

SURFACE WATER MANAGEMENT TOOL FOR ARID LANDS USING GIS - JORDAN DESERT

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Abstract

In Jordan as well as most of the developing countries located in the arid regions, water is a priority issue at national and individual levels. Several programs and management practices are in place to conserve water resources and implement new resources to meet the demand of various sectors of water users. With very high demand on the ground water resources, the limited surface water becomes a promising option for new and innovative water source. The limited rainfall amounts that fall over wide areas of the arid lands of Jordan (called the Badia) are of significant quantity and due to lack of proper management, the water is lost due to high evaporation rate.

In this study, HEC-1 modeling approach was used to estimate outflow volumes. This approach includes the Natural Resources Conservation Services (NRCS) Curve Number (CN), and unit hydrograph models. The surface runoff was simulated over the study area using the ArcView® software. ArcView® micro language, Avenue, was used to customize the Graphical User Interface (GUI) of the software. The simulation tool includes various steps of simulation used to estimate the runoff volume. The map data were accessed and displayed on the screen so the user can locate the catchment for further calculation. Other data files, which are the hydrologic database that describe the hydrology of the project area, also loaded.

Wadi Salma catchment (#11) were used to collect field rainfall-runoff data. Rainfall storms were recorded in this catchment during December 2000 and April 2001 as well as the runoff volumes. These data with the hydrologic database were used in the model to simulate the runoff and the results were compared to the observed field observation. The results showed that the simulation model did simulate the runoff volumes with acceptable estimation compared to the observed runoff. The model calculated the peak discharge and runoff volume with acceptable accuracy for the whole catchment (at Weir #1); the difference in peak discharge estimation was 2 -3% and in runoff volume was 0% for the first storm and 20% for the second one.

BACKGROUND

Jordan is a developing country situated off the southeastern shores of the Mediterranean Sea between longitudes 35° and 39° East and latitudes 29° and 33° North. It is bounded in the north by Syria, in the east by Iraq and Saudi Arabia, in the south by Saudi Arabia and the west by Jordan River and the Dead Sea. Its area is about 90,000 km² and consists of various distinctive topographic units trending in north-south direction. These units are the rift valley, high lands and the arid lands-desert region. The desert region (which is called the Badia) consists more than 80% of the country area. The Badia, with its large area, is rich in natural resources such as minerals and range lands.

These factors make it a potential area for future development. The Jordanian government is motivated to the development of the Badia as the Jordan Valley and the high land areas become over populated.

The Study area (Safawi area) is located in the northeastern Badia, which receives more rain volumes on the average than the other parts of the Badia (see Figure 1). The annual rainfall volumes in Safawi area vary between over 150 mm in the northwest to less than 50 mm in the southeast with an average of 70-80 mm, and the annual mean temperature in the area is 15° C. The monthly average temperature varies between 28° C in July to 8° C in January. An absolute maximum of 46.6° C was recorded in Safawi station in July 1978, while an absolute minimum of -6° C was recorded in January 1973. Evaporation rates are in general very high, with an average daily potential evaporation varying from a maximum of about 17 mm/day in July to a minimum of 3 mm/day in January (Taqiaddin et al., 1995)

The basaltic rocks cover 11,000 km² of the northeastern Badia. This basalt is part of the North Arabian Volcanic Province (Harrat Ash-Sham), which covers a total area of more than 46,000 km². Ibrahim et al. (2001) divided the basalt cover into three major phases. The first phase of Oligocene age 22.0 – 26.0 million years (my), the second phase of late Miocene age 8.0 – 12.0 my and the last phase is of Quaternary age <0.5 – 6.0 my. During these phases five main groups based on location and origin were subdivided and each group is formed of more than one geologic formations with different age and degree of weathering.

Gentle slopes and relatively flat topography characterize the surface area of the Badia region. In Safawi area, the surface elevation varies from less than 600 meter above sea level (ASL) to more than 1100 meter ASL in the northwest of the area (Figure 1). The geologic activities in the area dominate the surface geomorphology of the area. Faults developed into surface flood water courses (wadis) and the surface-covered-rocks made the development of channel network very limited except in some parts where the weathering rates are high. Large boulders are spread in the north and east of the area where the basalt of younger age is found. On the other hand, smaller sizes of rocks are found in the western part of the Badia where older basalt and higher rainfall volumes that helps in the weathering of rocks.

The poor channel network development resulted in blocking of most of the water courses in the Badia. This blocking creates natural pools in the depressions where most of the runoff ends and evaporates leaving salty fine soil. The depressions (also called Qa'a) spread widely in the Badia area and form major part of the surface geomorphology. Another type of depressions (called Marab) are formed in the course of major channels. These Marabs are formed when the topography is not high enough to block the water course, so the flood water fills these depression and finds its way out of that Marab. This process results in renewing the soil in these Marabs where only the coarse soil particles have the chance to settle and results in good productive soil for range land vegetation and some seasonal crops such as barley and wheat.

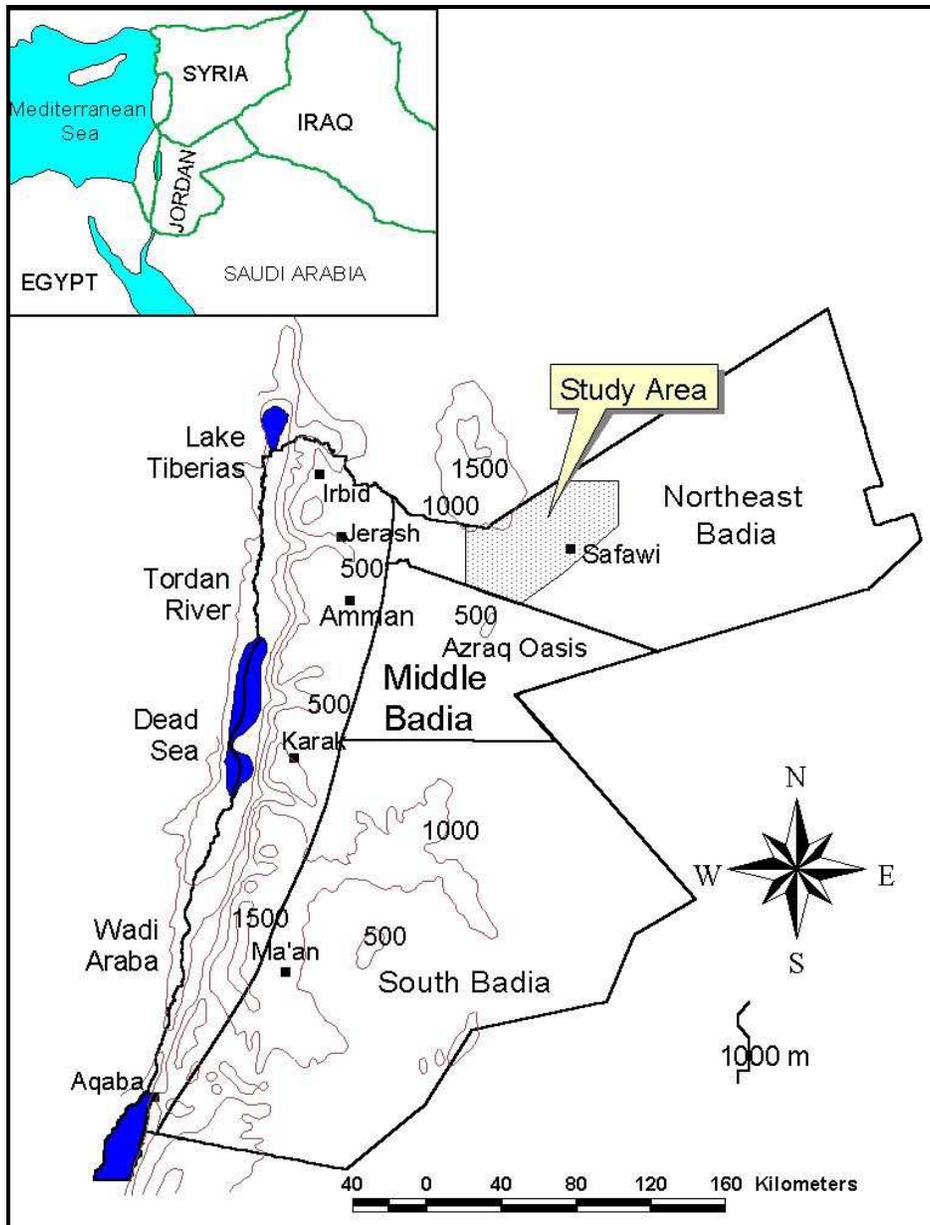


Figure 1 Location Map of Jordan and General Topography (in meters)

The parent soil material and the climatic parameters control the soil types and properties. In the Northeast Badia, the soil is associated with the basaltic lava and various soil units are related to topography and the degree of weathering. Most of the area soils are of depositional origin, which is dominant for arid lands. In areas with high erosion activities such as steep slopes, residual soils on rocks occur. The soils in the Northeast Badia basaltic area are classified based on the age and physical characteristics of lava flow and eruptive centers, It includes well developed xerochrepts in the areas of older basalt flows and high weathering effect and weakly developed xerothents on the more recent basalt flow. (HCST, 1992).

Rainfall as thunderstorms forms the great part of the total precipitation in Safawi area, which is characterized by irregular intensity and duration. The annual mean rainfall in the area varies between 70 and 80 mm, and its amount decreases from northwest where the annual rainfall value is about 200 mm to southeast where rainfall is less than 50 mm per year. Rainfall occurs mostly during winter months (October to April) with the highest intensities in the months of December to February. The daily rainfall data in Safawi Weather Station (F2) for the period 1985-1999 were plotted in Figure 2. The data show that the majority of the storms were less than 8 mm and a few of the storms are greater than 16 mm and these storms are the ones that could generate significant runoff. Also from this figure, there are very few rainfall storms with volumes greater than 24 mm.

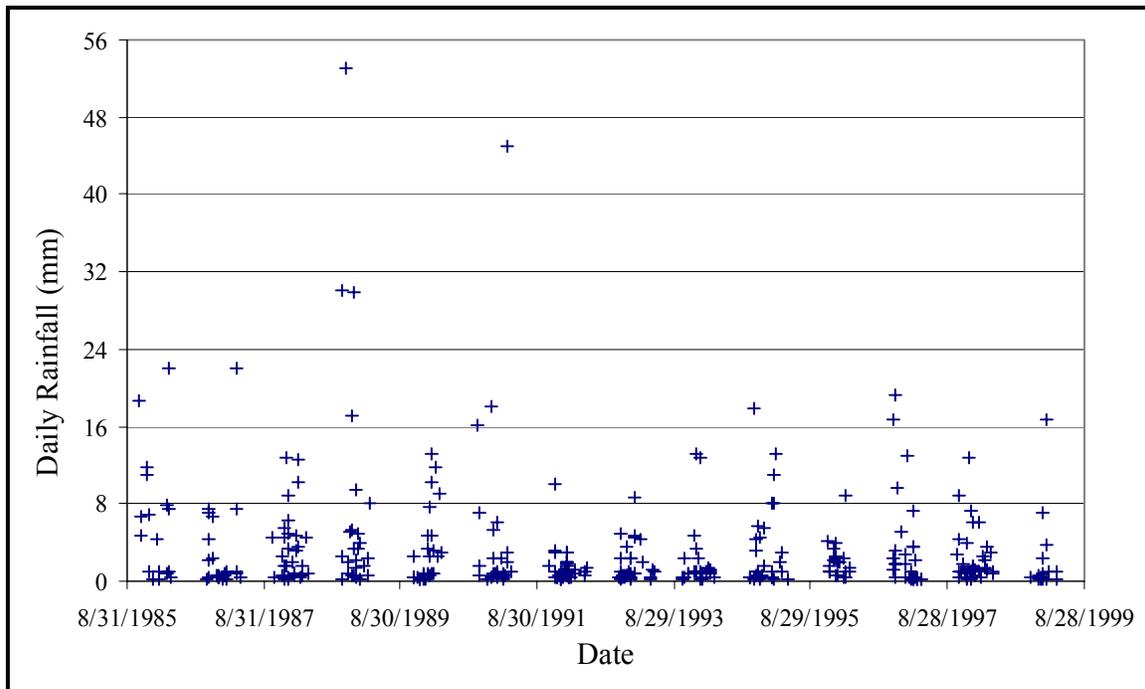


Figure 2, Daily Rainfall Data in Safawi Weather Station (F2) for the Period 1985-1999

MAP DATA

Other types of data that were collected for this study include thematic maps for the study area. Some of these maps were in print format such as the topographic maps of scale 1:50,000, others were in digital forms as ArcView shape files (*.shp) and ArcInfo format. Different thematic maps from various government and private institutions were used in the development of the data layers in ArcView files. Examples of the maps are the soil maps from the Agriculture Department and the geologic maps developed by the Jordan Badia Research and Development Program (JBRDP) and Royal Jordanian Geographic Center (RJGC). All the thematic maps were in Universal Transverse Mercator (UTM) coordinate system to allow the analyses and comparison of the different data layers.

Topographic paper maps with 1:50000 scales were used to identify the boundaries of the major catchments in the study area. Twelve major catchments with their respective areas varying between 28.70 km² and 209.09 km² were identified (Figure 3). Each one of

these catchments was divided into smaller sub-basins (with areas less than 20 km²) for modeling purposes and to meet HEC-1 model criteria. The sub-basin boundaries, channel network and the depression data layers for each catchment were developed in ArcView file format to be used in the model from the topographic paper maps. The other data layers, which were already in digital format, include contour lines, soil units and the geologic groups.

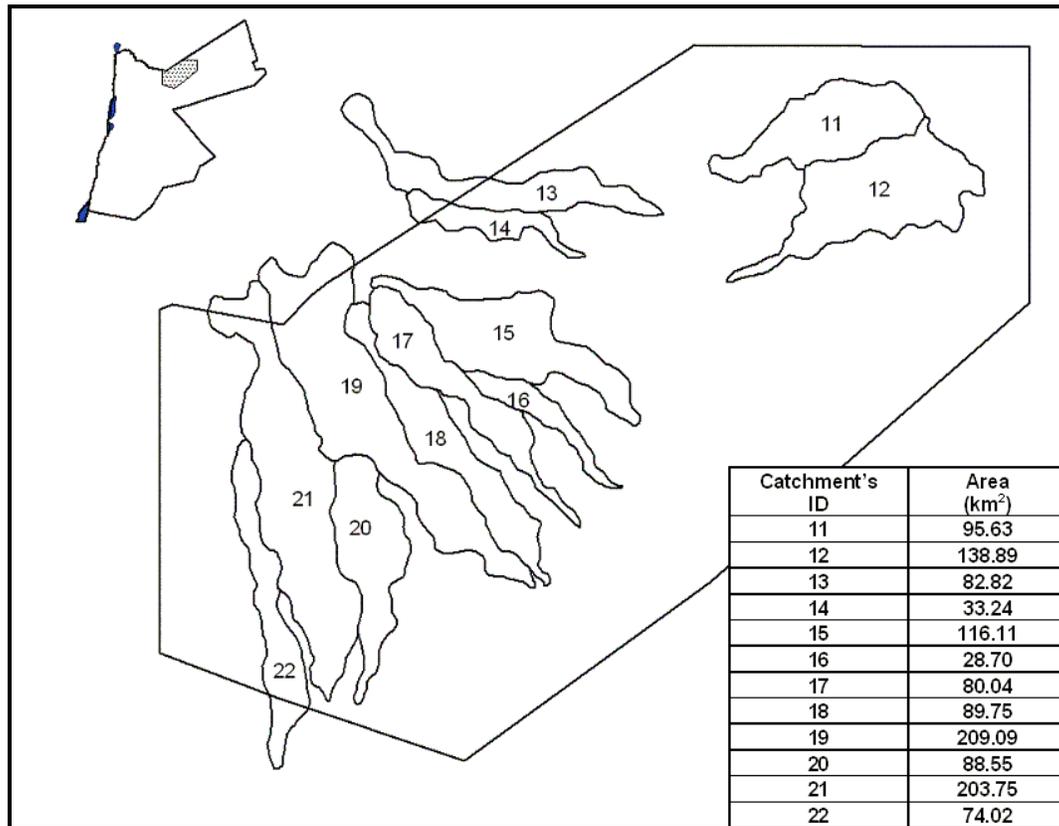


Figure 3 Major Catchments in the Study Area

MANAGEMENT TOOL OUTLINE

The modeling tool includes various stages of simulation. The first step is identifying the catchment to be analyzed, second step is reading the selected catchment data and display its map, third step is defining the modeling control data like the rainfall data and calculating the runoff and the last step is presenting the results.

The major catchments theme is the general map that shows the major catchments, their boundaries and locations with respect to each other. This theme is the first map that is displayed in the modeling system and the catchment to be analyzed and modeled can be selected by clicking on it. Figure 4 shows the layout of this window.

This is the second stage of the modeling where three menus are added to the tool to allow the execution of next steps of the hydrologic calculation. The first new menu is "Select", which allows the user to select new catchment for analysis. The second menu is "Modeling" that has items to control the various hydrologic calculation steps such as rainfall data entry and project selection. Finally the third menu is "Results" which has

items that control the way results are viewed and presented. Figure 5 shows the new menus in the selected catchment menu bar.

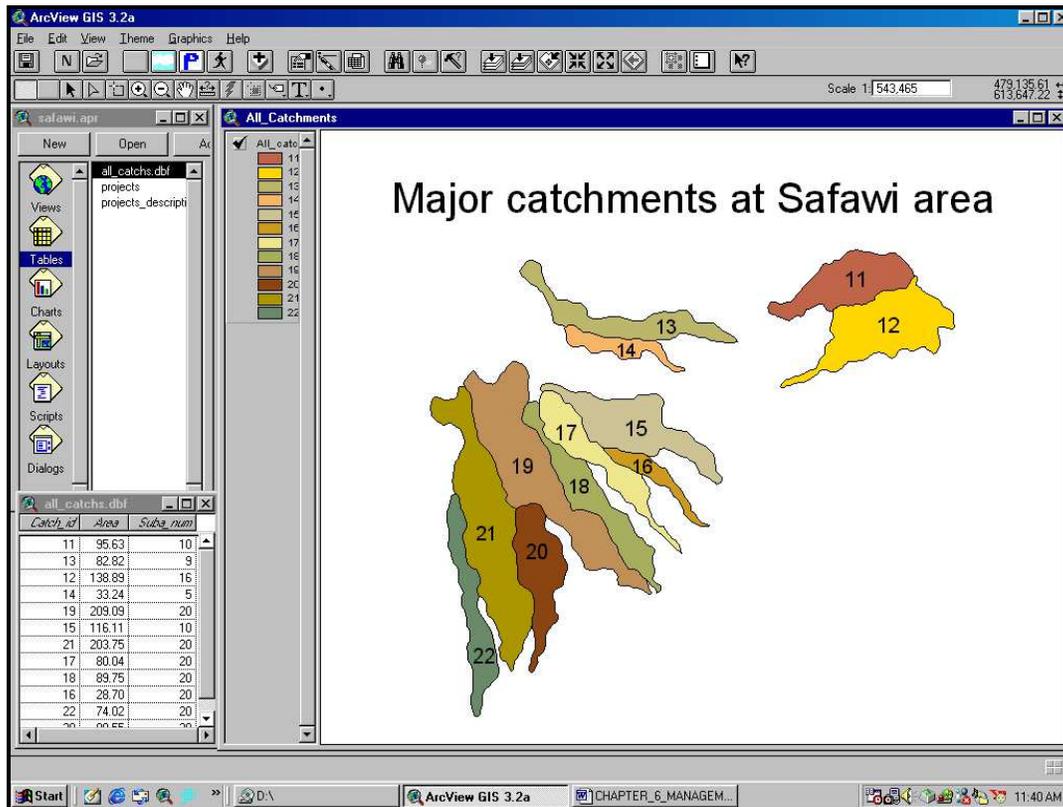


Figure 4 Major catchments map window

Modeling step

The “**Modeling**” menu has five items: “Enter Rainfall Data”, which activates a save file dialog window to save the new table with “rin” extension to differentiate it from other tables. Once the new rainfall table is created another dialog window form is activated, “Rainfall Data Input” form. The second menu item, “Load Rainfall Data”, activates open file dialog window and list all the rainfall files (*.rin) where the user can choose the rainfall table and load it into the modeling system.

The third menu item is “New Project”. This item is used to define a new project and once it is activated, a window form is opened where the name of the project and a description of it can be defined and after that an empty runoff table is created with fields for each one of the sub-basins in the selected catchment. A save dialog window is opened and unique name of the table file is automatically defined as the combination of the word “runoff”, the catchment number and the project name with “*.out” extension to differentiate it from other type of files such as the rainfall files.

The fourth menu item “Load Project” gives the user the option to retrieve saved project for the selected catchment, it activates a dialog window with list of all the saved projects in the selected catchment. Once the user select the name of the project to be

loaded, the runoff table of that project is added to the system and the “Run Model” menu item becomes active.

The last menu item, “Run Model”, is disabled by default and once the user defines new project or loads old project, this menu item become enabled. When this function is activated, it first checks for the availability of rainfall data table and the sub-basin data table. These tables are used in the calculation of the runoff of the analyzed catchment and its sub-basins. The simulation is performed in four steps using four different scripts. First script uses rainfall data and the curve numbers from the sub-basin data table to calculate the rainfall excess and stores it in temporary table for later use. Second script uses the data for the sub-basins to generate the unit hydrograph for each one of the sub-basins and stores it in another temporary table. Third script uses the rainfall excess and the unit hydrograph tables and the depression areas data from the sub-basins data table and generates runoff hydrograph for each sub-basin and stores it in the runoff table. The last script rout the runoff hydrographs for each sub-basin to the next downstream sub-basin until the most downstream one and update the runoff table to show the runoff at the outlet of each sub-basin including all the routed runoff from sub-basins upstream.

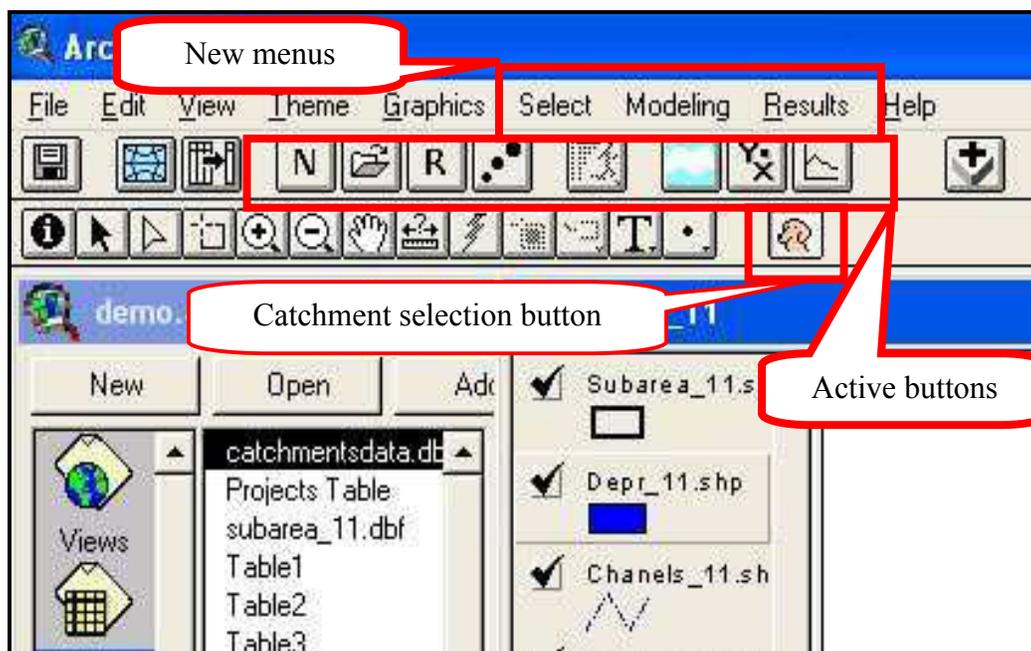


Figure 5 Selected Catchment New Menus and Buttons

Results presentation

The “**Results**” menu has items that control the way to view and present the model generated data and the results of the simulation. The first menu item “View Rainfall data” activates a window with the rainfall data tabulated and also gives the user an option to change the data and update the rainfall data table.

The second item in this menu is “View Model data”; this function opens a window where the sub-basin data and the project and its description are listed. The last menu item “View Runoff Results” activates a view window. In this window the name of

the project, the catchment number, and the project description are presented. The runoff rates for the sub-basin are also tabulated in this window with the total runoff volume and peak discharge for the whole catchment.

WADI SALMA CASE STUDY

The rainfall and runoff data for Wadi Salma catchment were used to verify and validate the model. The data used in the modeling of Wadi Salma catchment (catchment # 11) include: Curve numbers, sub-basins data from the hydrologic database that were developed for the study area catchments, Table 1, and The rainfall data.

Table 1 Sub-basins Data for Catchment #11 (Wadi Salma Catchment)

ID	A (km ²)	L_Col (km)	S_Col (m/m)	V_Pond (m ³)	K_Pond	Down_ID	L_Trav (km)	S_Trav (m/m)	n	CN
1101	19.26	7.62	0.0098	116000	0.8	1103	3.30	0.0152	0.05	91
1102	10.31	6.30	0.0127	0	0.0	1105	4.30	0.0119	0.05	91
1103	8.77	3.30	0.0152	0	0.0	1106	2.81	0.0053	0.05	91
1104	6.05	4.34	0.0150	32000	0.3	1107	3.12	0.0080	0.05	91
1105	13.78	5.04	0.0119	0	0.0	1108	3.20	0.0136	0.05	91
1106	4.48	2.81	0.0053	0	0.0	1107	3.12	0.0080	0.05	91
1107	4.69	3.12	0.0080	0	0.0	1109	4.00	0.0091	0.05	91
1108	7.75	5.15	0.0136	0	0.0	1109	4.00	0.0091	0.05	91
1109	13.26	7.13	0.0091	0	0.0	1110	4.04	0.0088	0.05	91
1110	8.25	5.68	0.0088	0	0.0	1110	0.00	0.0000	0.05	91

Another data needed for the modeling is the Manning's coefficient (n) and the hydraulic radius. From field observations, the channels in the study area are wide and have shallow flows with average water depth of 30 cm. This depth was used as the hydraulic radius in Manning's equation. On the other hand, the Manning's coefficient (n) was assumed as 0.05 for channels with boulders and gravel beds (J. Roberson et al., 1998).

A storm of 17.75 mm over eight hours, which was recorded during December 9, 2000, was used to simulate the runoff at Wadi Salma. The sub-basins' data were used with the rainfall information to calculate the runoff hydrographs and volumes for the catchment's sub-basins. Figure 6 shows the simulated runoff hydrographs at Weirs # 1 and #2 with the observed runoff hydrographs at the same locations during the above storm. At Weir #1, (the whole catchment), the simulated and observed peak discharges were 15.02 and 14.70 m³/s respectively, while at Weir #2 (outlet of Sub-basin 1107), the simulated and observed peak discharges were 6.12 and 5.92 m³/s respectively. On the other hand, the total simulated runoff volume (at Weir #1) was same as the observed runoff volume of 0.3 million cubic meters, while for part of the catchment (at Weir #2), the calculated and observed volumes were 0.10 and 0.18 million cubic meters respectively.

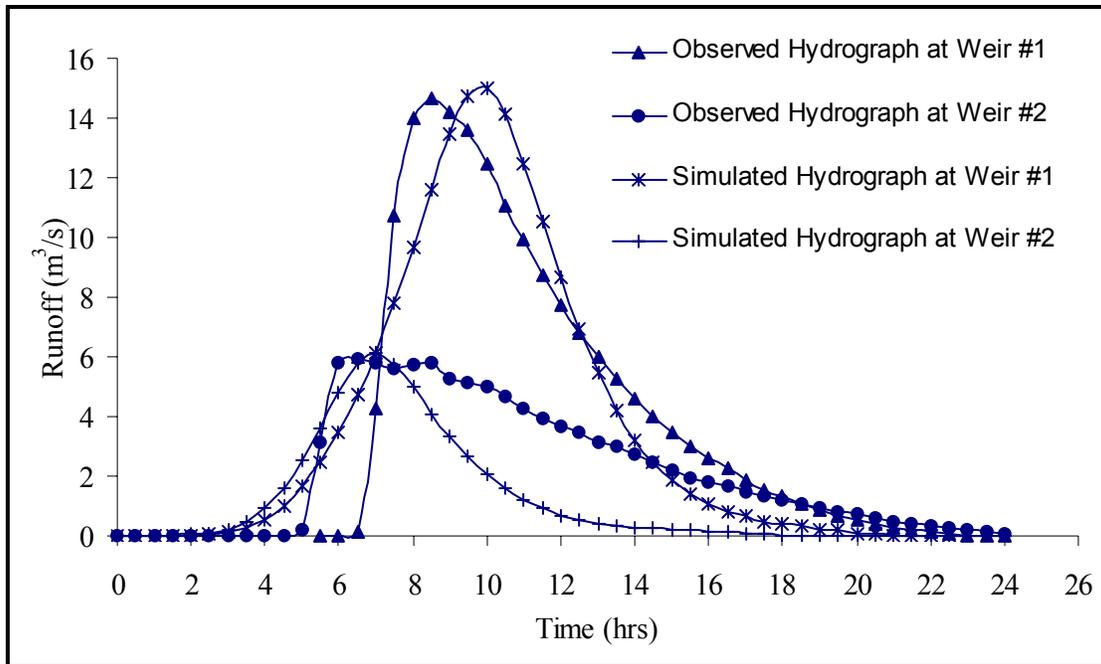


Figure 6 Observed vs Simulated runoff of December 9, 2000 storm

On April 4, 2001, a storm of 15.00 mm over thirteen hours was recorded and used to simulate the runoff Wadi Salma. The sub-basins' data were used with the rainfall information to simulate the runoff hydrographs and volumes for the catchment's sub-basins. At Weir #1, (the whole catchment), the simulated and observed peak discharges were 6.63 and 6.82 m³/s respectively, while at Weir #2 (outlet of Sub-basin 1110), the simulated and observed peak discharges were 2.53 and 2.27 m³/s respectively. On the other hand, the total runoff volume (at Weir #1) was simulated as 0.16 million cubic meters and observed as 0.20 million cubic meters, while for part of the catchment (at Weir #2), the simulated and observed volumes were 0.05 and 0.10 million cubic meters respectively. This storm also showed the same trend as the previous storm in the shape of the observed hydrographs where they peaked early and skewed to the left.

CONCLUSION

The simulation tool that was developed includes various steps of simulation used to estimate the runoff volume in the Badia. First the map data were accessed and displayed on the screen so the user can locate the catchment for further calculation. Other data files, which are the hydrologic database that describe the hydrology of the project area, also loaded.

Wadi Salma catchment (#11) were used to collect field rainfall-runoff data. Rainfall storms were recorded in this catchment during December 2000 and April 2001 as well as the runoff volumes. These data with the hydrologic database were used in the model to simulate the runoff and the results were compared to the observed field observation. The results showed that the simulation model did simulate the runoff volumes with acceptable estimation compared to the observed runoff. Since the total volumes of arid lands floods are the important parameter for water resources planning, the final model results were designed to estimate both peak flow rates and total volumes.

The model calculated the peak discharge and runoff volume with acceptable accuracy for the whole catchment (at Weir #1); the difference in peak discharge estimation was 2 -3% and in runoff volume was 0% for the first storm and 20% for the second one. For parts of the catchment (Weir #2), the peak discharges were estimated with error margin of 5% to 11% for storm 1 and storm 2 respectively, while the runoff volumes were estimated as 50-55% of the observed one.

The other observation was that the observed hydrographs were skewed to the left and peaked early. This is a result of more than one factor, but the major factors are the catchment shape and channel network density. The rainfall distribution over the rainfall duration is also another factor that shape the hydrograph.

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