ESTIMATE OF FLOOD WATER QUANTITIES EXPERIENCED BY DHUKNA CITY, QASSIM REGION, KSA

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ABSTRACT

Flood water dangerous are increasing worldwide as a result of frequent recurrence of large floods in many areas due to severe climatic changes taking place in the world in recent times and their impact on rainfall intensities and duration periods. Three years ago *Dhukna* city exposed to an extreme storm, which leads to that the right bank of the great valley passing on the Eastern side, U\S of the main culvert, has been collapsed. In addition, the water surface has been recorded to be passing over the main culvert (32 vents each of 2.5m x 1.5m) by more than one meter. The present paper introduces a study for the hydrological characteristics of *Dhukna* city, *Qassim* region, KSA, as one of the cities expected to be exposed to dangerous of floods due to a steady civil development in the different utilities, especially asphaltic surface roads areas. The characteristics of the different drainage basins spill its water to the city, have been well defined. The *SCS-CN* method has been used to estimate the flood water quantities for all surrounding drainage basins which drain its water directly to the main valley, especially that passing through the city. Also, the performance of the existing main culvert is evaluated and its efficiency has been checked. A proposal has been suggested to increase the main culvert efficiency and to accommodate the expected incoming flood water through the great valley.

keywords: Floods, IDF Curve, Overland Velocity, Watershed, Catchment Basin, Concentration Time, Critical Path, Storm Duration, Frequency.

1. Introduction

Floods are one of the most serious images of storm water runoff. This is owing to what gets in the kinetic energy during its very quickly decline on the mountain slopes. This is what gives it the large destructive power. This power must be controlled to protect cities and villages which may fall on both sides of the riverbed or oppose its course. The flood water has caused a lot of disasters in many countries of the world, so that it became difficult to overlook its negative effects if we want to continue in the processes of urban growth. *Dhukna* city in *Qassim* region of *KSA* is one of those cities characterized by the presence of many mountains surrounding it from the west side. So, it should be taking into account the negative impact of such heights in the compilation of flood water which giving them the enormous destructive power and its impact on the process of development and urban growth in the city in recent times. In the last few years, the city has exposed to intensive rainfalls more than 64 mm/day which lead to never foretime floods. Flood water get down a height of 100 m by high velocities washing out every thing through its way to the great main valley; named *Great Wadi*. There are also some small valleys; named *Shoeibs* which feed the great valley through paths inside the city. The main channel of the *Great Wadi* lays east the city. It starts from the western south

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running from south to north. The valley wide reaches to more than 250 m in some stations. There is a huge culvert on the *Great Wadi* at the eastern north of the city. This culvert consists of 32 vents each of size 2.50 m width and 1.50 m height. It can not compass the flood water at 2009 leading to an increase in water level over the culvert parapet by more than one meter and tends to a collapse in the eastern bank of the *Great Wadi*. Figure (1) shows the general geographic location of *Dhukna* city related to *Qassim* region. Figure (2) clarifies the location of the *Great Wadi* and the main culvert in *Dhukna* city. This paper aims to estimate the incoming storm water rate expected to fall on the drainage basins and passes through the city or reaches the *Great Wadi* to flow through the main culvert. It aims also to evaluate the performance of the existing main culvert and try to improve its efficiency.

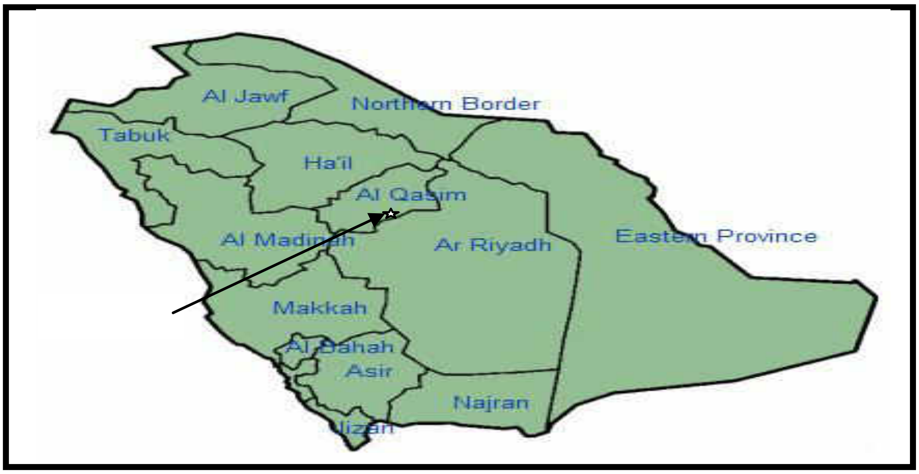

Fig. 1. General location of *Dhukna* city, *Qassim* region

2. Characteristics of drainage basins

From Dukhna watershed topography, it can be reported that the city is surrounded by a mountainous area from the west, south and east sides. The *Great Wadi* takes its path from the south to the north direction and passes besides the eastern boundaries of the city. The highest surface elevation of the watershed area reads (920, 880, 800 +msl) in the west, south and east sides of the city respectively. While it reads about (700 +msl) in the north and inside the city. In addition, some branches (named shoibs); especially from west side, take its paths through the city to spill its water in the *Great Wadi* upstream the main culvert. This caused serious difficulties and hazards for the citizens during the storm's periods in the last few years. Moreover, the city interior storm drainage network could not able to receive and safely pass the incoming storm water. The characteristics of all drainage basins, draining its water directly in the *Great Wadi* or indirectly through the city to pass through the main culvert, have been carefully studied.

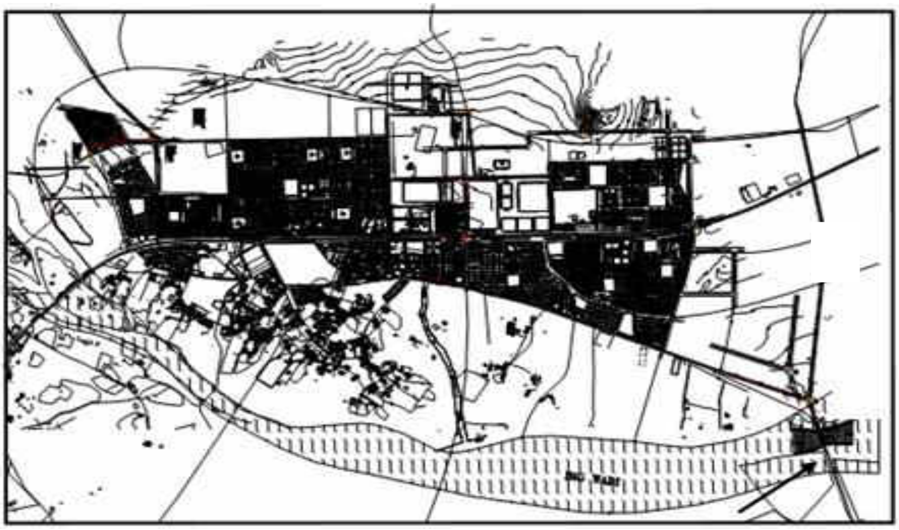

Fig. 2. Layout of *Great Wadi* and the Main Culvert, Dhukna City

The areas, surface slopes, and lengths of the critical paths of the drainage basins have been determined, see Figures (3), (4), and (5). The global surface area of all drainage basins is about 26,877 hectares resulting in a huge rate of falling water of rains, see Figure (3). Figure (4) shows that the storm water for some drainage basins travels more than 15 km, such as basin {L}. Also, some of the basins' land surfaces have steep slopes (8%) such as basin {A} resulting in higher surface velocities of flood waters. It has been noticed also that the drainage basins; their water passes through the city before reaching to the main valley, are only basins {A}, {B} and a small portion of basin {C} having a total area of 3,000 hectares. So, it is recommended for theses three basins to be trained in future, to protect the city against their distractive effects. This can be achieved through some arrangements as some local ground reservoirs or construction of some dams to reduce the overland flow velocities. Figure (6) Shows the city and the drainage basins.

3. Time of concentration

The time of concentration is the time after beginning of rainfall excess when all portions of the drainage basin are contributing simultaneously to flow at the outlet. It is often assumed to be the sum of two travel times; 1) the initial time required for the overland flow, and 2) the travel time in the conveyance elements (shallow streams, open channels, street gutters, storm closed networks, …… etc). Using an appropriate value for time of concentration is very important, although it is hard sometimes to judge what the correct value is. Four factors generally impact the time of concentration: surface slope, soil structure and wetness, land cover, and farthest distance to outlet. There are many scientific formulas generally used for calculating the time of concentration of the storm water flows either over the catchment basin land surface, the open channels or through the closed network. Roberson and Crowe (1985) [11] introduced an equation computing the average velocity of uniform laminar flow on an inclined plane. For turbulent flow over the basin land surface, the friction factor becomes independent of the Reynolds number and dependent only on the surface roughness. Chow, Maidment and Mays (1988) [2] applied Manning's equation to describe the mean velocity for turbulent flow. In addition, Zekai Sen (2008) [12] applied Chezy formula to describe the mean velocity for turbulent flow as a function of the time of concentration and the corresponding rainfall intensity.

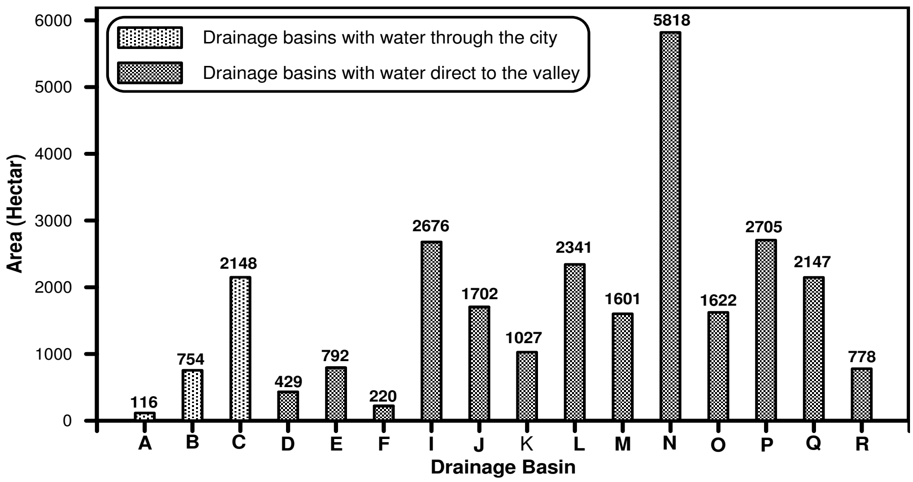

Fig. 3. Surface areas for the different drainage basins

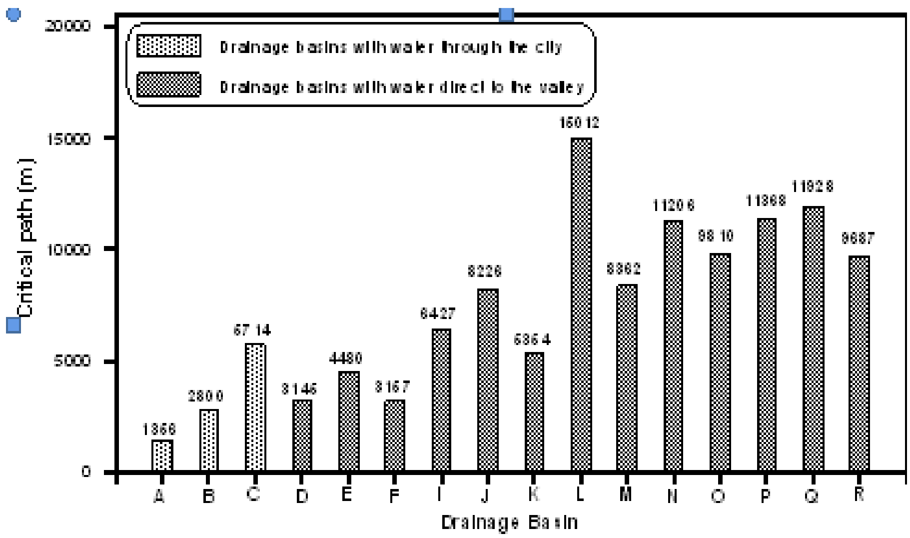

Fig. 4. Critical paths' lengths for the different drainage basins

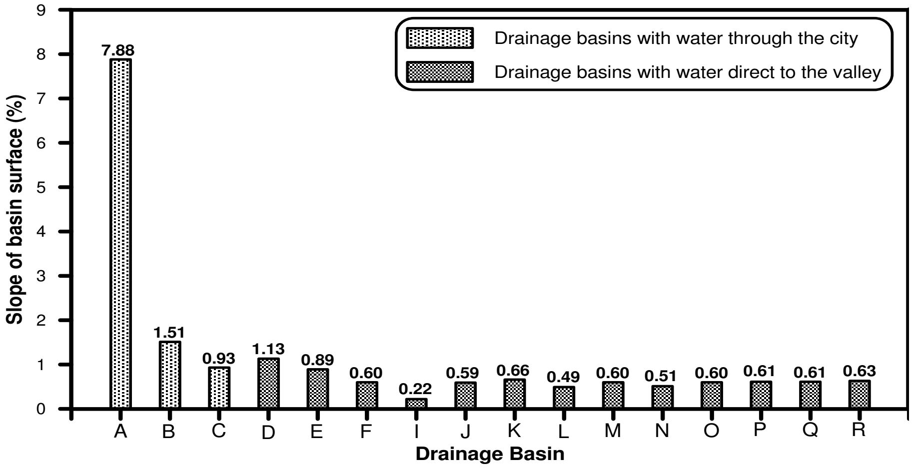

Fig. 5. Surface slopes for the different drainage basins

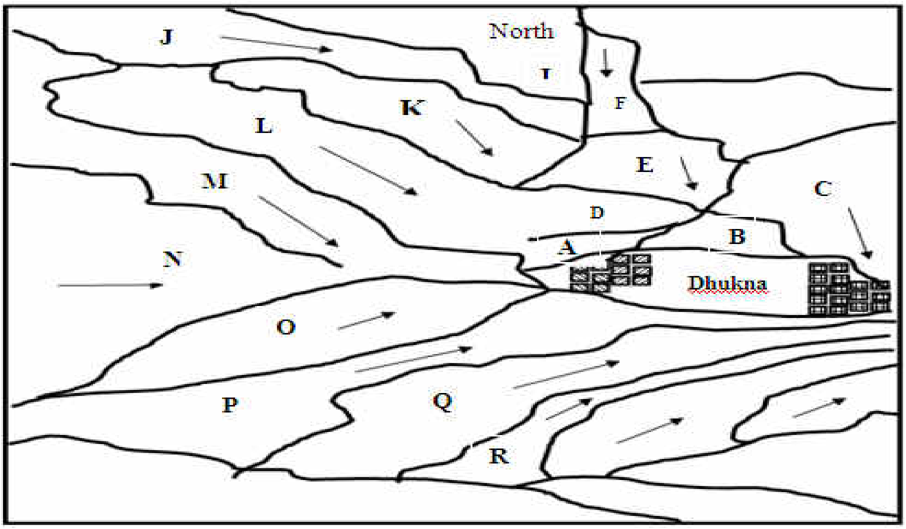

Fig. 6. Layout of the drainage basins and Dhukna city

In this study, Kirbich formula [7] is proposed to be used to estimate the time of concentration of flow for sheet flow type. It can be reported that the flow behaves as a sheet flow through a reach of length not more than 300 feet for paved surfaces and 100 feet for unpaved surfaces [6, 13]. Kirbich formula reads as:

$$T_{Sheet} = K_1 \left(\frac{60 \times L_{sheet}^{a_1}}{S_B^{a_2}} \right) \tag{1}$$

Where, T_{sheet} is the time of concentration for sheet flow type (minute), L_{sheet} is the critical path length on which the flow type is of sheet flow (km), S_B is the watershed surface slope (%), and K_1, a_1, and a_2 are constants depend on the watershed area characteristics.

To define the travel time through shallow streams, the flow velocity through such types is represented by:

$$V_{shallow} = K_2 \times S_B^{a_3} \quad \text{(Unpaved surfaces)} \tag{2}$$

and

$$V_{shallow} = K_3 \times S_B^{a_4} \quad \text{(Paved surfaces)} \tag{3}$$

Where, K_2, K_3, a_3, and a_4 are coefficients depend on the shallow streams dimensions and the water depth / bed width ratio.

Then, the travel time through the shallow streams has been computed using:

$$T_{Shallow} = \left(\frac{L_{shallow}}{60 \times V_{shallow}} \right) \qquad 4)$$

But through well formed open channels, the mean flow velocity has been computed using Manning's' formulas and the travel time through open channels has been computed using Eq. (4). The actual time of concentration for a certain catchment basin is the sum of sheet flow time plus the travel times through the shallow stream and open channel reaches; if exist. The minimum value for the global time of concentration along the total critical path is assumed to be not less than 10 minutes.

Figures (7) and (8) clarify the overland flow velocities and the global time of concentration for the different watershed basins. In some basins, flood and rain water falling upon the *Great Wadi* through the city reach at a time does not exceed

10 minutes from the beginning of the storm such as basin {A} due to its clear steepness. While for some basins the water reach after about four hours. So, it is recommended that basin {A}, should have the priority to create some artificial embankments and\or ponds in the way of water to prolong the time of the arrival of water to the city.

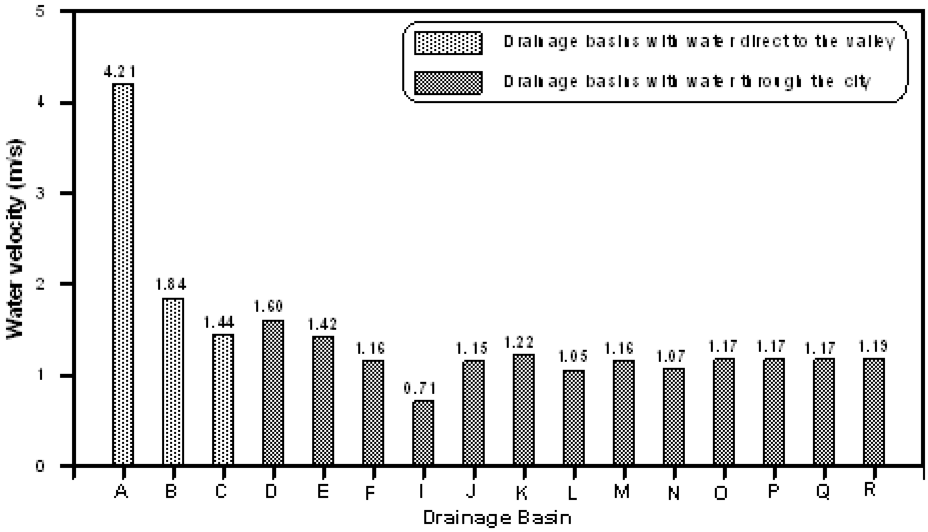

Fig. 7. Flood water velocity over different drainage basins

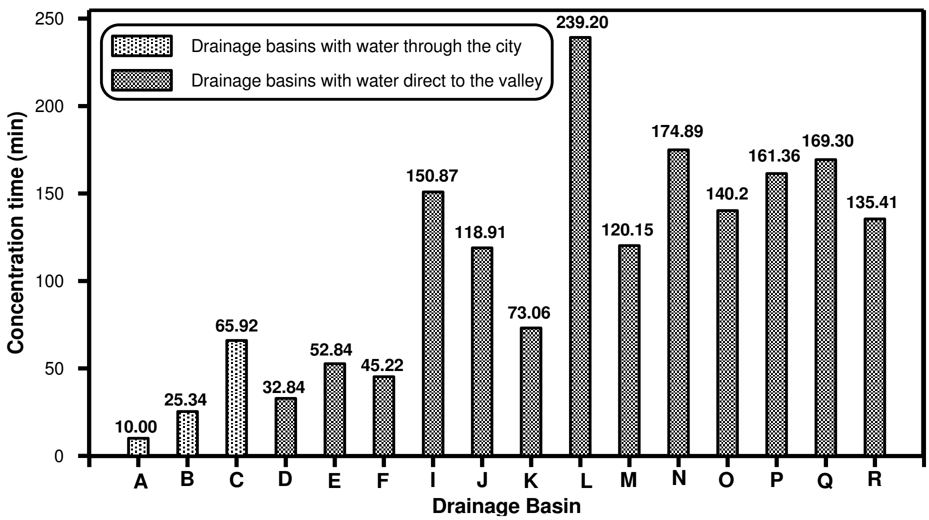

Fig. 8. Concentration time of flood water for different drainage basins

4. IDF- Curve

The rainfall Intensity-Duration-Frequency (*IDF*) relationship is one of the most commonly used tools in water resources engineering, either for planning, designing and operating of water resource projects, or for various engineering projects against floods. The establishment of such relationships was done as early as in 1932 (Bernard) [1]. Since, many sets of relationships have been constructed for several parts of the globe. The correct and safe estimation of the flood and rainfall water for a city depends on the records of rainstorms monitored for the city in eras past. Due to the scarcity of meteorological and climatic data and the lack of recorded rainfall rates for *Dhukna* or *Quseem* region, the *IDF*-Curve for *Riyadh* is used to estimate the rainfall rates due to its proximity and similarity of metrological and climatic conditions. The available meteorological data for *Dhukna* was merged with the data *Riyadh* city, taking into account a safety factor makes the highest rate of rainfall was about 66.5 mm/day, which is relatively greater than that was observed in the city in the past years (64 mm/day). Figure (9) shows the modified applied *IDF* curve.

In addition, the frequency period for a storm of certain intensity falling on a certain watershed area is defined as the time period necessary for this storm to be repeated with the same intensity on the same watershed area [12, 8]. In other words, it can be said that the expected recurrence period for a storm of certain intensity is defined as the reverse of its probability percent. The recurring time or frequency period was chosen to be 100 years. This value is the most suitable for the open valleys and the safest to achieve the city safety.

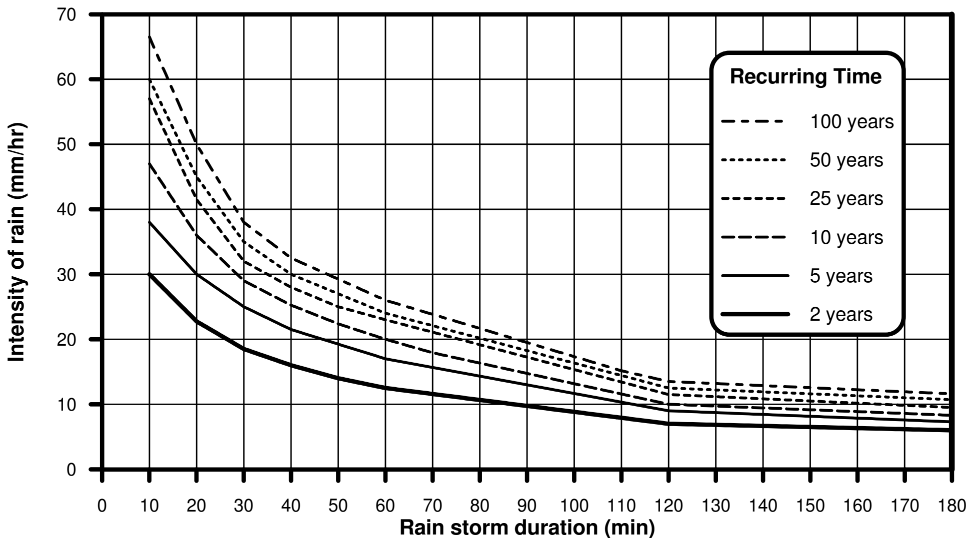

Fig. 9. IDF- Curve for Dhukna city

5. Estimation of Flood Water

The methods used to estimate the flood quantities are usually relative and generally built up on empirical formulas. It depends on many factors which are difficult to quantify accurately. These factors are generally obtained for the drainage basins of special characteristics and nature. So the accuracy of these equations depend on the area, the geographic location of the drainage basins in addition to weather and climate conditions that have the greatest influence in the selection of the formula that will be applied. From the field experiences, it can be reported that – if there are available records for the rainfall depths over a historical period more than 20 years ago - the Soil Conservation Service Curve Number (SCS-CN) method is of enough accurate and suitable to estimate the storm water quantities for catchment basins of areas more than 81 Ha [3, 4, 5, 12]. For basins of areas less than 81 Ha, the rational method may be used [3, 4, 5]. In case of there is no any records for the rainfall depths, the regression formulas; generated for similar hydrologic and topographic conditions, may be used with accepted tolerance [9, 10, 14]. For SCS-CN method, Equation (5) represents a relationship between the accumulated rainfall and accumulated runoff. This method was derived by Soil Conservation Services (SCS) from experimental plots for numerous soils and vegetative cover conditions. The accumulated direct runoff that may occur on a catchment basin land surface is computed as follows:

$$R = \frac{(P - I_a)^{a_5}}{(P - I_a) + S} \tag{5}$$

Where; R = accumulated direct runoff, P = potential maximum runoff (it equals the 24-hr rainfall depth, I_a= initial abstraction including surface storage, interception, and infiltration prior to runoff , S = potential maximum retention, and a_5 = coefficient depends on catchment basin features. Also, Equation (6) is used to compute the potential maximum retention (S) as follows:

$$S = z\left(\frac{100}{RCN} - 1\right) \tag{6}$$

Where; z = coefficient depends on the measurement units, and RCN = runoff curve number depending on the characteristics of the catchment area and the related on-life activities. In addition, I_a generally may be estimated as;

$$I_a = 0.20 \times S \tag{7}$$

The unit peak discharge q_u can be estimated as follows;

$$q_u = \left(10^{C_o - a_6}\right) \times \left(T_c^{C_1 + C_2 \log(T_c)}\right) \qquad (8)$$

Where; T_c = time of concentration, and c_o, c_1, c_2, a_6 are constants depend on the value of I_a/P.

Finally, Equation (9) is used to estimate the peak water discharge of a storm falling on a catchment basin as follows;

$$Q = q_u \times A_B \times R \times F \qquad (9)$$

Where; Q = peak storm discharge, q_u = unit peak discharge, R = accumulated direct runoff, A_B = watershed area, and F = pond adjustment factor (depends on pond percent within the watershed).

RCN is assumed to be 92 (such that the nature of the basins is mountainous with low permeability), the flood and rain water quantities falling on the different drainage basins are estimated, see Fig. (10). From the geographical nature of the city and the limits of drainage basins of all valley' branches draining its water upon the *Great Wadi*, it is noticed that the basins that drain water to the Great Wadi passing through the city from the western side are only [A] and [B] in addition, to a small part of [C]. About 15% of the rainwater falling on basin [C] passes through the city on the way to the main valley. On this basis, the quantities of flood water and rains expected to pass through the city from basins [A], [B] and [C] is estimated using Equation (6) to be about 101.7m^3/s. In addition,

the quantities of water floods and rains expected to arrive to the Great Wadi and pass through the main culvert is the water falling on all drainage basins is estimated to be about 526.23m^3/s, see Figure (10).

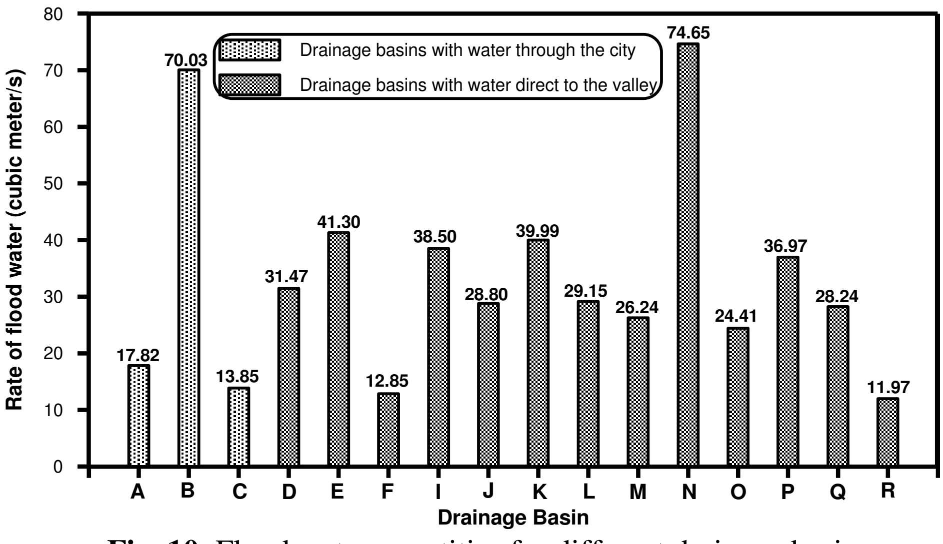

Fig. 10. Flood water quantities for different drainage basins

6. Main culvert performance

The huge culvert constructed on *Great Wadi* at the eastern north of the city could not compass the flood water of the storm occurred at 2009. As a result, an increase in water level over the culvert parapet has been recorded by more than one meter tends to a collapse in the *Great Wadi* eastern bank. The culvert efficiency is evaluated as follows:

$$\xi_{culvert} = \frac{Q_{Safe}}{Q_{Expected}} \times 100 \tag{10}$$

Where, Q_{safe} = safe storm discharge passing through the culvert, $Q_{Expected}$ = maximum expected storm discharge for recurrence period of 100 years which estimated to be 526.23m^3/s.

Using Manning's Equation, the safe flow discharge of the existing culvert is estimated to be Q_{safe} = 276.71m^3/s. This means that the culvert in its present case and characteristics can not accommodate more than 53% of the expected storm water falling on the watershed area for a frequency period of 100 years. To raise the operational efficiency of the culvert, it should be expanded to include some new vents. It has been found that 28 vents of the same existing dimensions need to be constructed beside the old culvert (32 vents) to accommodate the expected incoming storm discharge of frequency period of 100 years.

7. Conclusions

From this study one can find:

1- The characteristics of water drains area as follows,

a. The surface velocities of the flood waters on the different basins are often less than 1.50 m/s except that of basin {A}, it has reached more than 4.21 m/s.
b. In some basins, flood waters reach the *Great Wadi* at a time does not exceed 10 minutes from the beginning of the storm such as basin {A} due to its steepness. While for some basins the water reach after about four hours.
c. The basin {A}, which drains its water directly through the city, have the priority to create some embankments or artificial ponds in the flow way to prolong the arrival time of water to the city.

2- The flood water quantities falling on the city are well estimated according a modified *IDF*- curve which takes into account the available data of rainfall of *Dhukna* City with the data and the curve of *Riyadh* city.

3- Its recommended to use the (SCS–CN) method for estimating the flood water quantities for a recurrence period of 100 years.

4- The flood water quantities, expected to pass through the city in its path to the Great Wadi, are defined to come from the western and the north sides (basins of A, B and C) and estimated to be about 101.7 m^3/s.

5- Flood water expected to pass through the main culvert are about 526.23m^3/s.

6- The culvert in its present dimensions can not accommodate more than 53% of the expected incoming flood waters.

7- To increase the main culvert efficiency, it has been recommended to add 28 new vents with dimensions of 2.5 m x 1.50 m to the existing culvert in order to be able to accommodate the expected incoming flood waters (526.23m^3/s).

8. Recommendations

In order to create a feeling safe for the citizens from the storm waters; generally coming from the western side and expected to be increased due to the future climatic conditions, it is preferred to construct a strategic plan for the global storm water drainage for *Dukhna* city. The details of the proposed plan would be outlined in a future research paper.

Nomenclature

I_a	Initial abstraction.
IDF	Intensity Duration Frequency curve.
K	Constant.
L_c	Critical path length of a basin.
L_{sheet}	Critical path length on which the flow is of sheet.
$L_{shallow}$	Critical path length on which the flow is of shallow.
P	Rainfall precipitation intensity.
q_u	Storm unit peak discharge.
Q_{safe}	Safe discharge of the culvert.
$Q_{Expected}$	Maximum expected storm discharge for recurrence period of 100 years.
R	Accumulated direct runoff.
RCN	Runoff curve number.
S	Potential maximum retention.
S_B	Basin surface slope.
T_{sheet}	Time of concentration for sheet flow.
$V_{shallow}$	Flow velocity for shallow flow.
$\xi_{culvert}$	Efficiency of the main culvert.

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تقدير كميات مياه الفيضان التي تتعرض لها مدينة دخنة في بلدية القصيم بالمملكة العربية السعودية

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ملخص:

تتزايد خطورة الفيضانات نتيجة لتكرار حدوثها في جميع أنحاء العالم و ما تسببه من كوارث ويرجع ذلك للتغيرات المناخية الشديدة التي يشهدها العالم في الآونة الأخيرة وتأثيرها على معدلات هطول الأمطار وفترات سقوطها. تعرضت مدينة دخنة منذ ثلاث سنوات إلى عاصفة مطرية شديدة أدت إلى انهيار الجسر الأيمن للوادي الرئيسي الذي يمر بالجانب الشرقي للمدينة امام العبارة الرئيسية مما أدى إلى إنهيار العبارة حيث وصل ارتفاع الماء فوق العبارة لأكثر من متر. والهدف من هذا البحث هو دراسة الخصائص الهيدرولوجية لمدينة دخنة الواقعة في نطاق منطقة القصيم بالمملكة العربية السعودية, و التي تشهد عملية تطوير ونمو عمراني في الآونة الأخيرة باعتبارها واحدة من المدن المتوقع أن تتعرض لخطر الفيضانات. تم عمل دراسة لخصائص أحواض الصرف التي تصرف مياهها عبر المدينة. وقد تم استخدام أسلوب - SCS CNلتقدير كميات مياه الفيضان لجميع أحواض الصرف المحيطة بالمدينة والتي تصرف مياهها مباشرة إلى الوادي الرئيسي وخاصة التي تمر عبر المدينة. وقد تم تقييم أداء العبارة الرئيسية و كفاءتها التشغيلية في الوقت الراهن. كما تم تحديد عدد الفتحات اللازمة لتوسيع العبارة لزيادة كفاءتها التشغيلية لاستيعاب مياه الفيضان القادمة عبر الوادي الرئيسي.