MANAGEMENT OPTIONS OF WADI FARIA BASEFLOW

Sameer Shadeed[*] Hafez Shaheen[**] and Anan Jayyousi [**]

[*]Water and Environmental Studies Institute, An-Najah N. University,
Nablus, Palestine
[**]Civil Engineering Department, An-Najah N. University,
Nablus, Palestine

ABSTRACT

The availability of adequate water of appropriate quality has become a limiting factor for development, worldwide. In arid and semi-arid regions, where water scarcity is a dominant problem, the overexploitation of water resources threatens to deteriorate the availability of these natural resources. Wadi Faria catchments, located within the Jordan River Basin in Palestine, are under arid and semiarid conditions as characterized by the scarcity of its natural water resources and the low per capita water allocation. Wadi Faria is a perennial stream in which 11 fresh water springs form the baseflow. Annual discharges from these springs vary from less than 4 to 42 MCM with an approximate average of 13.5 MCM. These available water resources have sustainable-yield limits that do not meet the water needs. Management of the available water in Wadi Faria is essential for the sustainable development of the area. This has compelled the motivation for developing a set of management options to optimally manage the baseflow of Wadi Faria as a necessary step towards developing its water resources. This paper explores management options to set the framework for decision-making in regard of efficient practices that can be adopted to manage the scarce water resources of Wadi Faria catchments.

KEYWORDS: Management Options; Water Resources; Baseflow; Wadi Faria.

INTRODUCTION

In arid and semi-arid regions of the Mediterranean fresh water resources are finite and most of the economically viable development of these resources has already been implemented (Hamdy et al. [1]). There is a growing disparity between water supply and demand in arid and semi-arid regions. This disparity calls for developing management options to close the demand-supply gap. The options for closing the gap should consider various means of matching supply and demand and of satisfying environmental concerns. The problem of allocating scarce water among competing uses and users is the most serious issue among the matters that water resources management has to consider (Lee [2]). Water resources management is often seen as a potential answer to the water availability problems in areas facing serious water shortage, either periodically or throughout the year (Athens [3]). Worldwide, many semi-arid catchments suffer from the population growth and increasing demand for water, deteriorating water quality, increasing environmental degradation and impending climate change. This situation requires more effort to assess water resources for national planning and management in order to sustain development.

Wadi Faria is an important agricultural area which is considered as a basket food that provides the West Bank, Palestine with the main agricultural products. On average the annual obtainable water resources in Wadi Faria are very limited and do not exceed 28 MCM (millions cubic meters) of which 14 MCM from springs, 8 MCM from wells and the remaining are from surface runoff. Losses from springs are very large, about 5 MCM out of 14 MCM of annual yield are discharged in the rainy season from December up to March when irrigation demands are minimal. Storm water runoff within Wadi Faria was estimated at 6.4 MCM/year (PWA [4]) and most of surface runoff is lost in winter due to lack of storage facilities. This makes the annual obtainable water resources in Wadi Faria to decrease from 28 MCM to about 16 MCM. The total annual irrigation and domestic water demand in Wadi Faria is between 15.3 and 5.2 MCM respectively resulting in a deficit of about 5 MCM/year between supply and demand. The situation has worsened further owing to the increasing population and the associated expansion of agriculture activities imposing a tremendous strain on the limited water resources of Wadi Faria. The fertile irrigable areas in the Wadi require about 36 MCM of water per year, which will increase the demand-supply gap to 25 MCM/year.

The efficient management strategy and management practices of Wadi Faria water resources should include utilization of the surface runoff and baseflow. This paper explores the management of the baseflow as one important option for bridging the gap between supply and demand in Wadi Faria. Managing the baseflow as a major water resource will support the decision-making process and future sustainable development of Wadi Faria water resources.

WADI FARIA

Geographically, Wadi Faria is located in the northeastern part of the West Bank with a total area of about 320 km^2 accounting for 6% of the total area of the West Bank. Wadi Faria extends from the ridges of Nablus Mountains down the eastern slopes to the Jordan River and the Dead Sea (Figure 1). Wadi Faria overlies three districts of the West Bank, which are Nablus, Tubas and Jericho. It lies within the Eastern Aquifer Basin, which is one of the three major groundwater aquifers forming the West Bank groundwater resources. Ground surface elevations in Wadi Faria exceed 900 m above mean sea level (msl) in the western areas near Nablus and drop gradually down to 350 m below msl at the confluence where Wadi Faria meets the Jordan River.

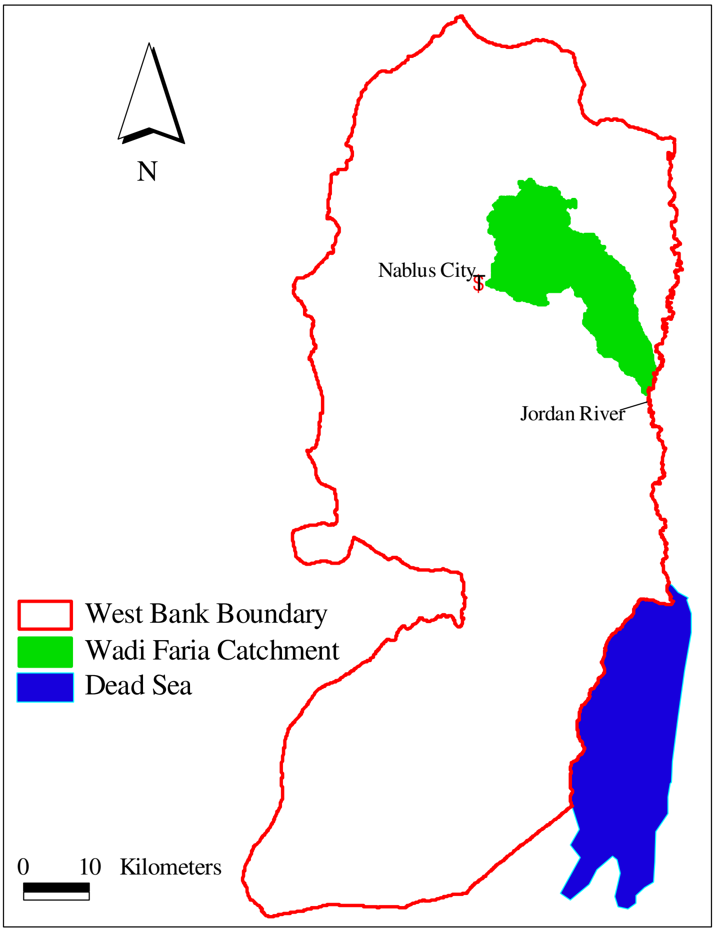

Figure 1: Location of Wadi Faria catchment

The climate in Wadi Faria is Mediterranean, semi-arid climate, characterized by mild rainy winters and moderately dry, hot summers. The climate is highly variable and is influenced by both elevations and the circulation of the air-streams. The winter rainy season is from October to April. Rainfall events predominantly occur in autumn and winter to account for 90% of the total annual precipitation. Wadi Faria is gauged by six rainfall stations and the rainfall distribution ranges from 640 mm at the headwater to 150 mm at the outlet to the Jordan River (Figure 2). In general, rainfall averages decrease moving from north to south and west to east. Wadi Faria is characterized by high temperature variations over space and time. The mean annual temperature changes from 18^{o}C in the western side of the catchment in Nablus to 24^{o}C in the eastern side of the catchment in Al-Jiftlik. Mean annual relative humidity changes from 61% in the western side to 58% in the eastern side of Wadi Faria.

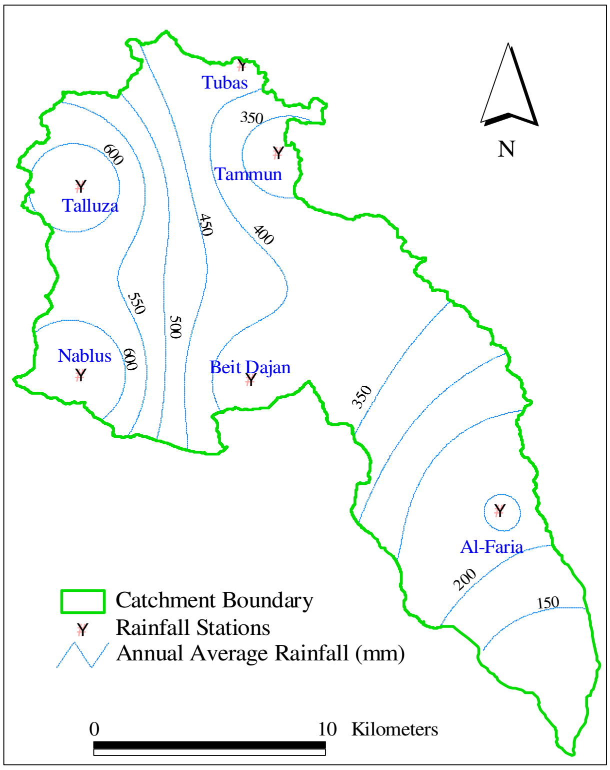

Figure 2: Rainfall distribution and rainfall stations in Wadi Faria

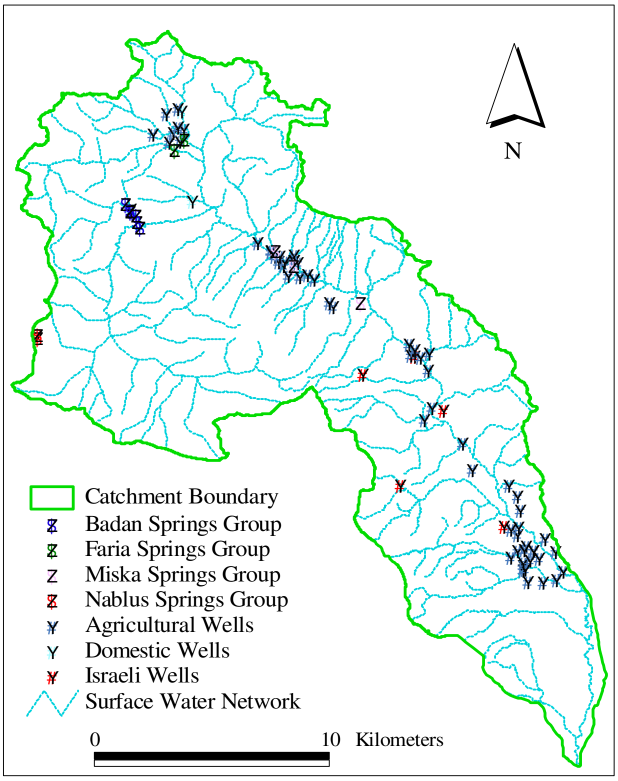

Figure 3: Water resources map of Wadi Faria

There are 11 fresh water springs in Wadi Faria forming three groups: Faria, Badan, and Miska in addition to another two springs that are entirely utilized by the city of Nablus. The discharge data of these springs experience high discharge variability. Their annual discharges vary from 3.12 to 45.72 MCM with an average amount of about 14 MCM. The sewage water of eastern Nablus is flowing raw and is mixed with the surface water of Wadi Faria. It is estimated that the city of Nablus discharges about 3 MCM/year of untreated industrial and domestic wastewater that discharge to the Wadi (EQA [5]).

There are 70 wells in Wadi Faria, of which 62 are agricultural, 3 are domestic and 5 are utilized by Israel. The annual total utilization of the Palestinian wells ranges between 4.4 and 11.5 MCM/year (Shadeed [6]). The wells, springs and surface water network within Wadi Faria are depicted in Figure 3.

In addition to agriculture, the most common economic activity, there are few small industrial and commercial activities in Wadi Faria. There are few recreational activities and tourist facilities in the eastern part of the Wadi. Agricultural patterns in Wadi Faria include rain-fed and irrigated agriculture. Rain-fed agriculture is mainly in the higher parts of the Wadi and includes vegetables, field crops and rain-fed trees; most common of which are olive trees where olives cover more than 1000 hectare. Field crops cover approximately 500 hectare while rain-fed vegetables cover less than 100 hectare. Irrigated agriculture includes open field vegetables, greenhouses and irrigated trees. Open field vegetables cover more than 2000 hectare (Figure 4).

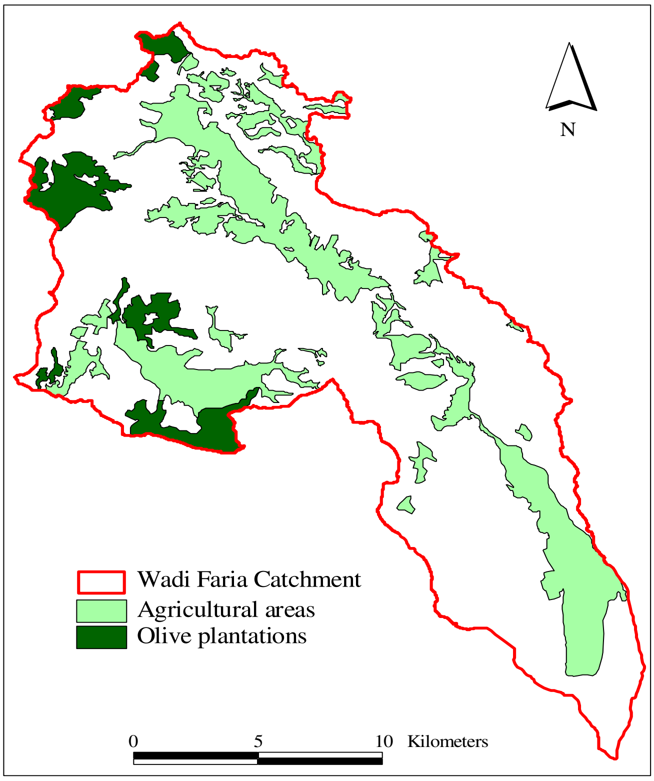

Figure 4: Agricultural areas in Wadi Faria

METHODOLOGY

The chart of Figure 5 depicts the overall methodology carried out for developing the management options. Data were first obtained and compiled in a composite database. Monthly discharge data of the springs forming the baseflow of Wadi Faria were analyzed for more than 30 years to capture the high variability of the springs and surface water discharges. The baseflow data at two measuring flumes were obtained for the three rainy seasons of the years 2003-2006. Analysis of the baseflow data was carried out to provide an overview and general approach to inspect the withdrawal and abstraction of water flows through Wadi Faria. Finally a set of management options were developed to manage the available baseflow in Wadi Faria and use it efficiently.

BASEFLOW ANALYSIS

Baseflow is the amount of water in a stream as of groundwater contributions. This is typically measured during times when there is no runoff from excess rainfall. Baseflow may vary considerably along the stream due to groundwater levels and geological influences, such as underlying soils and bedrock conditions. Measurements of baseflow are important as they indicate the sensitivity of the stream to land use changes, water extraction, or extended periods of dry weather. Continuous measurements of streamflow are needed at numerous locations in the catchment to build a long term database. This will facilitate the proper assessment and management of the water resources. In Wadi Faria, the baseflow is measured continuously since 2003 after the construction of two Parshall Flumes in context of GLOWA Jordan River project. These flumes were established at the upper part of Wadi Faria to measure runoff rates from both Al-Badan and Al-Faria catchments, which meet at Jiser Al-Malaqi, 10 km east of Nablus city. The flumes did not have automatic recorders during the first year. Automatic divers were constructed later and continuous records of 10 minutes time steps are available for about 5 months from November to March for the two years 2004-2006. Figures 6 and 7 present the runoff of Al-Badan and Al-Faria catchments for the years 2004-2006. From these two figures it can be inferred that one major runoff event, low-frequency and high-amplitude, is observed as part of the obvious continuous, high-frequency and low-amplitude baseflow.

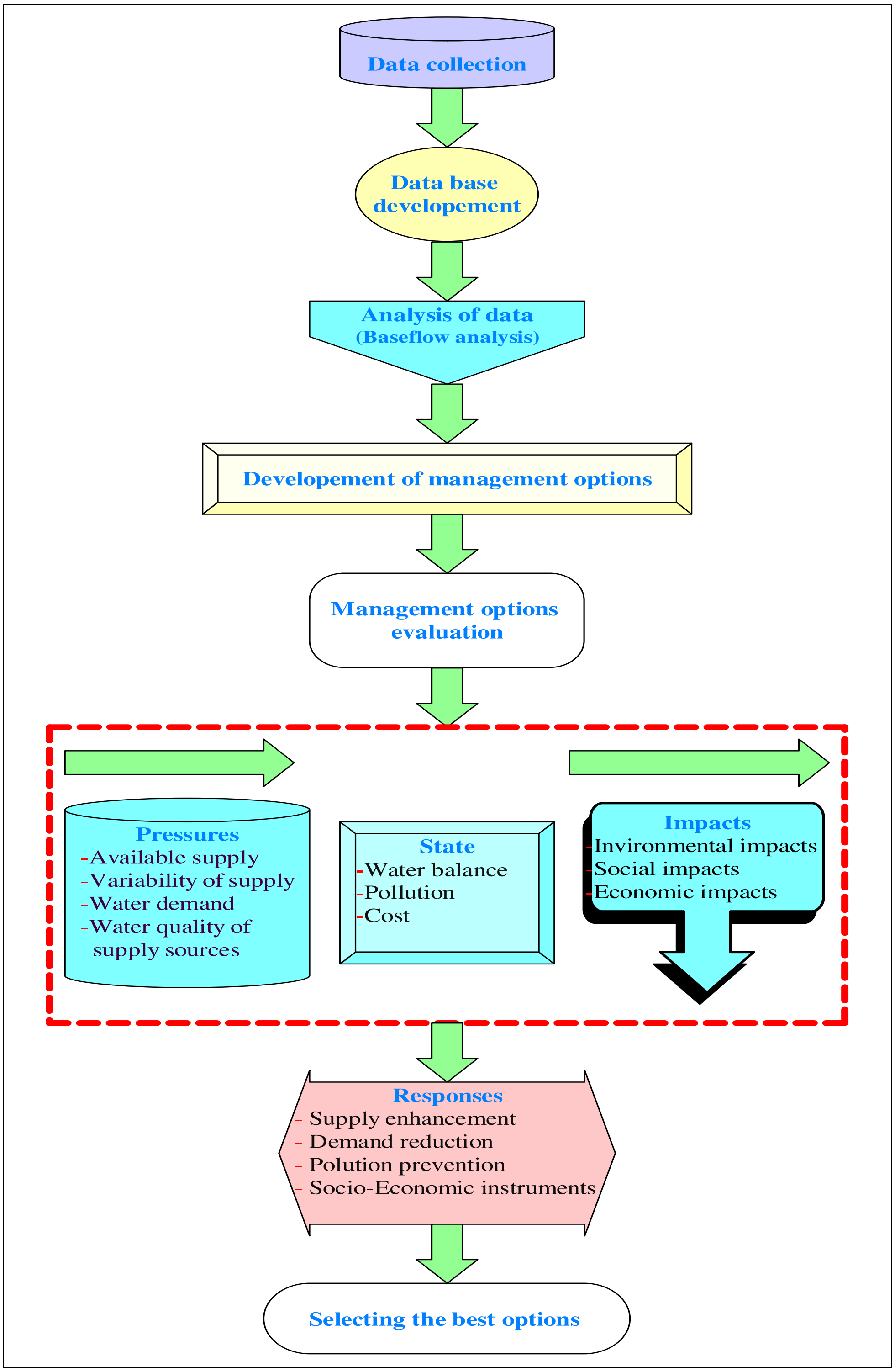

Figure 5: Management options development methodology of Wadi Faria baseflow

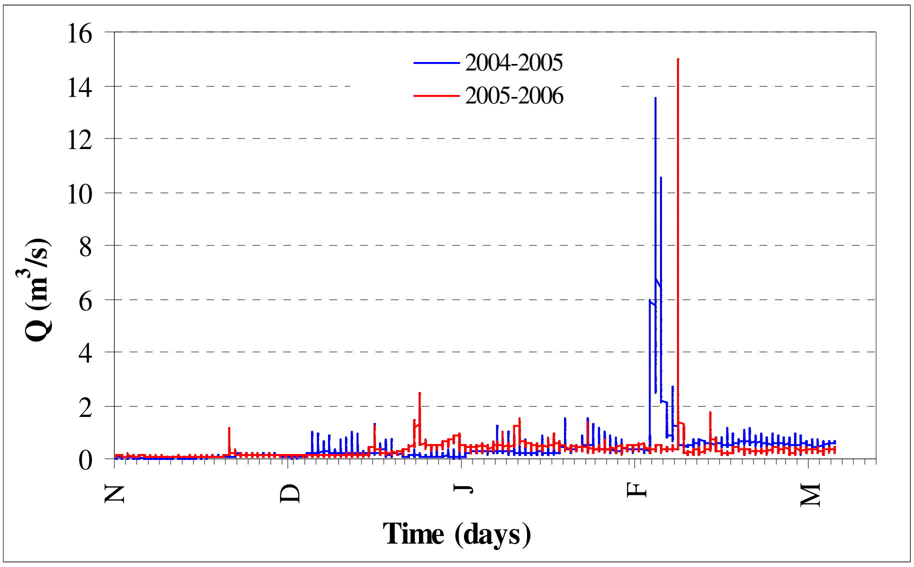

Figure 6: Rrunoff of Al-Badan catchment for the years 2004-2006

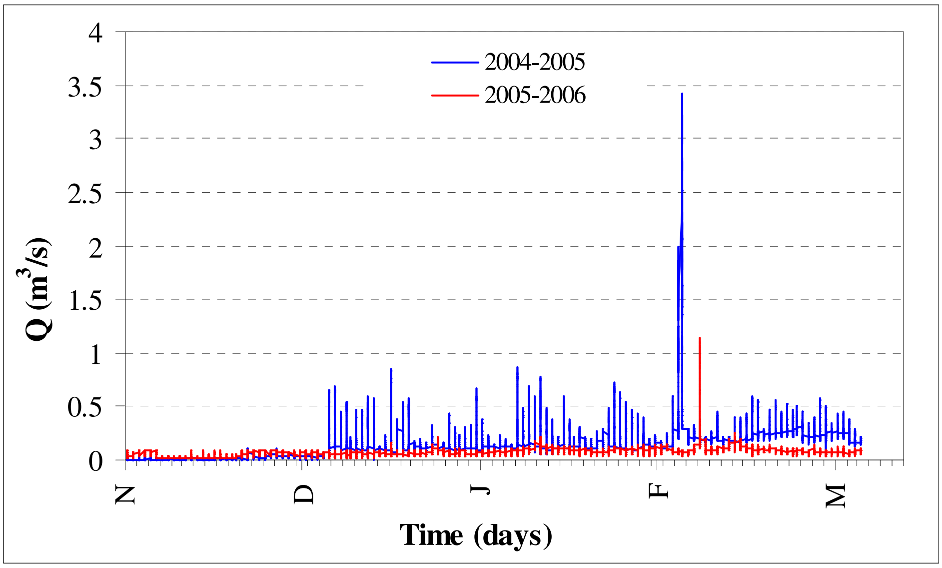

Figure 7: Rrunoff of Al-Faria catchment for the years 2004-2006

The measured runoff was separated into two components, the baseflow and the surface runoff. While objective baseflow separation is difficult in practice, several techniques have been developed for numerical separation of flow hydrographs into baseflow and surface runoff. The widely used Lyne and Hollick filter method of baseflow separation (Nathan and McMohan [7]) is applied in this paper as follows:

$$q_i = \alpha q_{i-1} + 0.5(1+\alpha)(Q_i - Q_{i-1}) \text{ , for } q_i \geq 0 \quad (1)$$

Q_i = total flow time series

q_i = high flow time series component (surface runoff)

QB_i = low flow time series component (baseflow)
i = time step index
α = separation parameter ($0<\alpha<1$).

For daily data a value of 0.925 is recommended for the separation parameter (α) (Savadamuthu [8]).

The baseflow component (QB_i) for each time step is constrained to be never less than zero or greater than total flow (Q_i). EXCEL spreadsheet was developed to solve equation (1). A conditional statement has been used; wherever the computed value of Q_i is less than zero, QB_i is set to Q_i, otherwise,

$$QB_i = Q_i - q_i \quad (2)$$

The developed spreadsheet was used to aggregate the daily data from the recorded 10 minutes time series and to separate the baseflow using the recommend value of α=0.925. The results for the two years 2004-2006 are shown in Figures 8 and 9 for Al-Badan and Al-Faria catchments respectively.

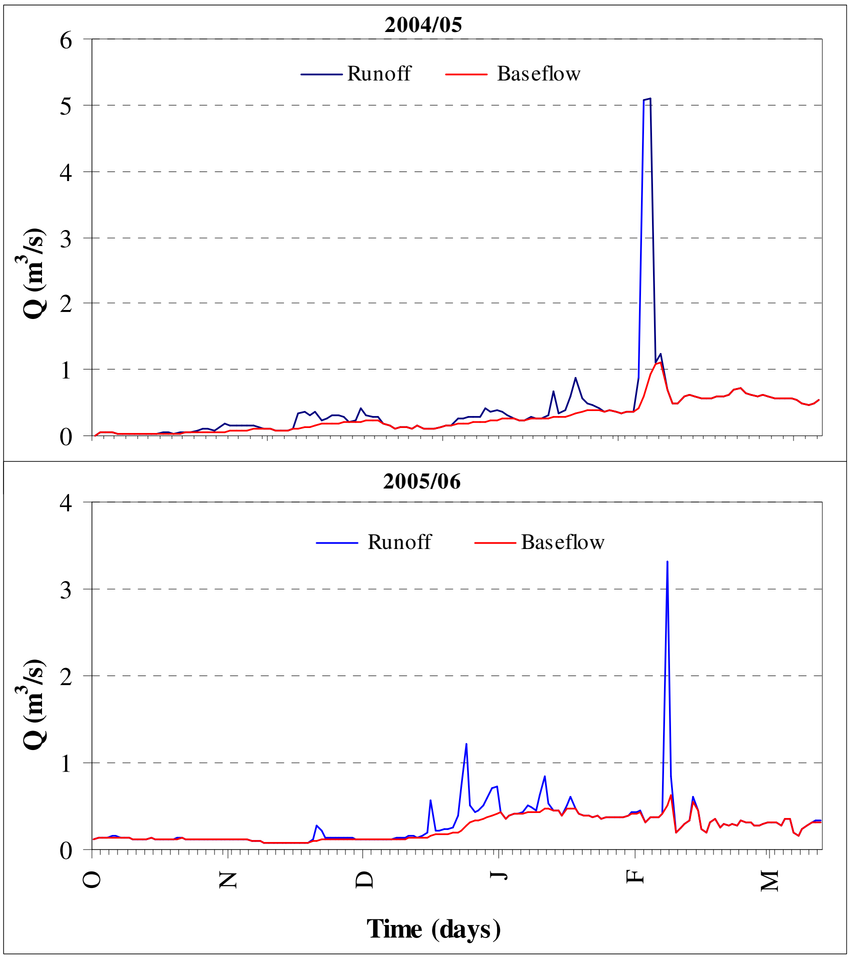

Figure 8: Runoff and separated baseflow of Al-Badan catchment

The volume of baseflow and total flow in addition to baseflow index, which is the volume of baseflow divided by the total volume of streamflow, are summarized in Table 1.

Table 1: Volume of QB_i , Volume of Q_i and Baseflow Index of Wadi Faria

Parameter	Season 2004-2005		Season 2005-2006	
	Al-Badan	Al-Faria	Al-Badan	Al-Faria
QB_i (MCM)	3.15	1.33	3.11	0.76
Q_i (MCM)	4.40	1.68	3.83	0.86
Baseflow Index	0.72	0.79	0.81	0.88

Table 1 indicates that the Wadi Faria baseflow index is 0.72 to 0.88. These values of baseflow contribution are expected to be higher than the adjacent catchments of the West Bank. This is because Wadi Faria is a perennial stream in which 8 fresh water springs contribute to the baseflow.

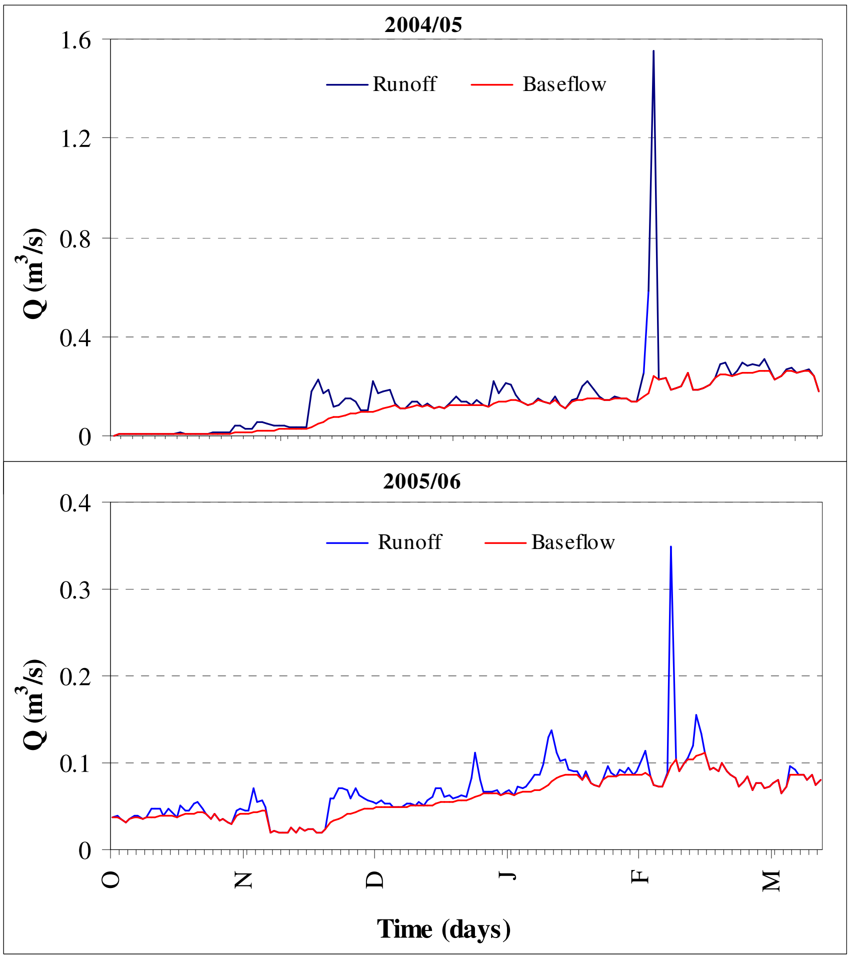

Figure 9: Runoff and separated baseflow of Al-Faria catchment

Statistical analysis has been applied to the baseflow and springs yield time series of Al-Badan and Al-Faria catchments. For the 5 months of November to March, Table 2 gives the average monthly volumes for the spring groups and the baseflow of Al-Badan and Al-Faria catchments. Figure 10 plots the average monthly baseflow and indicates that the baseflow increases from November to February and decreases slightly afterwards.

Table 2: Average monthly volumes of springs yield and base flow

Average Monthly Volumes (MCM)				
Months	**Al-Badan Baseflow**	**Al-Badan Springs**	**Al-Faria Baseflow**	**Al-Faria Springs**
November	0.17	0.25	0.05	0.43
December	0.40	0.43	0.16	0.50
January	0.80	0.37	0.25	0.56
February	1.02	0.43	0.32	0.61
March	0.82	0.59	0.29	0.70
Total	3.21	2.07	1.08	2.80
Springs - Baseflow	-1.138		1.721	

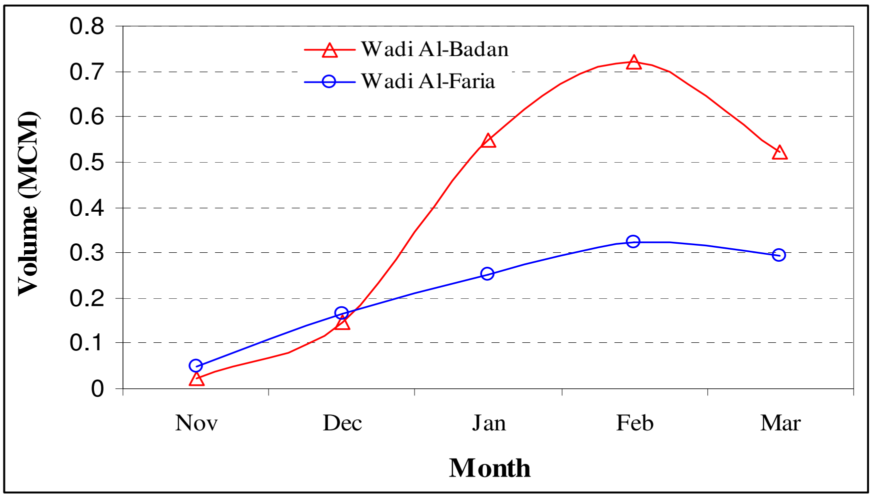

Figure 10: Average monthly baseflow of Al-Badan and Al-Faria catchments

The sum of the average volume of yields of Al-Badan spring group is less than the corresponding baseflow volume for the same period (Table 2). This is due to the wastewater effluent of the eastern parts of Nablus city towards Al-Badan Wadi. On average the volume of wastewater flowing from Nablus during the 5 months is about 1.25 MCM, which results in a difference between springs and baseflow of 0.11 MCM. It can be concluded that the abstraction and withdraw from Al-Badan and Al-Faria streams are 0.11 and 1.72 MCM respectively. The seasonal water budget has been estimated as shown in Figure 11. The seasonal volume of spring yields for Al-Badan and Al-Faria spring groups are 2.07 and 2.80 MCM respectively, whereas the baseflows are 1.96 and 1.08 MCM. The available baseflow that can be utilized annually downstream of Al-Malaqi Bridge is then 3 MCM. This amount is lost during winter and need to be managed.

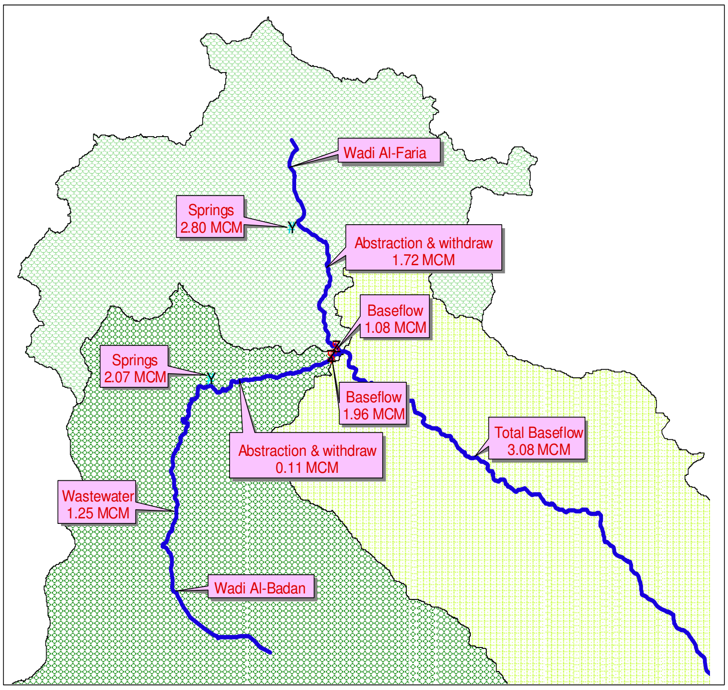

Figure 11: Seasonal Average Water Budget of Al-Badan and Al-Faria Catchments

From the aforementioned discussion it is clear that the baseflow variability is high due to the high variability of spring flows. The baseflow of the upper part of Wadi Faria comes from 8 springs. The variability and trend of baseflow in Wadi Faria are invested here to enhance the proper management of the water in the Wadi to be used during dry periods when the demand-supply gab is comparatively high.

BASEFLOW MANAGEMENT OPTIONS

In Wadi Faria the shortfall in water supplies has been compounded by a decrease in quality owing to the contamination of surface as well as groundwater resources. For instances surface water originating from the springs and contributing to the baseflow mixes with wastewater coming from Nablus City and Faria refugee camp. In the catchments when water is plentiful, the quantity of water is enough to dilute these pollutants to insignificant levels. But, in the case of Wadi Faria, which is characterized by its water resources scarcity, there is no natural filter for these pollutants with the result that the available resources are further reduced due to water quality problems.

Water shortage threatens to spread and become a permanent feature in Wadi Faria due to the increasing of demographic and agricultural growth. The fertile irrigable areas in Faria catchment require 36 MCM/year. Lack of proper management of the water resources causes over utilization of the Wadi Faria scarce water resources.

The management strategy to optimally manage the local water resources in Wadi Faria should consider the baseflow. The above analysis indicates that there is about 3 MCM of baseflow that is lost during winter when the water needs for agricultural purposes is very minimal. There are no storage structures to capture the baseflow. The proposed management options to bridge the supply-demand gap in Wadi Faria include:

1. Surface runoff and baseflow utilization through water harvesting;
2. Treated wastewater reuse;
3. Rehabilitation of the springs and other water resources;
4. Rehabilitation of water distribution systems; and
5. Adaptation of cropping patterns and other relevant agricultural activities to better cope with the limitations of the availability of water.

These options are ranked on scale from (1-10) according to the different technical, supply enhancement, socio-economic, environmental, institutional, and legal feasibilities. The ranking has considered the opinions of different experts in the water and agricultural sectors. The summary of the ranking is shown in Table 3.

Surface runoff and baseflow harvesting and adaptation of cropping patterns are the highest scored management options of Wadi Faria water resources. These two options will better cope with the limitations of the availability of fresh water.

Table 2: Evaluation of Different Management Options of Wadi Faria Baseflow

Management Options	**Feasibility Evaluation**					
	Technical	**Supply enhancement**	**Socio-economic**	**Environmental**	**Institutional and Legal**	**Overall Feasibility**
Water harvesting	4	8	5	6	8	**31**
Treated wastewater reuse	3	4	6	9	4	**26**
Rehabilitation of water resources	5	5	4	8	2	**24**
Rehabilitation of water systems	5	4	4	8	2	**23**
Cropping patterns	6	3	7	8	3	**28**
1 means low and 10 means high						

SUMMARY AND CONCLUSION

Wadi Faria is an important agricultural area at the national level in the West Bank, Palestine. The catchment is under semi-arid conditions as characterized by the scarcity of its natural water, low per capita water allocation and conflicting demands on its water resources. This situation has led to the limited availability of water resources and the dire need to manage these resources. Baseflow in Wadi Faria originates from 11 fresh water springs and is comparatively higher than that in the adjacent catchments.

This paper has analyzed the available baseflow records for the two flumes constructed on Al-Badan and Al-Faria catchments of Wadi Faria. The analysis focused on the baseflow separation of the daily runoff for five months from November to March. The separated baseflow data were studied and modeled and seasonal trends were reported. Baseflow management options were developed to enhance water availability for domestic and agricultural purposes and to bridge the supply-demand gap in Wadi Faria. The general conclusions are summarized as follows:

- There is an observed high variability in the baseflow trends from November to March.
- Estimated Baseflow Index is from 0.63 to 0.83 for Wadt Faria, which is expected higher than that in the adjacent catchments of the West Bank.
- The available baseflow that can be utilized downstream of Al-Malaqi Bridge is about 3 MCM/year. At present this amount is lost during winter due to lack of proper management.
- Considering different technical, supply enhancement, socio-economic, environmental and institutional and legal aspects, different management options are proposed. These options according to their ranking are:

  1. Surface runoff and baseflow utilization through water harvesting;
  2. Adaptation of cropping patterns and relevant agricultural activities;
  3. Treated wastewater reuse;
  4. Rehabilitation of water resources; and
  5. Rehabilitation of water distribution systems.

All the above management options need proper institutional and legal setup. The establishment of the Wadi Faria Authority is as an attractive solution for achieving comparative Wadi Faria development (EQA [5]).

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