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Review Article

# Introduction of Level Spreader Systems and Evaluation of the Land Imperviousness for Storm Water Management

**Jeffrey YC Cheng [1*] , Wang Xin Xia [2]**

[1] Department of Hydrologist and Environmental Engineer, St. Cloud State University, USA

[2] Deputy Chief Executive Officer, Hunan University Design And Research Institute Co., Ltd., China

[*] **Corresponding author:** Jeffrey YC Cheng, Department of Hydrologist and Environmental Engineer, St. Cloud State University, USA. Tel: +13203081049; Email: cycheng@stcloudstate.edu

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## Abstract

Level Spreaders commonly uses in combination with riparian buffers as a stormwater Best Management Practice (BMP) in many parts of the United States. These systems have not been extensively studied in urban environments to determine the impact on the flow path, nor do level spreaders have a complete detailed design guideline. This paper provides the Kinematics wave cascading model and runoff volume analysis as numerical techniques to model a level spreader system for comparison between effective imperviousness and traditional area weight method imperviousness.

**Keywords:** Cascading plane; Groundwater recharge; Imperviousness rate; Kinematics wave; Low Impact Development; Level spreader; Stormwater quality; Watershed

## Introduction

Urban stormwater quality problems result from urban growth and development. Without adequate environmental control practices, runoff pollution occurs when storm runoff washes the pollutants from urban landscapes and carries debris to receiving waters. Stormwater BMPs offer practical solutions to enhance the runoff filtering processes using various delivery and storage facilities.

Stormwater quality control BMP considers stormwater a natural resource and captures runoff through stormwater storage facilities including, wet ponds, wetlands, vegetative filters, and various infiltration practices. The concept of BMP takes the four following steps to manage on-site storm water [1]:

**Step 1:** Reduce runoff peaks and volumes by Minimizing Directly Connected Impervious Areas (MDCIA),

**Step 2:** Provide Water Quality Capture Volume (WQCV) for an on-site retention process,

**Step 3:** Stabilize downstream banks and stream beds along the waterways,

**Step 4:** Implement BMPs for special needs for industrial and commercial developments within the tributary area.

The major negative impact of urban stormwater is erosion and water quality issues. Low Impact Development (LID) design stragy introduce to the BMP for site design to solve these issues. A relatively new concept, in stormwater management, LID was proposed by Prince George's County, Maryland, in the early 1990s [2]. The goal of LID is to maintain or replicate the pre-development hydrologic regime through the use of design techniques to create a functionally equivalent hydrologic landscape. LID widely apply to urban stormwater management in recent years.

MDCIA is a commonly utilized strategy in LID. The principle behind MDCIA is twofold: to reduce impervious areas, and to direct runoff from impervious surfaces over grassy areas to slow down runoff and promote soil infiltration. Draining paved areas onto porous areas can reduce runoff volumes, rates, pollutants, and cost for drainage infrastructure [1]. One example of the MDCIA technique is a level spreader, which is a horizontal drain that releases storm runoff through rows of holes to produce sheet flows onto a gently sloping, vegetated surface for infiltration. Level spreaders target the removal of solids through settling and interception by soil infiltration. In addition to stormwater quality enhancement, the level spreader system can also provide on-site stormwater reuse.

The major function of level spreaders is to diffuse concentrated stormwater flow onto an infiltrating bed or and allow the stormwater on site infiltration. The spreader width and the onsite infiltration volume are related. Thus, the method to estimate the on site infiltration volume through the grass buffer area is required. The basins imperviousness is a primal key parameter to predict the entire basin runoff volume and peak runoff flow rate. In the traditional area weight method, the imperviousness did not consider the storm runoff flow path, which may cause the stormwater runoff volume to be over or underestimated [3]. This study developed the effective imperviousness To count the stromwater infiltration loss on the overland flow path and evaluate the effecitve imperviousness base on the runoff volume. Moreover, it created a numerical model to trace the cascading overland flows with consideration of infiltration volume. The effective impervious rate can be determined based on knowing the rainfall depth, infiltration volume, and system outflow.

## Level Spreader System

As illustrated in (Figure 1), a level spreader system has three major components: Imperviousness area or catchments basin, storm drainage structure, and pervious infiltration beds. During a rainfall event, the stormwater from the imperviousness area is collected by the stormsewer system into a spearder and convert into the sheet flow to infiltrate to the pervious surface or infiltration beds.

The design criteria for the system base on the water quality treatment, site erosion protection, irrigation for the lascaping, and the operation and maintenance. The major impact factors are the topography of the site, the design rainfall intensity and depth, land use of the site, the soil of infiltration beds, and the maintenance. These criteria are:

- The system requires the hydrological model to balance the water budget and sheet flow velocity control.
- The overall imperviousness and the minimum required widths of spreader
- Avoid concentrating flows or routing flows to areas sensitive to stormwater flows such as steep slopes, erosive soils, building foundations, or neighboring properties.
- The spreader lip needs the elevation control (to be level) to create the sheet flow for infiltration area.
- The infiltration basin graded as a plan with a positive slope for the overland flow infiltration process. The soil needs to be sandy or mix sandy material.
- Eliminate the storm sewer pipeline and water quality pond by applying spreader system when possible.
- Site evaluation and medication may require after the system installed.

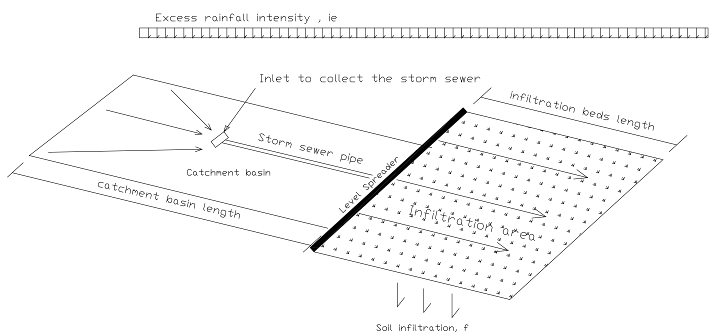


**Figure 1:** Level spreader system [3].

## Storm Catchment Basin (catchment basin)

The storm catchment basin upstream of the level spreader receives precipitation and collects runoff. Storm drainage system carries the storm flow to the level spreader and then diffuses it onto the downstream [4]. In most cases, the catchment basins usually have high imperviousness rate (impervious set as 100%) with a small amount of infiltration and depression volume capacity.

## Level Spreader

As (Figure 2) shows below, the level spreader structures are similar to concrete street inlets. The only difference between the two is that the street inlets collect runoff during a storm event, but level spreaders spread the runoff as sheet flow during the storm. During a major event, the storm runoff flow through both the spreader and storm drainage pipe. The level spreader structure transforms the concentrate flow into diffusive sheet flow with a control flow velocity to reduce the erosion and water quality impact.

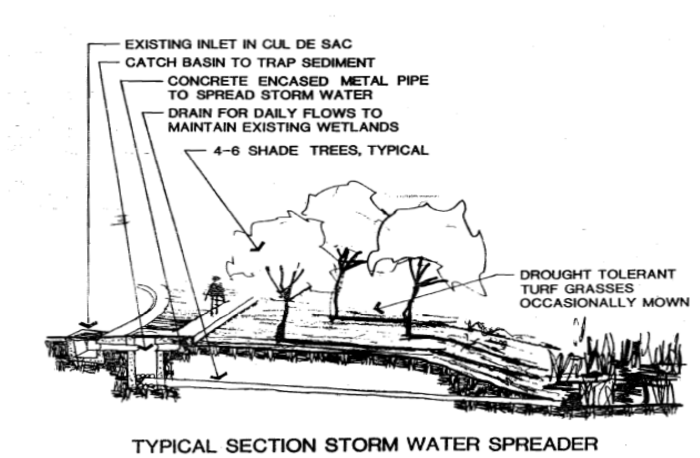


**Figure 2:** Typical Section Storm Water Spreader [5].


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As a rule of thumb, the spreader must evenly spread the runoff in the pipe. A simple design is to use a slotted CMP drain pipe shown in (Figure 3). The major functions of the level spreader are providing energy dissipation for the storm flow; reduce the flow velocity to protect infiltration basin erosion, convert the concentrated storm flow shown in (Figure 4) from drainage pipe into uniform sheet flows for even diffusion onto the infiltrating beds.

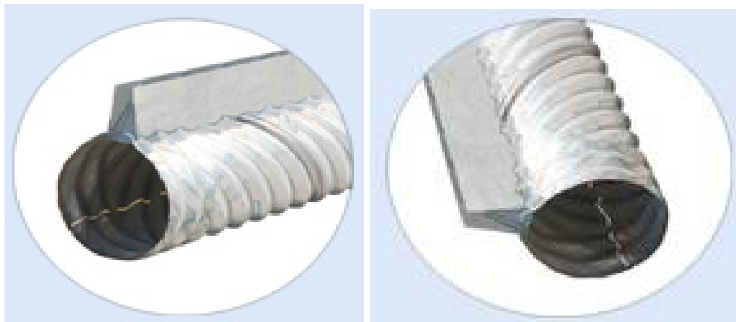

**Figure 3:** Typical CMP Drain pipe [5].

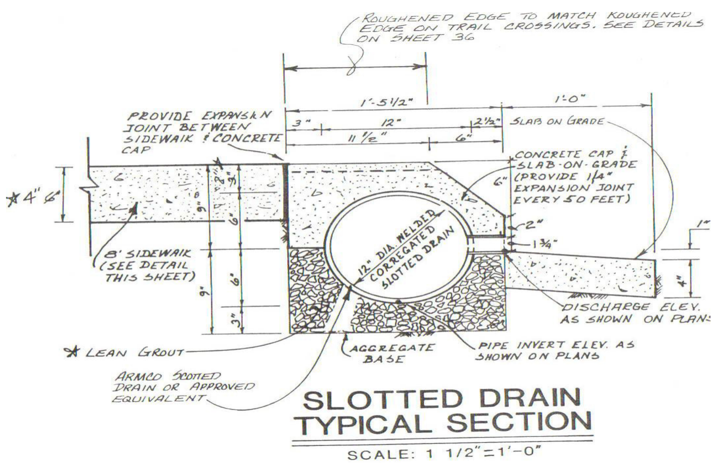


**Figure 4:** a detailed cross section for the spreader structure [5].

## Infiltration Beds

After the stormwater passes over the level spreader lip, the flow enters the riparian buffer, often called the buffer. As the stormwater passes through the buffer vegetation, the flow velocity decrease, which allows part of the water infiltrates and recharges to groundwater. Ideally, the buffer provides the filter effect to reduce the stormwater Total Suspended Solids.

The infiltration bed removes sediment and nutrients from runoff before it reaches the stream. Additionally, the infiltration bed needs high infiltration capacity soil to allow the upper catchment basin's storm outflow infiltrate and recharge the ground water.

## Cascading-Plane Model

The cascading-plane model is a distributed approach that applied on BMP designs when the overland flow paths allow onsite infiltration and the surface detention to the downstream [3], the landscape is defined shown in (Figure 5) right. In current practice, the micro-hydrology studies under the MDCIA concept demand an in-series flow system while the macro-hydrology approaches such as the rational method rely on a lumped parameter derived by the area-weighted method [3]. In this study, the cascading-plane model was applied to the specified level spreader layout to calculate the runoff hydrograph after the cascading process. In this paper, the effective imperviousness percentage is defined by the runoff to rainfall volumes. It expected that the cascading layout produces a low effective imperviousness percentage than the area-weighed method.

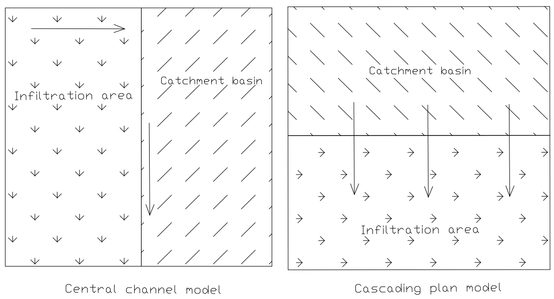


**Figure 5:** Central channel model and cascading plane model.

The function of a cascading landscape is to spread the runoff flow generated from the upper impervious plane onto the porous plane for additional infiltration [6]. In this study, a model of cascading planes shown in (Figure 5) is derived to simulate the overland flow through cascading planes. The upstream plane (catchment basin) is set to be 100% paved, and the downstream plane (infiltration beds) is set to be 100% unpaved with grass. Both planes are under the same rainfall event.

The continuity equation which describes the volume balance of inflow and outflow volumes within a finite time interval written as:

$$(Q_2 - Q_1)\Delta t + (A_2 - A_1)\Delta x = 0 \quad (1)$$

in which Q1=is the flow at cross section 1, Q2= is the flow at cross section2, A1 is the cross section area 1 A2 is the cross section area 2, Δ t= is the time different during flow travel Δx is the flow travel distance.

The kinematic wave theory has applied to the unit-width overland flow, the flow on a plane described as [6-8]:

$$\frac{\partial q}{\partial x} + \frac{\partial y}{\partial t} = i_e \quad (2)$$

in which q is the lateral flow runoff, y is the flow depth, i.e., is the rainfall excess.

The rainfall excess set to be as:

$$i_e = i - f \quad (3)$$

in which i is the rainfall intensity (L/T) and f is the soil infiltration rate (L/T) Re-arranging Eq 2 yields the finite difference form as:

$$\frac{\Delta Q}{\Delta x} = I_e - \frac{\Delta Y}{\Delta t} \quad (4)$$

The average values shal used for each time step. Eq 4 then converted into:

$$\frac{\overline{Q} - \overline{Q}_i}{\Delta x} = \overline{I}_e - \frac{Y(t+\Delta t) - Y(t)}{\Delta t} \quad (5)$$

Re-arranging Eq 5 yields:

$$\overline{I}_e \Delta x + \overline{Q}_i - \overline{Q} = \frac{Y(t+\Delta t) - Y(t)}{\Delta t}\Delta x \quad (6)$$

Since the surface detention is the storage volume under the water surface profile. Eq 6 essentially depicts the change rate of the storage volume in the unit-width surface. When, i.e., = *0*, Eq 7 reduced to the general hydrologic equation of continuity that states:

$$I - O = \frac{dS}{dt}; \text{ Inflow rate - outflow rate = change rate of storage volume} \quad (7)$$

Considering that the representative values for each time interval are the average, Eq 7 becomes:

$$\frac{I_e(t+\Delta t) + I_e(t)}{2}\Delta x + \frac{Q_i(t+\Delta t) + Q_i(t)}{2} - \frac{Q(t+\Delta t) + Q(t)}{2} = \frac{Y(t+\Delta t) - Y(t)}{\Delta t}\Delta x \quad (8)$$

An open channel flow described by Manning's equation as:

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2} \quad (9)$$

in which Q is the channel flow discharge rate, n is the Manning channel surface roughness number; A is flow cross section area, R is the hydraulic radius, and S is channel slope [9].

Considering the unit-width flow, the flow area A replaced by the flow depth Y as:

$$Q(t+\Delta t) = \frac{1.49}{n}[Y(t+\Delta t)]^{\frac{5}{3}}\sqrt{S_o} \quad (10)$$

Numerically, for each time step, the relationship between flow runoff Q(t+Δt) and flow depth Y(t+Δt) can be solved by Equation's 9 and 10.

### Storm catchments basin

The upper impervious plane or catchment basin in the cascading system doesn't receive any inflow. Thus Qi (t+Δt) =$Q_i$ (t) =0 and infiltration is ignored since we assume the imperious rate is 100% the catchment basin should not allow any infiltration into groundwater (f=0). Aided by Eq 4, Eq 9 can be rewritten as:

$$\frac{I(t+\Delta t)+I(t)}{2}\Delta x - \frac{Q(t+\Delta t)+Q(t)}{2} = \frac{Y(t+\Delta t)-Y(t)}{\Delta t}\Delta x \quad (11)$$

The boundary condition for the upper plane includes:

$Y(t)=0$ at x=0 (upper boundary) for all times (12)

The initial condition for the storm catchments plane is dry bed defined as:

$Y(x)=0$ at t=0 everywhere (13)

With Equation, 11 and 10, flow runoff Q (t+Δt) and flow depth Y (t+Δt) can be solved.

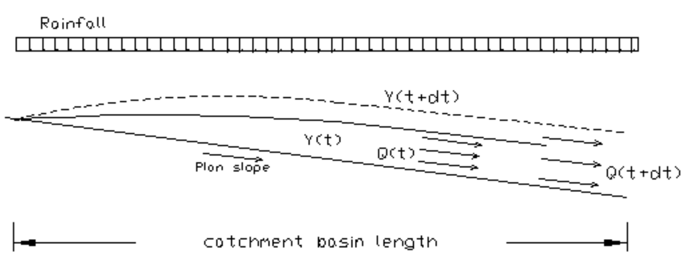


**Figure 6:** Catchments basin's flow profile.

### Infiltration beds

For the lower infiltration beds, the inflow, $Q_i$, is defined by the outflow hydrograph generated from the upper impervious plane. Moreover, the beds allow the infiltration into the ground (f>0), the equation 3 and 4 can be rewritten as:

$$\frac{\partial q}{\partial x} + \frac{\partial y}{\partial t} = I - f + Q_i \quad (14)$$

Moreover, equation 5 can be re-write as

$$\frac{\Delta Q}{\Delta x} = I - f + Q_i - \frac{\Delta Y}{\Delta t} \quad (15)$$

Since $I_e = I - f$, from equation 9 and 10 can be applied for infiltration beds, with two known and two unknown equations, flow runoff Q(t+Δt) and flow depth Y(t+Δt). The flow runoff and flow depth can be calculated. Having calculated the overland flow hydrograph at the outlet of the lower porous plane, the total runoff volume produced by these two cascading planes is calculated by [10]:

$$V_T = \sum_{t=0}^{t=T_b} q(t)\Delta t \quad (16)$$

In which $V_T$ = total unit-width runoff volume and $T_b$ = base time of runoff hydrograph.

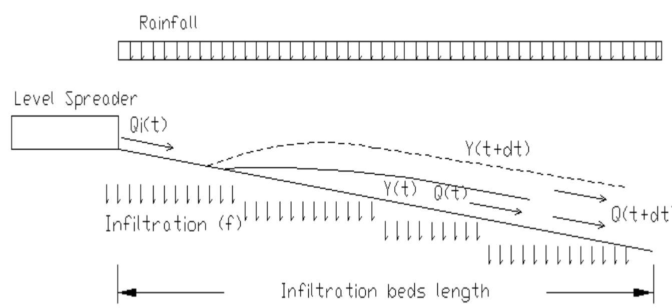


**Figure 7:** Infiltration beds cascading profile.

### Runoff volume and effective imperviousness

All volumes in the model must follow the mass balance principle. As:

$$V_T - V_f - V_o - V_s = 0 \quad (17)$$

In which $V_T$ = total unit-width runoff volume, $V_f$ = infiltration volume through the lower beds area, $V_o$ = entire level spreader outflow volume, and $V_{s.}$ = the storage volume, which is the storm runoff residual on both the upper and lower basins.

The total rainfall volume for an entire level spreader system is presented as the following

$$V_T = \sum_{t=0}^{t=T_b} I(t) \bullet A \quad (18)$$

In which I(t) is the rainfall depth for each time step

Moreover, the total outflow volume for the entire system is

$$V_O = \sum_{t=0}^{t=T_b} Q_{out}(t)\Delta t \quad (19)$$

In which $Q_{out}(t)$ is the stormwater runoff rate in each time step for the entire level spreader system.

With the equation 17, 18 and 19, the total infiltration volume for runoff discharge into groundwater described as

$$V_f = \sum_{t=0}^{t=T_b} [I(t) \bullet A - Q_{out}(t)\Delta t] - V_s \quad (20)$$

To evaluate the level spreader system land imperviousness, from the storm runoff volume point view the effective imperviousness for the level spreader cascading system is defined as:

$$I_{effective} = \frac{V_o}{V_T} \quad (21)$$

Traditional area weight method for imperviousness can be calculate as [1]

$$I_{area-weight} = \frac{\sum_{1}^{n} I_n A_n}{A} \quad (22)$$

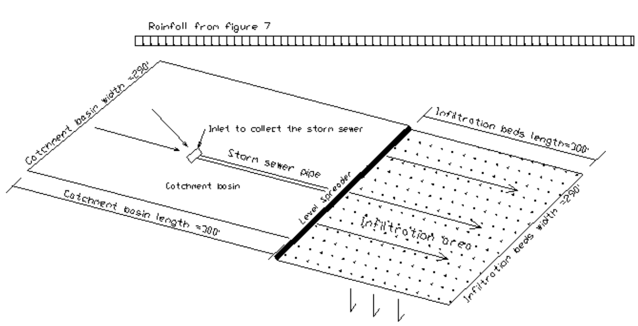


**Figure 8:** a case study for the level spreader system.

## Case Study

A testing site locates in the West of the U.S and evaluated for several years. As shown above, in (Figure 8), a level spreader system has an upper approximately 2.6 hectares paved asphalt concrete parking lot that drains onto on the lower approximately 100 meter long grass infiltration beds with approximately 90 meters of the level spreader on a continuous slope of 1.0% shown in (Figure 6). As recommended for asphalt concrete surface, the Manning's n of 0.016 applied to the upper paved plane, and 0.05 applied to the lower infiltration beds area. This paper caculated the effective imperviousness for the cascading overflow system and compared the results with the traditional area weighted method overland flow path.

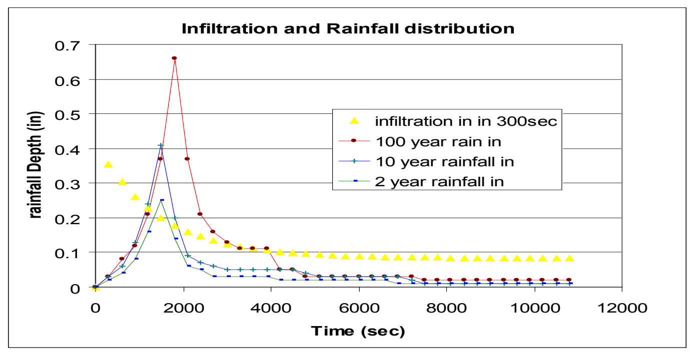


**Figure 9:** Rainfall depth distribution with infiltration rate applied to the testing site.

The impact of the rainfall intensity, rainfall depths, and soil infiltration to the peak runoff, this paper uses 30 to 89 mm of total rainfall depth and three different soils for infiltration. The entire rainfall' a distribution in three hours is shown below (see Figure 9). The soils placed on the infiltration bed can be classified as the sand soil, sand and clay mix soil and clay only soils, and the infiltration factor and volume presented in table 1. The infiltration rates distributed base on Horton infiltration model, [1].

| NRCS Hydrologic Soil Group | Infiltration (inches per hour) | | Decay |
|---|---|---|---|
| | Initial—fi (mm/hr) | Final—fo (mm/hr) | Coefficient—*a* |
| A | 127 | 25.4 | 0.0007 |
| B | 114 | 15.2 | 0.0018 |
| C &D | 76.2 | 12.7 | 0.0018 |
| A= sandy soil, B = clay and sandy mix, and C & D = clay. | | | |

**Table 1:** Soil infiltration, base on the NRCS hydrologic group classification.

With the cascading numerical model calculation, the total rainfall volume, infiltration volume and outflow volumes of the level spreader system calculated. These volumes are presented in (Table 2). As Table 2 presents, site infiltration volumes show minor increases which correspond to rainfall depth increases. This phenomenon indicates that the urbanization impact is greater in high frequency, low intensity rainfall events (minor design events), and less in low frequency, high intensity rainfall events (major design events).

| Total Rainfall depth (inch) | Total Rainfall Volume ($ft^3$) | Total Infiltration Volume ($ft^3$) | Outflow Volume from Upper basin ($ft^3$) | Total outflow volume from entire level spreader system ($ft^3$) |
|---|---|---|---|---|
| 3.28 | 47626 | 14274 | 23284 | 33028 |
| 1.98 | 28750 | 12268 | 14021 | 17431 |
| 1.27 | 18440 | 10854 | 9222 | 7550 |

**Table 2:** Total Volumes of Level Spreader System for Sand/Clay mix (Type B) soils.

The main purpose of this paper is to make a comparison between the traditional area weight method of imperviousness and effective imperviousness by calculating these rates at different volumes. As Figure 10 shows, the area weight method imperviousness does not affect rainfall depth, and the rate remains the same at 50%. The effective imperviousness rate with total rainfall depth has a positive ratio. With lower rainfall intensity events, the effective imperviousness rates are lower than when calculated with the traditional area weight method.

**Figure 10:** infiltration basin picture.

As the (Figure 10) shows, the level spreader provides some irrigation function for the grass area (infiltration beds); the picture shows that the grasses close to the level spreader are greener than the other grass areas.

**The evaluation of the spreader system and the advantages and disadvantages**

- Convert the concentrated flow into a sheet flow to prevent the surface erosion
- Provide the onsite stormwater treatment by fitter the high TSS flow through the vegetation field
- Allow the onsite stormwater infiltrate to the high porosity soil, and recharge into groundwater.
- Provide irrigation to the vegetation area and reduce the domestic water usages.
- Low the risk of local flood hazard by reducing the stormwater velocity and delay the on-site basin flow drain time (the time of concentration).

However, the level of the spreader system application has some concerns:

- More maintenance than the regular storm sewer system, the spreader structure usually plugged by a large amount of debriefs after the high-intensity rainfall occurs. Thus, the site inspection and clearing are the necessary operations for the maintenance.
- The system limited by the site layout and grading, the ideal cascading overland flow require the impervious surface on the upstream site and impervious surface on lower site to allow the additional onsite infiltration.
- The infiltration riparian areas need to be sandy or mixed sandy soil for good infiltration.

## Conclusion

In stormwater management, watershed imperviousness is a primal parameter in urban hydrology to evaluate the storm runoff rate and volume. This study used a cascading-plane model to represent the physical landscaping layout and use the runoff volume to evaluate effective imperviousness. The cascading model for the level spreader provides a new methodology to analyze the basin imperviousness. Under the traditional area weight method concept, the impervious rate for the case study should remain constant at 50% since the impervious area is equal to the pervious area. With the cascading model, however, the effective imperviousness can be represented from 14% to 81%, based on different rainfall depth and different soil infiltration rates. For a high frequency but low intensity rainfall event, the traditional area weight method over estimate the storm runoff volume. The main reason for the traditional area weight method to overestimate storm runoff is that the method does not consider the basin's flow path and ignores the additional soil infiltration volume when overflow passes over the pervious surface area.

This study introduces the effective imperviousness rate and provides the cascading model was successful at representing the physical behaviors in terms of runoff and infiltration of the level spreader system.

During the numerical modeling, this study found that lower infiltration beds intercepted part of the runoff generated from the upper impervious basin at an early stage of the rainfall event, which causes the entire system outflow to be less than the area weight method estimate. This paper also found that the effective imperviousness calculated by the cascading model is much less than traditional area weight method in most of the low intensity but high frequency event cases.

Additionally, the latest developments in stormwater management encourage reducing development land imperviousness rate by changing the site plan layout. In this study, the level spreader system was introduced to reduce the imperviousness rate under the MDCIA concept by direct runoff from impervious surfaces over grassy areas to slow runoff and promote soil infiltration. The use of an infiltration bed with a level spreader system is frequent in soils with good water infiltration capacity. The correct design of the level spreader system depends greatly on the accuracy in determining the volume of water from storm catchments basin.

If the catchments basin has any low points; however, the flow tends to concentrate. This concentrated flow with high flow velocity may cause an erosion problem. By installing a spreader structure, the concentrated flow can be diffused into sheet flow and decrease flow velocity to reduce erosion.

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