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ASSESSMENT OF USING HY-8 MODEL FOR SIZING CULVERTS UNDER HIGHWAYS IN IRAQ

Nidaa Adil Jasim[1], Mustafa Mohammed Ahmed[2], Mohammed Saeed Noori[3]

1. Assistant Prof., Highway and Transportation Department, Mustansiriyah Universit , Baghdad, Iraq
2. Engineer, Highway and Transportation Department, Mustansiriyah University, Baghdad, Iraq.
3. Engineer, Highway and Transportation Department, Mustansiriyah Universit , Baghdad, Iraq.

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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 km^2). 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 km^2. HY-8 computer software was used for sizing square and circular sections. 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 m^3/s and 32 m^3/s, 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 m^3/s, 68 m^3/s and 25 m^3/s in sequence. 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 m^3/s and 8 m^3/s in sequence. Diameters for circular sections were 3 m to 3.2 m and 2 m to 2.9 m under flow rates 23 m^3/ s and 8 m^3/s in sequence.

Keywords: *Highway drainage, culverts design, HY-8 program.*

تقييم استخدام برنامج HY-8 لحساب ابعاد القناطر المصممة للطرق الخارجية في العراق

الخلاصة:البنى التحتية في العراق ومنها الطرق الخارجية في تطور،لذا من الضروري الأخذ بنظر الأعتبار منشآت تصريف المياه من قبل البدء بأي مشروع للطرق الخارجية ومن هذه المنشآت القناطر والتي تحد من مشاكل مياه الأمطار على جانبي الطريق ،في هذه الدراسة تم اقتراح ابعاد القناطر المناسبة باستخدام الطريقة المنطقية Rational method لحساب اقصى تصريف للامطار من المساحات الصغيرة الأقل من 3كم^2 ،كما تم استخدام طريقة خدمة حفاظ التربة S-C-S Soil conservation service ورقم المنحني Curve number CN لحساب اقصى تصريف للامطار من المساحات بين 3- 30كم^2 .تم استخدام برنامج الحاسوب HY-8 لحساب ابعاد واقطار القناطر حيث تمت اقتراح مقطعين لحساب ابعادهما وهما المربع والدائري.الابعاد المناسبة للمقاطع المربعة والخاصة بالمساحات الكبيرة هي 3م و من 2 الى 2,9 م لتصريف اكثر من 114 م^3/ثا و32 م^3/ثا على الترتيب،لكن للمقاطع الدائرية كانت الاقطار لها 4,1 م و من 3 الى 3,8 م ومن 2,5 الى 2,9 م لتصريف اكثر من 160 م 3/ثا و68م^3/ثا و25م^3/ثا على الترتيب .بينما ولمساحات الصغيرة كانت ابعاد المقاطع المربعة هي 3م الى 3ز1 مو من 2م الى 2ز7 م لتصريف اكثر من 23 م^3/ثا و8م^3/ثا على الترتيب . اقطار المقاطع الدائرية كانت من 3 م الى 3,3 م و من 2 الى 2,9 متر لتصريف اكثر من 23 م^3/ثا و 8م^3/ثا على الترتيب.

*Corresponding Author eng.nidaa.adel@gmail.com

1. Introduction

Highway project should take into account stormwater drainage and design procedures should be used to ensure smooth flow under road or an embankment [1]. 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 [2] such as culverts located in forest area. These culverts are designed with special considerations by dividing the forest in to 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 [3].

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 [4] nomographs and computer programs. A computer program is developed to handle the hydraulic and structural design of culverts under field conditions [5]. 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 [6,7,8]**.** However, rational method is widely used to determine the maximum flow in small basins (less than 80 ha.) [9,10] This study aims to determine appropriate culvert size for different regions in Iraq and HY-8 software is utilized for this purpose.

2. Methodology

2.1 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, [11].

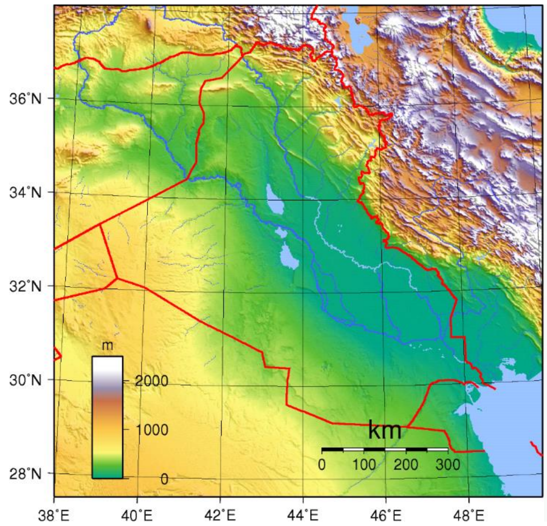

Figure 1.Terrain in Iraq.

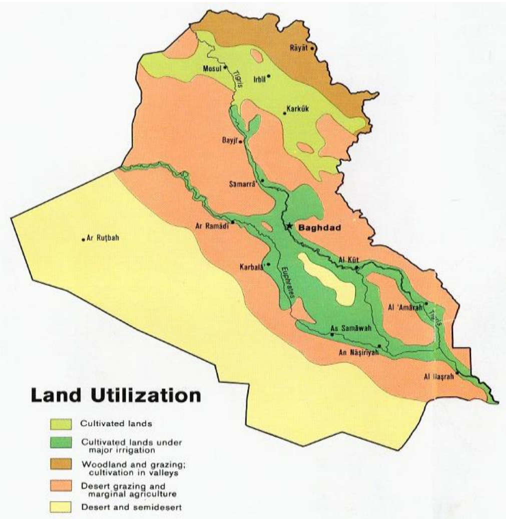

Figure 2. Land use map of Iraq

Table 1. Average annual and monthly precipitation in Iraq[11].

No.	station	Average annual (mm)	Average monthly (mm)	No.	station	Average annual (mm)	Average monthly (mm)
1	Mosul	352	130	20	Kaem	125	50
2	Baiji	190	50	21	Anneh	145	60
3	Haditha	132	60	22	Samara	160	50
4	Rutba	116	50	23	Tikreet	170	60
5	Khanaqin	288	100	24	Basraa	135	60
6	Al-baaj	215	60	25	Tel Abta	210	60
7	Rabiah	353	90	26	Aukashat	90	50
8	Erbil	700	250	27	Najaf	100	50
9	Kirkuk	345	100	28	Nukhaeb	75	50
10	Ramadi	110	40	29	AlHai	136	40
11	Baghdad	125	70	30	Samawa	92	60
12	HIlla	100	50	31	Karbalaa	92	40
13	Badra	170	80	32	Nasiria	122	60
14	Azizia	102	50	33	Diwaniya	105	60
15	Kut	130	60	34	Amara	170	70
16	Ain Al-tamur	80	50	35	Ali Algharbi	163	60
17	Sinjar	353	150	36	Fao	161	50
18	Makhmour	263	200	37	Heet	101	50
19	Tel Affar	305	130	38	Sulaimaniya	900	250

2.2 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 [12]. In this study, soil conservation service (SCS) rainfall-runoff depth relation is used to generate the unit hydrograph for the catchment areas [12,13]. 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) [12,13]. The SCS method prepared a table to select the runoff CN depending on the soil class or group [12,13,14]. 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. 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 hydrogrph 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 [12,13,15].

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		fair	36	60	73	79
Sega-grass		fair		51	63	70
Cultivated agricultural land-small grain-straight low	Baghdad (middle) and Basra(south)	fair	64	76	84	88
Small grain-		fair	62	74	82	85

conservation tillage						
Noncultivated land pasture		fair	49	69	79	84
Noncultivated land – meadow-grass		fair	44	65	76	82
Natural desert landscaping(previou)	Haditha (west)	fair	55	72	81	86

The rational method can be written as the following[13]:

$$Q=CIA \qquad (1)$$

And 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 [16]. After the time of peak has been calculated (in sub-area using the results of construction time estimation from Kirpich equation for small area)[3].

The duration (t_r) was estimated. Gumbel distribution methodology was selected to derive IDF (Intensity Duration Frequency) curves using excel program to find the rainfall intensity for four main rain gage stations in Iraq: Erbil (north zone), Baghdad (middle zone), Haditha (west zone), and Basra (south zone) from which they are shown in (Fig. 3, A, B, C and D), 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 .[12,13].

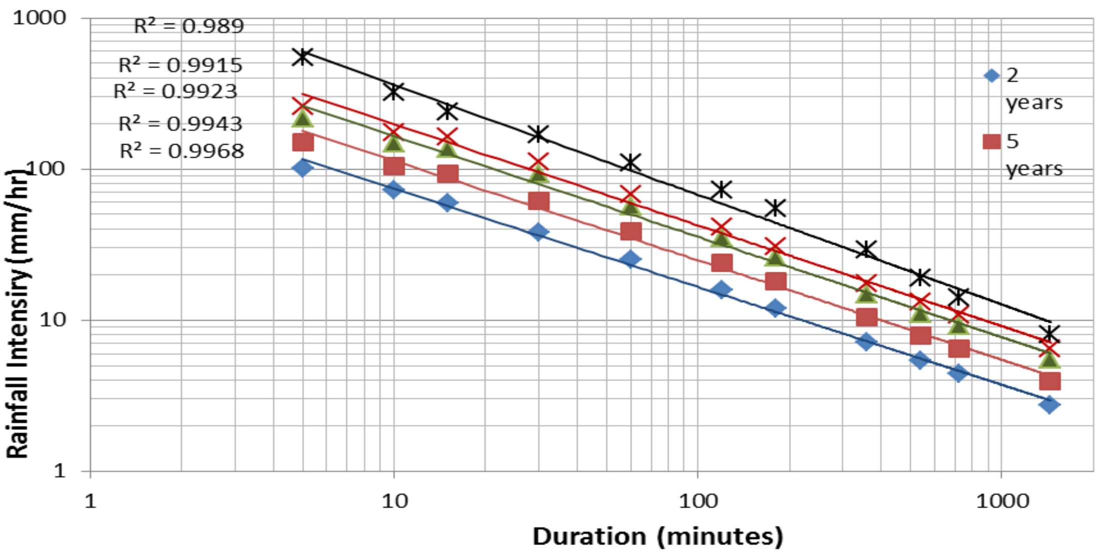

Figure 3.A: (IDF)curves of Erbil.

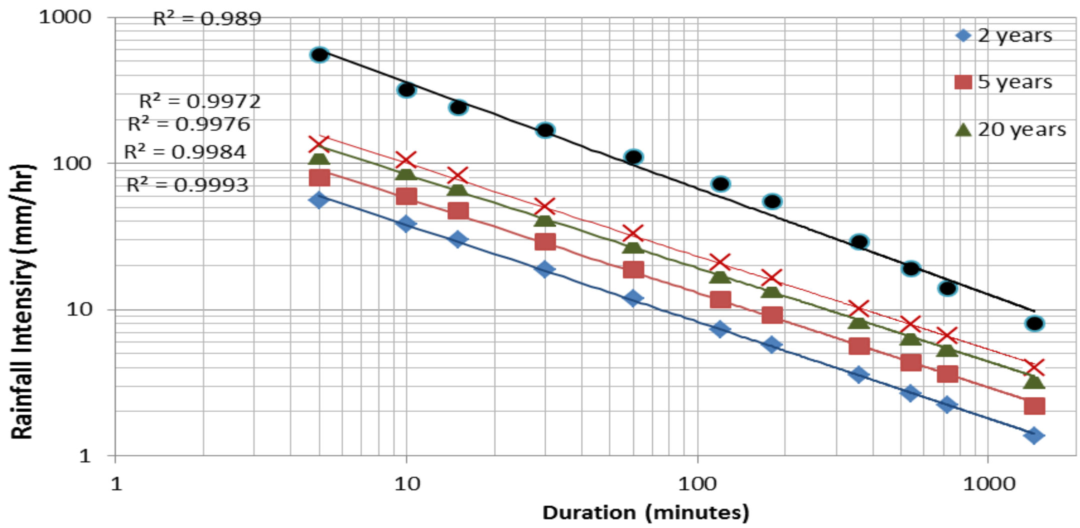

Figure 3.B: (IDF)curves of Baghdad.

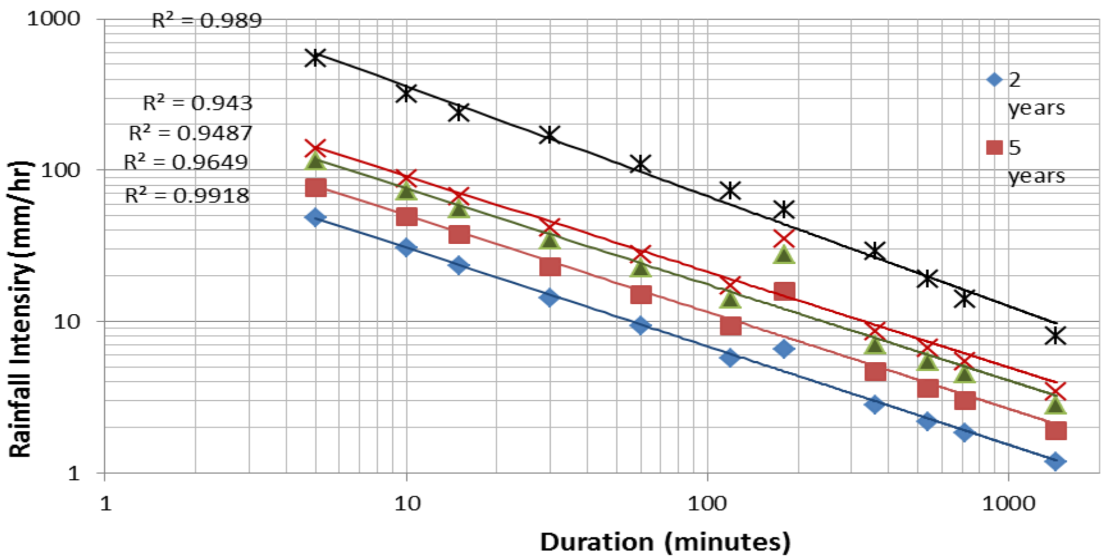

Figure 3.C: (IDF)curve of Haditha

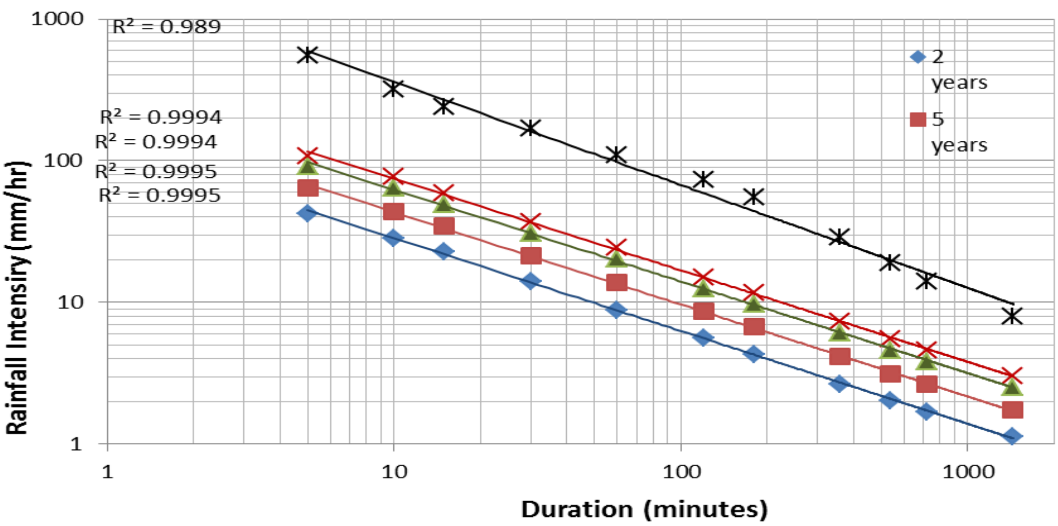

Figure 3.D . (IDF)curves of Basra.

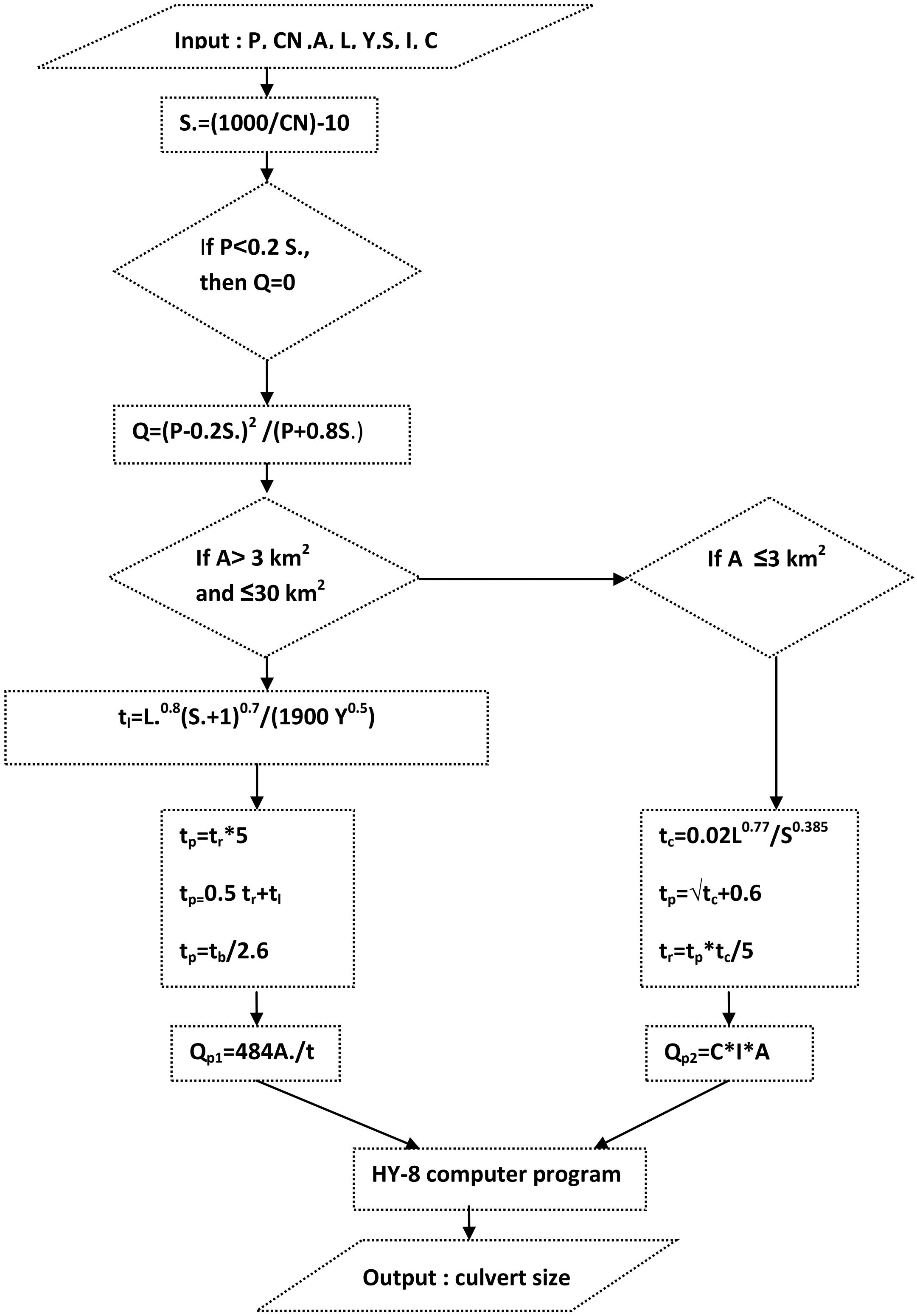

Figure 4. Flow diagram for culvert sizing using HY-8 program

3. 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 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 And Basra	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	4010.2	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%
Haditha	63	8.17	8.98	624	17.40	0.75%
	77	5.50	6.10	918.60	25.70	0.75%
	85	4.40	4.80	1167.50	32.70	0.75%
	88	3.80	4.25	1318.50	37	0.75%

Table 4. The maximum discharge over the small basins.

CN	$t_{l(hr.)}$	$t_{r(hr.)}$	Erbil		Baghdad		Haditha		Basra		S
			20yt.I (mm/hr)	Max. Q (m^3/s)	20yr.I (mm/hr)	Max.Q (m^3/s)	20yr. I (mm/hr)	Max. Q (m^3/s)	20 yr.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			15	6.25	0.08
76	0.75	0.84			29	12			22	9.10	0.08
84	0763	0.83			28	11.60			21	8.70	0.08
88	0.415	0.464			45	18.70			35	14.50	0.08
62	1	1.50			20	8.30			13	5.42	0.08
74	0.75	0.84			30	12.50			22	9.10	0.08
82	0.60	0.672			36	15			26	10.80	0.08
85	0.86	0.91			27	11.20			20	8.30	0.08
49	1.25	1.40			19	7.90			17	7	0.08
69	0.76	0.83			31	13			23	9.60	0.08
79	0.61	0.68			35	14.60			25	10.40	0.08
84	0.763	0.83			28	11.60			21	8.70	0.08
44	1.25	1.40			19	7.90			11	4.58	
65	1	1.50			20	8.30			12	5	
76	0.75	0.84			29	12			22	9.10	0.08
82	0.6	0.67			36	15			26	10.80	0.08
63	0.92	1.03					25	10.42			0.007
77	0.68	0.76					28	11.60			0.007
85	0.62	0.70					30	12.51			0.007

4. Hydraulic Design of Culverts Using HY-8 Computer Program

The HY-8 program was used, [10], 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. 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 live 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 [5]. Similar results were reported when box and circular sections culverts were designed using the optimization program[17,18].

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

4.1. 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

Table 7.results of applying HY-8 program.

Tailwater Velocity (m/s)	Outlet Velocity (m/s)	Tailwater Depth (m)	Outlet Depth (m)	Critical 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	0.000	45.00	0.00	0.00
2.249	1.992	0.344	0.265	0.305	0.249	0.298	0.521	45.52	1.16	1.16
2.761	1.882	0.560	0.560	0.484	0.403	0.529	0.827	45.83	2.32	2.32
3.072	2.094	0.755	0.755	0.634	0.528	0.746	1.083	46.08	3.48	3.48
3.290	2.243	0.940	0.940	0.768	0.647	1.320	1.305	46.32	4.64	4.64
3.456	2.356	1.119	1.119	0.891	0.759	1.532	1.509	46.53	5.80	5.80
3.586	2.445	1.294	1.294	1.007	0.867	1.736	1.700	46.74	6.96	6.96
3.693	2.518	1.466	1.466	1.115	0.971	1.933	1.882	46.93	8.12	8.12
3.782	2.579	1.636	1.636	1.219	1.072	2.124	2.059	47.12	9.28	9.28
3.858	2.631	1.804	1.804	1.319	1.172	2.312	2.235	47.31	10.44	10.44
3.923	2.675	1.971	1.971	1.415	1.270	2.496	2.414	47.50	11.60	11.60

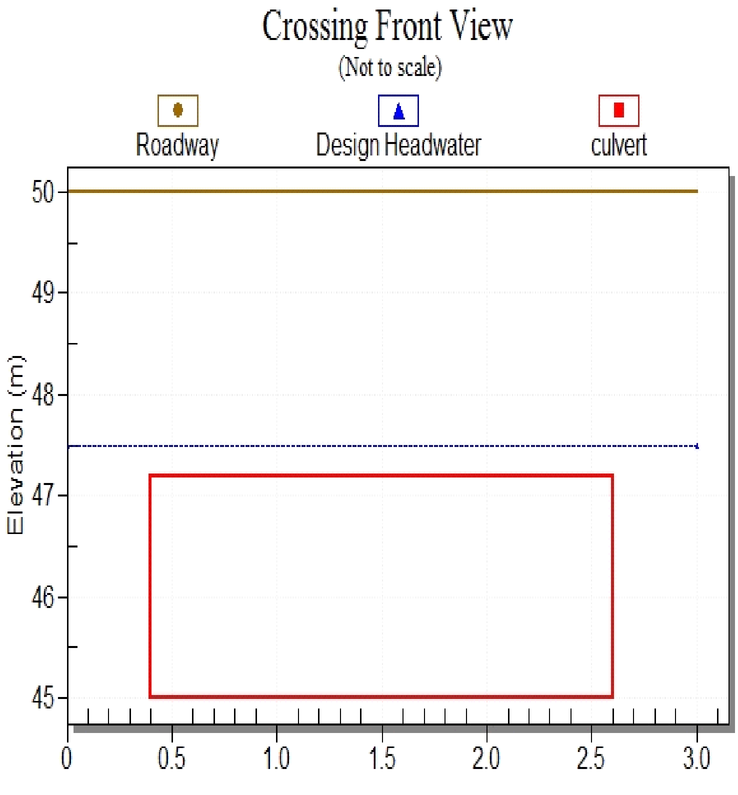

Figure 5. Cross section of box culvert (runoff is 11.6 m^3/s).

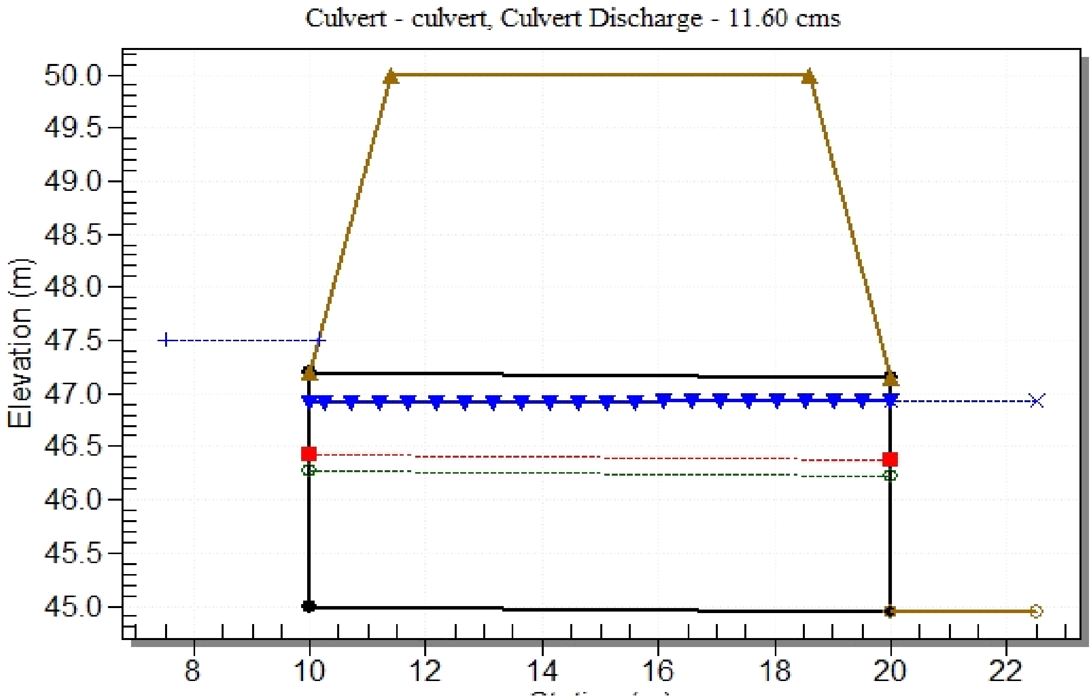

Figure 6. Longitudinal cross section of box culvert (flow rate 11.6 m^3/s).

The following data are supplementary information related to figures 5 and 6 which show the cross and longitudinal section of box culvert under 11.6m^3/s flow rate:

Site Data - culvert

Site Data Option: Culvert Invert Data

Inlet Station: 10.00 m, Inlet Elevation: 45.00 m

Outlet Station: 20.00 m, Outlet Elevation: 44.95 m

Number of Barrels: 1

Culvert Data Summary - culvert

Barrel Shape and material : Concrete Box

Barrel Span: 2200.00 mm

Barrel Rise: 2200.00 mm

Embedment: 0.00 mm

Barrel Manning's n: 0.0120

Culvert Type: Straight

Inlet Configuration: Square Edge (90º) Headwall

Inlet Depression: None

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 additional 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 noticed from table 7 that most of the outlet control head water depths are more than the inlet control, therefore the outlet control takes place[19]. If the culvert is installed on a mild slope, outlet control will occur for both a submerged or unsubmerged inlet and a submerged or unsubmerged 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[16].

5. Conclusions

Hydrologic studies for highways are important before any hydraulic design. From this study. Rational method is efficient in estimating the runoff over small catchment areas. In this study the maximum runoff calculated using SCS curve number is applied successfully and compare with the runoff obtained from applying conventional methods. In Iraq, application of HY-8 program reveal that culvert sizes are different for different regions this is because maximum runoff, topography, land use and precipitation are different at different regions. SCS-CN , rational method and HY-8 computer program are integrated and applied successfully in this study. The results of the application are shown in Tables 3, 4, 5, 6 and 7.

Abbreviations

Q	total runoff depth(mm)
P	rainfall depth(mm)
S.	the maximum potential water retention (mm)
CN	curve number, ranging (0-100)no unit
Q_{p1}	direct runoff for large basin(m^3/s)
Q_{p2}	direct runoff for small basin(m^3/s)
A.	catchment area($mi.^2$)
A	catchment area(km^2)
t_p	time of peak runoff(hr.)
t_l	lag time(hr.)
Y	slope of basin %
S	slope of basin (m/m)
L.	length of basin(ft)
L	length of basin(m)
t_r	rainfall duration(hr)
t_b	base time of unit hydrograph(hr.)

C	runoff coefficient
I	rainfall intensity(mm/hr)
t_c	time of concentration(hr)

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6. References

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