

PAPER • OPEN ACCESS

Ecological flows for Ecuadorian basins determined by the slope method of the mass-curve

To cite this article: E Arce *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **191** 012118

View the [article online](#) for updates and enhancements.

You may also like

- [Physical characteristics of materials of Ecuadorian origin for water treatment](#)
M Mayacela, L Maldonado, F Morales et al.
- [Ecuador's Yasuní Biosphere Reserve: a brief modern history and conservation challenges](#)
Matt Finer, Varsha Vijay, Fernando Ponce et al.
- [Extreme citizens science for climate justice: linking pixel to people for mapping gas flaring in Amazon rainforest](#)
Francesco Facchinelli, Salvatore Eugenio Pappalardo, Giuseppe Della Fera et al.



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Ecological flows for Ecuadorian basins determined by the slope method of the mass-curve

E Arce¹, W Sandoval¹, T Toulkeridis^{1,2}, D Carrera¹ and M J Merizalde Mora¹

¹Universidad de las Fuerzas Armadas ESPE, Sangolquí Ecuador

E-mail: ttoulkeridis@espe.edu.ec

Abstract. This study presents the results of the calculation of the ecological flows below the parameters base, maintenance and maximum of Ecuadorian basins that have hydrometric data, based on the new methodology called Slope Method to the Mass-Curve. For Ecuador to establish the flows is of vital importance for the preservation of the natural ecosystems, taking into account that currently the investment in hydraulic constructions such as dams, hydroelectric power stations and others is enormous. The results obtained allow to establish a baseline for all the projects that somehow affect the fluvial ecosystems, of the geographic basins of Ecuador, in agreement with the availability of the water. The values of the ecological flows are presented graphically according to the location of the hydrometric stations, allowing to appreciate the magnitude of variation of these flows.

1. Introduction

In engineering and environmental projects, establishing the ecological flows of a small or large basin allows us to know the quantity of water in quantity, quality and regularity to ensure the natural development of flora, fauna, river health and other aquatic ecosystems [1-3]. All construction work in a water source must include devices that maintain a minimum flow rate to guarantee the life, circulation and reproduction of the species that inhabit the water at the moment of installation of the work [4-7]. There is also the need to define flows in the minimum surface currents that allow, due to the different uses that are given to the water circulating through them, the existence or permanence of aquatic fauna to protect the environmental conditions and the ecological balance of the system [8-10]. In this way, determining the ecological flows is one of the most important parameters in any project that modifies the natural conditions of the ecosystem of a basin, because the existence of the same has a direct relation with the availability of water and this in turn with the precipitation in the basin [11-14]. Failing to establish an appropriate ecological flow may have a significant environmental impact, which may be critical to the plant and animal life of the area [3,15-16].

In order to determine the ecological flows for the main basins of Ecuador where hydrometric stations are available and to draw up a map of ecological flows, we propose to use the new methodology, called the Slope Method to the Mass-Curve (MPCM), which has been generated with flow data measured in a predetermined basin [17].

2. Methodology

Due to its condition of frequent use in projects, several methods were taken into account to compare the results obtained by the MPCM, such as the hydraulic method among others [18-23]. The hydraulic method used in Ecuador and in almost all Latin America, considers as a minimum flow 10% of the



average flow, which ensures 60% of the hydraulic parameters of the channel as area a wet perimeter and water strap [18,24-26].

$$Q_e = 0,1Q_m \quad (1)$$

Further studies [19,27-29] establish that the ecological flow is composed of a base flow Q_B corresponding to 20% of the average flow, meaning $Q_B = 0,2Q_m$, plus a flow rate of conditioning Q_A which is taken by 10% of the average flow, meaning $Q_A = 0,1Q_m$ by adding obtaining the flow or ecological maintenance with $Q_M = Q_B + Q_A$, which allows the conditions of maintenance for the flora and fauna of the channel, with:

$$Q_e = 0,3Q_m \quad (2)$$

An ecological flow is taken as a function of the average flows for the period of minimum runoff, according to the following relationships:

$$Q_{e1} \geq 0,7Q_{50\%} \quad (3)$$

$$Q_{e2} \geq 0,8Q_{75\%} \quad (4)$$

$$Q_{e3} \geq 0,9Q_{95\%} \quad (5)$$

Where Q_{e1} is the recommended flow rate to maintain the most adequate conditions of the channel, the Q_{e2} flow to ensure the basic conditions of life of the channel and Q_{e3} the minimum flow for the channel to exceed the conditions of extreme drought [25,30-31]. $Q_{50\%}$, $Q_{75\%}$ y $Q_{90\%}$ are the flow rates corresponding to the indicated percentages of the Flow Duration curve.

The Mexican Standard [21] defines that ecological flows range from 5% to 40% for permanent flows based on water supply and demand. Reference [23] recommends to determine the ecological flows with the following formulas, of which the first is not applicable to small flows.

$$Q_e = 15 \frac{Q_{95\%}}{(\ln Q_{95\%})^2} \quad (6)$$

$$Q_e = 0,25(Q_{95\%} + 0,075) \quad (7)$$

To determine the ecological flows by the MPCM method according to Reference [17] the average monthly flows should be ordered from the highest to the lowest value. Let the mean monthly flows be the values $Q_1, Q_2, \dots, Q_{12}$ and the mean annual flow rate Q_m . By ordering them from the highest to the lowest, the ascending and descending character of the flows in the basin is normalized. The variation of the increases or decreases of the monthly flows with respect to the average annual flow, is given analytically by the following relation (figure 1):

$$\frac{Q_i - Q_m}{Q_m} = \frac{Q_i}{Q_m} - 1 = k_i - 1 \quad (8)$$

Let the equation be $y = \int (k_i - 1)$

Its differential $dy = (k_i - 1)dk$

The slope m of the curve at each point may be $\frac{dy}{dk} = m = k_i - 1$

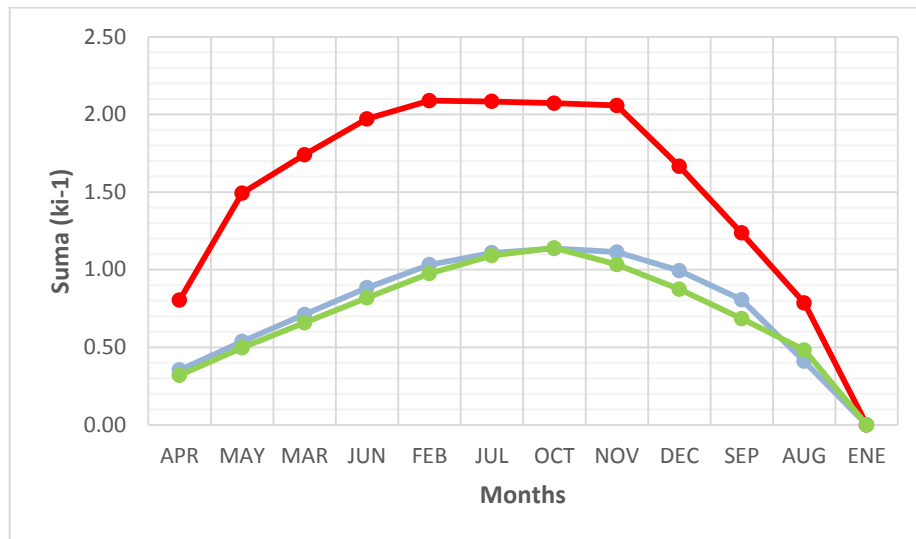


Figure 1. Integral mass-curves. The integral curve of masses of green color represents the maximum flow rate, medium flow blue color and red flow rate, respectively.

This slope m is determined graphically, which corresponds to the gradient of each month (figure 2).

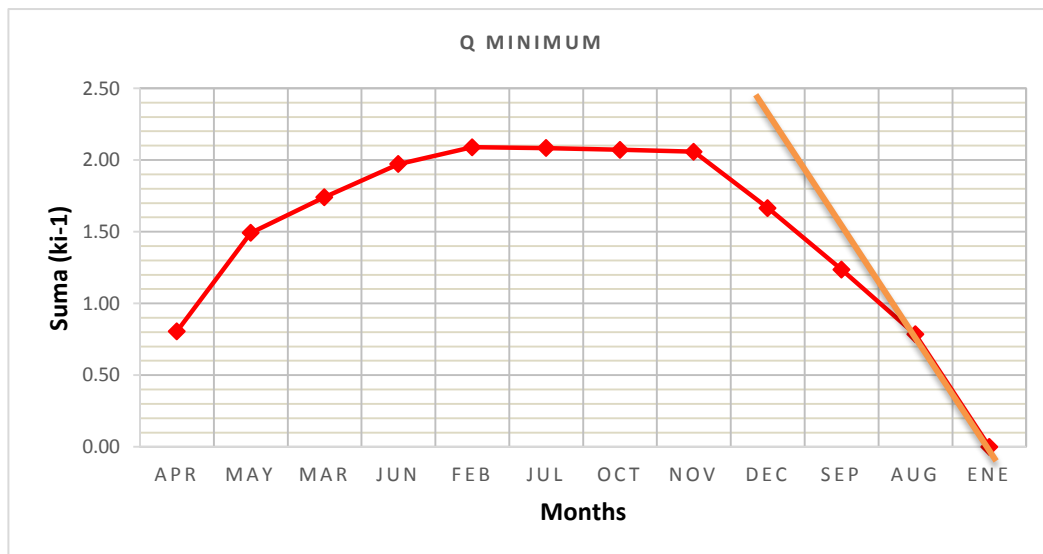


Figure 2. Slope of the minimum flows.

$$k_i = m + 1 = \frac{Q_i}{Q_m} \quad (9)$$

Here, Q_i is the value that the basin requires to overcome the negative gradient of the flow of the data series, which we will call ecological flow Q_e .

$$Q_e = Q_m(1 + m) \quad (10)$$

The ecological flows are determined from the hydrometric data of several available multi-year series [32]. The obtained results allow to know the minimum ecological availability of water of the geographical zones of Ecuador. With the information of average monthly flows available, the

methodology has been applied in the basin of the Mira river and in other different basins of Ecuador (tables 1-5).

Table 1. Morphometric parameters of the Mira Basin. The parameters are: P = Perimeter; ΔH = Altimetric difference of the Basin; Fj = Form Factor; Lr = Length of main river; Hm = Mean height; Ip = Slope Index; Im = Average slope of the basin; J = Slope of the channel.

Station	P	Fj	Lr	Hm	ΔH	Ip	Im	J
	[Km]	[-]	[Km]	masl	[M]	[%]	[%]	[%]
Apaqui D.J. Minas	77,3	1,29	30,3	2265	771	17,48	3,3	1,32
Apaqui en Gruta La Paz	103	1,32	40,2	2365	851	5,92	2,98	1,47
Apaqui A.J. Chota	122	1,26	43,3	1715	1155	19,39	4,82	2,58
Chota en Pte. Carretero	217	1,41	86,2	1515	1890	16,62	3,11	2,18
Jutanyacu A.J. Blanco	63	1,12	17,2	2470	1275	30,55	11,2	0,85
Ambi D.J. Cariyacu	123	1,26	43,1	2015	1580	22,46	6,00	1,3
Mira en Carchi	291	1,24	110	1250	1975	15,73	3,04	1,99
Blanco A.J. Mira	57	1,29	21,2	890	2085	34,92	12,8	8,8
Lita A.J. Mira	107	1,39	41,7	550	2630	27,77	7,32	5,63
Mira en Lita	350	1,38	136,7	530	2575	15,8	2,98	1,72

Table 2. Average, minimum and maximum monthly flows of the Mira Watershed in Lita.

Month	Q Aver. (m ³ /s)	Q Min.	Q Max.
JAN	171,455	15,733	335,610
FEB	175,364	81,773	294,156
MAR	175,019	91,320	295,248
APR	202,018	132,030	295,223
MAY	176,686	123,515	266,909
JUN	145,848	90,061	213,786
JUL	121,239	72,741	227,104
AUG	88,167	40,149	131,734
SEP	90,142	41,764	202,816
OCT	131,514	72,335	206,284
NOV	153,386	72,129	299,449
DEC	160,724	44,494	283,775

Table 3. Processing for the mass-curves.

m	-0,618	-0,403	-0,482
ki	0,382	0,597	0,518
Qe	27,94	89,160	131,72

Table 4. Comparison of our results with other methodologies. Method used in Ecuador proposed by [18] or Montana; European and Chilean Method according to [19], Russian Method according to the norm No. 314 (2007) of the Ministry of Natural Resources of the Russian Federation [20], use of the Mexican Standard NMX-AA-159 SCFI-2012 [21], Chamber of Deputies of the H. Congress of the Union [22], Swiss method and method of The principality of Asturias, according to [23].

Q (m ³ /s)	Asturias	Chile	Ecuador	Spain	México	Russia	Switzerland	Authors
Qe m í	19,33	29,86	14,93	29,86	7,46	69,52	61,32	27,94
Qe med				44,79	59,72	90,98		89,16
Qe m áx				-	-	107,27		131,72

Table 5. Data of the Ecuadorian Basins [32]. Explanation see text.

Name of the Basin	Area (Km ²)	Lr (Km)	Im (%)	Hm (masl)	Qmin (m ³ /s)	Qavg	Qmax
Zapotal en Lechugal	2187,39	107	4,10	40	12,24	139,32	936, 91
Jubones DJ S. Francisco	3376,37	99,30	3,34	712	9,23	48,71	200,17
Esmeraldas DJ Sade	19667,81	209,02	9,10	51	423,30	888,63	1832,99
Pindo AJ Amarillo	5802,03	72,46	2,12	520	9,49	24,79	56,36
Carrizal en Calceta	551,4	52,76	6,67	47	0,54	11,78	53,12
Puyango en CPTO. Militar	2739,85	174,18	2,00	300	28,06	87,58	233,87
Coca en San Rafael	3746,45	98,58	3,29	1160	157,63	287,18	439,13
Daule en la Capilla	10481	87,20	2,45	13	21,30	273,36	1064,60
Tomebamba en Monay	1274	37,44	5,40	2353	3,61	19,49	43,49
Arenillas en Arenillas	505,85	55,84	6,82	20	0,56	7,00	30,29
Uchima AJ Chamba	48,89	10,1	6,96	1603	0,66	2,54	6,67
Cebadas AJ Guamote	706,06	59,31	2,24	2840	3,61	19,49	43,49
Toachi AJ Pilaton	1522,80	115,9	2,97	820	13,95	42,22	96,04

3. Results

As a methodological proposal for the determination of the ecological flows, the hydrological study for the basin of the Mira river is presented, with data from the hydrometeorological station of the Lita Parish (figure 3). The Mira river that is constituted by the rivers Apaqui, Mataqu í Ambi, Chota is located to the extreme north of the country and forms part of the great Inter-Ecuadorian valley known as Chota-Mira. The Mira river basin is made up of ten sub-basins (table 1).

With the data of the series of the flows and the monthly average values, the integral mass--curve has been established for minimum, medium and maximum flows (table 2).

We ordered from the largest to the smallest the data and we calculated the integral mass-curve for the three series (figure 1). In each of these curves the slopes are determined graphically in the descent stage, as illustrated in figure 2.

For example, for the series of the minimum flows the equation of the line of the form $y=mx+b$ is obtained where the slope m is equal to -0.6181 , a value that we have replaced in equation (9) to obtain the ecological flow. For this case it corresponds to the minimum necessary flow that the basin needs to conserve its ecosystem.

For each of the series we obtained the values of the slopes, the coefficients of reduction of the flows k_i and the flow Q_e minimum, average and maximum as listed in table 3.

In order to compare the ecological flows obtained with other methodologies, the flow duration

curve has been required. This curve is the result of the frequency analysis of the historical series of ordered flows from highest to lowest (figure 4). There, Q represents the average monthly flows of the different years of the series and $p\%$ is the probability that these flows may be matched or exceeded. In the analyzed case, the Mira basin in Lita, the series consisted of 192 data.

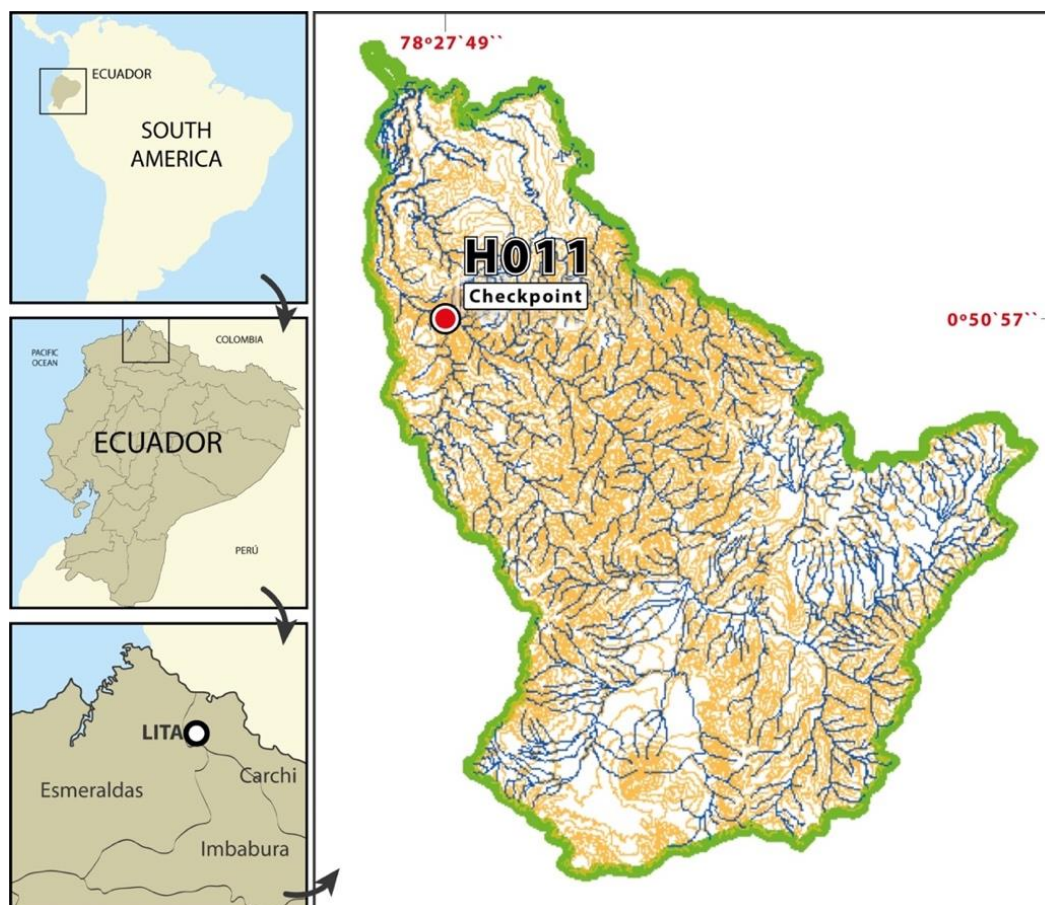


Figure 3. Mira Watershed in Lita with its rivers and contour lines, as well as the position of the Checkpoint.

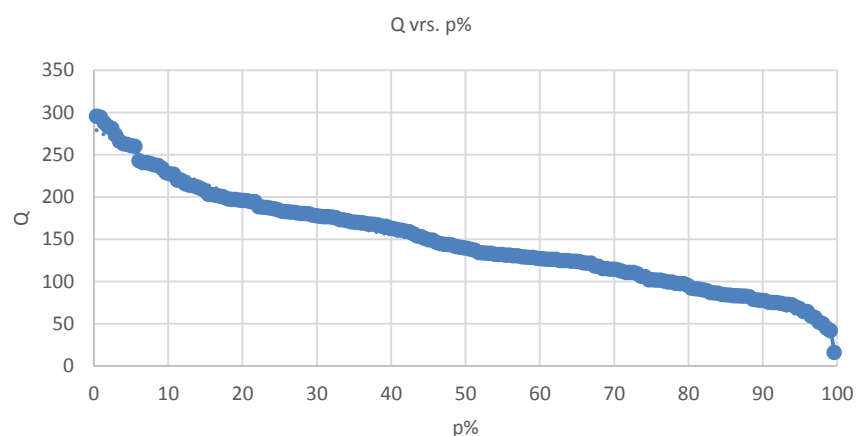


Figure 4. Flow duration curve.

We obtained an average annual flow of the Mira basin in Lita of about 149.3 m³/s (table 2) and the flow duration curve yields the following results:

$$Q_{50\%} = 143,03 \text{ m}^3/\text{s}; Q_{75\%} = 113,73 \text{ m}^3/\text{s} \text{ y } Q_{95\%} = 77,24 \text{ m}^3/\text{s}.$$

As the methodology used is hydrological, the results are only comparable with other hydrological and hydrological methodologies as listed in table 4.

Table 5 presents the morphological data of the Ecuadorian basins and the average, minimum and maximum flows that are necessary to establish the integral mass-curve [32].

The values of the basic, maintenance and maximum ecological flows for each of the basins obtained with the Slope Method of the Mass-Curve are presented, compared with other regulations already indicated (table 6). Some of the methodologies are not listed in table 6 because they consider a single value as an ecological flow, which does not allow comparison with the proposed methodology. Only Ecuador is included as the reference value used in this country.

Table 6. Comparison of results according to the methodology of some selected countries.

Name of the Basin	Q (m ³ /s)	Ecuador	Spain	Mexico	Russia	Proposed
Zapotlan en Lechugal	Qe min	13,93	27,86	6,97	29,31	4,50
	Qe avg		41,8	55,73	36,03	31,68
	Qe m áx		-	-	46,48	125,19
Jubones DJ S. Francisco	Qe min	4,87	9,74	2,44	9,52	4,06
	Qe avg		14,61	19,48	16,94	24,12
	Qe m áx		-	-	27,16	80,41
Esmeraldas DJ Sade	Qe min	88,86	177,73	44,43	155,25	156,03
	Qe avg		266,59	355,45	265,24	368,87
	Qe m áx				435,83	741,44
Pindo AJ Amarillo	Qe min	2,48	4,96	1,24	4,36	2,99
	Qe avg		7,44	9,92	5,84	7,37
	Qe m áx		-	-	15,54	16,43
Carrizal en Calceta	Qe min	1,18	2,36	0,59	0,79	0,18
	Qe avg		3,53	4,71	1,07	3,77
	Qe m áx		-	-	2,44	22,7
Puyango en CPTO. Militar	Qe min	8,76	17,52	4,38	13,61	10,42
	Qe avg		26,27	35,03	16,38	21,74
	Qe m áx		-	-	35,39	40,9
Coca en San Rafael	Qe min	28,72	57,44	14,36	91,9	80,06
	Qe avg		86,15	114,87	159,61	212,66
	Qe m áx		-	-	203,5	377,57
Daule en la Capilla	Qe min	27,34	54,67	13,67	9,93	5,5
	Qe avg		82,01	109,34	50,86	90,89
	Qe m áx		-	-	96,93	515,58

Tomebamba en Monay	Qe min	1,95	3,9	0,97	3,34	0,26
	Qe avg		3,9	7,8	7,93	12,95
	Qe m áx		-	-	12,17	28,1
Arenillas en Arenillas	Qe min	0,7	1,4	0,35	1,06	0,23
	Qe avg		2,1	2,8	1,95	3,55
	Qe m áx		-	-	2,92	11,2
Uchima AJ Chamba	Qe min	0,25	0,51	0,13	1,16	0,17
	Qe avg		0,76	1,02	1,51	1,68
	Qe m áx		-	-	1,89	4,32
Cebadas AJ Guamote	Qe min	2,06	4,12	1,03	7,15	2,91
	Qe avg		6,18	8,24	9,89	9,93
	Qe m áx		-	-	13,57	25,26
Toachi AJ Pílaton	Qe min	4,22	8,44	2,11	11,96	10,68
	Qe avg		12,67	16,89	15,12	20,91
	Qe m áx		-	-	23,24	33,26

4. Discussion

Forty percent of the methodologies used in all regions of the world in the last decades correspond to hydrological and hydraulics, among all the existing ones are the Tenant Method 1976 applied mainly in the developed countries of the northern hemisphere and in the Most of Latin American countries [18,31]. Habitat simulation methodologies are the second most used with 28% of the total among which includes the method of Idaho [33] used in the United States, the Norwegian river system simulator (RSS), which comprises hydrological, hydraulic and habitat simulation models for hydroelectric systems [34] and the French habitat assessment method [35,36] used in some European countries. Furthermore, there are the holistic methodologies based on explicit linkages between flux regime changes and biophysical environment consequences, which account for some 10% of the total in the used method, being the the building blocks method, which has been used frequently in South Africa, Australia and Swaziland [37-39].

With the data of the obtained ecological flows, for the facility of handling the results, we elaborated a map that illustrates the minimum allowable flows in the analyzed stations (figure 5). The calculated flow with the series of minimum monthly flows $Q_e \text{ min}$, should be considered as the minimum acceptable for the ecosystem of the channel. The calculated with the series of data of average flows $Q_e \text{ avg}$ corresponds to the optimal conditions for the ecosystem. The $Q_e \text{ Max}$ flow rate to the excellent and optimal conditions of regeneration of the high zones of the channel.

The ranges of variation of the obtained results using the MPCM methodology and those developed in other countries indicate that for the minimum ecological flow (base flow) there is a variation range of 85% to 0.5% between the different methodologies, while for the flow environment (maintenance flow) it is in the order of 72% to 0.4%. From this it follows that, among the best known methodologies for the calculation of ecological flows, there may be a marked difference in the results and that their application requires a very thorough analysis and not just be limited to the application of a formula.

Compared are the results with the methodologies proposed by Spain, Russia and the MPCM because they are more likely considered as an ecological flow. Those that establish a single ecological flow do not allow to define if they relate to the minimum, average or maximum flow. The methodologies that give higher values of ecological flow may somehow guarantee a sufficient amount of water for the preservation of the ecosystem of the area.

The values of the ecological flows determined with this methodology may be transferred

proportionally to other points of the basin in relation to its area, as long as the particular conditions of each sub-basin are considered. For ecological flows of other basins where hydrometric information is available, it is recommended to use a basin of the same regime, Pacific or the Atlantic.



Figure 5. Map of the minimum ecological flows (m^3/s) in hydrometeorological stations of Ecuador [40].

5. Conclusions

The flow regime is a basic issue, indispensable for all hydraulic designs and for many other constructions in which they are an important part. Therefore it is essential to calculate the critical water demand (ecological flow) to preserve the ecosystems of the corresponding channel.

The proposed methodology based on hydrometric data may be used to determine the value of discharges of ecological flows in any basin. Hereby, in none of the cases the ecological flow must be less than the minimum monthly flows of the channel for the dry months. Therefore, the results obtained by the MPCM are only comparable with hydrological and hydrological methodologies.

The proposed method also allows to obtain the ecological flow quickly, since this depends only on the hydrological data available, while the use of any other more complex method depends on the purpose and importance of the project.

More specific studies for specific species of flora and fauna require other more complete methods such as habitat simulation or holistic, which need more information than hydraulic and the hydrological because of the number of variables that must be taken into account.

References

- [1] Ward J V and Stanford J A 1995 Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation *Regul. River.* **11** 105-19
- [2] Poff N L, et al 1997 The natural flow regime *BioScience* **47** 769-84
- [3] Arthington A H, Bunn S E, Poff N L and Naiman R J 2006 The challenge of providing environmental flow rules to sustain river ecosystems *Ecol. Appl.* **16** 1311-8

- [4] Vaux H J and Howitt R E 1984 Managing water scarcity: An evaluation of interregional transfers *Water Resour. Res.* **20** 785-92
- [5] Griffin R C and Chang C 1991 Seasonality in community water demand *West. J. Agr. Econ.* **16** 207-17
- [6] Ward F A and Lynch T P 1997 Is dominant use management compatible with basin-wide economic efficiency? *Water Resour. Res.* **33** 1165-1170
- [7] McCarl B A, Dillon C R, Keplinger K O and Williams R L 1999 Limiting pumping from the Edwards Aquifer: an economic investigation of proposals, water markets, and spring flow guarantees *Water Resour. Res.* **35** 1257-1268
- [8] Davies S P and Jackson S K 2006 The biological condition gradient: a descriptive model for interpreting change in aquatic ecosystems *Ecol. Appl.* **16** 1251-1266
- [9] Cairns J and Pratt J R 1993 A history of biological monitoring using benthic macroinvertebrates *Freshwater Biomonitoring and Benthic Macroinvertebrates* **10** 27-36
- [10] Baron J S, *et al* 2002 Meeting ecological and societal needs for freshwater *Ecol. Appl.* **12** 1247-60
- [11] Wiens J A 1992 Ecological flows across landscape boundaries: A conceptual overview *Landscape Boundaries* (New York: Springer) pp 217-35
- [12] Poff N L and Zimmerman J K 2010 Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows *Freshwater Biol.* **55** 194-205
- [13] Cui B, Tang N, Zhao X and Bai J 2009 A management-oriented valuation method to determine ecological water requirement for wetlands in the Yellow River Delta of China *J. Nat. Conserv.* **17** 129-41
- [14] Bunn S E and Arthington A H 2002 Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity *Environ. Manage.* **30** 492-507
- [15] Poff N L, *et al* 2010 The ecological limits of hydrologic alteration (ELOHA): A new framework for developing regional environmental flow standards *Freshwater Biol.* **55** 147-70
- [16] Borja Á, Galparsoro I, Solaun O, Muxika I, Tello E M, Uriarte A and Valencia V 2006 The European water Framework directive and the DPSIR, a methodological approach to assess the risk of failing to achieve good ecological status *Estuar. Coast. Shelf S.* **66** 84-96
- [17] Sandoval W, Carrera D, Masabanda M, and Arce E 2016 Proposed methodology for determining the ecological flow with hydrometric data *World Multidisciplinary Earth Sciences Symposium, Prague, Czech Republic. IOP Conference Series: Earth and Environmental Science* **44** 22-30
- [18] Tennant D 1976 Instream flow regimes for fish, wildlife, Recreation and related environmental resources *Fisheries* **1** 6-10
- [19] Alcazar J 2007 *The Basic Flow Method for Determining Maintenance Dflows. Application to the Ebro Basin* (Lleida, Spain: University of Lleida, School of Agricultural Engineering) Doctoral Thesis p 179
- [20] Energy and Fuel Ministry of the Russian Federation 2007 *Guidelines for Drawing Up Rules for the Use of Water Reservoirs of Hydro Power Plants* (Moscow, Russia: Minener) p 78
- [21] Mexican Standard NMX-AA-159-SCFI-2012 2012 *Establishes the Procedure for Determining the Ecological Flow in Watersheds* (Mexico) **2** 123
- [22] Chamber of Deputies of the H. Congress of the Union 2002 *Regulation of the Law of National Waters* (México) p 69
- [23] Garcia E and Peace G 1997 Estimation of the water needs for the conservation of river ecology of rivers regulated *Mexican Federation of Sanitary Engineering and Environmental Sciences Mexico* p 8
- [24] Dudgeon D, *et al* 2006 Freshwater biodiversity: Importance, threats, status and conservation challenges *Biol. Review.* **81** 163-82
- [25] Richter B, Baumgartner J, Wigington R and Braun D 1997 How much water does a river need?

Freshwater Biol. **37** 231-49

- [26] Smakhtin V U 2001 Low flow hydrology: A review *J. Hydrol.* **240** 147-86
- [27] Hill M T, Platts W S and Beschta R L 1991 Ecological and geomorphological concepts for instream and out-of-channel flow requirements *Rivers* **2** 198-210
- [28] Jowett I G 1997 Instream flow methods: A comparison of approaches *Regul. River.* **13** 115-27
- [29] Acreman M C and Dunbar M J 2004 Defining environmental river flow requirements? A review *Hydrol. Earth Syst. Sci.* **8** 861-76
- [30] Richter B D, Mathews R, Harrison D L and Wigington R 2003 Ecologically sustainable water management: managing river flows for ecological integrity *Ecol. Appl.* **13** 206-24
- [31] Tharme R E 2003 A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers *River Res. Appl.* **19** 397-441
- [32] INAMHI (National Institute of Meteorology and Hydrology) 2014 *1963-2010 Yearbooks and Documents* (Quito, Ecuador: National Institute of Meteorology and Hydrology) p 149
- [33] Stalnaker C B and Arnette S C 1976 *Methodologies for the Determination of Stream Resource Flow Requirements: An Assessment* (US Fish and Wildlife Services, Office of Biological Services Western Water Association) p 199
- [34] Alfredsen K 1998 Habitat modelling in Norway-An overview of projects and future developments *Hydroecological Modelling. Research, Practice, Legislation and Decision-Making* eds S˘ Blaz˘kova˘, C Stalnaker and O Novicky˘ (Praha, Czech Republic: VUV) p 33
- [35] Dunbar M J, Gustard A, Acreman M C and Elliott C R N 1998 Review of overseas approaches to setting river flow objectives *Environment Agency R & D Technical Report W6B(96)4* (Wallingford, UK: Institute of Hydrology) p 82
- [36] French Government 1984 *About Freshwater Fisheries and the Management of Fishery Resources. French Water Law N °84-512* France 2039
- [37] King J M, Tharme R E and Brown C A 1999 *Definition and Implementation of Instream Flows. Thematic Report for the World Commission on Dams* (Cape Town, South Africa: Southern Waters Ecological Research and Consulting) p 87
- [38] King J M and Tharme R E 1994 *Assessment of the Instream Flow Incremental Methodology and Initial Development of Alternative Instream Flow Methodologies for South Africa* (Water Research Commission Report No. 295/1/94) (Pretoria, South Africa: Water Research Commission) p 339
- [39] King J M and Louw M D 1998 Instream flow assessments for regulated rivers in South Africa using the Building Block Methodology *Aquat. Ecosyst. Health Manage.* **1** 109-24
- [40] Sandoval W and Aguilera E 2014 Determination of flow in basins with little information *UNAMI Science* **7** 100-10