Quest Journals
Journal of Software Engineering and Simulation
Volume 9 ~ Issue 3 (2023) pp: 24-32
ISSN(Online) :2321-3795 ISSN (Print):2321-3809
www.questjournals.org

Research Paper

Assessment of the hydraulic analysis capability of the HY-8 software on the design of simple culverts. A case study of the box culvert located along the federal college of Education access road, Umunze, Nigeria.

1. Ndubuisi Christopher Nnaemeka[1]
[1] *Department of Civil Engineering, University of Benin, Benin City, Edo State,*
2. Izinyon, Osadolor Christopher[1]
[1] *Department of Civil Engineering, University of Benin, Benin City, Edo State, Nigeria.*

Abstract.
In this work, an existing and efficient double barrel box culvert was modeled using the HY-8 modeling tool. The culvert parameters, example: the length of the barrel, width and depth of each barrel and the depth of embedment, were gotten from field investigation. Hydrologic analysis was carried out on the watershed using the rational method to determine the maximum precipitation and its contribution to the culvert discharge. The time of concentration of the watershed was estimated using the kirpich and Kerby formulae and the peak discharge was estimated as recurrent discharge for return periods: 2, 5, 10, 25, 50 and 100 years and the 25-year recurrent discharge was chosen to be the design discharge as the culvert site is located in the rural area. The flowrate of an existing stream across the culvert system was ascertained by on-site method and the total discharge at the culvert crossing was the sum of the peak discharge and the stream discharge. The hydraulic analyses was carried out using the HY-8 software. The analyses were carried out for two conditions: condition A and condition B. In condition A, minimum and maximum boundary values of the design discharge were used and in condition B, the discharge values chosen were the recurrent discharges for the return periods 2, 5, 10, 25, 50 and 100 years. The basis for the assessment was to compare the headwater levels of the existing culvert and the model at their design discharges. The results of the HY-8 model showed headwater levels fairly identical with that of the existing culvert. The software also provided other relevant information about the culvert system. The HY-8 tool was recommended for simple culvert analysis in Nigeria.
Keywords*:Hydraulic Analysis, Hydrology, Return Period, Time of Concentration, Discharge.*

Received 06 Mar., 2023; Revised 017 Mar., 2023; Accepted 19 Mar., 2023 © The author(s) 2023. Published with open access at www.questjournals.org

I. Introduction.

Culverts are covered channels which are always relatively shorter than bridges and are employed to pass water (streams, rivers, stormflows)under embankments (e.g. roadways, railroads, dams etc.). Culverts are constructed from a variety of materials and they have different shapes and configurations. Culverts like every other engineering structure require to be safely designed. An exact or straight forward analysis of culvert flow is extremely complex because the flow is usually non-uniform with regions of gradually varying and rapidly varying flow [2].Due to the complexity of the analysis involved in the design of most hydraulic structures, the designs are made with simple manual analysis and rule of thumb considerations. This has been in practice most especially in developing countries over the years, making the design process prone to error as the numbers of hydraulicculverts tobe analysed increase [5].

Moreover, a culvert design entails estimating the culvert sizing that will pass the peak flow for which it is designed for. According to the US department of transportation (2009), a good culvert design should ensure that the culvert passes the peak flow, the design allowable headwater is minimal and does not in any case overtop the roadway, there is optimum energy loss as the flow passes through the culvert.The hydraulic performances of Culverts are the design discharge, the upstream total water level (head) and the maximum (acceptable) headloss in the barrel [11].

TheFederal Highway Administration (FHWA) developed procedures (HDS-series) for culvert analysis on the basis of a control section. A control section is a location where there is a unique relationship between the flow rate through the culvert and the upstream water surface elevation [2]. The FHWA method has been the basis for many culvert design manuals.

Traditionally, culverts are designed using rainfall data from the past to estimate flow rates. [3].Culverts are designed to pass a specific flow rate with the associated natural flood level. The maximum flow rate is called the peak flow. The peak flow has been, and continues to be, a major factor in the culvert design process [2].

For hydraulic designs on watersheds limited to 5000 hectares, a complete hydrograph of runoff is not always required. The maximum, or peak, of the unit hydrograph is sufficient for design [13]. There exists several methods for estimating the design discharge of small watersheds, one of such methods is the rational method. The rational method was developed by Kuichling in1889 for relatively small drainage basins in urban areas. The rational method is based on a simple formula that relates the runoff-producing potential of a watershed, the average intensity of precipitation for a given time (the time of concentration), and the watershed drainage area. The formula is:

$$Q_p = \frac{CIA}{360} \quad (1.)$$

Where: Q_p = peak discharge (m^3/sec), C= runoff coefficient (dimensionless between 0 and 1), I= design rainfall intensity (mm/hr), A= watershed drainage area (ha).

The runoff coefficient, C, is a dimensionless ratio which tends to indicate the amount of runoff generated by a watershed given an average rainfall intensity for a storm. The coefficient values were developed as a ratio of the total depth of runoff in a catchment and the total depth of rainfall for several natural runoff conditions. The formula is

$$C = \frac{R}{P} \quad (2.)$$

Where: R =Total depth of runoff (m), P = Total depth of precipitation.

The runoff coefficient represents the fraction of rainfall converted to runoff. For rural areas, C is calculated by aggregating individual values for the catchment surface slope, catchment permeability and vegetation ($C = C_s + C_p + C_v$)[7].

Rainfall intensity, *i*, is a function of geographic location and storm return period. It is a function of the total amount of rain (rainfall depth) falling during a given period of time. It is expressed in depth units per unit time, usually as mm per hour (mm/hr). The return period is the average time interval between occurrences of a hydrological event of a given or greater magnitude, usually expressed in years [1]. The relation between these three components, storm duration, storm intensity, and storm return interval, is represented by a family of curves called the intensity-duration frequency curves, or IDF curves.

For IDF curves, the following formula maybe used in approximating the rainfall intensity

$$i = \frac{b}{(t_c + d)^e} \quad (4.)$$

Where: i = design rainfall intensity (mm/hr), t_c= time of concentration (min) and d,b,e = Return interval parameters

The drainage area is the size of the catchment or the subcatchment under consideration [10].

HY-8 is a computer program that can be used to perform calculations for culvert analysis[4].The first versions of HY-8 were developed by the Pennsylvania State University in cooperation with FHWA. HY-8 capabilities includelocating the project area using a Virtual map plug-in, perform hydraulic analysis of up to 99 barrels at a particular crossing for different shapes, sizes and channel types, plots the hydraulic performance curve and the cross section of the culvert with the ensuing flow conditions and save the report files in rich text format (RTF) and portable document format (PDF). Some of the limitations of HY-8 include hydraulic jump computation; the length computed by HY-8 may or may not be correct since the equation used to compute hydraulic jump length is for box culverts only, but is applied to all the other possible HY- 8 culvert shapes. Also, HY-8 assumes the culvert cross section shape, size, and material does not change in the barrel except in the case of broken back run out sections, where you can change the material and Manning's roughness in the run out (lower) culvert section.

II. Methodology

2.1 The Study Area

The study area is in Umunze, Anambra State. Umunze is the Headquarters of Orumba South Local Government in Anambra State. Its geographic coordinates are 5° 56’ 36’’ North, 7° 13’ 45’’ East. The road leads to the Federal College of Education Technical. Umunze has a mean rainfall of about 2,100mm/year. The watershed area of Federal College of Education access road is about 1.34km^2 or 134hectares [12] The watershed is situated in the rural area and therefore the coefficient of runoff used in this Rational Formula was selected from table 1.

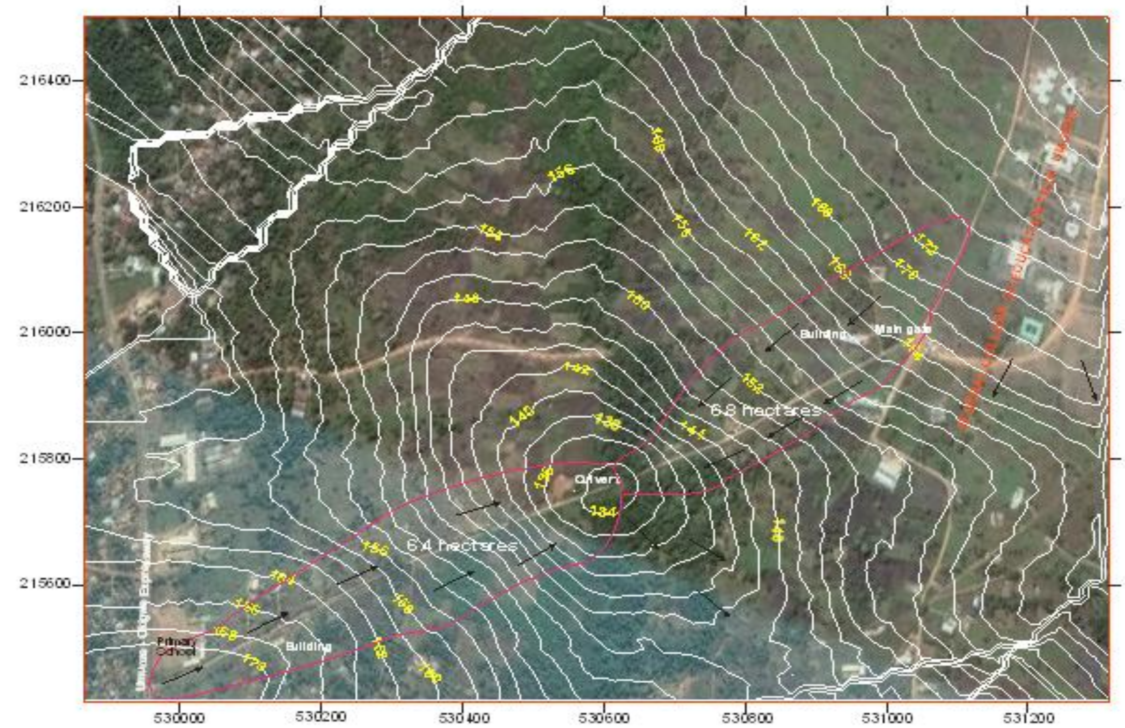

Figure 1: Topographic map of study area showing the elevation, area of watershed and culvert location.

Table 1: Runoff Coefficients for rural watersheds.

Watershed Characteristics	Extreme	High	Normal	Low
Relief = C_r	0.28 − 0.35 Steep, rugged terrain with average slopes above 30%	0.20 − 0.28 Hilly, with average slopes of 10 − 30%	0.14 − 0.20 Rolling, with average slopes of 5 − 10%	0.08 − 0.14 Relatively flat land, with average slopes of 0 − 5%
Soil Infiltration − C_i	0.12 − 0.15 No effective soil cover, either rock or thin soil mantle of negligible infiltration capacity	0.08 − 0.12 Slow to rake up water, clay or shallow loam soil of low infiltration capacity or poorly drained	0.06 − 0.08 Normal; well drained light or medium textured soils, sandy loams	0.04 − 0.06 Deep sand or other soil that takes up water readily; very light, well-drained soils
Vegetal Cover − C_v	0.12 – 0.16 No effective cover, bare or very sparse cover	0.08 − 0.12 Poor to fair clean cultivation, crops or poor natural cover, less than 20% of drainage area has good cover	0.06 − 0.08 Fair to good. About 50% of area in good grassland or woodland, not more than 50% of area in cultivated crops	0.04 − 0.06 Good to excellent, about 90% of drainage area in good grassland, woodland or equivalent cover.
Surface Cover − C_s	0.10 − 0.12 Negligible; surface depressions few and shallow, drainageways steep and small, no marshes	0.08 − 0.10 Well-defined system of small drainageways, no ponds or marshes.	0.06 − 0.08 Normal; considerable surface depression e.g. storage lakes and ponds and marshes.	0.04 − 0.06 Much surface storage, drainage system not sharply defined, large floodplain storage, large number of ponds and marshes.

2.2 Roadway Data

Design of road crossing culverts should take into account many engineering and technical aspects at the culvert site and the adjacent areas [6]. The Fedeal College of education access road is an arterial road of category B with a design period of 20 years with a total length of 1750m[12]. The road has the maximum elevation of 187m and a minimum elevation of 137m with a maximum slope of 0.0577 and a minimum slope of 0.015 [12]. The culvert site is located at the chainage 1+025 with elevation 137m, this being the lowest part of the road. At this point also, there is presence of a small stream which flows at 20m^3/s

2.3 Hydrology

The hydrologic analysis of the watershed was carried out using the rational method. The time of concentration was calculated using a combination of the Kerby's and Kirpich's formulae. For this work, the road was divided into two catchments, each on either side of the culvert, to be able to estimate the flow coming from the two slopes and find the earliest time of concentration. One section of the road started from the road entrance to the culvert location and the other section started from the culvert location to the school gate. The length of the overland flow is 365m from the main road to the culvert site and 350m from the school gate to the culvert site. The overland flows' times of concentration was calculated using the kerby's formula:

$t_c = 1.44(L \times N)^{0.467} S^{-0.235}$ (3.)

Where: L = the overland-flow length, in meters, N = Kerby's roughness coefficient (dimensionless), and S = Overland flow slope (m/m).

The channel length is 625m from the point where the first overland flow length ended and 400m from the point where the second overland flow length ended. The channel flow time of concentration was calculated using the kirpich's formula:

$t_c = 0.0195 L^{0.770} S^{-0.385}$ (4.)

Where: t_c= time of concentration (min), L= length of main channel (m), s= slope of the main channel (m/m). The total time of concentration was obtained by adding the overland flow time of concentration and the channel flow time of concentration.

$$t_c = t_{ov} + t_{ch} \quad (5)$$

From these times of concentration, the intensities were traced out from the IDF curve in Figure 2developed for the area using the NEWMAP template [8]

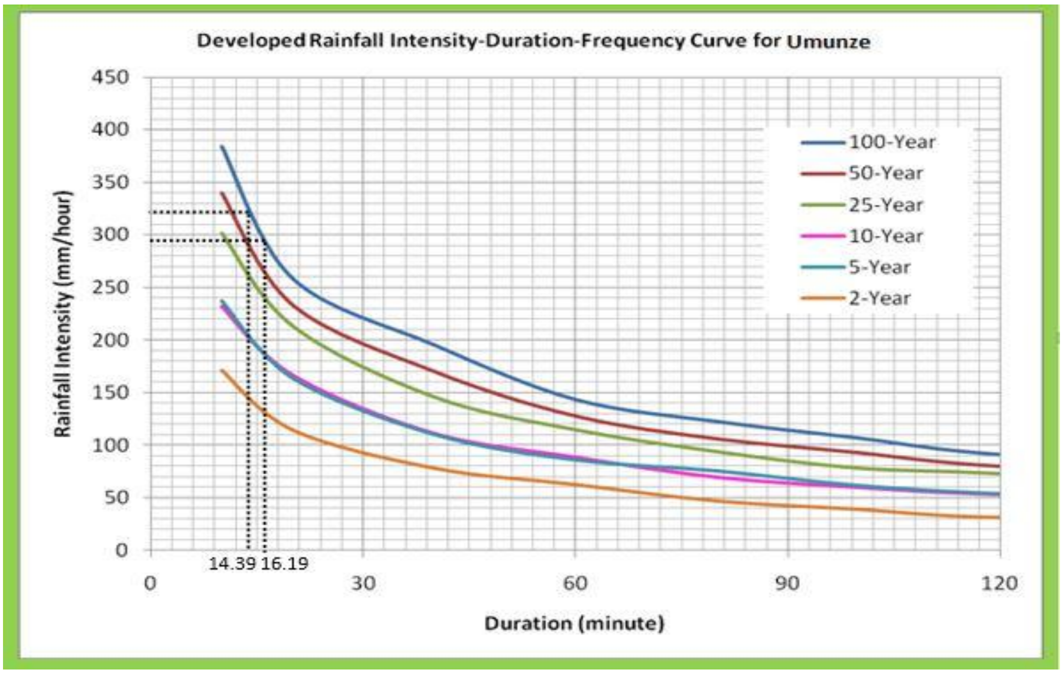

Figure 2: IDF Curve for Umunze, Anambra State.

2.4 Design Discharge

The design discharge is a sum of the estimated 25 year recurrent discharge which is closest to the recommended 20 years design storm for roads of category B as stipulated by the Nigerian federal Ministry of works [7] and the flowrate of the existing river ($20m^3/s$).

2.5 Design Conditions

2.5.1 Condition A

In this case, the discharge method was selected as having a minimum and maximum amount of discharge. Values were chosen as the minimum design discharge and the maximum design serving as a lower and upper bound to the design discharge (Q_{25T})

2.5.2 Condition B

In this case, the discharge method was selected as recurrent. The recurrent discharge was defined by inputting the individual values of the estimated recurrent discharges (2, 5, 10, 25. 50 & 100 year recurrent discharges).

2.6 Design Parameters.

Table 2: Design Parameters

Parameter	Value	Unit
Design discharge	Q_{25T}	m^3/s
Roadway Crest elevation	137.00	m
Roadway top width	16.00	m
Culvert length	25.00	m
Culvert shape	Box (Rectangular)	
Culvert material	Concrete (Manning's N= 0.012)	
Culvert Inlet	134.00	m
Culvert Outlet Elevation	133.50	m
Number of Barrels	2	nos.
Culvert station	1+025	m
Initial culvert sizing	2.0 x 2.0	m

2.7 Building the Project

Building a HY-8 project involves the design and analysis of single or multiple culverts at one or more crossings. The process of building a culvert project involved the following steps:

1. Locate Project: The first step in building the project was identifying the location of the crossing using the map viewer tool by entering coordinates (latitude, longitude) or the address of the crossing in the locator toolbar.
2. Culvert Crossing Data: In the HY-8 analysis, the user may choose up to 99 barrels for each culvert that is defined by the same site conditions, shape configuration, culvert type, and "n", and/or up to 6 independent culverts. The input properties define the crossing and culvert. The data defining each culvert were entered in the input parameters window.
3. Run Analysis: After defining the culvert and crossing data the culvert hydraulics were analysed. The Analyse Crossing feature could also be accessed from the culvert crossing data window. During the analysis, a summary of flows and overtopping at the crossing was displayed.
4. Report Generation: The report was generated in a PDF. The report included the culvert summary (site, tailwater, roadway, and culvert data) tables and crossing data, along with the downstream rating curves.

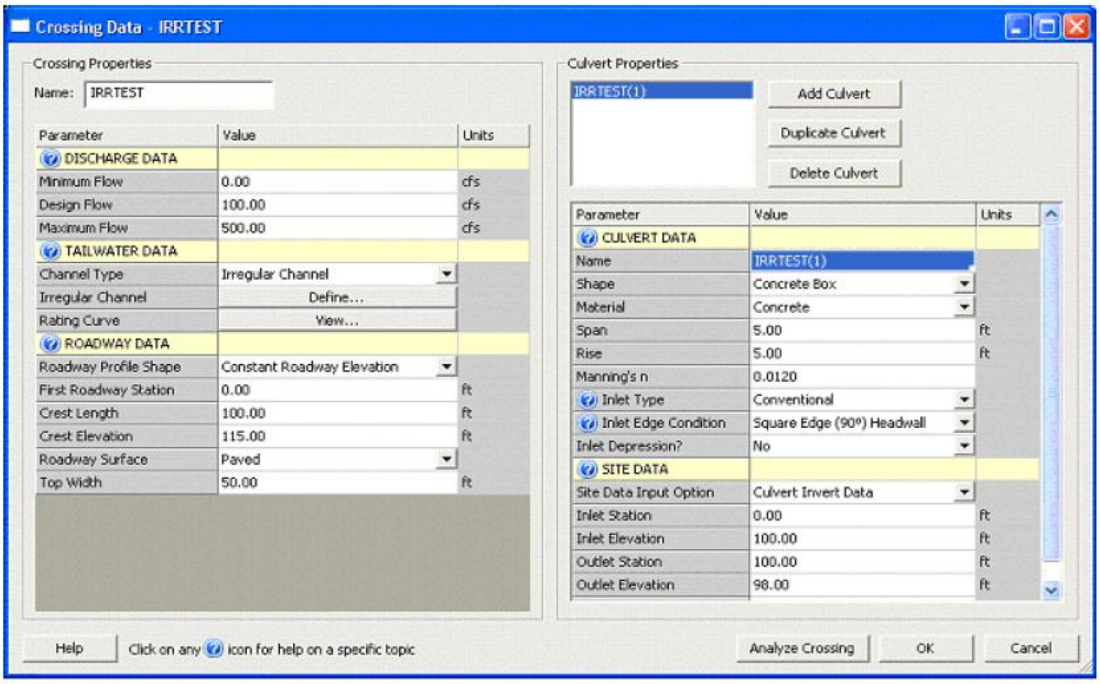

Fig 3: Typical HY-8 Culvert Crossing Input Interface

2.8 Headwater Calculation and Comparison

The basis for the assessment is the headwater level of the HY-8 model at the design discharge and the headwater level of the existing culvert. The headwater depth of the existing culvert was evaluated using hand calculation and the approach used was assuming a headwater depth and estimating the discharge corresponding to the headwater depth [12]. The discharge through the culvert barrel was estimated using the formula

$$H_t = \left[1 + Ke + \frac{2gL}{k_s^2 \cdot Rh^{4/3}}\right]\frac{Q^2}{2gA^2} \quad (6.)$$

Where H_t= Headwater level, K_e = Entrance coefficient, K_s = Roughness height,Rh = Hydraulic radius, Q = Discharge through the barrel, A = Wetted Area, g = Acceleration due to gravity.
The HY-8 tool uses the results of scaled model tests developed by the national bureau of standardsto evaluate the headwater level of the models. These model results were used to fit in a fifth degree polynomial through the three regions of flow: submerged, transition and unsubmerged [9]. The equation is as follows

$$\frac{HW}{D} = a + b\left[\frac{Q}{BD^{1.5}}\right] + c\left[\frac{Q}{BD^{1.5}}\right]^2 + d\left[\frac{Q}{BD^{1.5}}\right]^3 + e\left[\frac{Q}{BD^{1.5}}\right]^4 + f\left[\frac{Q}{BD^{1.5}}\right]^5 \qquad (7.)$$

HY-8 incorporates the polynomial coefficients for all culvert shapes and inlet configurations [2].

III. Results and Discussion

3.1 Time of concentration

The result of the time of concentration of the two catchments are summarised in Table 3.

Table 3: Time of concentration summary

	L_{ov} (m)	Kerby's N	H_1 (m)	H_2 (m)	S_{ov}	T_{ov} (mins)	L_{ch} (m)	H_1(m)	H_2(m)	S_{ch}	T_{ch} (mins)	$T_c = T_{ov} + T_{ch}$(mins)
From Umunze-Okigwe Road to Culvert	365	0.02	186	175	0.0302	8.2886	625	175	133	0.0657	7.9058	16.19
From School gate to Culvert	350	0.02	167	160	0.0216	8.7906	400	160	133	0.0657	5.6061	14.39

For the study area, the Time of Concentration is 16.19 and 14.39 minutes. t_c= 14.39 minutes was adopted for the analysis because the critical value is to be considered and it would produce a higher intensity.
From the developed IDF curve for the Area (see appendix), the intensities traced for 2 year – 100 year return period are

I_2 = 140mm $\qquad$ I_5 = 200mm
I_{10} = 200mm $\qquad$ I_{25} = 260mm
I_{50} = 295mm $\qquad$ I_{100} = 320mm

3.2 Recurrent Discharge

$$\text{Discharge } Q = \frac{CIA}{Z}$$

$Q_2 = \frac{CIA}{Z} = \frac{0.42*140*13.2}{360} = 2.16m^3/s$ $\qquad$ $Q_5 = \frac{CIA}{Z} = \frac{0.42*200*13.2}{360} = 3.08m^3/s$

$Q_{10} = \frac{CIA}{Z} = \frac{0.42*200*13.2}{360} = 3.08m^3/s$ $\qquad$ $Q_{25} = \frac{CIA}{Z} = \frac{0.42*260*13.2}{360} = 4.00m^3/s$

$Q_{50} = \frac{CIA}{Z} = \frac{0.42*295*13.2}{360} = 4.54m^3/s$ $\qquad$ $Q_{100} = \frac{CIA}{Z} = \frac{0.42*320*13.2}{360} = 4.93m^3/s$

3.3 Total Discharge

Q_{2T} = 20 + 2.16 = 22.16m^3/s $\qquad$ Q_{5T} = 20 + 3.08 = 23.08m^3/s
Q_{10T} = 20 + 3.08 = 23.08m^3/s $\qquad$ Q_{25T} = 20 + 4.00 = 24.00m^3/s
Q_{50T} = 20 + 4.54 = 24.54m^3/s $\qquad$ Q_{100T} = 20 + 4.93 = 24.93m^3/s

Design discharge: 25 year total discharge (24.00m^3/s)

3.4 Result from Conditions A and B

The results obtained from the analysis of Condition A are given in Table 4. Figure 4 shows the downstream rating curve for Condition A and Figure 5 is the longitudinal cross section of the culvert showing the headwater level, the hydraulic grade line (H.G.L) and energy grade line (E.G.L), the embankment and roadway data.
Table 5 shows the results obtained for Condition B. Figure 6 shows the downstream rating curve for Condition B and Fig 7 is the longitudinal cross section of the culvert showing the same details as in Condition B.

Table 4: Culvert Summary for Condition A

Total Discharge (cms)	Culvert Discharge (cms)	Headwater Elevation (m)	Inlet Control Depth(m)	Outlet Control Depth(m)	Flow Type	Normal Depth (m)	Critical Depth (m)	Outlet Depth (m)	Tailwater Depth (m)	Outlet Velocity (m/s)	Tailwater Velocity (m/s)
0	0	134	0	0	0-NF	0	0	0	0	0	0
3	3	134.12	0.12	0.0*	1-JS1t	0.01	0.07	0.39	0.39	0.15	0.53
6	6	134.19	0.19	0.11	1-JS1t	0.03	0.11	0.61	0.61	0.2	0.97
9	9	134.31	0.25	0.31	1-S1t	0.04	0.15	0.8	0.8	0.23	1.26
12	12	134.48	0.3	0.48	1-S1t	0.05	0.18	0.97	0.97	0.25	1.49
15	15	134.63	0.35	0.63	1-S1t	0.07	0.21	1.12	1.12	0.27	1.67
18	18	134.78	0.4	0.78	1-S1t	0.08	0.24	1.27	1.27	0.28	1.82
21	21	134.93	0.44	0.93	1-S1t	0.1	0.26	1.42	1.42	0.3	1.96
24	24	135.07	0.48	1.07	1-S1t	0.11	0.29	1.56	1.56	0.31	2.08
24.93	24.93	135.11	0.49	1.11	1-S1t	0.11	0.29	1.6	1.6	0.31	2.11
30	29.86	135.34	0.56	1.34	1-S1t	0.14	0.33	1.83	1.83	0.33	2.28

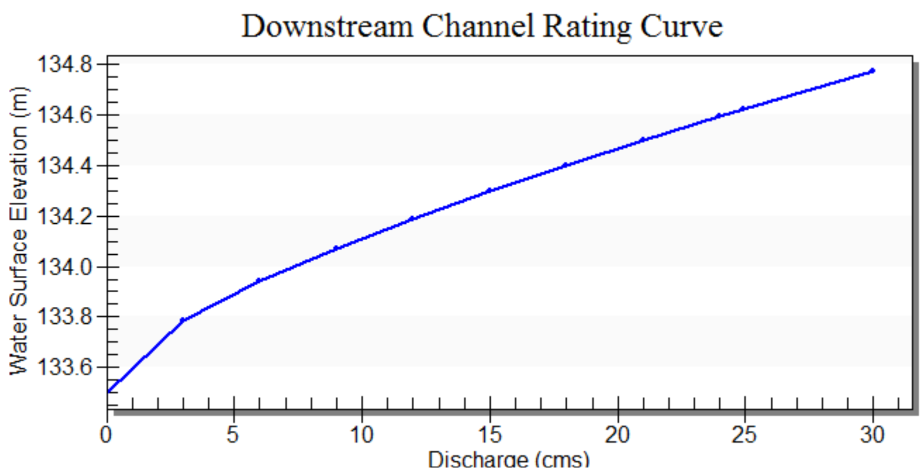

Fig 4**: Downstream Rating Curve for Condition A**

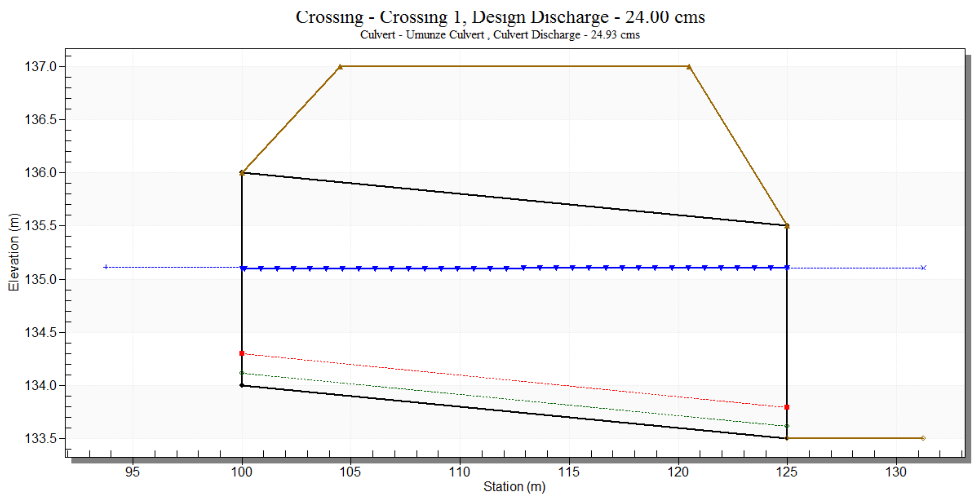

Figure 5**: Culvert longitudinal cross section (Condition A)**

Table 4.6: **Culvert Summary for Condition B**

Discharge Names	Total Discharge (cms)	Culvert Discharge (cms)	Headwater Elevation (m)	Inlet Control Depth(m)	Outlet Control Depth(m)	Flow Type	Length Full (m)	Length Free (m)
2 year	22.16	22.16	135.02	0.73	1.02	1-S1t	0	25
5 year	23.08	23.08	135.06	0.75	1.06	1-S1t	0	25
10 year	23.08	23.08	135.06	0.75	1.06	1-S1t	0	25
25 year	24	24	135.1	0.76	1.1	1-S1t	0	25
50 year	24.54	24.54	135.13	0.78	1.13	1-S1t	0	25
100 year	24.93	24.93	135.15	0.78	1.15	1-S1t	0	25

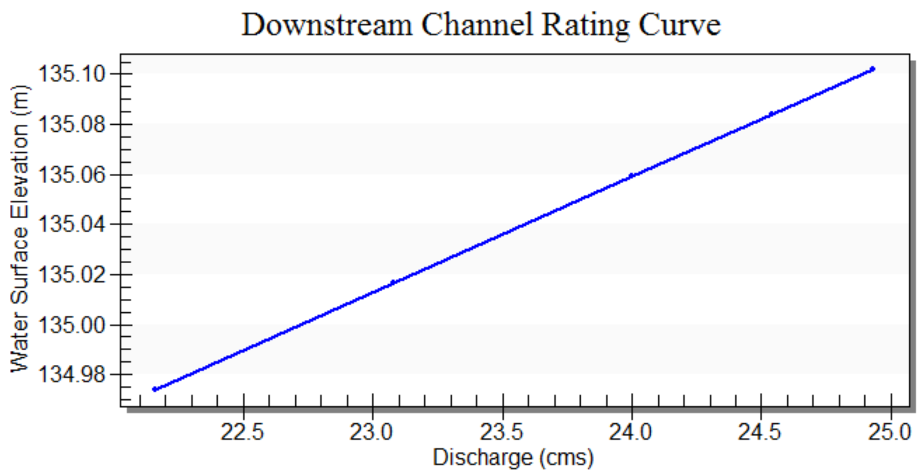

Fig 4.3**: Downstream Rating Curve for Condition B**

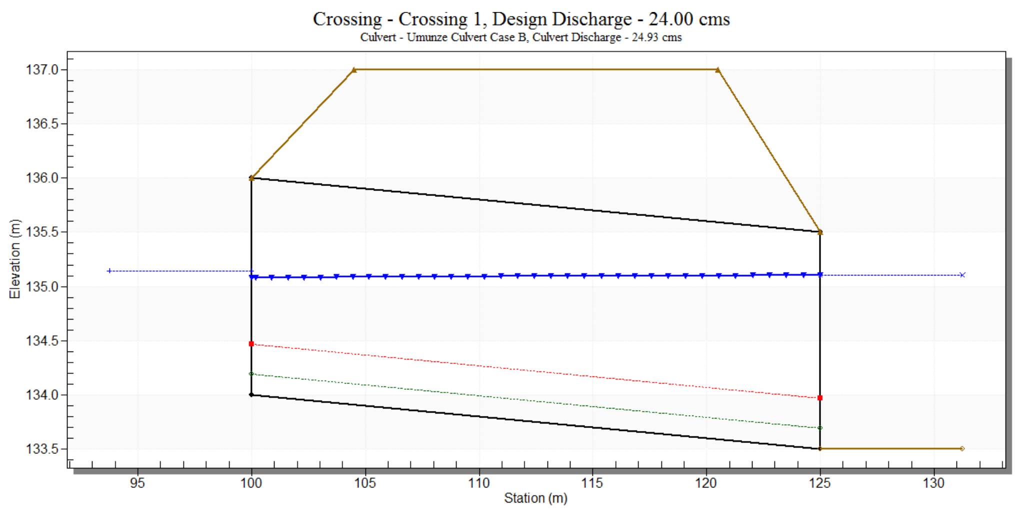

Figure 4.4**: Culvert longitudinal cross section (Condition B)**

3.5 Headwater Calculation and Comparison.

The size of the existing culvert is 2m x 2m (double barrel) box culvert. The headwater was assumed to be 2m; hence the discharge was estimated to be

$$H_t = \left[1 + Ke + \frac{2gL}{k_s^2 \cdot Rh^{4/3}}\right]\frac{Q^2}{2gA^2} \qquad (6.)$$

Where H_t = 2m K_e = 0.5 (Concrete head walls) L = 25m k_s = 66 (1/n, where n = 0.015) Rh = $\left[\frac{4}{8}\right]$ = 0.5m $A^2 = (4)^2 = 16m^2$ 2g = 19.62

$$2 = \left[1 + 0.5 + \frac{2 \times 9.81 \times 25}{66^2 \cdot (0.5)^{\frac{4}{3}}}\right] \cdot \frac{Q^2}{19.62 \times 16}$$

*Corresponding Author: Philips Seth .O

$Q = 19.34m^3/s$

Thus the double barrel will discharge (2 x 19.34) = $38.68m^3/s$

But the design discharge is $24.00m^3/s$, thus the sizing of 2 x 2 m double barrel concrete box culvert is adequate to pass the peak flow.

The headwater level corresponding to the design discharge (24.00/2 = $12.00m^3/s$ for each barrel) is estimated as follows

$$H_t = \left[1 + 0.5 + \frac{2 \times 9.81 \times 25}{66^2 \cdot (0.5)^{\frac{4}{3}}}\right] \cdot \frac{12.00^2}{19.62 \times 16}$$

$H_t = 1.05m$

Table 4.8: **Comparison between the HY-8 H_t and H_t = 1.05m**

CASE	HY-8 H_t	HY-8 Control depths	H_t from manual design
Condition A	1.093m	1.07m	1.05m
Condition B	1.559m	1.10m	1.05m

IV. Conclusion and Recommendation

The comparison made between the HY- 8 model and the manually designed Culvert shows that the HY- model replicates the manual design. The headwater depth from the existing culvert was estimated to be 1.05m from the culvert bed elevation while the depths at the control sections for both conditions of the HY- 8 model were 1.07m and 1.10m. Thus, it can be seen that given the same input data, the HY- 8 model almost gave the same result as the existing design.

The analysis using the HY- 8 program gave other relevant information missing in the manual design; information like the flow type across the culvert barrel, the critical depth, the velocity of flow, the fluid shear and the tailwater depth at every discharge value. Also, the HY- 8 program gave a diagrammatic representation of the lateral cross section of the culvert system showing the culvert elevation, the embedment depth, the headwater elevation and the flow elevation as it passes the entire length of the culvert barrel. . It is recommended that the program HY-8 be applied in the design of simple culvert systems in Nigeria.

References

[1]. Dawei Han. (2010) Concise Hydrology. 1st Edition. ISBN: 978-87-7681-536-3. p. 99.

[2]. Federal Highway Administration. (2012). Hydraulic design of highway culverts. Hydraulic design series number 5, 3rd edition. Publication No. FHWA-HIF-12-026.

[3]. Fernández-Pato et al. (2020) Analysis of the performance of different culvert boundary conditions in 2D shallow flow models. *Journal of Hydroinformatics* (5): 1093–1121. doi: https://doi.org/10.2166/hydro.2020.025

[4]. FHWA. HY-8 Quick Start Tutorials and User's Manual. Washington, DC: Federal Highway Administration, U.S Department of Transportation, 2013. (Distributed with the software)

[5]. G. Adeogun et al. (2019) Evaluation of Hy-8 Modeling Tool for Hydraulic Analysis of Selected Culverts along Ilorin -jebba Road, Kwara State, Nigeria. Arid Zone Journal of Engineering, Technology & Environment. AZOJETE. Vol. 15(1):133-141.

[6]. Günal, M., Ay, M., &Günal, A. (2017). Cross-Drainage Culvert Design by Using GIS. Special issue of the 3rd International Conference on Computational and Experimental Science and Engineering (ICCESEN 2016). Vol. 132. DOI: 10.12693/APhysPolA.132.595

[7]. Nigerian Federal Ministry of Works (2013). Highway manual Part 1: Design. Volume IV: Drainage design. Federal republic of Nigeria. p. 3-1 to 3-52

[8]. O. A. Oguaghamba, M. E. Onyia. (2019). Gully Erosion Control in Nigeria: World Bank / Newmap Perspective on Hydrological Data Analysis. LGT-UNN 1st International Multidisciplinary Conference on Technology. p 51. http://www.lgt-unn.unn.edu.ng/wp-content/uploads/sites/219/2018/06/OA_OGUAGHAMBA_GULLYEROSION.pdf

[9]. Rowley et al. (2006). Numerical Modeling of Culvert Hydraulics: Modernization of Existing HY8 Software. World Environmental and Water Resource Congress: Examining the Confluence of Environmental and Water Concerns.

[10]. Te Chow, V et. Al. (2010). Applied Hydrology. McGraw-Hill series in water resources and environmental engineering. 2010. p. 490-500. ISBN:9780070702424. books.google.com.ng/books?id=RRwidSsBJrEC

[11]. Texas Department of Transportation. 2019. Hydraulic Design Manual Updated. Hydraulic Design Manual Series. http://onlinemanuals.txdot.gov/txdotmanuals/hyd/manual_notice.htm

[12]. The Willie Obiano Boulevard Road design Report (2015). (TCL/FCETUMU/2015). Unpublished.

[13]. Theodore G. Cleveland David B. Thompson Xing Fang. (2011). Use ofthe Rational and ModifiedRational Methods for TxDOT Hydraulic Design. Research Report Number 0- 6070- 1. https://library.ctr.utexas.edu/hostedpdfs/techmrt_0-6070-1.pdf