LEVERAGING GIS AND SWMM WITH LOW IMPACT DEVELOPMENT TECHNIQUES TO IMPROVE URBAN DRAINAGE AND FLOOD MITIGATION: A CASE STUDY OF OPOLO HOUSING ESTATE, BAYELSA STATE.

BY

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1.0 INTRODUCTION

1.1 PROBLEM STATEMENT AND SITE CONTEXT

The Opolo Housing Estate residential area in Yenagoa, Bayelsa State, suffers considerable hydrologic issues that are exacerbated by its geographical location. Being in the Niger Delta, Yenagoa's landscape is characterized by low-lying topography and a high-water table. Together with the site's traditional, highly impermeable drainage system, this inherent vulnerability to saturation and inadequate drainage causes stormwater runoff to generate quickly. High peak flows that beyond the capacity of the system's current infrastructure occur during the 10-year design storm, causing localized flooding, manhole surcharge, and the discharge of non-point source pollution (NPSP) into receiving waterways.

1.2 PROJECT AIM

This project's main goal was to establish a sustainable Low Impact Development (LID) retrofit strategy to reduce flood risk by evaluating the current hydrological conditions (Baseline Scenario) and drastically reducing peak flow rates and total runoff volume, which will change the hydrologic response of the sub-basin into a more resilient, natural system.

2.0 METHODOLOGY

2.1 STUDY AREA

The study area (Figure 1) is a 15.23-hectare contiguous urban area in Yenagoa, which is in the Yenagoa Local Government Area of Bayelsa State.

There are distinct wet and dry seasons in the region's humid, tropical monsoon environment. Usually, the average yearly temperature falls between 25°C and 30°C (77°F and 86°F). The humid circumstances are exacerbated by the constant high relative humidity, which frequently surpasses 80% during the rainy season. Peak rainfall occurs between June and September, while the region experiences a distinct wet season from April to October. Rainfall ranges from 1,200 to 1,800 millimetres (47 to 71 inches) on average per year.

The study area has significant potential for the application of LID principles to improve stormwater management and reduce the danger of floods due to its high degree of urbanization. The region is separated into nine sub-catchments (Figure 2) based on surface runoff patterns, which are especially influenced by the road network, to model the drainage and runoff behaviour. There are four outfall nodes among the 38 nodes and 14 conduits that make up the drainage network under investigation. The conduit is 600 mm deep and 600 mm wide, forming an open rectangular (box) channel. Reinforced concrete (RCC), a common material for urban drainage infrastructure, is utilized in the stormwater drainage system. These channels aid in controlling the flow of stormwater across the basin.

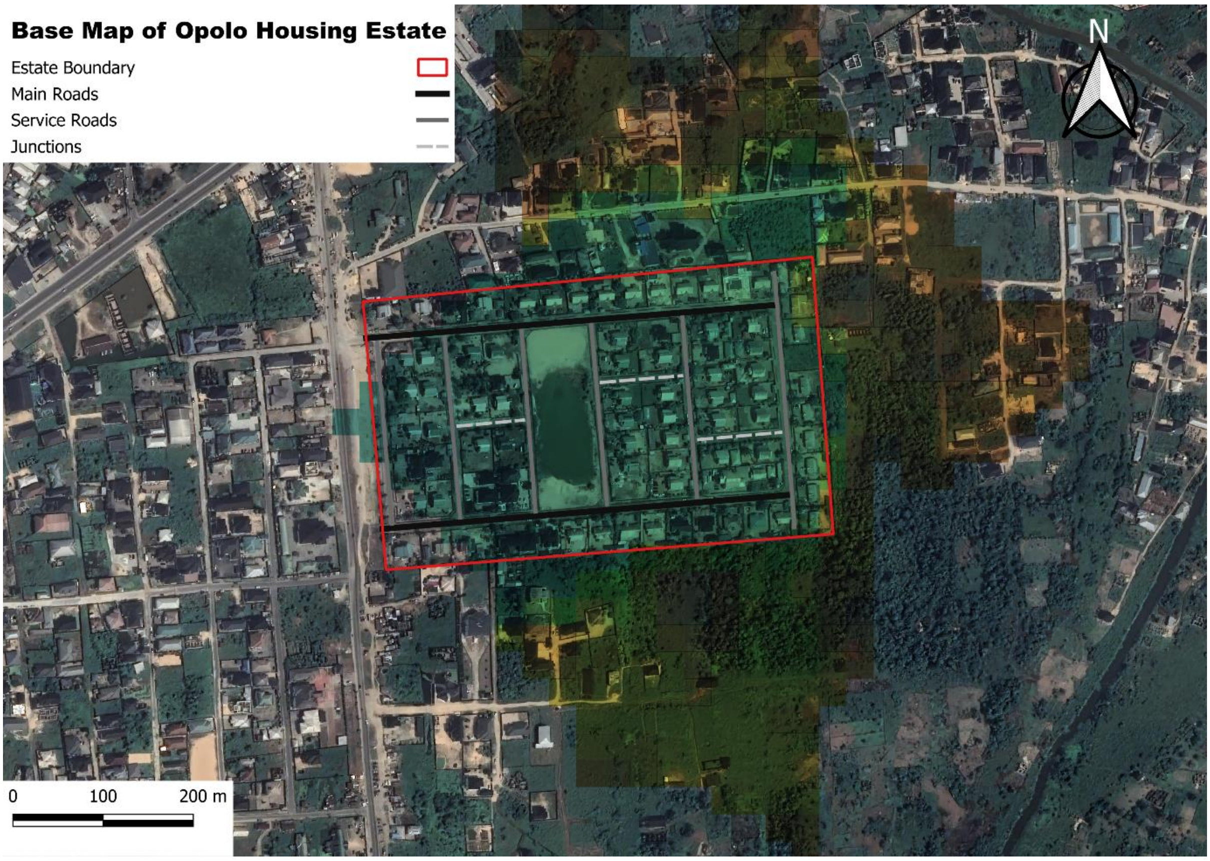


Figure 1. Study area map

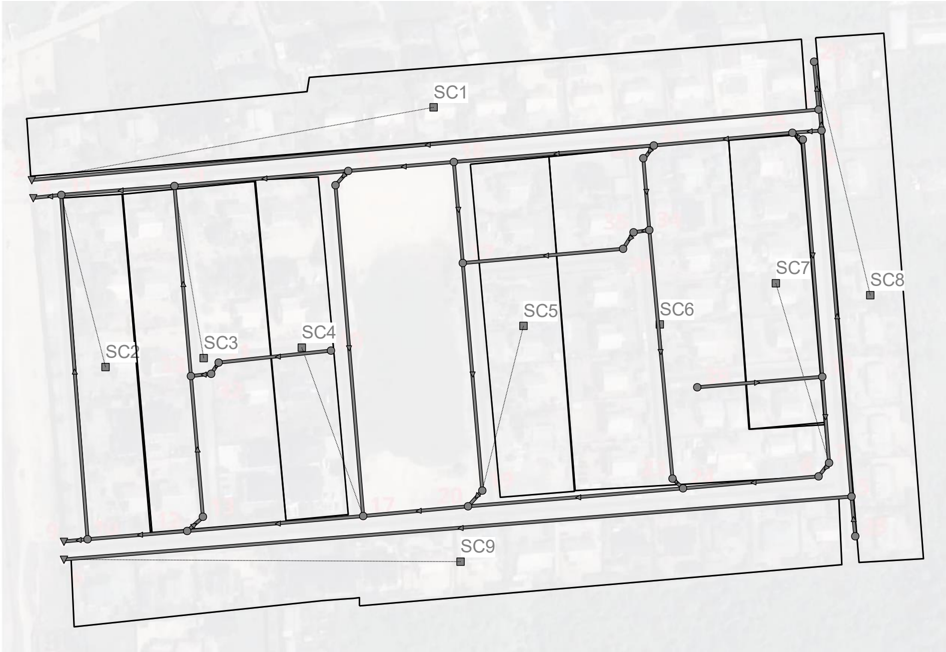


Figure 2. Network map (developed in SWMM software)

2.2 DATA

Accurate and comprehensive data is essential in any research or project, particularly for stormwater network modelling, which demands a wide range of inputs. For this project, vital resources where sourced from external sources:

1. Topographic Data (DEM): A 30m Digital Elevation Model (DEM) was sourced from USGS Earth Explorer and processed in QGIS to delineate the study area. QGIS analysis provided the 9 sub-catchments average slope, flow path lengths, and elevation data (used to define node inverts and conduits slopes).
2. Rainfall Data (IDF): The Intensity-Duration-Frequency (IDF) curve was derived from a local hydrologic study and converted into a Time Series Rainfall input for the 10-year, 120-minute design storm simulation (Table 1), (Figure 3).
3. Hydraulic Network Data: Conduits were modelled using the field-measured 600mm × 600mm open rectangular channel dimensions.

Table 1: Rainfall Intensities for Yenagoa

Frequency (Years)	5 Minutes	10 Minutes	30 Minutes	45 Minutes	60 Minutes	120 Minutes	180 Minutes	210 Minutes
2	191.4	120.2	57.8	44.1	36.5	23	17.55	15.85
5	242	151.9	73.15	55.8	46	29	22.12	20.06
10	275	173	83	63.4	52.4	33	25.2	22.7
25	314	198	95.5	72.7	60	37.8	28.9	22.97
50	346	217	104.5	79.8	66	41.4	31.7	28.6

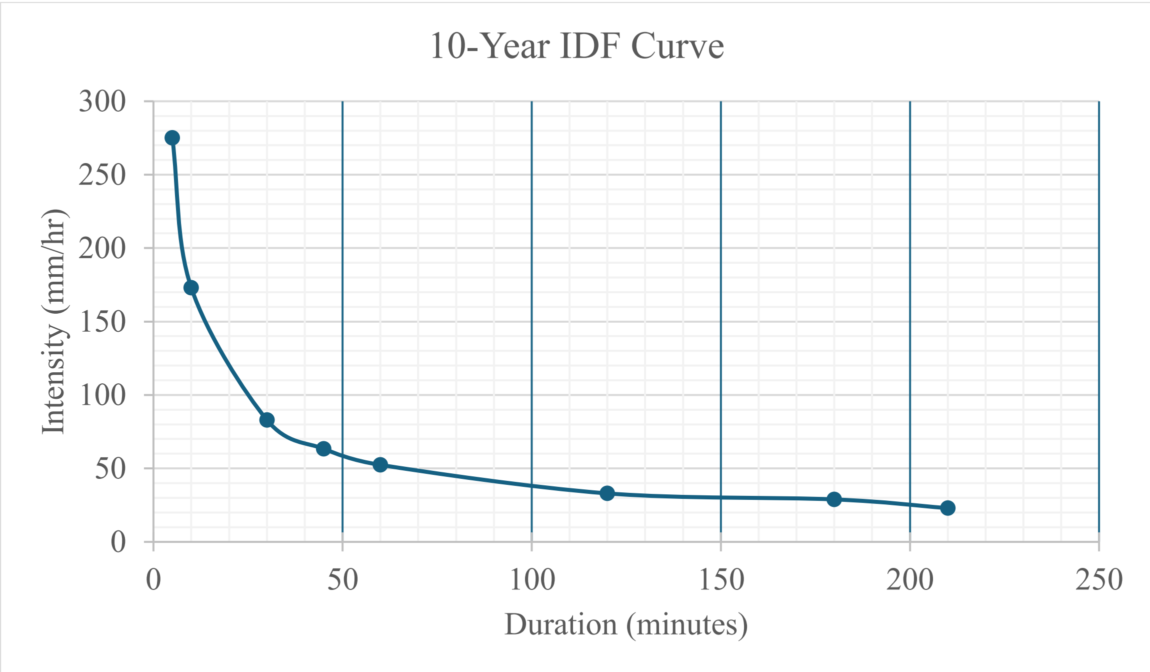
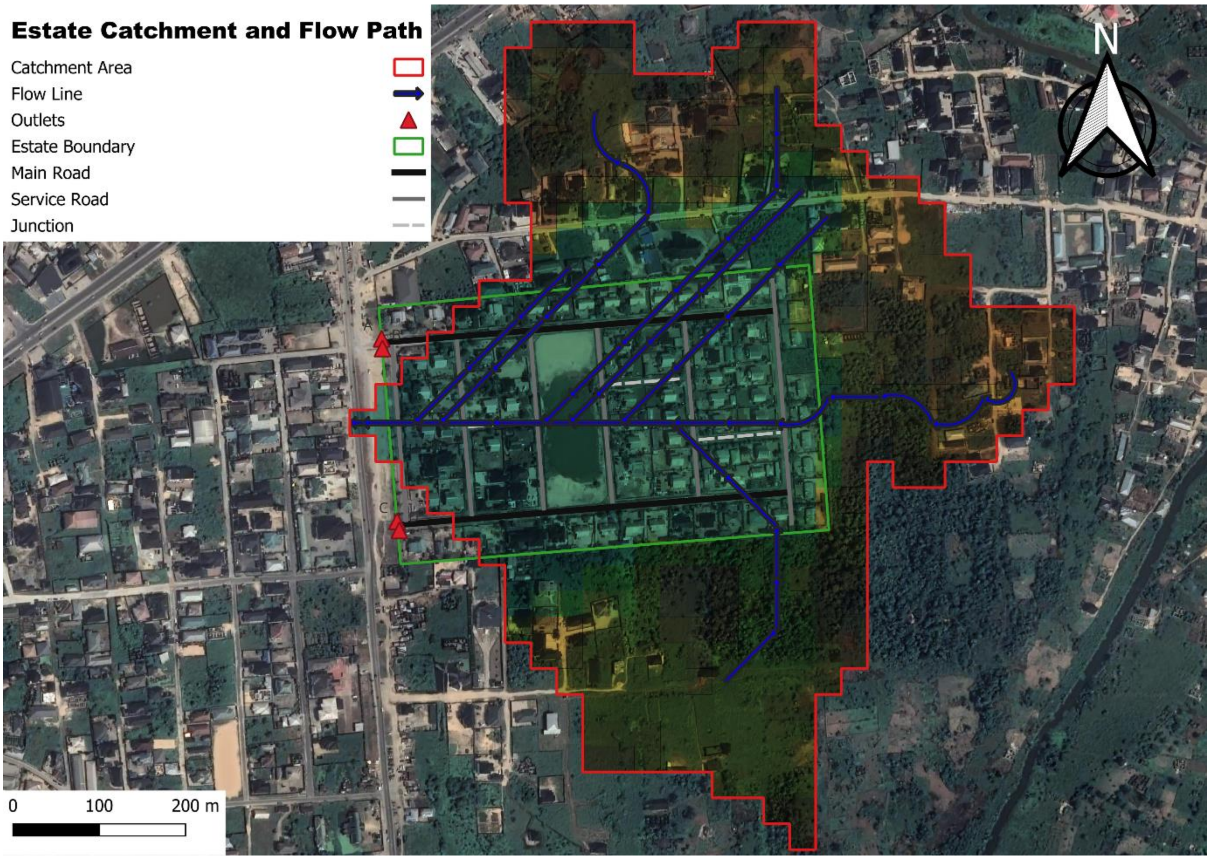


Figure 3. 10-year IDF Curve

2.3 GIS-BASED CATCHMENT DELINEATION

To precisely simulate the hydrological processes that occur inside the 15.23-hectare property (Figure 4), The physiographical features of the upstream catchment were identified, the study area's boundaries and flow topology were established, and all relevant information regarding areas, altitudes, slopes, morphometric parameters, and principal streams was obtained through the use of QGIS. The boundaries of the watercourses' catchment area that border or cross the site were established based on the information above.



2.3 DESIGN STORM DEVELOPMENT

The storm event used as the rainfall input for the SWMM model had a duration of 120 minutes (2 hours) and a 10-year return period. The storm depth was 66 mm, which was calculated using the IDF data's 120-minute intensity of 33 mm/hr. To determine the necessary 10-minute time series block, the following methods was used:

1. Cumulative and Incremental Depth: First, the entire storm depth was calculated. Next, the cumulative rainfall depth and incremental depth for the standard durations given by the IDF curve were calculated.

$$D_i = \frac{I \times T}{60} \quad (1)$$

Were,

D_i = Cumulative Depth

I = Rainfall Intensity

T = Duration

$$\Delta D_i = D_i - D_{i-1} \quad (2)$$

Were,

ΔD_i = Incremental Depth

2. Intensity Interpolation (Log-Log Method): Log-log interpolation was utilized to precisely determine the 10-minute time steps required for the hyetograph. Using known durations and their corresponding intensities from the IDF data, this process determined the exact intensity for the necessary short durations.

$$\log(D_i) = \log(D_A) + (\log(D_B) + \log(D_A)) \times \frac{\log(T_i) - \log(T_A)}{\log(T_B) - \log(T_A)} \quad (3)$$

Were,

D_i = Interpolated Cumulative Depth

T_i = Derived Duration

D_A, D_B = Known Cumulative Depth

T_A, T_B = Known Duration

To convert D_i back to cumulative depth we take its inverse

$$D_i = 10^{\log D_i} \quad (4)$$

3. Hyetograph Creation: Using the alternating block method, which guarantees that the peak rainfall intensity happens at the most advantageous period to maximize runoff and flood damage, the intensity values created in step 2 were utilized to create a design storm hyetograph (Figure 5). The subsequent incremental depths are positioned

alternately to the left and right of the peak, with the highest incremental depth being in the middle of the storm's 120-minute length. On the right side of the peak is the second-largest block, followed by the third-largest block on the left.

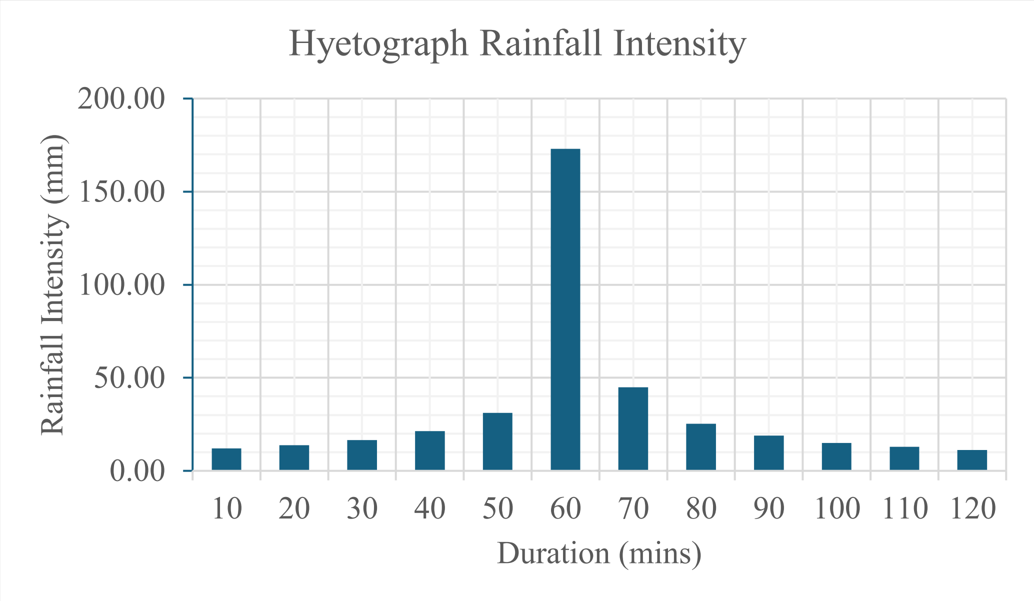


Figure 5. 10-year Rainfall Hyetograph

2.4 SWMM MODELLING PARAMETERS

For SWMM to accurately mimic the rainfall-runoff process, site-specific characteristics are needed. The input values in Table 2 chosen for this model are well suited to the estate's distinct land cover, which includes a subgrade with sandy soil (pervious area) and extensive usage of tightly spaced interlocking block pavement (impervious area). By using the Saint-Venant equations to account for backwater effects, flow reversal, and complicated network configurations, dynamic wave routing was chosen to improve the accuracy of flow prediction. To guarantee a more environmentally friendly method of managing urban stormwater.

Table 2: Modelling Parameters

Parameter	Description	Value
N-Imperv	Manning's roughness coefficient for impervious area	0.015
N-Perv	Manning's roughness coefficient for pervious area	0.05
Dstore-Imperv	Depth of depression storage on impervious area (mm)	3
Dstore-Perv	Depth of depression storage in the pervious area (mm)	3
Conduit roughness	Manning's roughness coefficient for conduit	0.015
Max Infil. Rate	Maximum rate on the Horton infiltration curve (mm/hr)	100
Min Infil. Rate	Minimum rate on the Horton infiltration curve (mm/hr)	25
Decay Constant	Decay constant for the Horton infiltration curve	4
Drying time	Time for a fully saturated soil to completely dry	7

2.5 LOW IMPACT DEVELOPMENT (LID)

All nine of the study area's subcatchments were the focus of the integration of LID methodologies. However, to optimize hydrological benefits, considerable thought was given to their spatial distribution and sizing requirements, going beyond simply putting LID concepts into practice. Permeable pavements were utilized in the front yards of every building in the subcatchments which have an average of 273 square meters because they allow stormwater penetration while being usable. In contrast rain barrels were utilized to collect and hold rainwater from building rooftops, which helped to minimize runoff into drainage systems during times of high flow. Each unit's roof had an average of 202 square meters. Table 3 shows the modelling parameters for the LID controls in SWMM.

Table 3: LID Modelling Parameters

LIDs type	Layer	Parameter	Value
Permeable Pavement	Surface	Berm Height (mm)	150
		Vegetation Volume Fraction	0
		Surface Roughness (Mannings n)	0.015
		Surface Slope (%)	1
	Pavement	Thickness (mm)	100
		Void Ratio	0.2
		Impervious Surface Fraction	0.05
		Permeability (mm/hr)	1000
		Clogging Factor	0
		Regeneration Interval (days)	0
		Regeneration Factor	0
	Soil	Thickness (mm)	150
		Porosity	0.45
		Field Capacity	0.1
		Wilting Point	0.05
		Conductivity (mm/hr)	10
		Conductivity Slope	10
		Suction Head (mm)	50
	Storage	Thickness (mm)	600
		Void Ratio	0.45
		Seepage Rate	0
		Clogging Factor	0
Rain Barrel	Storage	Barrel Height (mm)	2000

2.6 SCENARIOS

The study creates two different scenarios, one of which is the baseline and the other of which includes the LIDs. Rain barrel and permeable pavement are the chosen LIDs for the analysis; the baseline scenario, which only represents the grey system (concrete structure), is assessed for peak discharge and total runoff. After that, the LID system's performance is evaluated.

1. Baseline (No LID): The typical drainage system devoid of any LID components is shown by this scenario. Stormwater is gathered at several locations and sent to an outlet via conduits. Higher peak flows and runoff quantities occur when no LID elements are present.

2. Combined LIDs: Permeable pavements and rain barrels are combined in this scenario to optimize the effectiveness of stormwater management. These LID solutions work together to reduce runoff at several different locations. Together, permeable pavements and rain barrels improve drainage system performance and reduce peak flow by facilitating infiltration and providing temporary storage.

3.0 RESULTS

3.1 BASELINE SCENARIO ANALYSIS

The catchment acted like a normal impermeable metropolitan region under baseline conditions, with little infiltration and storage and a quick conversion of rainfall to surface runoff. The system produced about 0.315 hectare-meters (27.42 mm) of surface runoff overall. The outfall flow peaked at 1.058 m^3/s, with an average of 0.223 m^3/s. The system discharged approximately 3.118×10^6 litres in total. With a final surface storage measurement of 0.010 hectare-meters (0.914 mm), it was extremely low (Table 4).

Results at the subcatchment level indicated that overall runoff depths were approximately 25–29 mm, whereas infiltration values varied from 36–40 mm. About 42% of rainfall directly contributed to surface runoff, according to the catchment's average overall runoff coefficient of 0.42.

Table 4: Baseline subcatchment runoff summary

Subcatchment	Total Precipitation (mm)	Total Infiltration (mm)	Total Runoff (mm)	Total Runoff Volume (10^6 litre)	Peak Runoff (m^3/s)	Runoff Coefficient
SC1	66.03	36.43	28.79	0.5	0.26	0.436
SC2	66.03	38.64	26.7	0.19	0.1	0.404
SC2	66.03	38.16	27.12	0.42	0.22	0.411
SC4	66.03	38.29	26.72	0.2	0.08	0.405
SC5	66.03	38.91	26.64	0.24	0.15	0.403
SC6	66.03	40.22	25.4	0.56	0.37	0.385
SC7	66.03	37.61	27.59	0.2	0.1	0.418
SC8	66.03	36.05	29.41	0.35	0.23	0.445
SC9	66.03	36.85	28.39	0.5	0.27	0.43

3.2 COMBINED LIDs SCENARIO ANALYSIS

The LID scenario implemented several source-control strategies aimed at improving infiltration, encouraging retention on-site, and delaying the entry of runoff into the drainage system. The total amount of surface runoff dropped to about 0.046 hectares (4.04 mm). At the outfall, the peak flow drastically decreased to 0.140 m^3/s, while the average flow fell to 0.036 m^3/s. The amount of runoff that reached the system outlet was significantly reduced, as seen by the total volume discharged dropping to 0.443 × 10^6 litres. A significant increase in final surface storage to 0.457 hectare-meters (39.82 mm) was indicative of the catchment's enhanced retention capacity.

Data from subcatchments verified the better hydrologic balance. While total runoff depths decreased to between 3 and 5 mm, infiltration levels ranged roughly 21 to 27 mm. These findings demonstrate how well the LID measures worked to capture rainfall at its source, facilitating localized infiltration and retention (Table 5).

Table 5: LIDs subcatchment runoff summary

Subcatchment	Total Precipitation (mm)	Total Infiltration (mm)	Total Runoff (mm)	Total Runoff Volume (10^6 litre)	Peak Runoff (m^3/s)	Runoff Coefficient
SC1	66.03	21.7	3.47	0.06	0.04	0.053
SC2	66.03	24.99	3.79	0.03	0.02	0.057
SC2	66.03	24.50	3.6	0.06	0.03	0.055
SC4	66.03	22.64	2.59	0.02	0.01	0.039
SC5	66.03	25.76	4.96	0.04	0.03	0.075
SC6	66.03	27.33	5.26	0.12	0.08	0.08
SC7	66.03	21.95	3.21	0.02	0.01	0.049
SC8	66.03	22.48	4.73	0.06	0.04	0.072
SC9	66.03	22.08	3.53	0.06	0.04	0.053

3.3 COMPARATIVE ANALYSIS OF BASELINE AND LID SCENARIOS

The Baseline and LID simulation results were compared to determine the efficacy of the suggested Low Impact Development (LID) measures. Both hydrologic (infiltration, surface runoff, runoff coefficients) and hydraulic (flow rate, outfall discharge, storage) factors are the subject of this comparison.

The findings in Figures 6–11 and Tables 6 and 7 illustrate the variations in catchment response between the two regimes and the enhancements in performance brought about by LID integration.

3.3.1 HYDROLOGIC COMPARISON

For each of the nine subcatchments (SC1–SC9), the hydrologic factors considered include infiltration, runoff depth, and runoff coefficient.

Because of poor retention and the predominance of impermeable surfaces, infiltration values were often larger under the baseline condition, and surface runoff depths and coefficients were likewise substantial. On the other hand, because some rainwater is retained in the LID facilities and is not immediately recorded as infiltration in SWMM outputs, infiltration values appear lower numerically under the LID scenario. In every instance, however, the overall amount of surface runoff that left the subcatchments was significantly decreased.

Table 6: Comparison of Hydrologic Parameters per subcatchment

Subcatchment	Baseline Infiltration (mm)	LID Infiltration (mm)	Percentage Reduction (%)	Baseline Total Runoff Volume (10^6 litre)	LID Total Runoff Volume (10^6 litre)	Reduction (%)
SC1	36.43	21.7	40	0.5	0.06	88
SC2	38.64	24.99	35	0.19	0.03	84
SC3	38.16	24.5	36	0.42	0.06	86
SC4	38.29	22.64	41	0.2	0.02	90
SC5	38.91	25.76	34	0.24	0.04	83
SC6	40.22	27.33	32	0.56	0.12	79
SC7	37.61	21.95	42	0.2	0.02	90
SC8	36.05	22.48	38	0.35	0.06	83
SC9	36.85	22.08	40	0.5	0.06	88

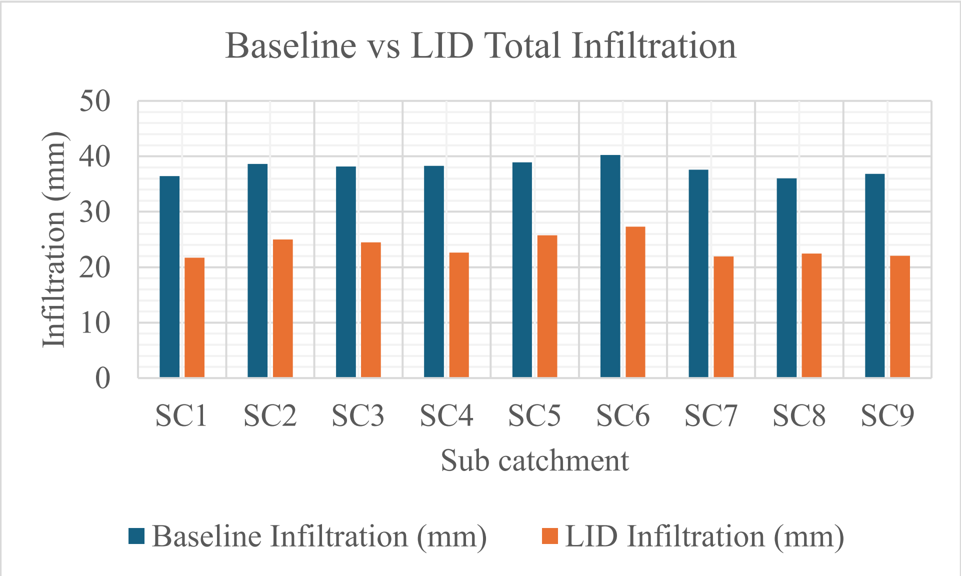


Figure 6. Baseline vs LID Infiltration comparison

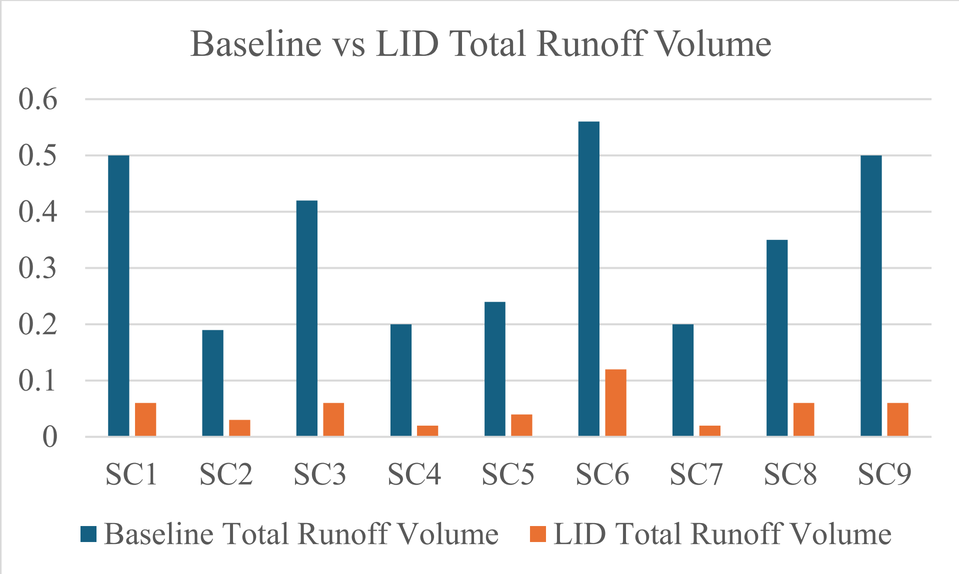


Figure 7. Baseline vs LID Total Runoff Volume Comparison

3.3.2 HYDRAULIC COMPARISON

Hydraulic performance was evaluated at the system level using final surface storage, total runoff volume, and average and peak outfall flow.

Table 7: System-Level Comparison of Hydraulic Parameters

Parameter	Baseline	LID	Reduction (%)
Total Surface Runoff (ha-m)	0.315	0.046	85
Runoff Depth (mm)	27.42	4.04	85
Average Outflow Flow (m^3/s)	0.223	0.036	84
Peak Outflow Flow (m^3/s)	1.058	0.14	87
Total Outflow Volume (10^6L)	3.118	0.443	86

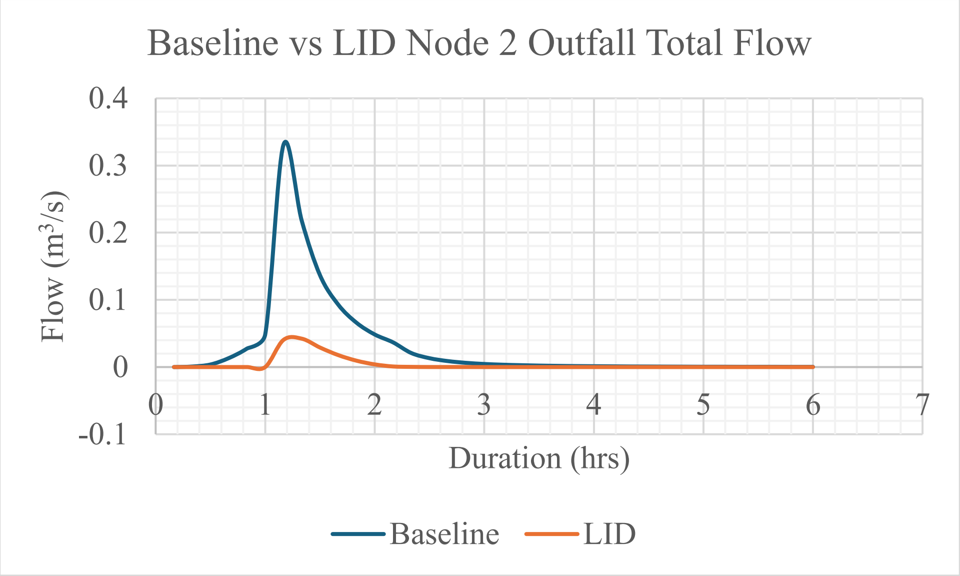


Figure 8. Hydrograph comparison at Node 2 showing reduced and delayed peak discharge under LID implementation.

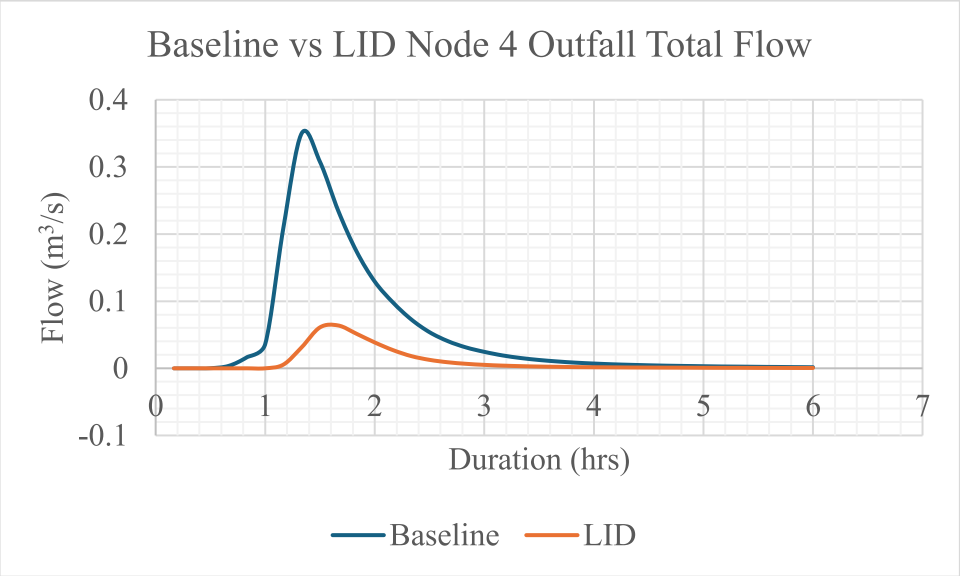


Figure 9. Hydrograph comparison at Node 4 showing reduced and delayed peak discharge under LID implementation.

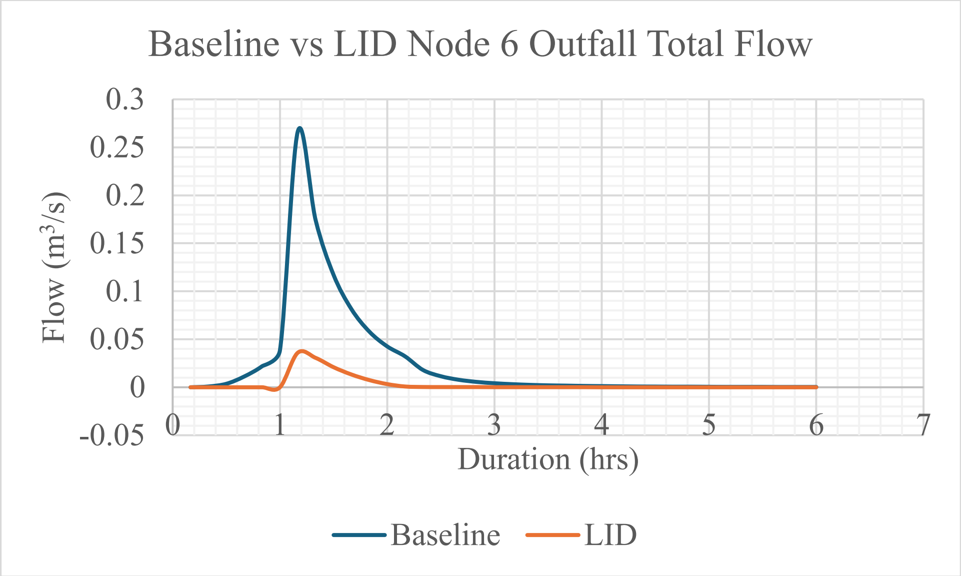


Figure 10. Hydrograph comparison at Node 6 showing reduced and delayed peak discharge under LID implementation.

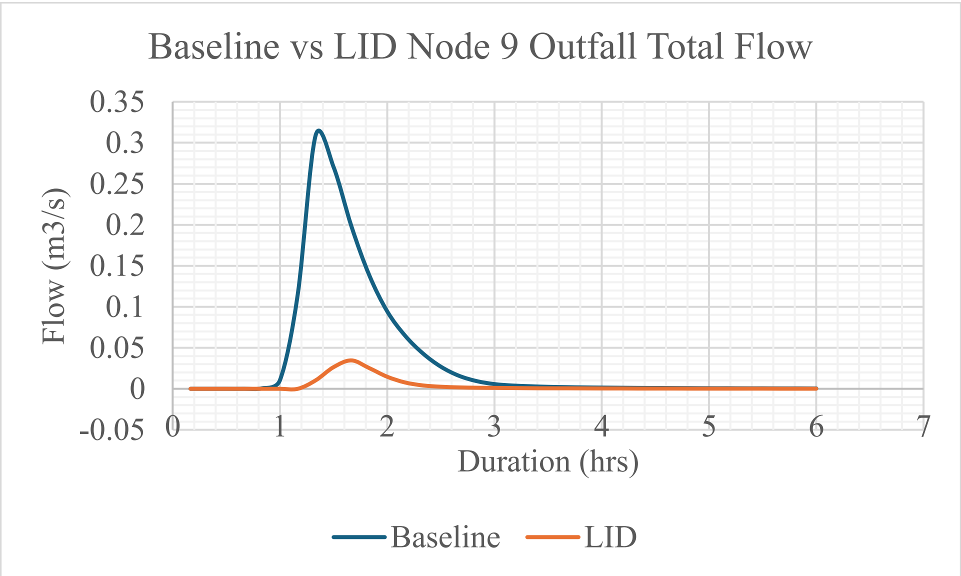


Figure 11. Hydrograph comparison at Node 9 showing reduced and delayed peak discharge under LID implementation.

Under the LID scenario, the hydrographs for every outfall clearly demonstrate a decrease in peak discharge. LID controls successfully contained and released runoff more gradually, as seen by the small increase in the time-to-peak. Overall, the hydrographs show that the system's overall discharge response is flattened when dispersed LID deployment lessens the synchronization and severity of runoff peaks.

3.4 DISCUSSION

Using hydrologic–hydraulic modelling with EPA SWMM and geospatial analysis in QGIS, this study assessed the possibility of sustainable stormwater management techniques in Opolo Housing Estate, Yenagoa.

Two scenarios for modelling were created:

1. The baseline scenario, which depicts the current traditional drainage system; and
2. Rain barrels and permeable pavements were included as decentralized Low Impact Development (LID) solutions in the LID scenario.

A realistic depiction of the catchment and a precise evaluation of the ways in which LID regulations affect runoff behavior inside the estate were made possible by the combination of QGIS and SWMM.

3.4.1 SPATIAL DATA PREPARATION AND CATCHMENT CHARACTERIZATION

The catchment's physical and hydrologic parameters were defined by fundamental spatial investigations carried out in QGIS prior to simulation.

In order to ensure appropriate flow direction toward the four specified outfalls, the research area was divided into discrete subcatchments using a high-resolution Digital Elevation Model (DEM) and site layout designs.

The terrain model was immediately used to extract important data like flow channel direction, drainage length, and slope.

The imperviousness percentages that were subsequently assigned in SWMM were based on the quantification of the impervious and pervious surface ratios for each subcatchment using land-use mapping in QGIS.

To create realistic hydrologic inputs for the baseline and LID setups, the generated layers were exported and included into the SWMM environment.

This geospatial pre-processing improved the accuracy of runoff estimates and infiltration dispersion during rainfall events by ensuring that the modeled catchment accurately represented conditions on the ground in Opolo Housing Estate.

3.4.2 HYDROLOGIC RESPONSE OF THE CATCHMENT

The catchment's high runoff generation under baseline conditions was caused by many impermeable surfaces, such as driveways, rooftops, and roads. Sharp hydrograph peaks were produced at all four outfalls because of the rapid surface flow concentration caused by the restricted infiltration capacity. In Yenagoa's dense residential layouts, where heavy rainfall events frequently cause transient surface ponding and minor floods, these results are in line with usual drainage performance.

The hydrologic response clearly improved when rain barrels and permeable pavements were included under the LID scenario.

Permeable pavements reduced direct surface runoff by allowing rainfall to seep into the sub-base via the pavement layer.

Rooftop runoff was gathered and held in rain barrels before being carefully released into the drains.

Effective runoff attenuation was confirmed by the ensuing hydrographs, which showed delayed time-to-peak and lower peak discharges than the baseline.

In general, the LID layout promoted localized infiltration and detention while decreasing rapid flow concentration by more uniformly distributing rainwater throughout the watershed.

3.4.3 OUTFALL DISCHARGES AND SYSTEM PERFORMANCE

After LID was implemented, the hydrograph comparisons for all four outfalls showed significant decreases in peak discharge and total inflow.

The greatest decreases were seen in outfalls downstream of subcatchments with permeable pavements, indicating that surface infiltration techniques offered the most immediate hydrologic advantages.

By reducing the amount of roof runoff that entered the network in the early phases of rainfall, the rain barrels enhanced this effect even more.

The LID scenario's flattened hydrographs attest to the fact that runoff was postponed and released gradually, lowering system stress and the possibility of surcharging. This enhanced flow control is a major step in the direction of the estate's sustainable drainage performance.

3.4.4 INFILTRATION, STORAGE, AND MODEL INTERPRETATION

Because the program distinguishes between infiltration and temporary storage inside LID controls, the LID model showed numerically lower infiltration values in SWMM results.

The captured rainfall in the LID setup is not immediately accounted for as infiltration since some of it is kept in pavement voids or barrels throughout simulation time steps and released gradually.

Nonetheless, the concurrent decrease in peak flow, surface runoff, and total outflow volume attests to the notable improvement in catchment retention overall.

The improved detention capacity brought about by the deployment of LID was highlighted by the final surface storage, which grew by more than forty times.

3.4.5 IMPLICATIONS FOR SUSTAINABLE STORMWATER DESIGN

The results of the Opolo Housing Estate model show that significant hydrologic and hydraulic advantages can be obtained from very basic and inexpensive LID improvements.

Critical runoff paths, subcatchment boundary optimization, and design alternative evaluation before to implementation were all made possible by the combination of SWMM for dynamic simulation and QGIS for catchment analysis.

According to the findings, using rain barrels for roof runoff control and permeable pavements in estate road designs can greatly lower peak discharges, lessen downstream flooding, and encourage groundwater recharge.

A cost-effective strategy to achieve sustainable urban drainage systems (SuDS) that are tailored to the flat topography and tropical rainfall features of Yenagoa may be to scale up such interventions across residential areas.

4.0 CONCLUSION

This study showed how well Low Impact Development (LID) techniques work to enhance stormwater management in Yenagoa's Opolo Housing Estate.
Two scenarios were created using QGIS's spatial analysis and EPA SWMM's hydrologic-hydraulic simulation: the Baseline system, which reflected the drainage conditions that were in place at the time, and the LID system, which included rain barrels and permeable pavements.

Due to large impervious surfaces, the baseline results showed limited infiltration, high peak flows, and quick surface runoff generation. These circumstances mimic the flooding issues frequently seen in residential layouts in Yenagoa.
The system response significantly improved with the implementation of LID controls. At all four outfalls, runoff volumes and peak discharges declined while time-to-peak rose,

suggesting efficient flow attenuation and retention. Lower, smoother peaks were verified by the hydrographs in the LID condition.

Because permeable pavements encourage infiltration through front yard surfaces and decrease direct runoff, they provide the greatest noticeable hydrologic benefits. In addition, rain barrels reduced the network's first-flush load by collecting roof drainage at the household level. When combined, these actions transformed the drainage system into a distributed, sustainable stormwater management system rather than a network that was only reliant on conveyance.

Accurately describing hydrologic parameters, extracting slopes, and defining subcatchments were all made possible by the integration of QGIS with SWMM. This process made sure that the local topography and surface features were accurately reflected in the simulation outcomes.

Overall, the findings support the notion that using rain barrels and permeable pavements together might improve hydrologic balance, lessen peak flow stress on existing drains, and help mitigate urban flooding in the Niger Delta environment in a sustainable manner.

4.1 RECOMMENDATIONS

Adoption of LID in Estate design: Rather than depending exclusively on open drains, future residential projects in Yenagoa should incorporate permeable pavements, rain barrels, and other source-control LIDs during the design phase.

Opportunities for Retrofit: Without undergoing a significant infrastructure overhaul, existing estates like Opolo can minimize surface runoff by implementing LIDs gradually, starting with permeable roadways, parking spaces, and residential rain-harvesting units.

Policy and Design Guidelines: Runoff reduction goals, infiltration design requirements, and maintenance procedures are just a few examples of the stormwater design standards that local planning authorities should create that include LID principles.

Building Capacity: To promote data-driven drainage planning, training courses on QGIS-based catchment analysis and SWMM modeling should be created for engineers, estate managers, and municipal employees.

Monitoring and Model Calibration: To confirm model predictions and improve design parameters for next applications, field monitoring of rainfall and runoff inside Opolo Housing Estate is advised.

More Research: To assess long-term system resilience under climate variability, more research might examine alternative LID methods such bioswales, infiltration trenches, or green roofs and model several storms return periods.

APPENDIX

MANUAL HYDROLOGIC AND HYDRAULIC CALCULATIONS

IDENTIFICATION OF OPOLO HOUSING ESTATE UTM ZONE USING THE MATHEMATICAL APPROACH

$$\text{UTM zone number} = \left(\frac{\text{Longitude} + 180}{6}\right)$$

Longitude = E6.3396° (Decimal degrees)

$$= \left(\frac{6.3396 + 180}{6}\right)$$

$= 31.0566$

$\simeq 32$

Latitude = N4.9356° (Decimal degrees)

Since the latitude is 4.9356 (North of the Equator), the zone is 32N.

AREA OF THE ESTATE CATCHMENT

$422{,}428.248\ m^2$

$\simeq 42.2428248\ ha$

P.S: Value gotten from QGIS

WIDTH

$$\text{Width} = \frac{\text{Catchment Area}}{\text{Average flow path length}}$$

$$= \frac{422{,}428.248}{457.28+60+60+30+120+30+90}$$

$= 498.5698329\ m$

SLOPE

$= 0.741\%$ (gotten from QGIS)

IMPERVIOUS AREA

Main Roads: $450m \times 10m = 4500m^2$

$4500m^2 \times 2 = 9000m^2$

Service Roads: $200m \times 6m = 1200m^2$

$1200m^2 \times 6 = 7200m^2$

Junctions

$1 = 73m \times 6m = 438m^2$

$2 = 88m \times 6m = 528m^2$

$3 = 93m \times 6m = 558m^2$

$= 438 + 528 + 558 = 1524m^2$

Road area $= 9000 + 7200 + 1524$

$= 17724m^2$

Roof Area

Average roof size in the estate is $202m^2$ and they are 85 houses

$\therefore 85 \times 202 = 17170m^2$

Paved area of the houses has an average of $273m^2$

$\therefore 85 \times 273 = 23205m^2$

$\therefore$ The total impervious area of the catchment area is

$17724 + 17170 + 23205 = 58099m^2$

$$\frac{58099}{422{,}428.248} \times 100$$

$= 13.75\%$ of impervious area

SUBCATCHMENTS

Subcatchment 1

Area $= 17347.75m^2$

No of houses $= 14$

Roof area $= 14 \times 202 = 2828m^2$

Paved area $= 14 \times 273 = 3822$

$2828 + 3822 = 6650m^2$

$$\text{Impervious area} = \frac{6650}{17347.75} \times 100$$

$= 38.33\%$

Subcatchment 2

Area = 6847.84 m^2

No of houses = 5

Roof area = 5×202 = 1010 m^2

Paved area = 5×273 = 1365 m^2

1010 + 1365 = 2375 m^2

~~23~~ impervious area = $\frac{2375}{6847.84} \times 100$

= 34.68%

Subcatchment 3

Area = 15456.63 m^2

No of houses = 11

Roof area = 11×202 = 2222 m^2

Paved area = 11×273 = 3003 m^2

2222 + 3003 = 5225 m^2

Impervious area = $\frac{5225}{15456.63} \times 100$

= 35.75%

Subcatchment 4

Area = 7615.77 m^2

No of houses = 6

Roof area = 6×202 = 1212 m^2

Paved area = 6×273 = 1638 m^2

1212 + 1638 = 2850 m^2

Impervious area = $\frac{2850}{7615.77} \times 100$

= 37.42%

Subcatchment 5

Area = 8930.64 m^2

No of houses = 6

Roof Area = 6×202 = 1212 m^2

Paved area = 6×273 = 1638 m^2

1212 + 1638 = 2850 m^2

impervious area = $\frac{2850}{893064} \times 100$

= 31.91%

Subcatchment 6

Area = 22526.37 m^2

No of houses = 14

Roof Area = 14×202 = 2828 m^2

Paved area = 14×273 = 3822 m^2

2828 + 3822 = 6650 m^2

Impervious area = $\frac{6650}{22526.37} \times 100$

= 29.52%

Subcatchment 7

Area = 7685.51

No of house = 6 ~~×202~~

Roof area = 6×202 = 1212 m^2

Paved area = 6×202 = 1638 m^2

1212 + 1638 = 2850 m^2

impervious area = $\frac{2850}{7685.51} \times 100$

= 37.08%

Subcatchment 8

Area = 11789.21

No of houses = 9

Roof area = 9×202 = 1818 m^2

Paved area = 9×273 = 2457 m^2

1818 + 2457 = 4275 m^2

Impervious area = $\frac{4275}{11789.21} \times 100$

= 36.26%

Subcatchment 9

Area = 17685.25

No of houses = 14

Roof area = 14×202 = 2828 m^2

Paved area = 14×273 = 3822 m^2

2828 + 3822 = 6650 m^2

Impervious area = $\frac{6650}{17685.25} \times 100$

= 37.60%

SUBCATCHMENT WIDTHS

Subcatchment 1

Area = $17347.75 m^2$

Length = $453.875 m$

$$W = \frac{\text{Area (A)}}{\text{Flow length (L)}} = \frac{17347.75}{453.875}$$

$= 38.22 m$

Subcatchment 2

Area = $6847.84 m^2$

Length = $199.117 m$

$$W = \frac{6847.84}{199.117} = 34.39 m$$

Subcatchment 3

Area = $15456.63 m^2$

Length = $193.680 m$

$$W = \frac{15456.63}{193.680} = 79.80 m$$

Subcatchment 4

Area = $7615.77 m^2$

Length = $193.613 m$

$$W = \frac{7615.77}{193.613} = 39.34 m$$

Subcatchment 5

Area = $8930.64 m^2$

Length = $192.640 m$

$$W = \frac{8930.64}{192.640} = 46.36 m$$

Subcatchment 6

Area = $22526.37 m^2$

Length = $187.613 m$

$$W = \frac{22526.37}{187.613} = 120.07 m$$

Subcatchment 7

Area = $7685.51 m^2$

Length = $189.354 m$

$$W = \frac{7685.51}{189.354} = 40.59 m$$

Subcatchment 8

Area = $11789.21 m^2$

Length = $278.015 m$

$$W = \frac{11789.21}{278.015} = 42.40 m$$

Subcatchment 9

Area = $17685.25 m^2$

Length = $452.356 m$

$$W = \frac{17685.25}{452.356} = 39.10 m$$

SUBCATCHMENT SLOPES

Subcatchment 1

$$S = \frac{\Delta h}{L} \times 100$$

$$= \frac{14.26 - 13.43}{453.875} \times 100 = 0.18\%$$

Subcatchment 2

$$= \frac{13.51 - 13.43}{199.117} \times 100 = 0.04\%$$

Subcatchment 3

$$= \frac{13.59 - 13.54}{193.680} \times 100 = 0.03\%$$

Subcatchment 4

$$= \frac{13.75 - 13.75}{193.613} \times 100 = 0\%$$

Subcatchment 5

$$= \frac{13.87 - 13.85}{192.640} \times 100 = 0.10\%$$

Subcatchment 6

$$= \frac{14.08 - 14.06}{187.613} \times 100 = 0.10\%$$

Subcatchment 7

$= \frac{14.24 - 14.20}{189.354} \times 100 = 0.02\%$

Subcatchment 8

$\frac{15.00 - 14.28}{278.015} \times 100 = 0.25\%$

Subcatchment 9

$\frac{14.28 - 13.45}{452.356} \times 100 = 0.18\%$

HYETOGRAPH FROM IDF USING ALTERNATING BLOCK METHOD (ABM)

10 years and 120mins was selected for generating the hyetograph as studies shown it is most suitable for urban drainage.

10 years table

Mins	Rainfall intensity	Cumulative Depth	Incremental Depth
5	275	22.92	22.92
10	173	28.83	5.91
30	83	41.50	12.67
45	63.4	47.55	6.05
60	52.4	52.40	4.85
120	33	66.00	13.60

Cumulative Depth $= \frac{i \times t}{60}$

where i = rainfall intensity
t = Duration (mins)

Incremental Depth = Δ in cumulative depth

But we want our hyetograph to be in 10mins step so we interpolate using the Log-Log interpolation formula

$\text{Log}(D_i) = \text{Log}(D_A) + (\text{Log}(D_B) - \text{Log}(D_A)) \times \frac{\text{Log}(T_i) - \text{Log}(T_A)}{\text{Log}(T_B) - \text{Log}(T_A)}$

where D_i = Interpolated cumulative depth
T_i = Desired duration
D_A, D_B = Known cumulative depth
T_A, T_B = Known duration

Convert D_i back to actual depth by taking the inverse log to get the final depth

$D_i = 10^{\log(D_i)}$

Depth at 20mins

$\text{Log}(D_{20}) = \text{Log}(28.83) + (\text{Log}(41.50) - \text{Log}(28.83)) \times \frac{\text{Log}(20) - \text{Log}(10)}{\text{Log}(30) - \text{Log}(10)}$

$\text{Log}(D_{20}) = 1.56$

$D_{20} = 10^{1.56} = 36.307 \simeq 36.31\text{mm}$

10 years table

Mins	Rainfall intensity	Cumulative Depth
10	173	28.83
20	217.85	36.31
30		
40		
50		
60		
70		
80		
90		
100		
110		
120		

Mins	Cumulative Depth	Incremental Depth	Rainfall intensity	
10	28.83	28.83	172.98	1
20	36.31	7.48	44.88	2
30	41.50	5.19	31.14	3
40	45.71	4.21	25.26	4
50	49.27	3.56	21.36	5
60	52.40	3.13	18.96	6
70	55.16	2.76	16.56	7
80	57.67	2.51	15.06	8
90	59.98	2.31	13.86	9
100	62.12	2.14	12.84	10
110	64.12	2	12	11
120	66.00	1.88	11.28	12