OECS

Contract No.: OECS/27/2016
PTT REF: OECS/GCCA/2015/SER_18 (LOT 2)
Financial Agreement No.: 024-114
Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

Draft Technical Analysis and Design Report

Prepared by:

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Alpha

ORIGINAL

2016.06.06

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Submitted to:

GCCA Project
Organisation of Eastern Caribbean States (OECS) Commission
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June 6th 2016

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1 INTRODUCTION

Alpha Engineering and Design (2012) Ltd. (Alpha) received an award on February 9th 2016 from the Organization of Eastern Caribbean States (OECS) for the provision of Technical Assistance for the Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill); a Global Climate Change Alliance Project on Climate Adaption and Sustainable Land Management in the Eastern Caribbean (PTT REF: OECS/GCCA/2015/SER_18-LOT 2) financed by the European Union. The main objective of the consultancy is to develop and implement solutions within the Cashew Hill area to mitigate the flooding currently being experienced.

Presented hereunder is the second deliverable under Phase 1 (Design Phase) of this project, the **Draft Technical Analysis and Design Report** which includes problem definition; catchment analysis; preliminary hydraulic outputs; consideration of available options for flood mitigation; preliminary cost estimates; preliminary design calculations; and recommendations for final designs.

2 SCOPE OF REPORT

The following is covered in the body of this report:

2.1 Site description.

2.2 Problem definition and stakeholder consultations.

2.3 Final hydrologic modeling for various recurrence interval storms.

2.4 Watershed analysis and catchment definition.

2.5 Preliminary hydraulic analyses.

2.6 Preliminary design options for solutions to flood mitigations within the site area.

2.7 Preliminary cost estimates for the solutions considered.

2.8 Preliminary schedule for the proposed works.

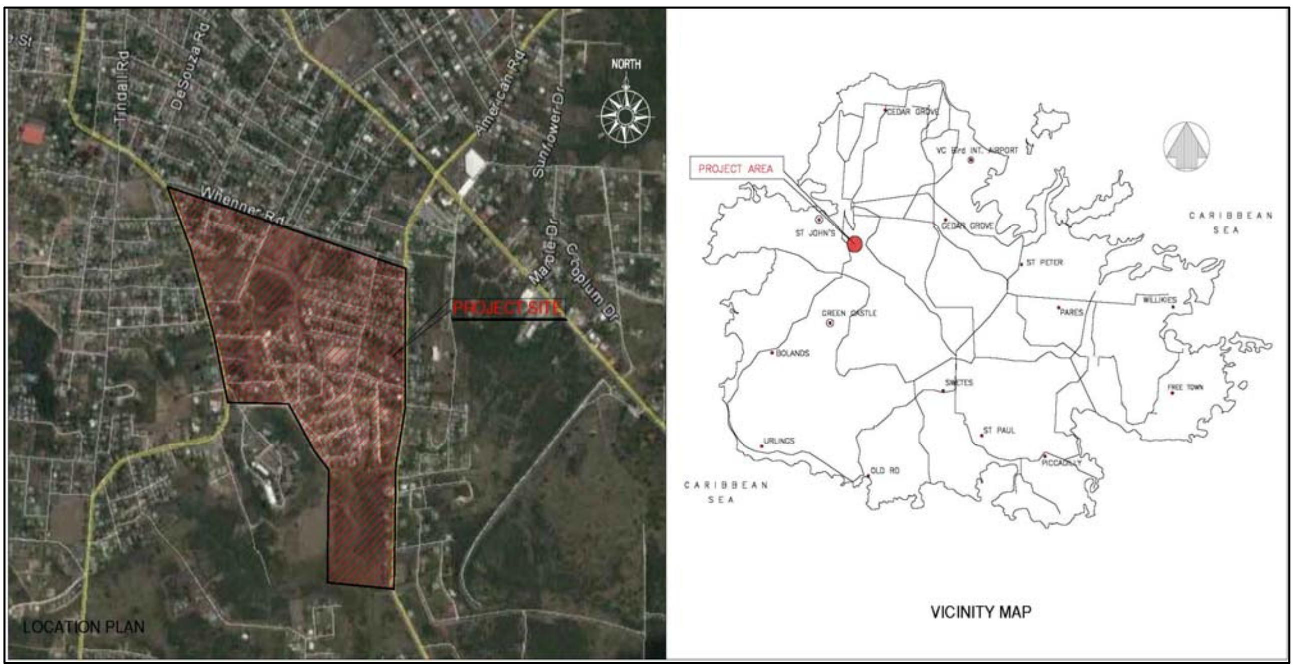
2.9 Recommendations for the way forward.

3 SITE DESCRIPTION

3.1. Location

The location of the site known as the Cashew Hill area, on the outskirts of the capital of Antigua and Barbuda, St John’s is given as 130 91 54.26” N, 610 101 33.49” W. The location is presented on a Google Map as **Figure 1** below:

Figure 1: Location Plan



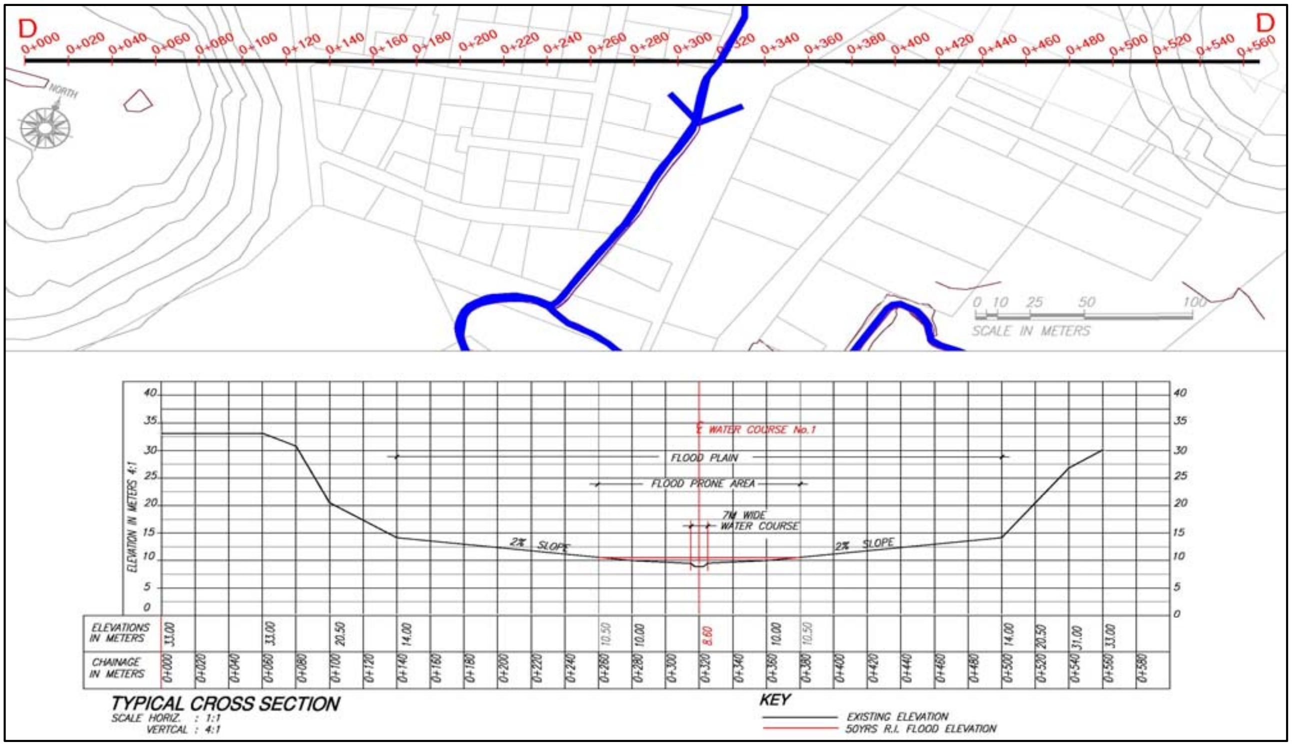
3.2. General Site Characteristics

A 1:25,000 scaled topographic map of the area was obtained from the Survey and Mapping Division and is shown as **Figure 2** below. On this map, the extent of the affected area and land ownership is also shown.

Figure 2: 1:25,000 Topographic Map from the Survey and Mapping Division

A typical cross section through the affected area shows the shape of the catchment as it relates to the affected area within Cashew Hill.

Figure 3: Typical Cross Section



The ground slopes range from as high as 40% in the elevated areas and reduce to 2% within the flood prone affected area, which is typical for areas like these and leads to the definition of the area as a flood plain.

The predominant geological formation at the site is within the Central Plain and consists of the following soil types, which are in hydrogeological terms very poor in terms of infiltration within the basin itself:

- Deep kaolinitic clay soils of the Central Plain. These are hard to work, heavy clays with impeded drainage and near neutral pH. Some are saline at various depths below the topsoil. Some calcareous clays are found in parts of this region.
- Generally shallow calcareous clay soils of the limestone areas in the north. Despite the high clay content, they possess good structure and have high base saturation." [5]

The site is significantly in an urbanized condition with very little natural vegetation, the latter of which is clustered around and within the existing watercourses in the flatter areas.

4 PROBLEM DEFINITION

The Cashew Hill area and environs succumb to frequent flooding during the rainy season from medium to high intensity rainfall events according to recent studies and documentation[2]. This adversely affects the residential population within the site who are reported to be generally on the lower end of the economic scale[2] and thus have a low capacity to deal with the consequences of the flooding.

It is clear from the site reconnaissance survey carried out by the Consultant that the drainage infrastructure within the site has not been developed to keep pace with the urbanization experienced in the Cashew Hill area within the last twenty years. The problem is compounded by the adhoc development practices currently being carried out throughout the Island of Antigua and specifically within the site.[5]

The existing watercourses have been encroached on by rapidly expanding anthropogenic development resulting in:

- Large reaches of constricted waterways;
- Inadequately sized hydraulic structures like culverts and bridges;
- Reduced natural wetland areas;
- Reduced natural infiltration; increased surface runoff;
- Contaminated surface runoff; and
- Decreased time of concentration for the catchment.

Anecdotal information indicates that the areas that succumb to the highest impacts during flooding within the site experience 0.5 meters of flooding and that it can last about 2 hours before the flood waters subside. **Figure 4** on the following page depicts the flood levels pointed out during the site reconnaissance/interview.

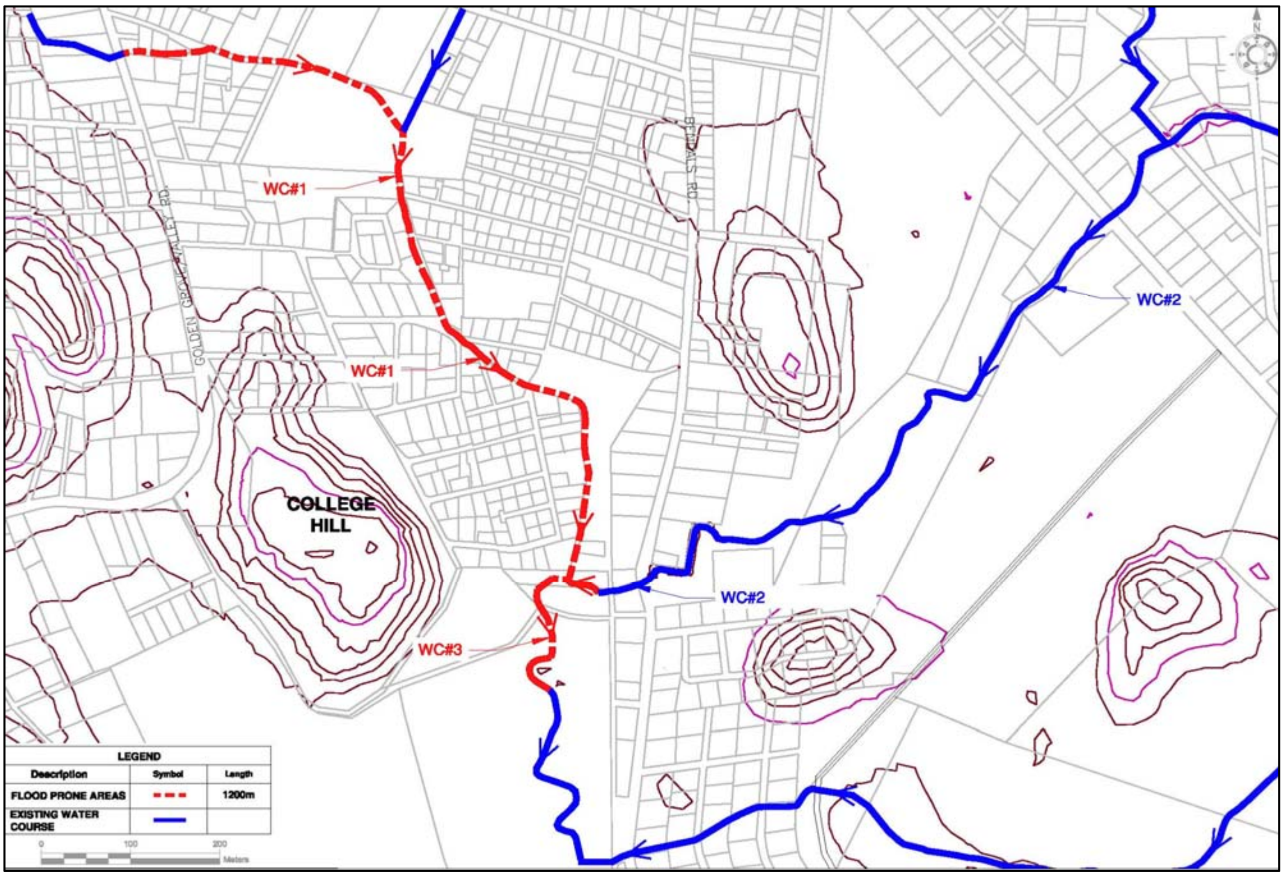
Figure 4: Observed Flood Elevations

The problem of stagnant contaminated water and breeding ground for insect vectors has also been reported[2]. Grab sampling and testing of surface water quality by the Department of Analytical Services based within the watercourse of the Cashew Hill area, show fecal contamination of such high values that it is clear sewage contamination is occurring from the adjacent development.

Based on consultations with the MP for the area, it is also clear that there are competing needs for the lands within the Cashew Hill area as development is likely to continue, which brings pressure to bear on the remaining open spaces for residential and recreational development as opposed to retaining these already limited spaces for drainage and flood mitigation infrastructure/solutions, to mitigate the impact of flooding. The problem is compounded by the fact that most of the land within the affected area is privately owned. This is shown in **Figure 5** where it can be seen that along the 850 metres of watercourse within the flood prone zone of what we define as Watercourse #1 (WC#1).

Only two areas for approximately 200 metres of the water course can be seen as open space, which are yet to be defined as Crown/State lands. WC#2 watercourse is conveying flows from the eastern catchment, while WC#3 is defined as the watercourse after the confluence of WC#1 and WC#2. The confluence of WC#1 and WC#2 has been identified as a problem due to the hydraulic inefficiency of present geometry and the backwater effect caused by the observed greater flows coming from WC#2.

Figure 5: Plan of Flood Prone Zone



5 STAKEHOLDER CONSULTATION

On March 15th 2016, Alpha met with government officials from the Department of Environment (DoE); Public Works Department (PWD); Survey and Mapping Division (SMD) as well as the MP and Minister of Health to gather information and get feedback on the details of the problems associated with the study area. The outcome of these meetings is documented in Section 4 of the Inception Report[1].

During the period April 14th to April 28th 2016, Alpha initiated consultation with Antigua based Climatologists as it relates to rainfall data and rainfall analysis for Antigua in general and the applicability to the Cashew Hill site in particular. Consensus was arrived at via information exchange and telephone conversations (Alpha/Mr. Dale Destin) on April 27th 2016. **Appendix 1** contains the relevant emails between Alpha and the Climatologist.

Ongoing stakeholder consultation is recommended after the completion and acceptance of this report to generate consensus and feedback relating to the proposed measures for flood mitigation within the area.

6 HYDROLOGICAL MODELING FOR THE SITE

The conversion of rural land to urban land or increase in urbanization usually increases erosion and the discharge and volume of storm runoff in a watershed. It also causes other problems that affect soil and water like flooding in downstream areas, as experienced at Cashew Hill. Engineering analyses must increasingly assess the probable effects of urban development, to inform hydraulic designs and implement measures that will minimize its adverse effects, like flood amelioration. In order to address this, rainfall analyses have to be carried out for the site taking due account of probability and of risk factors, contributing catchment definition and watershed analyses, including assessment of hydrogeological features and the development of site specific rainfall-runoff models that simulate flooding conditions for the design life under consideration.

Alpha carried out the final hydrological modeling for the site as follows:

6.1. Rainfall Data and Analysis

One of the most important elements of the drainage design of any development project is rainfall data relevant to the particular site. This data is most useful in Intensity Duration Frequency (IDF) and Depth Duration Frequency (DDF) formatted values of the storm rainfall, which the site could experience during the design life of the project.

Rainfall data collected for the Cashew Hill site was in the form of monthly totals from gauging stations at the VC Bird International Airport (VCBIA) and at Green Castle, both within 7km and 3km respectively of the Cashew Hill Site. Also supplied by Mr. Dale C.S. Destin - Climatologist, Antigua and Barbuda Meteorological Service, is a statistical analysis output that gives rainfall for return periods from 1:10-Yr., 1:20-Yr., 1:50-Yr. and 1:100-Yr. events based on 45 years of data available between (1971 to 2015) at VCBIA and from Cobbs Cross, St. Paul, Antigua; 21 years of data (1995 to 2015). This data does not allow for event specific analyses to be carried out by Alpha.

The following research was carried out by Alpha:

i) Documentation pertaining to disaggregation ratios for Sub -24hr. rainfall distribution; viz:
    a) ''The challenges of developing rainfall intensity - duration - frequency curves and nation flood hazard maps for the Caribbean" by D.M. Lumbroso, S. Boyce, H. Blast and N. Walmlsey; published in ''The Journal of Flood Risk Management" Volume 4, Number 1 January 2011 p.p. 42-52.

b) ''The effectiveness of the NRCS and Huff rainfall distribution methods for use in detention pond design" by Todd Wayne Dablement. (2010) Masters Thesis Paper 4757. Missouri University of Science and Technology.

ii) Documents pertaining to storm rainfall frequency:

a) Emerging and Sustainable Cities Initiative (ESCI) Report for Port of Spain - TT-61036.

b) IDB Loan -Trinidad and Tobago Flood Alleviation and Drainage Program -TT - L1036.

c) “Return Period to be used for Hydrologic Design” by Victor M. Ponce - Re. Table 1.

d) “Stormwater Drainage Manual” prepared by Gov. of Hong Kong Special Administrative Region. Re. Table 10.

The following analyses of the data reviewed were carried out for utilization within the project area to facilitate the modeling of flooding and design of drainage elements:

i) Selecting a viable distribution for sub-annual; sub-24 hr.; sub-6 hr.; and sub-1 hr. storm rainfall events.
ii) Choosing an acceptable recurrence interval for the design storm.
iii) Using the climate adjusted rainfall values together with disaggregation factors to compute sub-24hr. rainfall distribution.
iv) Producing the required DDF and IDF curves for recurrence intervals of 1 in 100-Yr.; 1 in 50-Yr.; 1 in 20-Yr.; 1 in 10-Yr.; 1 in 5-Yr.; and 1 in 2-Yr.

A correlation was also sought between the local rainstorm return period analyses and IDF curves developed for other islands as well and the NRCS Type II Storms for estimation of the 1:100-Yr. R.I. storm in the absence of other local data.

The complete analysis is presented in **Appendix 2.** Based on the results obtained from the methods outlined above, we recommend that the following rainfall depths, intensities and durations for the 1 in 50-Yr. recurrence interval storm be adopted for use in the hydraulic design and review of existing and planned drainage works within the Cashew Hill area for major watercourses and hydraulic structures. This is summarized in **Table 1** below:

Table 1: 50Yr. R.I. DDf and IDF Values

Durations for 1 in 50Yr. Recurrence Interval	Minutes					Hours			
	5	10	15	30	60	2	6	12	24
DDF Rainfall (mm)	37.2	53.2	61.2	79.8	98.4	125.0	172.8	212.7	265.9
IDF Rainfall (mm/hr.)	446.7	319.1	244.6	159.5	98.4	62.5	28.8	17.7	11.1

6.1.1. Probability and Risk

The risk of an event of a given annual exceedance probability (AEP) occurring in a period of M years is given by:

Equation 1 [8] $$R = [\, 1-(1-AEP/100)^{M} \,] \times 100$$

Therefore a low probability flood may have a significant likelihood of occurring over an extended period. For example using the above equation the 1:20-Yr. R.I. rainstorm event, has a 64% probability of occurring or being exceeded at least once within a 20-Yr. period:

Table 2: Probability for Extended Period and Risk

AEP / Probability		M =Period of Years	Risk R = [1-(1-AEP/100)^{M}] x 100
1:20	5%	5	23%
	5%	10	40%
	5%	15	54%
	5%	20	64%
AEP / Probability		**M =Period of Years**	**Risk R = [1-(1-AEP/100)^{M}] x 100**
1:50	2%	10	18%
	2%	20	33%
	2%	30	45%
	2%	40	55%

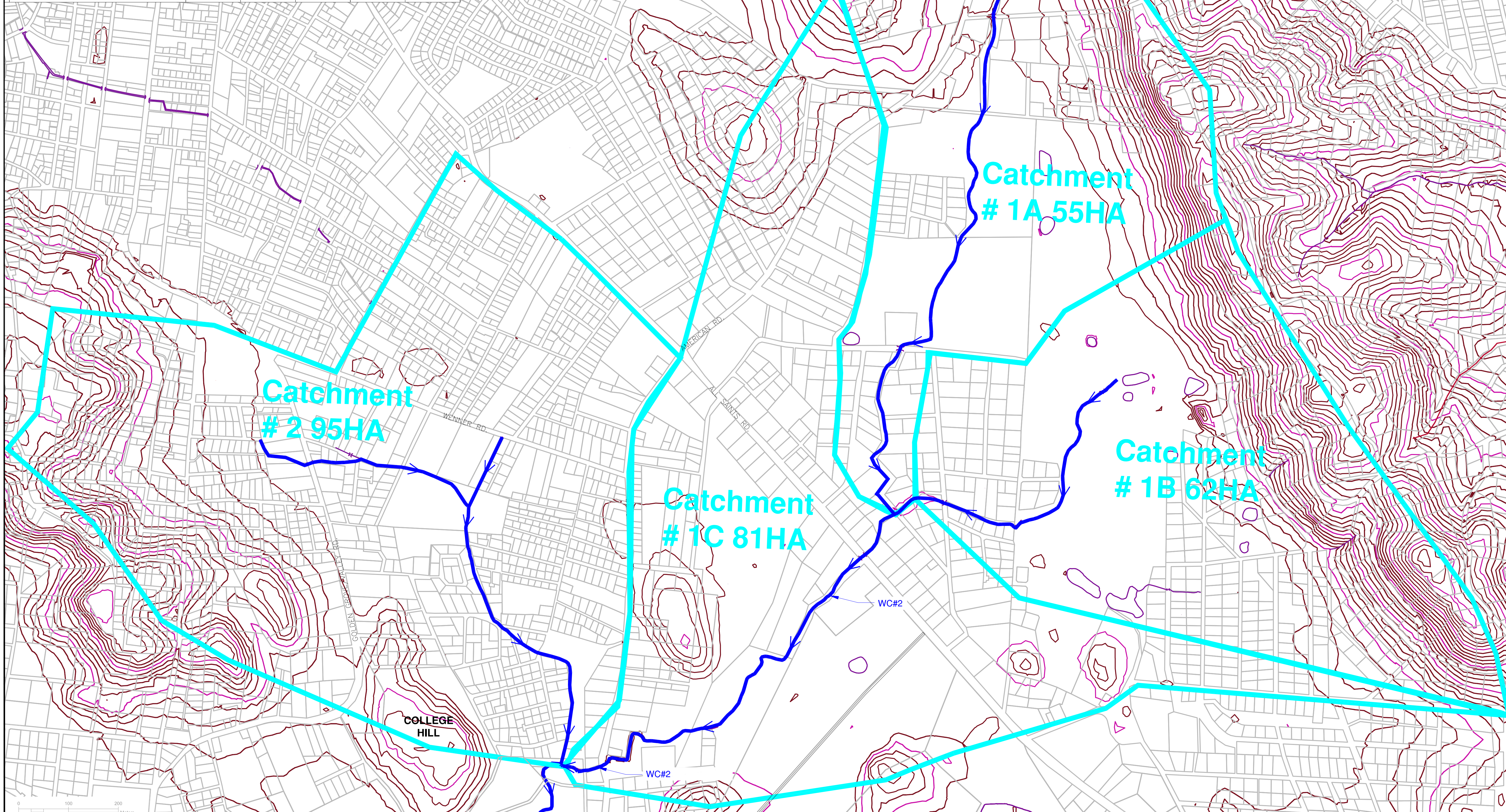
This is important for the practical application at Cashew Hill where flood levels of certain depths cannot be tolerated due to the density of built development and the potential for loss of life and property. For the design of the main watercourses, for instance a high degree of safety is required, therefore the 2% probability exceedance storm (1:50-Yr. R.I.) has been selected for a more conservative design as it has only a 33% chance of occurring in a 20-Yr. period. When we look at minor culvert and/or bridge crossings upstream the 5% probability exceedance storm (1:20-Yr. R.I.) can be selected as the potential for damage and real impact is less.

6.2. Catchment Definition and Watershed Analyses

Using the 1:25,000 topographical maps made available by the Survey and Mapping Division, the contributing catchment was defined to include all areas that contribute to surface runoff flow into the water courses that traverse the site. The limits of this watershed include the capital of St. Johns to the north and west; Potters Village to the east; Bendals to the south. The contributing catchments for the entire watershed and all main and tributary watercourses are shown in **Drawing #1** on the following page. A summary of the results of the catchment analysis is as follows:

i) The total area of the watershed is 293Ha., which when compared to the Cashew Hill area itself (35Ha.) is approximately 8 times as large.
ii) The total length of main watercourses within the Cashew Hill sub-catchment #2 is 1.10km, while the total watercourse lengths for the entire watershed up to the point of interest is 3.97km.
iii) The Cashew Hill sub-catchment shape is typically bowl-like with surrounding hills at elevations between 50 metres to 100 metres sloping into a large flat area which falls within the topographical zone, referred to as the Central Plains 2 at elevation between 12 metres to 6 metres above mean sea level.
iv) Over 90% of the catchment is developed with residential, infrastructure and public facilities.
v) There are four (4) main contributing sub-catchments which follow the classical dendritic pattern facilitating natural channelization from the upper reaches to the lower reaches of the catchment to the point of interest at the confluence of the major watercourses just west of College Hill.
vi) The average slope in the upper reaches of the catchment are between 10% and 15%, while in the lower flood prone areas the prevailing average slope is less than 1%.
vii) Underlying clayey soils make up the area within the flat areas of the basin which limits percolation or infiltration of runoff after rainfall and defines the hydrologic soil condition for the various contributing sub-catchments.

LEGEND		QUANTITY			
Description	Symbol	Catch. 1A	Catch. 1B	Catch. 1C	Catch. 2
Existing Watercourse	(dark blue line)	1240 m	670 m	985m	1100m
Catchment Boundary	(cyan line)	55 Ha	62 Ha	81 Ha	95 Ha



NOS.	DATE	R E V I S I O N S

CLIENT : Organization of Eastern Caribbean States (OECS)

PROJECT : Technical Assistance for Flood Mitigation and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill).

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DRAWING TITLE :

CATCHMENT LAYOUT

JOB No. 2016-014
FILE No. RW-02
SCALE : N.T.S.
DATE . : 2016.05.03
DES. : K.D
DRG. : S.P
REVS.: 00
SHEET No. 01

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6.3. Rainfall-Runoff Modeling and Analyses

Alpha has opted to utilize two widely used and accepted methods for generating peak runoff flows within urban catchments for the purpose of comparative analysis at this site to increase the reliability of the outcomes. These are:

- Rational Method; dependent on Intensity Duration Frequency (IDF) Curves; and estimating, Time of concentration and C-Factors for the sub-catchments.
- The SCS (TR55) Method; dependent on 24-hr. rainfall estimates; applying Curve Numbers (CN),Time of Concentration (T_c) and Time of Travel Estimates (T_t).

Both methods are based on generating rainfall excess for derivation of peak flows at points of interest within the site by imposing specific recurrence interval rainfall estimates on the contributing upstream sub-catchments.

6.3.1. Rational Method

This method considers that if rainfall is applied at a constant rate to an impervious surface, the runoff emanating from that surface would eventually reach a rate equal to the rate of the rainfall. The time required to reach this equilibrium is called the T_c for the catchment area.

Hence the formula:

$$Q = 0.0028\ CIA\ m^3/s \qquad (4.1)$$

Where: Q = Peak rate of runoff in (m^3/s)

C = Runoff coefficient for the catchment

I = Average Rainfall Intensity in (mm/hr)

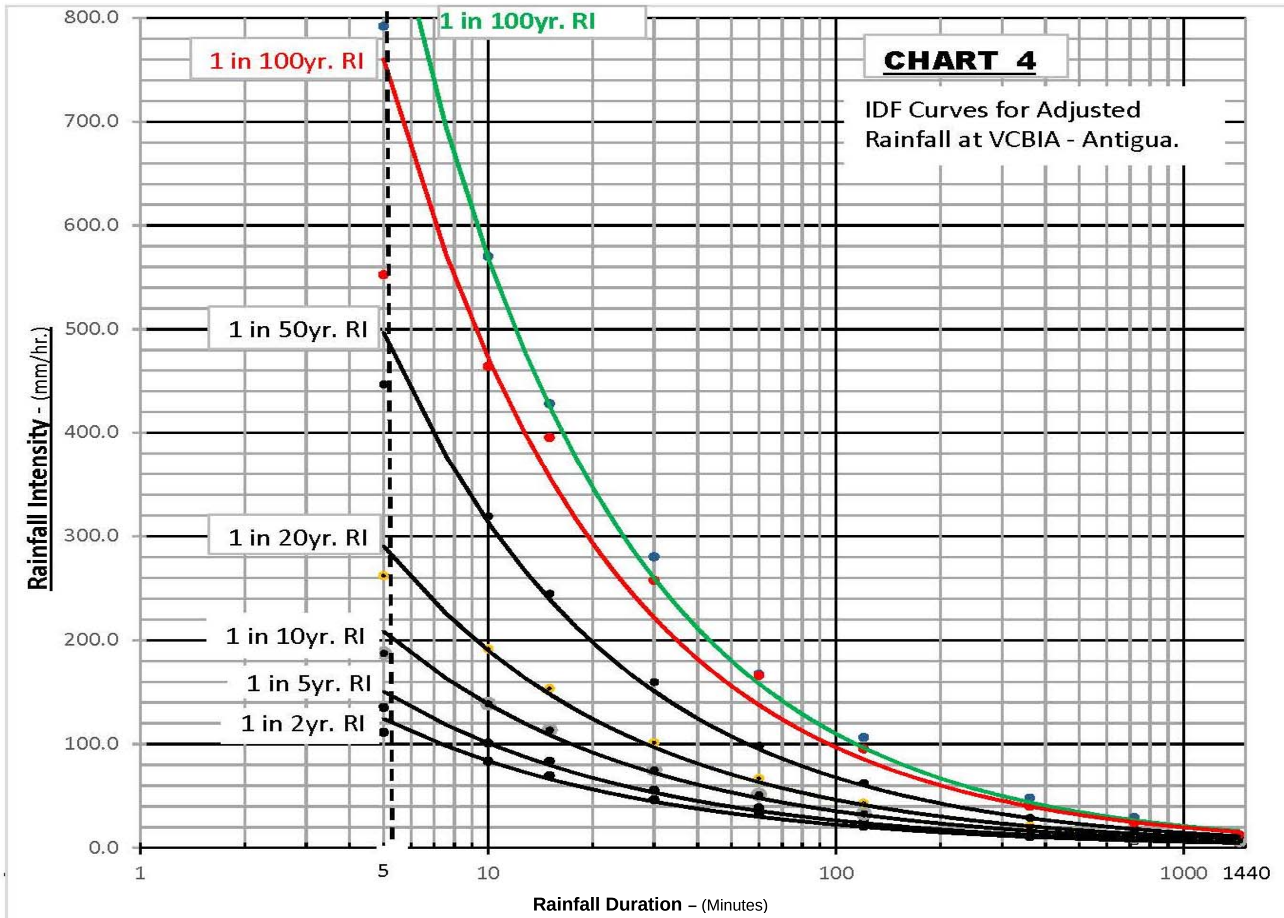
A = Area of the catchment In (Ha)

0.0028 = A conversion factor applicable to the metric units

The ***runoff coefficient*** C, represents the integrated effects of evaporation, transpiration, interception, storage, detention and infiltration of the portion of rainfall that does not show up as runoff. The aforementioned factors affect both the time distribution of the runoff, as well as the peak rates of runoff.

The ***average rainfall intensity*** I, used in the calculations is that rainfall intensity for the given duration (equal to the T_c of the catchment) of the storm design frequency occurrence.

Figure 6: IDF Curve for Adjusted Rainfall at VCBIA Station - Antigua



6.3.2. The Soil Conservation Method (SCS)

The summarized steps utilized in this SCS Method (*Ref: Urban Hydrology for Small Watersheds, USDA, NRCS, Technical Release 55*) [3] are as follows:

a) Determine Time of Concentration. (T_c) and Time of Travel (T_t) based on estimation of sheet flow, shallow concentrated flow and stream flow within each sub catchment.

b) Define sub-catchment Curve Number (CN) based on the hydrologic soil group (HSG), cover type, treatment, hydrologic condition and antecedent runoff condition (ARC). Another factor considered is whether impervious areas outlet directly to the drainage system (connected) or whether the flow spreads over pervious areas before entering the drainage system.

c) The SCS runoff equation is:

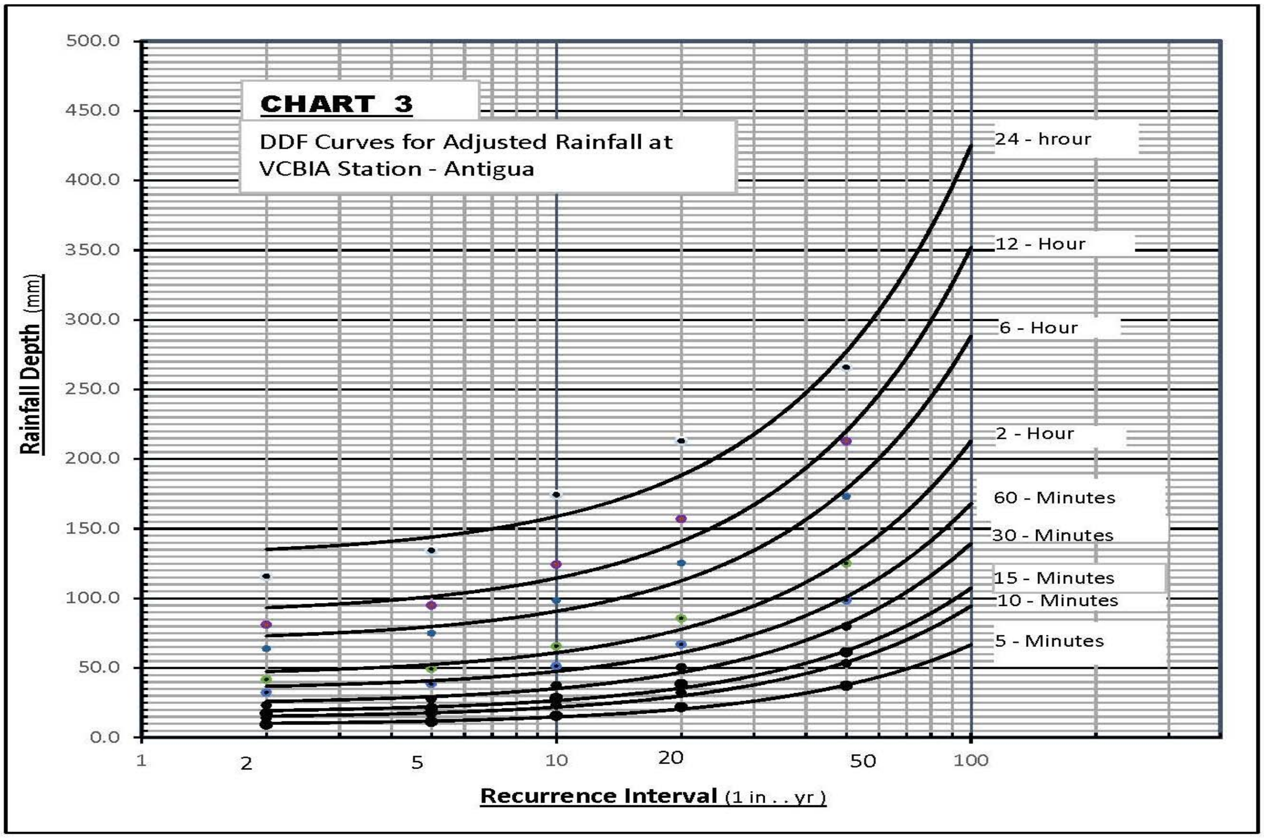
$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad \text{[eq. 2-1]}$$

where

Q = runoff (in)
P = rainfall (in)
S = potential maximum retention after runoff begins (in) and
I_a = initial abstraction (in)

Initial abstraction (I_a) is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. I_a is highly variable but generally is correlated with soil and cover parameters. P is the 24-hr. rainfall for the recurrence interval storm being applied generated from the DDF curves shown in **Figure 7** on the following page:

Figure 7: DDF Curves for Adjusted Rainfall at VCBIA Station - Antigua



6.3.3. Comparative Results and Catchment Calibration

Alpha used both methods described in rainfall-runoff models to determine peak discharges at various points of interest within the catchment and within the affected flooding area for various rain storm recurrence intervals. The comparative results are tabulated below and were generally found to be within 20% of one another, with the Rational Method invariably generating the higher values.

The average value was taken to cater for increased trends related to climate change so as to generate conservative results, but remain within the limits of an economically feasible design. **Table 3** summarizes the peak storm flow results for various recurrence interval rainstorms for WC#1 and WC#2 and the full detailed calculations are included in **Appendix 3:**

Table 3: Peak Flows Generated Per Sub-Catchment

Calculations		Units	Catchment 1A		Catchment 1B		Catchment 1C		Catchment 2	
			Storm R.I. Interval (Yr.)		Storm R.I. Interval (Yr.)		Storm R.I. Interval (Yr.)		Storm R.I. Interval (Yr.)	
			20	50	20	50	20	50	20	50
TR 55 Method	q_p=	m^3/s	4.89	12.55	5.68	15.34	7.34	18.77	8.95	23.31
Rational Method Peak Discharge = 0.00278 * C * I * A_m	Q=	m^3/sec	8.06	13.92	10.97	19.23	12.29	21.21	16.38	28.49
Average Peak Discharge (TR-55 & Rational)	Q=	m^3/sec	6.47	13.24	8.32	17.28	9.81	19.99	12.66	25.9

Runoff hydrographs were generated from the above values taking into account Time of Travel (T_t) to the downstream point of interest at the confluence of the main watercourses at the southern end of the Cashew Hill area. The summary peak discharges for various R.I. storms detailed in **Table 4** below are applicable to WC#3 and the complete analysis is provided in **Appendix 3:**

Table 4: Peak Flows at Confluence and Downstream Watercourse WC#3

Description	Unit	Storm R.I. Interval (Yr.)			
		5	10	20	50
Peak Flows at Confluence	m^3/s	14.29	21.54	34.38	70.43

Figure 8: 20Yr. Hydrograph at the Confluence Point

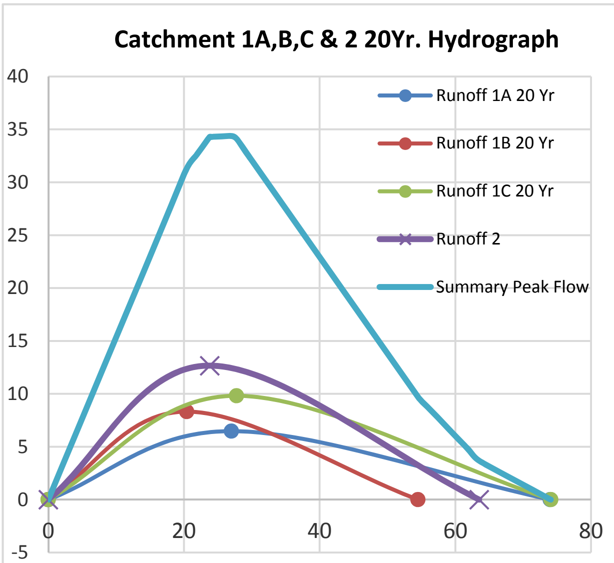
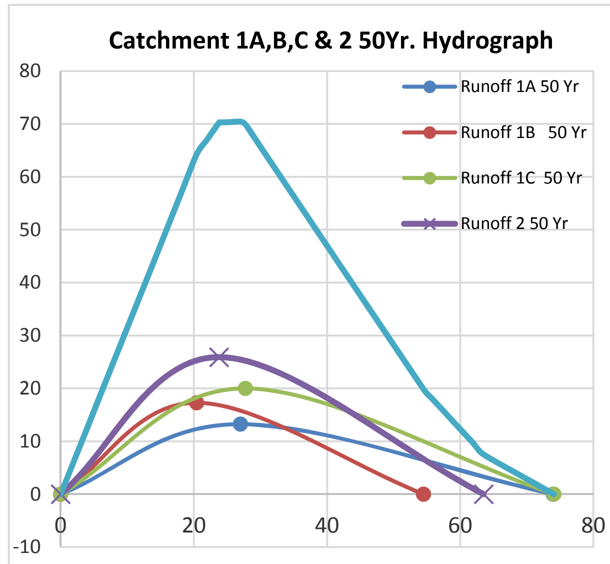


Figure 9: 50Yr. Hydrograph at the Confluence Point



Calibration of the rainfall-runoff models was carried out by verifying the flood levels reported[6] against field topographical surveys in the hydraulic analyses and iteratively adjusting C-Factors or CN Numbers to simulate the actual flood heights based on anecdotal data (see **Figure 4** above).

The basis of the above determination was made by verifying actual points of reported flood height within the catchment area and having these areas surveyed and related back to the survey control points for the site as described in the next section.

6.3.4. Field Survey Data

Limited survey data was collected between the period of April 2016 and May 2016 by two local surveyors based on the terms of reference supplied by Alpha[1]. More detailed field topographical surveys are required in order to meet the requirements of the scope of the RFP remains. In summary the information supplied is detailed per required survey scope between Chainages 0+000 to 0+596.9, while for the area within Cashew Hill itself, only centerline data was received for the stream with limited cross-sectional information. The areas surveyed are included in **Appendix 4.**

In order to complete the preliminary analyses in this report the Consultant estimated and projected data where required based on our understanding of the site from the site visit and ongoing collaboration with both engineering field surveyors and DoE Engineers.

7 PRELIMINARY HYDRAULIC CAPACITY CHECKS

Using the peak runoff flows determined in the foregoing Section 6, hydraulic checks were carried out using Manning's Equation for open channel flow:

$(Q = A. {}^{1}/_{n} \, s^{1/2} . R^{2/3})$ ----------------------Equation 2

Where:

Q is Channelized flow in m3/sec (Q = A.v)

A is the hydraulic area of the section or drainage element

n is Manning's constant for roughness of the channel

S is the hydraulic slope of the channel or drainage element

R is the hydraulic radius of the drainage element or Area/Wetted Perimeter (A/Wp)

for various affected areas with the flood prone areas of Cashew Hill (see **Figure 5** above):

i) Water Course Along Cashew Hill Catchment #2
ii) Culvert #1 along Catchment #2 Watercourse
iii) Culvert #2 along Catchment #2 Water Course
iv) Water Course from Bendals Road Catchment 1A, B & C
v) Water Course Down Stream of Confluence

The results of these checks are tabulated hereunder and the detailed calculations are included in **Appendix 5:**

Table 5: Capacity of Existing Drainage Elements v.s. Peak Flows

Drainage Element Description	Unit	Existing Capacity	Peak Flow Storm R.I. Interval (Yr.)			
			5	10	20	50
Water Course #1 in Catchment #2	m^3/s	2.1	5.29	7.95	12.66	25.9
Culvert #1 Catchment #2	m^3/s	4.49	5.29	7.95	12.66	25.9
Culvert #2 Catchment #2	m^3/s	7.78	5.29	7.95	12.66	25.9
Water Course #2 in Catchment #1	m^3/s	3.2	9.41	14.22	22.74	46.63
Water Course #3 After Confluence of Water Course 1 & 2	m^3/s	4.82	14.29	21.54	34.38	70.43

7.1. Discussion of Results and Detailed Problem Definition

Based on the foregoing modeling and analyses it is clear that the major drainage infrastructure within the Cashew Hill area is inadequate in terms of hydraulic capacity to carry high intensity design storms.

These results confirm what is being experienced on the ground as even localized high intensity rainstorms result in flooding of the area. The relatively low slopes within the most flood prone areas and negligible infiltration rates due to prevailing saturated clays (high antecedent moisture conditions), result in sustained flooding with lengthy periods before dissipating. The latter being attributed to:

- Increased storm flows in the catchment due to highly developed condition and anthropogenic changes in the watershed area over the last 20 years.
- The current practice by the MoW to use the 2.5" rainfall in a 24 hour period is inadequate and based on rainfall analyses of this study indicates that this criterion is less than a 5Yr. R.I. storm.
- Inadequate water way sections along major reaches of the watercourses to carry peak storm flows between 20cms and 45cms within the Cashew Hill catchment #2 and #1A, B and C respectively; and 70cms downstream of the confluence of the two major watercourses.
- Constricted outflows at waterway crossings due to unauthorized built development. In other words this area which is a natural flood plain has been compromised by anthropogenic development.
- Backwater effects upstream created by very high storm flow (70cms) at the confluence of the two main watercourses, as the velocity during flood stage for the catchment coming from the east is significantly larger than velocity of flow coming from the western watercourse/catchment passing through Cashew Hill itself.
- Backwater effect from downstream structures outside the area of study. It has been determined that the culvert on the road upstream of the agricultural pond south of the project area is creating the backwater effect. See **Appendix 6** for schematic details.
- Inadequate hydraulic capacity of:
  - Culvert No 02 within the Cashew Hill Area.

8 CONSIDERATION OF OPTIONS FOR FLOOD ALLEVATION

8.1 Generic Solutions to the Hydraulic Problems Identified

From the foregoing section where detailed problems have been identified that can be directly attributed to flooding in the Cashew Hill area, the following generic and specific solutions are tabulated hereunder for consideration:

Table 6: Summary of Problems Identifued and Possible Solutions

<table>
<tr><th>PROBLEMS IDENTIFIED</th><th>GENERIC SOLUTIONS DISCUSSED</th></tr>
<tr><td>I. Increased storm flows in catchment due to highly developed conditions and anthropogenic changes in the watershed area over the last 20 years.</td><td>Difficult to reverse especially in SIDs where land is limited but consider:
▪ Enforcing building regulations as it relates to set-backs from main watercourses and maintaining green areas to increase infiltration;
▪ Create upstream detention and or retention ponds to attenuate peak downstream storm flow discharges.</td></tr>
<tr><td>II. The current practice by the MoW to use the 2.5” rainfall in a 24 hour period is inadequate. Based on rainfall analyses this study indicates that this criterion is < a 5Yr. R.I. resulting in inadequate hydraulic structures.</td><td>Revise Design Practice:
▪ Consider island wide adoption of a drainage code of practice or;
▪ Different design guidelines as interim measure;
▪ Upgrade hydraulic structures deemed to be inadequate to carry design storm flows.</td></tr>
<tr><td>III. Inadequate water way sections along major reaches of the watercourses to carry peak storm flows between 20cms and 45cms.</td><td rowspan="2">Consider the following:
▪ Widen watercourses to carry increased storm flows;
▪ Construct paved watercourses to reduce hydraulic friction factor and increase flow velocity;
▪ Recreate flood plains by relocation of residents;
▪ Create alternate water way structures:
o Surface.
o Sub-surface (very expensive).
▪ Elevate watercourse walls/banks and tolerate lower flood levels based on local surface runoff only. This measure requires flap gates that operate under hydraulic pressure difference between stream flow and adjacent flow level.</td></tr>
<tr><td>IV. Constricted outflows through narrowed waterway crossings due to unauthorized built development. In other words this area which is a natural flood plain has been compromised by anthropogenic development.</td></tr>
</table>

PROBLEMS IDENTIFIED	GENERIC SOLUTIONS DISCUSSED
V. Backwater effects upstream created by very high storm flow (70cms) at the confluence of the two man watercourses as the velocity during flood stage for the catchment coming from the east is significantly larger than the other flow coming from the western watercourse/ catchment passing through Cashew Hill itself.	Increase hydraulic efficiency at confluence of watercourses by: ▪ Geometric reconfiguration at the watercourse confluence to reduce impact of higher flow on the affected area; ▪ Create flow separation design and immediate downstream design of channel with higher flow to lower normal depth to remove the backwater effect; ▪ Widen downstream channel and create detention areas to re-simulate flood plain conditions in the pre-developed state.
VI. Backwater effect from downstream structures outside the area of study. It has been determined that the culvert on the road upstream of the agricultural pond south of the project area is creating the backwater effect.	Consider the following: ▪ Adjust the culvert structure permanently to reduce backwater effect in the rainy season, to cater for high intensity peak runoff flows.

8.2 Potential Impact of the Generic Solutions Identified

The potential impact and efficacy of the foregoing generic solutions to the problems identified are tabulated hereunder to ascertain the optimal solutions with no consideration at this stage for the cost implication:

Table 7: Summary of Problems Identifued, Possible Solutions and Potential Impact

PROBLEMS IDENTIFIED	GENERIC SOLUTIONS DISCUSSED	POTENTIAL IMPACT
I. Increased storm flows in catchment due to highly developed conditions and anthropogenic changes in the watershed area over the last 20 years.	Difficult to reverse especially in SIDs where land is limited but consider: ▪ Enforcing building regulations as it relates to set-backs from main watercourses and maintaining green areas to increase infiltration; ▪ Create upstream detention and or retention ponds to attenuate peak downstream storm flow discharges.	Low in the medium short term but can arrest the worsening of the problem in the medium and long term: ▪ Low/medium positive impact but can result in negative socio-political impact; ▪ Medium based on land availability for sizing.
II. The current practice by the MoW to use the 2.5" rainfall in a 24 hour period is inadequate and based on rainfall analyses of this study indicates that this criterion is less than a 5Yr. R.I. rainstorm resulting in inadequate hydraulic structures.	Revise Design Practice: ▪ Consider island wide adoption of a drainage code of practice or; ▪ Different design guidelines as interim measure; ▪ Upgrade hydraulic structures deemed to be inadequate to carry design storm flows.	Easy to revise design practice but more difficult to implement projects required: ▪ Medium positive impact in short term; ▪ Potentially high positive medium term but engineering training would be required; ▪ High positive impact to carry design storm flows but aggressive implementation plan required.
III. Inadequate water way sections along major reaches of the watercourses to carry peak storm flows between 30cms and 40cms;	Consider the following: ▪ Engineer widen watercourses to carry increased storm flows.	▪ High negative social impact.

PROBLEMS IDENTIFIED	GENERIC SOLUTIONS DISCUSSED	POTENTIAL IMPACT
IV. Constricted outflows through narrowed waterway crossings due to unauthorized built development. In other words this area which is a natural flood plain has been comprised by anthropogenic development.	▪ Recreate flood plains by relocation of residents; ▪ Create alternate water way structures: surface and sub-surface (very expensive); ▪ Elevate watercourse walls/banks and tolerate lower flood levels based on local surface runoff only. This measure requires flap gates that operate under hydraulic pressure difference between stream flow and adjacent flow level.	▪ Medium positive impact if widening can also be achieved; ▪ High negative social-political impact; ▪ Surface alternative waterways impossible without relocation or creating problem in other areas; while subsurface waterways will be very expensive and disruptive. ▪ Can be complicated and requires higher levels of maintenance
VII. Backwater effects upstream created by very high storm flow (70cms) at the confluence of the two main watercourses as the velocity during flood stage for the catchment coming from the east is significantly larger than the other flow coming from the western watercourse/ catchment passing through Cashew Hill itself	Increase hydraulic efficiency at confluence of watercourses by: ▪ Geometric reconfiguration at the watercourse confluence to reduce impact of higher flow on the affected area; ▪ Create flow separation design and immediate downstream design of channel with higher flow to lower normal depth to remove the backwater effect; ▪ Widen downstream channel and create detention areas to re-simulate flood plain conditions in the pre-developed state.	Increase hydraulic efficiency at confluence of watercourses by: ▪ High positive impact with negligible impact on existing development once state/private land is sorted; ▪ High positive impact with negligible impact on existing development once state/private land is sorted; ▪ High positive impact with negligible impact on existing development once state/private land is sorted, but contingent upon determination of backwater effect from downstream, agricultural pond.

PROBLEMS IDENTIFIED	GENERIC SOLUTIONS DISCUSSED	POTENTIAL IMPACT
VIII. Backwater effect from downstream structures outside the area of study. It has been determined that the culvert on the road upstream of the agricultural pond south of the project area is creating the backwater effect.	Consider the following: ▪ Adjust the culvert structure permanently to reduce backwater effect in the rainy season, to cater for high intensity peak runoff flows.	▪ High positive impact to reduce upstream flood depth, as well as the length of time it takes for floods to dissipate.

9 RECOMMENDATIONS FOR FINAL DESIGN SOLUTIONS

Based on time constraints placed on this consultancy exercise to:

- generate solutions within tight timelines that can be implemented to bring early relief to the residents of the affected areas with respect to flood alleviation; and
- due consideration for minimizing the socio-political impact as it relates to private versus state ownership and residential relocation.

The proposed solutions recommended at this stage fall into the following three broad categories as we are of the opinion that non-structural solutions are equally important as structural solutions to achieve maximum positive impact:

A. Institutional strengthening and enforcement of existing land use laws;
B. Adjustment of engineering practices and adoption and/or development of codes of practice for infrastructure development with mandatory government agency approvals;
C. State implemented drainage improvement projects for flood alleviation.

9.1 Institutional Strengthening and Enforcement of Existing Land Use Laws:

i) Enforce building approval regulations.

ii) Establish watercourse reserves within the main channels and also enforce building line setbacks from the watercourse reserves.

iii) Preserve all remaining green spaces within the watershed and limit further single family type development.

iv) Consider revised development standards to facilitate medium rise development in remaining open areas, so as to retain maximum green spaces while accommodating some development.

v) Relocate residents within major watercourse channels that have to be expanded for the benefit of the majority of the citizens in the area.

9.2 Adjustment of Engineering Practices and Adoption and/or Development of Codes of Practice for Infrastructure Development with Mandatory Government Agency Approval:

i) Commission the development of a country wide drainage code with appropriate IDF and DDF curves development.

ii) Adopt higher storm recurrence interval for design of major waterways and hydraulic structures within urbanized areas.

iii) Building approvals to include drainage approval by the Ministry of Works before construction is allowed to commence.

iv) Future land developments to be mandated to attenuate peak post-development storm flows to bring them in line with peak pre-development storm flows using various hydraulic techniques.

v) Make it mandatory for all proposed works within the main watercourse of the watershed to be approved by the Ministry of Works to ensure that negative upstream or downstream impacts will not occur.

9.3 State-Implemented Drainage Improvement Projects for Flood Alleviation in the Cashew Hill Area:

The following work is proposed to be developed to detailed design levels and compiled as Tender Documents for immediate construction in order of priority, based on the meeting dated 2015.05.25 with OECS, DOE, MOW and Alpha to discuss the Preliminary Draft Technical Analysis and Design Report (see **Appendix 7** for Minutes of the Meeting).

i) Re-alignment of watercourse at confluence to separate flows and reduce the impact of WC#2 peak flows on WC#1.

ii) Construction of expanded channel downstream of watercourse confluence with:
   a) Either shallow wetlands to facilitate water quality improvement;
   b) Dry detention pond to facilitate dual purpose use;
   c) Or wet detention pond/lake design to facilitate improved downstream flows, but create an amenity for adjacent medium rise development and recreation.

iii) Widen existing main earthen channel within the Cashew Hill area using a reinforced concrete channel to increase storm flow and mitigate flood frequency and flood height.
   a) Minimum 5.0m wide for 1:20-Yr. storm flow;

iv) Re-construct the following culvert crossing in the main watercourse:

a) Culvert #2 to be reconfigured to take the 20Yr. storm flow.

An overall drainage improvement plan with the above proposed solution is shown in **Figure #10** and the proposed details are shown in **Figures # 11, 12, 13 and 14** below. The full set of preliminary designs are included in **Appendix 8**:

Figure 10: Overall Drainage Improvement Plan

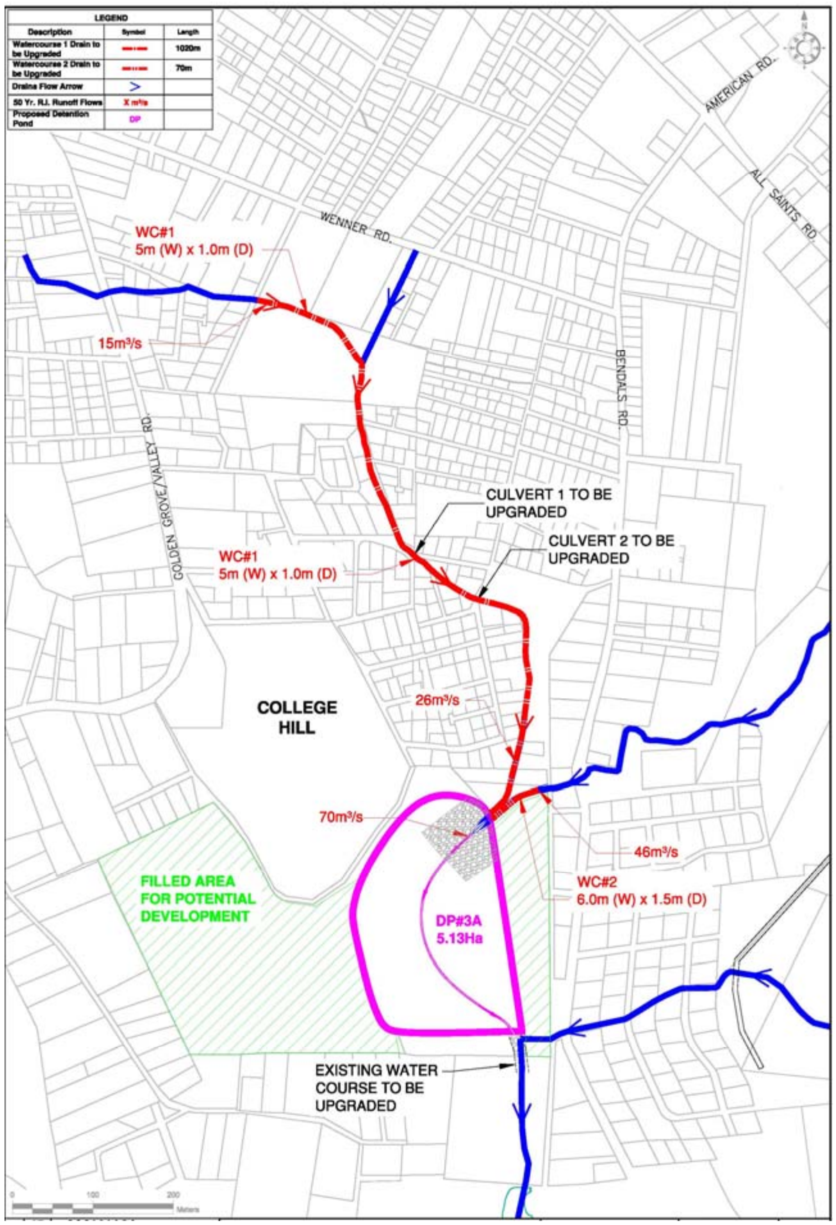


Figure 11: Confluence Detail

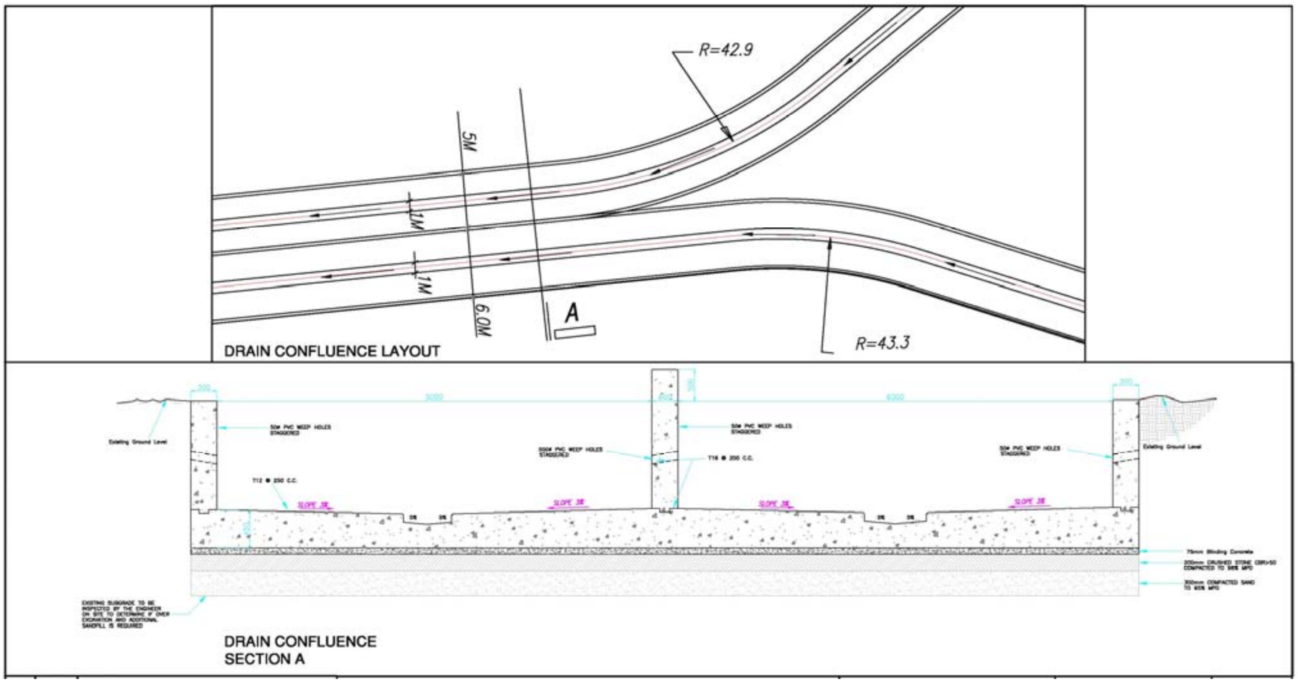


Figure 12: Typical R.C. Water Course Section

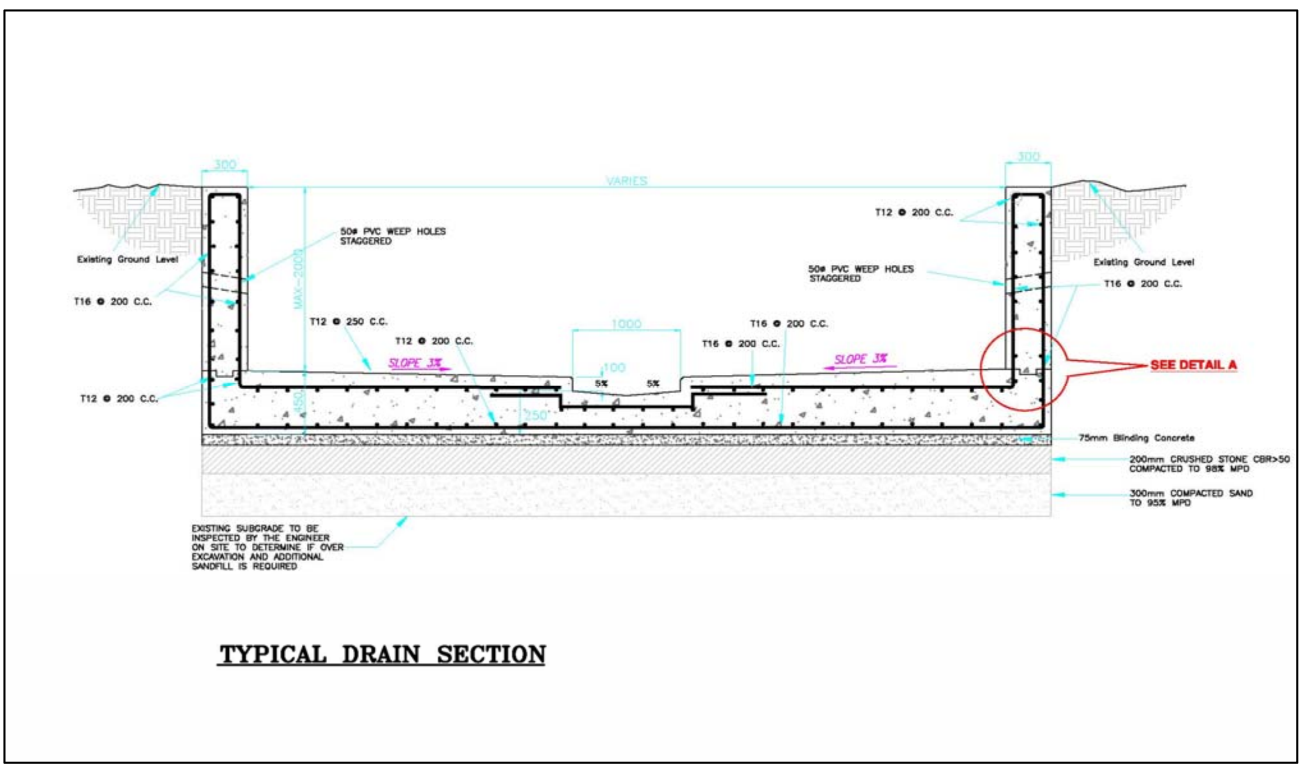


Figure 13: Dry Detention Pond Preliminary Layout

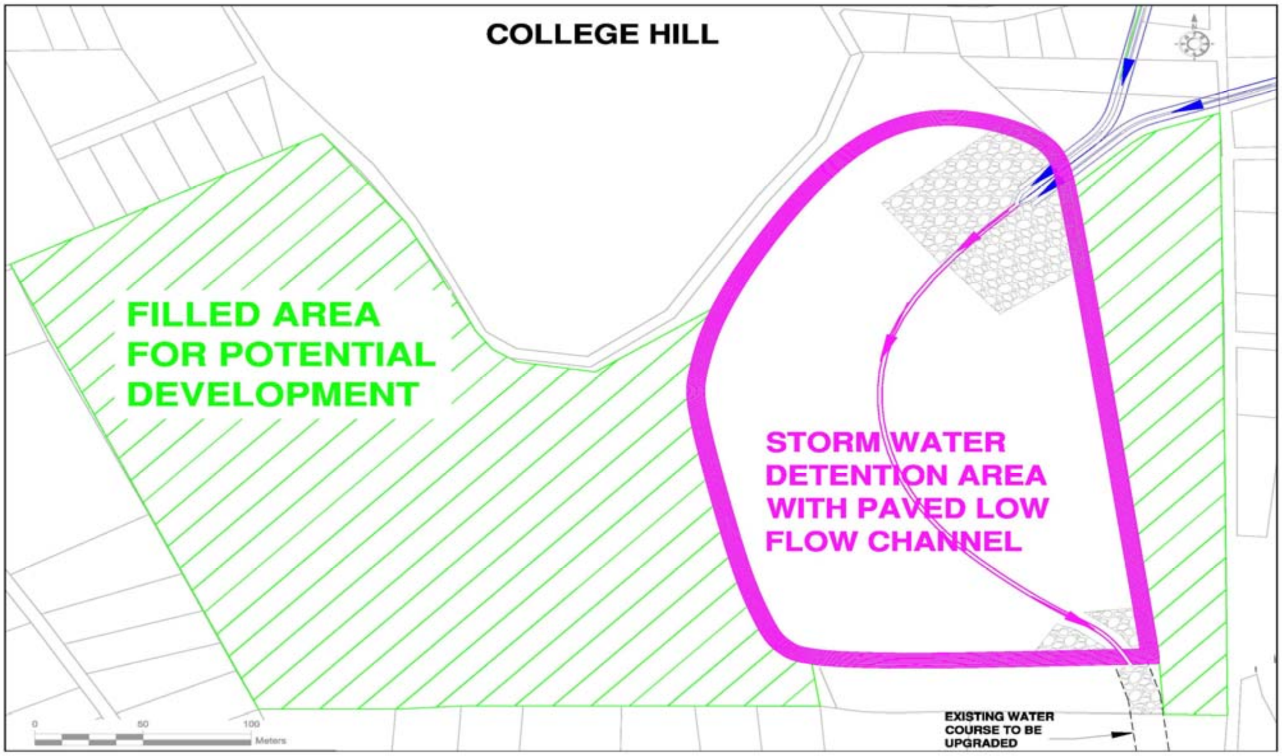
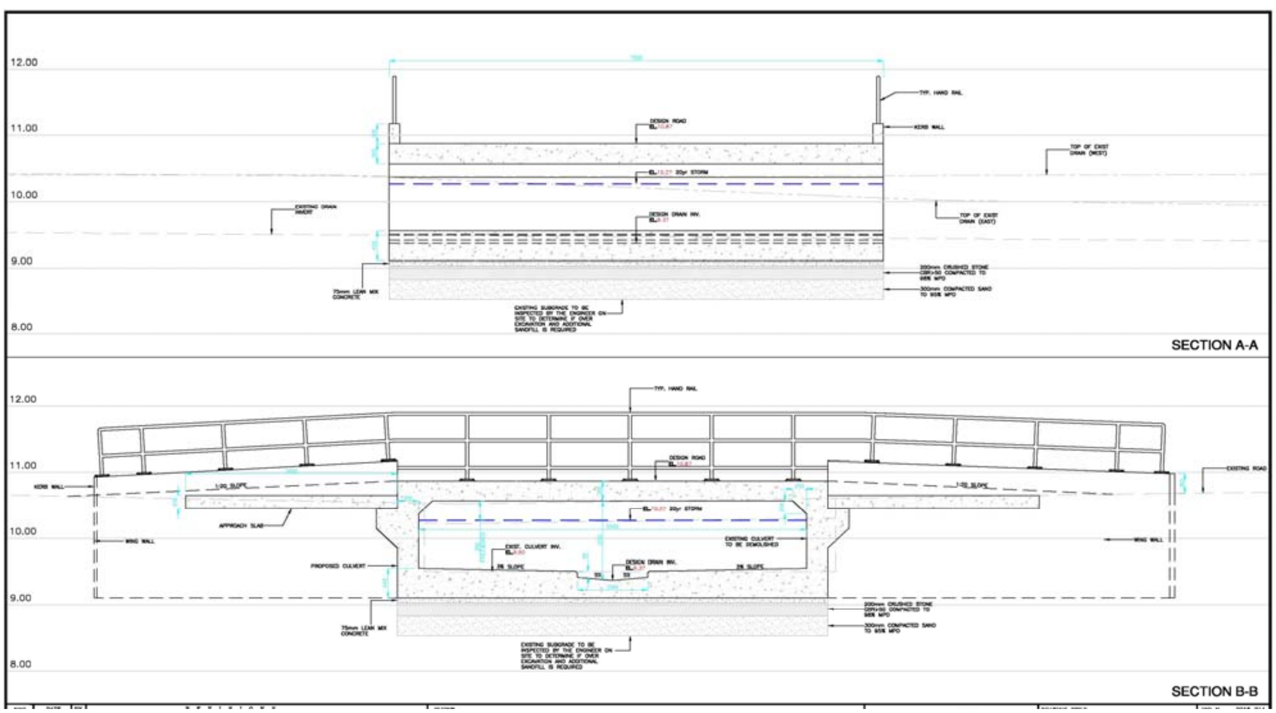


Figure 14: Culvert #2 Details



10 PRELIMINARY PROJECT ESTIMATE AND IMPLEMENTATION SCHEDULE

Preliminary time and cost estimates are generated to allow informed decisions to be made going forward in relation to the preparation of tender documents for the proposed flood alleviation works defined in section 9.3 above. See **Appendix 9** for a detailed preliminary engineer's cost estimate. The following assumptions have been made:

a. Estimates are based on present going rates for similar work.
b. Assumes that the work will be executed in 2016.
c. Competitive bidding is used to get competitive prices for execution.

Table 8: Summary of Preliminary Engineer's Cost Estimate

BILL NO.	DESCRIPTION		PRELIMINARY ENGINEER'S ESTIMATE $ECD	
100	PRELIMINARIES		$	1,054,000.00
200	WATER COURSE #1		$	3,398,080.16
300	WATER COURSE #2		$	825,442.11
400	DETENTION POND		$	2,164,250.00
500	CONFLUENCE		$	866,284.74
600	CULVERT #2		$	195,907.59
	SUB-TOTAL		**$**	**8,503,964.61**
	Add Contingency	10.0%	$	850,396.46
	TOTAL (Not Including VAT)		**$**	**9,354,361.07**
	Add VAT	15.0%	$	1,403,154.16
	GRAND TOTAL (E.C. DOLLARS)		**$**	**10,757,515.23**

In order to present options for the Client to execute the implementation based on the budget allocation (see **Appendix 10**), it is proposed that the works be carried out in a staged construction approach by creating distinct packages which can be financed accordingly. The summary costs for each package is included **Table 9** below and these are identified in Drawing #12 in **Appendix 8:**

Table 9: Summary of Preliminary Engineer's Cost Estimate for Packages

PACKAGE NO.	DESCRIPTION	PRELIMINARY ENGINEER'S ESTIMATE $ECD
1	Culvert #2 and Confluence	$ 1,529,642.83
2	Water Course #1 from confluence to Culvert #2, Water Course #2 upstream of confluence	$ 3,123,444.58
3	Detention Pond	$ 3,116,694.96
4	Water Course #1 from Culvert # 2 to Chainage 0+370 and Culvert #2	$ 1,256,698.80
5	Water Course #1 from Chainage 0+000 to 0+370	$ 1,731,034.06
GRAND TOTAL (E.C. DOLLARS)		**$ 10,757,515.23**

Note: All above prices include 10% Contingency, and 15% VAT.

It was mutually agreed that Alpha will develop the Tender Dossier for Package# 1 based on the funds available. An implementation schedule for this package is included in **Table 10** below.

Table 10: Implementation Schedule

Item	Duration (Mths)	Jun 2016	Jul 2016	Aug 2016	Sept 2016	Oct 2016	Nov 2016	Dec 2016
OECS Supply Tender Dossier Template	**0.25**	■						
Alpha develop and Issue Package# 1 Tender Dossier	**0.5**	■						
Tender, Evaluation and Procurement Period	**3**		■	■	■			
Construction Period	**3**					■	■	■

11 CONCLUSION AND RECOMMENDATIONS

This report is issued as the Draft Technical Analysis and Design Report which is deliverable #2.

Based on the above Section 10 the Tender Dossier for Package 1 will be issued on 2016.06.17 to include the following:

1. OECS template with Alpha review of Special Conditions.
2. Detailed Final Design Drawings as listed above.
3. Detailed Blank Bills of Quantities and Final Engineer's Estimate.
4. Materials and Workmanship Specifications.

Prepared By:	Input By:	Input By:	Date:
Fazir Khan	Kieran De Freitas	D. Eugene Winter	2016.06.06
Project Manager	**Project Engineer**	**Project Engineer**	

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APPENDIX 1

Email Correspondences between Alpha and Climatologist

Gmail **Kieran de Freitas <alphaeng.kierandefreitas@gmail.com>**

OECS/GCCA/2015/SER-18(Lot 2) - Rainfall Analyses

Dale Destin <dale_destin@yahoo.com> Thu, Apr 28, 2016 at 10:03 PM
Reply-To: Dale Destin <dale_destin@yahoo.com>
To: Fazir Khan <alphaeng.fazirkhan@gmail.com>
Cc: Dwight Laviscount <dwight.n.laviscount@gmail.com>, Chamberlain Emmanuel <cemmanuel@oecs.org>, Gerad Payne <gpayne2007@gmail.com>, Kieran de Freitas <alphaengkierandefreitas@gmail.com>, Janna Turpin <alphaeng.jannaturpin@gmail.com>, Eugene Winter <alphaeng.eugenewinter@gmail.com>, Adele Young <alphaeng.adeleyoung@gmail.com>, "PETERS, John" <johnapeters@hotmail.com>, Tanya Wright <twright@oecs.org>, Diann Black-Layne <dcblack11@gmail.com>, Jason Paul Williams <jaypwill@gmail.com>, Ruleta Camacho Thomas <sirmmab@gmail.com>

Noted with appreciation, all the best!

Regards,
Dale Destin BSc, PG Dip, MA
Climatologist
Antigua and Barbuda Meteorological Service Climate Section
P. O. Box 1051, St. John's, Antigua
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blog | instagram | tumblr | google+
flickr | youtube | webpage | newsletter

Antigua Met Service
@anumetservice

Mass coral bleaching is one of the immediate challenges of #climatechange: e360.yale.edu/feature/from_m…

Apr 28, 2016

On Wednesday, April 27, 2016 5:37 PM, Fazir Khan <alphaeng.fazirkhan@gmail.com> wrote:

Dear Mr Destin,
Thank you for taking the call this evening and for our very engaging discussions on the rainfall analyses presented.
In summary we mutually agree that notwithstanding that Green Castle appears to be a wetter area than VCBIA based on monthly averages (based on your data), it should not be directly correlated to increase in the 24 hr rainfall estimates (as you also pointed out in your email). Our experience doing similar work in wetter Islands like St Vincent leads us to consider that the VCBIA Intensities Alpha derived from the 24 hr rainfall estimates using appropriate disaggregation factors are not low.

We will therefore move forward by using a smaller % increase to develop the final IDF and DDF Curves to be utilized in the rainfall-runoff models, the latter of which we subject to calibration methods as well.

regards

Fazir Khan BSc., REng

Alpha Engineering & Design (2012) Ltd.

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Lot 10D, Chootoo Road,

El Socorro, San Juan South

Trinidad, W.I.

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T: (868) 735-6662

C: (868) 682-7005

On Thu, Apr 21, 2016 at 8:51 AM, Ruleta Camacho Thomas <sirmmab@gmail.com> wrote:

Fazir,

Please see comments below from Mr Dale Destin at the Antigua and Barbuda Met Office.

Hi Ruleta:

My views after somewhat carefully examining the document (forgive me for any typos, it's 4 am):

The methodology looks quite sound and a good basis for the final recommendation. However, since Green Castle (GC), which is next door to Cashew Hill, gets around 30% more rainfall than the Airport (VCBIA), I would recommend that base figure of 253.2 mm is increased by 30% and then disaggregated to obtain the other figures. So the recommended table would now look like this:

Durations for 1 in 50.yr .Recurrence Interval	Minutes					Hours			
	5	10	15	30	60	2	6	12	24
DDF Rainfall (mm)	34.6	52.7	65.8	92.8	124.4	158.0	227.1	277.5	**329.2**
IDF Rainfall (mm/hr.)	415.2	316.2	263.2	185.6	124.4	79.0	37.9	23.1	13.7

Now, 30% difference in rainfall may not necessarily translate to GC 1 in 50, 24-hr rainfall being 30% more than that of VCBIA but there SHOULD be an allowance for the fact the fact that GC is a wetter area.

Some other things:

- The annual total rainfall at VCBIA is almost equal to the wet season total for GC as described by Alpha Engineering and Designs.

- I understand the use of Ohio but I would not use it given the very different climate and from what I saw online, the annual total is about 355 mm less than that of GC.

- Using the EasyFit stats software, the best fit distribution model is Burr, followed by Log-Logistic (3P) and Gen. Extreme Value. However, I see Alpha choose to use Gumble to develop DDF Curves - CHART 1 for Annual, Wet Season and Dry Season Rainfall for various return frequencies. When compared to the best fit model, it works okay for the annual and dry season total; however, there are significant differences for the wet season. It understates the rainfall (dept) for the given return intervals, which is a problem.

- In the document, TABLE 2 is said to be the "Max. Daily Rainfall (mm) Recorded at Green Castle - BENDALS" but it looks instead to be the ranking of the seasonal rainfall for GC. Actually, no daily rainfall totals for GC exist to the best of my knowledge.

Feel free to call me (764-5030) for any clarifications.

Ruleta Camacho Thomas (Mrs)
Deputy Director
Department of Environment
Ministry of Health and the Environment
Victoria Park Botanical Gardens
St. John's, Antigua
1 268 464 5031

On Thu, Apr 14, 2016 at 5:44 AM, Fazir Khan <alphaeng.fazirkhan@gmail.com> wrote:

Dear Ruleta,

As promised, as we work through our next deliverable, "DRAFT Technical Analysis and Design Report' we will supply information as developed as part of our consultancy for you review and comments.

Please therefore find attached the **Draft Rainfall Analysis** prepared by our hydrologist Eugene Winter and note the following:

1. We have utilized the rainfall data supplied by VCBIA; the Green Castle Station and your Climatologist as well as other relevant Caribbean data/analyses
2. Current hydraulic designs reported to be carried out in Antigua are based on 2" rainfall depth in 6 hours.
3. We have carried out comparative rainfall analyses using the limited data provided and based on the following references:
    1. Disaggregation Factors for Sub - 24hr. Rainfall distribution in Eastern Caribbean Region - - ref. " St. Vincent RDVRP - Report on Design Storm Rainfall for Hydrological Review of Drainage Projects"
    2. "The challenges of developing Rainfall Intensity - Duration - Frequency curves and nation flood hazard maps for the Caribbean" by DM Lumbroso, S Boyce, H Blast and N Walmlsey ; published in "the Journal of Flood Risk Management" Volume 4 , Number 1 January 2011 pp 42-52.
    3. Synthetic Distribution of 24hr. Type II Rainfall Events. Ref. "Urban Hydrology for Small Watersheds - TR 55" and "TABLE 4A-6 Ratio of Shorter Duration to 24hr. Precipitation for Columbus,Ohio - Based on NOAA Atlas 14 Data"... by USDA / NRCS.
4. The results generated point to the use of the 1:50 Rainstorm Recurrence interval for the hydraulic design of major watercourse structures and waterways for the project site as it relates to flood mitigation solutions.
5. The analysis also produces curves for the 1: 20 RI Storm which can be used for minor structures and sub-developments as the risks associated with these are less.
6. CHART 1 which provides annual data for both wet and dry season will allow us to examine the scenarios as it relates to the sustainability of wetland type solutions in the dry season based on Water Balance type calculations
7. Note that both IDF Curves (See CHART 4) and 24 hours DDF Curves (See CHART 3) and have been developed and compared to the NRCS Type II Rainfall (Ref 3.3 above), which is widely used in the absence of other data/island-specific methodologies, regionally.

1. The former (IDF Curves) allows us to proceed to the Rainfall -Runoff Analyses using the Rationale Method
2. While the latter (24-hr Rainfall) allows us to apply the SCS Method for for small urban catchments.
    1. to generate in both cases peak flood flows in the watercourse points of interests through out the sub-catchments
3. As we move to the next stage (Rainfall-Runoff Modeling), climate change trends will be incorporated into the modeling

We look forward to any comments that your team may have in relation to the rainfall analyses.
In the meantime we are completing the Catchment Modeling (based on the 1:25000 topo maps) and building the Rainfall-Runoff Model for the Cashew Hill Catchment.
regards

Fazir Khan BSc., REng
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APPENDIX 2

Rainfall Data and Analysis

OECS Flood Relief Project in Antigua EC	SUMMARY	Page 1

The approach used in executing this project is summarised below in the following steps :

FINAL DRAFT

Step 1 ***Defining Project Objectives***

Preparation of (DDF) and (IDF) Rainfall CURVES for frequency occurrence intervals of up to 1 in 100 years for use in the hydraulic design and planning of drainage works in Antigua.

Step 2 ***Collecting Relevant Rainfall Data:***

Data collected was separated into two (2) categories :

Category a) Rainfall data supplied by the Client including ;

i) - Monthly Rainfall from 1957 to 2015 (incl.)
ii) - Daily Rainfall for October 2015 at V.C. Bird
iii) - 24 -hr. (average daily) Rainfall estimates
iv) - 6 -hr. Rainfall estimates for various return periods

Category b) Rainfall data researched by the Consultant including:

i) - Documentation pertaining to disaggregation ratios for Sub -24hr. Rainfall distribution ; viz. a)

a) "The challenges of developing Rainfall Intensity - Duration - Frequency Curves and nation flood hazard maps for the Caribbean" by DM Lumbroso, S Boyce, H Blast and N Walmlsey ; published in ''the Journal of Flood Risk Management" Volume 4, Number 1 January 2011 pp 42 - 52.

b) National Engineering Handbook (NEH), Part 603 - Hydrology, Part 4 - Storm Rainfall and Distribution of NRCS Type II Synthetic Storm Rainfall, Appendix 4a - TABLE 46a.

ii) - Documents pertaining to Storm Rainfall Frequency;

a) " Return Period to be used for Hydrologic Design" by Victor M. Ponce. Re. Table 1.

b) " Stormwater Drainage Manual " prepared by Gov. of Hong Kong Special Administrative Region. Re. Table 10 pg. 125.

Note: *Rainfall Data collected is described in greater detail on pages 2 & 3*

Step 3 ***Analysing Rainfall Data Collected:***

Analysis of the collected data focused on four (4) activities :

i) - selecting a viable distribution for Sub-Annual ; sub-24 hr. ; sub-6 hr. and sub-1 hr. storm rainfall events.

ii) - Choosing an acceptable recurrence interval for the design storm.

iii) - Using the climate adjusted rainfall values (Table 2-1) together with disaggregation factors to compute Sub-24hr. Rainfall Distribution .

iv) - Producing the required DDF and IDF curves for recurrence intervals of 1 in 100-Yr., 1 in 50-Yr., 1 in 20-Yr., 1 in 10-Yr., 1 in 5-Yr. and 1 in 2-Yr.

Note: *Hydrological analysis of rainfall data collected is described in greater detail on pages 4 to 7 incl.*

Step 4 ***Results and Recommendations***

On the basis the results obtained from the methods outlined in ***step 3***, we recommend that the following rainfall depths, intensities and durations for the 1 in 50-Yr. recurrence interval be adopted for use in the hydraulic design and review of existing and planned drainage works in Antigua:

Durations for 1 in 50.yr .Recurrence Interval	Minutes					Hours			
	5	10	15	30	60	2	6	12	24
DDF Rainfall (mm)	37.2	53.2	61.2	79.8	98.4	125.0	172.8	212.7	265.9
IDF Rainfall (mm/hr.)	446.7	319.1	244.6	159.5	98.4	62.5	28.8	17.7	11.1

Alpha
Alpha Engineering and Design (2012) Ltd.
Prepared by . D . E . Winter F.A.P.E. R. Eng.

OECS Flood Relief Project in Antigua EC | Rainfall Data Collected | Page 2

TABLE 1 -1: Monthly rainfall (mm) from 1957 to 2015 (incl.) Recorded at Green Castle - BENDALS

Year	DRY SEASON Months					WET SEASON Months									ANNUAL
	Jan.	Feb.	Mar.	Apr.	Sum	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Sum	Sum
1957	59.9	67.8	12.7	51.6	**192.0**	52.3	37.1	51.1	163.6	146.8	145.0	181.4	175.0	**952.2**	1144.3
1958	15.7	47.2	47.8	44.7	**155.4**	213.1	282.4	126.7	72.9	171.2	131.1	68.1	88.9	**1154.4**	1309.9
1959	125.2	34.3	25.1	126.7	**311.4**	217.9	36.3	76.7	118.9	92.7	80.5	82.6	175.5	**881.1**	1192.5
1960	61.5	129.8	104.9	48.5	**344.7**	102.6	101.3	196.3	131.6	112.3	121.7	100.1	118.9	**984.8**	1329.4
1961	58.4	78.5	40.1	28.2	**205.2**	71.4	61.5	134.1	205.7	99.1	165.4	186.9	96.0	**1020.1**	1225.3
1962	182.9	25.4	38.9	143.3	**390.4**	128.5	119.1	130.0	279.7	303.0	62.5	177.5	42.4	**1242.8**	1633.2
1963	133.1	35.8	15.2	62.2	**246.4**	169.9	383.0	205.2	49.5	99.6	167.6	205.7	40.6	**1321.3**	1567.7
1964	90.9	30.0	54.1	196.3	**371.3**	36.3	63.0	100.3	201.9	157.5	40.6	56.6	59.9	**716.3**	1087.6
1965	130.8	29.2	64.5	42.4	**267.0**	109.5	66.3	117.1	76.5	123.4	56.6	81.8	98.6	**729.7**	996.7
1966	37.3	37.1	34.5	32.5	**141.5**	95.5	21.8	95.8	146.1	118.1	129.8	131.3	88.4	**826.8**	968.2
1967	49.5	48.3	343.4	34.0	**475.2**	35.3	33.0	149.1	68.6	93.5	88.4	66.8	54.4	**589.0**	1064.3
1968	45.2	19.6	17.5	79.8	**162.1**	138.7	107.4	68.1	77.0	59.9	55.4	115.6	124.7	**746.8**	908.8
1969	99.6	45.5	23.9	140.5	**309.4**	354.3	80.5	133.9	117.9	127.8	230.9	141.0	57.7	**1243.8**	1553.2
1970	67.6	22.9	31.0	33.5	**154.9**	325.9	199.1	147.6	142.2	137.7	207.8	105.9	242.3	**1508.5**	1663.4
1971	195.1	68.3	45.0	30.5	**338.8**	121.4	53.6	157.7	117.1	152.4	129.8	38.1	341.6	**1111.8**	1450.6
1972	89.4	70.6	167.1	108.7	**435.9**	83.6	39.4	72.4	127.0	114.8	197.4	84.1	310.4	**1029.0**	1464.8
1973	70.1	69.1	40.4	22.9	**202.4**	18.5	51.3	76.7	149.1	130.6	67.1	53.3	62.2	**608.8**	811.3
1974	85.9	43.4	43.9	44.2	**217.4**	33.0	10.2	34.3	171.7	251.2	174.8	433.3	15.7	**1124.2**	1341.6
1975	67.8	45.0	10.2	38.1	**161.0**	148.3	21.8	42.7	100.8	119.1	142.2	196.3	157.5	**928.9**	1089.9
1976	69.1	103.4	61.0	59.9	**293.4**	50.0	68.8	12.2	113.8	110.2	258.3	146.3	138.4	**898.1**	1191.5
1977	225.3	30.5	37.1	50.8	**343.7**	19.1	16.8	29.0	179.3	174.5	162.8	439.9	83.6	**1104.9**	1448.6
1978	62.5	36.6	30.5	132.6	**262.1**	208.3	67.8	176.5	213.9	22.9	97.5	234.4	32.0	**1053.3**	1315.5
1979	77.0	66.8	28.2	76.5	**248.4**	384.3	136.4	140.2	86.4	99.6	164.3	256.0	238.3	**1505.5**	1753.9
1980	80.0	63.5	5.6	36.3	**185.4**	43.2	93.0	130.6	142.0	204.7	156.7	75.9	140.5	**986.5**	1172.0
1981	30.0	101.1	89.9	291.8	**512.8**	135.1	86.6	180.6	103.6	250.7	198.6	137.2	294.6	**1387.1**	1899.9
1982	73.7	150.9	37.8	195.3	**457.7**	39.6	16.5	112.8	148.6	62.7	140.0	246.4	152.4	**919.0**	1376.7
1983	64.8	6.4	38.1	48.0	**157.2**	139.2	35.6	134.9	87.4	75.9	55.1	47.0	64.0	**639.1**	796.3
1984	134.4	55.9	49.5	59.7	**299.5**	95.3	58.7	50.3	43.2	160.0	128.3	221.5	80.0	**837.2**	1136.7
1985	56.4	40.4	162.1	70.1	**328.9**	22.1	13.7	105.4	102.9	275.1	186.4	218.9	61.2	**985.8**	1314.7
1986	32.5	42.4	62.5	126.5	**263.9**	94.2	17.8	48.0	60.2	103.6	78.5	427.0	60.5	**889.8**	1153.7
1987	70.9	26.2	45.5	63.2	**205.7**	548.4	181.1	73.2	71.6	161.0	296.4	293.4	109.2	**1734.3**	1940.1
1988	116.6	77.2	84.3	50.8	**328.9**	38.1	67.3	176.3	316.0	169.9	120.4	114.0	74.4	**1076.5**	1405.4
1989	94.2	57.7	58.7	65.0	**275.6**	26.7	38.6	68.3	85.6	325.6	88.1	83.6	33.0	**749.6**	1025.1
1990	51.1	22.4	41.9	114.3	**229.6**	74.9	88.4	46.5	103.9	96.8	269.5	82.3	127.8	**890.0**	1119.6
1991	101.6	70.6	38.1	30.5	**240.8**	67.8	65.3	152.4	83.8	184.2	89.7	164.3	67.8	**875.3**	1116.1
1992	85.3	97.3	260.9	223.3	**666.8**	180.8	126.2	126.0	174.5	218.4	233.7	232.7	243.8	**1536.2**	2202.9
1993	77.2	49.3	29.7	50.5	**206.8**	355.6	138.4	173.0	52.1	93.0	96.5	101.9	80.0	**1090.4**	1297.2
1994	98.0	65.5	49.5	136.7	**349.8**	88.4	67.3	57.7	97.8	284.0	101.6	140.0	68.6	**905.3**	1255.0
1995	36.8	91.2	100.1	23.9	**252.0**	45.2	25.4	77.5	308.6	335.8	179.6	76.2	100.3	**1148.6**	1400.6
1996	66.8	67.6	20.1	89.7	**244.1**	72.4	113.3	189.2	108.0	80.0	147.3	128.0	313.7	**1151.9**	1396.0
1997	52.7	162.6	10.2	78.7	**304.1**	76.2	66.0	149.9	228.6	211.1	168.4	52.6	41.1	**993.9**	1298.0
1998	27.4	67.8	43.7	115.6	**254.5**	44.5	79.8	75.4	148.8	191.0	150.1	309.9	208.3	**1207.8**	1462.3
1999	58.9	34.8	93.5	119.6	**306.8**	72.9	55.9	190.8	54.9	91.9	151.4	474.0	78.0	**1169.7**	1476.5
2000	42.4	152.1	51.3	47.5	**293.4**	65.0	54.1	62.0	130.8	152.4	61.5	102.4	76.5	**704.6**	998.0
2001	41.7	18.0	16.5	46.5	**122.7**	5.1	9.1	168.7	59.7	88.1	181.1	98.6	292.1	**902.5**	1025.1
2002	34.3	20.3	42.4	252.2	**349.3**	31.8	52.8	120.9	73.4	93.7	170.2	81.0	71.4	**695.2**	1044.4
2003	51.6	47.0	21.3	34.0	**153.9**	46.5	96.5	66.3	96.8	43.9	205.7	237.2	116.3	**909.3**	1063.2
2004	64.5	158.8	74.9	74.4	**372.6**	365.8	113.0	146.6	63.2	66.3	254.5	223.3	195.8	**1428.5**	1801.1
2005	117.6	82.8	7.4	34.8	**242.6**	97.5	148.3	142.7	186.7	64.8	1064.5	163.8	47.8	**1916.2**	2158.7
2006	303.8	47.5	15.2	27.9	**394.5**	135.4	90.4	98.3	158.5	224.5	226.3	61.5	90.9	**1085.9**	1480.3
2007	117.9	61.0	34.8	65.0	**278.6**	27.2	49.3	97.3	95.8	124.7	247.4	162.8	116.1	**920.5**	1199.1
2008	180.1	60.5	56.9	53.8	**351.3**	85.1	66.5	83.1	109.7	202.7	423.9	147.1	113.5	**1231.6**	1582.9
2009	56.1	40.6	41.9	64.0	**202.7**	278.1	107.7	98.3	89.2	134.1	101.1	103.9	72.1	**984.5**	1187.2
2010	78.2	21.8	42.9	324.9	**467.9**	169.9	171.5	149.4	349.5	126.5	263.7	105.7	111.0	**1447.0**	1914.9
2011	50.5	56.9	97.0	74.9	**279.4**	262.1	70.6	276.1	243.6	198.6	94.2	276.6	109.2	**1531.1**	1810.5
2012	94.7	41.1	31.0	72.9	**239.8**	91.2	5.6	118.1	99.1	26.9	370.8	75.4	69.1	**856.2**	1096.0
2013	88.9	13.7	39.4	143.5	**285.5**	111.5	94.2	52.6	166.9	84.3	81.0	130.6	148.1	**869.2**	1154.7
2014	75.7	44.2	11.2	55.1	**186.2**	102.4	31.2	17.8	135.9	102.6	168.4	188.2	67.3	**813.8**	1000.0
2015	28.4	45.5	29.7	29.2	**132.8**	22.9	16.0	48.3	33.5	107.7	66.0	106.9	60.5	**461.8**	594.6

OECS Flood Relief Project in Antigua EC	Rainfall Data Collected . . Cont'd.	Page 3

TABLE 1 - 2: Average Daily Rainfall on Oct. 2015 at V.C. Bird

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
(mm)	0.0	0.1	0.3	0.0	0.1	0.0	8.2	7.1	0.0	0.0	0.5	0.3	4.3	2.5	2.4	22.0	5.4	16.8	0.9	0.1	0.0
Day	22	23	24	25	26	27	28	29	30	31											
(mm)	0.9	1.5	34.9	0.0	0.9	0.0	0.4	0.0	1.6	4.2	**115.7 mm. Total**										

TABLE 1 - 3: 24-hr. Rainfall Estimates (mm) for Various Recurrence Intervals

Station	Method Model	Recurrence Intervals in Years							
		5	10	20	50	100	200	500	1000
VCBIA	**Best-Fit Model**								
	Fatigue Life (3P)	127.9	165.1	202.8	253.2	291.7	330.5	382.1	421.5
	Adjusted for wetter site conditions (Add 5%)	**134.3**	**173.4**	**212.9**	**265.9**	**306.3**	**347.0**	**401.2**	**442.6**
	Second Best-Fit Model								
	Inv. Gaussian (3P)	127.1	164.6	203.2	256.0	297.1	339.2	396.0	439.5
C CROSS	**Best-Fit Model**								
	Johnson SB	182.5	203.7	215.2	223.2	226.6	-	-	-
	Second Best-Fit Model								
	Error	182.2	201.3	211.3	218.4	211.8	-	-	-

TABLE 1 - 4: 6-hr. Rainfall Estimates (mm) for Various Return Periods

Station	Method Model	5	10	20	50	100	200	500	1000
VCBIA	**Best-Fit Model**								
	Generalized Pareto	104.1	127.0	145.0	163.0	173.3	181.3	189.4	194.0
	Second Best-Fit Model								
	Johnson SB	102.0	125.3	145	166.3	175.9	190.5	202.4	209.7

NOTES : 1. Comments on the TABLES above are as follows :

i) VCBIA = V.C.Bird International Airport , St. George, Antigua ; 17.1353 N : 61.7912 W : 45 years (1971 to 2015)

ii) C.CROSS = Cobbs Cross, St. Paul, Antigua; 21 years of data (1995 to 2015)

iii) 24hr. Estimates are based on measured totals for the period 8 am to 8 pm

vi) 6hr. Estimates are based on measured totals for the periods 8 am to 2 pm : 2pm to 8pm : 8pm to 2am : 2am to 8am.

2. Comments on a Preliminary Draft Report (Prepared by Dale C.S.Destin - Climatologist, Antigua and Barbuda Meterological Service Climate] were reviewed and adressed as required in this revised report as followes :

i) Rainfall Dephs (mm) at Green Castle (GC) is approximately 30% > Rainfall Depths at VCBIA and as such the 24 hr. Rainfalls estimated for various return Frequencies at the VDBIA are increased by approximately 5% for use in the development of DDF and IDF Curves for use in Design of hydraulic structures.

3) Wet season rainfall values determined using the Burr Frequency Model were found to be higher than the Gumbel Model used in this analysis. However, since monthly rainfall values are not used in developing the required BBF and IDF Curves, the discrepancy between these Models was not adressed in this report.

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OECS Flood Relief Project in Antigua EC	Rainfall Analysis	**Page 4**

TABLE 2.1: DDF values for - Dry Season, Wet Season and Annual rainfall

Gumble Probability Distribution			Ranked Rainfall (mm) from TABLE 1 - 1		
Rank r	F = r/(n+1)	T = 1/F	Dry Season	Wet Season	Annual
1	0.017	59.00	666.8	1916.2	2202.9
2	0.034	29.50	512.8	1734.3	2158.7
3	0.051	19.67	475.2	1536.2	1940.1
4	0.068	14.75	467.9	1531.1	1914.9
5	0.085	11.80	457.7	1508.5	1899.9
6	0.102	9.83	435.9	1505.5	1810.5
7	0.119	8.43	394.5	1447.0	1801.1
8	0.136	7.38	390.40	1428.50	1753.87
9	0.153	6.56	372.62	1387.09	1663.45
10	0.169	5.90	371.35	1321.31	1633.22
15	0.254	3.93	343.66	1169.67	1476.50
20	0.339	2.95	309.37	1111.76	1405.38
25	0.424	2.36	293.37	1053.34	1329.44
30	0.508	1.97	266.95	985.77	1297.18
35	0.593	1.69	248.41	920.50	1191.51
40	0.678	1.48	239.78	898.14	1144.27
45	0.763	1.31	205.23	869.19	1089.91
50	0.847	1.18	185.42	749.55	1025.14
58	0.983	1.02	132.84	589.03	796.29

Brief notes on Hydrologic Analysis

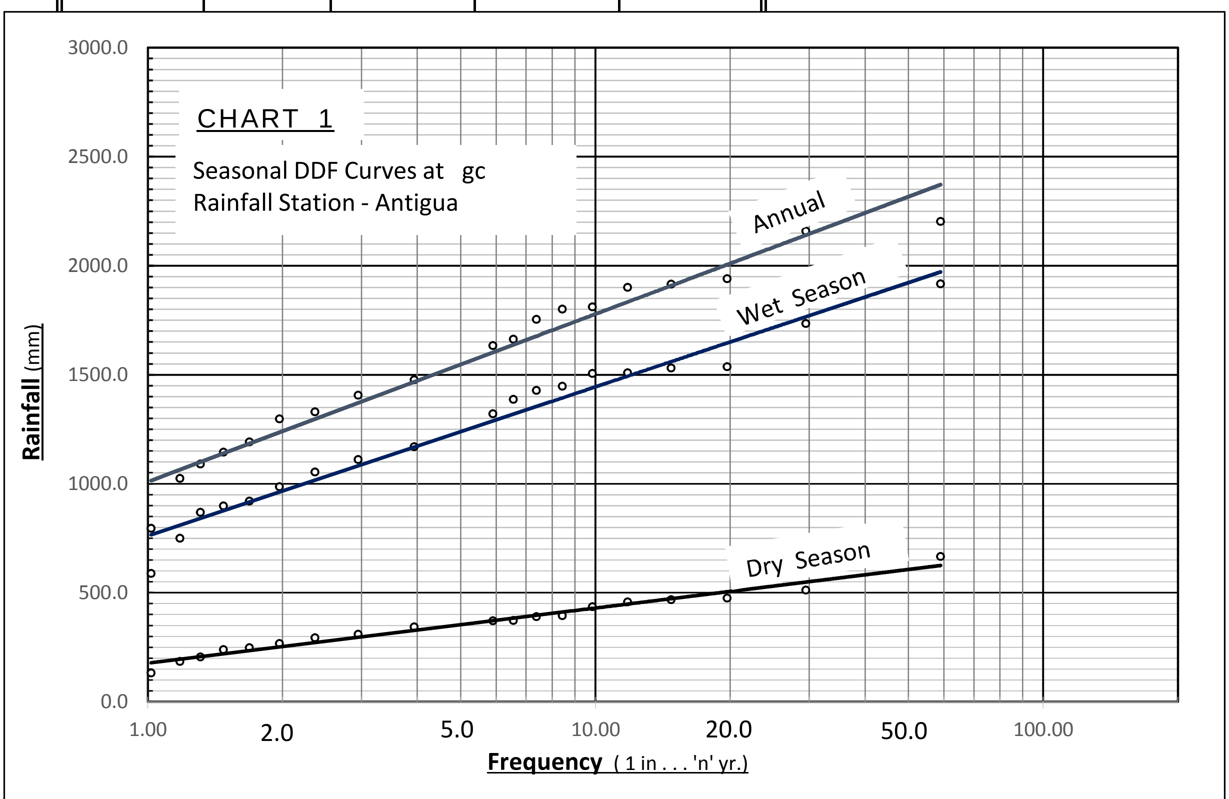
i) 'n' = Number of Monthly Rainfall events in the sample period (1957 - 2015) = 58 years ... ref. TABLE 1 - 1

ii) 'F' = Cumulative Distribution Factor in descending order of rank.

iii) Annual, Wet Season and Dry Season DDF CURVES are shown on CHART 1.

It should be noted that a comparison with the Burr distribution model this Gumble Distribution gives lesser Wet Season Values.

Note that the average monthly Rainfall was NOT used to develop the 24-hr. DDF and IDF Curves (CHARTS 3 abd 4 respectively) for use in Design of Hydraulic Structures.



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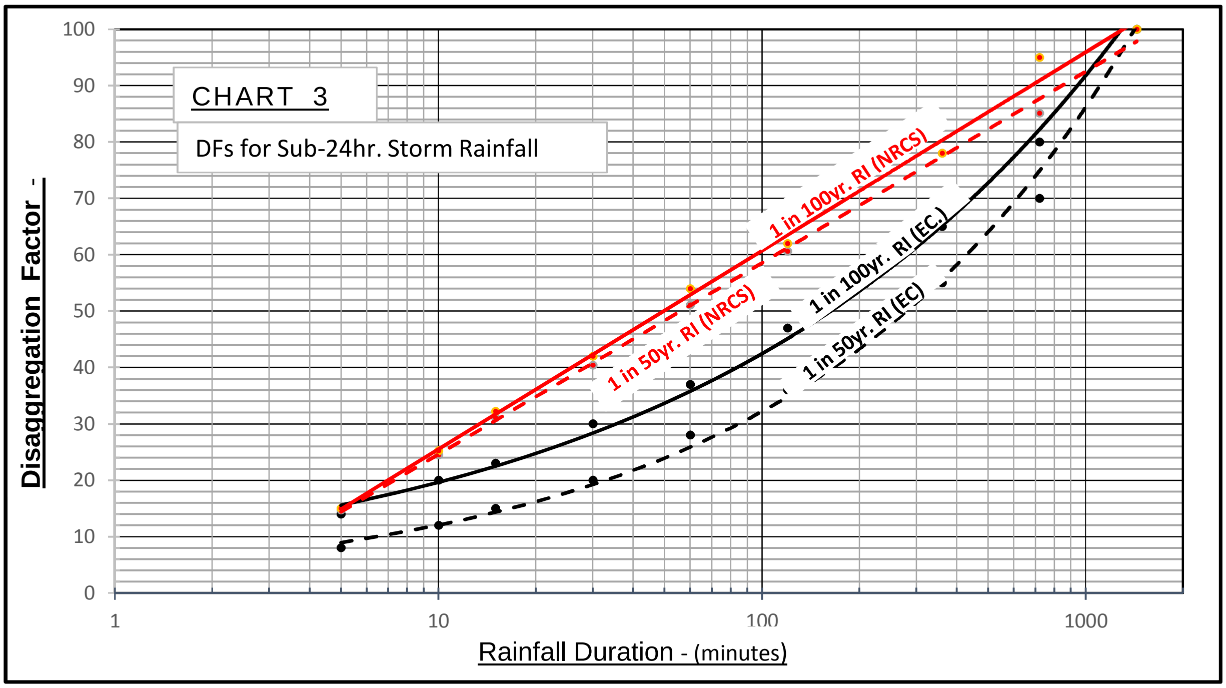
OECS Flood Relief Project in Antigua EC	Rainfall Analysis cont'd	Page 5

Sub 24 HR. Rainfall Disaggregation Factors (DF's)

TABLE 2-2	Rainfall Duration (Minutes)									
Frequency - (1 in x Yrs.)	1	5	10	15	30	60	120	360	720	1440
	DFs (%) for Eastern Caribbean Rainfall Distribution									
2	**0**	**8.0**	**12.0**	**15.0**	**20.0**	**28.0**	**36.0**	**55.0**	**70.0**	**100.0**
5	0	8.4	12.5	15.5	20.6	28.6	36.7	55.6	70.6	100.0
10	0	9.0	13.3	16.3	21.7	29.5	37.8	56.7	71.7	100.0
20	0	10.3	15.0	18.0	23.8	31.4	40.1	58.8	73.8	100.0
50	**0**	**14.0**	**20.0**	**23.0**	**30.0**	**37.0**	**47.0**	**65.0**	**80.0**	**100.0**
100										
	DFs (%) for NCRS Type II Synthetic Rainfall Distribution									
50	0	14.7	24.5	31.1	40.4	51.1	60.6	78.0	85.1	100.0
100	0	15.0	25.2	32.2	42.0	54.0	62.0	78.0	95.0	100.0



Brief notes on Hydrologic Analysis:

1 . Determination of Sub-24hr. Rainfall Distributation :

i) - 1 in 2yr. and 1 in 50yr. Disaggregation Factors (DF) % in TABLE 2-2 were taken directly from FIGURE 1 in Ref. Doc. a) (see page 1 step 2 category b) ; 5yr., 10yr. and 20yr. frequency DF's were estimated by interpolation between the 2yr. and 50yr. values.

ii) - 1 in 50 yr. and 1 in 100yr. DF's based on NRCS Type II Storms Distributation shown in TABLE 2 -2 above, were used for comparison with Eastern Caribbean DF's only, in order to estimate 1 in 100Yr. rainfall as this frequency was not avilable from the Eastern Caribbean DF distribution.

2. Selection of 1 in 50 year Design Storm Rainfall Frequency:

Two of several documents reviewed in the process of selecting a 1 in 50-Yr. design storm frequency are referenced on page 1, step 2. Information gathered from these reviews include:

a) - The design conditions for this project can be considered similar to those given in Item 2 of Table 1 of Ref. Doc. "Return Period to be used for Hydrologic Design" (see page 1, step 2 category b) with a Return Frequency range of 25 - 50 year. Considering the potential adverse effects of climate change and rising sea levels, on the operating works, the choice of the higher return period is reasonable.

b) - Table 10 , pp 125 of Ref. Doc." Drainage Design Manual" (see page 1,step 2 category b) recommends the use of 1 in 50-Yr. peak rainfall for medium size infrastructure works, i.e. hydraulic structures = or < 1200 m/sec. taking into consideration flood levels, climate change and sea level rise.

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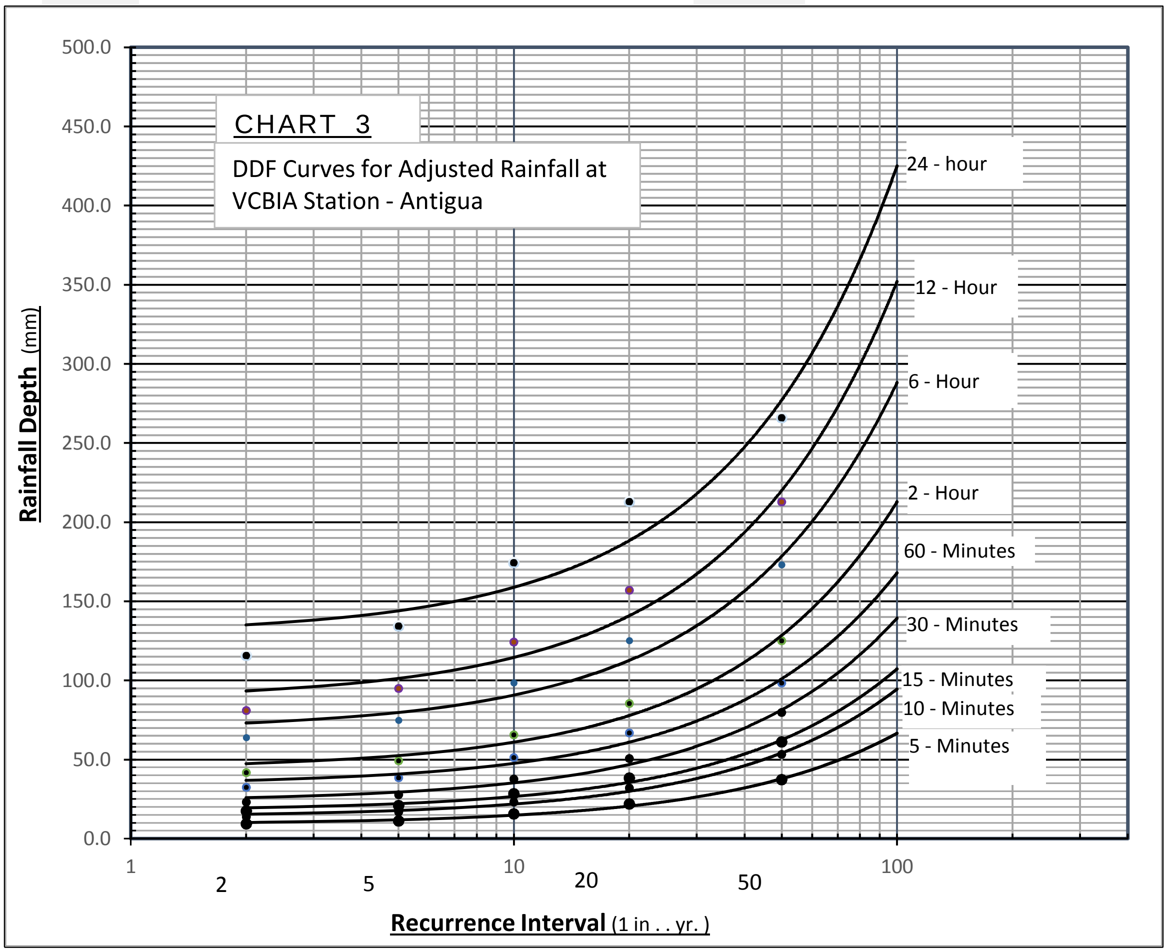
OECS Flood Relief Project in Antigua EC	Rainfall Analysis cont'd	Page 6

Depth Duration Frequency (DDF) Curves for Sub-24hr. Durations

TABLE 2 - 3

Rainfall Duration (min.)	Frequency (Recurrency Interval) in years. 2	5	10	20	50	100 (Green)	100 (Red)	REMARKS
5	9.3	11.2	15.6	21.8	37.2	66.0	46.0	100 year rainfall in Green reflect values projected from 1 in 50 year events.
10	13.9	16.8	23.1	31.9	53.2	95.0	77.3	
15	17.4	20.8	28.3	38.3	61.2	107.0	98.8	
30	23.1	27.7	37.6	50.6	79.8	140.0	128.8	
60	32.4	38.4	51.2	66.8	98.4	167.0	165.7	100 year rainfall shown in Red reflect values computed from the 50 year events and NRCS Type II storm DFs % Table 2-2.
120	41.7	49.3	65.6	85.4	125.0	212.5	190.3	
360	63.6	74.7	98.3	125.1	172.8	287.0	239.4	
720	81.0	94.8	124.3	157.0	212.7	350.0	291.6	
1440	115.7	134.3	174.3	212.9	265.9	425.0	306.9	



Brief notes on Hydrologic Analysis:

Estimated Rainfall values shown in Table 2 - 3 above were derived using the following equation:

Estimated Rainfall = 24 hr. Rainfall (Table 1 -3) X DFs (Table 2 - 2)/100

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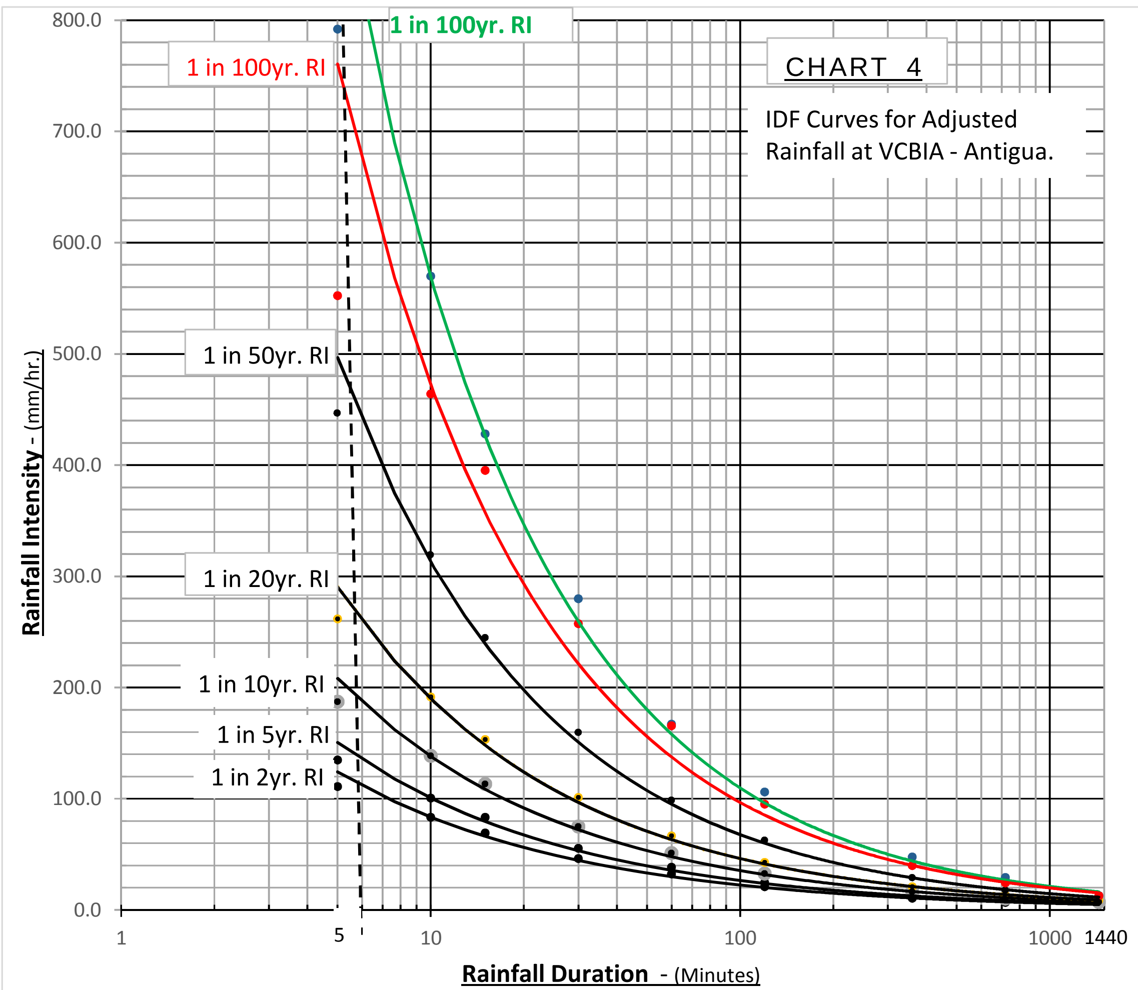
OECS Flood Relief Project in Antigua EC							Rainfall Analysis cont'd		Page 7
Intensity - Duration - Frequency (IDF) Curves for Sub-24hr. Durations									REMARKS
TABLE 2 - 4		Frequency (Recurrency Interval) in years.							
		2	5	10	20	50	100	100	
Rainfall Duration (min.)	1440	4.8	5.6	7.3	8.9	11.1	**12.8**	12.8	
	720	6.7	7.9	10.4	13.1	17.7	**29.2**	24.3	
	360	10.6	12.5	16.4	20.8	28.8	**47.8**	39.9	
	120	20.8	24.6	32.8	42.7	62.5	**106.3**	95.1	
	60	32.4	38.4	51.2	66.8	98.4	**167.0**	165.7	
	30	46.3	55.4	75.1	101.1	159.5	**280.0**	257.5	
	15	69.4	83.3	113.3	153.3	244.6	**428.0**	395.3	
	10	83.3	100.7	138.7	191.6	319.1	**570.0**	464.0	
	5	111.1	135.0	187.3	261.9	446.7	**792.0**	552.4	



Brief notes on Hydrologic Analysis:

The estimated rainfall intensities shown in Table 2 - 4 above were derived using following equation:

Rainfall Intensity (mm/hr.) = Rainfall Depth (mm) in Table 2 - 3 X 60 / Duration

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Prepared by . D . E . Winter F.A.P.E. R. Eng.

APPENDIX 3

Preliminary Hydrological Calculations

Figure 3-1 Average velocities for estimating travel time for shallow concentrated flow

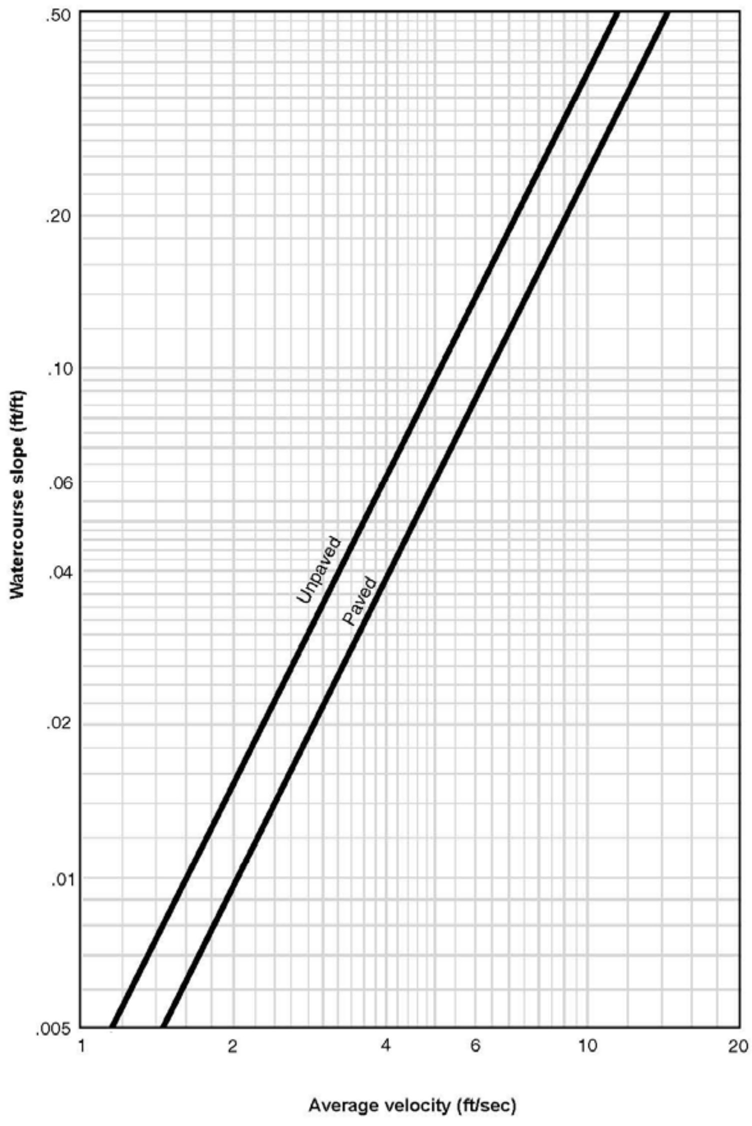


Figure 3.1

Table 3-1 Roughness coefficients (Manning's n) for sheet flow

Surface description	n [1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses [2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods: [3]	
Light underbrush	0.40
Dense underbrush	0.80

1 The n values are a composite of information compiled by Engman (1986).

2 Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.

3 When selecting n , consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Table 3.1

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

T_{t1} Sheet Flow (Segment A-B)

Reference	Time of Concentration Calculations (SCS Method)		1A	1B	1C	2	
Table 3.1 Roughness coeff. For sheet flow	Manning's roughness coefficient (Light Underbrush)	n=	0.4	0.4	0.4	0.4	
Antigua and Barbuda Meterological Service VC bird Best Fit	2- year, 24-Hour Rainfall	P_2=	4.5	4.5	4.5	4.5	in
1:25000 Topographic Map	Flow Length	L_m=	100	100	100.0	100.0	m
		L_{ft}=	328.1	328.1	328.1	328.1	Ft
	Upstream Elevation	E1=	40	100	58	55	m
	Downstream Elevation	E2 =	30	73	50	35	m
(E1-E2)/Lm	Slope of Hydraulic Grade Line	S =	0.10	0.27	0.08	0.20	m/m
Manning's kinematic Solution	$T_{t1}= 0.007(nL^{0.8)}/(P_2)^{0.5}S^{0.4}$	T_{t1} =	0.34	0.23	0.37	0.26	Hrs

T_{t2} Shallow Concentrated Flow Segment (B-C)

Reference	Time of Concentration Calculations (SCS Method)		1A	1B	1C	2	
	Surface Description		Unpaved	Unpaved	Unpaved	Unpaved	
1:25000 Topographic Map	Flow Length	L_m=	100	410	220.00	400.00	m
		L_{ft}=	328.1	280	721.82	1312.4	Ft
	Upstream Elevation	E1=	30	73	50	55	m
	Downstream Elevation	E2 =	20	20	15	16	m
(E1-E2)/Lm	Slope of Hydraulic Grade Line	S =	0.10	0.13	0.16	0.10	m/m
Avg. Velocities forshallow conc. Flow.Figure 3.1	Average Velocity	V =	5.10	5.75	6.50	5.00	ft/s
Time to travel Equation	$T_{t2}= L_{ft}/3600V$	**T_{t2} =**	0.02	0.01	0.03	0.07	Hrs

T_{t3} Channel Flow Segment (C-D)

Reference	Time of Concentration Calculations (SCS Method)		1A	1B	1C	2	
	Manings Roughness Coefficient	n=	0.025	0.025	0.025	0.025	
1:25000 Topographic Map	Flow Length	L_m=	1710	1650	980	1100	m
	Upstream Elevation	E1=	20	20	15	16	m
	Downstream Elevation	E2 =	8	8	8	8	m
(E1-E2)/Lm	Slope of Hydraulic Grade Line	S =	0.007	0.007	0.007	0.007	m/m
Estimated Using Ministry of Housing & Surveys -April 2016	Area	A =	12.25	12.25	12.25	12.25	m^2
	Wetter Perimeter	P=	7.5311	7.5311	7.5311	7.5311	m
	Hydraulic Radius = A/P	R =	1.63	1.63	1.63	1.63	m
Maning's Equation	Velocity = $1/n\ S^{1/2}\ R^{2/3}$	V =	4.63	4.72	4.68	4.72	ft/s
Time to travel Equation	$T_{t3}= L_{ft}/3600V$	**T_{t3} =**	0.10	0.10	0.06	0.06	Hrs

Total Tc (SCS Method)

Water Course Data

Bottom Width	=	3.5	m
Top Width	=	7	m
Side Slope	=	1.75	m
Depth	=	1	m

Tc = Tt1 + Tt2 +Tt3

	1A	***1B***	***1C***	***2***
Hrs	**0.46**	**0.34**	**0.46**	**0.40**

Tc Kirpich's Equation

Reference	Time of Concentration Calculations (Kirpich's Equation)		1A	1B	1C	2	
1:25000 Topographic Map	Maximum Runoff Distance	L=	1910	2160	1300	1600	m
		L=	6266.71	7086.96	4265.3	5249.6	feet
	Upstream Elevation	E1 =	40	100	58	55.0	m
	Downstream Elevation	E2 =	8	8	8	8	m
(E1-E2)/Lm	Watercourse slope	S =	0.017	0.043	0.038	0.029	m/m
Kirpich's Equation	$Tc= 0.0078(L^{0.77}/S^{0.385})$	Tc =	32	24	17	22	mins
	Factor for developed areas	C =	1.00	1.00	1.00	1.00	
		Tc =	31.59	24.25	17.06	22.20	mins
		Tc =	**0.53**	**0.40**	**0.28**	**0.37**	**Hrs**

Calc. Sheet #1

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

Catchment ID	Total Area (Ha)	Soil Group	Cover Type 1	% Cover Type 1	Area Cover Type 1 (Ha)	Cover Type 2	% Cover Type 2	Area Cover Type 2 (Ha)	*SCS Method*			*Rational Method*		
									Type 1 "CN"	*Type 2 "CN"*	*Weighted "CN"*	*Type 1 "C"*	*Type 2 "C"*	*Weighted "C"*
1A	55	C	Brush Fair Condition	30%	17	1/8 Acre Residential	70%	39	80	90	**87.00**	0.25	0.6	**0.50**
1B	62	C	Brush Fair Condition	30%	19	1/8 Acre Residential	70%	43	80	90	**87.00**	0.25	0.6	**0.50**
1C	81	C	Brush Fair Condition	25%	20	1/8 Acre Residential	75%	61	80	90	**87.50**	0.25	0.6	**0.51**
2	95	C	Brush Fair Condition	20%	19	1/8 Acre Residential	80%	76	80	90	**88.00**	0.25	0.6	**0.53**
Total	293				74			219			**87.46**			**0.51**

Calc. Sheet #2

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

Reference	Calculations		Units	Catchment 1A		Catchment 1B		Catchment 1C		Catchment 2	
				Storm R.I. (Yr.)		Storm R.I. (Yr.)		Storm R.I. (Yr.)		Storm R.I.(Yr.)	
				20	50	20	50	20	50	20	50
	Data										
Alpha DWG- 01	Catchment Area	A =	Ha	55	55	62	62	81	81	95	95
	Soil Group	Sg =		C	C	C	C	C	C	C	C
Calc. Sheet #1	Time of Concentration	Tc =	Hrs	0.46	0.46	0.34	0.34	0.46	0.46	0.40	0.40
	TR 55 Method										
Calc. Sheet 2	Weighted Curve Number	CN=		87.00	87.00	87.00	87.00	87.50	87.50	88.00	88.00
Urban Hydrology for Small Watersheds	Rainfall Duration = 170% Tc	d=	min	47.107	47.107	34.699	34.699	47.167	47.167	40.439	40.439
	Depth	D=	mm	57.58	87.72	51.16	79.18	57.61	87.76	54.28	83.35
	Potential Maximum Retention = (25400/CN)254	S =	mm	37.95	37.95	37.95	37.95	36.29	36.29	34.64	34.64
	Runoff = $(P-0.2S)^2$ / (P+0.8S)	Q =	mm	21.29	54.71	16.18	43.67	21.75	55.61	19.38	50.47
	Peak Discharge = q_u * A_m * Q * F_p	**q_p=**	**m^3/s**	**4.89**	**12.55**	**5.68**	**15.34**	**7.34**	**18.77**	**8.95**	**23.31**
	Rational Method										
	Duraation = Tc	D=	min	**28**	**28**	**20**	**20**	**28**	**28**	**24**	**24**
Hydrology Calculaions: Pg 1 Sec. 3	Rainfall Intensity	i =	mm/hr	101.5	159.2	122.4	195.1	101.4	159.1	111.4	176.2
	Runoff Coefficient	C =		0.50	0.54	0.50	0.54	0.51	0.56	0.53	0.58
	Peak Discharge = 0.00278 * C * I * A_m	**Q =**	**m^3/sec**	**8.06**	**13.92**	**10.97**	**19.23**	**12.29**	**21.21**	**16.38**	**28.49**
	Average Peak Discharge (TR-55 & Rational)	**Q =**	**m^3/sec**	**6.47**	**13.24**	**8.32**	**17.28**	**9.81**	**19.99**	**12.66**	**25.90**

Note: Peak Discharges Factored 1.05 for climate change

Calc. Sheet #3

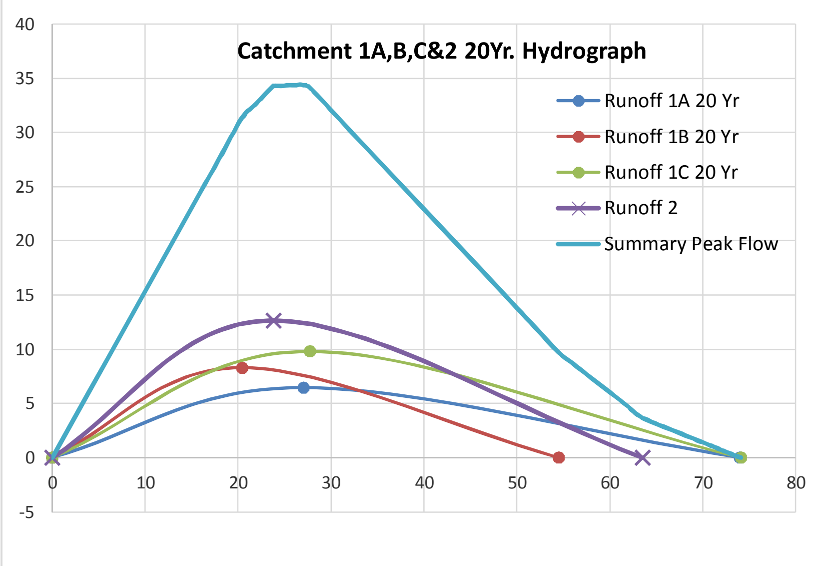
Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

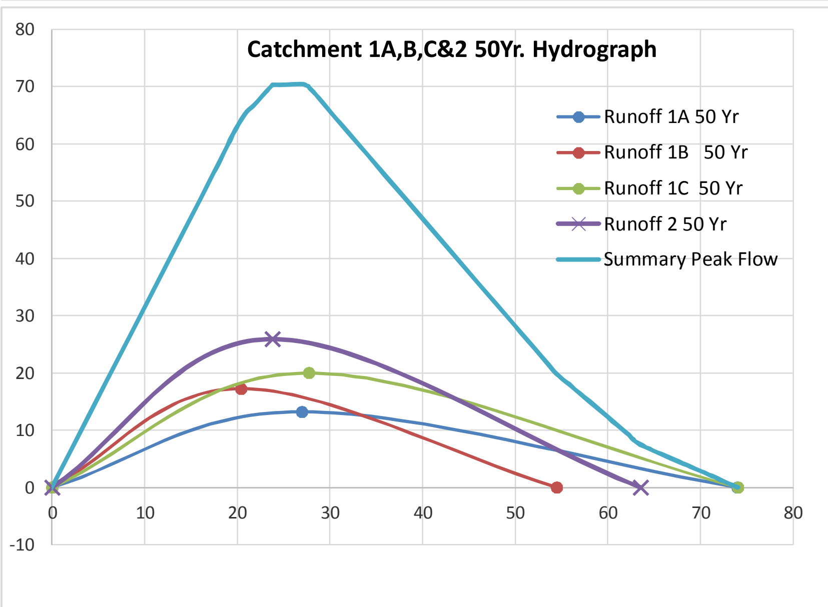
Reference	Calculations		Units	Catchment 1A		Catchment 1B		Catchment 1C		Catchment 2	
				Storm R.I. (Yr.)		Storm R.I. (Yr.)		Storm R.I. (Yr.)		Storm R.I.(Yr.)	
				20	50	20	50	20	50	20	50
	Data										
Alpha DWG- 01	Catchment Area	A =	Ha	55	55	62	62	81	81	95	95
	Soil Group	Sg =		C	C	C	C	C	C	C	C
Calc. Sheet #1	Time of Concentration	Tc =	Hrs	0.46	0.46	0.34	0.34	0.46	0.46	0.40	0.40
	TR 55 Method										
Calc. Sheet#2	Weighted Curve Number	CN=		87.00	87.00	87.00	87.00	87.50	87.50	88.00	88.00
Urban Hydrology for Small Watersheds	Rainfall Duration = 170% Tc	d=	min	47.107	47.107	34.699	34.699	47.167	47.167	40.439	40.439
	Depth	D=	mm	32.18	43.36	28.30	38.27	32.20	43.38	30.18	40.74
	Potential Maximum Retention = (25400/CN)254	S =	mm	37.95	37.95	37.95	37.95	36.29	36.29	34.64	34.64
	Runoff = $(P-0.2S)^2 / (P+0.8S)$	Q =	mm	5.15	10.90	3.66	8.02	5.34	11.20	4.67	9.88
	Peak Discharge = $q_u * A_m * Q * F_p$	q_p=	m^3/s	**1.13**	**2.38**	**1.22**	**2.68**	**1.72**	**3.60**	**2.06**	**4.34**
	Rational Method										
Hydrology Calculaions: Pg 1 Sec. 3	Duration = Tc	D=	min	**28**	**28**	**20**	**20**	**28**	**28**	**24**	**24**
	Rainfall Intensity	i =	mm/hr	55.8	75.5	66.6	90.5	55.7	75.4	60.9	82.6
	Runoff Coefficient	C =		0.50	0.50	0.50	0.50	0.51	0.51	0.53	0.53
	Peak Discharge = 0.00278 * C * I * A_m	Q =	m^3/sec	**4.22**	**5.71**	**5.68**	**7.72**	**6.43**	**8.70**	**8.53**	**11.56**
	Average Peak Discharge (TR-55 & Rational)	**Q =**	m^3/sec	**2.67**	**4.05**	**3.45**	**5.20**	**4.07**	**6.15**	**5.29**	**7.95**

Calc. Sheet #4

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

Catchment ID	Time of Concentration T_c (Mins)	Recession Time T_r (Mins)	20 YR Peak Flow (m^3/s)	50YR Peak Flow (m^3/s)
1A	28	74	6.47	13.24
1B	20	54	8.32	17.28
1C	28	74	9.81	19.99
2	24	64	12.66	25.90

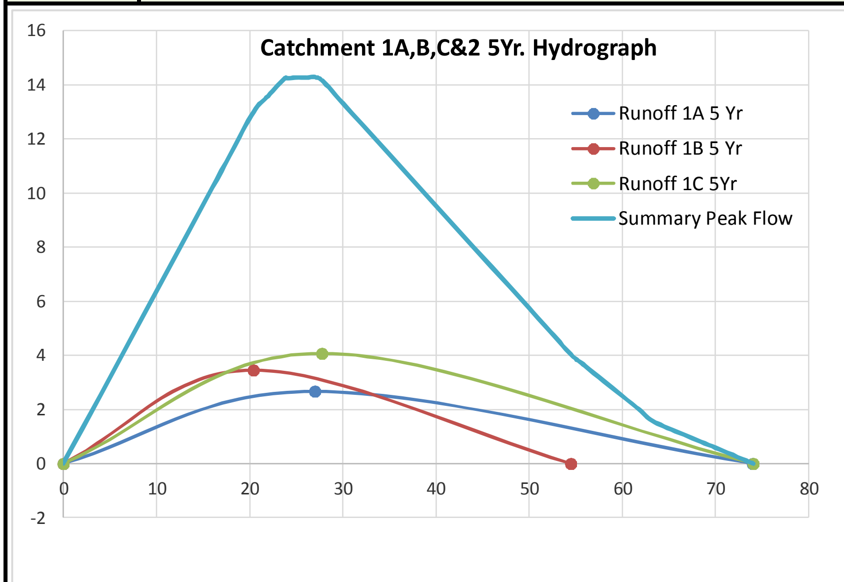


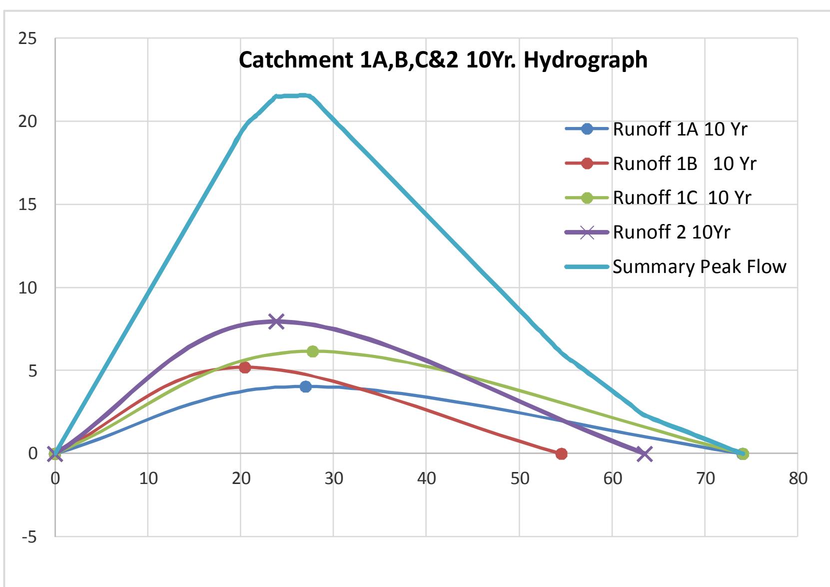


Calc. Sheet #5

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

Catchment ID	Time of Concentration T_c (Mins)	Recession Time T_r (Mins)	5 YR Peak Flow (m^3/s)	10YR Peak Flow (m^3/s)
1A	28	74	2.67	4.05
1B	20	54	3.45	5.20
1C	28	74	4.07	6.15
2	24	64	5.29	7.95

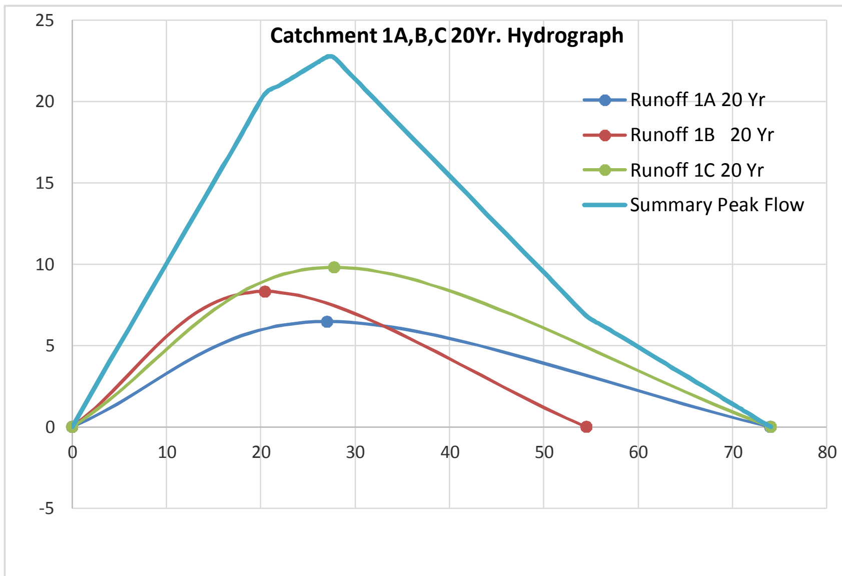


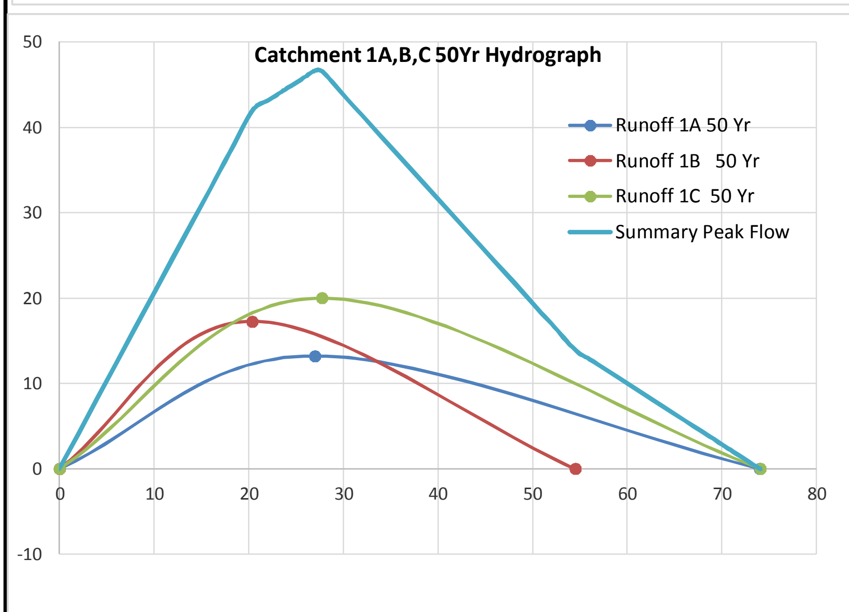


Calc. Sheet #6

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

Catchment ID	Time of Concentration T_c (Mins)	Recession Time T_r (Mins)	20 YR Peak Flow (m^3/s)	50YR Peak Flow (m^3/s)
1A	28	74	6.47	13.24
1B	20	54	8.32	17.28
1C	28	74	9.81	19.99

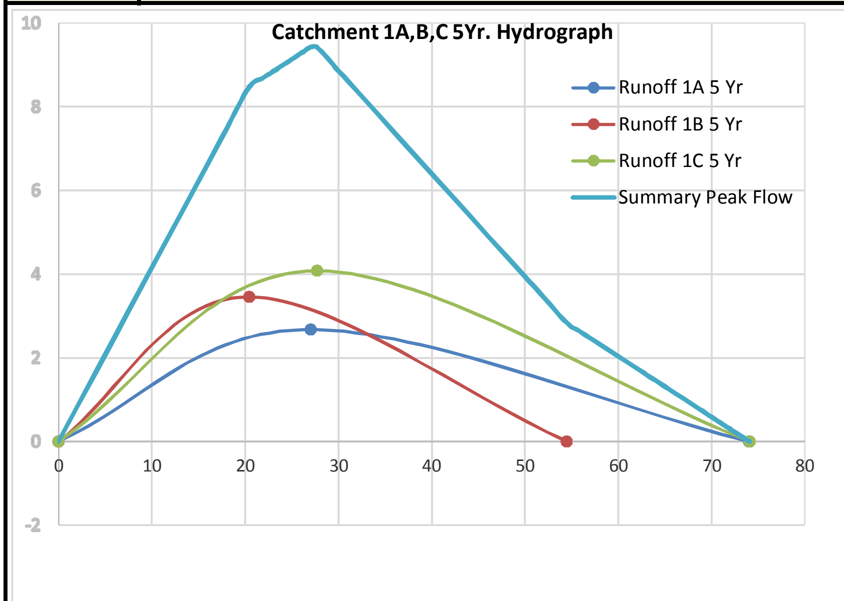


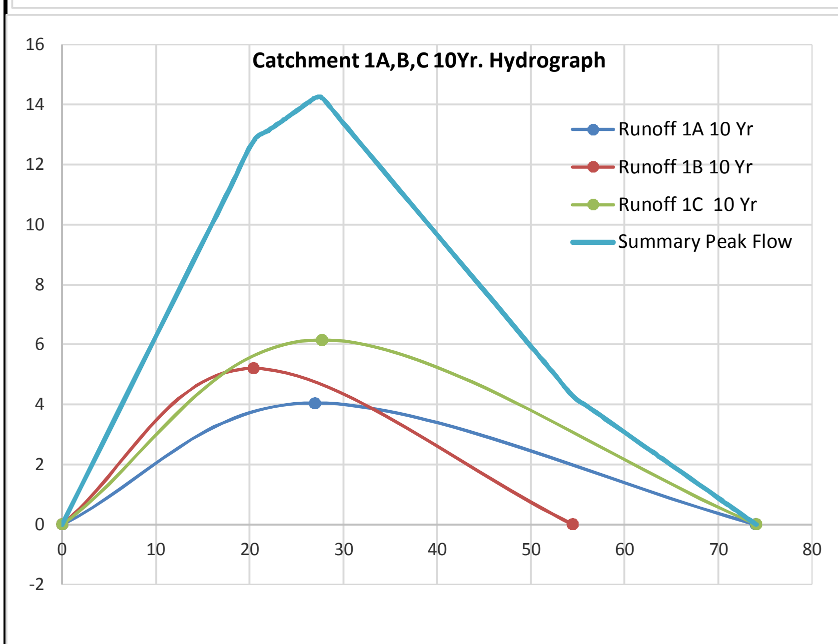


Calc. Sheet #7

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

Catchment ID	***Time of Concentration (Mins)*** T_c	***Recession Time*** T_r ***(Mins)***	***5 YR Peak Flow*** (m^3/s)	***10YR Peak Flow*** (m^3/s)
1A	28	74	2.67	4.05
1B	20	54	3.45	5.20
1C	28	74	4.07	6.15

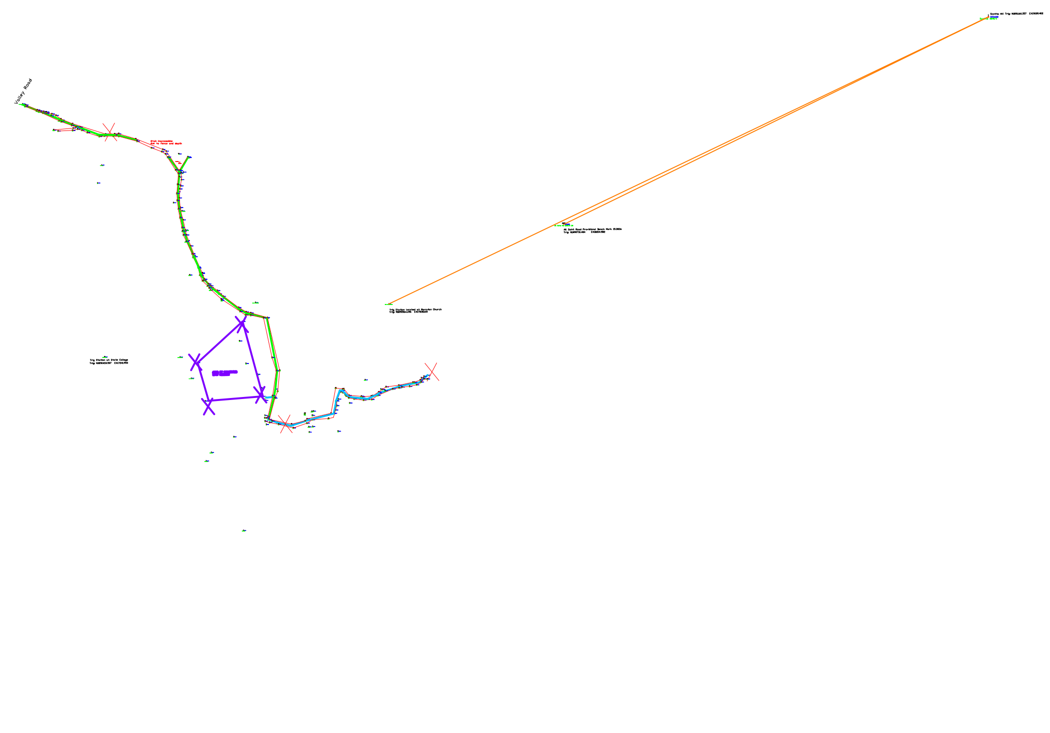


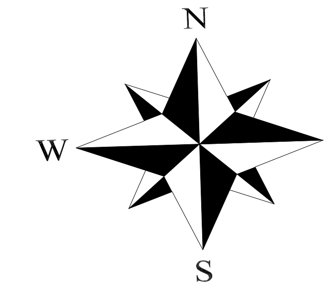


Calc. Sheet #8

APPENDIX 4

Field Survey Data





NOTE: Additional Spot Elevations were taken due to the meandering the water courses 1 and 2

PointNo.	Northing(Y)	Easting(X)	Elev(Z)	Description
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

PointNo.	Northing(Y)	Easting(X)	Elev(Z)	Description
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

PointNo.	Northing(Y)	Easting(X)	Elev(Z)	Description
134	1890923.876	417205.850	13.873	EoD
135	1890915.730	417230.955	13.782	EoD
136	1890916.825	417241.450	13.541	EoD
137	1890424.802	417602.185	9.438	EoD
138	1890425.523	417609.311	0.000	EoD/F
139	1890381.724	417605.019	0.000	EoD/F
140	1890452.410	417593.202	9.235	EoD
141	1890536.112	417583.381	9.963	EoD/F
142	1890545.915	417548.671	10.360	EoD
143	1890540.969	417548.688	10.372	EoD
144	1890535.366	417575.193	10.517	EoD
145	1890557.174	417523.118	10.456	EoD
146	1890548.213	417530.698	10.447	EoD
147	1890541.532	417537.875	10.194	EoD
148	1890549.047	417525.909	10.360	EoD
149	1890598.262	417461.282	10.939	EoD
150	1890580.722	417490.992	10.192	EoD/F
151	1890592.602	417478.597	10.277	EoD
152	1890602.813	417464.588	10.759	EoD
153	1890616.549	417451.423	10.869	EoD
154	1890629.783	417446.739	11.085	EoD
155	1890575.402	417486.437	10.876	EoD
156	1890602.672	417457.990	10.963	EoD/R
157	1890917.246	417232.413	13.808	EoD
158	1890916.390	417260.118	13.471	EoD
159	1890920.955	417263.131	13.534	EoD
163	1890883.921	417361.620	13.180	EoD
164	1890891.832	417340.356	13.480	EoD
165	1890905.792	417310.155	13.617	EoD
167	1890921.455	417270.874	14.464	EoD
168	1890888.521	417363.912	11.918	EoD
169	1890884.892	417371.036	11.866	EoD
170	1890839.545	417402.530	11.892	EoD
171	1890873.049	417416.313	12.755	EoD
172	1890844.128	417400.839	11.747	EoD
173	1890844.445	417398.233	11.792	EoD
174	1890825.230	417403.100	12.197	EoD
175	1890796.318	417383.383	11.295	EoD
176	1890814.335	417396.894	11.467	Invert
177	1890830.792	417398.988	11.635	Invert
178	1890812.249	417401.580	12.372	EoD
179	1890805.825	417399.734	11.882	EoD
180	1890786.935	417398.761	11.961	EoD
181	1890766.672	417400.857	12.359	EoD
182	1890838.070	417396.898	12.155	EoD
183	1890845.777	417390.760	12.336	EoD
184	1890740.948	417406.721	11.905	EoD
185	1890709.266	417413.661	11.635	EoD
186	1890686.417	417422.635	11.390	EoD
187	1890663.714	417431.236	10.998	EoD
188	1890669.733	417425.530	10.983	EoD
189	1890781.455	417394.411	11.620	EoD
190	1890764.131	417396.620	11.645	EoD
191	1890745.560	417399.858	11.677	EoD
192	1890724.752	417404.226	11.495	EoD

PointNo.	Northing(Y)	Easting(X)	Elev(Z)	Description
193	1890709.281	417407.318	11.628	EoD
194	1890370.172	417782.840	10.187	EoD
195	1890372.302	417804.581	10.055	EoD
196	1890371.680	417801.361	10.467	EoD
197	1890380.027	417816.901	10.635	EoD
198	1890385.527	417824.618	10.483	EoD
199	1890390.969	417832.256	10.359	EoD
200	1890394.297	417858.998	10.645	EoD
201	1890400.422	417888.444	10.904	EoD
202	1890371.873	417748.764	10.145	EoD
203	1890365.778	417765.274	10.620	EoD
204	1890362.982	417784.997	10.495	EoD
205	1890364.360	417802.237	10.603	EoD
206	1890373.036	417815.043	10.306	EoD/F
207	1890382.883	417830.508	10.405	EoD/F
208	1890386.452	417846.323	10.637	EoD
209	1890388.870	417859.743	10.590	EoD
210	1890390.353	417865.474	10.658	EoD
211	1890392.087	417881.726	11.602	EoD
212	1890395.269	417896.394	11.185	EoD
213	1890400.922	417905.921	10.725	EoD
214	1890407.586	417911.948	10.838	EoD
215	1890407.452	417918.846	11.073	EoD
216	1890413.027	417911.812	10.833	EoD
217	1890405.259	417903.941	10.895	EoD
218	1890400.462	417891.551	10.663	EoD
219	1890381.121	417736.565	9.922	EoD
220	1890361.332	417728.900	9.759	EoD
225	1890331.226	417677.723	9.555	EoD
226	1890321.998	417677.883	9.240	EoD
227	1890323.887	417666.549	9.765	EoD
228	1890372.339	417594.267	9.554	EoD/F
229	1890367.203	417599.020	8.879	EoD/F
230	1890328.295	417584.526	8.910	EoD
231	1890325.755	417582.209	8.710	EoD
232	1890325.873	417578.061	8.947	EoD
233	1890318.911	417578.716	9.298	EoD
234	1890316.232	417588.215	9.474	EoD
235	1890319.121	417593.274	9.045	EoD
236	1890322.810	417587.396	8.921	EoD
237	1890312.867	417634.016	706.499	EoD
238	1890312.537	417607.012	9.563	EoD
239	1890304.832	417637.769	9.878	EoD
240	1890371.195	417780.469	10.253	EoD/F
241	1890952.385	417150.472	0.000	CC
242	1890942.385	417174.598	0.000	CC
243	1890917.992	417265.047	13.741	EC
244	1890920.614	417244.253	13.197	EoD
245	1890921.661	417271.766	0.000	FP
246	1890879.165	417397.703	12.363	FP
248	1890365.122	417732.288	10.397	WP
249	1890352.124	417726.158	8.552	Invert
250	1890342.458	417726.166	10.089	EoD
251	1890335.420	417724.203	9.685	EoD
252	1890334.877	417722.524	8.582	Invert

PointNo.	Northing(Y)	Easting(X)	Elev(Z)	Description
253	1890324.595	417711.414	0.000	EoD/F
254	1890386.782	417743.580	0.000	EoD/F
255	1890388.403	417726.684	0.000	Fence
256	1890335.569	417716.845	0.000	FC
257	1890351.497	417720.565	10.345	EoD/F
260	1890372.929	417754.767	9.977	EoD
261	1890386.344	417741.311	0.000	EoD
263	1890339.823	417679.822	10.103	fence
264	1890314.752	417666.186	10.384	fence
265	1890335.334	417661.751	0.000	fence
266	1890332.675	417661.921	0.000	fence
267	1890335.225	417662.588	0.000	UP
268	1890319.821	417662.742	0.000	FC
269	1890695.206	417413.110	11.405	Boundary
270	1890572.136	417487.488	11.094	Fence
271	1890625.294	417420.450	11.538	EoR/BM
272	1890393.461	417736.487	10.251	EoD
273	1890379.194	417741.320	10.266	EoD
274	1890374.735	417746.380	10.211	EoD
275	1890383.302	417740.136	8.943	Invert
276	1890369.703	417754.395	9.135	Invert
277	1890383.570	417735.410	8.694	Invert
278	1890366.910	417770.692	9.104	Invert
279	1890374.343	417813.208	9.230	Invert
280	1890365.570	417793.323	10.388	Invert
281	1890367.717	417754.166	0.000	EoD
282	1890613.364	417447.070	11.017	EoD
283	1890613.525	417449.348	9.866	Invert
284	1890642.226	417437.905	10.570	EoD
285	1890640.101	417439.422	9.792	Invert
286	1890625.211	417441.879	10.969	EoD/F
287	1890628.654	417447.090	11.149	EoD
288	1890616.180	417451.590	10.875	EoD
289	1890606.711	417459.867	10.634	EoD
290	1890682.546	417427.770	0.000	EoD/F
291	1890686.511	417420.272	9.990	invert
292	1890717.186	417405.447	11.205	invert
293	1890815.149	417395.067	0.000	EoD
295	1890872.150	417374.136	12.858	EoD
296	1890878.993	417369.730	13.093	EoD
297	1890910.523	417307.529	0.000	EoD
2000	1890731.484	418204.902	15.303	All data Ad 1990/5 BM

Number of points listed= 263

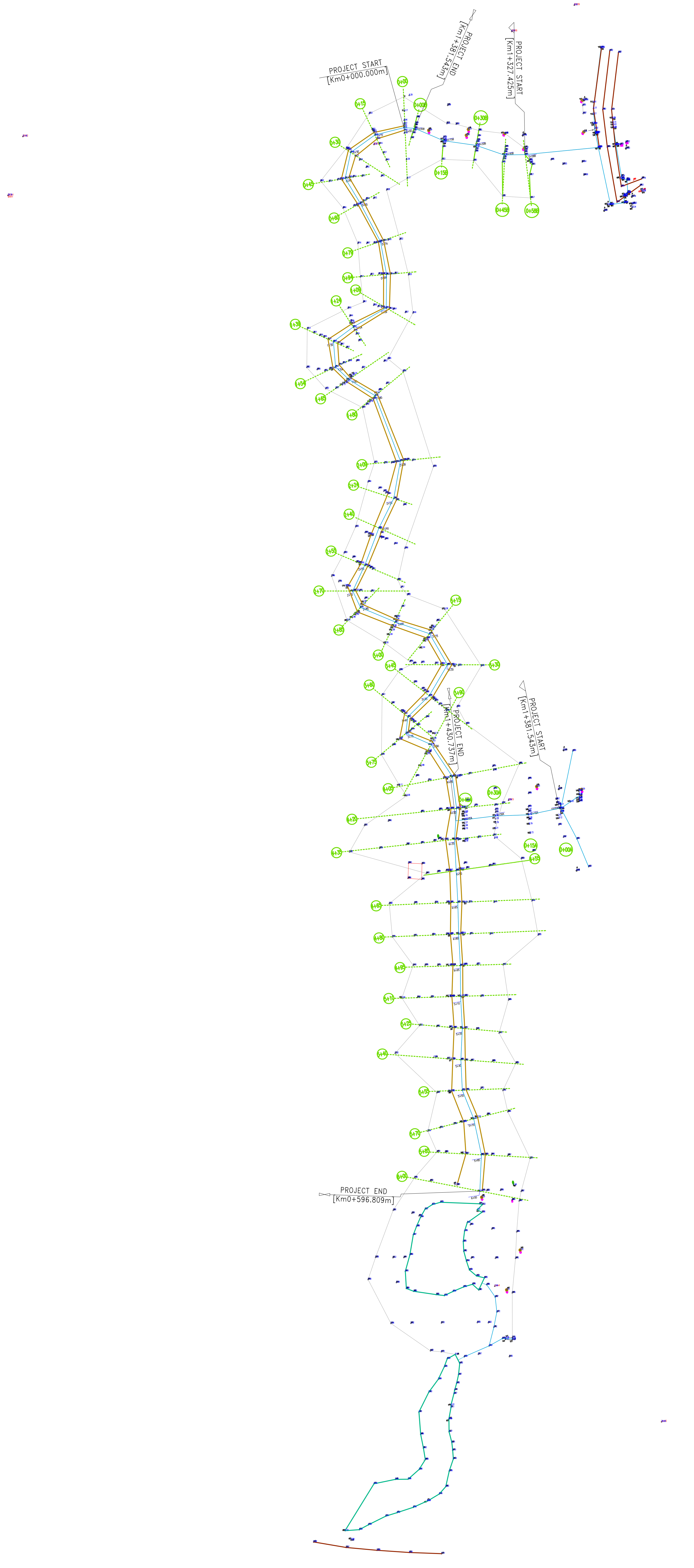
LEGEND

BM - Boundary Mark
WP - Wooden Peg
EoD - Edge of Drain
EoR - Edge of Road
Invert - Bottom of Drain
UD - U-Drain [concrete]
CD - concrete drain [u-drain]
SPH - Spot Height

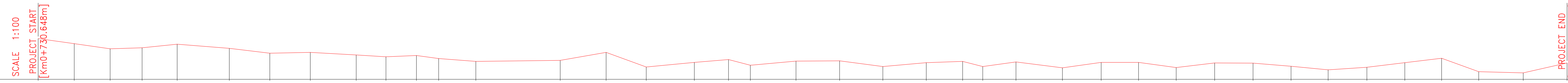
X Location of spot elevations along roadway
X Location of spot elevations along water course
Defined water course 1 (green-line)
Defined water course 2 (blue line)

CASHEW HILL SURVEY

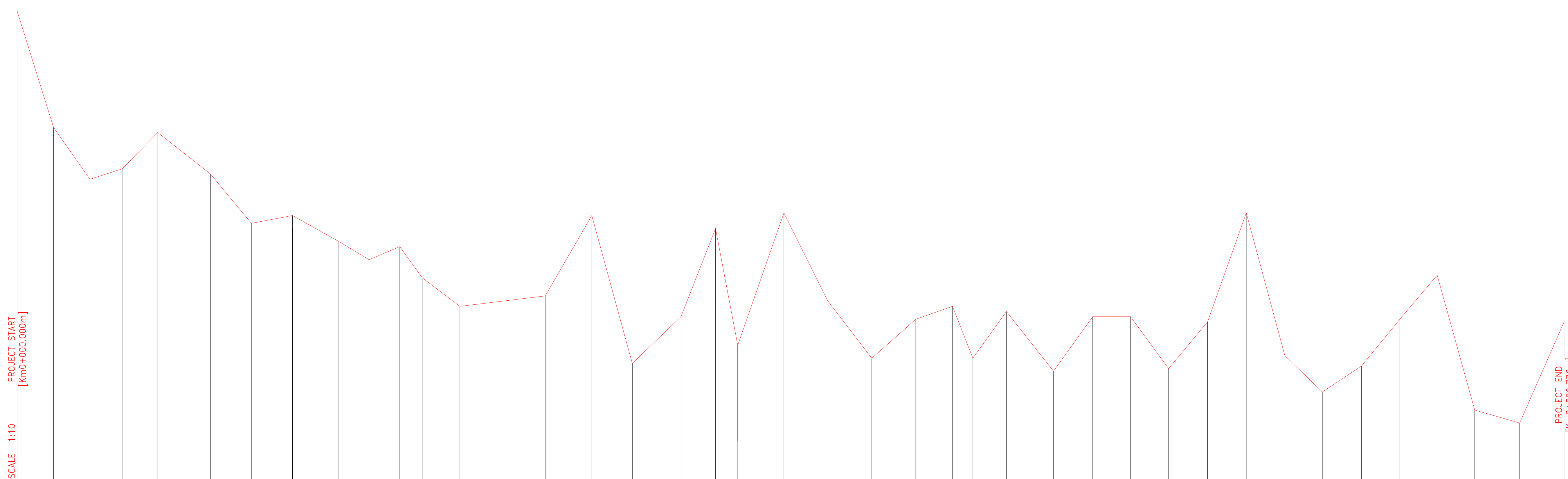
DRAWN	DATE	MIN:WORKS & HOUSING
Survey/GIS	28/Apr/16	Survey/ G.I.S. Section
APPROVED	DATE	Spot Heights
SCALE	SHEET	PROJECT NO.
1 = 50000	1	Water Course 1&2


PROJECT START
[Km0+000.000m]
PROJECT END
[Km1+381.543m]
PROJECT START
[Km1+327.425m]
PROJECT END
[Km1+430.737m]
PROJECT START
[Km1+381.543m]
PROJECT END
[Km0+596.809m]

LONGITUDINAL PROFILE 1



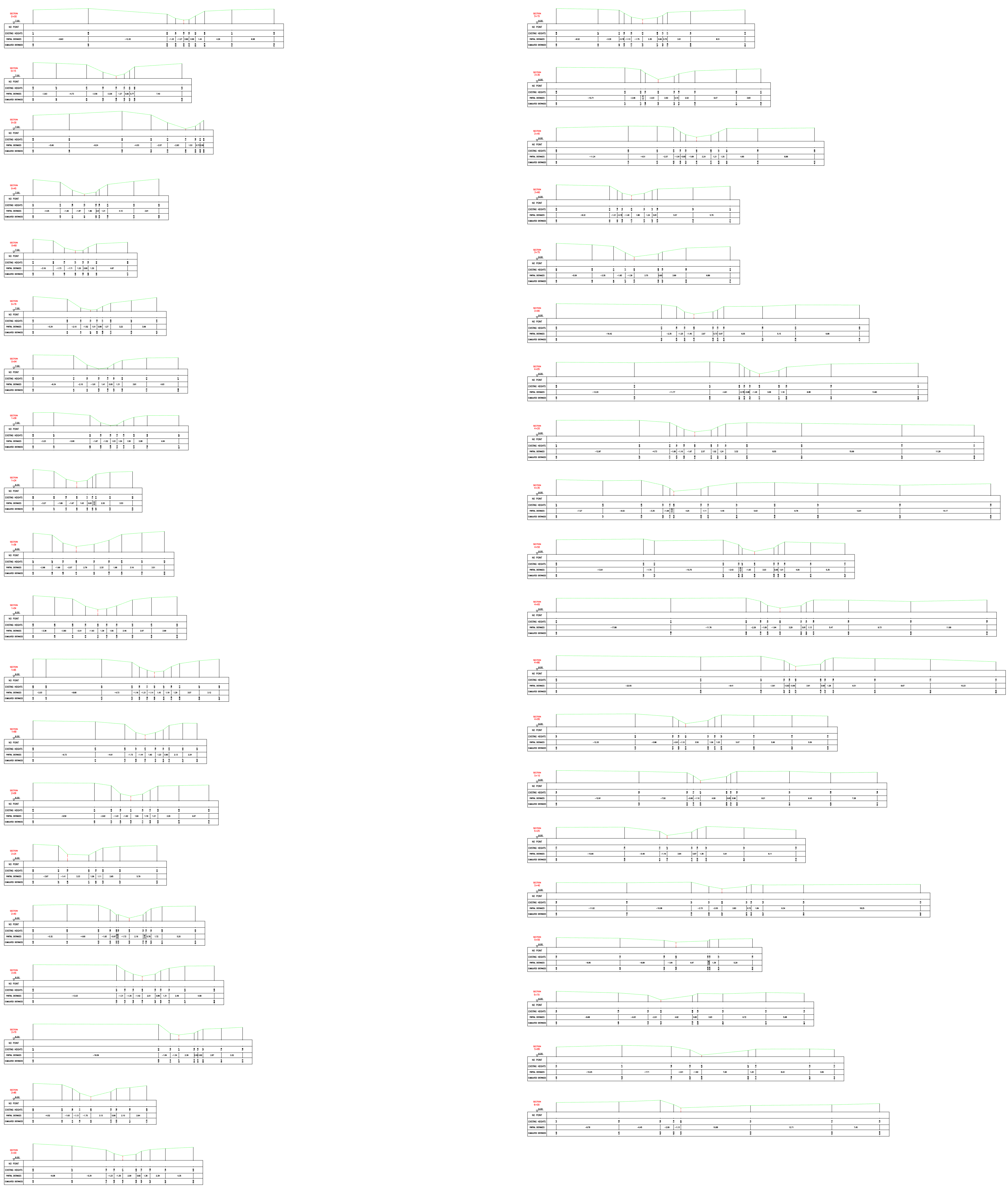
NO POINT	EXISTING HEIGHTS	PARTIAL DISTANCES (to next point)	CUMULATED DISTANCES	SECTIONS
4	7.59	14.09	0.00	
14	7.39	14.03	14.09	
23	7.19	12.45	28.13	
30	7.23	13.70	40.57	
40	7.37	20.36	54.27	
49	7.21	15.79	74.63	
58	7.02	15.81	90.43	
67	7.05	17.91	106.24	
77	6.95	11.62	124.15	
86	6.88	11.88	135.77	
96	6.93	8.67	147.65	
107	6.81	14.52	156.32	
118	6.70	32.94	170.83	
128	6.74	17.94	203.78	
138	7.05	15.64	221.72	
146	6.48	18.77	237.36	
158	6.66	13.34	256.13	
169	6.77	8.54	269.46	
177	6.55	17.81	278.01	
188	6.71	17.00	295.82	
198	6.72	16.90	312.82	
209	6.50	16.95	329.72	
219	6.65	14.20	346.67	
231	6.70	7.84	360.87	
242	6.50	12.96	368.70	
251	6.68	18.15	381.66	
262	6.45	15.12	399.81	
273	6.66	14.60	414.94	
286	6.66	14.69	429.53	
299	6.46	15.02	444.22	
310	6.64	14.95	459.23	
323	6.63	14.86	474.19	
334	6.51	14.48	489.05	
345	6.37	15.11	503.53	
356	6.47	14.79	518.64	
365	6.65	14.40	533.42	
375	6.82	14.47	547.83	
383	6.30	17.37	562.30	
392	6.25	17.11	579.67	
401	6.64		596.78	



LONGITUDINAL PROFILE

SCALE1:1000 6.00

NO. POINT	EXISTING HEIGHTS	PARTIAL DISTANCES (to next point)	CUMULATED DISTANCES	SECTIONS
4	7.59	14.09	0.00	
14	7.39	14.03	14.09	
23	7.19	12.45	28.13	
30	7.23	13.70	40.57	
40	7.37	20.36	54.27	
49	7.21	15.79	74.63	
58	7.02	15.81	90.43	
67	7.05	17.91	106.24	
77	6.95	11.62	124.15	
86	6.88	11.88	135.77	
96	6.93	8.67	147.65	
107	6.81	14.52	156.32	
118	6.70	32.94	170.83	
128	6.74	17.94	203.78	
138	7.05	15.64	221.72	
146	6.48	18.77	237.36	
158	6.66	13.34	256.13	
169	7.00	8.54	269.46	
177	6.55	17.81	278.01	
188	7.06	17.00	295.82	
198	6.72	16.90	312.82	
209	6.50	16.95	329.72	
219	6.65	14.20	346.67	
231	6.70	7.84	360.87	
242	6.50	12.96	368.70	
251	6.68	18.15	381.66	
262	6.45	15.12	399.81	
273	6.66	14.59	414.94	
286	6.66	14.69	429.53	
299	6.46	15.02	444.22	
310	6.64	14.95	459.23	
323	7.06	14.86	474.19	
334	6.51	14.48	489.05	
345	6.37	15.11	503.53	
356	6.47	14.79	518.64	
365	6.65	14.40	533.42	
375	6.82	14.47	547.83	
383	6.30	17.37	562.30	
392	6.25	17.11	579.67	
401	6.64		596.78	


SECTION
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7.00
NO POINT
EXISTING HEIGHTS
PARTIAL DISTANCES
CUMULATED DISTANCES
SECTION
0+15
SECTION
0+30

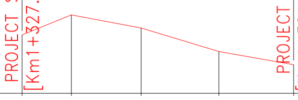
LONGITUDINAL PROFILE
B

SCALE 1:100

PROJECT START [Km1+327.425m]

PROJECT END [Km1+381.543m]

7.00



NO POINT	643	631	617	613	600
EXISTING HEIGHTS	8.16	8.56	8.30	7.83	7.57
PARTIAL DISTANCES	9.83	13.91	15.49	14.89	
CUMULATED DISTANCES	0.00	9.83	23.74	39.23	54.12
SECTIONS					

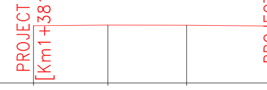
LONGITUDINAL PROFILE
A

SCALE 1:100

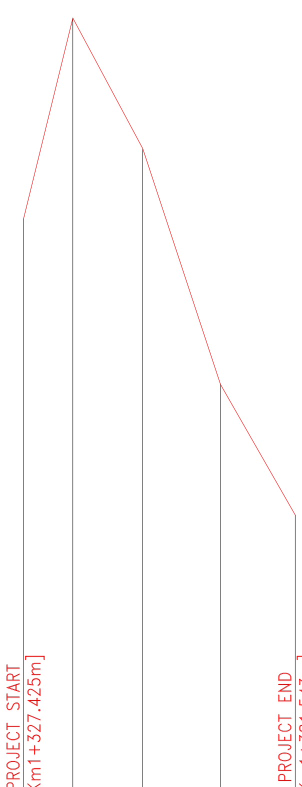
PROJECT START [Km1+381.543m]

PROJECT END [Km1+430.737m]

7.00



NO POINT	530	559	571	582
EXISTING HEIGHTS	7.37	6.76	6.88	6.64
PARTIAL DISTANCES	14.82	15.66	18.71	
CUMULATED DISTANCES	0.00	14.82	30.48	49.19
SECTIONS				



LONGITUDINAL PROFILE
B

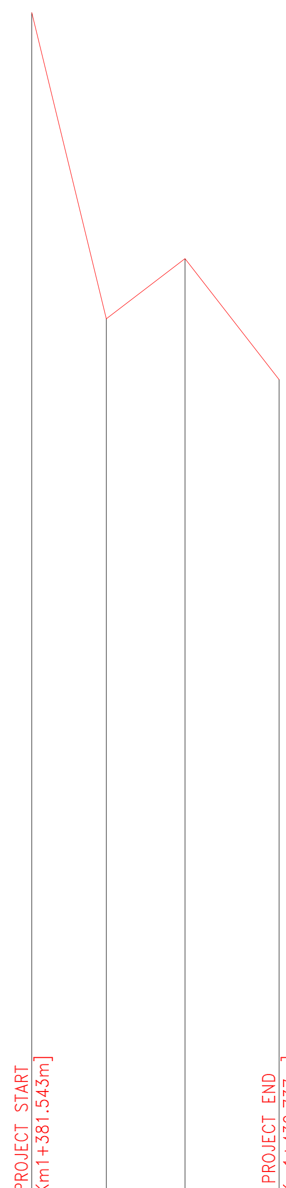
SCALE 1:10

PROJECT START [Km1+327.425m]

PROJECT END [Km1+381.543m]

7.00

NO POINT	643	631	617	613	600
EXISTING HEIGHTS	8.16	8.56	8.30	7.83	7.57
PARTIAL DISTANCES	9.83	13.91	15.49	14.89	
CUMULATED DISTANCES	0.00	9.83	23.74	39.23	54.12
SECTIONS					



LONGITUDINAL PROFILE
A

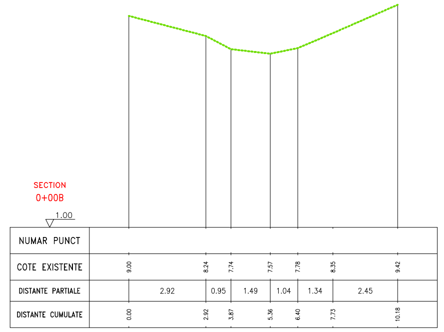
SCALE 1:10

PROJECT START [Km1+381.543m]

PROJECT END [Km1+430.737m]

6.00

NO POINT	530	559	571	582
EXISTING HEIGHTS	7.37	6.76	6.88	6.64
PARTIAL DISTANCES	14.82	15.66	18.71	
CUMULATED DISTANCES	0.00	14.82	30.48	49.19
SECTIONS				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0+00B
1.00
NUMAR PUNCT
COTE EXISTENTE
DISTANTE PARTIALE
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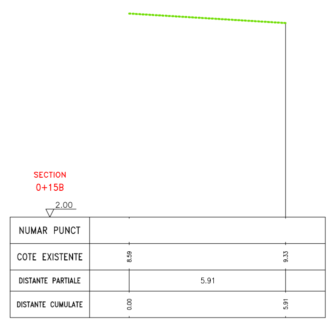
0.95
1.49
1.04
1.34
2.45
DISTANTE CUMULATE


SECTION
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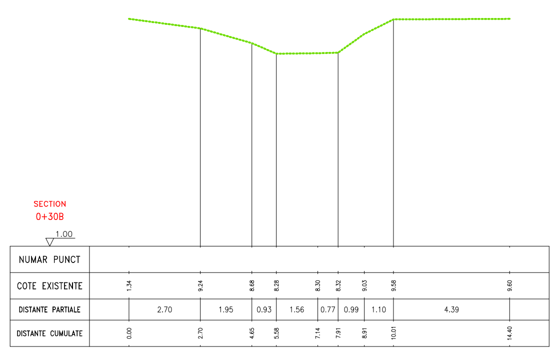
2.00
NUMAR PUNCT
COTE EXISTENTE
DISTANTE PARTIALE
5.91
DISTANTE CUMULATE


SECTION
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1.00
NUMAR PUNCT
COTE EXISTENTE
DISTANTE PARTIALE
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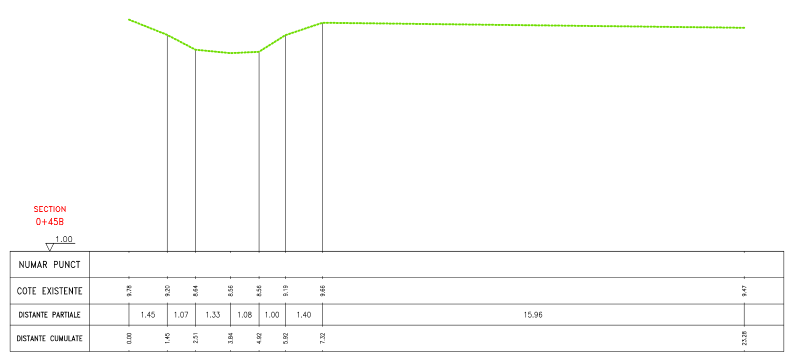
1.95
0.93
1.56
0.77
0.99
1.10
4.39
DISTANTE CUMULATE


SECTION
0+45B
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NUMAR PUNCT
COTE EXISTENTE
DISTANTE PARTIALE
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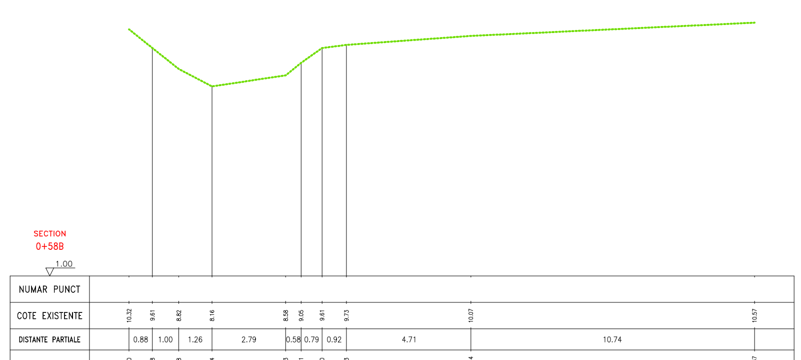
1.07
1.33
1.08
1.00
1.40
15.96
DISTANTE CUMULATE


SECTION
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1.00
NUMAR PUNCT
COTE EXISTENTE
DISTANTE PARTIALE
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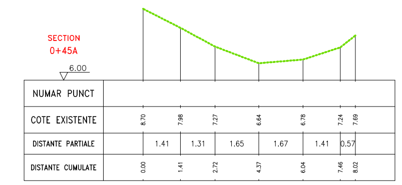
1.00
1.26
2.79
0.58
0.79
0.92
4.71
10.74
DISTANTE CUMULATE


SECTION
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6.00
NUMAR PUNCT
COTE EXISTENTE
DISTANTE PARTIALE
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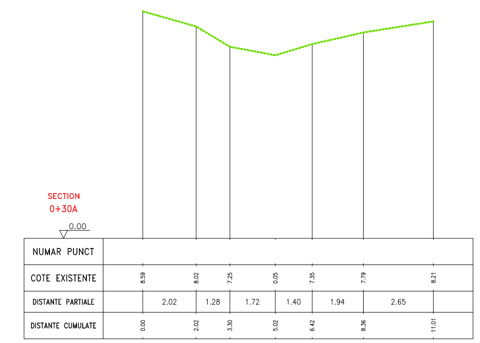
1.31
1.65
1.67
1.41
0.57
DISTANTE CUMULATE


SECTION
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0.00
NUMAR PUNCT
COTE EXISTENTE
DISTANTE PARTIALE
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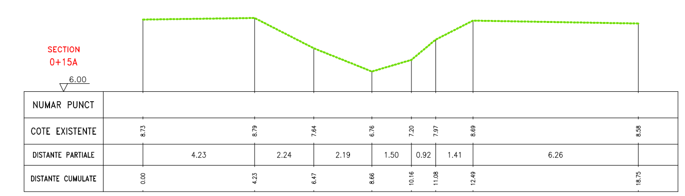
1.28
1.72
1.40
1.94
2.65
DISTANTE CUMULATE


SECTION
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6.00
NUMAR PUNCT
COTE EXISTENTE
DISTANTE PARTIALE
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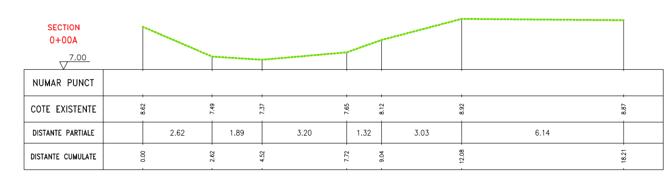
2.24
2.19
1.50
0.92
1.41
6.26
DISTANTE CUMULATE


SECTION
0+00A
7.00
NUMAR PUNCT
COTE EXISTENTE
DISTANTE PARTIALE
2.62
1.89
3.20
1.32
3.03
6.14
DISTANTE CUMULATE

APPENDIX 5

Preliminary Hydrological Calculations

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

REFERENCE	CATCHMENT 2 WATER COURSE CALCULATIONS			Existing Capacity	Existing Condition Output				Units
	Recurrence Interval	**R.I.**	=		**5**	**10**	**20**	**50**	**Yr.**
Calc Sheet #3	**Storm Runoff flow**	**Q**	=	**2.10**	**5.29**	**7.95**	**12.66**	**25.90**	**m^3/sec**
	Normal Depth Calculations, using Manning's Eqn								
Mannings Equation	Velocity of Flow, $V = 1/n\ S^{1/2}\ R^{2/3}$	**Symbol**		Unmaintained Eathern Channels					
Site Observations	Water Course Type								
Mannings n (Chow 1959)	Roughness	n	=	0.080	0.080	0.080	0.080	0.080	
Ministry of Works and Housing Cashew Hill Survey Dated 2016.04.28	Upstream of Elevation	e_1	=	11.29	11.29	11.29	11.29	11.29	m
	Down Stream Elevation	e_2	=	7.69	7.69	7.69	7.69	7.69	m
	Invert Elevation @ Point of Interest	e_3	=	9.00	9.00	9.00	9.00	9.00	m
	Bank Elevation @ Point of Interest	e_4	=	9.76	9.76	9.76	9.76	9.76	m
	Reach Length	L	=	610	610	610	610	610	m
	Slope of Water Course	s	=	0.006	0.006	0.006	0.006	0.006	m/m
Estimated based on site observations and Topo available.	Cross Section Shape				Trapizoid				
	Water Course Width	w	=	3	3.00	3.00	3.00	3.00	m
	Side Slope 1 (water course)	m_1	=	1.75	1.75	1.75	1.75	1.75	
	Side Slope 2 (Flood Plain)	m_2	=	40.00	40.00	40.00	40.00	40.00	
	Water Depth, by calculation	**d_n**	=	**0.76**	**1.03**	**1.12**	**1.25**	**1.47**	**m**
	Water Elevation @ Point Of Interest	**E_{w1}**	=	**9.76**	**10.03**	**10.12**	**10.25**	**10.47**	**m**
	Surface Water Width 1= $w+2*m*d_n$	b_1	=	5.66	5.66	5.66	5.66	5.66	m
	Surface Water Width 2= $w+2*m*d_n$	b_2	=	3.00	24.91	31.76	42.39	60.05	m
	Area 1 = $(w+b)*(d_n/2)$	A	=	3.29	8.66	11.57	17.25	29.80	m^2
	Wetted perimeter 1 = $w+2d_n*(1+m^2)^{0.5}$	P	=	6.06	17.02	20.45	25.76	34.60	m
	Hydraulic Radius = A/P	R	=	0.54	0.51	0.57	0.67	0.86	
	Velocity = $1/n\ S^{1/2}\ R^{2/3}$	V	=	0.64	0.61	0.66	0.73	0.87	m/s
	Flow = AV	**Q**	=	**2.10**	**5.29**	**7.59**	**12.66**	**25.90**	**m^3/sec**

Calc. Sheet #9

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

REFERENCE	**CATCHMENT 2 WATER COURSE CALCULATIONS**			**Proposed Solution #1 Output**				**Proposed Solution #2 Output**				**Units**
	Recurrence Interval	**R.I.**	=	**5**	**10**	**20**	**50**	**5**	**10**	**20**	**50**	**Yr**
Calc Sheet #3	**Storm Runoff flow**	**Q**	=	**5.29**	**7.95**	**12.66**	**25.90**	**5.29**	**7.95**	**12.66**	**25.90**	**m^3/sec**
	Normal Depth Calculations, using Manning's Eqn											
Mannings Equation	Velocity of Flow, $V = 1/n\ S^{1/2}\ R^{2/3}$	**Symbol**										
	Proposed Water Course Type			Concrete Lined Drain Using Existing Average Drain Depth of 0.76m				Concrete Lined Drain Using Existing Drain Depth of 1.00m				
Mannings n (Chow 1959)	Roughness	n	=	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	
Ministry of Works and Housing Cashew Hill Survey Dated 2016.04.28	Upstream of Elevation	e_1	=	11.29	11.29	11.29	11.29	11.29	11.29	11.29	11.29	m
	Down Stream Elevation	e_2	=	7.69	7.69	7.69	7.69	7.69	7.69	7.69	7.69	m
	Invert Elevation @ Point of Interest	e_3	=	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	m
	Bank Elevation @ Point of Interest	e_4	=	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	m
	Reach Length	L	=	610	610	610	610	610	610	610	610	m
	Slope of Water Course	s	=	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	m/m
	Cross Section Shape			Square				Square				
	Water Course Width	**w**	**=**	**2.30**	**3.07**	**4.71**	**8.89**	**1.73**	**2.26**	**3.38**	**6.11**	**m**
	Water Depth, by calculation	d_n	=	0.76	0.76	0.76	0.76	1.00	1.00	1.00	1.00	m
	Water Elevation @ Point Of Interest	E_{w1}	=	9.76	9.76	9.76	9.76	10.00	10.00	10.00	10.00	m
	Area 1 = $(w+b)*(d_n/2)$	A	=	1.74	2.33	3.58	6.76	1.73	2.26	3.38	6.11	m^2
	Wetted perimeter 1 = $w+2d_n*(1+m^2)^{0.5}$	P	=	3.82	4.59	6.23	10.41	3.73	4.26	5.38	8.11	m
	Hydraulic Radius = A/P	R	=	0.46	0.51	0.57	0.65	0.46	0.53	0.63	0.75	
	Velocity = $1/n\ S^{1/2}\ R^{2/3}$	V	=	3.03	3.25	3.53	3.83	3.06	3.35	3.75	4.24	m/s
	Flow = AV	**Q**	**=**	**5.29**	**7.59**	**12.66**	**25.90**	**5.29**	**7.59**	**12.66**	**25.90**	**m^3/sec**

Calc. Sheet #10

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

REFERENCE	CATCHMENT 1A, B & C WATER COURSE CALCULATIONS	Symbol		Existing Capacity	Existing Condition Output				Units
Calc Sheet #3	**Recurrence Interval**	**R.I.**	=		**5**	**10**	**20**	**50**	**Yr.**
	Storm Runoff flow	**Q**	=	**3.20**	**9.41**	**14.22**	**22.74**	**46.63**	**m^3/sec**
	Normal Depth Calculations, using Manning's Eqn								
Mannings Equation	Velocity of Flow, $V = 1/n\ S^{1/2}\ R^{2/3}$	**Symbol**							
Site Observations	Water Course Type			Unmaintained Eathern Channels					
Mannings n (Chow 1959)	Roughness	n	=	0.080	0.080	0.080	0.080	0.080	
Ministry of Works and Housing Cashew Hill Survey Dated 2016.04.28	Upstream of Elevation	e_1	=	8.80	8.80	8.80	8.80	8.80	m
	Down Stream Elevation	e_2	=	7.70	7.70	7.70	7.70	7.70	m
	Invert Elevation @ Point of Interest	e_3	=	8.16	8.16	8.16	8.16	8.16	m
	Bank Elevation @ Point of Interest	e_4	=	9.44	9.44	9.44	9.44	9.44	m
	Reach Length	L	=	80	80	80	80	80	m
	Slope of Water Course	s	=	0.014	0.014	0.014	0.014	0.014	m/m
Estimated based on site observations and Topo available.	Cross Section Shape				Trapizoid				
	Water Course Width	w	=	3	3.00	3.00	3.00	3.00	m
	Side Slope 1 (water course)	m_1	=	1.75	1.50	1.50	1.50	1.50	
	Side Slope 2 (Flood Plain)	m_2	=	40.00	40.00	40.00	40.00	40.00	
	Water Depth, by calculation	d_n	=	**0.76**	**1.43**	**1.58**	**1.73**	**1.99**	**m**
	Water Elevation @ Point Of Interest	E_{w1}	=	**8.92**	**9.59**	**9.74**	**9.89**	**10.15**	**m**
	Surface Water Width 1= $w+2*m*d_n$	b_1	=	5.66	6.84	6.84	6.84	6.84	m
	Surface Water Width 2= $w+2*m*d_n$	b_2	=	0.00	15.05	27.07	39.03	59.65	m
	Area 1 = $(w+b)*(d_n/2)$	A	=	3.29	8.69	12.88	18.84	33.33	m^2
	Wetted perimeter 1 = $w+2d_n*(1+m^2)^{0.5}$	P	=	6.06	13.64	19.65	25.63	35.95	m
	Hydraulic Radius = A/P	R	=	0.54	0.64	0.66	0.74	0.93	
	Velocity = $1/n\ S^{1/2}\ R^{2/3}$	V	=	0.97	1.08	1.10	1.19	1.39	m/s
	Flow = AV	**Q**	**=**	**3.20**	**9.41**	**14.22**	**22.47**	**46.43**	**m^3/sec**

Calc. Sheet #11

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

REFERENCE	CATCHMENT 1A, B & C WATER COURSE CALCULATIONS			Proposed Solution #1 Output				Proposed Solution #2 Output				Units
	Recurrence Interval	**R.I.**	=	**5**	**10**	**20**	**50**	**5**	**10**	**20**	**50**	**Yr**
Calc Sheet #3	**Storm Runoff flow**	**Q**	=	**9.41**	**14.22**	**22.74**	**46.63**	**9.41**	**14.22**	**22.74**	**46.63**	**m^3/sec**
	Normal Depth Calculations, using Manning's Eqn											
Mannings Equation	Velocity of Flow, $V = 1/n\ S^{1/2}\ R^{2/3}$	**Symbol**										
	Proposed Water Course Type			Concrete Lined Drain Using Existing Depth at Road of 1.00m				Concrete Lined Drain decrease hydraulic slope and increase drain depth at road to 1.50m				
Mannings n (Chow 1959)	Roughness	n	=	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	
Ministry of Works and Housing Cashew Hill Survey Dated 2016.04.28	Upstream of Elevation	e_1	=	8.80	8.80	8.80	8.80	8.20	8.20	8.20	8.20	m
	Down Stream Elevation	e_2	=	7.70	7.70	7.70	7.70	7.70	7.70	7.70	7.70	m
	Invert Elevation @ Point of Interest	e_3	=	8.86	8.86	8.86	8.86	8.20	8.20	8.20	8.20	m
	Bank Elevation @ Point of Interest	e_4	=	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	m
	Reach Length	L	=	80	80	80	80	80	80	80	80	m
	Slope of Water Course	s	=	0.014	0.014	0.014	0.014	0.006	0.006	0.006	0.006	m/m
	Cross Section Shape			Square				Square				
	Water Course Width	**w**	**=**	**2.16**	**2.98**	**4.37**	**8.13**	**1.76**	**2.37**	**3.36**	**5.92**	**m**
	Water Depth, by calculation	d_n	=	0.90	0.90	0.90	0.90	1.50	1.50	1.50	1.50	m
	Water Elevation @ Point Of Interest	E_{w1}	=	9.76	9.76	9.76	9.76	9.70	9.70	9.70	9.70	m
	Area 1 = $(w+b)*(d_n/2)$	A	=	1.94	2.68	3.93	7.32	2.65	3.56	5.04	8.88	m^2
	Wetted perimeter 1 = $w+2d_n*(1+m^2)^{0.5}$	P	=	3.96	4.78	6.17	9.93	4.76	5.37	6.36	8.92	m
	Hydraulic Radius = A/P	R	=	0.49	0.56	0.64	0.74	0.56	0.66	0.79	1.00	
	Velocity = $1/n\ S^{1/2}\ R^{2/3}$	V	=	4.85	5.31	5.78	6.37	3.55	4.00	4.51	5.25	m/s
	Flow = AV	**Q**	**=**	**9.41**	**14.22**	**22.74**	**46.63**	**9.41**	**14.22**	**22.74**	**46.63**	**m^3/sec**

Calc. Sheet #12

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

REFERENCE	CATCHMENT 1A, B & C WATER COURSE CALCULATIONS			Existing Capacity	Existing Condition Output				Units
Calc Sheet #3	**Recurrence Interval**	**R.I.**	=		**5**	**10**	**20**	**50**	**Yr.**
	Storm Runoff flow	**Q**	=	**4.82**	**14.29**	**21.54**	**34.38**	**70.43**	**m^3/sec**
	Normal Depth Calculations, using Manning's Eqn								
Mannings Equation	Velocity of Flow, $V = 1/n\ S^{1/2}\ R^{2/3}$	**Symbol**		Unmaintained Eathern Channels					
Site Observations	Water Course Type								
Mannings n (Chow 1959)	Roughness	n	=	0.080	0.080	0.080	0.080	0.080	
Ministry of Works and Housing Cashew Hill Survey Dated 2016.04.28	Upstream of Elevation	e_1	=	7.70	7.70	7.70	7.70	7.70	m
	Down Stream Elevation	e_2	=	6.64	6.64	6.64	6.64	6.64	m
	Invert Elevation @ Point of Interest	e_3	=	7.12	7.12	7.12	7.12	7.12	m
	Bank Elevation @ Point of Interest	e_4	=	8.72	8.72	8.72	8.72	8.72	m
	Reach Length	L	=	600	600	600	600	600	m
	Slope of Water Course	s	=	0.002	0.002	0.002	0.002	0.002	m/m
Estimated based on site observations and Topo available.	Cross Section Shape				Trapizoid				
	Water Course Width	w	=	3.00	3.00	3.00	3.00	3.00	m
	Side Slope 1 (water course)	m_1	=	1.75	1.75	1.75	1.75	1.75	
	Side Slope 2 (Flood Plain)	m_2	=	50.00	50.00	50.00	50.00	50.00	
	Water Depth, by calculation	**d_n**	=	**1.60**	**1.92**	**2.07**	**2.17**	**2.35**	**m**
	Water Elevation @ Point Of Interest	**E_{w1}**	=	**8.72**	**9.04**	**9.19**	**9.29**	**9.47**	**m**
	Surface Water Width 1= $w+2*m*d_n$	b_1	=	8.60	8.60	8.60	8.60	8.60	m
	Surface Water Width 2= $w+2*m*d_n$	b_2	=	3.00	35.29	49.91	60.07	78.46	m
	Area 1 = $(w+b)*(d_n/2)$	A	=	9.28	18.24	25.72	32.19	46.51	m^2
	Wetted perimeter 1 = $w+2d_n*(1+m^2)^{0.5}$	P	=	9.45	25.60	32.91	37.99	47.19	m
	Hydraulic Radius = A/P	R	=	0.98	0.71	0.78	0.85	0.99	
	Velocity = $1/n\ S^{1/2}\ R^{2/3}$	V	=	0.52	0.42	0.45	0.47	0.52	m/s
	Flow = AV	**Q**	**=**	**4.82**	**7.64**	**11.46**	**15.13**	**24.20**	**m^3/sec**

Calc. Sheet #13

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

REFERENCE	CATCHMENT 1A, B & C WATER COURSE CALCULATIONS			Proposed Solution #1 Output				Proposed Solution #2 Output				Units
	Recurrence Interval	**R.I.**	=	**5**	**10**	**20**	**50**	**5**	**10**	**20**	**50**	**Yr**
Calc Sheet #3	**Storm Runoff flow**	**Q**	=	**14.29**	**21.54**	**34.38**	**70.43**	**14.29**	**21.54**	**34.38**	**70.43**	**m^3/sec**
	Normal Depth Calculations, using Manning's Eqn											
Mannings Equation	Velocity of Flow, $V = 1/n\ S^{1/2}\ R^{2/3}$	**Symbol**										
	Proposed Water Course Type			Earthern Swale With Flood Plain maximum Flood depth 600mm				Concrete Lined Drain with maximum Depth of 1.6m				
Mannings n (Chow 1959)	Roughness	n	=	0.022	0.022	0.022	0.022	0.015	0.015	0.015	0.015	
Ministry of Works and Housing Cashew Hill Survey Dated 2016.04.28	Upstream of Elevation	e_1	=	7.70	7.70	7.70	7.70	7.70	7.70	7.70	7.70	m
	Down Stream Elevation	e_2	=	6.64	6.64	6.64	6.64	6.64	6.64	6.64	6.64	m
	Invert Elevation @ Point of Interest	e_3	=	7.12	7.12	7.12	7.12	7.12	7.12	7.12	7.12	m
	Bank Elevation @ Point of Interest	e_4	=	8.72	8.72	8.72	8.72	8.72	8.72	8.72	8.72	m
	Reach Length	L	=	600	600	600	600	600	600	600	600	m
	Slope of Water Course	s	=	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	m/m
	Cross Section Shape			Square				Square				
	Water Course Width	**w**	=	10.00	10.00	10.00	10.00	**3.82**	**5.28**	**7.76**	**14.49**	**m**
	Side Slope 1 (water course)	m_1	=	5.00	5.00	5.00	5.00	N/A	N/A	N/A	N/A	
	Side Slope 2 (Flood Plain)	m_2	=	50.00	50.00	50.00	50.00	N/A	N/A	N/A	N/A	
	Water Depth, by calculation	d_n	=	**0.77**	**0.96**	**1.22**	**1.76**	1.50	1.50	1.50	1.50	m
	Water Elevation @ Point Of Interest	E_{w1}	=	7.89	8.08	8.34	8.88	8.62	8.62	8.62	8.62	m
	Surface Water Width 1= $w+2*m*d_n$	b_1	=	17.66	19.55	22.21	26.00	N/A	N/A	N/A	N/A	m
	Surface Water Width 2= $w+2*m*d_n$	b_2	=	0.00	0.00	0.00	25.94	N/A	N/A	N/A	N/A	m
	Area 1 = $(w+b)*(d_n/2)$	A	=	10.59	14.12	19.67	35.81	5.73	7.92	11.64	21.73	m^2
	Wetted perimeter 1 = $w+2d_n*(1+m^2)^{0.5}$	P	=	17.81	19.74	22.45	34.29	6.82	8.28	10.76	17.49	m
	Hydraulic Radius = A/P	R	=	0.59	0.72	0.88	1.04	0.84	0.96	1.08	1.24	
	Velocity = $1/n\ S^{1/2}\ R^{2/3}$	V	=	1.35	1.53	1.75	1.97	2.49	2.72	2.95	3.24	m/s
	Flow = AV	**Q**	=	**14.29**	**21.54**	**34.38**	**70.43**	**14.29**	**21.54**	**34.38**	**70.43**	**m^3/sec**

Calc. Sheet #14

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

REFERENCE	**CATCHMENT 2 WATER COURSE CALCULATIONS**		**Existing Culvert #1 Capacity Output**	**Existing Culvert #2 Capacity Output**
	Culvert Capacity	**Q =**	**4.49**	**7.78**
	Normal Depth Calculations, using Manning's Eqn			
Mannings Equation	Velocity of Flow, $V = 1/n\ S^{1/2}\ R^{2/3}$	**Symbol**		
	Culvert Type		Existing Concrete Culvert	Existing Concrete Culvert
Mannings n (Chow 1959)	Roughness	n =	0.015	0.015
Ministry of Works and Housing Cashew Hill Survey Dated 2016.04.28	Upstream of Elevation	e_1 =	9.80	9.50
	Down Stream Elevation	e_2 =	9.60	9.20
	Invert Elevation @ Point of Interest	e_3 =	9.70	9.50
	Road Elevation @ Point of Interest	e_4 =	10.90	10.50
	Reach Length	L =	90	45
	Slope of Culvert	s =	0.002	0.007
	Cross Section Shape		Square	Square
	Culvert Width	w =	4.00	4.00
	Water Depth, by calculation	d_n =	0.60	0.60
	Water Elevation @ Point Of Interest	E_{w1} =	10.30	10.10
	Area 1 = $(w+b)*(d_n/2)$	A =	2.40	2.40
	Wetted perimeter 1 = $w+2d_n*(1+m^2)^{0.5}$	P =	5.20	5.20
	Hydraulic Radius = A/P	R =	0.46	0.46
	Velocity = $1/n\ S^{1/2}\ R^{2/3}$	V =	1.87	3.24
	Flow = AV	**Q =**	**4.49**	**7.78**

Calc. Sheet #15

Detention Pond Calculations

Location: DP 3

Return Period Storm 1:50 Year

Overflow Weir 1	**Overflow Weir 1**
C = 1.7	C = 1.7
Weir Elev. = 6.7	Weir Elev. = 8
Rectangular Weir	Rectangular Weir
Qout = CLH$^{1.5}$	**Qout = CLH$^{1.5}$**
Weir 1 Length (m) L= 6	Weir 2 Length (m) L= 10

OUTLET Parameters:

Outlet Elevation 6.7 m

INLET Parameters:

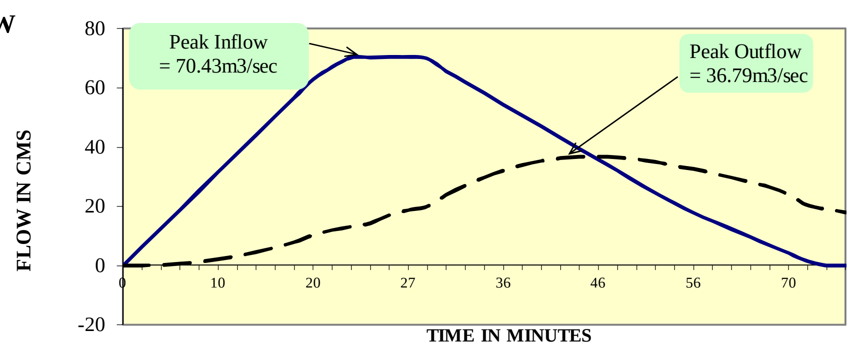
Inlet Elevation 7.59

Results:

Qmax-in	**70.43**	m^3/s
Qmax-out	**36.79**	m^3/s
Max Depth	**1.95**	m
Max W.S.E.	**8.65**	m

	INFLOW			Pipe	Depth	OUTFLOW		STORAGE			
TIME (min)	Qin (cms)	Qin (cms)	VOL (cm)	Flow	after dT	Qout (cms)	Vol. (cm)	Vol by calc	Vol (cm)	Depth (m)	WS el (m)
0.0	0	0									
2.0	6.29227	6.29227	377.5	0.00	0.018	0.03	2	376	376	0.018	6.72
4.0	12.5845	12.5845	1132.6	0.00	0.069	0.19	13	1,496	1,496	0.069	6.77
6.0	18.8768	18.8768	1887.7	0.00	0.146	0.57	45	3,338	3,338	0.146	6.85
8.0	25.1691	25.1691	2642.8	0.00	0.239	1.20	106	5,876	5,876	0.239	6.94
10.0	31.4613	31.4613	3397.8	0.00	0.345	2.07	196	9,077	9,077	0.345	7.05
12.0	37.7536	37.7536	4152.9	0.00	0.460	3.18	315	12,915	12,915	0.460	7.16
14.0	44.0459	44.0459	4908.0	0.00	0.582	4.52	463	17,360	17,360	0.582	7.28
16.0	50.3382	50.3382	5663.0	0.00	0.709	6.08	637	22,387	22,387	0.709	7.41
18.0	56.6304	56.6304	6418.1	0.00	0.840	7.86	837	27,968	27,968	0.840	7.54
20.0	62.877	62.877	7170.4	0.00	1.003	10.25	1087	35,303	34,052	1.003	7.70
22.0	67.0642	67.0642	7796.5	0.00	1.112	11.97	1333	40,438	40,516	1.112	7.81
23.0	70.2686	70.2686	4120.0	0.00	1.182	13.11	752	43,805	43,883	1.182	7.88
24.0	70.2796	70.2796	4216.4	0.00	1.252	14.28	822	47,200	47,278	1.252	7.95
26.0	70.383	70.383	8439.8	0.00	1.383	17.00	1877	53,762	53,840	1.383	8.08
27.0	70.4347	70.4347	4224.5	0.00	1.446	18.68	1070	56,916	56,994	1.446	8.15
27.7	69.8979	69.8979	3137.7	0.00	1.491	19.98	864	59,190	59,268	1.491	8.19
30.0	65.6769	65.6769	9170.4	0.00	1.612	23.85	2964	65,396	65,474	1.612	8.31
32.0	61.9328	61.9328	7656.6	0.00	1.702	26.99	3050	70,002	70,080	1.702	8.40
34.0	58.1887	58.1887	7207.3	0.00	1.777	29.75	3405	73,805	73,883	1.777	8.48
36.0	54.4445	54.4445	6758.0	0.00	1.837	32.07	3709	76,854	76,932	1.837	8.54
38.0	50.7004	50.7004	6308.7	0.00	1.883	33.92	3959	79,203	79,281	1.883	8.58
40.0	46.9563	46.9563	5859.4	0.00	1.917	35.30	4153	80,910	80,988	1.917	8.62
42.0	43.2121	43.2121	5410.1	0.00	1.939	36.22	4291	82,029	82,107	1.939	8.64
44.0	39.468	39.468	4960.8	0.00	1.950	36.70	4375	82,615	82,693	1.950	8.65
46.0	35.7239	35.7239	4511.5	0.00	**1.953**	**36.79**	4410	82,717	82,795	1.953	**8.65**
48.0	31.9797	31.9797	4062.2	0.00	1.946	36.51	4398	82,381	82,459	1.946	8.65
50.0	28.2356	28.2356	3612.9	0.00	1.931	35.90	4345	81,649	81,727	1.931	8.63
52.0	24.4915	24.4915	3163.6	0.00	1.910	35.01	4255	80,558	80,636	1.910	8.61
54.5	21.11	21.11	3417.3	0.00	1.876	33.62	5143	78,832	78,910	1.876	8.58
56.0	17.7648	17.7648	1751.7	0.00	1.851	32.65	2986	77,598	77,676	1.851	8.55
58.0	15.0347	15.0347	1968.0	0.00	1.815	31.21	3831	75,734	75,812	1.815	8.51
60.0	12.3046	12.3046	1640.4	0.00	1.775	29.69	3654	73,721	73,799	1.775	8.48
62.0	9.57448	9.57448	1312.7	0.00	1.733	28.11	3468	71,566	71,644	1.733	8.43
64.0	7.50864	6.7654	980.4	0.00	1.688	26.48	3275	69,271	69,349	1.688	8.39
70.0	2.88299	4.1564	1965.9	0.00	1.549	24.00	9086	62,151	62,229	1.549	8.25
72.0	1.45678	1.45678	336.8	0.00	1.503	20.35	2661	59,827	59,905	1.503	8.20
74.0	0.04049	0.04049	89.2	0.00	1.459	19.04	2347	57,568	57,646	1.459	8.16
74.1	0	0	0.1	0.00	1.457	18.00	104	57,464	57,542	1.457	8.16

INFLOW/OUTFLOW HYDROGRAPHS



Calc. Sheet #16

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

Detention Pond # 3 Cumulative Volume VS Depth Calculations						
Elevation (m)	Area (m^2)	Elevation Difference (m)	Depth	Volume (m^3)	Cumulative Volume (m^3)	Calculated Volume Check (m^3)
6.66	22457.5	0	0	0	0	0
6.86	27350.4	0.2	0.2	4981	4981	4774
7.06	32400	0.2	0.4	5975	10956	10855
7.26	37600	0.2	0.6	7000	17956	18063
7.46	42855	0.2	0.8	8046	26001	26221
7.66	48300	0.2	1.0	9116	35117	35149
7.86	49000	0.2	1.2	9730	44847	44669
8.06	49700	0.2	1.4	9870	54717	54602
8.26	50400	0.2	1.6	10010	64727	64770
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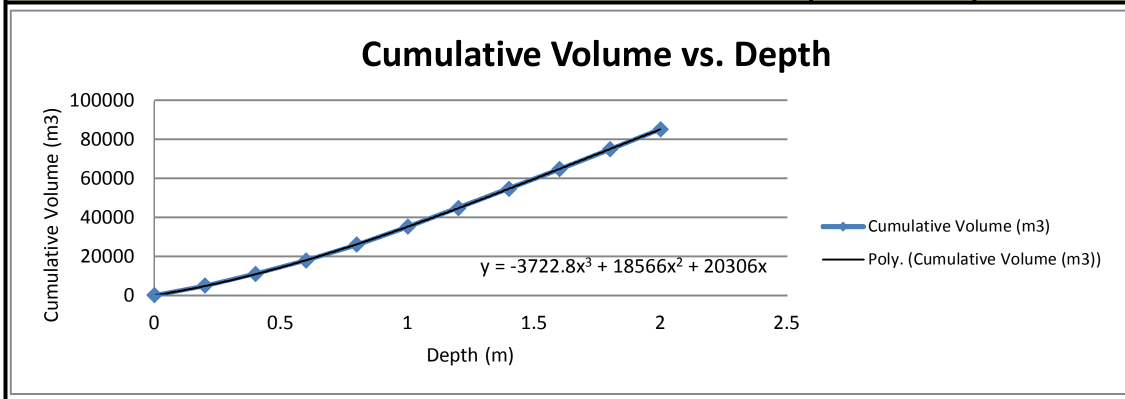
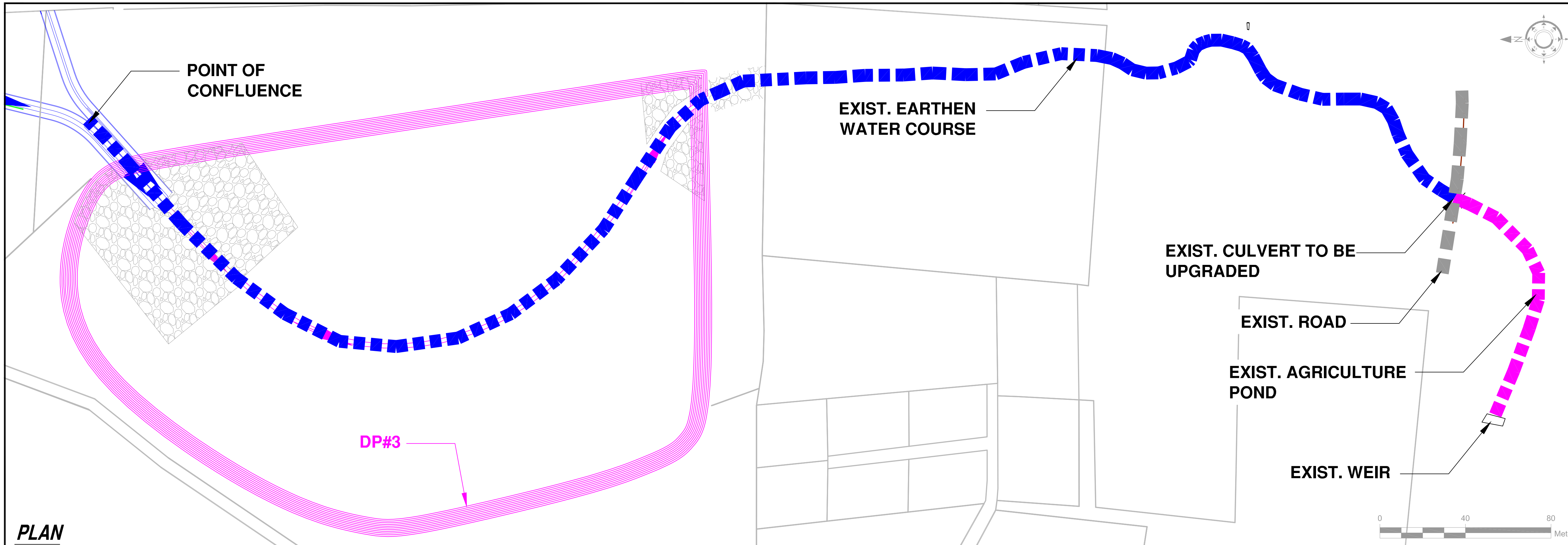
8.66	51800	0.2	2.0	10281	85149	85094



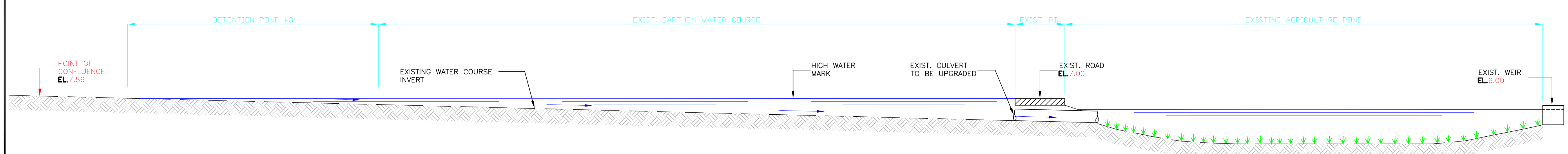
Calc. Sheet #17

APPENDIX 6

Schematic Backwater Plan and Profile



PLAN



PROFILE

DRAFT

NOS.	DATE	REVISIONS

CLIENT : Organization of Eastern Caribbean States (OECS)

PROJECT : Technical Assistance for Flood Mitigation and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill).

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PHONE: 735-6662, 484-3913

DRAWING TITLE : SCHEMATIC BACKWATER PLAN & PROFILE

JOB No. 2016-014
FILE No. RW-02
SCALE : N.T.S.
DATE : 06.06.2016
DES. : K.D
DRG. : S.P
REVS.: 00
SHEET No. 19

APPENDIX 7

MOM from Preliminary Draft Technical Analysis and Design Report Review

Gmail **Janna Turpin <alphaeng.jannaturpin@gmail.com>**

OECS/GCCA/2015/SER-18(Lot 2) - Preliminary Draft Technical Analysis and Design Report

Fazir Khan <alphaeng.fazirkhan@gmail.com> Wed, May 25, 2016 at 6:47 PM
To: Ruleta Camacho Thomas <sirmmab@gmail.com>
Cc: Chamberlain Emmanuel <cemmanuel@oecs.org>, Kieran de Freitas <alphaeng.kierandefreitas@gmail.com>, Eugene Winter <deugenewinter@gmail.com>, Dwight Laviscount <dwight.n.laviscount@gmail.com>, JOHN PETERS <johnapeters@outlook.com>, Tanya Wright <twright@oecs.org>, Janna Turpin <alphaeng.jannaturpin@gmail.com>, Neila Mendoza <alphaeng.neilamendoza@gmail.com>, Adele Young <alphaeng.adeleyoung@gmail.com>, Diann Black-Layne <dcblack11@gmail.com>, Gerad Payne <gpayne2007@gmail.com>, Lucine Hanley <lucinehanley@gmail.com>, Walter Christopher <walter.p.christopher@gmail.com>, Jan Oke <janiceokeiffe@gmail.com>, Daryll Matthew <daryll.matthew@gmail.com>, Churchill Norbert <Norbert.churchill@gmail.com>

Dear Ruleta,
Further to our meeting today to review the **Preliminary Draft Technical Analysis and Design Report,** we write to confirm the following that was mutually agreed for action going forward:

1. Relocation of any residents was unequivocally rejected as an option within Water Course #1 in Cashew Hill area based on social impact as articulated in the Alpha Report and corroborated by all the stakeholders present in the meeting.
    1. The DoE and MOW are prepared to accept a lower level of design R.I rain storm to accommodate flood mitigation solution in this instance.
        1. Alpha will determine based on field survey information provided and revise report accordingly.
    2. The DoE and MOW will address the issue identified in new projects as per Alpha recommendations on other sites.
2. The approved funding from the OECS for implementation phase of this project is $501,869.00 Euros, which approximates to $1.5M ECD
    1. A hybrid for proposed works implementation was mutually agreed to fit within this expenditure as follows:
        1. Modification of Package 1 - (Ref Alpha Addendum #1 dated 2016.05.24) , achieved by:
            1. Adding Culvert #2 per MOW request. *(Alpha emphasized the point that unless the downstream channel is upgraded, culvert#2 modification will not result in significant benefits as it relates to flood mitigation)*
            2. Reduced Scope of Confluence works as required for cost reduction in terms of length of paved channels
            3. Cleaning of the Existing Earthen Watercourse #1 between Culvert #2 and the Confluence of WC#1/WC#2.
            4. Adjusting Alpha BOQ rates per MOW review where deemed to be on the high side.
3. **Action to follow:**
    1. Antigua
        1. Surveyor Ms Janice O'Keiffe to supply outstanding details and sections at Culvert #2
        2. MOW to supply revised rates where applicable based on Alpha's present BOQs
        3. DoE to address land issue at confluence where WC#2 is proposed to be geometrically re-aligned and will fall within the private property on the northern side.
    2. Alpha
        1. Develop Detailed designs for Culvert # 2 and Confluence Works based on accepted preliminary designs presented
        2. Prepare Detailed BOQs for the proposed final designed works

3. Use the above to generate Final Engineer's Estimates (with revised rates and final quantities)
4. Prepare Package #1 Tender Document, using the above and inclusive of contract conditions and specifications]

regards

Fazir Khan BSc., REng
Alpha Engineering & Design (2012) Ltd.
Building Unit #1,
Lot 10D, Chootoo Road,
El Socorro, San Juan South
Trinidad, W.I.

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T: (868) 278-0400
T: (868) 735-6662
C: (868) 682-7005

[Quoted text hidden]

Gmail **Janna Turpin <alphaeng.jannaturpin@gmail.com>**

OECS/GCCA/2015/SER-18(Lot 2) - Preliminary Draft Technical Analysis and Design Report

Ruleta Work <sirmmab@gmail.com> Thu, May 26, 2016 at 10:41 AM
To: Fazir Khan <alphaeng.fazirkhan@gmail.com>
Cc: Chamberlain Emmanuel <cemmanuel@oecs.org>, Kieran de Freitas <alphaeng.kierandefreitas@gmail.com>, Eugene Winter <deugenewinter@gmail.com>, Dwight Laviscount <dwight.n.laviscount@gmail.com>, JOHN PETERS <johnapeters@outlook.com>, Tanya Wright <twright@oecs.org>, Janna Turpin <alphaeng.jannaturpin@gmail.com>, Neila Mendoza <alphaeng.neilamendoza@gmail.com>, Adele Young <alphaeng.adeleyoung@gmail.com>, Diann Black-Layne <dcblack11@gmail.com>, Gerad Payne <gpayne2007@gmail.com>, Lucine Hanley <lucinehanley@gmail.com>, Walter Christopher <walter.p.christopher@gmail.com>, Jan Oke <janiceokeiffe@gmail.com>, Daryll Matthew <daryll.matthew@gmail.com>, Churchill Norbert <Norbert.churchill@gmail.com>

Dear Fazir,

Thanks for your summary we find this to be an accurate reflection of the conclusions that we arrived at during yesterday's discussions. Please see a few comments below in brackets.

Best Regards.

Ruleta Camacho, Deputy Chief Environment Officer, Environment Division, Botanical Gardens, St. John's, Antigua.

On 25 May 2016, at 6:47 PM, Fazir Khan <alphaeng.fazirkhan@gmail.com> wrote:

> Dear Ruleta,
> Further to our meeting today to review the **Preliminary Draft Technical Analysis and Design Report,** we write to confirm the following that was mutually agreed for action going forward:
>
> 1. Relocation of any residents was unequivocally rejected as an option within Water Course #1 in Cashew Hill area based on social impact as articulated in the Alpha Report and corroborated by all the stakeholders present in the meeting.
>   1. The DoE and MOW are prepared to accept a lower level of design R.I rain storm to accommodate flood mitigation solution in this instance.
>   1. Alpha will determine based on field survey information provided and revise report accordingly.
>   2. The DoE and MOW will address the issue identified in new projects as per Alpha recommendations on other sites. (the DoE will agrees with the 1/50 year the higher level RI rain storm design for repair of existing primary water courses in other areas, as well as for any new developments. We feel that this is a sound recommendation. However, in cases where the solution triggers ESS red flags lower levels may be considered to minimize social disruptions this will apply only to existing water courses in densely populated areas.)
> 2. The approved funding from the OECS for implementation phase of this project is $501,869.00 Euros, which approximates to $1.5M ECD
>   1. A hybrid for proposed works implementation was mutually agreed to fit within this expenditure as follows:

1. Modification of Package 1 - (Ref Alpha Addendum #1 dated 2016.05.24) , achieved by:
    1. Adding Culvert #2 per MOW request. *(Alpha emphasized the point that unless the downstream channel is upgraded, culvert#2 modification will not result in significant benefits as it relates to flood mitigation)*
    2. Reduced Scope of Confluence works as required for cost reduction in terms of length of paved channels
    3. Cleaning of the Existing Earthen Watercourse #1 between Culvert #2 and the Confluence of WC#1/WC#2.(the DoE is already looking at options to have this cleaned by hand during June and maintained there after during the implementation of the project. Long term upkeep standards could be useful.)

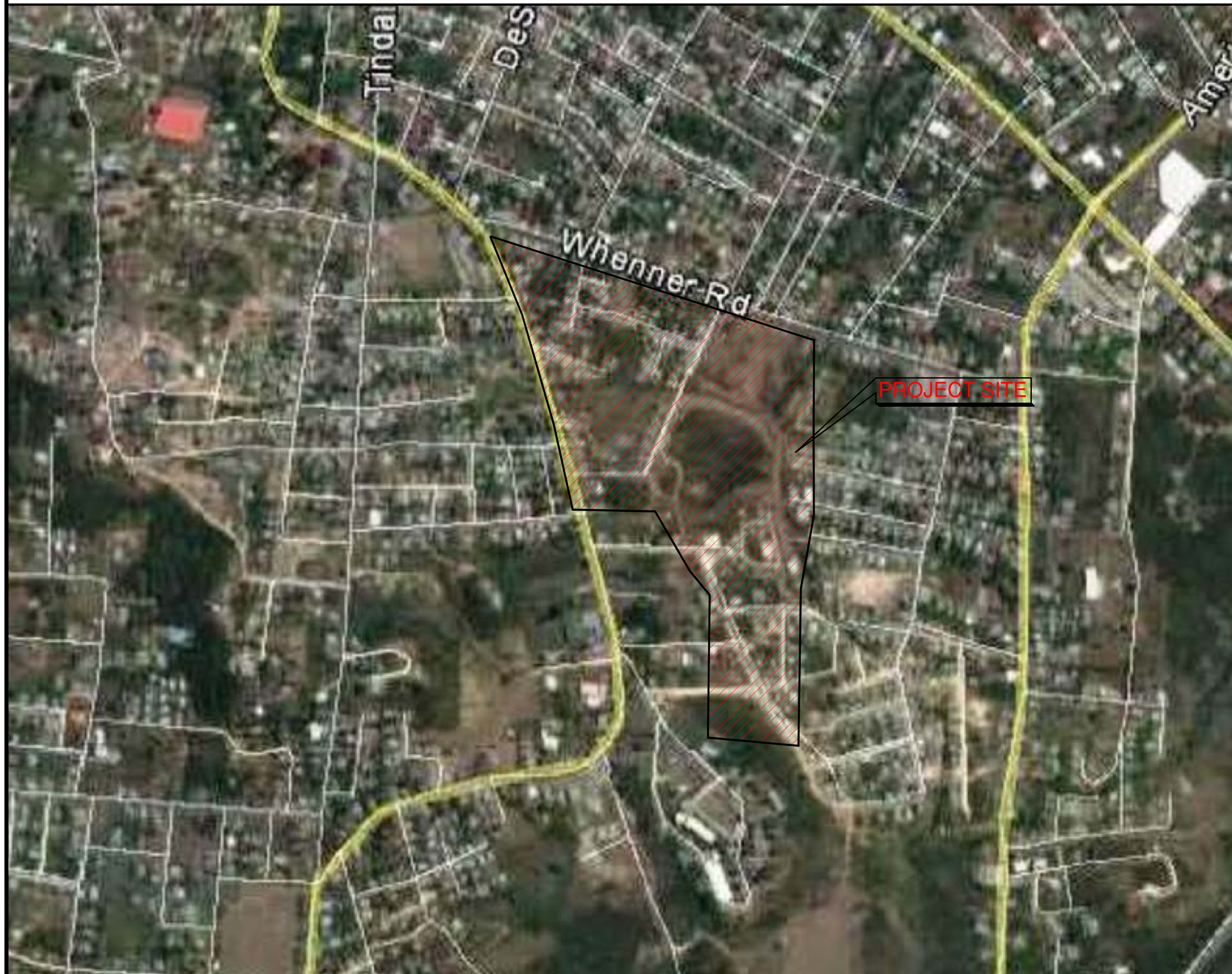
[Quoted text hidden]

APPENDIX 8

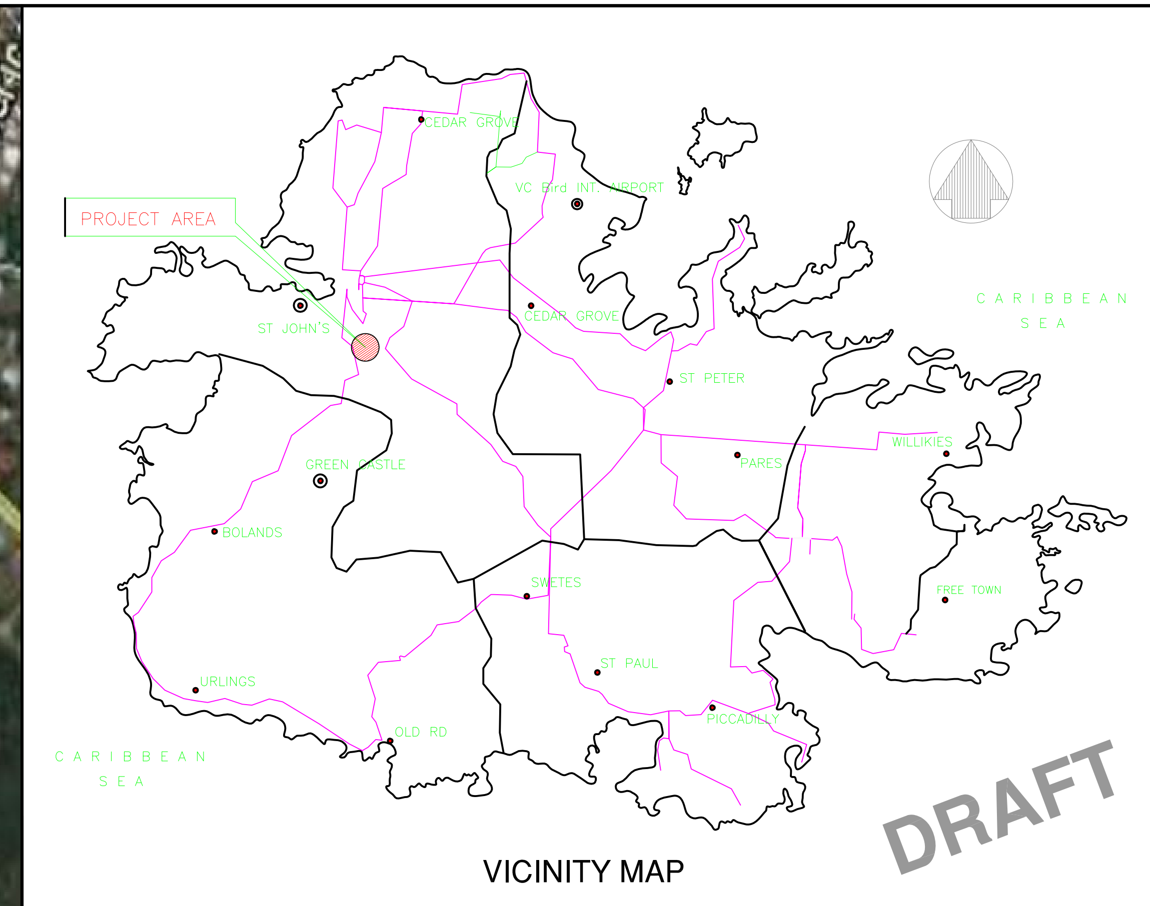
Draft Design Drawings

Organization of Eastern Caribbean States (OECS)

Technical Assistance for Flood Mitigation and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill).



LOCATION PLAN



VICINITY MAP

D R A W I N G   I N D E X

DRAWING No.	DESCRIPTION
00	Cover Sheet & Location Plan
01	Catchment Layout
02	Cashew Layout and Typical Cross Section
03	Main Water Course #1 Plan and Profile Sheet 1 of 2 Option #1
04	Main Water Course #1 Plan and Profile Sheet 2 of 2 Option #1
05	Main Water Course #1 Plan and Profile Sheet 1 of 2 Option #2
06	Main Water Course #1 Plan and Profile Sheet 2 of 2 Option #2
07	Main Watercourse #2 Plan and Profile
10	Confluence Details
11	Drainage Details
12	Work Package Layout
14	Water Course #1 Drain & Property Conflict Layout (5m Width)
15	Preliminary Watershed Plan (Option 2)
16	Detention Pond #3 Option #2 Layout
17	Culvert #2 Sections A-A & B-B
18	Culvert #2 Plan (Option 2)
19	Schematic Backwater Plan & Profile

NOS.	DATE	R E V I S I O N S

CLIENT : Organization of Eastern Caribbean States (OECS)

PROJECT: Technical Assistance for Flood Mitigation and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill).

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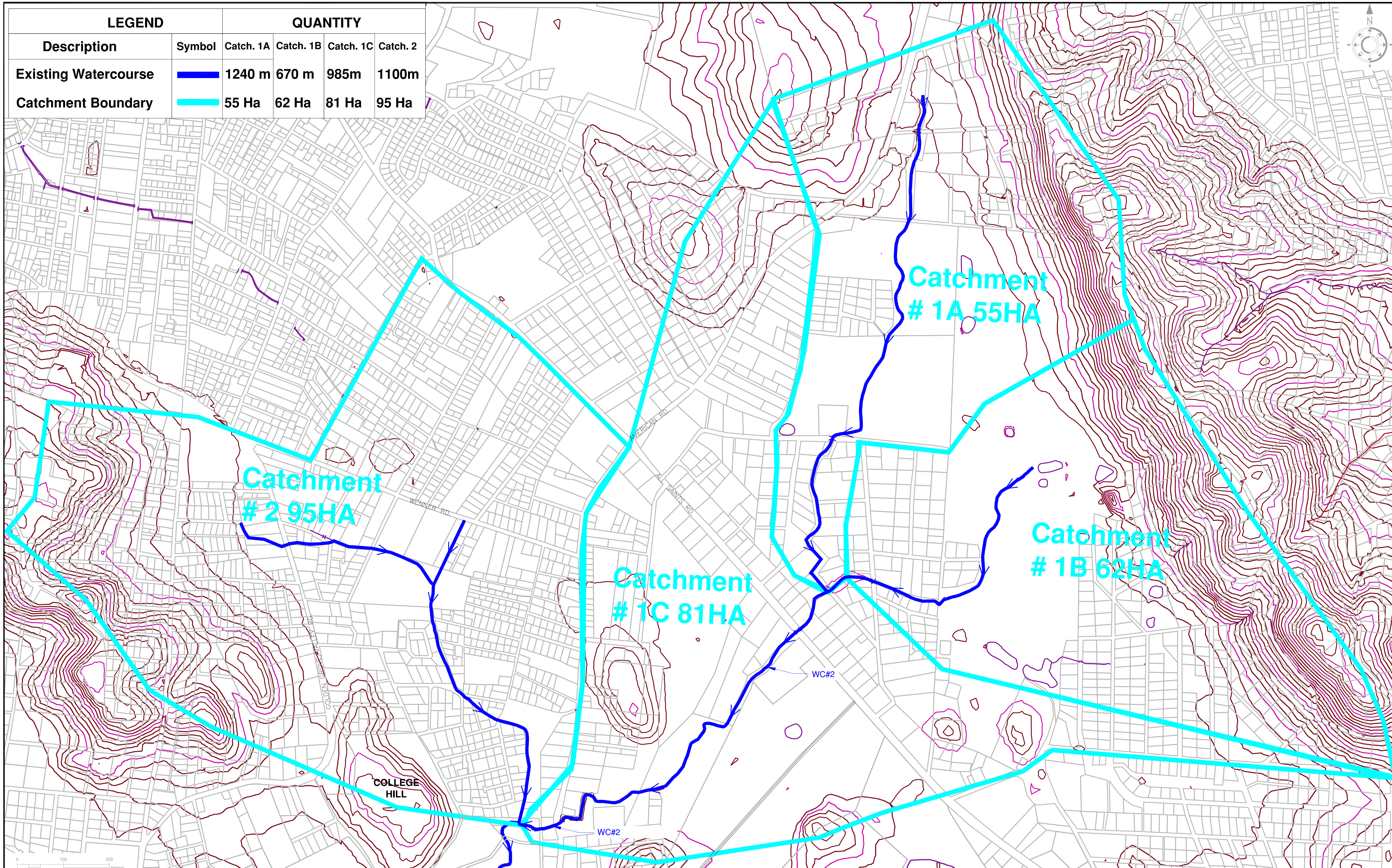
PHONE: 735-6662, 484-3913

DRAWING TITLE : COVER SHEET & LOCATION PLAN

JOB No. : 2016-014
DRG No.
SCALE : As Shown
DATE : 2016.05.018
DES.: K.D.
DRG.L.A.M.
SHEET No. 00

LEGEND		QUANTITY			
Description	Symbol	Catch. 1A	Catch. 1B	Catch. 1C	Catch. 2
Existing Watercourse	(dark blue line)	1240 m	670 m	985m	1100m
Catchment Boundary	(cyan line)	55 Ha	62 Ha	81 Ha	95 Ha



NOS.	DATE	REVISIONS

CLIENT : Organization of Eastern Caribbean States (OECS)

PROJECT : Technical Assistance for Flood Mitigation and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill).

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DRAWING TITLE :
CATCHMENT LAYOUT

JOB No. 2016-014
FILE No. RW-02
SCALE : N.T.S.
DATE : 2016.05.03
DES. : K.D
DRG. : S.P
REVS.: 00
SHEET No. 01

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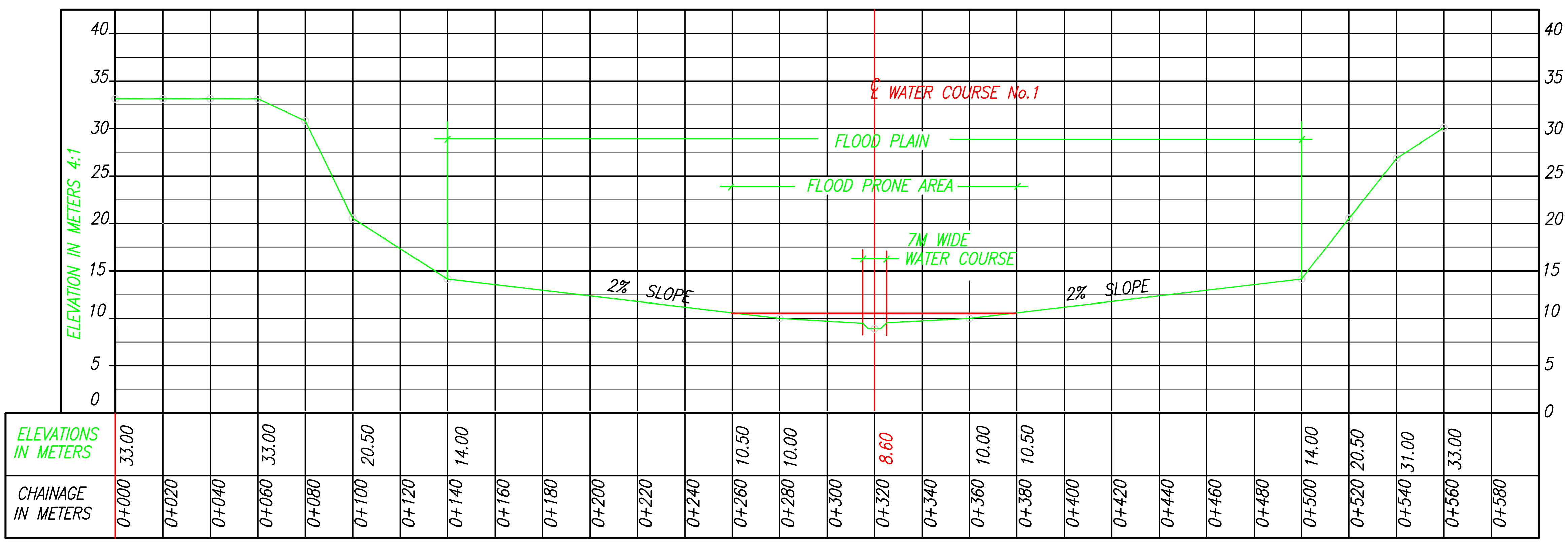

TYPICAL CROSS SECTION

SCALE HORIZ. : 1:1
VERTCAL : 4:1

KEY

EXISTING ELEVATION
50YRS R.I. FLOOD ELEVATION

NOS.	DATE	REVISIONS

CLIENT : Organization of Eastern Caribbean States (OECS)

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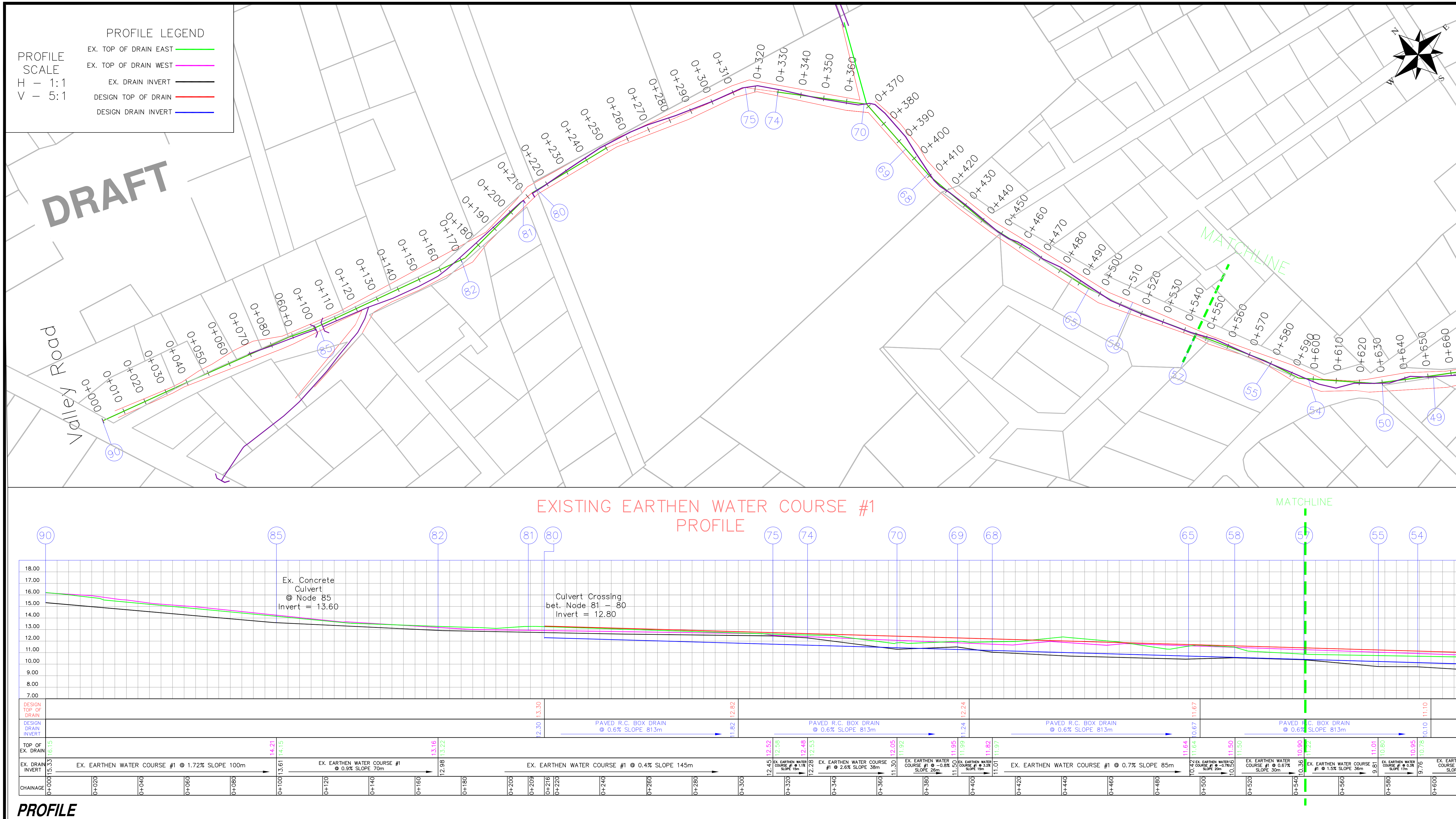
DRAWING TITLE : LAYOUT AND TYPICAL CROSS SECTION

JOB No. 2016-014
FILE No. EW-02
SCALE : N.T.S.
DATE : 2016.03.24
DES. : K.D
DRG. : N.W
REVS.: 00
SHEET No. 02



NOS.	DATE	BY	REVISIONS

CLIENT : ORGANIZATION OF EASTERN CARIBBEAN STATES

PROJECT : TECHNICAL ASSISTANCE FOR FLOOD MANAGEMENT AND SLOPE STABILIZATION INTERVENTIONS IN ANTIGUA AND BARBUDA (CASHEW HILL)

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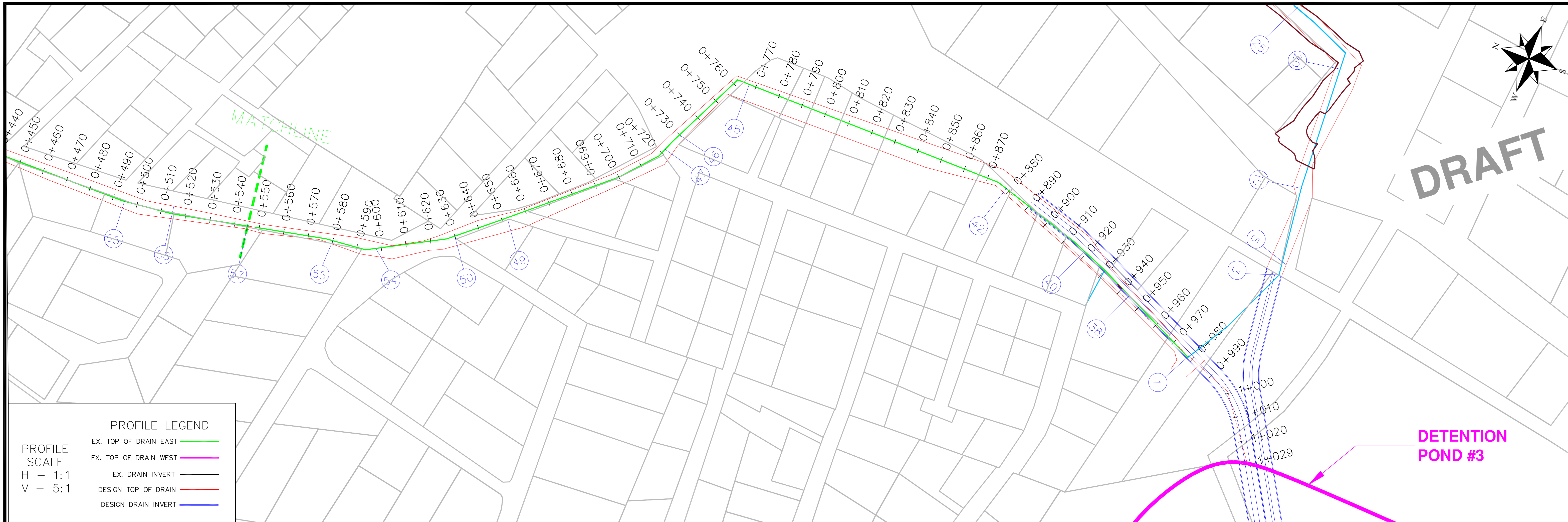
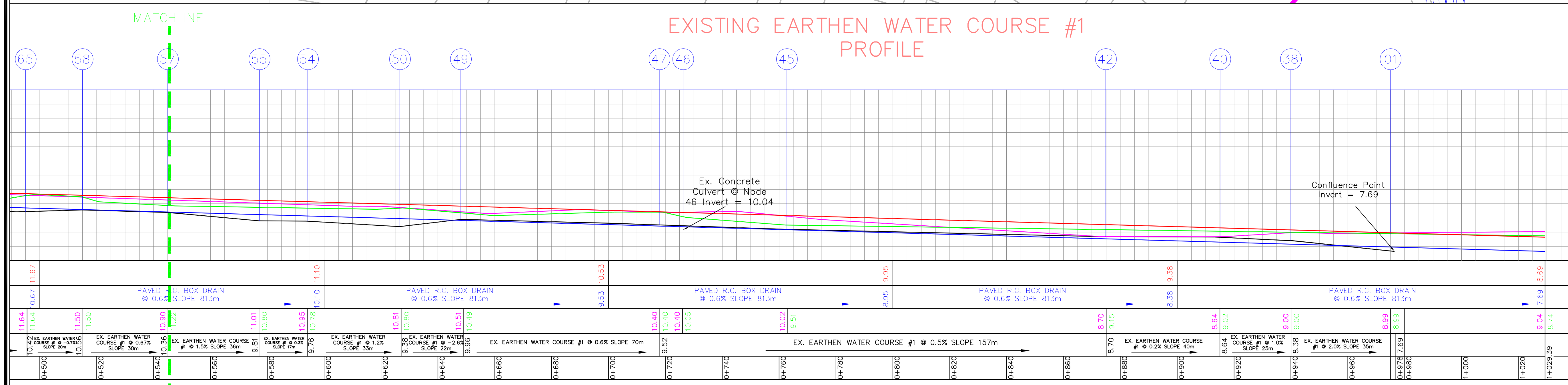
Tobago Office: Tobago, W.I. Tel/Fax: (868) 682-7005
Alpha Engineering & Design (2012) Ltd.
Email : alphaeng@tstt.net.tt

DRAWING TITLE : MAIN WATER COURSE #1 PLAN AND PROFILE OPTION #1 SHEET 1 OF 2

JOB No.	2016-014
FILE No.	
SCALE :	AS SHOWN
DATE :	17.05.2016
DES. K.D.	SHEET No. 03
DRG. F.M.	
REVS: 00	





PROFILE

NOS.	DATE	BY	REVISIONS

CLIENT : ORGANIZATION OF EASTERN CARIBBEAN STATES

PROJECT : TECHNICAL ASSISTANCE FOR FLOOD MANAGEMENT AND SLOPE STABILIZATION INTERVENTIONS IN ANTIGUA AND BARBUDA (CASHEW HILL)

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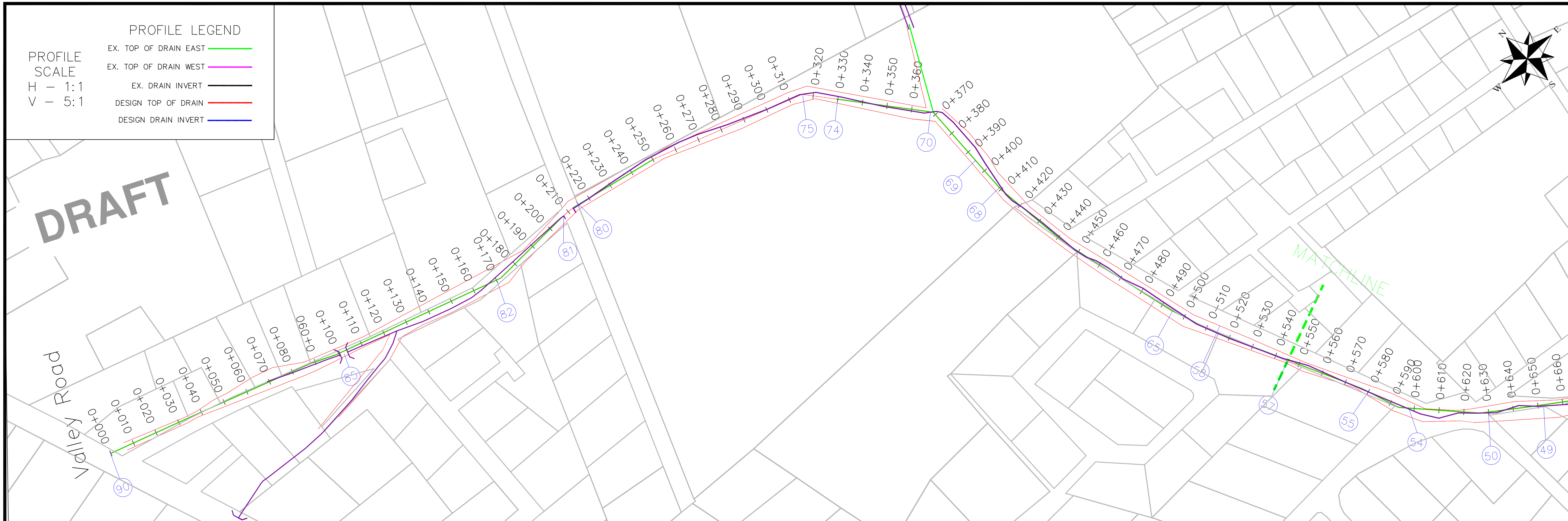
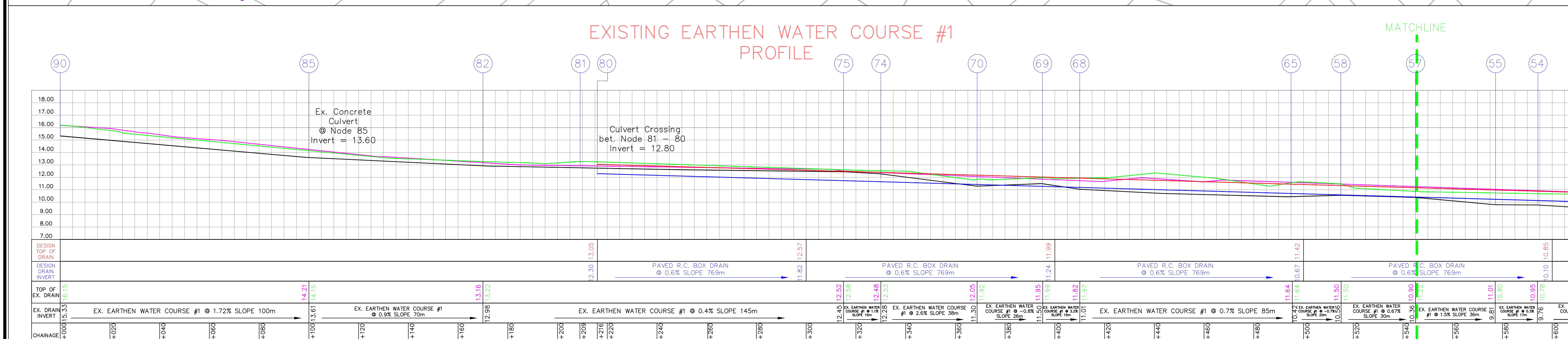
DRAWING TITLE : MAIN WATER COURSE #1 PLAN AND PROFILE OPTION #1 SHEET 2 OF 2

JOB No.	2016-014
FILE No.	
SCALE :	AS SHOWN
DATE :	17.05.2016
DES.	K.D.
DRG.	F.M.
REVS:	00
SHEET No.	04





PROFILE

NOS.	DATE	BY	R E V I S I O N S

CLIENT : ORGANIZATION OF EASTERN CARIBBEAN STATES

PROJECT : TECHNICAL ASSISTANCE FOR FLOOD MANAGEMENT AND SLOPE STABILIZATION INTERVENTIONS IN ANTIGUA AND BARBUDA (CASHEW HILL)

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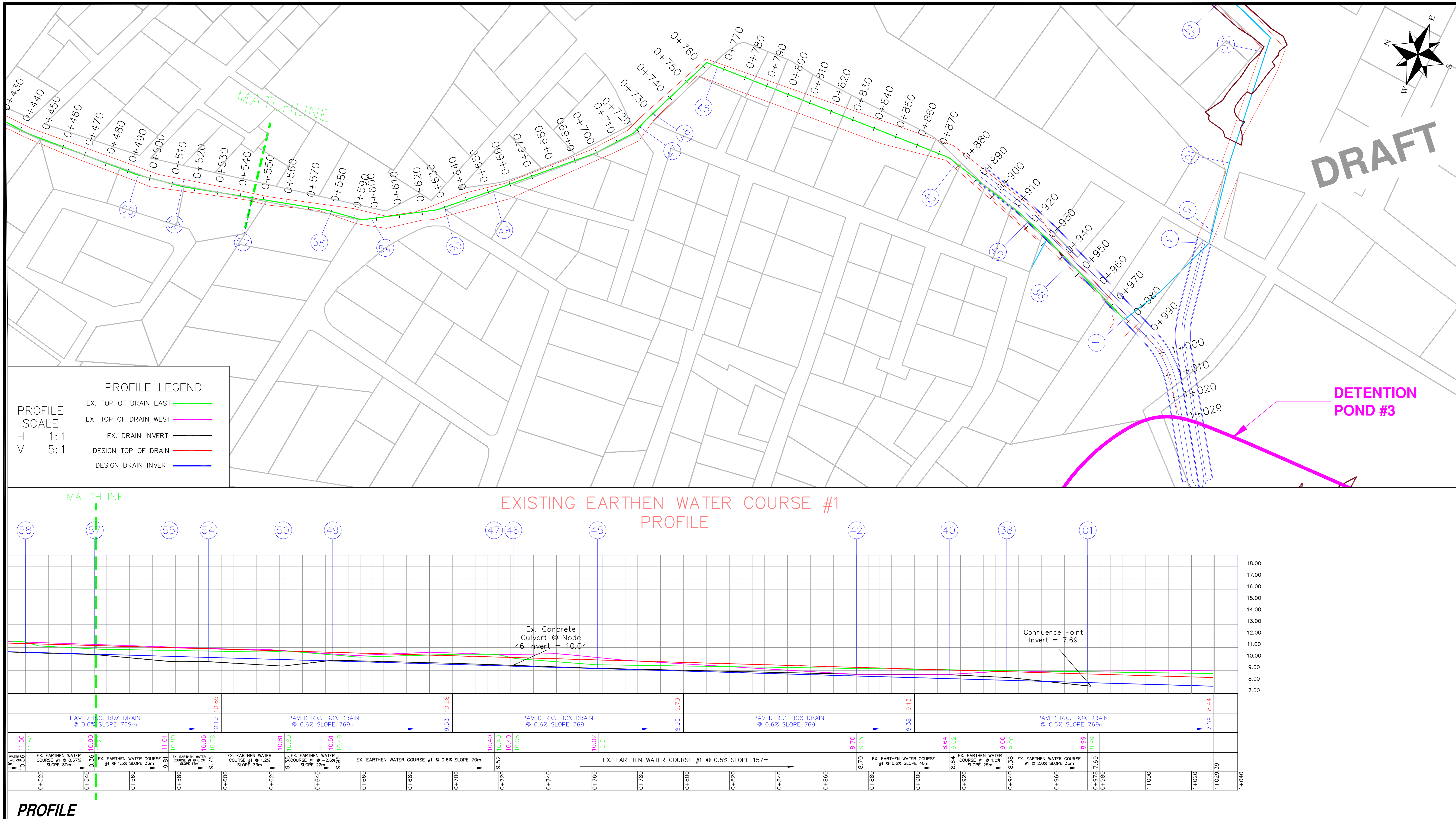
Email : alphaeng@tstt.net.tt

DRAWING TITLE : MAIN WATER COURSE #1 PLAN AND PROFILE OPTION #2 SHEET 1 OF 2

JOB No. 2016-014
FILE No.
SCALE : AS SHOWN
DATE : 17.05.2016
DES. K.D.
DRG. F.M.
REVS: 00
SHEET No. 05



NOS.	DATE	BY	REVISIONS

CLIENT : ORGANIZATION OF EASTERN CARIBBEAN STATES

PROJECT : TECHNICAL ASSISTANCE FOR FLOOD MANAGEMENT AND SLOPE STABILIZATION INTERVENTIONS IN ANTIGUA AND BARBUDA (CASHEW HILL)

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Tobago Office: Tobago, W.I. Tel/Fax: (868) 682-7005

DRAWING TITLE : MAIN WATER COURSE #1 PLAN AND PROFILE OPTION #2 SHEET 2 OF 2

JOB No.	2016-014
FILE No.	
SCALE :	AS SHOWN
DATE :	17.05.2016
DES. K.D.	SHEET No. 06
DRG. F.M.	
REVS: 00	

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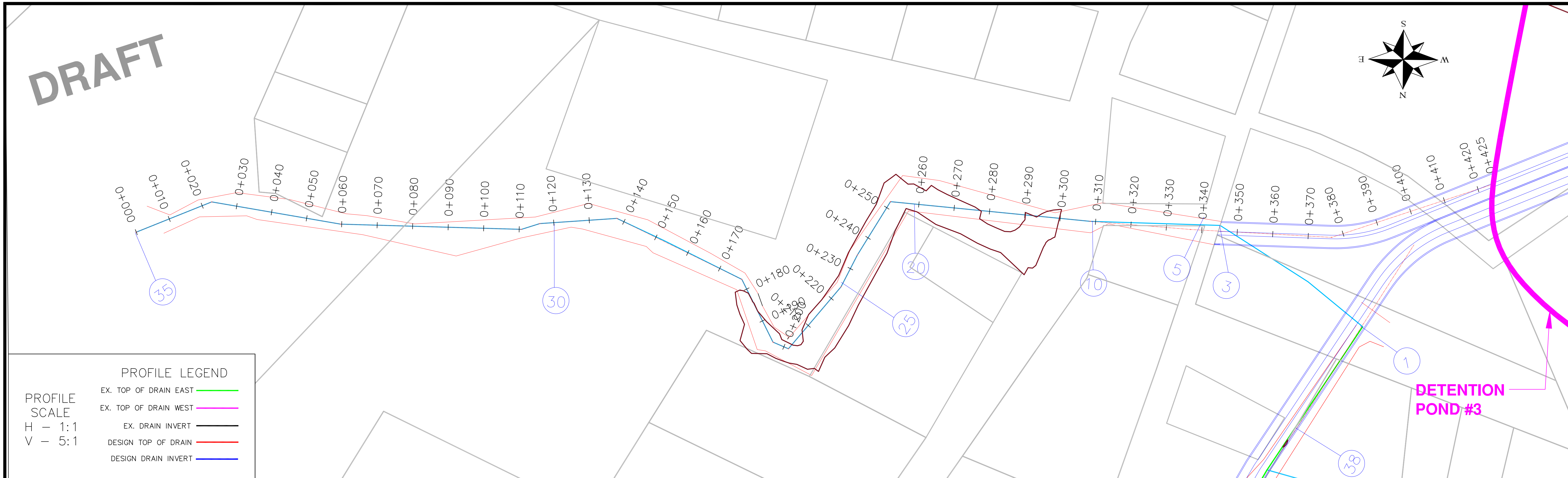
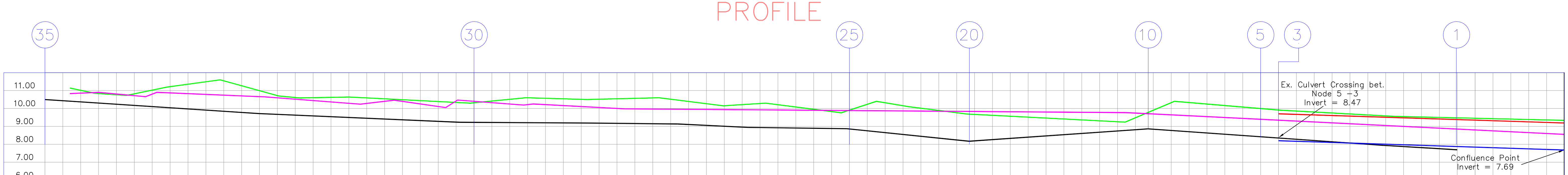


PROFILE

EXISTING EARTHEN WATER COURSE #2 PROFILE



CHAINAGE	DESIGN TOP OF DRAIN	DESIGN DRAIN INVERT	TOP OF BANK		DRAIN INVERT
0+000					10.48
0+020			10.73	10.71	
0+040			10.92	11.45	
0+060			10.65	11.00	
0+080			10.46	10.71	
0+100			10.40	10.47	
0+120			10.40	10.32	9.22
0+140			10.21	10.52	
0+160			10.01	10.61	
0+180			9.98	10.45	
0+200			9.96	10.29	
0+220			9.92	9.88	8.88
0+240			9.91	10.15	
0+260			10.90	9.75	8.11
0+280			9.87	9.47	
0+300			9.82	9.33	8.86
0+320			9.61	10.40	
0+340	9.70	8.20	10.48	10.00	
0+360			9.17	9.89	
0+380			9.00	9.62	7.69
0+400					
0+420					
0+425	9.19	7.69			

DRAIN INVERT: EX. EARTHEN WATER COURSE #2 @ 1.05% SLOPE 120m; EX. EARTHEN WATER COURSE #2 @ 0.32% SLOPE 105m; EX. EARTHEN WATER COURSE #2 @ 2.3% SLOPE 34m; EX. EARTHEN WATER COURSE #2 @ –1.5% SLOPE 50m; EX. EARTHEN WATER COURSE #2 @ 1.4% SLOPE 86m

DESIGN DRAIN INVERT: PAVED R.C. BOX DRAIN @ 0.6% SLOPE 80m

NOS.	DATE	BY	REVISIONS

CLIENT : ORGANIZATION OF EASTERN CARIBBEAN STATES

PROJECT : TECHNICAL ASSISTANCE FOR FLOOD MANAGEMENT AND SLOPE STABILIZATION INTERVENTIONS IN ANTIGUA AND BARBUDA (CASHEW HILL)

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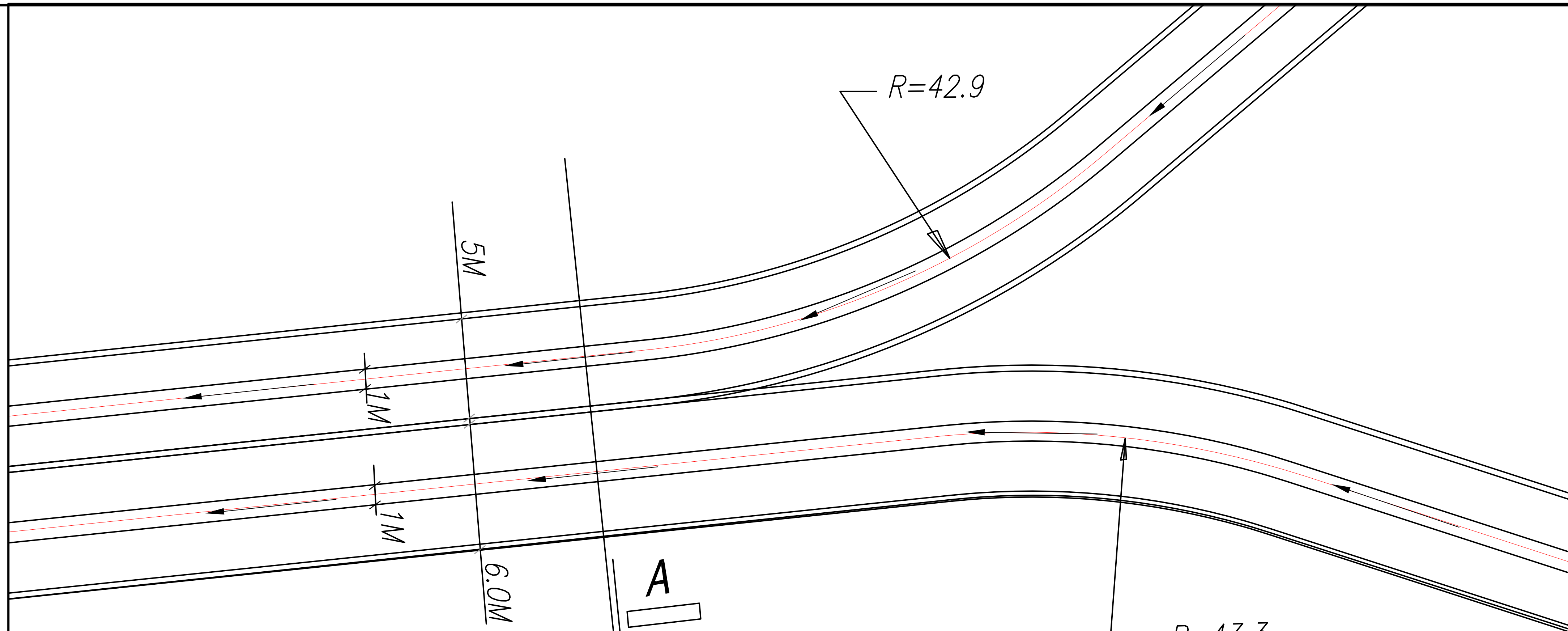
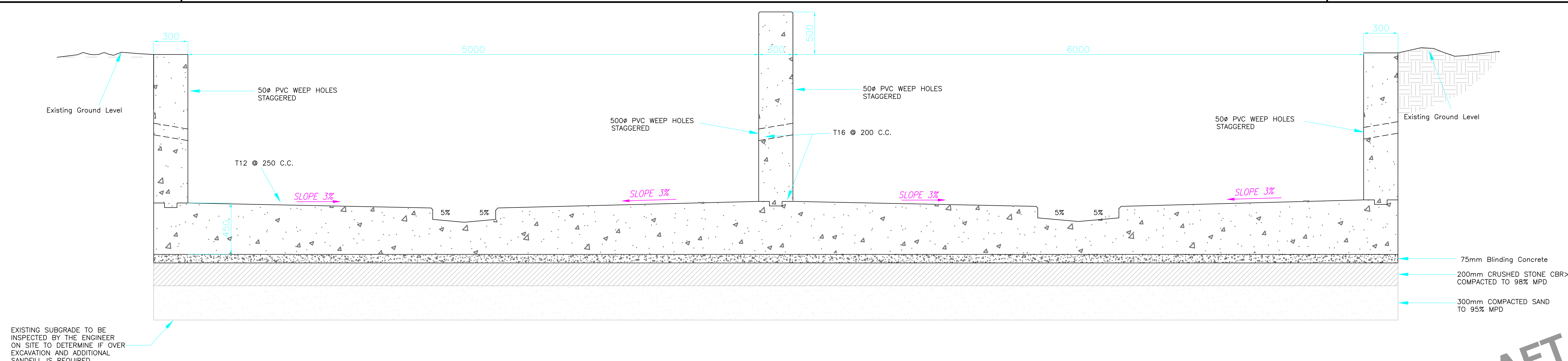
DRAWING TITLE : MAIN WATER COURSE #2 PLAN AND PROFILE

JOB No.	2016–014
FILE No.	
SCALE :	AS SHOWN
DATE :	17.05.2016
DES.	K.D.
DRG.	F.M.
REVS:	00
SHEET No.	07



DRAIN CONFLUENCE LAYOUT



DRAIN CONFLUENCE
SECTION A

NOS.	DATE	REVISIONS
01	06.06.2016	DETAILS REVISED

CLIENT : Organization of Eastern Caribbean States (OECS)

PROJECT : **Technical Assistance for Flood Mitigation and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill).**

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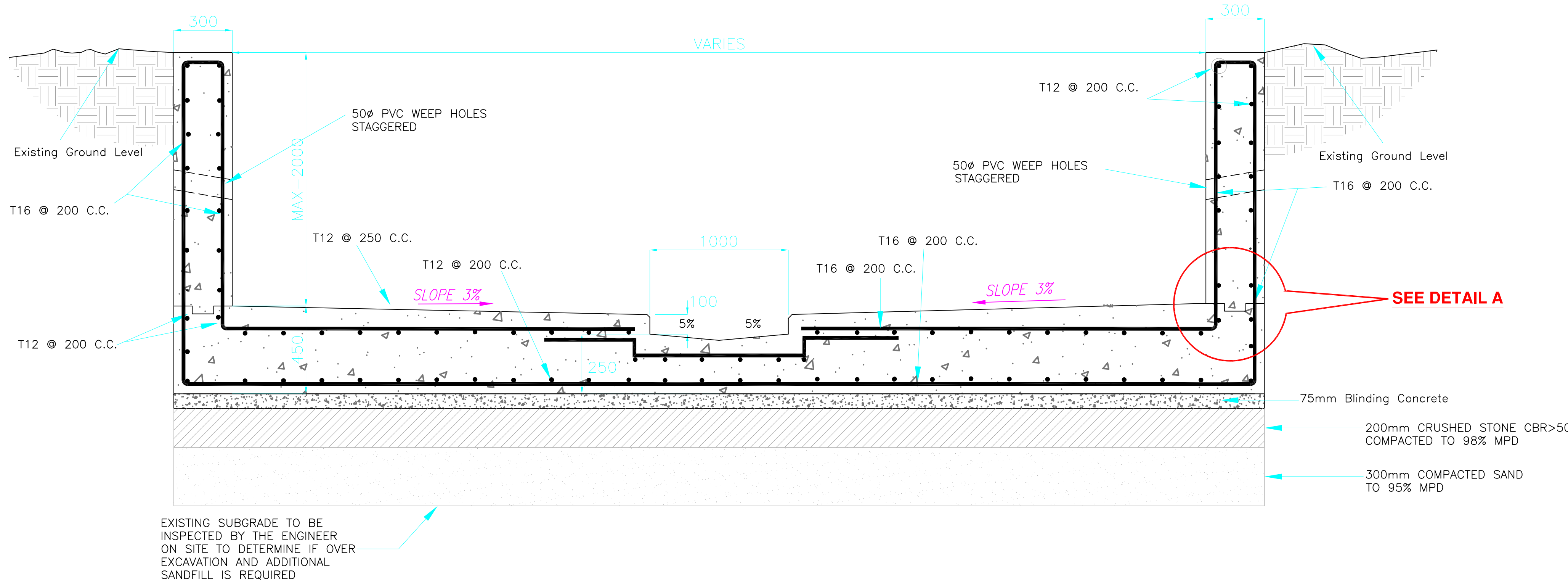
LOT 10D CHOOTOO RD, EL SOCORRO SOUTH.
PHONE: 735-6662, 484-3913

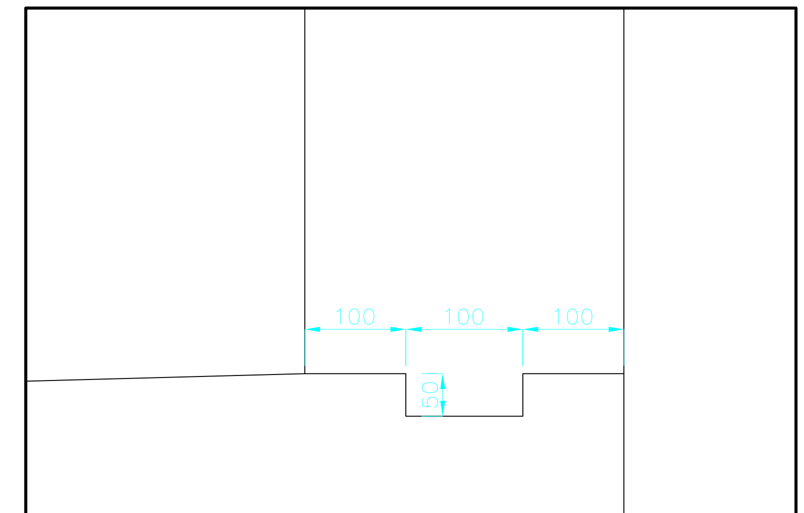
DRAWING TITLE :

CONFLUENCE DETAILS

JOB No.	2016-014
FILE No.	RW-02
SCALE	N.T.S.
DATE	2016.05.13
DES.	K.D
DRG.	LM
REVS.	01
SHEET No.	10



TYPICAL DRAIN SECTION



DETAIL A

DRAFT

NOS.	DATE	REVISIONS
01	06.06.2016	DETAILS REVISED

CLIENT : Organization of Eastern Caribbean States (OECS)

PROJECT : **Technical Assistance for Flood Mitigation and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill).**

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DRAWING TITLE : DRAINAGE DETAILS

JOB No. 2016-014
FILE No. RW-02
SCALE : N.T.S.
DATE : 2016.04.24
DES.: K.D
DRG.: N.W
REVS.: 01
SHEET No. 11

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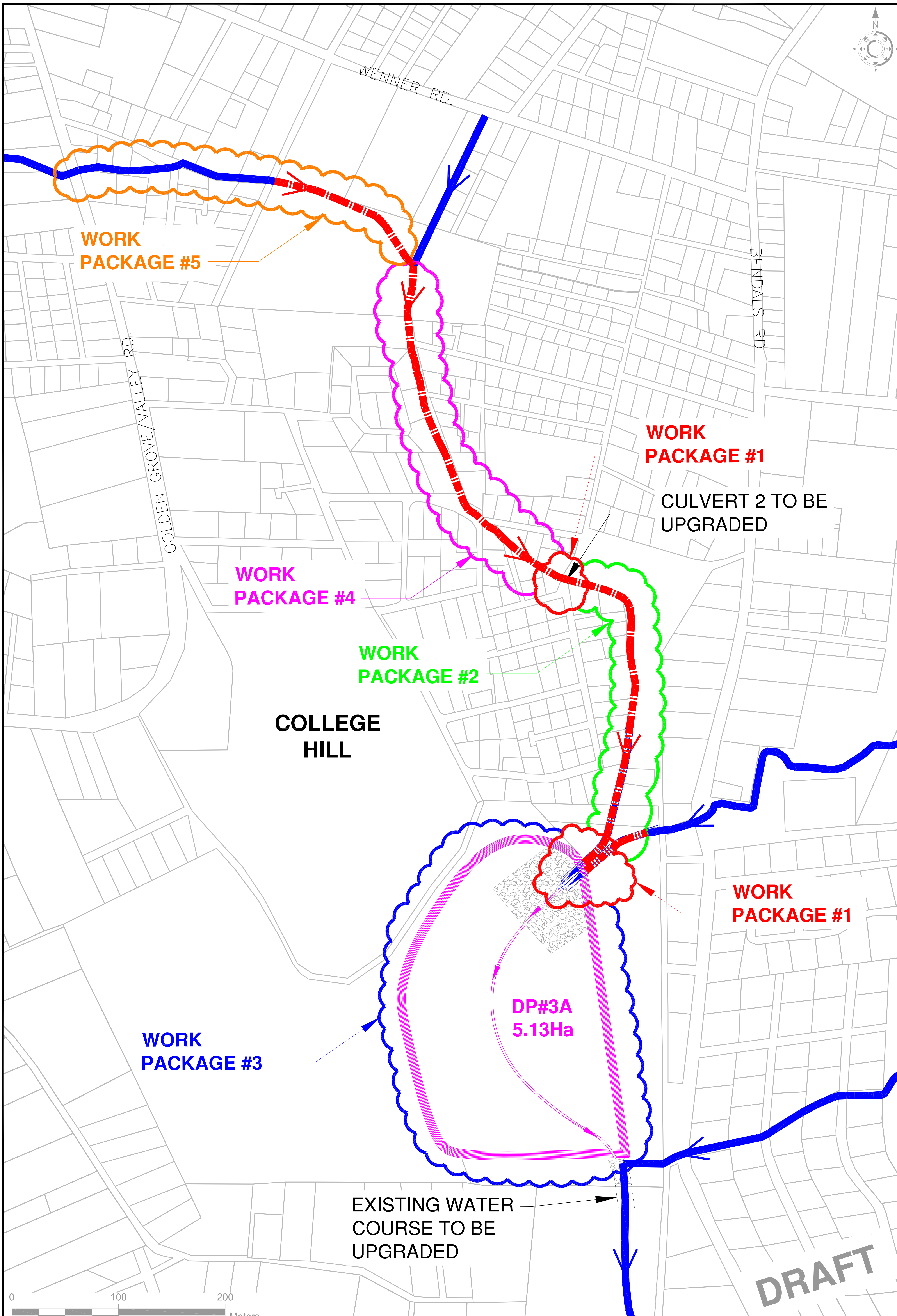


NOS.	DATE	REVISIONS
01	06.06.2016	WORK PACKAGES 1 & 2 REVISED

CLIENT : Organization of Eastern Caribbean States (OECS)

PROJECT : Technical Assistance for Flood Mitigation and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill).

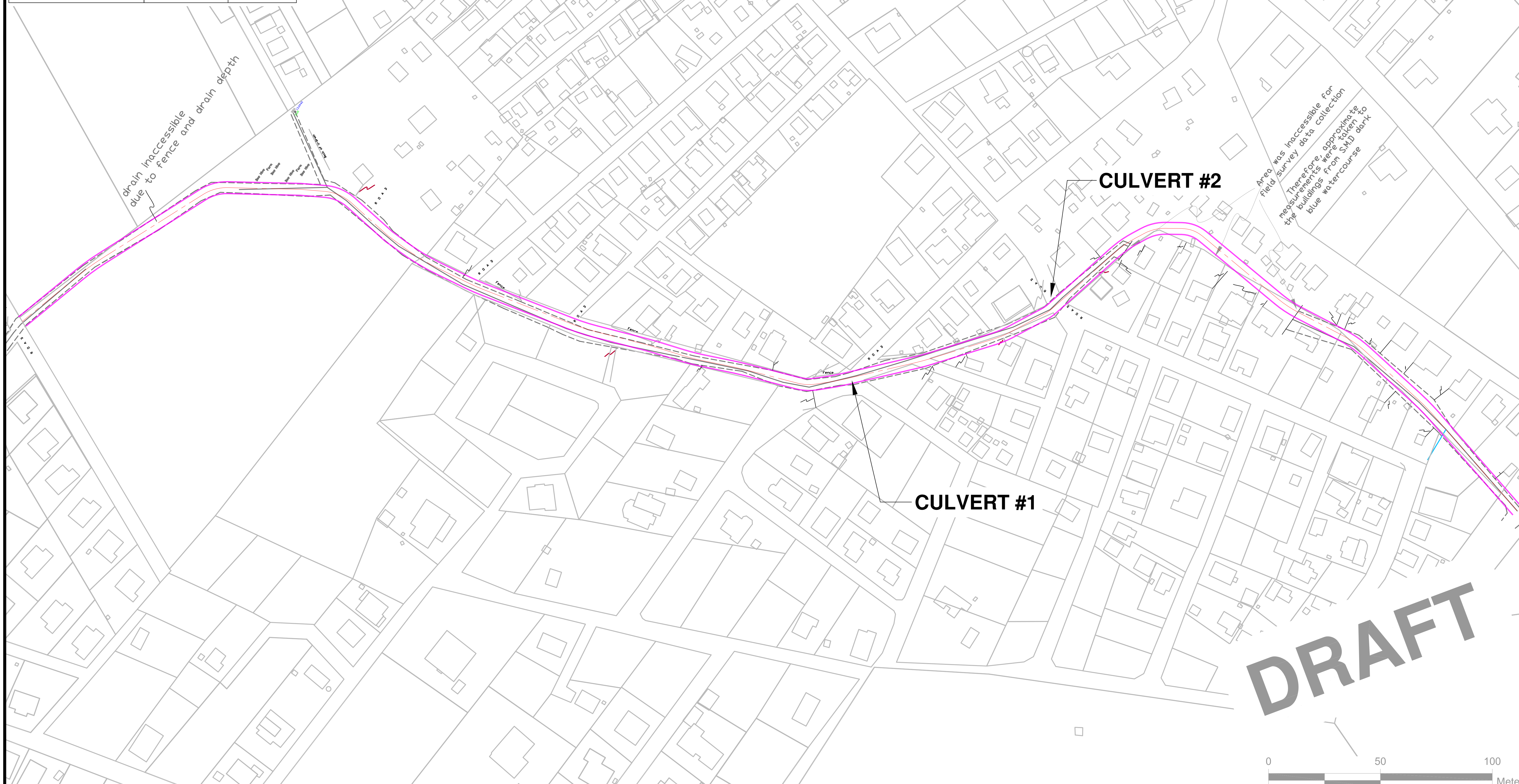
Alpha
Alpha Engineering & Design (2012) Ltd.
Website: www.aedl2012.com
LOT 10D CHOOTOO RD, EL SOCORRO SOUTH.
PHONE: 735-6662, 484-3913

DRAWING TITLE : WORK PACKAGE LAYOUT

JOB No. 2016-014
FILE No. RW-02
SCALE : N.T.S.
DATE . : 2016.04.24
DES. : K.D
DRG. : S.P
REVS.: 01
SHEET No. 12

Z:\CAD\S.Pryor\2016-014 Antigua\Latest Drawings 25th May 2015\Cashew Hill Catchmentrev5.dwg, 6/6/2016 4:26:45 PM, Adobe PDF

LEGEND		
Description	Symbol	Qty.
Proposed Drain 5m Width		
Existing Water Course #1		



NOS.	DATE	BY	REVISIONS
01	06.06.2016	S.P.	WATER COURSE SIZE CHANGED

CLIENT : ORGANIZATION OF EASTERN CARIBBEAN STATES

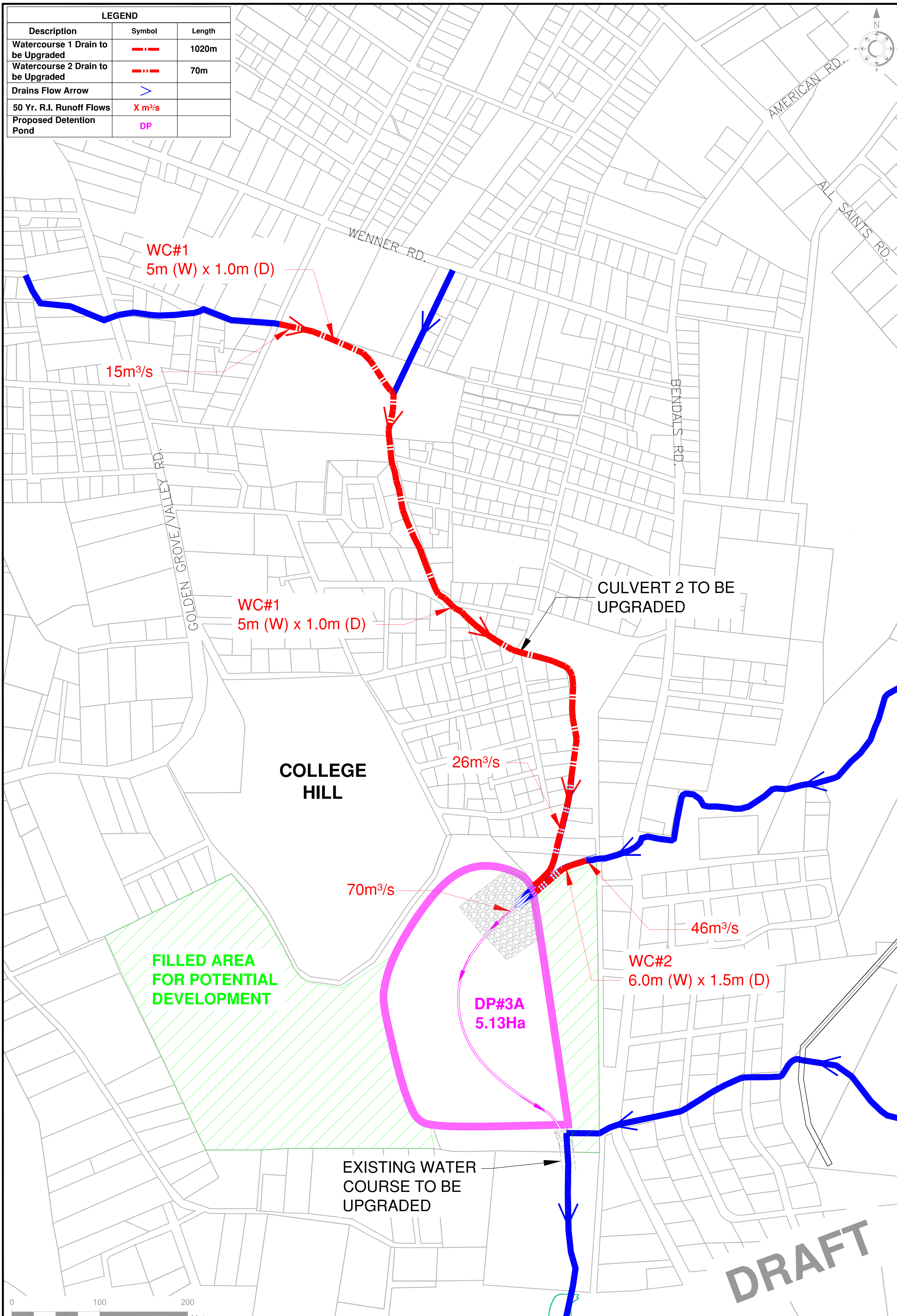
PROJECT : TECHINICAL ASSISTANCE FOR FLOOD MANAGEMENT AND SLOPE STABILIZATION INTERVENTIONS IN ANTIGUA AND BARBUDA (CASHEW HILL)

Alpha
Head Office: Building Unit 1, Lot 10D Chootoo Road, El Socorro, San Juan South Trinidad,W.I.
Tel: (868) 735-6662 ; (868) 365-7765
Tobago Office: Tobago, W.I. Tel/Fax: (868) 682-7005
Alpha Engineering & Design (2012) Ltd.
Email : alphaeng@tstt.net.tt

DRAWING TITLE : WATER COURSE #1 DRAIN & PROPERTY CONFLICT LAYOUT 5m WIDTH

JOB No.	2016-014
FILE No.	
SCALE :	AS SHOWN
DATE :	24.05.2016
DES.	K.D.
DRG.	S.P.
REVS:	01
SHEET No.	14

Z:\CAD\S.Pryor\2016-014 Antigua\Latest Drawings 25th May 2015\Water Course 1 Property Conflict Layout rev1.dwg, 6/6/2016 3:49:04 PM, Adobe PDF



NOS.	DATE	REVISIONS

CLIENT : Organization of Eastern Caribbean States (OECS)

PROJECT : Technical Assistance for Flood Mitigation and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill).

Alpha
Alpha Engineering & Design (2012) Ltd.
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LOT 10D CHOOTOO RD, EL SOCORRO SOUTH.
PHONE: 735-6662, 484-3913

DRAWING TITLE : PRELIMINARY WATERSHED PLAN OPTION 2

JOB No. 2016-014
FILE No. RW-02
SCALE : N.T.S.
DATE . : 31.05.2016
DES. : K.D
DRG. : S.P
REVS.: 00
SHEET No. 15

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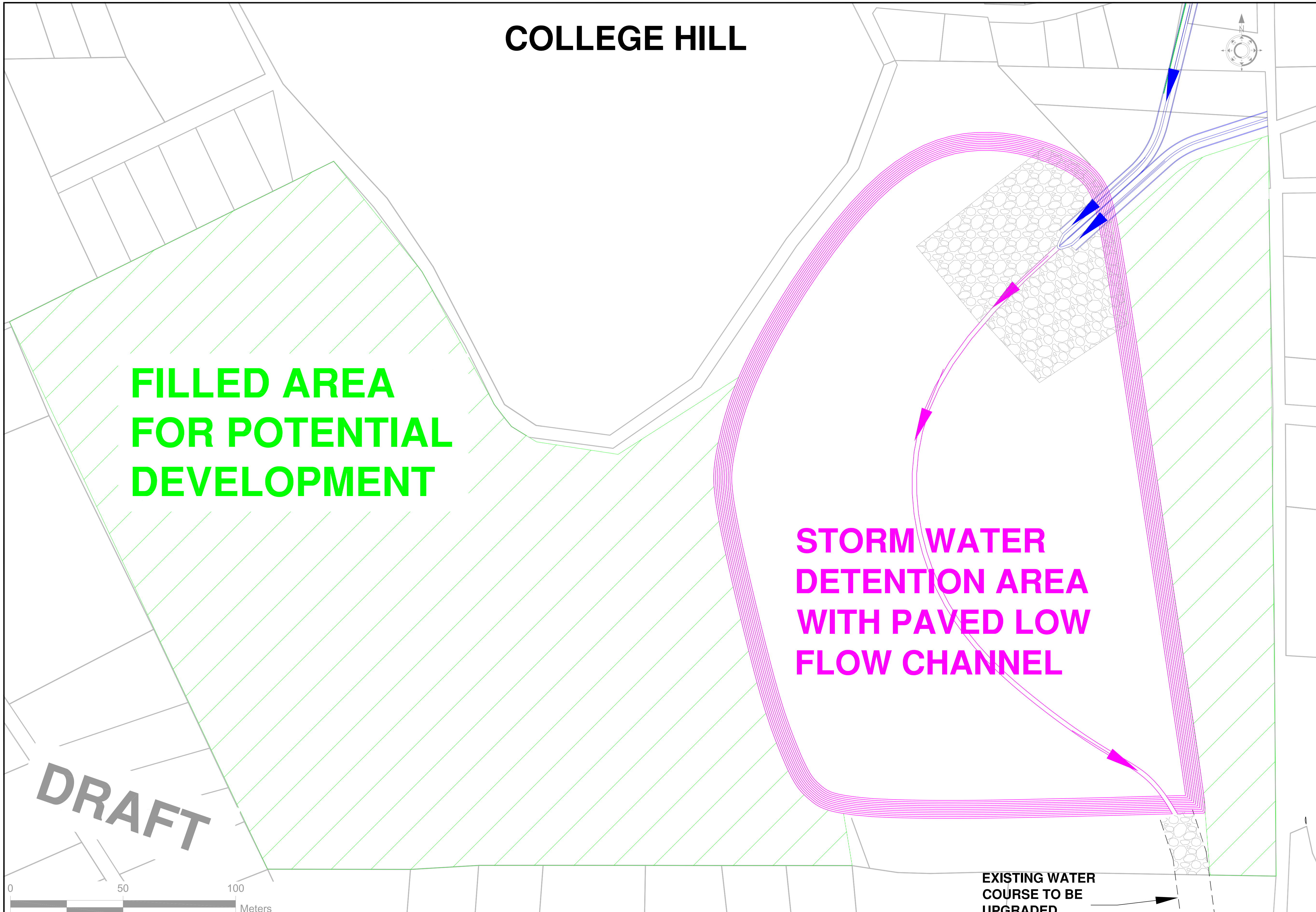

NOS.	DATE	REVISIONS
01	06.06.2016	CONFLUENCE DRAIN SIZE ADJUSTED

CLIENT : Organization of Eastern Caribbean States (OECS)

PROJECT : Technical Assistance for Flood Mitigation and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill).

Alpha
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PHONE: 735-6662, 484-3913

DRAWING TITLE : DETENTION POND #3 OPTION #2 LAYOUT

JOB No. 2016-014
FILE No. RW-02
SCALE : N.T.S.
DATE : 31.05.2016
DES. : K.D
DRG. : S.P
REVS.: 01
SHEET No. 16

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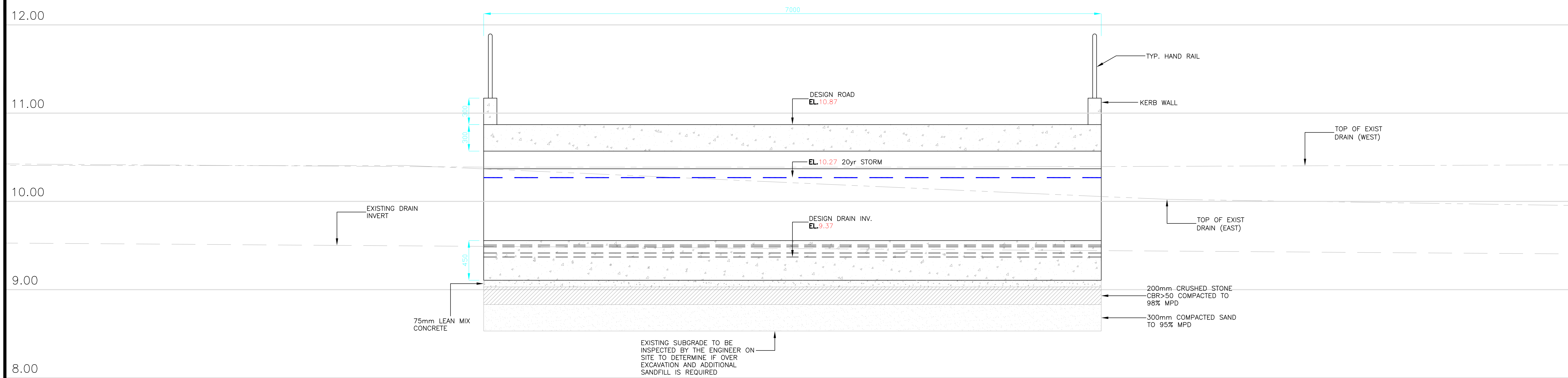
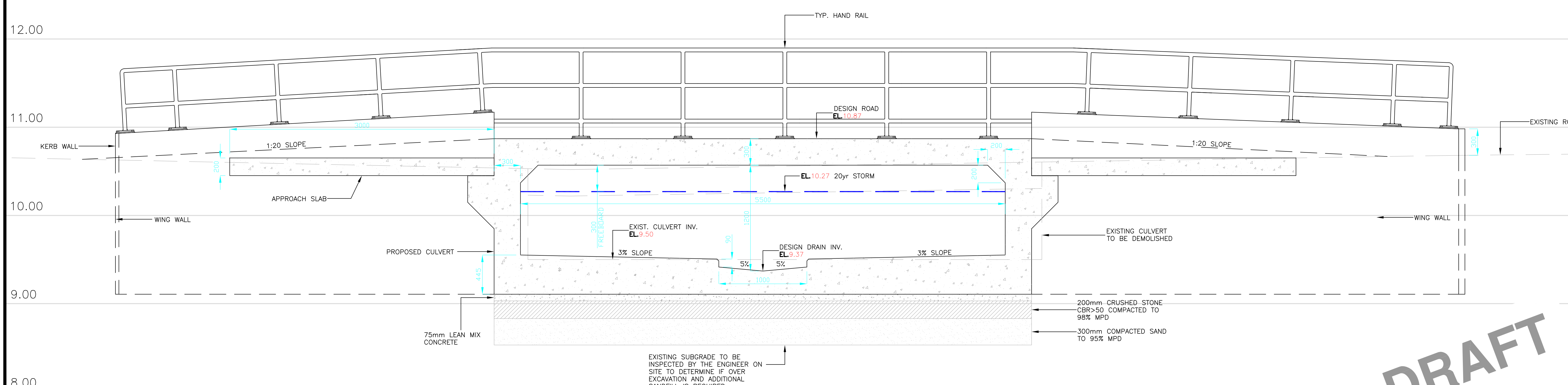


SECTION A-A



DRAFT

SECTION B-B

NOS.	DATE	BY	REVISIONS

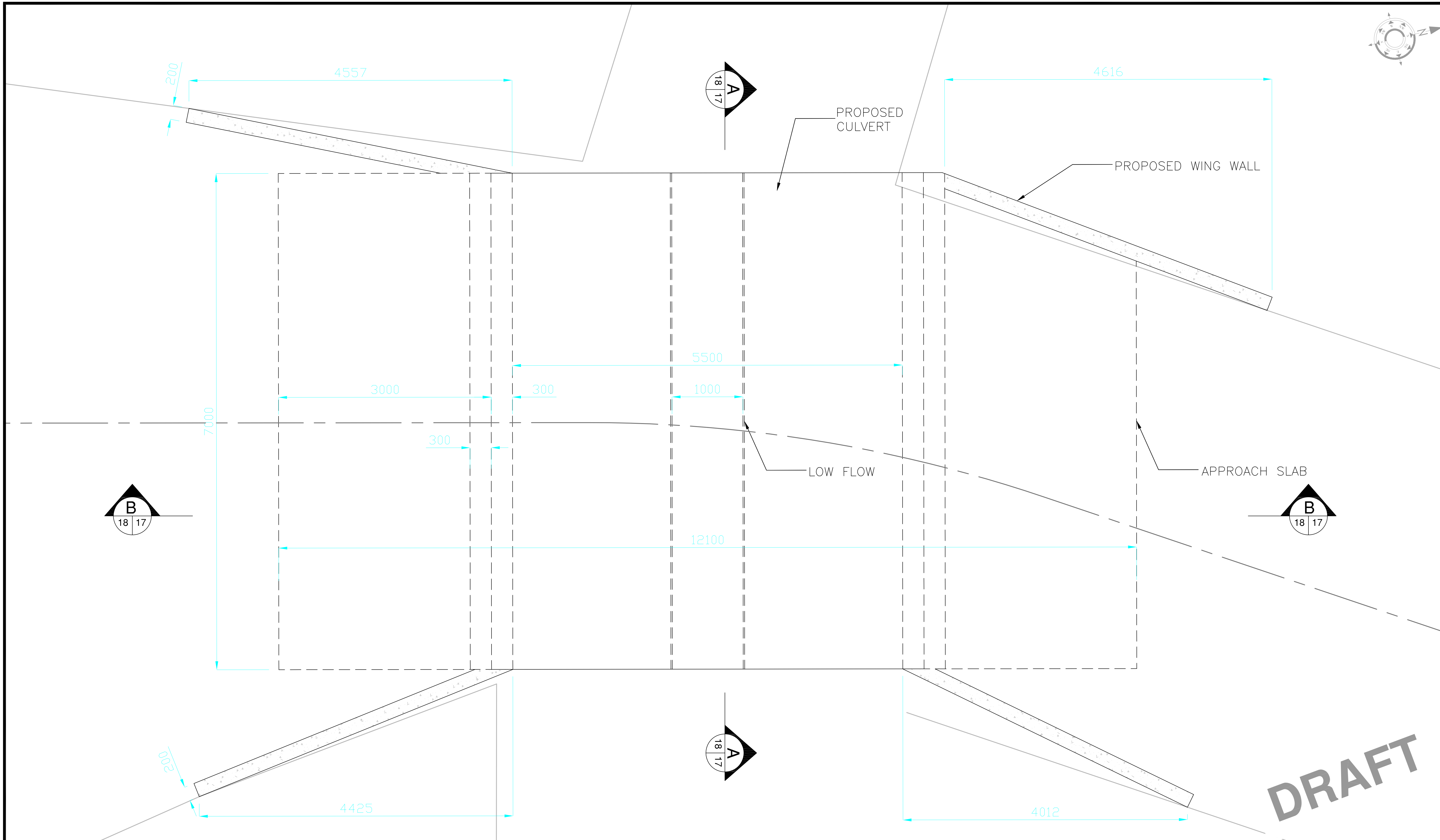
CLIENT : ORGANIZATION OF EASTERN CARIBBEAN STATES

PROJECT : TECHNICAL ASSISTANCE FOR FLOOD MANAGEMENT AND SLOPE STABILIZATION INTERVENTIONS IN ANTIGUA AND BARBUDA (CASHEW HILL)

Alpha
Alpha Engineering & Design (2012) Ltd.
Email : alphaeng@tstt.net.tt
Head Office:
Tobago Office:

DRAWING TITLE : CULVERT #2 SECTIONS A-A & B-B

JOB No.	2016-014
FILE No.	
SCALE :	AS SHOWN
DATE :	01.06.2016
DES. K.D.	SHEET No. 17
DRG. S.P.	
REVS: 00	



NOS.	DATE	BY	R E V I S I O N S

CLIENT : ORGANIZATION OF EASTERN CARIBBEAN STATES

PROJECT : TECHNICAL ASSISTANCE FOR FLOOD MANAGEMENT AND SLOPE STABILIZATION INTERVENTIONS IN ANTIGUA AND BARBUDA (CASHEW HILL)

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Tobago Office: Tobago, W.I. Tel/Fax: (868) 682-7005
Alpha Engineering & Design (2012) Ltd.
Email : alphaeng@tstt.net.tt

DRAWING TITLE :

CULVERT #2
PLAN (OPTION 2)

JOB No.	2016-014
FILE No.	
SCALE :	AS SHOWN
DATE :	01.06.2016
DES. K.D.	SHEET No. 18
DRG. S.P.	
REVS: 00	

APPENDIX 9

Preliminary Engineer's Cost Estimate

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

Preliminary Engineer's Estimate

SUMMARY

BILL NO.	DESCRIPTION		PRELIMINARY ENGINEER'S ESTIMATE $ECD		% of Total
100	PRELIMINARIES		$	1,054,000.00	12.4%
200	WATER COURSE #1		$	3,398,080.16	40.0%
300	WATER COURSE #2		$	825,442.11	9.7%
400	DETENTION POND		$	2,164,250.00	25.4%
500	CONFLUENCE		$	866,284.74	10.2%
600	CULVERT #2		$	195,907.59	2.3%
	SUB-TOTAL		**$**	**8,503,964.61**	100.0%
	Add Contingency	10.0%	$	850,396.46	
	TOTAL (Not Including VAT)		**$**	**9,354,361.07**	
	Add VAT	15.0%	$	1,403,154.16	
	GRAND TOTAL (EC DOLLARS)		**$**	**10,757,515.23**	

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

Preliminary Engineer's Estimate

BILL 100 - PRELIMINARIES

ITEM	DESCRIPTION	QTY	UNIT	RATE $ECD	AMOUNT $ECD
100	**PRELIMINARIES (assuming 6 months construction period)**				
101	Mobilization	1	LS	$ 125,000.00	$ 125,000.00
102	Supply and Maintain Temporary Facilities for Engineer	8	Mths	$ 28,000.00	$ 224,000.00
103	Road Maintenance and Traffic Control	8	Mths	$ 20,000.00	$ 160,000.00
104	General Testing in Accordance with Specifications for QA/QC	1	LS	$ 70,000.00	$ 70,000.00
105	Insurance Securities and Bonds	1	LS	$ 75,000.00	$ 75,000.00
106	Provision for Environmental Mitigation and compliance with CEC	8	Mths	$ 20,000.00	$ 160,000.00
107	Provision for Health, Safety compliance with OSHA	8	Mths	$ 20,000.00	$ 160,000.00
108	Provision for dewatering during drainage works for the duration of the Contract	1	LS	$ 80,000.00	$ 80,000.00
TOTAL BILL 100 TO SUMMARY					**$ 1,054,000.00**

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

Preliminary Engineer's Estimate

BILL 200 - WATER COURSE #1

ITEM	DESCRIPTION	QTY	UNIT	RATE $ECD		AMOUNT $ECD	
200	**WATER COURSE #1**						
201	Clearing and grubbing inclusive of carting away materials	0.3	Ha.	$	4,200.00	$	1,330.56
202	**Excavation inclusive of carting away materials to an approved dump site**						
202.1	Excavation for drains	1,901	cu.m	$	20.00	$	38,016.00
203	**Embankment**						
203.1	Supply and install compacted sand 300mm thk to underside of watercourse base	950	cu.m	$	90.00	$	85,500.00
203.2	Allow for base material with CBR>50	640	cu.m	$	170.00	$	108,800.00
203.3	Allow for over excavation and stabilization of soft areas with sandfill as specified by the Engineer	1	PS		75,000.00	$	75,000.00
204	**Concrete Works**						
	(inclusive of all labor, weepholes, chamfer strip, formwork, reinforcement)						
204.1	Main drain (6.5m wide x 1m deep)						
204.2	Cast-in-place concrete class 9 (cylinder strength) - Concrete blinding 75mm thick	266	cu.m	$	1,000.00	$	266,112.00
204.3	Cast-in-place concrete class 35 (cylinder strength) in drain base	1242	cu.m	$	1,600.00	$	1,986,969.60
204.4	Cast-in-place concrete class 35 (cylinder strength) in drain walls	380	cu.m	$	2,200.00	$	836,352.00
	TOTAL BILL 200 TO SUMMARY					**$**	**3,398,080.16**

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

Preliminary Engineer's Estimate

BILL 300 - WATER COURSE #2

ITEM	DESCRIPTION	QTY	UNIT	RATE $ECD	AMOUNT $ECD
300	**WATER COURSE #2**				
301	Clearing and grubbing inclusive of carting away materials	0.063	Ha.	$ 4,200.00	$ 266.11
302	**Excavation inclusive of carting away materials to an approved dump site**				
302.1	Excavation for drains	760	M^3	$ 20.00	$ 15,206.40
303	**Embankment**				
303.1	Supply and install compacted sand 300mm thk to underside of watercourse base	190	cu.m	$ 90.00	$ 17,100.00
303.2	Allow for base material with CBR>50	130	cu.m	$ 170.00	$ 22,100.00
303.3	Allow for over excavation and stabilization of soft areas with sandfill as specified by the Engineer	1	PS	40,000.00	$ 40,000.00
304	**Concrete Works**				
	(inclusive of all labor, weepholes, chamfer strip, formwork, reinforcement)				
304.1	Main drain (6m wide x 1.5m deep)				
304.2	Cast-in-place concrete class 9 (cylinder strength) - Concrete blinding 75mm thick	52	cu.m	$ 1,000.00	$ 52,272.00
304.3	Cast-in-place concrete class 35 (cylinder strength) in drain base	244	cu.m	$ 1,600.00	$ 390,297.60
304.3	Cast-in-place concrete class 35 (cylinder strength) in drain walls	131	cu.m	$ 2,200.00	$ 288,200.00
	TOTAL BILL 300 TO SUMMARY				**$ 825,442.11**

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

Preliminary Engineer's Estimate

BILL 400 - DETENTION POND

ITEM	DESCRIPTION	QTY	UNIT	RATE $ECD	AMOUNT $ECD
400	**DETENTION POND**				
401	Clearing and grubbing inclusive of carting away materials	5.7	Ha.	$ 3,750.00	$ 21,450.00
402	**Excavation inclusive of carting away materials to an approved dump site**				
402.1	Excavation for detention pond	57,200	M^3	$ 20.00	$ 1,144,000.00
402.2	Shaping and grading of detention pond	57,200	M^2	$ 7.00	$ 400,400.00
403	**Concrete Works**				
	(inclusive of all labor, weepholes, chamfer strip, formwork, reinforcement)				
403.1	Confluence inlet	1	LS	$ 45,000.00	$ 45,000.00
403.2	Outlet structures	1	LS	$ 65,000.00	$ 65,000.00
403.3	Low flow channel (2000mm wide x 200mm thick)	222	cu.m	$ 2,200.00	$ 488,400.00
	TOTAL BILL 400 TO SUMMARY				**$ 2,164,250.00**

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

Preliminary Engineer's Estimate

BILL 500 - CONFLUENCE

ITEM	DESCRIPTION	QTY	UNIT	RATE $ECD	AMOUNT $ECD
500	**CONFLUENCE**				
501	Clearing and grubbing inclusive of carting away materials	0.1	Ha.	$ 4,200.00	$ 355.74
502	**Excavation inclusive of carting away materials to an approved dump site**				
502.1	Excavation for drains	462	cu.m	$ 20.00	$ 9,240.00
503	**Embankment**				
503.1	Supply and install compacted sand 300mm thk to underside of watercourse base	260	cu.m	$ 90.00	$ 23,400.00
503.2	Allow for base material with CBR>50	170	cu.m	$ 170.00	$ 28,900.00
503.3	Allow for over excavation and stabilization of soft areas with sandfill as specified by the Engineer	1	PS	30,000.00	$ 30,000.00
504	**Concrete Works**				
	(inclusive of all labor, weepholes, chamfer strip, formwork, reinforcement)				
504.1	Main drain (6.5m wide x 1m deep)				
504.2	Cast-in-place concrete class 9 (cylinder strength) - Concrete blinding 75mm thick	70	cu.m	$ 1,000.00	$ 70,455.00
504.3	Cast-in-place concrete class 35 (cylinder strength) in drain base	329	cu.m	$ 1,600.00	$ 526,064.00
504.4	Cast-in-place concrete class 35 (cylinder strength) in drain walls	81	cu.m	$ 2,200.00	$ 177,870.00
	TOTAL BILL 500 TO SUMMARY				**$ 866,284.74**

Technical Assistance for Flood Management and Slope Stabilization Interventions in Antigua and Barbuda (Cashew Hill)

Preliminary Engineer's Estimate

BILL 600 - CULVERT #2

ITEM	DESCRIPTION	QTY	UNIT	RATE $ECD		AMOUNT $ECD	
600	**CULVERT #2**						
602	**Excavation inclusive of carting away materials to an approved dump site**						
602.1	Excavation for culvert	61	M^3	$	20.00	$	1,220.00
603	**Embankment**						
603.1	Supply and install compacted sand 300mm thk to underside of culvert base	15	cu.m	$	90.00	$	1,350.00
603.2	Allow for base material with CBR>50	10	cu.m	$	170.00	$	1,700.00
603.3	Allow for over excavation and stabilization of soft areas with sandfill as specified by the Engineer	1	PS		25,000.00	$	25,000.00
604	**Concrete Works**						
	(inclusive of all labor, weepholes, chamfer strip, formwork, reinforcement)						
604.1	Main drain (6m wide x 1.5m deep)						
604.2	Cast-in-place concrete class 9 (cylinder strength) - Concrete blinding 75mm thick	4	cu.m	$	1,500.00	$	5,717.25
604.3	Cast-in-place concrete class 35 (cylinder strength) in culvert inclusive of run-on slab and wingwalls	61	cu.m	$	2,200.00	$	133,422.34
605	**Road Works**						
605.1	Subbase - 450mm thk.	24	cu.m	$	110.00	$	2,640.00
605.2	Granular Base Course - 250mm thk.	13	cu.m	$	150.00	$	1,950.00
605.3	Surface Course - 75mm	8	cu.m	$	1,250.00	$	10,000.00
605.4	Saw cutting existing asphalt 50mm deep	48	lm	$	21.00	$	1,008.00
606	**Ancillary Works**						
606.1	Supply, fabricate, install and paint handrail as per drawing inclusive all materials, labor and equipment	14	lm		850.00	$	11,900.00
	TOTAL BILL 600 TO SUMMARY					**$**	**195,907.59**

APPENDIX 10

Construction Budget Allocation

Gmail **Kieran de Freitas <alphaeng.kierandefreitas@gmail.com>**

Concept Note for Alpha Engineering Ser-18 Lot 2

Vergille T Xavier-Antoine <vtxantoine@oecs.org> Wed, Mar 9, 2016 at 4:00 PM
To: Fazir Khan <alphaeng.fazirkhan@gmail.com>, Janna Turpin <alphaeng.jannaturpin@gmail.com>, Kieran de Freitas <alphaeng.kierandefreitas@gmail.com>, ruleta comacho <sirmmab@gmail.com>, "Cc: rcamacho@environmentdivision.info" <rcamacho@environmentdivision.info>, Diann Black-Layne <dcblack11@gmail.com>, gccaproject <gccaproject@oecs.org>, Gerad Payne <gpayne2007@gmail.com>, Delamine Andrew <delamine_andrew@yahoo.com>

Good Day

Please find the attached on the above captioned.

Grateful if you would acknowledge receipt.

Beneficiary MS	Design-Supervision Tender Reference	PAP Project Name/Scope	Implementation Budget (EUR)
Antigua and Barbuda	OECS/GCCA/2015/SER-18(2)	(PAP_8.1) Restoration of waterways and drainage infrastructure and remediation of water-related health issues in Cashew Hill community.	501,869

Vergille Tadia XAVIER-ANTOINE (Mrs)
Surmhfw#Dvvlvwdqw#¡# Joredo#Fdp dwh#Fkdqjh#Doodqfh#+JFFD,#Surmhfw#
RHFV#Frp p lvvlrq
G luhfw=# (758) 455 6363#¡#Hp dlo=vtxantoine@oecs.org#2#gccaproject@oecs.org

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Concept Note for Alpha Engineering Ser-18 Lot 2.docx
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