Hydrological Study & Flood Protection Report
Electrical Express Train-Blue Line
Sector 'C' Part (2)
From St. (431+800) to St. (480+280)

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Abbreviations

Sector 'C' Part (2)	The Sector of Electrical Express Train from Station 431+800 to station 480+280

1 Introduction

A successful development in the transportation sector in Egypt is noticed in the recent years. In this context, a new huge national project "Electrical Express Train" is started with an estimated design speed of about 250 km/h for the train, that means that the distance from 6th of October City, Luxor, Aswan and Abu Simbel near the Sudan border can be traveled in about 5.5-hrs. The project aims to construct a new train with new luxury touristic stations with total length 2000km.

The network of The Electrical Express Train is planned to connect Upper Egypt with lower Egypt. Also, the project will participate in the development of Upper Egypt.

The National Authority for Tunnels and the General Authority for Embankments and Bridges have commissioned the floods protection consultant to perform the hydrologic study for the (EET) route. In accordance with this, this report presents the results of the conducted study, specifically for Part (2) of Sector 'C' that extends from station (431+800) to the station (480+280) (Manflout - Gerga).

1.1 Report Structure

The document is divided into six chapters as follows:

Chapter One: Introduction

This section will briefly describe the project location. In addition, the scope of study within the project will be presented, the international standards & codes applied and utilized in the hydrologic study of the project area.

Chapter Two: Meteorological Analysis

This section will briefly describe the outcomes of the frequency analysis carried out for the collected rainfall data and the IDF curves developed for these data.

Chapter Three: Morphological Analysis

This part will present the delineation of the external watersheds affecting the embankment in addition, estimation of the Morphological parameters for these watersheds, which are presented in some important characteristics such as area, length, and average slope.

Chapter Four: Hydrological Analysis

This part shows the study of hydrological parameters and theories which have been used in the calculations for this study and how to apply it according to the inputs and the type of the studied place. The outcome of this study is to determine the peak design flows from each watershed and its corresponding runoff hydrograph.

Chapter Five: Hydraulic Design Criteria

This part shows the Hydraulic Basis which will be taken into consideration while designing the proposed structures, Also the Specifications & Details of the proposed structures.

Chapter Six: Protection Works and Recommendations

This chapter illustrates the adopted design standards, the proposed flood protection systems, and recommendations from the flood consultative that must be followed to ensure the efficiency of the proposed protection works.

1.2 Study Area

The EET path (Sector 'C') extends from Manflout northward to Gerga southward, Scope of this report is Part (2) of the Sector 'C' which extends from station 431+800 to station 480+280 with an approximate length of 49 km, the Sector 'C' area is located between Latitude 26°00', 27°30' and Longitude 30°50', 31°55' as shown in figure 1.

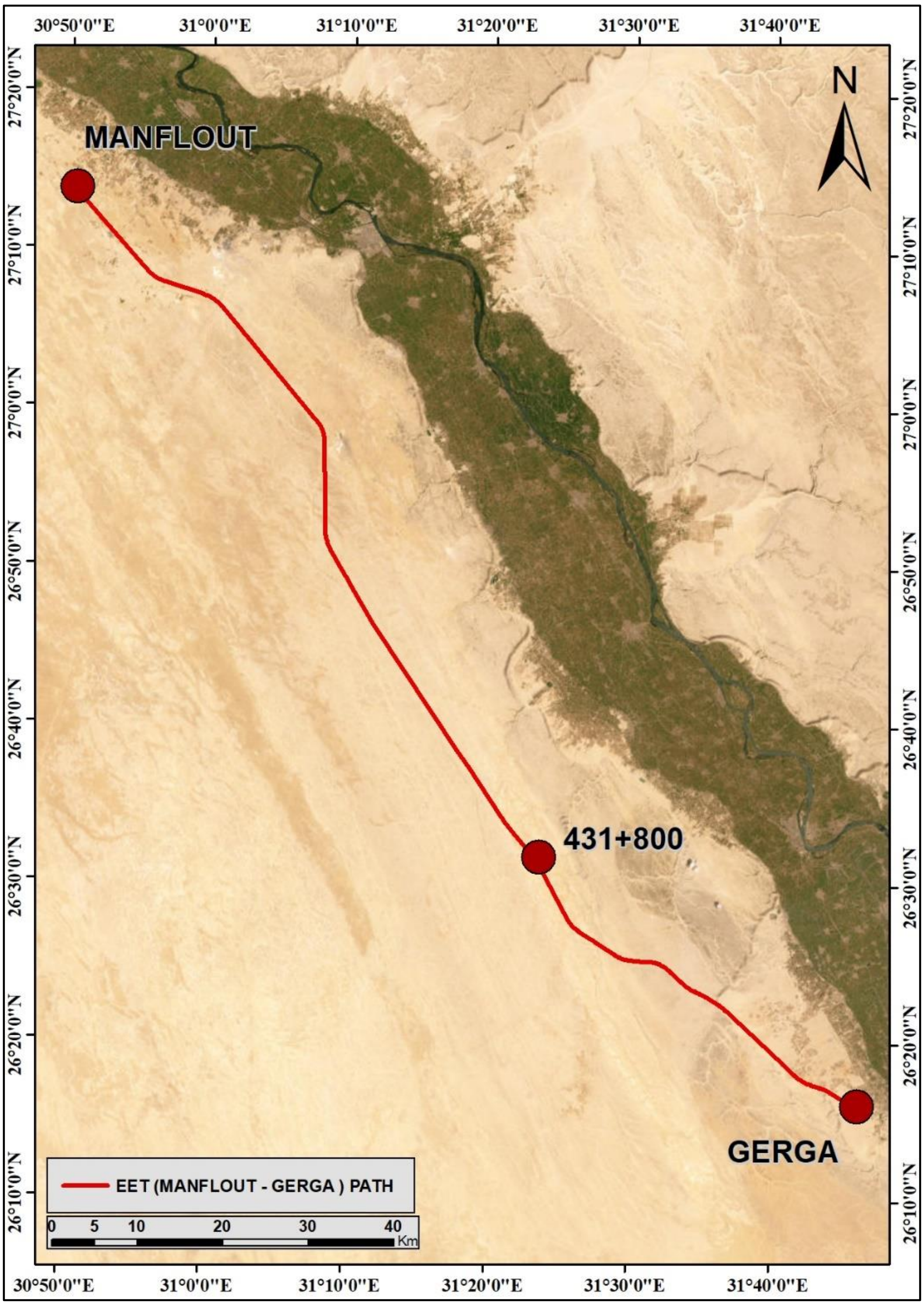


Figure 1 General Location of the Study Area

1.3 Study Objectives & Scope of Work

The hydrological Study aims to define the hydrological conditions in the study area, thereafter, comes setting design strategies and different solutions then choosing the most adequate, and finally reach the optimal proposed design and carry out detailed design for its elements:

The study will be carried out through the following tasks:

- Collecting Data.
- Design Criteria and Standards.
- Designed Return Period.
- Rainfall Analysis.
- Calculate Peak design flows and estimate flood hydrographs.
- Providing solutions and recommendations.
- Detailed Design of Flood protection works.

1.4 Standard Codes & Software Packages

The hydrological studies and hydraulic design/analysis in this study follows:

- `Chapter 7 (Protection of Embankment from Rainfall, Floods and Quicksand). (2008). In HBRC, The Egyptian Code for Urban Embankment Works. HBRC.
- Subramanya, K. (2015). FLOW IN OPEN CHANNELS (Fourth ed.). McGraw Hill Education (India) Private Limited

Also, the following Programs and software packages are used in the design and analysis of the study:

- AutoCAD Civil 3D
- ArcGIS + Arc Hydro tools
- HEC-HMS
- Global Mapper
- SAS Planet
- HYFRAN+
- Bentley FlowMaster
- Bentley CulvertMaster

2 Meteorological Analysis

2.1 General

The statistical analysis of rainfall data is one of the most important analytical studies to be carried out in any flood protection and storm drainage project, where rainfall is the main element causing the flow in streams , and this is why this study was given maximum priority from the compilation of data, study and detailed analysis, conducting a series of statistical tests on them using the best means to deduce the design storms, and developing the IDF curves, for which design flows will be calculated., Figure 2 shows the distribution of avg. annual daily rainfall depth in Egypt from 1990 to 2020, Also shows that the avg. annual rainfall depths varies from 0 to 68.64 mm at the most regions.

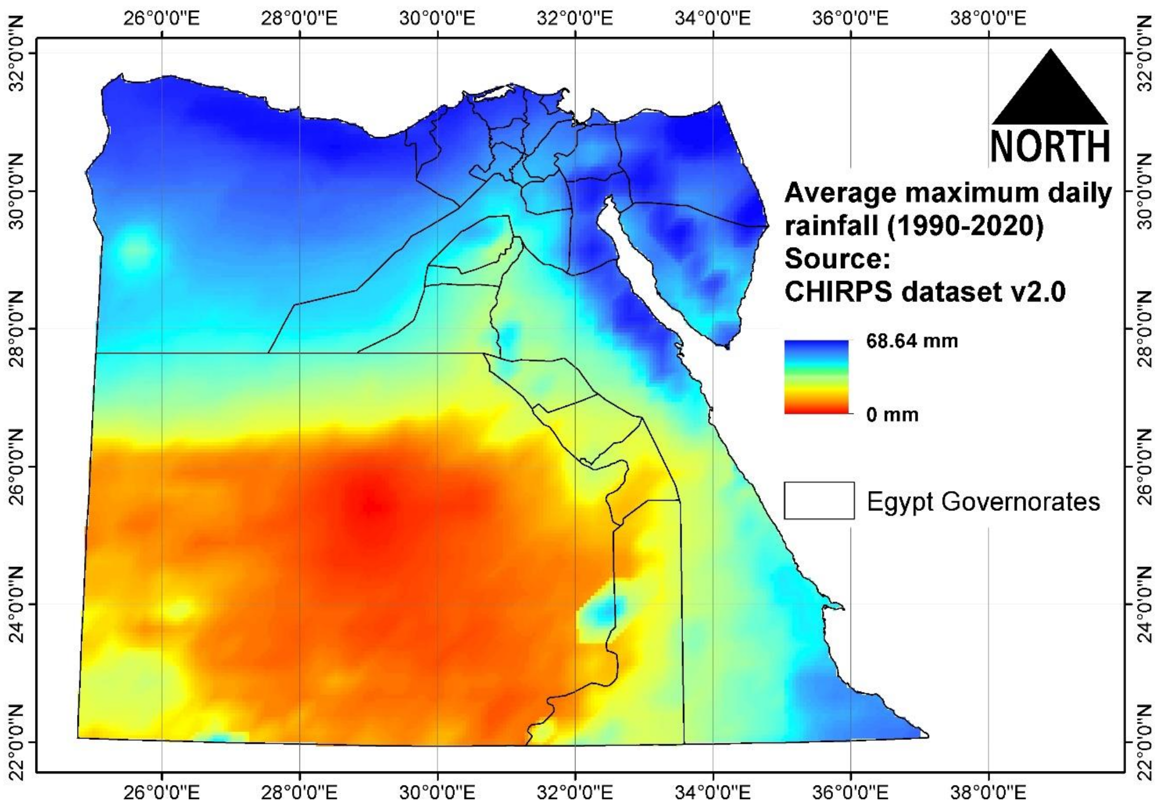


Figure 2 Distribution of Avg. Maximum Daily Rainfall Depth in Egypt (1990 – 2020)

2.2 Rainfall Data Collection

Figure 3 shows the location of Assiut Airport Rainfall Station, which is spatially near to the project location. Thus, its data have been collected in order to perform the meteorological and hydrological study.

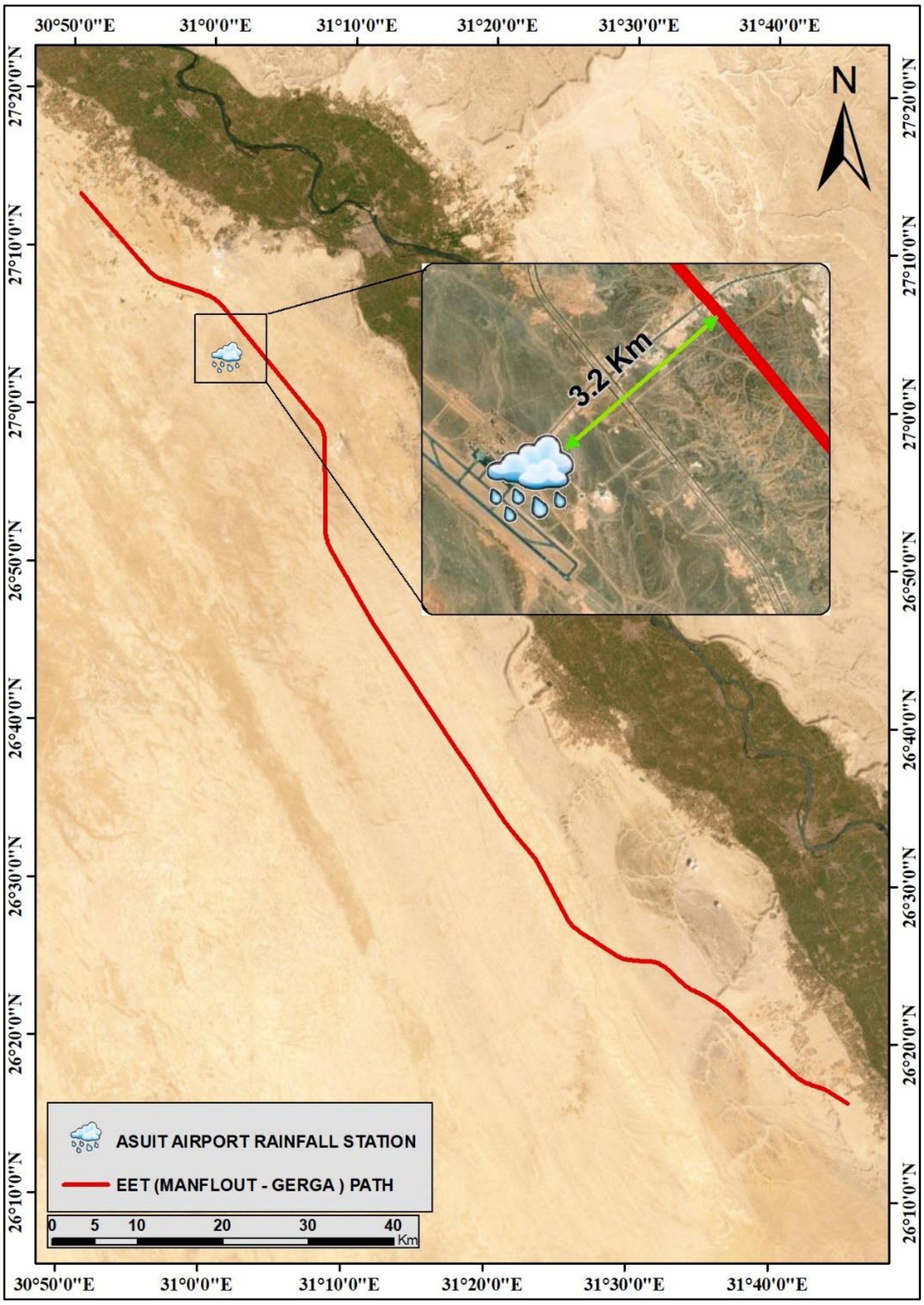


Figure 3 Location of Assiut Airport Rainfall Station relative to the project location

Max Daily Rainfall Depths were collected for Assiut Airport Rainfall Station from 1961 to 2018, the max daily rainfall depth is **24** mm in 1994, Figure 4 shows the max daily rainfall depths records for Assiut Airport Rainfall Station from 1961 to 2018.

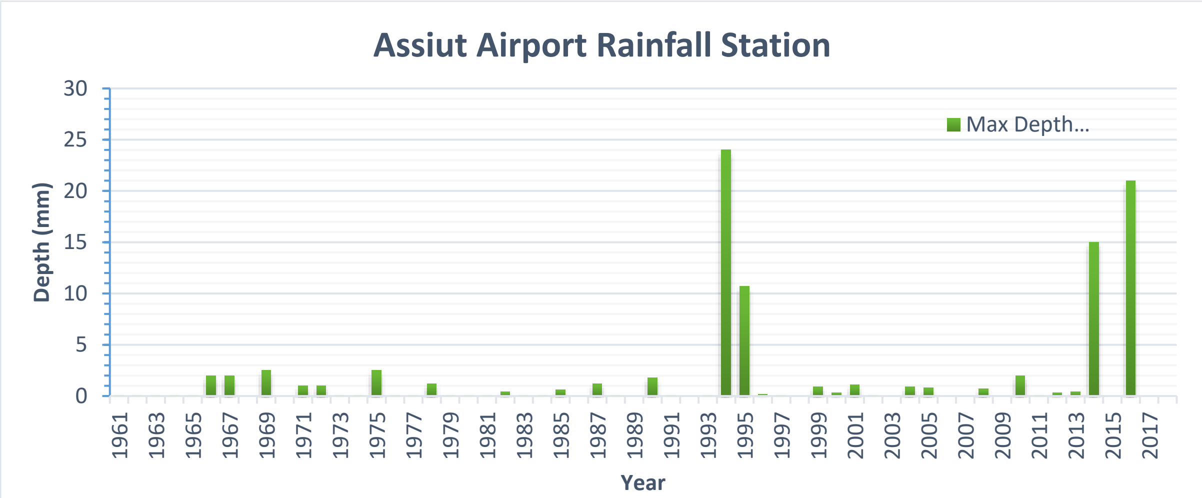


Figure 4 Max Daily Rainfall Depth for Assiut Airport Rainfall Station from (1976-2020)

2.3 Statistical Analysis for Assiut Airport Rainfall Station Data

Statistical analysis of rainfall data was carried out in several ways using HYFRAN+ program and it was found that (Weibull) was the best distribution that matches the statistical characteristics of Assiut Airport Rainfall Station data, then deduce the maximum daily rain depth of the return period 2, 5, 10, 25, 50 and 100 years as there as there are no rainfall data for short duration periods less than daily period.

Table 1 shows Max Daily Rainfall Depth for Assiut Airport Rainfall Station for Different Returned Periods.

Table 1 Max Daily Rainfall Depth for Assiut Airport Rainfall Station for Different Returned Periods.

Name	Distribution	P 100y (mm)	P 50y (mm)	P 25y (mm)	P 10y (mm)	P 5y (mm)
Assiut Airport Rainfall Station	Weibull	36.14	27.59	19.95	11.51	6.36

Note: A storm with a depth of **60 mm** has been recorded and reported by the National Water Resources Center (NWRC) at Assiut airport rainfall station. Hence, this value cannot be ignored and will be used a rainfall depth equal to **60 mm** (maximum 24 hrs. rainfall depth) has been used as a design value for the protection works.

For obtaining the intensity-duration-frequency (IDF) curves, the results of previous statistical analysis and Bell Ratios (as shown below) have been used, Figure 5 shows the developed IDF curve for Assiut Airport Rainfall Station for the different returned periods.

$$\text{Bell's Ratio} = (0.54 * D^{0.25}) - 0.5$$

D = Duration of rainfall (min)

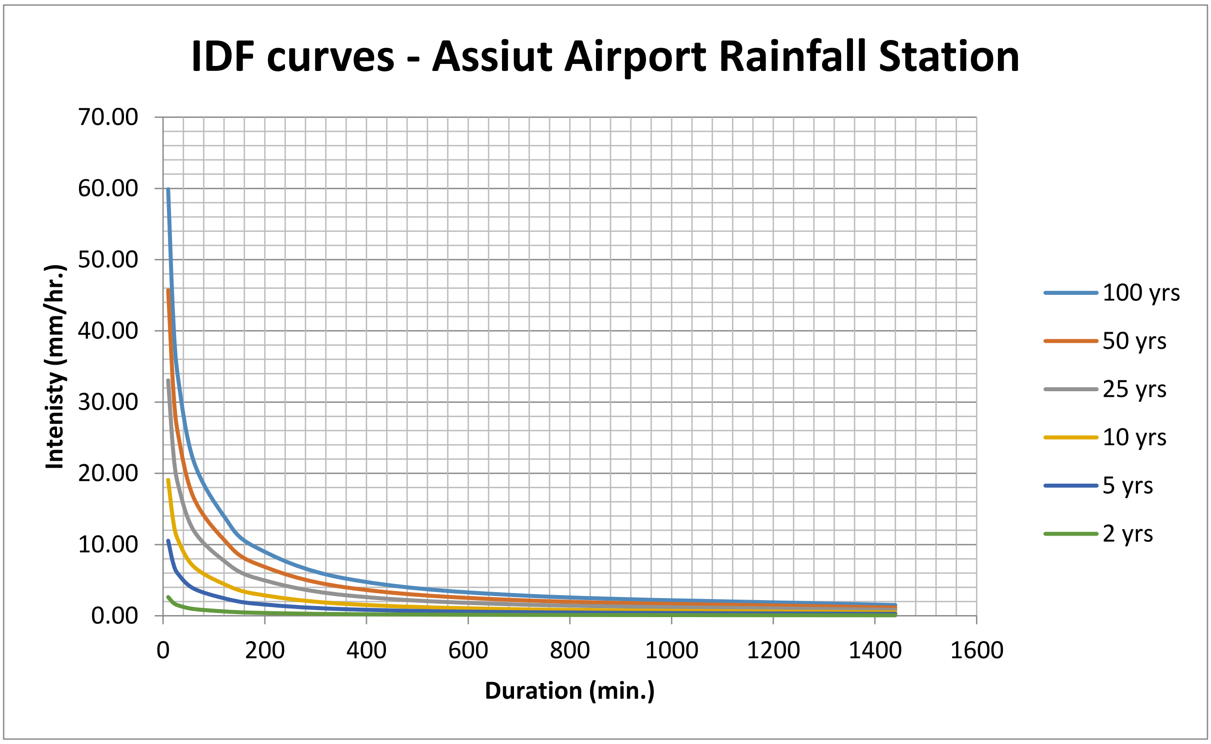


Figure 5 IDF curve for Assiut Airport Rainfall Station

3 Morphological Analysis

3.1 General

Morphological analysis is the stage of determination the main external streams affecting the study area, determining their relevant watersheds and their morphological parameters (i.e. area, time of concentration, slope, curve number …etc.), then by using these parameters and rainfall data we carry out the Hydrological analysis to determine the peak discharges, runoff hydrographs and the water volume to design the flood protection structures, Topographic maps & DEM (Digital Elevation Model) were used to carry out a complete morphological analysis for the study area to identify the major watersheds affecting it, as well as the different morphological parameters such as:

1. Watershed Extent
2. Longest Flow Path
3. Watershed Area
4. Watershed Slope
5. Watershed Shape
6. Time of concentration

The morphological parameters calculated as follows:

1. **Wadi Slope**

$$S = H / L_B$$

Where:

S: Wadi Slope

H: Elevation difference in meters

L_B: Wadi length in meters

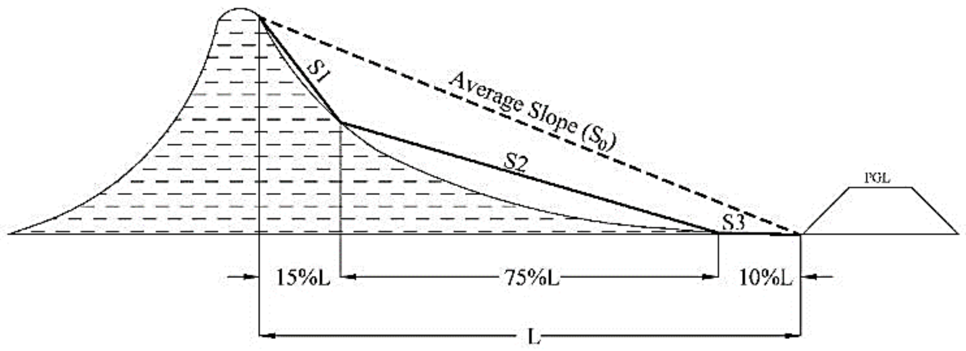


Figure 6 Slope Calculations

2. Time of Concentration

It's the time needed for the full contribution of the watershed to form the peak flood discharge and it's the same travel time that runoff needs from the most distant point in the watershed till the outlet, and there are few equations to calculate the time of concentration and the most commonly used and most recommended in this study is Kirpich equation:

$$T_C \text{ (min.)} = 0.01944 \, (LB)^{0.77} / (S)^{0.385}$$

Where:

LB: The length of the stream in meters

S: The slope of the stream as a m/m

3. Lag Time

The standard lag time is defined as the time between the center of mass for the excess rainfall and the peak flow of the resulting hydrograph.

$$T_L \text{ (min.)} = 0.6 * T_C$$

Where:

T_L: lag time (minutes)

T_C: time of concentration (minutes)

3.2 Morphological Study Results

Using the Arc GIS software and by simulating the natural terrain under study, the main streams affecting the embankment and their watersheds are identified and their morphological parameters are determined.

The DEM (Digital Elevation Model) of the study area & surrounding areas were used to determine the streams affecting the railway embankment. Arc Hydro Tools, one of the applications used within the ArcGIS program, was used to determine the watersheds affecting the study area. Figure 7 shows the watersheds resulting from the GIS program.

The recent satellite images and topo maps have been used to verify the output delineation results of the ArcGIS. After the completion of the simulation and the verifications required to determine the streams affecting the embankment under study, Figures 8 & 9 show the watersheds that are affecting the project, while Table 2 shows the morphological parameters of the watersheds that affect the study area.

Table 2 Morphological parameters of watersheds that affect the study area

No.	WS Name	Area (km^2)	LFP (m)	ElevUP	Elev85	Elev10	ElevDS	S over 85	S 85 10	S less 10	T_c (min)	T_{Lag} (min)
1	W-01	2.49	2250	405	397	379	374	2.37%	1.07%	2.22%	47	28
2	W-02	7.46	3818	425	413	375	374	2.10%	1.33%	0.26%	77	46
3	W-03	7.88	4233	425	410	375	374	2.36%	1.10%	0.24%	88	53
4	W-04	0.19	339	381	380	373	371	1.96%	2.75%	5.89%	8	5
5	W-05	1.85	1444	373	366	352	349	3.23%	1.29%	2.08%	31	19
6	W-06	0.75	1540	366	361	359	358	2.16%	0.17%	0.65%	63	38
7	W-07	5.05	5826	391	378	347	336	1.49%	0.71%	1.89%	113	68
8	W-08	0.14	377	359	356	351	346	5.30%	1.77%	13.25%	9	5
9	W-09	73.97	16243	385	379	343	336	0.25%	0.30%	0.43%	383	230
10	W-10	1.39	1692	358	357	334	324	0.39%	1.81%	5.91%	37	22
11	W-11	1.24	1790	362	358	316	313	1.49%	3.13%	1.68%	31	19
12	W-12	26.09	11675	374	346	271	263	1.60%	0.86%	0.69%	192	115
13	W-13	7.52	6867	339	306	208	200	3.20%	1.90%	1.17%	96	58
14	W-14	0.56	1634	309	295	234	196	5.71%	4.98%	23.26%	21	12
15	W-15	2.63	2705	277	265	173	171	2.96%	4.54%	0.74%	40	24
16	W-16	1.27	2356	268	248	178	174	5.66%	3.96%	1.70%	33	20

No.	WS Name	Area (km^2)	LFP (m)	ElevUP	Elev85	Elev10	ElevDS	S over 85	S 85 10	S less 10	T_c (min)	T_{Lag} (min)
17	W-17	197.97	35727	393	354	196	163	0.73%	0.59%	0.92%	521	312
18	W-18	5.77	4133	275	262	159	155	2.10%	3.32%	0.97%	59	36
19	W-19	6480.34	185735	472	457	255	149	0.05%	0.15%	0.57%	3408	2045
20	W-20	1.45	1145	280	269	165	161	6.40%	12.11%	3.49%	14	8
21	W-21	4.01	4060	281	273	148	144	1.31%	4.11%	0.99%	58	35
22	W-22	0.11	730	212	173	138	137	35.60%	6.39%	1.37%	11	7
23	W-23	0.05	249	149	148	146	140	2.67%	1.07%	24.07%	8	5
24	W-24	0.02	174	151	150	141	140	3.84%	6.90%	5.75%	4	2
25	W-25	0.55	1332	275	252	129	127	11.51%	12.31%	1.50%	16	9
26	W-26	4.02	4271	290	272	133	125	2.81%	4.34%	1.87%	53	32
27	W-27	6.65	5313	288	221	130	124	8.41%	2.28%	1.13%	72	43
28	W-01S	0.51	1973	363	358	354	344	1.69%	0.27%	5.07%	63	38
29	W-02S	17.87	6211	400	382	333	332	1.93%	1.05%	0.16%	125	75
30	W-03S	0.81	2234	371	361	333	332	2.98%	1.67%	0.45%	45	27
31	W-04S	0.70	1872	363	352	333	332	3.92%	1.35%	0.53%	40	24
32	W-05S	55.54	20444	374	335	195	180	1.27%	0.91%	0.73%	294	177
33	W-06S	1.44	2598	269	176	158	157	23.86%	0.92%	0.38%	56	33
34	W-07S	2.83	2739	279	271	155	152	1.95%	5.65%	1.10%	38	23

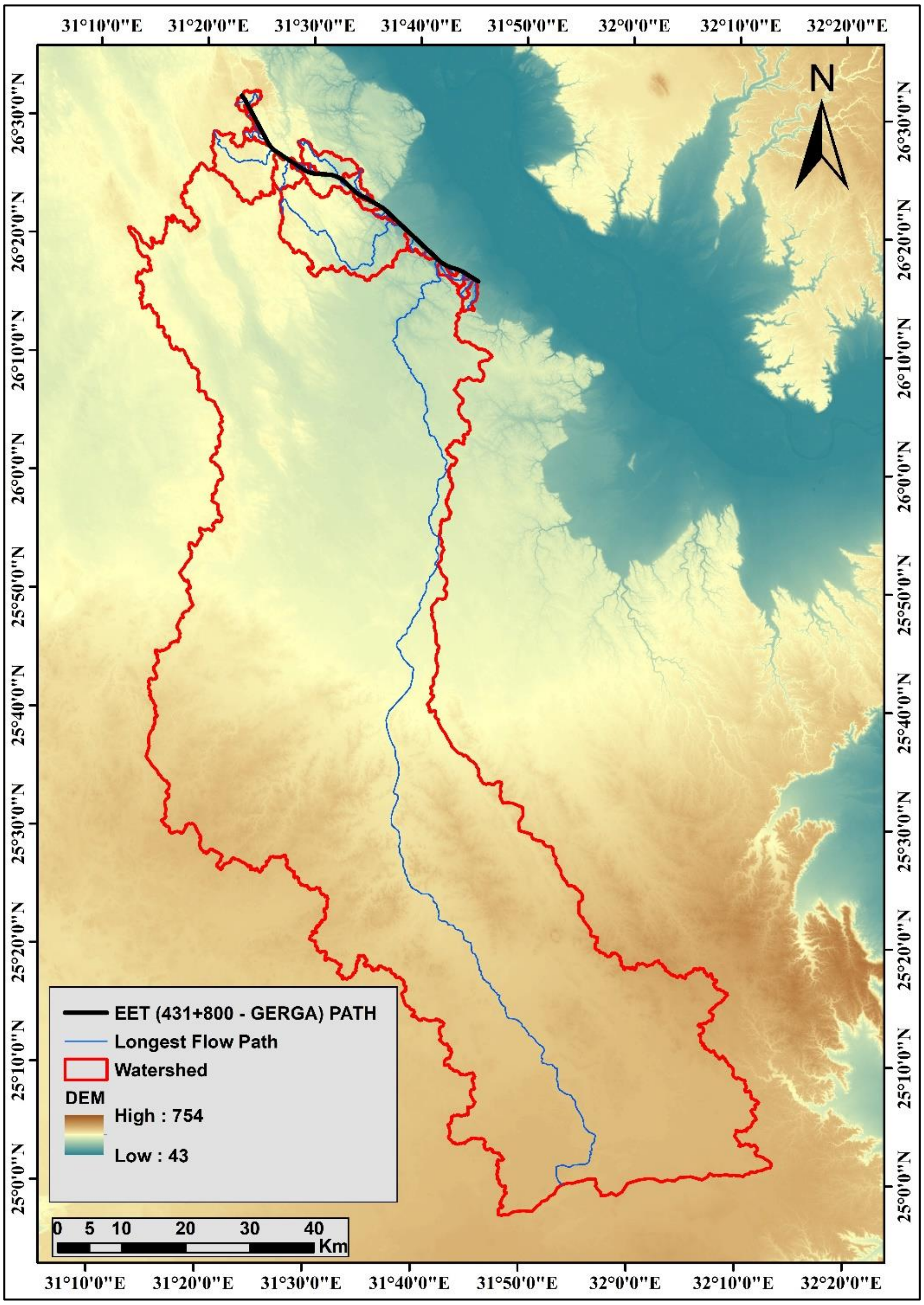


Figure 7 Watersheds generated from GIS program

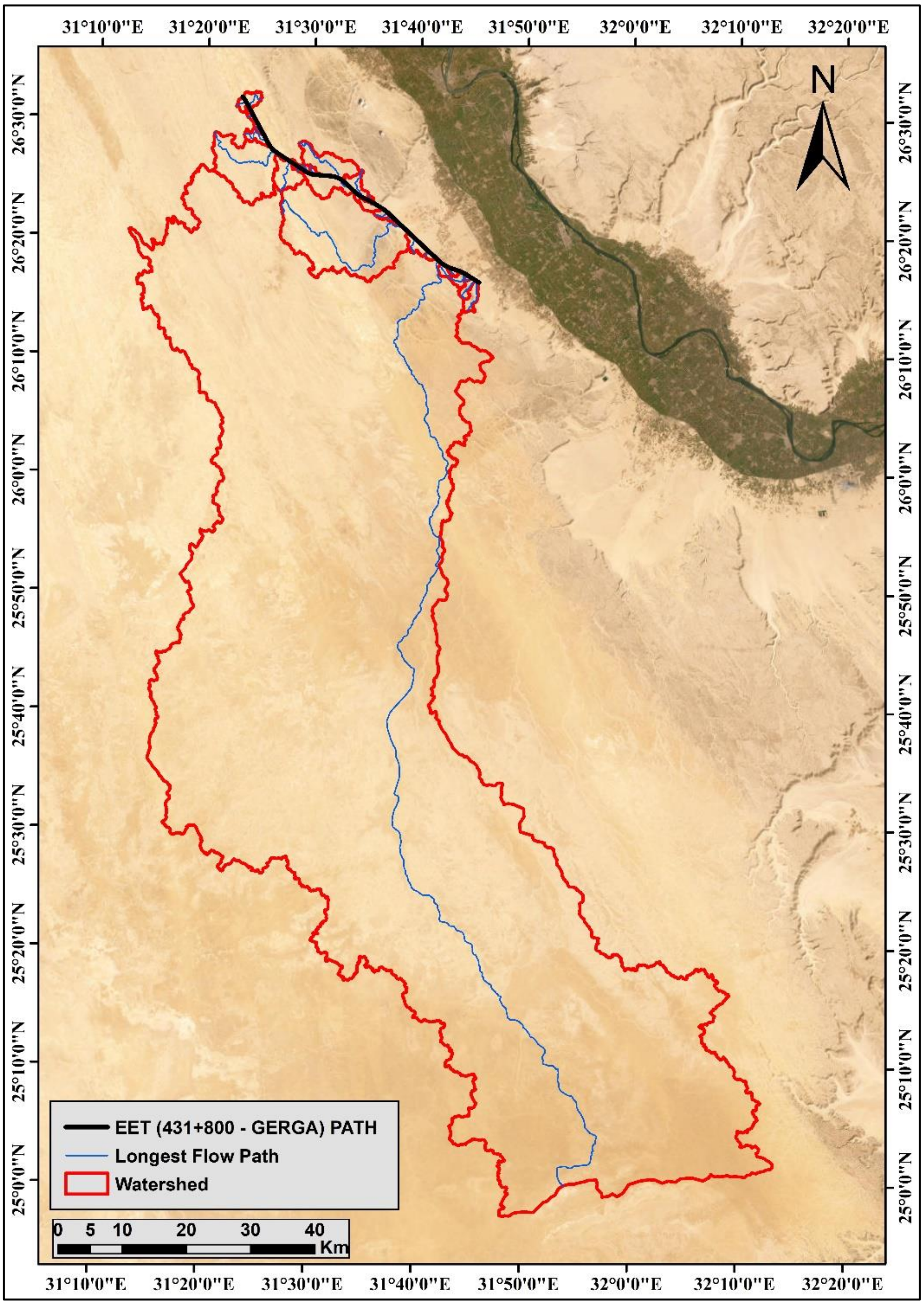


Figure 8 Watersheds affecting the study area on Satellite image

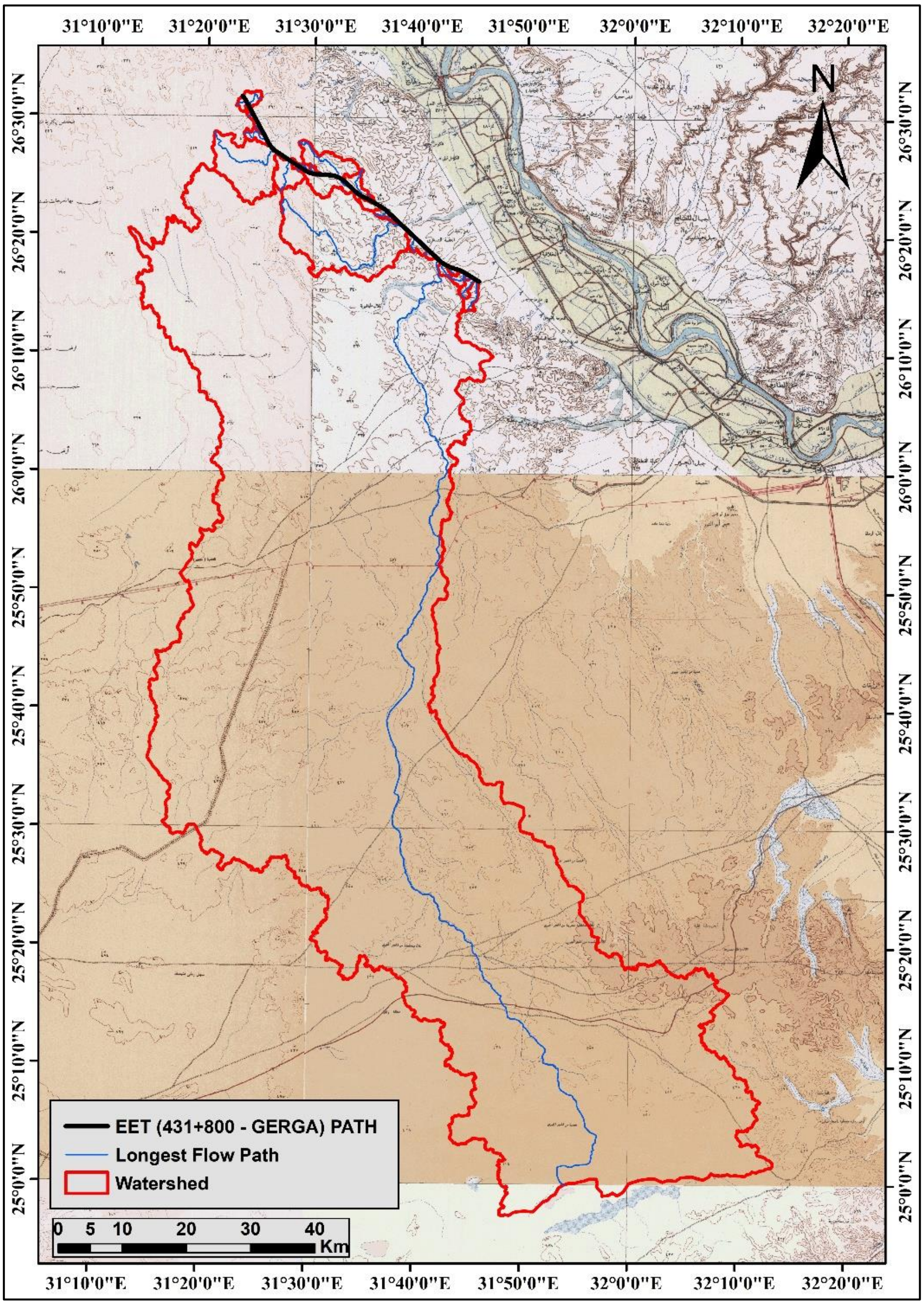


Figure 9 Watersheds affecting the study area on Topographic Map

4 Hydrological Analysis

The hydrological study aims to determine the peak values of surface runoff and flowing water volumes depending on the morphological and meteorological study taking into account the design storms and their distribution and the areas affected by these storms, and Surface runoff is the rate of movement or discharge of water (volume / time) in natural watercourses.

Factors affecting runoff can be divided into rainfall-related factors such as rainfall intensity, duration of rainfall, return period of rainfall, distribution of rainfall over watershed, and other factors associated with the watershed such as the area, the length of the main stream, the slope of the main stream and the shape of the watershed, as well as soil-related factors such as infiltration and land cover/use types, the following are the mathematical methods that can be used to estimate the maximum runoff from the contributing watersheds to the embankment under study according to the data available and the most relevant to the case being studied.

4.1 Design Storm Distribution

The SCS Type II design storm distribution is the most commonly used rainfall distribution in the arid and semi-arid regions as it provides logical and safe values, due to its dependence on the concentration of the bulk of rainfall in a short time. Figure 10 shows a sample of the SCS type II storm distribution for 24 hours.

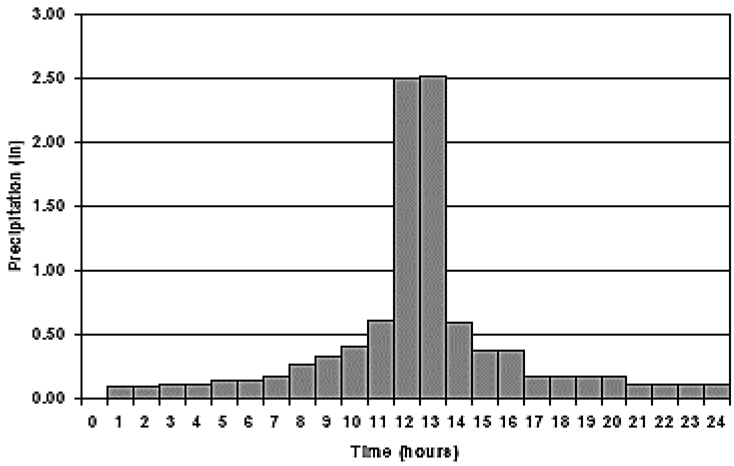


Figure 10 Distribution of SCS type II storm for 24 hours

In order to calculate the peak flood discharge, the Rational equation is applied to watersheds with areas less than 1 km^2, for watersheds with areas greater than 1 km^2, SCS Unit Hydrograph method is used to avoid high illogic runoff values resulting from the use of the "Rational method" for large watersheds so as not to result in unnecessary large mitigation structures.

4.2 Rational Method

Rational method is the most commonly used method in urban areas & relatively small watersheds in rural areas for calculating the max discharge at the outlet of the watersheds.

These terms should be taken into consideration when using this method:

- Area of watershed less than 100 hectares.
- Time of concentration less than 2 hours.
- The watershed has no bonds.
- The connectivity of the surfaces that has low permeability like (asphalt-concrete - Rocky surface).

Rational Method Formula:

$$Q_p = 0.278\ CIA$$

Whereas:

Qp: The peak discharge (m^3/s)

C: Runoff Coefficient

I: Precipitation Intensity (mm/hr)

A: Watershed area (km^2)

4.2.1 Runoff Coefficient (C)

Runoff Coefficient: is the ratio of rainfall flowing from drainage basins. This coefficient is affected by the nature of the drainage basin, It is value varies between (0-1), the more the value were near to zero the higher the permeability of the soil & the soil keeps most of the rainfall, The more the value were near to one the lower the permeability of the soil & most of the rainfall would runoff on the soil surface, Table 3 shows the runoff coefficient values for different kinds of surfaces & Land uses.

Table 3 Runoff Coefficient values for Rational Method

Watershed characteristic	Extreme	High	Normal	Low
Relief - C_r	0.28-0.35 Steep, rugged terrain with average slopes above 30%	0.20-0.28 Hilly, with average slopes of 10-30%	0.14-0.20 Rolling, with average slopes of 5-10%	0.08-0.14 Relatively flat land, with average slopes of 0-5%
Soil infiltration - C_i	0.12-0.16 No effective soil cover; either rock or thin soil mantle of negligible infiltration capacity	0.08-0.12 Slow to take up water, clay or shallow loam soils of low infiltration capacity or poorly drained	0.06-0.08 Normal; well drained light or medium textured soils, sandy loams	0.04-0.06 Deep sand or other soil that takes up water readily; very light, well-drained soils
Vegetal cover - C_v	0.12-0.16 No effective plant cover, bare or very sparse cover	0.08-0.12 Poor to fair; clean cultivation, crops or poor natural cover, less than 20% of drainage area has good cover	0.06-0.08 Fair to good; about 50% of area in good grassland or woodland, not more than 50% of area in cultivated crops	0.04-0.06 Good to excellent; about 90% of drainage area in good grassland, woodland, or equivalent cover
Surface Storage - C_s	0.10-0.12 Negligible; surface depressions few and shallow, drainageways steep and small, no marshes	0.08-0.10 Well-defined system of small drainageways, no ponds or marshes	0.06-0.08 Normal; considerable surface depression, e.g., storage lakes and ponds and marshes	0.04-0.06 Much surface storage, drainage system not sharply defined; large floodplain storage, large number of ponds or marshes
Note: The total runoff coefficient based on the 4 runoff components is $C = C_r + C_i + C_v + C_s$				

When the land use varies through the study area then we use a weighted runoff coefficient as follow:

$$C\ (\text{Weighted}) = \frac{c_1 \text{Area}_1 + c_2 \text{Area}_2}{\text{Area}_1 + \text{Area}_2}$$

4.3 SCS Curve Number Method

The SCS (CN/Unit Hydrograph) method is applied to watersheds with areas greater than 1 km^2, where part of the rainfall infiltrates when it falls into the ground. Surface soil type, slope and geometric dimensions of the stream reaches control the increase or decrease of losses.

In order to calculate the excess rainfall values, which causes the surface runoff affecting the embankment under study after taking into consideration the different losses, mathematical equations to determine these losses and connect between rainfall land resultant runoff values are required.

Accordingly, the Soil Conservation Service (SCS) - Curve Number (CN) method, which is one of the most widely used practical methods for determining losses, is based on Soil Type and Land Use. The following equations are applied to calculate the runoff value:

$$P_e = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Where:

Pe: Excess rainfall, is the value of rain that contributes to runoff (mm)

Ia: Initial abstraction, is the value of the initial interception, which includes interstitial losses, leaching and surface storage, all of which occur before the start of surface runoff (mm).

$$I_a = 0.2 \times S$$

S is the soil retention which depends on the type of soil and the surface cover of the drainage basins which is dependent on the curve number value ranging between 1 and 100, the following equation shows the relationship between them:

$$S = \frac{25400}{CN} - 254$$

According to the geological classification of surface soil, surface cover and land use, the value of the curve number and therefore the amount of water lost by infiltration can be estimated using the above equations as well as the amount of excess rainfall that causes the runoff, and the hydrological model has been fed with all these data for use in calculating the hydrograph.

Figure 11 shows the values of Curve Number (CN) for the different regions in Egypt.

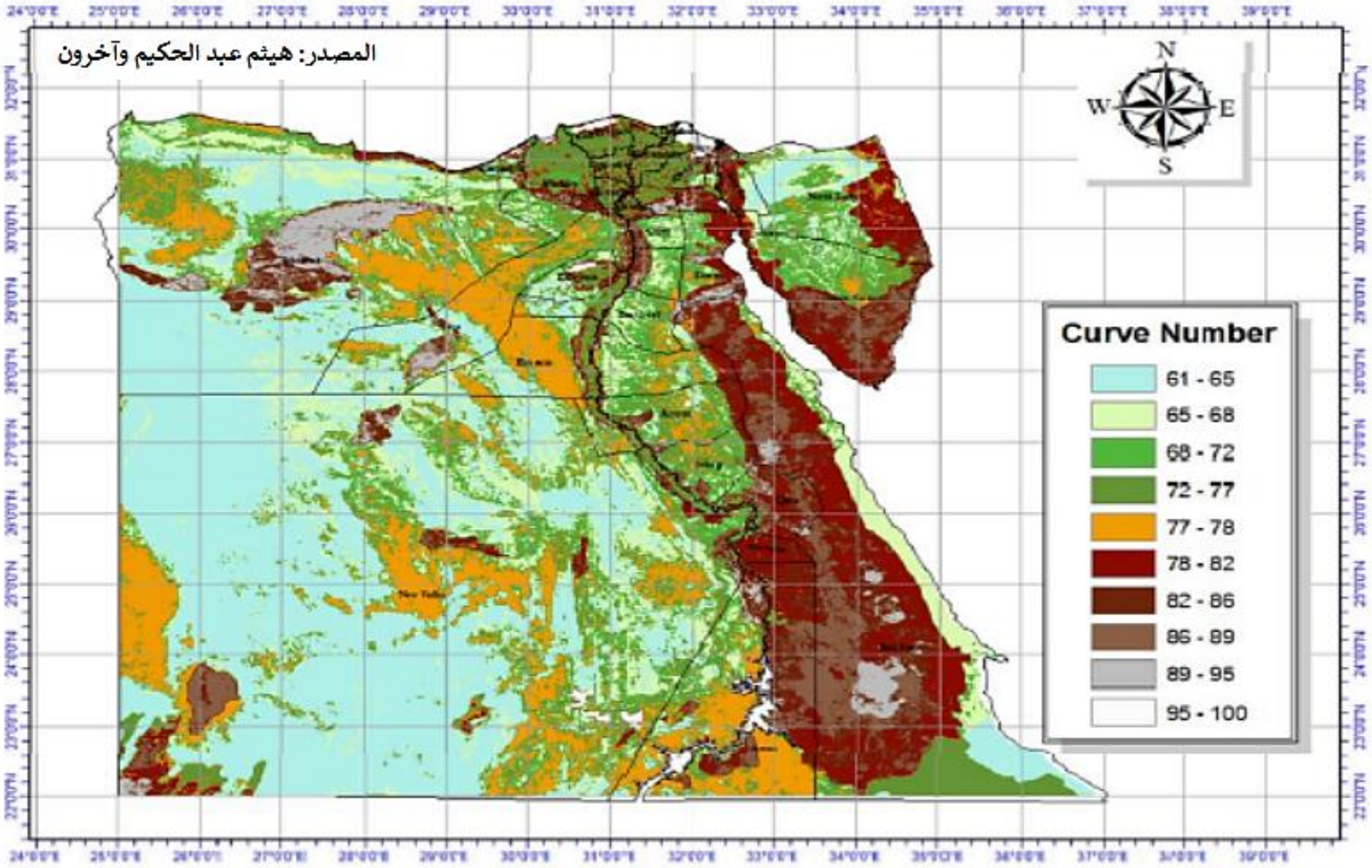


Figure 11 Curve Number (CN) map for Egypt, (https://www.tandfonline.com/doi/full/10.1080/02626667.2015.1027709)

Table 4 shows the values of Curve Number (CN) depending on soil type & land use.

Table 4 Curve Number (CN) values for arid & semi-arid areas

Cover description		Curve Numbers for hydrologic soil group			
Cover Type	Hydrologic condition	A	B	C	D
Herbaceous—mixture of grass, weeds, and low-growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both; grass understory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush, greasewood, creosote bush, black brush, bursage, Paloverde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

Poor: <30% ground cover (litter, grass, and brush).
Fair: 30 to 70% ground cover.
Good: > 70% ground cover.

4.4 Hydrological Study Methodology

Based on the above, the methodology of the hydrological study that is used when dealing with the problem of flood risk mitigation can be summarized in the following steps:

1. The morphological & Hydrological different parameters would be determined according to the basis at chapter 3 & 4.
2. Using the morphological parameters of the watersheds, the hydrological model of each watershed is determined.
3. The runoff coefficient and the curve number values are determined based on the land use/land cover types and using the above-mentioned coefficients and reference tables.
4. The longest flow path for the mainstream within each watershed is determined and the slope of this path and the time of concentration is calculated.
5. The design rainfall depth of each watershed is obtained according to its condition and the above mentioned, the returned period that taken in design of flood protection works is 100 years.
6. The different mentioned formulas would be applied (Rational Method – SCS-Curve Number) to calculate the discharges & volumes which we will use to take the right decision.
7. Any existing structure that is likely to affect the hydrograph at the watershed outlet, such as dams, artificial lakes and marshes have been taken into consideration.

4.5 Hydrological Study Results

Table 5 shows the results of the hydrological study by using the above-mentioned methods.

Table 5 Hydrological Study Results

No.	Watershed Name	Area (km2)	CN	C	Calc. Method	T_C (min)	Q (m^3/s)
1	W-01	2.49	79	--	SCS	47	8.20
2	W-02	7.46	79	--	SCS	77	17.00
3	W-03	7.88	79	--	SCS	88	16.20
4	W-04	0.19	--	0.4	Rational	8	1.55
5	W-05	1.85	79	--	SCS	31	8.00
6	W-06	0.75	--	0.4	Rational	63	2.09
7	W-07	5.05	80	--	SCS	113	9.30
8	W-08	0.14	--	0.4	Rational	9	1.14
9	W-09	73.97	79	--	SCS	383	49.60
10	W-10	1.39	85	--	SCS	37	8.30
11	W-11	1.24	85	--	SCS	31	8.10
12	W-12	26.09	86	--	SCS	192	48.60
13	W-13	7.52	87	--	SCS	96	25.20
14	W-14	0.56	--	0.4	Rational	21	3.10
15	W-15	2.63	80	--	SCS	40	10.40
16	W-16	1.27	80	--	SCS	33	5.70
17	W-17	197.97	83	--	SCS	521	139.10
18	W-18	5.77	78	--	SCS	59	14.50
19	W-19	6480.34	77	--	SCS	3408	650.20
20	W-20	1.45	78	--	SCS	14	9.20
21	W-21	4.01	84	--	SCS	58	16.10
22	W-22	0.11	--	0.4	Rational	11	0.80
23	W-23	0.05	--	0.4	Rational	8	0.42
24	W-24	0.02	--	0.4	Rational	4	0.18
25	W-25	0.55	--	0.4	Rational	16	3.50
26	W-26	4.02	85	--	SCS	53	18.40
27	W-27	6.65	85	--	SCS	72	24.60
28	W-01S	0.51	--	0.4	Rational	63	1.44
29	W-02S	17.87	80	--	SCS	125	30.50
30	W-03S	0.81	--	0.4	Rational	45	2.79
31	W-04S	0.70	--	0.4	Rational	40	2.60
32	W-05S	55.54	85	--	SCS	294	69.30
33	W-06S	1.44	79	--	SCS	56	4.20
34	W-07S	2.83	79	--	SCS	38	10.70

5 Hydraulic Design Criteria

5.1 General

The hydraulic design is a fundamental factor in the design of projects exposed to the danger of floods, whether as protection against the danger of flash floods or storm water drainage. Whenever water attacks the area under development, the flows must be estimated accurately as possible and transported safely, so the design aims to provide drainage facilities that are capable of accommodation of the largest flood discharges with the least maintenance over its lifetime.

The hydraulic design process consists of setting standards, developing, and evaluating alternatives, and selecting the alternative that meets the design standards.

5.2 Returned Period

It is the frequency of storms within a specified period of time. The extent of the storm frequency reflects the severity of the floods. The choice of the design period depends on the importance and location of the proposed protection work. Table 6 shows the proposed protection works & their returned periods.

Table 6 Returned periods for the protection works

Protection work	Returned period for the design storm
Dams	100-200 years
Bridge	100 years
Culvert	100 years
Slope protection	100 years
Chute	100 years
Diversion Channel	100 years
Side Ditch	100 years
Dike	100 years

5.3 Design Standards

- Water drained as much as possible into the natural wadi path instead of diverting it or allowing water to be stored and stagnant.
- Minimize the protection works as possible.
- All protection works for this project are designed/assessed against return period of 100 years' storm event.
- Taking into consideration the economic aspects by decreasing the cost of required protection system as much as possible by achieving safe and optimum design.
- Water velocity should be kept within the allowable range to avoid the risks of scouring in the downstream of the flood mitigation structures.

5.4 Hydraulic design basis

5.4.1 Culvert

The following considerations are taken in designing and evaluating culverts:

- The minimum size of the circular culvert is Two openings with diameter (1 meter).
- The minimum size of the Box culvert is Two opening with Width=2m and Height =1.5m
- The maximum water level in the upstream of the flow before entering the culvert should not exceed 1.2 x (culvert height).
- Grading should be provided when needed at the entrance and exit of the culvert as the natural condition of some areas includes scattered small hills specially in the downstream area of the culvert that may cause obstruction of flow.
- Protection work should be provided at the entrance and exit of the culvert for protection against scouring. It is recommended to use loose riprap protection when the flow velocity is less than 6.5 m/s and if the velocity exceeds 6.5 m/s, an energy dissipater system should be used.

Generally, flow in culverts occurs under one of this two situations: inlet control culvert or outlet control culvert. For culverts designed according to the condition of inlet control, the characteristics of the culvert entrance will be such that losses occurred at entrance section are the dominant element in determining the height of the water level of the culvert.

It is customary for the culvert to be designed under conditions of flows that are not fully submerged, meaning that the entrance surface of the culvert is above the water level flowing through it wherever possible. Note that the maximum water level in the upstream of the culvert before entering the drain facilities should not exceed 1.2 x (height of the culvert).

The general equations used while the design phase of culverts are as follows:

For box culverts:

$$Q = n * 1.5 * W * H^{1.5}$$

For pipe culverts:

$$Q = n * 1.232 * D^{2.5}$$

Whereas:

n: No. of Culvert openings.

W: Box Culvert Width (m).

H: Box Culvert Height (m).

D: Pipe Culvert Diameter (m).

(CulvertMaster) program will be used to determine the sizes of the proposed culverts, as well as to determine the level of water level at the entrance of the culvert and the exit velocity of water from it.

Box Culverts are designed of reinforced concrete in streams and wadis where the concrete allows the passage of maximum discharges while using an economical concrete section. The multi-openings culverts are used in watersheds and waterways when needed instead of bridges, in the case of watersheds that are characterized by long, mild & very wide longitudinal slopes, and the cross-section of the wadi is not well defined. The multi-openings culverts are designed to accommodate the maximum flows that are likely to pass through.

Entrance and exit structures are connected to the culvert in order to reduce the erosion of the embankment or the rail and slopes in the downstream, to prevent seepage, protection of embankments and structural fixation of the ends to improve the hydraulic properties of the culvert.

5.4.1.1 • Types of Culverts Control.

A general description of the characteristics of inlet and outlet control flow is given below. A culvert flowing in inlet control has shallow, high velocity flow categorized as "supercritical." For supercritical flow, the control section is at the upstream end of the barrel (the inlet). Conversely, a culvert flowing in outlet control will have relatively deep, lower velocity flow termed "subcritical" flow. For subcritical flow the control is at the downstream end of the culvert (the outlet). The tail water depth is either critical depth at the culvert outlet or the downstream channel depth, whichever is higher.

a. Inlet Control

Figure 12 depicts several different examples of inlet control flow. The type of flow depends on the submergence of the inlet and outlet ends of the culvert. In all of these examples, the control section is at the inlet end of the culvert. Depending on the tailwater, a hydraulic jump may occur downstream of the inlet.

Figure 12-A depicts a condition where neither the inlet nor the outlet end of the culvert are submerged. The flow passes through critical depth just downstream of the culvert entrance and the flow in the barrel is supercritical. The barrel flows partly full over its length, and the flow approaches normal depth at the outlet end.

Figure 12-B shows that submergence of the outlet end of the culvert does not assure outlet control. In this case, the flow just downstream of the inlet is supercritical and a hydraulic jump forms in the culvert barrel.

Figure 12-C is a more typical design situation. The inlet end is submerged, and the outlet end flows freely. Again, the flow is supercritical and the barrel flows partly full over its length. Critical depth is located just downstream of the culvert entrance, and the flow is approaching normal depth at the downstream end of the culvert.

Figure 12-D is an unusual condition illustrating the fact that even submergence of both the inlet and the outlet ends of the culvert does not assure full flow. In this case, a hydraulic jump will form in the barrel. The median inlet provides ventilation of the culvert barrel. If the barrel were not ventilated, sub-atmospheric pressures could develop which might create an unstable condition during which the barrel would alternate between full flow and partly full flow.

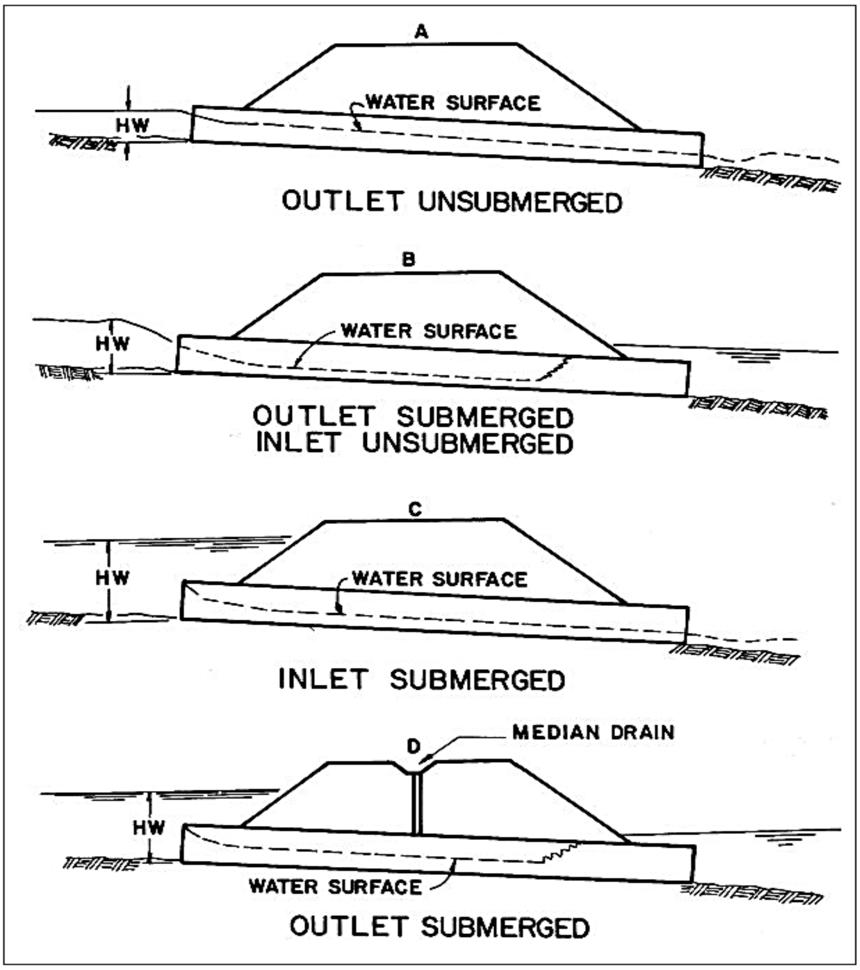


Figure 12 Types of inlet control

• Factors Influencing Inlet Control

Since the control is at the upstream end in inlet control, only the headwater and the inlet configuration affect the culvert performance. The Head water depth is measured from the invert of the inlet control section to the surface of the upstream pool. The inlet area is the cross-sectional area of the face of the culvert. Generally, the inlet face area is the same as the barrel area, but for tapered inlets the face area is enlarged, and the control section is at the throat. The inlet edge configuration describes the entrance type. Some typical inlet edge configurations are thin edge projecting, mitered, square edges in a headwall, and beveled edge. The inlet shapes usually the same as the shape of the culvert barrel; however, it may be enlarged as in the case of a tapered inlet. Typical shapes are rectangular, circular, and elliptical. Whenever the inlet face is a different size or shape than the culvert barrel, the possibility of an additional control section within the barrel exists.

An additional factor which influences inlet control performance is the barrel slope. The effect is small, however, and it can be ignored, or a small slope correction factor can be inserted in the inlet control equations.

The inlet edge configuration is a major factor in inlet control performance, and it can be modified to improve performance.

• Inlet Control Calculations

The inlet control calculations determine the headwater elevation required to pass the design flow through the selected culvert configuration in inlet control. The approach velocity head may be included as part of the headwater, if desired.

The inlet control nomographs are used in the design process. For the following discussion, refer to the schematic inlet control nomograph shown in Figure 13.

a. Locate the selected culvert size (point 1) and flow rate (point 2) on the appropriate scales of the inlet control nomograph. (Note that for box culverts, the flow rate per foot of barrel width is used.)

b. Using a straightedge, carefully extend a straight line from the culvert size (point 1) through the flow rate (point 2) and mark a point on the first headwater/culvert height (HW/D) scale (point 3). The first HW/D scale is also a turning line.

c. If another HW/D scale is required, extend a horizontal line from the first HW/D scale (the turning line) to the desired scale and read the result.

d. Multiply HW/D by the culvert height, D, to obtain the required headwater (HW) from the invert of the control section to the energy grade line. If the approach velocity is neglected, HW equals the required headwater depth (HWi). If the approach velocity is included in the calculations, deduct the approach velocity head from HW to determine HWi.

e. Calculate the required depression (FALL) of the inlet control section below the stream bed as follows:

Possible results and consequences of this calculation are:

(1) If the FALL is negative or zero, set FALL equal to zero and proceed to step f.

(2) If the FALL is positive, the inlet control section invert must be depressed below the streambed at the face by that amount. If the FALL is acceptable, proceed to step f.

(3) If the FALL is positive and greater than is judged to be acceptable, select another culvert configuration and begin again at step a.

f. Calculate the inlet control section invert elevation as follows:

Eli = ELsf - Fall

where Eli is the invert elevation at the face of a culvert (ELf) or at the throat of a culvert with a tapered inlet (ELt).

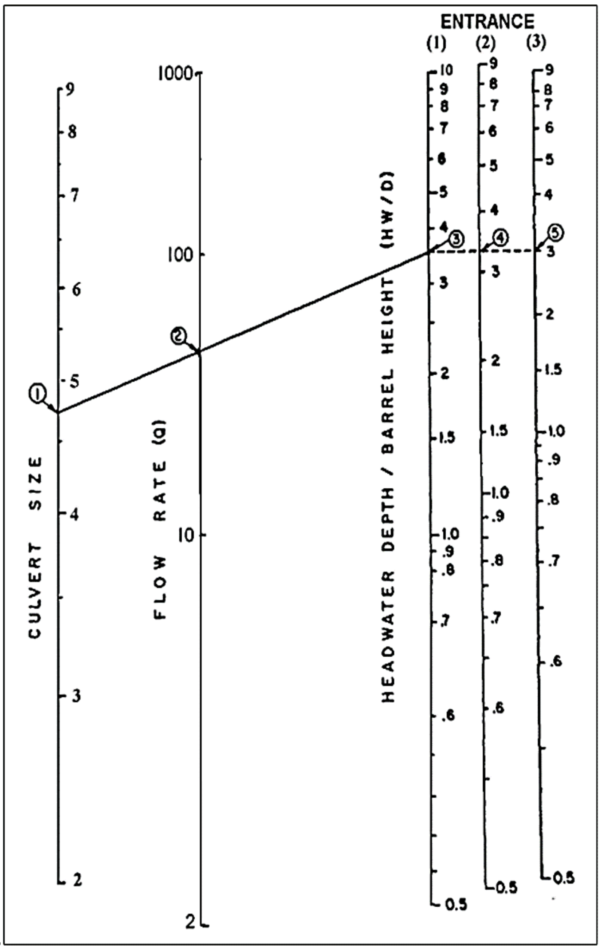


Figure 13 Inlet Control Nomograph (schematic)

b. Outlet Control

Figure 14 illustrates various outlet control flow conditions. In all cases, the control section is at the outlet end of the culvert or further downstream.

Condition 14-A represents the classic full flow condition, with both inlet and outlet submerged.

The barrel is in pressure flow throughout its length. This condition is often assumed in calculations, but seldom actually exists.

Condition 14-B depicts the outlet submerged with the inlet unsubmerged. For this case, the headwater is shallow so that the inlet crown is exposed as the flow contracts into the culvert.

Condition 14-C shows the entrance submerged to such a degree that the culvert flows full throughout its entire length while the exit is unsubmerged. This is a rare condition. It requires an extremely high headwater to maintain full barrel flow with no tailwater. The outlet velocities are usually high under this condition.

Condition 14-D is more typical. The culvert entrance is submerged by the headwater and the outlet end flows freely with a low tailwater. For this condition, the barrel flows partly full over at least part of its length (subcritical flow) and the flow passes through critical depth just upstream of the outlet.

Condition 14-E is also typical, with neither the inlet nor the outlet ends of the culvert submerged.

The barrel flows partly full over its entire length, and the flow profile is subcritical.

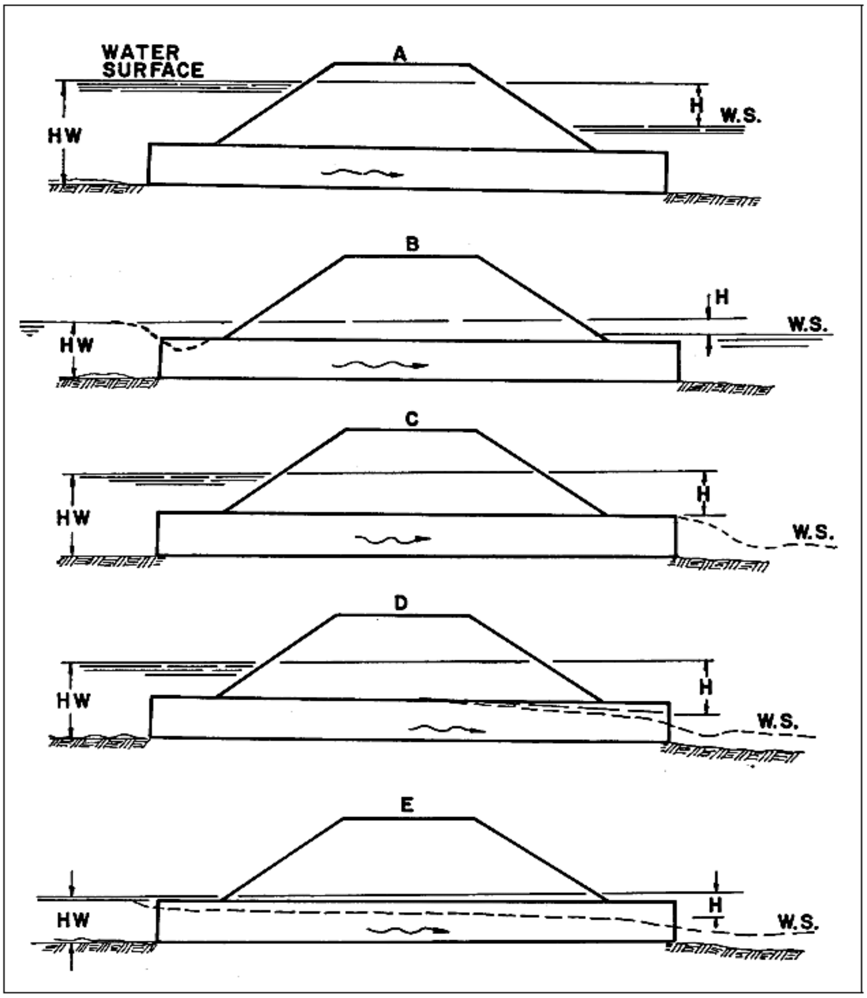


Figure 14 Types of Outlet Control

• Factors Influencing Outlet Control.

All the factors influencing the performance of a culvert in inlet control also influence culverts in outlet control. In addition, the barrel characteristics (roughness, area, shape, length, and slope) and the tailwater elevation affect culvert performance in outlet control.

The barrel roughness is a function of the material used to fabricate the barrel. Typical materials include concrete and corrugated metal. The roughness is represented by a hydraulic resistance coefficient such as the Manning's n value.

The barrel area and barrel shape are self-explanatory.

The barrel length is the total culvert length from the entrance to the exit of the culvert. Because the design height of the barrel and the slope influence the actual length, an approximation of barrel length is usually necessary to begin the design process.

The barrel slope is the actual slope of the culvert barrel. The barrel slope is often the same as the natural stream slope. However, when the culvert inlet is raised or lowered, the barrel slope is different from the stream slope.

The tailwater elevation is based on the downstream water surface elevation. Backwater calculations from a downstream control, a normal depth approximation, or field observations are used to define the tailwater elevation.

• Outlet Control Calculations

The outlet control calculations result in the headwater elevation required to convey the design discharge through the selected culvert in outlet control. The approach and downstream velocities may be included in the design process, if desired. The critical depth charts and outlet control nomographs of Appendix D are used in the design process. For illustration, refer to the schematic critical depth chart and outlet control nomograph shown in Figures 15 and 16, respectively.

a. Determine the tailwater depth above the outlet invert (TW) at the design flow rate. This is obtained from backwater or normal depth calculations, or from field observations.

(1) If the Manning's n value given in the outlet control nomograph is different than the Manning's n for the culvert, adjust the culvert length using the formula:

$$L_1 = L\left(\frac{n_1}{n}\right)^2 \tag{9}$$

L_1	is the adjusted culvert length, m (ft)
L	is the actual culvert length, m (ft)
n_1	is the desired Manning's n value
n	is the Manning's n value from the outlet control chart

Then, use L1rather than the actual culvert length when using the outlet control nomograph.

(2) Using a straightedge, connect the culvert size (point 1) with the culvert length on the appropriate scale (point 2). This defines a point on the turning line (point 3).

(3) Again, using the straightedge, extend a line from the discharge (point 4) through the point on

the turning line (point 3) to the Head Loss (H) scale. Read H. H is the energy loss through the culvert, including entrance, friction, and outlet losses.

Note: Careful alignment of the straightedge in necessary to obtain good results from the outlet control nomograph.

g. Calculate the required outlet control headwater elevation.

$$EL_{ho} = EL_o + H + h_o \tag{10}$$

where Elo is the invert elevation at the outlet. (If it is desired to include the approach and downstream velocities in the calculations, add the downstream velocity head and subtract the approach velocity head from the right side of Equation (10).

h. If the outlet control headwater elevation exceeds the design headwater elevation, a new culvert configuration must be selected, and the process repeated. Generally, an enlarged barrel will be necessary since inlet improvements are of limited benefit in outlet control.

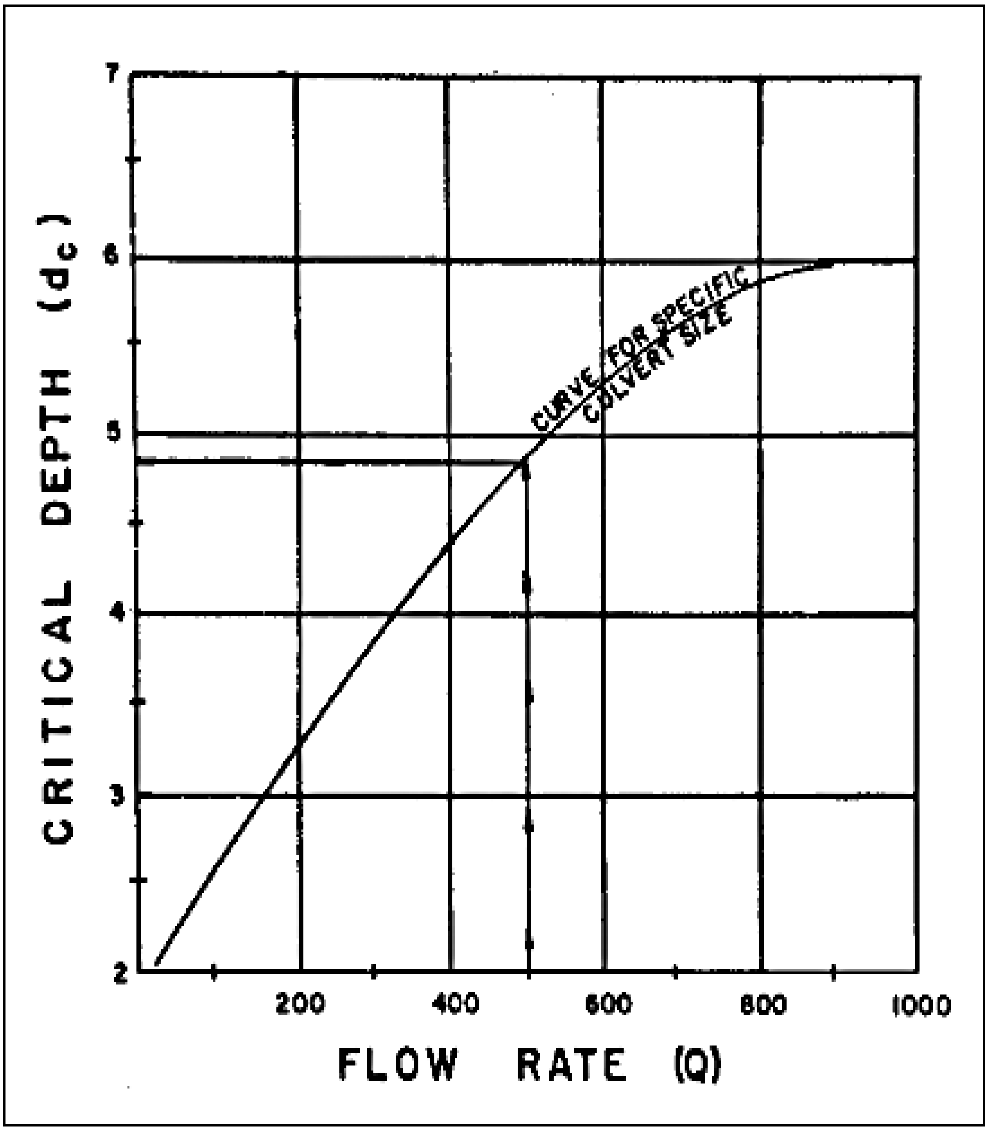


Figure 15 Critical Depth Chart

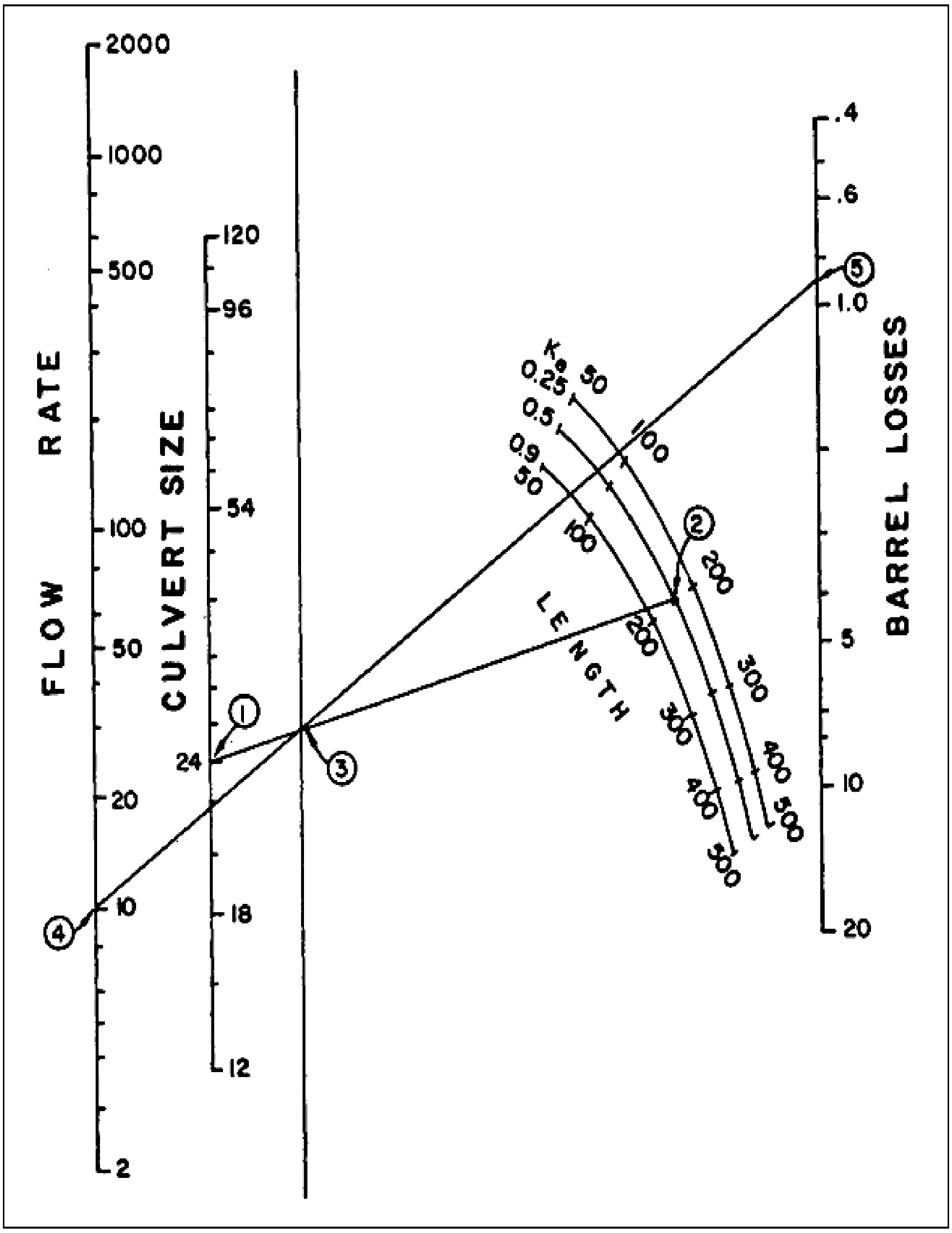


Figure 16 Outlet Control Nomograph

5.4.2 Protection works from erosion

Erosion and abrasion are familiar conditions that occurs in wadis, at drainage structures such as culvert exits and at drainage points, as the velocity of water at the exit in the culverts is greater than the velocity in the natural channels.

As mentioned previously, the velocity at the culvert exit varies between 3 and 6 m/s and may exceed this value for culverts on steep slopes. Under these conditions a minimum level of protection against erosion and abrasion should be provided. The objective of providing the required protection and its quality is to resist the velocity of water, with taking into consideration the natural conditions of the site. The proposed protection structures can withstand the design storm, (design flows and resulting velocities).

Generally, appropriate protection works will be provided in the entrance & exit of the structures: Loose riprap will be used in the entrance & exit of each culvert.

The dimensions of the stones used in protection depends on the velocities at the entrance & exit of the culvert, Isbach equation will be used to calculate D50 for the stones as follow:

$$D_{50} = \frac{1}{\varphi^2} \times \left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right) \times \frac{V^2}{2g}$$

Whereas:

D50: Avg. Diameter of stones (m).

Φ: Empirical factor (1.2).

γw: Specific weight of water (1 t/m^3).

γs: Specific weight of stones (2.65 t/m^3).

g: gravitational acceleration (9.81 m/s^2).

v: water velocity (m/s).

The thickness of the protective layer is twice the average diameter of the stones (2xD_{50}), and the length of the protective layer can be twice the height of the culvert.

5.4.3 Open channel

Manning's equation is commonly used to determine the velocity in open channels/ gravitational storm drainage pipes under uniform flow conditions. The equation is expressed as follows:

$$V = \frac{1}{n} R^{2/3} S^{0.5}$$

Where:

V, is the mean velocity of flow, in m/s.

n, is the Manning's roughness coefficient for open channel flow, n should be taken from appropriate tables, depending on channel types and materials, etc.

R, is the hydraulic radius in m.

S, is the slope of energy grade line, or channel bed slope, in m/m.

Acceptable free board:

The minimum permissible vertical distance from the maximum water surface inside the channel to the upper level of the channel (min. Free board) is 25 cm, the behavior of higher frequency discharges and the extent of their influence on both sides of the channel, as well as the effect of horizontal curves in the channel's path on the depth of water would be studied.

Design speed for open channels:

The design velocities for the flow should be non-settling and non-scouring. Minimum velocities should be self-cleaning and prevent solids sedimentation in the drainage, the maximum velocity shall be determined to reduce the negative effects of channel erosion.

- Min velocity in open channels is 0.75 m/s (self-cleaning velocity).
- Max Velocity in the lined channels of the entire cross section is 4.5 m/s for Grouted riprap & 6 m/s for lined concrete.

5.4.3.1 Side Ditch

The water is drained at cut sections by side ditches that convey the water drained from the embankment and cut slopes. After the runoff water is drained & collected to side ditch, it will be transported to fill sections then drained to natural ground level, Figure 17 shows the proposed typical side ditch at cut section along the EET in the natural condition and in agricultural/high water level areas (as some excavation works observed it).

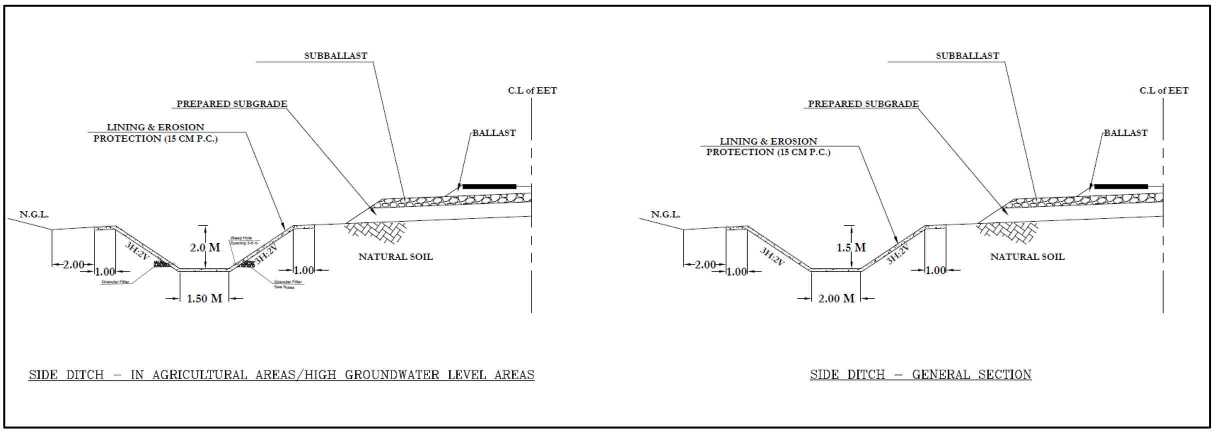


Figure 17 Proposed Typical Details for Cut Ditches at EET

5.4.3.2 Diversion Channel

The water is diverted from wadis (sloping towards the EET) by using diversion channels to be drained to the nearest culvert or diverted to the nearest wadi which would divert the water away from the project area, Figure 18 shows the typical detail of the diversion channels for the different cases along the EET.

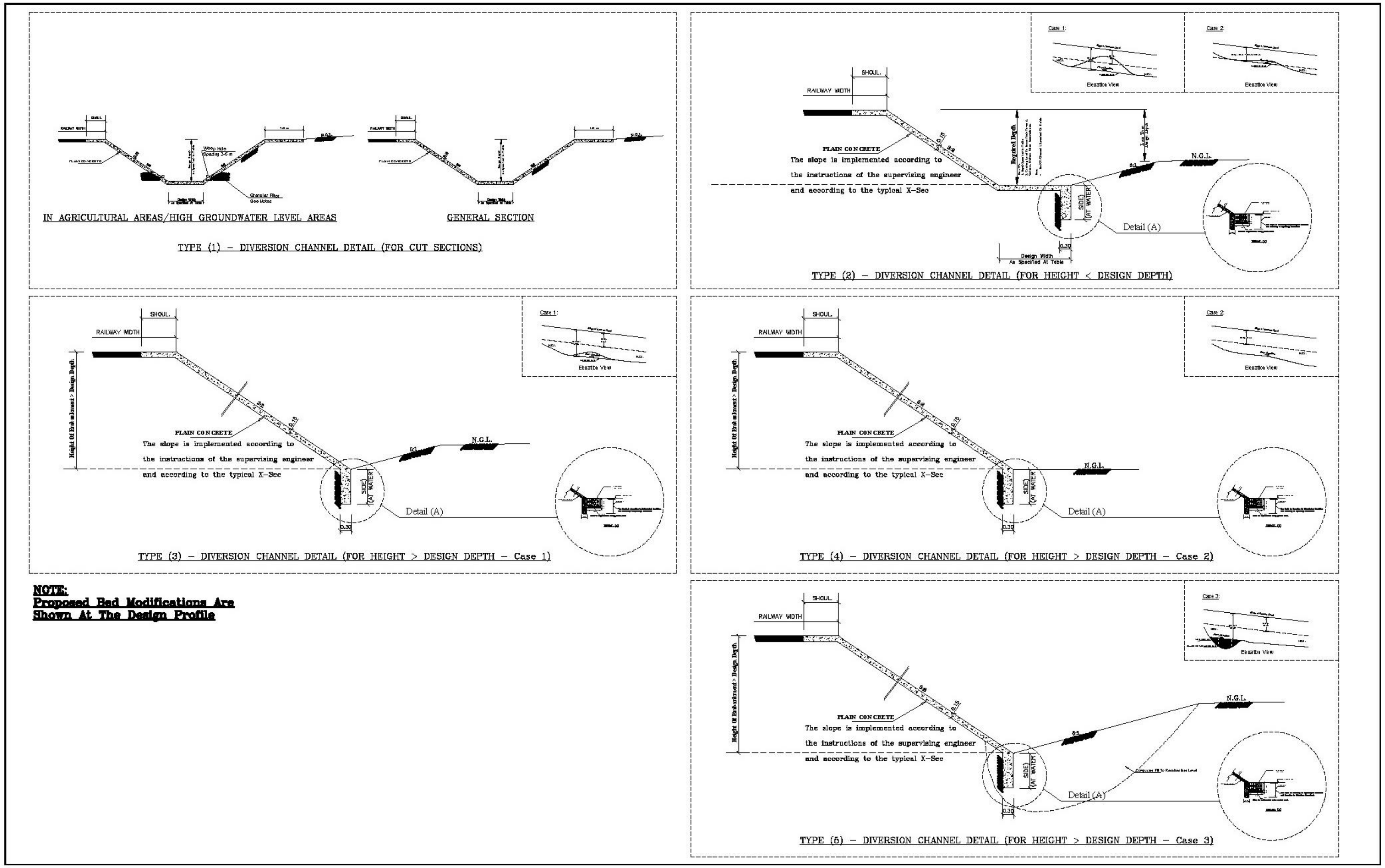


Figure 18 Typical Details for Proposed Diversion Channels at EET

5.4.4 Dike

The dike is used adjacent to some culverts in order to divert the flooding water to the culverts. The height of the dike is proposed to be higher than the water depth upstream the culvert. Figure 19 shows the typical detail of the dike along the EET.

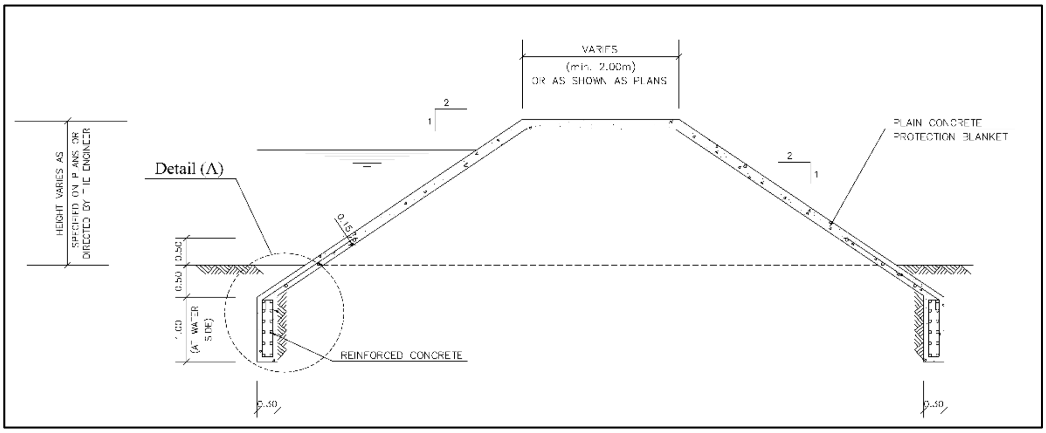


Figure 19 Typical Details for Proposed dike at EET

6 Protection works and recommendations

6.1 Proposed Works

Based on the hydrological study, the morphological & meteorological analysis, the following works were proposed to protect the area with all its components from the dangers of floods:

6.1.1 Proposed Culverts

Water is drained in the fill sections of the EET at the directions of natural wadis which is among the design criteria so that the water is not allowed to be stored or stagnant, Table 7 shows the data of the proposed culvert at the project.

Table 7 Proposed Culverts Data at EET Sector ''C'' Part (2)

No.	Station	Effective Watershed	No. of Vents	Size (mm)	Skew angle (°)	USIL (m)	DSIL (m)	Length (m)	Slope
1	433+345	W-01	7	Ø 1000	65°	368.89	368.16	59	1.24%
2	433+695	W-02	3	2000*1500	42°	366.64	366.3	81	0.42%
3	434+105	W-03	3	2000*1500	69°	366.7	366.61	52	0.17%
4	434+780	W-04	2	Ø 1000	66°	367.98	367.15	37	2.24%
5	435+850	W-05	6	Ø 1000	36°	343.97	342.71	182	0.69%
6	438+165	W-06	2	Ø 1000	79°	352.36	352.01	36	0.97%
7	440+070	W-07	7	Ø 1000	41°	332.08	329.38	144	1.87%
8	440+335	W-08	2	Ø 1000	85°	346.07	333.75	60	20.53%
9	440+960	W-09	6	2000*2000	39°	326.17	325.65	172	0.30%
10	447+930	W-10	7	Ø 1000	65°	321.51	320.34	46	2.54%
11	449+125	W-11	7	Ø 1000	81°	309.24	308.77	31	1.52%
12	452+920	W-12	8	2000*1500	86°	259.66	258.37	69	1.87%
13	458+875	W-13	5	2000*1500	72°	203.86	192.55	84	13.46%
14	459+545	W-14	6	Ø 1000	79°	202.64	189.42	61	21.67%
15	462+500	W-15	1	3000*3000	80°	171.26	170.5	65	1.17%
16	464+380	W-16	5	Ø 1000	57°	170.78	170.7	57	0.14%
17	466+000	W-17	15	2000*2000	71°	163.06	162.75	39	0.79%
18	469+590	W-18	3	2000*1500	87°	154.84	154.22	40	1.55%
19	473+165	W-19	25	3000*3000	84°	148.03	147.44	67	0.88%
20	475+315	W-20	7	Ø 1000	84°	160.05	158.89	36	3.22%
21	477+855	W-21	3	2000*1500	87°	135.83	134.37	61	2.39%
22	478+005	W-22	2	Ø 1000	72°	135.29	133.41	61	3.08%
23	478+280	W-23	2	Ø 1000	61°	133.84	132.25	57	2.79%
24	478+485	W-24	2	Ø 1000	48°	135.77	133.09	45	5.96%
25	478+800	W-25	3	Ø 1000	66°	125.07	123.83	65	1.91%

No.	Station	Effective Watershed	No. of Vents	Size (mm)	Skew angle (°)	USIL (m)	DSIL (m)	Length (m)	Slope
26	479+260	W-26	4	2000*1500	62°	122.83	121.84	53	1.87%
27	480+020	W-27	4	2000*1500	83°	118.21	117.7	37	1.38%

6.1.2 Proposed Diversion Channels

Diversion Channels were used to collect the water from the streams and transport it to the nearest culvert, Table 8 shows the data of the proposed diversion channels for both EET and parallel road, the attached drawings show the location and direction of the proposed channels on the plan and the profile, while the attached typical details show the X-Sec of the EET at channels location.

Table 8 Proposed Diversion Channels data at EET Sector "C" Part (2)

No.	Station		Effective Watershed	Location to EET Center line	Length (m)	Bottom Width (m)	Depth (m)	Side Slope (H:V)
	From	To						
1	432+670	433+320	W-02	Left	650	2	1.25	3:2
2	432+690	433+310	W-01	Right	620	2	1	3:2
3	433+830	434+030	W-03	Right	200	2	1.5	3:2
4	434+230	434+770	W-04	Right	540	2	1	3:2
5	436+720	435+770	W-05	Right	950	2	1	3:2
6	439+680	440+025	W-07	Right	345	2	1.25	3:2
7	442+205	443+620	W-01S	Right	1415	2	1	3:2
8	444+210	444+625	W-04S	Left	415	2	1	3:2
9	446+190	444+670	W-04S	Left	1520	2	1	3:2
10	445+590	444+710	W-03S	Right	880	2	1	3:2
11	448+830	449+125	W-11	Left	295	2	1	3:2
12	449+275	452+915	W-12	Left	3640	2	2	3:2
13	454+430	454+720	W-13	Left	290	2	2	3:2
14	454+720	457+520	W-13	Left	2800	2	2	3:2
15	457+550	458+865	W-13	Left	1315	2	1.75	3:2
16	462+790	464+370	W-16	Right	1580	2	1.5	3:2
17	467+560	469+580	W-18	Right	2020	2	1.5	3:2
18	470+540	469+580	W-18	Right	960	2	1.5	3:2
19	471+030	472+120	W-06S	Right	1090	2	1.5	3:2
20	472+380	472+720	W-06S	Right	340	2	1	3:2
21	474+620	473+230	W-07S	Right	1390	2	1.25	3:2
22	475+750	475+315	W-20	Right	435	2	1	3:2
23	476+210	477+505	W-21	Right	1295	2	1.25	3:2
24	477+940	478+010	W-22	Right	70	2	1	3:2
25	478+240	478+290	W-23	Right	50	2	1	3:2
26	479+150	479+270	W-26	Right	120	2	1.5	3:2
27	Road 7+640	Road 14+940	W-05S	Right To Parallel Road Center line	7300	2	3	3:2

6.1.3 Proposed Slope protections

Slope protections were used in all the fill sections to protect the side slopes from erosion, the attached typical details show the typical detail of the proposed slope protections.

6.1.4 Proposed Side Ditches

Side Ditches are relied on in all the cut sections of the project to collect water and transport it to the fill sections where the water is drained, the attached typical details show the details of the side ditch. Also, following dimensions are the standard dimensions of all Side Ditches at cut sections:

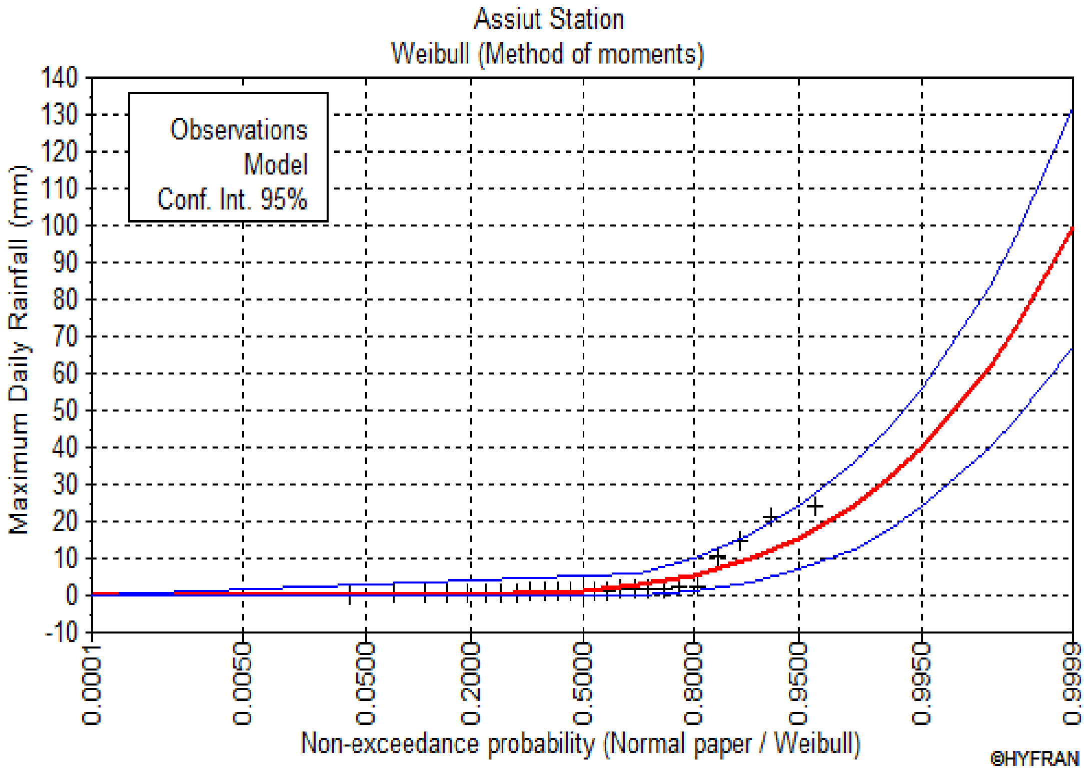
- General Case:
  - Bed Width = 2.00 m
  - Design Depth = 1.50 m
  - Side Slope (H:V) = 3:2

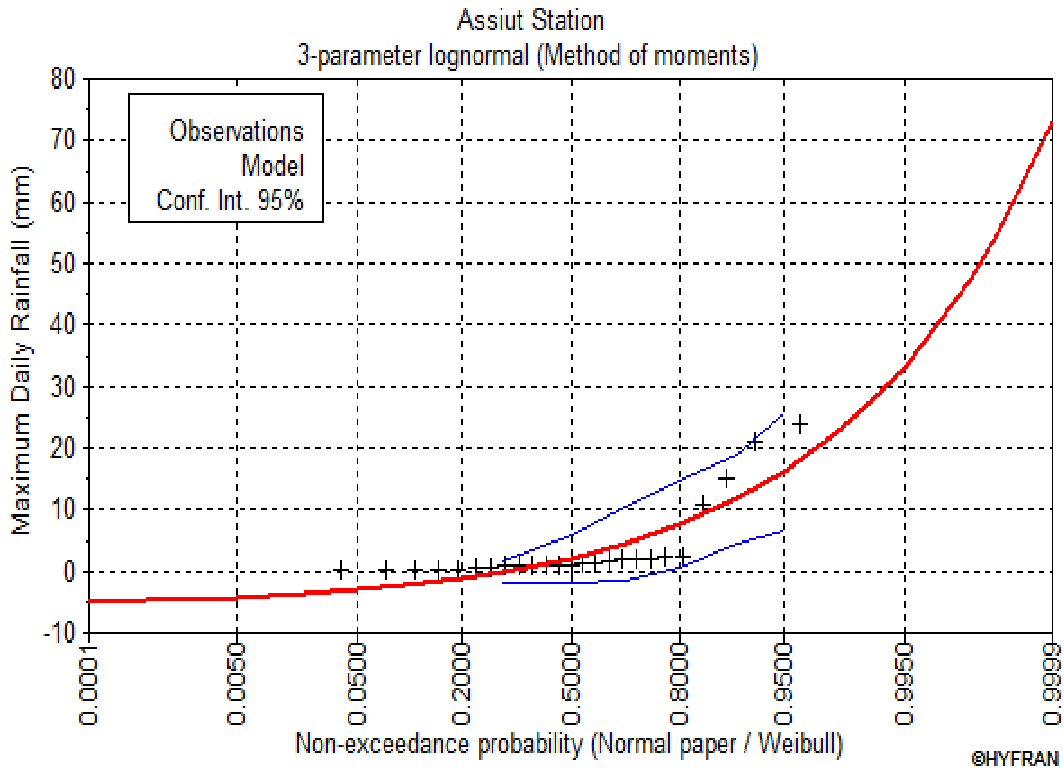
- Agricultural/high water level areas:
  - Bed Width = 1.00 m
  - Design Depth = 2.00 m
  - Side Slope (H:V) = 3:2

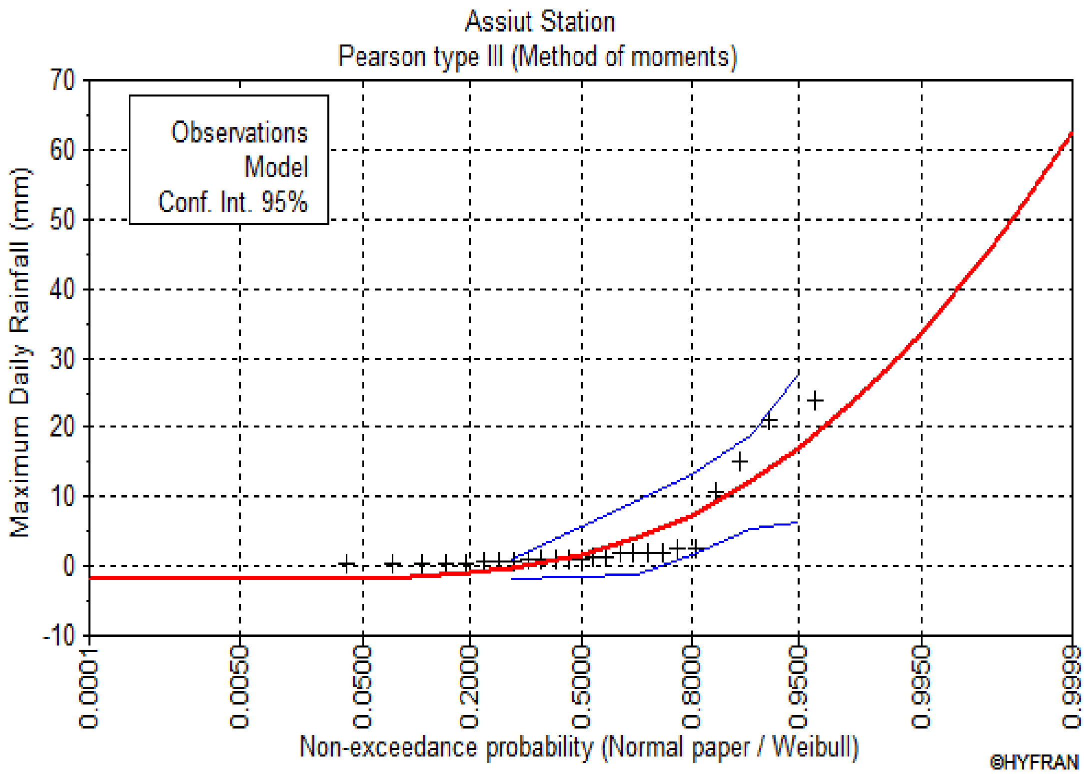
Address: Egypt: Villa 65, Mohamed Farid Axis, Hamd Sq., 5th Settlement, Cairo.
USA: 1856 Algonquin rd., Iowa City, IA 52245, Iowa State
Email: info@aiecons.com
Website: www.aiecons.com

7 Annex 1

7.1 Annex 1: Some of the different studied probability distributions for Assiut Airport Rainfall Station by HyFrAn+




Assiut Station
3-parameter lognormal (Method of moments)
Observations
Model
Conf. Int. 95%
Maximum Daily Rainfall (mm)
80
70
60
50
40
30
20
10
0
-10
0.0001
0.0050
0.0500
0.2000
0.5000
0.8000
0.9500
0.9950
0.9999
Non-exceedance probability (Normal paper / Weibull)
©HYFRAN


Assiut Station
Pearson type III (Method of moments)
Observations
Model
Conf. Int. 95%
Maximum Daily Rainfall (mm)
70
60
50
40
30
20
10
0
-10
0.0001
0.0050
0.0500
0.2000
0.5000
0.8000
0.9500
0.9950
0.9999
Non-exceedance probability (Normal paper / Weibull)
©HYFRAN

7.2 Annex 2: Bentley CulvertMaster reports for proposed culverts

Culvert Calculator Report
433+345

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.02
Computed Headwater Elevation	369.91 m	Discharge	8.2000 m³/s
Inlet Control HW Elev.	369.84 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	369.91 m	Control Type	Entrance Control

Grades

Upstream Invert	368.89 m	Downstream Invert	368.16 m
Length	59.00 m	Constructed Slope	0.012373 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.46 m
Slope Type	Steep	Normal Depth	0.46 m
Flow Regime	Supercritical	Critical Depth	0.62 m
Velocity Downstream	3.28 m/s	Critical Slope	0.004735 m/m

Section

Section Shape	Circular	Mannings Coefficient	0.013
Section Material	Concrete	Span	1.00 m
Section Size	1000	Rise	1.00 m
Number Sections	7		

Outlet Control Properties

Outlet Control HW Elev.	369.91 m	Upstream Velocity Head	0.26 m
Ke	0.50	Entrance Loss	0.13 m

Inlet Control Properties

Inlet Control HW Elev.	369.84 m	Flow Control	N/A
Inlet Type	Square edge w/headwall	Area Full	5.5 m²
K	0.00980	HDS 5 Chart	1
M	2.00000	HDS 5 Scale	1
C	0.03980	Equation Form	1
Y	0.67000		

Culvert Calculator Report
433+695

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.09
Computed Headwater Elevation	368.28 m	Discharge	17.0000 m³/s
Inlet Control HW Elev.	368.12 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	368.28 m	Control Type	Entrance Control

Grades

Upstream Invert	366.64 m	Downstream Invert	366.30 m
Length	81.00 m	Constructed Slope	0.004198 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.93 m
Slope Type	Steep	Normal Depth	0.93 m
Flow Regime	Supercritical	Critical Depth	0.94 m
Velocity Downstream	3.06 m/s	Critical Slope	0.004087 m/m

Section

Section Shape	Box	Mannings Coefficient	0.013
Section Material	Concrete	Span	2.00 m
Section Size	2000X1500	Rise	1.50 m
Number Sections	3		

Outlet Control Properties

Outlet Control HW Elev.	368.28 m	Upstream Velocity Head	0.47 m
Ke	0.50	Entrance Loss	0.23 m

Inlet Control Properties

Inlet Control HW Elev.	368.12 m	Flow Control	N/A
Inlet Type	45° wingwall flares - offset	Area Full	9.0 m²
K	0.49700	HDS 5 Chart	13
M	0.66700	HDS 5 Scale	1
C	0.03020	Equation Form	2
Y	0.83500		

Culvert Calculator Report
434+105

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.04
Computed Headwater Elevation	368.26 m	Discharge	16.2000 m³/s
Inlet Control HW Elev.	368.13 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	368.26 m	Control Type	Outlet Control

Grades

Upstream Invert	366.70 m	Downstream Invert	366.61 m
Length	52.00 m	Constructed Slope	0.001731 m/m

Hydraulic Profile

Profile	M2	Depth, Downstream	0.91 m
Slope Type	Mild	Normal Depth	1.25 m
Flow Regime	Subcritical	Critical Depth	0.91 m
Velocity Downstream	2.98 m/s	Critical Slope	0.004047 m/m

Section

Section Shape	Box	Mannings Coefficient	0.013
Section Material	Concrete	Span	2.00 m
Section Size	2000X1500	Rise	1.50 m
Number Sections	3		

Outlet Control Properties

Outlet Control HW Elev.	368.26 m	Upstream Velocity Head	0.30 m
Ke	0.50	Entrance Loss	0.15 m

Inlet Control Properties

Inlet Control HW Elev.	368.13 m	Flow Control	N/A
Inlet Type	45° wingwall flares - offset	Area Full	9.0 m²
K	0.49700	HDS 5 Chart	13
M	0.66700	HDS 5 Scale	1
C	0.03020	Equation Form	2
Y	0.83500		

Culvert Calculator Report
434+780

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	0.80
Computed Headwater Elevation	368.78 m	Discharge	1.5500 m³/s
Inlet Control HW Elev.	368.70 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	368.78 m	Control Type	Entrance Control

Grades

Upstream Invert	367.98 m	Downstream Invert	367.15 m
Length	37.00 m	Constructed Slope	0.022432 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.32 m
Slope Type	Steep	Normal Depth	0.32 m
Flow Regime	Supercritical	Critical Depth	0.50 m
Velocity Downstream	3.55 m/s	Critical Slope	0.004138 m/m

Section

Section Shape	Circular	Mannings Coefficient	0.013
Section Material	Concrete	Span	1.00 m
Section Size	1000	Rise	1.00 m
Number Sections	2		

Outlet Control Properties

Outlet Control HW Elev.	368.78 m	Upstream Velocity Head	0.20 m
Ke	0.50	Entrance Loss	0.10 m

Inlet Control Properties

Inlet Control HW Elev.	368.70 m	Flow Control	N/A
Inlet Type	Square edge w/headwall	Area Full	1.6 m²
K	0.00980	HDS 5 Chart	1
M	2.00000	HDS 5 Scale	1
C	0.03980	Equation Form	1
Y	0.67000		

Culvert Calculator Report
435+850

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.11
Computed Headwater Elevation	345.08 m	Discharge	8.0000 m³/s
Inlet Control HW Elev.	345.02 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	345.08 m	Control Type	Entrance Control

Grades

Upstream Invert	343.97 m	Downstream Invert	342.71 m
Length	182.00 m	Constructed Slope	0.006923 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.60 m
Slope Type	Steep	Normal Depth	0.60 m
Flow Regime	Supercritical	Critical Depth	0.67 m
Velocity Downstream	2.72 m/s	Critical Slope	0.005058 m/m

Section

Section Shape	Circular	Mannings Coefficient	0.013
Section Material	Concrete	Span	1.00 m
Section Size	1000	Rise	1.00 m
Number Sections	6		

Outlet Control Properties

Outlet Control HW Elev.	345.08 m	Upstream Velocity Head	0.29 m
Ke	0.50	Entrance Loss	0.15 m

Inlet Control Properties

Inlet Control HW Elev.	345.02 m	Flow Control	N/A
Inlet Type	Square edge w/headwall	Area Full	4.7 m²
K	0.00980	HDS 5 Chart	1
M	2.00000	HDS 5 Scale	1
C	0.03980	Equation Form	1
Y	0.67000		

Culvert Calculator Report
438+165

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	0.95
Computed Headwater Elevation	353.31 m	Discharge	2.0900 m³/s
Inlet Control HW Elev.	353.24 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	353.31 m	Control Type	Entrance Control

Grades

Upstream Invert	352.36 m	Downstream Invert	352.01 m
Length	36.00 m	Constructed Slope	0.009722 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.47 m
Slope Type	Steep	Normal Depth	0.47 m
Flow Regime	Supercritical	Critical Depth	0.59 m
Velocity Downstream	2.87 m/s	Critical Slope	0.004517 m/m

Section

Section Shape	Circular	Mannings Coefficient	0.013
Section Material	Concrete	Span	1.00 m
Section Size	1000	Rise	1.00 m
Number Sections	2		

Outlet Control Properties

Outlet Control HW Elev.	353.31 m	Upstream Velocity Head	0.24 m
Ke	0.50	Entrance Loss	0.12 m

Inlet Control Properties

Inlet Control HW Elev.	353.24 m	Flow Control	N/A
Inlet Type	Square edge w/headwall	Area Full	1.6 m²
K	0.00980	HDS 5 Chart	1
M	2.00000	HDS 5 Scale	1
C	0.03980	Equation Form	1
Y	0.67000		

Culvert Calculator Report
440+070

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.10
Computed Headwater Elevation	333.18 m	Discharge	9.3000 m³/s
Inlet Control HW Elev.	333.12 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	333.18 m	Control Type	Entrance Control

Grades

Upstream Invert	332.08 m	Downstream Invert	329.38 m
Length	144.00 m	Constructed Slope	0.018750 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.44 m
Slope Type	Steep	Normal Depth	0.44 m
Flow Regime	Supercritical	Critical Depth	0.66 m
Velocity Downstream	3.96 m/s	Critical Slope	0.005048 m/m

Section

Section Shape	Circular	Mannings Coefficient	0.013
Section Material	Concrete	Span	1.00 m
Section Size	1000	Rise	1.00 m
Number Sections	7		

Outlet Control Properties

Outlet Control HW Elev.	333.18 m	Upstream Velocity Head	0.29 m
Ke	0.50	Entrance Loss	0.15 m

Inlet Control Properties

Inlet Control HW Elev.	333.12 m	Flow Control	N/A
Inlet Type	Square edge w/headwall	Area Full	5.5 m²
K	0.00980	HDS 5 Chart	1
M	2.00000	HDS 5 Scale	1
C	0.03980	Equation Form	1
Y	0.67000		

Culvert Calculator Report
440+335

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	0.67
Computed Headwater Elevation	346.74 m	Discharge	1.1400 m³/s
Inlet Control HW Elev.	346.57 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	346.74 m	Control Type	Entrance Control

Grades

Upstream Invert	346.07 m	Downstream Invert	333.75 m
Length	60.00 m	Constructed Slope	0.205333 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.16 m
Slope Type	Steep	Normal Depth	0.16 m
Flow Regime	Supercritical	Critical Depth	0.43 m
Velocity Downstream	7.31 m/s	Critical Slope	0.003923 m/m

Section

Section Shape	Circular	Mannings Coefficient	0.013
Section Material	Concrete	Span	1.00 m
Section Size	1000	Rise	1.00 m
Number Sections	2		

Outlet Control Properties

Outlet Control HW Elev.	346.74 m	Upstream Velocity Head	0.16 m
Ke	0.50	Entrance Loss	0.08 m

Inlet Control Properties

Inlet Control HW Elev.	346.57 m	Flow Control	N/A
Inlet Type	Square edge w/headwall	Area Full	1.6 m²
K	0.00980	HDS 5 Chart	1
M	2.00000	HDS 5 Scale	1
C	0.03980	Equation Form	1
Y	0.67000		

Culvert Calculator Report
440+960

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.03
Computed Headwater Elevation	328.24 m	Discharge	49.6000 m³/s
Inlet Control HW Elev.	328.07 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	328.24 m	Control Type	Outlet Control

Grades

Upstream Invert	326.17 m	Downstream Invert	325.65 m
Length	172.00 m	Constructed Slope	0.003023 m/m

Hydraulic Profile

Profile	M2	Depth, Downstream	1.20 m
Slope Type	Mild	Normal Depth	1.40 m
Flow Regime	Subcritical	Critical Depth	1.20 m
Velocity Downstream	3.44 m/s	Critical Slope	0.004467 m/m

Section

Section Shape	Box	Mannings Coefficient	0.013
Section Material	Concrete	Span	2.00 m
Section Size	2000X2000	Rise	2.00 m
Number Sections	6		

Outlet Control Properties

Outlet Control HW Elev.	328.24 m	Upstream Velocity Head	0.44 m
Ke	0.50	Entrance Loss	0.22 m

Inlet Control Properties

Inlet Control HW Elev.	328.07 m	Flow Control	N/A
Inlet Type	45° wingwall flares - offset	Area Full	24.0 m²
K	0.49700	HDS 5 Chart	13
M	0.66700	HDS 5 Scale	1
C	0.03020	Equation Form	2
Y	0.83500		

Culvert Calculator Report
447+930

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.03
Computed Headwater Elevation	322.54 m	Discharge	8.3000 m³/s
Inlet Control HW Elev.	322.46 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	322.54 m	Control Type	Entrance Control

Grades

Upstream Invert	321.51 m	Downstream Invert	320.34 m
Length	46.00 m	Constructed Slope	0.025435 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.39 m
Slope Type	Steep	Normal Depth	0.38 m
Flow Regime	Supercritical	Critical Depth	0.63 m
Velocity Downstream	4.17 m/s	Critical Slope	0.004761 m/m

Section

Section Shape	Circular	Mannings Coefficient	0.013
Section Material	Concrete	Span	1.00 m
Section Size	1000	Rise	1.00 m
Number Sections	7		

Outlet Control Properties

Outlet Control HW Elev.	322.54 m	Upstream Velocity Head	0.27 m
Ke	0.50	Entrance Loss	0.13 m

Inlet Control Properties

Inlet Control HW Elev.	322.46 m	Flow Control	N/A
Inlet Type	Square edge w/headwall	Area Full	5.5 m²
K	0.00980	HDS 5 Chart	1
M	2.00000	HDS 5 Scale	1
C	0.03980	Equation Form	1
Y	0.67000		

Culvert Calculator Report
449+125

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.01
Computed Headwater Elevation	310.25 m	Discharge	8.1000 m³/s
Inlet Control HW Elev.	310.18 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	310.25 m	Control Type	Entrance Control

Grades

Upstream Invert	309.24 m	Downstream Invert	308.77 m
Length	31.00 m	Constructed Slope	0.015161 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.45 m
Slope Type	Steep	Normal Depth	0.43 m
Flow Regime	Supercritical	Critical Depth	0.62 m
Velocity Downstream	3.35 m/s	Critical Slope	0.004709 m/m

Section

Section Shape	Circular	Mannings Coefficient	0.013
Section Material	Concrete	Span	1.00 m
Section Size	1000	Rise	1.00 m
Number Sections	7		

Outlet Control Properties

Outlet Control HW Elev.	310.25 m	Upstream Velocity Head	0.26 m
Ke	0.50	Entrance Loss	0.13 m

Inlet Control Properties

Inlet Control HW Elev.	310.18 m	Flow Control	N/A
Inlet Type	Square edge w/headwall	Area Full	5.5 m²
K	0.00980	HDS 5 Chart	1
M	2.00000	HDS 5 Scale	1
C	0.03980	Equation Form	1
Y	0.67000		

Culvert Calculator Report
452+920

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.14
Computed Headwater Elevation	261.37 m	Discharge	48.6000 m³/s
Inlet Control HW Elev.	261.21 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	261.37 m	Control Type	Entrance Control

Grades

Upstream Invert	259.66 m	Downstream Invert	258.37 m
Length	69.00 m	Constructed Slope	0.018696 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.60 m
Slope Type	Steep	Normal Depth	0.57 m
Flow Regime	Supercritical	Critical Depth	0.98 m
Velocity Downstream	5.09 m/s	Critical Slope	0.004148 m/m

Section

Section Shape	Box	Mannings Coefficient	0.013
Section Material	Concrete	Span	2.00 m
Section Size	2000X1500	Rise	1.50 m
Number Sections	8		

Outlet Control Properties

Outlet Control HW Elev.	261.37 m	Upstream Velocity Head	0.49 m
Ke	0.50	Entrance Loss	0.24 m

Inlet Control Properties

Inlet Control HW Elev.	261.21 m	Flow Control	N/A
Inlet Type	45° wingwall flares - offset	Area Full	24.0 m²
K	0.49700	HDS 5 Chart	13
M	0.66700	HDS 5 Scale	1
C	0.03020	Equation Form	2
Y	0.83500		

Culvert Calculator Report
458+875

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.01
Computed Headwater Elevation	205.37 m	Discharge	25.2000 m³/s
Inlet Control HW Elev.	205.23 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	205.37 m	Control Type	Entrance Control

Grades

Upstream Invert	203.86 m	Downstream Invert	192.55 m
Length	84.00 m	Constructed Slope	0.134643 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.26 m
Slope Type	Steep	Normal Depth	0.26 m
Flow Regime	Supercritical	Critical Depth	0.87 m
Velocity Downstream	9.80 m/s	Critical Slope	0.003993 m/m

Section

Section Shape	Box	Mannings Coefficient	0.013
Section Material	Concrete	Span	2.00 m
Section Size	2000X1500	Rise	1.50 m
Number Sections	5		

Outlet Control Properties

Outlet Control HW Elev.	205.37 m	Upstream Velocity Head	0.43 m
Ke	0.50	Entrance Loss	0.22 m

Inlet Control Properties

Inlet Control HW Elev.	205.23 m	Flow Control	N/A
Inlet Type	45° wingwall flares - offset	Area Full	15.0 m²
K	0.49700	HDS 5 Chart	13
M	0.66700	HDS 5 Scale	1
C	0.03020	Equation Form	2
Y	0.83500		

Culvert Calculator Report
459+545

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.12
Computed Headwater Elevation	203.76 m	Discharge	8.2000 m³/s
Inlet Control HW Elev.	203.60 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	203.76 m	Control Type	Entrance Control

Grades

Upstream Invert	202.64 m	Downstream Invert	189.42 m
Length	61.00 m	Constructed Slope	0.216721 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.24 m
Slope Type	Steep	Normal Depth	0.24 m
Flow Regime	Supercritical	Critical Depth	0.67 m
Velocity Downstream	9.64 m/s	Critical Slope	0.005131 m/m

Section

Section Shape	Circular	Mannings Coefficient	0.013
Section Material	Concrete	Span	1.00 m
Section Size	1000	Rise	1.00 m
Number Sections	6		

Outlet Control Properties

Outlet Control HW Elev.	203.76 m	Upstream Velocity Head	0.30 m
Ke	0.50	Entrance Loss	0.15 m

Inlet Control Properties

Inlet Control HW Elev.	203.60 m	Flow Control	N/A
Inlet Type	Square edge w/headwall	Area Full	4.7 m²
K	0.00980	HDS 5 Chart	1
M	2.00000	HDS 5 Scale	1
C	0.03980	Equation Form	1
Y	0.67000		

Culvert Calculator Report
462+500

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	0.62
Computed Headwater Elevation	173.13 m	Discharge	10.4000 m³/s
Inlet Control HW Elev.	172.95 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	173.13 m	Control Type	Entrance Control

Grades

Upstream Invert	171.26 m	Downstream Invert	170.50 m
Length	65.00 m	Constructed Slope	0.011692 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.73 m
Slope Type	Steep	Normal Depth	0.69 m
Flow Regime	Supercritical	Critical Depth	1.07 m
Velocity Downstream	4.72 m/s	Critical Slope	0.003322 m/m

Section

Section Shape	Box	Mannings Coefficient	0.013
Section Material	Concrete	Span	3.00 m
Section Size	3000x3000	Rise	3.00 m
Number Sections	1		

Outlet Control Properties

Outlet Control HW Elev.	173.13 m	Upstream Velocity Head	0.54 m
Ke	0.50	Entrance Loss	0.27 m

Inlet Control Properties

Inlet Control HW Elev.	172.95 m	Flow Control	N/A
Inlet Type	45° wingwall flares - offset	Area Full	9.0 m²
K	0.49700	HDS 5 Chart	13
M	0.66700	HDS 5 Scale	1
C	0.03020	Equation Form	2
Y	0.83500		

Culvert Calculator Report
464+380

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.03
Computed Headwater Elevation	171.81 m	Discharge	5.7000 m³/s
Inlet Control HW Elev.	171.72 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	171.81 m	Control Type	Outlet Control

Grades

Upstream Invert	170.78 m	Downstream Invert	170.70 m
Length	57.00 m	Constructed Slope	0.001404 m/m

Hydraulic Profile

Profile	M2	Depth, Downstream	0.61 m
Slope Type	Mild	Normal Depth	N/A m
Flow Regime	Subcritical	Critical Depth	0.61 m
Velocity Downstream	2.26 m/s	Critical Slope	0.004678 m/m

Section

Section Shape	Circular	Mannings Coefficient	0.013
Section Material	Concrete	Span	1.00 m
Section Size	1000	Rise	1.00 m
Number Sections	5		

Outlet Control Properties

Outlet Control HW Elev.	171.81 m	Upstream Velocity Head	0.14 m
Ke	0.50	Entrance Loss	0.07 m

Inlet Control Properties

Inlet Control HW Elev.	171.72 m	Flow Control	N/A
Inlet Type	Square edge w/headwall	Area Full	3.9 m²
K	0.00980	HDS 5 Chart	1
M	2.00000	HDS 5 Scale	1
C	0.03980	Equation Form	1
Y	0.67000		

Culvert Calculator Report
466+000

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.14
Computed Headwater Elevation	165.33 m	Discharge	139.1000 m³/s
Inlet Control HW Elev.	165.11 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	165.33 m	Control Type	Entrance Control

Grades

Upstream Invert	163.06 m	Downstream Invert	162.75 m
Length	39.00 m	Constructed Slope	0.007949 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	1.10 m
Slope Type	Steep	Normal Depth	1.05 m
Flow Regime	Supercritical	Critical Depth	1.30 m
Velocity Downstream	4.23 m/s	Critical Slope	0.004609 m/m

Section

Section Shape	Box	Mannings Coefficient	0.013
Section Material	Concrete	Span	2.00 m
Section Size	2000X2000	Rise	2.00 m
Number Sections	15		

Outlet Control Properties

Outlet Control HW Elev.	165.33 m	Upstream Velocity Head	0.65 m
Ke	0.50	Entrance Loss	0.32 m

Inlet Control Properties

Inlet Control HW Elev.	165.11 m	Flow Control	N/A
Inlet Type	45° wingwall flares - offset	Area Full	60.0 m²
K	0.49700	HDS 5 Chart	13
M	0.66700	HDS 5 Scale	1
C	0.03020	Equation Form	2
Y	0.83500		

Culvert Calculator Report
469+590

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	0.98
Computed Headwater Elevation	156.31 m	Discharge	14.5000 m³/s
Inlet Control HW Elev.	156.17 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	156.31 m	Control Type	Entrance Control

Grades

Upstream Invert	154.84 m	Downstream Invert	154.22 m
Length	40.00 m	Constructed Slope	0.015500 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.56 m
Slope Type	Steep	Normal Depth	0.52 m
Flow Regime	Supercritical	Critical Depth	0.84 m
Velocity Downstream	4.30 m/s	Critical Slope	0.003962 m/m

Section

Section Shape	Box	Mannings Coefficient	0.013
Section Material	Concrete	Span	2.00 m
Section Size	2000X1500	Rise	1.50 m
Number Sections	3		

Outlet Control Properties

Outlet Control HW Elev.	156.31 m	Upstream Velocity Head	0.42 m
Ke	0.50	Entrance Loss	0.21 m

Inlet Control Properties

Inlet Control HW Elev.	156.17 m	Flow Control	N/A
Inlet Type	45° wingwall flares - offset	Area Full	9.0 m²
K	0.49700	HDS 5 Chart	13
M	0.66700	HDS 5 Scale	1
C	0.03020	Equation Form	2
Y	0.83500		

Culvert Calculator Report
473+165

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.15
Computed Headwater Elevation	151.48 m	Discharge	650.2000 m³/s
Inlet Control HW Elev.	151.15 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	151.48 m	Control Type	Entrance Control

Grades

Upstream Invert	148.03 m	Downstream Invert	147.44 m
Length	67.00 m	Constructed Slope	0.008806 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	1.57 m
Slope Type	Steep	Normal Depth	1.47 m
Flow Regime	Supercritical	Critical Depth	1.97 m
Velocity Downstream	5.53 m/s	Critical Slope	0.004046 m/m

Section

Section Shape	Box	Mannings Coefficient	0.013
Section Material	Concrete	Span	3.00 m
Section Size	3000x3000	Rise	3.00 m
Number Sections	25		

Outlet Control Properties

Outlet Control HW Elev.	151.48 m	Upstream Velocity Head	0.99 m
Ke	0.50	Entrance Loss	0.49 m

Inlet Control Properties

Inlet Control HW Elev.	151.15 m	Flow Control	N/A
Inlet Type	45° wingwall flares - offset	Area Full	225.0 m²
K	0.49700	HDS 5 Chart	13
M	0.66700	HDS 5 Scale	1
C	0.03020	Equation Form	2
Y	0.83500		

Culvert Calculator Report
475+315

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.10
Computed Headwater Elevation	161.15 m	Discharge	9.2000 m³/s
Inlet Control HW Elev.	161.08 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	161.15 m	Control Type	Entrance Control

Grades

Upstream Invert	160.05 m	Downstream Invert	158.89 m
Length	36.00 m	Constructed Slope	0.032222 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.40 m
Slope Type	Steep	Normal Depth	0.38 m
Flow Regime	Supercritical	Critical Depth	0.66 m
Velocity Downstream	4.50 m/s	Critical Slope	0.005017 m/m

Section

Section Shape	Circular	Mannings Coefficient	0.013
Section Material	Concrete	Span	1.00 m
Section Size	1000	Rise	1.00 m
Number Sections	7		

Outlet Control Properties

Outlet Control HW Elev.	161.15 m	Upstream Velocity Head	0.29 m
Ke	0.50	Entrance Loss	0.15 m

Inlet Control Properties

Inlet Control HW Elev.	161.08 m	Flow Control	N/A
Inlet Type	Square edge w/headwall	Area Full	5.5 m²
K	0.00980	HDS 5 Chart	1
M	2.00000	HDS 5 Scale	1
C	0.03980	Equation Form	1
Y	0.67000		

Culvert Calculator Report
477+855

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.05
Computed Headwater Elevation	137.41 m	Discharge	16.1000 m³/s
Inlet Control HW Elev.	137.26 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	137.41 m	Control Type	Entrance Control

Grades

Upstream Invert	135.83 m	Downstream Invert	134.37 m
Length	61.00 m	Constructed Slope	0.023934 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.51 m
Slope Type	Steep	Normal Depth	0.48 m
Flow Regime	Supercritical	Critical Depth	0.90 m
Velocity Downstream	5.29 m/s	Critical Slope	0.004042 m/m

Section

Section Shape	Box	Mannings Coefficient	0.013
Section Material	Concrete	Span	2.00 m
Section Size	2000X1500	Rise	1.50 m
Number Sections	3		

Outlet Control Properties

Outlet Control HW Elev.	137.41 m	Upstream Velocity Head	0.45 m
Ke	0.50	Entrance Loss	0.23 m

Inlet Control Properties

Inlet Control HW Elev.	137.26 m	Flow Control	N/A
Inlet Type	45° wingwall flares - offset	Area Full	9.0 m²
K	0.49700	HDS 5 Chart	13
M	0.66700	HDS 5 Scale	1
C	0.03020	Equation Form	2
Y	0.83500		

Culvert Calculator Report
478+005

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	0.55
Computed Headwater Elevation	135.84 m	Discharge	0.8000 m³/s
Inlet Control HW Elev.	135.77 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	135.84 m	Control Type	Entrance Control

Grades

Upstream Invert	135.29 m	Downstream Invert	133.41 m
Length	61.00 m	Constructed Slope	0.030820 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.21 m
Slope Type	Steep	Normal Depth	0.21 m
Flow Regime	Supercritical	Critical Depth	0.36 m
Velocity Downstream	3.38 m/s	Critical Slope	0.003807 m/m

Section

Section Shape	Circular	Mannings Coefficient	0.013
Section Material	Concrete	Span	1.00 m
Section Size	1000	Rise	1.00 m
Number Sections	2		

Outlet Control Properties

Outlet Control HW Elev.	135.84 m	Upstream Velocity Head	0.13 m
Ke	0.50	Entrance Loss	0.07 m

Inlet Control Properties

Inlet Control HW Elev.	135.77 m	Flow Control	N/A
Inlet Type	Square edge w/headwall	Area Full	1.6 m²
K	0.00980	HDS 5 Chart	1
M	2.00000	HDS 5 Scale	1
C	0.03980	Equation Form	1
Y	0.67000		

Culvert Calculator Report
478+280

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	0.39
Computed Headwater Elevation	134.23 m	Discharge	0.4200 m³/s
Inlet Control HW Elev.	134.17 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	134.23 m	Control Type	Entrance Control

Grades

Upstream Invert	133.84 m	Downstream Invert	132.25 m
Length	57.00 m	Constructed Slope	0.027895 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.16 m
Slope Type	Steep	Normal Depth	0.16 m
Flow Regime	Supercritical	Critical Depth	0.25 m
Velocity Downstream	2.70 m/s	Critical Slope	0.003797 m/m

Section

Section Shape	Circular	Mannings Coefficient	0.013
Section Material	Concrete	Span	1.00 m
Section Size	1000	Rise	1.00 m
Number Sections	2		

Outlet Control Properties

Outlet Control HW Elev.	134.23 m	Upstream Velocity Head	0.09 m
Ke	0.50	Entrance Loss	0.05 m

Inlet Control Properties

Inlet Control HW Elev.	134.17 m	Flow Control	N/A
Inlet Type	Square edge w/headwall	Area Full	1.6 m²
K	0.00980	HDS 5 Chart	1
M	2.00000	HDS 5 Scale	1
C	0.03980	Equation Form	1
Y	0.67000		

Culvert Calculator Report
478+485

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	0.25
Computed Headwater Elevation	136.02 m	Discharge	0.1800 m³/s
Inlet Control HW Elev.	135.96 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	136.02 m	Control Type	Entrance Control

Grades

Upstream Invert	135.77 m	Downstream Invert	133.09 m
Length	45.00 m	Constructed Slope	0.059556 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.09 m
Slope Type	Steep	Normal Depth	0.09 m
Flow Regime	Supercritical	Critical Depth	0.17 m
Velocity Downstream	2.73 m/s	Critical Slope	0.004005 m/m

Section

Section Shape	Circular	Mannings Coefficient	0.013
Section Material	Concrete	Span	1.00 m
Section Size	1000	Rise	1.00 m
Number Sections	2		

Outlet Control Properties

Outlet Control HW Elev.	136.02 m	Upstream Velocity Head	0.06 m
Ke	0.50	Entrance Loss	0.03 m

Inlet Control Properties

Inlet Control HW Elev.	135.96 m	Flow Control	N/A
Inlet Type	Square edge w/headwall	Area Full	1.6 m²
K	0.00980	HDS 5 Chart	1
M	2.00000	HDS 5 Scale	1
C	0.03980	Equation Form	1
Y	0.67000		

Culvert Calculator Report
478+800

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.02
Computed Headwater Elevation	126.09 m	Discharge	3.5000 m³/s
Inlet Control HW Elev.	126.02 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	126.09 m	Control Type	Entrance Control

Grades

Upstream Invert	125.07 m	Downstream Invert	123.83 m
Length	65.00 m	Constructed Slope	0.019077 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.41 m
Slope Type	Steep	Normal Depth	0.41 m
Flow Regime	Supercritical	Critical Depth	0.62 m
Velocity Downstream	3.85 m/s	Critical Slope	0.004727 m/m

Section

Section Shape	Circular	Mannings Coefficient	0.013
Section Material	Concrete	Span	1.00 m
Section Size	1000	Rise	1.00 m
Number Sections	3		

Outlet Control Properties

Outlet Control HW Elev.	126.09 m	Upstream Velocity Head	0.26 m
Ke	0.50	Entrance Loss	0.13 m

Inlet Control Properties

Inlet Control HW Elev.	126.02 m	Flow Control	N/A
Inlet Type	Square edge w/headwall	Area Full	2.4 m²
K	0.00980	HDS 5 Chart	1
M	2.00000	HDS 5 Scale	1
C	0.03980	Equation Form	1
Y	0.67000		

Culvert Calculator Report
479+260

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	0.95
Computed Headwater Elevation	124.25 m	Discharge	18.4000 m³/s
Inlet Control HW Elev.	124.12 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	124.25 m	Control Type	Entrance Control

Grades

Upstream Invert	122.83 m	Downstream Invert	121.84 m
Length	53.00 m	Constructed Slope	0.018679 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.50 m
Slope Type	Steep	Normal Depth	0.47 m
Flow Regime	Supercritical	Critical Depth	0.81 m
Velocity Downstream	4.63 m/s	Critical Slope	0.003927 m/m

Section

Section Shape	Box	Mannings Coefficient	0.013
Section Material	Concrete	Span	2.00 m
Section Size	2000X1500	Rise	1.50 m
Number Sections	4		

Outlet Control Properties

Outlet Control HW Elev.	124.25 m	Upstream Velocity Head	0.41 m
Ke	0.50	Entrance Loss	0.20 m

Inlet Control Properties

Inlet Control HW Elev.	124.12 m	Flow Control	Unsubmerged
Inlet Type	45° wingwall flares - offset	Area Full	12.0 m²
K	0.49700	HDS 5 Chart	13
M	0.66700	HDS 5 Scale	1
C	0.03020	Equation Form	2
Y	0.83500		

Culvert Calculator Report
480+020

Solve For: Headwater Elevation

Culvert Summary

Allowable HW Elevation	0.00 m	Headwater Depth/Height	1.15
Computed Headwater Elevation	119.94 m	Discharge	24.6000 m³/s
Inlet Control HW Elev.	119.77 m	Tailwater Elevation	0.00 m
Outlet Control HW Elev.	119.94 m	Control Type	Entrance Control

Grades

Upstream Invert	118.21 m	Downstream Invert	117.70 m
Length	37.00 m	Constructed Slope	0.013784 m/m

Hydraulic Profile

Profile	S2	Depth, Downstream	0.70 m
Slope Type	Steep	Normal Depth	0.64 m
Flow Regime	Supercritical	Critical Depth	0.99 m
Velocity Downstream	4.39 m/s	Critical Slope	0.004159 m/m

Section

Section Shape	Box	Mannings Coefficient	0.013
Section Material	Concrete	Span	2.00 m
Section Size	2000X1500	Rise	1.50 m
Number Sections	4		

Outlet Control Properties

Outlet Control HW Elev.	119.94 m	Upstream Velocity Head	0.49 m
Ke	0.50	Entrance Loss	0.25 m

Inlet Control Properties

Inlet Control HW Elev.	119.77 m	Flow Control	N/A
Inlet Type	45° wingwall flares - offset	Area Full	12.0 m²
K	0.49700	HDS 5 Chart	13
M	0.66700	HDS 5 Scale	1
C	0.03020	Equation Form	2
Y	0.83500		

Annex 3: Bentley FlowMaster reports for proposed diversion channels

Worksheet for From St. 432+670 to St. 433+320

Project Description

Friction Method	Manning Formula	
Solve For	Normal Depth	

Input Data

Roughness Coefficient	0.015	
Channel Slope	1.38000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	17.00	m^3/s

Results

Normal Depth	0.92	m
Flow Area	3.11	m^2
Wetted Perimeter	5.31	m
Hydraulic Radius	0.58	m
Top Width	4.76	m
Critical Depth	1.39	m
Critical Slope	0.00269	m/m
Velocity	5.47	m/s
Velocity Head	1.53	m
Specific Energy	2.45	m
Froude Number	2.16	
Flow Type	Supercritical	

Worksheet for From St. 432+690 to St. 433+310

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	1.38000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	8.20	m^3/s

Results

Normal Depth	0.62	m
Flow Area	1.83	m^2
Wetted Perimeter	4.25	m
Hydraulic Radius	0.43	m
Top Width	3.87	m
Critical Depth	0.94	m
Critical Slope	0.00293	m/m
Velocity	4.47	m/s
Velocity Head	1.02	m
Specific Energy	1.64	m
Froude Number	2.08	
Flow Type	Supercritical	

Worksheet for From St. 433+830 to St. 434+030

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	0.43000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	16.20	m³/s

Results

Normal Depth	1.21	m
Flow Area	4.60	m²
Wetted Perimeter	6.35	m
Hydraulic Radius	0.72	m
Top Width	5.62	m
Critical Depth	1.35	m
Critical Slope	0.00271	m/m
Velocity	3.52	m/s
Velocity Head	0.63	m
Specific Energy	1.84	m
Froude Number	1.24	
Flow Type	Supercritical	

Worksheet for From St. 434+230 to St. 434+770

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	0.91000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	1.50	m³/s

Results

Normal Depth	0.27	m
Flow Area	0.65	m²
Wetted Perimeter	2.97	m
Hydraulic Radius	0.22	m
Top Width	2.81	m
Critical Depth	0.35	m
Critical Slope	0.00364	m/m
Velocity	2.31	m/s
Velocity Head	0.27	m
Specific Energy	0.54	m
Froude Number	1.53	
Flow Type	Supercritical	

Worksheet for From St. 436+720 to St. 435+770

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	1.13000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	8.00	m^3/s

Results

Normal Depth	0.65	m
Flow Area	1.94	m^2
Wetted Perimeter	4.34	m
Hydraulic Radius	0.45	m
Top Width	3.95	m
Critical Depth	0.93	m
Critical Slope	0.00294	m/m
Velocity	4.13	m/s
Velocity Head	0.87	m
Specific Energy	1.52	m
Froude Number	1.89	
Flow Type	Supercritical	

Worksheet for From St. 439+680 to St. 440+025

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	0.45000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	9.30	m³/s

Results

Normal Depth	0.90	m
Flow Area	3.01	m²
Wetted Perimeter	5.24	m
Hydraulic Radius	0.57	m
Top Width	4.70	m
Critical Depth	1.01	m
Critical Slope	0.00289	m/m
Velocity	3.09	m/s
Velocity Head	0.49	m
Specific Energy	1.39	m
Froude Number	1.23	
Flow Type	Supercritical	

Worksheet for From St. 442+205 to St. 443+620

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	0.21000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	1.40	m³/s

Results

Normal Depth	0.40	m
Flow Area	1.02	m²
Wetted Perimeter	3.42	m
Hydraulic Radius	0.30	m
Top Width	3.19	m
Critical Depth	0.34	m
Critical Slope	0.00368	m/m
Velocity	1.37	m/s
Velocity Head	0.10	m
Specific Energy	0.49	m
Froude Number	0.77	
Flow Type	Subcritical	

Worksheet for From St. 444+210 to St. 444+625

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	2.98000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	2.60	m^3/s

Results

Normal Depth	0.26	m
Flow Area	0.63	m^2
Wetted Perimeter	2.95	m
Hydraulic Radius	0.21	m
Top Width	2.79	m
Critical Depth	0.49	m
Critical Slope	0.00338	m/m
Velocity	4.12	m/s
Velocity Head	0.86	m
Specific Energy	1.13	m
Froude Number	2.77	
Flow Type	Supercritical	

Worksheet for From St. 446+190 to St. 444+670

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	1.06000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	2.60	m^3/s

Results

Normal Depth	0.35	m
Flow Area	0.90	m^2
Wetted Perimeter	3.28	m
Hydraulic Radius	0.27	m
Top Width	3.06	m
Critical Depth	0.49	m
Critical Slope	0.00338	m/m
Velocity	2.90	m/s
Velocity Head	0.43	m
Specific Energy	0.78	m
Froude Number	1.71	
Flow Type	Supercritical	

Worksheet for From St. 445+590 to St. 444+710

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	0.93000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	2.80	m^3/s

Results

Normal Depth	0.38	m
Flow Area	0.99	m^2
Wetted Perimeter	3.38	m
Hydraulic Radius	0.29	m
Top Width	3.15	m
Critical Depth	0.51	m
Critical Slope	0.00335	m/m
Velocity	2.83	m/s
Velocity Head	0.41	m
Specific Energy	0.79	m
Froude Number	1.61	
Flow Type	Supercritical	

Worksheet for From St. 448+830 to St. 449+125

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	0.78000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	8.10	m³/s

Results

Normal Depth	0.72	m
Flow Area	2.23	m²
Wetted Perimeter	4.61	m
Hydraulic Radius	0.48	m
Top Width	4.17	m
Critical Depth	0.93	m
Critical Slope	0.00294	m/m
Velocity	3.63	m/s
Velocity Head	0.67	m
Specific Energy	1.40	m
Froude Number	1.59	
Flow Type	Supercritical	

Worksheet for From St. 449+275 to St. 452+915

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	1.34000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	48.60	m³/s

Results

Normal Depth	1.57	m
Flow Area	6.80	m²
Wetted Perimeter	7.64	m
Hydraulic Radius	0.89	m
Top Width	6.70	m
Critical Depth	2.35	m
Critical Slope	0.00238	m/m
Velocity	7.14	m/s
Velocity Head	2.60	m
Specific Energy	4.17	m
Froude Number	2.26	
Flow Type	Supercritical	

Worksheet for From St. 454+430 to St. 454+720

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	0.38000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	25.20	m³/s

Results

Normal Depth	1.55	m
Flow Area	6.67	m²
Wetted Perimeter	7.57	m
Hydraulic Radius	0.88	m
Top Width	6.64	m
Critical Depth	1.70	m
Critical Slope	0.00257	m/m
Velocity	3.78	m/s
Velocity Head	0.73	m
Specific Energy	2.27	m
Froude Number	1.20	
Flow Type	Supercritical	

Worksheet for From St. 454+720 to St. 457+520

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	1.22000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	25.20	m^3/s

Results

Normal Depth	1.16	m
Flow Area	4.33	m^2
Wetted Perimeter	6.18	m
Hydraulic Radius	0.70	m
Top Width	5.48	m
Critical Depth	1.70	m
Critical Slope	0.00257	m/m
Velocity	5.81	m/s
Velocity Head	1.72	m
Specific Energy	2.88	m
Froude Number	2.09	
Flow Type	Supercritical	

Worksheet for From St. 457+550 to St. 458+865

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	0.72000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	25.20	m^3/s

Results

Normal Depth	1.32	m
Flow Area	5.27	m^2
Wetted Perimeter	6.77	m
Hydraulic Radius	0.78	m
Top Width	5.97	m
Critical Depth	1.70	m
Critical Slope	0.00257	m/m
Velocity	4.79	m/s
Velocity Head	1.17	m
Specific Energy	2.49	m
Froude Number	1.63	
Flow Type	Supercritical	

Worksheet for From St. 462+790 to St. 464+370

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	0.08000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	5.70	m^3/s

Results

Normal Depth	1.09	m
Flow Area	3.96	m^2
Wetted Perimeter	5.93	m
Hydraulic Radius	0.67	m
Top Width	5.27	m
Critical Depth	0.77	m
Critical Slope	0.00306	m/m
Velocity	1.44	m/s
Velocity Head	0.11	m
Specific Energy	1.19	m
Froude Number	0.53	
Flow Type	Subcritical	

Worksheet for From St. 467+560 to St. 469+580

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	0.35000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	14.50	m^3/s

Results

Normal Depth	1.20	m
Flow Area	4.57	m^2
Wetted Perimeter	6.33	m
Hydraulic Radius	0.72	m
Top Width	5.61	m
Critical Depth	1.28	m
Critical Slope	0.00274	m/m
Velocity	3.17	m/s
Velocity Head	0.51	m
Specific Energy	1.72	m
Froude Number	1.12	
Flow Type	Supercritical	

Worksheet for From St. 470+540 to St. 469+580

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	0.40000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	14.50	m^3/s

Results

Normal Depth	1.16	m
Flow Area	4.35	m^2
Wetted Perimeter	6.19	m
Hydraulic Radius	0.70	m
Top Width	5.49	m
Critical Depth	1.28	m
Critical Slope	0.00274	m/m
Velocity	3.33	m/s
Velocity Head	0.57	m
Specific Energy	1.73	m
Froude Number	1.20	
Flow Type	Supercritical	

Worksheet for From St. 471+030 to St. 472+120

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	0.03000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	4.20	m^3/s

Results

Normal Depth	1.20	m
Flow Area	4.53	m^2
Wetted Perimeter	6.31	m
Hydraulic Radius	0.72	m
Top Width	5.59	m
Critical Depth	0.65	m
Critical Slope	0.00318	m/m
Velocity	0.93	m/s
Velocity Head	0.04	m
Specific Energy	1.24	m
Froude Number	0.33	
Flow Type	Subcritical	

Worksheet for From St. 472+380 to St. 472+720

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	0.86000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	4.20	m^3/s

Results

Normal Depth	0.49	m
Flow Area	1.35	m^2
Wetted Perimeter	3.78	m
Hydraulic Radius	0.36	m
Top Width	3.48	m
Critical Depth	0.65	m
Critical Slope	0.00318	m/m
Velocity	3.11	m/s
Velocity Head	0.49	m
Specific Energy	0.99	m
Froude Number	1.60	
Flow Type	Supercritical	

Worksheet for From St. 474+620 to St. 473+230

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	0.55000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	10.70	m³/s

Results

Normal Depth	0.92	m
Flow Area	3.10	m²
Wetted Perimeter	5.31	m
Hydraulic Radius	0.58	m
Top Width	4.75	m
Critical Depth	1.09	m
Critical Slope	0.00284	m/m
Velocity	3.45	m/s
Velocity Head	0.61	m
Specific Energy	1.53	m
Froude Number	1.37	
Flow Type	Supercritical	

Worksheet for From St. 475+750 to St. 475+315

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	0.82000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	9.20	m^3/s

Results

Normal Depth	0.76	m
Flow Area	2.40	m^2
Wetted Perimeter	4.75	m
Hydraulic Radius	0.51	m
Top Width	4.29	m
Critical Depth	1.00	m
Critical Slope	0.00289	m/m
Velocity	3.83	m/s
Velocity Head	0.75	m
Specific Energy	1.51	m
Froude Number	1.63	
Flow Type	Supercritical	

Worksheet for From St. 476+210 to St. 477+505

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	1.33000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	16.10	m^3/s

Results

Normal Depth	0.90	m
Flow Area	3.03	m^2
Wetted Perimeter	5.25	m
Hydraulic Radius	0.58	m
Top Width	4.71	m
Critical Depth	1.35	m
Critical Slope	0.00271	m/m
Velocity	5.32	m/s
Velocity Head	1.44	m
Specific Energy	2.35	m
Froude Number	2.12	
Flow Type	Supercritical	

Worksheet for From St. 477+940 to St. 478+010

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	5.20000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	0.80	m^3/s

Results

Normal Depth	0.11	m
Flow Area	0.24	m^2
Wetted Perimeter	2.40	m
Hydraulic Radius	0.10	m
Top Width	2.34	m
Critical Depth	0.24	m
Critical Slope	0.00400	m/m
Velocity	3.30	m/s
Velocity Head	0.55	m
Specific Energy	0.67	m
Froude Number	3.27	
Flow Type	Supercritical	

Worksheet for From St. 478+240 to St. 478+290

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	6.52000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	0.40	m^3/s

Results

Normal Depth	0.07	m
Flow Area	0.15	m^2
Wetted Perimeter	2.25	m
Hydraulic Radius	0.06	m
Top Width	2.21	m
Critical Depth	0.15	m
Critical Slope	0.00447	m/m
Velocity	2.75	m/s
Velocity Head	0.38	m
Specific Energy	0.45	m
Froude Number	3.41	
Flow Type	Supercritical	

Worksheet for From St. 479+150 to St. 479+270

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	0.40000	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	18.40	m^3/s

Results

Normal Depth	1.31	m
Flow Area	5.19	m^2
Wetted Perimeter	6.72	m
Hydraulic Radius	0.77	m
Top Width	5.93	m
Critical Depth	1.45	m
Critical Slope	0.00267	m/m
Velocity	3.55	m/s
Velocity Head	0.64	m
Specific Energy	1.95	m
Froude Number	1.21	
Flow Type	Supercritical	

Worksheet for Road From St. 7+640 to St. 14+940

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.015	
Channel Slope	0.27300	%
Left Side Slope	1.50	m/m (H:V)
Right Side Slope	1.50	m/m (H:V)
Bottom Width	2.00	m
Discharge	69.30	m³/s

Results

Normal Depth	2.67	m
Flow Area	16.05	m²
Wetted Perimeter	11.63	m
Hydraulic Radius	1.38	m
Top Width	10.02	m
Critical Depth	2.78	m
Critical Slope	0.00228	m/m
Velocity	4.32	m/s
Velocity Head	0.95	m
Specific Energy	3.62	m
Froude Number	1.09	
Flow Type	Supercritical	