New Methodology for Determining of the Ecological Flow with Hydrometric Data

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Abstract. Although there are several methods to calculate the ecological flow, however, in Ecuador did not develop yet a technique that suits the reality of the water systems. Therefore, we proposed a new methodology to determine the ecological flow through of hydrometric data such as minimum flows, average flow and monthly peak flows in a specific basin. The values obtained with the applied methodology are unique for the studied basin and do not correspond to percentage flow. This is fundamental since engineers use a variety of methods and need to choose at its discretion the best fitting one.

1. Introduction

Santa Cruz [1] defines as ecological flow like the flow regime in a body of water that keeps the functioning of the aquatic ecosystem in natural conditions, which is understood that shall be this the minimum amount of water needed to maintain the flora, fauna, environmental, and adaptability capacity by the effect climatological and hydrological extremes. According to the Mexican Standard [2] the ecological flow is the quantity, quality and variation in spending or water levels reserved to preserve environmental conditions, components, functions, processes and resilience of ecosystems being dependent of aquatic and terrestrial hydrological, geomorphological, ecological and social processes.

There are several definitions of ecological flow, which consider multiple parameters such as Mexican Standard. Therefore, it seems a complex issue to establish a unique method for calculating ecological flows in the watershed. Additionally, it is necessary to apply several methods corresponding to the complexity of every basin. However, it is considered that each watershed establishes the biotic and abiotic conditions related to the availability of water resulting from water cycles set by nature, i.e., the set values of ecological flow for a basin are not necessarily applicable to another. Therefore, the ecological flow is not a constant percentage of the average flow.

2. Existing methods to calculate the ecological flow

There are variety methods able to calculate the ecological flow. In this study we limited such application the hydrometric method.

2.1. Hydrometric method

The hydraulic method proposed by Tennant [3] also called Montana method explains that the minimum ecological flow may obtain equal to 10% of the average flow (F_A), as this value guarantee for the most

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basins analysed 60% of the hydraulic parameters of the basin of the studied area, wetted perimeter and water depth.

$$F_E = 0.10 F_A \tag{1}$$

According to Alcazar [4] the ecological flow consists of a base flow (F_B) plus a conditioning flow (F_C), which summed up provides the ecological flow (F_E), $F_E = F_B + F_C = F_M$ (maintenance flow). Similarly, it includes the concept of generator flow F_G, which is large enough to fully occupy the section of the river preserving the conditions of flora, fauna, as well as hydraulic and morphometric in the basin. The base flow (F_B) in the most studied rivers is set as 20% of the average flow, [4].

$$F_B = 0.20 F_A \tag{2}$$

The conditioning flow can reach up to 56%, however, it may be usually of 10% in average.

$$F_C = 0.10 F_A \tag{3}$$

From where

$$F_M = 0.30 F_A \tag{4}$$

Standard No. 314 (2007) of the Ministry of Natural Resources of the Russian Federation explains that if information is hydrometric, sanitary flow (ecological flow) is taken as on the average flow for the period of minimum runoff, according to the following relationships:

$$F_{E1} \geq 0.70 F_{50\%} \tag{5}$$

$$F_{E2} \geq 0.80 F_{75\%} \tag{6}$$

$$F_{E3} \geq 0.90 F_{95\%} \tag{7}$$

F_{E1} is flow recommended to maintain conditions fulfilling the usual conditions of the river. F_{E2} is a flow, which ensures basic living conditions in the river. F_{E3} is the minimum required for survival for a period of extreme drought conditions.

$F_{50,} F_{E1,} F_{E1}$ are the corresponding percentages indicated as flow rates of the flow duration curve.

Mexican Standard [2] determines the environmental objective from the ecological importance and pressure of water uses, being calculated as a percentage of the allocated volume and concession regarding the annual average availability. With the environmental objective, environmental flows are defined from 5% to 40% for perennial streams.

Garcia and Paz [5] cited as Swiss method to ecological flow calculated with the following formula that does not apply to small flows.

$$F_E = 15 \frac{F_{95\%}}{(\ln F_{95\%})^2} \tag{8}$$

The principality of Asturias, also according to [5] recommends determine the flow as follows.

$$F_E = 0.25(F_{95\%} + 0.075) \tag{9}$$

Sandoval and Aguilera [6] with regard to basins in Ecuador, suggest without hydrometric data to calculate the ecological flow in relation to precipitation P (mm) and the basin area A (km^2) to the following relationship:

$$F_E = (1 to 2.5)(P \times A \times 10^{-6}) \tag{10}$$

2.2. Method Proposed

Runoff from a runway, together with other hydrological, geographical, geological and topographical conditions, are part of the plant and animal life as well s of the ecological corridor. Hydrometric data from a basin express the natural variation of the flow in a controlled section and these relate to the demand for water flora and fauna. The monthly average flows characterize the contributions of water ecological corridor during the time and the monthly change may ascend or descend. According Bagapova [7] and [8] the ecological flow corresponds to the minimum critical water demand in periods in which the flow is less than a certain value and that may be determined from the hydrograph average monthly flows during several yeas.

In this study we propose to determine the flow through of the integral mass curve, the data to form an integral mass curve has been ordinated from major to minor. The flows F_1, F_2, … F_{12} are monthly average flows and F_A is the average flow of every year. The flows were here by ordered from higher to lower. A curve has been determined and normalized with data flow obtained the series. In the same same series the variation with respect to the mean value has been calculated according to following expression.

$$\frac{F_i - F_A}{F_A} = \frac{F_i}{F_A} - 1 = k_i - 1 \tag{11}$$

The integral mass curve in the function $\int (k_i - 1)$

The differential is $dy = (k_i - 1)dk$

The gradient of the mass flow is given by (s) $\frac{dy}{dk} = s = k_i - 1$

The slope is determined in graphical form taken out of the integral equation. With the known slope known is feasible to determine the value of k_i.

$$k_i = s + 1 = \frac{F_i}{F_A} \tag{12}$$

In the last equation F_i appears the value that requires the basin to overcome the negative gradient flow of the data series, which may be called ecological flow F_E.

$$F_E = F_A(1 + s) \tag{13}$$

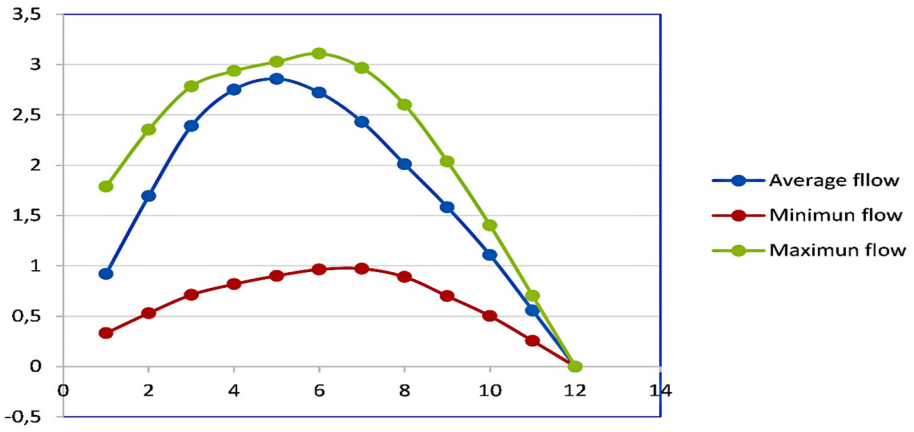


Figure 1. Integral mass curve

The procedure described above has been applied to the Toachi Pilaton AJ basin with hydrometric information available on the website of the National Institute of Meteorology and Hydrology of Ecuador (INAMHI, [9]) (Table 1), of which data correspond to the years 1964 to 2010. The data are sorted from largest to smallest in order to develop the mass integral curve. This has been calculated for three series (Table 2). The results were plotted as shown Figure 1 where the slope of the curves in its descent stage has been determined using a typical calculations software.

Table 2 lists the values calculated with the equation of the slope on the descent stage as indicated, while the slope values determine the reduction coefficients k_i flow and ecological flow for each column.

Table 1. Average flow, minimum flow and maximum flow [m^3/s]

Month	Average flow	Minimum flow	Maximum flow
January	46.702	16.483	110.807
February	71.575	15.118	150.319
March	74.921	16.728	137.371
April	81.064	18.593	267.792
May	57.501	15.439	103.852
June	36.485	14.831	60.909
July	24.426	14.059	35.093
August	18.98	12.809	28.543
September	18.666	10.507	28.733
October	22.132	11.197	42.034
November	24.226	10.394	82.314
December	29.927	11.294	104.761

Table 2. Processing for mass curves

		S (k_i - 1)	
Month	**Average Flow**	**Minimum Flow**	**Maximum Flow**
APR	0.92017055	0.33241765	1.78822206
FEB	1.69483128	0.53118506	2.35332764
MAR	2.390235	0.71239519	2.78362001
ENE	2.75226656	0.81878986	2.93733081
DEC	2.8585012	0.90218092	3.02809129
MAY	2.72272481	0.9650049	3.10938736
NOV	2.43160845	0.97250555	2.96643205
JUN	2.0101894	0.8904283	2.60061014
OCT	1.58403293	0.69978262	2.03826371
JUL	1.10827568	0.5021857	1.40364833
SEP	0.55785671	0.25514177	0.70281329
AUG	-9.992E-16	5.5511E-16	1.9984E-15
m	**-0.5047**	**-0.2346**	**-0.6537**
k_i	0.4953	0.7654	0.3463
Ecological Flow	20.91	10.68	33.26

With the help of the Excel functions slope is calculated in its descent stage (Figure 2).

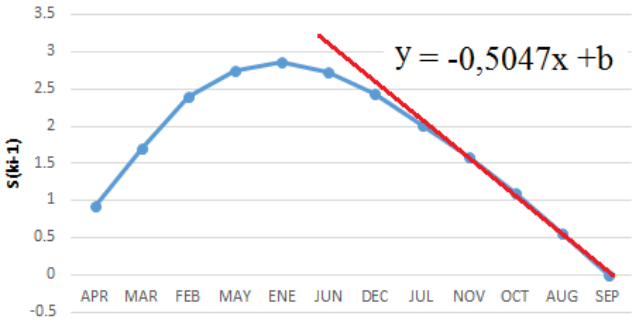


Figure 2. Determination of descent gradient

It is necessary to compare this method with others though the flow duration curves (Figure 3).

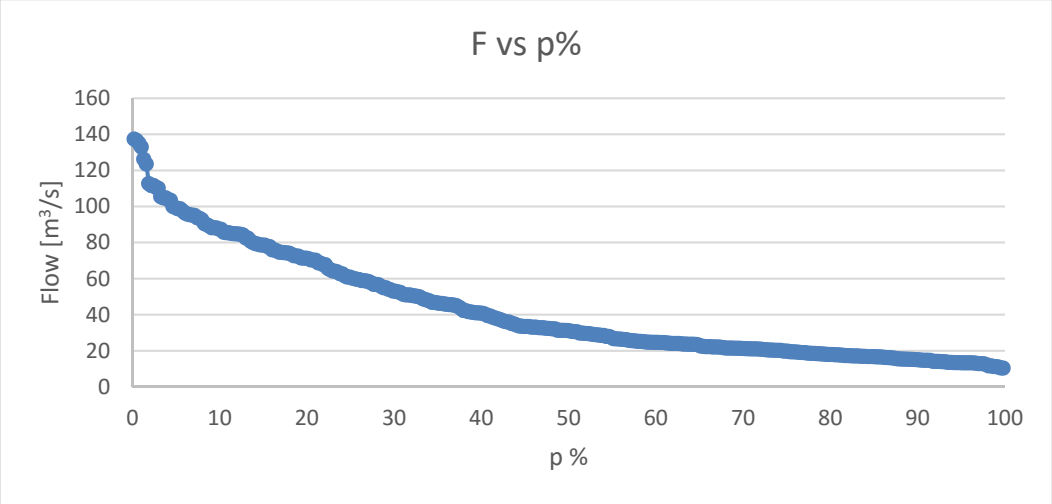


Figure 3. Flow duration curve

The annual average flow in the Toachi Pilaton AJ basin is 42.22 m^3/s (Table 1) and the flow duration curve was obtained the following values: $F_{50\%}$= 30.99 m^3/s; $F_{75\%}$= 18.90 m^3/s y $F_{95\%}$= 13.29 m^3/s. The ecological flows were calculated with different methodologies and are presented in Table 3.

Table 3. Comparison of results with other methodologies

E_F (m^3/s)	Asturias	Chile	Ecuador	España	México	Rusia	Suiza	Own
Ecological flow minimum				8.44	2.11	11.96		10.68
Ecological flow average	3.34	8.44	4.22	12.66	16.89	15.12	29.79	20.91
Ecological flow maximum						23.24		33.26

3. Results and Discussions

The proposed methodology is based on hydrometric data and fits the conditions of water behaviour of the studied basin and may be compared with other existing methodologies lesser or greater complexity. The calculated flow rate with the number of monthly minimum flows should be considered as the minimum acceptable for the ecosystem of the river (dry season). The calculated data series of average flow corresponds to excellent conditions for the ecosystem while the maximum flow corresponds to optimal conditions for regeneration of the high areas of the river. The results of the calculated ecological flow with this methodology should not be necessarily transferred to other basins, as such conditions need to handed individually for each basin.

4. Conclusions

The proposed methodology has been based on hydrometric data and may be used to determine the discharge of ecological flow in any basin. In either case the river flow, in dry seasons, should be less than obtained from the monthly minimum flow.

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