Innovative Energy & Research
ISSN: 2576-1463

Research Article Open Access

Assessing Environmental Flow for Small Hydropower Plant Case of Catchments with Similar Size

Elena Carcano*

Dipartimento DICAT. V, Università degli Studi di Genova Montallegro, Genova, Italy

Abstract

The paper aims to discuss how the formula for environmental streamflow estimation (EF), (Magra Formula) mostly based upon topographical data such as catchment's size and overall slope besides river's major length, should be used carefully in order prevent streamflow hydrological peculiarities fade away.

Analysis is referred to a real case, namely a restoration of a small hydropower plant located in North Western Italy, in the town of Pogli di Ortovero.

The formula is applied to the case under debate and to a catchment of similar size emphasizing how a detail insight of catchment's behavior and hydrological and biological features are encouraged so that environmental flow assessment becomes definitely more real.

Keywords: Hydropower plant; Topographical data; Catchment

Study Case

Arroscia catchment closed at the only hydrometrical section located at Pogli di Ortovero is 202 Km^2 size. The major Arroscia watercourse, together with Lerrone and Neva, merges into Centa river in the nearby of Albenga town, and the conjunction is roughly placed 25 km downstream Pogli di Ortovero.

For the gauging section long sequences of mean daily streamflow data are available referred to periods: 1925-1943, 1946-1975, 1996. No information has been collected recently from the central office in charge Ufficio Idrografico Statale, due to its dismantlement [1].

Thus, being the scenario, the longest period of continuous data, besides some lacks due to malfunctioning in level registrations, corresponds to 1951-1971 both for this and nearby catchments.

The following are referred: first to the hystorical hydrometrical section placed, prior 1996 next to the pedestrian gangway in Marmoreo and second to the actual hydrometrical section, placed after the abovementioned gangway and in line with the Franciscan monk's church.

Temperature and Rainfall Information of Reference

Rainfall stations located inside the Arroscia catchment and nearby are: Pogli di Ortovero (90 m s.l.) , Pieve di Teco (263 m) Colle di Nava (930 m sl), Alto (630 m), Castelvecchio (250 m), and Triora (780 m). The stations recently installed by ArpaL are: Pornassio (500 m sl), Ranzo (310 m), Testico (435 m), Poggio Fearza (1845 m) and Conna (360 m). Still, both Pieve di Teco and Pogli have guaranteed the longest continuity in observations and are the most reliable rain gauges both for the upper and lower part of the catchment which is next to the hydrometrical section. The mean annual precipitation datum for Pogli is equal to 1142 mm (information detected from daily data in the period of reference 1951-1975). The hystorical section of Pogli has been dismantled at the beginning of March 2017 and has been replaced by one located in Onzo at almost 2 km apart. Table 1 reports the monthly cumulative precipitation for year 2017 both for Pogli di Ortovero and Ranzo stations (Table 1).

Stream flow Measures and Procedure

Hydrometrical or streamflow information has been updated through a direct streamflow campaign with almost one streamflow

Month	Pogli di Ortovero	Ranzo
January	65	67.8
February	126	122.4
March	Rainfall gauge located at Onzo near Ranzo	55
April		8.6
May		76.2
June		83.2
July		13.6
August		80.4
September		69.2
October		401.2**
November		175.6
December		198
Cumulative rainfall		*1351.20 far above threshold value*
January		79.8
February		63.8
March		189.6
April		19.2
May		0.6*
June		112.8
July		16.6
August		10.4
Cumulative rainfall		*492.80*

Table 1: Extreme rainfall event registered in the entire Ligurian Regione during October.

***Corresponding author:** Elena Carcano, Dipartimento DICAT. V, Università degli Studi di Genova Montallegro, Genova, Italy, E-mail: elecarcano@libero.it

Received August 31, 2020; **Accepted** September 01, 2020; **Published** September 28, 2020

Citation: Carcano E (2020) Assessing Environmental Flow for Small Hydropower Plant Case of Catchments with Similar Size . Innov Ener Res 9: 236

measure conducted each month using a traditional OTT current meter. Data are collected by a joint collaboration between Università degli Studi di Genova and Arpa Liguria (the nowadays office in charge of the management of the hydrometrical sections in Italy). Each time a measure is conducted a check between the observed beam level (indicated in circle in 2) and the level registered by electronic sensor is conducted in order to control potential drifts and malfunctioning of the sensor itself. Table 2 lists the collected data (Table 2).

The level registered by the sensor can display strong drifts especially due to moisture effects which envelop the hydrometrical beam and cause interferences with the signal. The errors should be compensated by a technician prior use of data.[2]

The following shows the link between the streamflow –height curves referred to: measured streamflows and observed levels.

The measures prior 2016 have been inherited from Arpa Liguria, but no land survey has been provided.

Therefore, since no additional information is given, apart from the only streamflow datum, a change in the downstream conditions can be suspected and this change is able to modify the streamflow –level relation , as it can be easily detected by Table 2.

Assessing height-flow law, in fact, is a common procedure used by Ufficio Idrografico Statale (nowadays replaced by Arpa Office).

The procedure consists in determining a unique correlation link (or multiple links) between level values (H) and the corresponding flows(Q). Starting from a sufficient number of observed pairs H-Q, after the link has been assessed, the remaining streamflow values for all the days during which the sensor has worked can be estimated

Q (m^3/s), H(m) sensor and beam read				
Num.	Date	Q	H sensor	H beam
1	13/3/2014	0.999	0.37	0.37
2	29/5/2014	1.08	0.40	0.40
3	3/10/2014	0.31	0.27	0.27
4	10/6/2015	3.930	0.50	0.51
5	8/7/2015	1.130	0.25	0.27
6	31/7/2015	0.57	0.17	0.18
7	20/8/2015	0.40	0.13	0.15
8	3/12/2015	3.887	0.48	n.r.
9	22/12/2015	9.900	0.65	n.r.
10	5/1/2016	3.109	0.39	n.r.
11	30/1/2016	3.884	0.41	n.r.
12	11/2/2016	8.370	0.63	0.68
13	6/3/2016	8.590	0.69*	0.68
14	22/4/2016	6.640	0.62	0.60
15	14/5/2016	5.360	0.48	0.48
16	5/12/2016	3.500	0.41	n.r.
17	22/1/2017	3.103	0.40	n.r.
18	20/3/2017	3.187	0.37	0.36
19	24/4/2017	1.883	0.30	0.30
20	30/5/2017	1.555	0.28	0.26
21	18/6/2017	1.871	0.29	0.28
22	3/8/2017	0.595	0.11	n.r.
23	18/8/2017	0.601	0.14	n.r.
24	4/9/2017	0.425	0.08	0.10
25	14/10/2017	0.494	0.10	0.12
26	28/10/2017	0.615	0.12	0.10
27	12/12/2017	7.296	0.32	0.59

Table 2: Streamflow measured data.

Formula 1 introduces the Herschy link

$$Q = c \cdot (H - e)^{\beta} \qquad (1)$$

Whereas:

- H is the beam observed level;
- *e* is a value in correspondence to which the streamflow datum equals to zero;

Proceeding in the estimation of parameters c and β it must be noticed that, in the common practice, streamflow Q difficultly reaches null values [3]. Null stream flows are reached in case of frozen watercourses or in case the flow, during dry periods covers only a part of the total available bed far away from the sensor location. Putting arbitrarily *e* equal to a very low value and estimating the remaining parameters using the least mean error method, formula (1) becomes:

$$Q = 15.5 \cdot (H - 0.05)^{1.45} \qquad (2)$$

From now on, the remaining streamflows can be calculated relying on the abovementioned mathematical law. Therefore, the streamflow-height relation, for Arroscia at Pogli can be synthesized as follows: (Table 3)

Subsequently the hourly registered levels for the hydrometrical section of Pogli during year 2017 can be considered and corresponding mean daily streamflows estimation can be conducted. Sensor levels are registered every 15 minutes and the mean daily flow is averaged through 96 [24*4] hourly registrations) relying on formula (2). All the mean daily values above the threshold of 8 m^3/s will be set equal to 8 m^3/s (since no relation on high flows is available).

The sensor of Pogli hasn't worked during the following days: October 16th, 27th, November 29th, 30 and December 1-12th.

Besides these lacks of information the streamflow-height link can be synthetically introduced as follows: (Table 4)

Comparisons between Streamflow Duration Curves: Hydrological Year of Long-Term Period and Typical Year of Reference

In order to assess the optimum streamflow value to design a hydropower plant, the typical year of reference, selected in the basket of the total years 1951-1971, can be helpful.

Observed H (m)	Measured streamflow (m^3/s)	Calculated streamflow (m^3/s)
0.10	0.425	0.201
0.12	0.494	0.328
0.15	0.4	0.550
0.13	0.615	0.398
0.18	0.57	0.805
0.26	1.555	1.613
0.28	1.871	1.840
0.3	1.883	2.077
0.36	3.183	2.837
0.37	0.999	2.970
0.4	1.08	3.382
0.48	5.36	4.559
0.51	3.939	5.027
0.59	7.296	6.343
0.6	6.64	6.514
0.68	8.37	7.932
0.69	8.59	8.115

Table 3: Comparison between measured and calculated streamflows.

Total duration period: 342 days	Q
23	➢ 8m³/s
60	➢ 5 m³/s
129	➢ 2 m³/s
241	➢ 1 m³/s

Table 4: Defined part of the streamflow duration curve Arroscia at Pogli.

A custom often used by the Ufficio Idrografico Statale is to tabulate annual streamflow duration curves at given days, thus obtaining, the so-called streamflow curves at assigned durations. This stratagem enables an immediate comparison between the streamflow duration curve of the generic year and the corresponding streamflow of the long-term year, at same assigned days. The curve is set at the extreme values in correspondence of 10 and 355 days and in correspondence to intermediate durations: 91, 182, 274 days thus obtaining in a rapid way information referred to: 3,6,9 ,12 months [4].

Recently characteristic durations have been introduced and those are referred to: 10,30, 60, 91, 135, 182, 274 and 355 days while in the font prior to 1960 durations related to 30, 60, 135 have been disregarded.

Typical year will be assessed evaluating the difference between streamflow value of the long-term year and each year belonging to the basket of those considered: 1951-1971 (Table 5).

Duration (days/year)	Hydrological year of long term period (A)	Typical year 1963 (B)	(A)-(B) $\left\|m^3/s\right\|$
10	22.90	23.70	0.80
30	10.30	11.70	1.40
60	6.32	6.20	0.12
91	4.50	4.60	0.10
135	3.03	3.20	0.17
182	2.00	2.35	0.35
274	0.97	1.13	0.16
355	0.36	0.70	0.34

Table 5: Streamflow curves assessed at characteristic durations.

Comparison between Different Duration Curves

Herein two extracts of flow duration curves of catchments of similar sizes are presented. The first is related to Vara and second to Arroscia catchment.

These catchments are put to comparison so to spark further clues about the estimation of environmental release.

The writer believes that an indiscriminate and, therefore, abstract application of the formula of EF estimation, namely called Magra river's EF formula, for basins of same size but different rainfall regime, should be discouraged [5].

As a matter of fact, Arroscia and Vara catchments have similar size, respectively equal to: 202, 206 Km² at their gauging sections, but are characterized by appreciably different water availability and biological features.

Below the corresponding curves of the hydrological year of long-term period are compared [6].

Synthetically streamflow information can be expressed in the table 6 (Table 6)

The mean streamflow value for River Arroscia at Pogli equals to 4.29 m³/s while for River Vara at Nasceto equals to 10.25 m³/s. It can notice that both the mean daily streamflows are greater than the corresponding median data for both catchments.

Duration (days/year)	Long term hydrological year, Pogli	Long term hydrological year, Nasceto	Difference $\left\|m^3/s\right\|$
10	22.90	44.90	22
30	10.30	20.40	10.10
60	6.32	12.10	5.78
91	4.50	8.30	3.80
135	3.03	5.44	2.41
182	2.00	3.58	1.58
274	0.97	1.58	0.61
355	0.36	0.45	0.09

Table 6: Streamflow curves assessed at characteristic durations comparison between different catchments.

Evaluation of Environmental Flow Using the EF Magra Formula

Environmental flow assessement is applied for Arroscia and Vara Catchments at their gauging sections.

Vara basin is located 150 km eastern from the one under study.

The EF formula entails:

$$EF = S \cdot Rspec \cdot P \cdot A \cdot Q \cdot N \cdot G \cdot \left(1 + L_{7,5} \cdot d\right) + M10 \quad (3)$$

Whereas:

- S represents the catchment size at the capture section;
- Rspec specific release equal to 1.6 l/s*km2;
- P average precipitation, set between 1 8if P is less than 1200 mm/year) and 1.8 (if P is higher than 1800 mm/year) (we have assumed a precipitation detected from tewenty years of information data)
- A altitude variable from 1.2 (for heights beween 0-400 m s.l) 1 (for heights between 400-600 m sl) 1.10 (for heights between 600-800 m sl) and, again, 1.2 8for heights higher than 800 m sl)
- Q watercourse quality which varies between 1 (not polluted) and 1.4 (very polluted)
- N naturality coefficient beween 1 (high polluted areas) and 1.6 areas of great quality)
- G geomorphological parameter which, in case of absence of further information, is set equal to one.
- L7.5 pipe length evaluated between the capture weir and the restitution opera; we can assume a percentage of 7.5% for ecag km of the pipe considered;
- M 10 modulation contribution equal to 10% of the difference between natural flow and environmental flow detected without modulation contribution;
- D distance between the capture weir and the restitution opera measured along the bed.

Common data for both sections are

- L7.5 equal to 775 m;
- A mean catchment altitude equal to 1.10 (700 m for Arroscia 801 for Vara)
- Q 1 not polluted

- N 1.30

Data for Pogli section

- S 202 km^2;
- P 1 (mean annual preicpitation value of Pogli equal to 1149 mm, value detected from 1951-1971)

Data for Nasceto section

- S 206 km^2
- P 1.6 (mean annual precipitation value of Nasceto equal to 1743 mm, value detected from 1953-1975)

the following EF are obtained, respectively equal to:

EF, Pogli= 489 l/s

EF, Nasceto=798 l/s

Table 7 compareses the obtained value through (3) and the corresponding associated durations (Table 7).

Sections	Associated duration	EF(330 days)	EF(335 days)
Pogli	325 gg	460 l/s	420l/s
Nasceto,$_{1}$	323 gg	720 l/s	670l/s
Nasceto$_{,2}$	318 gg		

Table 7: EFs two compared catchments.

Comments

The EF evaluation based on Magra formula leads to an overestimated value of environmental flow respect the corresponding value detected form the streamflow duration curve of long-term period by equaling environmental flow to Q (330).

A particular attention must be addressed to parameters N and Q abovementioned. Those values need to be confirmed by appropriate biological surveys. In case this won't happen, data obtained using formula 3 won't probably found any validation with low flows of the curve (Q330-Q335- Q347) this leading to abstract values for environmental flow estimation.

Moreover, Magra formula completely disregards the hydrological regime of the watercourse under debate because the only precipitation value P itself is not sufficient to explain water catchment's availability.

Still the second part of the formula (3) namely called modulation contribution allows a variability in the EF estimation which can be seasonally different and can follow the river pattern. It is known that constant environmental value may cause excessive flow releases during some period of the year which may not found real direct correspondence in biological requests.

In the nutshell the application of modulation environmental release has to be devised with biologists, and in general, the application of Magra formula (3) should consider proper insight on the catchment behaviour, also.

References

1. Del Monaco G (2009) Piccole Centrali idroelettriche, Libri Sandit, II Edizione Novembre 2009.Available: https://www.ibs.it/piccole-centrali-idroelettriche-libro-gino-del-onaco/e/9788889150801
2. Fraenkel P, Paish O, Bokalders V, Harvey A, Brown A, et al. (1991) Micro-Hydro Power: a guide for development workers. London: IT Publications Ltd.
3. Harvey A (1993) Micro-Hydro Design Manual. London: IT Publications Ltd.
4. Paish Oliver (2002) Micro-Hydro Power: Status And Prospects. J Power Energy Prof Eng Publ.
5. Vogel RM, Fennessey NM (1994) Flow duration curves. I: new interpretation and confidence intervals. J Water Resour Plan Manag 4: pp. 485-504.
6. Vogel RM, Fennessey NM (1995) Flow duration curves II: A review of applications in water resources planning. Water Resour Bull. 6: pp. 1029-1039.