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Hydraulic Performance Assessment of a Campus Drainage System: A Case Study of Delta Park, University of Port Harcourt, Rivers State, Nigeria

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Abstract
This study focused on the evaluation of the hydraulic performance of a specific drainage system within the Delta Park area of the University of Port Harcourt. Data collection involved manual measurements using measuring tape and digital mapping through ArcGIS Pro 2012 software. The drainage systems across the campus were found to exhibit a trapezoidal cross-section. To determine the peak discharge for the selected studied drain, D10, peak discharges were calculated for three interconnected drains, namely D7, D7a, and D8. These interconnected drains receive runoff discharges from Crab-Theatre, UDPS-Gas station and Admission Office-Hostel block areas (catchments A, B, and C, respectively. The hydrological and hydraulic calculations employed the Rational Method and Manning's equations, following guidelines from the Federal Ministry of Works Drainage Manual. The findings revealed a design intensity of 109.84 mm/hr. The calculated design flow for D10 was 2.98 cu. m/sec, surpassing the capacity of the existing drain, which was rated at 2.55 cu. m/sec. Consequently, Drain D10 exhibited an overflow of 0.43 cu. m/sec, indicating its inadequacy. To address this issue, a redesigned trapezoidal channel section was proposed to accommodate a flow capacity of 3.27 cu. m/sec. Importantly, the results highlight that the new design will promote self-cleansing due to the average velocity of 2.81 m/s, reducing the likelihood of sedimentation within the drainage system.

Keywords: *Hydraulic performance, Drainage system, Peak discharge, Trapezoidal channel, Catchment, Rational method, Manning's equations, Design intensity, Self-cleansing, Sedimentation, University of Port Harcourt*

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1. Introduction

The impact of floods can be extremely destructive, encompassing inundation of built-in properties, loss of lives, disruptions in traffic flow, and challenges for civilized society (Evans, 2004; NJSWM, 2004). Storm water drainage systems are designed to manage excess water from streets, sidewalks, roofs, buildings, and other areas. These systems are commonly referred to as storm drains, although they are also known as storm sewers and drainage wells. Modern drainage systems encompass two types of fluids: wastewater and storm water (Butler and Davies, 2000).

Lanciani (1898), Angelakis and Rose (2014) and Davis (1913) have described the shared characteristics of drainage systems in some Roman and European capitals, reflecting their historical functionality. They emphasized that these drains were designed to simultaneously handle both town sewage and refuse along with rainwater. The ultimate approach to storm water management aims to create efficient drainage systems while minimizing adverse environmental impacts (SFDT, 2017). Few drainage systems in inhabited areas retain their natural state due to modifications in land use and drainage patterns, which can contribute to drainage issues in rural systems.

The redesign of a drainage system generally involves two phases. The first phase is hydrological analysis, which entails collecting rainfall data from local meteorological authorities. This data is essential for calculating surface runoff from the contributing catchment using the rational formula. The second phase is hydraulic analysis, where the existing storm water drain capacity is determined using Manning's equation. Estimating the two runoffs is crucial: one represents the proposed or design capacity required for drainage, while the other indicates the existing capacity of the drain. Comparing these runoffs allows us to ascertain the amount of overflow occurring per second at a given section (Zhang, 2018; WB & GN, 2002).

This study takes into account hydrological and hydraulic data, processes the data, draws valuable insights from the information produced, and provides appropriate recommendations to follow. The significance of the study was to assess the hydraulic performance of a selected drain (D10 as shown in Fig. 5) which in several rainy events showcases some noticeable volume of overflow. Prior to this investigation, records on data related to the hydraulic study on any of the drains within the Study area barely exists in literature. This study bridges the gap, posing to be the first.

2. Materials and methods

2.1 Study area

The study area is located at Delta Park, University of Port Harcourt, Choba, Rivers State, Nigeria. It is located in coordinates 4°54’03.3” N and 6°54’22.7” E. Within it are several catchment areas, although the drain of study is limited only to three catchment areas where it gets its contributories of runoff. Delta Park is the campus were the Vice Chancellor and other prestigious Professors of the University of Port Harcourt, amongst others have their officially allocated residential homes. Fig. 1, is the map of Delta Park, showing all catchment areas. The shaded sections in the three different areas, represents the portions of the three catchments that are contributing runoff to the studied drain; catchment A to East (the smallest shaded portion: Crab theatre area), catchment B is the shaded portion on the West of A (UDPS-Gas station area) and catchment C is underneath B to the South (Admission office- Jaja hostel block C & D mainly).

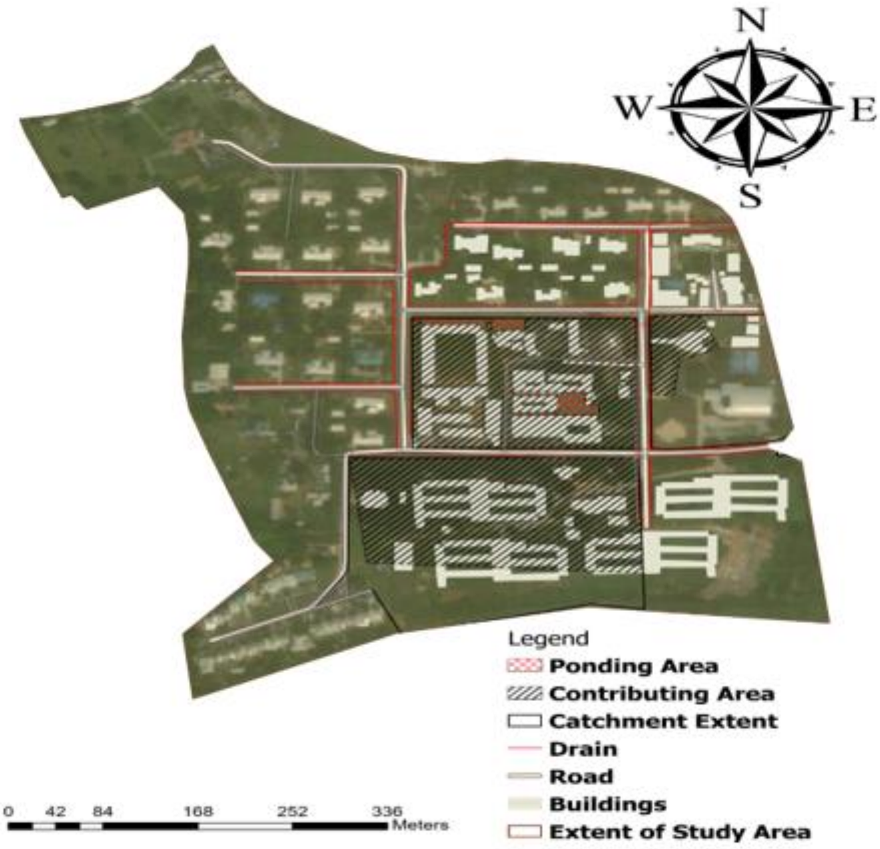

Fig. 1: Map of study area

2.2 Watershed characteristics and features

Delta Park is another campus of the University of Port Harcourt, and it has within its boundary basically asphaltic ground cover, as it has a good connection of wide paved flexible pavement. Roofs made of aluminium was a general feature of the roof cover material notable in the area, and it was used throughout in the computation of data. Also, a very large percentage of lawn, long grasses, were also common within the region, and the most uncommon ground covers were ordinary/bare ground and concrete which had the least number presence. Thus, the major groups of cover material within the study area are; Lawn areas, Rooftop areas, Asphaltic areas, Bare ground, and concrete area.

2.2.1 Contributory areas

Each area or catchment of study whether of area A, area B, or area C had apart from the sub-total of their individual areas which held back rainwater. These took forms that depended on either or both the terrain and the vegetation type of the part in consideration, or on an entirely different scenario which may be that a portion within the study area never held back any amount of water, but rather contributed its own runoff into another drain nearby.

2.2.1.1 Watershed area A (Crab-theatre area)

Area A, which is Crab-ASUU building area, had only a few direct contributions from the catchment. This contribution was from the crab building and a few areas around it (the shaded portion in Fig. 2). The football field had a terrain that is on average a flat and saggy one (the left bottom area of Fig. 2), and in such that it could hold any amount of flow for a period until most of this water seeps through the soil and the rest evaporates into the atmosphere. ASUU building area (the area joining the football field to the right, channels all its runoff into another drain (not the design drain) and passing through Outlet 7 (O 7 in Fig. 5) outside the campus. Fig. 2 is a map that shows the area variation in contribution within the region.

Fig. 2: The contributory areas in area A

2.2.1.2 Watershed area B (UDPS-gas station)

Area B (the UDPS-Gas station area) had less similar variation as compared to the non-contributing area dominance in Crab-Theatre area. The form it took in this catchment was more of the ponding and sinking area as described by words of mouth with a Professor of Civil engineering (Water Resources), University of Port Harcourt (Nwaogazie, 2022). Only a few areas in this region ponded or sunk in water, others effectively gave up their flow into the Contributory drains bounding the watershed area. Fig. 3 shows the small ponding area as compared to the larger contributing area within the catchment’s area.

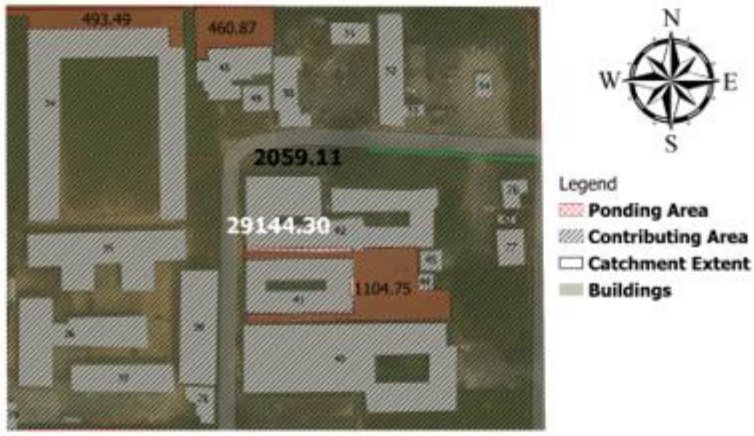

Fig. 3: The contributory areas in watershed B

2.2.1.3 Watershed area C (Admission office – hostel block)

Unlike the other two, catchment area C had its non-contributory areas outside the normal environment for proper daily human activity; it flowed backwards through farmlands, and towards the fence into the river behind it. This detail is upheld in the Fig. 4.

Fig. 4: The contributory areas in catchment C

2.3 Data collection method

This work was such that the collection of data was majorly done with the aid of a Geographical Information Software (ArcGis pro-2012), which was used to estimate the length of roads, drains and area of rooftops. This process is called the Digitization of the boundary elements. Digitization of the measurable features within the study area could surprisingly not capture all areas, especially those having lots of shading from the canopies of big trees. Therefore, all inaccessible ground cover areas needed for flow estimations were measured out manually using measuring tape and followed by instant recording of the data measured.

2.3.1 Hydrology data

This method drew its strength from already developed constants and equations for rainfall intensity calculations, put together by Oyebande (1983). However, the hydrology discharge (Q) was estimated from the Rational method as shown in Equation (1). Details on the steps involved and the calculation for the hydrology and hydraulics parameters used in this design are better presented in the Appendix of Onyemachi (2023).

$$Q = 0.278CIA \qquad (1)$$

where Q is the Quantity of runoff or Discharge (cubic metres per second); C is the Runoff coefficient (expressed as a percentage of the imperviousness of the watershed surface); I is the rainfall intensity (millimetre per hour) for a certain time of concentration; and A, the area of watershed (square kilometres).

Onyemachi (2023) calculated the rainfall intensity in their work as I = 109.84mm/hr.

2.3.1.1 Drain Network and Numbering

All the existing drains in Delta Park are designed in a trapezoidal shape. The specific drain under study (D10) spans a length of 160 meters. It directly receives runoff from the watershed, referred to as Catchment Area A. Additionally, it indirectly collects runoff from its immediate surroundings, which includes drainage from D8 and a branch of D7 known as D7a, measuring 158 meters in length. D7a is a tributary of the main drain, D7. On the other hand, Catchment Area B is bounded by three drains: D7, D7a, and D8, with D8 being 345 meters in length. Another drain joins D7a, which is a significant contributor to D7a's flow. D7a and D8 merge and connect to D10 (the studied drain) on the opposite side of the road through a culvert. Furthermore, during on-site observations, it became apparent that drain D7 also receives contributions from other sources. This flow originates from a separate catchment area located on the opposite side of the road from D7. To provide context, when facing the Main gate, drain D7 is on the left-hand side, and the area from which it receives additional water is connected to D7 via a culvert, separated by the width of the road. A sketch showing the drain flow pattern and interconnections are as illustrated in Fig. 5.

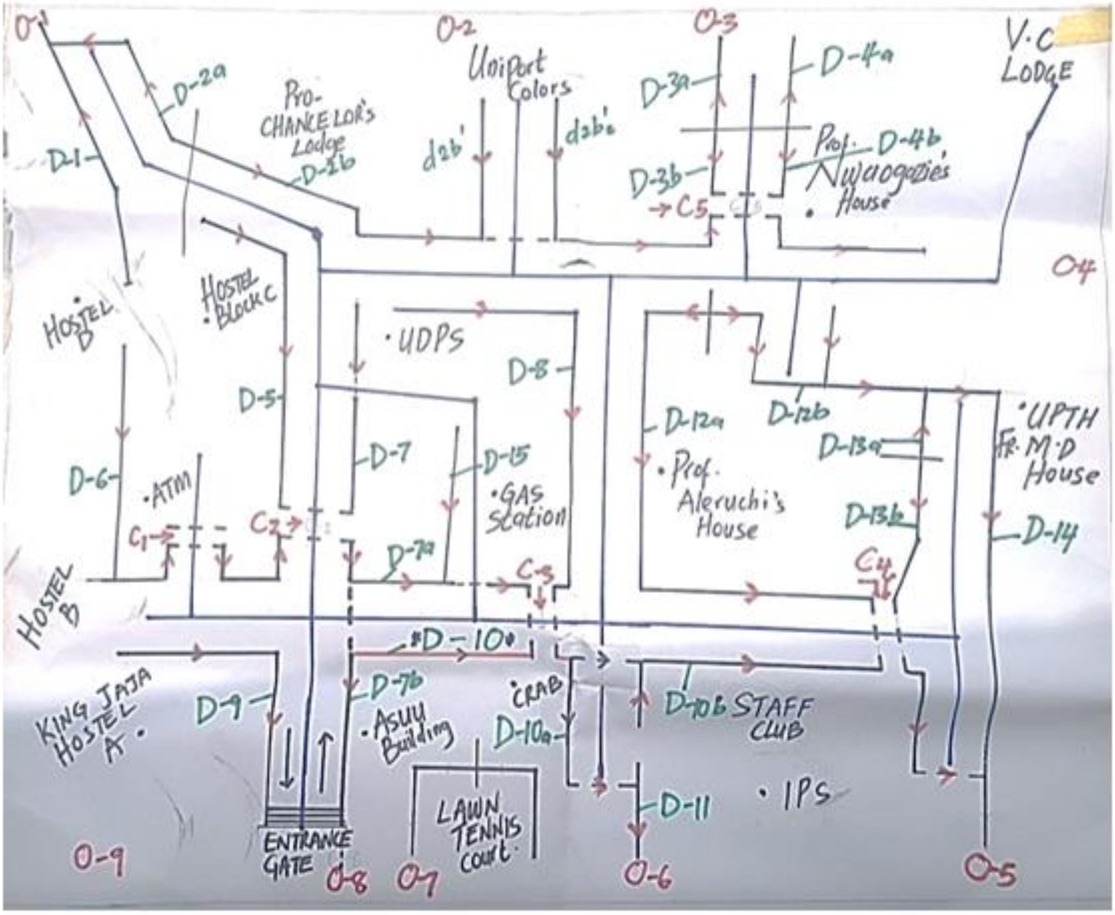

Fig. 5: Drawing of the drainage network and flow pattern

2.3.2 Hydraulics data

The quantity of water flowing (Q), the depth of flow (y), and the velocity of flow (V), depends upon the channel shape, roughness, and the slope (S) (Federal Ministry of Works Highway manual, 2013). The flow or Discharge capacity of the channel Q, is computed using Equation (2)

$$Q = AV \qquad (2)$$

Substituting Manning's V into the flow equation gave Equation (3)

$$Q = A\frac{R^{\frac{2}{3}}S^{\frac{1}{2}}}{n} \qquad (3)$$

Thus, for specified values of *n, Q and S*, Equation (3) was used to determine the normal depth of a given channel. where n is Manning's coefficient of channels roughness; V, Mean velocity in metres per second (m/s); R, Hydraulic radius in metres (Equation (4)); and S, the Slope of the channel in metres per metres.

$$R = \frac{A}{P} \quad (4)$$

where A is the cross-sectional area of the flowing water in square metres taken at right angles to the direction of flow; and P, the Wetted Perimeter in metres. For redesign purpose of this study, the most efficient Hydraulic section was selected as the standard hydraulic design procedure. The application of the most efficient Hydraulic section on drainage structures is vital for reduction in construction (Nwaogazie et al., 2015).

3. Results and discussion

3.1 Hydrology data

Hydrology data in drain design quantifies the amount or volume of rainfall precipitates descending on a given area, duration and return period; this parameter is known as rainfall intensity (I). The rainfall intensity was calculated for a duration equal to the time of concentration for the catchment under study (45 minutes) and for 10 years return period. Tables 1 – 4 summarizes the data estimate for the ground cover areas, adopted runoff coefficients and Rational formula-estimated peak discharge for drains D7, D7a, D8 and D10 as gathered from the field measurements, where rainfall intensity, I is 109.84mm/hr (3.051E-5 m/s). The interconnections between the drains are such that D7a is a drain branching from D7, while D7a joins D8 to meet D10 (study drain) through a culvert C3. Therefore, the total flow expectation on D10 was dependent and the summation of the other three (D7, D7a, D8 and D10). The result of the rainfall intensity from the hydrology of this study (109.84mm/hr) is similar to that of Oyegoke and Adebanjo (2018) on drainage redesign for an estate in Epe, Lagos State Nigeria; had an intensity 106.44mm/hr and 92.8mm/hr for 33- and 45-minutes durations, respectively and 10 years return period.

Assume half of the runoff from D7 flows into D7a. Therefore, % D7 flowing into D7a is 0.2657cu. m/sec. Therefore, total flow in D7a is the sum of the total flow from Table 2 and the percentage contributing into it. This value is equal to *0.4772 cu. m/sec.* Note: Drain D-10's total is the summation of drain D-8 combined flow + Total D-7a combined (including 50% D-7 contribution) + D-10 self-flow, estimated to be *0.8295cu. m/sec.*

Table 1: All contributory data for drain D7

S/N	Ground cover type	Area sq. m	Runoff C	C×A sq. m	Q cu. m/sec
1.	Asphalt	2965.42	0.8	2372.33	0.0724
2.	Lawn	21533.76	0.2	4306.75	0.1314
3.	Rooftop	10394.77	0.95	9875.03	0.3013
4.	Bare ground	844.00	0.3	253.20	0.0077
5.	Concrete	762.65	0.8	610.12	0.0186

Table 2: All contributory for drain D7a

S/N	Ground cover type	Area sq. m	Runoff C	C×A sq. m	Q cu. m/sec
1.	Asphalt	3621.5	0.8	2897.20	0.0884
2.	Lawn	2903.00	0.2	580.60	0.0177
3.	Rooftop	3601.65	0.95	3421.57	0.1044
4.	Bare ground	104.00	0.3	31.20	0.0010
5.	Concrete	-	0.8	-	-

Table 3: All contributory for D8 (UDPS + other contributories)

S/N	Ground cover type	Area sq. m	Runoff C	C×A sq. m	Q cu. m/sec
1.	Asphalt	2962.58	0.8	2370.06	0.0723
2.	Lawn	6547.07	0.2	1309.41	0.0400
3.	Rooftop	5771.06	0.95	5482.51	0.1673
4.	Bare ground	1314.06	0.3	394.22	0.0120
5.	Concrete	22.50	0.8	18.00	0.0005

Table 4: Area estimates for the study drain D10

S/N	Ground cover type	Area sq. m	Runoff C	C×A sq. m	Q cu. m/sec
1.	Asphalt	1453.69	0.8	1162.95	0.0355
2.	Lawn	1596.50	0.2	319.00	0.0097
3.	Rooftop	449.93	0.95	427.43	0.0130
4.	Bare ground	-	0.3	-	-
5.	Concrete	10.00	0.8	8.00	0.0002

3.2 Hydraulics data

The hydraulics information includes the data of the drain slopes, cross-sectional dimensions, drain capacity computation and others, but the listed being the basics. Apart from having trapezoidal channels for all drains in Delta Park campus, dimensions such as the depth, and bottom width for all existing drains within the Study area (including those not captured by the study) had same measurement; except for the slight variations in the top width and slopes. The slope of 0.0089 as seen in the graph in Figure 6 implies a height difference of 0.89meters in 100 meters length. Information of the hydraulic section characteristics and survey information are presented from Tables 5 – 8 and Figure 6 shows the slope/invert graph for the design drain D10. The maximum velocity of the drain D10 (2.78m/s), implies that there will be no case of sedimentation or siltation as it far surpassed the limit recommended by Leton (2004). Leton (2004), stated that velocity above 0.5m/s will prevent sedimentation. This claim was more also strengthened by the works of Nwaogazie et al. (2015), where they set the limit for velocity as 1.0m/s to re-design the drains for Bonny Island, including providing sections with the most economical design. It should be noted that there will be no need to redesign the drain section as the rational peak discharge of 0.8295 cu.m/sec is far less than the existing drain full capacity of 2.55 cu.m/s. Given the results from the study, the drain D10 is therefore considered adequate.

Table 5: Four inter-linked drains cross-sectional area characteristics

S/N	Drain	Top width B (m)	Bottom width b (m)	Full depth/ Diameter (m)	Flow depth (m)	Full Area (sq. m)	Flow Area (sq. m)
1.	D-7 (Trapezoidal)	0.53	0.35	0.45	0.18	0.1980	0.0792
2.	D-7a (Trapezoidal)	0.59	0.35	0.45	0.14	0.2115	0.0650
3.	D-8 (Trapezoidal)	0.53	0.35	0.45	0.38	0.1980	0.1672
4.	D-10 (Trapezoidal)	0.59	0.35	0.45	0.19	0.2115	0.0893

Table 6: The Cumulative value for rational formula discharge vs Manning's full flow

S/N	Drain	Rational Q Cu. m/sec	Manning's full capacity Q Cu. m/sec
1.	D-7	0.5314	0.1166
2.	D-7a	0.2115	0.1300
3.	D-8	0.2921	0.1166
4.	D-10	0.0602	0.1300

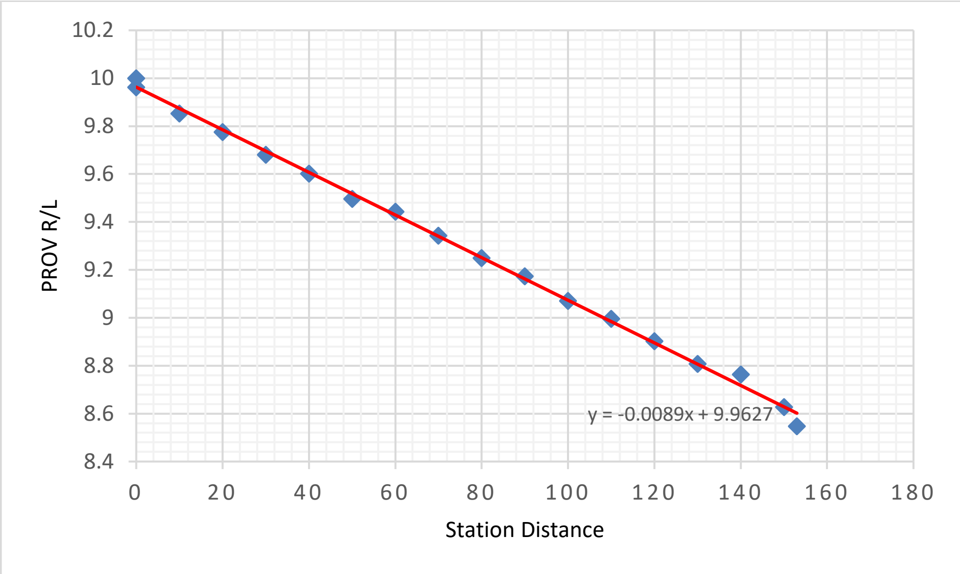

Fig. 6: Drain D-10 invert profile

Table 7: Levelling data for the design drain invert

S/N	Station Distance	R/L
1	TBM 1	10
2	0	9.962
3	10	9.853
4	20	9.775
5	30	9.68
6	40	9.602
7	50	9.497
8	60	9.443
9	70	9.343
10	80	9.25
11	90	9.173
12	100	9.07
13	110	8.996
14	120	8.903
15	130	8.808
16	140	8.763
17	150	8.628
18	153	8.548

Table 8: Old and new design drain comparison

S/N	Drain dimensions	Drain D-10
1.	b	0.35m
2.	B	0.59m
3.	y	0.45m
4.	S	0.0089m/m
5.	z	3.75
6.	A max	0.917sq. m
7.	V max	2.78m/s
8.	Q max	2.55cu. m/sec

4. Conclusion

Field investigation reveals that only approximately 19.86% of the total area of Catchment A, 70.64% of Catchment B, and 66.96% of Catchment C constitute the contributing area to the studied watershed. Most of the drains in Delta Park are situated alongside the East and West sides of each road network. The storm's design intensity, as derived from the work of (Oyebande, 1983), is measured at 109.84 mm/hr. Consequently, the Rational Formula Q = 0.278CIA becomes a useful tool, considering Manning's coefficient for various ground covers. The result from the study on D10 implies that rational peak discharge of 0.8295 cu.m/sec is far less than the existing drain full capacity of 2.55 cu.m/s. Therefore, the drain D10 is therefore considered adequate. Although, during severe rainy events, a few cases of overflow have been seen to occur in D10 and around the culvert, C3; this is due to the surge from the discharge emptying towards the last five meters of the drain length. Had the runoff being evenly spread beginning from the earlier part of the drain length, there will not have been an overflow. This can be achieved by constructing a second culvert from the drain D7a to a point at least 20 meters from D10 starting point.

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