Modelling the applicability of Low Impact Development (LID) technologies in a university campus in the Philippines using Storm Water Management Model (SWMM)

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Abstract. Progressive land development increases the imperviousness of an area which disrupts the water balance and results to the degradation of water quality, high peak flow, and excessive volume of surface runoff. One efficient approach to address this issue on water is the application of Low impact development (LID) technologies. LID helps improve the water quality and water quantity of an area to maximize its land-use. In this study, the eight LID technologies available in SWMM namely, bio retention cell, infiltration trench, rain garden, green roof, permeable pavement, rain barrel, rooftop disconnection, and vegetative swale were applied in simulating the area of the De La Salle University - Laguna Campus, a pre-developed area in Binan, Laguna which currently undergoes land-use change. This study area was simulated without the use of LID, with the use of varying LID, and capturing the 80, 90, and 95 percent of all the rainfall from 1989-2018. Digital elevation model and disaggregated rainfall data were used as input in SWMM. The ArcMap 10.4 was utilized to delineate and produce the three sub catchments with an area of 24.13 ha., 10.18 ha., and 4.34 ha., respectively while Storm Water Management Model (SWMM) software was used in analyzing these sub catchments to produce water balance values. Results showed that more than 60 percent of the disaggregated rainfall was under the one-year return period. Also, bioretention cell with 80th percentile rainfall maximizes the reduction of runoff while infiltration trenches with 95th percentile rainfall were the most effective in increasing the infiltration among the eight LID technologies. It was also indicated that the surface runoff in first sub catchment was reduced to more than 80% using bioretention cell, infiltration trench, rain garden, or rooftop disconnection. Finally, the area of a sub catchment has a positive correlation in its reduced runoff while a negative correlation in its infiltration when integrating the LID technologies. This research can be a resource for further studies and in to support SDGs 6, 9, and 11 to have a better water management, resilient infrastructures, and attain sustainable cities and communities.

1. Introduction
Simultaneous with the rapid increase of population and urbanization is land development. It is an ingredient and indicator for the progress of a developing city or country [1]. These include the erection of more infrastructures such as roads, bridges, highways, buildings, and power supplies which creates more impervious areas and reduces green spaces. Imperviousness is correlated to a faster time of concentration, a higher volume of peak flow rates, and an increase of pollutants to water bodies [2]. Moreover, it contributes to the impacts of climate change and the destruction of the natural ecosystem [3].

In the Philippines, almost half of the Filipino lived in urban and cities, [4] and its capital, Manila is considered the world’s most densely populated city. Urban sprawl is evidently seen which increases the impacts of rapid urbanization and climate change. These impacts include water scarcity and shortages, urban flooding, and degradation of water quality [5] which were evidently seen in the aftermath of the recent super typhoons that struck the Philippine archipelago. Additionally, Greenpeace (2007) stated nine water-critical urbanized area which includes Metro Manila, Metro Cebu, Davao, Baguio City, Angeles City, Bacolod City, Iloilo City, Cagayan de Oro City, and Zamboanga City. These areas will suffer from a lack of supply of fresh water due to increasing demand every year and the worsening of EL Niño or drought.

Currently, programs of the government focus on improving the existing drainage systems. However, these drainage systems only address the water quantity, not water quality and the implementation of sustainable development ideas and concepts in metropolitan urban areas is important to mitigate the impacts of these water issues and to the environment [6]. One approach is the Low impact development (LID) [7]. LID is a stormwater management approach that addresses the rainfall at the source and uses a micro-scale and mimics a site predevelopment hydrology by using design techniques that infiltrate, filter, store, evaporate and detain runoff controls [8]. Some types of LID are bioswales, rain gardens, green roofs, permeable pavements, and bioretention cells [9]. Bioswales are effective in capturing runoff from unusual rainfall event [10], proper biological design of rain gardens helps in reducing non-point source (NPS) pollution and maintains its efficiency through time [11], green roofs efficiently decrease the urban heat island effect on an area [12], fully permeable pavements minimizes the negative effects of stormwater runoff [13] while bioretention cells help in infiltrating stormwater from roads and parking lots and contributes in metal removal [14]. These LID technologies were also used in developed countries such as United States, South Korea, China, Australia, and UK namely, best management practices (BMPs), smart city, sponge cities, water-sensitive urban design (WSUDS), and sustainable urban drainage systems, respectively [15] and economically cost less than conventional stormwater management [16][17].

Geographic information system (GIS) is a framework for gathering, managing, and analyzing spatial data and organizes it into layers of information and was used to subdivide the sub catchments [18]. It helps in visualizing maps and 3D scenes using patterns, relationships, and situations of an area [19]. This is also utilized in different hydraulic engines, one of which is the Stormwater Management Model (SWMM). SWMM is used throughout the world in processing hydrologic phenomena in urban and non-urban areas. Different LID technologies which include rain gardens, bio-retention cells (bioswales), vegetative swales, infiltration trenches, green roofs, rooftop (downspout) disconnection, rain barrels or cisterns (rainwater harvesting), and continuous permeable pavement systems were included in the software. It is the only existing free software that simulates both water quantity and water quality [17]. Moreover, studies in South Korea used SWMM in assessing the hydrologic impact [20] and a tool for assessing flood impact [21]. Geomorphologic characteristics of watersheds as parameters in analyzing pre-developed conditions were used and a pre-developed state is more effective for the construction of LID technologies in terms of efficiency and cost [22].

In this study, the main objective is to determine the applicability and effectiveness of LID technologies in DLSU Laguna Campus using SWMM by comparing the performance of a conventional drainage system and a drainage system with LID. An 80th, 90th, and 95th percentile of rainfall was considered with the varying LID technologies in producing the water balance.

The findings of this study could be useful for further investigation and application of LID technologies in the campus to address the excess surface runoff and maximize the use of limited space.

2. Methodology

2.1. Site Description
DLSU Laguna Campus is a 52-ha campus located in Biñan, Laguna (14 15’ 46.64” N, 121 02’ 34.30” E, Figure 1) which has an annual rainfall of 944 mm. The dry season is from December 27 to May 21 while the wet season is from May 21 to December 27. The topography within 3.21 km of Biñan is essentially flat and covered by artificial surfaces (58%) and water (31%) [23]. At present, the DLSU
Laguna Campus occupies mostly green spaces or areas with pervious surfaces and envisioned to be the center of research and technology in the Philippines by which construction of more infrastructures are necessary. It is also located on the southwestern part of Laguna de Bay, the largest lake in the Philippines. Improvements on the drainage network are in the early phase and the application of LID technologies will minimize the effects of future urban flooding, high volume, and peak flow rates in its area and surrounding water bodies [24].

Figure 1. The DLSU Laguna Campus (right) with its delineated sub catchments (lower left) modelled from ArcMap 10.4 and SWMM 5.1 and Laguna de Bay (upper left).

2.2. Research Method
Shown in Figure 2 is the flowchart of research methodology which comprises of five parts namely, data gathering, processing of data, modeling and simulations, results of SWMM, and analysis of results.
2.2.1. Data Gathering.

The data gathered for this research include a 30-year daily rainfall data from 1989-2018 of Ambulong, Batangas and a 28-year rainfall data from 1991-2018 of NAS-UPLB, Laguna which were the nearest available rain gage stations to DLSU Laguna Campus in Biñan, Laguna. These data were acquired from Philippine Atmospheric, Geophysical and Astronomical Services and Administration (PAGASA) and all data marked with blank, ‘-’, or ‘-2’ value are considered no data. Also, one-day rainfall data was considered one rainfall event though multiple rainfall events may occur in one day.

For the Digital Terrain Model acquired from the National Mapping and Resource Information Authority (NAMRIA) in the form of raster files in .tiff format, a 10 km radius was extended around the perimeter of the actual site. Other parameters such as slope, runoff coefficient, and soil composition were based on the topographic and land use map.

2.2.2. Processing of Data.

All raw data from the different government agencies were processed. The DEM file of DLSU Laguna Campus from NAMRIA was delineated using ArcMap 10.4 to produce sub catchments [25]. The rainfall data from PAGASA of the given two rain gage stations were calculated using Inverse Distance Weighting (IDW) method, equation (1) to produce a combined single rainfall data. It was disaggregated using the triangle method to produce hourly data from daily rainfall data [26] and plotted using Weibull plotting position formula, equation (2) to calculate the 80th, 90th, and 95th percentile [27].

\[
Z_j = \frac{\sum \left( \frac{Z_i}{d_{ij}} \right)}{\sum \left( \frac{1}{d_{ij}} \right)}
\]  

(1)

Where,

- \(Z_i\) = the value of known point
- \(d_{ij}\) = the distance to known point
- \(Z_j\) = the unknown point
- \(n\) = a user selected exponent (often 1, 2 or 3)
\[ P = \frac{m}{N+1} \]  

Where,  
\( P \) = probability of occurrence  
\( N \) = total number of years recorded  
\( m \) = the rank of descending values with the largest equal to 1

2.2.3. Modelling, Simulation, and Analysis of Results. 
EPA SWMM 5.1 was used in the simulation [25]. All processed data including soil composition, runoff coefficient, curve number, and slope were used as input. After applying all the parameters of the SWMM model shown in Table 1, the disaggregated rainfall data for the 80th, 90th and 95th percentile was included. The model has been set and the simulation was conducted. Simulation without the use of LIDs served as a point of comparison. The variables are the varying percentiles and the eight different LIDs available in SWMM 5.1 for the three subcatchments.

| Table 1. Characteristics of the sub catchments and parameters used in SWMM. |
|---|---|---|---|---|---|---|---|---|
| Sub catchment | Area (ha) | % Imperviousness | Width (m) | Curve Number, CN | Node, N | Invert elevation (m) | Link | Length (m) | Manning’s Roughness |
| 1 | 21.13 | 20 | 182 | 80 | 1 | 90 | LO1 | 107 | 0.013* |
| 2 | 10.18 | 10 | 258 | 80 | 2 | 94 | LO2 | 140 | 0.013* |
| 3 | 4.34 | 25 | 151 | 80 | 3 | 98 | LO3 | 463 | 0.013* |

Note: *Manning’s roughness for concrete pipes.

Each sub catchment has a scenario by which the eight different LID technologies and a simulation without LID were applied and all these scenarios were simulated to the three different percentiles. Overall, a total of 81 scenarios were conducted for the three subcatchments.

Since evapotranspiration is negligible, the results focused on the total infiltration, and total surface runoff. A comparison between an analysis without LID and an analysis with each of the 8 LID technologies were calculated. Also, the volume reduction with respect to surface area/catchment area (SA/CA) ratio was presented. It was produced based on the designed total surface area of each LID technology on the area of each sub catchments.

3. Results and Discussion

3.1. Rainfall Characteristics  
Distant rain gauges stations were common in developing countries like the Philippines. Rainfall data need to be analyzed first using statistical models to have a compatible input to different softwares like ArcMap 10.4 and SWMM 5.1[25]. Figure 3 shows the average monthly rainfall and cumulative frequency of the processed 30-year rainfall data from Ambulong, Batangas and 28-year rainfall from NAS-UPLB Laguna rain gage stations with their standard deviations included. February has the lightest monthly rainfall with an average total accumulation of 28.47 mm while the heaviest rainfall occurs in July (344.61 mm) with the largest standard deviation of 186.59 mm. The total accumulated annual rainfall is 1855.32 mm.
Figure 3. Average and cumulative monthly rainfall data with their standard deviation from the processed rainfall data from PAGASA (1989-2018).

The 80th, 90th, and 95th percentile were used in this study. As observed in Figure 4 (a), a visible change in slope was seen at around 0.8 and considered the minimum significant value. The value at 0.9 was used as the middle value and the value at 0.95 was used as the maximum significant value. The value near 1 to 1 was not considered as the maximum value because changes in that area were very minimal. Also, the 95th rainfall percentile event is based on the Section 438 Technical Guidance of USEPA [28]. Figure 4 (b) depicts the trendline of the disaggregated rainfall data with respect to the return period. The cost of the urban drainage design could be minimized by using the optimal rainfall return period [29].

The trendline was used in Figure 4 (c) which showed that more than 60% of rainfall were found in the 1-yr return period, less than 5% of the total rainfall were found in the 2 and 5-yr return period, and more than 30% of the total rainfall were found in the 10 and 20-yr return period.

An hourly time series with respect to rainfall depth for each respective 80th, 90th, and 95th percentile occurrence frequency disaggregated from daily rainfall data covering a period from 1989 to 2018 was shown in Figure 5. The values of these 80th, 90th, and 95th percentile were 4.80 mm, 15.10 mm, and 28.89 mm, respectively. This method was used as an alternative due to the lack of hourly rainfall data in the study area. The peak flow is always around the middle of the day and proportionately distributed throughout the day. This was used as input in the SWMM simulation.
Figure 4. (a) Cumulative distribution function (CDF) of the disaggregated rainfall data from Ambulong, Batangas and NAS – UPLB Laguna rain gage stations, (b) Trendline of the disaggregated rainfall data, and (c) CDF of the disaggregated rainfall data with respect to return period using Weibull plotting position.

Figure 5. Hourly time series of rainfall depth of the 80th, 90th, and 95th percentile occurrence frequency of the disaggregated rainfall data (1989 – 2018) in DLSU Laguna Campus
3.2. Water balance of the different scenarios of each sub catchments

Shown in Figure 6 (a) were the water balances of the different scenarios of the simulation without the use of LID and using the eight LID technologies installed in SWMM. The 80th, 90th, and 95th percentile were used on each of the scenarios. There is a total of 27 scenarios in sub catchment 1 which has an area of 21.13 hectares by which NL stands for No LID, BC for bioretention cells, IT for infiltration trenches, RG for rain garden, GR for green roof, PP for permeable pavement, RB for rain barrel, RD for Rooftop disconnection, and VS for vegetative swale. Results showed that BC, IT, and PP created the most significant decrease in total runoff [30] while IT and PP significantly increase the infiltration of the area in the different percentiles. Poor performance was found in GR and VS in reducing the runoff and BC, RG, GR, RB, RD, and VS in increasing the infiltration in the three percentiles. Among the three percentiles, the 80th percentile has the most reduction in total runoff and the 95th percentile for the highest increase in the percentage of infiltration.

Figure 6 (b) shows the water balances of different scenarios same as in Figure 6 (a) but applied in sub catchment 2 with an area of 10.18 hectares. Also, there were a total of 27 scenarios and the same legend was applied. Results showed that LID technologies, including BC, IT, PP, and RD have the most significant total runoff reduction [31] and varying results for the increase of infiltration. For the 80th percentile, GR, and RB for increasing the infiltration and for the 90th and 95th percentile, PP showed a better result for infiltration. Among the three percentiles, same as in sub catchment 1, the 80th percentile has the most reduction in total runoff and the 95th percentile for the highest increase in the percentage of infiltration.

In Figure 6 (c), the water balances of the different scenarios applied in sub catchment 3 which has an area of 4.34 ha. were shown. Same scenarios and legend were used as in sub catchment 1 and 2. Also, there is a total of 27 scenarios. Results showed that BC, IT, and RG were effective in runoff reduction, and IT in increasing the infiltration on the different percentiles. Same trend as in the sub catchment 1 and 2 for the three percentiles, in the 80th percentile showed the most significant decrease in total runoff and in the 95th percentile showed the most significant increase in infiltration.
Figure 6. Comparison of the water balances of the scenarios with no LID (NL), with bioretention cell (BD), with infiltration trench (IT), with rain garden (RG), with green roof (GR), with permeable pavement (PP), with rain barrel (RB), with rooftop disconnection (RD), and with vegetative swale (VS) on the 80th, 90th, and 95th percentile rainfall of (a) sub catchment 1, (b) sub catchment 2, (c) sub catchment 3.

3.3. Efficiency of LID

The SA/CA ratio was an important factor in evaluating the performance of an LID in the reduction of runoff and pollutant loads [32]. Shown in Figure 7 is the reduced runoff or the equivalent increase in infiltration and storage in the 3 sub catchments vs SA/CA ratio [33]. It was produced from the SWMM model on each scenario was all less than 10% but effectively reduce the runoff on selected LID technology. The highest reduced runoff was found on the 80th percentile of sub catchment 1. These are the BC, IT, RG, and RD which reduced the runoff to 87%. The values found near 0 to 0 were results from the 90th and 95th percentile of sub catchment 3. These are the GR, PP, RB, RD, and VS. Also, results showed that reduced runoff in sub catchment 1 on the different LIDs, which has the largest surface area among the 3 sub catchments, have the highest reduced runoff.
4. Conclusion
Being sustainable is an essential ingredient in the progress of developing countries like the Philippines. Part of it is improving the water system of an area which includes controlling the excess water in the form of surface runoff, utilizing it for alternative use, and improving its water quality to minimize the degradation of water quality. One innovative approach is the use of LID technologies but challenges like insufficiency in data lead us to adapt other statistical methods to model and simulate different scenarios in an area unlike the methods used by developed countries. In this study in DLSU Laguna Campus located in Binan, Laguna, a developing city, the researcher focused on water quantity. Results showed that more than 60% of the rainfall data were within the one-year return period. Also, there is a significant increase in infiltration in using infiltration trenches and an effective decrease in surface runoff in using bioretention cells compared to the other available LID technologies in SWMM. In this site, using the 80th percentile rainfall was also best in maximizing the effectiveness of LID technologies compared to the 90th and 95th percentile rainfall. The sub catchments with at least 10 hectares had a greater amount of reduced runoff and a lesser amount of infiltration. Also, applying the LID technologies does not require a large surface area and would mean a lesser cost. It is recommended to have an empirical data to support and improve the simulated results. This study serves as a pioneering research work and reference for future researchers interested in exploring LID applications not only in the Philippines but also in other developing countries.

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