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Research Paper

Design of Box Culvert in Iraqi Highways Considering Catchment Areas

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Abstract

In Iraq, the infrastructures are developing rapidly, so it is necessary to consider the hydrology of the developed catchment before constructing any drainage facilities such as culvert to prevent traffic disruption during rain. In this study, sizing of box culvert for highways in Iraq is proposed using rational method for determination of peak runoff from small catchment (less than 3 km2). Rainfall depth was used to derive the intensity duration frequency curve, and then the rainfall intensity was found. However, soil conservation service curve number (SCS-CN) was used in the estimation of peak runoff from catchment with size ranging from 3 to less than 30 km2 using the soil classification and the curve number. HY-8 computer software was used for sizing square and circular sections. Circular sections were also calculated. The appropriate sizes for square sections in large basins are 3 m to 4 m and 2 m to 2.9 m for more than 114 m3/s and 32 m3/s respectively, but for circular sections, diameters were 4.1m, from 3 m to 3.8 m and from 2.5 m to 2.9 m under flow rates more than 160 m3/s, 68 m3/s and 25 m3/s respectively. However, for small basins, square sections sizes were 3m to 3.1m and 2 m to 2.7 m for flow rates more than 23 m3/s and 8 m3/s respectively. Diameters for circular sections were 3 m to 3.2 m and 2 m to 2.9 m under flow rates 23 m3/ s and 8 m3/s respectively.

Keywords: *Box culvert, Culvert design, Curve number, Highway drainage, HY-8 program, Iraqi highways.*

1. Introduction

Highway projects should take into account stormwater drainage and design procedures should be used to ensure smooth flow under road or an embankment (Randall, et al., 2002). Culverts are important hydraulic structures used to convey water across a road corridor or in one of a range of other situations. Culverts must be designed to carry runoff of certain return period without bonding. Also, the design should consider the environmental conditions (Road Drainage Manual). Such as culverts located in forest area. These culverts are designed with special considerations by dividing the forest into subareas, then the flow gravity is measured by numerical curve method for each area and it can notice that runoff amount decrease because of the land use type is forest (Mazdi1, et al., 2012).

In Iraq, the annual rainfall is not evenly distributed due to differences in topography and climatic situations. Therefore, size of culvert for rainfall with certain return period is not the same at different locations. Thus, consideration of hydrologic conditions is essential in culvert design. There are many methods for culvert design and these methods are, equations (Chanson, 2000), nomographs and computer programs. A computer program is developed to handle the hydraulic and structural design of culverts under field conditions (Abdul-Hadi, et al., 2008). Discharge was measured by using GIS method to calculate the size of box culvert, the results were factual comparing with rational method (Gunal et al.,2017).Modeling (Ruopu et al.,2013). Soil conservation service curve number (SCS-CN) method is applied to design hydraulic structures such as culverts based on estimating the amount of rainfall that infiltrated in to the ground and the amount of over land flow in large basins (Tejram, et al.,2012, Atiaa, er al., 2013, Zakaria, et al.,2014), or taking into account critical storm duration (Kang 2009). However, rational method is widely used to determine the maximum flow in small basins (less than 80 ha.) (Richard H., 2004). This study aims to determine appropriate culvert size for different regions in Iraq considering the variation of climate and rainfall depth, by using rational method for small basins and soil conservation services for large basins to calculate the total discharges, then to apply the resultant data in HY-8 software to get the suitable sizes.

2. Methodology

Study area: Figures 1 and 2 show the map of Iraq, the terrain and land use which confirm that Iraq landscape is varied. It has borders with Turkey from the north, Iran from east, Kuwait from the south, Saudi Arabia from the south and the south-west and Jordan and Syria from the west. Iraq's landscape is varied. The country can be divided roughly into four geographic zones: the rocky and sandy desert of the west and south-west, the mountains, hills, and steppes of the north and north-east, along the Turkish and Iranian borders, the hills and plains south of that region, and the marshy lowlands, the delta of the Tigris and Euphrates, where the rivers confluence at the Arabian Gulf. In the north, the mountain tops can be as high as 3600 m, in the mountainous North and North-East. Most of the precipitation between November and April is in the form of rain or snow. Towards the far south, the land is barely above sea level, also precipitation falls in the other regions, but less than the north especially in the desert region in the west and south-west that is a part of the Syrian Desert. The middle region falls under the category of medium and slight rainfall depth. Regarding the runoff, culverts must be constructed to prevent the road way overtopping. Available data that have been obtained includes annual and monthly rainfall data basis from 1974-2011 for Iraqi cities are presented in Table 1, (Iraqi Meteorological Organization and Seismology, 2011, Al-Lami, A, et al.,2014).

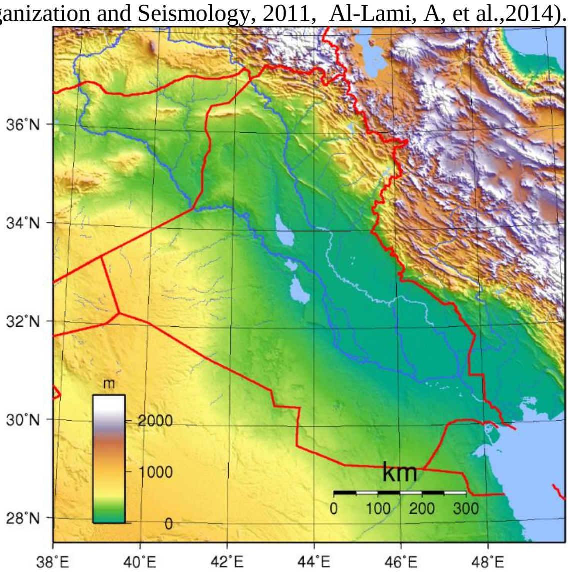

Fig. 1: Terrain in Iraq.

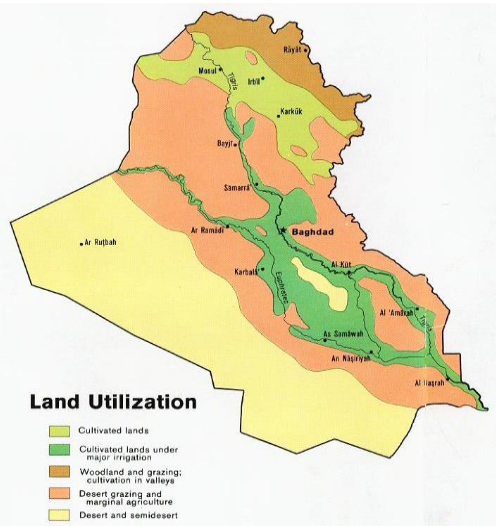

Fig. 2: Land use map of Iraq

Table 1: Average annual and monthly precipitation in Iraq. Iraqi Meteorological Organization and Seismology

station	Average annual (mm)	Average monthly (mm)	station	Average annual (mm)	Average monthly (mm)
Mosul	352	130	Kaem	125	50
Baiji	190	50	Anneh	145	60
Haditha	132	60	Samara	160	50
Rutba	116	50	Tikreet	170	60
Khanaqin	288	100	Basraa	135	60
Al-baaj	215	60	Tel Abta	210	60
Rabiah	353	90	Aukashat	90	50
Erbil	700	250	Najaf	100	50
Kirkuk	345	100	Nukhaeb	75	50
Ramadi	110	40	AlHai	136	40
Baghdad	125	70	Samawa	92	60
Hilla	100	50	Karbalaa	92	40
Badra	170	80	Nasiria	122	60
Azizia	102	50	Diwaniya	105	60
Kut	130	60	Amara	170	70
Ain Al-tamur	80	50	Ali Algharbi	163	60
Sinjar	353	150	Fao	161	50
Makhmour	263	200	Heet	101	50
Tel Affar	305	130	Sulaimaniya	900	250

Analysis: There are many methods to estimate the runoff from a catchment, simulation of runoff was conducted after rainfall was separated to direct runoff, initial abstraction and losses. Soil type is the first reason for the preparation of the soil (Richard, 2004). In this study, soil conservation service (SCS) rainfall-runoff depth relation is used to generate the unit hydrograph for the catchment areas (Richard, 2004, Bedient, et al., 1992). Water retention and the initial abstraction depends on the land use Fig.2, infiltration, depression storage, interception and moisture content. The SCS method is used to select the runoff curve number to calculate values of the maximum potential water retention(S) (Richard, 2004),(Bedient, et al., 1992). The SCS method prepared a table (table 2),(Bedient, et al., 1992), to select the runoff CN depending on the soil class or group (Richard, 2004, Bedient, et al., 1992, Soil Conservation Service,1986), Thus, soil is classified into four hydrological soil groups namely, A, B, C and D (A is sand, B is sandy loam, C is clay loam or shallow sandy loam and D is heavy plastic clay) taking into account the antecedent moisture condition , which had been classified into classes I (dry), class II (normal) and class III (wet) condition. In order to specify each class, the antecedent rainfall amount of five-day and seasonal data are considered. The soil types at the study area are shown in Table 2 which indicate that soil types can be identified as A, B, C and D. The next step is to find the curves (CN) values from Table 2, (Bedient, et al., 1992). The soil in Iraq differs from place to another according to material, geological formation, and the climatic conditions. The study area is divided in to four types depending on soil type and land use as shown in Table 2 and Fig. 2.Therefore, 30 (CN) curves are chosen. All values of (CN) curves are assumed as fair (medium) for vegetation land cover and hydrologic condition. Unit hydrograph can be derived depending on SCS-CN method were sizes of the catchment areas are assumed to be within 3 to 30 km^2. The maximum volume and direct runoff for a hydrograph resulted from 10 mm storm is evaluated by using SCS-CN method(Richard, 2004, Bedient 1992. Chow, V.T, 1964). The following equations were used to calculate the maximum runoff for the large basin areas (Richard, 2004, Bedient 1992. Chow, V.T, 1964):

$$t_l=L.^{0.8}(S.+1)^{0.7}/(1900\ Y^{0.5}) \quad (1)$$

$$t_p=0.5\ t_r+t_l \quad (2)$$

$$Q_1=484A./t_p \quad (3)$$

Where:
T_l is the legged time (hr), S is the catchment slope (m/m), Y is the catchment slope (%), t_p is the time of peak runoff (hr.), t_r is the rainfall duration (hr.) and $Q_{p1}$is the maximum runoff on the large basins (m^3

The rational method can be written as the following to estimate the maximum runoff on the small basins (Bedient, et al. 1992):

$$Q_2 = CIA \quad (4)$$

From which:
Q_2 is the maximum runoff (m^3/s), C is the runoff coefficient and it depends on the land cover type, I is the rainfall intensity(m/s) and A is the basin area (km^2). Equation number one is used to calculate the maximum runoff (direct runoff) from the small catchment areas (not less than 3 km^2 for each catchment). The C values depend on surface type and in this study the value of C is taken as 0.5 (Garber, et al.2009), After the time of peak has been calculated (in sub-area using the results of construction time estimation from Kirpich equation for small area) (Mazdi, et al.,2014).

$t_c=0.02L^{0.77}/S^{0.385}$ (5)

The duration (t_r) was estimated.

$t_p=\sqrt{t_c}+0.6$ (6)

$t_r=t_p*t_c/5$ (7)

where:
t_c is the time of concentration (hr.), L is the length of the area (m), S is the slope of the area (m/m), t_p is the time of peak runoff (hr.) and t_r is the rainfall duration (hr.).
Gumbel distribution methodology was selected to derive IDF (Intensity Duration Frequency) curves using excel program to find the rainfall intensity for two main rain gage stations in Iraq: Erbil (north zone) and Baghdad (middle zone), from which they are shown in (Fig. 3, A and B), therefore the rational equation was applied to calculate the maximum discharge through the small basins in the culverts, and the culvert sizing calculation are shown in Fig.4 (Richard, 2004, Bedient, et al., 1992).

Table.2: Curve number of various land use.

Land use			Hydrologic soil group			
Cover type	Zone location	Hydrologic condition	A	B	C	D
Forest-range herbaceous	Erbil (north)	fair		71	81	89
woods	Erbil (north)	fair	36	60	73	79
Sega-grass	Erbil (north)	fair		51	63	70
Cultivated agricultural land-small grain-	Baghdad (middle)	fair	64	76	84	88
Small grain-conservation tillage	Baghdad (middle)	fair	62	74	82	85
Noncultivated land pasture	Baghdad (middle)	fair	49	69	79	84
Noncultivated land – meadow-grass	Baghdad (middle)	fair	44	65	76	82

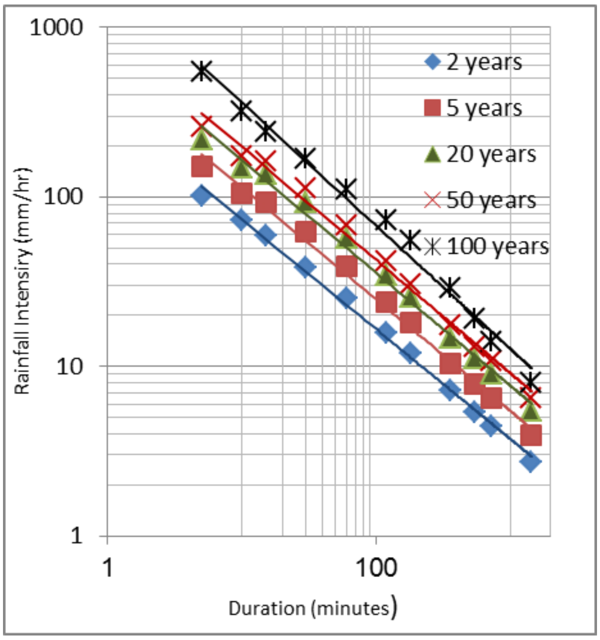

Fig. 3. A: (IDF) curves of Erbil city.

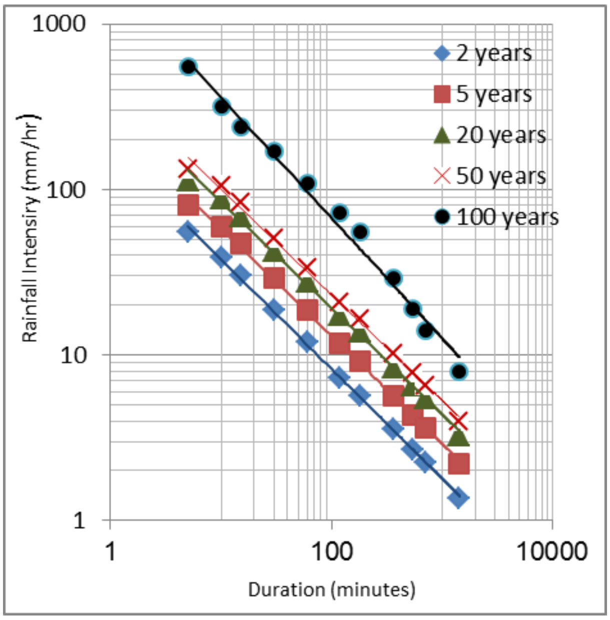

Fig. 3.B: (IDF) curves of Baghdad city.

3. Results And Discussion

Results of Maximum Runoff*:* The catchment areas discharge towards the locations of the culverts under the highways are found with different sizes (3 to 30 km^2). Also, the general slopes towards the highway and curve number CN. Table 3 shows the results of the maximum runoff from a catchment with a size equal to 30 km^2 for four groups of fair soil and hydrological conditions while Table 4 shows the results for the maximum discharge from the small basins. Obviously, it can be seen that the runoff volume from the large size catchment is higher than runoff volume from small basin. The runoff volume from catchment with steeper slope is becoming grater. In this study, three average slopes are selected, and these are, 25% for north region, 8% for middle region and 0.75% for west region. The selected slope gave maximum runoff and this resulted in a safe culvert design. Computation revealed that runoff increase when the curve number CN increase and vice versa , this is because the high CN curve number describes soil with solid surface, while the small CN curve number describe soft soil or soil with high infiltration rate.

Table 3: The maximum runoff for each type of soil (CN), over the large basins

Region	CN	t_l (hr.)	t_p(hr.)	Max.Q(cfs)	Max.Q (m^3/s)	Slope%
Erbil	71	1.12	1.23	4556	127	25%
	81	0.80	0.92	6091	170.80	25%
	89	0.63	0.69	8005	224	25%
	36	2.80	3.08	1868	52.30	25%
	60	1.49	1.64	3417	93	25%
	73	0.90	0.98	4793.80	134.20	25%
	79	1.31	1.44	5718	160	25%
	51	1.92	2.12	2802	67.20	25%
	63	1.38	1.52	3736	89.60	25%
	70	1.90	2	2802	67.20	25%
Baghdad	64	2.30	2.60	2115	60	8%
	76	1.70	1.88	2949.70	82.50	8%
	84	1.33	1.46	3786	106	8%
	88	1.15	1.26	4379	122.50	8%
	62	2.50	2.74	2075	58.10	8%
	74	2.10	2.31	2425	68.90	8%
	82	1.50	1.65	3546.80	99.30	8%
	85	2	2.20	4010.20	114.30	8%
	49	3.46	3.80	1474.70	41.30	8%
	69	2.07	2.28	2415.50	67.30	8%
	79	1.56	1.717	3220.60	90.17	8%
	84	1.32	1.46	4002.80	112.80	8%
	44	3.94	4.33	1273.60	35.60	8%
	65	2.30	2.53	2241.60	62.70	8%
	76	1.70	1.88	2949.70	82.50	8%
	82	1.50	1.65	3546.80	99.30	8%

Table 4: The maximum discharge over the small basins.

			Erbil		Baghdad		S
CN	$t_{l(hr.)}$	$t_{r(hr.)}$	20yt.I (mm/hr)	Max.Q (m^3/s)	20yr.I (mm/hr)	Max.Q ($m^{3/}s$)	m/m
71	0.41	0.46	80	33.36			0.25
81	0.321	0.36	100	41.70			0.25
89	0.287	0.321	102	42.50			0.25
36	2.50	0.83	55	22.93			0.25
60	0.58	0.658	65	27.10			0.25
73	0.40	0.448	90	37.53			0.25
79	0.317	0.355	100	41.70			0.25
51	0.70	0.784	55	22.90			0.25
63	0.64	0.71	60	25			0.25
70	0.763	0.854	53	22.10			0.25
64	1	1.50			22	9.10	0.08
76	0.75	0.84			29	12	0.08
84	0763	0.83			28	11.60	0.08
88	0.415	0.464			45	18.70	0.08
62	1	1.50			20	8.30	0.08
74	0.75	0.84			30	12.50	0.08
82	0.60	0.672			36	15	0.08
85	0.86	0.91			27	11.20	0.08
49	1.25	1.40			19	7.90	0.08
69	0.76	0.83			31	13	0.08
79	0.61	0.68			35	14.60	0.08
84	0.763	0.83			28	11.60	0.08
44	1.25	1.40			19	7.90	
65	1	1.50			20	8.30	
76	0.75	0.84			29	12	0.08
82	0.6	0.67			36	15	0.08
63	0.92	1.03					0.007
77	0.68	0.76					0.007
85	0.62	0.70					0.007

Hydraulic Design of Culverts Using HY-8 Computer Program: The HY-8 program was used, Federal Highway (Administration FHWA, 2008**),** to estimate the dimensions and/or the diameters of the culvert using input data such as maximum runoff, culvert materials, culvert shape, length and slope. This program is easy to apply, ideal results, simple basic information, updating, consider separate design alternatives of the same crossing within the same project file, save for time and quick. Table 5 shows the dimensions and diameters of the suggested culverts for each curve number (CN) for large catchment, while Table 6 shows the results for small basins. Tables 5 and 6 show that runoff is a dominant factor which controlling culvert size. The maximum runoff computed because of curve number CN, catchment size, land use and inlet water level in the approach channel. In this study, 20 years return period was used in the computing culvert size and this is because the average life of the highway project is estimated to be 20 years. From Tables 5 and 6 twin pipes or box culvert are most economical when the runoff rate greater than 26 m^3/s. Same results were obtained when culvert had been designed with discharges of (0.5, 1.0, 1.5, 2.5, 5.0, 10.0, and 15.0 m^3/s) to represent small, medium, and big discharges (Abdul-Hadi, et al.2008).Similar results were reported when box and circular sections culverts were designed using the optimization program (Salma, 2012, Kalyanshetti, et al. 2014).

Table 5: Sizes of pipe and box culverts for large basins.

Max.Q (m^3/s)	Concrete pipe size(m)	No. of pipes	Concrete box size(m)(square)	No.of boxes	slope
127	3.7	3	3.5	3	0.25
170.8	3.8	3	3.5	3	0.25
224	4.1	3	4	3	0.25
52.3	2.6	2	2.9	1	0.25
93	3.3	2	3.1	2	0.25
134.2	3.8	3	3.6	3	0.25
160	4.1	2	3.9	2	0.25
67.2	2.9	2	2.7	2	0.25
89.6	3.2	2	3.1	2	0.08
60	2.8	2	2.7	2	0.08
82.5	3.2	2	3.1	2	0.08
106	3.6	2	3.4	2	0.08
122.5	3.8	3	3.6	3	0.08
58.1	2.8	2	2.7	2	0.08
68.9	3	2	2.9	2	0.08
99.3	3.5	2	3.3	2	0.08
114.3	3.7	3	3.5	3	0.08
41.3	2.9	2	2.7	2	0.08
67.3	2.9	2	2.8	2	0.08
90.17	3.4	2	3.2	2	0.08
112.8	3.7	2	3.5	2	0.08
35.6	2.7	2	2.5	2	0.08
62.7	2.9	2	2.7	2	0.08
82.5	3.2	2	3.1	2	0.08
17.4	2.9	1	2.8	1	0.007
25.7	3.2	1	3	1	0.007
32.7	2.5	2	2.5	2	0.007
37	2.8	2	2.6	2	0.007

Table 6: Size of pipe and box culverts for small basins.

Max.Q (m^3/s)	Concrete pipe size(m)	No. of pipes	Concrete box size(m) (square)	No.of boxes	slope
33.36	2.50	2	2.50	2	0.25
41.70	2.90	2	2.70	2	0.25
42.50	2.90	2	2.70	2	0.25
22.93	3	1	3	1	0.25
27.10	3.20	1	3.10	1	0.25
37.53	2.80	2	2.60	2	0.25
25	3.20	1	3	1	0.25
22.10	2.80	1	2.70	1	0.25
9.10	2	1	2	1	0.08
12	2.50	1	2.50	1	0.08
11.60	2.20	1	2.20	1	0.08
18.70	2.90	1	2.80	1	0.08
8.30	2	1	2	1	0.08
12.50	2.50	1	2.50	1	0.08

15	2.80	1	2.70	1	0.08
11.20	2.20	1	2.20	1	0.08
7.90	2	1	2	1	0.08
13	2.70	1	2.50	1	0.08
14.60	2.70	1	2.50	1	0.08
11.60	2.20	1	2.20	1	0.08
7.90	2	1	2	1	0.08
10.42	2.50	1	2.50	1	0.007
11.60	2.50	1	2.50	1	0.007
12.51	2.70	1	2.70	1	0.007
15.80	2.80	1	2.70	1	0.007

Sample of Results: Table 7 and Figures 5 and 6, show a sample of results obtained from applying HY-8 program, for runoff rate 11.6 m^3/s**.** It is clear that the outlet velocity is required for every culvert. High outlet velocities can cause erosion for downstream of an outlet. Where possible, culverts should be designed to provide acceptable velocities without the need for more channel protection, so that from table 7 the outlet velocities are ranged from 1.992 m/s to 2.675 m/s which they are very adequate velocities, actually they are less than the tailwater velocities because of energy losses when the water just get out the culvert. Outlet depths are more than normal and critical depths, in this case the flow if critical. It can notice from table 7 that most of the outlet control head water depths are more than the inlet control, therefore the outlet control takes place Federal Highway Administration (FHWA),(2004). If the culvert is installed on a mild slope, outlet control will occur for both a submerged or non-submerged inlet and a submerged or non-submerged outlet. If the culvert is installed on a steep slope, outlet control will occur, if the tailwater is more than critical depth as shown in table 7, at the upstream end of the culvert or to cause full barrel flow throughout Garber, (2009).

Table 7: Results of applying HY-8 program.

Tailwater Velocity (m/s)	Outlet Velocity (m/s)	Tailwater Depth (m)	Outlet Depth (m)	Normal Depth (m)	Outlet Control Depth (m)	Inlet Control Depth (m)	Headwater Elevation (m)	Culvert Discharge (cms)	Total Discharge (cms)
0.000	0.000	0.000	0.000	0.000	0.000	0.000	45.00	0.00	0.00
2.249	1.992	0.344	0.265	0.249	0.298	0.521	45.52	1.16	1.16
2.761	1.882	0.560	0.560	0.403	0.529	0.827	45.83	2.32	2.32
3.072	2.094	0.755	0.755	0.528	0.746	1.083	46.08	3.48	3.48
3.290	2.243	0.940	0.940	0.647	1.320	1.305	46.32	4.64	4.64
3.456	2.356	1.119	1.119	0.759	1.532	1.509	46.53	5.80	5.80
3.586	2.445	1.294	1.294	0.867	1.736	1.700	46.74	6.96	6.96
3.693	2.518	1.466	1.466	0.971	1.933	1.882	46.93	8.12	8.12
3.782	2.579	1.636	1.636	1.072	2.124	2.059	47.12	9.28	9.28
3.858	2.631	1.804	1.804	1.172	2.312	2.235	47.31	10.44	10.44
3.923	2.675	1.971	1.971	1.270	2.496	2.414	47.50	11.60	11.60

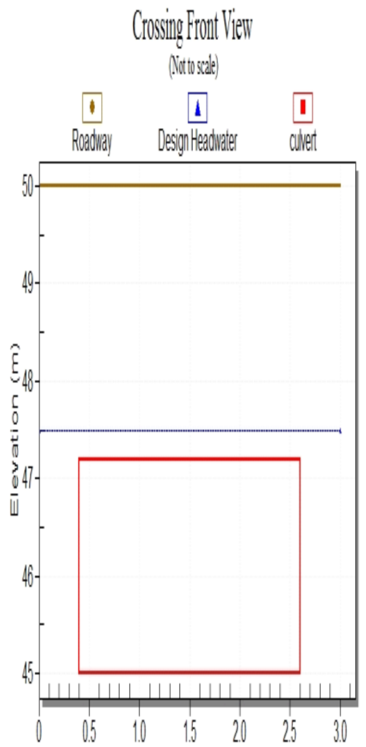

Fig. 5: Cross section of box culvert (runoff is 11.6 m^3/s).

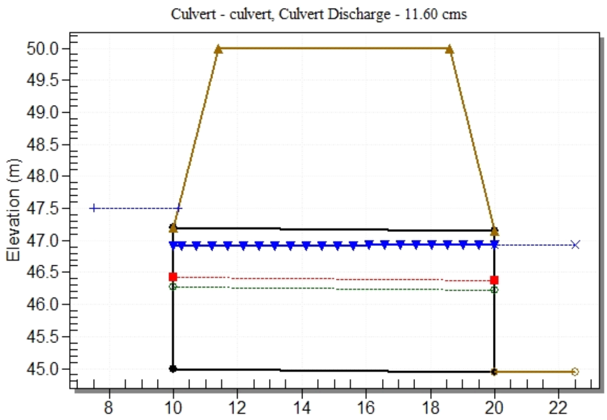

Fig. 6: Longitudinal cross section of box culvert (runoff is 11.6 m^3/s)

4. Conclusions

Hydrologic studies for highways are important before any hydraulic design. The different in rainfall depth from region to another in Iraq and its effect on the intensity will need to be investigated. Rational method is more dependable than other methods to calculate the runoff over small catchment areas. The maximum runoff calculated using SCS curve number is applied successfully and compare with the runoff obtained from applying conventional methods for large basins.The variation in rainfall depth from region to another in Iraq and its effect on rainfall intensity is the reason for the variation in results. SCS-CN, rational method and HY-8 computer program are integrated and applied successfully in this study. HY-8 model can benefit for both box and circular culvert sections.

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