WATERSHED MODELLING OF WADI SUDR AND WADI AL-ARBAIN IN SINAI, EGYPT.

By

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Abstract

The development and the application of rainfall-runoff models have been a corner-stone of hydrological research for many decades. In general, the purpose of the development of these models is two-fold. The first is to advance our understanding and state of knowledge about the hydrological processes involved in the rainfall-runoff transformation. The second is to provide practical solutions to many of the related environmental and water resources management problems.

Sinai falls in the arid and semi-arid region, which is characterized by unpredictable rainfall patterns, sometimes of high intensity, short duration and uneven distribution. In Egypt, rainfall distribution varies considerably from one year to another with changeable average annual rainfall volume. Sinai is under going a rising development, and it needs an accurate evaluation of its water resources. Therefore, this study investigates the watershed modeling of different wadis in Sinai with respect to their meteorology, geomorphology, and geology and hydrology. These wadis are wadi Sudr in the Southern West part of Sinai and Wadi Al-Arbain at South of Sinai.

The Watershed Modeling System (WMS, WMS – Hydro, Version 2) has been applied to analyze and simulate the surface runoff storms using HEC-1 model. This model was used to simulate runoff volumes and hydrographs at the two main wadis for different real world measured storms. The digital terrain modeling functions of WMS were used to create terrain models using Geographic Information Systems (GIS) data, and girded Digital Elevation

Models (DEMs). These data were used to delineate watersheds, streams and sub-basins. In this study, different unit hydrograph methods, different loss estimation methods and different methods of lag-time computation have been analyzed.
The range of the Curve Number (CN) was obtained from standard tables according to the soil type and cover of each basin. Since there are no definite calibration procedures in this software, the method of lag-time (TL) computation was selected according to the lag-time of each storm at each basin; and the CN in order to match the derived hydrograph with the observed one with respect to the volume, the peak, and the time to peak.

Introduction

Rainfall-runoff models are normally used as components in river flow forecasting systems. The efficient forecasting of river flows is beneficial in many aspects for the prosperity of those societies living in river basins. These forecasts are necessary to provide warnings against floods in order to prevent loss of life and to minimize damages to both property and livestock. The extent of damages caused by floods undeniably highlights the importance of the issue of river flow forecasting. In general, the forecasting of wadis flows is necessary for the proper management of water resources and flood preparedness. Therefore, in order to issue flood warnings confidently and to manage water resources optimally, it is desirable that the best possible enhanced forecasts should be made.

In the application of hydrological forecasting models, the major challenging problem is the fact that the simulated discharge hydrographs in general differ from the observed ones. This problem may be attributed to many factors such as:

1) The inadequacy of the model structure in its representation of the constituent hydrological processes and their interaction.
2) Poor estimation of the model parameters which may be due to several reasons, among these being model calibration with unrepresentative data and inability of the optimization procedures to identify appropriate parameter values.
3) Data errors which may be systematic or random either in the inputs, outputs or both. Errors in the input data may be due to the various effects of data lumping both in time and in space and in such cases the data may not be truly representative of the natural variation within the catchments. The systematic errors in the observed discharges may be caused, for example, by the use of inadequate rating curves.

Objectives of the study

The objective of this research is to run the Watershed Modelling System software with the HEC-1 model on two catchments within the region of Sinai, with a view of application in flood forecasting activities, design of water resources, estimation of missing data, extension of short historical records and investigation of the impacts of land use change or climatic change on the wadi flow. The forecasting of river flows is also essential for the following applications in the arid and semi-arid region:

- Operation of various hydraulic structures since such operations is normally governed by rules which in some way or other depend on the future values of the river flow.
- Proper management of water resources. Therefore, in order to issue flood warnings confidently and to manage water resources optimally, it is desirable that the best possible enhanced forecasts should be made.
- Investigation of the climatic change on the wadi flow
- Saving tenths of millions of cubic meters of flooded water from discharging in the sea.

General Description of the Selected Catchments:

Table (1) gives a summary of the physiographic characteristics of the two selected catchments. Figure (1) gives the general location maps of the two catchments. The two catchments were selected to represent the changes in topography, geology, and the climatic conditions in Sinai (WRRI Report 2002). These catchments are described (Sonbol M. Ali 2001) as follows:

Wadi Sudr, South - East of Sinai.

Sudr catchment is located at the South-Western side of Sinai between Lats 29° 30' and 29° 55' ; Longs 32° 40' and 33° 20'. The basin is one of the largest wadis in South – West of Sinai which flows westward and discharges into the Gulf of Suez at Sudr town. It covers a total area of 560 km^2 and a drainage area of 360 km^2 at the water level recorder of the flow measuring station. The wadi originates in the hill slope of EL-Tih plateau. All the physiographic characteristics of the catchment and the digital elevation map (DEM) were calculated by the WMS software. Table (2) gives the geomorphologic characteristics of the basin and its sub-basins.

Table (1): The Physiographic Characteristics of the Selected Catchments

Characteristics	Representative Catchments	
	Sudr	AL Arbain
1- Location	S-W of Sinai	South Sinai
2- Origin	Gable EL-Raha and Somar	EL Egma and ELTeh Plateau
3- Outlet	W. Sudr and Gulf of Suez	Wadi Feiran and Gulf of Suez
4- Surface Geology	Limestone; Upper Cretaceous; Cenomanian	Basement Granite
5- Area (km^2) Length (km)	360 76	32 7

Table (2): Geomorphologic Characteristics of Wadi Sudr Basin.

Order	No. of Streams	Mean Stream Areas (km^2)	Mean Stream Lengths (km)	Mean Stream Slopes (m/km)
1	165	223.70	1540	0.035
2	45	78.75	2130	0.029
3	11	41.50	4055	0.020
4	2	21.33	10300	0.011
5	1	14.77	10200	0.010

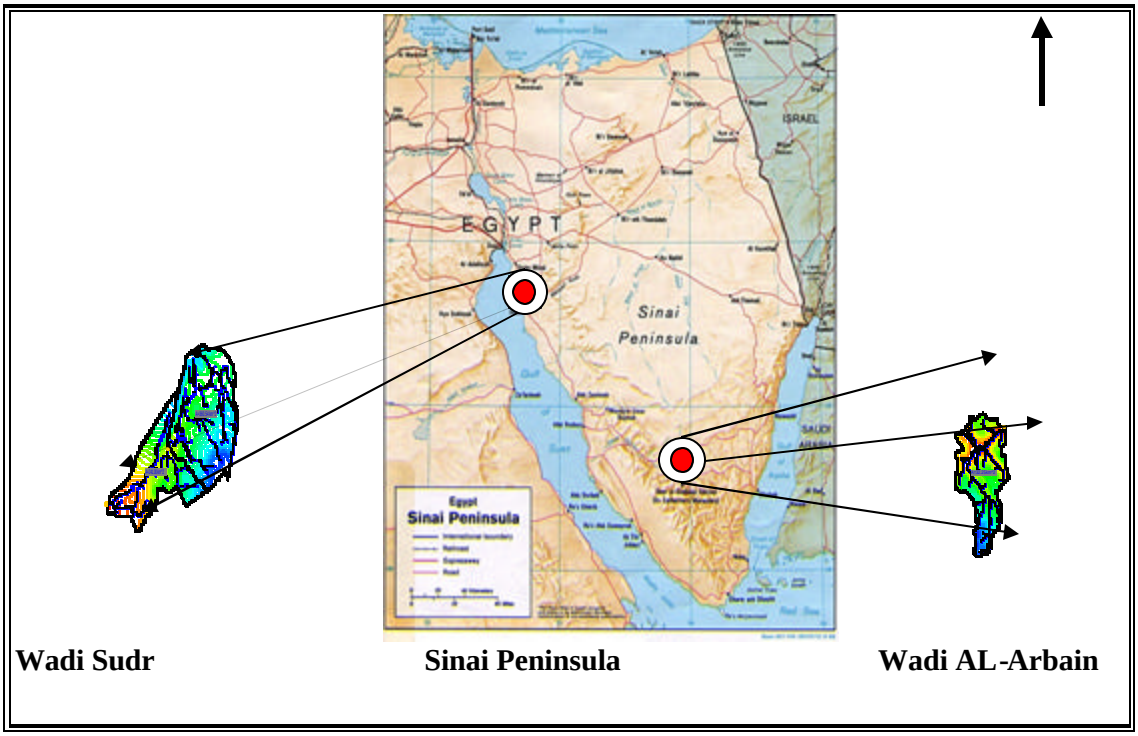


Figure (1) General location maps of the two wadis in Sinai.

Wadi AL-Arbain, South Sinai:

AL-Arbain is located in the Southern part of Sinai at the upper part of Wadi Feiran (1865 sq. km.) which represents the mountainous area of EL Egma and EL Teih plateau at ST. Kathrien. It is located between lats 28^{o} 30', 28^{o} 45' North and longs 33^{o} 55', 34^{o} 05'East. It covers an area of 32 sq. kms. Table (3) gives the geomorphologic characteristics of the basin and its sub-basins.

Table (3): Geomorphologic Characteristics of Wadi AL-Arbain Basin.

Order	No. of Streams	Mean Stream Areas (km^2)	Mean Stre am Lengths (km)	Mean Stream Slopes (m/km)
1	18	12.05	1.10	364
2	8	8.70	4.40	85
3	4	5.60	3.20	209
4	2	3.60	3.00	57
5	1	2.10	1.10	18

It can be noticed from the previous tables that the selected basins have different gemorphological characteristics. Wadi Sudr - South Sinai represents the system of the basins draining into the Gulf of Suez in the Western - South part of Sinai. It has steep slopes and the first order streams have relative large areas. Wadi AL-Arbain at the upper part of wadi Feiran - South Sinai represents the mountainous area of EL-Egma and EL-Teih plateau at St. Kathrien.

Hydrologic and Spatial Data

In the arid and semi-arid regions like Sinai, flash floods are characterized by a high spatial variability of rainfall and the resulting hydrographs exhibit very short rise times even for the large

basins. The hydrologic data includes the stream flow data which were measured by the flow measuring devices that were mounted on the hydraulic structure at the main stream of each wadi. These hydraulic structures are sharp crested weir of a 10 m width at wadi Sudr and a rectangular cross-section of 4.7 m width at wadi AL-Arbain. The stream flows were measured as individual events according to the characteristics of the arid regions. The rainfall was measured at the same times as the flow data. The measured rainfall and runoff data for each basin were obtained to be used for the simulation purposes.

For the spatial data, thematic coverage (soil type, vegetation cover, rainfall, evaporation, etc) are compiled for the whole basin by the WMS software. The availability of this type of information is highly variable throughout the basin. In arid regions like Sinai, the geology and soils are the most dominant factors in the estimation of the resulting runoff. It is also known that in such regions, evaporation rate is very high and there is neither land-use nor vegetation cover. The runoff from each wadi was calculated on the basis of synchronous observation of water levels, velocity and wetted cross section of the control section of the measurement. Such observations are used to depict the relationship between the stage (levels) and the flooding discharge that is known by the rating curve. Based on the discharge rating curves, the runoff hydrographs together with the causative rainfall hyetographs are evaluated. Many different hydrologic parameters were also determined such as rainfall intensity; lag-time; rainfall duration; loss by infiltration and evaporation; peak flow and the runoff coefficient.

Applications of WMS Software

Computer programs have been developed and used for hydraulic modeling for the past 30 years (Chow et al., 1988). HEC-1 was used for simulation of the two small agricultural watersheds in eastern South Dakota. HEC-1 was developed by the Hydraulic Engineering Center (HEC) in Davis, California. The model was developed mainly for coastal regions and for large watersheds (USACE, 2000). A user's manual for the (Flood Hydrograph Package, 1990) was developed by the Hydrologic Engineering Center, US Army of Engineers. This manual describes the concepts, methodologies, input requirements and output formats used in HEC-1.

The HEC-1 model components are used to simulate the rainfall-runoff process as it occurs in an actual river basin. The model components function based on simple mathematical relationships hich are intended to represent individual meteorologic, hydrologic and hydraulic processes which omprise the precipitation-runoff process. The WMS and HEC-1 models were applied for the two selected wadis in Sinai. The WMS provides tools for all phases of watershed modeling including automated watershed and sub-basins delineation, geometric parameter computation, hydraulic parameter computation {e.g. Curve Number (CN) and Lag-Time (TL)} and result visualization. The HEC-1 model was developed by the Army Corps of Engineers and used to model the watershed as a series of interconnected basins and reaches. The image data from topographic maps of scale 1:25,000 was gathered. A Triangular Irregular Network was created from the topographic contour maps, and converted to DEM by using the ARC-GIS software. The watershed, streams and sub-basins were delineated, and hence the geometric watershed characteristics were automatically calculated. The HEC-1 parameters were setup as follows:

Precipitation: A precipitation hyetograph is used as the input for all runoff calculations. The recipitation – time distribution was entered with a time step of fifteen minutes. The total depth of the rainfall was also given.

Loss method: One of several different loss methods can be chosen when generating synthetic hydrographs. In this study, the SCS and Uniform methods were selected.

Unit hydrograph method: One of several different unit hydrograph methods can be chosen when generating synthetic hydrographs. The SCS dimensionless Unit Hydrograph, Snyder, and the Derived Unit Hydrograph methods were used.

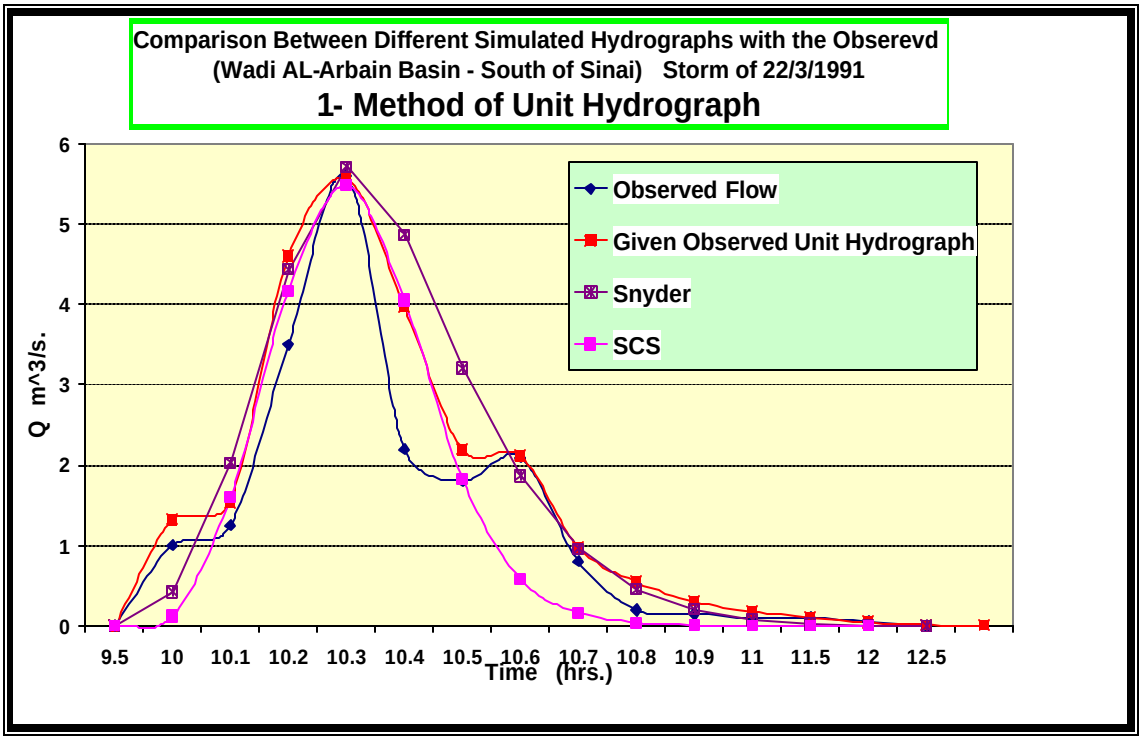
Lag-Time: The SCS and the Riverside (mountains, foothills and valley) method of Lag-Time computation have been analyzed. The Curve Number (CN) was obtained from standard tables according to the soil type and cover of each basin.

WMS Application for Wadi AL-Arbain

The DEM of Wadi AL-Arbain was prepared, the sub-basins were delineated and the geometric data were computed as shown in Figure (2). The HEC-1 parameters (precipitation, loss method and the Lag-Time) were setup and the outflow hydrographs for the given rainfall events were generated. The simulated hydrographs are compared with the observed storm of 22/3/1991 (WRRI Report, 1990) as shown in figure (3).



Figure (2): The DEM of Wadi AL-Arbain, drainage streams and basin data.



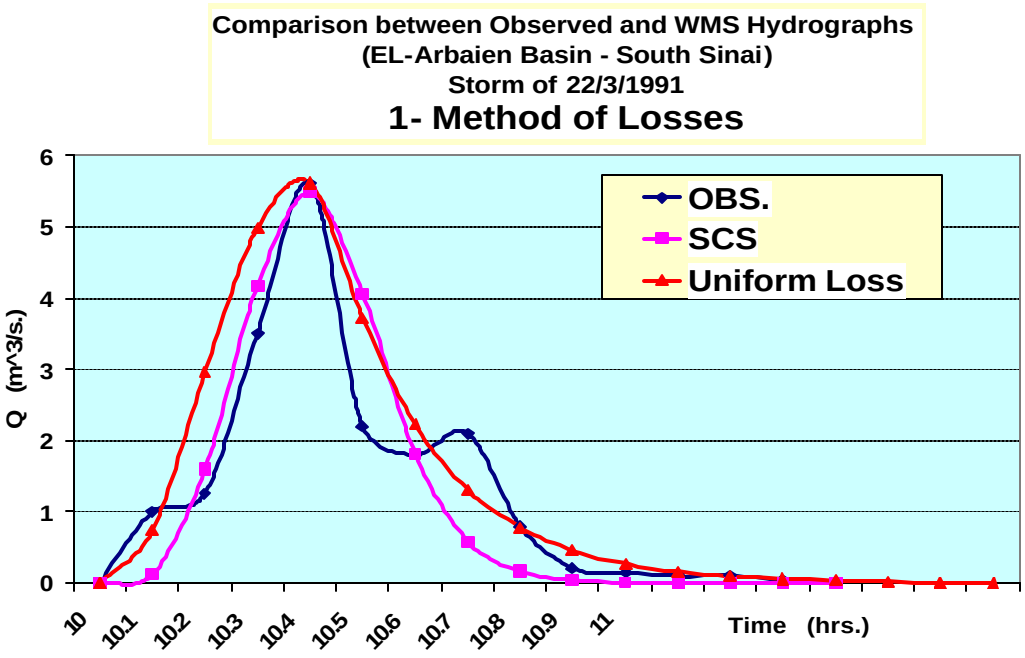


Figure (3): Comparison between Observed and Estimated hydrographs by WMS at AL-Arbain basin (Storm of 22/3/1991).

WMS Application for Wadi Sudr

The same previous procedures have been applied for Wadi Sudr and the results are represented in figures (4) and (5).

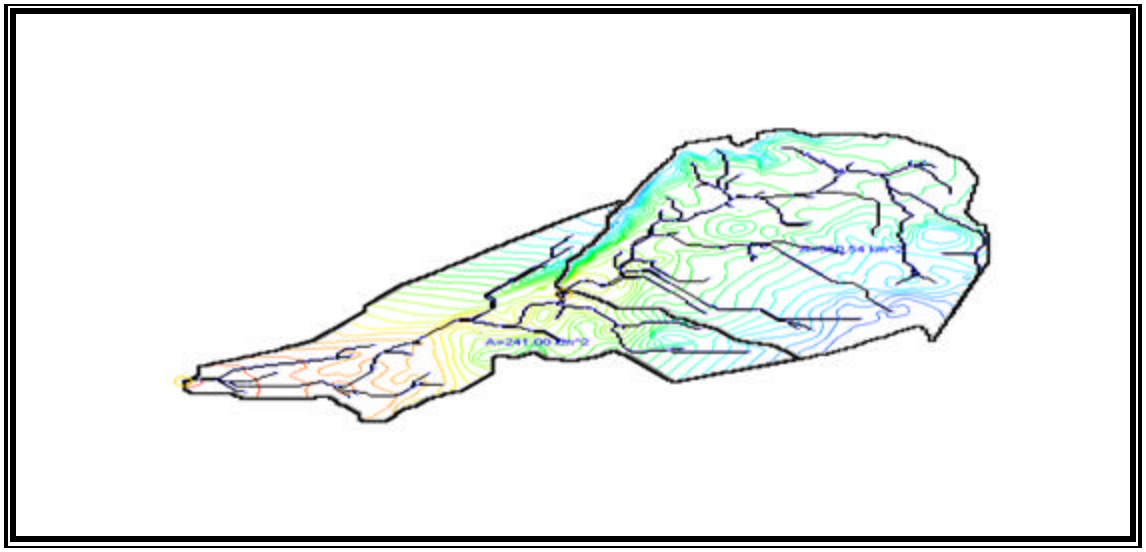


Figure (4): DEM; drainage streams and geometric data of Wadi Sudr Basin – South Sinai.

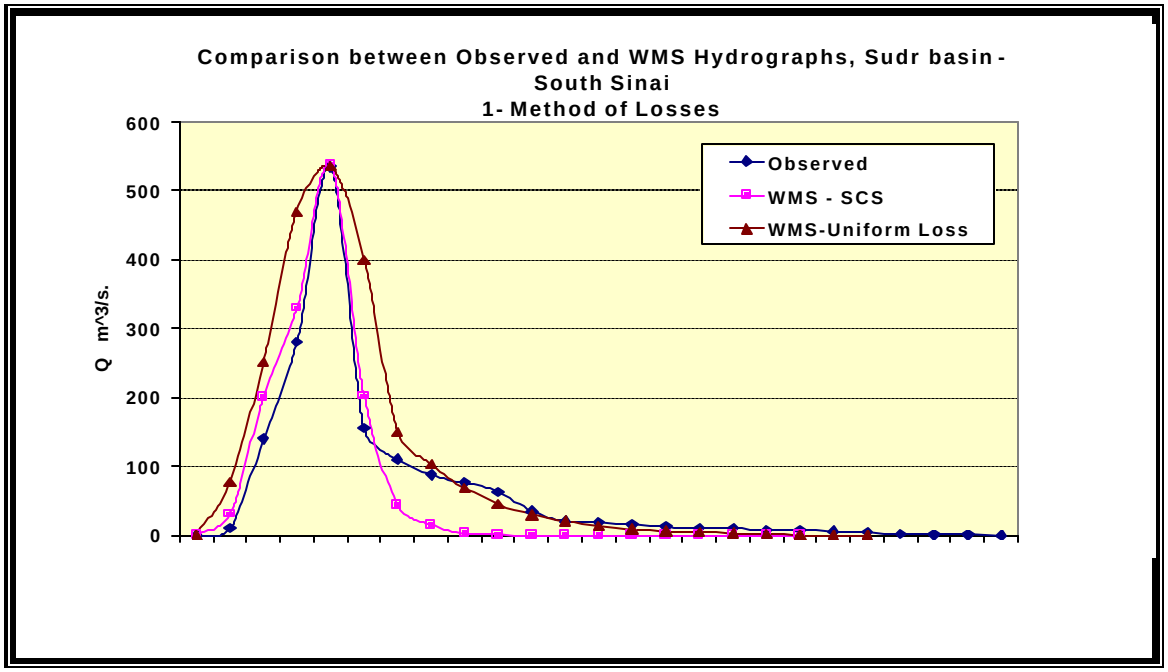


Figure (5): Comparison between Observed and WMS hydrographs at Wadi Sudr. (Storm of 22/3/1991).

Sensitivity Analysis

(1) Methods of Lag-Time Computation

One of several different methods of lag-time computation can be chosen when generating synthetic hydrographs according to boundary conditions of the catchment area. The lag-time can be given as a function of some geometric parameters of the watershed as given in the following form:

$$T_L = Ct\ (L, Lca, S)^m$$

Where:
TL : lag-time (hrs.)
L : length of the longest flow distance (mi);
Lca : length to the centroid (mi) ;
S : slope of the max flow distance (ft/mi);
Ct and m are coefficients that depend on the method of calculations.

The lag-time was also calculated using the Riverside County and the Tulsa Rural methods of lag-time as well as all the different methods of the WMS software and the results were compared as shown in Table (4) and Figure (6) for Wadi Sudr (storm of 22/3/1991). It was found that the short lag-time results in a short time to peak and high peak flow.

Table (4): Lag-Time Computation Parameters.

Wadi	Lag-Time Parameters					
	L (mi)	Lca (mi)	S (ft/mi)	Ct	m	Method of Computation
AL-Arbein:	8.814	3.291	569.855	1.200	0.38	Riverside Mountains Method
Sudr	27.440	9.912	67.078	1.420	0.39	Denver Method

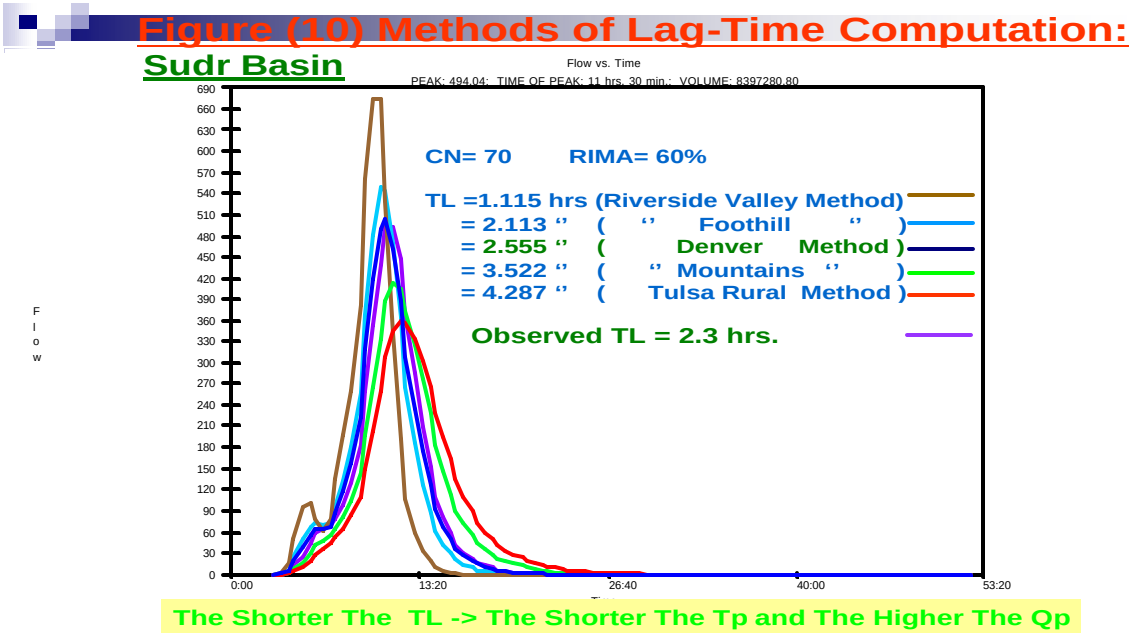


Figure (6): Sensitivity of the Lag-Time to the method of computation.

(2) The Curve Number (CN)

The curve number depends on the soil type, general hydrologic conditions of the watershed, the land use and the maximum potential retention which is equal to the difference between the rainfall and the resulting flow. Figure (7) shows the sensitivity of the derived hydrographs to different values of CNs at Wadi Sudr basin. It was found that the high CN gives high peak flow. The values of the CN are given in a standard tabular form for each soil type and cover.

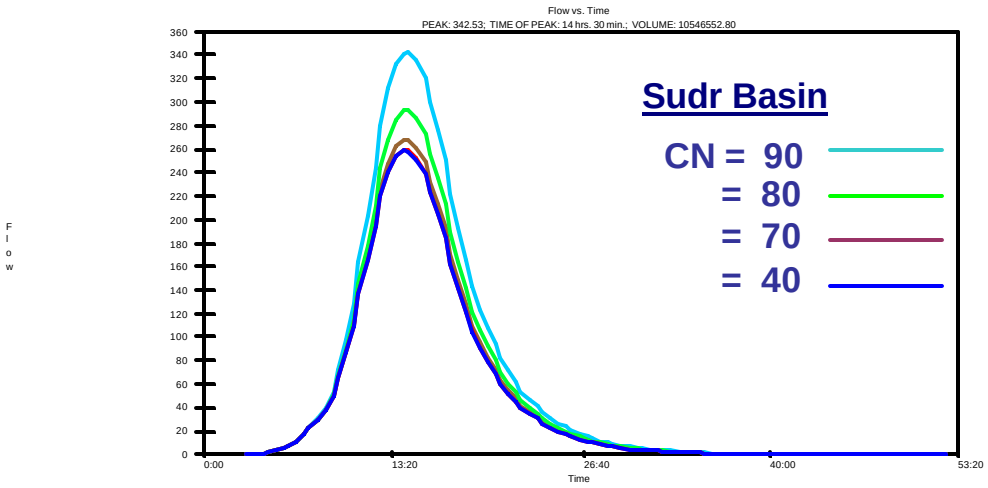


Figure (7): Sensitivity of the hydrographs to the different values of CNs at Sudr basin.

Discussion of Results:

In this study, the SCS unit hydrograph method and the Riverside County method of Lag-Time computation have been used. The range of the Curve Number (CN) was obtained from standard tables according to the soil type and cover of each basin. Since there are no definite calibration procedures in this software, the method of Lag-Time computation was selected according to the lag-time of each storm at each basin, the initial abstraction and the CN were increased or decreased in order to match the derived hydrograph with the observed one using the mean square error (MSE) with respect to the volume, the peak, and the time to peak. Table (5) gives the set up of the parameters of the HEC-1 for the derived hydrographs by WMS from the two selected basins. The plots of the comparison between the observed and simulated hydrographs are shown previously in figures (3) for Wadi Al-Arbain and (5) for Wadi Sudr.

Table (5) The set up parameters of the HEC-1 for the derived hydrographs, (Storm of 22/3/1991).

Wadi	Loss Method			Precipitation Depth (mm)	Lag-Time (hrs)
	Initial Loss (mm)	Curve Number CN	RIMA		
AL-Arbain	16.0	85	0.0	35.0	0.899
Sudr	14.2	79	0.0	34.5	2.555

Conclusions and Recommendations

- The available geometric, hydrologic and climatic data in the two selected catchments in Sinai, Egypt have been used in the WMS applications. The basins geometric characteristics and the WMS hydrographs calculated by using different methods of unit hydrograph and losses estimation were analyzed.
- The HEC-1 model in the WMS Package, reasonably predicted runoff volume and peak flow. However, there was high discrepancy between the predicted runoff volume and peak flows with the measured values for Wadi Sudr.

- Sensitivity analysis for the methods of Lag-Time computation and CN was carried out. It was found that the short lag-time results in short time to peak and high peak flows and the high CN gives high peak flow. The short Lag-Time results in earlier and higher peaks. The best T_L was estimated by the Riverside Mountainous Method as 0.899 hr for Wadi Al-Arbain and by the Denver Method as 2.555 hrs for Wadi Sudr, while the observed value was equal to 2.3 hrs. The best values for the CN was estimated for Wadi Al-Arbain as 85 and for Wadi Sudr as 79.

- It is recommended to use more rainfall and runoff data in order to apply all the different methods of the unit hydrographs or using the estimated basin's unit hydrograph to obtain more accurate results. It is also recommended to make a water balance for each storm in the selected basin to obtain the right ratio of the initial losses as well as the excess rainfall.

- We believe the model is helpful in proposing the locations of the water resources projects since it evaluates the amount of the flood volume in different locations throughout any proposed area of study. It may also give the runoff hydrograph for any selected return

period rainfall storm to provide (a) warnings against floods in order to prevent loss of life and to minimize damages to property and livestock, (b) proper management of water resources and flood preparedness.

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