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Hydrologic and Hydraulic Analysis on a Selected Drain in Delta Park, University of Port Harcourt

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Abstract
The objective of this study was to perform hydrological and hydraulic analyses of a specific drainage channel located in Delta Park within the University of Port Harcourt. The drainage channels within Delta Park exhibit a trapezoidal shape and feature interconnected segments. Among the identified catchments (A, B, and C), focus was directed towards catchment B due to its exclusive contribution to the target drain, D7. A thorough survey revealed that the invert bed slope of D7 measured 0.0164 for the area. Data acquisition employed both manual measurements with a measuring tape and ArcGIS Pro 2022 software. Incorporating the Rational method and Manning's equations, coupled with guidelines outlined in the Federal Ministry of Works Drainage Manual (2013 edition), hydrological and hydraulic calculations were conducted. Notably, the derived design intensity stood at 109.84 mm/hr. The anticipated peak discharge into D7 was determined to be 1.05 cu. m/s, while the drain's existing capacity was found to be 3.09 cu. m/s. Consequently, the analysis demonstrated that the current drain capacity is sufficient to accommodate the projected discharge derived from the hydrological investigation. Furthermore, the results suggest that D7 will undergo self-cleansing rather than sedimentation, supported by a Manning's velocity value of 3.27 m/s at full capacity.

Keywords: *Hydrological analysis, Hydraulic analysis, Drainage channel, Delta Park, University of Port Harcourt, Trapezoidal drains, Catchment, Rational method, Manning's equations, Design intensity, Peak discharge, Drain capacity, Self-cleansing, Sedimentation, Velocity value*

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1. Introduction

The prioritization of water usage, as outlined in the National Water Resources Master Plan Executive Summary of 2013, encompasses a range of sectors, commencing with the essential stream flow requirements and extending to municipal demands, irrigation necessities, and diverse water supply domains, including the realm of hydropower generation. This comprehensive approach to water allocation underscores its significance not only across these designated fields but also its reach into areas like livestock consumption, freshwater aquaculture, hydropower generation, and inland water navigation, as emphasized by Evans (2004).

The criticality of water's demand and utility on our planet remains unparalleled, with its role in sustaining all forms of life, including human survival, indisputably at the forefront. Concurrently, the unchecked conveyance of water, which should ideally be directed away from the environment and into designated water bodies or wetlands, carries the potential for adverse environmental ramifications. Such repercussions can reverberate negatively, casting a shadow on the economic prospects of the affected region. The aftermath of such occurrences often manifests as flooding or overflow predicaments, as highlighted by Nwaogazie et al. (2015).

In this context, the establishment of efficient drains and a robust drainage network system becomes imperative, precisely for the purpose of channelling runoff that fails to infiltrate, into the ground, into appropriate repositories, such as streams, rivers, and swamps. The design and implementation of storm drainage collection systems necessitate a comprehensive consideration of variables such as flood runoff, topographical attributes, storm water outlet specifications, and the regulatory directives from local authorities. The extent of the drainage system's coverage relies intrinsically on the expertise, discernment, and practical knowledge of the drainage engineer.

Consequently, the reliability and efficacy of the ensuing data hinge upon the acquisition of ample and pertinent information, pivotal for informed interpretation.

In tandem with the pivotal role played by roadways, roadside drainage networks assume the crucial task of diverting and expelling surface runoff from the highway's expanse. A well-structured highway drainage channel, equipped to handle prescribed charges, necessitates a bifurcated approach. The initial phase involves formulating a channel section that aligns with the designated discharge under the prevailing slope conditions. Subsequently, attention is turned to determining the requisite degree of protective measures to avert erosion within the channel, a parameter underscored by both the Federal Ministry of Works Highway manual (2013) and Zhang (2018). The gap this paper intends to fill is to provide a documentation on the state of the art of the drains within the University's premises. This is in order to keep the functionality in routine check and thus being the second publication of this sort.

2. Materials and methods

2.1 Study area

Delta Park, one of the three campuses of the University of Port Harcourt, Choba, Port Harcourt, is located at Rumuokoro-Rumu-Ahunwa Road, 500102, Choba (4°54'03.3" N and 6°54'22.7" E), Rivers State, Nigeria. Aside a few lecturers' quarters and the Jaja Block A to D female hostels, Delta Park boundary houses controversially the most popular destinations within the university's environment. This includes, The Vice-chancellors' lodge, the Pro-chancellors' lodge, the admission office of the University, the University Demonstration Primary School, Academic Staff Union of Universities (ASUU) secretariat, and the Senior Staff Club of the University. Fig. 1, is the map of the Delta Park, University of Port Harcourt as sketched from ArcGis pro software 2022.

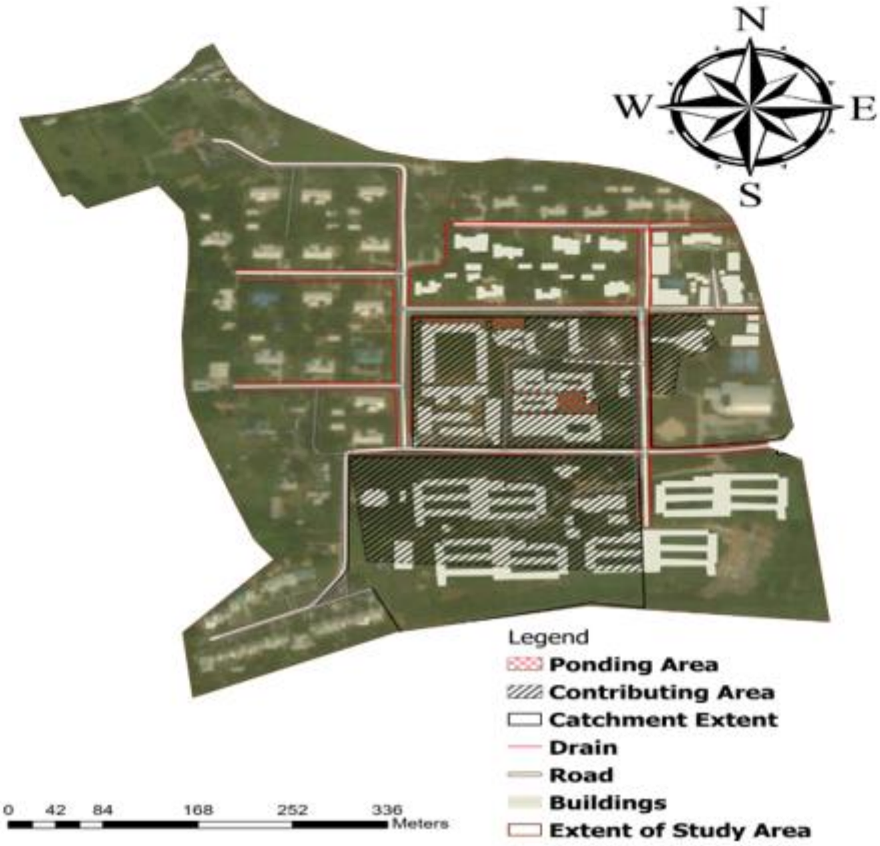

Fig. 1: Map of study area

2.2 Field measurement method

In response to the practical complexities encountered during the research, certain regions characterized by obscured visibility due to their positioning or partial obstruction by tree cover necessitated the exploration of alternative methodologies for accurate assessment. In these instances, the implementation of manual tape measurements, involving a collaborative effort of at least two individuals, emerged as a requisite strategy. While the process of gathering data through manual means inherently presented itself as more labour-intensive, it was nonetheless instrumental in furnishing granular insights into the precise dimensions of flow areas earmarked for diversion into each distinct drainage conduit.

Supplementary to this, the research encompassed additional field measurements, encompassing the determination of the cross-sectional area pertaining to the identified drains of interest. Additionally, a surveying exercise was conducted using precision level instruments, facilitating the acquisition of data pertaining to the average invert elevation of the underlying channel bed.

2.3 Hydrological analysis method

The method employed in this study was the rational formula method.

2.3.1 Watershed characteristics and features

Delta Park, a distinct campus affiliated with the University of Port Harcourt, is characterized by a notable terrain composition. Within its confines, there exists a prevalence of asphaltic ground surfaces, with an extensive network of wide, well-maintained flexible pavements. Notably, the predominant roofing material utilized across the area comprises aluminium, a detail integral to our data computation processes.

Moreover, a substantial proportion of the landscape within this locale is characterized by the presence of lush lawns and tall grasses. Conversely, the least encountered ground cover materials within this study area are ordinary bare ground and concrete. Consequently, we can categorize the principal groups of ground cover materials within this research framework into the following categories:

1. Lawn Areas: These encompass expansive regions adorned with well-maintained grassy terrain.
2. Rooftop Areas: Referring to sections characterized by aluminium roofing structures, which form a prominent aspect of the landscape.
3. Asphaltic Areas: Comprising the extensive network of paved, asphalt surfaces that interconnect within the campus.
4. Bare Ground: Denoting areas devoid of vegetative or structural cover, presenting as open, exposed earth.
5. Concrete Areas: These areas, though less prevalent, consist of solid, man-made concrete surfaces.

This delineation of ground cover materials serves as a foundational element in our research, guiding the subsequent analyses and assessments conducted within the study area.

2.3.2 Watershed area B (UDPS-gas station)

Area B is the University Demonstration Primary School-Gas station area having the drain of study as captioned in this report as drain D7, located West-wing, with UDPS gate on the North. Drain D7 is a trapezoidal drain that has a length spanning approximately 345 meters and flowing into a culvert just a turn from the University's Senior Staff Club. 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. 2 Map shows the variations

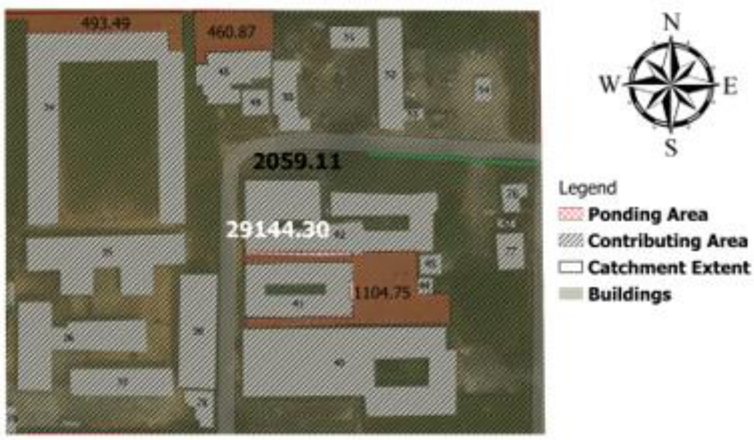

Fig. 2: The Contributory Areas in watershed B

2.4 Rational method of estimating peak discharge

The runoff or design flow depends on the duration and intensity of rainfall, storm frequency, slope, size, shape, imperviousness of the drainage area, and the probable development of the area (Oyegoke and Adebanjo, 2018). Runoff estimate as put by the Rational Method is related as follows:

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

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

2.4.1 Runoff coefficient

The runoff coefficient, denoted as "C," stands as a pivotal and multifaceted variable within the Rational Method. This parameter assumes a critical role in quantifying both rainfall losses and the rate of runoff, acknowledging the potential for variability within a specific drainage area. Determining the suitable value of C for a particular location demands a comprehensive evaluation of the site. This evaluation should rest upon a foundation of extensive experience and engineering expertise, drawing upon keen judgment to discern and interpret the prevailing conditions inherent to the contributing areas.

Table 1: Manning's coefficient for runoff surfaces

RUNOFF COEFFICIENTS FOR THE RATIONAL FORMULA			
Typical Composite Runoff Coefficients by Land Use		Normal Range of Runoff Coefficients	
Area Description	C-value	Surface Characteristic	C-value
Business		**Lawns**	
Downtown Areas	0.70-0.95	Sandy Soil, Flat (2%)	0.05-0.10
Neighborhood Areas	0.50-0.70	Sandy Soil, Ave. (2-7%)	0.10-0.15
		Sandy Soil, Steep (>7%)	0.15-0.20
Residential		Heavy Soil, Flat (2%)	0.13-0.17
Single Family Areas	0.30-0.50	Heavy Soil, Ave. (2-7%)	0.18-0.22
Multi-Units (detached)	0.40-0.60	Heavy Soil, Steep (>7%)	0.2500.35
Multi-Units (attached)	0.60-0.75		
Suburban	0.25-0.40	**Agricultural**	
Apartments	0.50-0.70	Bare Packed Soil	
		Smooth	0.30-0.60
Industrial		Rough	0.20-0.50
Light Use	0.50-0.80	Cultivated Rows	
Heavy Use	0.60-0.90	Heavy Soil, no crop	0.30-0.60
Railroad Yards	0.20-0.35	Heavy Soil, with crop	0.20-0.50
Unimproved Areas	0.10-0.30	Sandy Soil, no crop	0.20-0.40
		Sandy Soil, with crop	0.10-0.25
Park		Pasture	
Park/Cemeteries	0.10-0.25	Heavy Soil	0.15-0.45
Playgrounds	0.20-0.35	Sandy Soil	0.05-0.25
Pavement		**Woodland**	0.05-0.25
Asphalt and Concrete	0.70-0.95		
Brick	0.70-0.85		
Roof	0.75-0.95		
The presented C-values are typical for return periods of 2-10-year storms with the higher values for the larger design storms. Judgement must be used to select the appropriate C-value within the range for the land use. Generally, larger areas with permeable soils, flat slopes, and dense vegetation should have the lower C-value; and smaller areas with low permeability soils, steep slopes and sparse vegetation should be assigned higher a C-value.			

Source: Chow (1959)

2.4.2 Time of concentration

Time of concentration is the time required for an entire watershed to contribute runoff to the point of interest. There are several equational models developed by many authors to calculate the time of concentration, but this study adopted the Kerby method for overland flow, and Kirpich method for channel flow, (Equations (1) & (2), respectively).

$$t_c = K(LN)^{0.467}S^{-0.235} \quad (2)$$

Equation (1) is Kerby equation for overland flow time of concentration estimation.

Where K is a constant equal to 1.44 in S.I units; L, is length of flow (m); N, Roughness factor related to Manning's values; and S, slope.

$$t_c = KL^{0.770}S^{-0.385} \quad (3)$$

where K is a constant 0.0195 in S.I units; L, and S, are same as defined before.

2.5 Rainfall intensity as developed by Oyebande

Professor Lekan Oyebande, of the department of Geography at the University of Lagos, made a detailed report that allows for the calculation of rainfall intensity at any location in Nigeria for a range of durations and storm frequencies or return periods. His study on rainfall Intensity-Duration Frequency (IDF) were undertaken using annual extreme rain fall series available for 35 meteorological stations throughout Nigeria. In order to obtain data for design floods of high frequency with a good confidence, the whole country was split into ten rainfall zones. The IDF estimates where then used to generate curves for the ten different zones and for the individual stations (Oyebande, 1983). IDF isohyetal maps were drawn and generated from the graphical estimates based on the individual stations. Similar models were developed for Port Harcourt as seen in the works of Nwaogazie and Duru (2002). Oyebande, (1983) derived two basic equations for the calculation of rainfall intensity given the rainfall zone, return period, and storm duration (Equations (4) & (5)). The equations are listed below:

$$y = \alpha(x - \beta) \quad (4)$$

$$y = \ln(Tr) - \frac{1}{2Tr} - \frac{1}{24Tr^2} - \frac{1}{8Tr^3} \quad (5)$$

where α and β are the scale and location parameters**;** x is Rainfall Intensity**;** and Tr, Return period or Frequency of occurrence.

Now, making intensity, which is our interest the subject of formula,

$$x = \beta + y(1/\alpha) \quad (6)$$

where x is the Rainfall Intensity. Table 2 presents the constants for each zone, while Table 3 shows parameter estimates for individual stations

Table 2: Estimates of parameters of the equation $x = \beta + y(1/\alpha)$ for each zone

Zone	(1/α), β	0.2 h	0.4 h	1 h	3 h	6 h	12 h	24 h
I	1/α	23.52	19.19	12.10	6.63	3.74	1.87	0.98
	β	118.94	97.43	60.13	26.25	14.48	7.63	4.03
II	1/α	24.83	20.97	14.36	6.29	3.88	2.16	1.26
	β	113.16	85.74	55.06	23.58	13.30	7.03	3.81
III	1/α	19.57	14.99	11.32	5.59	2.94	1.49	0.85
	β	108.78	78.59	43.63	17.43	9.55	4.85	2.61

Source: (Oyebande, 1983)

Table 3: Estimates of the parameters of the equation $x = \beta + y(1/\alpha)$ for Individual Stations

Station	Zone	(1/α), β	0.2 h	0.4 h	1 h	3 h	6 h	12 h	24 h
Port Harcourt*	I	1/α	26.43	15.22	14.00	6.45	3.70	1.61	0.85
		β	121.03	100.13	61.35	27.31	15.53	8.10	4.29
Warri*	II	1/α	29.33	22.65	14.57	4.85	3.44	1.68	1.04
		β	120.78	92.47	59.91	27.53	15.06	7.90	4.52
Lagos*	II	1/α	23.55	22.17	16.66	6.82	3.93	1.97	1.11
		β	105.69	80.18	55.97	25.06	15.03	8.04	4.12

Source: (Oyebande, 1983)

2.6 Hydraulics analysis

In a drainage channel, 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 relationship between these quantities is expressed in Mannning's equation:

$$v = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \quad (7)$$

where n is Mannings coefficient of channels roughness; V, Mean velocity in metres per second (m/s); R, Hydraulic radius in metres; and S, Slope in metres per metres

$$\mathrm{R} = \frac{\mathrm{A}}{\mathrm{P}} \quad (8)$$

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, Wetted Perimeter in metres. The flow or Discharge capacity of the channel Q is computed as follows:

$$\mathrm{Q} = \mathrm{AV} \quad (9)$$

Substituting Mannings V into the flow equation, it becomes:

$$\mathrm{Q} = \mathrm{A}\frac{\mathrm{R}^{\frac{2}{3}}\mathrm{S}^{\frac{1}{2}}}{\mathrm{n}} \quad (10)$$

Thus, for specified values of *n, Q and S*, the Equation (10) was solved to determine the normal depth of a given channel. This may be done using the design chart presented by Chow (1959). Leton (2004) specified self-cleansing velocities in drains to begin from at least 0.5 m/s. According to him, channels with lesser flow velocities will deposit sediment

3. Results and discussion

3.1 Hydrology data

Drainage design was done involving the hydraulic and hydrology parameters and with the rational formula for peak discharge computation. Table 6 represents the final flow result as derived from the field and data calculation and the summation of the flow Q (0.3396 cu. m/s) is the peak runoff estimate flowing into D7. This was calculated using Equation (1) with the intensity value of 109.84mm/hr as detailed in the work of Onyemachi (2023). The rainfall intensity from the IDF curve of Agunwamba (2000) for 45 minutes time of concentration was 105.75 mm/hr is approximately same with the 109.84mm/hr as applicable to this investigation. Area data as measured from the field survey including the ground cover runoff coefficients adopted for this study are presented in the Tables 4 – 6 and the rainfall intensity estimated using the Rational method.

Table 4: UDPS area estimate (a sub contributory of D7)

S/N	Ground cover type	Area sq. m	Runoff C	C×A sq. km	Q cu. m/sec
1.	Asphalt	217.08	0.8	173.66	0.0053
2.	Lawn	4991.07	0.2	998.21	0.0304
3.	Rooftop	4575.75	0.95	4346.96	0.1326
4.	Bare ground	1284.06	0.3	385.21	0.0117
5.	Concrete	-	0.8	-	-

Table 5: Data for other contributories into D7

S/N	Ground cover type	Area sq. m	Runoff C	C×A sq. km	Q cu. m/sec
1.	Asphalt	2745.50	0.8	2196.40	0.0670
2.	Lawn	1556.00	0.2	311.20	0.0095
3.	Rooftop	1195.31	0.95	1135.54	0.0346
4.	Bare ground	30.00	0.3	9.00	0.0003
5.	Concrete	22.50	0.8	18.00	0.0005

Table 6: Combination area collection for D7 (UDPS + other contributories)

S/N	Ground cover type	Area sq. m	Runoff C	C×A sq. km	Q cu. m/sec
1.	Asphalt	2962.58	0.8	2370.06	0.0723
2.	Lawn	6547.07	0.2	1309.41	0.0399
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

3.2 Hydraulics of the study drain

The hydraulic study has to do with drain cross-sectional characteristics and bed slope/invert. Although the old D7 drain section is trapezoidal with top width of 0.53 meters, bottom width (0.35 meter) and height (0.45 meter) proved adequate with a flow capacity (4.40 cu. m/s). This section seemed oversized, therefore a more acceptable design adopting the most efficient section and for a rectangular cross-section was considered. Mannings equation in combination with formula for the most efficient section were utilised in the drain sectional calculations. Given the measured slope of drain D7 is 0.0164 as shown in Fig. 3, the Area of the drain was calculated for the most efficient rectangular section by obtaining the dimensions for depth y and bed-width, b as did by Nwaogazie et al. (2015). Consequently, the depth y (0.307 meters), bed-width (0.614 meters) and non-silting velocity (1.8 m/s), and an improved slope of 0.279 yielded an area of 0.1886 sq. Meters, and flow Q (0.3395 cu. m/s), respectively. Therefore, to freely convey the expected discharge through the drain, the depth y was adjusted to 0.40 meters; this increased the flow area to 0.244 sq. meters and the drain capacity to 0.4392 cu. m/s which now surpasses the rational peak discharge (0.3396 cu. m/s).

Table 7: Levelling data for drain D-7 invert

S/N	Station Distance	R/L
1	TBM3	10
2	0	9.955
3	20	9.578
4	40	9.212
5	60	9.035

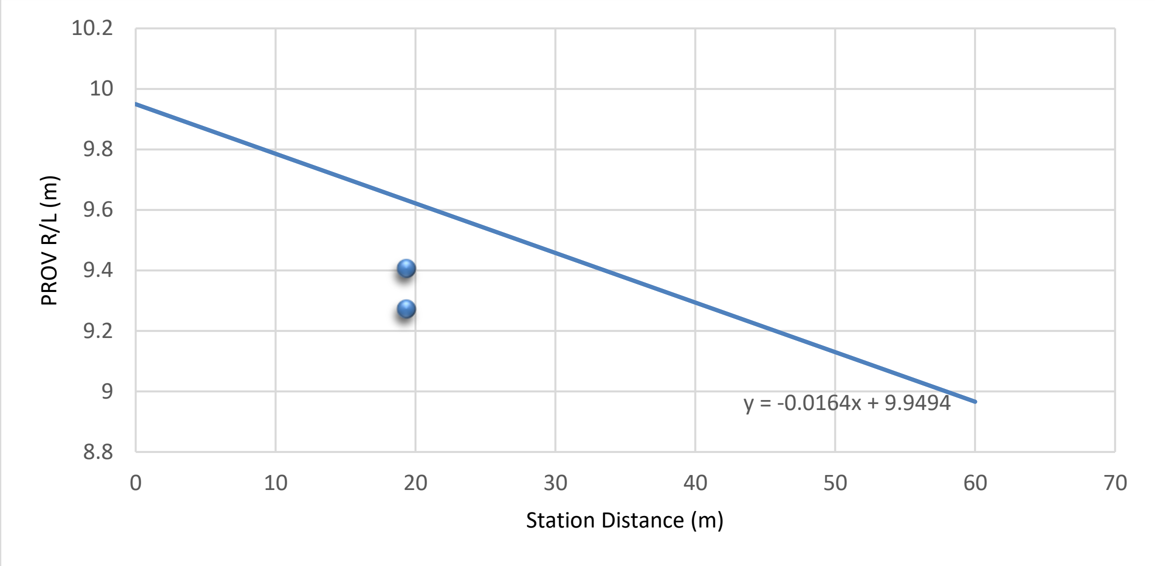

Fig. 3: Drain D-7 invert profile

4. Conclusion

Field investigations have unveiled that approximately 70.64% of catchment B constitutes the contributing portion of the watershed under examination in this study. Notably, within the Delta Park campus, the predominant drainage infrastructure consists of roadside drains situated on both the Eastern and Western sides of the road network. The outcomes of the result of the study have led to several key conclusions. Firstly, the hydrological and hydraulic design is rooted in field-generated data. The Rational Method, in conjunction with fundamental hydraulic equations, served as our primary tools. These calculations were informed by established constants, as documented by Oyebande (1983) and in conformity with the Federal Ministry of Works Design Manual of (2013). Data collection involved a concerted effort, combining manual measurements using measuring tape and software-driven measurements through ArcGIS. The rainfall intensity was calculated for a duration 45 minutes and the result (109.84 mm/hr); the hydraulic design showed that depth y was adjusted from 0.307 to 0.40 meters, to allow for free conveyance of runoff; with the bed-width value (0.614 meters) and non-silting velocity (1.8 m/s). Also, an improved slope from 0.0164 to 0.279 and yielded an area adjusted from 0.1886 to 0.244 sq. meters, and flow Q (0.3395 cu. m/s), respectively. The resultant effect on the dimensional adjustments were evident on the drain capacity which increased from 0.3396 to 0.4392 cu. m/s which now exceeds the rational peak discharge value. Therefore, the new rectangular section is regarded adequate and the most economical in terms of cost of construction and material cost.

References

Agunwamba, J.C. (2000) Water Engineering systems, Immaculate publications limited Enugu, Enugu State, Nigeria, pp. 92-188.

Chow, V.T. (1959) Open Channel Hydraulics_1st Ed. McGraw-Hill Book company, Inc., New York, 199-187.

Evans, T. (2004) Urban Drainage and the water Environment; a sustainable Future. Foundation for Water Research. 2nd Ed., 5-6, 8-13.

Federal Ministry of Works, (2013) Highway Manual, Drainage Design. Vol 4, 4-150.

Leton, T.G. (2004) Civil Engineering Fluid Mechanics 1st Ed. Wellsprings Publications Nigeria Limited, Lagos, 85.

Nwaogazie, I.L. and Duru, E.O. (2002) Developing annual and time series rainfall models for Port Harcourt City. Nigeria Society of Engineers Technical Transaction, 2(3): 1-8.

Nwaogazie, I.L., Uba, L.O. And Dike, C.C. (2015) Drainage Network Analysis and Incidence of flooding in Bonny Island, Nigeria. 2-4, 7-8.

Nwaogazie, I.L. (2022) Watershed characteristics and drainage design, a personal communication, Department of Civil and Environmental Engineering, University of Port Harcourt, Choba, Rivers State Nigeria.

Onyemachi, I.P. (2023) Performance Evaluation of Selected Drains in Delta Park campus, University of Port Harcourt, a Final year Project Report, Department of Civil and Environmental

Engineering, University of Port Harcourt, Choba, Rivers State Nigeria.

Oyebande, L. (1983) Rainfall Intensity, Duration, Frequency curves and maps for Nigeria. Department of Geography, University of Lagos.

Oyegoke, S.O. and Adebanjo, A.S. (2018) Design of Storm Water Drainage for an estate at Epe in Lagos state, Nigeria. International Journal of Hydrology, 2(4): 471-480.

Zhang, H. (2018) Construction of Water Supply and Drainage Engineering. ISWSO. Vol 2, 3.