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Article

Curve Number Applications for Restoration the Zarqa River Basin

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Abstract: The heavy demand of water resources from the Zarqa River Basin (ZRB) has resulted in a base-flow reduction of the River from $5m^3/s$ to less than $1m^3/s$. This paper aims at predicting Curve Numbers (CN) as a baseline scenario and proposing restoration scenarios for ZRB. The method includes classifying the soil type and land use, predicting CNs, and proposing CN restoration scenarios. Prediction of existing CNs will be in parallel with the runoff prediction using the US Army Corps of Engineers HEC-1 Model, and Rainfall-Runoff Model (RRM). The models have been set up at the land use distribution of 0.3% water body, 9.3% forest and orchard, 71% mixture of grass, weeds, and desert shrubs, 7.0% crops, 4.0% urban areas, and 8.4% bare soil. The results show that CN under dry condition are 59, 78 under a normal condition and 89 under a wet condition. During vegetation period, CN are 52, 72 and 86 for the dry, normal and wet condition respectively. The restoration scenarios; CN decreases runoff, and increases soil moisture when using the contours, terraces and crop residues. Analyzing results of CN scenarios will be a fundamental tool to support end-users related to their targets to achieve watershed restoration.

Keywords: water scarcity; watershed restoration; land use distribution; soil type; curve number; Zarqa River's flow simulation; end-users

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1. Introduction

The Curve Number (CN) is one of the most often used methods for predicting runoff, and determining rainfall-runoff relationships [1-2]. Curve Numbers represent average antecedent runoff condition for urban, cultivated agricultural, and arid and semi-arid range land uses. Curve Numbers can be determined from soil type, land use, soil moisture condition, and hydrologic condition. In hydrology, CN values are used to determine how much rainfall is lost (initial abstractions and infiltration) and how much becomes runoff. A high CN means high runoff and low losses as with urban areas, whereas a low CN means low runoff and high infiltration. The SCS CN is a function of land use and hydrologic soil group and is calculated using a table relating the two [3-4]. For each land use type there is a corresponding CN for each of the SCS hydrologic soil types A, B, C, and D, with values ranging theoretically from 0-100 [2]. Selection of CN is generally accomplished using lookup tables and site-specific information based on soils, land use, vegetative cover, and antecedent moisture. Previous studies have focused on identification, utilization, and suggested adjusting CN for watersheds conservation [5-6] [7-8].

Several models can calculate watershed runoff [9]. Each component of the model is an aspect of the rainfall-runoff process, such as precipitation, losses, runoff transformation, and river storage and routing. Representing one of these components requires a set of parameters, which specify the particular characteristics of the watershed in terms of mathematical and empirical relations of the physical processes. Two such models that can predict watershed runoff that are used in this study include the HEC-1 Model, and Rainfall Runoff Model (RRM).

Surface water resources in Jordan are mainly used for agriculture because they are mixed with treated water and cannot be used for domestic purposes. Groundwater is also used for domestic purposes but is not enough to satisfy the growing demand for domestic and industrial sectors[10]. Surface water resources are distributed among 15 major basins in Jordan, with the Zarqa River Basin (ZRB) considered as one of the most significant basin with respect to its economic, social and agricultural importance because it is the second main tributary to the Jordan River. Zarqa River Basin has been taken as a case study because it suffers several water problems ranging from management, quality and conflict issues as well as allocation among sectors [10-11]. It is considered as the most affected area by water scarcity because of its limited water resources and high demand due to the fact that the basin houses about 52% of Jordan's population [12-13]. The heavy utilization of Zarqa Basin has resulted in reducing the base flow of Zarqa River from 5m³/s to less than 1 m³/s and the discharge of springs from an average 317 MCM prior to 1985 to less than 130 MCM after 2000.

The Zarqa Basin drains 4,120 square kilometres and extends from Syria to Amman, and then to the Jordan River. The highest point in the basin is located near the Syrian town of Salkhad in Jebel Al-Arab at an elevation of 1,460 m. The basin discharges its water at the confluence of the Zarqa River with Jordan River at an elevation of -350 m below sea level. Steep bed slopes of the river and its tributaries are in the range of 0.7 to 1.5 percent on average. The stream flow of the Zerqa River is impounded by the King Talal Dam (KTD), South-West of the town of Jaresh at an altitude of about 120 m above sea level, which has a storage capacity of 75 MCM, the largest Dam in Jordan. The flood (runoff) gauge station of New Jerash Road Bridge is the only gauge in Zarqa Basin. It is the only one in the whole Zarqa River Basin for which the database is long enough to be suitable for evaluations. The station near Ain Ghazal, important for monitoring the Runoff from Amman, stopped operating in 1979. Zarqa River Basin spans five governorates, namely; Amman, Balqa'a, Zarqa, Jerash, and Mafraq [14]. Figure 1 shows the location of the Zarqa River Basin and the main cities it contains.

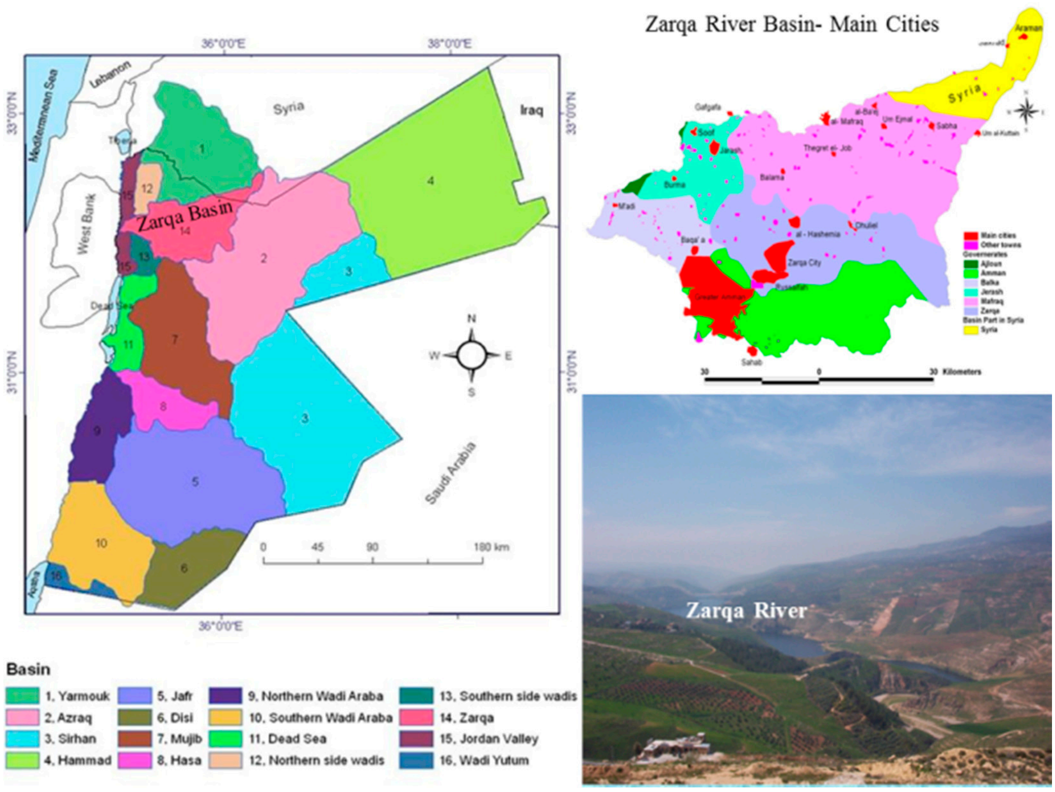

Figure 1. Location of the Zarqa River Basin and the main cities it contains

The soils of Zarqa Basin differ widely according to slope. In the most humid west, reddish to brownish clay and clay loams prevail. Toward the east, the soil become silty loam to loamy in texture, yellowish brown to strong brown with very high carbonate content. Soil erosion on the steeper slope is main cause of alluvial processes where sheet erosion is more pronounced in the eastern part [15].

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Land use in Zarqa River Basin has undergone considerable changes [15]. Recently, the expansion of Amman and surrounding towns has been extensive, where before large expanses of grazing land and more fertile agricultural lands could be found between Amman and other towns, it has now developed into a sprawling urban conglomerate. The Basin has regions of natural forests occurring in the mountainous part that are composed of oak, pine, juniper, wild olive and cypress. Agriculture is scattered within the basin comprising rain-fed orchards, olive, and field crops, with irrigated agriculture on the river basin banks. Major industrial activities in the basin include: Hussein thermal plant, petrol refinery, textile industry, paper processing, leather production, and intermediate petrochemicals.

The critical situation of Zarqa Basin requires a proper management to enhance watershed restoration. For this purpose, the identification of CN values based on existing land uses and hydrologic soil groups (HSGs) classification is an important first step for developing a model dealing with watershed management problems. This paper presents possible solutions for watershed restoration by using the HEC-1 and RRM models, with the aim of estimating the baseline CN values and proposing new CN values that would represent restoration scenarios. Prediction of CNs for the average rainy season of 2001/ 2002 will be in parallel with the prediction of runoff using the HEC-1 and RRM models. HEC-1 model is developed by the US Army Corps of Engineers [16], while the RRM is implemented as web-based distributed client-server systems and provided by Environmental Software Systems- ESS, Austria [17-18].

2. Methodology

The data used for running the models includes the 2001-2002 water year from 1/10/2001 to 30/9/2002. The water year of 2001/2002 is taken because it is an average rainy season with good distribution of rainfall amounts. For that year, all data related to rainfall and runoff records are available on daily basis. The gauging station of New Jerash Road Bridge is the most essential gauge that has a complete record and is used for the HEC-1 and RRM model calibrations, where the simulated flow from HEC-1 and RRM can be compared with the actual data to calibrate parameters and verify the accuracy of the model. Other data for the same year that are also available include the metrological data, satellite imageries, soil maps, elevation, and basin characteristics.

2.1. Watershed Modeling System (WMS): HEC-1 Model

The Watershed Modeling System (WMS) is a comprehensive graphical modeling environment for all phases of watershed hydrology and hydraulics. WMS includes tools to automate model parameterization such as automated basin delineation, geometric parameter calculations, and GIS overlay computations and cross-section extraction from terrain data. The WMS software supports many hydrologic models, including HEC-1 [19] and can be used for estimation of the similar parameters used by RRM.

HEC-1 is one of the most widely-used lumped parameter models available. It is designed to simulate the surface runoff response of a river basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components. It simulates a single storm event, and includes several options for modeling and computing total runoff volume for a rain storm event. Precipitation loss is calculated based on CN values and initial surface moisture storage capacity. CN and surface moisture storage capacity are related to a total runoff depth for a storm. The certainty of HEC-1 application will be deduced from the compatibility of the modeled flow to the actual flow data. For instance, the availability of daily runoff data allows the calibration of the modeled flow with known data series.

2.2. WaterWare System: Rainfall-Runoff Model (RRM)

The WaterWare system is a model-based information and decision support system for water resources management. The system is designed to support the implementation of the Water

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Framework Directive or similar national legislation. The system is a modular client-server system that smoothly integrates several data bases, GIS, and a range of dynamic simulation and optimization models for a wide range of Integrated Water Resources Management (IWRM) tasks. The system is implemented in a fully web-enabled environment, supporting the seamless integration of databases, simulation and optimization models, and analytical tools into a common, easy-to-use framework. This includes a multi-media user interface with Internet access, a GIS with hierarchical map layers, object data bases, time series analysis, reporting functions, an embedded expert system for estimation, classification and impact assessment tasks. Monitoring data acquisition, automatic forecast runs and reporting, is driven by a real-time rule based expert system. The components of the WaterWare System can be summarized in the following: a- Data base management for all components of a basin including monitoring time series b- Embedded GIS functionality c- A set of dynamic simulation models in the base system. The WaterWare system provides the following: a- scenario analysis b- continuous monitoring, now-casting and scheduled forecasting c- event based operation triggered by user defined events.

The WaterWare on-line system and data bases include; Water Resources Model (WRM), Rainfall-Runoff Model (RRM), Irrigation Water Demand, Irrigated Crops Data Base, Water Quality Models, Optimization Scenarios, Water Technologies Data Base, Discrete Multi Criteria DSS, River Basin Object Data Base, Monitoring Station Data Base, Water Institutions Database, and Water Issues Questionnaire [18].

WaterWare system has been developed through a series of applications, where different institutions from several Mediterranean countries are involved in OPTIMA project (Optimization for Sustainable Water Management), sponsored by the EU under FP6 with contract No. INCO-CT-2004-50909: namely, Austria, Italy, Greece, Cyprus, Malta, Turkey, Lebanon, Jordan, Palestine, Tunisia, and Morocco [20-21]. The RRM Rainfall-Runoff model is one of the components of the WaterWare system [18]. It is a dynamic, spatially lumped basin scale water budget model that operates at a daily time step. It is designed for un-gauged basins, estimating their outflow as a function of basin characteristics including, primarily, elevation distribution, and land use distribution, rainfall in mm and average air temperature in degree Centigrade as dynamic inputs.

Editing a scenario for the Rainfall-Runoff Model involves major components:

- Basic data as setting the basin characteristics such as basin size, and channel characteristics;
- Defining basin morphometry, and geometry;
- Specific model parameters including the initial conditions;
- Land use as forest, pastures, agricultural practices, built up areas;
- Temperature and precipitation as a time series of daily data;
- Model results are as a time series of daily runoff. These data are shown together with the observed runoff data that can also be used for model calibration, and
- Rainfall- Runoff Model provides its main output as time series of daily runoff data, as well as a stand-alone model for analysis, or in a file format that is compatible with the Water Resources Model (WRM) in order to be used as input for the WRM.

2.3. Soil and land Use Classification for Predicting Curve Numbers

The soil and land use classification are used for predicting baseline CN values of the Zarqa River Basin. This is by overlaying the classification of Hydrologic Soil Groups and the land use maps of Zarqa River Basin. Identification of existing curve number for the average rainy year will be in parallel with the prediction of Runoff using HEC-1 Model, and Rainfall- Runoff model (RRM).

The rule of the classification is based on Soil Conservation Service [2], which considers soil texture, soil depth, infiltration rate, and layers that impede downward movement of water. Four hydrologic soil groups A, B, C and D are considered for the basic classification of soils of the watershed as defined in Table 1. Soil textures of Zarqa River Basin differ according to slope and soil depth in terms of percentages of silty clay loam, clay, silty clay, clay loam, sandy clay loam, and others. Properties of the representative soil profiles of each soil map unit and the description of each soil map unit are classified into their hydrologic soil groups.

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Table 1. Hydrologic Soil Groups (HSGs) classification [2].

HSG	Properties
Group A	Soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist mainly of deep, well to excessively drained sand or gravel and have a high rate of water transmission.
Group B	Soils have moderate infiltration rates when thoroughly wetted and consist mainly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse texture. These soils have a moderate rate of water transmission.
Group C	Soils have low infiltration rates when thoroughly wetted and consist mainly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission.
Group D	Soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist mostly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission.

The land use classes from the September 2001 Landsat Enhanced Thematic Mapper (ETM) imagery of the Zarqa Basin have been classified into 6 different classes by using ENVI software for satellite data analysis. The classes are represented in percentages.

CN values for each unique area are found using the soil type and assigned land use in lookup tables of the Soil Conservation Service (SCS) [2]. An example of the values which are considered as a reference for determining the Zarqa Basin CNs is shown in Table 2. The weighted value of CN for Zarqa Basin is determined according to the equation 1.

Table 2. Curve Numbers of the Soil Conservation Service (SCS) [2]-Example.

CN for Arid and Semiarid for Range Lands					
Cover Type	**Hydrologic Condition**	**CN and Soil Type**			
		A	B	C	D
Herbaceous-mixture of grass, weeds and low-growing brush	Poor	-	80	87	93
	Fair	-	71	81	89
	Good	-	62	74	85
	Runoff CN for Urban Areas				
Urban Areas		89	92	94	95

$$CN\ (weighted) = \sum (CNi \times Ai) / A, \quad (1)$$

CN= Weighted curve number.

CNi= Curve number for each unique soil and land use.

Ai= Area with curve number CNi, and A= Total area.

The CN for average antecedent moisture condition AMC II can be converted to the dry condition AMC I and the wet condition AMC III using equations 2 and 3 [3]:

$$CN\ (I) = 4.2\ CN\ (II)/10 - 0.058\ CN\ (II), \quad (2)$$

$$CN\ (III) = 23\ CN\ (II)/10 + 0.13\ CN\ (II), \quad (3)$$

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3. Results and Discussion

3.1. *HEC-1 Model, and Rainfall Runoff Model*

Prior to running the HEC-1, and RRM models, all parameters are checked for consistency. The profile of each soil map unit has been classified and resulted in two Hydrologic Soil Groups (HSGs); HSG B, and HSG C, whereas, the land use (existing condition of the land) of the September 2001 Landsat Enhanced Thematic Mapper (ETM) imagery of the Zarqa Basin has been classified into 6 different classes. The different land use classes are water body, forest and orchard, mixture of grass, weeds and desert shrubs, crops, urban areas, and the bare soil. Table 3 shows the land use classification of the Zarqa River Basin in percentages. The Zarqa River Basin hydrologic soil group map and the land use classification map are overlaid to determine the CNs of the entire watershed using HEC-1 Model. Figure 2 shows the Zarqa River Basin's soil and land use classification maps.

Table 3. Land use classification of the Zarqa River Basin in %.

No.	Class	%
1	Water body	0.3
2	Forest and orchard	9.3
3	Mixture of grass, weeds, and desert shrubs	71
4	Crops	7.0
5	Urban areas	4.0
6	Bare soil	8.4

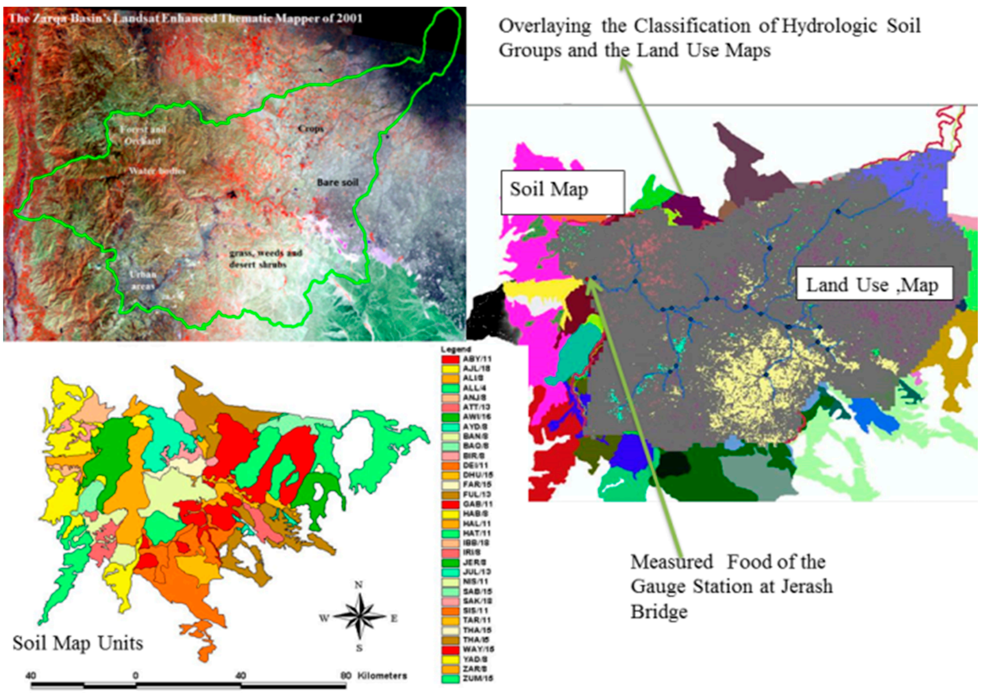

Figure 2. Zarqa River Basin's soil and land use classification maps.

The standard SCS Table [2] is used to estimate an initial CN values, then, HEC-1 is run the simulations and adjust the CN values until the measured runoff computed within a close amount. Table 4 shows the weighted CNs for the Zarqa Basin, where, the average weighted CNs for Zarqa River Basin are 59 (dry), 78 (normal) and 89 (wet). During the growing season, the average curve numbers are 52, 72 and 86. These weighted baseline CNs are the keys to modeling/simulating the runoff at Zarqa Basin's outlet; Runoff Gauge at Jerash Bridge, and expected CN adjustments for restoration scenarios.

Table 4. Weighted curve numbers for the Zarqa Basin.

Remaining Time			Vegetation Period (Growing Season)		
Dry Condition	Normal Condition	Wet Condition	Dry Condition	Normal Condition	Wet Condition
59	78	89	52	72	86

HEC-1 is run using Watershed Modeling System (WMS) [16-19]. The results of running HEC-1 Model are achieved and show that the annual calibrated (modeled) Runoff volume is 36.4 MCM from the total rainfall storms, which totaled 911 MCM. In comparison with measured (actual or observed) total runoff volume of the Zarqa Basin outlet which was 36.6 MCM. Thus, the simulated runoff with a value of 36.4 MCM very well matches the figures of the gauged values from the Ministry of Water and Irrigation. It should be noted that this excludes the base flow. The base flow consists of the effluent of wastewater treatment plant of khirbet es-Samra is about 2.0 m^3 /sec. The calibrated runoff value of 36.4 MCM is achieved after adjusting the CN values (model calibration), and shows that the land uses are 0.3% water body, 9.3% forest and orchard, 71% mixture of grass, weeds, and desert shrubs, 7.0% crops, 4.0% urban areas, and 8.4% bare soil. Thus, the amount of runoff in the HEC-1 model is a function of the parameters, primarily, the composite CN of Zarqa River Basin of a specific year. Using land uses percentages of HEC-1 model into RRM will also simulate the flow for the same year 2001/2002. RRM incorporates the existing conditions by setting up the basin's parameters as rainfall, temperature, geometry, morphometry, and land use distributions.

Rainfall-Runoff model (RRM) is run online using the huge capability of ESS server [17-18]. **Figure 3** shows the Zarqa River Basin's flow simulation. It also shows the time series of precipitation (mm/day), the average daily Temperature (C^o), the measured and modeled flow for the studied year (1/10/2001 to 30/9/2002). The results of running RRM show that the average modeled flow (runoff +base-flow) about 2.97 m^3/sec or about 93.7 MCM/year, which matches the figures of the Ministry of Water and Irrigation 2002, with an average value of 2.96 m^3/sec or about 93.4 MCM/year. The simulated flow is highly compatible to the current (measured) flow due to the simulation capability of RRM, which has been set up based on existing conditions of the basin, primarily the land use for that year.

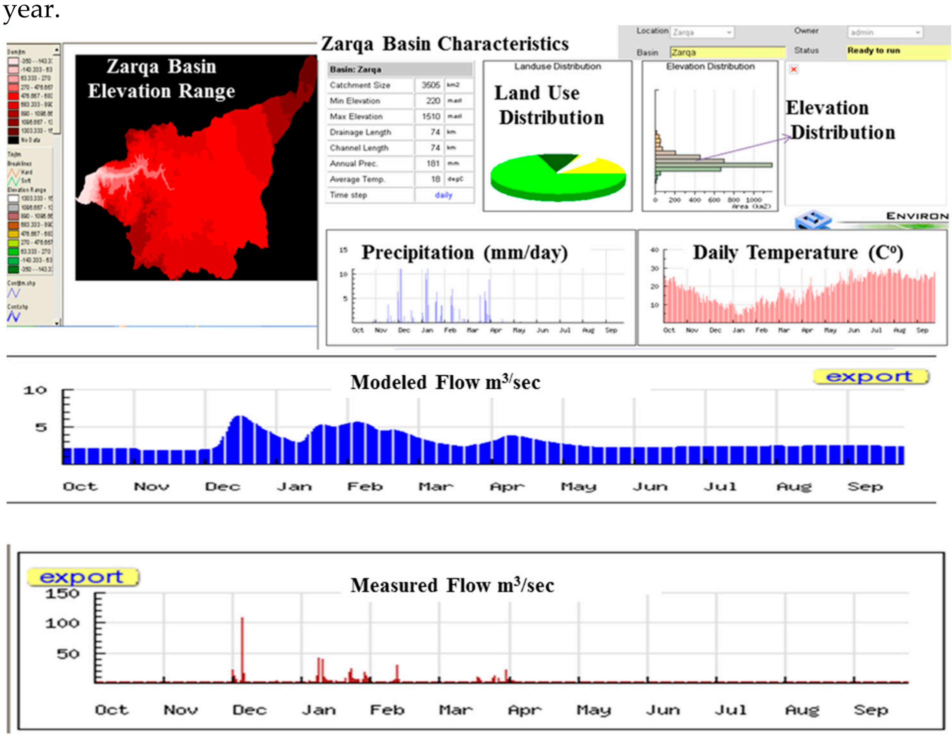

Figure 3. Zarqa River Basin's flow simulation.

Comparing the results of HEC-1 (in predicting the runoff) and RRM models (in predicting the flow) proved their simulation efficiency of Zarqa River Basin. Nevertheless, the HEC-1 is a single storm event and is based on values of curve number, while RRM is a dynamic, spatially lumped model that operates at a daily time step, and estimating the flow as a function of basin characteristics. The models' predictions for the real runoff and flow definitely establish the modeling certainty and help water resources developers to incorporate different basin features for watershed simulation and restoration.

3.2. *CN Applications for Watershed Restoration*

Using the baseline result from section 3.1, proposed changes in land use can be simulated via HEC-1 and provide a mechanism to evaluate conservation mechanisms for Zarqa River Basin restoration planning. Two scenarios are developed as tools for making decisions on land class [22] of mixtures of grass, weeds, and desert shrubs. Table 5 shows the weighted CNs for the Zarqa Basin restoration simulated using the HEC-1 model.

First scenario: proposing the use of contour to lands of mixture of grass, weeds, and desert shrubs. The average weighted CNs for Zarqa River Basin are 58, 76 and 88 under dry, normal and wet conditions respectively. During the growing season, the averages CNs are 51, 71 and 85. The results of running the HEC-1 model show that the annual average predicted runoff volume is 33.1 MCM from the total rainfall storms.

Second scenario: proposing the use of contours, terraces and crop residues to lands of mixture of grass, weeds, and desert shrubs. The average weighted CN for the Zarqa River Basin are 57, 75 and 87. During the growing season, the averages CNs are 50, 70 and 84. The results of running the HEC-1 Model show that the annual predicted Runoff volume in 28.4 MCM from the total rainfall storms of average rainy season 2001/2002.

Table 5. Weighted curve number (CN) applications for the Zarqa Basin restoration using HEC-1 Model.

Land Use Change	**Remaining Time**			**Vegetation Period (Growing Season)**			
	Dry Condition	Normal Condition	Wet Condition	Dry Condition	Normal Condition	Wet Condition	**Predicted Runoff**
Contour	58	76	88	51	71	85	33.1 MCM
Contour Terraces & Crop Residue	57	75	87	50	70	84	28.4 MCM

Comparing results of running HEC-1 and RRM models as baseline scenarios for Runoff prediction; HEC-1 shows that the average calibrated runoff is about 36.4 MCM (excluding the base-flow), whereas RRM shows that the average modeled flow (runoff+ base-flow) is about 2.97 m^3/sec; about 93.7 MCM/year. Land use changes scenarios are affecting CN's. The predicted runoff decreases from 36.4 to 33.1 by applying contour, and 28.4 by applying contour, terraces and crop residues. These land use changes will help in enhancing the penetration of water into the soil to increase soil moisture storage, while maintaining sufficient surface water downstream of the basin. Thus, these models can present, simulate, predict the flow, and provide watershed restoration options for decision makers.

4. Conclusions

The conclusions derived from using modeling tools for the Zarqa River Basin restoration; HEC-1 and RRM are in the following:

- The water resources of the Zarqa River Basin are of a complex system because water is transferred into and out of the basin. In addition, treated wastewater and desalinized water contribute to the system;
- The Basin is under pressure by the rapid growth of various industrial, agricultural, and commercial activities; therefore, using modeling tools is highly needed to simulate the basin's flow, and find applicable scenarios for basin restoration;
- HEC-1 was used with baseline CNs based on existing conditions, primarily the land uses distribution for the targeted year (the average rainy year), and proposing CN restoration scenarios is a successful tool for the Zarqa River Basin. The calibrated runoff value of 36.4 MCM (excluding the base-flow) is achieved and shows that average weighted CNs for Zarqa River Basin are 59, 78 and 89 for the dry, normal and wet condition respectively. During the growing season, the average CNs are 52, 72 and 86;
- RRM successfully in simulated the Zarqa River Basin in a model that incorporates the existing conditions by setting up the basin's parameters as rainfall, temperature, geometry, morphometry, and land use distribution. The average simulated flow is about 2.97 m^3/sec; about 93.7 MCM/year, which matches the measured flow of 2.96 m^3/sec; about 93.4 MCM/year (base-flow+ runoff). Further application via RRM on basin restoration is needed.
- HEC-1 and RRM models have been set up at the land use distribution of 0.3% water body, 9.3% forest and orchard, 71% mixture of grass, weeds, and desert shrubs, 7.0% crops, 4.0% urban areas, and 8.4% bare soil. Therefore, changing the percentages of land use distribution through the models will change the daily time series of runoff. This points out the importance of land use change scenarios. The first scenario of using contour shows a reduction in annual predicted runoff volume by 3.3 MCM. Whereas, the second scenario of using contour, terraces and crop residues shows a reduction in annual predicted runoff volume by 8 MCM. These reductions in runoff volumes will minimize the long-term negative impacts for the Basin by enhancing the penetration of water into the soil, increasing soil moisture storage, and recharging ground water while maintaining sufficient surface water downstream of the Zarqa River Basin. The approaches in changed land use will allow the validation of future scenarios.
- HEC-1 and RRM are useful tools for watershed restoration scenario simulation, where decision makers can implement land uses distribution to simulate the behavior of a river basin over time using the models parameters. Implementations and decision making are based largely on economic consideration. Thus, decision makers can evaluate the feasibility and the applicability of the land use change approaches towards Basin restoration.
- HEC-1 and RRM are not only strengthening the cohesion between scientific scenarios of modeling, but also as offering of new ways of indirect watershed restoration.

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