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Runoff Estimation For Algadeer Alabyad Watershed In Jordan Using Rational Method And Geographic Information System

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ABSTRACT
Jordan is characterized by severe weather conditions, therefore great temporal and spatial variations in rainfall, runoff and evaporation amounts are expected .This research aims to use GIS for investigating the potential of runoff for Algadeer alabyad watershed using the **"Rational equation".**The annual runoff volume for each catchment area was estimated based on using simple equation that takes into consideration the sub-watershed area, annual rainfall and annual runoff coefficient. The Rational Formula was applied as the most commonly used method of determining runoff volume for medium to large watersheds. The runoff coefficient is the key parameter in this model.
It was found that the estimated annual runoff that could be utilized for water harvesting on annual basis at sub-watershed 1 is **244359 m^3**, at sub-watershed 2 is **374925 m^3**, at sub-watershed **3 is 148807 m^3** and at sub-watershed 4 is **46700 m^3** .The total annual runoff volume that could be collected in the earth dam location on the average long term rainfall depth is **768091 m^3** to provide a source of water for irrigation and for the benefit of local community and livestock owners. The runoff percentage is estimated to be 3.9 % of the annual rainfall over the total area of Algadeer alabyad watershed.

Keywords: Runoff, Watershed, GIS, Rational equation

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I. INTRODUCTION

Jordan is characterized by severe weather conditions, therefore great temporal and spatial variations in rainfall; runoff and evaporation amounts are expected [1]. This research was based on the fact that water resources in Jordan are very limited and the country needs an intensive work to come up with more water resources to cover the sharp increase in water consumption for all sectors. Hydrological data collection such as rainfall intensities and flood volumes started in Jordan not long ago and it is concentrated in the humid parts of the country (2).

Hydrologic calculations are used to determine the volume of seasonal water runoff from precipitation and quantify precipitation losses which occur as part of the hydrologic cycle. A wide variety of procedures have been developed to estimate runoff volume and peak discharge rate. The Curve Number and Rational Methods are versatile and widely used procedures for runoff estimation. These methods include several important properties of the watershed namely soil permeability, land use and antecedent soil water conditions which are taken into consideration.

Watershed is the area covering all the land that contributes runoff water to a common point. Watershed characteristics which may be mostly readily compared to estimating the volume of runoff that will result from a given amount of rainfall are soil type, land cover/ landuse and topography. The problem most often encountered in hydrological studies is the need for estimating runoff from a watershed for which there are records of precipitation and no records of runoff. The availability of accurate information on runoff is scarcely available in most sites. However, quickening of watershed management programmed for conservation and development of natural resource management has necessitated the runoff information. Advances in computational power and the growing availability of spatial data have made it possible to accurately predict the runoff. The possibility of rapidly combining data of different types in GIS has led to significant increase in its use in hydrological applications. The application of GIS for catchment area analysis have been addressed in the literature in many researches (3)

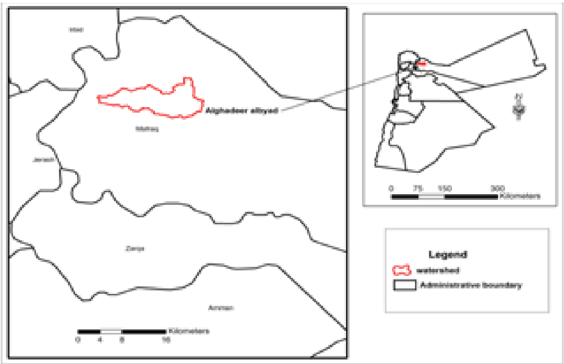
II. MATERIALS AND METHODS

2.1 Study site

The study area named Algadeer alabyad is located in the northeastern part of Jordan, figure (1).The area of the watershed (within which the dam is located) is 82 km^2. The topography is dominated by an undulating to rolling terrain with low, rounded hills in Tertiary calcareous rocks with slope ranging from 0 to more than

6%.The annual rainfall varies from 200 to 250 mm. Rainfall as thunderstorms, characterized by irregular intensity and duration, forms the greatest part of total precipitation in the area (4). Rainfall occurs mostly during winter months (October to April). Altitude ranges from 634 to 934 m above sea level. Twenty six percent of the total area is classified as agricultural lands whereas 56% is dominated by rangeland.

Figure (1): Location of Alghadeer alabyad watershed in Al Mafraq , Jordan



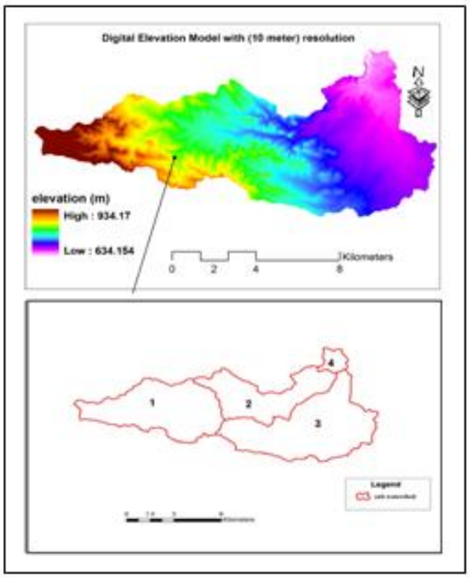
2.2 Data collection and preparation:

Data sets have been obtained from different sources to achieve the main objectives of this study. GIS tools were used in data preparation, processing and data analysis.

2.2.1Watershed delineation and area calculation

The watershed was delineated based on DEM with a 10 meter resolution. The hydrological tool in GIS was used to derive four sub-watersheds as shown in figure (2). The purpose of the division is intended to facilitate the hydrological analysis that would be undertaken in this research.

Figure (2): Sub-watershed derived from DEM



The area of sub-watersheds was calculated as shown in **table (1).**

Sub water shed number	area (Km²)
1	27.19
2	18.74
3	33.84
4	2.39
total	82.16

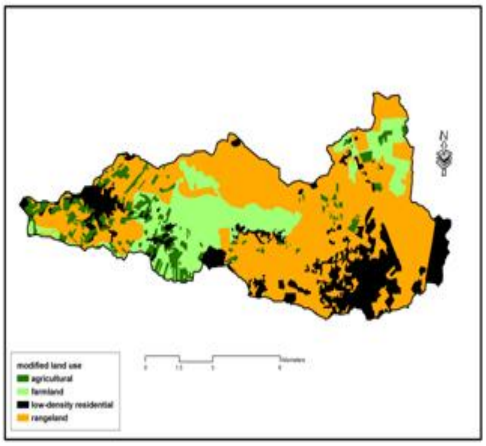
2.2.2 Existing land use

The land use / land cover map was prepared by Royal Jordanian Geographic Center (RJGC) that represents year 2011.The map is classified into seven classes. The classes of land use have been modified into four classes to meet the runoff coefficient table, as shown in table (2), figure (3).

Table (2): shows original land use classes and modified classes

Land use class	Area %	Modified Land use class
Airport	2.04	low-density residential
continuous urban	8.27	low-density residential
Bare rock	0.001	low-density residential
Bare soil	55.71	rangeland
Quarries	0.56	low-density residential
Discontinuous urban	6.6	low-density residential
Rangeland	0.08	rangeland
Fruit trees	7.77	agricultural
Field crops	18.98	farmland

Figure (3): Shows the modified land use /land cover map.



2.2.3 **Determination of Hydrological soil group (HSG)**

The hydrological soil groups (HSG) were obtained from table (3) based on soil texture (5).

Table (3): Hydrological soil properties classified by soil texture

Texture class	SCS hydrologic soil grouping
Sand	A
Loamy sand	A
Sandy loam	B
Loam	B
Silt loam	C
Sandy clay loam	C
Clay loam	D
Silty clay loam	D
Sandy clay	D
Silty clay	D
clay	D

Therefore, the texture data were extracted from field observations surveyed by Ministry of agriculture (MOA). Soil texture in Algadeer alabyad watershed represents five classes: (Clay, Clay loam, Loam, Silt, Silty clay) which means that the watershed has two HSG classes: B and D.

The United States Soil Conservation Service (SCS) has identified four soil group classifications (A, B, C, or D) that can be used to help in determining values for drainage area runoff coefficients (6). Determination of which SCS soil group fits a particular soil maybe on the basis of a measured minimum infiltration rate for the soil or on the basis of a description of the soil. Table (4) explains the classes of HSG.

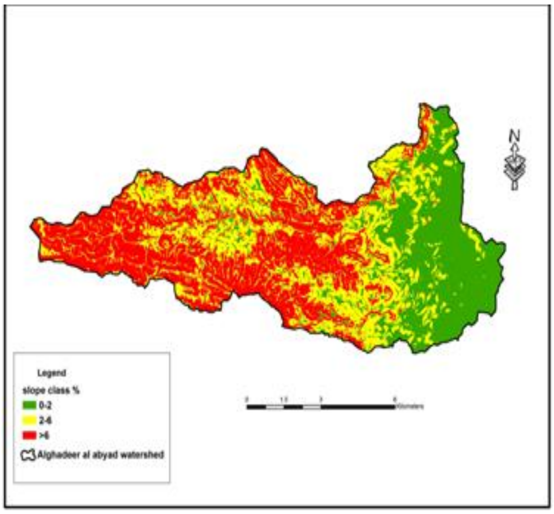
Table (4): SCS hydrological soil groups

Soil group	description
A	Lowest runoff potential. Includes deep sands with very little silt and clay, also deep rapidly permeable gravel.
B	Moderately Low runoff potential. Mostly sandy soils less deep and less aggregated than A, but the group as a whole has above average infiltration after thorough wetting
C	Moderately high runoff potential. Comprise shallow soils and soils containing considerable clay and colloids, though less than those of group D. The group has below average infiltration after saturation.
D	High runoff potential. Includes mostly clays of high swelling percentage but the group also includes some shallow soils with nearly impermeable sub-horizon near the surface.

2.2.4 Slope

Slope map was derived for the watershed using the DEM received from the RJGC. This map was classified into 3 classes: (0-2 %, 2-6%, > 6%) as shown in fig (4).The Arc /map standard command (slope) was used to derive slope grid. Slope steepness is one of the most important factors for selecting the runoff coefficient necessary for the hydrological study. In general, watershed with a greater slope will have a higher runoff coefficient than the one with lesser slope.

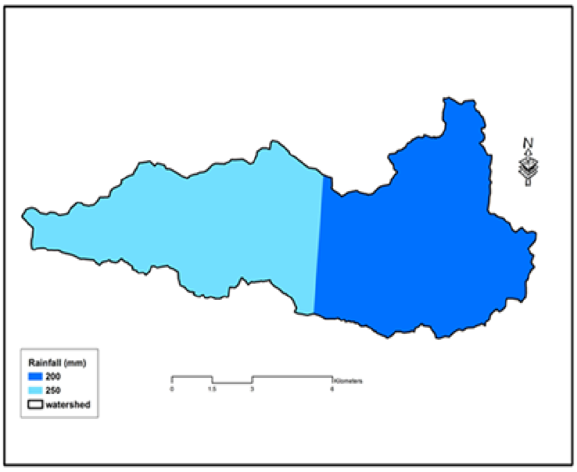
Figure (4): Slope map for Algadeer alabyad watershed



2.2.5 Rainfall

Rainfall map is an important factor in estimating runoff using the rational equation. Figure (5) shows that the sub water sheds of Algadeer Alabyad are located within annual rainfall range of 200 – 250 mm.

Figure (5): rainfall isohyets for Algadeer alabyad watershed.



2.3 **Data processing and analysis**

2.3.1 Intersect:

The layer of Field Observations with Hydrological soil group related to soil texture was converted into Thiessen to represent surface information. To combine required data for derivation of runoff coefficients, intersect command was applied on three layers: (slope, landuse and hydrological soil groups).

2.3.2 Clip:

All required layers were clipped using GIS for the four sub-watersheds: (Slope, landuse and hydrological soil groups), figures (6-9).

Figure (6): GIS layers for sub-watershed 1

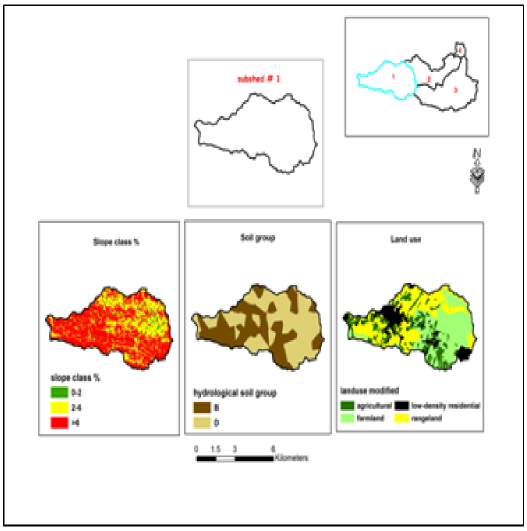


Figure (7): GIS layers for sub-watershed 2

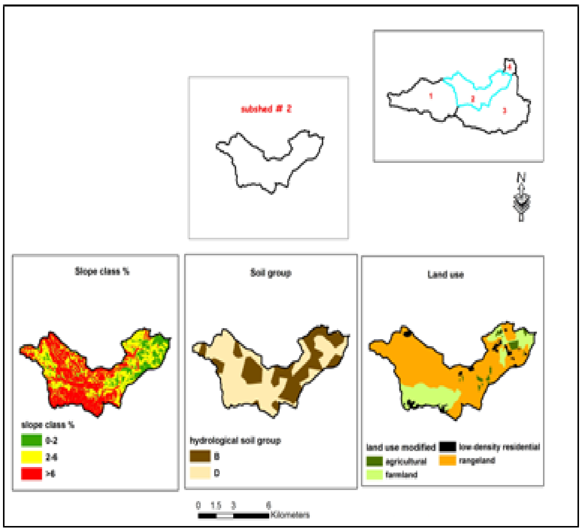


Figure (8): GIS layers for sub-watershed 3

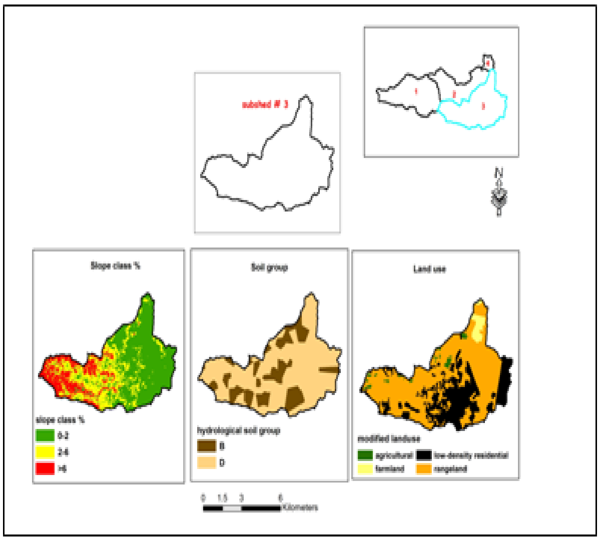
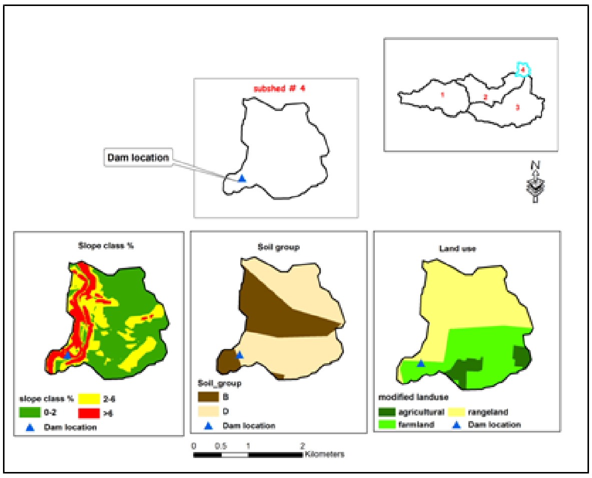


Figure (9): GIS layers for sub-watershed 4



III . DATA ANALYSIS AND RESULTS

3.1 Runoff coefficient (RC):

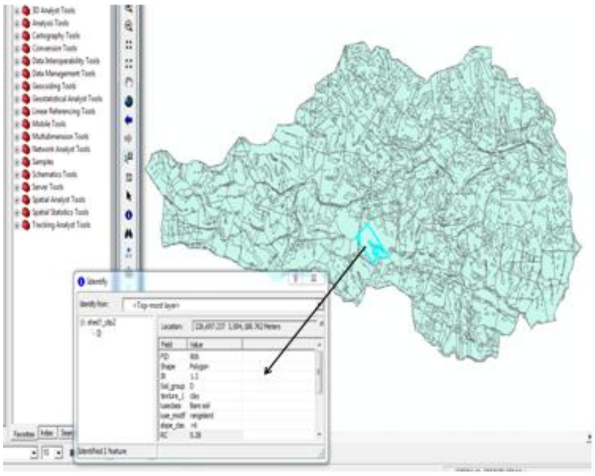
The runoff coefficient (C) is a dimensionless coefficient relating the amount of runoff to the amount of precipitation received. It is a larger value for areas with low infiltration and high runoff (pavement, steep gradient), and lower for permeable, well vegetated areas (forest, flat land). Since the physical interpretation of the runoff coefficient is the fraction of the rainfall on the watershed that becomes surface runoff, it must have a value between one and zero. The runoff coefficient is the key parameter in this model. To determine the runoff coefficient for each sub-watershed, the map produced by intersects was clipped by the boundary of the four sub-watersheds. The runoff coefficients were extracted from table (5) according to slope, landuse and HSG for each polygon as shown in figure (10).

Table (5): Runoff coefficients C for use “Rational equation" .

Hydrological soil group		B			D		
Slope %		0-2 %	2-6%	>6 %	0-2%	2-6%	>6 %
Landuse/original	Landuse /modified class						
Airport continuous urban Bare rock Quarries Discontinuous urban	low-density residential	0.17	0.21	0.26	0.24	0.28	0.35
Rangeland Bare soil	Open space (grass/forest)	0.08	0.13	0.19	0.16	0.21	0.28
Fruit trees Field crops	Agricultural land	0.11	0.15	0.21	0.18	0.23	0.31

Higher runoff coefficients for use with storm recurrence intervals of 25 years or more (7).

Figure (10): polygons produced by intersect command to estimate the runoff coefficient (example).



3.2 **Composite runoff coefficient:**

The composite run off coefficient was determined as weighted average for each sub-watershed:

∑Single run off coefficient * area of polygon / total area for sub-watershed.

Table (6) shows the composite runoff coefficient for the four sub-watersheds.

Table (6): Summarizes the composite runoff coefficient for the four sub-watersheds.

Sub-watershed No.	Area (m^2)	composite runoff coefficient
1	27150991.6	0.26
2	18746276.2	0.23
3	33819785.9	0.2
4	2382653.6	0.19

3.3 Effective composite Runoff coefficient (CRC)

For each sub-watershed the composite Runoff coefficient was modified according to specific features existing in the sub-watershed like urban areas, and roads intersected with streams that affect the runoff collected at the outlet. The decision was made visually using Google Earth to specify the location of urban areas and roads. The assumptions were:

- Urban areas (that impact the path of runoff flow) reduce the Runoff coefficient by 50%.

-Each intersect of stream with road (culverts) reduces the Runoff coefficient by 1.5%.

Therefore, the composite Runoff coefficients were recalculated according to assumptions as shown in table (7)

Table (7): Shows the effective runoff coefficient for the four sub-watersheds.

sub watershed No.	effective runoff coefficient
1	0.036
2	0.1
3	0.022
4	0.098

3.4 <u>Runoff Estimation:</u>

A simple model is the Rational equation, which calculates the runoff volume using the catchment area, rainfall volume and runoff coefficient. The Rational Formula was applied as the most commonly used method of determining runoff volume for medium to large watersheds. The Rational Formula (8) is expressed as:

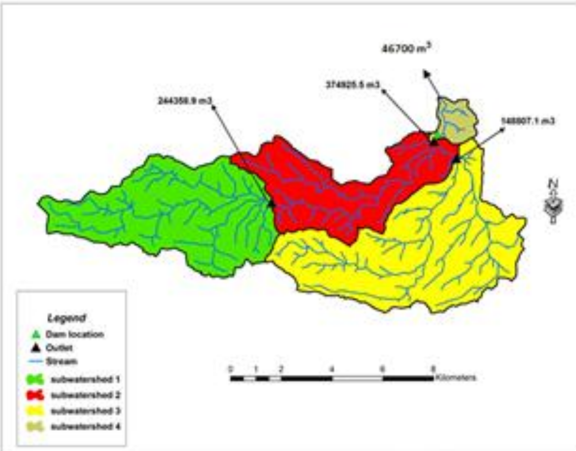
Runoff volume (m^3) =catchment area (m^2) ×annual rainfall (m) ×annual runoff coefficient %

The annual runoff volume for each watershed was estimated as shown in table (8) and figure (11):

Table (8): Shows the surface runoff estimated for the three sub-watersheds

Sub-watershed No.	Area (m^2)	Rainfall (m)	Effective runoff coefficient	Runoff (m^3)
1	27150991.6	0.25	0.036	244359
2	18746276.2	0.2	0.1	374925
3	33819785.9	0.2	0.022	148807
4	2382653.6	0.2	0.098	46700

Figure (11): Shows the runoff volume for all sub watersheds.



The total annual runoff volume that could be collected in the earth dam on the average long term rainfall depth is 768091 m^3 as shown in figure (12).

The total surface runoff at the earth dam outlet is shown in **figure (12)**

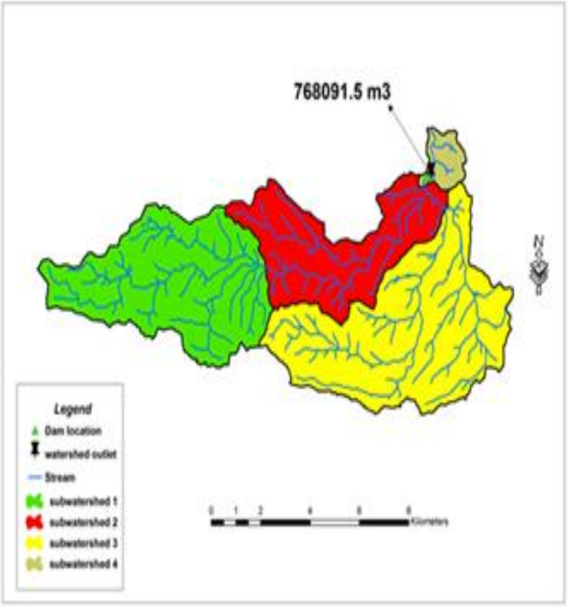


Table (9) provides a summary for the hydrologic parameters in the targeted catchments and the estimated runoff volumes. This table shows that the estimated runoff that could be harvested on annual basis at these sites varies between **46700** cubic meters to **374925** cubic meters, while the total runoff volume that would be collected for the whole watershed is estimated as **814791.5** m^3. The runoff percentage is estimated to be 3.9 % of the annual rainfall over the total area of Algadeer alabyad watershed. This indicates that these sites have the potential for small scale water harvesting that could be utilized by local livestock owners in the area to secure animal watering in those locations.

Table (9): Hydrologic parameters and runoff volumes for targeted catchments**.**

Catchment No.	1	2	3	4
Catchment Area (Km^2)	27.2	18.7	33.8	2.39
Main Channel Length (km)	11.8	10.8	12	2.2
Highest Elevation (m)	934.17	782.481	840.596	671.588
Lowest Elevation (m)	719.9	651.318	840.596	634.154
Average Slope (%)	9.15	9.5	9	9.86
Annual Rainfall (mm)	250	200	200	200
Effective Runoff Coefficient (%)	0.036	0.1	0.022	0.098
Runoff Volume (m^3)	244359	374925	148807	46700
Total runoff Volume (m^3)				**814791.5**

IV. CONCLUSION

The annual runoff volume for each catchment area was estimated based on using a simple equation that takes into consideration the sub-watershed area, annual rainfall and annual runoff coefficient. GIS was used in determining the catchment area, annual rainfall and determining the potential runoff volume for each catchment.

It was found that the estimated annual runoff that could be utilized for water harvesting at sub-watershed 1 is 244359 m^3, at sub-watershed 2 is 374925 m^3, at sub-watershed 3 is 148807 m^3 and at sub-watershed 4 is 46700 m^3.

The total annual runoff volume that could be collected in the earth dam is on the average long term rainfall depth 768091 m^3 to provide a source of water for irrigation and for the benefit of local community, and does not necessarily mean that it could be collected each year. Therefore, any future changes in the land management and landuse in the watershed may increase or decrease the runoff water volume.

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