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Hydrologic Calculations in Wadis Hada Al Sham and Usfan

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Abstract. In this research, hydrologic calculations have been made for Wadis Hada Al Sham and Usfan including the runoff, the interception, the infiltration, and the sediment load. These calculations have depended on the meteorological, the morphological, and the geological characteristics of the wadis as well as the results of infiltration tests and sieve analyses of soil samples from the wadis. The calculations were repeated for storms of different return periods 2, 5, 10, 20, 50, and 100 years and variable storm duration of 0.5, 1.0, and 2.0 hours. The study results are presented in the form of runoff hydrographs and tables including water volumes and rates at the outlet of the wadis. A hydro-morphological model developed by MIT has been used in the calculations. It had been calibrated in Wadi Ghuran that extends on the northern boundary of the studied wadis and has runoff records. Results of study are presented only at the outlet of Hada Al Sham and Usfan at sections L2 and U1, respectively. Calculations at section U1 have shown that if the entire region is subject to a storm of one hundred-year and duration of half an hour (as an extreme case), the resulting runoff hydrograph has three peaks with a maximum discharge of 10100 m^3/sec. The corresponding water volumes of interception, infiltration and runoff are 23.64, 79.47, and 163 millions cubic meters, respectively. The corresponding equivalent heights are 0.012, 0.043, and 0.0876 m over the entire area that is about 1861 km^2. The sum of these equivalent heights is equal to the precipitation value (0.143 m) coming with the corresponding storm. It has been recommended to install gauging stations, for the runoff, at the outlet of the sub-basins of the studied wadis to provide continuous records that would help in any future calibration of the hydro-morphological model. Also, it has been advised to apply this methodology of study in other wadis of similar conditions.

Location of Area of Study

The attached location map (Fig. 1) shows the location of Wadi Hada Al Sham and Wadi Usfan as well as the neighboring ones which are Wadis Khulays in north and Wadi Fatimah in the south. The area of study is located between longitudes 30º14′ and 40º15′

East and latitudes 21°30′ and 22°15′ North. Wadi Hada Al Sham flows into Wadi Usfan that runs in East-West direction having its outlet towards the Red Sea at a distance 105 km North of Jeddah. Wadi Usfan comprises of four main basins: Ash-Shamiya, Faydah, Sughu and Al Lusub. Wadi Hada Al Sham contains four main sub-basins which are Madrakah, Al Alaq, Sima, and Hishash. The largest town in the area is Usfan which is located at about 75 km north west of the holy city of Makkah.

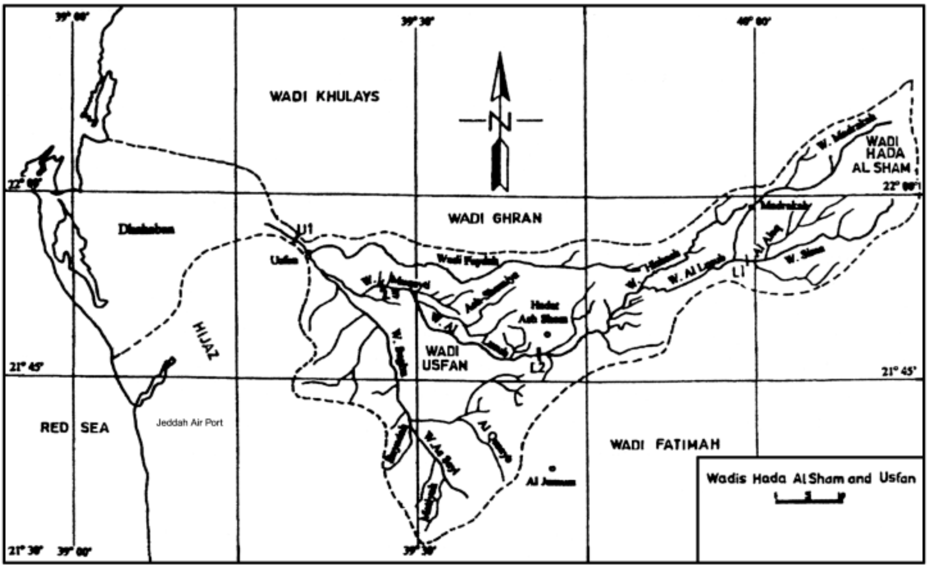

FIG.1. Location map for the region of study.

Background

Rainfall-Runoff Process

The conversion of rainfall to runoff has been studied by scientists and engineers to develop an understanding of the process and to design hydraulic systems needed for runoff control. Concepts such as interception, infiltration, and surface flow are described in hydrology textbooks as abstraction or losses. Interception is defined as a segment of the gross precipitation that wets and adheres to above ground objects until it returns to the atmosphere by evaporation. Precipitation striking vegetation may be retained on leaves or blades of grass, flow down the stems of plants and become stream flow, or fall off the leaves to become a part of the throughfall. The amount of water intercepted is a function of 1) the storm character, 2) the species, age, and density of prevailing plants and trees, and 3) the season of the year. Usually about 10 to 20% of the precipitation that falls during the growing season is intercepted and returned to the hydrologic cycle by evaporation (Gupta, 1989). Precipitation that reaches the ground may infiltrate, flow over the surface, or become trapped in numerous small depressions from which the only escape is evaporation or infiltration. The nature of depressions, as well as their size, are largely a function of the original land form and the use practices. Infiltration is the flow of water into the ground through the earth's surface. It can affect not only the timing, but also the distribution and magnitude of the surface runoff. The rate at which it occurs is influenced by such factors as type and extend of vegetal cover, condition of the surface crust, temperature, rainfall intensity, physical properties of the soil, and water quality. After water crosses the surface interface, its rate of downward movement will be controllled by the transmission characteristics. The remaining water, "rainfall excess", forms detention storage that builds up on permeable and impermeable surfaces within the watershed and gathers in small rivulets carrying the water as overland flow into small channels, then into larger channels, and finally as channel flow to the watershed outlet. As precipitation excess continues, enough time elapses for progressively distant areas to add to the outlet flow. Consequently, the duration of rainfall dictates the proportionate area of the watershed amplifying the peak, and the intensity of rainfall during this period of time determines the resulting highest discharge.

Hydro-morphological Models

In watershed analysis, the major categories of models include lumped parameter versus distributed parameter, event versus continuous, and stochastic versus deterministic models. Lumped parameter models transform actual rainfall input into runoff output by conceptualizing that all watershed process occurs at one spatial point. Synthetic unit hydrographs are a widely used example. Distributed parameter models attempt to describe physical processes and mechanisms in space, as evidenced by certain classes of hydrologic simulation models.

Event models, such as the Flood Hydrography Package, HEC-1 (Hydrologic Engineering Center, 1981) the EPA Storm Water Management Model (SWMM) (Huber and Dickinson 1988) or the SCS TR20 (US Soil Conservation Service, 1975), simulate single-storm responses for given rainfall input data. Unit hydrograph or kinematic wave methods are used to generate storm hydrographs, which are then routed within stream channels. Continuous models such as the Stanford Watershed Model, SWMM and STORM are based on long-term water balance equations and thus account directly for antecedent conditions.

Some models may include stochastic components to represent the input rainfall, which is then used to generate time series of stream flow such as the Markov technique. It assumes that the next flow in a sequence is related to a subset of previous ones and is usually restricted to shorter time interval of analysis. Details of stochastic models can be found in Rodriguez and Valdes (1979).

Description of the Model Used

The hydro-morphological model used was originally developed by Rodriguez and Valdes in 1979. During the period 1981 through 1984, the model was adopted and modified by the MIT water resources group. Later, the model has been applied in many wadis all over Egypt through Cairo University/MIT Technological Planning Program. In 1994, it was modified by El-Didy (El-Didy and Werwer, 1994). The basic idea of the model is finding the unit impulse response function of each basin from its morphological parameters. This function is known as the Instantaneous Unit Hydrograph (IUH) of the basin, and once it is determined, all other hydrological responses of the basin can be obtained. The hydro-morphological model is probabilistic in nature and its foundation relies mainly on that if a water particle is injected randomly over the basin, it will follow a certain path through the overland catchment regions and the channels before arriving to the outlet. The path probability function is the probability that a particle follows a certain path among all possible paths quantified based on the Strahler scheme. Each path has its own probability depending on the number of orders of the basin and their linking system. The model simulates the different branches of the basin in such a manner to represent the dynamic transitions of water from one sub-basin in the system to the next. The basic assumptions of such a model are: 1 – The model is divided into states equal to the highest order of the basin. A drop may start in any state, but all drops eventually terminate in the highest numbered state. 2 – Transition is the change of the state of certain probability depending on the number of links in the system. A probability transition matrix is written for each basin with elements that are mainly a function of the bifurcation ratio. 3 – The transition from one state to another follows the Markovian hypothesis. 4 – The holding time of the water in any state is independent of the destination state.

In this model, the instantaneous unit hydrograph, IUH for the third-order basin is given by Rodriguez and Valdes (1979) as:

$$\mathrm{IUH}(t) = \frac{d\theta_4(t)}{dt} = \theta_1(0)\frac{d\Phi_{14}(t)}{dt} + \theta_2(0)\frac{d\Phi_{24}(t)}{dt} + \theta_3(0)\frac{d\Phi_{34}(t)}{dt}$$

where $\theta(t)$ is the state matrix whose elements give the probability that the drop occupies state i at time t, $\theta(0)$ is the initial state probability vector whose elements $\theta_i(0)$ give the probability that a drop starts at state i (stream of order i), and $\phi(n)$ is a multi-step transition probability matrix whose elements give the probability that the drop goes from state i to state j after n transitions. The probability that a drop at random in state i (i =1, 2, 3, 4) has reached the outlet at time t is given by

$$\Phi_{14}(t) = 1 + \frac{\lambda_3(\lambda_2 - \lambda_1 p_{13})}{(\lambda_2 - \lambda_1)(\lambda_1 - \lambda_3)} e^{-\lambda_1 t} + \frac{\lambda_1 \lambda_3 p_{12}}{(\lambda_2 - \lambda_1)(\lambda_3 - \lambda_2)} e^{-\lambda_2 t}$$

$$+ \frac{(\lambda_1 \lambda_2 - \lambda_1 \lambda_3 p_{13})}{(\lambda_3 - \lambda_1)(\lambda_2 - \lambda_3)} e^{-\lambda_3 t}$$

$$\Phi_{24}(t) = 1 + \frac{\lambda_2}{(\lambda_2 - \lambda_3)} e^{-\lambda_2 t} + \frac{\lambda_2}{(\lambda_3 - \lambda_2)} e^{-\lambda_3 t}$$

$$\Phi_{34}(t) = 1 - e^{-\lambda_3 t}$$

$$\theta_1(0) = R_B^2\ R_A^{-2}$$

$$\theta_2(0) = \frac{R_B}{R_A} - \frac{R_B^3 + 3R_B^2 - 2R_B}{R_A^2(2R_B - 1)} \qquad \theta_3(0) = 1 - \frac{R_B}{R_A^2} - [\frac{R_B(R_B^2 - 3R_B + 2}{(2R_B - 1)}]$$

$$p_{12} = \frac{R_B^2 + 2R_B - 2}{2R_B^2 - R_B} \quad \text{and} \quad p_{13} = \frac{R_B^2 - 3R_B + 2}{2R_B^2 - R_B}$$

R_B, R_L, and R_A represent the bifurcation ratio, the length ratio, and the area ratio.
The term λ_i is a different mean waiting time for each stream order.

Combining all the above assumptions, the model gives the instantaneous hydrograph with the basin assuming that there is no infiltration. Such infiltration effect is later compensated using the US Soil Conservation method. The potential maximum retention, *S* is related to the curve number, CN (US Soil Conservation Service, 1975) that is obtained from the standard tables of the US Soil Conservation Service. These tables relate the choice of the curve number to the hydrologic soil group, the type of land cover, the hydrologic condition and antecedent moisture condition, and the cropping practice in the case of cultivated land. The soil group is a function of the soil texture and their measured infiltration rate. Once the IUH of the wadi is computed, it is mathematically convoluted with the storm to obtain the expected hydrograph. This hydrograph is then reduced by a factor to compensate for the infiltration effect of the wadi. In the program, each sub-division of the wadi is fed separately and the model is then operated for building IUH after obtaining all the morphological parameters. The superposition principle is then invoked for summing the different IUH's at the outlet of the wadi after being weighted by their own areas and imposing the delay time from the outlet of the sub-basin to the main wadi outlet. This gives the overall IUH of the wadi. The IUH is then mathematically convoluted with uniform storms with unit volumes but of different duration, to yield the corresponding normalized hydrological responses. Such responses are then multiplied by the wadi area, the rainfall intensity, and the runoff-rainfall ratio to provide the actual hydrographs of the wadi.

The iteration procedure was adopted in the modeling process starting with a rough estimate for the velocity using the table of the US Navy, Technical Publication Navdocks (United States Dept. of Interior, 1977) for similar basins. Depending on the average velocity in the main trunk of each basin and the distance between the outlet of each basin and the main outlet of the valley, the lag time in hours was estimated for each sub-basin.

The input file of the morphological model includes the wadi name, the number of sub-basins of the studied wadi, the rainfall intensity, the return period and the duration of the concerned storm, and the infiltration curve number. For each sub-basin, an initial estimate of the mean velocity in the main stream is included in addition to the number of streams of the different order, their average length, and the corresponding drained areas. The lag time between the outlet of the related sub-basins and the concerned section of study is given, too. The output file provides the main morphological parameters of the wadi, the runoff hydrograph of the storm in forms of tables and plots, and the corresponding water volume of the runoff and the infiltration.

The sediment rate per unit width of the main trunk of the wadi is calculated using the duBoys formula (Morris and Wiggert 1972). It is a function of Manning coefficient, the flow rate per unit width, the average slope of the wadi stream, and an empirical constant. This constant is dependent on the the mean grain size and the specific gravity of the bed material of the wadi main stream.

Meteorological Data

The most important climatic factors that would affect the hydraulic behavior of a wadi are rate, duration, distribution, and return period of storm precipitation. The climate of the studied wadis is a typical arid one. However, transitional zones between Mediterranean and Monsoon climates predominate in Winter and Spring causing rainy storms. Meteorological data (mainly rainfall) has been collected from seven stations covering the region of study. The stations are Al-Aziziyah (J-219), Al-Barzah (J-239), Khulys (J-211), Usfan (J-221), Madarakah (J-214), Hada Al-Sham (J-104), and Al Jumum (J-135). Three stations lie inside the basins of study. The stations J-135 and J-239 are located just at on the border of the studied area. The other two stations (Khulys and Usfan) are located outside the studied wadis.

Using Gumbel distribution, after computation of the mean and standard deviation of the rain records at every station, the values of the event reached or exceeded were calculated and plotted versus the return period on the extreme probability papers (Gumbel, 1954 and 1958). From the plots (El-Didy, 1998), the rainfall for the return periods 2, 5, 10, 20, 50, and 100 years was computed. Then, the average value of precipitation over each basin was determined using Thiessen polygon method. The calculated average values at the different stations are presented in Fig. 2 for different return periods.

Geological Description

The area of study is a part of the western Arabian Shield which is a complex of metamorphic and platonic rocks. The central part of the area consists of sedimentary rocks of Tertiary age which are overlain by basaltic lava flows. The sedimentary rocks cover about 50 % of the total surface area. They are classified into two groups, the Usfan formation and the Shumaysi formation. Usfan Formation consists mainly of sandstone, shale, marls and fossiliferous carbonate wedges. Shumaysi Formation is composed of sandstone, siltstone and oolitic ironstone bands (Chebotarev, 1955). According to Kotb *et al.,* 1983; the upstream area of the valley has deposits of pebbles in layers alternating with coarse sand. Then, at downstream it changes gradually to silt and clayey silt. Thickness of the alluvium deposit varies in the range of 35 to 75 m in the middle portion.

Morphological Characteristics

The morphological characteristics of watersheds control their hydraulic response during the rainy storms by affecting the runoff hydrograph in terms of peak discharge, run-

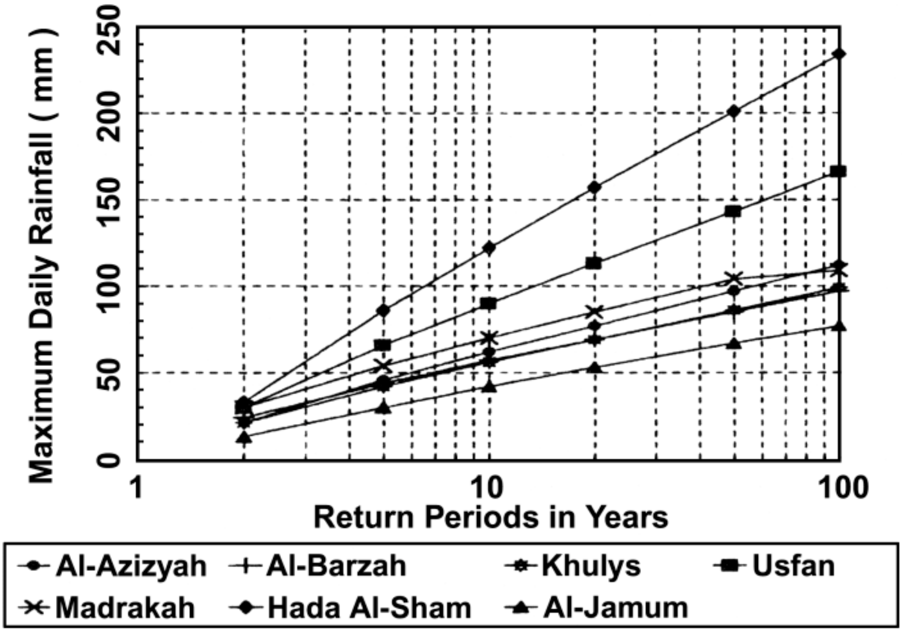

FIG. 2. Maximum daily rainfall reached or exceeded (mm) versus return period (years) at the different meteorological stations.

off duration, start time of runoff, and water volume. The main affecting morphological features are order of streams, number of branches of the different orders, their corresponding length and drainage area, slope of streams and velocity of flow.

Al-Lusub is the main stream in the catchment of study. It drains the basins Madrakah, Sima, Hishash and Alaq that initiate from the plateau of the Harat Rahat. It continues running to pass the Hada Al Sham village by about 5 kilometers where it enters the Usfan plain. There, it drains the Muqayti and Ash Shaiya basins near a village called Al Shamiyah. To the east of the town of Usfan, wadi Faydah and wadi Sughu discharge into Al Lusub stream. Wadi Faydah has a narrow valley that cuts through the Tertiary sandstone of the Khulays formations. Wadi As Sughu comes from the south draining the sub-basins of As Sayl, Al Qusayb, Matiyah, and Baradah.

Strahler approach was applied for ranking the order of the different branches in each basin. Maps with scale 1:50,000 were employed because order of a branch is extremely sensitive to the map scale. First, second, and third order branches were identified. A first-order stream is a small unbranched tributary. A second-order stream has only first-order tributaries. A third-order stream has first- and second-order tributaries. The number of branches, the average length and the drainage area of each order were calculated. The area has been subdivided into ten main basins and five other smaller ones. A summary of the morphological characteristics is presented in Table (1).

TABLE 1. Morphological characteristics of the basins sharing in the region of study.

Wadi	No. of branches			Average length of branches (km)			Area served by the branches (km^2)			Average slope (m / km)
	1st Order	2nd Order	3rd Order	1st Order	2nd Order	3rd Order	1st Order	2nd Order	3rd Order	
Madrakah	22	9	13	3.863	1.877	2.808	115.825	25.387	53.500	9.70
Al Alaq	11	6	4	2.382	3.750	3.850	61.325	33.275	23.15	12.36
Hishash	20	8	10	3.000	1.663	1.080	76.475	16.450	14.400	7.90
Hada Sham at Sec. L2	53	21	30	3.342	3.338	2.590	306.815	104.850	95.785	11.27
Faydah	25	7	15	2.500	1.729	3.567	101.025	10.750	122.65	4.80
Sughu	43	19	14	2.674	1.674	1.821	195.050	31.850	38.325	6.35
Muqayti	3	2	–	9.133	2.500	–	126.450	25.650	–	3.87
Usfan at section U1	89	40	45	2.975	2.880	2.796	570.465	168.375	203.175	7.02

Field Trips

Several field trips had been done for achieving the following tasks:

– Identifying features of the area of study including the wadis, the nature of ground surface, vegetation cover and passage of runoff.

– Collecting soil samples for sieve analysis whose results were used in determining the rate and the volume of sediment load carried by the runoff.

– Carrying out infiltration tests at eight sites using the cylinder (ring) infiltrometer to determine the rate of water infiltration into the soil. The results showed that steady values of infiltration rate varies between 0.05 and 0.2 cm/min with an average one 0.07 cm/sec.

Calibration of the Model

Unfortunately, no gauge stations have been found in the studied wadis for measuring and recording the runoff due to rainy storms. The nearest gauging station was found in Wadi Ghuran which is a sub-basin in Wadi Khulys. The basin of wadi Ghuran extends on the northern border of the studied region. It has a common border with Faydah, Hishash, and Madrakah basins which are sub-basins flowing to the studied wadi. The gauging station number is J-410 and is located at Latitude 22º 05′ East and Longitude 39º 40′ North. Wadi, Ghuran runs between Latitudes 21º 13′ and 22º 15′ East and Longitudes 39º 30′ and 40º 40′ North. The catchment total area is about 1240.875 square kilometers with an average slope 6.64 m/km. Trial runs have been made for wadi Ghuran, using the morphological model, to determine a guide value for the curve number that could represent the region and give numerical results that would be close to the measured values. Fig. 3 presents comparison between the calculated and the measured hydrographs on December 18th, 1985, when data is available about the runoff distribution. The error between the calculated and the measured values were is 8% for the maximum runoff discharge and 10% for the runoff volume. The used Curve Number has been employed as a guide for the value used in the neighboring sub-basins of the studied wadis. Little modification would be needed according to the nature of each basin in terms of infiltration rate, vegetation cover, and type of surface soil.

Description of the Study

The hydraulic response of Wadis Hada Al Sham and Usfan have been determined by investigating five separate sub-basins and four other sections on the main stream in the region where combinations of the sub-basins contribute. The separate sub-basins are Madrakah, Hashish, Faydah, Al Alaq , and Sughu. The hydraulic response of each one has been determined at the outlet into the main wadi. On the main stream of the main wadis, the sections L1, L2, L3 and U1 (Fig. 1) have been considered in the study. The basins Madrakah, Al Alaq and a part of wadi Al Lusub contributes at section L1. Section L2, which lies in the area of Hada Al Sham, receives runoff flow from wadis Madrakah, Al Alaq, Hishash and a greater part of wadi Al Lusub. Section L3 receives water from the same sources of section L2 in addition to more area from wadi Hada Al Sham. Section U1 represents the outlet of Wadi Usfan which receives water from the entire concerned region including all the above mentioned sub-basins. The hydraulic response at each section assumes that rainy storms covers the entire area that could contribute to the studied section. Only, results at sections L2 and U1 are shown here. The calculations are repeated for storms of return periods 2, 5, 10, 20, 50 and 100 years. Storms of duration 0.5, 1.0, and 2 hours are considered. For each section three figures are included showing the runoff hydrographs for the different storms duration. Figures are included giving the water volume of interception, infiltration, and runoff. Tables 2 and 3 show the sediment load carried by the runoff in the main stream of the wadis has been determined in the form of rate and volume.

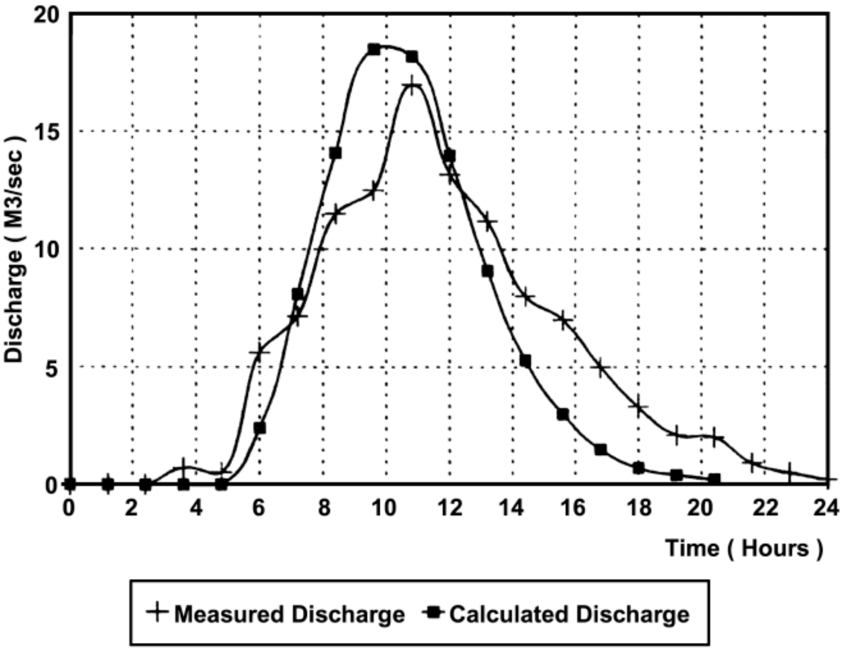

FIG. 3. Comparison between the measured and the calculated hydrographs in Wadi Ghuran on Dec. 18th, 1985 (calibration process).

TABLE 2. Rate and volume of sediment transport carried by runoff of storms of different return periods and variable duration at section L2.

Return period (years)	Rate of sediment load (m^3 / sec) for different storm duration (hour)			Volume of sediment load (millions m^3) for different storm duration (hour)		
	0.5	1.0	2.0	0.5	1.0	2.0
2	1.358	1.285	1.218	0.061620	0.061049	0.060509
5	12.022	11.722	11.447	0.623195	0.620180	0.618127
10	22.954	22.100	21.898	1.239490	1.231445	1.229806
20	36.512	35.833	34.833	1.971623	1.965434	1.956218
50	54.259	52.258	51.857	3.047213	3.034235	3.024299
100	64.544	62.264	61.686	3.624777	3.6196980	3.597520

TABLE 3. Rate and volume of sediment transport caried by runoff of storms of different return periods and variable duration at section U1.

Return period (years)	Rate of sediment load (m^3 / sec) for different storm duration (hour)			Volume of sediment load (millions m^3) for different storm duration (hour)		
	0.5	1.0	2.0	0.5	1.0	2.0
2	1.345	1.312	1.296	0.092958	0.092575	0.092387
5	12.864	12.576	12.437	0.972536	0.968874	0.967073
10	24.730	24.191	23.930	1.922993	1.915949	1.912484
20	37.758	37.354	36.958	3.017645	3.012237	3.006886
50	58.334	57.097	56.496	4.662019	4.645398	4.637220
100	71.937	70.411	68.945	5.749175	5.728678	5.708612

Discussion of the Results

It is known that rainy storms of more return period brings more rain than storms of less return period. More rain produces more runoff, and infiltration. For the same amount of rain, longer storm duration gives runoff of less peak discharge and longer runoff period. Different values of storm duration do not affect the volume of water in runoff or infiltration. The volume of intercepted water is constant and does depend on the storm duration or return period as long as the storm brings enough water to cover for the interception.

In addition to the upstream part of wadi Hada Al Sham, section L2 receives runoff from wadis Madrakah, Al Alaq, and Hishash at their outlet sections that are located at distances 6.53, 6.785, and 4.54 km upstream the concerned section L2. The total area that discharges to section L2 is about 927.225 square kilometers. Calculations assumes that rain covers the entire area at the same time. Because of the different distances between sinks of the contributing wadis and the studied section, the runoff hydrograph has three peaks as shown in Figs. 4 through 6. The first peak is the highest and the sharpest one. The middle peak, which the shortest one merges with the third peak for longer storm duration. The ratio between the first and the third peak is about two. The runoff duration ranges between 12.8 and 16.2 hours. Volume of runoff, infiltration and interception are shown in Fig. 7. The largest values are caused by the least frequent storm (return period is 100 years) whose total rain is 145.19 mm. Results of sediment calculations are demonstrated in Table 2 in the form of rate and volume.

Section U1 in Wadi Usfan

Section U1 in Wadi Usfan collects runoff from the entire region of study assuming that rainy storms affect the whole area at the same time. Figs. 8 through 10 present the main features of the runoff hydrographs for different storm duration and 2, 5, 10, 20, 50 , and 100 years return period. As shown in the figures, each hydrograph is characterized by four peaks. The first and the second peaks merge together for storms of longer duration. The last two peaks merge, too. The highest runoff discharge amounts to about 10100.00 cubic meters per second due to a storm of 100 years return period and 0.5

hour duration. The range of runoff duration is between 19.2 hours for a storm of 2 years return period with duration 0.5 hour, and 23.0 hours for 100 year storm with 2.0 hours duration. Fig. 11 presents volumes of interception, infiltration, and runoff for the storms of different return periods. Finally, Table 2 presents the rate and the volume of sediment load carried by the runoff in the main stream of the wadi for storms of different return periods and variable duration.

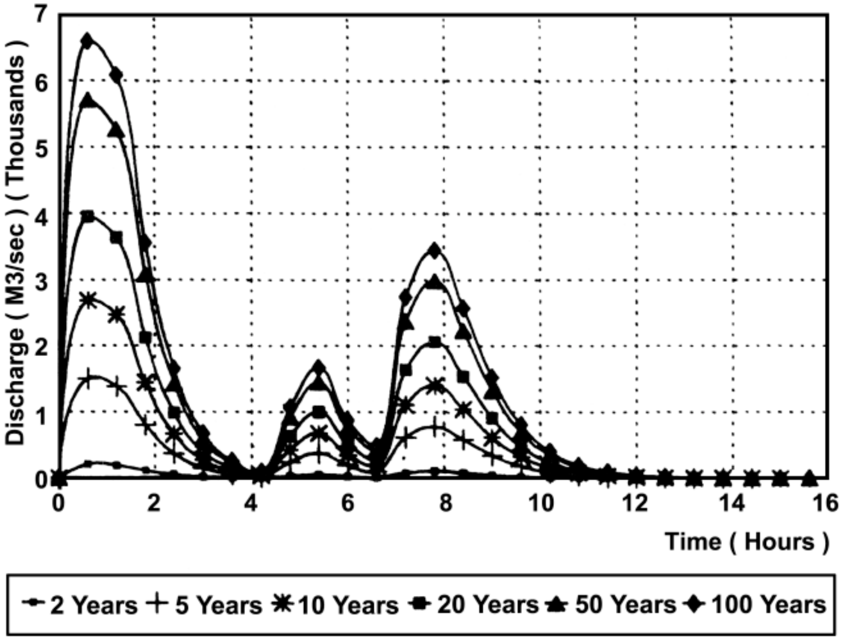

FIG. 4. Runoff hydrographs at section L2 in Wadi Hada Al Sham for storms of different return periods and duration 0.5 hour.

Section U1 represents the final neck of the entire studied area. Considering the worst storm that would happen in the region, the corresponding return period is 100 years with a storm of duration 0.5 hours brings a storm with 143.00 mm rain. Assuming that the entire basin is subjected uniformly to the same rain, the corresponding water volume that comes with the storm is 266.18 millions m^3. As a check for the model calculations, summing up the calculated volume of water of interception, infiltration and runoff which are 23.64, 79.47, and 163.07 millions m^3 respectively, the result is 266.18 millions cubic meters that agrees with the water volume coming with the storm. If the water volume is changed to an equivalent height over the studied area, the interception, the infiltration and the runoff become 0.012 m, 0.043, and 0.0876 m, respectively. The sum of these values is equal to the total storm precipitation which is 0.143 m. Another check could be performed by calculating the area under the corresponding runoff hydrograph. This area gives a runoff volume of 163.07 millions cubic meters and that approximately agrees with the calculated value by the computer. The related sediment volume that is 5.749 millions cubic meters, gives an equivalent height of 0.003 m over the entire region.

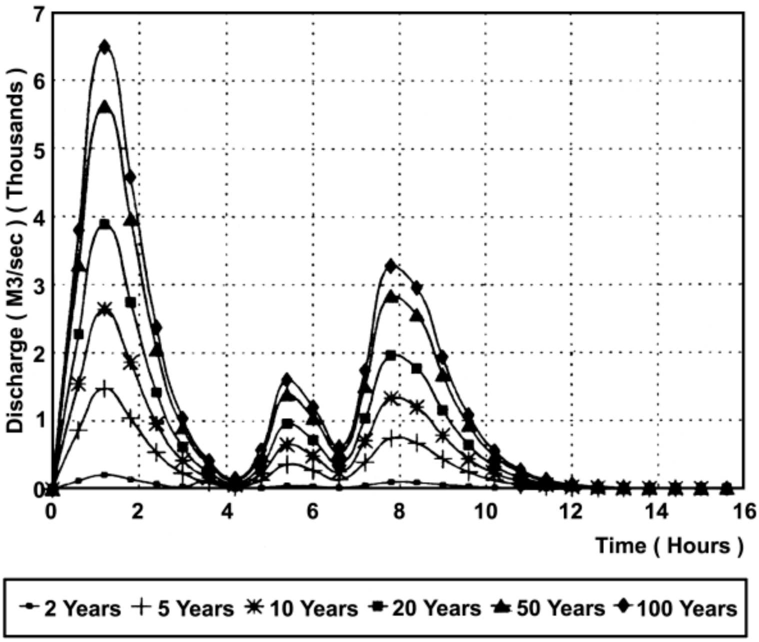

FIG. 5. Runoff hydrographs at section L2 in Wadi Hada Al Sham for storms of different return periods and duration 1.0 hour.

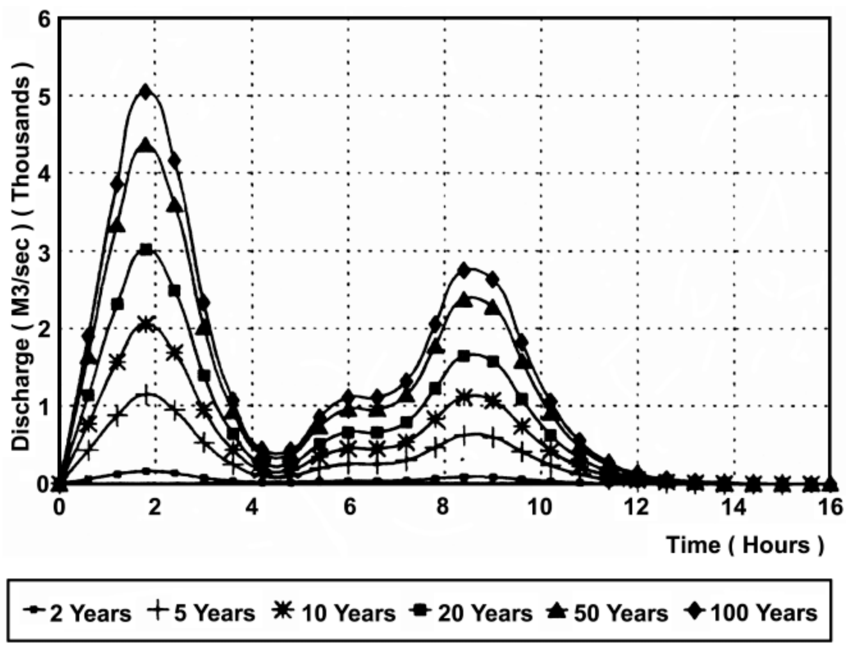

FIG. 6. Runoff hydrographs at section L2 in Wadi Hada Al Sham for storms of different return periods and duration 2.0 hours.

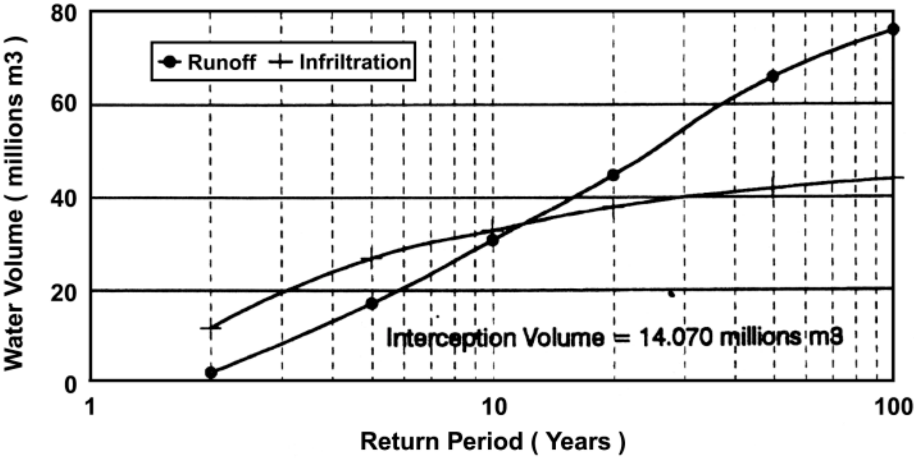

FIG. 7. Volume of runoff, infiltration, and interception at section L2.

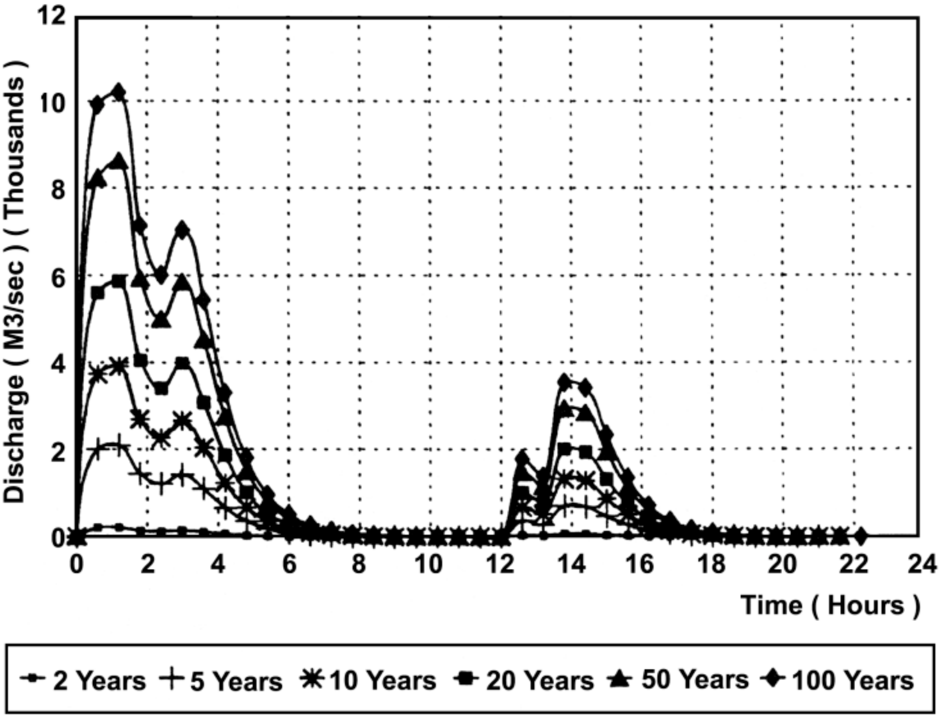

FIG. 8. Runoff hydrographs at section U1 in Wadi Usfan for storms of different return periods and duration 0.5 hour.

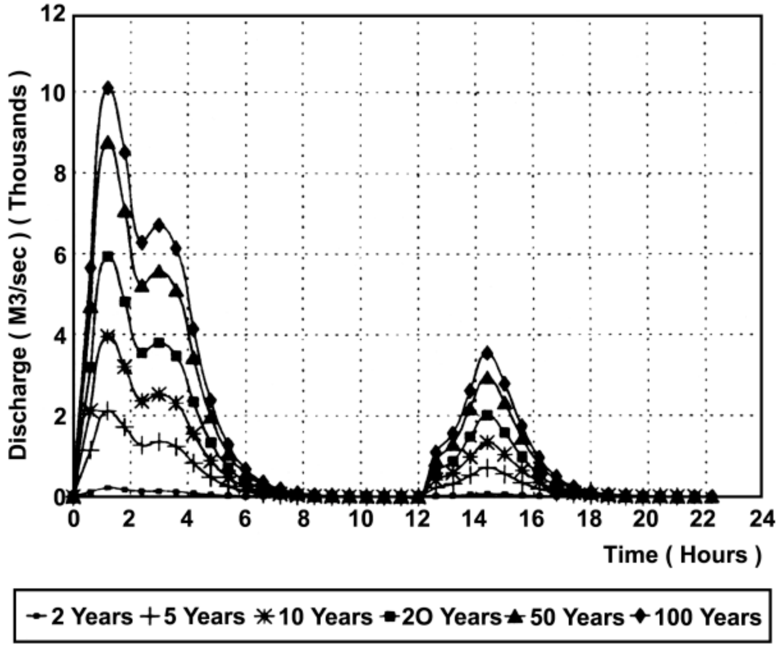

FIG. 9. Runoff hydrographs at section U1 in Wadi Usfan for storms of different return periods and duration 1.0 hour.

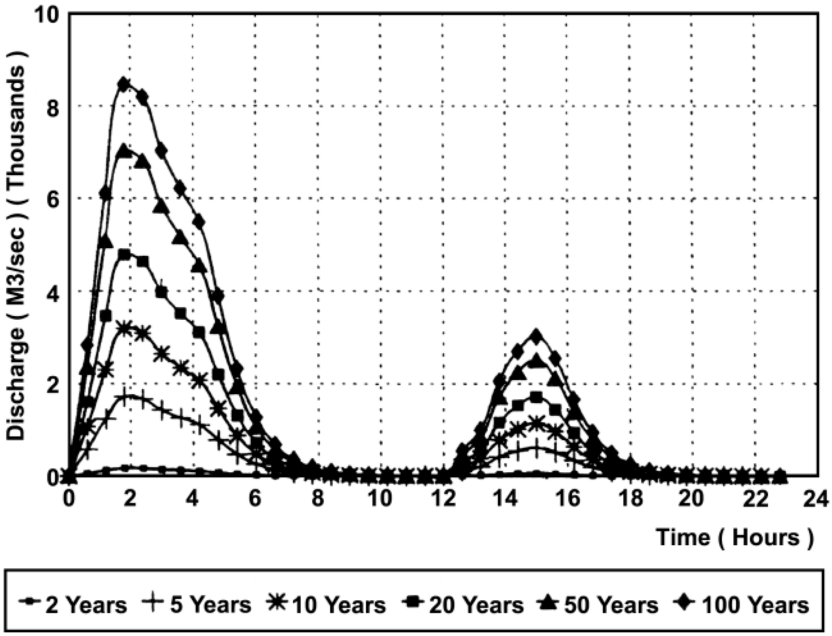

FIG. 10. Runoff hydrographs at section U1 in Wadi Usfan for storms of different return periods and duration 2.0 hours.

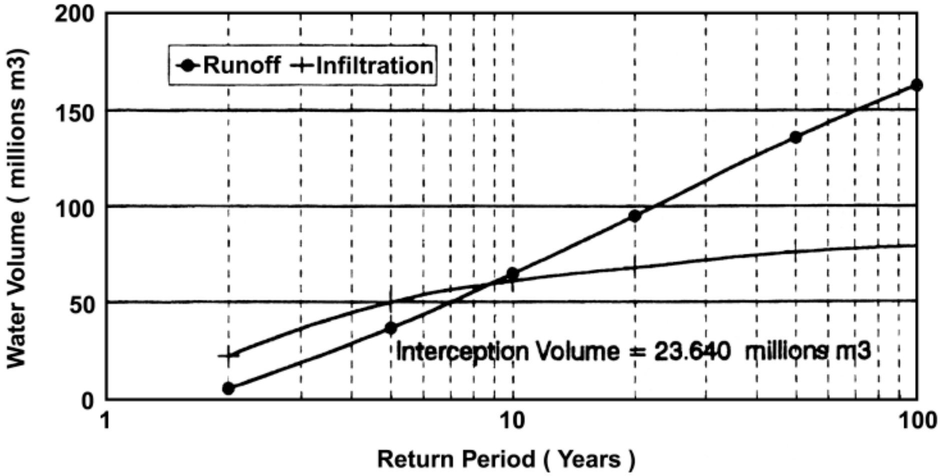

FIG. 10. Runoff hydrographs at section U1 in Wadi Usfan for storms of different return periods and duration 2.0 hours.

Conclusion

The results of the study could be summarized in the following:

– The field visits have shown clear signs of considerable amount of runoff such as debris, erosion of embankments, destruction of some roads, destroyed trees, and extracted plants that are conveyed by the runoff water from other sites.

– The infiltration tests gave steady infiltration rates between 0.05 and 0.2 cm/min.

– The sieve analysis of soil samples has shown that most of the surface soil brought by the runoff water is coarse to medium sand and fine gravel. The mean diameter of soil particles (d_{50}) is in the range of 0.15 mm and1.0 mm.

– The results present the hydraulic response concerning interception, infiltration and runoff in terms of runoff hydrographs, water volume, and sediment load.

– The study has been repeated for storms of return periods 2, 5,10, 20, 50,100 years. The least frequent storms bring more rain than the most frequent ones.

– The study has been performed for storms of different values of duration 0.5, 1, and 2 hours.

– The result of such a study are important for authorities concerned in planning, development of water resources, and design of water structures for runoff control.

– The research presents a typical procedure for studying the hydraulic response of wadis that could be applied to any other region.

Recommendations

– It is beneficial to repeat this procedure of study in other wadis of interest for water resources or protection against flash floods.

– Gauging stations for measuring runoff depth, velocity and discharge at the outlets of the wadis of study, in this research, are needed. These recording stations will provide measured data that is useful in calibrating the computer models.

– Culverts and drainage pipes under roads, that intersect runoff routes, need to be maintained to improve their performance.

– Some roads and embankments still need protection measures against flash floods.

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حسابات مائية في وادي هدا الشام ووادي عسفان

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المستخلص. لقد تم خلال هذا البحث عمل حسابات هيدروليكية في أحواض وادي هدا الشام ووادي عسفان شاملة معدلات وحجم مياه السيول السطحية التي قد تحدث أثناء العواصف الممطرة بالإضافة إلى كميات المياه المحجوزة على سطح الأرض والمياه المتسربة في التربة ثم كميات ومعدلات المواد الرسوبية المحمولة مع مياه السيل وذلك باستخدام بيانات الأمطار بالإضافة إلى خواص الوديان المورفولوجية والجيولوجية ونتائج تجارب الرشح والتحليل المنخلي لعينات التربة المأخوذة من الطبيعة. وقد تم تكرار هذه الدراسة لعواصف ممطرة ذات مدد عودة مختلفة مع تغيير مدد استمرار العواصف. وقد تم عرض هذه النتائج في شكل هيدروجرافات وجداول تحتوى على القيم العددية لنتائج هذه الحسابات. وقد تم عمل هذه الحسابات باستعمال نموذج هيدرومورفولوجي تمت معايرته في وادي غران الملاصق لمنطقة الدراسة لما يتوفر عنه من بيانات عن السيول فيه. وقد أظهرت نتائج الدراسة إنه في حالة تعرض كل منطقة الدراسة لكثافة مطر منتظمة وفي نفس الوقت ناتجة من العاصفة التي تعود كل مائة عام ولمدة نصف الساعة (تمثل حالة افتراضية قصوى) فإنه تنتج هيدروجراف سيل ذو ثلاثة قمم وأكبرهم تبلغ ١٠١٠٠ متر مكعب في الثانية، وكان الحجم الناتج للمياه المعترضة على سطح الأرض والمتسربة في التربة ثم المتدفقة على سطح الأرض ٢٣,٦٤، ٧٩,٤٧، ١٦٣ مليون متر مكعب على التوالي وذلك يناظر ارتفاعات مكافئة ٠,٠١٢، ٠,٠٤٣، ٠,٠٨٧٦ متر على المساحة الكلية للوادي والتي تبلغ حوالي ١٨٦١ كيلو متر مربع، ويبلغ مجموع هذه الارتفاعات المكافئة ٠,١٤٣ متر وهو يساوي قيمة المطر الذي سقط على الوادي في العاصفة المدروسة. وفي نهاية الدراسة تم التوصية بتركيب

محطات لقياس تصرفات السيل عند حدوثه وذلك في مخارج أحواض الوادي لتكوين بنك معلومات عنه يساعد في أي معايرة مستقبلية للنموذج الحسابي المستخدم من أجل الحصول على نتائج قد تكون أكثر دقة ويمكن الاعتماد عليها في الدراسات المختلفة وكان من التوصيات أيضًا طلب تطبيق منهج هذه الدراسة في وديان أخرى والاستفادة من نتائجها .