Design of Storm Water Drainage System: A study in Lae City, Papua New Guinea

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Abstract

A drain is the drainage system component that collects runoff from inlets and transfers the runoff to a point where it is then drained into a stream, water source, or piped system. It is very significant that all roads must have a proper storm drainage design to avoid further problems such as, poor highway traffic due to flood on the main road, potholes causing accidents, and erosion on the road sub-grades. This research focuses on designing the storm water drainage system of Independence Drive in Lae City. Its purpose is to provide a complete summary of the existing drainage situation and facilitate the best alternative drainage design, including suitable ways to improve the current conditions of the road in terms of its drainage network. In order to design a better drainage network for the road, it is important to take into consideration, the users' point of view with regards to the problem, the availability and reliability of geographical data, and the data analysis tools. Therefore, the research engaged a survey to obtain information about the state of the Independence Drive drainage system and the effect of poor drainage on road users, including the surrounding environment. Based on the survey findings, the research focuses on providing solutions to the drainage problem encountered along the Independence Drive using both survey and GIS data, processing of the data using spatial survey and geographical information tool and providing the appropriate drainage design output.

Key words: *Drainage, surveying, Unitech, culvert, Independence Avenue, Lae City, PNG*

1. Introduction

The purpose of a drain is to collect storm water runoff from the road way and carry it to an outflow as an expression of the desires of visitors and the local community through which it passes (Minnesota, 2000). In case of precipitation, the rivers are separated from other rainwater components such as streams on the earth surface, while the other components percolate into the soil mass in the form of free water to the lower surfaces of the earth. Some water is kept in the pores of soil density and on the floors of particles that cannot get drained by standard gravitations, such as potholes on the avenue or all rain water that cannot go down below the earth's surface.

The current study focuses on Independence Drive that links Unitech, Igam Baracks, East and West Taraka, Butibam and Busu Road in Lae, Morobe Province, Papua New Guinea. The road is about 2.1 km in length. A major problem experienced within the study region is that, during a heavy rainfall run-off from the surrounding areas flow onto the road resulting in water flooding that generates severe erosions on the soil. High floods are generated from the storm water in the affected areas resulting in land sinking, enamours potholes and cracks on the land surface especially along the road. From field visitation, it is evident that the road is very wide covering about 27 m, which exceeds the normal standard size of 13m recommended. This has been caused by moving traffic on the road as vehicles try to avoid the cracks and open potholes on the road; instead the road continues to expand beyond its normal size. Rainwater above or beneath the road pavement is the single paramount cause of damage to the roadway of Independence Drive. Problems linked to flooding include rutting, cracking, potholes, erosion, washouts, heaving, flooding, and premature failure of the roadway. It is, therefore, significant that the appropriate authorities make sure that adequate designs with enough drainage provisions are constructed in order to promote local economic growth through easy transportation of people and goods and smooth flow of traffic. Most significantly, proper road construction will reduce recurrent expenditure on roads through repairs and maintenance**.**

1.1. Location of the Study

The case study (Figure 1) is in Lae City, capital of Morobe Province in Papua New Guinea. Independence Drive is 17.7 km long. Out of this, the affected portion of the road due to poor drainage is around 5.78 km. However, this study focuses only on 2.1 km drainage design from the Morobe Concrete Products road junction to Igam barracks road junction on Independence Drive. The study area is in geographic coordinates between -6° 40′ 38.23″ S latitude, 146°59′ 20.91″ E longitude and -6°39′39.96” S latitude and 146°59′40.11” E longitude. The altitude of the study area ranges around 64-65 meters above mean sea level. The maximum annual temperature of the study area is 32°C, which occurs in the month of March (the hottest month of the year); July is the coldest month with temperatures averaging 29 °C. The mean annual temperature is 30.5ºC.

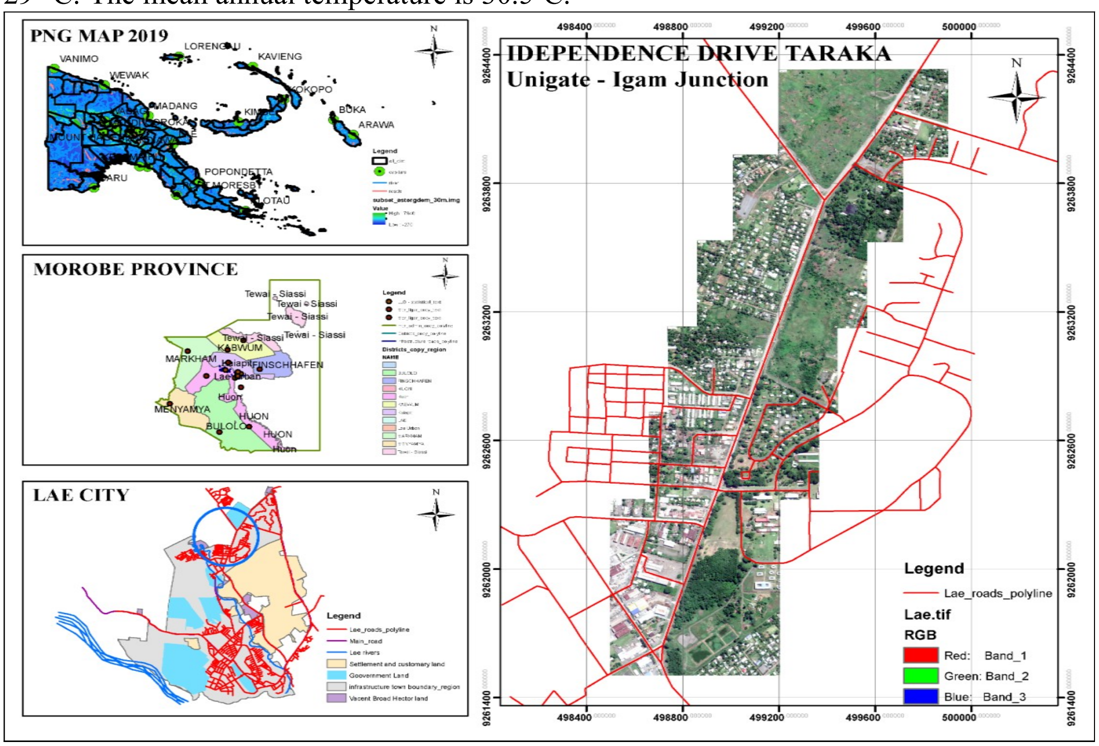

Figure 1: Study area locality map

2. Research Methods

The study comprises both descriptive and exploratory research methods. The descriptive method was used to describe the existing conditions and coverage of roads and storm water drainage facilities, while the exploratory method was particularly used to explore the existing condition and making some required physical measurements and comparing them to global standards. A survey was done to obtain information that would outline the existing state of drainage under the surface structure around Morobe Concrete Product Gate towards Igam Junction road (Independence Drive Road) and how sadly the poor drainage system has affected road users and the residents living adjacent the road including the surroundings during the rainy seasons. Different methods of data collection such as photographs, questionnaires, observations, interviews with others were conducted during the study to obtain the information required to meet the study objectives. Data collection was by using different materials. After the data collection was done, it was analysed using descriptive and exploratory techniques, such as rational, SCS methods and field survey. Qualitative and applied methods are illustrated in Figure 2.

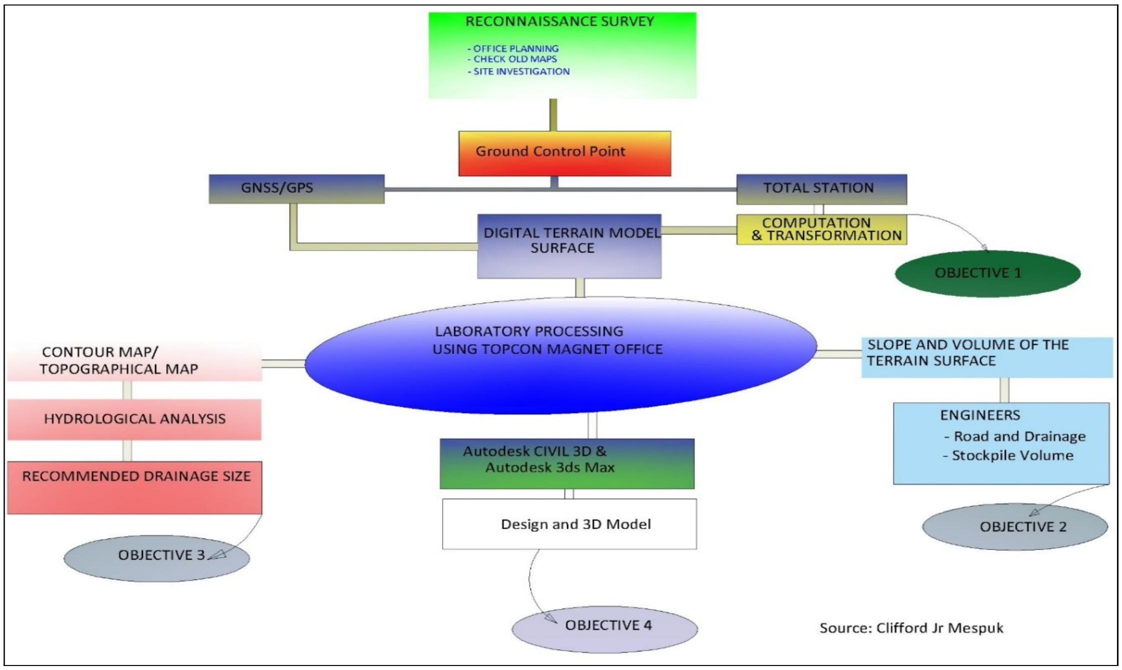

Figure 2: Methodological Flow Chart

2.1 Data and Analysis

2.1.1 Primary data

Questionnaires were used to gather primary data. They were written in two forms: one involving responses by Morobe Department of Works and the Engineer in charge of highway construction and maintenance of the drainage systems; the other involved responses from people who live adjacent to the area in question and road users. Site visit was also carried out to ascertain current conditions of poor drainage around Independence Drive in comparison with the acceptable standards. The research employed the use of a physical observation checklist, which was completed through observations with the aid of a digital camera used to take photographs of the current state of the road and the drainage system. Furthermore, field survey including measuring the site features with tape, GPS, Google Earth Map and total station was also conducted and then finalised by oral interviews. Oral questions were asked to get more information and to clarify ambiguous responses.

2.1.2 Secondary data

Secondary data is the data that had been collected earlier by other researchers and is readily accessible from other sources, for example, journals, and the Internet. Secondary data is economical and time saving. It helps to make primary data collection more definite; this is because the researcher can identify the gaps and deficiencies and what additional information needs to be collected. It also assists in understanding the problem which provides a basis for comparison of the data obtained from the field. In the course of this research, secondary data was extensively used. This data was obtained from analysis of the relevant literature concerned with road construction, road drainage construction and the design of the road drainage systems. The literature used in this research was extracted from drainage books, journals, research projects and the Internet.

2.1.3 Surveying Field data

Reconnaissance survey for information collection and organising the plan for the field project within the office was carried out followed by establishing survey control stations within the study region. The filed survey and data collection were furthered into detailed terrain model (DTM) as pick up of the project site or the topographical survey of the catchment area that was done using total station. Furthermore, field data calculations and reductions were manually calculated using HP calculator and application of a standard formula for calculating the angle reductions, bearing miss-close, coordinates, distances, slopes, linear accuracy, linear miss-close, departure, latitude and the applicable convergent that were applied on the field data. Finally, the adjusted field data was plotted on Magnet office and the DTM model of the project site was viewed, before it was again plotted on the AutoCAD on which the outcome of the data was designed.

2.1.4 Hydrological Analysis

Designing of road drainage system was done by calculating the hydrological parameters of the catchment area. Proper hydrological analysis design is important for road drainage system to pass peak discharge without blockage, interruptions, destruction of the drainage system and property adjoining the road crossing. Moreover, after the recommended hydrological analysis design, proper planning was very significant for the road drainage construction to function properly for the proposed purpose. The fact is that there was no drainage system linking Papua New Guinea University of Technology Gate to Igam Barracks junction, which was a major concern for pedestrian safety, road safety and the traffic safety of the motorists using the road.

3. Results and Discussions

This section presents the analysis of data obtained from the research questionnaires and field observations recorded during the study.

3.1 Questionnaires and Interview Results

Questionnaires were delivered to the engineers from Morobe Department of Works. Another set of questionnaires was given to the bus drivers plying Independence Drive and people who use the road, who are referred to as road users. The questionnaires comprise open-ended and structured questions on issues that are related to the study (Table 1).

Table 1: Response Rate of Participation in Field Survey

Respondent	**No. of planned questionnaires**	**The response**	**The response rate**
Road users	20	20	100%
Bus Drivers	10	8	80%
Engineers	4	4	100%
Total	**34**	**32**	**94.11%**

A response rate of 50% is adequate for data analysis and reporting, 60% is good and above 70% is very good (Mugenda, 1999). There was a response rate of 94.1% for this study and, therefore, very good for this study. The responses from the Morobe Works Engineers indicated that the drainage system provided for Independence Drive was a deep concern causing road deterioration on the main road leading from the University of Technology Gate to Igam Barracks. The study also attempted to investigate road users' perceptions on whether the washing away of Independence Drive (Unitech Gate - Igam Barracks Junction) a year after construction was expected. The engineers responded that it was never expected because studies were done before the inception of the road to ascertain the drainage requirements. It was, therefore, against expectations that due diligence was not exercised during the construction.

The engineers agreed that the drainage facilities were in poor condition and needed immediate action. The Morobe engineer in charge of Independence Drive reported that they always carry out inspections of the road and its drainage facilities yearly; unfortunately, there was poor funding from the government authorities at all times whenever requests were submitted.

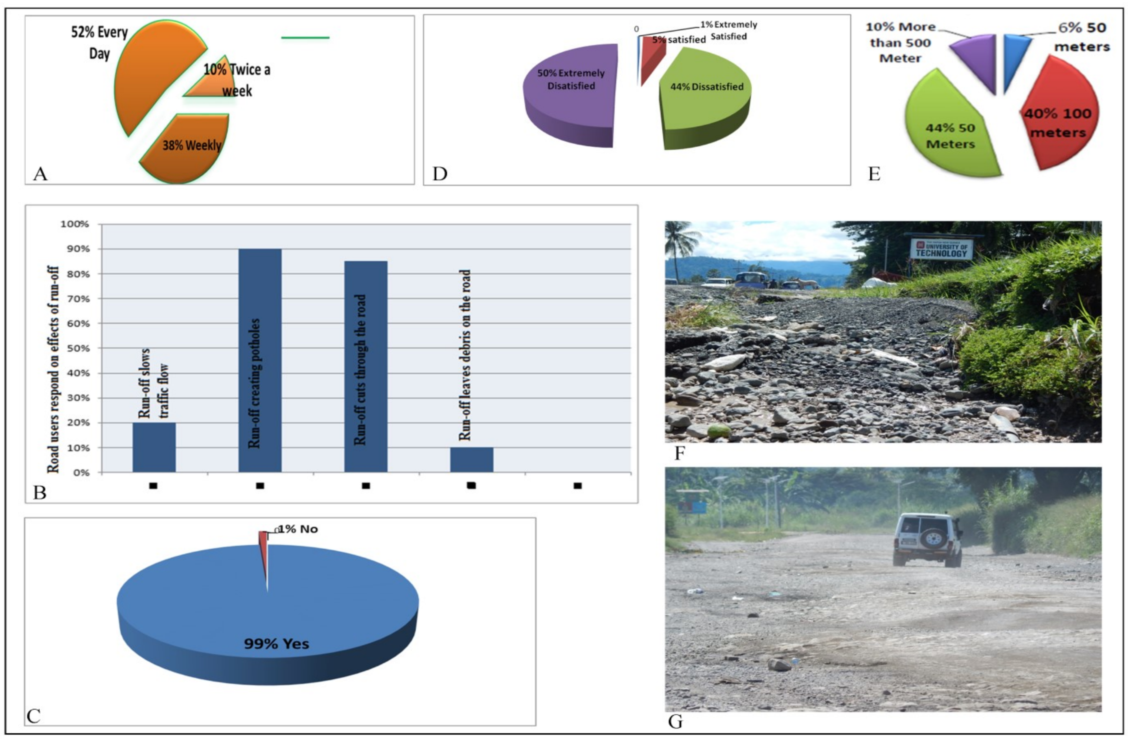

Figure 3: Questionnaire and interview response: **A.** Percentage of Road Users **B.** Effects of run-off on the road causing poor drainage **C.** Improvement actions needed and response from road users **D.** Road users' satisfaction level **E.** Response from residents living along the road **F.** Road bitumen cracked as a result of flood in the middle of the road **G.** Poor condition of the road due to inadequate drainage system in place.

Figure 3 (A) elaborates on the number of the respondents either using the road every day, weekly or twice a week. The data collected shows that 90% of the respondents use the road daily and on a weekly basis, while 10% use the roads twice a week. Feedback is important to this study because it shows that the respondents could be relied on to give authentic information to achieve the study's objectives. Road users agreed when it came to the effects of the poor drainage system on the road. Majority reported that runoff washes away the road surface creating potholes during the rains thereby hindering free movements of vehicles on the road. A significant proportion of respondents reported that runoffs cut through the road and leave debris on the road after the rains; the debris would then hinder movement along the road and therefore cause inconvenience to the road users, who then arrive late at their places of work or business or other engagements (Figure 3B). Figure 3C indicates that there has been an ongoing activity geared towards the improvement of the drainage system. Almost 99 % of the respondents have observed improvement activities on the road; however, 1% disagreed. Figure 3D illustrates the level of road user satisfaction. Figure 3E eloborates on how the residents feel when they are affected by the poor drainage in the area. Majority of the respondents reported that runoff had had adverse effects on the road creating potholes and producing dust. They commented that runoffs have eroded the land beside their home and also created more air polution and dusts. This study also employed both observations and photographs as tools for collecting data. These involved recording observations and taking photographs to show the current state of the drainage system along Independence Drive (Figures 3F & G). From observations, the state of the drainage system on Independence Drive is poor. However, some parts of the road have no problem with drainage; for example, from Eriku to Chemica frontage (Independence Drive), the drainage system is fairly good although the system is poorly maintained. As a result of the poor drainage conditions on Independence Drive, the top gravel of the road pavements has been washed/eroded away to the side of the road creating gullies and blockage.

3.2 Field Survey and Calculation

The surveying and the field work were done as per times scheduled. All the necessary data and information including the calculations and adjustments were done. The calculations and results shown below are the final output from the research methodologies. Reconnaissance survey was carried out according to the time scheduled. In the reconnaissance survey, all the permanent survey marks were identified and Temporary Bench Marks and Stations where adapted on which the main survey control network was established. The survey control was established and connected from known datum for the purpose of controlling the survey network of the road. The main control was started from a known point (BM 44 and BM 43) from the Papua New Guinea University of Technology gate with known bearing and distance and it was then closed back to the same point (close loop survey). The filed data were collected, and calculations were carried out, as follows:

3.2.1 Linear Mis-close

Known coordinates for BM 44: Easting= 499175.590; Northing = 9262356.190
Calculated coordinates for BM 44: Easting= 499175.6407; Northing = 9262356.191
Linear Mis-close: 0.055082072; Linear Accuracy = 61,110.62673 = 1:61 000

3.2.2 Starting Datum (Opening datum)

i. Known DATUMS
   BM 43: Easting = 499009.597; Northing = 9262366.436
   BM 44: Easting = 499175.590; Northing = 9262356.190
ii. Calculation of the opening datum (BM 44 - BM 43)

A. Bearing (BM43–BM44): Starting Point Datum Bearing BM44–BM43 = 273°31'55.6"
B. Closing Back @ BM 43 -BM 44 = 93°31'50"
C. Mis-close Adjustment = +00°00'0.35"

3.2.3 Survey data on World Geodetic System 1984 (WGS 84)

The survey data consist of the full summary detailed information obtained from the area of interest. This data was obtained using surveying instrument especially the Total Station. The data were captured on the WGS 84 reference datum.

Table 2: The adjusted coordinates, bearings and distances

Station	**Bearing**	**Distance**	**Easting**	**Northing**
BM 44 - 43	273°31'55.6"	166.3089	499175.590	9262356.190
BM 43 - TBM 1	260°21'12.3"	58.912	499009.5952	9262366.436
TBM 1 - 2	9°51'19.7"	146.6335	498951.5156	9262356.564
TBM 2 - 3	24°24'40.05"	166.448	498976.6122	9262501.034
TBM 3 - 4	12°48'23.4"	198.8235	499045.4005	9262652.602
TBM 4 - 5	26°03'36.75"	143.275	499089.4693	9262846.479
TBM 5 - 6	11°27'54.1"	174.606	499152.4106	9262975.188
TMB 6 - 7	23°37'35.45"	216.7863	499187.1159	9263146.310
TBM 7 - 8	12°16'13.8"	242.503	499273.9956	9263344.924
TBM 8 - CS 44	31°19'27.15"	136.581	499325.5314	9263581.887
CS 44 - TBM 9	211°52'17.5"	137.1214	499396.5356	9263698.560
TBM 9 - 10	199°18'58.8"	249.2042	499324.1318	9263582.112
TBM 10 - 11	199°24'19.2"	386.4422	499241.6964	9263346.937
TBM 11 - 12	196°33'39.5"	338.5585	499113.2972	9262982.448
TBM 12 - 13	198°00'35.9"	336.5784	499016.7922	9262657.934
TBM 13 – BM 43	73°32'53.25"	100.9581	498912.7243	9262337.847
BM 43 - BM 44	93°31'55.6"	166.36	499009.5479	9262366.439
At BM 44			499175.590	9262356.190

3.2.4 The Linear Mis-close and Accuracy

After all the adjustments were done, the linear mis-close and accuracy was calculated.
Known coordinates for BM 44: Easting= 499175.590; Northing = 9262356.190
Calculated coordinates for BM 44: Easting= 499175.6407; Northing = 9262356.191

I. Linear Mis-close**:** 0.037247754
II. Linear Accuracy**=** 90,370.54888 = 1: 90 000

3.2.5 Raise and fall

To appreciate the slope of the surface, Table 3 tabulates the reduced level carried out using dumpy level to investigate rise and fall along the road profile.

Table 3: The Reduced Level: Rise and Fall Method

Backsight	**Foresight**	**Rise/Fall**	**Reduced Level**	**Remarks**
1.238			54.079	BM43
1.754	1.099	0.139	54.218	TBM 1
1.865	0.538	1.216	55.434	TBM 2
1.792	1.043	0.822	56.256	TBM 3
1.751	0.553	1.239	57.495	TBM4
2.543	0.717	1.034	58.529	TBM 5
1.428	0.532	2.011	60.540	TBM6
2.330	0.602	0.826	61.366	TBM 7
2.285	0.055	2.275	63.641	TBM 8

0.871	0.862	1.423	65.064	CS 44
0.053	2.299	-1.428	63.636	TBM 8
0.597	2.282	-2.229	61.407	TBM 7
0.486	1.427	-0.830	60.577	TBM 6
0.712	2.493	-2.007	58.570	TBM 5
0.475	1.736	-1.024	57.546	TBM 4
1.037	1.742	-1.267	56.279	TBM 3
0.539	1.873	-0.836	55.443	TBM 2
1.099	1.777	-1.238	54.205	TBM 1
	1.209	-0.110	54.095	BM 43
BS 22.855		∑= 0.016	=0.016	
FS 22.839				
= 0.016				

3.2.6 Digital Terrain Model (DTM)

The Digital Terrain Model was carried out after the survey control was established along the Independence Drive. The DTM was carried out using total stations on which points were recorded according to its specific descriptions. The DTM survey was carried out according to the time as scheduled on the proposed report and all the data were captured for the study area. The DTM pick commences from the University of Technology Gate to Ten City Junction. All necessary information along and adjacent to the road where recorded. The final captured data was then processed using the Topcon Magnet Office, ArcGIS and AutoCAD civil3d for analysis and design.

3.2.7 Field Data Calculations and Reductions

All field data calculations and reductions were completed following the basic methods of surveying. Formulas and calculators where used to adjust, reduce and compute for the extraction of the final output. The final adjusted data were then entered into the software CAD for analysis and design. The CADS are the Magnet office and the AutoCAD - civil3D. The Topcon Magnet Office is a special tool that reads smart draw files (SDR) extracted from the Total Stations. The smart drawing file is read as point file format in the design cads; thus these point files are governed by known coordinate system on which the reduced level (height), eastings, northings, bearings and distances are shown. AutoCAD-civil3D is a drawing and is a multipurpose planning and designing tool. In land surveying, it uses survey data to create design of roads, drains, subdivisions and others. The data captured from the Independence Drive was then extracted and transferred to the cads on which the final designs were made. In contrary, further designs were made using the existing data captured in the field. The design was purposely for the drainage alone; however, road design was also done in order to standardize the position of the drainage. Further calculations with the aid of the two CADS were made to determine the exact design of the drainage system.

3.3 Hydrological Analysis

Notes were prepared to summarize the hydrology design undertaken for Independence Drive’s storm drainage system. The size of the catchment area usually determines how the hydrology design method is applied. The methods used in carrying out the drainage assessment are based on the method outlined in the Papua New Guinea Flood Estimation Manual (SMEC, 1990), as indicated in Table 4.

Table 4: Catchment sizes and the hydrological methods

Approximate Catchment Size	Method
Less than $4km^2$	Rational Method
More than $4km^2$ & Less than 100 km^2	Regional Flood Frequency Method

The *Rational Method* (SMEC, 1990) was used for flood estimation for small catchments. The calculation method was derived from the Papua New Guinea Flood Estimation Manual including some other additional information from other sources. This method is used when the design peak flood discharge is required for an urban catchment and when the catchment area is less than 4 km^2. The method is based on the use of the rational method, using standard design chart and formulae for the hydrological calculation.

The *Runoff Coefficients* for the *Rational Method* are based on values derived statistically on several urban catchments in Australia. There are no hydrological data for urban catchments in Papua New Guinea. For the main centres of Port Moresby, Lae, Madang and Rabaul the point *rainfall intensity* (I_{TP} mm/h) of specified return period (T, years) and durations (t, hours) may be read directly from the individual rainfall intensity – duration-frequency graphs. This graph was based on the frequency analysis of f*luvio-graphy* data recorded at each of these locations, with adjustment being made based on the frequency analysis of long-term daily rainfall data at the same location. The *Time of Concentration* for a catchment is based on the sum of times of travel across pervious and impervious surfaces and travel times, down street gutters, and storm water channels.

The *Rational Method* Formula: $Q_T = C_I I_{Tt} A/360$

Where: Q_T – is the peak discharge (m^3/s) for return period, T years

I_{Tt}-is the point rainfall intensity (mm/h) of return period, T years and storm duration, t (hours)

A- Catchment Area (ha)

C_T- is the runoff coefficient for return period T+0

The hydraulic calculations for determining travel times, down conduits and gutters are based on Manning's formula.

A. The method described below is for determining the peak discharge of a single location "point of interest" in an urban catchment:

   (1) The catchment and sub-catchments of the existing drainage including definition and measurement of the sub-catchments were determined. The sub-catchments were selected with similar previous/impervious area ratios.

   (2) The time of concentration for the point of interest for both the full and possible partial areas was determined, as follows: (a) The overland flow time from the sub-catchment most distant from the point of interest was determined using an appropriate formula. First method – for urban areas with appreciable impervious area, but with natural rather than formal drainage systems, the time of concentration was calculated using the Kirpich Method (1940) which is an equation.

B. Estimation of overland flow times:

$t_c = 0.387\ (L/S^{0.5})^{0.77}$
Where, t_c –Time of concentration (hours)
L – Mainstream length (km)
S – Mainstream slope (%) by equal area method
For smaller, plain, homogeneous, impervious/pervious areas the kinematic wave equation was used.

$t_0 = 27.63\ (L_o\ n^*)^{0.6}\ /I^{0.4}\ S_o^{\ 0.3}$
Where,
t_o – Overland flow time (min)
L_o – Vertical flow path length
n^* - Surface roughness or Retardance coefficient
I – Rainfall intensity (mm/h)
S_o –Surface slope (%)

C. Estimation of travel times in gutters and drains from Manning's Formula

$Q=AV = (AR^{2/3}S^{1/2})/\ n$
Where,
Q – Discharge (m^3/s)
A – Cross Sectional Area of Flow (m^2)
V – Velocity (m/s)
P_w – Wetted Perimeter
R – Hydraulic radius (m) equal to A/Rw
S – Longitudinal Slope (m/m)
n – Roughness Coefficient

(3) The rainfall intensity was determined from the rainfall intensity – duration- frequency graph for Lae in (mm/h) for specified return period.
(4) The fraction f, of impervious area for the sub-catchments upstream of point of interest was estimated.
(5) The value of C_{10} for each sub-catchment was determined.
(6) From Table 5, the frequency factor, F_T, for required return period T was selected.
(7) The peak discharge was computed from the equation:
$Q_T = (C_T I_{Ttc} A)/360$
A – Catchment Area (ha)
C_T – Runoff coefficient = $C_{10} – F_T$
I_{Ttc} – Point rainfall intensity of duration tc and return period T (mm/h)

Table 5: Frequency factor and return period /years for urban areas, SMEC 1990

Return Period (T) (Years)	Frequency Factor FT = CT/C10
1	0.80
2	0.85
5	0.95
10	1.00
20	1.05
50	1.15
100	1.20

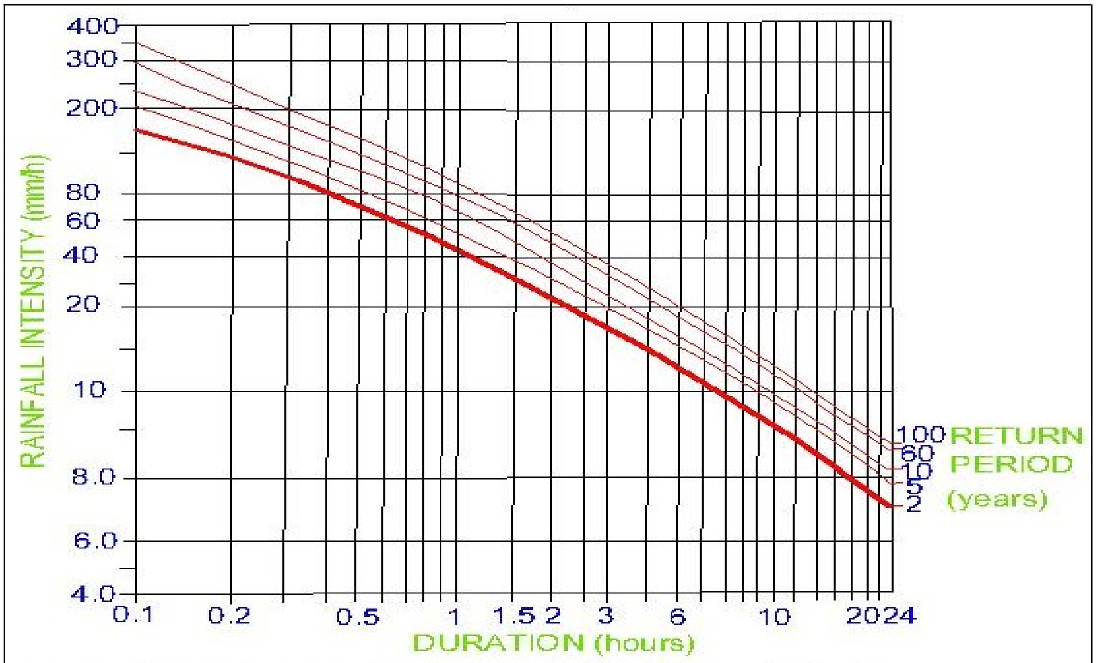

Figure 4: Rainfall Intensity Curve for Lae, Morobe, PNG (SMEC, 1990)

Table 6: Manning's Roughness Coefficient "n" for open channels (Engineering toolbox, 2004)

Surface Type	Roughness Coefficient (n)
Concrete Pipes or Box Sections	0.013
Concrete (Trowel finish)	0.012 – 0.015
Concrete (formed, without finishing)	0.013 – 0.018
Sprayed concrete (gunite)	0.016 – 0.020
Bricks	0.014 – 0.016
Pitches or Dressed Stone in Mortar	0.015 – 0.017
Random stones in Mortar or Rubble Masonry	0.020 – 0.035
Rock lining or Riprap	0.025 – 0.030
Corrugated Metal (depending on size)	0.020 – 0.033
Earth (clear)	0.018 – 0.025
Earth (with weeds or gravel)	0.025 – 0.035
Rock Cut	0.035 – 0.040
Short Grass	0.030 – 0.035
Long Grass	0.035 – 0.050

Table 7: Surface Roughness and the Retardance Coefficient (Woolhiser et al., 1990)

Surface Type	Retardance Coefficient (n)
Concrete or Asphalt	0.010 – 0.013
Bare Sand	0.010 – 0.016
Graveled Surface	0.012 – 0.030
Bare Clay-Loam Soil (eroded)	0.012 – 0.033
Sparse Vegetation	0.053 – 0.130
Short Grass, Grassland	1.00 – 2.00
Lawns	0.170 – 0.480

Table 8: Runoff Coefficient for the Rational Method

Type of cover	Flat (<2%)	Rolling (2-10%)	Hilly (>10%)
Pavement and Roofs	0.90	0.90	0.90
Earth Shoulders	0.50	0.50	0.50
Drives and Walks	0.75	0.80	0.85
Gravel Pavement	0.85	0.85	0.85
City Business Areas	0.80	0.85	0.85
Apartment Dwelling Areas	0.50	0.60	0.70
Light Residential: 1 to 3 units/acre	0.35	0.40	0.45
Normal Residential: 3 to 6 units/acre	0.50	0.55	0.60
Dense Residential: 6 to 15 unit/acre	0.70	0.75	0.80
Lawns	0.17	0.22	0.35
Grass Shoulders	0.25	0.25	0.25
Side Slope, Earth	0.60	0.60	0.60
Side Slope, Turf	0.30	0.30	0.30
Median Areas, Turf	0.25	0.30	0.30
Cultivated Land, Clay and Loam	0.50	0.55	0.60
Cultivated Land, Sand and Gravel	0.25	0.30	0.35
Industrial Areas, Light	0.50	0.70	0.80
Industrial Areas Heavy	0.60	0..80	0.90
Parks and Cemeteries	0.10	0.15	0.20
Playgrounds	0.20	0.25	0.30
Woodland and forest	0.10	0.15	0.20
Meadow and Pasture Land	0.25	0.30	0.35
Unimproved Areas	0.10	0.20	0.30

3.3.1 Catchment Computations

The computations were divided according to different section numbers (sub-catchment areas), from the highest slope height to the lowest. The entire catchment area was divided into 9 sub-catchment (section) areas for detailed hydrological analysis. Sub-catchment area (section) 9 is shown below. The other 8 sections were calculated in the same procedure. Table 8 and Figure 5 indicate the summary of all the sections calculations.

A. Sub-catchment area (A)= 6970.7564m^2/0.6971ha L= 192.9042m/0.1929km S= 1.17%
B. (Time of concentration) $t_c = 0.387\ (L/S^{0.5})^{0.77}$
$= 0.387\ (0.1929/1.17^{0.5})^{0.77}$
$= 0.1026h$
$= 6.16min$
C. Rainfall Intensity
Return period, T = 10 year, 248mm/h
D. The fraction Impervious for Catchment Area 1 – pavement and gravel
E. The runoff coefficient of the catchment Area 1 – 0.85
F. Frequency Factor from Table 1.3
T = 10 year
$F_T = 1.0$ Therefore, $C_T = C_{10.}\ F_{T = 1.0}$ x 0.85 = 0.85
G. The Q or the discharge peak (the amount of water the catchment will produce)
$Q_T = Q_{10} = (C_T I_{T,tc}\ A)/360 = (0.85) * (248) * \mathbf{0.697}/360$
$Q_T = 0.4081m^3$

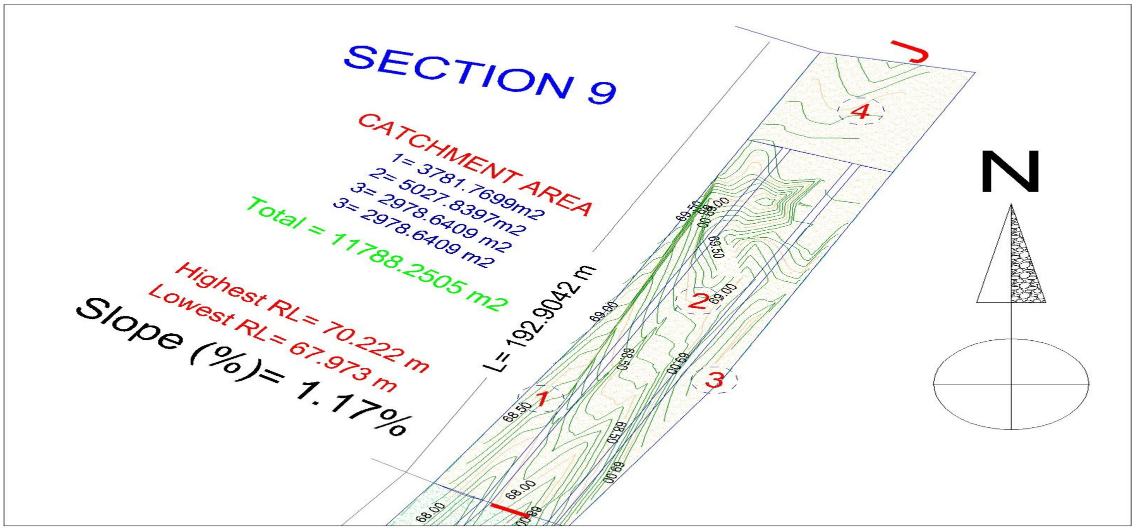

Figure 5: Section 9 indicates sub-catchment area and slope analysis and its topographical design plan outline (*NB: The same rainfall intensity return period of T 10 years was used in all the other sections as well*)

Table 9: Summary of the hydrological calculations for all the nine (9) sub-catchment areas

Sub-catchment area	**Area in Hectares**	**Rainfall Intensity**	**Discharge (m^3/s)**	**Runoff Coefficient G/pavement**	**Slope (%)**	**Time of Concentration (minute)**
9	0.69707564	248mm/h	0.4081	0.85	1.17	6.16
8	1.30665033	248mm/h	0.76509	0.85	0.93	10.287
7	0.5254	248mm/h	0.30765	0.85	0.98	4.8494
6	0.557979379	248mm/h	0.3267	0.85	0.88	6.028
5	1.105644	248mm/h	0.6474	0.85	0.83	10.99
4	0.99567252	248mm/h	0.58300	0.85	0.79	10.06
3	1.14681051	248mm/h	0.6715	0.85	0.79	11.408
2	1.14727775	248mm/h	0.6718	0.85	0.34	13.0
1	0.000532443	248mm/h	0.0311	0.85	0.88	0.348/20sec
SUM	**7.64897**	**248mm/h**	**4.39098m^3/s or 4390.98L/s**	**0.85**	**Mean 0.80**	**Mean 8.1256**

3.3.2 Standard Recommended Type of Drainage (DOW)

There are 9 standard types of drainage system that are often recommended for use by local Works Department when designing drainage. Provided below is the summary of the nine (9) types of recommended drainage system. In this drainage design report, the hydrological calculations prove that the drainage type five (5) and type seven (7) have been used. Further calculations have been provided in order to explain why they were selected.

3.3.3 Drain and culvert computation to cope with the design peak runoff rate

The two types of drainage determined on the graph shown below (Figure 6) were based on the channel depth and slope graph.

$Q_{SUM\ (9+8+7)}$ = 1. 48084m^3/s or 1480.84 L/s and Slope 0.96%.
$Q_{SUM\ (9+8+7+6+5+4+3+2+1)}$ = 4.39098m3/s or 4390.98L/s Flow Rate and slope of 0.79%.

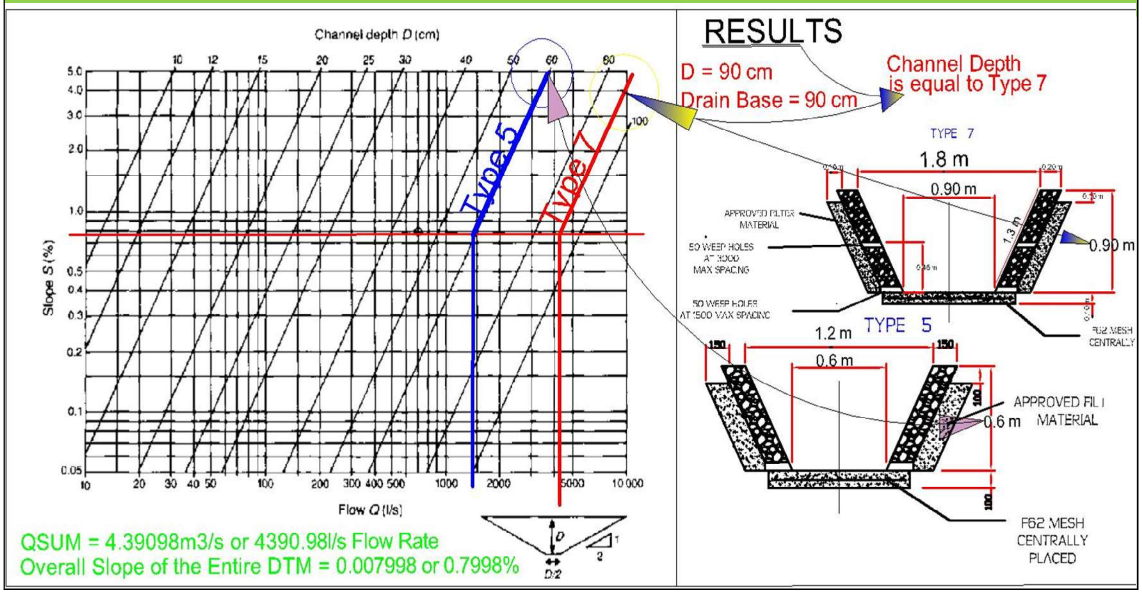

Figure 6: Channel depth and the procedure applied to determine the type and size of drainage. [*Source: WHO, 2016*]

Drain #	Drain Types from DOW (2014)	Slope (%)	Drain Cross-section Area (ha).	Hydraulic Radius	Drain Discharge (L/s)	Sections	Peak Discharge (L/s).
1	5	0.96%	0. 108 m^2	0.254	2023.647	(9-7)	1480.84
2	7	0.79%	2.34 m^2	1.2444	12079.57	(9 -1)	4390.98

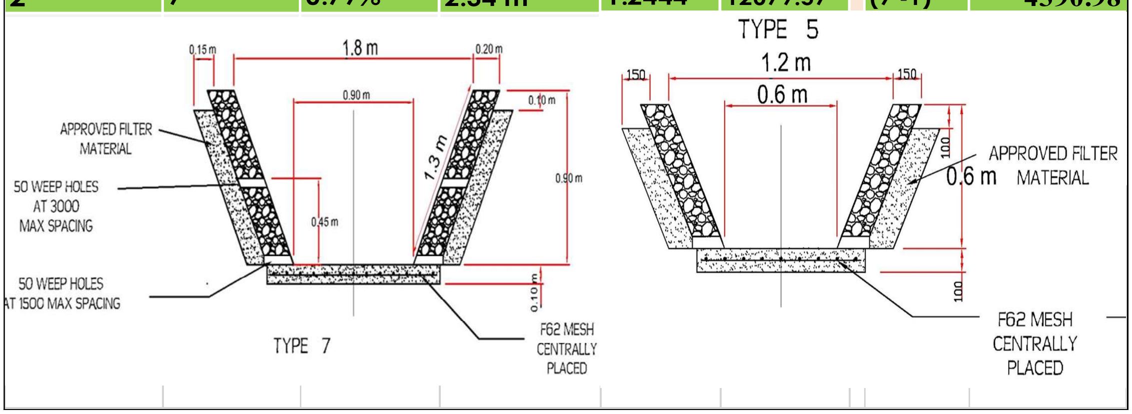

Figure 7: Drainage discharge and the catchments area of the discharge with both design of drainage type 7 and type 5

Calculating the peak runoff rate (amount of water) the Type 7 and Type 5 drain can carry in one second which is in litters. Hence, by having in mind the Manning's roughness coefficient that is; for earth drains, 0.025; brick drains, the hydraulic radius is the surface area of the cross section of the flow/the total length of the contact between water and drain; Hydraulic radius = (a x b) / (a + b + c).

$$Q_{capacity} = 1000\ (\frac{A \times R^{0.67} S^{0.5}}{N})$$

Where, Q: the capacity of discharge of the drain (in l/s)
A: the cross-section Area of the flow (ha)
R: the hydraulic radius of the drain (in m)
S: the gradient of the drain
Density of water = 1000

3.3.4 The Design of type 7 and type 5 drainage

Figure 8 shows the complete output design for both type 5 and 7 drainages. This design was done using the Topcon magnet office and AutoCAD Civil 3d.

A. Demonstrates the surface conceptual model after drainage design.
B. Shows the natural surface with the final drainage design.
C. Shows the left side drainage which includes both type 5 and 7 drainage
D. Shows the right-side drainage, both type 5 and 7
E. E & F show types 7 and 5 drainage plans.

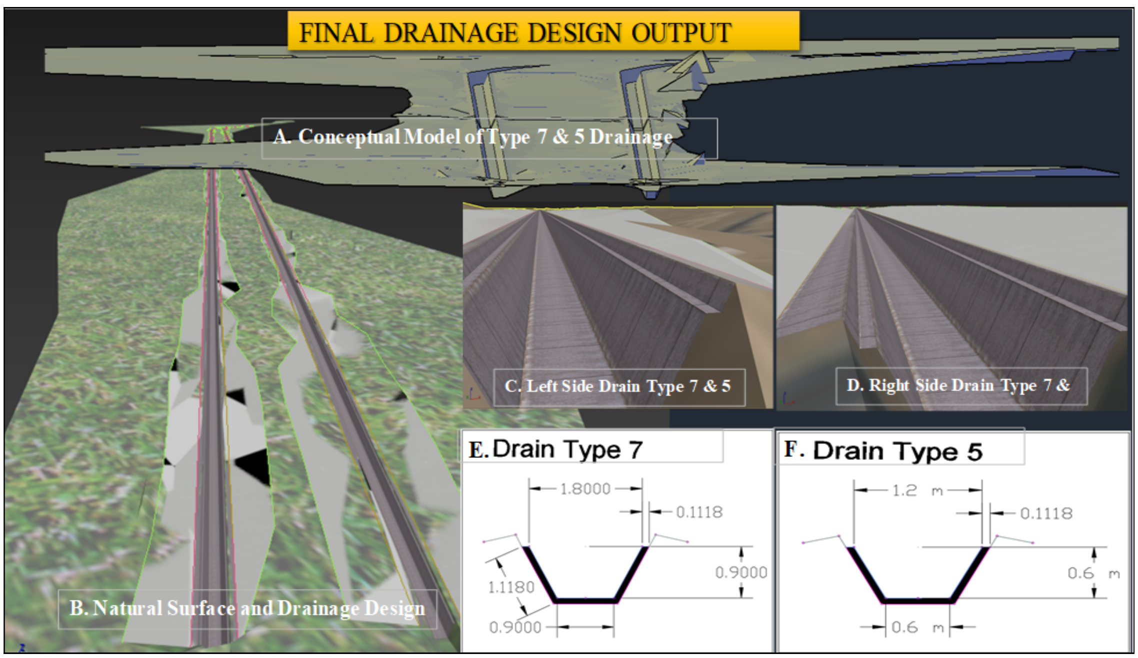

Figure 8: Showing the final designs of both types 5 & 7 drains.

3.3.5 The typical cross-section and standard profile for both drains

All the cross-sections and the standard profile was not provided because it is already in the design RL computed in Table 10, however the following shown below is shown as an illustration for both drainage design. Culverts can be installed according to road intersections, especially in residential driveways, and other access ways. However, for this project, 5 culverts were designed according to the DTM data extracted. Four (4) culverts with a diameter of 52.5 cm were constructed for the drain type 7, while 1 culvert of diameter 37.7 was installed for drain type 5.

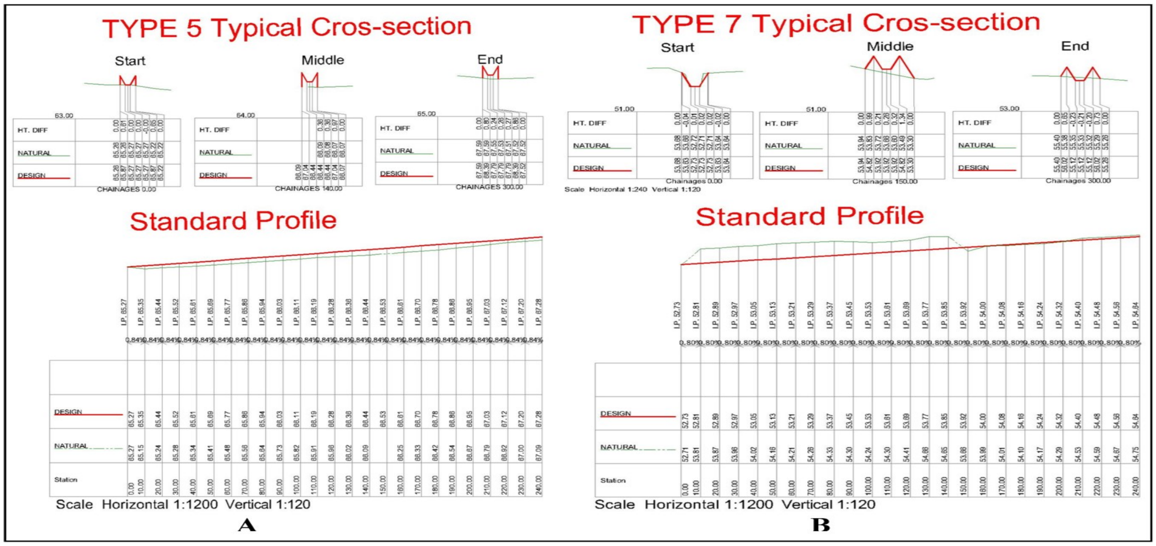

Figure 9: Part of typical cross-section. a. Standard profile for type 5 drainage, b. Standard profile for drain type 7.

3.3.6 Volume and Drainage Design Reduce Level

The final volume report and the design reduced the level of both type 7 and 5 drainages. The volume report shows the amount of cut and fill required in the cross-section profile of the catchment area. The cut and fill report are for both sides of the road, left and right.

3.3.7 Culverts

Culverts can be installed according to road intersections, especially in residential driveways, and other access ways. However, for this project, 5 culverts will be designed according to the DTM data extracted. Four culverts with diameter of 52.5 cm will be constructed for the drain type 7, while one culvert of diameter 37.7 will be installed for drain type 5. Further specific designs of the culvert are not provided in this paper due to obvious constraints.

4.0 Conclusion and Recommendations

Inadequate storm water drainage design at Independence Drive in Lae City has had a lot of far-reaching consequences on the road network, residents and other users of the road. It has contributed to runoff washing away of road pavements causing road deterioration and traffic redirection. Hence, it has led to the erosion of the road pavement further, creation of gullies on the road, creation of deep potholes and road gravel loss. If no mitigation measures are taken into consideration and quickly implemented, the storm water will continue to destroy the road, adversely impacting the traffic, road users and other major services delivery. Therefore, this research has focused on providing better drainage solutions by collecting survey data, processing it and designing the final drainage output according to best practices and method as analysed above. The drainage designed will provide and control conveyance of peak discharge from surface and rain water. All the storm water will then be emptied into the proposed drainage designed, which will effectively minimize the challenges currently facing the road including the drainage problems experienced at Independence Drive, between UNITECH Gate and Igam Junction. The recommendations made may be implemented in two ways, which include the short-term and the long-term measures:

i) The short-term period recommendations are: (a) Improvement of drainage facilities through constructions and maintenance (b) Public awareness campaign so that the responsible authority can do its job to fix the current condition of the drainage system (c) Continuous inspections to check the faults that may occur on the road, which may affect the drainage system (d) Building of gabions/healing of gullies using gabions (e) Constructing soil and water conservation structures including water pans (f) Continuous monitoring of rainfall in the area through establishment of rainfall observation stations, and (g) Improvement of the drainage systems along the highways.

ii) The long-term period recommendations are: (a) Design and implementation of a new drainage system (b) Complete investigations and reconstruction of the whole system (c) Proper and frequent maintenance of the drainage facilities at Independence Drive and (d) Long-term funding by all arms of government of all roads and drainage facilities in Lae City and other towns and cities in PNG is a necessity for city sustainability and liveability.

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