives of the catchment.

The selection process has the following aspects:

- Identification of problems and treatment objectives;
- Familiarisation with capabilities of the alternative treatment devices and treatment mechanisms;
- Familiarisation with constraints on use of various treatment devices; and
- Cost considerations.

The advantages or disadvantages of each BMPs facility, constraints on use and some factors likely to affect cost are summarised.

3.4.1 Types

Only the more universally accepted BMPs types are recommended for present use. They are infiltration facilities, bioretention facilities, swales, gross pollutant traps and water quality pond and wetlands. It is to be expected that more newer and improved BMPs facilities will be developed worldwide and the designer should keep up-to-date with these in the future.

(a) *Infiltration Facilities*

Infiltration devices can take a number of structural forms including pits, trenches, or basins. All of these devices work by storing stormwater flow and promoting infiltration into the soil. They are primarily for removing soluble and fine materials from stormwater.

(b) *Bioretention Facilities*

These devices use a filtering action to remove pollutants, mainly particulate material. Two types of filtration are used: biofiltration, using biological methods, and media filtration through porous media such as sand. Bioretention facilities are good for abstracting nutrients and fine colloidal particles, which are difficult to be retained in sediment basins and water quality ponds.

(c) *Gross Pollutant Traps*

Gross pollutant traps (GPTs) remove floating and submerged gross litter, hydrocarbons and coarse solids. They can be either built in-situ or pre-fabricated. The GPTs mainly help improve the visual quality of the storm runoff. However, these facilities require frequent maintenance for them to be performed to meet the designed efficiency. Choked GPTs in the drains may cause nuisance flooding in the locality.

(d) *Swales*

Swales are vegetated drains that can be used to convey and filter runoff. They take advantage of biological processes to improve pollutant removal from the storm runoff. Biological controls provided by swales are typically cheaper and have better aesthetic than structural controls, but may involve more maintenance and landtake.

(e) Water Quality Pond and Wetlands

Water quality ponds have a beneficial effect on stormwater quality treatment by controlling the volume of runoff and providing treatment by gravity settling, biological stabilisation of soluble pollutants such as nutrients, and adsorption and decomposition of biodegradable pollutants such as BOD and light oils. The function of wetlands is similar to that of ponds, except that areas of active vegetation growth are the main component of wetlands instead of open water. This promotes biological action in preference to sedimentation. In practice, most water quality ponds contain wetlands areas and vice versa so it is convenient to consider the two types together.

3.4.2 Treatment Objectives

The primary objective of the treatment BMPs in this manual (with the exception of oil separators) is to remove total suspended solids and sediment-bound compounds. Removal of TSS will result in the removal of many of the contaminants of concern, including:

- Particulate trace metals;
- Particulate nutrients; and
- Oil and grease on solids.

The overall objective of removing 80% of the TSS load (on a long-term average basis) in a catchment has been adopted in this Manual (refer to Chapter 1). A higher degree of removal would require a large increase in treatment device size and cost. In some retrofitting cases in older developed catchments, it may not be possible to meet the 80% removal objectives due to space limitations. For oil and grease removal, the objective of treating over 90% of the total annual runoff is proposed.

3.4.3 Selection

The permanent facilities such as infiltration basins, swales, GPTs, bioretention facilities, water quality ponds and wetlands are to be provided to take care of the runoff laden pollutants generated from the developed areas. Table 3.3 provides a rating from low to high for each treatment BMPs type against its removal efficiency and other factors such as maintenance and cost. Consideration should be given to the intended catchment area to be treated, as some systems such as wetlands take up considerable amounts of land.

Table 3.3: Selection of BMPs for Various Pollutants (Adapted from Melbourne Water, 2005)

BMPs Type	Pollutant Removal Efficiency			Other factors			
	Gross Pollutants	TSS	Nutrient (TN & TP)	Maintenance	Land Required	Treatable Catchment Area	Cost
Infiltration	Low	High	High	Medium	High	Medium	Low
Bioretention	Low	High	High	Low	Medium	Medium	Medium
Swale	Low	Medium	Medium	Low	Low	Low	Low
GPT	High	Low	No	Medium	Medium	Medium	Medium
Water Quality Pond	Medium	Medium	Medium	Medium	High	High	High
Wetlands	Medium	High	High	High	Medium	High	High

Note: In order to remove the desired contaminants for the application being considered, a composite system incorporating numerous design elements may be required. This is commonly referred to as a 'treatment train'. In this instance, an order of suitability can be obtained by referencing various combinations of design elements and their associated pollutant treatment ability and other factors as listed above. The higher the level, the more suitable that combination of design elements will be.

The definitions of low, medium and high capture or treatment target for each of the BMPs for TSS and nutrients is given in Table 3.4.

Table 3.4: Classification of Treatment Targets for Individual BMPs (Adapted from Melbourne Water, 2005)

Pollutant	Target of Treatment		
	Low	Medium	High
TSS	Less than 40% of particulates greater than 0.125mm retained.	40-70% of particulates greater than 0.125mm retained.	More than 70% of particulates greater than 0.125 mm retained.
Nutrients (TN & TP)	Less than 10% reduction	10-40% reduction	More than 40% reduction

Note: There is insufficient data available to give firm guidance on gross pollutants. The level of treatment chosen has an effect on the area required for the BMPs. However, in all situations, the overall pollutant reduction by any BMPs or treatment train (at least) ***must comply*** with the criteria given in Table 1.4.

Suitability of BMPs also depends on the type and size of the development and its associated landuse. Table 3.5 provides a guide to select the most appropriate BMPs for different development types while Table 3.6 provides commentary on benefits and siting considerations for different BMPs elements.

Table 3.5: Suitability of BMPs for Various Landuses (Adapted from City of Knox, 2002)

Development Types/Landuse	Bioretention	Swale	Wetlands	Water Quality Pond	Infiltration	GPT
New Roads and Highways						
- On slopes less than 4%	High	High	High	High	High	High
- On slopes greater than 4%	Medium	Medium	Medium	Medium	Medium	Medium
Old Roads and Highways						
- On slopes less than 4%	High	Medium	High	High	Medium	High
- On slopes greater than 4%	Medium	Low	High	Medium	Low	High
New Residential/Commercial/ Industrial Development	High	High	High	High	High	High
Old Residential/Commercial/ Industrial Development	Medium	Low	Low	Medium	High	High

3.5 PRELIMINARY SIZING OF BMPs

Removal curves are presented in this Section for the preliminary estimate of BMPs sizes. They are for swale, water quality pond and wetlands application only. The simplified procedure is used for the purpose of planning submission to a regulatory local authority for initial assessment. The "planning application process" usually entails an applicant submitting to a local regulatory authority the prepared plans and associated documentation that outline the intent and extent of the proposed development. Detailed design is not undertaken at this stage, as the authority is likely to provide recommendations or conditions during the initial assessment. Local regulatory authority can, therefore, also use the preliminary design outcomes to assess submissions based on the methodology proposed in this section.

This process is by no means intended to replace the more rigorous processes outlined in the design Chapters of the Manual, and as such should not be used to determine final treatment sizing or efficiency. Designers should

Table 3.6: Treatment Application Guide (Landcom, 2004)

BMPs	Potential Benefits	Suitable Site Condition	Unsuitable Conditions
GPT	Reduces litter and debris Can reduce sediments Pre-treatment for other measures	Conventional drainage systems	Sites Larger than 100 ha Natural channels
Infiltration	Reduce runoff Pollutant removal Passive irrigation	Sandy to sandy-clay soils (k more than 36mm/hr) Flat terrain (less than 2%) Deep groundwater table	Silty clay to clay soils Steep terrain Shallow groundwater table Highly polluted runoff
Swales	Medium and fine particulate removal Passive irrigation	Mild slopes (less than 4%)	Steep slopes (more than 4%)
Bioretention	Fine and soluble pollutants removal Small ARI Frequent flood retardation	Flat terrain	Steep terrain High groundwater table
Water Quality Pond	Storage for reuse Fine sediment removal Flood retardation Community and wildlife asset	Steep terrain with confined valleys	Proximity to airports, landfill High groundwater table
Wetlands	Community asset Medium to fine particulates and some soluble pollutant removal Wildlife habitat	Flat terrain	Steep terrain High groundwater table Acid sulphate soils

recognise that local factors may strongly influence the results from the process and take these into account in their final decision in sizing the BMPs.

The preliminary BMPs sizing procedure is given below:

Step 1: Identify the main non-point source (NPS) pollutants that would be generated by the proposed development (Table 3.3).

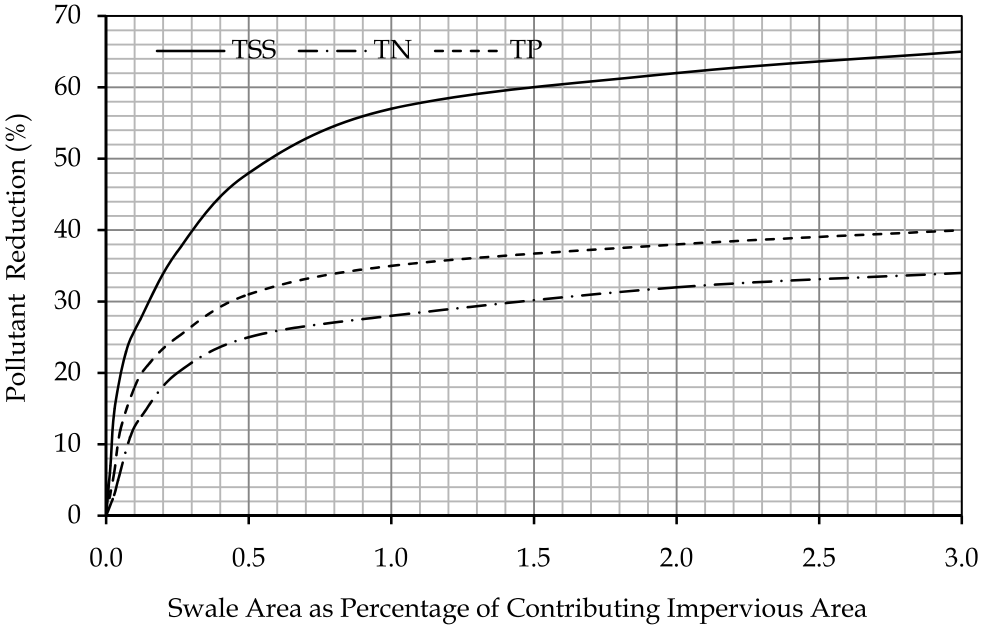
Step 2: Choose the BMPs best suited to the target the NPS pollutants (Step 1) and landuse (Table 3.5).

Step 3: Choose the level of treatment and reduction target required for the BMPs (Table 1.4).

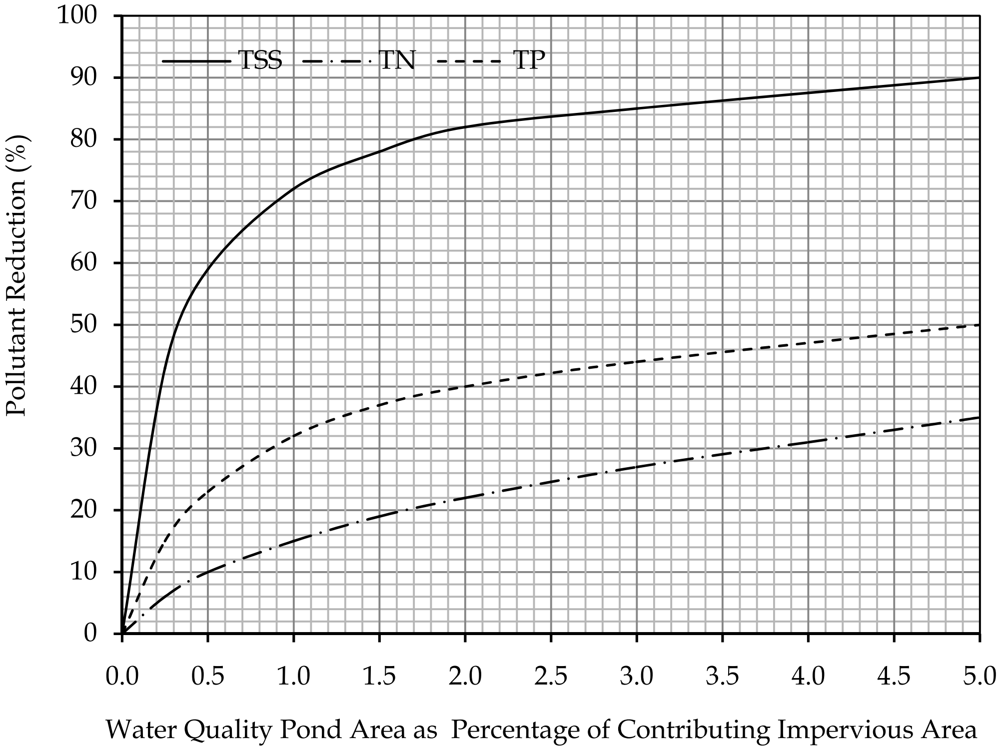
Step 4: Work out the BMPs area required by reading the target pollutant reduction value from the Y-axis of the relevant chart. Then move horizontally right and meet the curve of the target pollutant. Then move vertically down and read the BMPs/Catchment Impervious Area ratio in percentage (%) from the appropriate chart in Figure 3.1. Estimate the BMPs area by multiplying the BMPs/Catchment Impervious Area ratio by the estimated impervious area (in ha) of the catchment and dividing by 100. If the impervious area is not available, a relevant runoff coefficient (Table 2.6) appropriate for the target landuse can be used instead of the imperviousness (%).

Step 5: Choose the appropriate layout plans and guideline drawing(s) and for the proposed BMPs.

Step 6: Collate the results and submit the information to the local regulatory authority for initial approval.

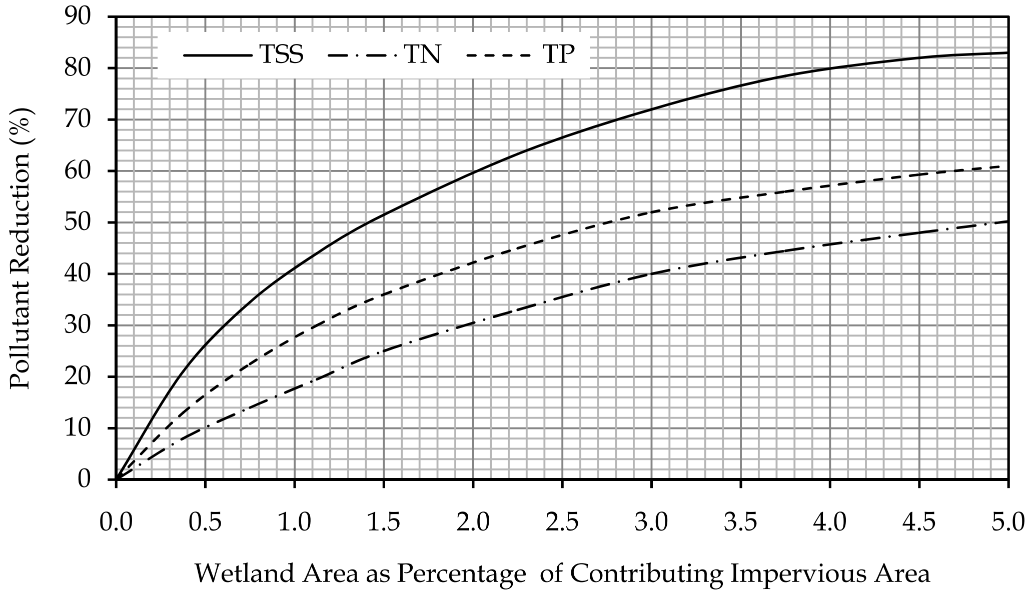


a) Swale



b) Water Quality Pond

Figure 3.1: Pollutant Reduction Curves (Adapted from Melbourne Water, 2005 and Darwin Harbour, 2009)



c) Wetlands

Figure 3.1: Pollutant Reduction Curves (Adapted from Melbourne Water, 2005 and Darwin Harbour, 2009)

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APPENDIX 3.A EXAMPLE - POLLUTION LOAD FROM MULTIPLE LANDUSES

Problem:

Determine the annual pollution loading (in tonnes/yr) generated from a 753.28 ha mixed development area located in upstream of Sg. Buloh catchment shown in Figure 3.A1. The mean annual rainfall for the catchment is 2850 mm.

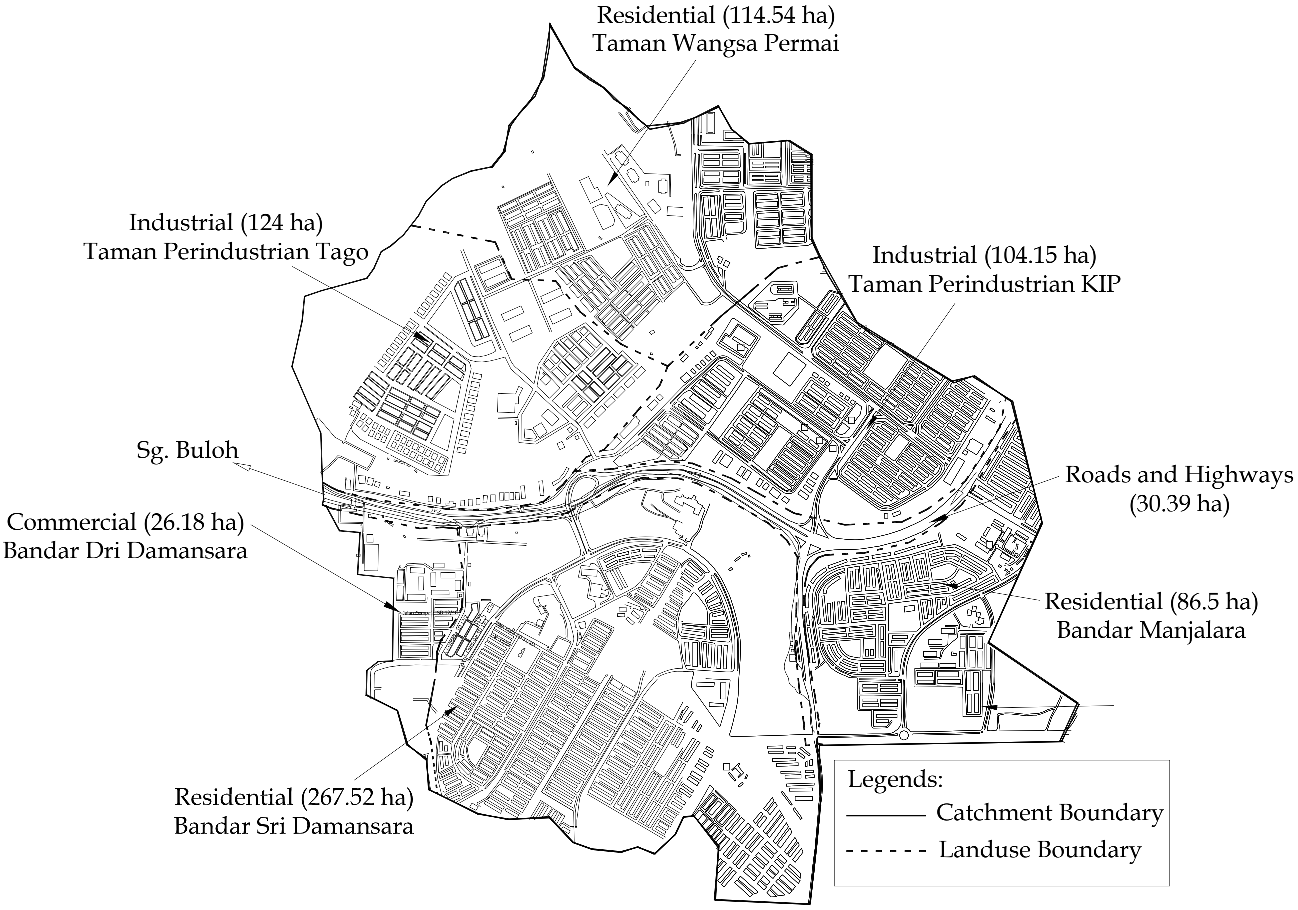


Figure 3.A1: Catchment Area for the Calculation of Pollution Load

Solution:

Reference	Calculation	Output
Table 2.5 Equation 2.4	Step 1: Get the mean annual rainfall (MAR) data for the catchment (in this case, 2850 mm) and multiply with the corresponding runoff coefficient to calculate the annual runoff from each landuse.	Table 3.A1
Table 3.2 Equation 3.2	Step 2: Pick the EMC values for each pollutant corresponding to the landuse and use Equation 3.2 to calculate the pollutant loading. The results are summarised in Table 3.A1.	Table 3.A1

Reference	Calculation	Output
	Step 3: Calculate the total annual pollution load for TSS, TP and TN in tonne per year.	
	They are summed as follows: TSS = TSS from Residential + Industry + Commercial + Road and Highway	
	= 1299.07 + 971.44 + 81.93 + 65.84 =	2418.28 tonne/year
	Similarly TP = 3.45 + 2.87 + 0.22 + 0.13 =	6.67 tonne/year
	TN = 42.73 + 29.26 + 3.25 + 1.85 =	77.09 tonne/year

Table 3.A1: Calculation of Pollution Loading from Various Catchments

Landuse	Area (ha)	Volumetric Runoff Coefficient (C_v)	Pollutant	EMC (mg/L)	Annual Runoff (mm)	Annual Loading	
						(kg/year)	(tonne/year)
Residential	468.56	0.76*	TSS	128	2166	1299073	1299.07
			TP	0.34		3451	3.45
			TN	4.21		42727	42.73
Industry	228.15	0.90	TSS	166	2565	971440	971.44
			TP	0.49		2868	2.87
			TN	5.00		29260	29.26
Commercial	26.18	0.90	TSS	122	2565	81925	81.93
			TP	0.32		215	0.22
			TN	4.84		3250	3.25
Roads and Highways	30.39	0.95	TSS	80	2708	65837	65.84
			TP	0.16		132	0.13
			TN	2.25		1852	1.85

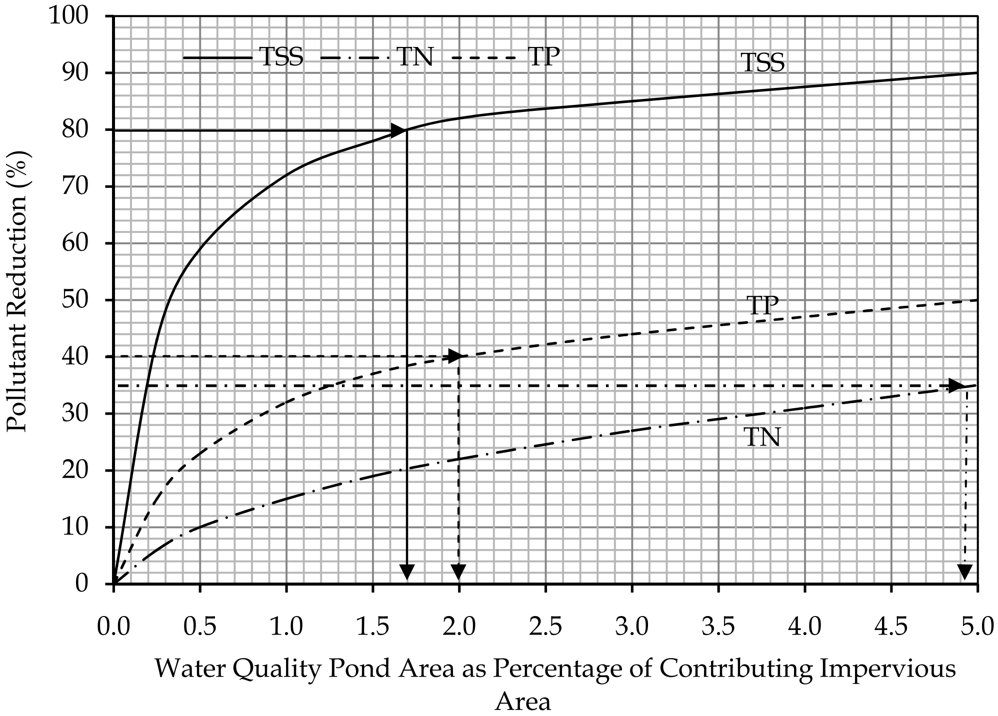
* Area-weighted average volumetric runoff coefficient for the residential areas (using Table 2.5 and Equation 2.4).

APPENDIX 3.B EXAMPLE - PRELIMINARY SIZING OF WATER QUALITY POND

Problem:

Estimate the preliminary size of a water quality pond required to reduce the TSS, TN and TP by 80%, 35% and 40%, respectively from the residential area (Taman Wangsa Permai, 114.54 ha), as given in Example 3.A (Figure 3.A1). The average runoff coefficient of the area is 0.55, which was calculated based on the actual imperviousness of the mixed development residential area (e.g. Bungalow, Link House and Open Spaces).

Solution:

Reference	Calculation	Output
Figure 3.1b	Step 1 - Calculate the contributing impervious area as 0.55 x 114.54 ha =	63 ha
	Step 2 - Identify the percentage of pollutant needed to be removed by the proposed pond and draw the horizontal lines as shown below: 	
	Step 3 - Determine the ratio of Pond Area/Contributing Impervious Area ratio in %, from the X-axis as shown above, which are: For TSS = For TN = For TP =	 1.7% 4.95% 2.0%
	Step 4 - Now the preliminary pond area must be determined based on the maximum area required which is 4.95% for the TN removal. Therefore, the water quality pond area should be, (4.95 x 63 ha) /100 =	3.12 ha.

APPENDIX 3.C EXAMPLE - PRELIMINARY SIZING OF TREATMENT TRAIN

Problem:

Estimate the preliminary sizes of a BMPs treatment train using swale, wetlands and water quality pond shown in Figure 3.C1, to reduce TSS by 80% from a residential subcatchment, Taman Bukit Rahman Putra located in Upper Sg. Buloh Catchment, with an area of 14.46 ha (Figure 3.C1). The average contributing imperviousness of the residential area is 75%.

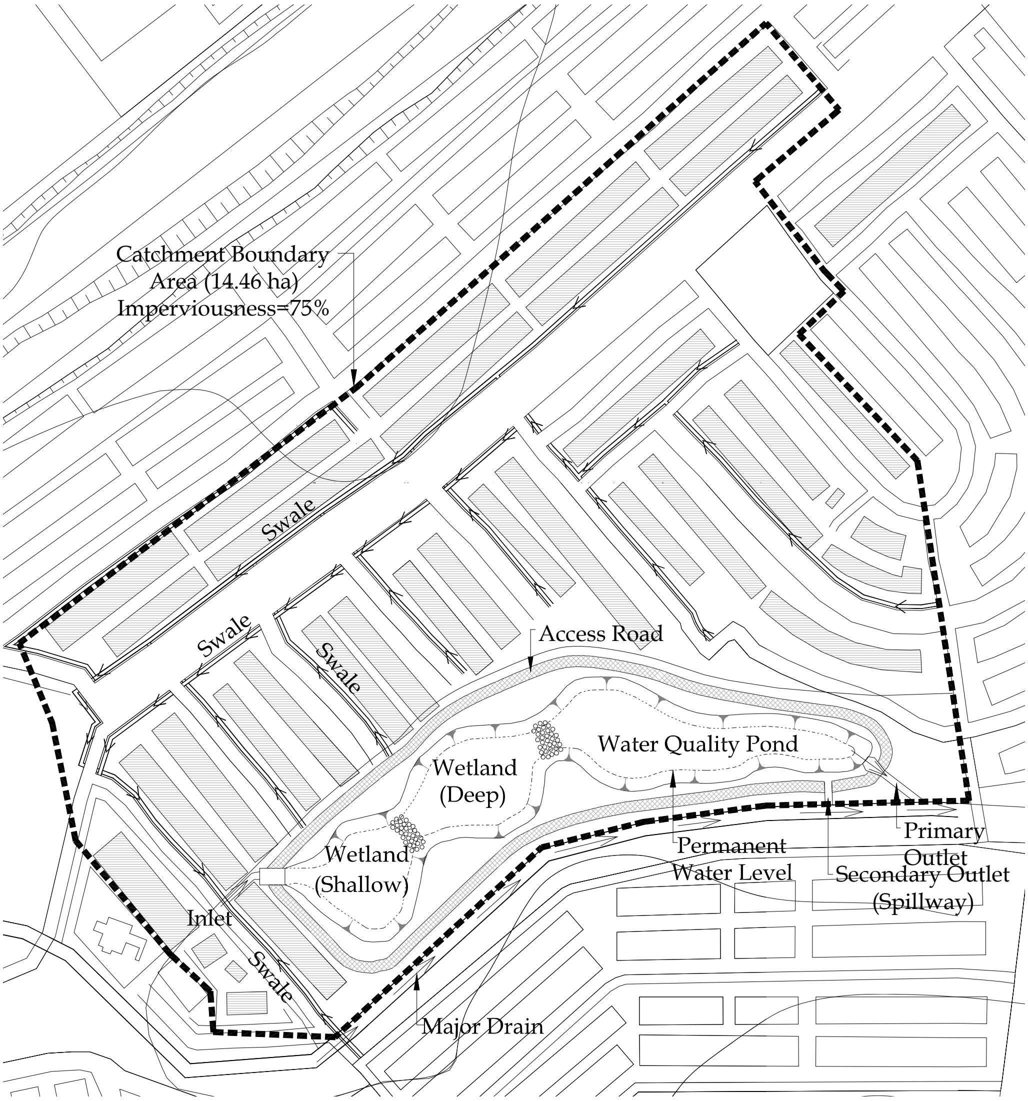
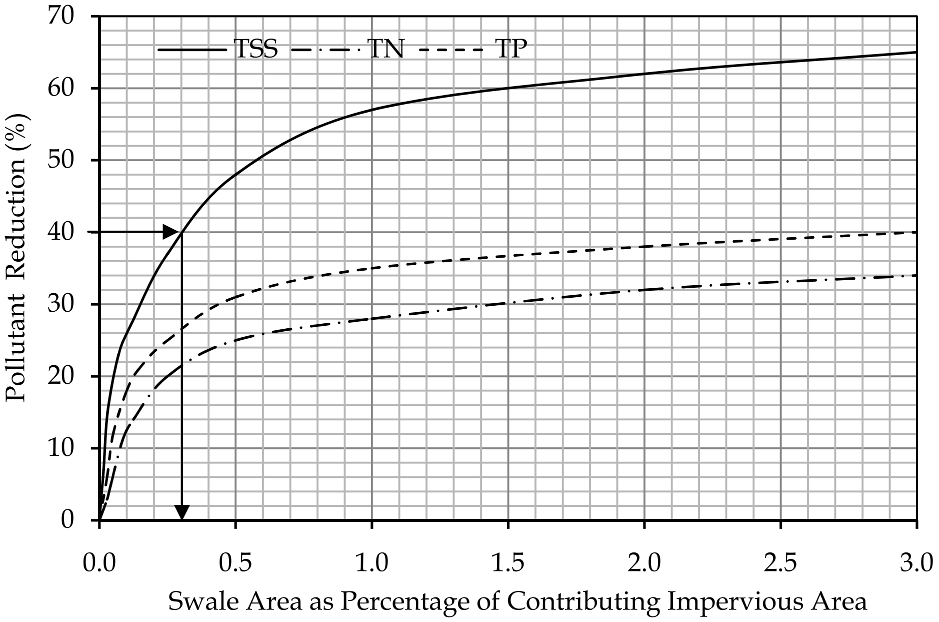
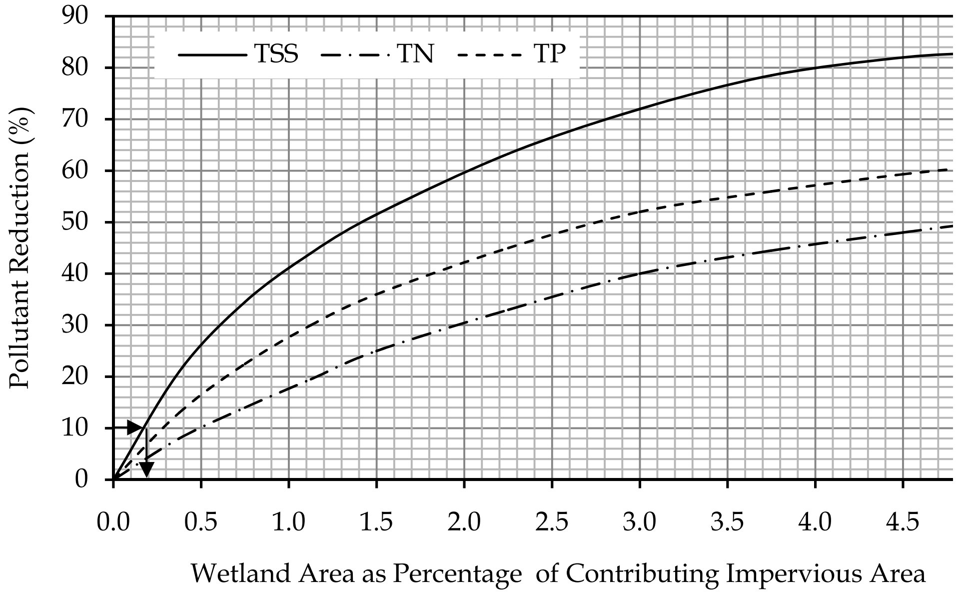


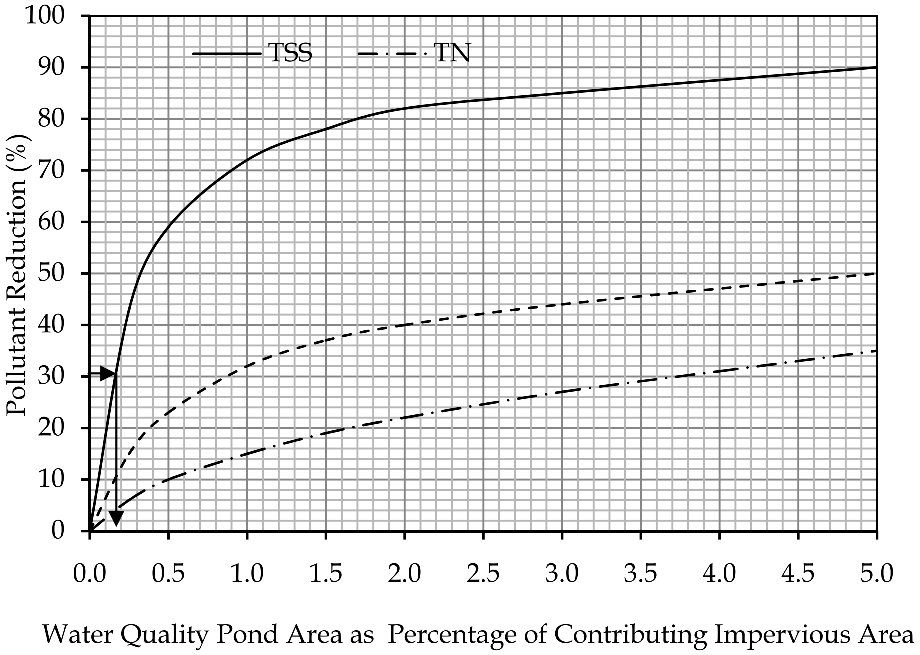
Figure 3.C1: Layout of the Proposed of BMPs Treatment Train

Solution:

Reference	Calculation	Output
Table 3.3 and 3.4	Step 1: Assuming TSS removal within the treatment train is distributed as follows : Swale (40%) → Wetlands (10%) → Water Quality Pond (30%)	
Figure 3.1a	Step 2: Top widths of the swales are assumed to be 3 m wide, including the drainage reserves that act as buffer strip. Now the total area of the swales required to remove 40% of the TSS can be determined using Figure 3.1a, which is shown below: 	
	So, the total swale area required is 0.30% of the contributing impervious area, = 0.30/100 x 14.46 x 0.75 = 0.033 ha	= 330 m^2
	Swale length (for width 3m)	= 110 m
Figure 3.1c	Step 3: The next step is to estimate the size of wetland to remove 10% of the TSS. A preliminary size of the wetland is estimated from the Figure 3.1 (c). The required wetland area to remove 10% of the TSS is 0.20%, i.e.	
	Wetlands area = 0.20/100 x 14.46 x 0.75 = 0.022 ha	= 220 m^2
	The area is divided into two units of wetlands, as shown in Figure 3.C1. One is for shallow pool (100 m^2) and the other is for deep pool (120 m^2) with submerged macrophytes.	
Figure 3.1b	Step 4: The remaining 30% of the TSS needed to meet the removal target of 80% will be removed by the water quality pond, which is the last component of the proposed treatment train BMPs. Preliminary size of the pond is estimated from the Figure 3.1 (b). The required water quality pond area to remove 30% of the TSS is 0.18%, i.e.	
	Water quality pond area = 0.18/100 x 14.46 x 0.75 = 0.020 ha	= 200m^2

Reference	Calculation	Output





Summary and flow of the estimated BMPs sizes are as follows:

Swale (330m²) ⟶ Wetland 1 (100m²) ⟶ Wetland 2 (120m²) ⟶ Water Quality Pond (200m²)

Back To Top