SIZING STORMWATER BEST MANAGEMENT PRACTICES

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ABSTRACT

Stormwater pollution is of growing concern throughout the country, with many regional, district and city councils establishing criteria for the installation of stormwater treatment devices. Councils are providing guidelines on how much water is to be treated as well as on the extent of treatment required i.e. what contaminants are to be treated and what percentage removal is to be obtained.

Most council's have adopted the use of total suspended solids (TSS) as a surrogate pollutant. It is presumed that effective control of TSS (commonly adopted 75% reduction) will provide control of other contaminants such as metals and nutrients. The Auckland Regional Council (ARC) regulates 75% removal of TSS on all sites; however, the additional removal of metals and dissolved metals is required on some land uses such as highly trafficked sites and industrial sites. Defined performance targets have yet to be set for these contaminants. City councils need to not only consider what pollutants need to be removed and what removal rate is to be achieved, but also need to establish a methodology for the sizing of the treatment measure to treat a given amount of water considering the treatment mechanisms it uses.

There are many methods of treating stormwater and these are commonly called Best Management Practices or BMP's. This article summarizes the methods adopted in New Zealand and Australia for sizing a BMP and suggests a method of equivalence when comparing BMP's sized with different methodologies.Keywords

KEYWORDS: Stormwater Treatment Device, BMP's, Sizing, Sizing Models, Design Storms, Efficiency

PRESENTER PROFILE

Mike Hannah is the technical director of Stormwater 360. He has had 15 years experience in stormwater infrastructure engineering. Mike has design, constructed, implemented, monitored and tested numerous stormwater treatment facilities. Mike has also presented some of his research at stomwater conferences in Australia, New Zealand and the USA. Co-founder of Enviropod NZ ltd, Mike has been involved in developing innovative solutions to stormwater management. Stormwater 360 in New Zealand's only specialized stormwater engineering company with an extensive research and development program into innovative treatment solutions.

1 INTRODUCTION

Stormwater pollution is of growing concern throughout the country, with many regional, district and city councils establishing criteria for the installation of stormwater treatment devices. Councils are providing guidelines on how much water is to be treated as well as on the extent of treatment required i.e. what contaminants are to be treated and what percentage removal is to be obtained.

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2 RAINFALL AND RUNOFF RELATIONSHIP

The logical place to start when sizing a Stormwater treatment measure is flow. Historically the method for runoff in New Zealand has been the rational method Q=CiA. The rational method was developed over 160 years ago, to estimate peak runoff from relatively small and homogenous catchments (same land use and land cover across the catchment).

The rational method does not automatically calculate volume. An estimate of runoff volume can be calculated by assuming a hydrograph of a specific shape, for example a triangle and fitting the hydrograph to match the peak flow and time of concentration.

The rational method is extremely conservative as any amount of rainfall will produce runoff which in reality is not the case. However it is a very good approach to obtain a quick estimate for a highly impervious area. Such is often required for the design of an urban stormwater treatment system.

In 2003 the ARC released the 2nd edition of Technical Publication 10 (T.P.10) Stormwater management devices: Design guidelines manual. This manual prescribes the use of T.P.108: Guidelines for Stormwater Runoff Modelling in the Auckland Region for calculating runoff. T.P.108 recommends the use of U.S. Soil Conservation Service (SCS) rainfall-runoff model to catchments in the Auckland Region. The SCS method was developed for relatively large storm events in primarily agricultural catchments of the Midwestern United States. The method uses a theoretical standard storm (figure below). This storm event has never occurred and never will occur.

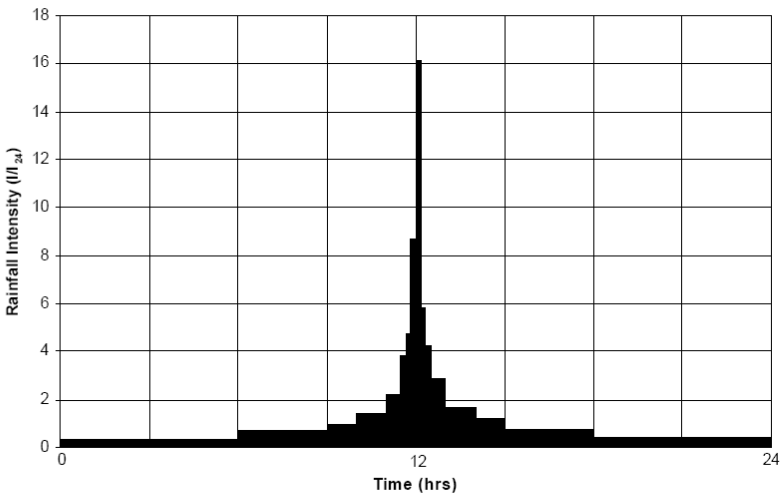

Figure 1: ARC T.P.108 Standard Design Storm

The table below compares the flows and volumes from these 2 methods from three, flat, hypothetical 100% impervious catchments in North Shore City. As it can be seen there is a large variance in results. The rational method is a conservative estimate on peak flows. The magnitude of overestimate increased as the catchment size increases. On the other hand assuming a hydrograph with duration equal to 3 x the time of concentration the rational method underestimates the treatment volume.

	0.1 Ha	1 Ha	10 Ha
Rational Flow (l/sec)	**6.16**	**51.05**	**334.5**
SCS Flow (l/sec)	**4.08**	**37.87**	**101**
Rational Volume - 3Tc (m3)	**2.90**	**59.93**	**998.83**
SCS Volume (m3)	**22.30**	**223**	**2232**

Table 1: Rational Method SCS Method Comparison

North Shore City Council only permits the use of the rational method on catchments areas less than 1 hectare.

3 A SUMMARY OF DESIGN APPROACHES

There are two basic design approaches for sizing a BMP: Volume based and Flow based. A volume based treatment BMP such as ponds, are sized on the volume of water they need to hold which is usually a multiplier of the water quality volume (WQV).

Flow based design BMP's such as swales are sized based on the calculation of a peak flow resulting from a design storm or unit hydrograph.

There are many variants and hybrids of these two approaches. For example, a sand filter is sized on a volume basis but can be given a sizing credit for the volume of water treated while it is filling.

The average annual load method correlates the efficiency of a BMP with the flow distribution from hydrological data. This method is adopted by some modeling software such the CRC for catchment hydrology's MUSIC model. Other methods include mass based design and effluent limiting design.

3.1 VOLUME-BASED SIZING

In USA, volume-based sizing is predominant in areas of intense rainfall patterns. Volume-based design is used for ponds, sand filters, wetlands, rain gardens and detention basins.

The inherent principle of volume-based sizing is that the "first flush" is contained and treated. Typically, the council specifies a depth of runoff over the site that must be captured and treated (for example: 25 mm rainfall depth, this also commonly referred to as "first flush"). The WQV volume is typically calculated using the rational or SCS method. The volume to be treated is primarily influenced by the total amount of rainfall or runoff.

Sizing of these facilities is usually a multiple of the WQV. For example T.P. 10 prescribes the stormwater quality pond is to hold 50% of the WQV in the permanent pool and 50% in live storage Alternatively the ARC allows a 37% credit off the WQV when designing a sand filter in the Auckland region.

3.2 PEAK FLOW AND FLOW-BASED SIZING

Some BMP's are capable of treating large volumes of water in a short period of time. This is possible because of their configuration and treatment mechanisms adopted e.g., a swale has a large surface area promoting a more rapid uptake of metals, where alternately a proprietary filter may utilize a filter media that has a high permeability enabling a higher flow rate while maintaining an acceptable removal capability.

As with the WQV credit given to a sand filter we need to consider flow based BMP's can treat water at the same rate or higher as it enters. Obviously there are limitations if the depth of water travelling across a swale gets too deep then its removal efficiency will decrease. Likewise a proprietary filter will require a certain driving head to produce the required flow through the filter. At this high flow the elevated head may cause the system to go into bypass.

For a flow-based sizing methodology, a design storm event is used to calculate a design discharge flow rate. Typically the design storm event is specified by the regulatory agency as a certain depth of rainfall over a certain period of time (e.g. 1/3 of a 2 year 24 hr design storm using the SCS method) or as an intensity (e.g. 1/3 2 yr storm of duration equal to the time of concentration). The discharge flow rate is primarily influenced by the distribution of the rainfall.

How do you ensure a volume based BMP and a flow based system are sized to achieve the same result i.e. 80% of the annual runoff? Consider a small site, highly impervious with a short time of concentration (Tc) and a peak flow of 15 l/sec. Not far away is a large pervious site with a long Tc which has the same peak flow of 15 l/sec. The engineer would design the same size system for each site. However there is likely to be a greater volume of runoff and load from the large catchment than the small one which could result in a higher maintenance frequency.

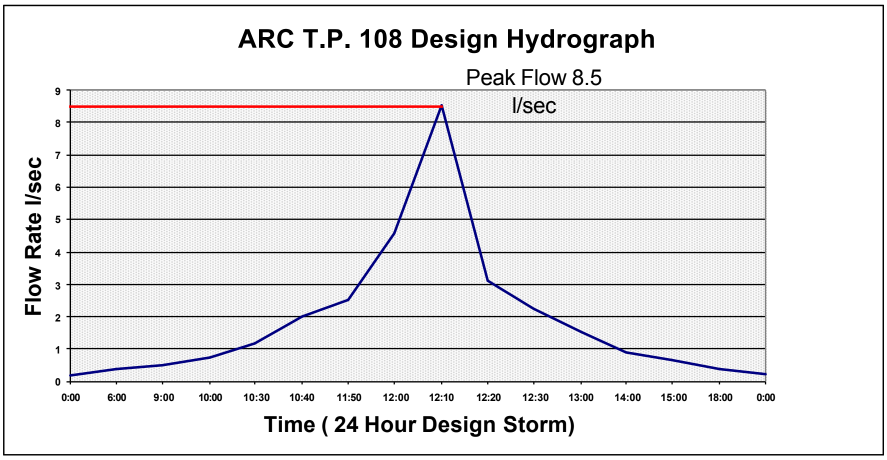

Figure 2: Peak Flow for ARC T.P.108 Design Hydrograph

3.3 AVERAGE ANNUAL LOAD MODEL AND FLOW-BASED SIZING MODEL

In Australia it is now common practice to size BMP's using the Model for Urban Stormwater Improvement Conceptualization Model (MUSIC). MUSIC calculates the reduction of the average annual mass load of a pollutant such as TSS. The model mimics a year's rainfall over the catchment and calculates the runoff and contaminants entrained in the flow. The model also generates a pollutant load dependent on the land use. The rational method is used to calculate runoff from the catchment and a 6 minute to daily time step is applied to the rainfall from an "average" year. Contaminant loads are statistically generated from the historical data and algorithms are derived relating to key design parameters and influent concentration to the performance of the BMP. The model then calculates the removal efficiency of the BMP's employed calculating the annual load removed.

The MUSIC model is a very good method of evaluating the performance of a BMP because it considers all levels of flow rather than just the peak. It also considers the performance of the BMP in terms of influent concentration and focuses on the removal of contaminates rather than the volume of water to be treated.

The ARC has developed a Contaminate Load Model that estimates loads from various land uses in the Auckland area. This model also estimates a contaminant reduction by a BMP. The model is used in comprehensive catchment management plans to look at the overall effect of a collection of BMP's in a catchment. The model however does not assist in appropriately sizing a BMP to the ARC's criteria of treating 80% of the annual runoff.

In addition to the contaminant load model the ARC in conjunction with industry partners have developed a flow based sizing model for sizing proprietary filtration devices in the Auckland region.

The table below is an extract from one of these models. The model uses rainfall from August 2000, deemed to represent an average year's rainfall. A simple "tank" model is developed where the flow through the filter is proportional to the head of water in the vault. The model calculates the volume of water treated and the volume of water bypassing. The figure below is a graphical presentation of this where Qin equals runoff entering the BMP, Q_{out} equals flow filtered and Q_o equals flow bypassed. The model is only an approximation as the 6 minute time step results in a much larger volume of flow than the volume of the tank.

Time	mm	Qin (m3/hr)	h	Primed?	Q filtered (m3/hr)	Vin (m3)	dh/dt=(Q-Qf)/A	Q overflow (m3/hr)
17-Aug-00 23:30	0	0	0.001	0	0.000	0.000	0.000	0.000
17-Aug-00 23:36	0	0	0.001	0	0.000	0.000	0.000	0.000
17-Aug-00 23:42	0	0	0.001	0	0.000	0.000	0.000	0.000
17-Aug-00 23:48	0.28	11.9	0.001	0	3.780	0.378	6.939	0.000
17-Aug-00 23:54	0.56	23.8	0.695	1	31.920	3.192	-6.939	0.000
18-Aug-00 00:00	0.56	23.8	0.001	0	3.780	0.378	17.108	9.617
18-Aug-00 00:06	0	0	0.890	1	10.403	1.040	-8.890	0.000
18-Aug-00 00:12	0.187	7.9475	0.001	0	3.780	0.378	3.561	0.000
18-Aug-00 00:18	0.28	11.9	0.357	0	3.780	0.378	6.939	1.884
18-Aug-00 00:24	0.374	15.895	0.890	1	26.298	2.630	-8.890	0.000
18-Aug-00 00:30	0.093	3.9525	0.001	0	3.780	0.378	0.147	0.000
18-Aug-00 00:36	0	0	0.016	0	0.173	0.017	-0.147	0.000
18-Aug-00 00:42	0	0	0.001	0	0.000	0.000	0.000	0.000
18-Aug-00 00:48	0	0	0.001	0	0.000	0.000	0.000	0.000
18-Aug-00 00:54	0	0	0.001	0	0.000	0.000	0.000	0.000
18-Aug-00 01:00	0	0	0.001	0	0.000	0.000	0.000	0.000
18-Aug-00 01:06	0	0	0.001	0	0.000	0.000	0.000	0.000
18-Aug-00 01:12	0	0	0.001	0	0.000	0.000	0.000	0.000
18-Aug-00 01:18	0	0	0.001	0	0.000	0.000	0.000	0.000
18-Aug-00 01:24	0	0	0.001	0	0.000	0.000	0.000	0.000
18-Aug-00 01:30	0	0	0.001	0	0.000	0.000	0.000	0.000
18-Aug-00 01:36	0.093	3.9525	0.001	0	3.780	0.378	0.147	0.000
18-Aug-00 01:42	0.56	23.8	0.016	0	3.780	0.378	17.108	9.789
18-Aug-00 01:48	0.56	23.8	0.890	1	34.203	3.420	-8.890	0.000
18-Aug-00 01:54	0.187	7.9475	0.001	0	3.780	0.378	3.561	0.000
18-Aug-00 02:00	0.467	19.8475	0.357	0	3.780	0.378	13.730	9.832
18-Aug-00 02:06	0.467	19.8475	0.890	1	30.251	3.025	-8.890	0.000
18-Aug-00 02:12	0	0	0.001	0	0.000	0.000	0.000	0.000
18-Aug-00 02:18	0.28	11.9	0.001	0	3.780	0.378	6.939	0.000
18-Aug-00 02:24	0.187	7.9475	0.695	1	16.068	1.607	-6.939	0.000
18-Aug-00 02:30	0	0	0.001	0	0.000	0.000	0.000	0.000
18-Aug-00 02:36	0.467	19.8475	0.001	0	3.780	0.378	13.730	5.664
18-Aug-00 02:42	0	0	0.890	1	10.403	1.040	-8.890	0.000
18-Aug-00 02:48	0.28	11.9	0.001	0	3.780	0.378	6.939	0.000
18-Aug-00 02:54	0.187	7.9475	0.695	1	16.068	1.607	-6.939	0.000
18-Aug-00 03:00	0.467	19.8475	0.001	0	3.780	0.378	13.730	5.664
18-Aug-00 03:06	0	0	0.890	1	10.403	1.040	-8.890	0.000
18-Aug-00 03:12	0	0	0.001	0	0.000	0.000	0.000	0.000
18-Aug-00 03:18	0	0	0.001	0	0.000	0.000	0.000	0.000
18-Aug-00 03:24	0	0	0.001	0	0.000	0.000	0.000	0.000

Table 2: Example Flow Based Sizing Model

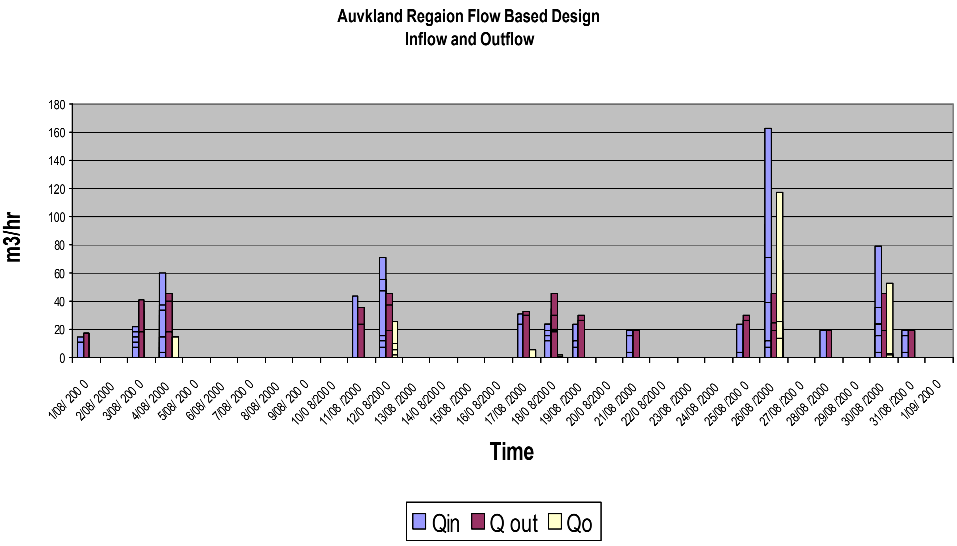

Figure 3: Graphical Representation of Flow based Model

3.4 MASS / SOLID BASED DESIGN

In New Zealand some proprietary suppliers undertake mass or solids based design to size BMP's, this practice is also common place overseas where regulatory bodies require the designer to calculate the load caught by the device. In the first edition of T.P.10 the manual prescribed a method of checking the maintenance frequency of a pond by relating the TSS load the pond was likely to receive with the contaminant storage volume provided. Unfortunately this design step was omitted from the 2nd edition.

Mass based design provides a "sanity check" on other approaches. Any BMP designed to remove solids and other pollutants requires periodic maintenance. The designer needs to have an understanding of the load capacity of the BMP but also be able to estimate annual mass load derived from the catchment. The Table below is from the ARC's T.P. 10 and lists contaminant loading rates from various land uses

Land Use	TSS (kg/ha/yr)
Commercial	242 - 1369
Residential (low)	60 - 340
Residential (high)	97 - 547
Terraced	133 - 755
Bush	26 - 146
Grass	80 - 588
Roof	50-110(5)
Pasture	103 - 583

Table 3: Contaminated Loading Ranges for Various Land Uses; Source T.P.10

In addition to the TSS load, consideration should be made from the volume of gross pollutants and bed load. It is not uncommon for over 1m^3/ha of gross pollutants and bed load to be entrained in stormwater flows.

Mass based design should govern the design of a BMP when it is downstream of a detention tank, however this is frequently over looked. Detention tanks are designed to attenuate the flow extending the hydrograph. If a BMP downstream of the tank is sized with a flow based methodology to the attenuated flow it will be very small with the respect to the catchment it is treating. However the mass of contaminants entering the device is the same as catchment without the detention system (less some minimal pre-treatment provided by the tank). If this is overlooked, the small system design will require a very high degree of maintenance as it will be overwhelmed by the contaminant load.

3.5 EFFLUENT LIMITED DESIGN

Effluent limited design is when a regulatory body places a maximum allowable concentration of the target pollutant. The ARC has placed such a regulation on discharges from industrial sites, however in order to do so a council must firstly set effluent quality limits. Often the trigger levels from the Australian and New Zealand Environment and Conservation Council (ANZECC) water quality guide lines are prescribed as a proxy limit for effluent concentrations, however this is a misuse of the guidelines as they describe these trigger levels to be for ambient water conditions after dilution and mixing and not discharge effluent quality. In some cases the ARC have deemed a "10x the ambient water trigger level" as being an acceptable stormwater effluent limit.

Effluent limited design is a good method as it considers that the percentage removal will diminish as the influent concentration approaches irreducible concentration. The method is also good as it directly address the water quality issue, however setting limits implies that monitoring must be carried out and for this to be reasonably accurate and defensible it would require more than grab sampling.

For effluent limited design to be appropriately implanted there needs to be protocol for dealing with violations and a understanding of what is a reasonable performance; considering the conditions the BMP is subjected to.

3.6 METHOD OF EQUIVALENCY

Given the above range of design approaches, challenges arise when one type of BMP which is designed in according to one approach is proposed for use in areas where the regulations have a different design basis. Frequently agencies that have volume based criteria do not provide guidelines for flow based technologies, and therefore some method of design equivalency needs to be established.

Establishment of a water quality rainfall depth or a first flush depth is derived from the desire to capture and treat a certain amount of the annual rainfall or runoff. For example, Environment Canterbury accepts the capture of the first 12.5 mm of rainfall which will achieve treatment of 58% of Christchurch's average annual rainfall. Similarly ARC T.P. 4 determined that a 25 mm storm equates to 1/3 of a 2 yr storm and in turn treatment of 80% of the annual runoff volume.

Therefore with some historical rainfall information it is very easy to calculate the level of flow or rainfall required to be treated to achieve a desired level of treatment i.e. 80% of the annual runoff. This can be accomplished by constructing a cumulative probability distribution. The figure below shows the cumulative distribution for the ARC August 2000 rainfall which is deemed to be representative of Auckland rainfall. The plot details a 1 Hectare 100% impervious site using a coefficient of runoff of 0.9. From the plot, 80% of runoff is below 19.5 l/sec. Therefore a flow based system designed to treat 19.5 l/sec will be equivalent to volume based system designed to treat 25 mm. Likewise Figure 5 for Christchurch has 80% of volume being a 7.0 l/sec.

It should also be noted that with less intense rainfall comes a finer particle size distribution entrained in the flow and perhaps the device will need to be oversized to remove these finer particles. For example a pond will be designed with a greater residence time or a filter is designed with a lower specific flow rate.

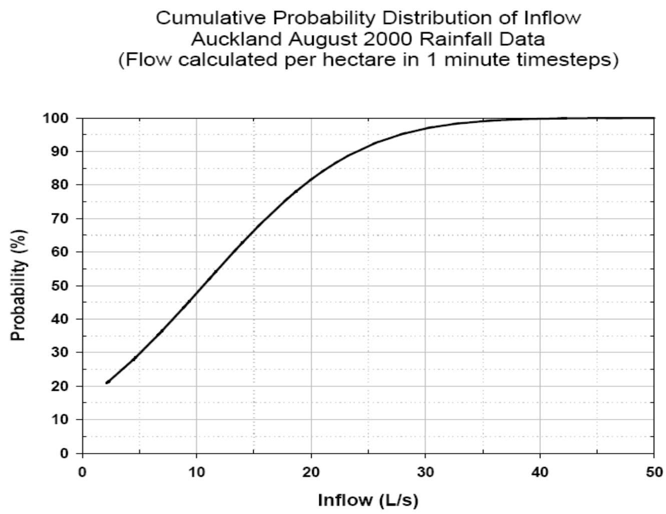

Figure 4: Example Cumulative Probability Graph for Auckland

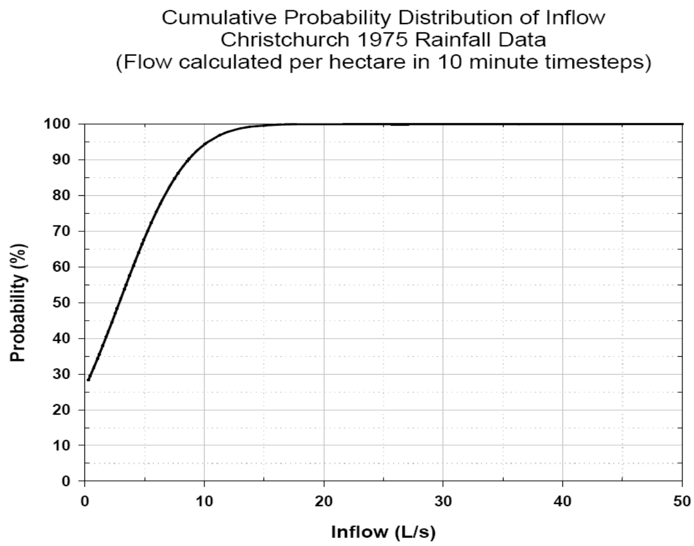

Figure 5: Example Cumulative Probability Graph for Christchurch

4 CONCLUSIONS

There many methods for sizing a BMP, but what is important is that the method used to size the device is appropriate to the method for treating the stormwater. Whether sizing for flow or for volume the same overall annual volume of water should be treated. More sophisticated models can look at overall contaminant removal in addition to treating just the first flush or WQV. The designer should always consider the loading rates and load capacity of the BMP and take into account maintenance frequency in their design.

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