STORMWATER QUALITY CONTROL BASIN WITH MICROPOOL

James C. Y. Guo1, Hui-Ming Max Shih2, Ken A. MacKenzie3

ABSTRACT
Since the early 1990’s, a water quality capture volume (WQCV) has been recommended for stormwater quality enhancement designs. However, lacking further guidance on how to shape the basin for this recommended volume, the current practice is to assume that the WQCV should lead to a satisfactory sediment trap efficiency, provided that the drain time can be as long as 40 hours. In this study, the sediment trap efficiency method is modified to take basin’s dimension, drain time, and micropool into consideration. A water quality control basin (WQCB) should be designed with a pre-selected drain time and water surface area, and then evaluated by its sediment trap efficiency. For a typical urban residential development with sediment particles consisting of clay, silt and sand, a drain time for WQCB can be between 12 and 40 hours with its sediment trap efficiency varied from 60 to 80%. A drain time longer than 12 hours may result in a diminishing return on sediment trap efficiency. The performance of WQCB can be improved with a micropool. The case study indicates that a micropool can only increase the sediment trap efficiency from 80 to 89% when its storage volume increases from none to WQCV. It implies that the major function of micropool is to control re-suspended solids and buoyant debris. Based on the case study, the annual sediment settlement amount from a typical urban residential area is approximately 0.6% of WQCV. Considering a minimum maintenance schedule at once every three years, a micropool can be 1.8% of the WQCV for the purpose of sediment storage.

Key Words: Sediment Trap Efficiency, Water Quality Capture Volume, Detention Basin, Micropool, Drain time.

1. Professor and Director, Civil Engineering, U of Colorado Denver, E-mail: James.Guo@UCDenver.edu
2. Water Resources Engineer, URS Denver, Colorado
3. Senior Manager, UDFCD, Denver, Colorado

INTRODUCTION
A retention basin is operated with a permanent pool for water quality enhancement while a detention basin is often designed to have a micropool that can increase sediment trap ratio. A permanent pool is sustained by the local groundwater table and results in a vegetative wetland environment. On the contrary, a micropool is a depressed cavity in front of the outlet structure. Referring to Figure 1, an extended detention basin is shaped to provide an adequate storage volume to accommodate the multiple design events, including micro (3-month event), minor (5 to 10-year storm), and major event (50 to 100-year storm). The outlet structure is built with a perforated plate for slow release of the water quality capture volume, an orifice for 10-year release, and then a top grate for the 100-yr release. Of course, an emergency weir should be installed on top of the dam for safe release of extreme events (UDFCD 2010).

A water quality control basin (WQCB) is often nested in the bottom of extended flood control detention basin. A WQCB is sized for frequent, micro events because stormwater quality problems are more associated with these events at the magnitude of street flush volume that carries the highest concentration of solids and pollutants (Guo and Urbonas 1996). A WQCB is designed for water quality capture volume (WQCV) that is gradually released through the perforated plate over a drain time of 12 to 40 hours. Like a
sedimentation basin, a WQCB should be equipped with a micropool that provides a sediment storage volume (Guo 2009). The water level of a micropool is often set to the bottom of the perforated plate. Between two adjacent storm events, the micropool may or may not be dry, depending on evaporation and infiltration losses. As soon as stormwater plunges into the micropool, re-suspended solids will be limited near the bottom area of the micropool. During the extended release, buoyant material in stormwater becomes saturated and settles to the bottom of the micropool. Without a micropool, buoyant material will be sucked into the holes on the perforated plate. It only takes small pieces of newspaper, leaves, and plastic bags to plug the perforated plate.

Figure 1: Extended Detention Basin with Micropool in Water Quality Control Basin

Without a micropool, perforated plates are so vulnerable to the buoyant clogging that many extended detention basins are found to be inundated with a prolonged drain time. Although a micropool is highly recommended in the design criteria manual (UDFCD 2010), the performance of micropool is depicted qualitatively rather than quantitatively. The lack of a quantitative design method results in randomly sized micropools. The paradox is that a micropool is designed to enhance the settlement of solids, but the sediment trap efficiency is an uncertainty in the micropool design. In this study, a design method is developed to size the dimensions of a micropool. The method provides a quantitative basis to evaluate the sediment trap efficiency (TE) with or without a micropool for a short or long drain time.

DEFINITION OF DESIGN EVENT FOR MICROPOLL SIZING

Using the annual maximum or exceedance data series, the minor and major events are defined by the flood flow-frequency relationship using the Log Pearson Type III distribution (USGS Bulletin 17, 2010). Similarly, micro events must be analyzed using the complete data series and exponential distribution (Guo 2002). In this study, the one-parameter exponential distribution is employed to fit the frequency distribution of rainfall event depths (Wanielista and Yousef in 1993). The exponential distribution is described as:

\[ f(D) = \frac{1}{D_m} e^{-\frac{D}{D_m}} \]  

(1)

in which \( f(D) \) = frequency function, \( D \) = rainfall event depth, and \( D_m \) = the average rainfall event depth that has been summarized for the US continent in several reports (Guo 2002, Driscoll et. al 1989). According to the Poisson process, the cumulative probability distribution of Eq (1) can be derived as:
\[ P_D(0 \leq d \leq D) = 1 - e^{-\frac{d}{D}} \]  

Eq (2) depicts the distribution of non-exceedance probability, \( P_D \), representing the chance to have an event depth, \( d \), not to exceed the design depth, \( D \). For convenience, the WQCV is often expressed in depth for the watershed [L]. The runoff produced by the design event is expressed as:

\[ V_o = C (D - D_i) \]  

(3)

In which \( V_o \) = WQCV depth in [L] for the watershed, \( C \) = runoff coefficient, \( D \) = watershed design rainfall depth in [L], and \( D_i \) = incipient watershed surface depression in [L]. As reported, with \( D_i = 2.5 \text{ mm} \), approximately 20 to 30% of rainfall events are purged out of the rainfall data series (Guo and Urbonas in 1996). Substituting Eq (3) into Eq (2) yields:

\[ C_V = P_D(0 \leq V \leq V_o) = P_D(0 \leq d \leq D) = 1 - k e^{-\frac{V_o}{CD_w}} \]  

(4)

In which \( C_v \) = runoff volume capture rate, \( V_o \) = WQCV selected for design, \( P_D(0 \leq V \leq V_o) \) = probability of an event that produces a runoff depth less than \( V_o \), and \( k \) = incipient runoff constant. The value of \( k \) is defined by the initial surface depression and the average event rainfall depth as:

\[ k = e^{-\frac{D_i}{D}} \]  

(5)

In practice, the target runoff volume capture rate is set to be 80%. With the known local average event rainfall depth, the corresponding WQCV or \( V_o \) can be computed by Eq (4). Based on the characteristics of sediment particles, a proper drain time for the basin can be selected, such as 12 or 24 hours. The average release from the WQCB is computed as:

\[ Q = \frac{V_o}{T_d} \]  

(6)

Where \( Q \) = average release in \([L^3/T]\) and \( T_d \) = drain time in [T]. According to the surface loading concept, the performance of a WQCB is critically related to its basin geometry. For instance, the cross sectional average flow velocity is defined by the basin’s width and depth as:

\[ U = \frac{Q}{WH} \]  

(7)

Where \( U \) = cross sectional water flow velocity in the longitudinal direction in [L/T], \( W \) = average basin width in [L] and \( H \) = average basin depth in [L]. The water surface area for the pool is defined as:
\[ A_s = LW \] (8)

Where \( L \) = average basin longitudinal length or stream path length in \( [L] \) and \( A_s \) = average water surface area in \( [L^2] \). Although many design curves have been produced for convenient use, the potential risk is that the case under design may not be consistent with the default condition behind those design curves. For instance, Chen (1975) attempted to compare the sediment trap efficiency (TE) developed for turbulent flows with the empirical models reported by Brune (1953) and Churchill (1948). The conclusion was that these empirical models over-predict sediment TE for fine sediments but under-predict TE for coarse sediments. Therefore, in this study, the fundamental theory behind the sediment trap ratio was reviewed and then expanded into the micropool design as a vital part of extended detention basin design.

SEDIMENT TRAP EFFICIENCY IN DRY BASINS

Often a detention basin is dry at the onset of a runoff-producing event. During the event, sediments, solids, chemicals, and debris are washed into a basin. In a cycle of operation, the loading time to fill up a WQCB is much shorter than the required residence time for particle settlement. Over the residence time, suspended particles travel with the water flow through the pool and also become stratified in the gravity direction, according to particle's size and fall velocity. As a result, the continuity equation of sediment flux is rewritten as:

\[ \frac{\partial Q_{sx}}{\partial x} + \frac{\partial Q_{sz}}{\partial z} = 0 \] (9)

Where \( Q_{sx} \) = sediment flux in the longitudinal direction from the inlet to the outlet, \( Q_{sz} \) = sediment flux in the gravity direction from water surface to basin floor, \( x \) = horizontal distance in the longitudinal direction, and \( z \) = vertical distance in gravity direction. With a drain time as long as 12 to 24 hours, the diffusive and mixing effects are negligible compared to the advective flux associated with the water flow in the longitudinal direction. As a result, the volume-based components in the sediment flux are expressed as:

\[ Q_{sx} = UC_s \] (10)
\[ Q_{sz} = -\omega C_s \] (11)

Where \( C_s \) = event mean concentration or EMC, and \( \omega \) = particle fall velocity in \( [L/T] \) in the gravity direction. Substituting Eq (10) and (11) into (9) yields:

\[ \frac{\partial UC_s}{\partial x} + \frac{\partial (-\omega C_s)}{\partial z} = 0 \] (12)

In practice, the suspended load is described by its particle size distribution. Eq (9) can be solved for a selected particle size, or for a fraction of the size distribution. The fall velocity for the selected particle size is computed as:
\[ \omega = \frac{8V}{D_s}[(1 + 0.0139D_s^3)^{0.5} - 1] \quad (13) \]

\[ D_* = D_s\left(\frac{(S-1)g}{v^2}\right)^{1/3} \quad (14) \]

Where \( D_s \) = particle size in [L], \( D^* \) = dimensionless particle size, \( S \) = specific gravity for a sediment particle (such as 2.56), \( g \) = gravitational acceleration, \( v \) = water viscosity in \([L^2/s]\). The fall velocity is determined by a trial and error until Eq's (13) and (14) are satisfied. Considering that the water flow velocity in Eq (7) associated with the gradually varied flow in the basin is nearly a constant, the partial derivative of the water flow velocity in the longitudinal direction is vanished as:

\[ \frac{\partial U}{\partial x} \rightarrow 0 \quad (15) \]

Eq (15) implies that the change of sediment concentration is dominated by particle settlement on the basin floor or the sediment concentration only varies with respect to the distance. As a result, at each section, the concentration of sediment is linearly distributed along the water depth as:

\[ \frac{\partial C_s}{\partial z} = -\frac{C_s}{H} \quad (16) \]

Aided with Eq's (15), (16), Eq (12) becomes:

\[ U \frac{dC_s}{dx} + \frac{\omega C_s}{H} = 0 \quad (17) \]

The solution for Eq (17) is an exponential decay function with respect to the horizontal distance in the longitudinal direction as:

\[ C_s(x) = C_o e^{-\frac{x}{\omega H}} = C_o e^{\frac{-\omega W}{Q}} \quad (18) \]

Where \( C_s(x) \) = sediment concentration at a distance \( x \) from the entrance and \( C_o \) = inflow sediment EMC at the entrance or \( x = 0 \). At the basin outlet, \( x = L \), the sediment concentration associated with the outflow is:

\[ C_L = C_o e^{\frac{-Q}{\omega H}} = C_o e^{\frac{-Q}{\omega s}} \quad (19) \]
In which \( C_L = \) sediment EMC at the outlet i.e. \( x=L \), and \( U_s = \) surface loading velocity in \([L/T]\). As recommended (Chen 1975 and Julien 1994) and aided by Eq’s (6) and (7), the TE for the selected particle size is defined and computed as

\[
TE = \frac{C_o - C_L}{C_o} = 1 - e^{-\frac{U_s}{H}}
\]  

(21)

Eq (21) is closely similar to the conventional surface loading theory for sediment pond operation, but it is much easier in computation.

TRAP EFFICIENCY IN WET BASINS

A wet basin may be a permanent pool in a retention system, a wet micro pool in a detention system, or a depressed wetland area. As expected, a wet basin will have an enhanced pollutant removal rate. During an event, stormwater carries suspended sediment load into the existing water body in the basin, the mixing efficiency between these two water volumes becomes a key factor in determination of sediment removal rate. Using the volume-weighting method, the mixing concentration between the WQCB and its micropool is defined as

\[
C_m = \beta \frac{V_o}{(V_o + V_w)} C_o = \frac{\beta}{(1 + V_w/V_o)} C_o
\]  

(22)

\[
1.0 \leq \beta \leq \frac{1}{(1 + V_w/V_o)}
\]  

(23)

where \( C_m = \) mixing EMC in WQCV, \( \beta = \) mixing coefficient, and \( V_w = \) existing water volume in micropool before the event. In practice, the two water volumes may not be completely mixed. Therefore, the mixing coefficient, \( \beta \), is employed to take the uncertainty into consideration. The minimum value of \( \beta \) is unity that represents the case where the two volumes are completely mixed, while the maximum value of \( \beta \) (where \( \beta = \frac{1}{(1 + V_w/V_o)} \), represents the case of no mixing at all. For instance, a micropool in the bottom of a WQCB may have a storage volume of approximately 5 to 20% of the WQCV. During operation, however, the water volume remaining in the micropool between events may change between zero (a dry condition) to WQCV (a full condition), depending on the inter-event time in the rainfall pattern. For instance, \( \beta = 1.0 \) when \( V_w = 0 \), representing that the micropool is dry. 1.0s \( \beta \leq 1.2 \) when \( V_w = 0.2V_o \), representing that the micropool is full. Or 1.0s \( \beta \leq 2.0 \) when \( V_w = V_o \), representing that the WQCB is full in a wet season.

Substituting Eq (22) into Eq (19) and (21), the sediment trap efficiency for the selected particle size is derived as:
\[ T_{ME} = 1 - \frac{\beta}{(1 + V_w/V_o)} e^{-\frac{eT}{H}} \]  \hspace{1cm} (24)

Where \( T_{ME} \) = trap efficiency for mixed volume. As recommended (EPA 1986, Haan et al. in 1994), Eq (24) shall be further modified with a factor to take non-ideal settlement condition into consideration as:

\[ T_{ME} = 1 - \frac{\beta}{(1 + V_w/V_o)} e^{\frac{-eT}{1.2H}} \]  \hspace{1cm} (25)

The factor of 1.2 in Eq (25) accounts for non-circular particles, uncertainties in flow turbulence, re-suspension of small solids etc. For a given grain-size distribution for the sediment load in the stormwater, Eq (25) can be repeatedly applied to each fraction of grain size, then the total sediment trap efficiency for all particles can be integrated along the grain-size distribution. As a result, the total sediment trap ratio is estimated as:

\[ TT_{ME} = 1 - \frac{\beta}{(1 + V_w/V_o)} \sum_{i=1}^{n} \left[ e^{\frac{-eT_i}{1.2H}} \times \Delta X_i \right] \]  \hspace{1cm} (26)

Where \( TT_{ME} \) = total sediment trap efficiency, \( \Delta X_i \) = fraction for the \( i \)-th grain size, and \( n \) = number of particle sizes. In practice, a drain time is firstly selected for the target sediment trap efficiency. The corresponding average release, \( Q \), and basin geometry are determined by Eq’s (6), (7), and (8). The performance of this basin is examined by Eq (26).

EVALUATION ON AS-BUILT BASIN – A CASE STUDY

The Orchard Pond detention basin was designed and constructed in 1998 as an extended detention basin at the Grant Ranch residential subdivision in Denver, Colorado. The tributary catchment is 16.9 acres of residential development with a runoff coefficient of 0.60. The Orchard Pond detention basin was built at the watershed outfall point to remove pollutants and reduce the post-development flood peak flows. The pond provides a WQCV to capture the 80\(^{th}\) percentile runoff events with an average event-depth: \( D_m = 0.41 \) inch and runoff incipient depth: \( D_i = 0.1 \) inch. Based on the given information, the WQCV for this tributary area is determined as:

\[ \frac{-D_i}{k} = e^{D_m} = e^{0.41} = 0.78 \]

\[ C_V = P_D (0 \leq V \leq V_o) = 1 - ke^{CD_m} = 1 - 0.78e^{\frac{-V_o}{0.60 \times 0.41}} = 0.8 \]

The WQCV for this case is found to be: \( V_o = 0.34 \) inch per watershed area or 20858 \( ft^3 \). The drain time for the WQCV is set to be 40 hours. The water surface area for WQCV is set to be: \( L = 128 \) ft, \( W = 70 \) ft, or \( A_s = 8,960 \) \( ft^2 \). The average water depth is:
The Orchard Pond detention system is equipped with a forebay that captures solid particles >1.0 mm in diameter. The suspended particles <1.0 mm in stormwater will reach the permanent pool that was built to have a storage volume, $V_w = 0.056 V_o$. From the field, the sediment sample at the entrance of this permanent pool was analyzed for the particle-size distribution. Table 1 presents the calculation of sediment capture for the as-built condition under the assumption of $\beta = 1.0$ and $V_w/V_o = 0.056$. This retention system is predicted to trap 80% of the suspended load in the basin.

| Grain Size | Sieve Analysis mm | Percent of Solids Passing % | Normalized Area under Grain-size Curve | Dimensionless Particle Size $D^*$ | Fall Velocity mm/s | Trap Efficiency TE | Cumulative Trap Efficiency TT_ME 
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0001</td>
<td>0.00</td>
<td>0.000</td>
<td>0.0022</td>
<td>0.00001</td>
<td>0.345</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>0.0002</td>
<td>50.00</td>
<td>0.406</td>
<td>0.0044</td>
<td>0.00003</td>
<td>0.547</td>
<td>0.222</td>
<td></td>
</tr>
<tr>
<td>0.0005</td>
<td>60.00</td>
<td>0.107</td>
<td>0.0110</td>
<td>0.00018</td>
<td>0.850</td>
<td>0.091</td>
<td></td>
</tr>
<tr>
<td>0.0010</td>
<td>65.00</td>
<td>0.041</td>
<td>0.0220</td>
<td>0.00071</td>
<td>0.976</td>
<td>0.040</td>
<td></td>
</tr>
<tr>
<td>0.0050</td>
<td>70.00</td>
<td>0.094</td>
<td>0.1099</td>
<td>0.01773</td>
<td>1.00</td>
<td>0.094</td>
<td></td>
</tr>
<tr>
<td>0.0100</td>
<td>75.00</td>
<td>0.041</td>
<td>0.2199</td>
<td>0.07090</td>
<td>1.00</td>
<td>0.041</td>
<td></td>
</tr>
<tr>
<td>0.0310</td>
<td>80.00</td>
<td>0.066</td>
<td>0.6816</td>
<td>0.68067</td>
<td>1.00</td>
<td>0.066</td>
<td></td>
</tr>
<tr>
<td>0.0630</td>
<td>90.00</td>
<td>0.083</td>
<td>1.3851</td>
<td>2.78877</td>
<td>1.00</td>
<td>0.083</td>
<td></td>
</tr>
<tr>
<td>0.5000</td>
<td>95.00</td>
<td>0.121</td>
<td>10.9929</td>
<td>65.50939</td>
<td>1.00</td>
<td>0.121</td>
<td></td>
</tr>
<tr>
<td>1.0000</td>
<td>100.00</td>
<td>0.041</td>
<td>21.9859</td>
<td>107.47366</td>
<td>1.00</td>
<td>0.041</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1.00</td>
<td></td>
<td></td>
<td>0.80</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Sediment Trap Efficiency for Particle-Size Curve in Mixing Volume

The Bowles Metropolitan District has been collecting water quality and flow data from the Orchard Retention Pond since 2004. Based on the observed data from 2004 to 2006 (Loilier, 2006), the average EMC in the stormwater inflows was 94.9 mg/L among micro events. The average EMC of sediment in the outflows was 17.3 mg/L for these monitored events. The average removal rate for total suspended sediment (TSS) is 81.8 % that closely agrees with the predicted TT_ME in Table 1.

As shown in Figure 2, a sensitivity study was also conducted on drain time. Keeping $T_d = 40$ hours for all cases, the sediment TT_ME increases from 0.80 to 0.89 when the $V_w/V_o$ ratio increased from none to one. Keeping $V_w/V_o = 0.056$, the sediment TT_ME increases slowly and then exponentially. With $T_d \leq 6$ hr, the TT_ME in this case is subject to increasing returns while with $T_d \geq 12$ hr, the basin begins to experience diminishing returns in TT_ME. As shown in Figure 2, the case of $T_d = 40$ hr and $V_w/V_o = 0.056$ can achieve the same sediment trap efficiency of 80% as another case with $T_d = 12$ hr and $V_w/V_o = 1.0$. Obviously, there exists a tradeoff between the drain time and the size of the micropool. Although an excessive drain time may encourage the growths of mosquito beds and algae, it does capture more suspended solids with a smaller micropool.
Figure 2: Variation of Trap Efficiency With Respect to Drain Time and Micropool

In addition to the increase of $TT_{ME}$, the proper size of a micropool also depends on the annual sediment amount captured. For this case, the annual precipitation depth at the project site is approximately 14 inches per year. As a result, the annual runoff volume captured in the basin is expected as:

$$V_r = CP_a AC_v = 0.6 \times \frac{14}{12} \times 16.9 \times 43560 \times 0.8 = 412252 \text{ ft}^3 = 11687340 \text{ liters}$$

As mentioned above, the event mean concentration at $x = L$ is $C_L = 94.9 \text{ mg/L}$. As a result, the annual weight of sediment is computed as:

$$W_S = C_L \times TT_{ME} \times V_r = 94.9 \times 0.8 \times 11687340/1000000 = 1107.6 \text{ kg}$$

where $V_r = \text{annual runoff volume in [L$^3$]}, P_a = \text{annual rainfall depth in [L] such as 14 inches}, W_S = \text{annual sediment weight in [kg]}, V_S = \text{annual sediment volume in [m}^3$$. Considering $S = 2.56$, the annual sediment volume is $0.43 \text{ m}^3$ or $12.3 \text{ ft}^3$, equivalent to $0.6\%$ of the WQCV for this case. This ratio closely agrees with the as-built micropool, i.e. $V_w/V_o = 0.56\%$ or $V_w = 10.5 \text{ ft}^3$.

CONCLUSION

With rapid development in low impact design technology and the increasing regulation of high standards for stormwater quality enhancement, it is urgent to know how to properly size, shape, and how to drain a WQCB for an optimum performance. Since the early 1990’s, the approach of WQCV has been implemented without quantitative guidance on the design of basin geometry and selection of drain time. The major assumption is that the WQCV will lead satisfactory sediment trap efficiency if the drain time is extended to 40 hours (EPA 1986). In this study, the theory of sediment trap efficiency was modified to predict the performance of a WQCB with and without a micropool. It was found that basin’s WQCV, micropool volume, water surface area, drain time, and particle-size distribution are the key factors in determining the suspended sediment trap efficiency. The design procedure begins with the selections of
water surface area and micro pool volume, according to the basin’s constraints. Then, a range of drain times shall be evaluated until the target sediment trap efficiency is achieved.

In this study, an as-built detention system with a micropool was evaluated. The predicted sediment trap efficiency for this as-built basin closely agrees with the field monitoring of TSS removal over two years. Furthermore, the sensitivity analyses indicate that the selection of drain time can be critical. For an urban residential development with sediment particles consisting of clay, silt and sand, a drain time between 12 to 40 hours may trap 60 to 80% of suspended solids in stormwater. The performance of a WQCB can be improved with a micropool. The case study indicates that a micropool increases \(TT_{ME}\) from 0.80 to 0.89 when the micropool’s volume increases from none to one WQCV. It means that sediment trap efficiency is more sensitive to drain time rather than micropool's volume, or the major function of micropool is to control the re-suspended solids and buoyant debris. Based on the case study, the annual sediment settlement amount from a typical residential area is approximately 0.6% of WQCV. Considering a minimum maintenance schedule at once every three years, a micropool can be 1.8% of the WQCV.

REFERENCES


APPENDIX II: NOTATIONS

\( A_s \) = average water surface area in \([L^2]\)

\( C \) = runoff Coefficient

\( C_s \) = sediment event-mean-concentration or EMC

\( C(x) \) = sediment EMC at a distance \( x \) from the entrance

\( C_o \) = inflow sediment EMC at the entrance or \( x=0 \)

\( C_m \) = mixing EMC in WQCV,

\( C_L \) = sediment EMC at the outlet i.e. \( x=L \),

\( C_v \) = runoff volume capture rate

\( D \) = rainfall event-depth,

\( D_m \) = average rainfall event-depth

\( D_s \) = particle size in \([L]\),

\( D^* \) = dimensionless particle size

\( f(D) \) = frequency function,

\( g \) = gravitational acceleration,

\( H \) = average basin’s depth in \([L]\).

\( k \) = incipient runoff constant

\( L \) = average basin’s longitudinal length in \([L]\)

\( n \) = number of particle sizes

\( V_o \) = WQCV selected for design

\( P_D(0 \leq V \leq V_o) \) = probability to have an event that produces a runoff depth less than \( V_o \)

\( P_a \) = annual rainfall depth in \([L]\)

\( Q \) = average release in \([L^3/T]\)

\( Q_{sx} \) = sediment flux in the longitudinal direction from the inlet to the outlet,

\( Q_{sz} \) = sediment flux in the gravity direction from water surface to basin’s floor,

\( S \) = specific gravity for sediment particle such as 2.56,

\( T_d \) = drain time in \([T]\)
\[ T_{ME} = \text{trap efficiency for mixed volume} \]
\[ TT_{ME} = \text{total sediment trap efficiency} \]
\[ U = \text{cross sectional water flow velocity in the longitudinal direction in } [\text{L/T}] \]
\[ U_s = \text{surface loading velocity in } [\text{L/T}] \]
\[ V_w = \text{existing water volume in micropool before the event} \]
\[ V_R = \text{annual runoff volume in } [\text{L}^3] \]
\[ V_S = \text{annual sediment by volume in } [\text{m}^3] \]
\[ W = \text{average basin's width in } [\text{L}] \]
\[ W_s = \text{annual sediment by weight in } [\text{kg}] \]
\[ \Delta X_i = \text{fraction for the } i\text{-th grain size} \]
\[ x = \text{distance in the longitudinal direction} \]
\[ z = \text{vertical distance in gravity direction} \]
\[ \beta = \text{mixing coefficient} \]
\[ v = \text{water viscosity in } [\text{L}^2/\text{s}] \]
\[ \omega = \text{particle's fall velocity in } [\text{L/T}] \text{ in the gravity direction} \]