KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

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Review of the Hydraulic Capacity of Some Existing Culverts on Selected Roads in Kumasi Metropolis (Ghana)

by

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Of

MASTER OF SCIENCE

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DECLARATION

I hereby declare that this submission is my own work towards the MSc Roads and Transportation engineering and that to the best of my knowledge, it contains no material previously published by another person , nor material which has been accepted for the award of any other degree of the university, except where due acknowledgment has been made in the text.

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DEDICATION

I would like to dedicate all this work to my children, Nana Kwadwo Arhin-Acquah, nana Yaw Arhin-Acquah and nana Akosua Arhin-Acquah, I wish them God blessing and guidance in life.

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ABSTRACT

Culverts are one of the most important and common crossing structures that allow roadways to traverse rivers and streams. Due to their importance, their design and construction are to be done in such a way as to avoid overflow of water. Inadequate sizing of culverts leads to ponding of water behind the structure and eventually flooding of the culvert and the roadway. Inadequate sizing of culverts in the country has come about because engineers have been relying on their experience to select the sizes without going through vigorous computational design. This research work looks at 16 culverts in the Kumasi metropolis, which have been experiencing frequent flooding. The 16 culverts were selected after series of interviews, consultation and field visits with the various road agencies of the Kumasi metropolis. Thereafter, landsat images for various years were used to obtain catchment areas contributing flow to the various culverts. The satellite images also enabled us to determine areas of vegetation and settlement over the years. Areas of vegetation represent areas of high permeability while areas of settlement denote areas of high imperviousness.

With these areas of settlement and vegetation, runoff coefficients of the contributing catchment were calculated over the years. Times of concentrations were then computed by the Brandy Williams equation. The intensities of rainfall were then defined at 25 years return period with the aid of IDF curves of Kumasi and subsequently the discharge at the various culvert sites computed using the modified rational formula. The Civil 3D software was then used to size the various drains at different years. The results show that out of the 16 culverts investigated only four (4) were found to have adequate sizes and that the frequent floods that were experienced here were due to other factors such as silting and blockages while twelve (12) were found to be inadequate. The results show that in general some form of computation, especially determination of hydrological flow at the culvert site must be done to enable quick use of culvert nomograms for selecting the appropriate culvert size.

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CHAPTER 1: INTRODUCTION

1.1 Background

Culverts are important component of the transportation network. They provide effective and inexpensive roadway passage over streams, rivers and intermittent drainage paths. Additionally, they are used for human, and vehicle underpasses. Culverts can be classified into three main functional types:

1. Stream Crossing
2. Runoff Management
3. underpasses for stock, human, and vehicle

The stream crossing culvert type is a culvert, which is constructed across the roadway to allow water to pass from one side of road embankment to the other. Runoff management culvert is one which is strategically placed to manage and route roadway runoff along, under, and away from the roadway. The last group is underpass culverts for stock, human, and vehicle for easy and safe passage

The proper understanding of flow through culverts is necessary for the assessment of its performance to improve flooding situations and to guarantee safe roads usage.

As our nation's infrastructure continues to expand and develop, accurate and advanced monitoring of transportation systems will become increasingly important.

Culverts are constructed from a variety of materials and are available in many different shapes and configurations. The selection of materials for a culvert depends on structural strength, hydraulic roughness, durability and constructability. Concrete, corrugated metal are the most common materials used for culvert construction. Cross-sectional shapes of the culverts can be circular, rectangular, elliptical, and pipe-arch.

The most commonly used configurations include projecting culvert barrels, cast in place headwalls and wing walls, precast end sections, culvert ends mitred to conform to the slope of the embankment and single- multi box culverts.

The selection of a particular culvert type depends upon many factors such as roadway profiles, channel characteristics, flood damage evaluations, construction and maintenance costs, and estimates of service life.

It is a usual practice in almost all the road agencies in Ghana (Ghana Highway Authority, Department of Urban Roads and Department of Feeder Roads), to size drainage structures, especially culverts, by selecting the size based on engineer's experience rather than going through rigorous design processes. This is done especially when the selected culvert size is less than 1.8m mostly for pipe culverts. In some cases, the culvert size could be above the 1.8m diameter pipe. Among the reasons why this practice is adapted are;

i. Historical observation of the performance of such structures
ii. Area restriction especially within built up areas.

The situation can lead to the danger of wrong sizing of culverts impacting negatively on either the hydraulic capacity of the structure or value for money.

In the case of the Kumasi Metropolis, most of the culverts, were constructed from 19992004, some years ago when Kumasi was less developed and the catchment areas had significant proportion of farm lands, resulting in low surface runoff. However, with rapid urbanization of the Kumasi metropolis and the surrounding area as a whole, the land use has changed dramatically with large proportion of the land area paved. This has increased the surface runoff during rainfall events, since infiltration of rain into the soil has reduced as a result of the relatively impervious paving of large surfaces. Since the existing culverts have not been design to accommodate such high surface run-off, they are often overwhelmed and over topped (flooded)

In recent times, some suburbs in Kumasi metropolis have been experiencing flooding during low intense and low duration rainfall, which previously would not have caused flooding.

The possible causes may include;

i. Rapid increase in urbanization which tends to increase imperviousness of the land use resulting in high runoff coefficient
ii. Inadequate sizes of drainage structure such as drains and culverts. iii. Silted drains, culverts and water channels due to poor maintenance.
iv. Blocking of water course by negative human activities. (ie throwing debris and building on water courses)

The problem of flooding due to poor drainage system in the Kumasi Metropolis has led to loss of life, property and has negatively impacted on the economy. For examples, Daily graphic of 12th March 2008 back page, 3 die after rainstorm in Kumasi and The Chronicle of April 19th 2013, Rains cause 4 Death in Kumasi.). As part of the effort to improve the drainage systems in Kumasi metropolis in order to minimize the problem of flooding of the roads and its environs, this research seeks to review the hydraulic capacity of some of the existing culverts in the metropolis and determine the adequacy or otherwise of their sizes, by carrying out hydrologic and hydraulic analysis and design of the culverts.

1.2 Problem statement

1. It has been observed that flooding occurs frequently in many parts of the country, including some suburbs in Kumasi metropolis during normal rainfall. This used not to be so for those places and there requires investigations into the causes.
2. The selection of culvert size through engineer's experience instead of rigorous analysis and design sizing which also needs to be examined for adequacy and accuracy in performance

1.3 Objective of study

The objective of this was to review the hydraulic capacity of some selected culverts in the Kumasi Metropolis with respect to identified problems of flooding.

The specific objectives were

i. To undertake condition survey of culverts and identify existing culverts on selected roads in Kumasi which undergo flooding during rainfall.
ii. To undertake hydrological computation at selected sites to enable accurate sizing of the culverts
iii. To compare the designed sizes with the existing culvert sizes in order to establish the adequacy of their hydraulic capacity

1.4 Justification of study

The flooding of the Kumasi metropolis in the past decade has been causing destructions of properties and death of its citizens, which call for remedial action.

1.5 Scope of work

The study will be limited to some 16 number selected culverts, which undergo flooding during rainfall in the Kumasi metropolis. The hydrologic- and hydraulic design of the existing culvert will be carried out and their sizes obtained will be compared to the existing culvert sizes.

1.6 Organisation of the thesis work

This research work has been structured with the following contents,

Chapter 1. Introduction

Chapter 2. Literature review

Chapter 3. Methodology

Chapter 4. Results and Discussion

Chapter 5. Conclusion and Recommendation.

The rest of the material which was used for the research is located in appendix 1-4.

CHAPTER 2: LITERATURE REVIEW

2.1 General concept of drainage and urban drainage in particular

Drainage is the process of interception, removal and transporting water or waste water from a vicinity or an area. This involves surface drainage and sub-surface drainage and the Land-use also influences the interception rates (Camorani et al., 2005)

As land is converted from fields or woodlands to residential areas and industrial area turning the area to urban with road, markets and lot of human activities which changes the natural land environment and changes these areas into urbanized areas (Hapuarachchi, Wang, & Pagano, 2011) , and these can enable one to say Urbanization is a natural part of development (Henderson, 2002)

2.1.1 Urban Drainage

Drainage systems are needed in developed urban areas because of the interaction between human activity and the natural water cycle and urbanized land usually leads to a decrease in surface roughness thereby greatly shortens the time of runoff (Shi et al., 2007).The direct or indirect impacts on the hydrological regime brought by land use changes has contributed to some water problems, such as flooding, with different extent hydrological process and the variability and availability of water resources would change a lot due to land use change(He, Lin, & Chen, 2013).

Urbanization of catchments areas introduces many different man-made materials that are less common in rural catchments and which can cause blockage of structure. These includes building materials, mattresses, garbage bins, large industrial containers and vehicles. Garbage bins can easily be washed down a street and into a stream or drainage structure, a situation made worse if large rainfall event occurs on the same day as rubbish collection within the catchment, when bins are placed in streets for collection.((Rain, Engstrom, & Ludlow, 2011)

2.1.2 Effect of Urbanization on drainage

During urbanization, the urban areas are enlarged, which increases the contributing areas to generate runoff and in addition, green lands are replaced by impervious roofs, roads and parking lots, which reduce the capacity of surface to absorb water and decreases the concentration time of surface runoff. (Eigege, 2014) and reduces the infiltration rate and soil water redistribution process which influence soils saturated hydraulic conductivity. (Camorani et al., 2005).

Urbanization could result in a two- to six-fold increase in runoff compared to what would occur on natural terrain (Hapuarachchi et al., 2011) .This rapid increase in runoff flows into the existing drainage network making it undersized, unconnected or improperly channelled drains. In addition, lack of developmental control, limited garbage collection and disposal, block channels and sewers slowing the rate of drainage flows through the city when it rains.

2.1.3 Urban Land Development in Kumasi

In Ghana, urbanization has resulted in the rapid growth of its major cities especially Kumasi. The urbanization pattern is similar to the rest of world. Kumasi is located in the transitional forest zone of Ghana and a distance of about 270km north of Accra the national capital. Kumasi, the capital of the Ashanti Region, according to Census of 2010 has population 2 035 064 with remarkable consistent rate of over 5% per annum between 1984 and 2010, making it the fastest growing major city in Ghana. (Oduro, Ocloo, & Peprah, 2014))

2.2 Landsat Satellite Images showing the land used in Kumasi

Landsat satellite images showing land cover for Kumasi in 2004 (Knust, Geomatic Department

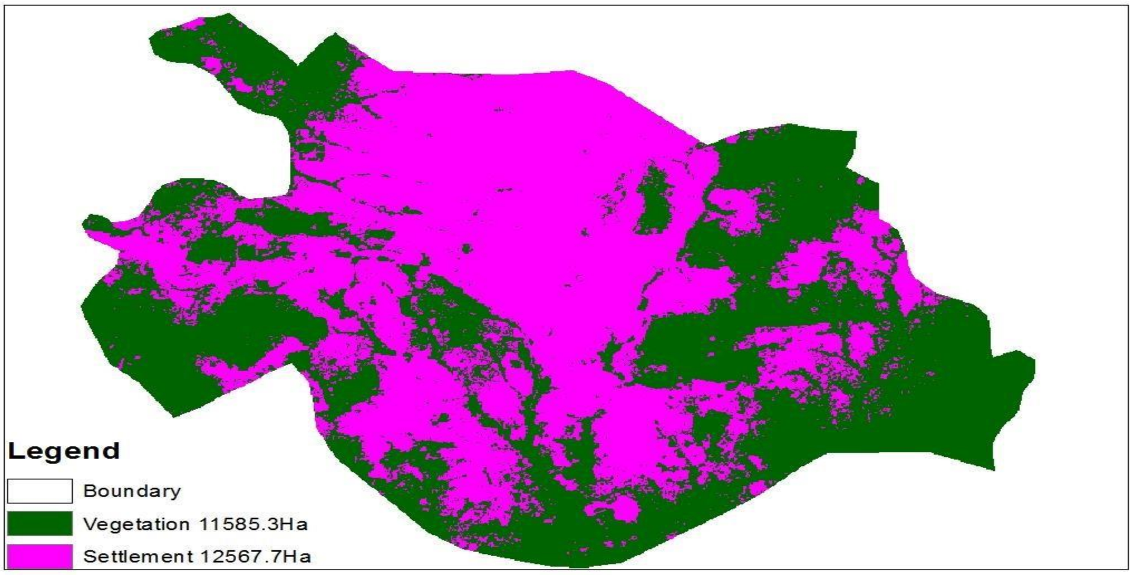

Figure 2.1: Urbanization of Kumasi metro as of in 2004

The figure above shows the general view of Kumasi with land area of 24153 Ha, the ratio of vegetation cover to settlement in the year 2004 was 11585.3Ha: 12567.7Ha or 48%:

52%.

Table 2.1: land use data in kumasi metroplis

Year	Vegetation area Ha	Vegetation area %	Settlement area Ha	Settlement area %
2004	11585.3	48	12567.7	52
2007	8285	34	15867.3	66
2010	4648.32	19.2	19504	80.8
2015	3686.13	15.3	20466.8	84.7

2.3 Road Drainage System

Highway drainage is the process of collection and removal of water from the top, under and within the structure of the pavement. Highway drainage is one of the main factors, which have an effect on road design and construction. (Tawfiq, 2012).

One of the most important aspects of the design of a road is the provision made for protecting the road from surface water and groundwater. Water on the pavement slows traffic and contributes to accidents from hydroplaning and loss of visibility from splash and spray. (Chang, 1984). If water is allowed to enter the structure of the road, the strength and deformation resistance of the pavement and sub-grade will be weakened. Water can enter the road as a result of rain penetrating the surface, or as a result of the infiltration of groundwater. When roads fail, it is often due to inadequate drainage. Water can also have a harmful effect on shoulders, slopes, ditches, and other features of the road.

The drainage system has four main functions:

i. To convey storm water from the surface of the carriageway to outfalls;
ii. To control the level of the water-table in the subgrade beneath the carriageway;
iii. To intercept ground and surface water flowing towards the road;
iv. To convey water across the alignment of the road in a controlled fashion

The first three functions are performed by longitudinal drainage, in particular side drains, while the fourth function requires cross-drainage structures, such as culverts, fords, drifts, and bridges. (Camorani et al., 2005).

The system is made up of the roadside drains structures and the cross drainage structures forming the drainage network in roads.

2.3.2 Cross Drainage

Cross Drainage structures comprising of culverts, causeways and bridges are essential components of any highway. Cross-drainage structures are common features in the road network and they play an important role in keeping the road network free from flooding, overtopping or breaching during floods. Any wrong siting, sizing or design of these Cross Drainage structures could disrupt the transportation system of the area concerned. With limited time, this thesis will be focus on cross drainage and to be more specific culverts. (Karnataka state highway manual. -CROSS DRAINAGE)

2.4 Culverts

A culvert is a hydraulic structure constructed to increase the water carrying capacity away from highway and buildings in it surrounding environment (Tawfiq, 2012). Culverts come in many shapes, some of the more common shapes include, circular, rectangular, elliptical and arch. The most common materials used are reinforced concrete, steel and aluminium (IDOT, 2011). The materials and the shapes depend upon the judgement of the drainage engineer but the sizes will depend on the hydrology of the area if only proper effectiveness is required Performance of a culvert is directly proportional to its remaining design service life which is defined as the period of service without a need for major repairs (AASHTO, 1999). Major factors influencing the performance or service life of a culvert are:

1. Durability factors (Corrosion, Abrasion, and Erosion)
2. Loss of Structural Integrity (Joint Separation, Misalignment, Seam Defects, Seam cracking, Longitudinal cracks, Transverse cracks)
3. Environmental Factors (Scaling, Delamination, Spalling, Efflorescence, Honeycombs, Pop outs)
4. Hydraulic (Insufficient capacity and Flooding Operational Factors, Roots, Debris blockage, Maintenance procedures, (Salem & Mohammad, 2008)

2.5 Hydraulic Failure of a Culvert

When the performance of a culvert is reduced due to hydraulic factors, safety of the commuters, financial condition of the agency, and environment may be affected adversely. These impacts can be due to the flooding of adjacent properties or downstream areas from unexpected headwater depths. Hydraulic factors liable to cause failures are:

1. Insufficient capacity,

2. Operational,

3. Piping,

4. Debris blockage,

5. Maintenance procedures

2.5.1 Insufficient Capacity

Insufficient capacity either at inlet or at outlet may result from poor designs, debris blockage (GTV report 3rd June 2015)

Plate 2.1. Culvert with insufficient capacity

2.5.2 Operational

The failure mechanism due to operational defects originates from an increase in demand (runoff) and a decrease in capacity (size). Other Factors affecting operations are (Gradient, Depth,) (Salem & Mohammad, 2008).

Plate 2.2. Failed culvert

2.5.3 Piping

It is the process where water seep beneath the culvert instead through the barrel. This can be attributed to poor construction of the culvert.

Plate 2.3. Culvert with piping failure

2.5.4 Maintenance

It is the process of preserving a condition or situation or the state of being preserved. Maintenance can be categories into routine and periodic.

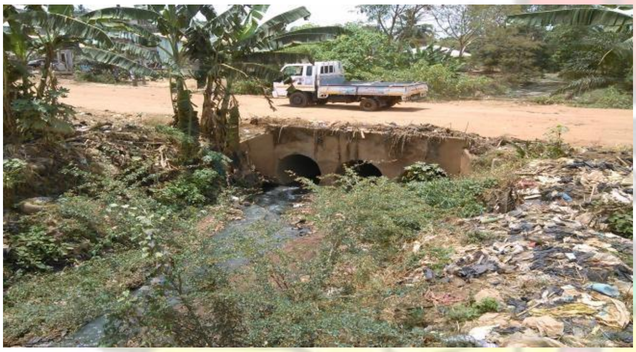

Plate 2.4 Unmaintained culvert

2.6 Ministry of Roads and Highways Policy on Culverts

The drainage design manual, developed by the Ministry of Roads and Highways and adopted by the various Agencies and Departments such as Ghana Highway Authority, Department of Urban Roads, Department of Feeder Roads and Hydrological Services Department under the Ministry of Water Resources, Works and Housing, has the following summarises for design:

I. Rainfall Frequency of Occurrence

The design rainfall frequency of occurrence for the hydrologic analysis table below:

Type of Structure / Drainage system	Frequency of Occurrence (years)
Side Culvert	10
Closed System Drainage	10
Cross culvert	25
Minor/ medium span bridges	50

Major/Long span bridges	100

II. Sections of culverts

Circular culverts / Closed System Drains

Minimum diameter for all culverts : 900mm

Maximum diameter for cross culvert : 1,800mm

Rectangular Culverts

Minimum internal height : 1,000mm

Cover over Culvert

Minimum cover for all pipes shall be 0.3m. For pipes under railways, the minimum cover shall be 1.2meters.

III. Manning's roughness

Concrete lined channel.	0.013 – 0.015
Sand Crete block	0.015 – 0.020
Masonry	0.017 – 0.030
Earth (new)	0.018 – 0.030
Earth (existing)	0.022 – 0.060

IV. Flow Velocities in Road size drains

Maximum Velocities:

Concrete 2.5 – 6.0 m/s

Minimum Velocities:

Minimum flow velocities in all Concrete 0.80 m/s

Almost all the study areas fall under the department of urban roads with few under feeder roads. The study roads fall under the classification of Arterial roads, inter district, collector and access roads.

The ministry has its own maintenance policies, for routine works it is done at least twice a year whereas the periodic is done where and when the need arrives.

2.7 Analysis and Design of Hydraulic Structures

The analysis and design of hydraulic structures can be divided into two phases

1). Hydrologic design

2) Hydraulic design

2.7.1 Hydrology

It is the scientific study of the movement, distribution and quality of water on the earth and the planets, including the hydrologic cycle, (IDOT, 2011).The hydrologic cycle describes the occurrence, distribution, and continuous movement of water, as well as the interrelationship between these factors which influence the discharge of surface runoff into streams which are Interception, infiltration and evapotranspiration ((Tawfiq, 2012)). The design of each highway drainage facility requires the determination of dischargefrequency relationships. Some facilities require the determination of a momentary peak flow rate while others require a runoff hydrograph providing an estimate of runoff volume. The momentary peak flow rates are most often used in the design of bridges, culverts, roadside ditches, (IDOT, 2011).

The most commonly used method for estimating runoff for highway pavement drainage is the Rational Method. In recent years, however, digital computers have made it possible to use more sophisticated methods. In general, the methods are much too complex, take more computer time than is warranted for the design of pavement drainage and the improvement in accuracy is problematic(Chang, 1984). Other runoff estimating methods which do not require the use of computers are also available, including the British Road Research Laboratory method (TRRL), the unit hydrograph method, and the Soil Conservation Service methods. The unit hydrograph method requires rainfall and runoff data to develop the unit graph and has little applicability to pavement inlet design.

However, in the drainage manual developed by the ministry of Roads and Highways, two methods have been adopted for estimating peak discharges for hydraulic structures at ungauge locations. These are:

1. Modified Rational Method
2. NRCS WinTr 20 Model

2.7.2 Modified Rational Method

The modified rational formula is an empirical formulae used for the estimation of peak discharges for catchment areas up to 25km².Unlike the traditional rational formula or method that can be used for catchment areas up to 0.8km^2

This formula is given as:

Q = 0.278 FCIA **(2.1)**

Where,

Q = Design discharge (m^3/s)

C = Run-off coefficient (dimensionless)

I = Rainfall intensity (mm/hr)

F = Areal reduction factor (dimensionless) A

= Catchment area (km^2)

Some of the assumptions implicit in the Rational Method and Modified Rational Method are

i. The rate of runoff resulting from any rainfall intensity is greatest when the rainfall intensity lasts as long as or longer than the time of concentration
ii. The probability of exceedance of the peak runoff rate as computed is the same as the probability of the average rainfall intensity used in the method.
iii. A straight-line relationship exists between the maximum rate of runoff and a rainfall intensity of duration equal to or longer than the time of concentration, e.g., a 2-inch/hour (5 mm/hr) rainfall will result in a peak discharge exactly twice as large as a 1-inch/hour (2.5 mm/hr) average intensity rainfall.
iv. The coefficient of runoff is the same for storms of all recurrence probabilities. .
v. The coefficient of runoff is the same for all storms on a given watershed.

(Chang, 1984)

Area Reduction factor (F)

The rainfall analysis is often based on localized (point) rainfall that is not reflective of spatial distribution. The areal reduction factor converts, point rainfall distribution to spatial distribution for each catchment.

The areal reduction equation developed by Rodier in 1975 for West Africa is often used in Ghana due to lack of this factor / equation for Ghana. This equation is given as: F = 1-0.001(log A) *(9*log N -0.042*P +152) **(2.2)**

Where:

F= areal reduction factor

N= return period of rainfall (years)

P= average annual rainfall (mm)

A= catchment area (km^2)

Time of Concentration

For peak flow rates, the design rainfall intensity is that which has duration approximately equal to the time of concentration for the catchment under consideration. Bransby William's formula is often used in Ghana according to the drainage manual for the determination of the time of concentration. This formula is given as:

$$T_c = 0.975L/ (A^{0.1}*S^{0.2}) \qquad (2.3)$$

Where:

L	=	Mainstream length (km)
A	=	Catchment area (km^2)
S	=	Mainstream slope (m/km)
T_c	=	Time of concentration (hrs),

These are from (Department of Urban Roads manual, 2006)

2.7.2 Coefficient of Runoff

The rainfall run-off coefficients are estimated based on topography, soil type in the catchment, the vegetation cover as well as the land use pattern projecting into the future. The physical interpretation of the runoff coefficient for a watershed is the fraction of rainfall on that watershed that becomes storm water runoff. Thus the runoff coefficient must have a value between zero and one

The "C" value can be calculated from any type of land use and known percent impervious surface from the following equation:

$C = 0.3 + 0.6 * I$, ---------------- equation 2.7.2 where

I=Percent imperious divided by 100. (County, Program, & Manual, 2013.)

2.7.3 Land Use

The usage of the land brings about its degree of saturation. Surfaces that are relatively impervious like streets and parking lots have runoff coefficients approaching one. Surfaces with vegetation to intercept surface runoff and those that allow infiltration of rainfall have lower runoff coefficients

2.7.4 Topography Or Slope:

All other things being equal, a watershed with a greater slope will have more storm water runoff and thus a higher runoff coefficient than a watershed with a lower slop.

2.7.5 Soil Type

Soils that have a high clay content do not allow very much infiltration and thus have relatively high runoff coefficients, while soils with high sand content have higher infiltration rates and low runoff coefficients (Bright Hub Inc , 2012)

Where drainage areas are composed of parts having different runoff characteristics, a weighted run-off coefficient for the total drainage area is computed by dividing the summation of the products of the area of the parts and their coefficients by the total area.

$$Cw = (C_1A_1 + C_2A_2 + \ldots\ldots\ldots + C_NA_N)/A\ total \qquad (2.5)$$

2.7.6 NRCS WinTR20 Model

For catchment areas larger than $25km^2$, a hydrograph method is more appropriate. This is because rational method assumes rainfall intensity over entire catchment to be uniform, which is incorrect especially for larger areas. NRCS WinTR-20 method is one of the hydrograph methods widely used and adopted by Ghana. The method requires the following basic data:

- Catchment area (km^2)
- Runoff curve number (RCN) (dimensionless)
- Time of concentration (hr)
- 24hr-Rainfall depth (mm)

Run-off curve number (RCN)

The run-off curve number (RCN) is a function of the vegetation characteristics of the contributing area, land use and hydrologic soil type. A high RCN represents an area with little infiltration, while low RCN is an indication of a pervious surface. The hydrologic soil type of various areas has been compiled in the Highway drainage manual of Ministry of Roads and Transport (Ghana).

2.8 Hydraulic

Hydraulic Design Considerations

1. Design Flood Discharge

I. Watershed characteristics

II. Design flood frequency or return interval

III. All designs should be evaluated for flood discharges greater than the design flood

2. Headwater Elevation -check upstream water surface elevation

3. Tailwater -check that outlet will not be submerged

4. Outlet Velocity -usually controlled by barrel slope and roughness

2.8.1 Types of Flow Control

A. Inlet Control -flow capacity is controlled at the entrance by the depth of headwater and entrance geometry, including the barrel shape, cross sectional area and the inlet edge.

B. Outlet Control hydraulic performance controlled by all factors included with Inlet Control, and additionally include culvert length, roughness and tailwater depth.

2.8.1 Culvert Hydraulics-Inlet Control Two possible conditions:

UNSUBMERGED -steep culvert invert and headwater not sufficient to submerge inlet. Culvert inlet acts effectively like a weir.

Q = Cw B (HW) 2/3 (2.6)

B = width of weir crest

A weir coefficient Cw = 3.0 may be assumed for initial calculations.

<u>SUBMERGED</u> -headwater submerges top of culvert inlet but the barrel does not necessarily flow full. Culvert inlet acts like an orifice or sluice gate.

$$CdA\sqrt{2g(HW-\frac{b}{2})} \qquad (2.7)$$

b = culvert height

HW –b/2 = head on culvert measured from barrel centerline Orifice discharge coefficient, C_d , varies with head on the culvert, culvert type, and entrance geometry.

2.8.2 Culvert hydraulics -outlet control

Outlet control will govern if the headwater is deep enough, the culvert slope is sufficiently flat, and the culvert is sufficiently long.

Three possible flow conditions:

1. Both inlet and outlet submerged, with culvert flowing full.

2. Inlet is submerged but the tail water does not submerge the outlet. In this case the barrel is full over only part of its length.

3. Neither the headwater nor tail water depths are sufficient for submergence. Culvert capacity determined from energy equation: HW+SoL=TW +He +Hf +Hv (2.8)

Where

HW -TW = headwater -tail water

= total energy head loss (feet)

He = entrance head loss (feet)

Hf = friction losses (feet)

Hv= velocity head (feet)

Entrance Head Loss, He

$$He = Ke\left(\frac{V^2}{2g}\right) \quad (2.9)$$

Friction Losses, Hf

Manning's Equation

$$Hf = \left(\frac{1.49}{n}\right) Rh^{2/3} S^{1/2} \quad \text{or } Hf = 29\frac{n^2L}{Rh^{4/3}}\left(\frac{V^2}{2g}\right) \quad (2.10)$$

$$\text{Design equation: } HW = TW + \left[Ke + \frac{29n^2L}{Rh^{4/3}} + 1\right]\left(\frac{V^2}{2g}\right) - SoL \quad (2.11)$$

Where So= slope of the culvert

L= length of the culvert

(Culverts and Bridges design)

CHAPTER 3: METHODOLOGY

3.1 Introduction

The main purpose of this study is to know the effect of urbanization on hydrology of catchment area and hydraulic capacity of culverts.

The methodology is based on the following specific objectives.

1. To undertake condition survey of culverts and identify existing culverts on selected roads in Kumasi Metropolis which undergo flooding during normal rainfall.

A preliminary survey or desk studies was done in Kumasi metropolis on the roads network. The study shows that, all the roads structures in the metropolis are owned by the Government of the Republic of Ghana and it is under the Ministry of Roads and Highways.

Within the ministry, the roads in Kumasi metropolis are administered by the Department of Urban Roads DUR and Department of Feeder Roads DFR.

A request was made to both agencies DUR and DFR to give the necessary information on their culverts which floods frequently whenever it rains within their administrative area.

In all Department of Urban Roads supplied a list of 14culverts whiles Department of Feeder Roads gave 2 culverts.

Upon receipts of response to request, a field survey was conducted on the information by the administrative managers of various agencies. During the field survey, inspection was done on the existing culvert structures, stream channels and the surroundings. Coordinates of the culverts were pick with Global position system (GPS). All the 16 culverts were selected for the study

Interviews were conducted with the residents living around the culvert area to know the severity of the flooding, (eg. How wide does the flood cover, the level of the flood and how long does it take for the water to drain off.). This was the way the 15 culverts were selected.

2. To assess the adequacy of the culvert by undertaking hydrological computation of flow at the various culverts

After identifying the culverts and its coordinate, a contact was made with the Geomatics Engineering Department where assistance were sought in using satellite images to locate the catchment area of various streams from the topographical map of Ghana. The following data were also extracted from the topographical map.

1. L = overland flow length of the runoff (m)
2. Catchment heights, the highest and lowest levels.
3. The area of settlement against the area of vegetation for various years 2004, 2007, 2010 and 2015.
4. A graph of years (y-axis) plotted against percentage of impervious-settlement (xaxis) and a line of best fit drawn.
5. The line of best fit gives a linear equation and the regression co-efficient.
6. The line of best fits enables the runoff co-efficient C to be calculated using the equation C=0.3+0.6(P).

   Where

   C- runoff co-efficient

   P- % of impervious

   The discharges at various years were then calculated using the Rational Method for each co-efficient obtain (C). The Rational Method formula is expressed as follows:

$$Q = 0.278\ FCIA \quad \mathbf{(2.1)}$$

Where,

Q = Design discharge (m^3/s)

C = Run-off coefficient (dimensionless)

I = Rainfall intensity (mm/hr)

F = Areal reduction factor (dimensionless) A

= Catchment area (km^2)

3. To come out with recommendation for various culvert sizes**.**

With the help of civil 3D software and the discharges of various years, culvert size were determined using different values of co-efficient (C) from different years for a particular culvert. These will show how changes of discharge with respect to size of culvert will behave for the different years under consideration

CHAPTER 4 : RESULTS AND DISCUSSION

4.1 Data Analysis

Sixteen culvert of different shapes and size were investigated during the study in the Kumasi metropolis, which experience flooding when it rains. Out of the sixteen culverts fourteen are under the administration of Department of Urban Roads and two under the administration of Department of Feeder Roads. All the culverts were made of concrete materials. The culverts had headwalls, wing walls and cutoff walls (toe walls).

Generally, access to design flow data to educate us on the discharge used for the design of the various culvert structures could not be obtained from the various roads administrators. The approach taken to define the flows at the various culvert sites for this research work is underlined below.

4.1.1 Land Site Images

Land site images obtained from (Geomatic Engineering Department) were used to find the land cover of settlement and vegetation. The percentage of settlement was found for various years and was taken as the percentage of imperviousness while the area covered by vegetation was taken as percentage pervious areas.

EXAMPLE 1.

ROAD NAME; Napo Drive. Ch 0+050

The data from catchment area of Kwadaso Stream has been tabular in table 4.1 in appendix 4 showing the various land use (vegetation and settlement) computed from satellite images to indicate percentage of settlement and percentage of vegetation. A plot of years on the Y-axis against percent imperviousness on X-axis gives the changes of areas of imperviousness over the years as shown in Fig. 4.1. on the next page.

Figure 4.1. show the changes of percentage of imperviousness with years and could help us interpolate the unknown information within the equation. The results of the plot show that the Kwadaso Stream catchment has experienced rapid urbanization within the past 12 years. In 2004 the percentage imperviousness was around 75.10%, however by 2015 this valve had increase to about 99.71%.

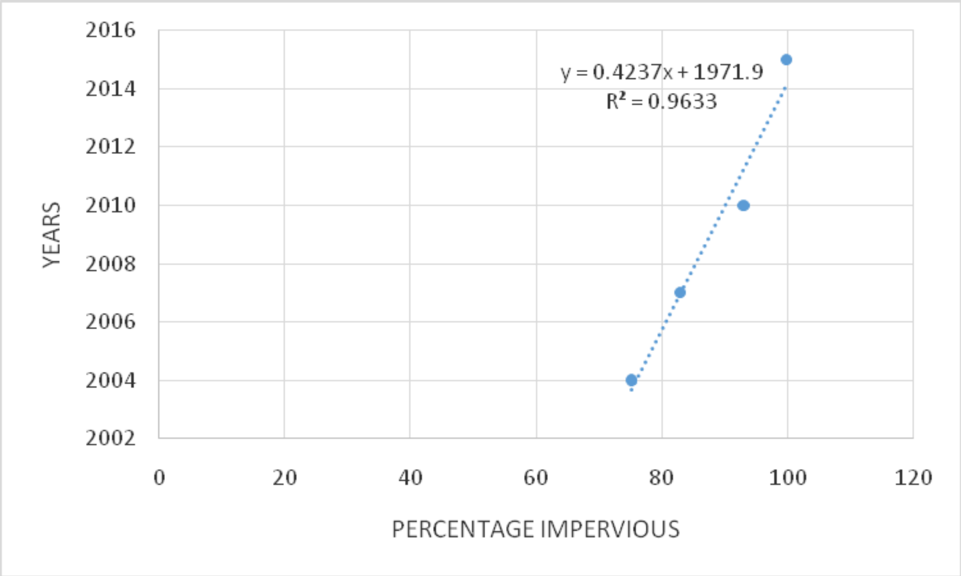

Fig 4.1. A Plot of Years Against % Impervious

Where 0.0 % ≤ X ≥ 100%

4.2 Determination of Runoff Coefficient

Years of construction of culverts in the study area were obtained from the various roads administrators and were used in conjunction with the equation 2.7.2 to find the changes of imperviousness in the area with years. Runoff coefficient were computed using equation (2.4).

C = 0.3 + 0.6 * *IP …………………. eq. 2.7.2,*

where I = Percent impervious divided by 100 for each stage of development. The fig 4.2. below shows changes of runoff coefficient with years for Kwadaso Stream catchment

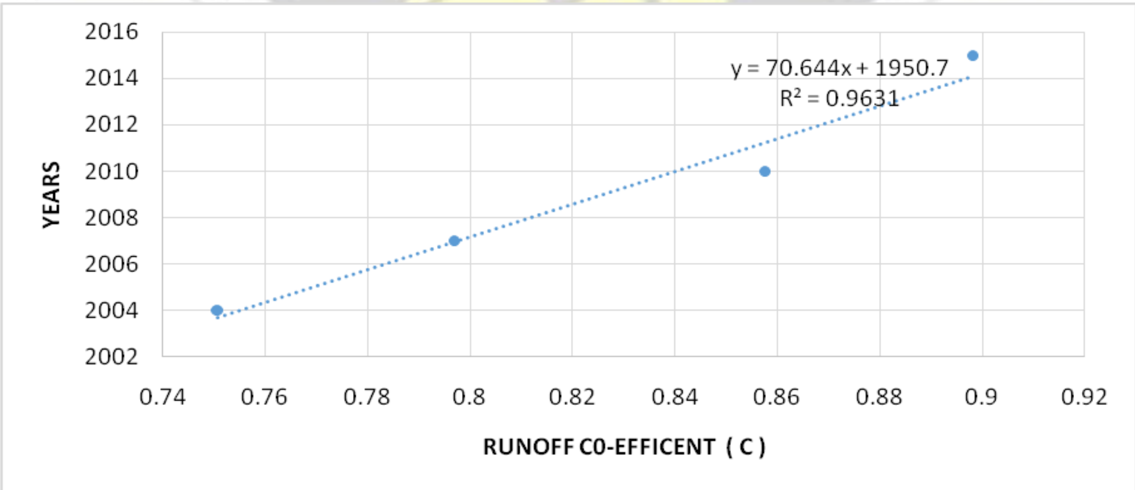

Fig 4.2: Runoff Coefficient as a function of years.

4.3 Time Of Concentration

The time of concentration was determined by Bransby William's formula, using equation (2.3).

Table 4.1: Computation of time of concentration

Station	Length (km)	Elevation H. at culvert site (m)	Elevation H. at highest point on catchment (m)	Area, A of catchment (km²)	$T_c = 0..975L/ (A^{0.1}*S^{0.2})$
Kwadaso	4.7	253.8	289.4	4.4	2.6

4.4. Computation of Rainfall Intensity I, of Kwadaso Stream

The rain intensity is obtained by the use of the intensity-duration – frequency relation of J. B. Dankwa, presented in the tabular form in appendix 5. The time of concentration obtained above is used as the duration of rainfall and at the frequency of 25years, which is usually adopted by the Road Agencies, the intensity is read from the table.

The intensity for the Kwadaso catchment area was obtained to be 54.45 mm/hr.

4.4.1 Computation of Flow, at Culvert Site

The flow at the culvert sites were computed using the general modified rational equation (2.1)

$$Q = 0.278 \text{ FCIA} \qquad (2.1)$$

Where,

Q = Design discharge (m³/s)

C = Run-off coefficient (dimensionless)

I = Rainfall intensity (mm/hr)

F = Areal reduction factor (dimensionless) A

= Catchment area (km²)

The area reduction factor F is determined by the Rodier equation

F = 1-0.001(log A) *(9*log N -0.042*P +152) ----------equation 2.6.1B

Where:

F= areal reduction factor

N= return period of rainfall (years)

P= average annual rainfall (mm)

A= catchment area (km^2)

4.4.2 Flow

Since the runoff coefficient, C, changes with percentage imperviousness which could be taken as the rate of urbanization. A plot of the computed discharge from the satellite images and the percentage impervious can gives an equation as shown on the figure 4.3, which could be used to estimate the discharge at any percentage impervious was estimated.

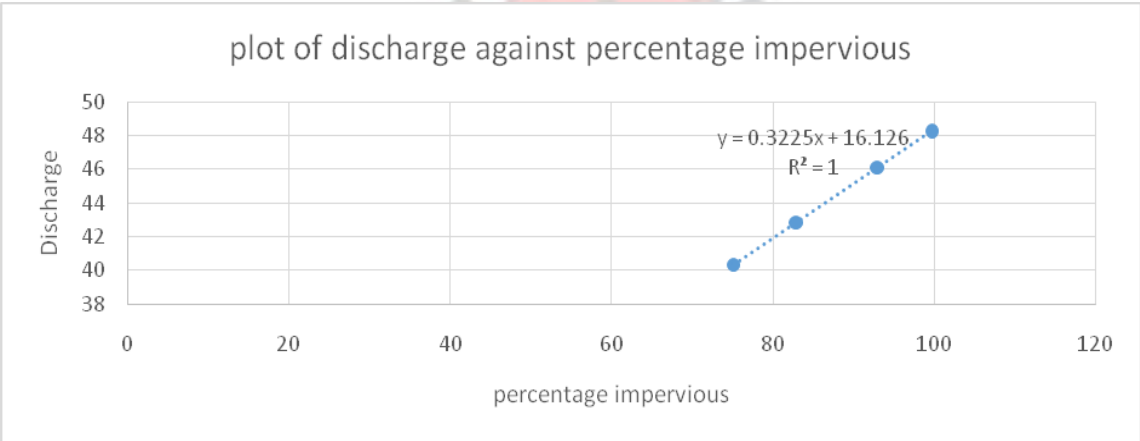

Fig. 4.3 Plot of discharge against percentage of imperviousness

The flow at a given site also changes with time as the rate of urbanization changes with time. From the figure 4.3, various discharge could be obtained at any percentage imperviousness required.

Adequacy of culvert size at constructed period for Kwadaso

With the discharge determined at the design estimated percentage of impervious, the size of the culvert is calculated with the aid of civil 3D software. The civil 3D software requires the following data inputs, flow, Q, the length, L, of the culvert, width of road, W, slope, S, of the culvert, shape of the culverts, the invert levels (upstream and downstream) and number of cells. The civil 3D gives the following output, flow adequacy, velocity (upstream and downstream), and the headwater to depth ratio. If the culvert is already in place, and the flow at the site is known, civil 3D software can analyse and determine the adequacy or otherwise of the culvert. For instance, if the culvert size is inadequate, civil 3D can give the overflow that would occur. Example is given on Kwadaso stream; these computation gives a discharge of 37.52m³/s at the year 2000. With the help of the civil 3D, fig 4.4C shows the pictorial view of the culverts structure and the overflow of the stream on the culvert structure. The civil 3D software computation shows that at year 2000, when the flow calculated to be 37.52m³/s, the existing 3(1.2m Ø) would have had an overflow of 26.6 m³/s. This implies that the size given at the culvert site at the time of construction was woefully inadequate. Apart from size being inadequate, velocities of 3.52m/s at inlet and outlet lies in the ministries maximum velocity range of 2.5m/s-6m/s and for such velocities, if measures like strong toe are not built or stabilizing the outlet/inlet with boulders, are not taken to reduce such velocities or strengthen the outlet, it would cause washout when the soil is not firm or unstable as show on plate 3. From fig 4.4, it also shows that the headwater/diameter ratio of 1.8 is higher than the ministries maximum of 1.5.

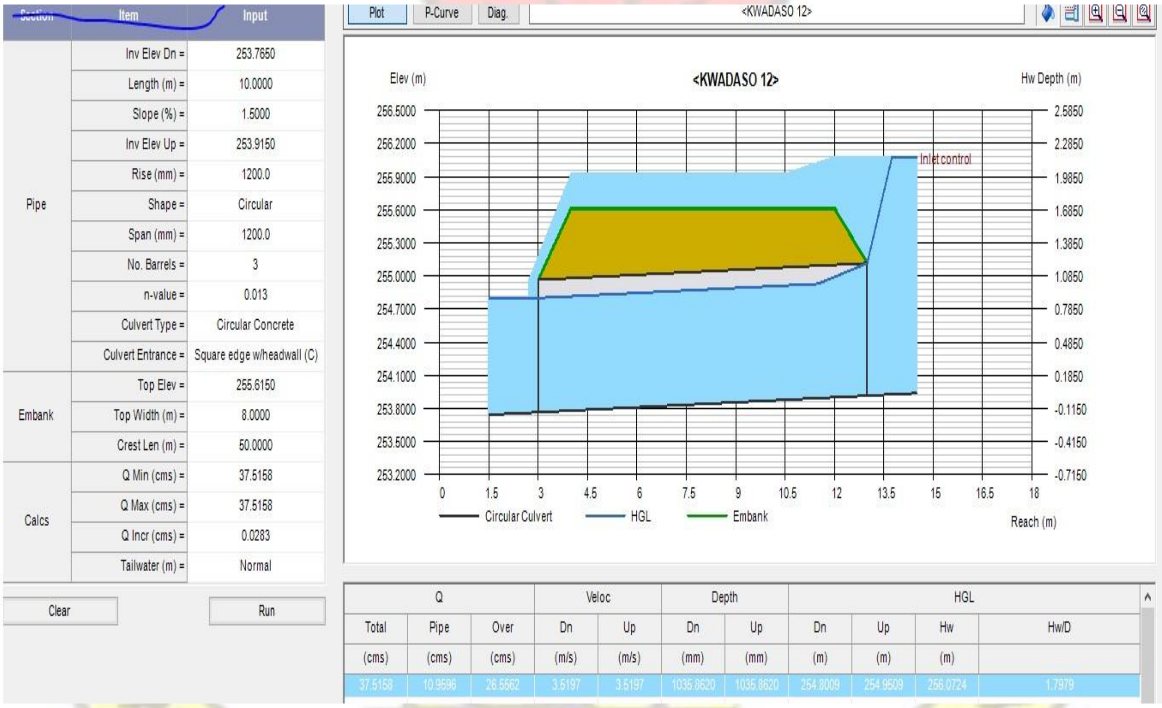

Fig 4.4. Computation of adequacy of culvert by Civil 3D for flow of 37.52m^3/s.

From the Civil 3D computation, it shows the size is very small.

Plate 4.1: Kwadaso culvert site on a dry day. Plate 4.2: Kwadaso culvert site on a rainy day

Plate 4.1 is a picture showing the culvert area in a dry day and the structure is function well. Plate 4.2 is the same area during rainfall and shows the whole area is flooded. Plate 4.3 shows washouts at the sides of the culvert which could be as a result of the overflow and washout at the outlet as a result of high velocity.

Plate 4.3: Erosion of culvert outlet

Minimum proposed size using the computed discharge of 37.52m³/s at the year 2000 (construction year) is show on the fig 4.5 which gives a size of 3 (2.0m X 2.5m) box culvert. The minimum size of 3 (2.0m X 2.5m) box culvert also has velocities 4.7m/s and 3.9 m/s upstream and downstream respectively. These velocities are too high and lie in the ministries maximum range. With such high velocities both the inlet and outlet need to be stabilized with boulders and strong toe are to be built. The head/water ratio of 1.2 is within the ministries range of less than 1.5 and shown on Fig 4.5.

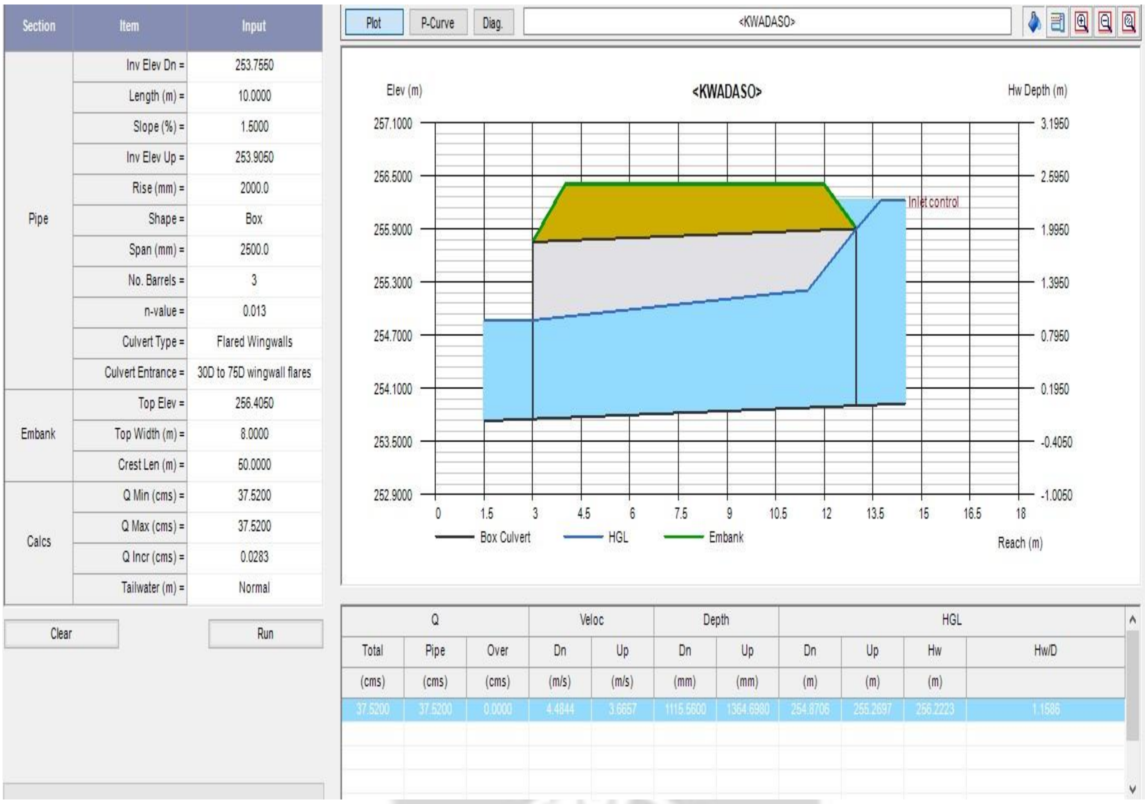

Fig. 4.5: Computation of the appropriate size of culvert for flow of 37.52m^3/s

The design return period of culverts under the Ministry of Roads and Highways is 25year. The design is done to 99.7% impervious, which fall on 2015 from the satellite image data. The computed discharge at the culvert site at year 2000, Q_{2000} = 37.5158 m³/s and at year 2015, Q_{2015}=48.3783m³/s which is likely to be the maximum discharge of the stream, if all natural conditions remain the same. The hydraulic sizing of the culvert done with the aid of civil 3D software is shown below with such data in Fig 4.6.

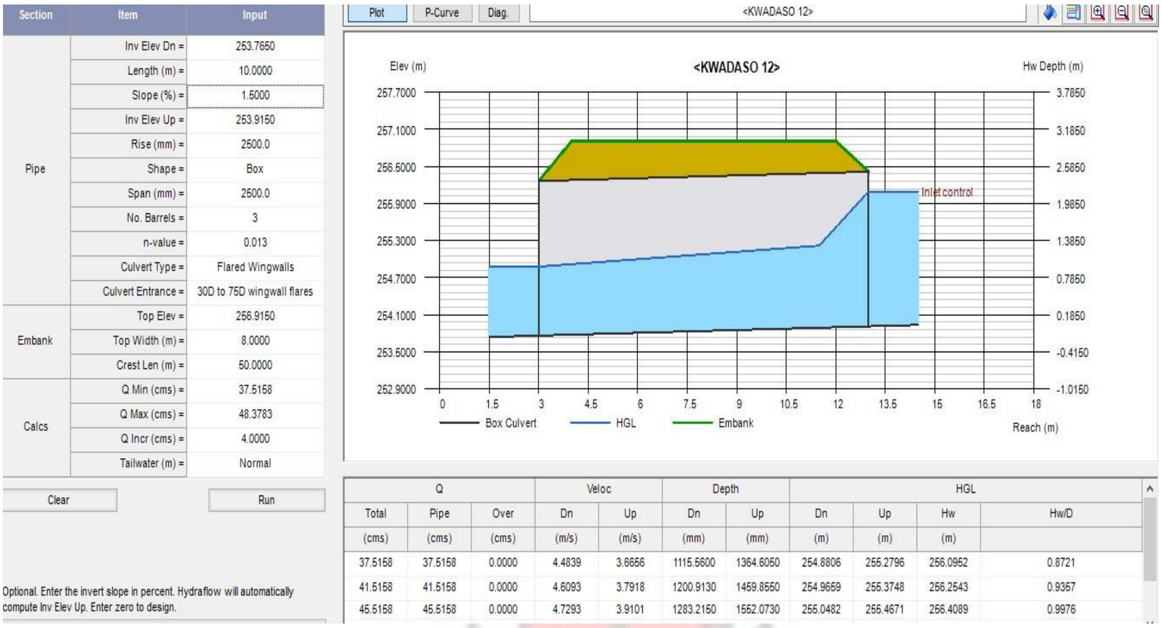

Fig 4.6: Computation of the appropriate size of culvert for flow of 48.38m^3/s

From fig 4.6 above, the proposed size generated by the civil 3D is 3(2.5m X 2.5m) which is adequate for the flow of 99.7% imperviousness and headwater/diameter ratio 1.0 less than the 1.5. The design shows a velocity of 3.9 upstream and 4.7 downstream, which need stabilisation at both inlet and outlet to prevent washouts.

4.5 Summary of the Results of all the 16 Culverts Studied

Table 4.2A and B below is a summary of all the computation, analyses and the results obtain in all the 16 culverts, which were selected for this research work. It shows the road name at which the culvert is located, stream name, the year the existing culvert was constructed, the computated discharge at the construction year, the size of culvert place at construction year, the computated discharge at 99.7% percentage impervious at 25 years return period and the proposed culvert size with that discharge.

4.6 Adequacy of existing culvert

Further assessment was done on all the culvert which had the tendency of overflowing. To establish their adequacy. The result are tabulated in Table 4.2 below. The results show that the computation discharge was more than the capacity of the culvert size chosen at that time of construction.

Table 4.2; Checking the adequacy or otherwise of existing culverts. CULVERTS FROM DEPARTMENT OF URBAN ROADS

Road name	Stream name	Yrs. const.	Computation discharge at const. year (m^3/s)	Existing culvert size	Design flow at 99.7% impervious (25 yrs R.P) m^3/s	Proposed culvert. size
Napo Drive	Kwadaso	2000	37.52	3(1.2m Ø)	48.38	3(2.5m X2.5m)
Adiebra-Atasomanso	Atasin	2010	12.88	2(1.8m Ø)	13.00	2(1.8m Ø) (OK)
Kwensi Bonsu	Suatem(south-suntreso)	2014	9.718	1.5m X2.5m	10.46	1.5m X2.5m (OK)
Samual Sarpong Drive	Pata	1999	5.3966	2(1.2m Ø)	6.5952	2(1.5m X1.5m)
Abusuakruwa	Tatasi	2002	14.9464	1.8m Ø	15.0821	2(2m X2m)
Nwamase	Nwam	2004	1.289	2m X2m(BIG)	3.6276	1.5m X 1.5m
Barekese (Abrepo)	Akuoso	2008	13.1703	2(1.8m Ø)	13.6717	2(1.8m Ø) (OK)
Barekese (Atafoa)	Anyinasu	2008	30.314	3m X3m	33.77	2(2.5m X2.5m)
Islamic Anomamgye	Akuoso	2000	15.93	3(1.2m Ø)	17.2135	3(1.8m Ø)
Nurse Quarters	Punpunasi (koto)	2007	46.3283	2(1.8m Ø)	48.4582	3(2.5m X2.5m)
Archbishop sarpong	Suatem (T.U.C)	2010	49.9243	2(2.0m X2.5m)	55.3444	3(2.5m X2.5m)
The dish	Punpunasi (Ampa)	2005	8.7064	2m X2m	9.9078	2m X2m (OK)
Major Conbina	Suatem(Denyame)	2014	38.3512	2(2m X2m)	40.6176	2(2.5mx3m) or 2(3mx3m)
P.V Obeng	Asuowirentuo	2004	97.9320	3(2.5m X2.5m)	98.7417	3(3.5m X3.5m)

Table 4.3; Checking the adequacy or otherwise of existing culverts. CULVERTS FROM DEPARTMENT OF FEEDER ROADS

ROAD NAME	STREAM NAME	YRS CONST.	Q_1 const. year (m^3/s)	Existing cul. size	Design Q_2(m^3/s)	Proposed cul. size
Santasi-Daku	Danyame (SantasiDaku)	2009	31.9364	2(1.2m Ø)	39.4634	2(2.5m X3.m) OR 2(3mX3m)
Santasi-Daku	Kokoroma	2009	24.873	2(1.2m Ø)	33.464	2(2.5m X2.5m)

CHAPTER 5 : CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The following are major conclusion deduce from this study and arrange according to the specific objectives.

i. 16 number of culverts in the Kumasi metropolis were found to be experiencing frequent flooding. This was achieved through series of interviews, consultation and field visits with the various road agencies of the Kumasi metropolis Department of Urban Roads and Department of Feeder Roads. The data is at appendix 1,

ii. Though the discharge at construction period was not available, the civil 3D software in conjunction with the satellite image analysis enable us to compute discharge at construction period to be $37.52m^3/s$. The size at construction period 3(1.2mɵ pipe) was found to be inadequate. The appropriate size was computed to be 3(2.0m x2.5m) box. At 99.7% imperviousness, the size for the culverts was calculate to be 3(2.5m x2.5m) box culvert.

iii. The results show that out of the 16 culverts investigated only four (4) were found to have adequate sizes and that the frequent floods that were experienced here were due to other factors such as silting and blockages while twelve (12) were found to be inadequate.

5.2 Recommendations

The following recommendations are given for the consideration to the ministry of roads and highways

i. Much attention should be given to the sizing of the culverts as it is done to the pavement structure. The whole road system is a network, and failure of one means failure to the network. therefore, proper analysis should be done before selecting size the culverts.

ii. With the high velocities, strong and firm toe should be provided, and if possible the places with weak materials, can be stabilized with boulders to prevent scoring as it also undermines the culvert and causes hydraulic failure as well

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APPENDIX 1: INVENTORY DATA.

Appendix 1: Survey Data.

Upon request to the various administrators Urban Roads and Feeder Roads on data on culverts flooding under the Kumasi metropolis. A list was given which have the following data,

1. Road Name:
2. Stream Name:
3. Area in which the culvert can be located in Kumasi metropolis:
4. Chainage of the culverts:
5. Size of the culvert:
6. Year of construction of the culvert:
7. Year they notice flooding of the culvert:

The information given were taken to the field, which came up to be the except the chainages which were having a small deviation, and for uniformity theirs were use.

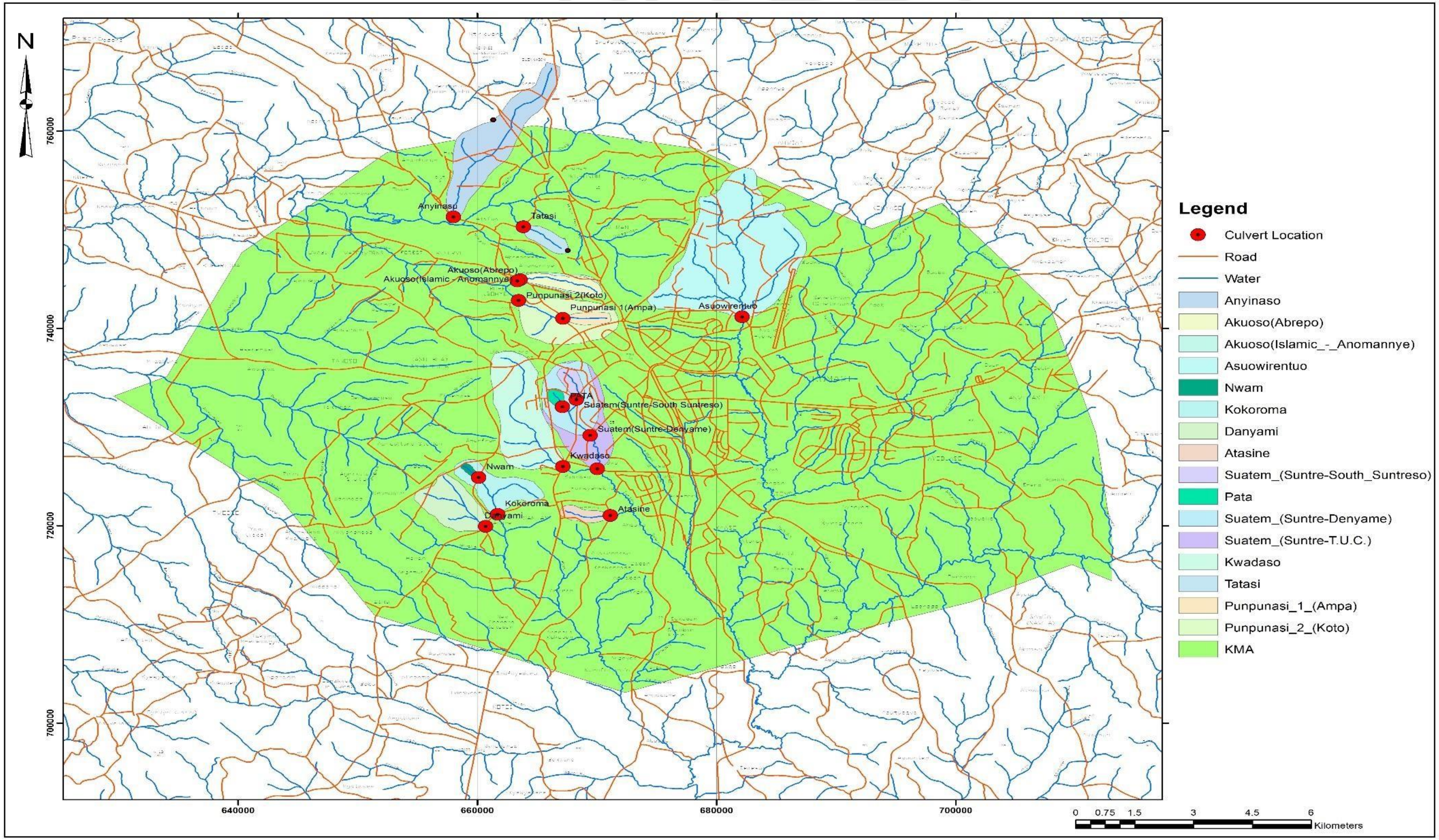
Additional information was also picked from the field, culvert length and road width which upon verify from the two Agencies came out to be the same with them. The following table on appendix 1 shows the formation data.

INVENTORY DATA FORM

ROAD NAME	STREAM NAME BY LOCAL CITIZEN AND TOPO MAP	STREAM NAME BY ROAD AGENCIES	YRS CONST.	AREA	CH.	EXISTING CUL. SIZE	CUL. LENGTH	ROAD WIDTH	YEAR FLOOD ING START
Napo Drive	Kwadaso	Kwadaso	2000	Kwadaso Estate	0+050	3(1.2m Ø)	10m	8m	2004
Adiebra-Atasomanso	Atasin	Atasin	2010	Adiembra	0+920	2(1.8m Ø)	10m	7.5m	-
Kwensi Bonsu	Suatem(southsuntreso)	Suntre	2014	South Suntreso	0+008	1.5m X2.5m	9m	8m	-
Samual Sarpong Drive	Pata	Pata	1999	Patasi	0+750	2(1.2m Ø)	10m	7.5m	2004
Abusuakruwa	Tatasi	Tikasi	2002	Mpatsi	0+900	1.8m Ø	12m	8.5m	-
Nwamase	Nwam	Nwam	2004	Nwamase	0+780	2m X2m	10m	7.5m	-
Barekese (Abrepo)	Akuoso	Akuoso	2008	Abrepo	1+600	2(1.8m Ø)	12m	8m	2012
Barekese (Atafoa)	Anyinasu	Anyinasu	2008	Atafoa	2+500	3m X3m	12m	9m	2012
Islamic Anomamgye	Akuoso	Akuosu	2000	Suame	0+950	3(1.2m Ø)	12m	10m	2004
Nurse Quarters	Punpunasi (koto)	Koto	2007	Adowato	0+220	2(1.8m Ø)	10m	7.5	2010
Archbishop sarpong	Suatem (T.U.C)	Kwada	2010	T U C	0+012	2(2.0m X2.5m)	10M	8m	2012
The dish	Punpunasi (Ampa)	Ampa	2005	Ampabame	0+280	2m X2m	12m	7.5m	2007
Major Conbina	Suatem(Denyame)	Suntre	2014	Denyame	0+750	2(2m X2m)	12m	7.5m	2015
P.V Obeng	Asuowirentuo	-	2004	Jofel-Airport Roundabout	0+900	3(2.5m X2.5m)	18m	16m	2007

APPENDIX 2: MAP OF KUMASI METROPOLITAN ASSEMBLY (STUDY AREA)

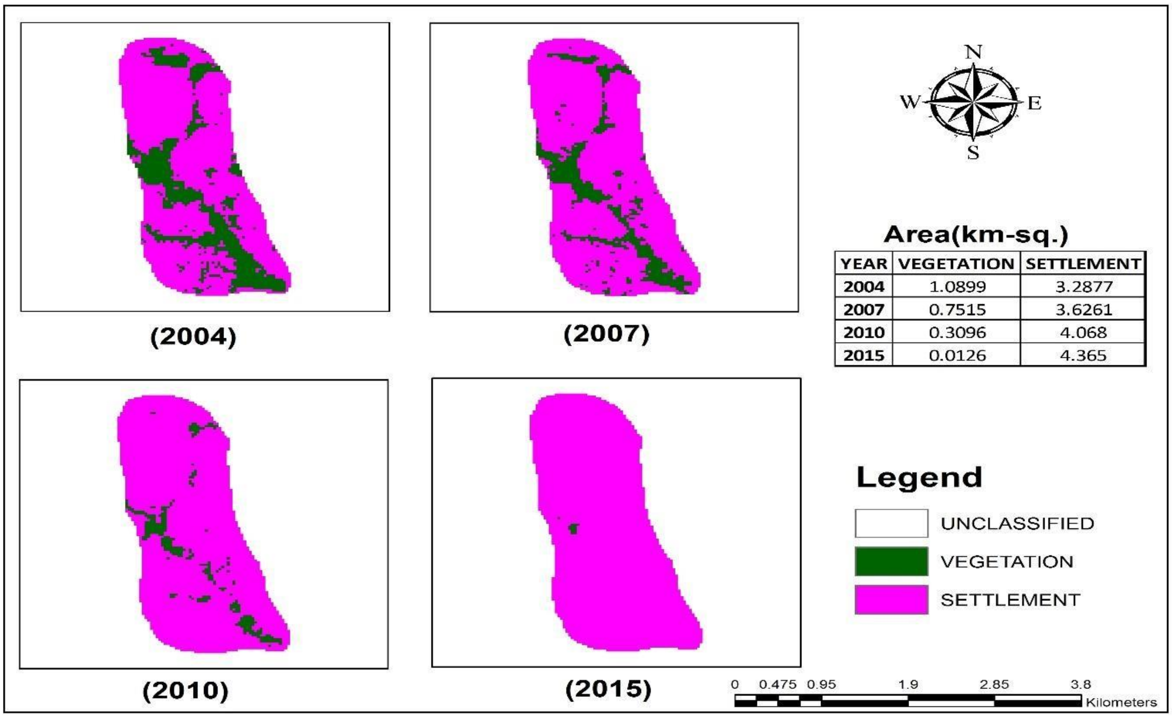
APPENDIX 2; MAP OF KUMASI METRO SHOWING ALL THE CULVERT POSITIONS AND THEIR CATCHMENT ARES



APPENDIX 3: SATELITE IMAGES SHOWING THE AREA OF VEGETATION AND SETTLEMENT

Appendix 3

1.0 KWADASO CATCHMENT AREA



2.0 ATASIN CATCHMENT AREA

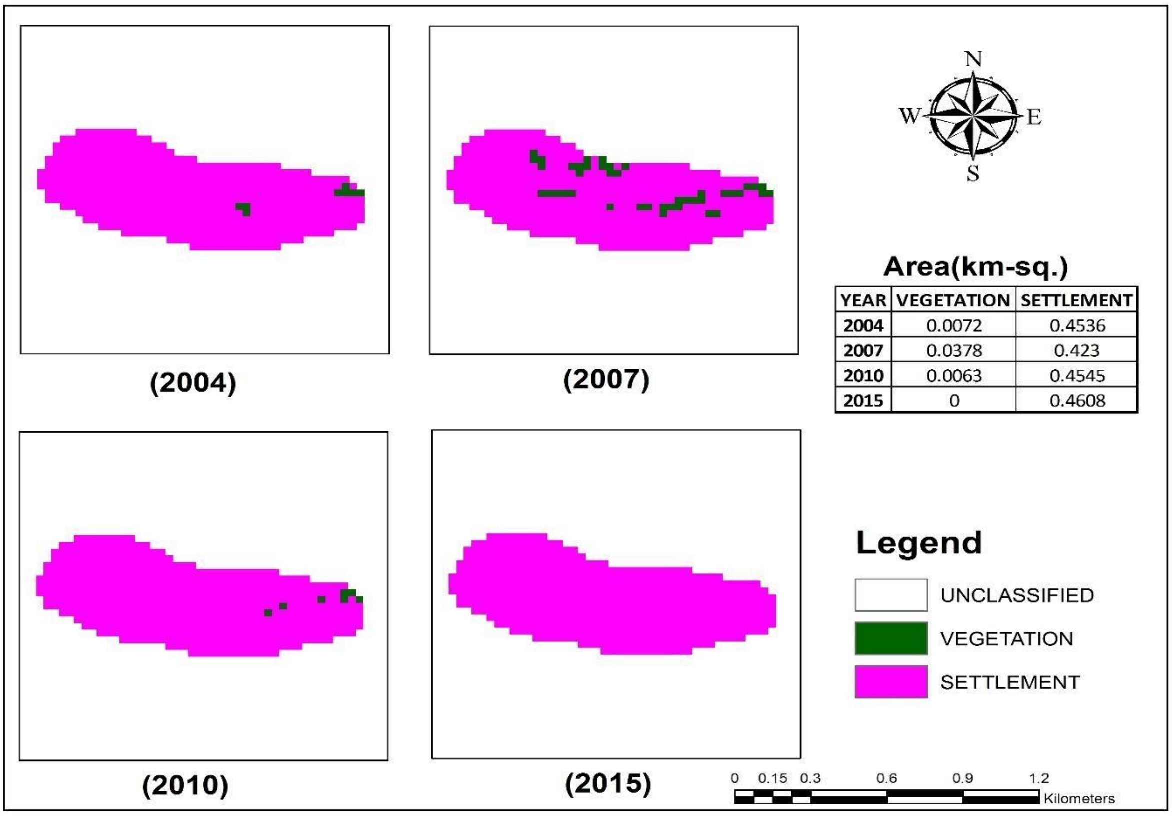
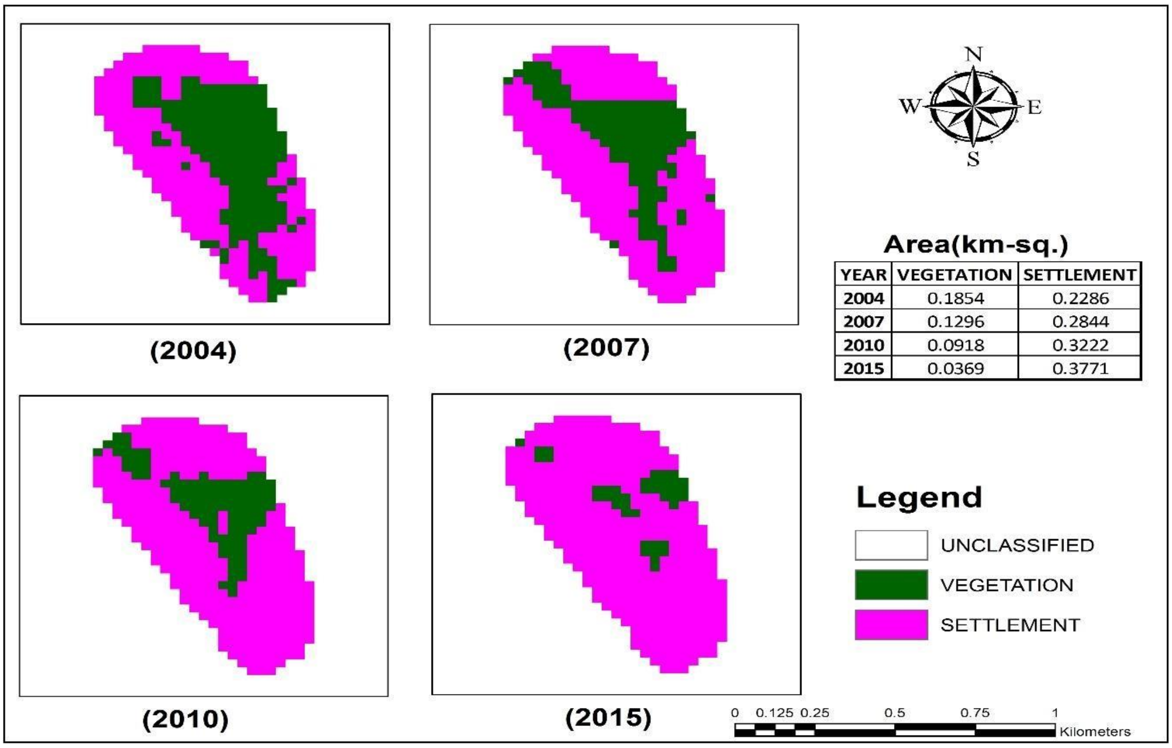
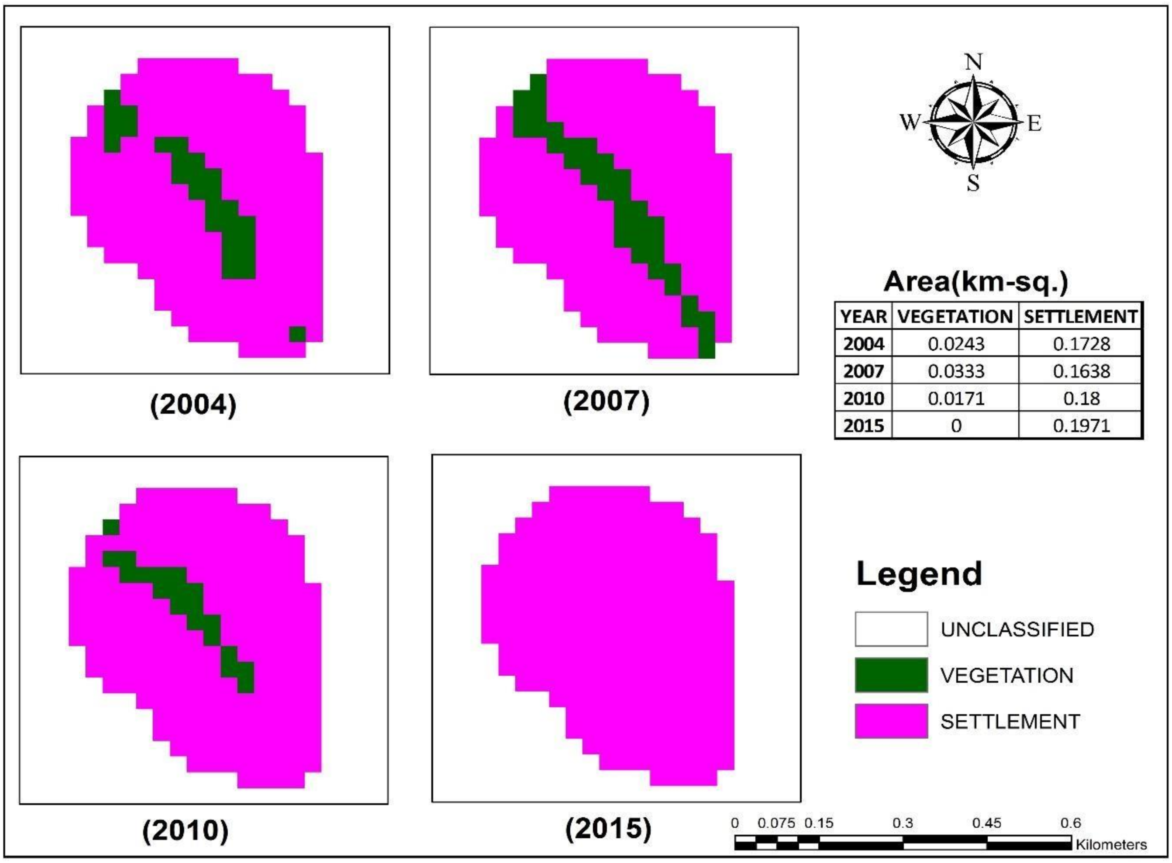


FIG 2.0 ATASIN CATCHMENT AREA

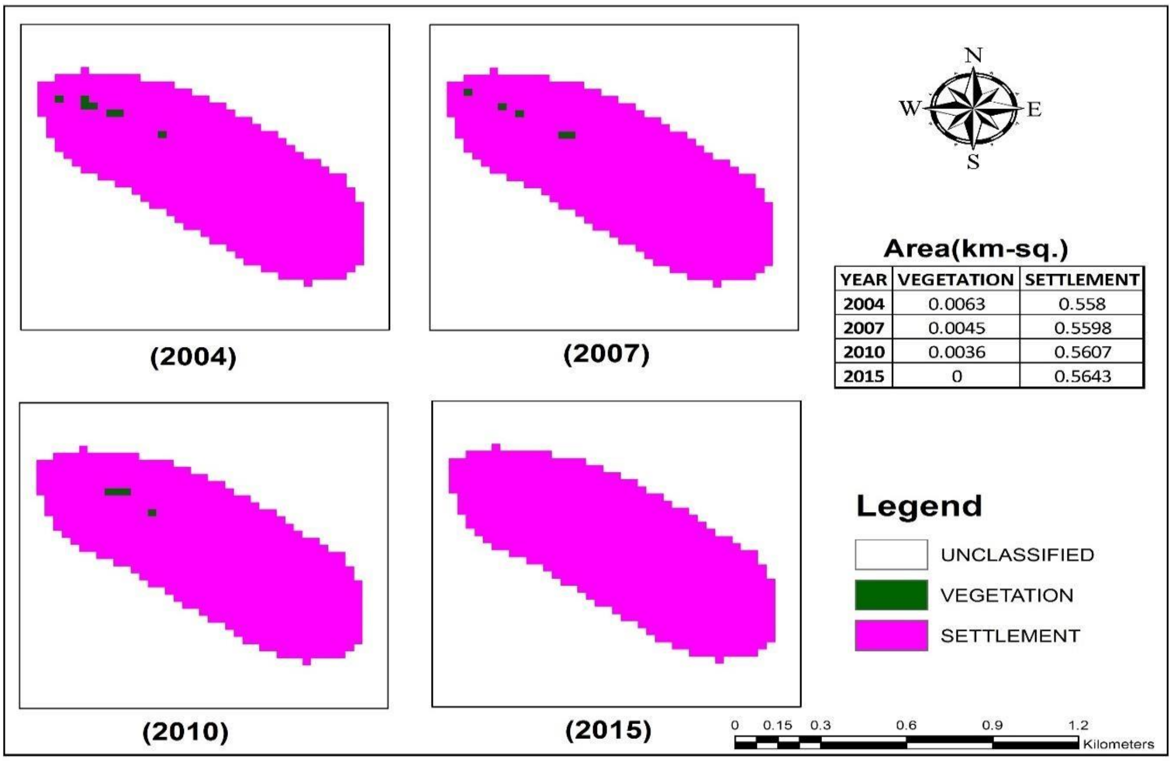
3.0 CATCHMENT AREA OF SUATEM (SOUTH-SUNTRESO)



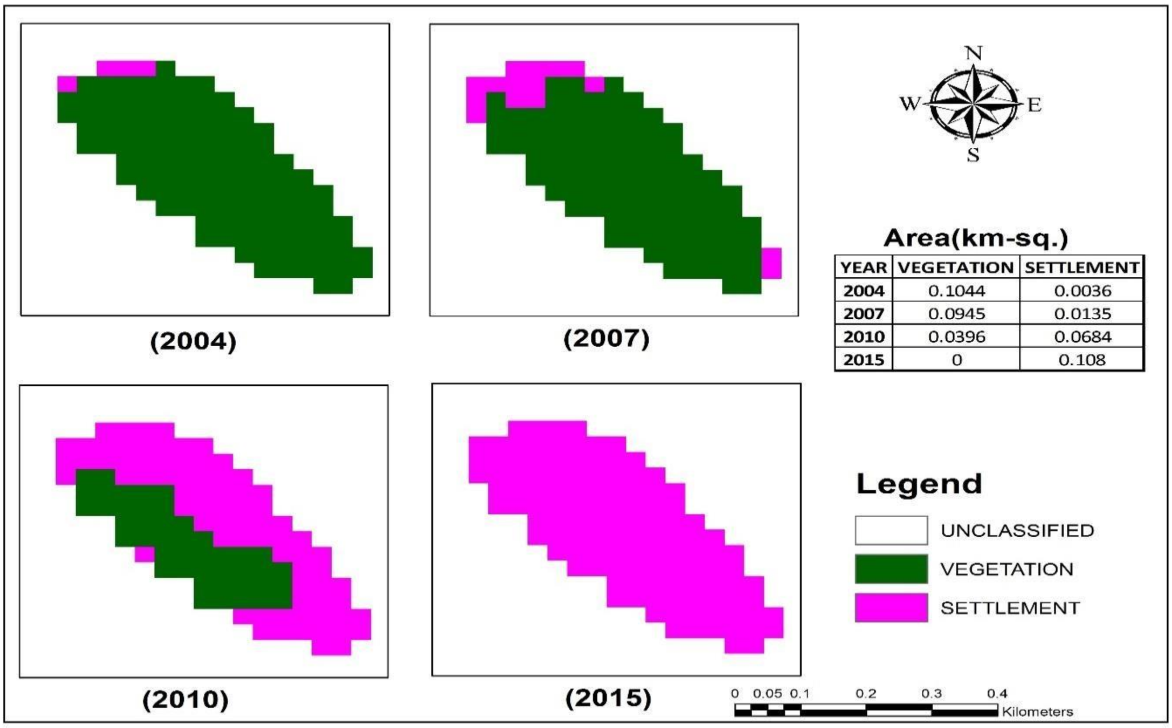
4.0 CATCHMENT AREA OF PATA



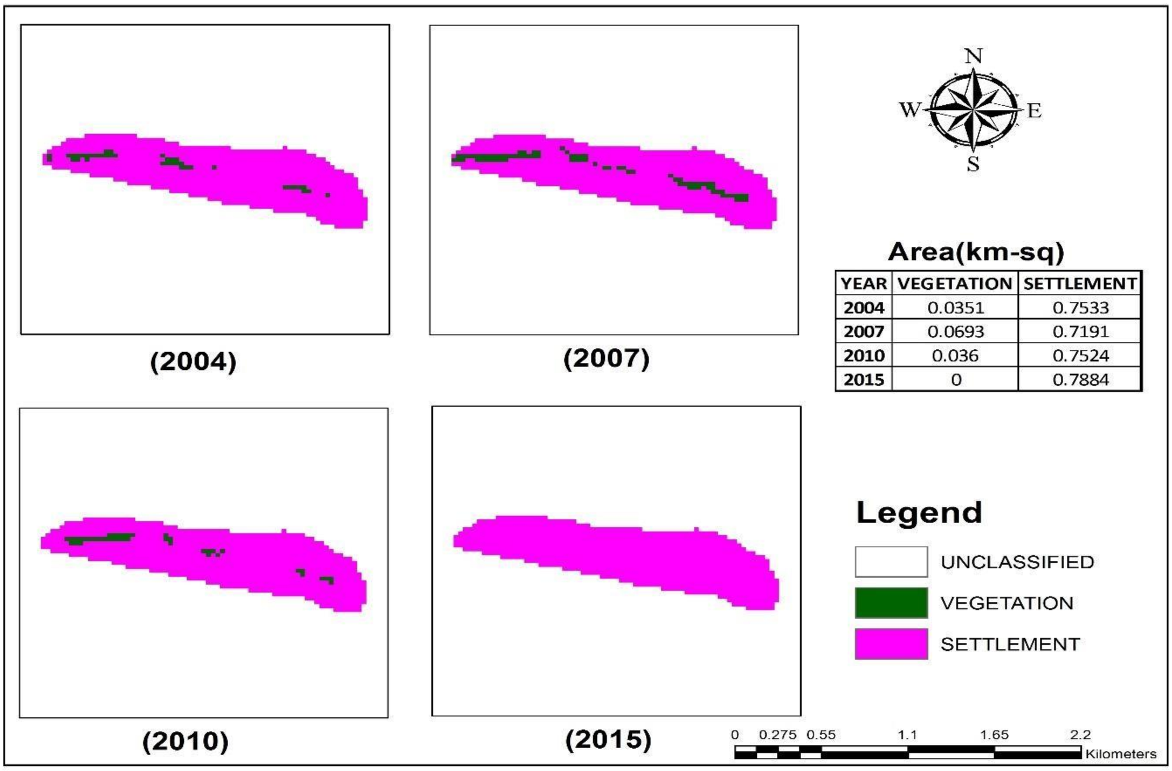
5.0 CATCHMENT AREA OF TATASI



6.0 CATCHMENT AREA OF NWAM

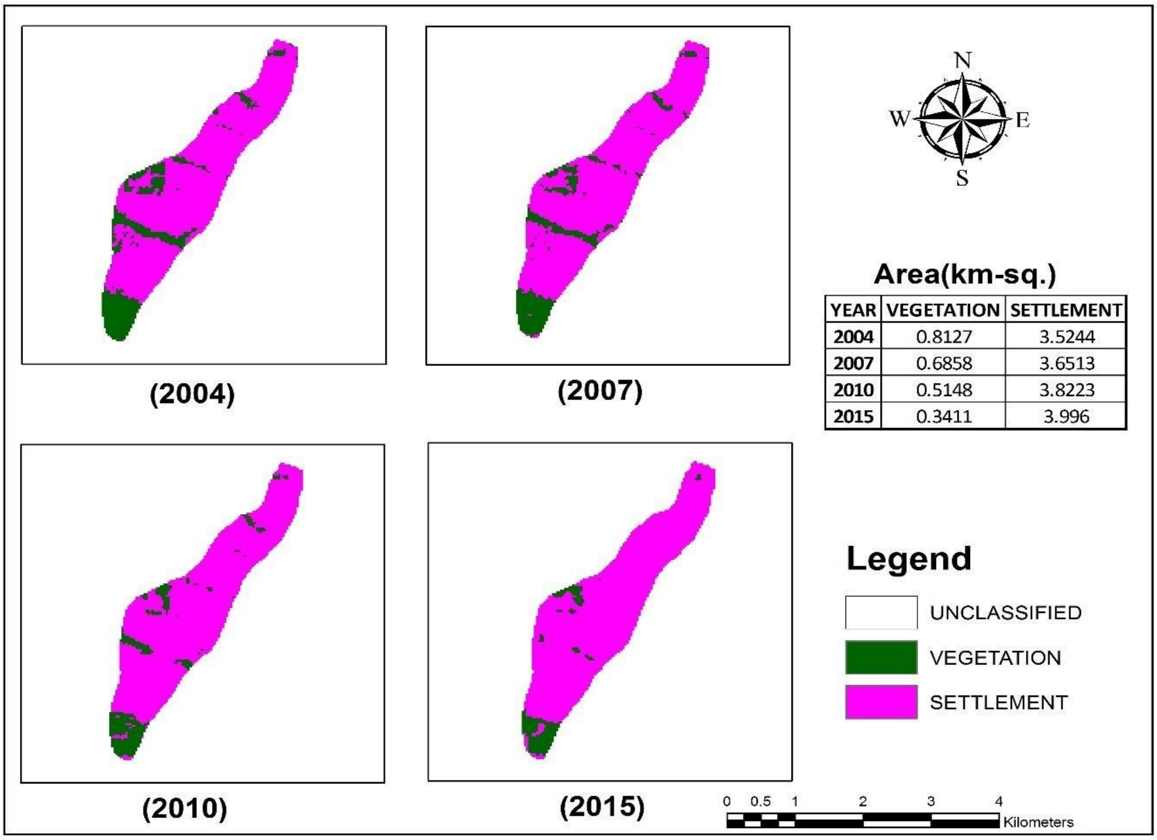


7.0 CATCHMENT AREA AKUOSO-ABREPO



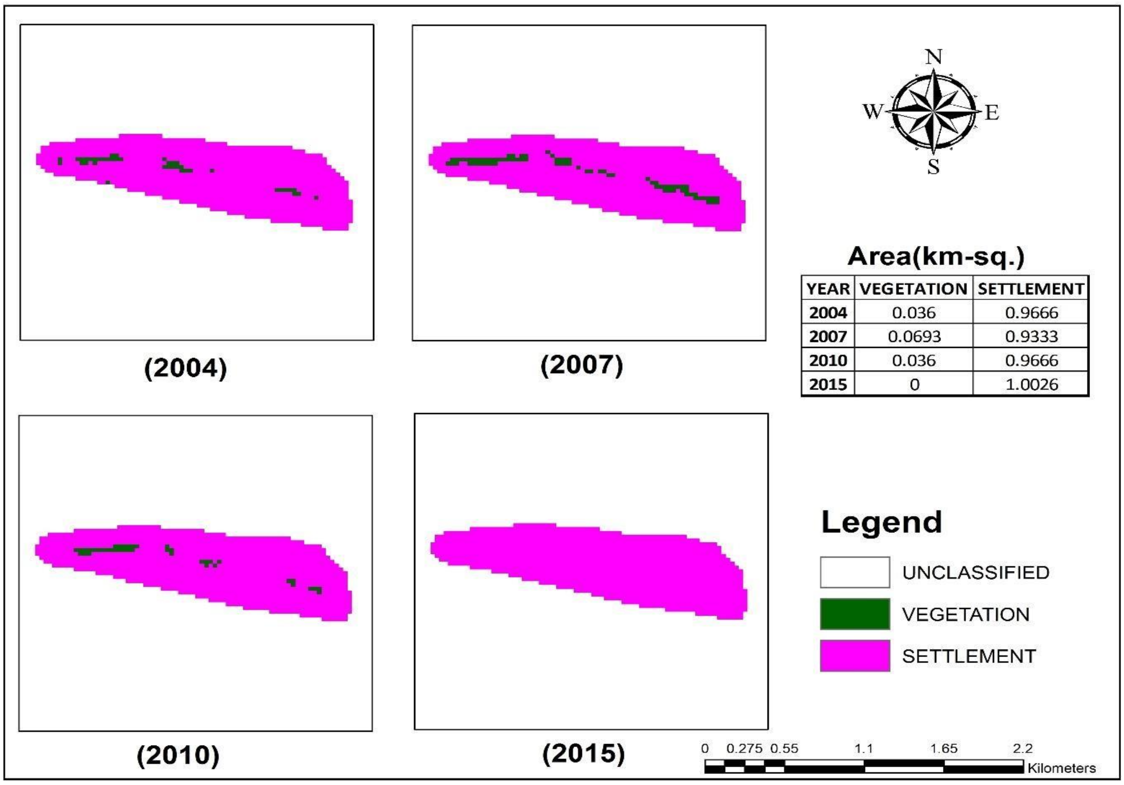
YEAR	VEGETATION	SETTLEMENT
2004	0.0351	0.7533
2007	0.0693	0.7191
2010	0.036	0.7524
2015	0	0.7884

8.0 CATCHMENT AREA ANYINASU



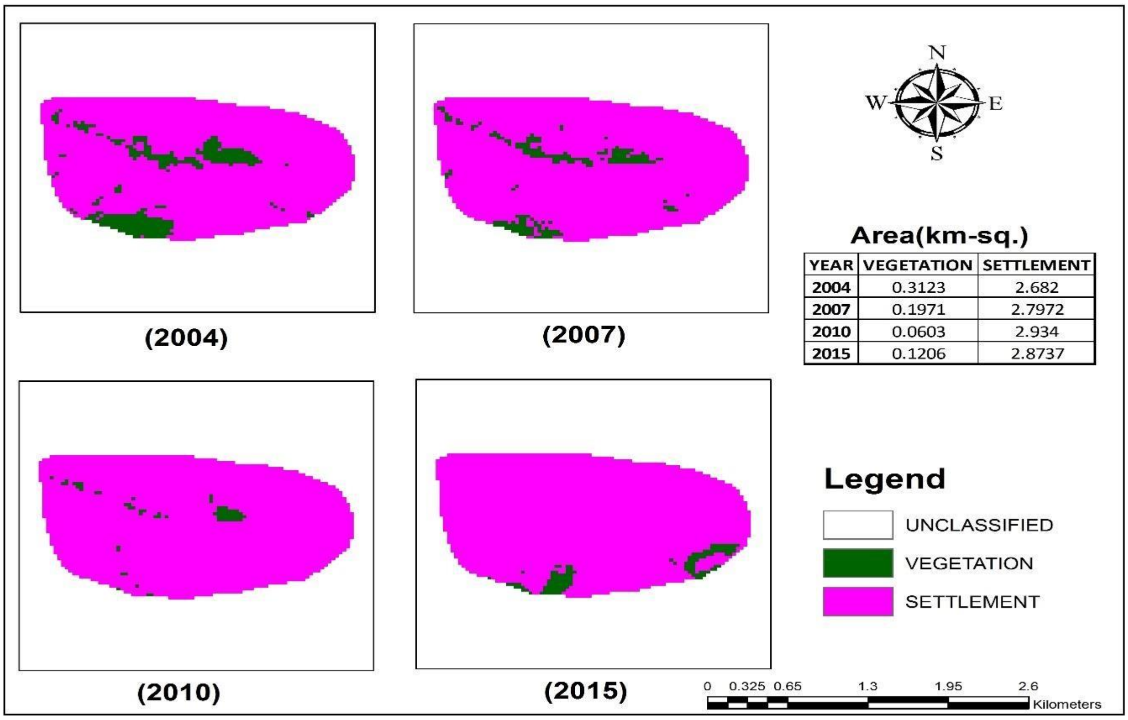
YEAR	VEGETATION	SETTLEMENT
2004	0.8127	3.5244
2007	0.6858	3.6513
2010	0.5148	3.8223
2015	0.3411	3.996

9.0 CATCHMENT AREA AKUOSO ISLAMIC

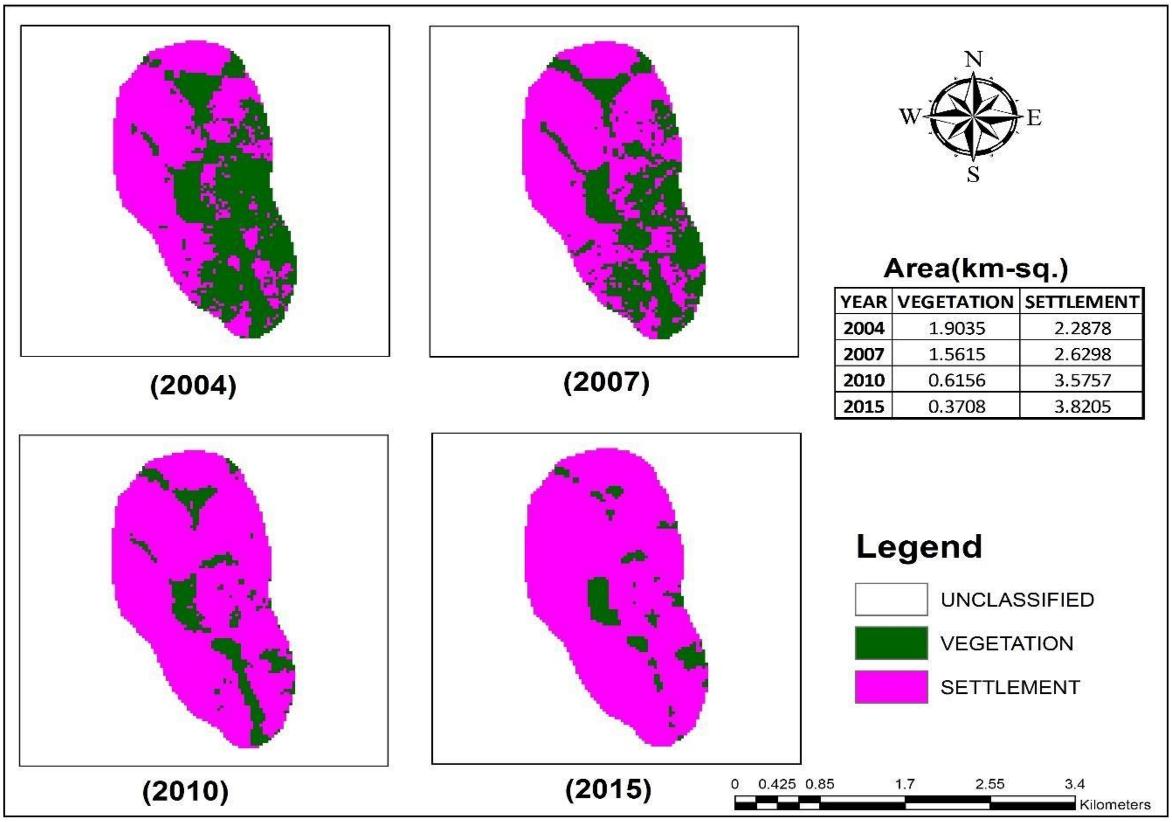


10.0 CATCHMENT AREA PUNPUNASI

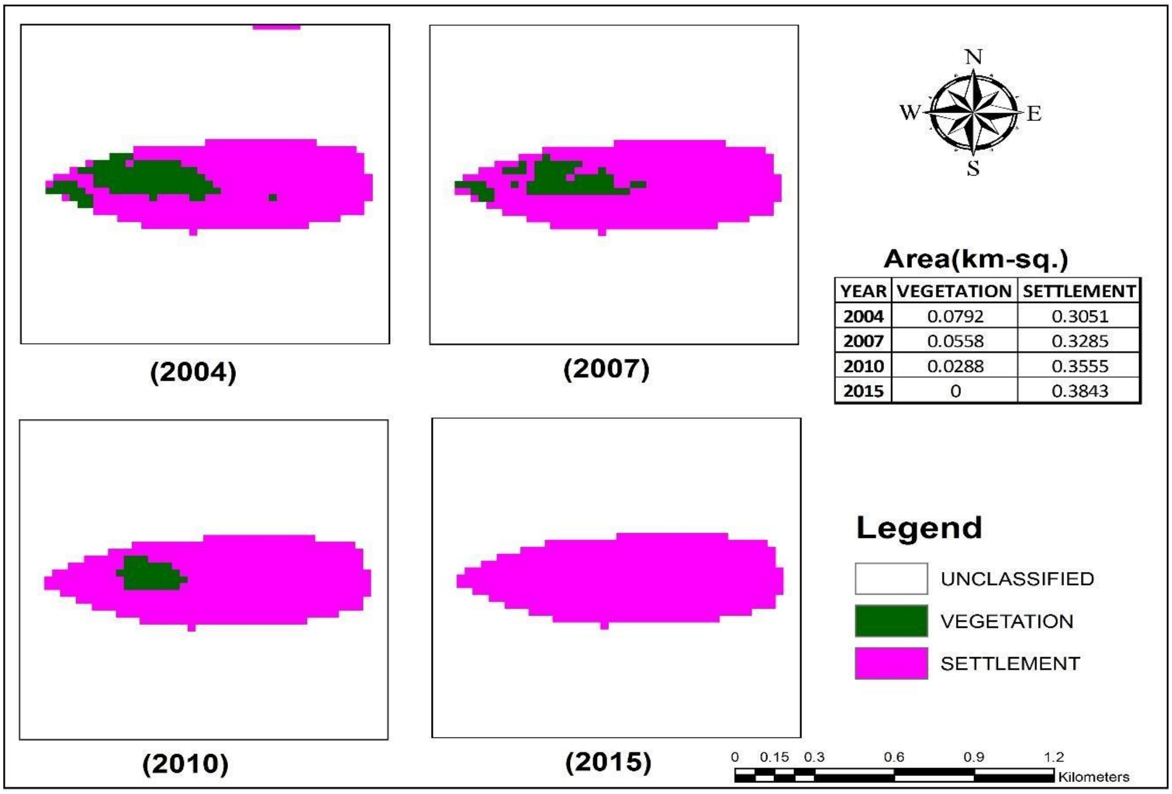
(KOTO)



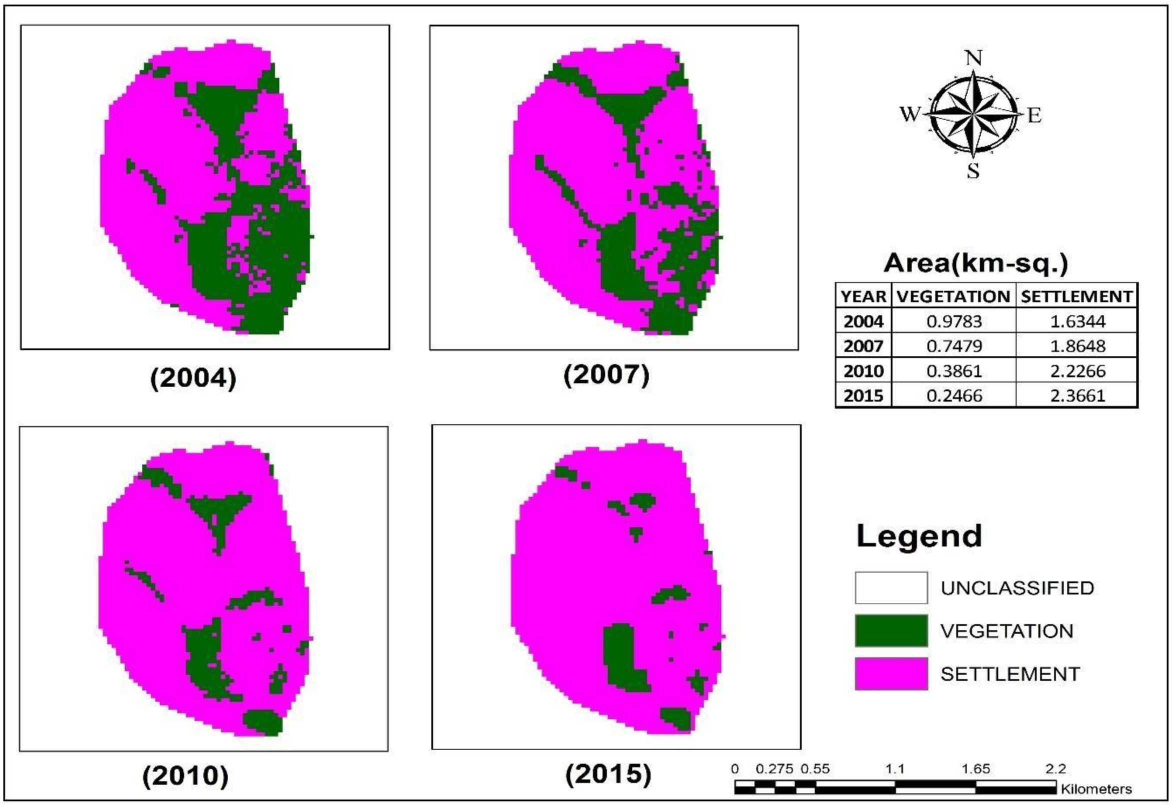
11.0 CATCHMENT AREA SUATEM (TUC)



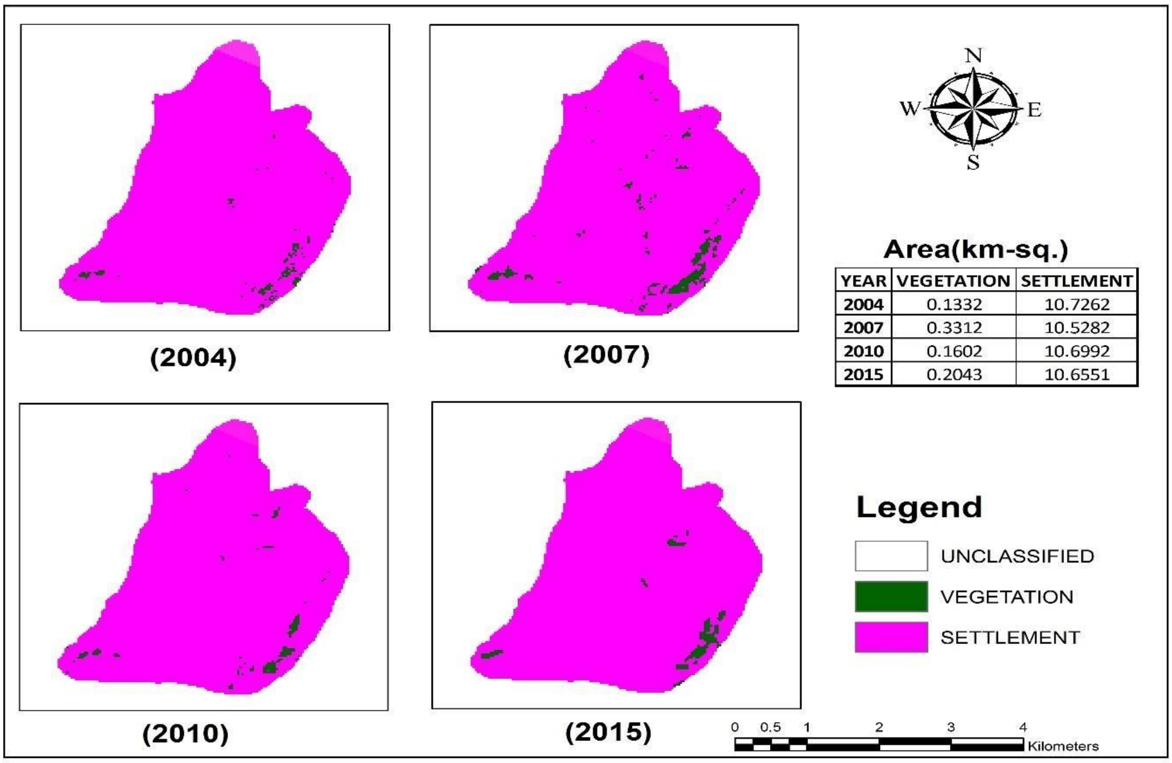
12.0 CATCHMENT AREA AMPA



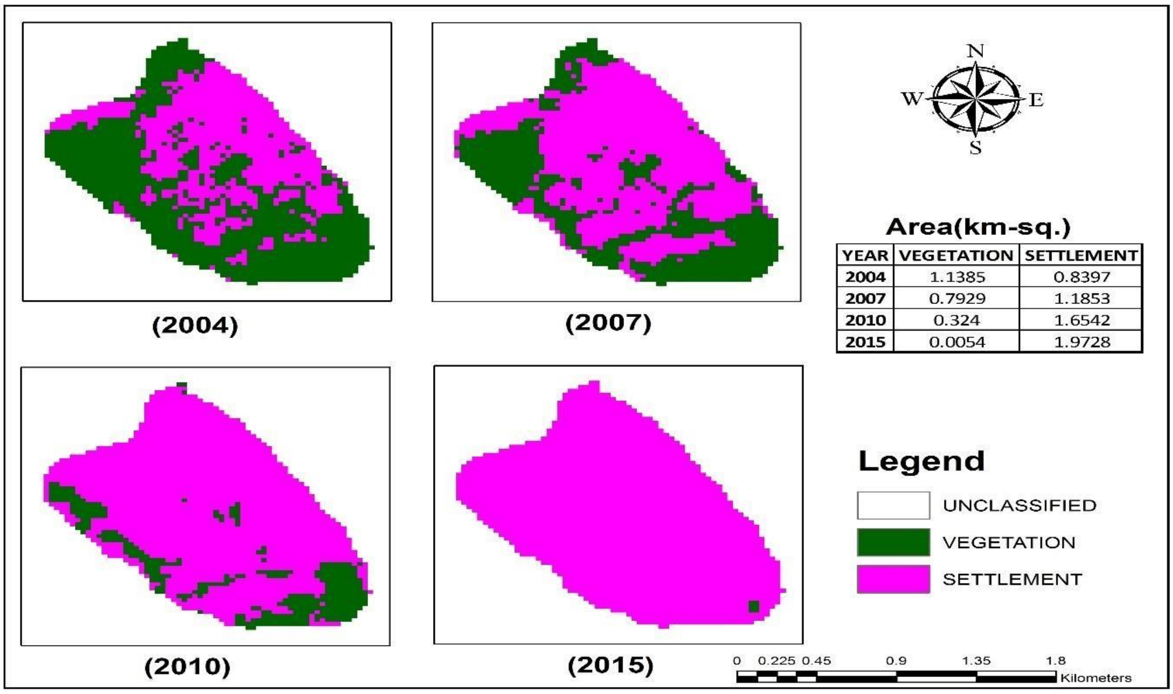
13.0 CATCHMENT AREA SUATEM (SUNTRE-DANYAME)



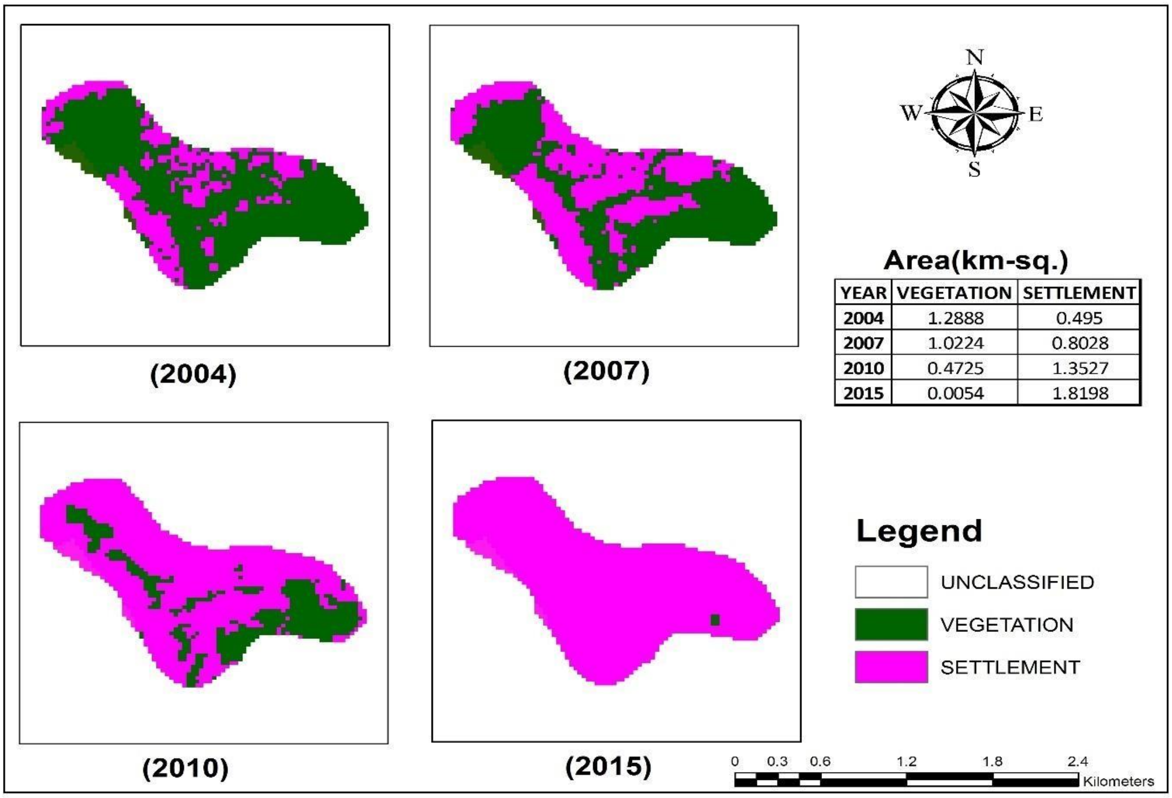
14.0 CATCHMENT AREA OF ASUOWIRENTUO



15.0 CATCHMENT AREA OF DANYAME (SANTASI-DARKO)



16.0 CATCHMENT AREA OF DANYAME (SANTASI-DARKO)



APPENDIX 4: RESULTS AND ANALYSIS OF OTHER CULVERTS

Appendix 4

1.0 Data

Table 4.1.1: Shows the percentage of settlement to respective years (Rate of Urbanization).

STREAM	YEAR	AREA OF VEGETATION (km²)	AREA OF SETTLEMENT (km²)	PERCENTAGE (%) OF SETTLEMENT
	0-1972			0
	*2000			66.32
	2004	1.0899	3.2877	75.10
	2007	0.7515	3.6261	82.83
	2010	0.3096	4.068	92.93
KWADASO	2015	0.0126	4.365	99.71
TOTAL AREA 4.3776				

Table 4.2.1 Changes of runoff coefficient with years at Kwadaso site.

STREAM	YEAR	PERCENTAGE IP %	C =0.3+0.6**IP*,
KWADASO	0-1972	0	0.3
	2000	66.32	0.69
	2004	75.1	0.75
	2007	82.83	0.79
	2010	92.93	0.86
	2015	99.71	0.90
	-	100	0.9

Table 4.4.2: Changes of flow with years at Kwadaso

YEAR	%	C	I=2.63Hrs=52.45 mm/hr	**F**	**Q (m³/s)**
0-1972	0	0.3	52.45	0.84	16.13
*2000	66.32	0.69	52.45	0.84	37.52
2004	75.1	0.75	52.45	0.84	40.35
2007	82.83	0.79	52.45	0.84	42.84
2010	92.93	0.86	52.45	0.84	46.10
2015	99.71	0.90	52.45	0.84	48.28

2.0 DATA

ROAD NAME; Adiembra-Atasomanso Ch 0+920

Area=0.4608 F = 1-0.001(log A) *(9*log N -0.042*P +152)

= 0.8578

Rainfall intensity = 131.46mm/hr slope of culvert 1.5

Table ……

	YEAR	VEGETATION	SETTLEMENT	PERCENTAGE % OF SETTLEMENT
	2004	0.0072	0.4536	98.4375
	2007	0.0378	0.423	91.796875
	2010	0.0063	0.4545	98.6328125
	2015	0	0.4608	100
ATASINE	TOTAL AREA	0.4608		

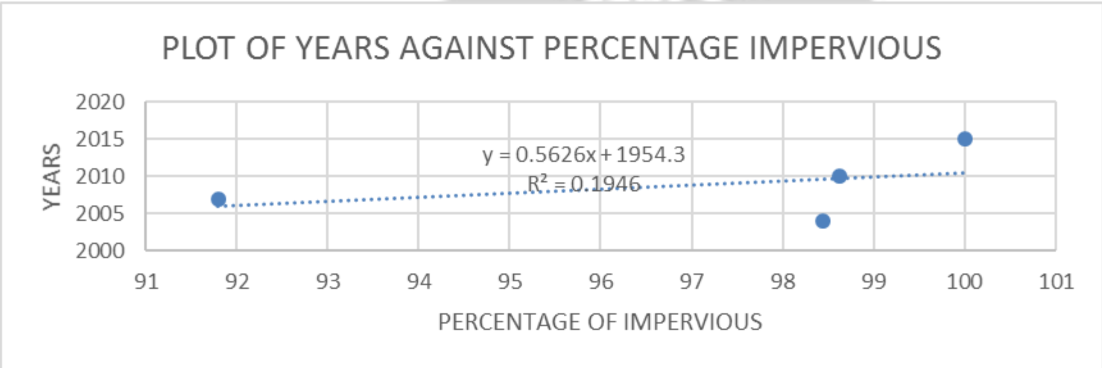


Fig.

Table 4.3: Computation of time of concentration

STATION	L (km)	H at culvert site(m)	H,at highest point on catchment (m)	A (km^2)	$T_c = 0.975L/ (A^{0.1}*S^{0.2})$
Atasine	1.382302	212.720374	286.115094	0.4608	0.658027325

Table … Computation of Discharge

STREAM	YEAR	PERCENTAGE IP %	C =0.3+0.6*IP,	**Q = 0.278 FCIA (m^3/s)**
	0-1972	0	0.3	4.333465251
	2010	99	0.894	12.91372645
	2004	98.44	0.89064	12.86519164
	2007	91.8	0.8508	12.28970745
	*2010	98.63	0.89178	12.88165881
Atasine	2015	100	0.9	13.00039575

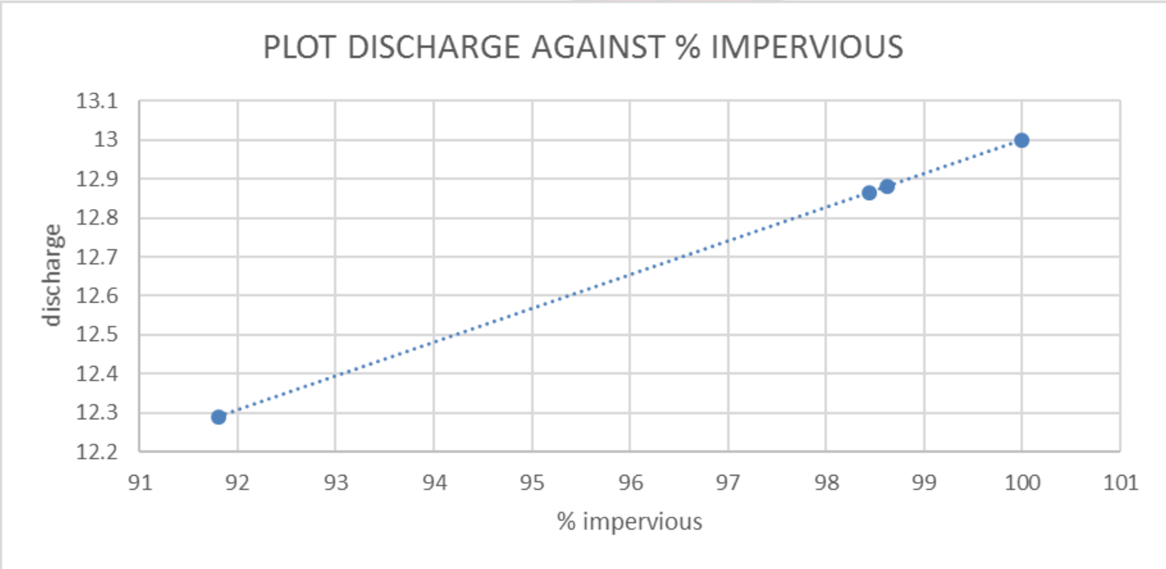
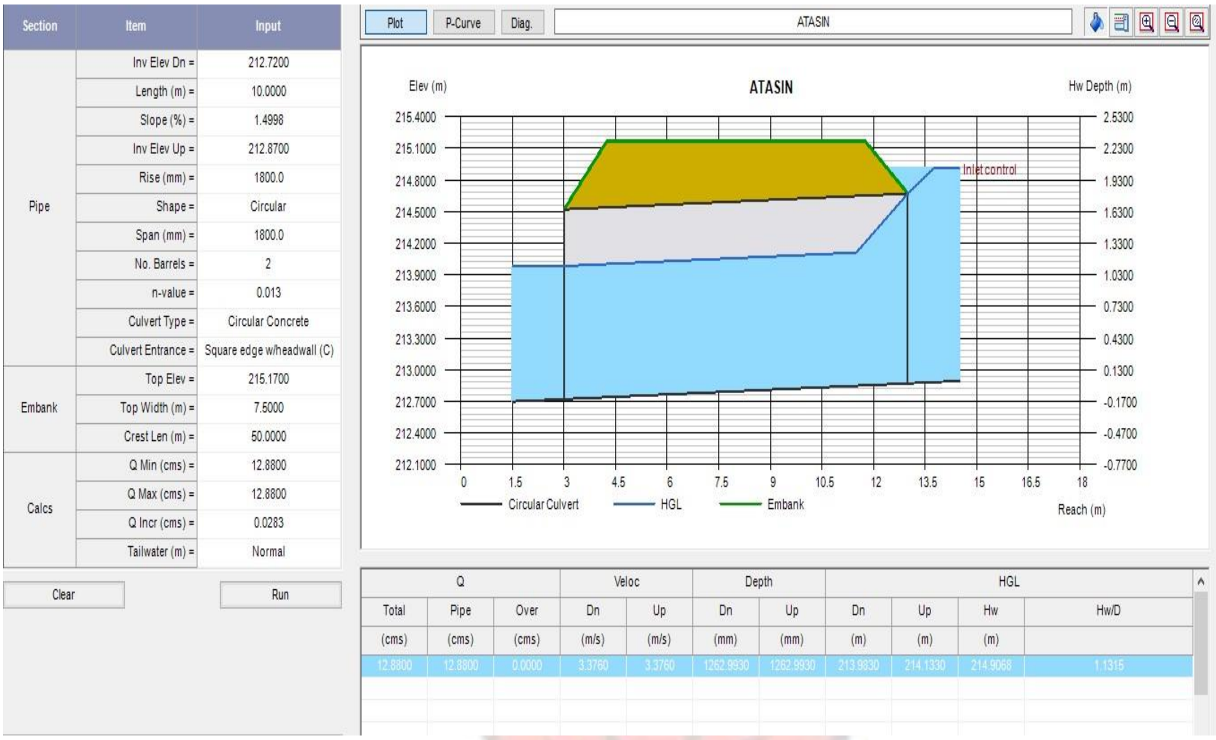


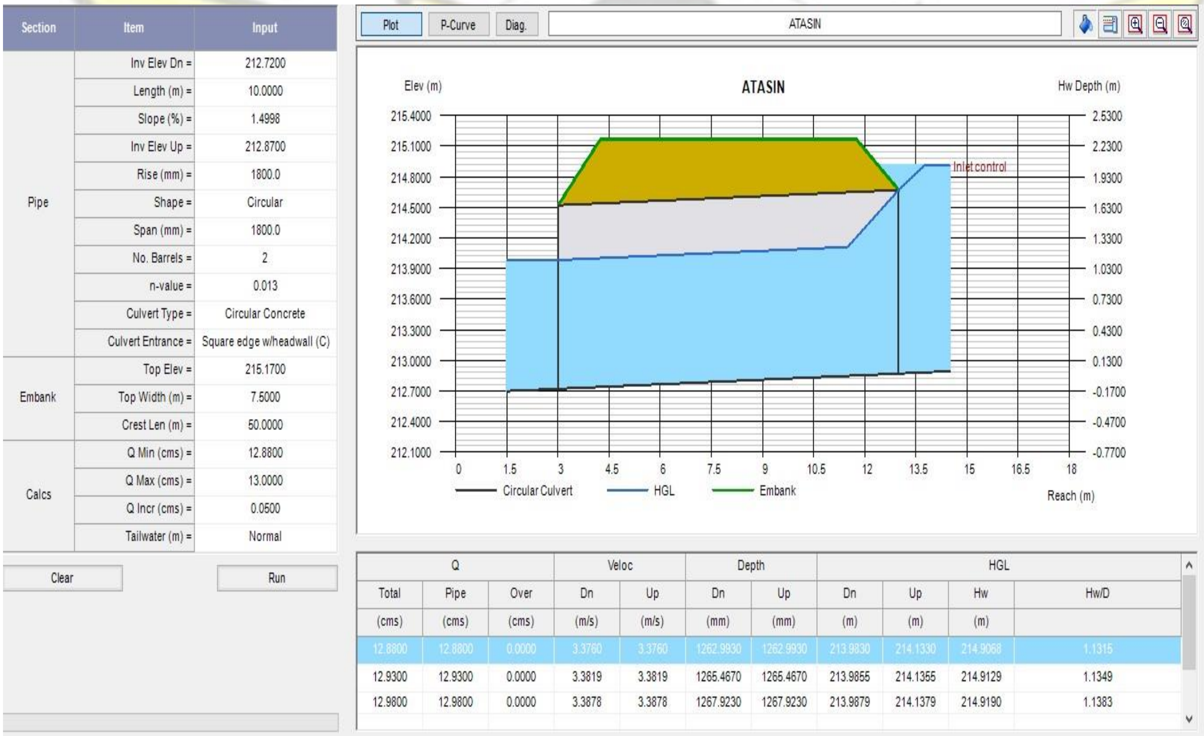
FIG …

Sizing of the culvert at the construction year 2010



Fig

Sizing of the culvert for almost 100% impervious



3.0 DATA

ROAD NAME; Kwasi Bonsu Ch 0+008

Area=0.414km^2 F = 1-0.001(log A) *(9*log N -0.042*P +152) = 0.8578

Rainfall intensity =117.74mm/hr   slope of culvert 1.5

Table ……

	YEAR	VEGETATION	SETTLEMENT	PERCENTAGE %
SUATEM(SUNTRESO)	2004	0.1854	0.2286	55.2173913
	2007	0.1296	0.2844	68.69565217
	2010	0.0918	0.3222	77.82608696
	2015	0.0369	0.3771	91.08695652
	TOTAL AREA =0.414Km^2			

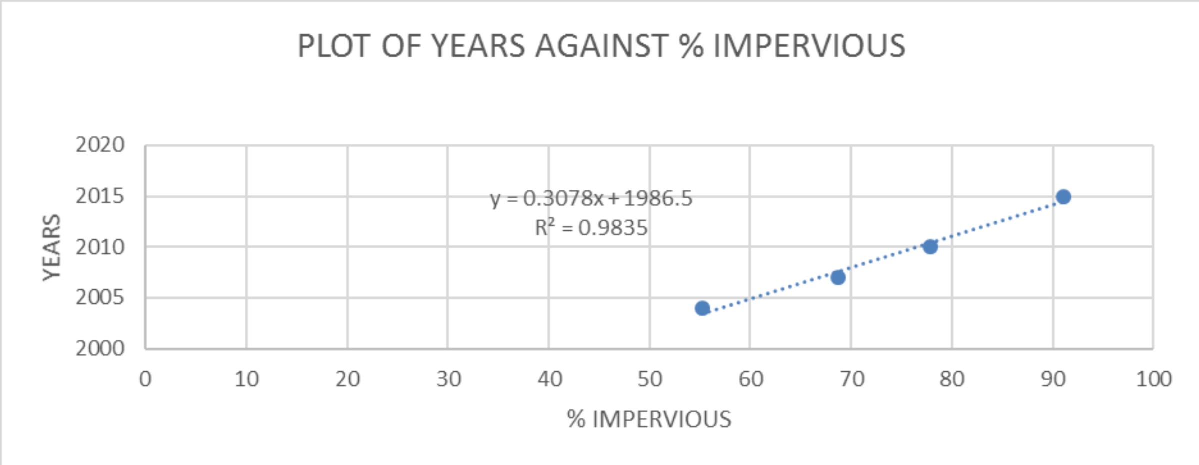


Fig.

Table 4.3: Computation of time of concentration

STATION	L (km)	H at culvert site(m)	H,at highest point on catchment (m)	A (km²)	$T_c = 0.975L/(A^{0.1}*S^{0.2})$
Suatem(Suntre-South Suntreso)	1.195196	259.08919	274.3200558	0.414	0.765044365

Table … Computation of Discharge

STREAM	YEAR	PERCENTAGE IP %	C =0.3+0.6**IP*,	**Q = 0.278 FCIA (m³/s)**
Suatem (Suntre-South Suntreso)	0-1987	0	0.3	3.487049596
	2014	89.34	0.83604	9.717709815

	2004	55.22	0.63132	7.338147171
	2007	68.7	0.7122	8.278255742
	2010	77.83	0.76698	8.914990998
	2015	91.09	0.84654	9.839756551
	2017	100	0.9	10.46114879

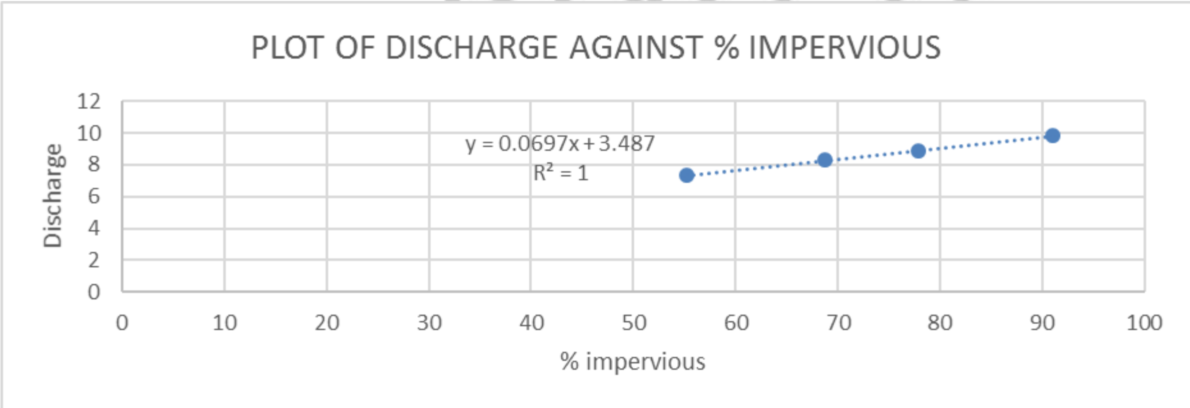
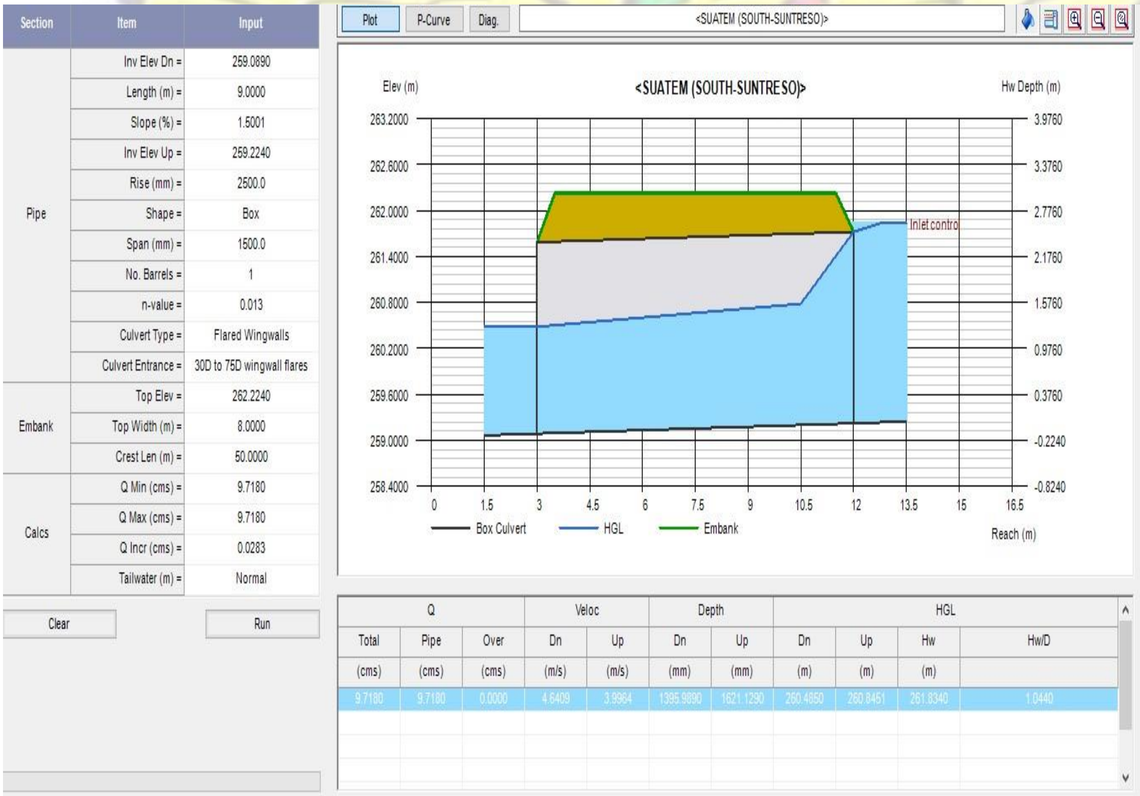
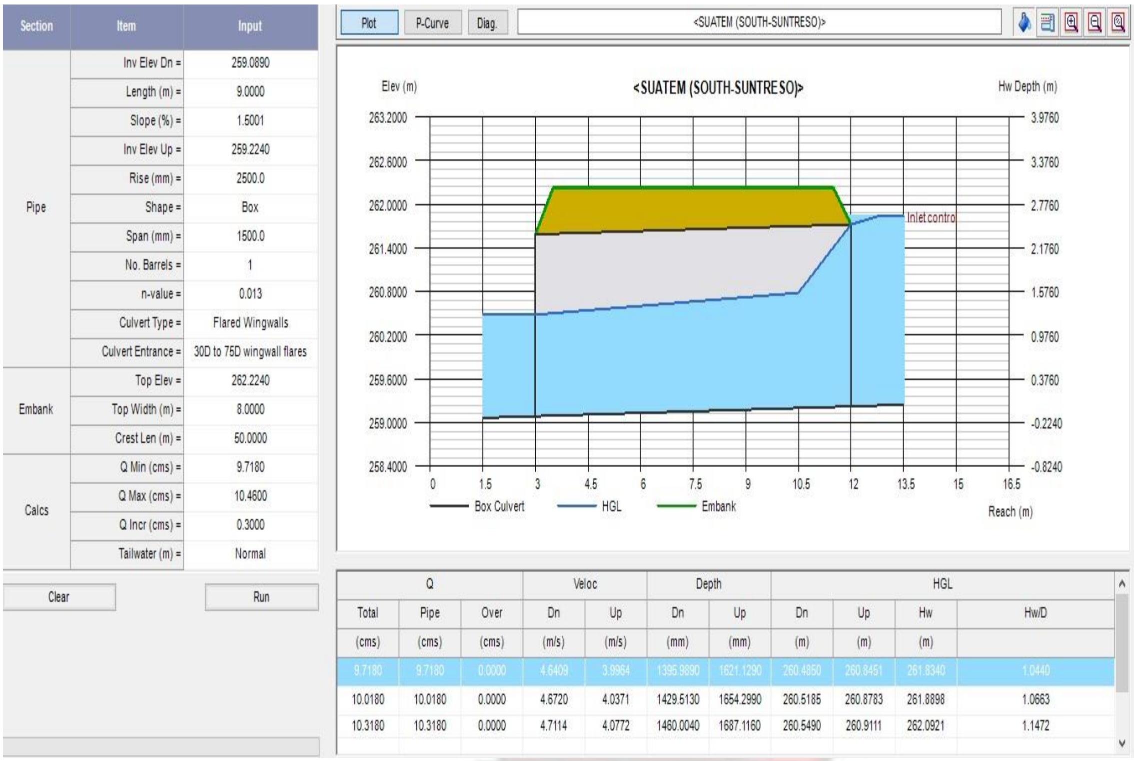


FIG …

Sizing of the culvert at the construction year 2010



Sizing of the culvert for almost 100% impervious



4.0 Data

ROAD NAME; Samuel Sarpong Draive Ch 0+750

Area=0.1971 F = 1-0.001(log A) *(9*log N -0.042*P +152) = 0.8634

Rainfall intensity = 154.9mm/hr slope of culvert 1.5

Table ……

	YEAR	VEGETATION	SETTLEMENT	PERCENTAGE %
	2004	0.0243	0.1728	87.67123288
	2007	0.0333	0.1638	83.10502283
	2010	0.0171	0.18	91.32420091
	2015	0	0.1971	100
PATA	TOTAL ARE =0.1971			

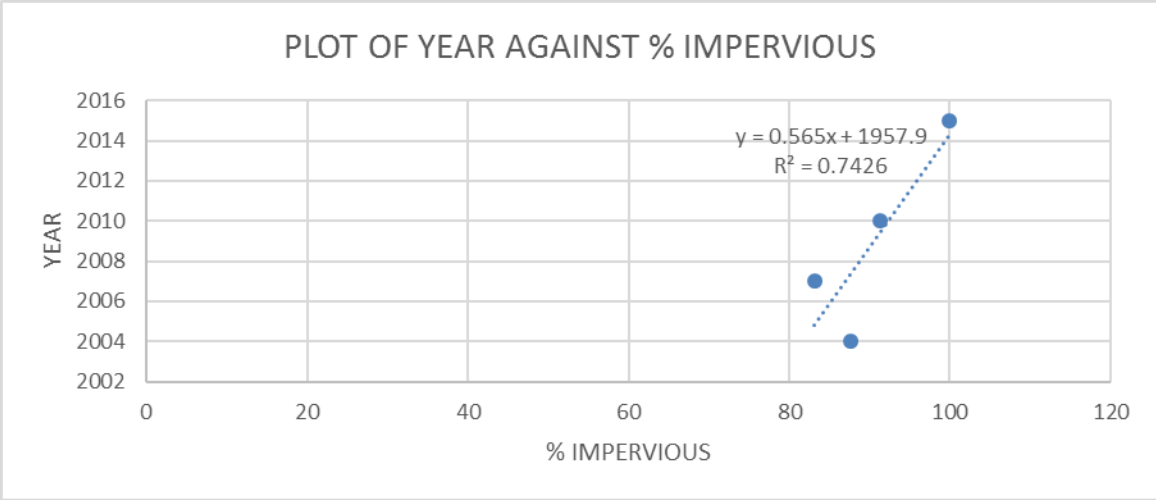


Fig.

Table 4.3: Computation of time of concentration

STATION	L (km)	H at culvert site(m)	H,at highest point on catchment (m)	A (km^2)	$T_c = 0.975L/ (A^{0.1}*S^{0.2})$
Pata	0.664225	259.101543	276.9650105	0.1971	0.394385611

Table … Computation of Discharge

STREAM	YEAR	PERCENTAGE IP %	C =0.3+0.6**IP*,	**Q = 0.278 FCIA (m^3/s)**
	0-1958	0	0.3	2.198395932
	*1999	72.74	0.73644	5.396622335
	2004	87.67	0.82602	6.05306336
	2007	83.11	0.79866	5.852569651
	2010	91.32	0.84792	6.213546263
Pata	2015	100	0.9	6.595187797

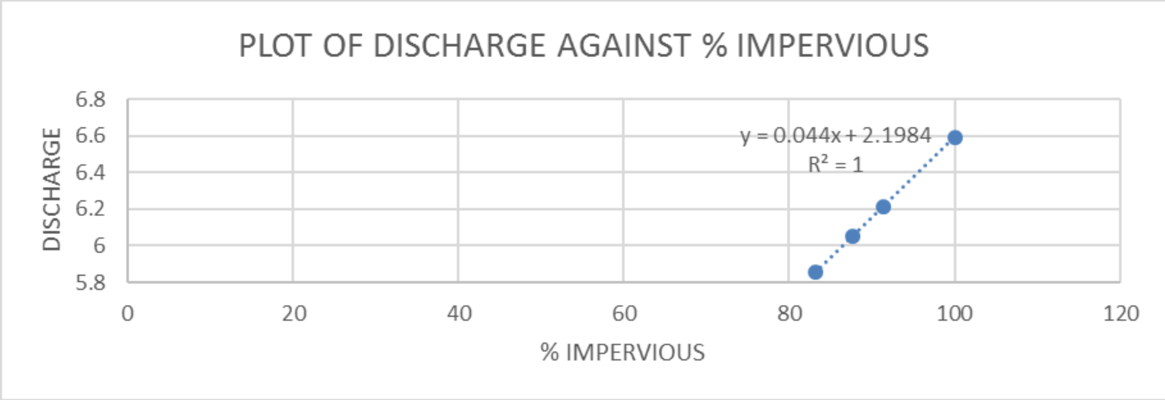
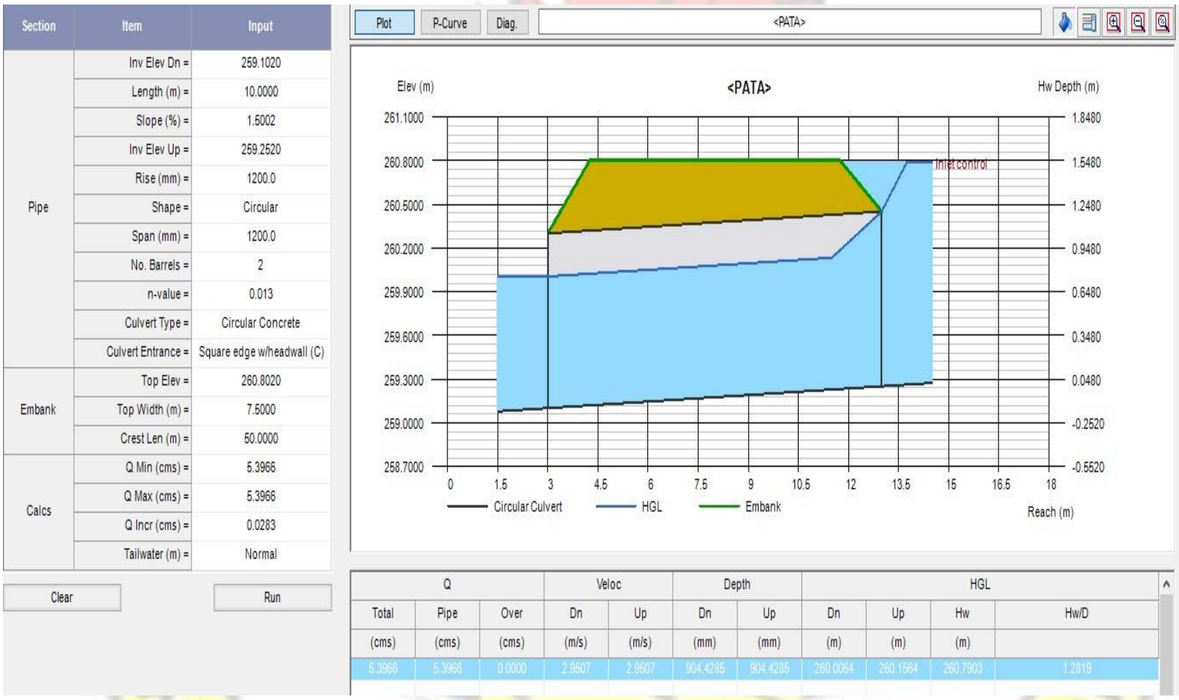


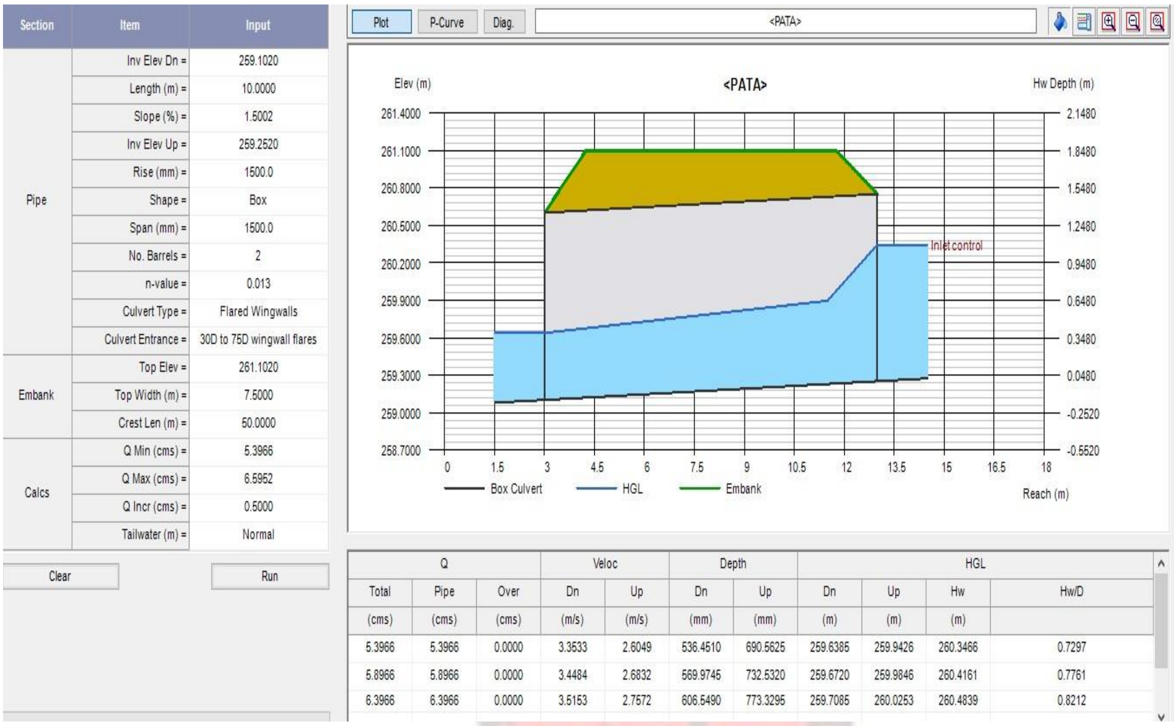
FIG …

Sizing of the culvert at the construction year 1999



Fig

Sizing of the culvert for almost 100% impervious



5.0 Data

ROAD NAME; Abusuakruwa RD Ch 0+900

Area=0.5643 F = 1-0.001(log A) *(9*log N -0.042*P +152) = 0.8564

Rainfall intensity = 124.74mm/hr slope of culvert 1.5

Table ……

	YEAR	VEGETATION	SETTLEMENT	PERCENTAGE % settlement
	2004	0.0063	0.558	98.88357257
	2007	0.0045	0.5598	99.20255183
	2010	0.0036	0.5607	99.36204147
	2015	0	0.5643	100
TATASI	TOTAL AREA =0.5643			

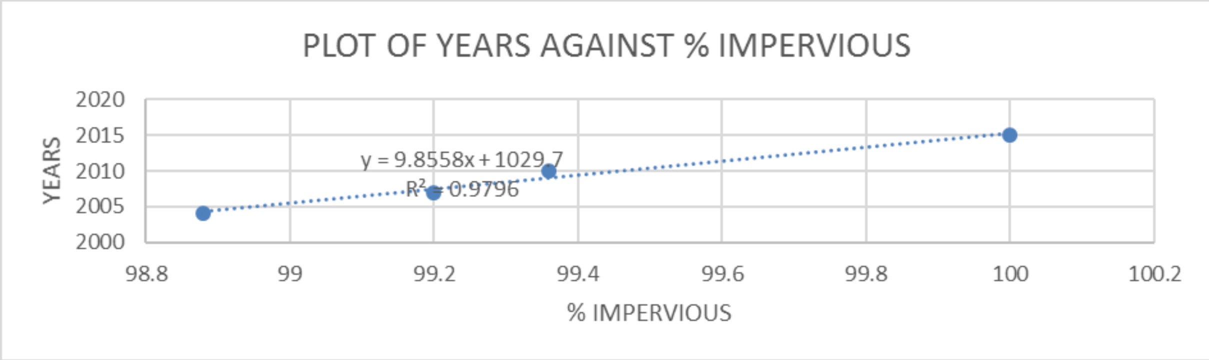


Fig.

Table 4.3: Computation of time of concentration

STATION	L (km)	H at culvert site(m)	H,at highest point on catchment (m)	A (km²)	$T_c = 0.975L/ (A^{0.1}*S^{0.2})$
Tatasi	1.393611	224.2663	281.4665033	0.5643	0.684453542

Table … Computation of Discharge

STREAM	YEAR	PERCENTAGE IP %	C =0.3+0.6**IP*,	**Q = 0.278 FCIA (m³/s)**
	0-1030	0	0.3	5.02737147
	*2002	98.65	0.8919	14.94637538
	2004	98.88	0.89328	14.96950129
	2007	99.2	0.8952	15.00167647
	2010	99.36	0.89616	15.01776405
Tatasi	2015	100	0.9	15.08211441

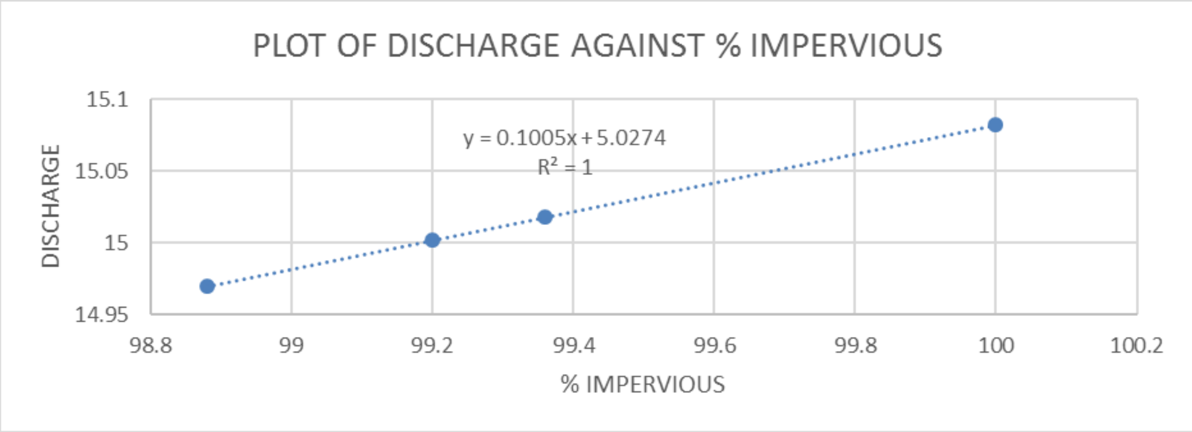
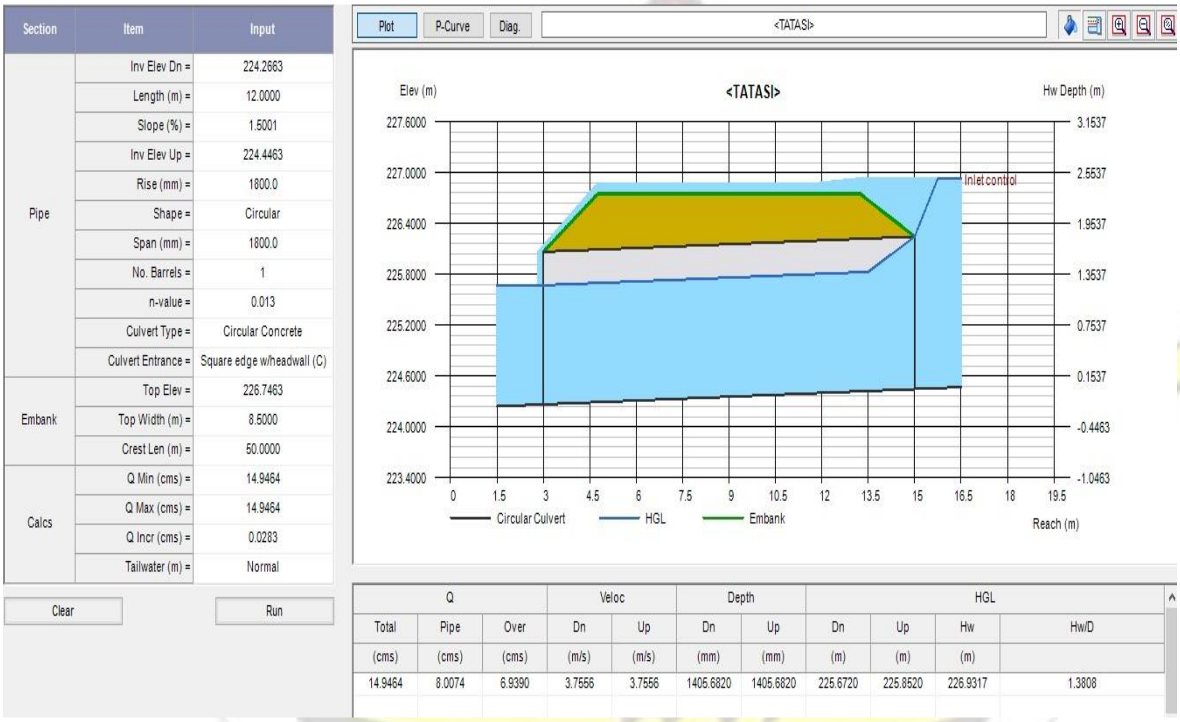


FIG …

Sizing of the culvert at the construction year 2002



Fig

Sizing of the culvert for almost 100% impervious

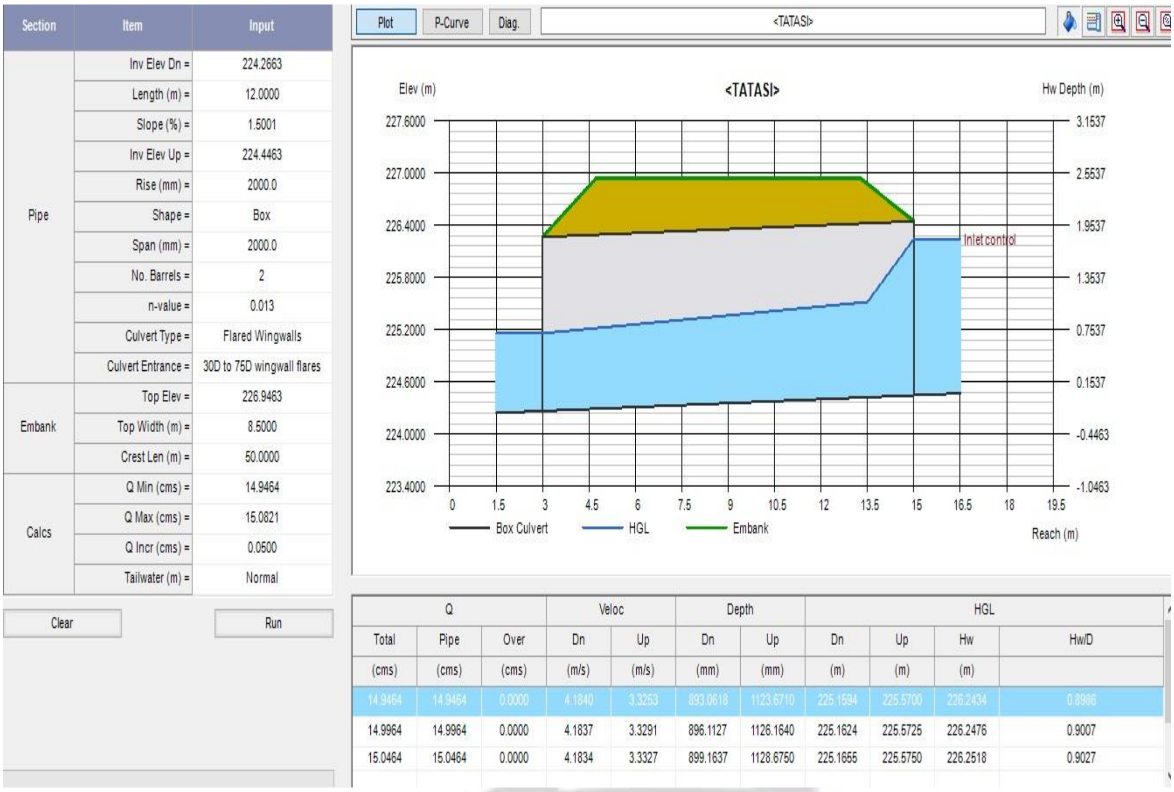


Fig.

6.0 DATA

ROAD NAME; Nwamase RD Ch 0+780

Area=0.108 F = 1-0.001(log A) *(9*log N -0.042*P +152) = 0.8666

Rainfall intensity = 154.9mm/hr slope of culvert 1.5

Table ……

	YEAR	VEGETATION	SETTLEMENT	PERCENTAGE %
	*2004	0.1044	0.0036	3.333333333
	2007	0.0945	0.0135	12.5
	2010	0.0396	0.0684	63.33333333
	2015	0	0.108	100
NWAM	TOTAL AREA =0.108			

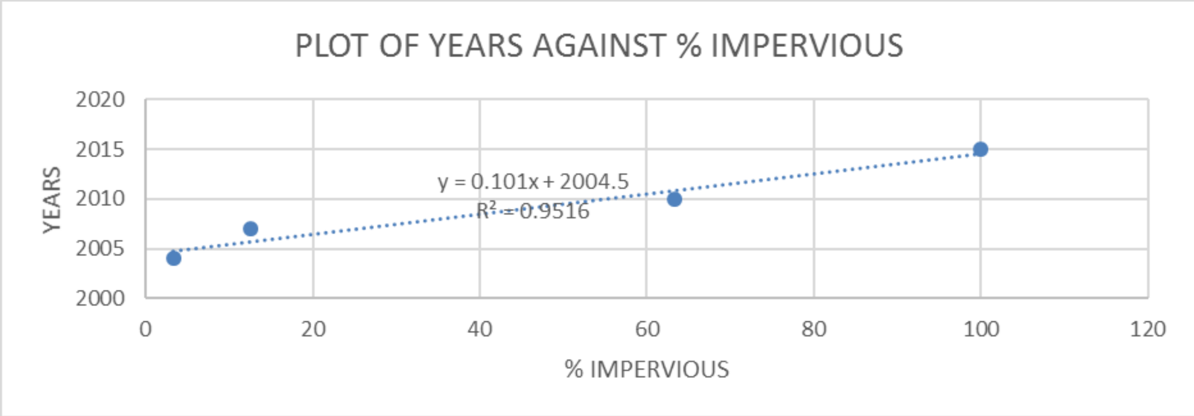


Fig.

Table 4.3: Computation of time of concentration

STATION	L (km)	H at culvert site(m)	H,at highest point on catchment (m)	A (km^2)	$T_c = 0.975L/ (A^{0.1}*S^{0.2})$
Nwam	0.613757	257.652776	270.4448133	0.108	0.407258393

Table … Computation of Discharge

STREAM	YEAR	PERCENTAGE IP %	C =0.3+0.6*IP,	**Q = 0.278 FCIA (m^3/s)**
	0-2003	0	0.3	1.209186679
	2004	3.33	0.31998	1.289718512
	2007	12.5	0.375	1.511483349
	2010	63.33	0.67998	2.740742526
Nwam	2015	100	0.9	3.627560037

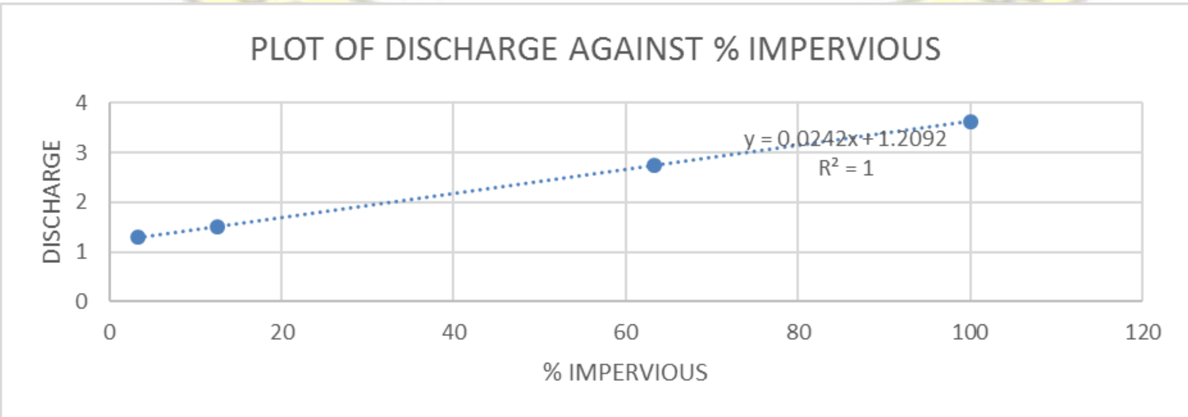
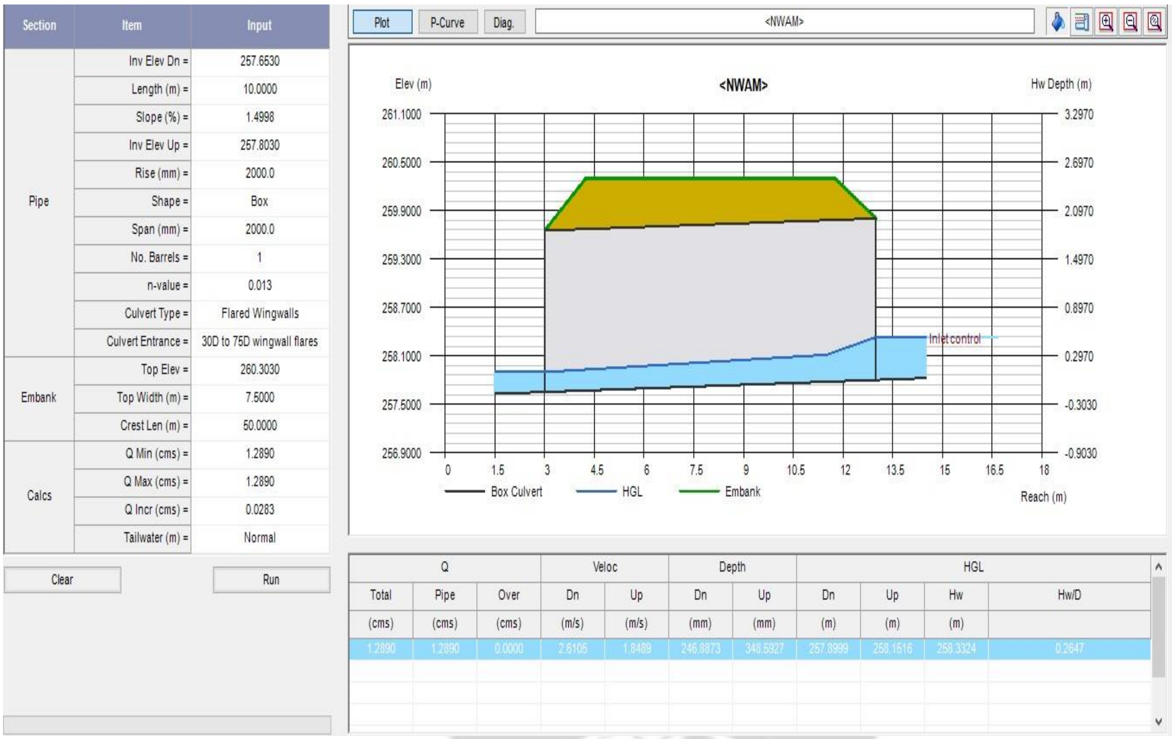


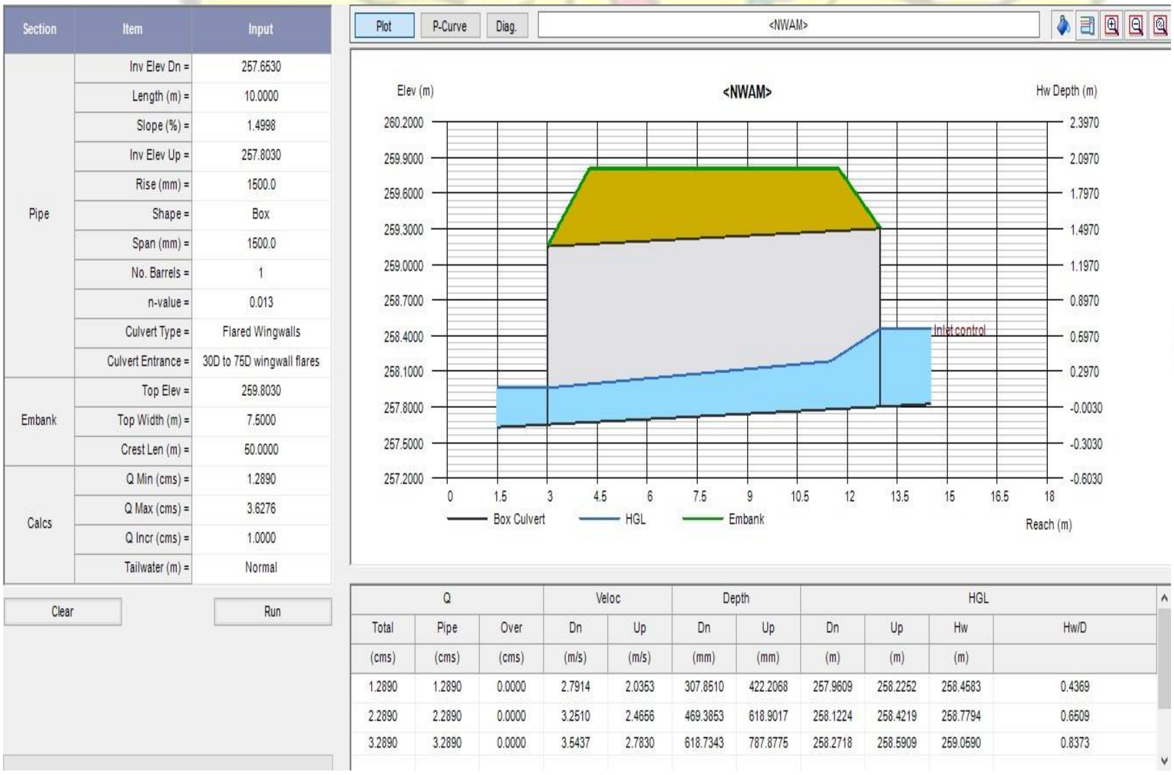
FIG …

Sizing of the culvert at the construction year 2004



Fig

Sizing of the culvert for almost 100% impervious



7.0 Data

Road Name; Barekese RD (Abrepo)   Ch 0+920

Area=0.7884 F = 1-0.001(log A) *(9*log N -0.042*P +152)

= 0.8527

Rainfall intensity = 81.28mm/hr slope of culvert 1.5

Table ……

	YEAR	VEGETATION	SETTLEMENT	PERCENTAGE %
AKUOSO (Abrepo)	2004	0.0351	0.7533	95.54794521
	2007	0.0693	0.7191	91.21004566
	2010	0.036	0.7524	95.43378995
	2015	0	0.7884	100
	TOTAL AREA= 0.7884			

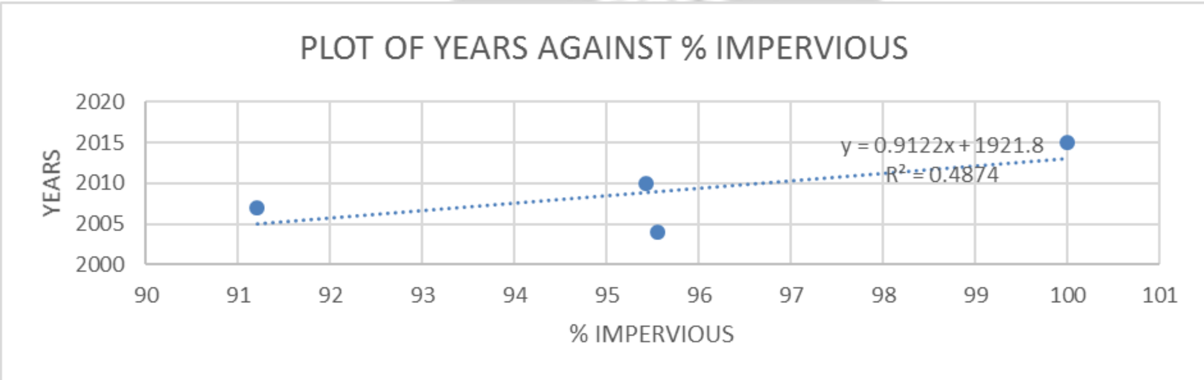


Fig.

Table 4.3: Computation of time of concentration

STATION	L (km)	H at culvert site(m)	H,at highest point on catchment (m)	A (km^2)	$T_c = 0.975L/(A^{0.1}*S^{0.2})$
Akuoso(Abrepo)	2.309471	259.108371	289.5566701	0.7884	1.376677965

Table … Computation of Discharge

STREAM	YEAR	PERCENTAGE IP %	C =0.3+0.6**IP*,	**Q = 0.278 FCIA (m^3/s)**

	0-1922	0	0.3	4.557211272
	*2008	94.5	0.867	13.17034058
	2004	95.55	0.8733	13.26604201
	2007	91.21	0.84726	12.87047607
	2010	95.43	0.87258	13.25510471
Akuoso(Abrepo)	2015	100	0.9	13.67163382

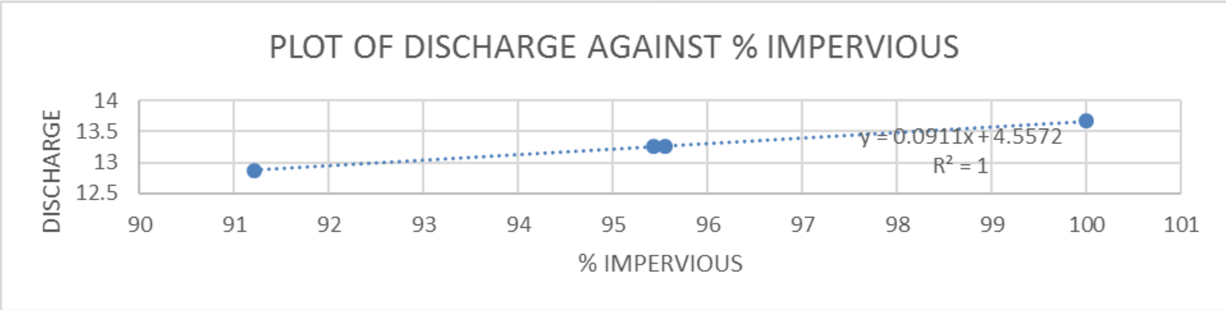
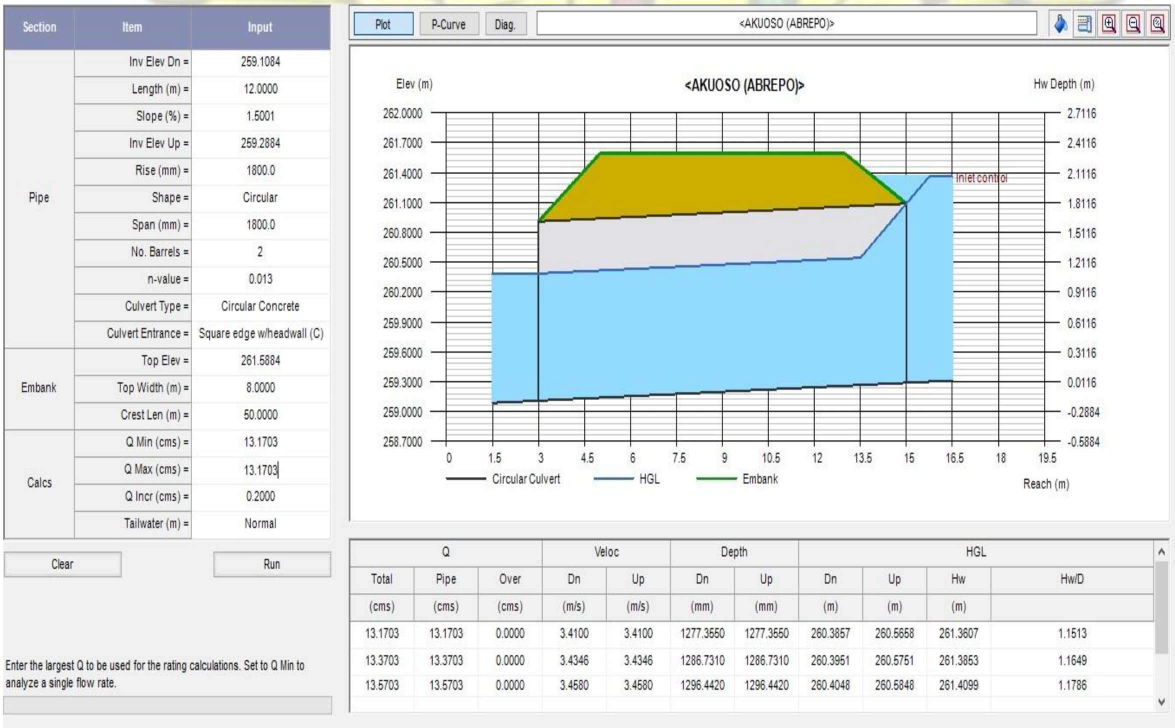


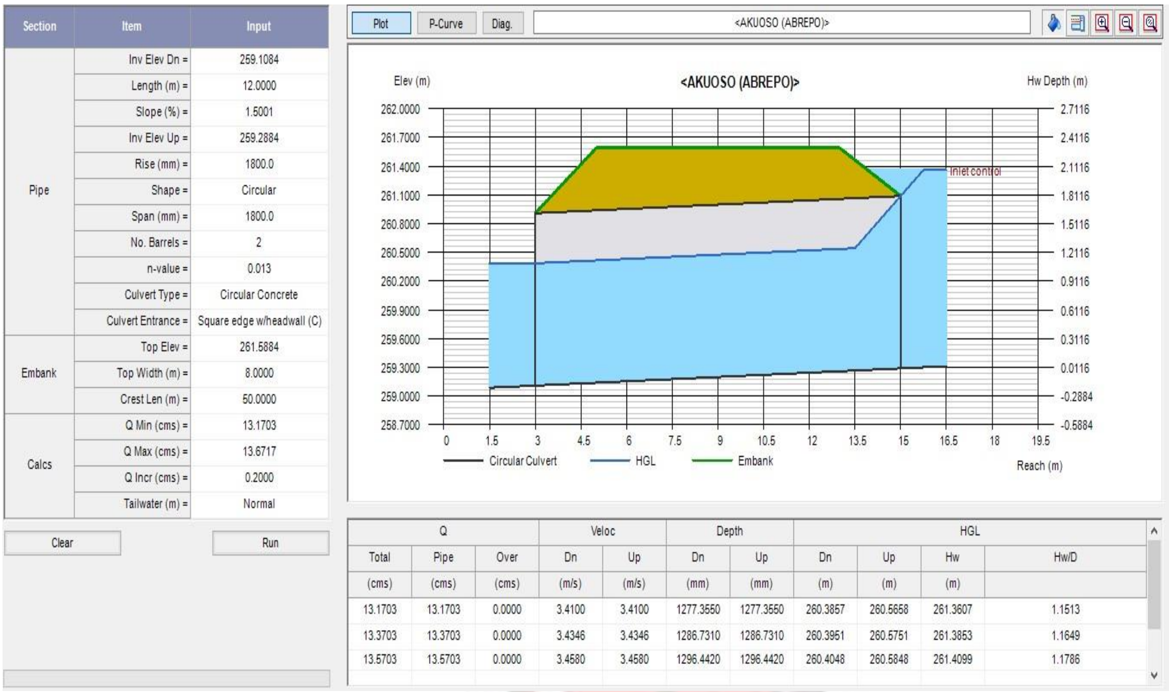
FIG …

Sizing of the culvert at the construction year 2008



Fig

Sizing of the culvert for almost 100% impervious



Fig

8.0 Data

Road Name; Barekese RD (Atafoa)   Ch 2+500

Area= 4.3371   F = 1-0.001(log A) *(9*log N -0.042*P +152) = 0.8415 Rainfall

intensity = 36.98mm/hr   slope of culvert 1.5

Table ……

	YEAR	VEGETATION	SETTLEMENT	PERCENTAGE %
	2004	0.8127	3.5244	80.50986842
	2007	0.6858	3.6513	83.40871711
	2010	0.5148	3.8223	87.31496711
	2015	0.3411	3.996	91.28289474
ANYINASU	TOTAL AREA= 4.3371			

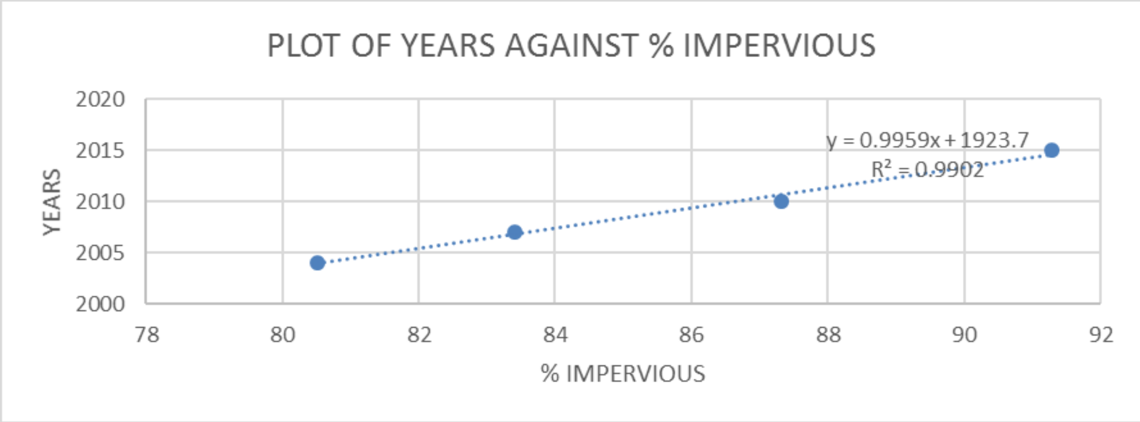


Fig.

Table 4.3: Computation of time of concentration

STATION	L (km)	H at culvert site(m)	H,at highest point on catchment (m)	A (km^2)	$T_c = 0.975L/ (A^{0.1}*S^{0.2})$
Anyinasu	5.869179	252.938124	263.5570103	4.3371	4.38896082

Table … Computation of Discharge

STREAM	YEAR	PERCENTAGE IP %	C =0.3+0.6**IP*,	**Q = 0.278 FCIA (m^3/s)**
	0-1924	0	0.3	11.25654799
	*2008	84.65	0.8079	30.31388373
	2004	80.51	0.78306	29.38184156
	2007	83.41	0.80046	30.03472134
	2010	87.31	0.82386	30.91273208
	2015	91.28	0.84768	31.80650199
ANYINASU	-	100	0.9	33.76964396

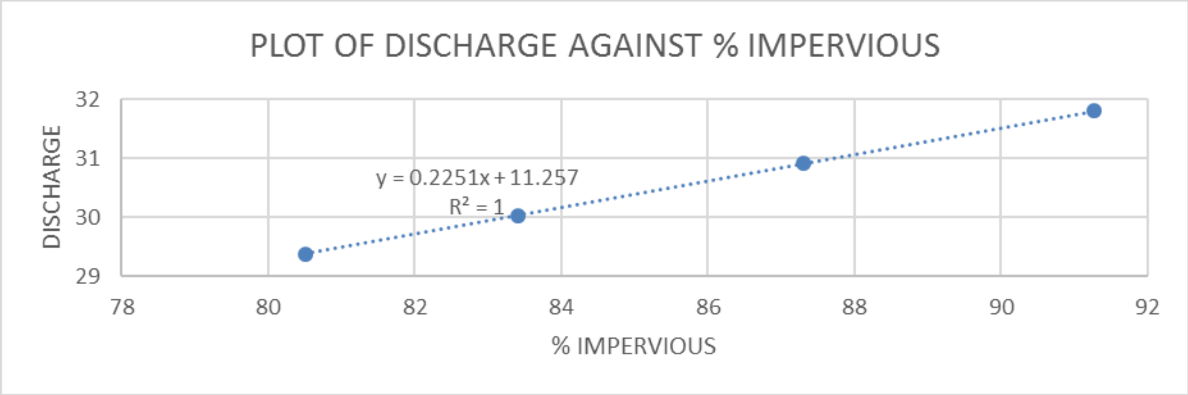
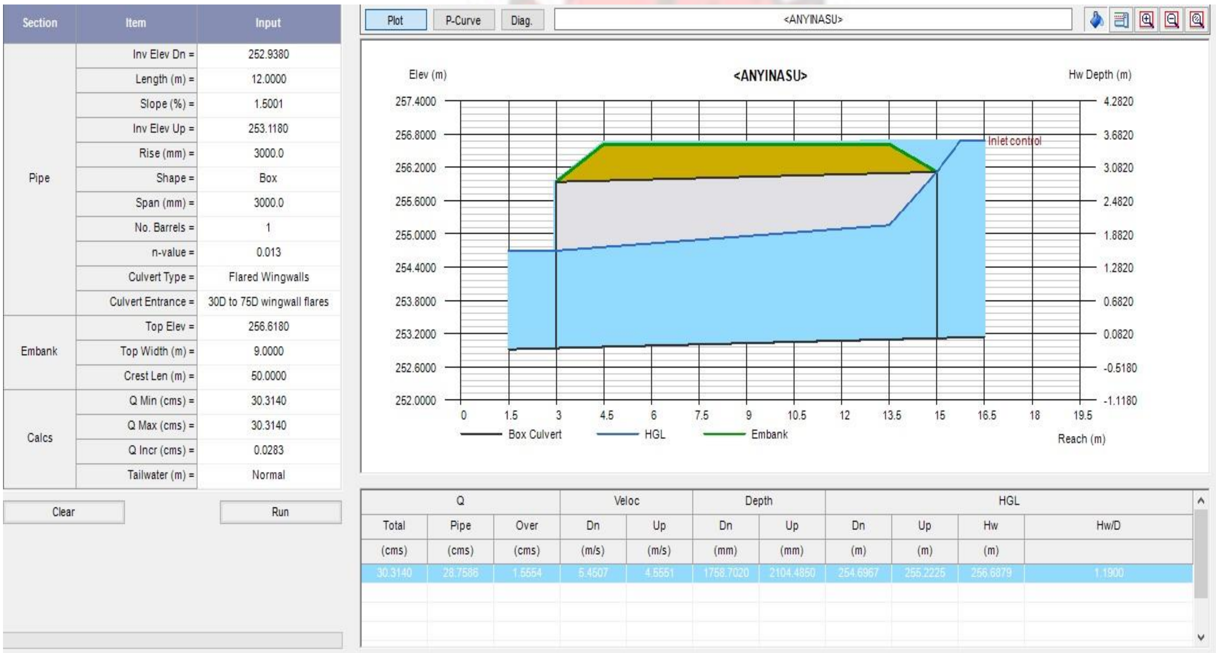


FIG …

Sizing of the culvert at the construction year 2008

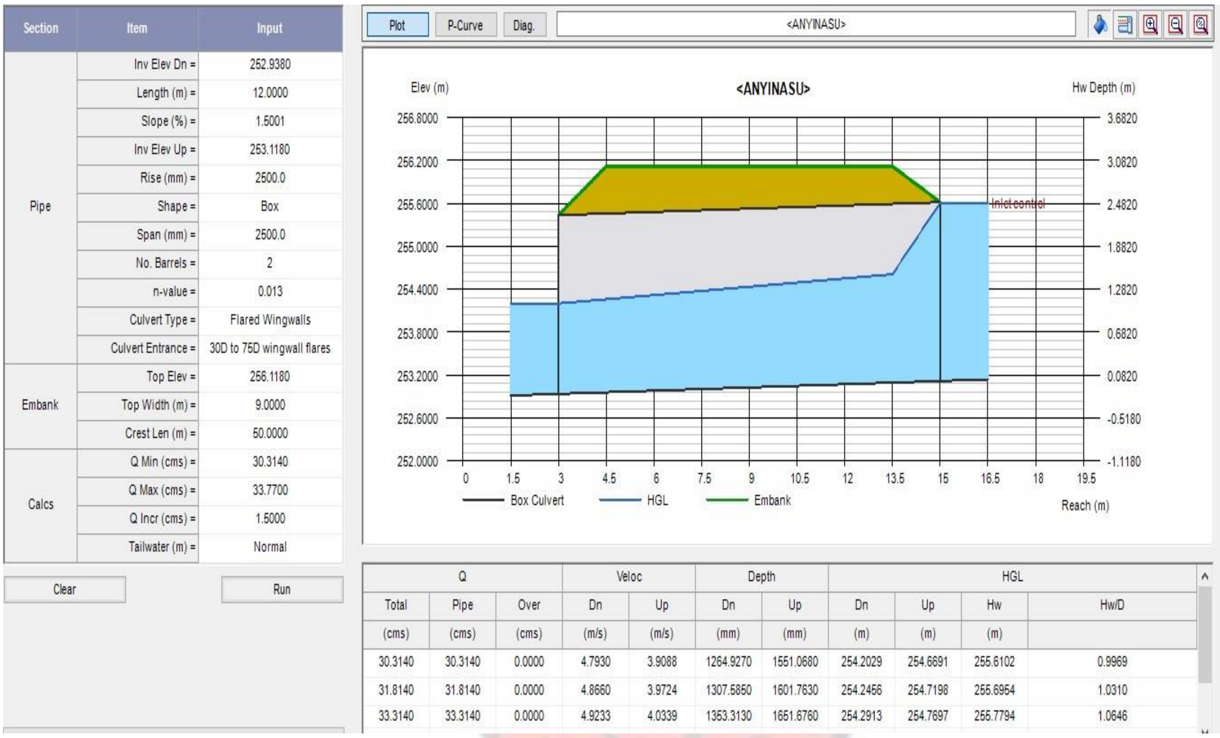


Section	Item	Input
Pipe	Inv Elev Dn =	252.9380
	Length (m) =	12.0000
	Slope (%) =	1.5001
	Inv Elev Up =	253.1180
	Rise (mm) =	3000.0
	Shape =	Box
	Span (mm) =	3000.0
	No. Barrels =	1
	n-value =	0.013
	Culvert Type =	Flared Wingwalls
	Culvert Entrance =	30D to 75D wingwall flares
Embank	Top Elev =	256.6180
	Top Width (m) =	9.0000
	Crest Len (m) =	50.0000
Calcs	Q Min (cms) =	30.3140
	Q Max (cms) =	30.3140
	Q Incr (cms) =	0.0283
	Tailwater (m) =	Normal

Q			Veloc		Depth		HGL			
Total	Pipe	Over	Dn	Up	Dn	Up	Dn	Up	Hw	Hw/D
(cms)	(cms)	(cms)	(m/s)	(m/s)	(mm)	(mm)	(m)	(m)	(m)	
30.3140	28.7586	1.5554	5.4507	4.5551	1758.7020	2104.4850	254.6967	255.2225	256.6879	1.1900

Fig

Sizing of the culvert for almost 100% impervious



Fig

9.0 Data

Road Name; Islamic -Anomangye Ch 0+950

Area=1.0026 F = 1-0.001(log A) *(9*log N -0.042*P +152) = 0.8514 Rainfall intensity = 80.6mm/hr slope of culvert 1.5

Table ……

	YEAR	VEGETATION	SETTLEMENT	PERCENTAGE %
AKUOSO-ISLAMIC	2004	0.036	0.9666	96.40933573
	2007	0.0693	0.9333	93.08797127
	2010	0.036	0.9666	96.40933573
	2015	0	1.0026	100
	TOTAL AREA =1.0026			

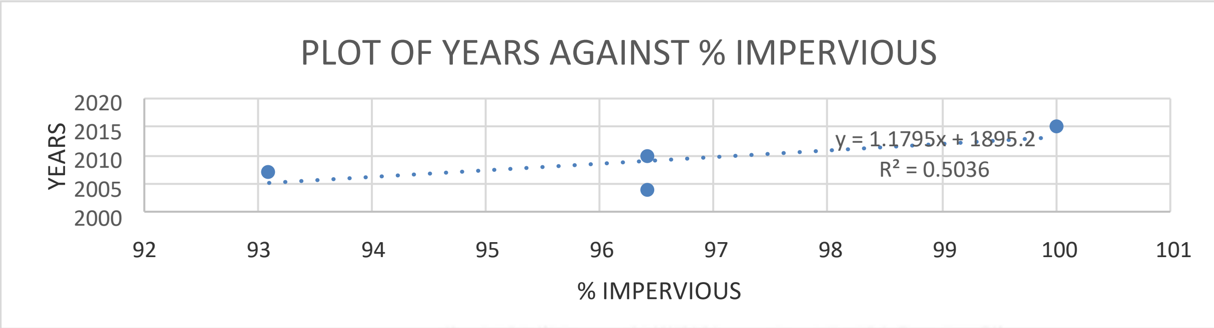


Fig.

Table 4.3: Computation of time of concentration

STATION	L (km)	H at culvert site(m)	H,at highest point on catchment (m)	A (km²)	$T_c = 0.975L/(A_{0.1}*S_{0.2})$
Akuoso(Islamic Annomannye)	2.3916	259.072094	289.5566701	1.0026	1.40120625

Table … Computation of Discharge

STREAM	YEAR	PERCENTAGE IP %	C =0.3+0.6**IP*,	**Q = 0.278 FCIA (m³/s)**
Akuoso(Islamic Annomannye)	0-1896	0	0.3	5.737829667
	*2000	88.85	0.8331	15.93395298
	2004	96.41	0.87846	16.80151283
	2007	93.09	0.85854	16.42052094
	2010	96.41	0.87846	16.80151283
	2015	100	0.9	17.213489

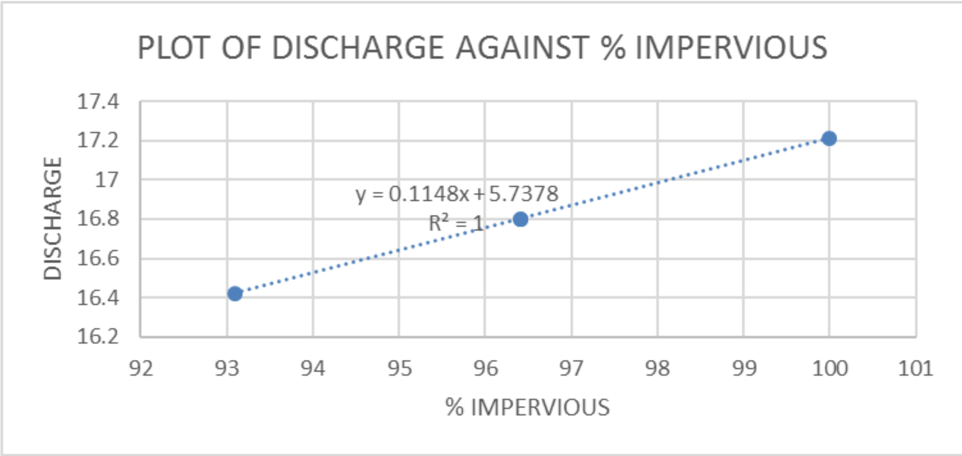
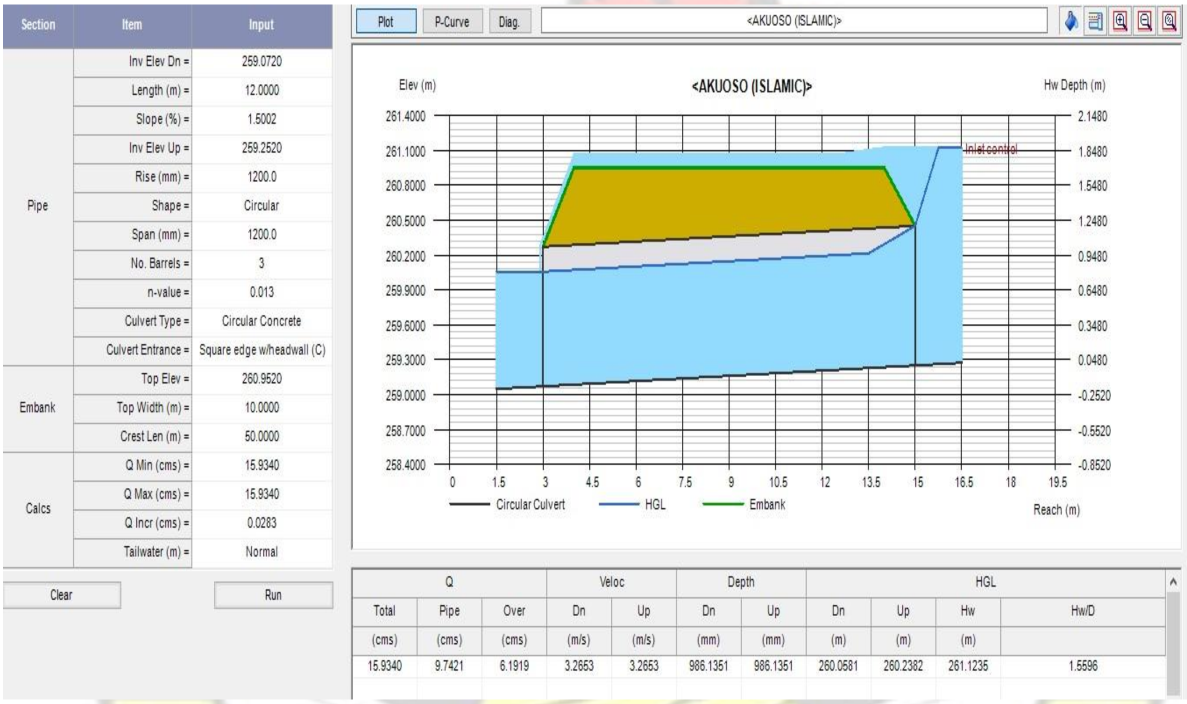


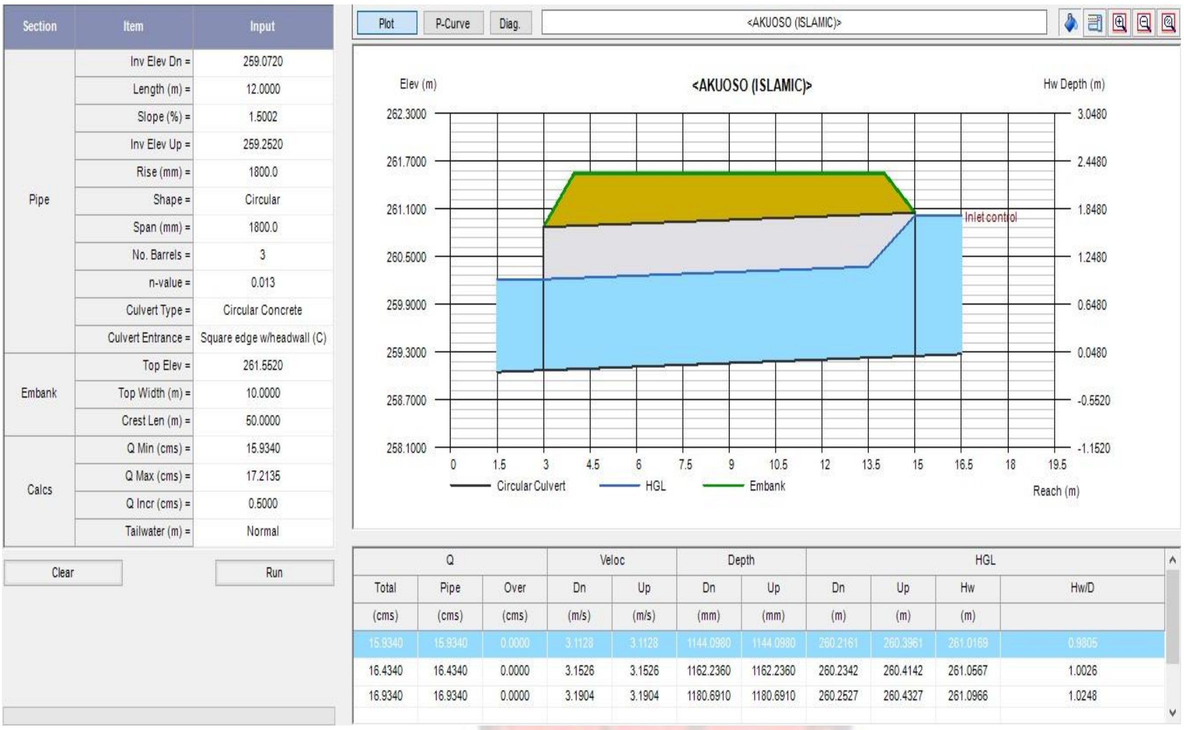
FIG …

Sizing of the culvert at the construction year 2010



Fig

Sizing of the culvert for almost 100% impervious



Fig

10.0 DATA

ROAD NAME; Nurses Quarters RD Ch 0+220

Area=2.9943 F = 1-0.001(log A) *(9*log N -0.042*P +152)

= 0.845

Rainfall intensity = 76.52mm/hr slope of culvert 1.5

Table ……

	YEAR	VEGETATION	SETTLEMENT	PERCENTAGE %
PUNPUNASI 2(KOTO)	2004	0.3123	2.682	89.57018335
	2007	0.1971	2.7972	93.41749324
	2010	0.0603	2.934	97.98617373
	2015	0.1206	2.8737	95.97234746
	TOTAL AREA=2.9943			

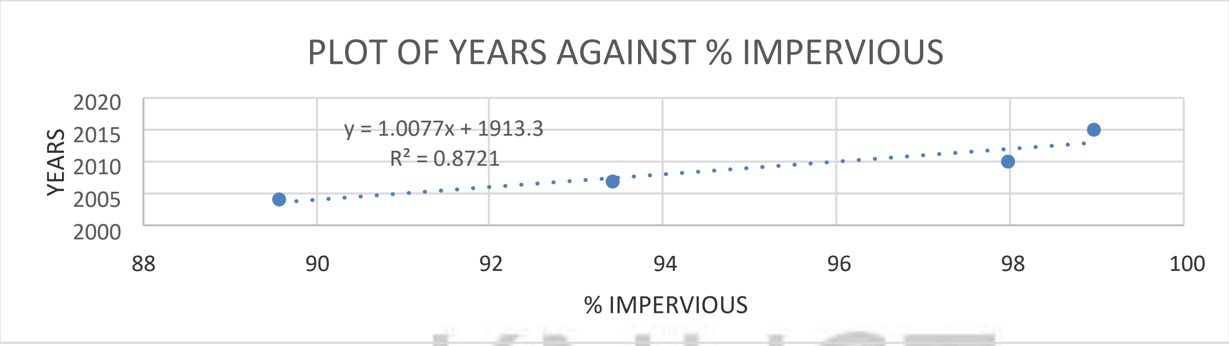


Fig.

Table 4.3: Computation of time of concentration

STATION	L (km)	H at culvert site(m)	H,at highest point on catchment (m)	A (km^2)	$T_c = 0.975L/(A_{0.1}*S_{0.2})$
Punpunasi_2(KOTO)	2.851826	259.071256	293.1577711	2.9943	1.517072003

Table … Computation of Discharge

STREAM	YEAR	PERCENTAGE IP %	C =0.3+0.6**IP*,	**Q = 0.278 FCIA (m^3/s)**
	0-1914	0	0.3	16.15127385
	2004	89.57	0.83742	45.08466582
	*2007	93.42	0.86052	46.3283139
	2010	97.99	0.88794	47.80454033
Punpunasi_2(koto)	2015	98.97	0.89382	48.1211053

Q_{100}=48.4582**m^3/s**

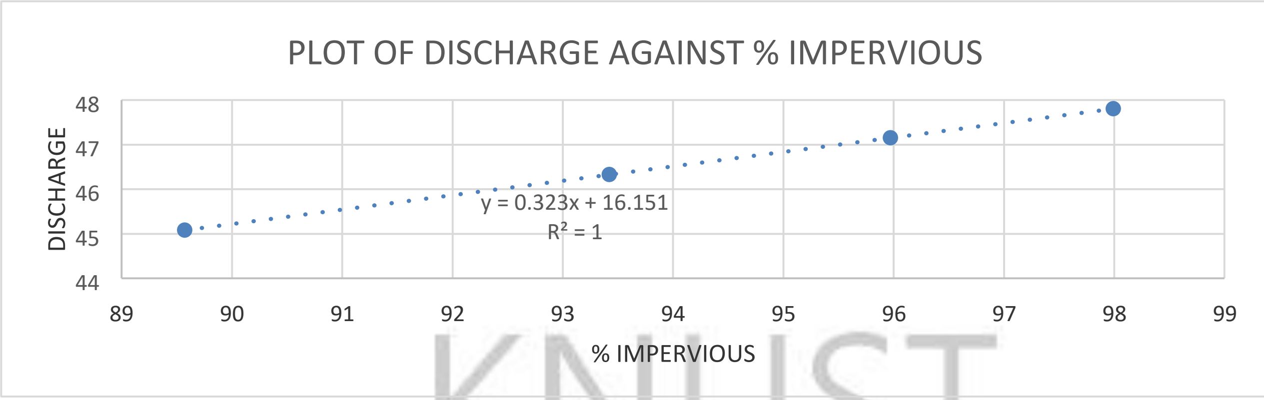
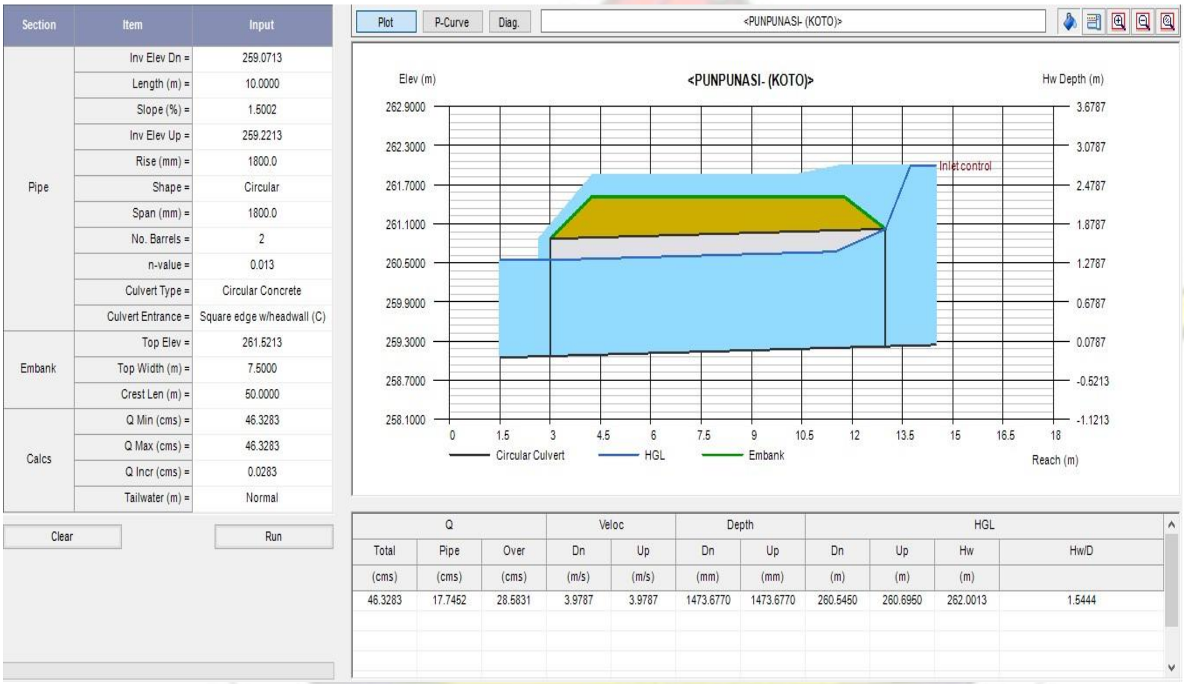


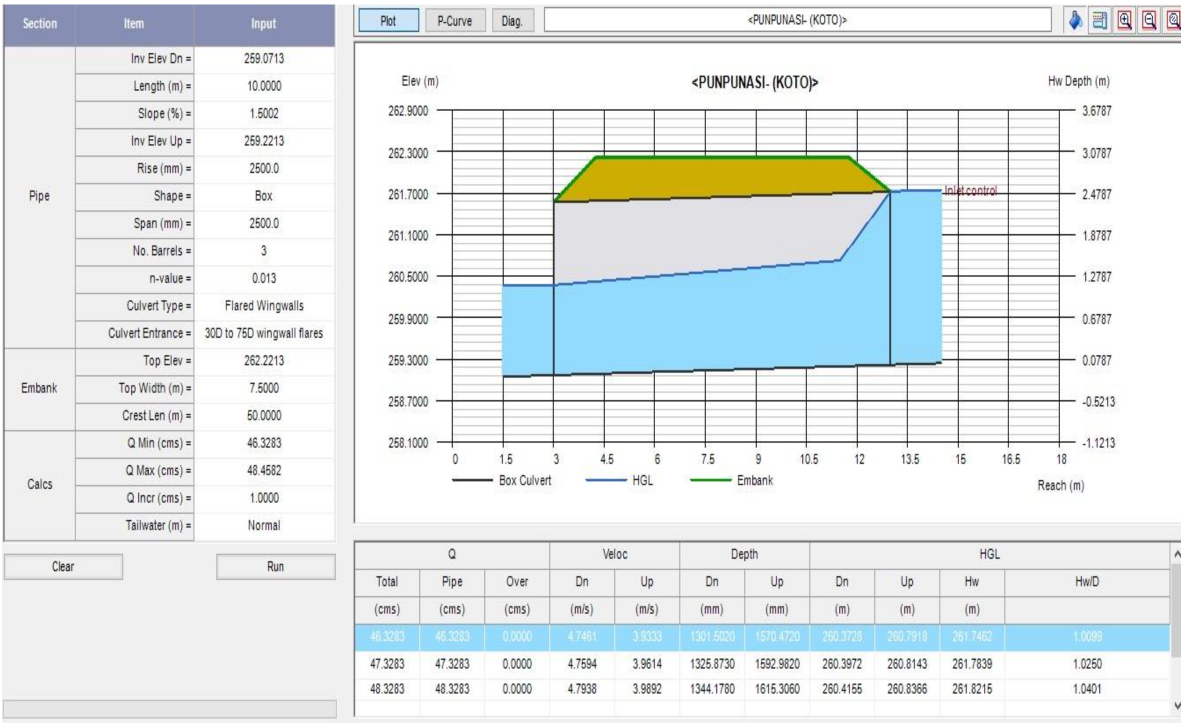
FIG …

Sizing of the culvert at the construction year 2007



Fig

Sizing of the culvert for almost 100% impervious



Fig

<u>11.0 Data</u>

Road Name; Archbishop Sarpong (TUC)   Ch 0+012

Area= 4.1913   F = 1-0.001(log A) *(9*log N -0.042*P +152) = 0.8428

Rainfall intensity = 62.62mm/hr   slope of culvert 1.5

Table ……

	YEAR	VEGETATION	SETTLEMENT	PERCENTAGE %
	2004	1.9035	2.2878	54.58449646
	2007	1.5615	2.6298	62.74425596
	2010	0.6156	3.5757	85.3124329
	2015	0.3708	3.8205	91.15310286
SUATEM (KWADA-TUC)	TOTAL AREA=4.1913			

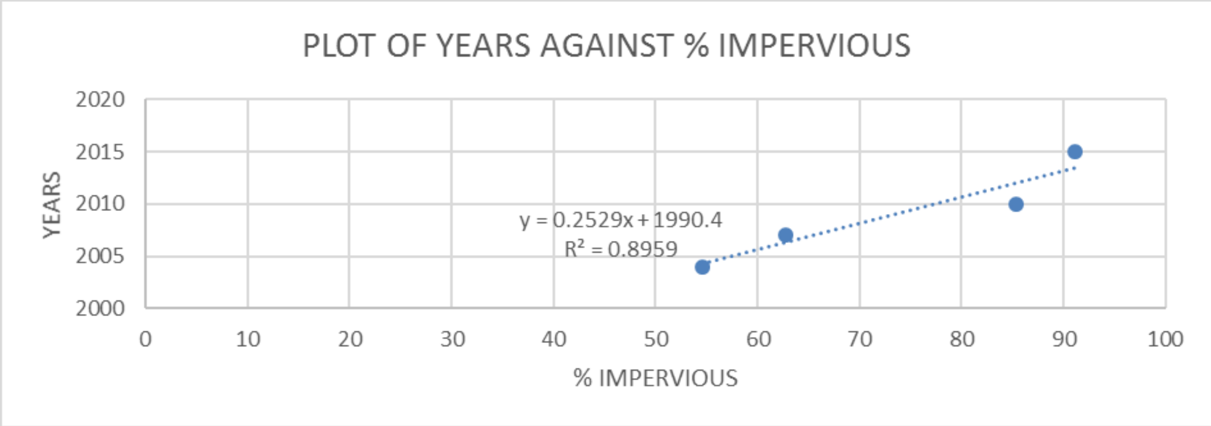


Fig.

Table 4.3: Computation of time of concentration

STATION	L (km)	H at culvert site(m)	H,at highest point on catchment (m)	A (km^2)	$T_c = 0.975L/(A_{0.1}*S_{0.2})$
Suatem(KWADA-T.U.C.)	4.104637	228.936724	277.6332674	4.1913	2.114461684

Table … Computation of Discharge

STREAM	YEAR	PERCENTAGE IP %	C =0.3+0.6**IP*,	**Q = 0.278 FCIA (m^3/s)**
Suatem(KWADA-T.U.C.)	0-1991	0	0.3	18.44813126
	2004	54.58	0.62748	38.58611135
	2007	62.74	0.67644	41.59684637
	2010	85.31	0.81186	49.92433282
	2015	91.15	0.8469	52.07907455
	2016	100	0.9	55.34439378

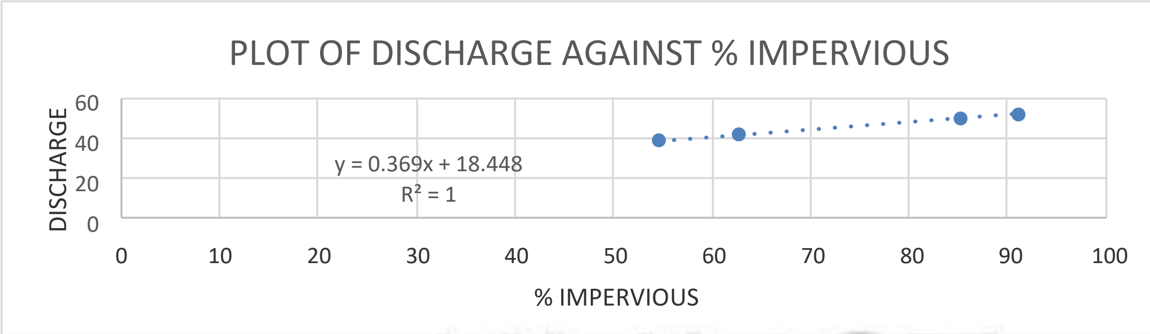
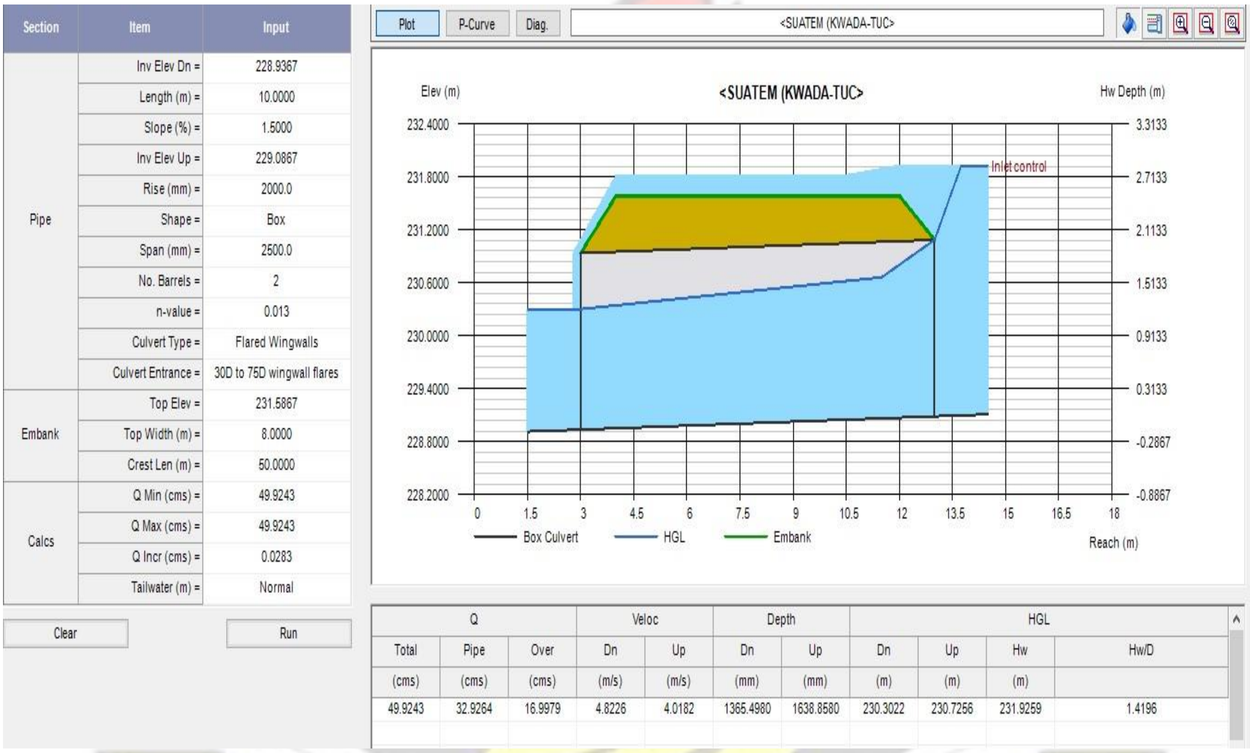


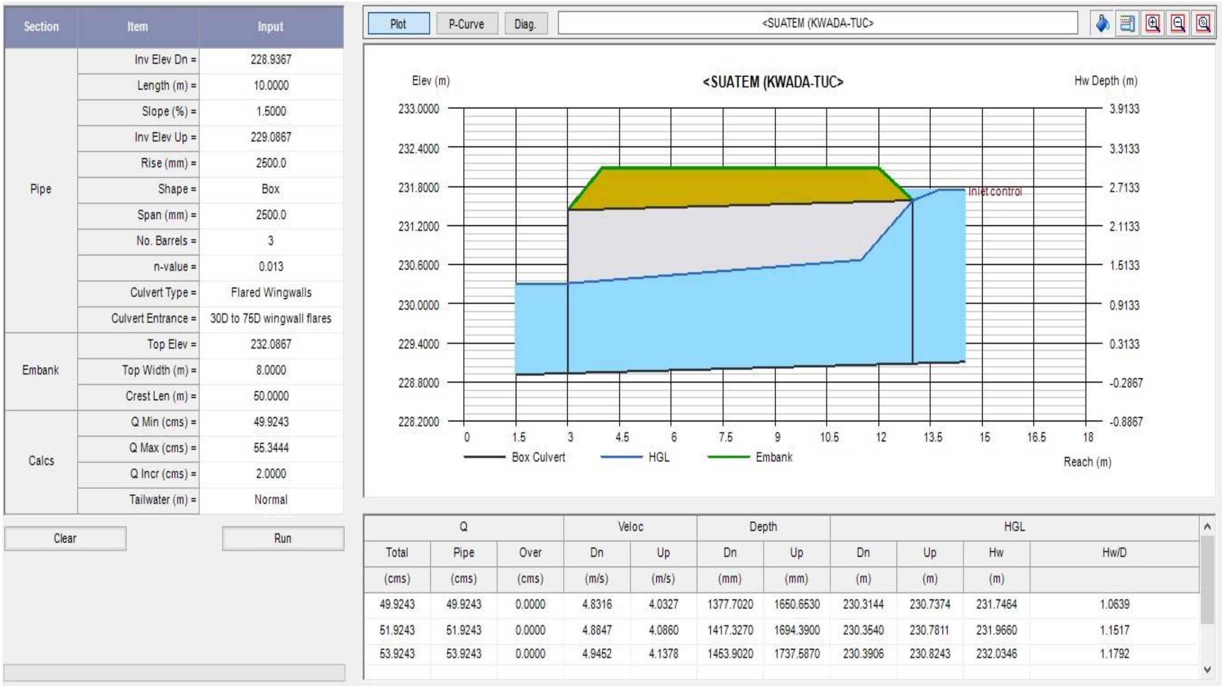
FIG …

Sizing of the culvert at the construction year 2010



Fig

Sizing of the culvert for almost 100% impervious



Fig

12.0 DATA

ROAD NAME; The Dish RD Ch 0+280

Area=0.3843 F = 1-0.001(log A) *(9*log N -0.042*P +152)

= 0.8583

Rainfall intensity = 120.06mm/hr slope of culvert 1.5

Table ……

	YEAR	VEGETATION	SETTLEMENT	PERCENTAGE %
	2004	0.0792	0.3051	79.3911007
	2007	0.05581	0.3285	85.48009368
	2010	0.0288	0.3555	92.5058548
	2015	0	0.3843	100
PUNPUNASI (AMPA)	TOTAL AREA =0.3843			

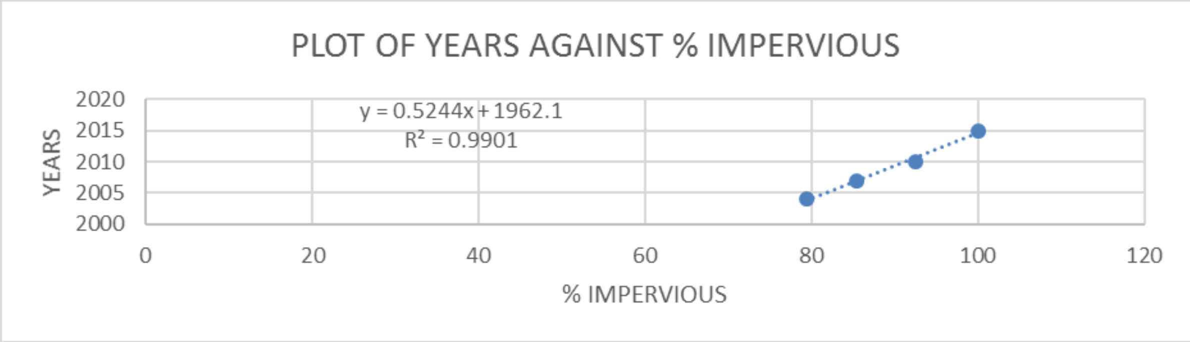


Fig.

Table 4.3: Computation of time of concentration

STATION	L (km)	H at culvert site(m)	H,at highest point on catchment (m)	A (km^2)	$T_c = 0.975L/(A_{0.1} * S_{0.2})$
Punpunasi_1(Ampa)	1.283201	259.14483	289.474368	0.3843	0.731337858

Table … Computation of Discharge

STREAM	YEAR	PERCENTAGE IP %	C =0.3+0.6**IP*,	**Q = 0.278 FCIA (m^3/s)**
	0-1962	0	0.3	3.30261296
	*2005	81.81	0.79086	8.706348286
	2004	79.39	0.77634	8.546501819
	2007	85.48	0.81288	8.948760078
	2010	92.51	0.85506	9.41310746
Punpunasi_1(ampa)	2015	100	0.9	9.907838881

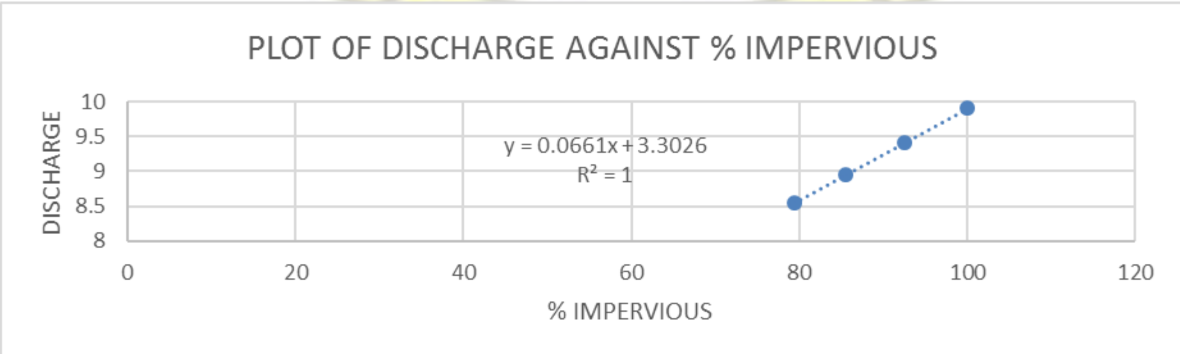
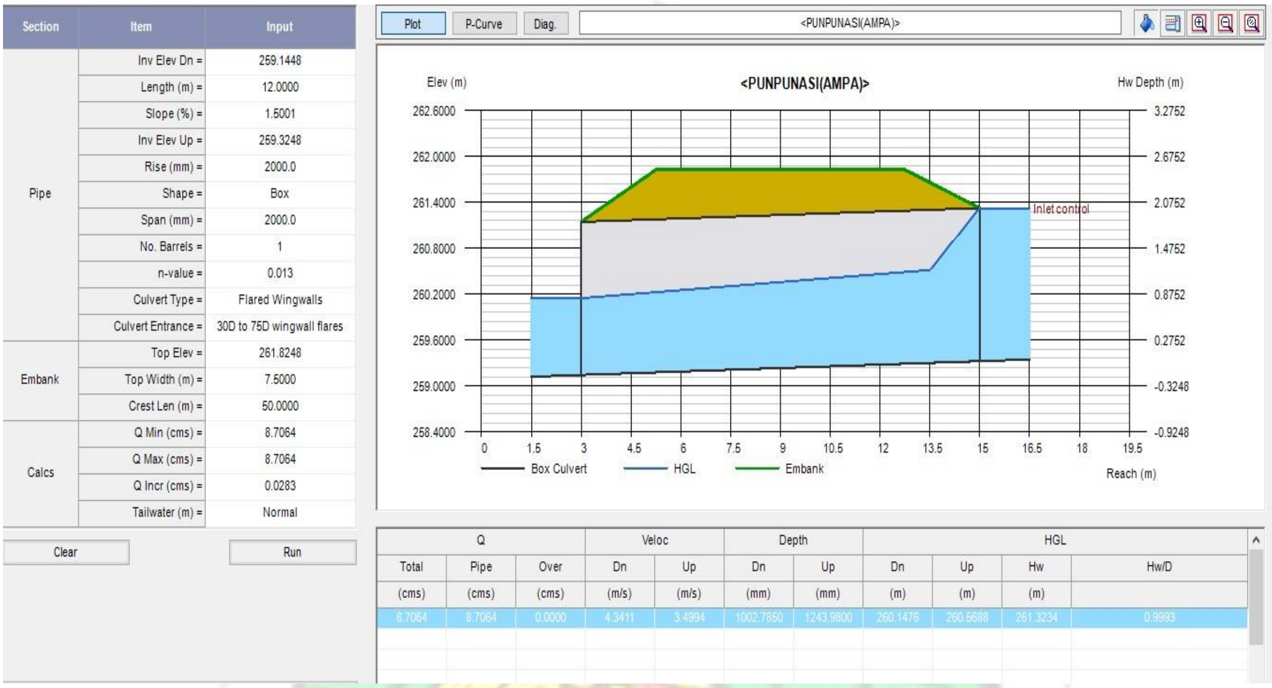


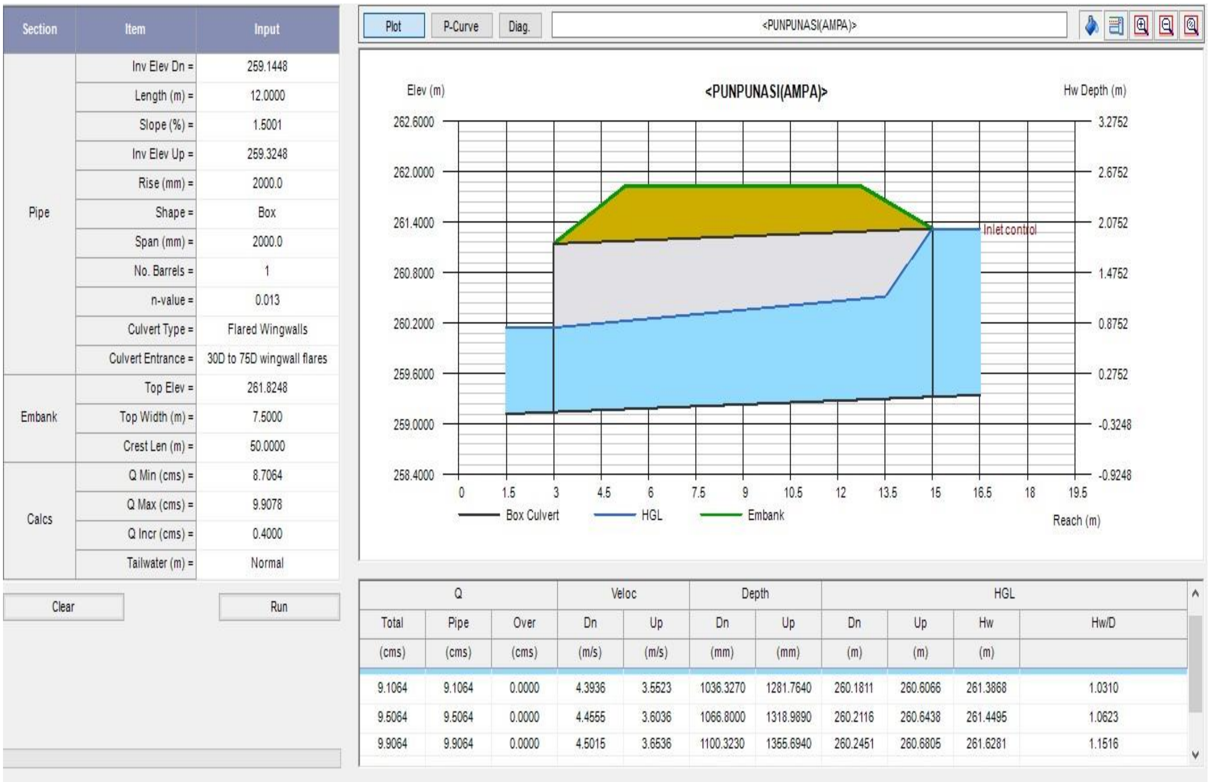
FIG …

Sizing of the culvert at the construction year 2005



Fig

Sizing of the culvert for almost 100% impervious



Fig

13.0 DATA

ROAD NAME; Major Cobina RD Ch 0+750

Area= 2.6127 F = 1-0.001(log A) *(9*log N -0.042*P +152)

= 0.8578

Rainfall intensity = 120.06mm/hr slope of culvert 1.5

Table ……

	YEAR	VEGETATION	SETTLEMENT	PERCENTAGE %
	2004	0.9783	1.6344	62.55597658
	2007	0.7479	1.8648	71.37444023
	2010	0.3861	2.2266	85.22218395
	2015	0.2466	2.3661	90.56148812
SUATEM(SUNTRE-DANYAME)	TOTAL AREA =2.6127			

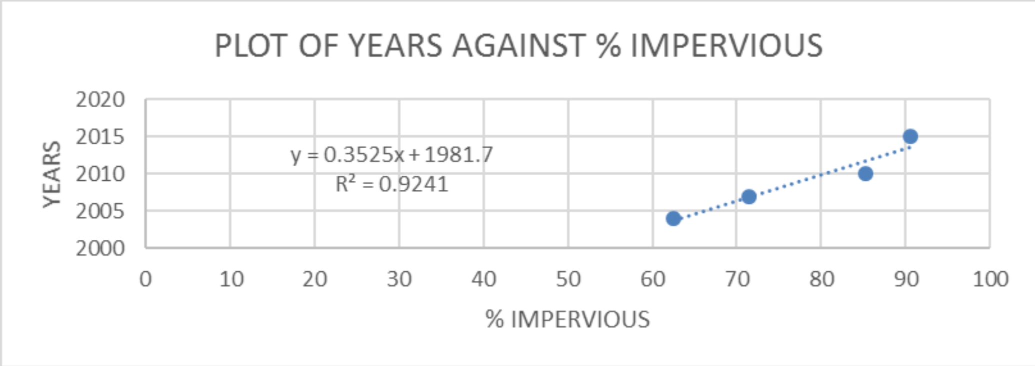


Fig.

Table 4.3: Computation of time of concentration

STATION	L (km)	H at culvert site(m)	H,at highest point on catchment (m)	A (km^2)	$T_c = 0.975L/ (A_{0.1}*S_{0.2})$
Suatem(Suntre-Denyame)	2.786463	253.741275	277.0655814	2.6127	1.613607297

Table … Computation of Discharge

STREAM	YEAR	PERCENTAGE IP %	C =0.3+0.6**IP*,	**Q = 0.278 FCIA (m^3/s)**
	0-1982	0	0.3	13.53921768
	*2014	91.63	0.84978	38.351188
	2004	62.56	0.67536	30.47948684
	2007	71.37	0.72822	32.865097
	2010	85.22	0.81132	36.6154603
	2015	90.56	0.84336	38.06144874
Suatem(Suntre-Denyame)	2017	100	0.9	40.61765304

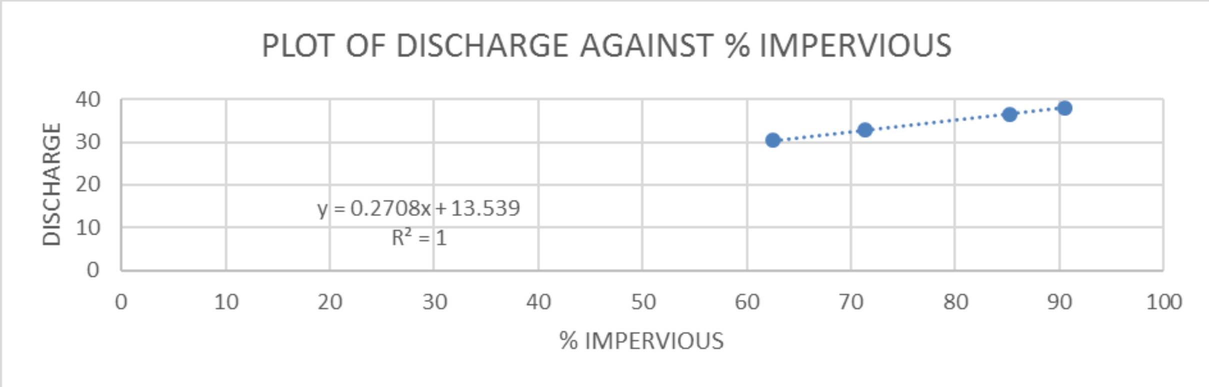
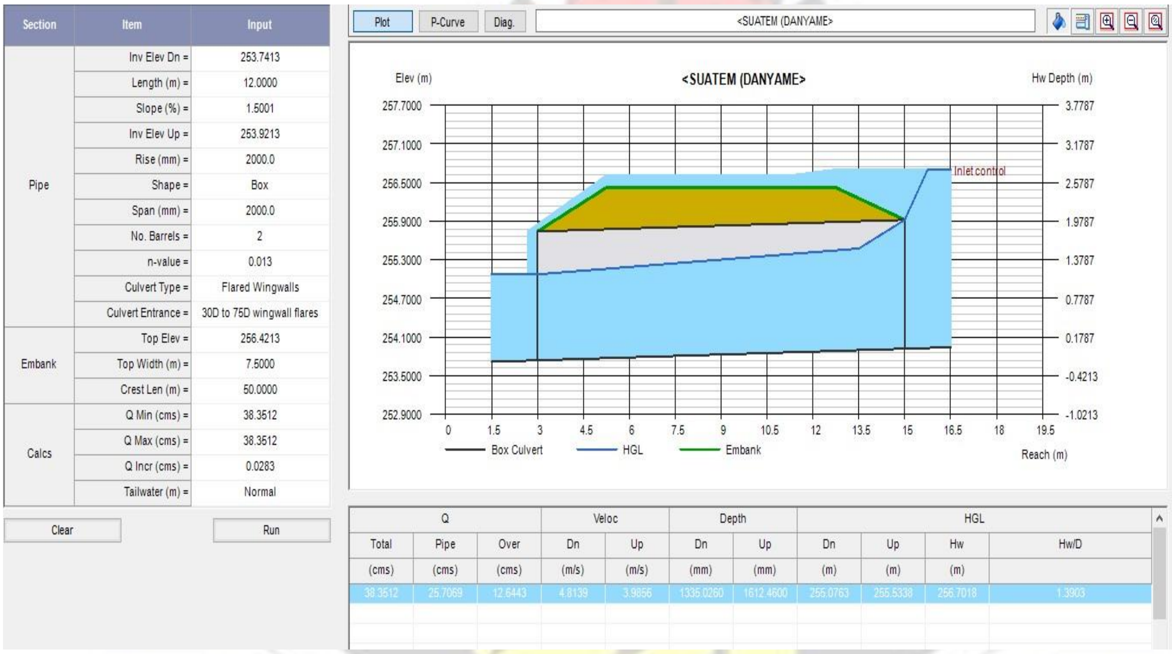


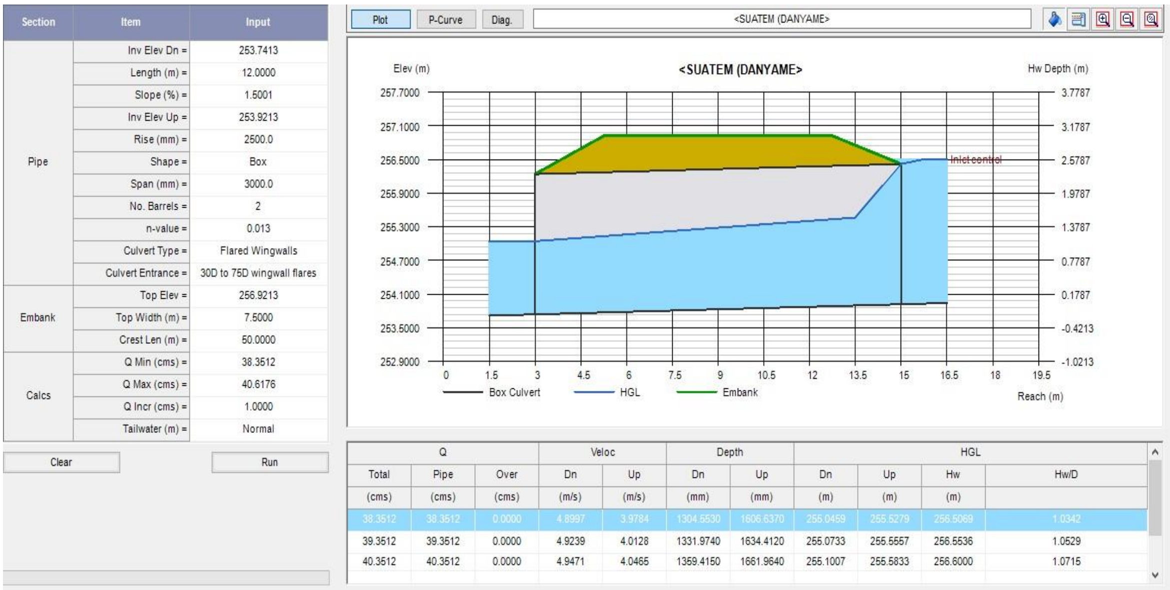
FIG …

Sizing of the culvert at the construction year 2014



Fig

Sizing of the culvert for almost 100% impervious



Fig

<u>14.0 Data</u>

Road Name; P.B Obeng RD Ch 0+900

Area=10.8594 F = 1-0.001(log A) *(9*log N -0.042*P +152) = 0.8578

Rainfall intensity = 131.46mm/hr slope of culvert 1.5

Table ……

	YEAR	VEGETATION	SETTLEMENT	PERCENTAGE %
	2004	0.1332	10.7262	98.7734129
	2007	0.3312	10.5282	96.95010774
	2010	0.1602	10.6992	98.52478037
	2015	0.2043	10.6551	98.11868059
ASUOWIRENTUO	TOTAL AREA =10.8594			

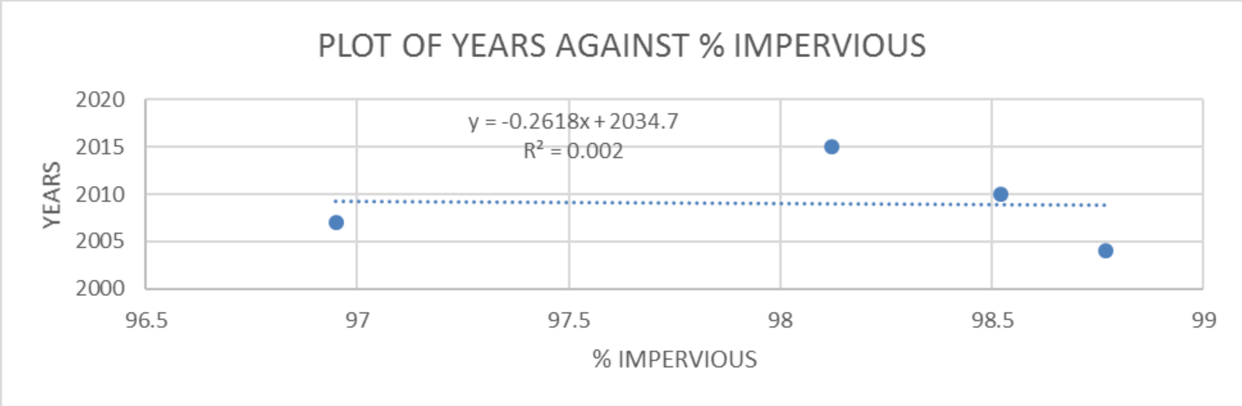


Fig.

Table 4.3: Computation of time of concentration

STATION	L (km)	H at culvert site(m)	H,at highest point on catchment (m)	A (km^2)	$T_c = 0.975L/(A_{0.1}*S_{0.2})$
Asuowirentuo	5.186792	256.880841	269.9692888	10.8594	3.310739449

Table … Computation of Discharge

STREAM	YEAR	PERCENTAGE IP %	C =0.3+0.6**IP*,	**Q = 0.278 FCIA (m^3/s)**
Asuowirentuo	0-1972	0	0.3	32.9138956
	2004	98.77	0.89262	97.93200496
	2007	96.95	0.8817	96.73393916
	2010	98.52	0.89112	97.76743548
	2015	98.12	0.88872	97.50412431
	-	100	0.9	98.74168679

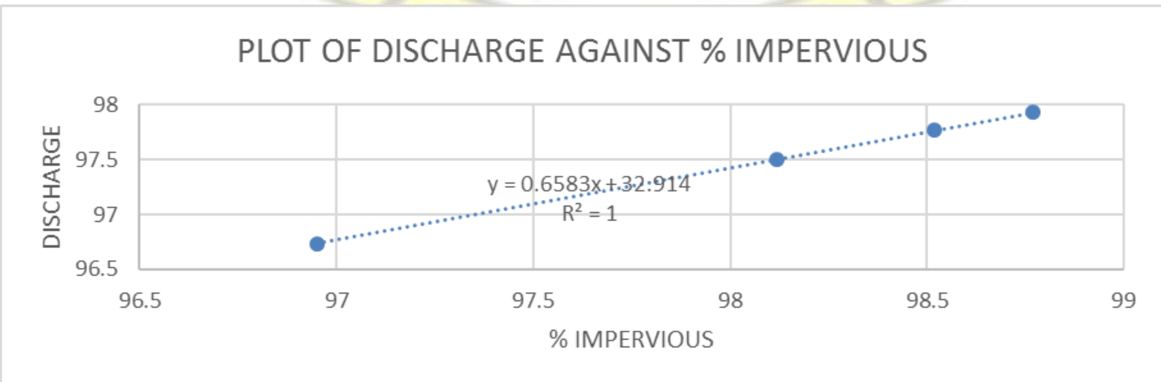
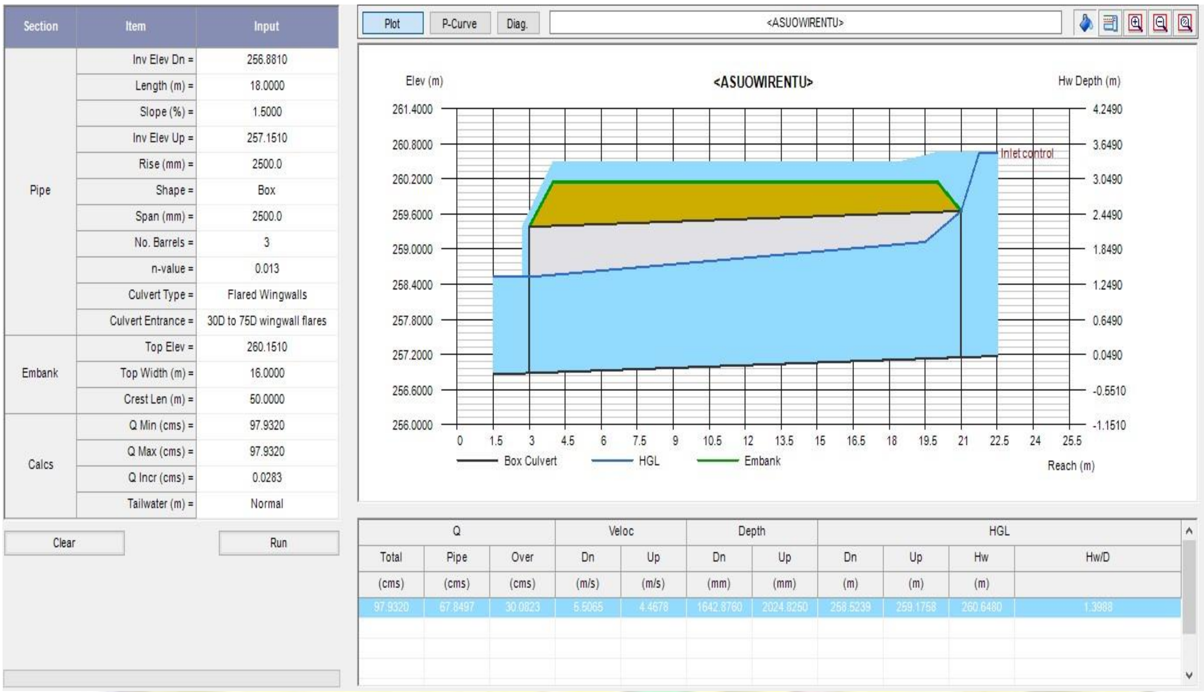


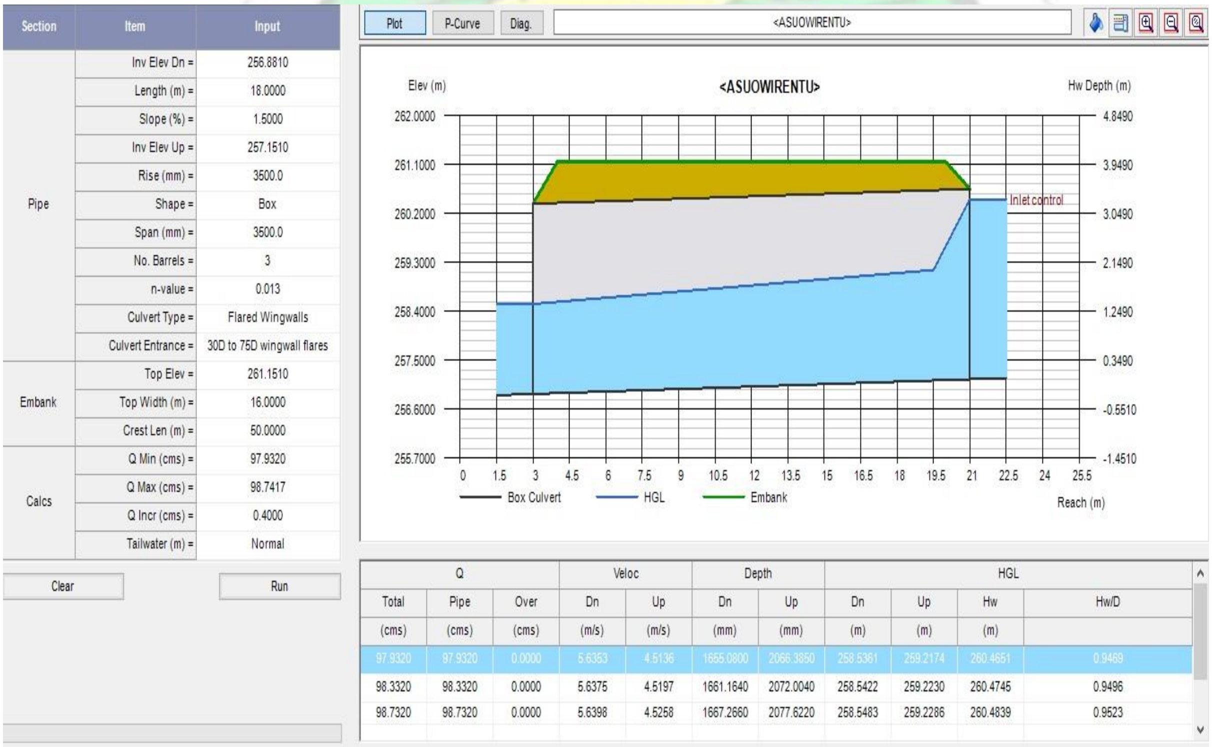
FIG …

Sizing of the culvert at the construction year 2004



Fig

Sizing of the culvert for almost 100% impervious



Fig

Road Name; Santasi-Apra-Daku RD   Ch 1+000

Area=1.9782   F = 1-0.001(log A) *(9*log N -0.042*P +152)

= 0.8482

Rainfall intensity = 94mm/hr   slope of culvert 1.5

Table ……

	YEAR	VEGETATION	SETTLEMENT	PERCENTAGE %
	2004	1.1385	0.8397	42.44767971
	2007	0.7929	1.1853	59.91810737
	2010	0.324	1.6542	83.62147407
	2015	0.0054	1.9728	99.72702457
DANYAMI	TOTAL AREA= 1.9782			

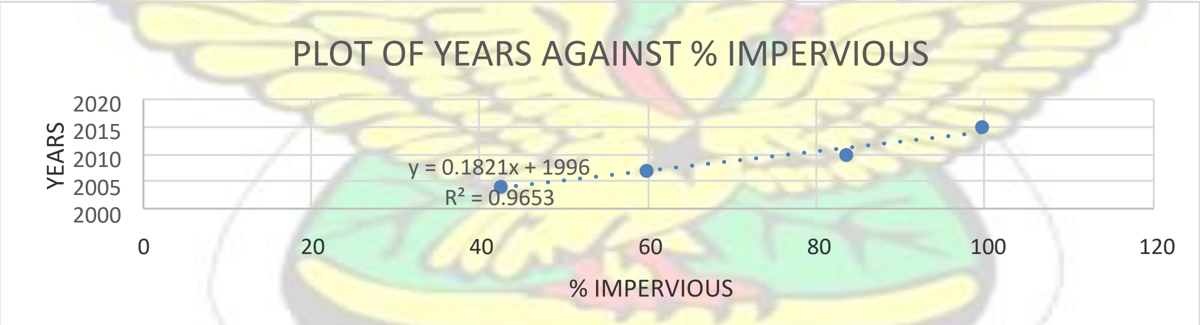


Fig.

Table 4.3: Computation of time of concentration

STATION	L (km)	H at culvert site(m)	H,at highest point on catchment (m)	A (km^2)	$T_c = 0.975L/(A^{0.1}*S^{0.2})$
Danyami	2.081367	239.6971	274.5016446	1.9782	1.079117666

Table … Computation of Discharge

STREAM	YEAR	PERCENTAGE IP %	C =0.3+0.6*IP,	**Q = 0.278 FCIA (m³/s)**
	0-1924	0	0.3	13.15445502
	2009	71.39	0.72834	31.93638589
	2004	42.45	0.5547	24.32258733
	2007	59.92	0.65952	28.91875391
	2010	83.62	0.80172	35.15396559
	2015	99.73	0.89838	39.39233099
DANYAMI	-	100	0.9	39.46336505

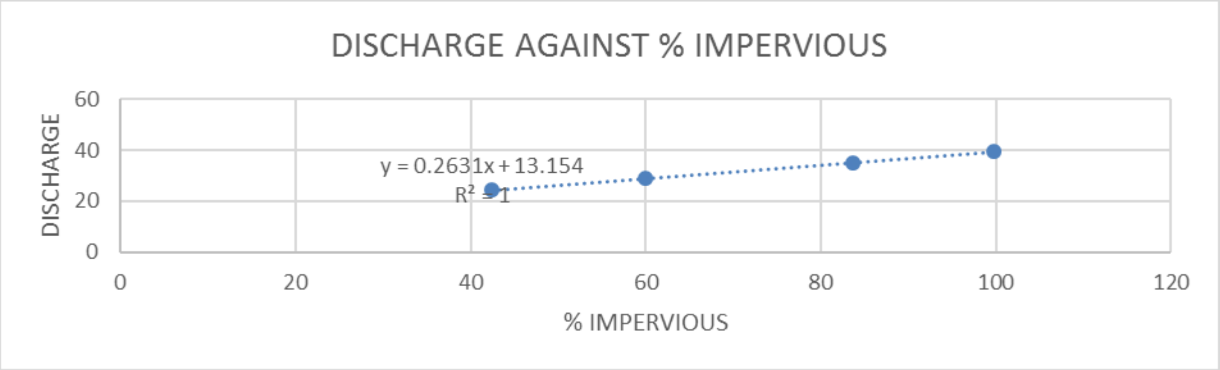
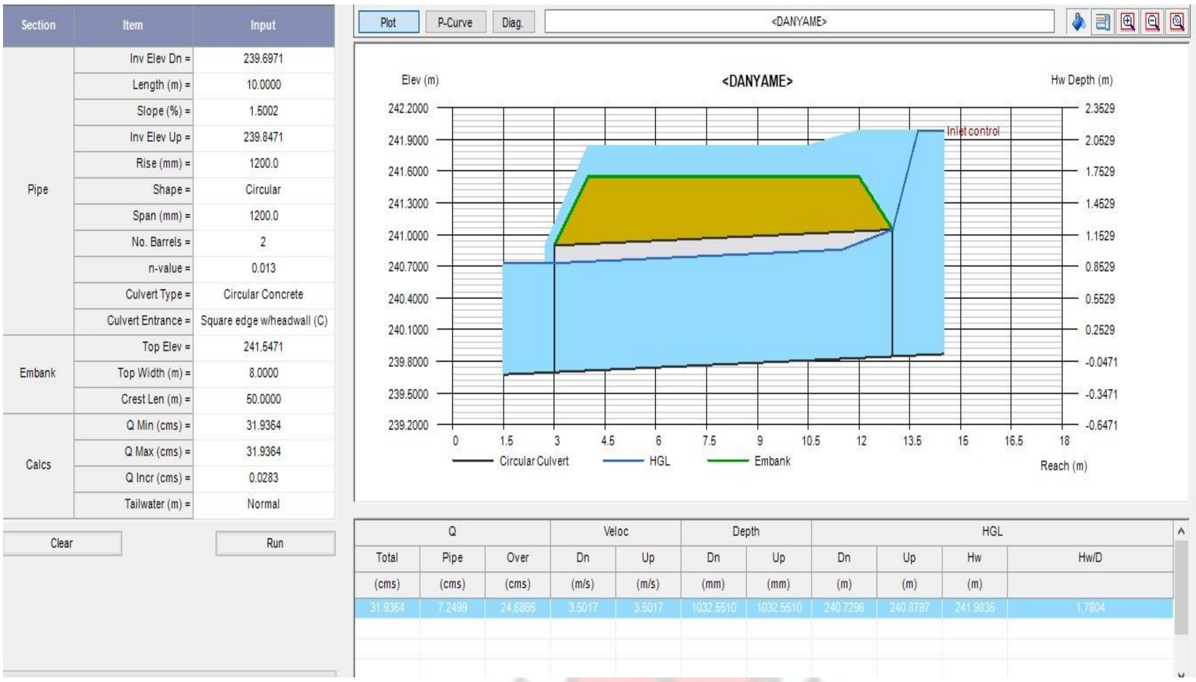


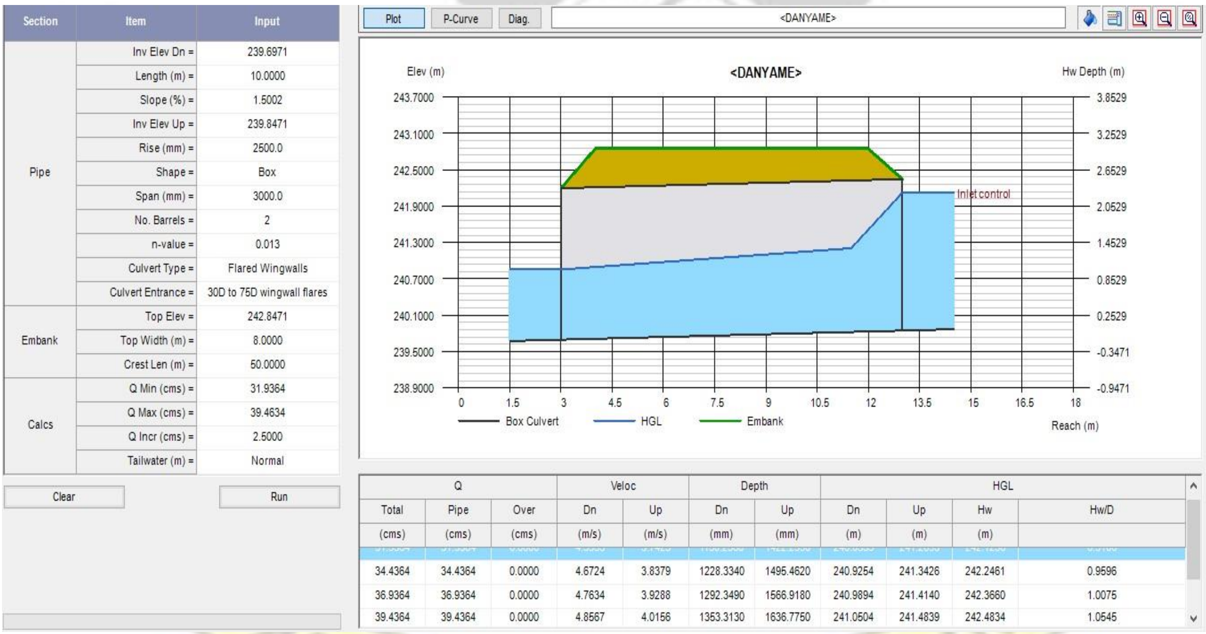
FIG …

Sizing of the culvert at the construction year 2009



Fig

Sizing of the culvert for almost 100% impervious



Fig

Road Name; Santasi-Apra-Daku RD Ch 1+200

Area=1.8252 F = 1-0.001(log A) *(9*log N -0.042*P +152) = 0.848 Rainfall intensity = 86.38mm/hr slope of culvert 1.5

Table ……

	YEAR	VEGETATION	SETTLEMENT	PERCENTAGE %
	2004	1.2888	0.5364	29.38856016
	2007	1.0224	0.8028	43.98422091
	2010	0.4725	1.3527	74.11242604
	2015	0.0054	1.8198	99.70414201
KOKOROMA	TOTAL AREA= 1.8252			

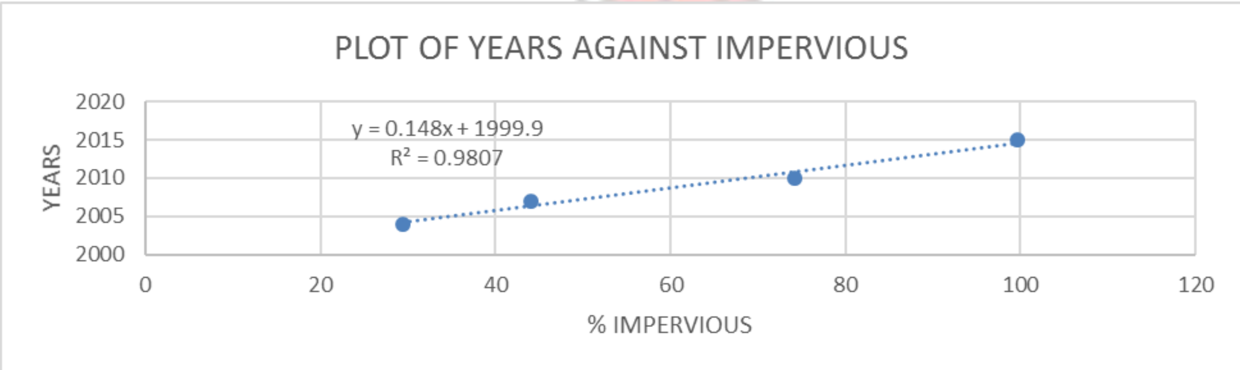


Fig.

Table 4.3: Computation of time of concentration

STATION	L (km)	H at culvert site(m)	H,at highest point on catchment (m)	A (km^2)	$T_c = 0.975L/(A_{0.1}*S_{0.2})$
Kokoroma	2.041541	257.4919	274.2668685	1.8252	1.229959906

Table … Computation of Discharge

STREAM	YEAR	PERCENTAGE IP %	C =0.3+0.6**IP*,	**Q = 0.278 FCIA (m^3/s)**
	0-2000	0	0.3	11.15474907
	2009	61.49	0.66894	24.87285948
	2004	29.39	0.47634	17.71151058
Kokoroma	2007	43.98	0.56388	20.96646636

	2010	74.11	0.74466	27.68831815
	2015	99.7	0.8982	33.39731873
	-	100	0.9	33.46424722

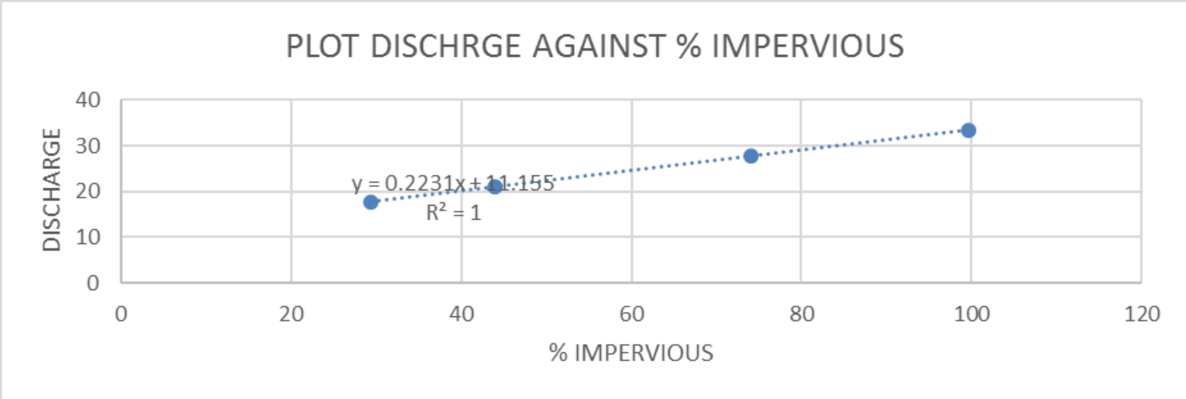
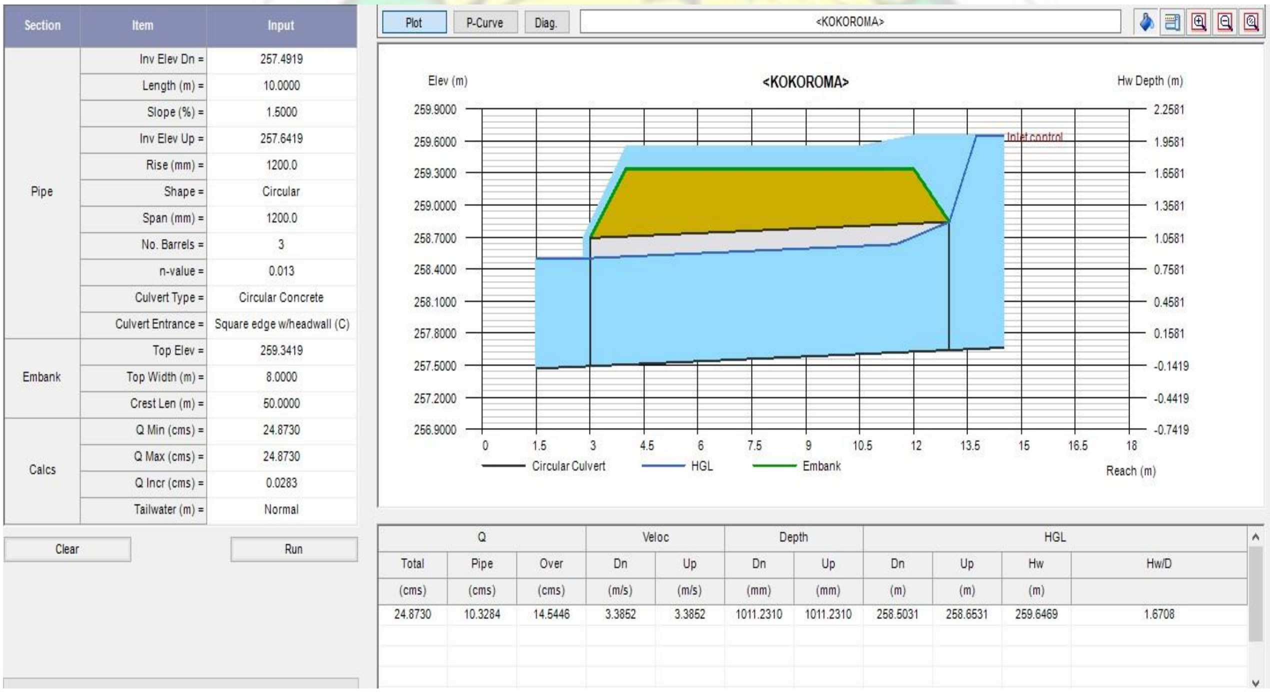


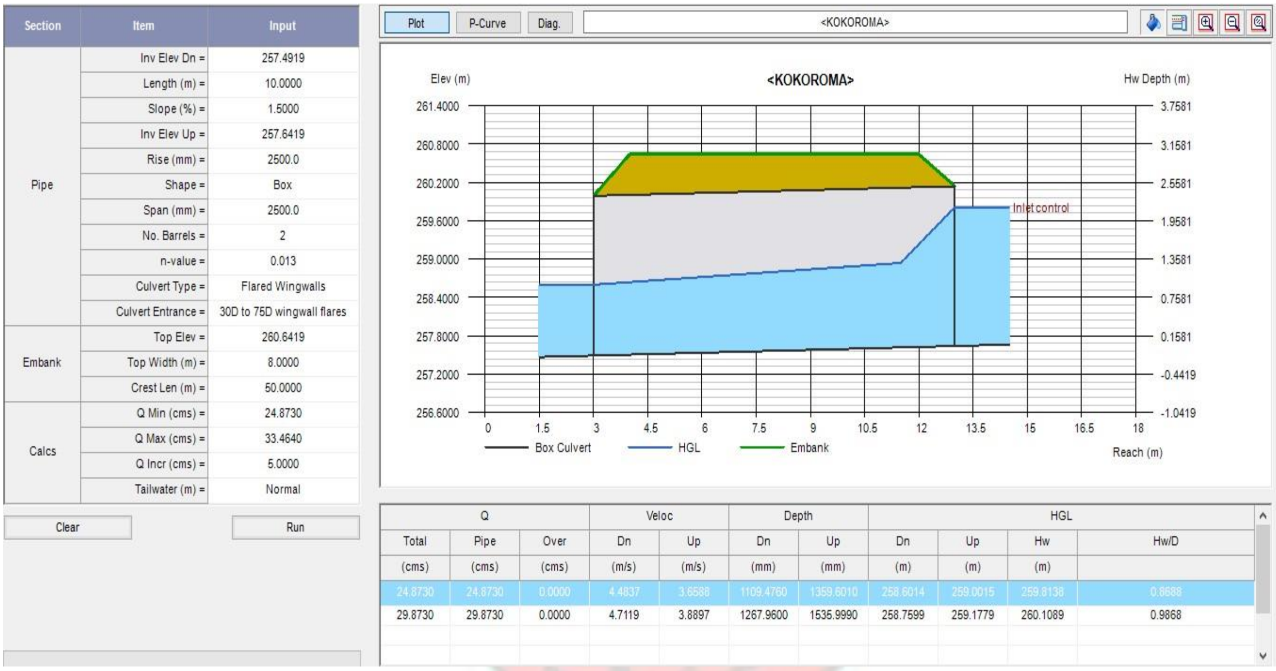
FIG …

Sizing of the culvert at the construction year 2009



Fig

Sizing of the culvert for almost 100% impervious



Fig

APPENDIX 5: RAINFALL INTENSITY

REPUBLIC OF GHANA

GHANA METEOROLOGICAL SERVICES DEPARTMENT

DEPARTMENTAL NOTE No. 23

MAXIMUM RAINFALL INTENSITY-DURATION FREQUENCIES IN GHANA

by

J. B. DANKWA, B. Sc., M. Sc.

Legon
1974

(K. N. Aboagye)

MAXIMUM RAINFALL INTENSITIES AND RETURN PERIODS

(INTENSITIES IN INCHES/HOURS)

KUMASI

DURATION HOURS \ RETURN PERIOD YEARS	5	10	15	25	50	100
0.2	5.40	6.05	6.45	6.95	7.55	8.20
0.4	4.65	5.00	5.65	6.10	6.70	7.30
0.7	3.69	4.10	4.50	4.84	5.31	5.79
1.0	3.04	3.30	3.71	4.01	4.41	4.81
2.0	1.80	2.10	2.37	2.55	2.90	3.19
3.0	1.30	1.52	1.63	1.78	1.98	2.30
6.0	0.76	0.90	0.98	1.08	1.21	1.35
12.0	0.41	0.49	0.54	0.60	0.68	0.71
24.0	0.21	0.25	0.28	0.31	0.35	0.38

A X I M

DURATION HOURS \ RETURN PERIOD YEARS	5	10	20	50	100
0.2	5.40	6.15	6.75	7.65	8.45
0.4	4.60	5.15	5.85	6.55	7.23
0.7	3.83	4.31	4.79	5.39	5.84
1.0	3.16	3.50	4.00	4.50	5.00
2.0	2.15	2.43	2.62	3.00	3.29
3.0	1.64	1.83	2.97	2.34	3.54
6.0	0.96	1.96	1.17	1.31	1.44
12.0	0.54	0.61	0.68	0.77	0.85
24.0	0.29	0.33	0.37	0.41	0.45

H O

DURATION HOURS \ RETURN PERIOD YEARS	5	10	15	25	50	100
0.2	5.30	5.50	5.95	6.55	6.80	7.40
0.4	4.32	4.90	4.70	5.22	5.62	6.00
0.7	3.30	3.65	3.50	4.11	4.44	4.78
1.0	2.58	2.88	2.80	3.25	3.52	3.79
2.0	1.60	1.92	1.72	1.95	2.20	2.40
3.0	1.15	1.31	1.30	1.50	1.65	1.81
6.0	0.66	0.77	0.74	0.83	0.99	1.09
12.0	0.34	0.38	0.42	0.46	0.51	0.55
24.0	0.18	0.21	0.23	0.25	0.28	0.30

TAKORADI

DURATION HOURS \ RETURN PERIOD YEARS	5	10	15	25	50	100
0.2	4.95	5.75	6.25	6.80	7.60	8.35
0.4	4.48	5.20	5.63	6.15	6.85	7.55
0.7	3.64	4.20	4.51	4.51	5.44	5.97
1.0	3.10	3.86	3.90	4.20	4.50	5.00
2.0	2.02	2.32	2.49	2.71	2.99	3.27
3.0	3.46	1.67	1.78	1.93	2.12	2.29
6.0	0.82	0.94	1.00	1.09	1.19	1.30
12.0	0.46	0.52	0.56	0.61	0.68	0.74
24.0	0.26	0.30	0.33	0.36	0.40	0.45

A K U S E

DURATION HOURS \ RETURN PERIOD YEARS	5	10	15	25	50	100
0.2	6.00	6.00	6.60	7.20	7.80	8.60
0.4	5.05	5.58	5.90	6.27	6.80	7.30
0.7	3.88	4.40	4.40	4.70	5.10	5.70
1.0	3.06	3.39	3.57	3.80	4.20	4.70
2.0	1.84	2.06	2.19	2.35	2.70	2.90
3.0	1.38	1.59	1.70	1.85	2.03	2.24
6.0	0.78	0.92	0.94	1.06	1.15	1.26
12.0	0.3	0.46	0.50	0.55	0.62	0.68
24.0	0.21	0.24	0.27	0.29	0.33	0.37

SALTPOND

DURATION HOURS \ RETURN PERIOD YEARS	5	10	15	25	50	100
0.2	7.00	8.75	9.6	10.70	12.20	13.70
0.4	5.60	6.93	7.63	8.60	9.85	11.10
0.7	4.16	5.10	5.63	6.30	7.17	8.06
1.0	3.35	4.09	4.50	5.03	5.72	6.41
2.0	1.93	2.35	2.58	2.87	3.26	3.64
3.0	1.39	1.68	1.85	2.06	2.33	2.61
6.0	0.76	0.91	1.00	1.10	1.24	1.38
12.0	0.41	0.49	0.54	0.60	0.68	0.76
24.0	0.21	0.25	0.28	0.31	0.35	0.39