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Rain Garden as an Alternative Flood Mitigation Technique Using Storm Water Management Model

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***Abstract*—**Manila, Philippines is a low-lying topography having relatively flat areas, became susceptible to frequent flooding. In 2009, Typhoon Ondoy has inflicted damages in the city due to flooding. Improvements on sewer lines and drainages are continuously implemented but still experiencing gutter and half-knee deep floods. Rain garden is a Low Impact Development system composed of berms planted on an engineered soil, allowing 30% of the surface runoff water to infiltrate into the ground. To assess rain garden as a flood mitigating technique, EPA Storm Water Management Model dynamic rainfall-runoff modelling software was utilized that allows simulation of rainfall events and analysis of its effect onto the area. The simulation of the design case with rain garden resulted to a lesser flood volume as compared to the current design. The maximum percentage difference calculated between the base design and catchment with rain garden model is 53.52% and the minimum is 38.29%.

***Keywords*—**Flood Mitigation, Low Impact Development, Rain Garden, Surface Runoff, Storm Water Management

I. INTRODUCTION

Manila City is classified as 1st Class City and highly urbanized having a land area of about 35,966,479.65 square meters. The Pasig River subdivides the Manila City into two - the North and South, with small rivers or "esteros" and large storm sewers which collect runoff water from the large areas of the city.

The city's climate is monitored in PAG-ASA Climate Station located in Port Area. The city’s annual mean temperature is 28.2°C, ranging from 25.2 to 31.2°C. The monthly rainfall recorded at 486 mm with 22 rainy days mostly occurring during the wet period from July and August.

The City of Manila is a flood-prone area because of its topography being moderately flat and some areas are below sea level.

Flooding incidents still occur in the city especially in the study area, Barangay 659 and Barangay 659-A of Ermita, Manila, even though the city is equipped with sewers and drainages. On June 9, 2018, the Metropolitan Manila Development Authority (MMDA) released a flood alert in Manila City Hall where the vicinity is experiencing a gutter deep flood. On August 19 &20, 2017, the vicinity of Manila City Hall and nearby areas experienced a half-knee deep flood that the streets became impassable for light vehicles. In the same year on September 12, the flooding incident occurred again in the vicinity making the area not passable to vehicles which caused heavy traffic. In the previous years, there have been more cases of flooding in the area which contributed to the heavy traffic condition. This concludes that the existing drainages in the area are incapable of draining all the surface runoffs during heavy rains which results in flooding. Flooding occurs due to climate change that alters the spatial and temporal variability of precipitation patterns, inaccuracy in the estimation of IDF curves [1]. The Low Impact Development (LID) is an emerging practice in mitigating flood and a possible solution to the problem.

LID is an approach to urbanization that preserves and protects nature from hazardous ways of development using the natural processes in order to protect the water quality and its aquatic habitat. LID preserves and recreates the natural landscape and improves the impervious land masses that will act as drainage that can treat stormwater as a resource. LID has similar principle to rain gardens in which water can be managed in a way that promotes and preserves the natural movement of water. LID can maintain, improve, or restore a watershed's hydrologic and ecological functions [2]. In this study, the researchers focused on assessing rain garden mitigating floods on Barangay 659 – 659A. LID implementation all over the globe has concluded that countries have different ways in instigating Low Impact Development. Western countries, such as United States, focuses on the improving the water quality while Eastern countries focuses on flood prevention and rainwater harvesting. Governments and administrations should support the implementation of LID to improve the state of global issues [3].

The construction of rain garden is very similar to creating a conventional garden. It differs from a conventional garden in location of construction, size, garden depth, soil amendments and soil mix, and plant selection [4]. Rain garden will help not only in reducing flooding in Barangay 659 and 659-A but also to maintain sustainable development by using Low Impact Development (LID). To assess rain garden as a flood mitigation technique, the researchers used EPA Storm Water Management Model (SWMM) in the development of the catchment area and simulation of rainfall events.

The SWMM, developed by the US EPA, creates a simulation model that records the quantity and quality of runoff, infiltration and evaporation losses in areas considering the simulated rainfall events. The developed model in SWMM includes sub-catchment areas receiving precipitation, in which the generated runoff is diverted on another sub-catchment transported through conduits or infiltrated to the ground [5]. The topographic map of Manila City and its existing drainage system layout were used in the development of the catchment model of Barangay 659 and Barangay 659-A. The rainfall intensity data of Typhoon Ondoy (international name KETSANA) recorded in Port Area Station was used for the calibration and for the simulation of the two design cases in the study which are the current design case and the catchment with rain garden. After running the simulation, the maximum volume of ponded surface water for the two design cases were compared to assess the effectiveness of rain garden as a flood mitigating technique in Barangay 659 and 659 -A.

II. RELATED WORK

Abi Aad et. al. assessed the use of rain barrels and rain gardens using the LID control modules of EPA SWMM. The study estimated the runoff peak and volume reduction, and the delay of runoff hydrograph. It is concluded that rain garden has a significant effect on both runoff peak reduction and runoff volume reduction [6].

III. METHODOLOGY

The study area is in Barangays 659 and 659-A located in Ermita, Manila City, Philippines with the coordinates of 14.5891° N, 120.9826° E and 14.5930° N, 120.9826° E.

Figure 1 illustrates the location and the boundaries of the study area as captured from Google Map. Barangays 659 and 659-A are located below Pasig River, which made it a part of District V, Southern Manila. Several establishments including Manila City Hall, SM City Manila, YCMA of Manila, Philippine Normal University, Unibersidad de Manila, and most of the city government offices, as well as LRT Line 1 Central Station, are situated in the area. Based on the city's Flood Hazard Map, during heavy rains or even a sudden thunderstorm, the area experiences a flood height of 0.5 to 1 meter and flood duration of one (1) to three (3) days. These flooding incidents in the area often affect and worsen the traffic congestion of the area.

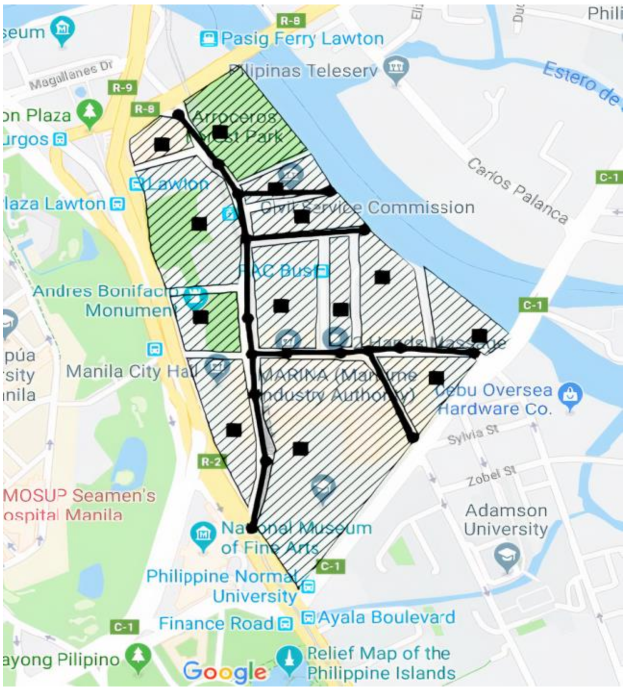

Figure 1. Location Map

3.1. Data Gathering

The topographic map was used for the determination of the slope and the boundaries of each sub-catchment.
The rainfall intensity data of Typhoon Ondoy [Typhoon Ketsana] was gathered from the Port Area Station, Manila City of Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAG-ASA) since it is the nearest weather station in the Barangay 659 and 659-A.

Table 1 shows the rainfall intensity data from PAG-ASA that was recorded from September 25, 2009 until September 27, 2009 in 6-hour interval. The highest rainfall intensity during Typhon Ondoy accounted to 169.00 mm/hr, recorded on September 26, 2009 at 12:00 am.

Table 1. Rainfall Intensity Data of Typhoon Ondoy

Date	Elapsed Time (hr)	Intensity (mm/hr)
09/25/2009	00:00	0.00
	06:00	1.00
	12:00	19.00
	18:00	30.00
09/26/2009	00:00	169.00
	06:00	37.00
	12:00	5.00
	18:00	3.00
09/27/2009	00:00	0.00

The existing drainage system of Barangays 659 and 659-A was gathered from the Department of Public Works and Highways South Manila District Engineering Office in Manila City. Figure 2 shows the drainage system layout of Barangay 659 and 659-A which was obtained from DPWH. This layout was used for the determination of sub-catchment boundaries as well as the location of the conveyance elements on the study area. The pipe sizes and the direction of runoff indicated in the drainage layout were used to modify the properties of the conduits in SWMM.

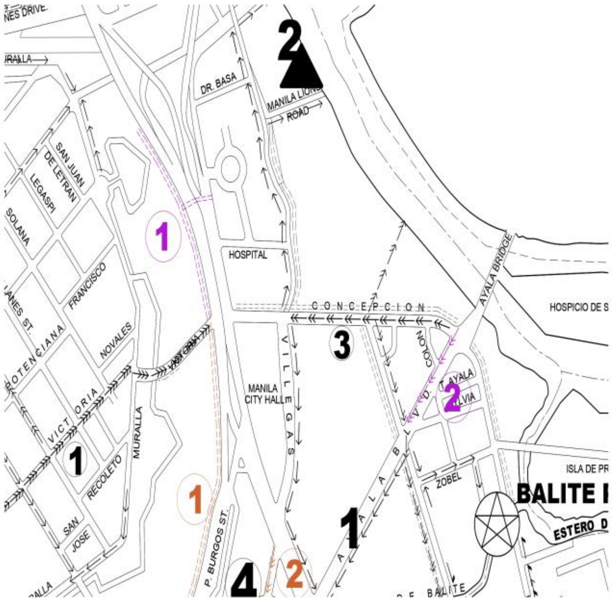

Figure 2. Drainage System Layout of Barangays 659 and 659-A

3.2. Software Used

The EPA SWMM Version 5.1 was used in assessing the effectiveness of rain garden as an alternative flood mitigation technique. It is a dynamic rainfall-runoff simulation model which allows simulation of single or continuous rainfall events in urban/suburban catchment. It has an LID control module which can be manipulated and placed in the catchment model for further evaluation of its performance. A combination of different vertical layers defined per-unit-area basis can be modified in LID controls. Moisture balance during simulations is applied that records the quantity of water that flows and/or stored in between each layers. After running the simulation, SWMM quantifies the generated runoff, flow rate, and flow depth in each pipe and channel. It also generates output on node flooding, which includes the peak volume of ponded surface water, which was the focus of the study

3.3. Development of Catchment Model

The determination of the sub-catchment boundaries and plotting the conveyance elements according to the existing drainage system layout as gathered from the DPWH South Manila District Engineering Office in Manila City were done to develop the catchment model of Barangays 659 and 659-A.

The map of Barangay 659 and 659-A was scaled and used as the backdrop image of the catchment. The properties of the sub-catchment, including the slope percentage, percent of imperviousness and perviousness, and the infiltration information, were modified in SWMM. The researchers utilized Google Earth in obtaining the highest and lowest elevations within a sub-catchment to determine the slopes.
The existing drainage system map of Barangay 659 and 659-A, gathered from DPWH South Manila District Engineering Office in Manila City, was plotted in SWMM. The conveyance elements connected in each sub-catchment were plotted and modified using the Hydraulic option of SWMM. The hydraulic components of the catchment include the nodes and links with their properties. Junction nodes are the representation of the manholes in the sewer system. Conduits represent the pipelines in a drainage system which transports precipitation to and from the junction. The conduits are laid out in the sub-catchment in reference to the drainage system map obtained from DPWH. The shape of the conduit, the maximum depth, and the roughness are modified in SWMM.

3.4. Calibration of Catchment Model

Calibration is an important consideration in catchment modeling since this process allows the model to be a precise representation of the scenarios happening in the actual catchment area. The rainfall data recorded during the Typhoon Ondoy in 2009 was used in the calibration. After modeling the catchment area and modifying its properties, an initial simulation of the Typhoon Ondoy was recorded. The flood depth obtained from this initial simulation will be compared to the actual flood depth on the area during Typhoon Ondoy.

The value for the ponded area of each node and the Manning's N value of impervious area were the most crucial parameter in the model calibration. The ponded area was modified using the grid weighted mean, and the Manning's N value was adjusted until the flood depth generated from the initial simulation reflected the value of the actual flood depth during Typhoon Ondoy.

The Typhoon Ondoy was simulated into two design cases. The first design case was the calibrated catchment which contains only the existing drainage system while the second case was the calibrated catchment containing the combination of the existing drainage system and rain garden.

3.5. Simulation of Rainfall Event to the Sub-catchment with Rain Garden

In reference to the different literature review for designing a rain garden, the researchers have designed the rain garden with the parameters listed in Table 2. Ten percent of each sub-catchment is assigned as rain garden each having the same parameters.

Table 2. Parameters of Rain Garden

PARAMETER	UNITS	VALUES
Berm Height	mm	228.6
Vegetation Volume Fraction		0.1
Surface Roughness (Mannings n)		0.41
Surface Slope	%	0
Thickness	mm	900
Porosity	volume fraction	0.437
Field Capacity	volume fraction	0.105
Wilting point	volume fraction	0.047
Conductivity	mm/hr	508.104
Conductivity Slope		30
Suction Head	mm	60.96

3.6. Statistical Treatment of Data

Single factor analysis of variance (ANOVA) was utilized to assess whether the rain garden can be an alternative flood mitigation technique in Barangay 659 and 659-A. ANOVA is a method of testing the significance of the difference between 2 or more sets of data. It allows the comparison of the means on each set of sample data to make a generalization about the population means [7]. The variation of values within a data set is compared to the variation of values within another set of data. If the difference between the variations of the two data sets is larger than the variation of the values within the data set, the samples will have significant difference. For this study, the flood volume generated in each junction for the current design case was compared to the flood volume generated in each junction for the case with rain garden.

IV. RESULTS AND DISCUSSION

4.1. Catchment Model of the Study Area

The catchment model of Barangays 659 and Barangay 659-A is divided into 14 sub-catchments, basing on the existing drainage layout as gathered from the DPWH of Manila District V. Table 3 presents the geometric parameters of each sub-catchments. The sub-catchments have an average/mild slope ranging from 0.50% to 5%.The surface imperviousness of the area was based on the zoning map obtained from the City Planning and Development Office of Manila City, indicating that the land usage of Barangays 659 and Barangay 659-A is divided into General Institutional Zone and University Cluster Zone. It was generally considered as commercial and business zone, having an imperviousness of 85%. The soil of the study area is classified under Hydrologic Soil Group C, indicating that the soil has a moderately high runoff potential. Considering its soil classification and land usage of the area, SCS Runoff Curve Number of the catchment is assigned as CN=79. The Manning's "n" of the sub-catchments are also based on the imperviousness of the area which is 0.011 for smooth asphalt.

Table 4 shows the ponded area in each junction, its invert elevation and its maximum depth. Based from the cross section of manhole obtained from the DPWH, the invert elevation and the maximum depth of each junction are 0.5 m and 2.61 m, respectively.

Table 5 lists the geometric shape of the conduits, its dimensions and its roughness coefficient. The catchment have 30", 36" and 24" diameter circular conduits and 14 box culverts, represented as closed rectangular conduit, having a dimension of 2.00m by 1.61m. Each conduit is made of cement material having a corresponding Manning roughness coefficient of 0.011.

Table 3. Parameters of the Sub-catchments

Sub-catchment	Area (ha)	Slope (%)	Imper-viousness (%)	Manning's 'n' Value	Hydrological Soil Group	Curve Number
S1	1.46	1.16449	85	0.011	C	79
S2	2.58	0.758	85	0.011	C	79
S3	2.04	1.1588	85	0.011	C	79
S4	0.18	4.9927	85	0.011	C	79
S5	0.35	0.50	85	0.011	C	79
S6	0.39	2.72723	85	0.011	C	79
S7	0.87	0.525	85	0.011	C	79
S8	1.21	0.5	85	0.011	C	79
S9	1.62	1.06125	85	0.011	C	79
S10	1.49	0.12707	85	0.011	C	79
S11	2.07	0.817	85	0.011	C	79
S12	0.96	1.47	85	0.011	C	79
S13	0.58	2.175	85	0.011	C	79
S14	1.49	0.695	85	0.011	C	79

Table 4. Parameters of Junctions

JUNCTIONS	Ponded Area (m2)	Invert Elevation (m)	Maximum Depth (m)
J01	17253	0.5	2.61
J02	38029	0.5	2.61
J03	26335	0.5	2.61
J04	25800	0.5	2.61
J05	12780	0.5	2.61
J06	12680	0.5	2.61
J07	12931	0.5	2.61
J08	12947	0.5	2.61
J09	17510	0.5	2.61
J10	7628.1	0.5	2.61
J11	14900	0.5	2.61
J12	20878	0.5	2.61
J13	7886.1	0.5	2.61
J14	2410	0.5	2.61
J15	4099.7	0.5	2.61
J16	8296.9	0.5	2.61
J17	11127	0.5	2.61
J18	9949.6	0.5	2.61
J19	29673	0.5	2.61
J20	10381	0.5	2.61

Table 5. Parameters of Conduits

CONDUITS	Shape	Length (m)	Dimension (m)	Roughness Coefficient
C-01	CIRCULAR	70.20	0.6096	0.011
C-02	CIRCULAR	69.89	0.6096	0.011
C-03	CIRCULAR	129.03	0.6096	0.011
C-04	CIRCULAR	41.80	0.6096	0.011
C-05	CIRCULAR	39.53	0.6096	0.011
C-06	CIRCULAR	55.95	0.6096	0.011
C-07	CIRCULAR	74.97	0.6096	0.011
C-08	CIRCULAR	68.91	0.6096	0.011
C-09	CIRCULAR	145.84	0.6096	0.011
C-10	CIRCULAR	186.32	0.6096	0.011
C-11	CIRCULAR	74.83	0.762	0.011
C-12	CIRCULAR	79.92	0.6096	0.011
C-13	CIRCULAR	163.18	0.9144	0.011
C-14	CIRCULAR	387.63	0.9144	0.011
C-15	CLOSED RECTANGULAR	367.99	2.00 x 1.61	0.011
C-16	CLOSED RECTANGULAR	314.88	2.00 x 1.61	0.011

4.2 Calibration and Simulation of Catchment Model

To assess the response of the catchment design scenario to an extreme rainfall event, Typhoon Ondoy, which accumulated the highest recorded flood depth, is used for this study.

Table 6 shows the maximum depth of flood water in each junction for the initial simulation and calibrated sub-catchment of Typhoon Ondoy on the sub-catchment area. This simulation uses the initial parameters set by the researchers. After adjusting the Manning's 'n' of the sub-catchments, it shows the maximum depth per junction of the calibrated catchment. These depths reflect the actual flood depth during the Typhoon Ondoy on Barangay 659 and Barangay 659-A.

After the simulation of the rainfall event for the sub-catchment with rain garden, the flood volume in each junction are summarized in Table 7. The highest recorded ponded flood volume is 16.47 x 106 liters at Junction JO2.

Table 6. Initial Flood Depth

JUNCTION	Initial Flood Depth for the Initial Simulation (m)	Initial Flood Depth of the Calibrated Sub-catchment (m)
J01	1.372	0.863
J02	1.359	0.857
J03	1.272	0.831
J04	1.074	0.771
J05	0.524	0.539
J06	0.515	0.530
J07	0.509	0.524
J08	0.496	0.521
J09	0.560	0.573
J10	0.665	0.675
J11	0.818	0.820
J12	1.946	0.874
J13	1.946	0.874
J14	0.892	0.892
J15	0.738	0.738
J16	0.738	0.738
J17	1.373	0.864
J18	1.225	0.782
J19	1.224	0.781
J20	1.225	0.782

Table 7. Initial Flood Depth

JUNCTION	MAXIMUM PONDED FLOOD VOLUME 10^6 (liter)
J01	7.42
J02	16.47
J03	11.72
J04	10.24
J05	3.99
J06	3.85
J07	3.96
J08	3.90
J09	5.50
J10	3.07
J11	7.54
J12	8.89
J13	3.36
J14	1.20
J15	1.41
J16	2.85
J17	4.80
J18	3.65
J19	10.86
J20	3.81

4.3. Comparison of Flood Volume Difference

Table 8 and Figure 3 show the flood volume difference generated by the two design cases. Figure 3 shows the flood volume difference between the two design cases – the current design case and the case with rain garden. This figure is a visual representation of the percentage difference which is tabulated in Table 8.

Analysis of variance (ANOVA) was conducted to test the difference between the two cases in the study. Table 9 shows the results of the Analysis of Variance. The computed F value of 7.818 is higher than the critical F of 4.098, which means that the variance of the flood volume for the two cases has significant difference. Implies further that rain garden can reduce flood volume and is an effective alternative flood mitigation technique using Storm Water Management Model.

Table 8. Flood Volume Difference

JUNCTION	BASE DESIGN	W/ RAIN GARDEN	DIFFERENCE	PERCENT DIFFERENCE
J01	14.89	7.42	7.47	50.17%
J02	32.59	16.47	16.12	49.47%
J03	21.88	11.72	10.17	46.45%
J04	19.89	10.24	9.65	48.51%
J05	6.89	3.99	2.90	42.12%
J06	6.72	3.85	2.87	42.64%
J07	6.78	3.96	2.82	41.60%
J08	6.75	3.90	2.85	42.23%
J09	10.03	5050	4.54	45.20%
J10	5.15	3.07	2.07	40.30%
J11	12.22	7.54	4.68	38.29%
J12	18.25	8.89	9.35	51.26%
J13	6.89	3.36	3.53	51.26%
J14	2.15	1.20	0.95	44.28%
J15	3.03	1.41	1.62	53.52%
J16	6.12	2085	3.28	53.52%
J17	9.61	4.80	4.82	50.12%
J18	7.78	3.65	4.13	53.07%
J19	23.17	10.86	12.31	53.14%
J20	8.12	3.81	4.31	53.07%

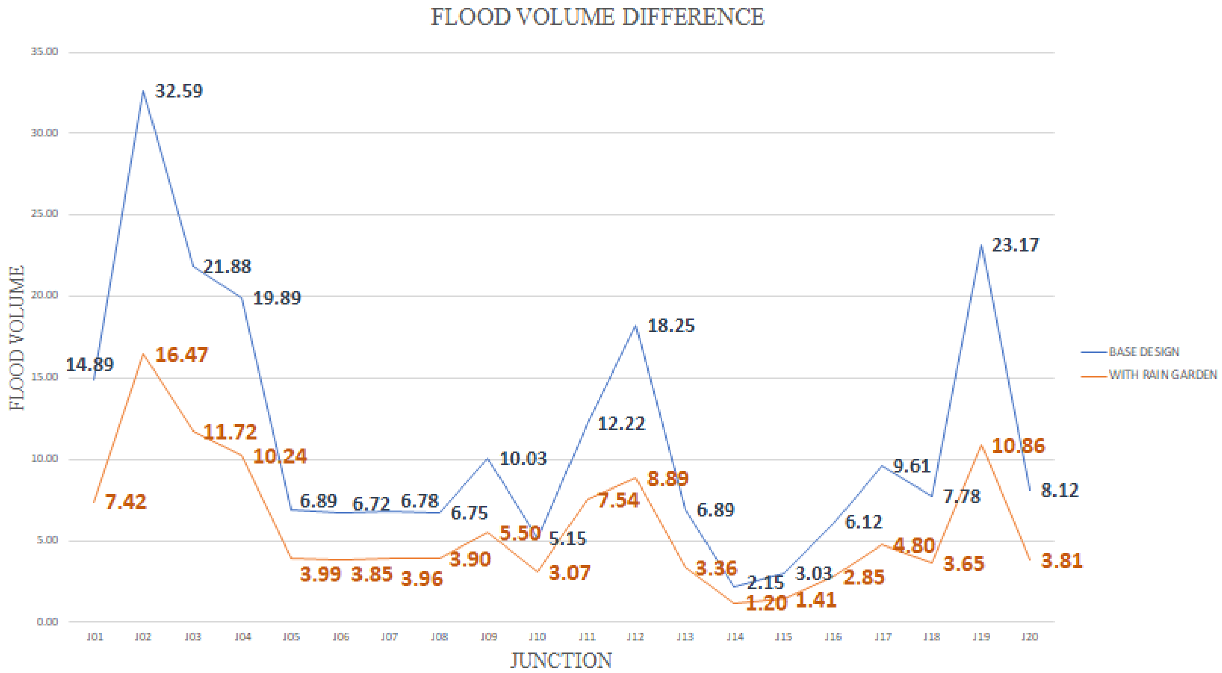

Figure 3. Flood Volume Difference

Table 9. Results of ANOVA

SOURCE OF VARIATION	SS	Df	MS	F	P-VALUE	Fcrit
	304.905	1	304.905	7.818	0.00807	4.098
	1482.017	38	39.000			
TOTAL	**1786.922**	**39**				

V. CONCLUSION AND FUTURE SCOPE

Manila, Philippines is geographically low-lying in nature making it more prone to frequent flooding. The rainfall data from Typhoon Ondoy (international name KETSANA) was used to calibrate and simulate the catchment model into the current design case and catchment with rain garden. The simulation of Typhoon Ondoy to the design case with rain garden resulted to a lesser flood volume compared to the current design case. The maximum percentage difference calculated between the base design and catchment with rain garden model is 53.52% and the minimum is 38.29%. The results show a significant difference in the flood volume. The study generally concludes that rain garden will help in the reduction of flooding in Manila. Philippines.

It is recommended using rain garden to mitigate flooding problems. The percentage difference ranging from 38.29% to 53.52% is a significant change considering the condition of the City of Manila during the rainy season. LID will help reduce flood volume in the area. The researchers considered the drainage system layout in the simulation, which means that in due time the drainage system be compromised, the results will not be the same. It can however be improved by proper waste disposal and maintaining regular drainage cleaning.

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AUTHORS PROFILE

Dr. Florante D. Poso, Jr., pursed BSCE in Adamson University, MCE and PhD in the University of Eastern Philippines, in 1996, 2004 & 2008 respectively. He is a Philippine registered civil engineer and registered professional secondary teacher. He had been working for more than 20 years in various fields of civil engineering both in the construction industry and in the academe. At present, working as a full-time professor of Far Eastern University (FEU) Institute of Technology. He worked with Daewoo Engineering and Construction Co., Ltd. as Civil Engineer/Quantity Surveyor for the construction of Safi Independent Power Plant Project in Safi, Morocco. He performs analysis to develop design solutions using computer softwares such as Structural Analysis Program (SAP), Structural Analysis Aided Design (STAAD), GeoSlope, Plaxis and AutoCAD2010. He worked as Design Engineer in Duqm Drydock and Shipyard Project and as Civil Engineer in Sur Independent Power Plant (SIPP) Project both in Sultanate of Oman under Daewoo Engineering and Construction Co., Ltd.

Lady Lyn E. Escarieses was born in Polillo, Quezon, Philippines in 1994. In 2015, she received the degree in Bachelor of Science in Civil Engineering from FEU Institute of Technology. She became a licensed Civil Engineer in the Philippines in May 2016. At present, she is also a candidate of Master of Science in Civil Engineering major in Water Resources Engineering at MAPUA University. She joined the Civil Engineering Department of FEU Institute of Technology in 2016 as an Instructor that focuses on teaching Fluid Mechanics and Hydraulics.

Coleen P. Clarita is a graduate of Bachelor of Science in Civil Engineering at Far Eastern University - Institute of Technology. She was a dedicated member of the Artist Connection - Music Synergy from 2015 to 2017, Association of Civil Engineering Students from 2015 to 2020, and Junior Philippines Institute of Civil Engineering from 2018 to 2020. She has attended several seminars in relation to Civil Engineering such as the ACI Philippines Student Convention 2019, FEU Tech Converse 3: The Earth Against Humanity, and the Civil Engineering Research Symposium, to name a few. She did her internship at Momentum Construction and Development Corporation (MCDC) from August to November of 2019. Her most recent contribution was for a research entitled Assessment of Rain Garden as an Alternative Flood Mitigation Technique Using Storm Water Management Model (SWMM).

Christine Fabian is a graduate of Bachelor of Science in Civil Engineering (BSCE). She obtained her degree in 2020 from Far Eastern University – Institute of Technology (FEU-IT). She attended several seminars regarding soil, water and environmental engineering and was present during the ACI Philippines Student Convention 2019. She was a member of the Association of Civil Engineering Students since 2015 and Junior Philippines Institute of Civil Engineering since 2018 until 2020. She attended several seminars regarding soil, water and environmental engineering and was present during the ACI Philippines Student Convention 2019. She was part of a research aiming to assess rain garden as an alternative flood mitigation using Storm Water Management Model (SWMM).

Lovil Christian D. Moreno graduated from Far Eastern University – Institute of Technology in 2020 with the degree of Bachelor of Science in Civil Engineering. He was a scholar of Commission on Higher Education (CHED) during college and an academic scholar of Surigao Education Center during high school which he graduated top of his class. He was a member of the Junior Philippine Institute of Civil Engineers from 2018 until 2020 and the Association of Civil Engineering Students since 2016. His research interests include hydrology, stormwater management technologies, and environmental engineering.

Rowena O. Satira is a graduate of Bachelor of Science in Civil Engineering from Far Eastern University - Institute of Technology. She was a part of different student organizations including Association of Civil Engineering Students (2015-2020), Junior Philippine Institute of Civil Engineering (2018-2020), and American Concrete Institute (2018-2020). She became an intern of Momentum Construction and Development Corporation under Quantity Surveying Department. Her recent accomplishment is a study conducted to assess rain garden as an alternative flood mitigation technique using Stormwater Management Model (SWMM).