Irrigation & Drainage Systems Engineering

Research Article Open Access

Green Concept in Storm Water Management

James C.Y. Guo*

Professor and Director, Dept. of Civil Engineering, University of Colorado Denver, USA

Abstract

Storm runoff is considered one of important water resources for urban areas. Over a geologictime, streams and lakes are periodically refreshed with flood water and continually shaped with the flood flows. Urban development always results in increases of runoff peak rates, volumes, and frequency of higher flows. As a result, flood mitigation has become a major task in urban developments. Before 1970's, storm water drainage systems in an urban area were designed to remove flood water from streets as quickly as possible. From 1970 to 1980, the US EPA conducted a nationwide stormwater data collection and reached a conclusion that stream stability is more related to frequent, small storm events rather than the extreme, large events. Since man-made stormwater systems were designed to pass extreme events, the large inlets and outlets release frequent events without any detention effect. As a result, urban pollutant and sediment solids are transported and deposited in the receiving water bodies. Under a US Congress mandate starting in 1980's, a nationwide stormwater best-management-practices (BMPs) program was developed and implanted in major metropolitan areas. The tasks in BMPs include: (1) retrofitting the existing drainage facilities to achieve a full-spectrum control on peak flows, and (2) applications of Low-Impact -Development (LID) designs to reduce runoff volumes under the post-development condition. With the latest observations in climate change, the uncertainty in the design floodhas imposed unprecedented challenges in flood mitigation designs. The flexibility in freeboards and easements need to be refined in order to accommodate the changes in extreme rainfall events. This paper presents a summary of the Green approach in stormwater management and LID designs as the engineering measures to preserve the watershed regime.

Keywords: Stormwater; BMP; LID; Detention; Urban drainage; Green concept

Introduction

Before 1970's, designs of urban drainage systems were mainly aimed at efficient removal of stormwater from streets for traffic safety [1]. Urban drainage systems were essentially sized to pass extreme events. Under the concept of "bigger is better", urban areas were equipped with street gutters, inlets, culverts, and storm drains. From 1970 to 1980, the US EPA conducted a nation-wide investigation on urban storm water [2]. As reported, urbanization process results in tremendous increases in storm runoff rates, volumes, and frequencies of high flows. Also it is confirmed that man-made drainage systems are efficiently transport urban pollutants into receiving water bodies. These findings trigger the 1972 Federal Clean Water Act. Under a Congress mandate, all metro areas in the US must improve the urban drainage systems to protect urban water environment. This paper documents the evolvement of the green concept from Best Management Practices (BMPs) to Low-Impact-Development (LID) in storm water management and flood mitigation.

Basic problems in urban storm water

Since 1970's, storm water detention was introduced to mitigate urban flooding problems [3,4]. As suggested, a sewer trunk line shall drain into a detention basin before the storm runoff is released into the downstream water body [5]. The storage effect in a detention basin reduces the peak flow and also delays the time to peak. Both conveyance and storage systems are utilized to drain and to store excess storm water. This practice implies that both runoff volume and flow rate shall be taken into consideration when sizing an urban drainage network [6,4].

As illustrated in Figure 1, an urban lot is composed of impervious and pervious surfaces. Under a rainfall event, overland flows are produced from roofs, pavements, and driveways. As a shallow and wide sheet flow, overland flows sweep streets, and carry urban pollutants and debris. After a concentrated flow is formed, the peak flow is accumulated along the waterway. Wherever the peak flow exceeds the capacity of the drainage system, flooding problems occur. A shown in Figure 2,

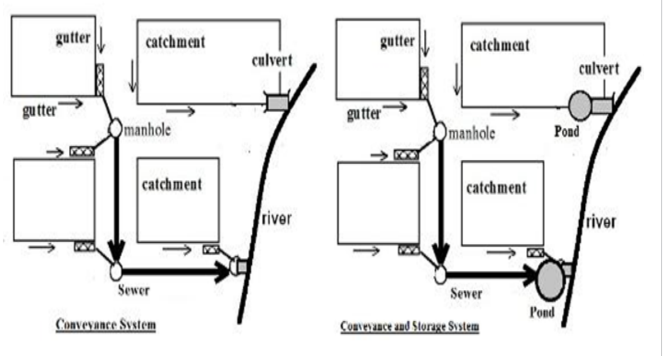


Figure 1: Urban Drainage Systems.

the *V-problem* is referred to as the storm water quality issues that are directly related to the shallow water depths in overland flows, while the *Q-problem* is referred to as the flooding issues that are caused with the concentrated flow [7]. Under the mandate of the 1972 Federal Clean Water Act, the *V-problem* is associated with water quality enhancement, while the Q-problem is related to flood mitigation. Under the green concept for storm water management, there are two distinct approaches developed to cope with these two problems:

(1) How to reduce the increased on-site runoff volume from the

***Corresponding author:** James C.Y. Guo, Professor and Director, Dept. of Civil Engineering, University of Colorado Denver, USA, Tel: 303-556-2849; Email: James.Guo@ucdenver.edu

Received October 16, 2013; **Accepted** December 16, 2013; **Published** December 20, 2013

Citation: Guo JCY (2013) Green Concept in Storm Water Management . Irrigat Drainage Sys Eng 2: 114. doi:10.4172/2168-9768.1000114

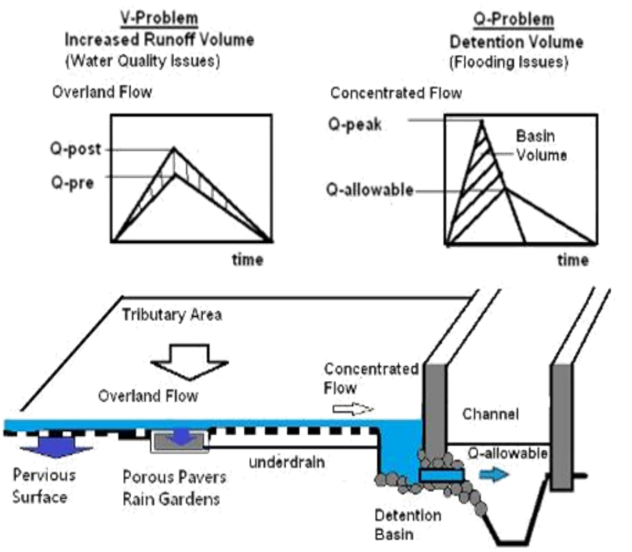


Figure 2: V- and Q-problems Associated with Urban Stormwater Runoff.

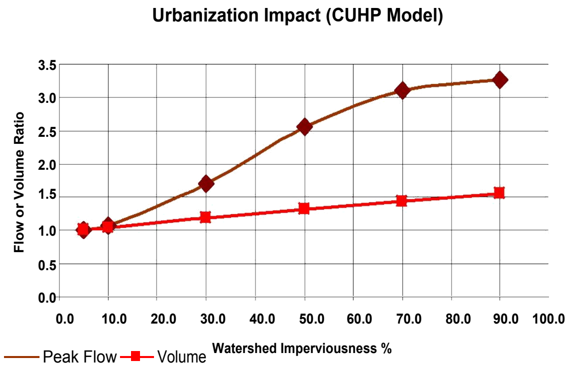


Figure 3: Urbanization Impacts on Runoff Volumes and Flow Rates.

post-development to the predevelopment condition using LID devices such as porous pavers, rain gardens etc., [8] and

(2) How to regulate the flow releases from the post-development peak flows to the allowable flow rates using detention and retention facilities at strategic locations [9,10].

The key factor in urban hydrology is watershed imperviousness. Urban development always leads to more pavements, roofs, driveways, and parking lots. All these changes in land use increase the area-imperviousness percent. Figure 3 presents the impact of increased watershed imperviousness on the increases of runoff volumes and peak flows. Using the case of imperviousness of 5% as the basis, the peak flow will be increased 3.25 times and the runoff volume will be increased 1.5 times after the watershed is developed to an area-imperviousness of 90% [11,12]. Figure 3 implies that an effective urban drainage system should be designed to dispose the local increased runoff volume through the on -site infiltration practices, and then to convey the excess runoff flows to the strategic locations where storm water storage practices can be implemented to reduce the post-development flows to its pre-development condition. In the last decade, there are various methods developed to mitigate stormwater *V-and Q-problems.* In general, the *V-problem* is alleviated with on-site infiltration -based devices, while the Q-problem is managed with extended storm water detention process [13].

Green approach for urban drainage planning

The 1972 *US Federal Clean Water Act* has significantly expanded storm water management in the United States from flood mitigation into both storm water quality and quantity controls. As recommended, an urban drainage plan shall observe the following steps [14]:

(1) Minimize the Directly Connected Impervious areas (MDCIA),

(2) Dispose on-site runoff volume using LID devices,

(3) Convey concentrated runoff using a cascading flow system,

(4) Store runoff flows at strategic locations,

(5) Control flow release at the pre-development rate and frequency,

(6) Apply erosion and sediment controls at all construction sites.

Applications of the above are discussed in details in the following sections.

Land use under Mdcia practice: The watershed's response to a rainfall event is very sensitive to how the storm drains are networked together. Conventionally, roof areas are connected together through roof gutters that collect storm runoff from roofs and then drain onto the driveways. All driveways are linked through storm drains to pass storm water directly to the adjacent streets. This drainage pattern is termed *Distributed System*. A distributed flow system is efficient to remove storm water, but it tends to result in higher peak and faster runoff flows. As illustrated in Figure 4, a distributed flow system uses two independent flow paths to drain storm water from the pervious and impervious areas separately, while a cascading flow system in Figure 5 is laid to spread storm water from the upper impervious area onto the lower pervious area.

Under the concept of MDCIA, a LID device or grass swale is placed between two adjacent impervious areas to slow down runoff flows for the purpose of filtering and infiltration benefits. As a rule of thumb, the impervious area is 2 to 3 times the receiving pervious area. For instance, a case of 3 units of impervious area draining onto one unit pervious area will result in an area-impervious percentage of 75% [7].

In practice, the land uses within the project site hardly result in a complete interception of the cascading flow. As recommended in Figure 6 EPA SWMM, the catchment is divided into the upper impervious and the lower pervious areas. Mathematically, the intercepted runoff volume generated from the upper impervious area is directly added to the lower pervious area as:

$$V_R = PA \tag{1}$$

$$V_P = m[r(P-D_{vi})I_a A + (P-D_{vp}-F)(1-I_a)A] \tag{2}$$

Where V_R=rainfall volume in [L^3], P=precipitation depth in [L per watershed], A= watershed area in[L^2], V_p=runoff volume from pervious area in [L^3], D_{vi} = depression loss on impervious area in [L], I_a = impervious area ratio, D_{vp}=depression loss on pervious area in [L], F=infiltration amount in [L], m = 1 if V_p>0 or 0 if V_p≤0, and r = flow interception ratio of V_m. When r=1, Eq (2) represents a complete flow interception, while r=0, Eq (2) reproduces the flow condition in a distributed flow system. For $0<r<1$, the residual runoff volume is directly released to the street as:

$$V_m = (1-r)(P-D_{vi})I_a A \tag{3}$$

Citation: Guo JCY (2013) Green Concept in Storm Water Management . Irrigat Drainage Sys Eng 2: 114. doi:10.4172/2168-9768.1000114

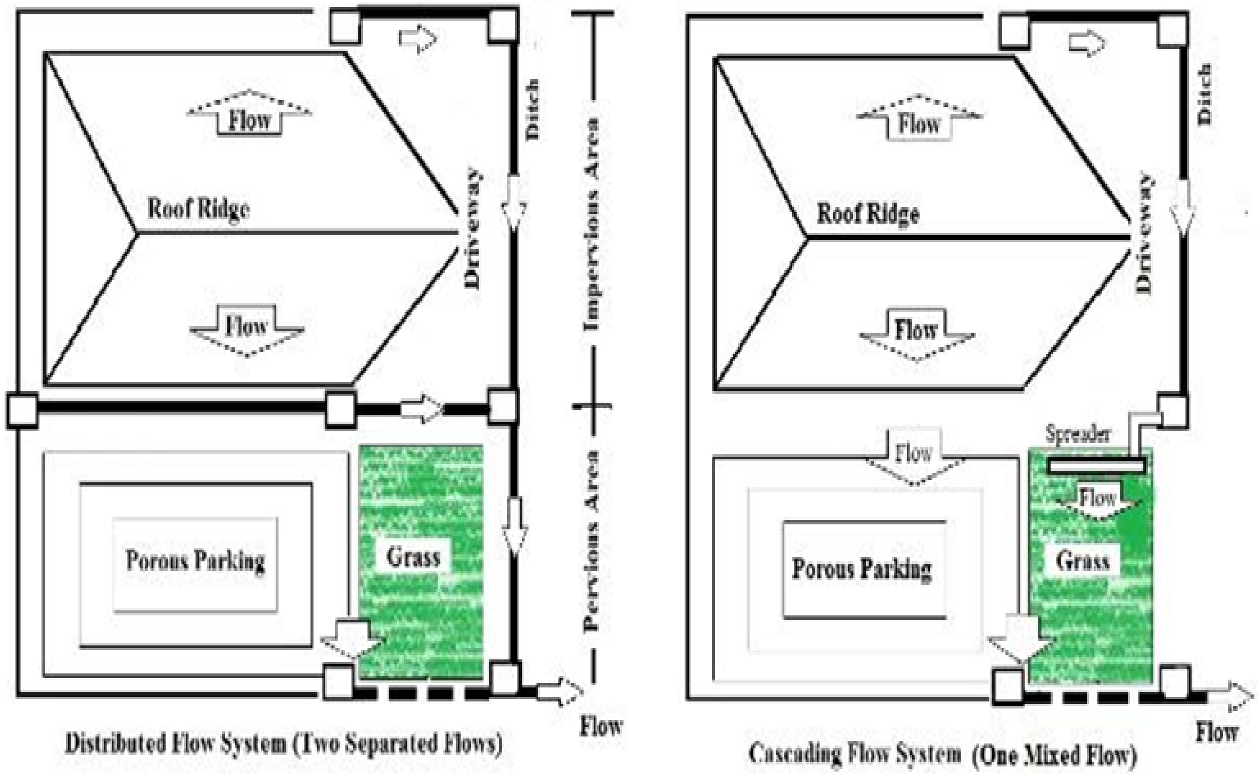


Figure 4: Distributed and Cascading Drainage Systems.

Figure 5: Examples of MDCIA Practice.

V_m = runoff volume from impervious area in [L^3]. The resultant runoff coefficient is calculated as:

$$V_F = V_P + V_m \quad (4)$$

$$C = \frac{V_F}{V_R} = (1-r)(1-\frac{D_{vi}}{P})I_a + m[r(1-\frac{D_{vi}}{P})I_a + (1-\frac{D_{vp}}{P} - \frac{F}{P})(1-I_a)] \quad (5)$$

Where C=runoff coefficient. For a distributed flow system, r=0 or Eq (5) is reduced to

$$C = \frac{V_F}{V_R} = (1-\frac{D_{vi}}{P})I_a + m(1-\frac{D_{vp}}{P} - \frac{F}{P})(1-I_a) \quad (6)$$

Like the rational method, the runoff coefficients in Eq (5) and (6) are linear with respect to watershed imperviousness. As a sum of two separated flows, Eq (6) is always dominated by the impervious areas or V_m. Numerically, runoff coefficients in Eq (6) is always greater than zero as long as $P>D_{vi}$.

Eq 6 has been tested and accepted in UDSWCM 2001 update. Considering Denver's hydrologic parameters: D_{vi} =0.1 inch, D_{vp}=0.4 inch, F=0.88 inch, P_1= 2.6 inch for the 100-yr event, 1.35 inch for the 5-yr event, and 0.95 inch for the 2-yr event, the 100-, 5- and 2-yr runoff coefficients for a cascading flow system are produced and presented in Fig 6. For comparison, the effect of cascading flow was tested for 3 cases, including r=0 (no flow interception), r=0.5 (50% of flow intercepted), and r=1.0 (100% flow interception) . Under an impervious percent of 45%, a case of complete flow interception results in a reduction of runoff coefficient from 0.4 to 0.2.

On-Site Stormwater disposal using lid design: Porous pavements and rain gardens (RG) were first tested in the State of Maryland in 1993. Over the years, they have spread out as the most popular infiltrating practice in the USA for storm runoff on-site treatment devices [15-17]. As illustrated in Figure 7, both rain gardens and pavers are structured as a two-layered basin. The surface basin in a RG is designed to intercept the water quality capture volume (WQCV) with a maximum water depth from 12 to 15 inches (30.5 to 38 cm).

A RG is often covered with selected grass and plants. During an intense event, the surface basin will be filled up to its maximum capacity, and then the excess storm water overflows into the downstream manhole. The subsurface filtering layers underneath a RG consist of an upper sand-mix layer of 18 inches (45.7 cm), a lower gravel layer of 8 inches (20.3 cm), and a sub-drain system that is formed with 4 -inch (10.2 cm) perforated pipes networked together to drain infiltrating water into an adjacent manhole [18].

Water Quality Capture Volume (WQCV) in a RG is the storage volume reserved for the water quality treatment. The infiltration pool is constructed with a filtering and infiltrating bed to dispose WQCV into the local groundwater table for water recharge. As reported [19],WQCV was empirically derived from the break-even point on the distribution of runoff-depth population. A WQCV is found to be equivalent to the rainfall amount of 3- to 6-month event. Furthermore, the one-parameter exponential distribution was adopted to describe the frequency distribution of rainfall event depths [20]. The exponential distribution is described as:

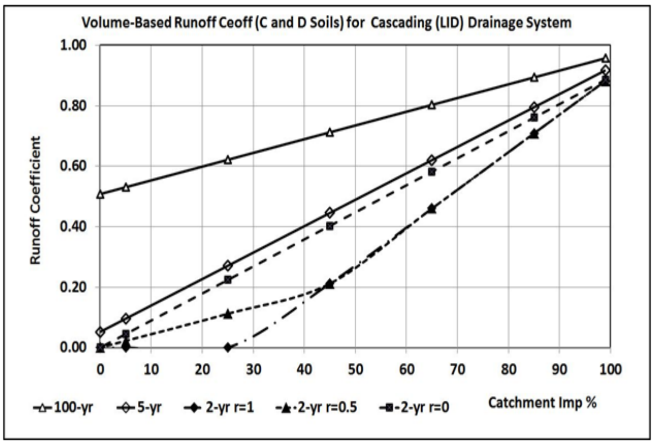


Figure 6: Runoff Coefficients for Cascading Flow System.

$$f(D) = \frac{1}{D_m} e^{\frac{-D}{D_m}} \qquad 7$$

in which $f(D)$ = frequency of rainfall event-depth, D, and D_m = average rainfall event-depth. The WQCV can then be related to its design rainfall depth, D, as:

$$V_o = C(D - D_i) \qquad 8$$

in which V_o= *WQCV* in mm per watershed, C= runoff coefficient, D = design rainfall depth, and 8D_i = incipient runoff depth recommended to be 2.5 mm. Aided with Eq 7, Eq 7 can be integrated into

$$C_v = P_D(0 \le V \le V_o) = P_D(0 \le d \le D) = 1 - ke^{\frac{-V_o}{CD_m}} \text{ and } k = e^{\frac{-D_i}{D_m}} \qquad 9$$

in which C_v = runoff volume capture rate between zero and unity, V_o= *WQCV* selected for design, $P_D(0V\ V_o)$ = probability to have an event that produces a runoff depth less than V_o. The value of k is definedby the incipient runoff depth and the average event rainfall depth. The value of k varies in a narrow range between 0.80 and 0.90. Eq 9 represents the synthetic runoff capture curves normalized by local average rainfall event-depth, runoff coefficient, and runoff incipient depth. Figure 8 presents a set of generalized runoff capture curves produced using Eq 9 with runoff coefficients of 0.4, 0.6, 0.8, 0.9, and 1.0. It is noticed that the curvature of runoff capture curve increases when the runoff coefficient decreases. The runoff capture curve becomes almost a linear response between rainfall depth and runoff amount when C=1.0. This tendency reflects the fact that the higher the imperviousness in a watershed, the less the surface depression and detention. As a result, the response of a watershed to rainfall is quick and direct. As recommended [19],a WQCV basin will intercept up to 80% of runoff flow population, and bypasses the top 20% larger events.

The uncertainty in a RG's operation is directly related to its infiltration rate through the filtering layers. Considering clogging effects, the design infiltration rate is defaulted to be 1.0 inch/hr (2.5 cm/hr) [21]. In fact, a newly constructed RG may have an infiltration rate as high as 10.0 to 15 inch per hour (25.4 to 38.1 cm/hr) [18]. Over the years in service, the infiltration rate in the RG is gradually reduced due to clogging effects. In practice, a RG can be an independent unit, or nested in the bottom of an extended detention basin [22].

Conveyance system for multiple design events: Urban stormwater drainage systems are designed or renewed to have three layers of cascading flows. They are Micro, Minor and Major Flow Systems as shown in Figure 9 and Figure 10. Storm runoff generated from

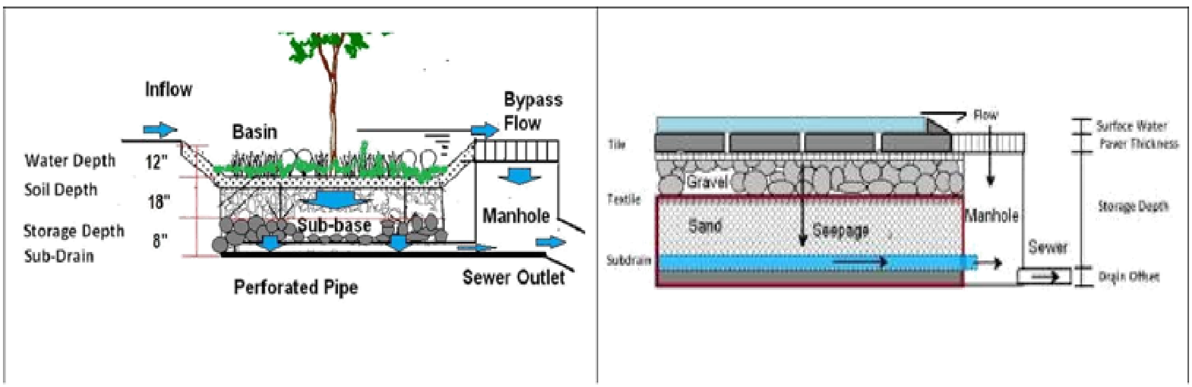


Figure 7: Layout Of Rain Garden And Porous Paver.

Citation: Guo JCY (2013) Green Concept in Storm Water Management . Irrigat Drainage Sys Eng 2: 114. doi:10.4172/2168-9768.1000114

impervious surfaces shall be drained onto a Micro Flow System for water filtering and infiltration. A micro flow system consists of porous pavers, grass swales, bio-retention basins that are designed to treat the WQCV [23]. Overflows from a micro facility will be drained into the that consists of street inlets and storm drains. After the underground storm sewers become full, the excess storm water will be carried on the streets which are considered the Major Flow System. A micro drainage system is also termed LID facility. In practice, a LID facility is composed of a surface storage basin and subsurface filtering layers. Most porous pavers are conveyance-based with a thin water depth on the surface, while a bio-basin is a storage -based facility with 12- to 18-inch (30- to 45-cm) depth of water in the surface basin. A storage-based LID is also called bio-retention, rain garden, or landscaping detention basin.

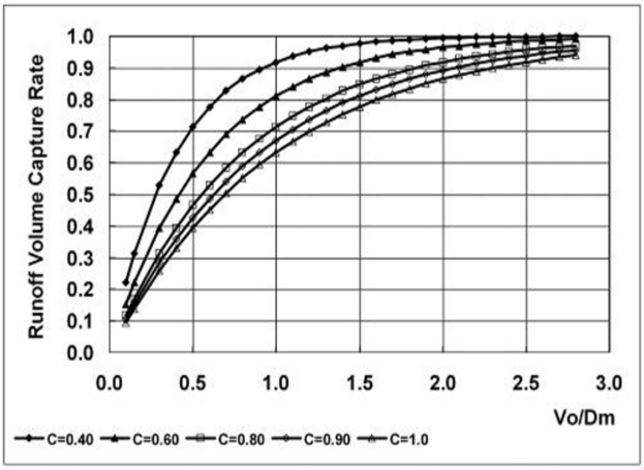


Figure 8: Water Quality Capture Volume.

Detention system for flow release control: As illustrated in Figure 11, the storm water detention volumes for the 10- and 100 -yr events are determined using the post-development hydrographs and allowable release rates [24,25]. In practice, the allowable release rate is directly related or equal to the pre-development peak flow. For convenience, the after-detention hydrograph is approximated using a linear rising limb to the allowable flow. The required detention volume is the difference between the post-development and after-detention hydrographs.

Similarly, a detention system in Figure 12 is designed to have 3 layers of storage volumes when shaping the basin's geometry. The bottom layer provides the required WQCV for micro events. The mid and upper layers are designed to control flow releases for the minor (or 10-yr) and

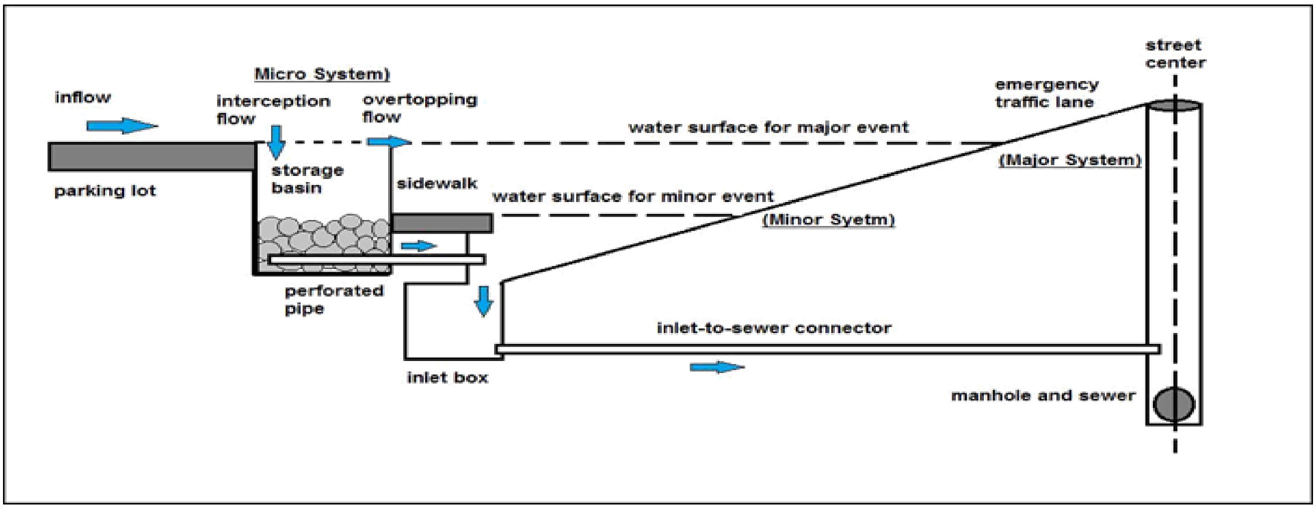


Figure 9: Micro-Minor-Major Conveyance Systems In Street.

Minor and Major System	*Micro, Minor, and Major Systems*

Figure 10: Comparison of Conventional and Renewed Urban Drainage System.

Citation: Guo JCY (2013) Green Concept in Storm Water Management . Irrigat Drainage Sys Eng 2: 114. doi:10.4172/2168-9768.1000114

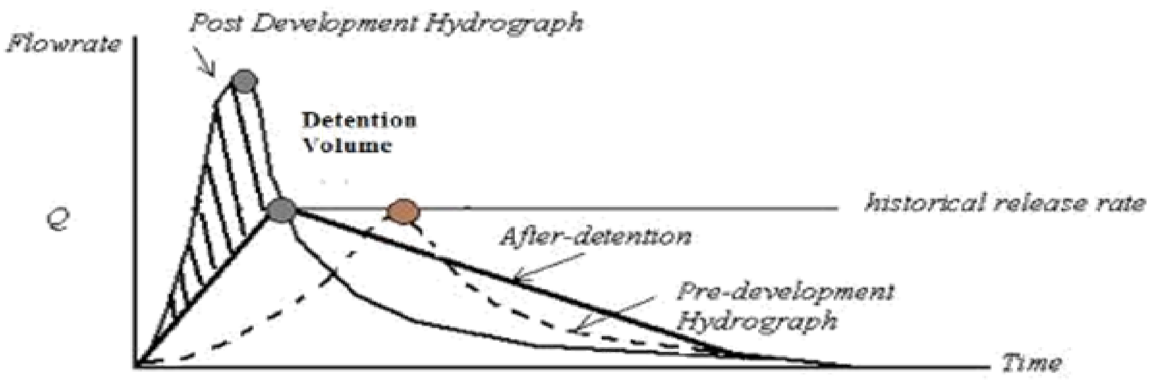


Figure 11: Stormwater Detention Volume.

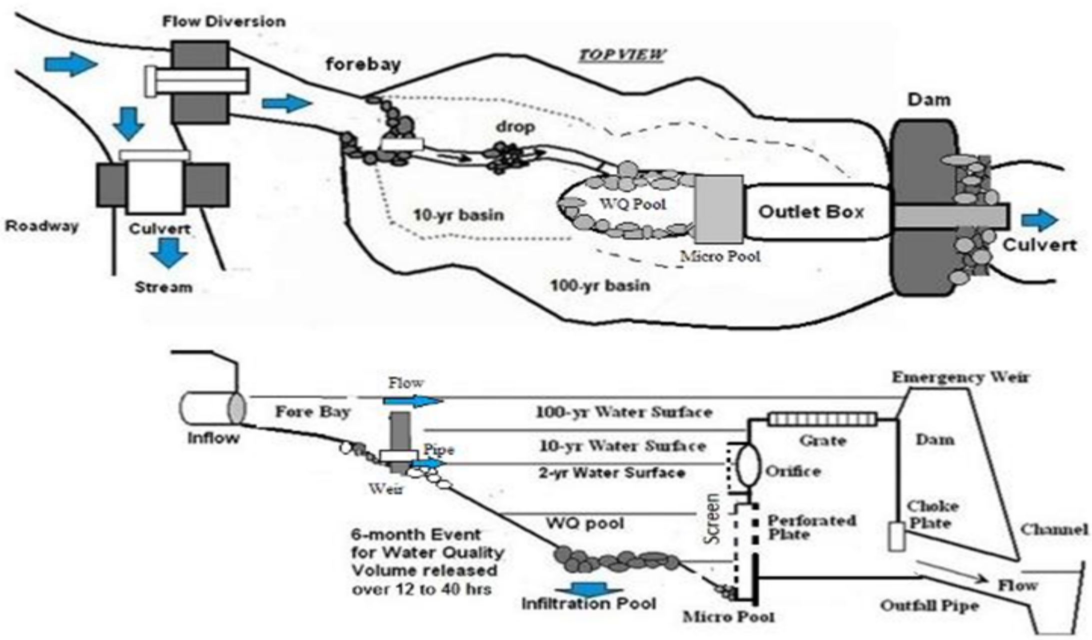
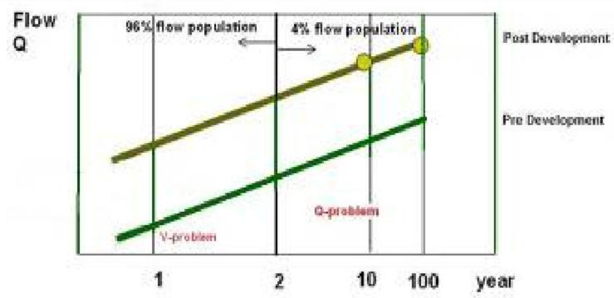


Figure 12: Multiple Layered Detention System.

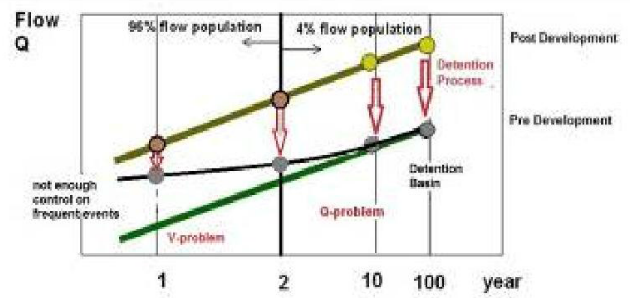
Detention Basin	Outlet Structure

Figure 13: Example of Urban Detention Basin and Outlet Structure.

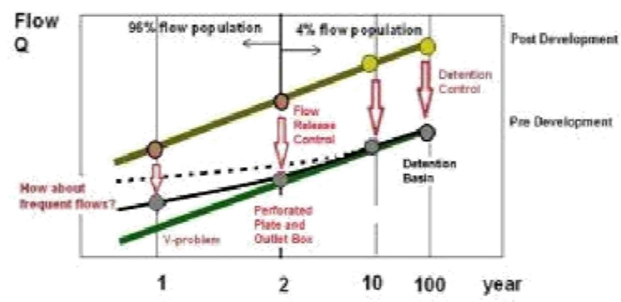
Citation: Guo JCY (2013) Green Concept in Storm Water Management . Irrigat Drainage Sys Eng 2: 114. doi:10.4172/2168-9768.1000114



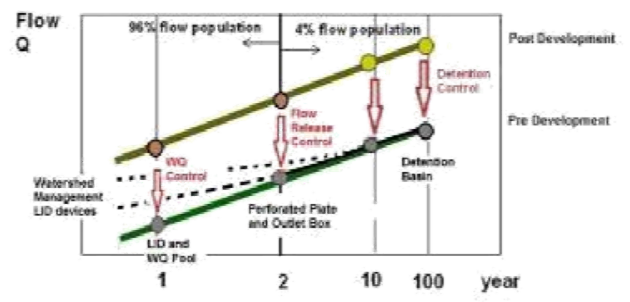
Without any mitigation on post-development flows



Using 10- and 100-yr detention for flow release control



Using WQCV, 10-, and 100-yr extended detention for flow release control



Using on-site LID, WQCV, 10-, and 100-yr extended detention for flow release control

Figure 14: Impact of Stormwater Mitigation on Watershed Regime Preservation.

major (or 100-yr) events. These two layers add more storage volumes to control the flow releases from the 10- to 100-yr events. A fore bay at the entrance is designed to have a low flow pipe and an overtopping weir. All low flows will bed rained through the pipe opening, while high flows overtop the weir. The settlement process at the fore bay will trap solids>1 mm in diameter. From the fore bay to the WQCV pool is a lined trickle channel. The WQCV pool is sized for the purpose of water quality enhancement, and placed immediately upstream of the outlet structure. The outlet structure in a detention basin is also designed as a 3 -layer outlet system, including a micro-flow outlet using a perforated plate or a vertical riser, a minor-flow outlet using a vertical orifice, and a major-flow outlet using a horizontal grate on top of the structure. A micro pool in Figure 13 is always preferable because it serves as a siphon in case that the orifice and riser are clogged [26,27].

Evaluation of green storm water management: The Green concept in storm water management is to apply a micro-scale on-site design strategy with a goal of maintaining or replicating the predevelopment hydrologic regime [28]. The natural hydrologic functions of storage, infiltration, and ground water recharge, as well as the volume and frequency of runoff flows are maintained using integrated and cascading flow systems. In practice, the qualitative goal for a Green storm water strategy is translated into various functional landscapes that act as on-site or regional storm water facilities for storm water flow, volume, frequency, and WQ controls. Although many hydrologic methods have been developed for event-based analyses [29],the ultimate goal of a LID design is in fact to warrant the preservation of the hydrologic regime [30]. For instance, the long-term runoff statistics may be employed as the basis to quantify the impact of the development on the watershed hydrologic regime [31]. A standard detention volume is defined by the storm water storage volume required to preserve the mean and standard deviation of runoff volume population under the predevelopment condition. Consequently, a detention basin is considered oversized if the after-detention runoff volume population has a lower mean flow, while a undersized detention basin produces a mean flow higher than that under the pre-development condition.

As illustrated in Figure 14, the upper left case is the 1950 to 1970 conventional approach that has neither flood mitigation nor WQ control. The upper right case is the 1970 to 1980 detention approach that was developed for extreme-event controls only. The lower left case is the 1980 to 2000 extended detentions approached that provides a full -spectrum flow control (EPA 2007). The last one shows the complete mitigation using on-site LID's for watershed improvements and regional extended detention basins for peak flow reduction. The flow-frequency relationship represents the watershed's response in flow rates to local rain storms. Figure14 is a recommended measure to quantify the preservation of watershed regime [31]. Of course, watershed regime is characterized more than flow rates. The latest development in the US EPA's studies, flow-duration curves are also recommended as one of the basic approaches to quantify the impact of development. A flow duration curve presents the distribution of both flow rate and flow frequency [32]. Flow-duration curves have to be produced from the long-term continuous storm water simulations for both pre- and post-development conditions. This new approach will set a higher standard for storm water simulation to become more a full-spectrum flow release control rather than the extreme events only.

Conclusion

In the last 3 decades, the Green concept for storm water management has been evolved from BMP's into LID. Many Green innovative ideas for urban renewal are still on the rising swing. The ultimate goals of Green storm water management are to protect, maintain and enhance the public health, safety, and general welfare by establishing minimum requirements and procedures to reduce the adverse impacts associated with increased storm water runoff. Many innovative engineering concepts and methods have been developed to apply environmental on-site facilities to the maximum extent practicable (MEP) to reduce stream channel erosion, pollution, siltation, sedimentation, and local flooding, and to use appropriate structural best management practices (BMPs) only when necessary. The Green storm water approach will restore, enhance, and maintain the chemical, physical, and biological integrity of streams, and to minimize damage to public and private property, and reduce the impacts of land development. Apparently, the trend in storm water engineering practice is continually being shifted from an event-based approach to a long- term continuous simulation, and also from flood flow control to storm water quality and quantity controls. Any and all urban drainage facilities must be designed to mimic the pre-development hydrologic condition for all events. A new innovative stormwater approach will be tested, monitored, and then evaluated with its outcomes for both stormwater management and flood mitigation. In the near future, retrofitting the existing drainage facilities and maintaining the new systems will become joint efforts for urban renewal projects. The Green concept will lead to a softer, cooler, cleaner, and more balanced water environment in urban cities.

References

1. Chow VT, Maidment David R, Mays Larry W (1998) Applied Hydrology, McGraw Hill Book Company, New York, USA.
2. EPA Report (1983) Results of the Nationwide Urban Runoff Program. U.S. Environmental Protection Agency, Washington DC, USA.
3. Guo James CY (2004) Hydrology-Based Approach to Storm Water Detention Design Using New Routing Schemes. J Hydrol Eng 9: 333-336.
4. Guo James CY (2007) Stormwater Detention and Retention LID systems. Journal of Urban Water Management.
5. USWDCM (2001) Urban Storm Water Design Criteria Manual, Urban Drainage and Flood Control District, Denver, Colorado, USA.
6. Guo James CY (2003) Design of Infiltrating Basin by Soil Storage and Conveyance Capacities. Int J Water 28: 411-415.
7. Guo James CY, Blackler EG, Earles A, MacKenzie K (2010) Effective Imperviousness as Incentive Index for Stormwater LID Designs. J Environ Eng 136: 1341-1346.
8. Guo James CY, Hughes William (2001) Runoff Storage Volume for Infiltration Basin. J Irrig Drain Eng 127: 170-175.
9. Guo James CY (2009) Retrofitting Detention Basin for LID Design with a Water Quality Control Pool. J Irrig Drain Eng 135: 671-675.
10. Guo James CY, Cheng JYC (2008) Retrofit Storm Water Retention Volume for Low Impact Development (LID). J Irrig Drain Eng 134: 872-876.
11. Blackler G, Guo James CY (2013a) Field Test of Paved Area Reduction Factors using a Storm Water Management Model and Water Quality Test Site. J Irrig Drain Eng.
12. Blackler G, Guo James CY (2013b) Paved Area Reduction Factors under Temporally Varied Rainfall and Infiltration. J Irrig Drain Eng 139: 173-179.
13. Guo James CY, Urbonas B, MacKenzie K (2011) The Case for a Water Quality Capture Volume for Stormwater BMP. J Stormwater.
14. Guo James CY, Urbonas B (2013) Volume-based Runoff Coefficient. J Irrig Drain Eng.
15. Booth DB (1990) Stream-channel Incision Following Drainage Basin Urbanization. Water Resour Bull 26: 407-417.
16. EPA Report (2006) Low Impact Development Methods. U.S Environmental Protection Agency, Washington DC, USA.
17. EPA Report (2007) Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices. U.S. Environmental Protection Agency, Washington DC, USA.
18. Guo James CY, Kocman S, Ramaswami A (2009) Design of Two-layered Porous Landscaping LID Basin. J Environ Eng 135: 1268-1274.
19. Guo James CY, Urbonas Ben (2002) Runoff Capture and Delivery Curves for Storm Water Quality Control Designs. J Water Resour Plann Manage 128: 208-215.
20. Guo James CY (2002) Overflow Risk of Storm Water BMP Basin Design. J Hydrol Eng 7.
21. Guo James CY (2012b) Cap-orifice as a Flow Regulator for Rain Garden Design. J Irrig Drain Eng 138: 198-202.
22. Guo James CY, Shih HM, MacKenzie K (2012) Stormwater Quality Control LID Basin with Micro pool. J Irrig Drain Eng 138:
23. Guo James CY (2008) Runoff Volume-Based Imperviousness Developed for Storm Water BMP and LID Designs. J Irrig Drain Eng 134: 193-196.
24. Guo James CY, Clark J (2006) Rational Volumetric Method for Off-line Storm Water Detention Design. Journal of PB Network for Water Engineering and Management 21.
25. Guo James CY (2012a) Off-stream Detention Design for Stormwater Management. J Irrig Drain Eng 138: 371-376.
26. Jones J, Guo JCY, Urbonas B (2006) Safety on Detention and Retention Pond Designs. J Storm Water.
27. Waugh PD, Jones JE, Urbonas BR, MacKenzie KA, Guo JCY (2002) Denver Urban Storm Drainage Criteria Manual. Journal of Urban Drainage 112.
28. LID-Practice (2003) The Practice of Low Impact Development, US Department of Housing and Urban Development, Office of Policy Development and Research, Washington DC, USA.
29. LID-Hydro Analysis (1999) Low--Impact Development Hydrologic Analysis, Prince George's County, Department of Environmental Resources Programs and Planning Division, Maryland, USA.
30. LID-Strategy (1999) Low-Impact Development Design Strategies: An Integrated Design Approach, Prince George's County, Department of Environmental Resources Programs and Planning Division, Maryland, USA.
31. Guo James CY (2010) Preservation of Watershed Regime for Low Impact Development using (LID) Detention. J Hydrol Eng 15: 15-19.
32. EPA Report (2008) Development of Duration-Curve Based Methods for Quantifying Variability and Change in Watershed Hydrology and Water Quality. U.S. Environmental Protection Agency, Washington DC, USA.

Citation: JCY (2013) Green Concept in Storm Water Management . Irrigat Drainage Sys Eng 2: 114. doi:10.4172/2168-9768.1000114