

unwieldy number of input parameters when used at a large watershed scale. SWMM also specifically includes a framework for input of LID elements.

LID APPLICATIONS IN SWMM

The EPA added LID modeling capabilities to SWMM in 2000 with additional improvements in 2005. (Niazi, Nietch et al. 2017, Rossman 2017) The LID elements that are explicitly built into SWMM include bio-retention cells, infiltration trenches, porous pavement, rain barrels, vegetated swales, green roofs, and street planters. SWMM idealizes each of these LID features as a series of fully mixed layers. The layers that are considered for each of these LID elements are summarized in Table 1. The conceptual relationship between layers is illustrated in Figure 2; an example of a bio-retention cell as modeled in SWMM.

Table 1 – SWMM Layers Used for Explicit LID Elements, after Rossman (2015)

LID Features	Layers				
	Surface	Pavement	Soil	Storage	Underdrain
Bio-Retention Cell	x	-	x	o	o
Rain Garden	x	-	x	-	-
Green Roof	x	-	x	-	x
Permeable Pavement	x	x	o	x	o
Infiltration Trench	x	-	-	x	o
Rain Barrel	-	-	-	x	x
Roof Disconnect	x	-	-	-	x
Vegetative Swale	x	-	-	-	-

Note: “x” indicates input is required, “o” indicates input is optional, “-” indicates the layer is not applicable.

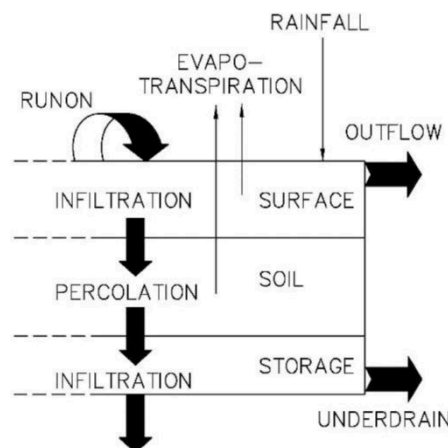


Figure 2 – Conceptual Diagram of Bio Retention Cell, based on Rossman (2015)

The storage of moisture within each layer is controlled by the infiltration, drainage, and overflow parameters associated with each layer during the modeling simulation. The model estimates moisture movement through the soil layer according to an exponential relationship between hydraulic conductivity and the soil moisture content. (Niazi, Nietch et al. 2017) Infiltration within growth media is estimated according to the Green-Ampt Equation and the outflow from the soil beneath the LID element is based on a constant rate that is defined by the user. The under drain storage discharge rate is based on an exponential relationship defined by

the user. The relative position of the LID elements within the larger subcatchment level hydrologic analyses performed by SWMM is illustrated in Figure 3. Note that at this time SWMM does not explicitly link pollutant removal to LID elements at the subcatchment level. The user can still model pollutant removal from LID elements by inputting the anticipated removal efficiencies into the land use editor. LID elements can be modeled as being distributed within a subcatchment or may be defined as covering a subcatchment entirely.

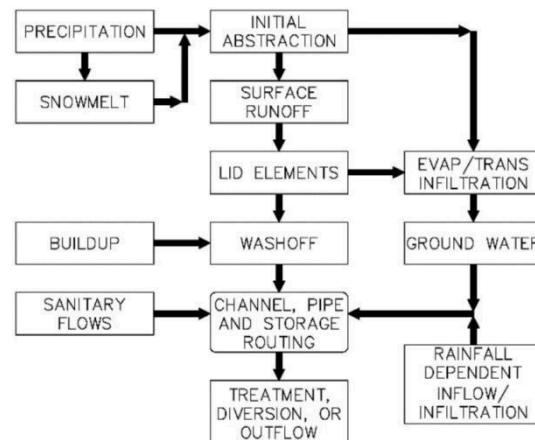


Figure 3 – Processes Modeled by SWMM, based on Rossman (2015)

CS IN SWMM AND ANALYSES OF RESULTS

CS capabilities are also built into the SWMM environment. The current user's manual (Rossman 2015) includes a CS example in the Quick Start Tutorial and the input files are available for download with the SWMM installation file. An example is also provided in the SWMM Applications Manual (Gironas, Roesner et al. 2009). The reader is referred to the general guidance for setting up these simulations provided in these references. Additional guidance and insight are provided herein to supplement the existing references.

Both the SWMM User's Manual and the Applications Manual reference precipitation input files in National Climatic Data Center (now known as the National Centers for Environmental Information (NCEI)) standard formats, DSI-3240 and DSI-3260. The Applications Manual also references the "standard user-prepared format" for inputting historical precipitation records. It has been the authors' experience that expedient access to historical precipitation records from the NCEI are most easily obtained in ASCII file or CSV format for hourly and sub-hourly rainfall records through the NCEI Map Viewer (<https://gis.ncdc.noaa.gov/maps/ncei/cdo/hourly>). Note these files are not in the standard formats, DSI-3240 and DSI-3260, and require front end processing to address issues including duplicate entries, out of order time stamps, and incomplete records among others. This task is well suited for the filtering tools in Microsoft Excel.

There are two possible ways to link an external precipitation data file to the SWMM model; 1) link a rain gage node to the external file, or 2) link a time series to the external file and link a rain gage to the time series. The latter offers a bit more flexibility and is the method recommended by the authors. Note that even for large models and long historical records, the SWMM model will run swiftly on a modern desktop computer. If the model does not appear to run within 10 to 30 seconds of starting the simulation, there is most likely an error in the precipitation record.

Once the simulation is complete, SWMM offers a number of statistical tools for evaluating

the results. These tools are described in the Application Manual. Users may also choose to export the raw results as data tables in text file format for further analysis. The Log Pearson Type III distribution is commonly used to describe return frequencies for extreme precipitation and stream flow events. It can be applied readily to the results of a SWMM CS analysis in a spreadsheet or similar software according to the following relations, based on Wurbs and Welsey (2002):

$$\begin{array}{ccc}
 \text{Parameter of Interest (X)} & & \\
 X = 10^{\overline{\log X} + K S_{\log X}} & & \\
 \begin{array}{c} \text{Mean} \\ \overline{\log X} = \sum_{i=1}^n \log X_i \end{array} & \begin{array}{c} \text{Standard Deviation} \\ S_{\log X} = \sqrt{\sum_{i=1}^n (\log X_i - \overline{\log X})^2} \end{array} & \begin{array}{c} \text{Skew coefficient} \\ G_{\log X} = \frac{n \sum_{i=1}^n (\log X_i - \overline{\log X})^3}{(n-1)(n-2) S_{\log X}^3} \end{array}
 \end{array}$$

The values for the Pearson III Frequency Factor (K) may be obtained from tables in references such as Harter (1969) or Wurbs and James (2002). However, when evaluating multiple parameters and performing iterative modeling simulations the interpolation of values within tables can be time consuming and tedious. A simple regression of the frequency factors presented in Wurbs and James (2002) suggests that the following equations may be used to closely approximate the Pearson III Frequency Factor from the Skew Coefficient. Figure 4 illustrates the tabular values (Wurbs and James 2002) plotted against the lines defined by these regression equations.

$$K_{0.5\%} = -0.024G^3 + 0.028G^2 + 0.926G + 2.552$$

$$K_{1\%} = -0.019G^3 + 0.003G^2 + 0.732G + 2.304$$

$$K_{2\%} = -0.014G^3 - 0.016G^2 + 0.538G + 2.033$$

$$K_{4\%} = -0.009G^3 - 0.032G^2 + 0.350G + 1.735$$

$$K_{10\%} = -0.003G^3 - 0.041G^2 + 0.111G + 1.274$$

$$K_{20\%} = 0.001G^3 - 0.036G^2 - 0.048G + 0.839$$

$$K_{50\%} = 0.005G^3 - 0.001G^2 - 0.171G + 0.001$$

$$K_{99\%} = -0.019G^3 - 0.003G^2 + 0.732G - 2.304$$

CS OF LID EXAMPLE IN SWMM

To illustrate the utility of CS for evaluating LID, an analysis was performed on a bio-retention cell designed for a newly renovated hotel parking lot in the Nashville, Tennessee area. The bio-retention cell was designed according to Metro Nashville's Low Impact Development Stormwater Management Manual (Manual). The Manual uses a design approach that is based on treatment of the full Treatment Volume (Tv); the equivalent to the runoff volume from a 1-inch storm over the contributing drainage area, according to the Curve Number of the contributory surface(s). Metro Nashville has developed a Microsoft Excel spreadsheet tool to estimate this value. The method used in the Manual is intended to produce LID designs that are capable of converting 80% of potential runoff to infiltration for all storms greater than 1-inch in depth, preceded by a period of 72 hours without precipitation. This statistic is based on a historical precipitation analyses performed by Metro. In the case of a bio-retention cell, the Manual specifies that the cell must have adequate ponding and media storage to temporarily retain the Tv

for infiltration.

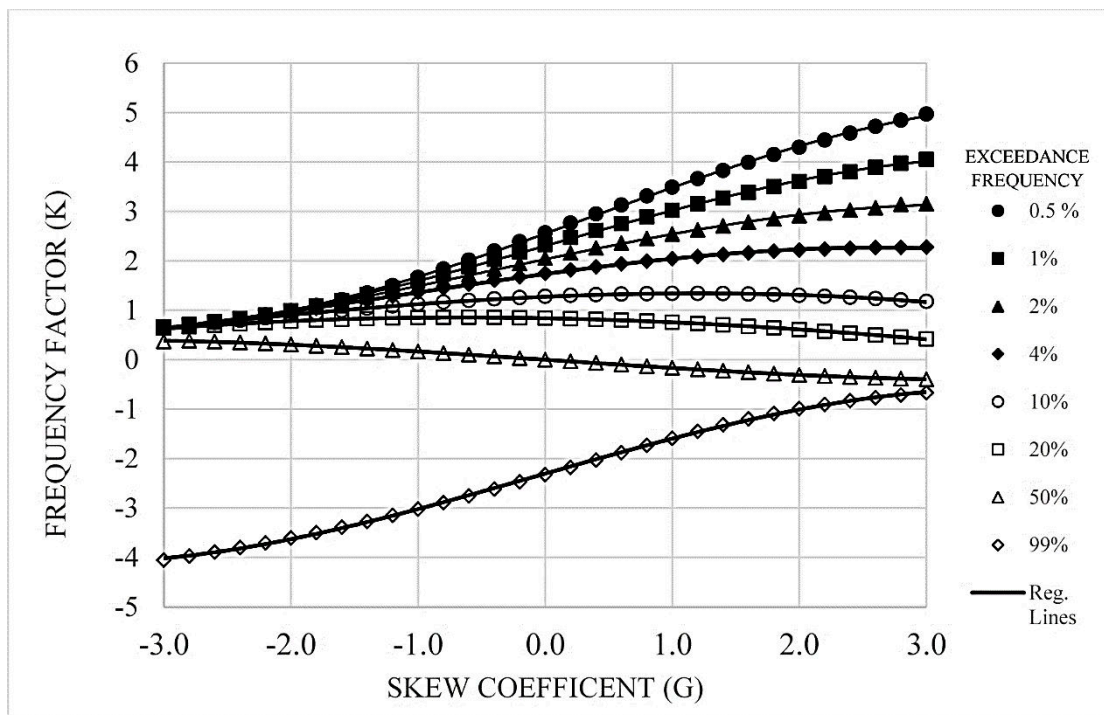


Figure 4 – Skew Coefficient vs Frequency Factor, for Pearson Type III and Log-Pearson Type III Distributions

The bio-retention cell designed for the hotel parking lot has a ponding depth of 12-inches, a soil media depth of 36-inches, and a stone filled infiltration sump of 12-inches. The infiltration rate of the soils (underlying and within the cell) was modeled as 0.5 inches per hour. The porosity of the soil was modeled as 0.4. The void ratio of the stone in the sump was assumed to be 0.6. A perforated underdrain was included in the infiltration sump. The plan view area of the cell is approximately 1,700 square feet and it receives runoff from a parking lot with an area of approximately 1-acre. CS analyses were performed using hourly precipitation records from 1948 to 2013. These records were obtained from NCIE for the Nashville International Airport. The precipitation data were preprocessed in Microsoft Excel to address any potential errors (duplicate entries, out of order time stamps, incomplete records). The CS was performed to answer the following simple questions:

1. What is the average annual infiltration volume of the bio-retention cell as a percentage of total precipitation?
2. What are the 2, 10, and 100-year discharge rates for overland flows discharging from the bio-retention cell?
3. Does the bio-retention cell provide a reduction in the 2, 10, and 100-year discharge rates from the parking area?

To address the first question, the model results were queried in SWMM using the Statistics Report tool to estimate the total annual volumes of precipitation and the total annual volumes of runoff over the modeled duration; these volumes were tallied in Excel. The model results indicate that approximately 68% of the precipitation volume is infiltrated by the bio-retention cell. To address the second question, the Statistics Report tool was used in SWMM to generate an annual series of peak overland discharge values from the bio-retention cell. This annual series

of values was analyzed using the Log Pearson Type III distribution as described in the previous section. The results of this analysis are summarized in Table 2. To address the third question, the Statistics Report tool was used to generate an annual series of peak flows discharging to the bio retention cell from the parking area. The same Log Pearson Type III distribution was applied to this annual series. These results are also provided in Table 2.

Table 2 – Continuous Simulation, Statistical Results for Peak Discharges

Recurrence Interval	Discharge from Bio- Retention Cell (cfs)	Discharge to Bio-Retention Cell (cfs)
2 Years	1.3	1.4
10 Years	2.1	2.1
100 Years	2.9	3.0

These results indicate that a significant amount of water is infiltrated on an annual basis; approximately 68% of the average annual rainfall of approximately 47 inches. This percentage is not as high as the 80% that is assumed using the design method, but accounts for changes in soil moisture and timing between storm events and is a significant portion of the annual water budget. The results in Table 2 indicate that the bio-retention provides little in the way of reduction of peak flows. Given the scale of the feature and the design intent, this is not a surprising result. What these results do not explicitly show but do support is that the duration of flows leaving the site has been reduced. Statistical analysis of the change in duration of these peak flows is beyond the scope of the present paper, but can be performed using results of CS.

SUMMARY AND CONCLUSION

The CS capabilities of commonly available software such as SWMM provide the stormwater management community the opportunity to analyze and evaluate the hydrologic performance of LID elements over long periods of historical precipitation. The results of such modeling coupled with appropriate statistical analyses can provide insight into the degree to which an LID feature meets its designed intent. The example discussed in the previous section is very simple in its hydrologic make up, however the use of CS is also applicable to much larger and complex hydrologic models. The evaluation of watershed scale dynamics using CS can provide designers and regulators results that have the potential to guide design practices that can better and better approximate the hydrology of the undeveloped watershed condition and further address the cause of hydromodification of our urban and suburban watersheds.

The software and hardware for performing these analyses are readily available and in common use in the engineering community. The historical precipitation records are easily accessed for use. It is the hope of the authors that the use of this hydrologic modeling technique becomes more and more common as we work towards the common goal of healthy watersheds.

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Towards Dual Thinking of Ecology: Raingardens Design in Northern China

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ABSTRACT

LID practices have been booming in China since Sponge City Directives—Low Impact Development Rainwater System Construction released in 2014. Functional or technical indicators required the regulation of sponge city are involved to evaluate the implementation of LID, which is leading much more attentions technology, such as to deal with rainwater qualities and quantities, but less on humanity. Values and behaviors of human play a vital impact on solving essentially ecological issue based spiritual ecology. Dual thinking of ecology in this article would addresses both technical and human of thinking in ecology. The purpose of this article would demonstrate that design of raingardens in northern China participated by authors how to combine technical and human ecology as one whole to fulfill the amenity of stormwater management. Creations of four raingardens with different type and scale in northern China would be discussed and analyzed further including UP+S raingarden (200 m²), campus raingarden (1400 m²), raingardens in residential area (7 hm²), and raingardens in Business Park (20.5 hm²) in which not only amenity for users are created with pavilions, spatial recreation, and art installation, but promoted users to more ecological perception of rainwater, even strengthened their ecological ethics by employing eco-revelatory design.

INTRODUCTION

Rapid development of urbanization in China impacts a nation's development in a number of ways. It leads to the improved infrastructure to provide decent services and bring about major changes in people's standards of living. It cannot be denied that fast urbanization has changed the permeable rate of the ground, damaged landscape hydrology, caused flooding, even lost life. Many cities encountered to overflow on the land after stormwater in recent years. Under the situation Sponge City Directives in China has been released in 2014 based on the Low Impact Development. LID practices have been booming since then, and construction of sponge city has been among the nation's major accomplishments. 30 cities have been active participants in implementing varied LID projects since 2015. Both stormwater management and polluted rivers have been carried out in different parts of the country.

Functional or technical indicators required by the regulation of sponge city are involved to evaluate the implementation of LID, which is leading much more attentions technology, such as to deal with rainwater qualities and quantities, but less on humanity. Values and behaviors of human play a vital impact on solving essentially ecological issue based spiritual ecology^[1]. Dual thinking of ecology in this article would addresses both technical and human of thinking in ecology.

UP+S Design is one of the pioneers to practice raingardens how to contribute to sustainable sponge city in China under the circumstance of less knowledge of raingarden for the public, even

professionals. The purpose of this article would demonstrate that raingardens in northern China created by UP+S Design how to combine technical and human ecology as one whole to fulfill the amenity of storm water management. Those raingardens have not only created amenity for users with pavilions, spatial recreation and art installation, but promoted users to more ecological perception of rainwater, even strengthened their ecological ethics by employing eco-revelatory design^[2]. The author hopes to use those cases to arouse people's dual thinking of Ecology, especially on the humanity.

ISSUES OF STORMWATER MANAGEMENT

Functional or technical indicators required that the regulation of sponge city is involved to evaluate the implementation of LID, which is leading much more attentions on technology, such as to deal with rainwater qualities and quantities, but less on humanity. Researchers focus more penetration in the soil penetration, structured packing, decontamination capability, hydrological effects, structural level, and the selection of plants and other aspects of research in low-impact development. As part of built environment, built new spaces or sites based stormwater management maintain potentially to serve as multifunctional recreation like gardens or parks. Less collaboration among different professionals, such as landscape architecture, pedology, ecology, environment engineering, etc., resulted in the built environment lack of art and amenity. A well-designed raingarden should be able to invite people into experience and enjoy it instead of only looking at it from outside.

Furthermore, projects of stormwater management could be deserved to prompt the public ecological education which is still less discussion on professionals. People are always paying more attention on the solution of ecological problems to the related technical management measures, ignoring motivation of human beings. The values and consciousness of individual will devote greatly to the ecology crisis according to spiritual ecology.

Actually stormwater management seems to be a systematic framework provided in different scale. It could be from city scale to small gardens or parks, and how to organize effectively runoff trial and how to meet up the requirement with absorbing rainwater runoff less than 70% on site^[3]. Some projects collect rainwater combing pipes and LID facilities to reach up the requirements with higher cost. It would be low cost if stromwater management is treated as green infrastructure via eco-relevatory design, and more important to improve the microclimate around the site.

Generally innovations of stormwater management need multiple- and cross-disciplinary collaboration. It is necessary not only to fulfill the technical requirements of stormwater management, but also to layout space and facilities according to functions, human behavior and aesthetics.

CASES STUDY OF RAINGARDENS BY UP+S DESIGN

During the practice, UP+S Design has formulated successfully its own design strategies for sustainable construction of Sponge city. Firstly, a new raingarden concept has been coined. It is raingarden that used to be one of LID facilities, and here it is definitely described as^[4]one type of gardens integrating function, art and technology which is similar vision as Artful Rainwater Design put forward by Stuart Echols and Eliza Pennypacker. Secondly, raingarden is one cell of sponge city which would be created through one by one raingardens with one network. It is easy to catch up different scale in the city through raingarden system. Thirdly, raingarden design with eco-revelatory design will contribute to ecological cognition and enhance spiritual ecology while

visitors or users have a movement in the gardens. Eco-revelatory design is defined to reveal and explain the processes and relationships of ecological phenomena through visualized representation of space. Finally, it is cold and long-time winter in northern China. How to create regional raingarden with adaptive climate also has been explored. Raingardens created by UP+S Design have not only provided amenity for users with pavilions, spatial recreation and art installation, but promoted users to more ecological perception of rainwater, even strengthened their ecological ethics by employing eco-revelatory design, eventually for self-educating unconsciously.

1) UP+S raingarden in 768 Creative Park, 200m², 2015, Beijing

UP+S raingarden, located in 768 Creative Park in Beijing, is small and has been impressively featured with platform and terraced (Fig.1). It seemed almost the first raingarden built responding to Sponge City Directive. According sponge construction requirements of the city, it is “permeation, retention, storage, purification, utilization and water drainage” that have been applied into the garden. Rainwater goes down in the pipe from roof, then the pool operating to discard initial flow through, next rainwater harvested flows down through the terraces planting ornamental grasses, and finally down to pond planting native vegetation. Rainwater in pond would flow into underground tank to be stored if overflowed the planned level. Terraced form offers not only the way of rainwater running but also to make up a terrain by utilizing the dug soil when built the pond, even created 3D viewing in so small space. In winter the yellow platform, terraces and art installation together enrich the spatial changes and display a vivid timescale. UP+S raingarden have played key role to educate the public since established because many professionals and students from colleagues or universities have visited in different seasons.



Fig. 1

2) BJTU Raingarden, 1200m², 2016, Beijing

Located U-shaped courtyard in the campus of Beijing Jiaotong University (Fig.2), BJTU Raingarden has been created to celebrate 120th anniversary of university. It is key part of main green structure in campus as well the end of the axis of library garden. It is quite short of land use in campus because of its location in downtown of the city. Inspired by good reputation of green campus in Jiaotong University, courtyard redesign has been created multiple function outdoor based on sponge campus through eco-revelatory design, including recreation, rainwater collecting and purifying through planters with plants and then manmade wetland (Fig.3). Students are able to recognize the visualized runoff trail by the rainwater delivered through planters, ditches and wetland in situ. After treatment, rainwater is used to supply the reflecting pool on the left of manmade microwetland and watering plants in the garden. In the unconscious environmental education, students positively learn the knowledge of ecology to

nutrition their own spiritual ecology. The ecological processes of collecting, processing, and recycling are presented in the garden as obviously as possible based on sponge campus and rainwater recycle by collecting and purifying. Under the goal of rainwater management, raingarden creation has combined functional, technical with artistic demands for users. The garden has been arranged functional space for displaying, communication, small stage, relaxation and walking. Applying the contrast of texture and fabric of materials and color, raingarden design has tried to send warm and attractive invitation for the teachers and students to step in.



Fig. 2 Before construction



Fig. 3

Solar energy developed by the researchers from School of Electrical Engineering has been used for lighting and power in the courtyard. Lighting boxes made by Corten steel in the garden warmly welcome people to go in with yellow light and to enhance the vibrancy of the campus nightscape. After the garden was built, besides school teachers and students, local residents and children came to visit raingarden which has become a place for children to play. Therefore, raingarden will company them with growing, this would be wonderful way for environmental education. Volunteers of students will monitor and test the quality of rainwater and periodically make maintenance BJTU raingarden by themselves.



Fig.4 Layout of LID facilities in Fengxi residential area / Rendering

3) Raingardens in Fengxi residential area, 7hm², 2016, Xixian New district

Raingarden design of Fengxi residential area is located in the Sponge-City Demonstration zone in Xixian New District in which is required to strictly follow the guideline issued by State Council which is at least 70% of the rainwater runoff should be retained and utilized on site, 20%