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Assessment of environmental flow using morphological characteristics of river (case study: Karoon River, Iran)

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Abstract

The relationship between wetted perimeter and discharge is sometimes used as an expedient technique for determining the minimum flow allowable for environmental purposes. The critical minimum discharge is supposed to correspond to the point where there is a break in the shape of the curve (usually a logarithmic or power function). Below this discharge, wetted perimeter declines rapidly. The appearance of a break in the shape of the curve is strongly dependent on the relative scaling of the axes of the graph. This subjectivity can be overcome by defining the break in shape using mathematical techniques. The important break in the shape of the curve can be systematically defined by the point where the slope equals 1, or where the curvature is maximized. These two methods were applied to Karoon River, Iran. Seven cross section were selected. Their survey data were used to derivate relationship between wetted perimeter and discharge. After determining breakpoints on the curves, corresponding value of discharge was calculated from the curves. Analysis of results showed that the slope method has reasonable and accurate output. Finally, the amount of environmental flow for Karoon river was calculated as 209.4 cms.

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Introduction

Environmental flow may be defined as water that is left in a river system, or released into it, for the specific purpose of managing the condition of that ecosystem. During the last five decades, about 100 different approaches have been described for advising on environmental flows, and more than 30 countries have begun to use such assessments in the management of water resources (Tharme, 1996; King *et al.*, 1999). There are four main types of flow-assessment approaches: hydrological, hydraulic rating, habitat rating, and holistic (King *et al.*, 1999). Those based solely on hydrological data were among the earliest. They are essentially desktop methods that use summary statistics of flow, which may or may not be ecologically relevant, to advise on suitable flows, often for fish habitat. Because of their lack of sensitivity to individual rivers, hydraulic-rating methods were developed which use field measurements to describe channel-discharge relationships. Though providing river-specific data, these failed to indicate the significance of changes in the measured physical conditions for the aquatic biota.

The wetted perimeter-discharge relationship is a basic tool in the 'transect' approach to environmental flow evaluations. One procedure is to derive the relationship from channel cross-section surveys at several discharge levels. The transects are often located only at riffle sites, or at sites where fish passage is likely to be limited. Alternatively, the relationship can be modeled using the channel morphology, and other data, using a flow equation such as the Manning equation (Annear and Conder, 1984). A line is generally fitted through the surveyed or modeled points. The lowest breakpoint in the curve is taken to represent a critical discharge below which habitat conditions for aquatic organisms (usually fish or macro invertebrates) rapidly become unfavorable. The breakpoint indicates where small decreases in flow result in increasingly greater decreases in wetted perimeter (Gordon *et al.*, 1992). IFIM relies heavily on transect data for physical habitat assessment. While sophisticated hydraulic habitat modeling techniques such as PHABSIM are available, they require detailed hydraulic and morphological surveys, and knowledge of habitat preferences for the species of interest. For these reasons, the simpler approach based on examination of the wetted perimeter–discharge relationship is more appropriate in many locations. The wetted perimeter–discharge breakpoint has been used to define optimum or minimum flows for fish rearing (food production) in the US and Australia (Collings, 1974; Cochnauer, 1976; Nelson, 1980; Richardson, 1986). Stalnaker and Arnette reported that the breakpoints for some US streams occurred at discharges corresponding to approximately 80% of the maximum available wetted perimeter. The Oregon Department of Fish and Wildlife recommend (among other criteria) that at least 50% of the maximum wetted perimeter be provided at riffles (Stalnaker and Arnette, 1976). Filipek *et al.* found that for Arkansas streams the breakpoint in the wetted perimeter–discharge relationship occurred at 50% of the mean flow. Below this discharge, riffle areas became exposed and unproductive, stream bank cover for fish diminished, the water quality decreased and fish overcrowding was possible (Filipek *et al.*, 1987). For a river in Portugal, Alves also defined the breakpoint as corresponding to a threshold discharge below which habitat quality becomes significantly degraded (Alves, 1994). For Wyoming and Montana streams, Tennant found that the flow equivalent to 10% of the average flow provided about 50% of the maximum wetted perimeter, while flows greater than 30% of the average flow provided close to the maximum wetted perimeter (Tennant, 1976). Nelson found that wetted perimeter curves for streams in Montana had single, well-defined breakpoints. The discharges at the breakpoints corresponded to the minimum flow levels required to maintain trout populations. Use of multiple transects resulted in less distinct breakpoints (Nelson,1980). Prewitt and Carlson reported that the wetted perimeter approach did not suit the unique fauna of the Upper Colorado River Basin (Prewitt and Carlson, 1977). Smakthin and Eriyagama developed a software package for global desktop assessment on environmental flows. Their results showed that the software can be used as a tool for rapid preliminary environmental assessment (Smankthin Eriyagama, 2008). Yin and Yang conducted a research about river morphology changes impact on water supply of environmental flow (Yin and Yang, 2012).

In this paper, wetted perimeter method which has hydraulically basis has been used for Karoon River (Fig. 1).

The studied reach is located inside the Ahwaz city and has important applicable aspects especially aesthetics and ecological. Therefore, it is necessary to evaluate the minimum required flow in the river for mentioned aspects. The hydraulic approach is developed basically for ecological assessment. This method is pioneer of advanced models which are used to simulate biological environment (Marchand, 2006).

Materials and methods

The hydraulic rating methods use changes in hydraulic variables, such as those in the 'wetted perimeter', the area of riverbed submerged, to define environmental flows. These provide simple indices of available habitat in a river at a given discharge. The method is based on the assumption that fish rearing is related to food production, which is turn is related to how much of the river bed is wet. It uses relationships between wetted perimeter and discharge, depth and velocity to set minimum discharge for fish food production and rearing (including spawning). The relationships are constructed from measuring the length of the wetted perimeter at different discharges in the river of interest. The resulting recommend discharges are based on the inflection points on the wetted perimeter-discharge curve, which are assumed to represent the maximum habitat for minimum flow before the next inflection point.

The breakpoint in the wetted perimeter versus discharge relationship (Fig. 2) is referred to in the literature almost universally as a point of 'inflection'.

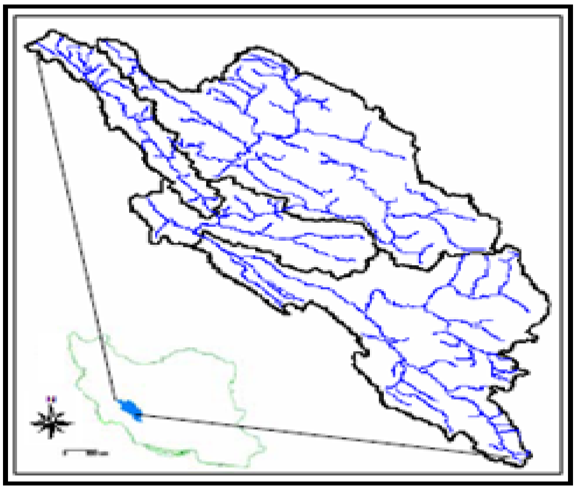

Fig. 1. Karoon River catchment.

The breakpoint on wetted perimeter versus discharge curves that is being sought is not an inflection point, but rather is a point where the curvature is maximized, or where there is a marked change in the slope of the curve. Most people probably try to select the point corresponding to where the tangent to the curve is 45° (i.e. the apparent slope is unity). It is not possible to select this point reliably by eye, since the appearance of the slope of the curve is strongly dependent on the relative scaling of the axes. Variability in the presentation of the graphs will cause inconsistency in the selection of breakpoints. The shape of the relationship between wetted perimeter and discharge is a function of the geometry of the channel, and the manner in which discharge increases with depth (Gippel and Stewardson, 1998).

Defining of Breakpoint

One method of determining the breakpoint is to select the point on the curve where the slope, $\frac{\Delta P}{\Delta Q}$, (first derivative $\frac{dy}{dx}$) equals a nominated value. It is necessary to normalize the two axes to cover the same range. This can be done by expressing each discharge and wetted perimeter value as a proportion of their respective measured or modeled maximum values. Alternatively, discharge may be expressed as a percentage of a flow index, such as mean annual flow. At the point where the slope of the curve is unity, a small change in discharge (as a percentage of the maximum value considered) will produce the same change in wetted perimeter (as a percentage of the maximum value considered). At higher discharges where the slope is greater than 1, a large increase in discharge will produce a small increase in wetted perimeter. At lower discharges, where the slope is less than 1, a small decrease in discharge will produce a large decrease in wetted perimeter. In this study, we decided to use a slope value of 1 ($\frac{dy}{dx}=1$), but a different slope could be used to determine the breakpoint, depending upon the relative values attached to discharge and habitat area.

A second systematic method of selecting the breakpoint in the curve is to define the point of maximum curvature. The curvature (k) is the rate at which a curve turns; it is a function of the angle that the tangent to the curve makes with the x-axis, and the arc length (Goodman, 1980):

$$k=\frac{\frac{d^2y}{dx^2}}{[1+(\frac{dy}{dx})^2]^{1.5}}$$

The $\frac{dy}{dx}=1$ and k_{max} methods give similar breakpoints. The slope method of selecting the breakpoint is intuitively the most appropriate, and the simplest to apply. The selected breakpoints for the rectangular channel geometries are close to the bases of the banks. This is appropriate as a minimum discharge for maintaining flowing water over most of the bed. For the trapezoidal and triangular channel geometries, the breakpoint is determined more by the way discharge increases with depth (non-linear), than the way the wetted perimeter changes with depth (linear).

Karoon River is the most important permanent river at the south-west of Iran which has vital ecological and economic roles. In this research, it was selected to apply wetted perimeter approach to evaluate environmental flow. Ahwas station was selected for calibration and verifying of hydraulic and hydrological data. Figures 3 and 4 show rating curve and duration flow curve of Ahwaz station.

Analysis of daily statics of flow and also flow classification (wet period, normal period, dry period) have been presented in tables 1 and 2, respectively. In the next section, calculation of environmental flow for Karoon river has been done.

Results and discussion

Environmental flow assessment in Karoon River has much importance because according to Fig. 2, the share of monthly discharge of Jun. to Dec., which are located in dry period, is 35.8% of annual discharge. This time of year, rive has the less discharge, and it is necessary to conservation aquatic habitat and vegetation. For application of wetted perimeter approach to evaluate environmental flow in Karoon river, Ahwaz station, seven cross sections were selected which are plotted in figures 5 to 11.

Table 1. Flow parameters at Ahwaz station.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Mean	1415.2	930.4	654.5	876.2	1020.8	477.6	447	250.2	207.1	357.1	409.5	568.8	634.5
STDEV	515.6	118.3	152.7	447.1	331.8	124.3	83.4	67.5	45.4	98.5	100.4	141.2	156.3
Max	2273	1166	1158	2143	1673	657	625	389	265	688	763	948	2273
Min	643	769	505	477	534	237	289	132	76.8	242	289	426	76.8

Table 2. Frequency analysis of Karoon River discharge Flow parameters at Ahwaz station.

	Wet period					Mean	Dry period				
Return period	50	25	20	10	5	634.5	5	10	20	25	50
Discharge (m^3/s)	2240	2113	1958	1768	1464		242	198	168	160	125

Three cross sections are located at downstream and upstream of Ahwaz station, respectively. The shape of the relationship between wetted perimeter and discharge is a function of the geometry of the channel, and the manner in which discharge increases with depth. The form of this relationship is accentuated by the way discharge increases with water depth. At low flows the velocity is low; as depth increases, flow velocity increases, so that discharge increases at a faster rate than depth. The nature of this relationship is described by the Manning equation:

$$Q=\frac{1}{n}AR^{\frac{2}{3}}\sqrt{S_o}$$

Which Q is discharge, n is Manning roughness coefficient, A is wetted area, R is hydraulic radius, and S_o is bed slope. Roughness coefficient was determined using geometric characteristics and rating curve of Ahwaz station (Fig. 10).

Table 3. Final results of Wetted Perimeter-Discharge approach to evaluate environmental flow.

Station	Slope method (dy/dx=1)		Maximum curvature method			Difference:
	Relative Discharge	Q_{EF}	Relative Discharge	Maximum curvature	Q_{EF}	$(Q_{EF})_{Slop}-(Q_{EF})_{Curvature}$
1	0.31	196.7	0.25	1.08	158.6	38.1
2	0.2	126.9	0.12	1.67	76.1	50.8
3	0.22	139.6	0.16	1.74	101.5	38.1
4(Ahwaz)	0.27	171.3	0.2	1.25	126.9	44.4
5	0.21	133.2	0.15	1.74	95.1	38.1
6	0.33	209.4	0.25	1.23	158.6	50.8
7	0.21	133.2	0.15	1.79	95.1	38.1
Mean	0.25	158.6	0.183	1.5	116.0	42.6
STDEV	0.053	33.8	0.051	0.3	32.7	6.0

For different values of flow depth, geometric characteristics of channel section and discharge were calculated from geometric relationship and rating curve, respectively. Using Eq. (2), the value of n was estimated. Its worth noting that longitudinal slope, S_o, was determined using above seven bed elevation. Following determination of n value, direct step method was used to verify roughness coefficient. The final result of mentioned procedure led to n=0.028. Using Manning roughness coefficient and cross sectional profile, relative wetted perimeter (P/P_{mean}) vs. discharge (Q/Q_{mean}) curve have been plotted for seven cross sections (Figs. 5 to 11). In these figures, x and y axis are relative discharge and relative wetted perimeter, respectively. For each section, relationship between (P/P_{mean}) and (Q/Q_{mean}) has been determined. Then, using slope and maximum curvature methods, the graph of slope and curvature vs. relative discharge was drawn.. For each cross section, the value of <slope=1> and maximum curvature was determined for specific relative discharge. The results of calculations are presented at table 3.

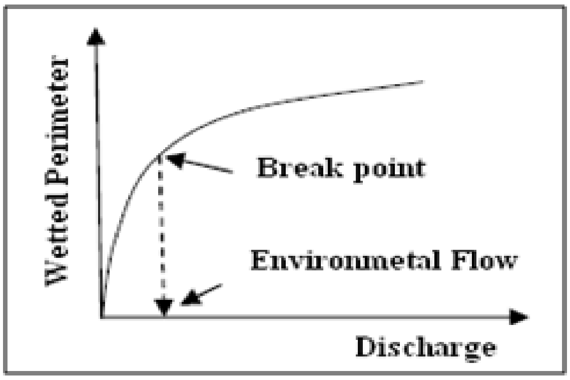

Fig. 2. Schematic view of breakpoint wetted perimeter-discharge curve.

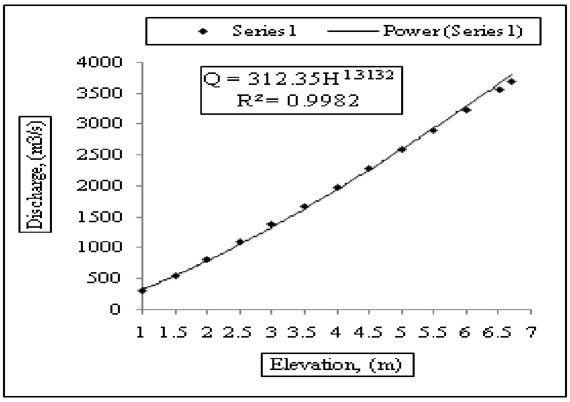

Fig. 3. Rating curve graph of Ahwaz Station.

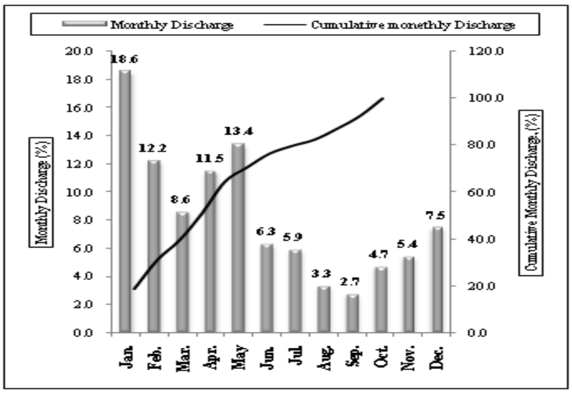

Fig. 4. The variation of flow discharge.

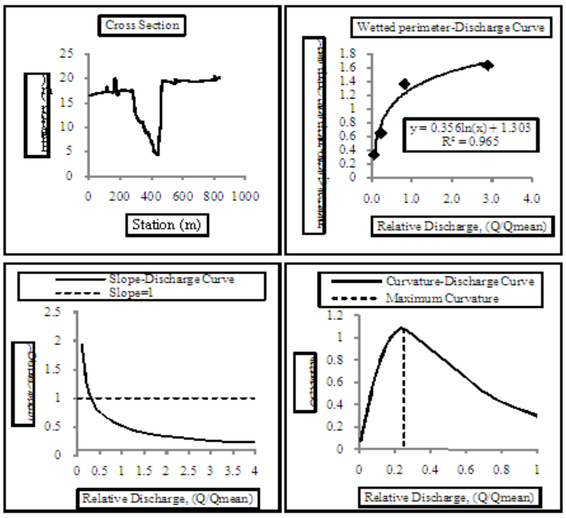

Fig. 5. Cross section, Wetted perimeter-Discharge Graph, Curvature and Slope of wetted perimeter relationship for the first section.

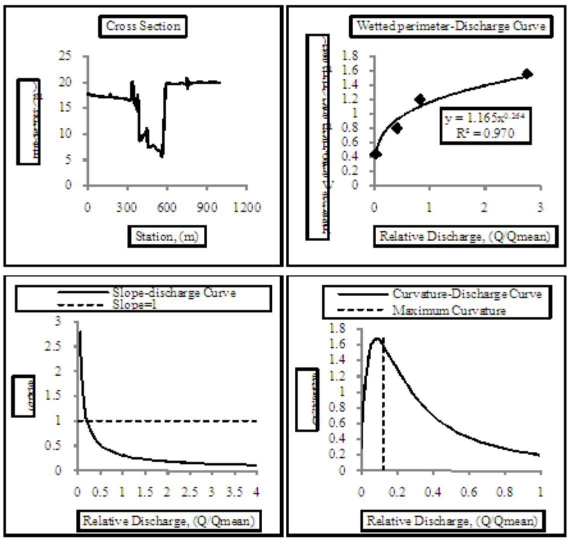

Fig. 6. Cross section, Wetted perimeter-Discharge Graph, Curvature and Slope of wetted perimeter relationship for the second section.

According to table 3, the amount of Q_{EF} using slope and curvature method is between 126.9 to 209.4 and 76.1 to 158.6 $m^3.s^{-1}$, respectively. According to Fig. 12, these two methods have no good overlapping, but as it clear, slope method output is more than curvature method.

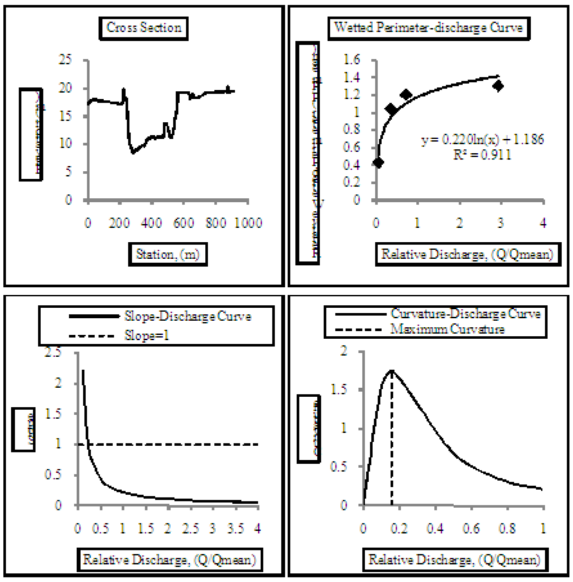

Fig. 7. Cross section, Wetted perimeter-Discharge Graph, Curvature and Slope of wetted perimeter relationship for the third section.

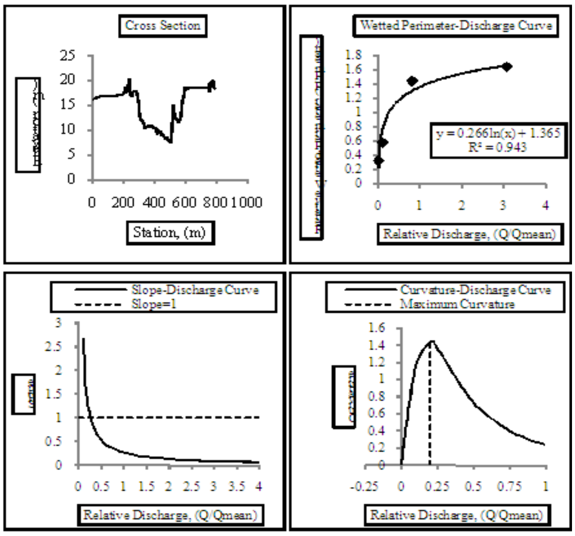

Fig. 8. Cross section, Wetted perimeter-Discharge Graph, Curvature and Slope of wetted perimeter relationship for the forth section.

The environmental flow has different role than the mean flow. On the other hand, mean flow has vital role at morphology development whereas environmental flow plays the role of environment protection. Then, the amount of Q_{EF} must be less than Q_{mean}. As regards to Fig. 12 and table 2, the amount of environmental flow is determined as 209.4 $m^3.s^{-1}$.

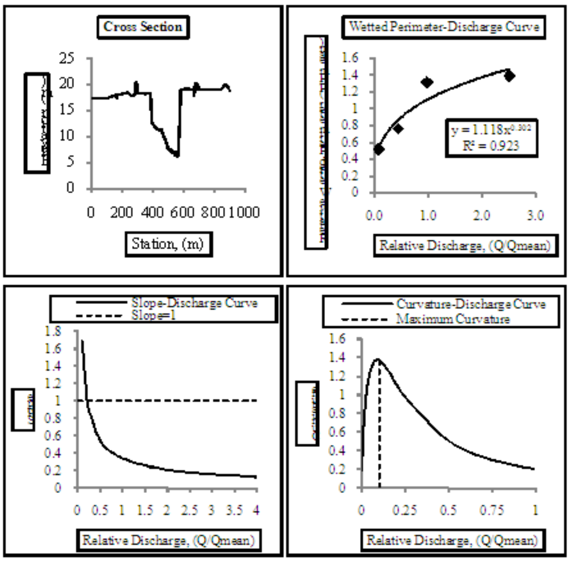

Fig. 9. Cross section, Wetted perimeter-Discharge Graph, Curvature and Slope of wetted perimeter relationship for the fifth section.

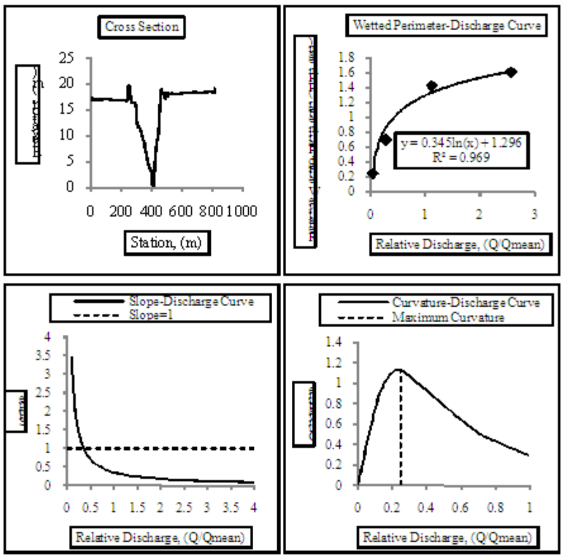

Fig. 10. Cross section, Wetted perimeter-Discharge Graph, Curvature and Slope of wetted perimeter relationship for the sixth section.

Conclusion

Using the relationship between wetted perimeter and discharge to determine minimum environmental flows in regulated streams is problematic, and it should only be used in conjunction with other techniques, which together produce a recommended environmental flow regime. This paper provides a method of overcoming the major problem of subjective interpretation of the breakpoint in the wetted perimeter discharge curve. Provided a curve can be fitted to the data, the breakpoint of the curve can then be determined mathematically by calculating the point of maximum curvature or the point where the slope is equal to 1 (or some other selected value). Of these two approaches, the slope method is simpler to apply, but requires selection of a suitable slope.

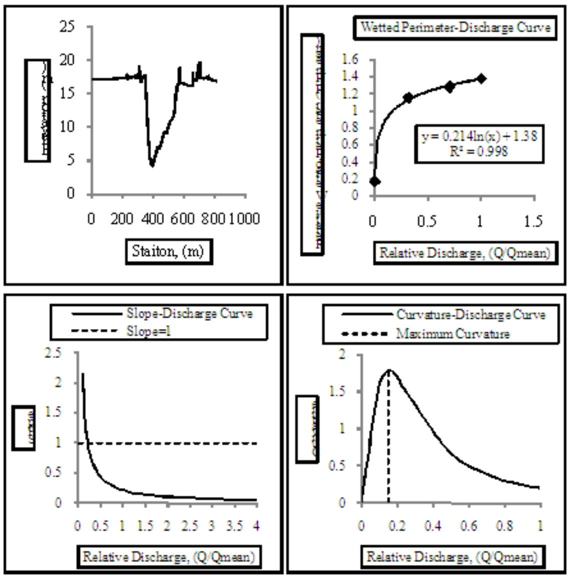

Fig. 11. Cross section, Wetted perimeter-Discharge Graph, Curvature and Slope of wetted perimeter relationship for the seventh section.

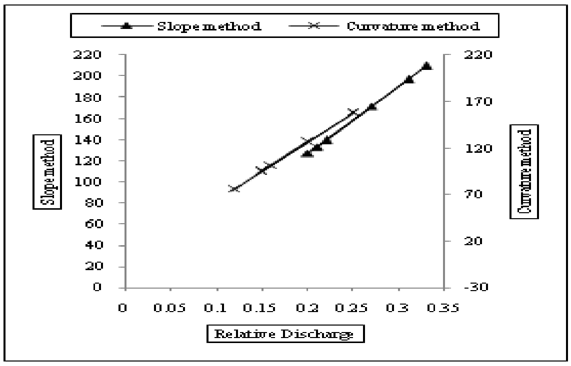

Fig. 12. Comparison between slope and curvature method for Q_{EF} assessment.

The suggested method of breakpoint determination can also be applied to curves of flowing water perimeter and fish habitat area as a function of discharge, provided the habitat variable increases with discharge over the range of interest. In this paper, wetted perimeter-discharge curve was used to evaluate environmental flow in Karoon River, Iran. Seven cross sections were selected for this method. After determining breakpoint of wetted perimeter-discharge curve for each cross section, corresponding discharge of each breakpoint was derived from the curve. The results showed that slope method has acceptable and reasonable output than the curvature method. The amount of environmental flow for Karoon river was determined as 209.4 $m^3.s^{-1}$. According to results, hydraulic approach which use characteristics of ecological habitat and river flow can estimate environmental flow with acceptable accuracy.

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