UNIVERSITÀ POLITECNICA DELLE MARCHE

MASTER DEGREE IN ENVIRONMENTAL ENGINEERING

Analysis of the Misa River watershed and numerical simulations of the river hydrodynamics during low- and high-flow conditions

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Summary

Abstract

In the present thesis, the Misa River watershed is analysed, passing through the precipitation, temperature and discharge of the watershed. The analysis was done using the following stations: Arcevia, Bettolelle, Barbara, Colle and Corinaldo. In a first time it was calculated the daily value of precipitation, temperature and discharge for each station, and later the monthly value for all the parameters that characterize the watershed. Once it was calculated the average value of each parameter, passing through the Inverse Distance Weighted Method, the data were used for the application of a hydrological model aimed at finding the river discharge. Simulations have also been carried out using the HEC-RAS software, that gives information about the water level, that is calculated passing through the discharge. The simulation with HEC-RAS was done for all the sections of the river but for comparison purposes, only the sections of Bettolelle and Ponte Garibaldi have been analyzed. Close to the Ponte Garibaldi station there is the horizontally acoustic doppler current profile (H-ADCP), that is a gauge that gives as output data only relatively high values of water level. The data of this river gauge are collected and used, mainly the data of November, to find a rating curve for the Ponte Garibaldi station. With the aim to extract the rating curve, the H-ADCP data and the results obtained from the HEC-RAS simulations have been compared.

Chapter 1: Introduction

The aim of this study is the hydrological modelling of the Misa River watershed, throughout the temperature, the precipitation and the discharge of the river. The water flow in a river follows the typical laws of open channels and is characterized by a free surface, that is subjected to the atmospheric pressure. For simplicity it is assumed that the flow is parallel to the bed and has a uniform velocity distribution and the slope is not so high. One of the most common classifications distinguish between natural or artificial channels. The flow condition in the open channel, e.g. the Misa River, is complicated to analyze because of the possible variation in the space and in the time. It is normal to consider that the shape of the open channel is not completely defined and can vary from circular to the irregular form. In this study, it is possible to have a view of the cross sections when the HEC-RAS software is used. The steady flow of the river is based on the assumption that the flow rate does not change, hence it can be defined as constant during the considered time. Otherwise if the flow rate changes with the time, it is considered unsteady. The streamflow in a river cannot be measured directly and is typically derived with a rating curve model. The watershed is defined as “any portion of the earth's surface within a physical boundary defined by topographic slopes that divert all runoff to the same drainage outlet.”

1.1 Watershed hydrology

The water balance equation for a long time period over a watershed can be written as follow:

$$P = Q + E$$

Where:

- E is the evapotranspiration, that plays one of the major roles in water and energy balances and is one of the components in the hydrological cycle
- P is the precipitation, falling into the defined watershed
- Q is the discharge (runoff) in the watershed.

Hydrological variables such as precipitation are strongly dependent on atmospheric circulation and on the local orography (Soldini L. & Darvini G., 2017). Climate change affects the hydrological processes and induce alterations in precipitation, evaporation, soil moisture availability and time of flow routing (Dey P. & Mishra A., 2017). Further, the hydrological process is affected by the presence of land use that alters soil properties, interception of precipitation, surface roughness (Zheng, H., Wang, Z., Deng, X., Herbert, S., & Xing, B., 2013) and flood frequency (Brath, A., Montanari, A., & Moretti, G., 2006), while urbanization causes higher surface runoff generation and reduced lag time between precipitation and runoff leading to increase in peak flow.

1.2 Misa River

The Misa River flows in the Marche Region (central Italy, see Figure 1) and runs for about 48 km from the "Appennino umbro-marchigiano" (central Italy) to the municipality of Senigallia (Marche Region), one of the most important touristic towns of the Italian Adriatic Sea (Brocchini et al., 2017). The source of the river is located in Arcevia in the province of Ancona, with an approximate level of 793 m above the sea, as it could be seen in the Figure 2.

Figure 1 Misa River location in the Marche region

Figure 2 Misa River watershed

The watershed extension (Figure 2) of the Misa River is $383km^2$, with discharges of about 400, 450, and 600 $\frac{m^3}{s}$ for return periods of 100, 200, and 500 years, respectively. The Misa River has a marked torrential regime with impetuous floods in the rainy seasons. The area of the Misa watershed is characterized by tectonic lines that reflect the structural trend of the "Appennino umbro-marchigiano". The structure could be divided into two areas:

- Mountainous area, where the Apennine Mountains are comprised of brittle sedimentary rocks, remnants of the Tethys Sea, which are highly extended and heavily fractured (Doglioni, 1994). Consequently, the mountain surfaces are easily eroded and supply relatively large quantities of gravel and sediment to the Adriatic Sea (Milliman, 1992). Sediment mineralogy reflects the characteristics of the sedimentary source materials that dominate the Apennine Mountains such as limestone, shale, and sandstone (Brocchini et al., 2017)
- Hill and flood plain area, where the geological formations are characterized by clays and sand-silty clay, that could increase the transport of sediment in the Misa River.

The Misa River is subjected to the climate which affects the Marche Region and an increase of extreme climate events has been observed (e.g., heat waves, sea level rise, heavy rainfall events) since about 1950, some of these being attributed to human influence (R.K., 2014). A problem of this type requires in-depth analyses, as possible variations in rainfall and thermometric regime may have significant impacts on the availability of water resources, but also on the ecosystem and on human activity in general. For the Marche Region, an extended analysis was developed to define a regional model for estimating a design storm (Castellarin A., 2005), but no explicit information about the rainfall statistics changes were provided. (Appiotti F., et al., 2014) presented an integrated analysis of recent climate change by considering meteorological, oceanographic and river gauges during the period 1961–2009. The analysis of daily precipitation data by Brunetti M. , Maugeri M., & Nanni T. (2001) shows that the average annual number of wet days has a significant negative trend, mainly in spring and autumn. The trend analysis of the annual and seasonal rainfall shows that total precipitation decreases for almost the entire year, except the autumn, influencing river flow change (G. Darvini & F. Memmola, 2020).

Chapter 2: Methodology

In this study, the methodology used could be divided into two parts. In the first part, it is necessary to analyze the data downloaded from the site of Sirmip, as described in the chapter 2.1, where the monthly values used in the hydrological model are found. After the monthly evaluation of the precipitation and temperature, that will be the input of the hydrological model, the model is ran to have the statistical value of the discharge in Bettolelle. In the end of this part, a comparison between the value of the discharge reconstructed with the rating curve and the discharge calculated with the model is performed. In the second part, a numerical analysis performed with the HEC-RAS software is described. Starting from the value of the discharge at Bettolelle, that was calculated with the rating curve, the value of the hydrometric level is found. After the simulation, the data was compared with the data collected at Ponte Garibaldi by the H-ADCP gauge. A rating curve using such data is also attempted.

2.1 Data collection

The Civil Protection Multirisk Functional Center manages the monitoring network of the Marche Region and publicly shares the collected data through the "SIRMIP" database, which stands for "Sistema Informativo Regionale Meteo-Idro-Pluviometrico". Such network is formed by the merger of two networks, a mechanical network (RM) and a telemetric network (RT). The mechanical network was established in 1916 by the National Hydrographic and Mareographic Service (SIMN). The available sensors are thermometers and rain gauges, whose quantity, operating period and location on the territory has evolved over the years undergoing a considerable series of changes. Figure 3 illustrates the homepage of the SIRMIP database.

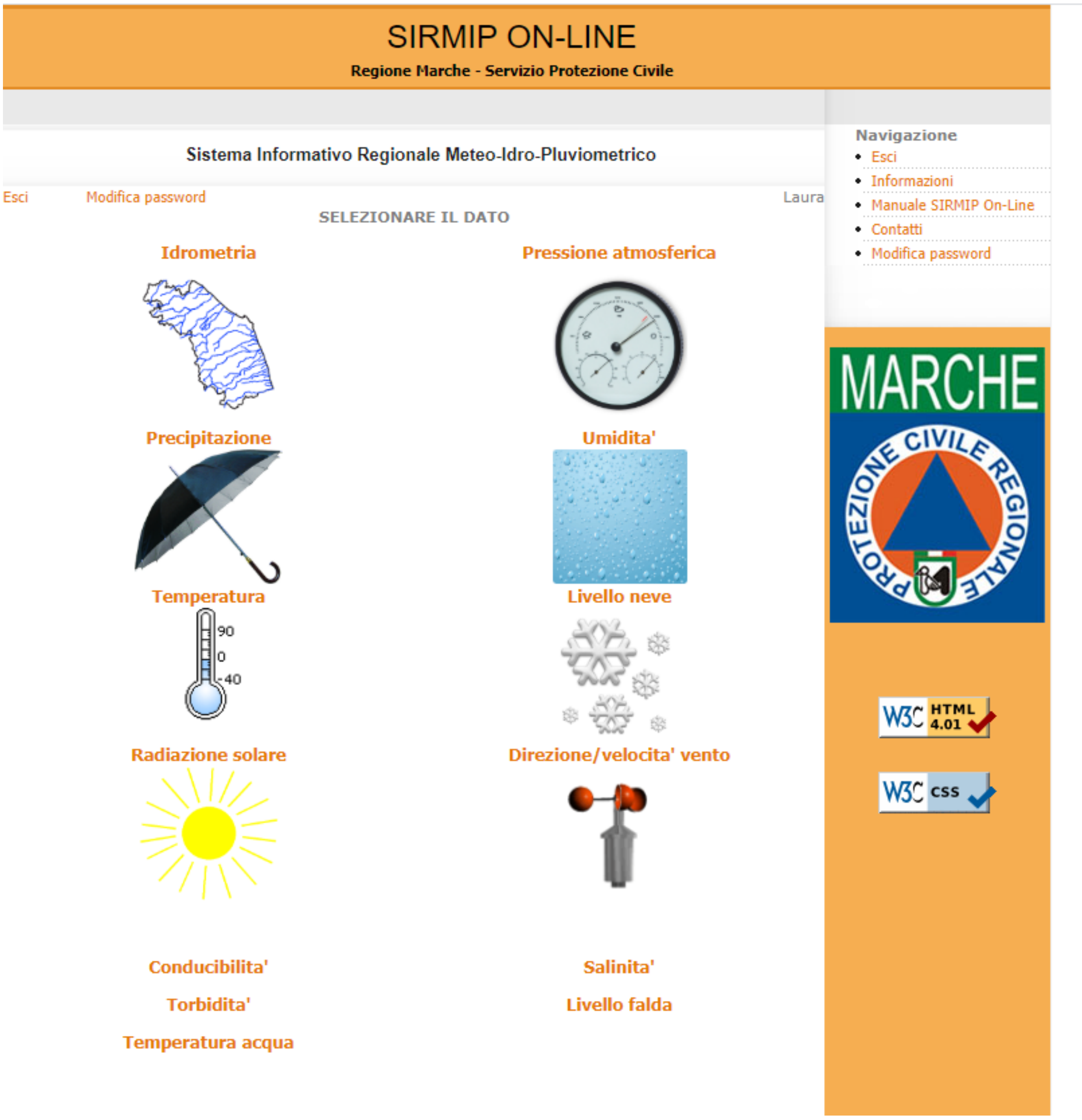


Figure 3 SIRMIP website

The first core of telemetric network (RT) was activated in June 2000, starting from 2004, the telemetric network (RT) gradually expanded to arrive, in March 2009, to have 53 thermometers, 77 rain gauges, 13 anemometers, 15 barometers, 30 hygrometers, 16 solar radiation and 7 snow meters. There are also 70 ultrasonic and microwave hydrometers, 52 of which are associated with a hydrometric rod for measuring calibration. From Figure 4, it is shown that it could be possible to download data about temperature, precipitation, hydraulic level, atmospheric pressure, relative humidity, solar radiation and wind/velocity direction. The data extracted from the site for the present thesis work are original data, as it is shown in the Figure 4. Original data represent the data recorded by the sensor without any verification.

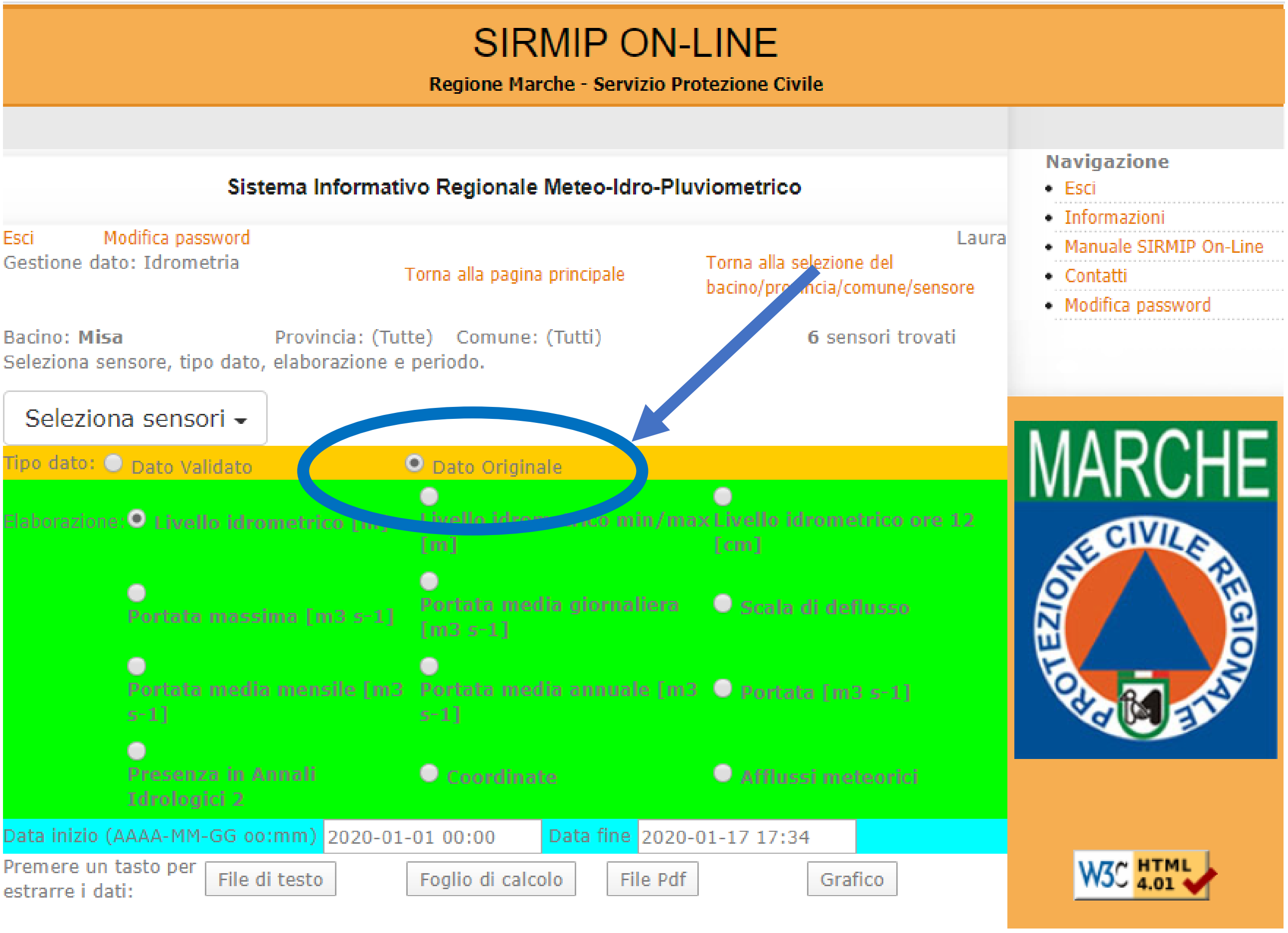


Figure 4 Original Data from the site Sirmip

The study concerns an evaluation of the data about the temperature, precipitation and discharge at different stations. For the analysis of the discharge, the hydraulic level data collected by the station of Bettolelle are only downloaded, as it is illustrated in the Figure 5.

Figure 5 Bettolelle respect to Senigallia

To apply the hydrological balance and with the aim to analyze the precipitation data, the following stations are considered:

- Arcevia
- Barbara
- Bettolelle
- Colle
- Corinaldo

While for the temperature data, the stations are:

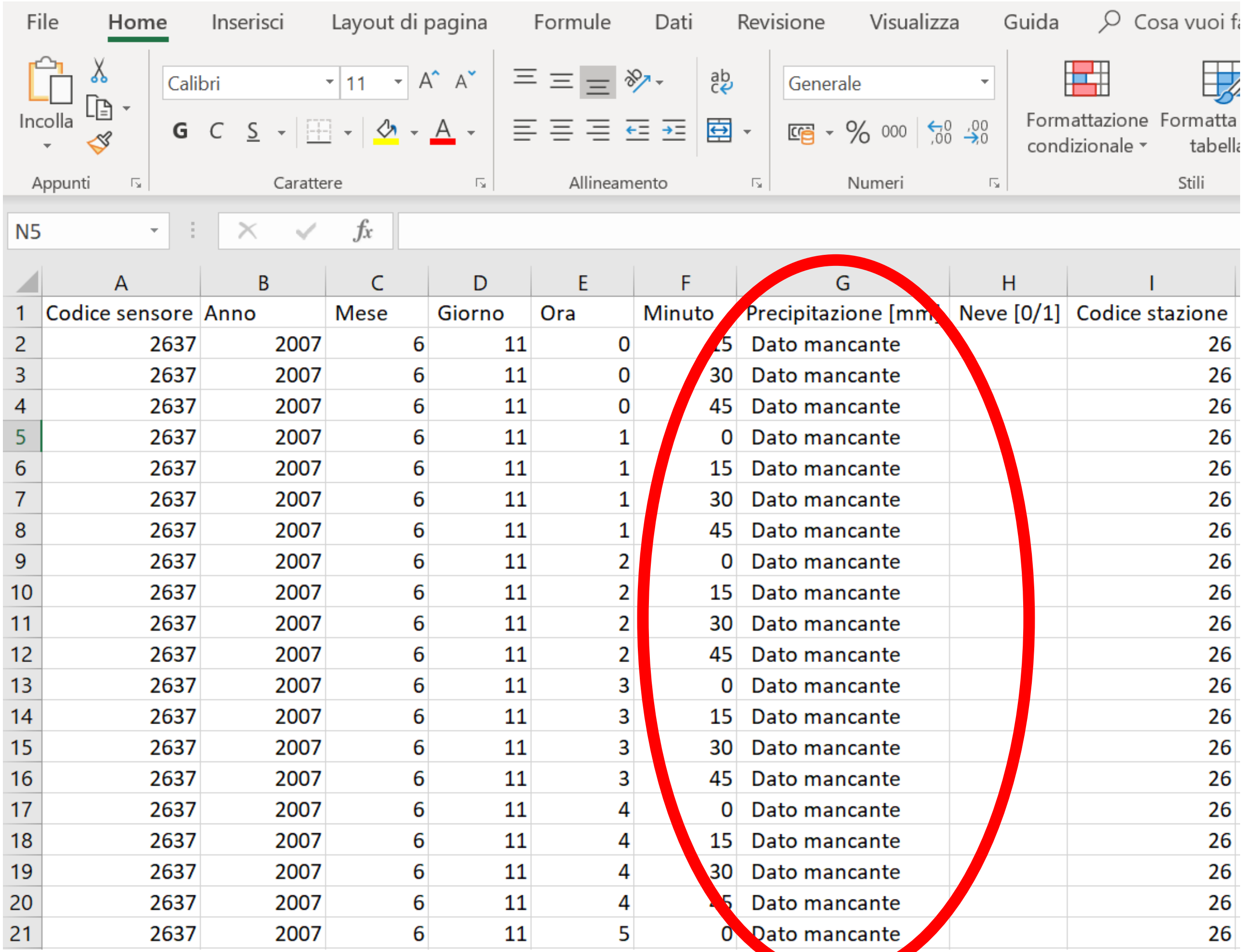
- Arcevia
- Bettolelle
- Colle
- Corinaldo

To do that, the SIRMIP database has also been used, thanks to which it was possible to select the station of interest. The data from the 2005-2019 about rainfall, temperature and hydraulic level data were downloaded as it is shown in the Figure 3. In the Figure 6 it could be seen where it is possible to select the sensor (inside the red circle) and where it is possible to change the date of the file to download (inside the blue circle).

Figure 6 Time and sensor windows

2.2 Monthly precipitation

The study of the watershed starts from the analysis of the data of precipitation, that was downloaded, as an Excel file, and then collected in a folder. The file includes the code of the sensor, year, month, day, hour, minute, precipitation value, snow and station code, all related to the defined station. Figure 7 shows the configuration of the file, where the term “Dato mancante” refers to missing data, due to periods during which the gauge did not work.



	A	B	C	D	E	F	G	H	I
1	Codice sensore	Anno	Mese	Giorno	Ora	Minuto	Precipitazione [mm]	Neve [0/1]	Codice stazione
2	2637	2007	6	11	0	15	Dato mancante		26
3	2637	2007	6	11	0	30	Dato mancante		26
4	2637	2007	6	11	0	45	Dato mancante		26
5	2637	2007	6	11	1	0	Dato mancante		26
6	2637	2007	6	11	1	15	Dato mancante		26
7	2637	2007	6	11	1	30	Dato mancante		26
8	2637	2007	6	11	1	45	Dato mancante		26
9	2637	2007	6	11	2	0	Dato mancante		26
10	2637	2007	6	11	2	15	Dato mancante		26
11	2637	2007	6	11	2	30	Dato mancante		26
12	2637	2007	6	11	2	45	Dato mancante		26
13	2637	2007	6	11	3	0	Dato mancante		26
14	2637	2007	6	11	3	15	Dato mancante		26
15	2637	2007	6	11	3	30	Dato mancante		26
16	2637	2007	6	11	3	45	Dato mancante		26
17	2637	2007	6	11	4	0	Dato mancante		26
18	2637	2007	6	11	4	15	Dato mancante		26
19	2637	2007	6	11	4	30	Dato mancante		26
20	2637	2007	6	11	4	45	Dato mancante		26
21	2637	2007	6	11	5	0	Dato mancante		26

Figure 7 Presence of missing data in the downloaded file

As illustrated in Figure 7, the rainfall recorded by the sensor every 15 minutes throughout the day, month and throughout the year. The presence of missing data underlines the necessity to validate the downloaded data. It was thus decided to define a threshold, which was 10% of missing data every month. If such threshold was overcome, the month was not used in the analysis. This approach was applied to evaluate the admissible months. Then, such months were used to calculate the daily precipitation and the monthly precipitation.

2.3 Monthly temperature

In this part, temperature data were downloaded and elaborated as it was done for the data of precipitation. Even if for the precipitation, the data were collected every fifteen minutes, for the temperature the sensor records data every 30 minutes. For the validation of the data it was used the same evaluation, that was used for the precipitation data (up to 10% of missing data for each month). To have an evaluation of the monthly temperature, it was necessary to do the average of the collected and suitable values. Both daily average and monthly average of the temperature were calculated.

2.4 Inverse Distance Weighted method

In almost all branches of science and engineering working with natural system, there is a need for interpolating from point-wise irregularly-spaced data to produce a continuous function either in space and/or time and space. These point support irregularly spaced locations might take different attributes in various disciplines. In hydrology, almost all hydrologic processes are distributed in space and time and are monitored in point support manner (e.g., rainfall, temperature, soil moisture, piezometric head, etc.). In this study, the inverse distance weighted method was used for the analysis of precipitation and temperature data, because it is one of the most popular methods used by scientists due to facility of implementation and interpretation. This method takes into account the distance of each station from the centroid of the basin (Figure 8). The measured value which is closer to the prediction location have more influence on the predicted value than those farther away. Inverse distance weighted assumes that each measured point has a local influence that diminishes with distance. It gives greater weights to points closest to the prediction location, and the weights diminish as a function of distance, hence the name Inverse Distance Weighted (IDW) method.

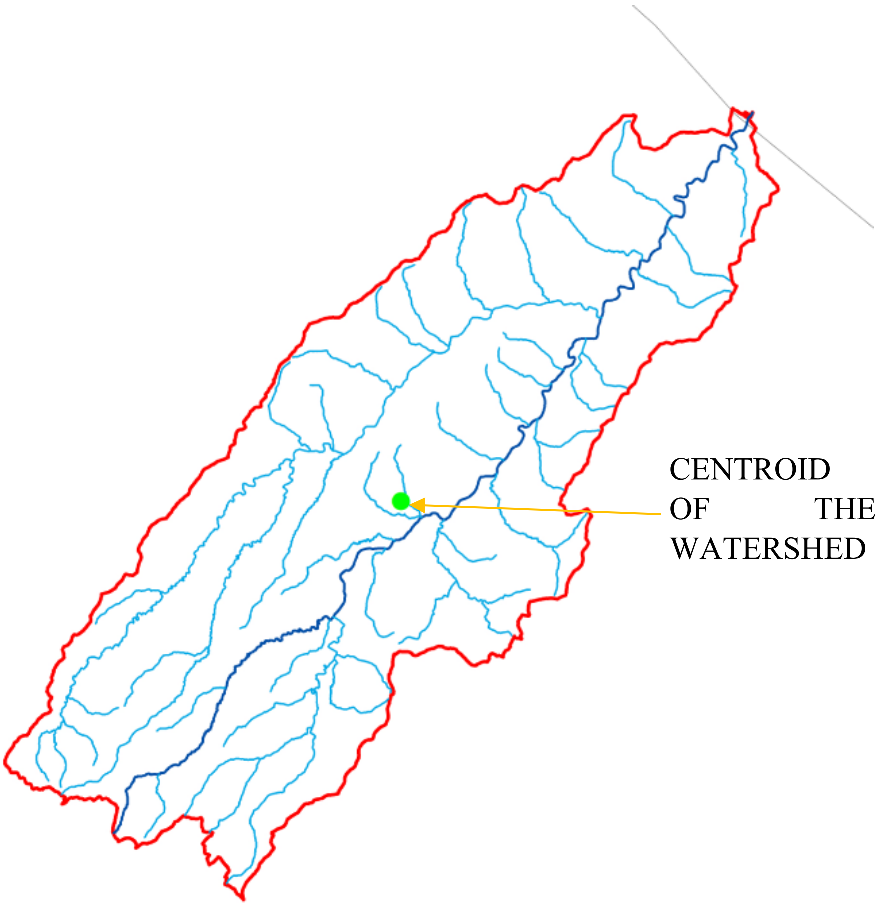


Figure 8 Example of distance from the centroid

IDW is based on the concept of Tobler's first law (the first law of geography) from 1970. It was defined as "everything is related to everything else, but near things are more related than distant things". The IDW method was developed by the U.S. National Weather Service in 1972 and is classified as a deterministic method. It is relatively fast and easy to compute, and straightforward to interpret. Its general idea is based on the assumption that the attribute value of an unsampled point is the weighted average of known values within the neighbourhood, and the weights are inversely related to the distances between the prediction location and the sampled locations. (W.Wong, 2008). The IDW formulas are given as:

$$\hat{R}_p = \sum_{i=1}^{N} w_i \cdot R_i$$

where:

$$w_i = \frac{{d_i}^{-\alpha}}{\sum_{i=1}^{N} {d_i}^{-\alpha}}$$

where:

- $\hat{R}_p$ is the average rainfall;
- R_i is the rainfall value of known rainfall stations;
- N is the amount of rainfall stations;
- w_i is the weight of each rainfall station;
- d_i isthe distance from each rainfall station to the watershed centroid;
- α is the power, and is also a control parameter, generally assumed equal to 2, as done by Zhu and Jia (2004) and Lin and Yu (2008), or 6, as set by Gemmer et al. (2004).

To use this method, it important to know the coordinates and the distance from the centroid of the watershed and it is shown in Table 1Table 1 Coordinates and distance of each station from the centroid of the watershed.

Measuring station	River	North coordinate	East coordinate	UTM East	UTM North
Arcevia	Misa	43°29'50'' N	12°56'12'' E	4823451,0	818216,0
Barbara	Misa	43°34'55'' N	13°01'33'' E	4833212,0	824967,0
Bettolelle	Misa	43°39'50'' N	13°09'57'' E	4842839,0	835821,0
Colle	Misa			4828082,0	827694,0
Corinaldo	Misa	43°38'57'' N	13°02'46'' E	4840758,0	826240,0

Table 1 Coordinates and distance of each station from the centroid of the watershed

2.5 HEC-RAS modeling

To analyze the flow discharge at "Ponte Garibaldi", the program "HEC-RAS" has been used. This is a software that allows the user to perform one-dimensional steady flow, and two-dimensional unsteady flow calculations, sediment transport/mobile bed computations, and water temperature/water quality modelling. For the study of the Misa River, it was analysed using the steady flow condition. In details, the steady flow refers to depth and velocity, at a given channel location, which do not change with time. The basic computational procedure is based on the solution of the energy equation:

$$H = z + Y + \frac{\alpha V^2}{2g}$$

where:

- H is the total energy at any given location along the stream
- z+ Y is the sum of the potential energy
- $\frac{\alpha V^2}{2g}$ is the kinetic energy where the V is the mean velocity and g is the gravity acceleration.

So, talking about the cross section of the river, as it is shown in the Figure 9 there could be some variable that is analyzed, the Y is the water depth, the z is the high of the datum with the respect of the sea level, in this case, and the H is the high of the water from the sea level.

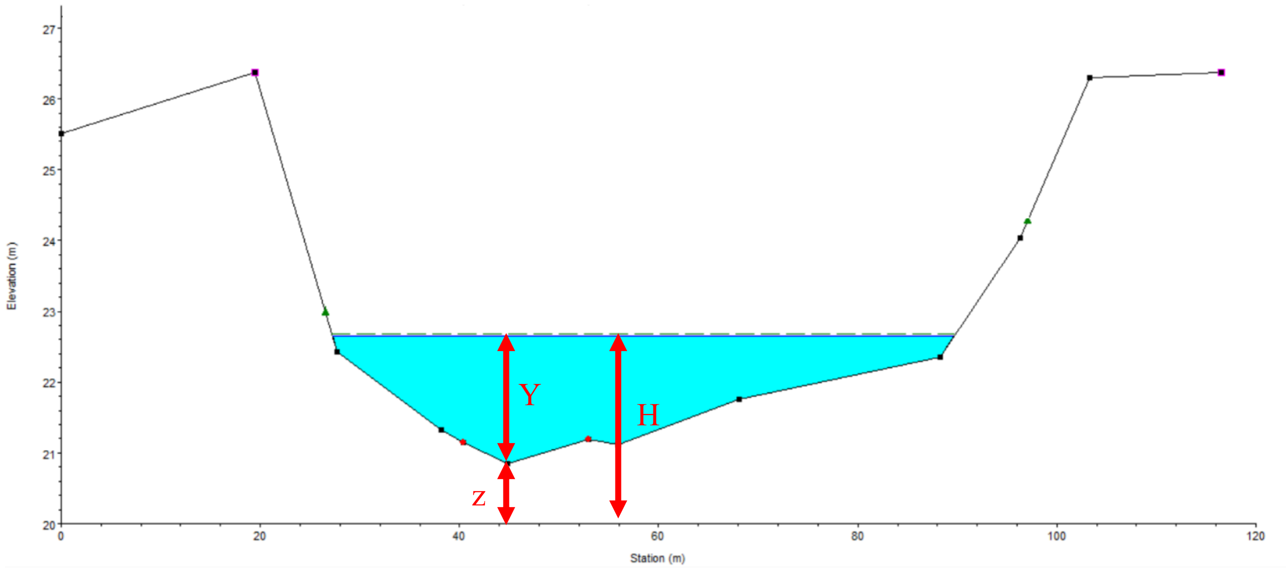


Figure 9 Cross section with the water level, the distance from the bottom

To analyse the steady flow using the HEC-RAS software, the main project window (see Figure 10) needs to be used.

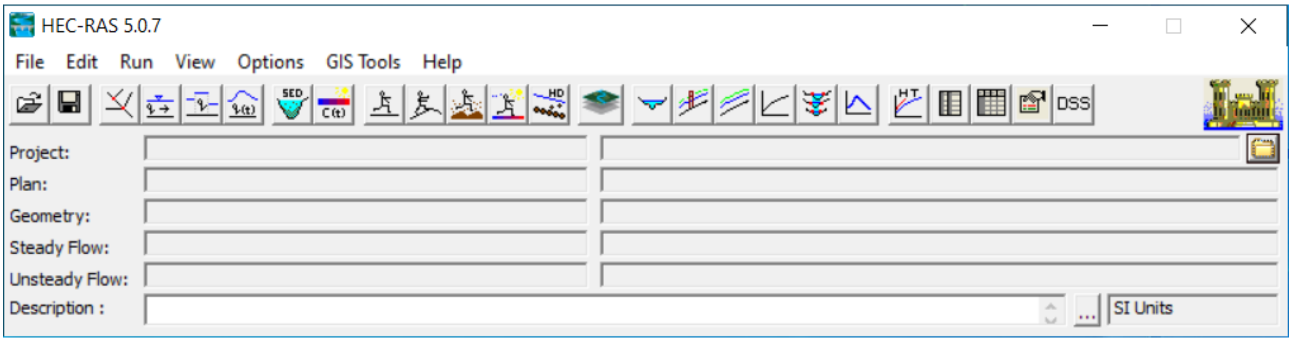


Figure 10 HEC-RAS window

In this study, an existing project of the Misa River has been used, where the geometrical data referring to both main flow axis and cross sections of the Misa River were already provided (Figure 11).

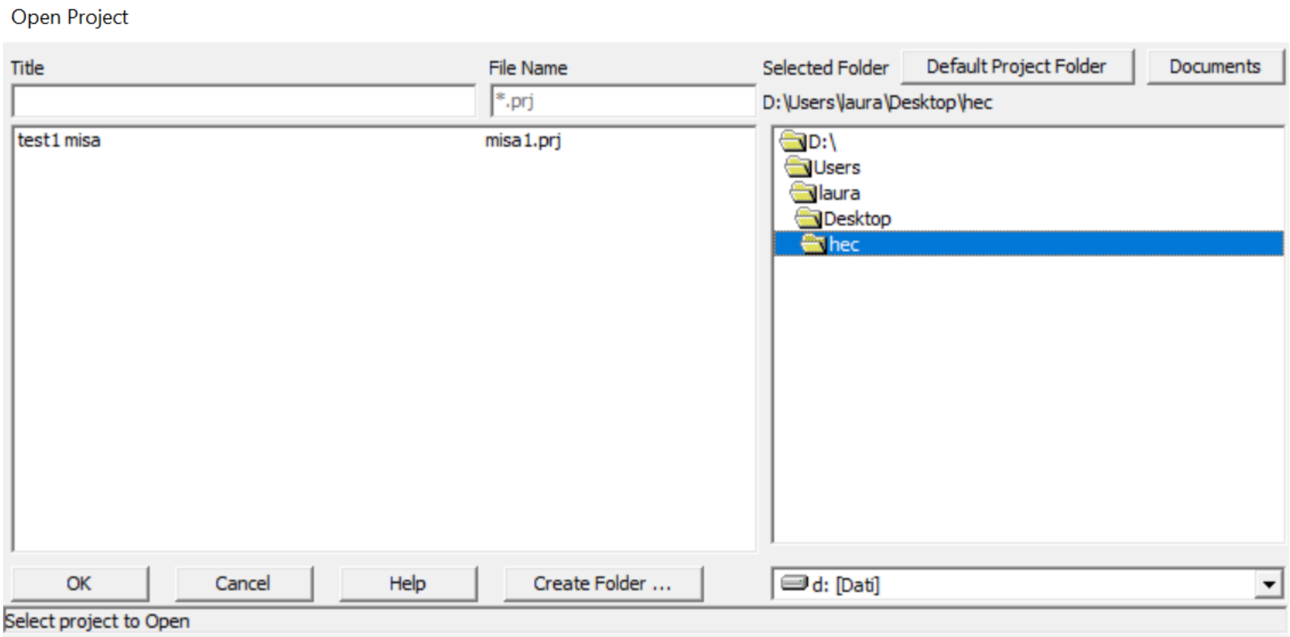


Figure 11 Misa River file project

The geometrical data of the project could be seen, going from the main window to "Edit" and after in the "Geometric data" and it will be seen in (Figure 12). In this study it was necessary to add a new cross section in Ponte Garibaldi, whose location is highlighted by the red circle in Figure 12.

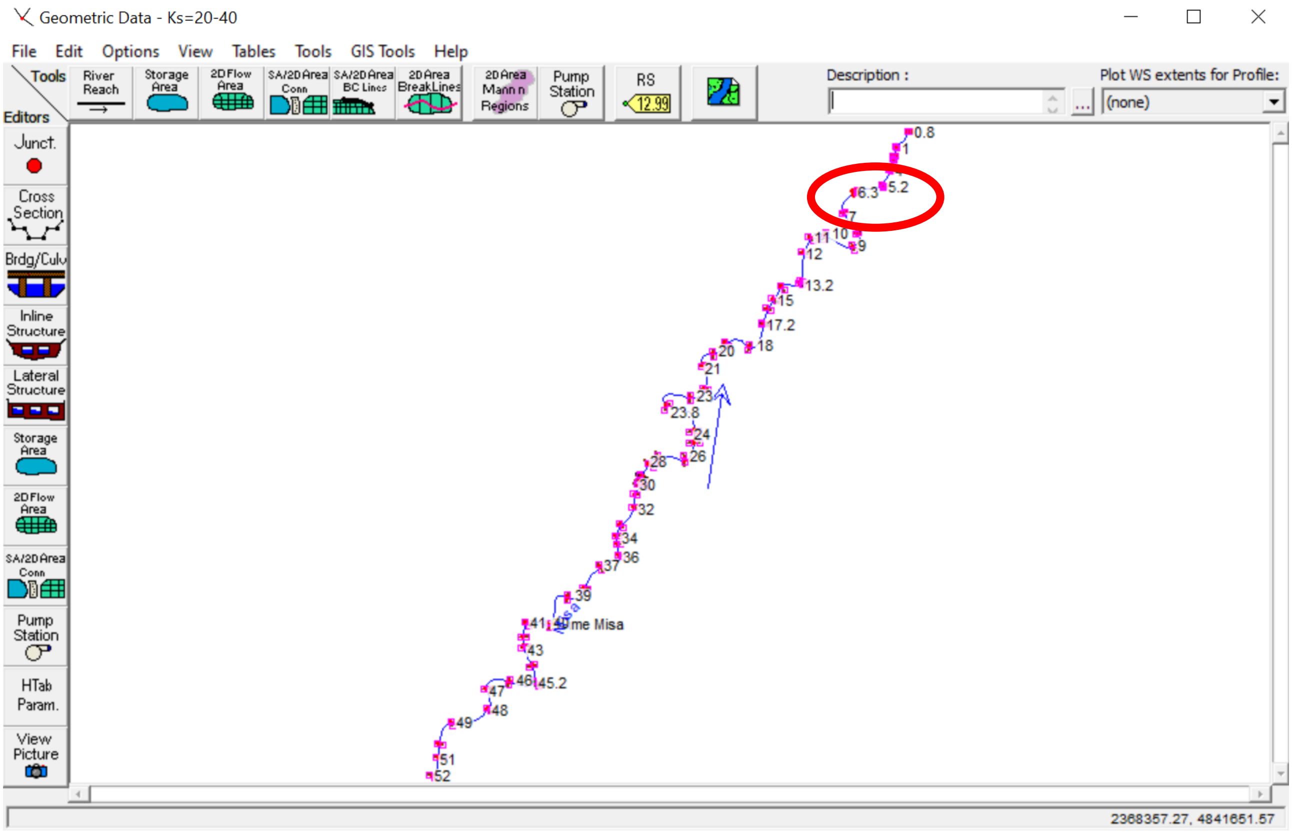


Figure 12 Geometric data in HEC-RAS

To add the Ponte Garibaldi cross section, it was necessary to have information about the bathymetry at that location. Actually, it was surveyed on 27th September 2019, as shown in Figure 13.

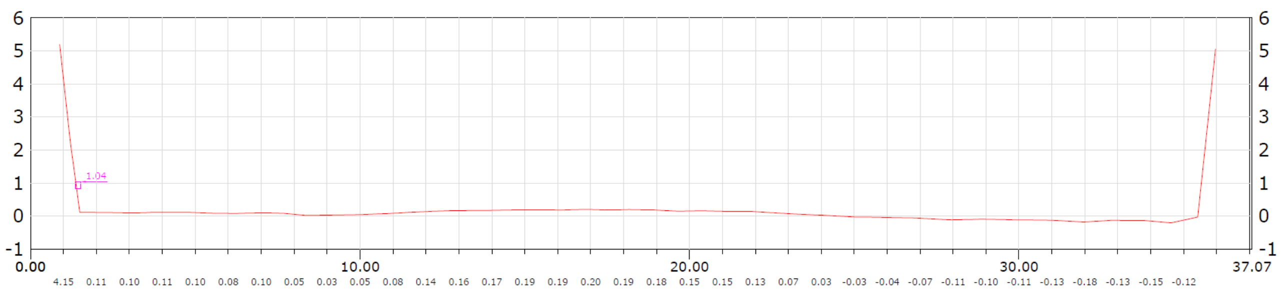


Figure 13 Cross-section of the Misa River in Ponte Garibaldi (survey of 27th November 2019)

The cross section of Figure 13 was used in HEC-RAS, as a cross section number 6,3. In the dedicated window, the cross-section coordinates were inserted, together with the downstream reach lengths and the main channel bank station (Figure 14).

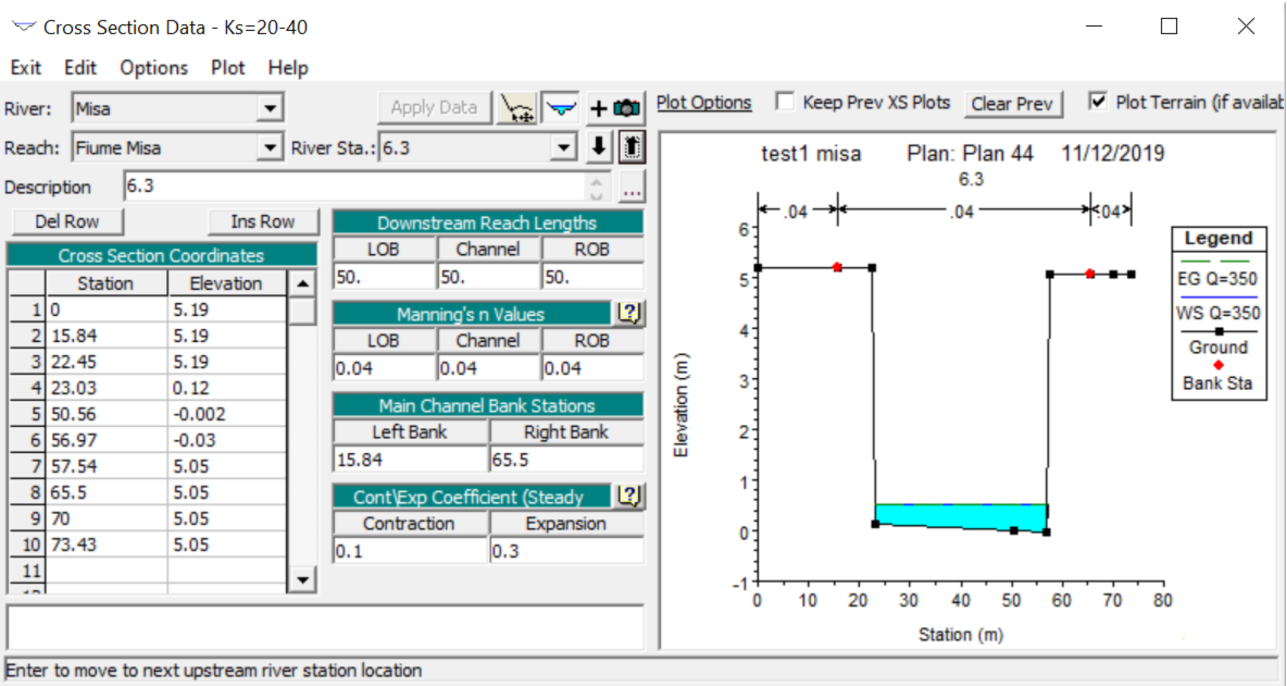


Figure 14 Cross section added

After the inclusion of the new cross section, the discharge data that one wants to analyse have been inserted (see Figure 15). To do the analysis, it is necessary to save the value, passing through "File > Save Flow data as" and insert the name that one wants to add.

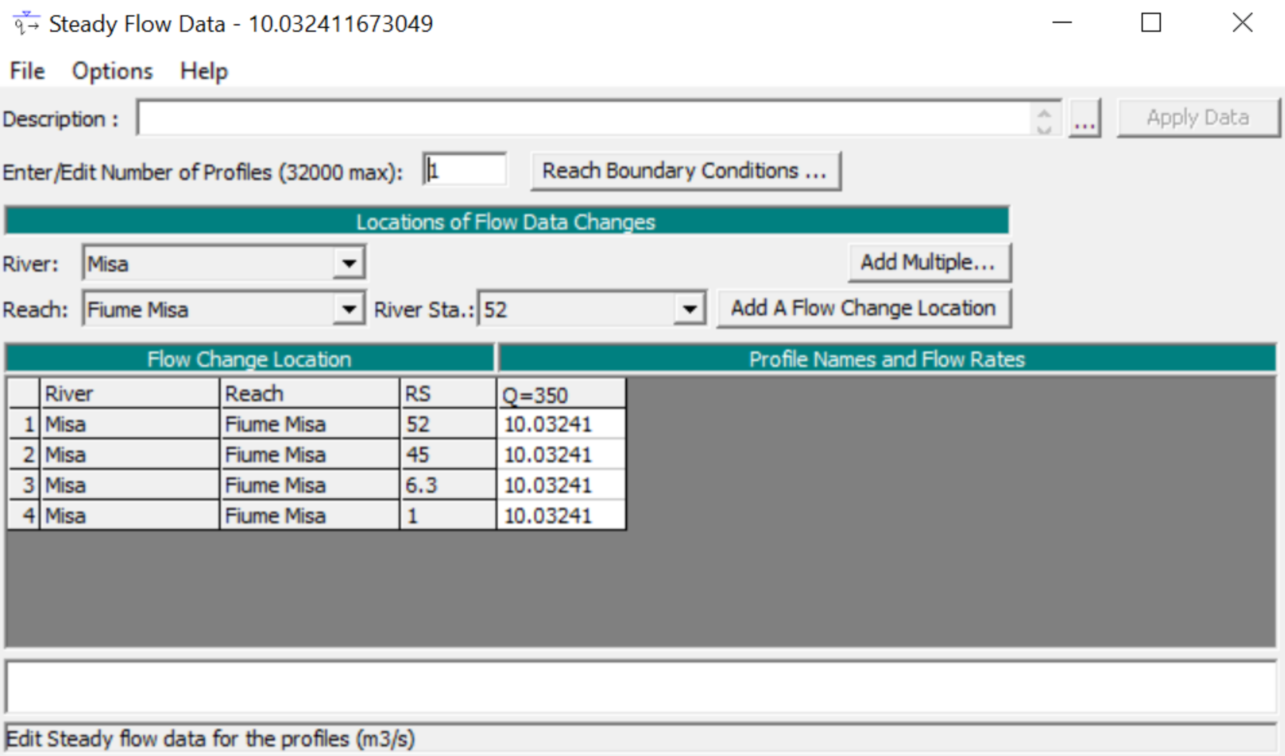


Figure 15 Steady flow data

Then, it is necessary to go back to the main window to start the analysis using the command "Run > Steady Flow Analysis" and pushing the "Compute" button to do the analysis. (Figure 16)

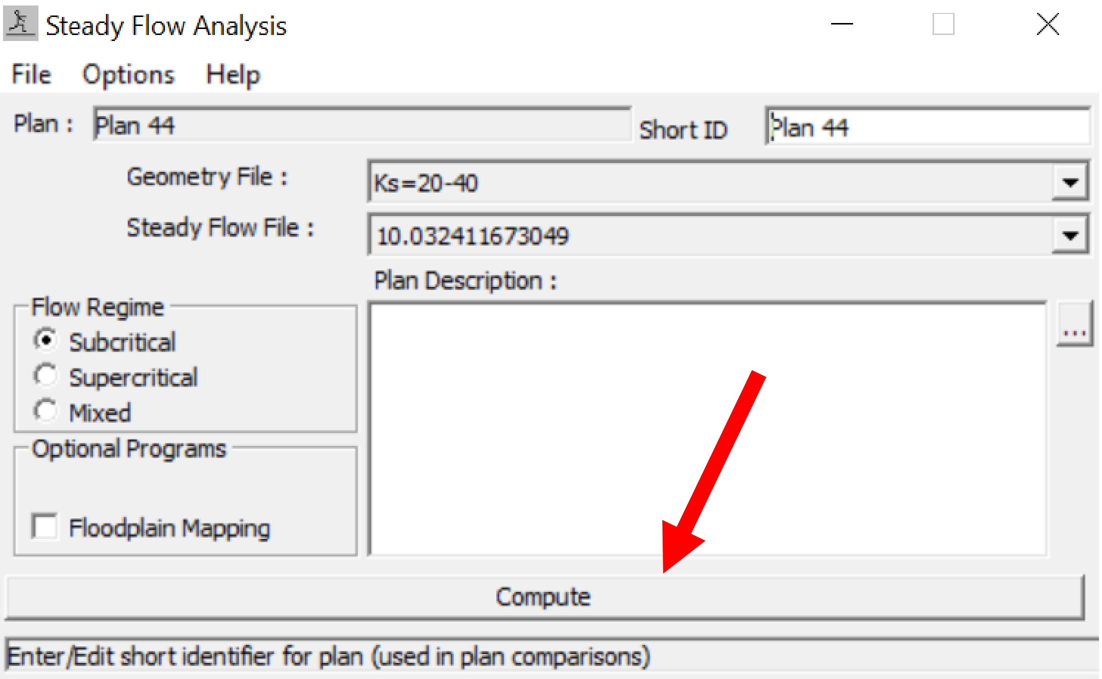
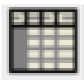


Figure 16 Steady flow analysis window and to do the analysis it is necessary to push in the bottom Compute

The following window is that shown in Figure 17, which highlights the ongoing computation. At the end of the analysis, the table button  in the main HEC-RAS window allows one to have a table with the result of the analysis.

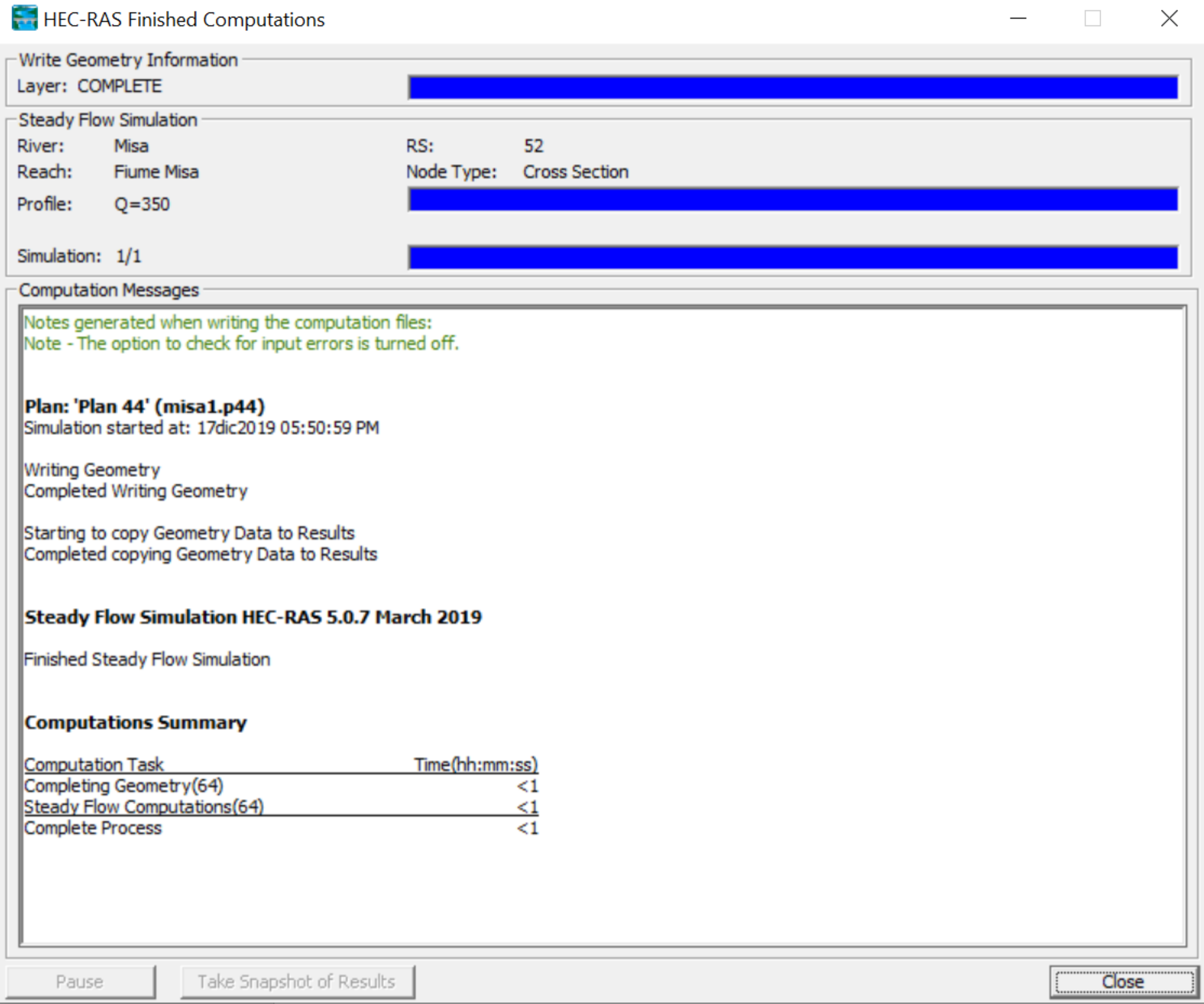


Figure 17 Computation window

The result table is shown in Figure 18, where there are thirteen columns. The most important columns are:

- The second column, where there is the cross-section number;
- The fourth column, where there is the discharge in $\frac{m^3}{s}$;
- The fifth column, where the minimum channel elevation is given in m;
- The sixth column, where the water level elevation is given in m.

Profile Output Table - Standard Table 1

File Options Std. Tables Locations Help

HEC-RAS Plan: Plan 93 River: Misa Reach: Fiume Misa Profile: Q=350

Reload Data

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Fiume Misa	52	Q=350	31.99	25.61	26.90	26.90	27.36	0.013264	3.19	11.34	12.77	0.94
Fiume Misa	51	Q=350	31.99	23.53	26.87	24.78	26.88	0.000120	0.56	77.24	52.08	0.10
Fiume Misa	50	Q=350	31.99	24.02	26.83	25.68	26.85	0.000320	0.82	61.19	52.83	0.16
Fiume Misa	49	Q=350	31.99	24.01	26.40	25.58	26.60	0.002476	2.11	18.66	16.06	0.45
Fiume Misa	48	Q=350	31.99	24.06	25.39	24.82	25.46	0.001755	1.27	29.21	27.93	0.35
Fiume Misa	47	Q=350	31.99	22.75	24.38	24.05	24.65	0.005470	2.46	14.71	12.39	0.63
Fiume Misa	46	Q=350	31.99	20.95	22.76	22.23	22.98	0.003597	2.15	16.75	12.40	0.52
Fiume Misa	45.2	Q=350	31.99	20.85	22.45	21.72	22.48	0.000691	0.84	51.17	61.06	0.22
Fiume Misa	45.1		Bridge									
Fiume Misa	45	Q=350	31.99	20.85	22.44	21.72	22.47	0.000718	0.85	50.52	60.99	0.23
Fiume Misa	44	Q=350	31.99	20.21	21.77	21.48	22.08	0.006437	2.58	13.52	11.00	0.68
Fiume Misa	43	Q=350	31.99	18.84	20.82	20.11	21.00	0.002606	1.94	18.42	12.34	0.45
Fiume Misa	42	Q=350	31.99	18.53	20.52	19.79	20.68	0.002458	1.89	19.05	12.67	0.44
Fiume Misa	41	Q=350	31.99	18.16	19.84	19.37	20.08	0.004291	2.24	15.58	11.52	0.57
Fiume Misa	40	Q=350	31.99	16.77	18.51	18.07	18.77	0.004607	2.31	14.92	10.89	0.58
Fiume Misa	39	Q=350	31.99	14.86	17.02	16.15	17.18	0.002067	1.82	19.46	12.57	0.41
Fiume Misa	38	Q=350	31.99	14.13	16.45	15.44	16.59	0.001653	1.71	21.64	16.54	0.37
Fiume Misa	37	Q=350	31.99	13.53	15.97	14.84	16.09	0.001308	1.58	23.97	16.79	0.33
Fiume Misa	36	Q=350	31.99	12.93	15.49	15.06	15.61	0.001989	1.97	25.10	25.28	0.41
Fiume Misa	35	Q=350	31.99	12.61	15.09	14.76	15.28	0.002810	2.29	20.44	19.54	0.48
Fiume Misa	34	Q=350	31.99	12.35	14.52	14.47	14.84	0.005584	2.93	16.24	20.59	0.66
Fiume Misa	33	Q=350	31.99	12.04	14.18	13.31	14.33	0.001963	1.76	20.22	12.75	0.40
Fiume Misa	32	Q=350	31.99	11.47	13.59	12.76	13.74	0.002052	1.79	20.11	12.98	0.41
Fiume Misa	31	Q=350	31.99	11.09	13.27	12.38	13.41	0.001879	1.75	20.64	12.99	0.39
Fiume Misa	30	Q=350	31.99	10.80	13.19	11.99	13.24	0.000683	1.12	39.47	37.22	0.24
Fiume Misa	29.8	Q=350	31.99	11.69	12.68	12.68	13.12	0.017380	2.94	10.96	12.82	0.98
Fiume Misa	29.2	Q=350	31.99	10.51	12.62	11.87	12.71	0.001722	1.50	27.64	30.19	0.35
Fiume Misa	29.1		Bridge									
Fiume Misa	29	Q=350	31.99	10.51	12.58	11.87	12.68	0.001910	1.56	26.43	29.25	0.37
Fiume Misa	28	Q=350	31.99	9.97	11.78	11.37	12.11	0.006051	2.80	14.90	17.99	0.68
Fiume Misa	27	Q=350	31.99	9.56	11.24	10.76	11.41	0.003559	1.98	19.56	20.71	0.51
Fiume Misa	26	Q=350	31.99	8.67	10.76	9.88	10.81	0.000921	1.17	33.55	25.30	0.27
Fiume Misa	25	Q=350	31.99	8.32	10.58	9.39	10.62	0.000515	0.93	41.61	26.80	0.20

Total flow in cross section.

Figure 18 Results of the steady flow analysis

The analysis of the discharge was done with the program HEC-RAS, and it was well described in the chapter 2.5. Starting from the result of the program, it was extrapolated the data in the two section of interest, in Bettolelle and in Ponte Garibaldi, as it is shown in the HEC-RAS maps in the Figure 19.

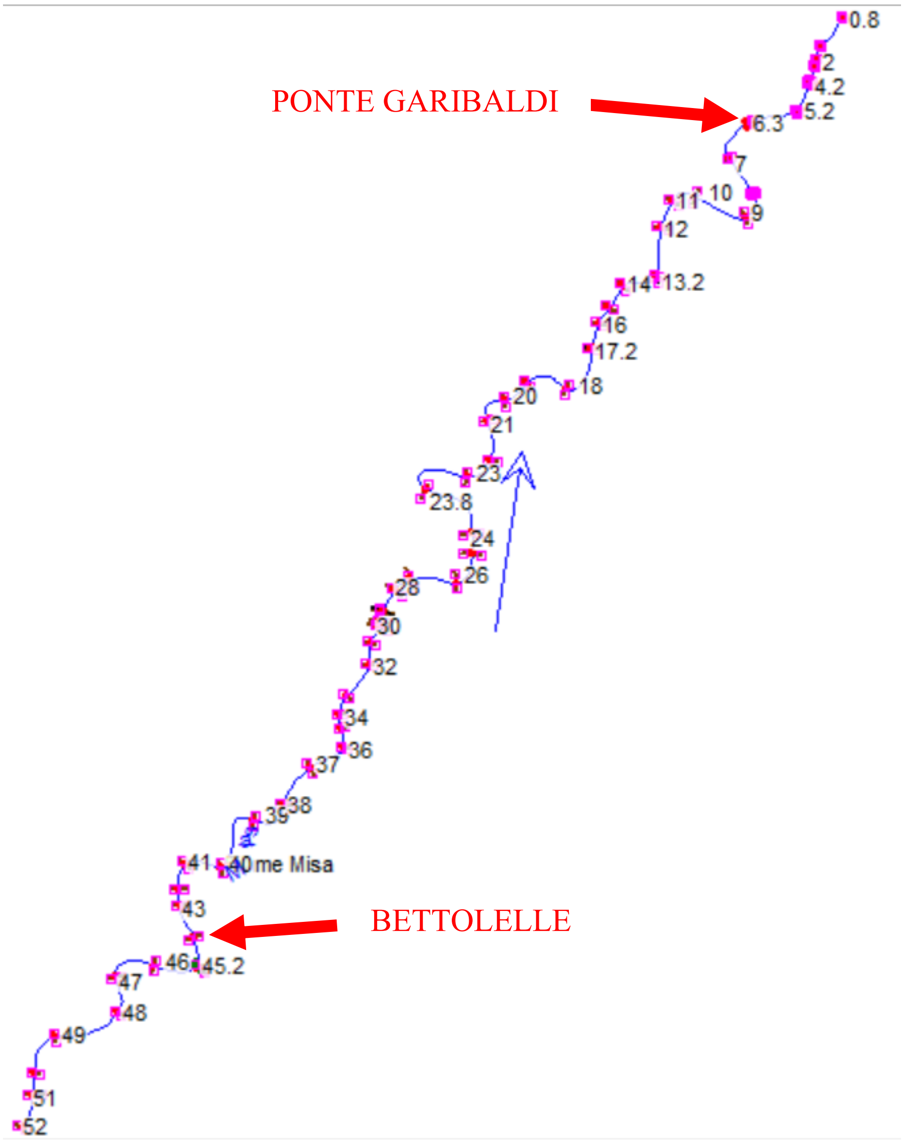


Figure 19 Position of Ponte Garibaldi and Bettolelle

From the column of the Figure 18, it was extrapolated the data of the minimum channel elevation and the water surface elevation. To have the water high (Y in the Figure 9) it is necessary to calculate the difference between the water surface elevation and the minimum channel elevation for both sections. The simulation was done with the boundary condition of water surface of 0.5 meter, and it is possible to see, from the result, the section that are close to the river estuary are affected by the downstream condition. So, in second time it was decided to change the value of the downstream condition in HEC-RAS. The new boundary condition, for the downstream section, about the water surface was find in the ISPRA data (R.M.N. Rete Mareografica Nazionale) of the water level during the period of sea storm, in the maximum value recorded during the November of 2019. It was decided to use the data in the November period because of the data of the H-ADCP. The value of the water surface in the downstream section it will be 0,94 meter, that it was recorded at the 00:40 in the 13th of November 2019. After this new simulation it was decide the comparison with the result rating curve of both the simulation and the H-ADCP result. Both the simulation, with the downstream boundary condition of 0,5m and 0,94m was used for the comparison with the H-ADCP data.

2.6 H-ADCP data

The data of the horizontal acoustic doppler current profile (H-ADCP) was downloaded with the program "MORSE" (Modelling and Observation of River-Sea Exchanges) that give all the data recorded from the gauge. The aim of the MORSE Project is that of performing long-term observations and intensive mathematical/numerical modelling to develop a data assimilation/morphological forecasting system. The MORSE project wants to investigate the short- to long-term dynamics of a small-scale engineered river mouth environment and study the exchanges of river-sea water and sediments, as well as the complex morphodynamics characterizing these kinds of environments. The data, collected from the gauge, are about the water level, the velocity of the water, the discharge and the temperature, as it could be seen in the Figure 20.

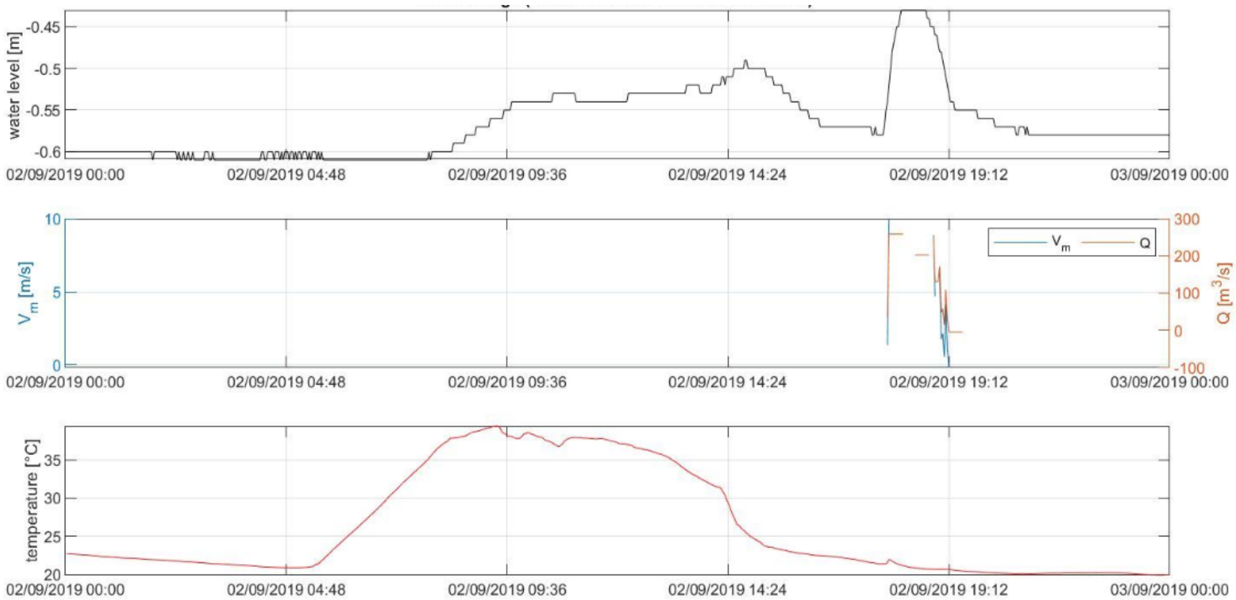


Figure 20 MORSE data: water level, velocity, discharge and temperature

The data, collected from the H-ADCP, are shown in the Table 2 where in the column there are the time (divided in year, month, day, hour, minute, second), the water level, that has a unit of measure of meter, the velocity, that has a unit of measure in $\frac{m}{s}$ and the discharge, that has a unit of measure $\frac{m^3}{s}$.

Year	Month	Day	Hour	Minute	Second	Water level	Velocity	Discharge
2018	8	5	4	10	0	0,55	-14,82	-81,3
2018	8	8	7	12	0	0,58	-6,56	-38,16
2018	8	26	20	24	0	0,48	-88,11	-415,61
2018	8	26	21	50	0	0,48	-4,81	-22,88
2018	9	24	10	10	0	0,55	0,12	0,66
2018	9	24	10	12	0	0,56	-0,35	-1,95

Table 2 H-ADCP data

2.7 Rating curve

The discharge of a stream is defined as the volume that flows out in the unit of time through a given section. The measurement of this physical quantity is addressed indirectly going to measure the stage above the datum quantities related to it. In hydrology, a rating curve is a graph of discharge versus the stage above the datum and it is usually plotted as discharge on x-axis versus stage (surface elevation) on y-axis. For the measurement of the discharge in a natural river, as it is the Misa River, it is referred to the measurement of the water height in the section, which is carried out with respect to a predetermined geometric level, the hydrometric zero. Generally, the flow scales, numerical or analytical, reported in the "Annali Idrologici" are varying from one year to another and, sometimes, even within the same year. The variations may be linked to changes in the location of the measuring instrument or the creation of artifacts along the riverbed, which modify the outflow regime. In all these cases there is the modification of the hydrometric zero. To represent the variability of the curves it is more appropriate to define the rating curve through the law proposed by Herschy (1985):

$$Q = \alpha(H - H_0)^{\beta}$$

where:

- α, β represent coefficients, which need to be estimate;
- H_0 is the an estimation of the hydrometric zero.

In this study the rating curve provided by SIRMIP was used, as it is shown in Figure 21.

Figure 21 Rating curve in the site SIRMIP

The file of the rating curve is present in Bettolelle station, while for the Ponte Garibaldi station there is not rating curve, because of it is placed in the 2016, so there is not a rating curve. The "Scala di deflusso" file, that permits the calculation of the discharge starting from the hydrometric level, contains the time range of validity, the interval of hydrometric level, that it could be used in the calculation of the discharge, and the rating curve as it is shown in Table 3.

Starting validity	Ending validity	Interval stage above the datum	Rating curve
01/01/2005 00:01	01/01/2006 00:00	0,56≤H≤4,34	$Q = 8{,}39 * [H - 0{,}55]^{2{,}323} + 0$
01/01/2006 00:01	01/01/2007 00:00	1,02≤H≤5,01	$Q = 23{,}351 * [H - 1{,}011]^{1{,}659} + 0$
01/01/2007 00:01	13/12/2008 07:00	0,77≤H≤4,33	$Q = 9{,}4265 * [H - 0{,}76]^{2{,}137} + 0$
13/12/2008 07:01	01/01/2011 00:00	0,77≤H≤4,01	$Q = 11{,}4929 * [H - 0{,}76]^{1{,}8516} + 0$
01/01/2011 00:01	01/03/2011 10:30	0,77≤H≤9999	$Q = 11{,}4929 * [H - 0{,}76]^{1{,}8516} + 0$
05/03/2011 00:01	23/05/2015 06:30	0,55≤H≤4,39	$Q = 6{,}195 * [H - 0{,}517]^{2{,}576} + 0$
05/03/2011 00:01	23/05/2015 06:30	4,4≤H ≤6,35	$Q = 185{,}568 * [H - 4{,}39]^{1{,}138} + 202{,}776$
23/05/2015 06:31	07/03/2017 16:00	0,2≤H≤1,51	$Q = 5{,}9 * [H - 0{,}148]^{2{,}934} + 0$
23/05/2015 06:31	07/03/2017 16:00	1,52≤H≤3,01	$Q = 27{,}549 * [H - 1{,}51]^{1{,}188} + 14{,}609$
23/05/2015 06:31	07/03/2017 16:00	3,02≤H≤6,5	$Q = 101{,}284 * [H - 3{,}01]^{1{,}061} + 59{,}209$
07/03/2017 16:01	01/01/2030 00:00	0,95 ≤H≤3,02	$Q = 14{,}388 * [H - 0{,}942]^{1{,}974} + 0$
07/03/2017 16:01	01/01/2030 00:00	3,03≤H ≤6,5	$Q = 100{,}396 * [H - 3{,}02]^{1{,}068} + 60{,}954$

Table 3 Rating curve of Bettolelle

2.8 Hydrological model

Hydrological models are becoming more and more widespread, mainly due to their capacity to simulate the impact of environmental changes on water resources. Considering the water balance, as it is shown in the Figure 22, it is possible to see that this is determined by the local interaction of fluctuating water supply (precipitation) and demand (potential evapotranspiration), mediated by water storage in the soil (Roger N. Jones, 2005). In general, therefore, use of a water-balance technique implies measurement of both storages and fluxes (rates of flow) of water, though appropriately selecting the volume and period of time for which the balance will be applied. The water balance equation, i.e.

$$P = Q + E + \Delta S$$

is valid for any natural area (such as a river basin), and is composed by precipitation (P), i.e. rainfall and snow actually received at the ground surface, the evapotranspiration, from the surface of the water body and watershed (E), and the water content in the soil (ΔS). Evapotranspiration consists in the quantity of water (referred to the unit of time) that from the ground passes through the air to the vapor state due to the joint of transpiration, through the plants, and evaporation, directly from the ground.

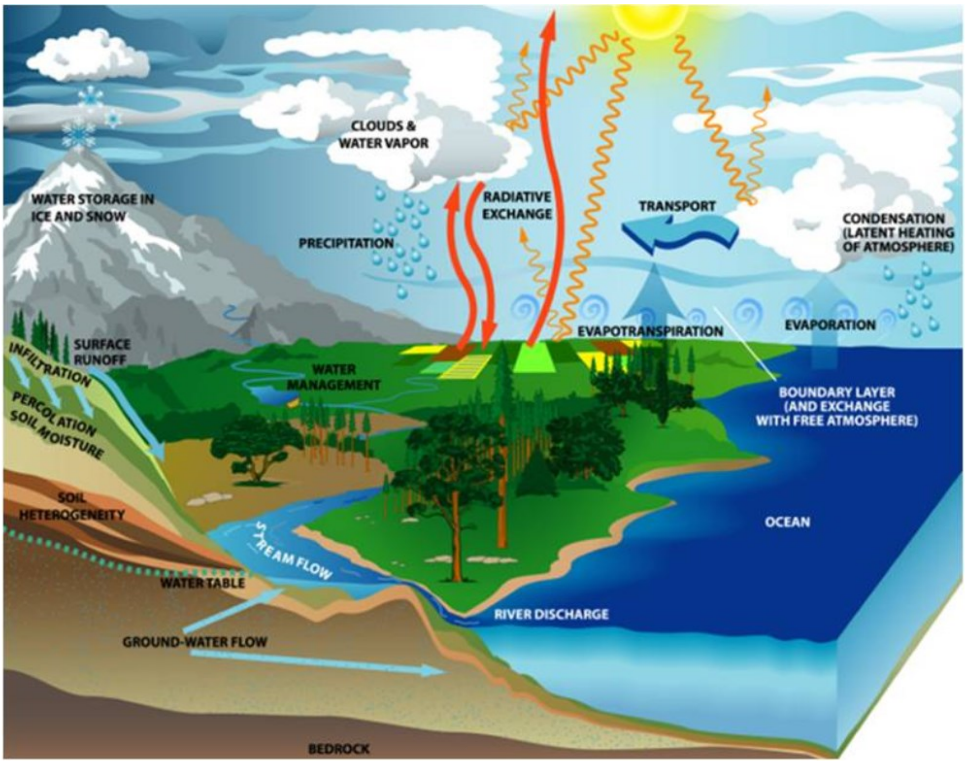


Figure 22 Water balance

Runoff is usually considered as a streamflow that involves surface runoff and groundwater flow that reaches the streams. Surface runoff is function of intensity, duration, and distribution of rain precipitation, permeability of ground surface, surface coverage (i.e., arid or semiarid), geometry of stream channel, depth of water table, and the slope of the land surface. The water infiltrates the soil and depends on the kind of soil present in the basin. The potential evapotranspiration is different, referring to a standard environmental condition in which the incidence of external factors, agronomic, biological, and part of the climatic factors is not considered. The purpose of this variable is to make the evapotranspiration values in space and time comparable. (G. Darvini & F. Memmola, 2020) For this reason, potential evapotranspiration refers to the maximum amount that can be lost in the unit of time by evaporation and transpiration without external limitations. Many formulas are available for the calculation of the real evapotranspiration of a basin. Usually, the method, that is considered is the Thornthwaite method. The Thornthwaite method was developed from rainfall and runoff data for several drainage basins. The result is basically an empirical relationship between potential evapotranspiration and mean air temperature. In spite of the inherent simplicity and obvious limitations of the method, it performs surprisingly well. Following the Thornthwaite method, a potential evapotranspiration estimation $EP_{pot\,nc}$ is obtained for each month, considering a month is 30 days long and there are 12 theoretical sunshine hours per day, applying the following equation:

$$EP_{pot\,nc} = 16 * \left(\frac{10 * t}{I}\right)^{\alpha}$$

where:

- t is the average monthly temperature;
- I is the annual heat index calculated as $I = \sum_{i=1}^{12} i$ where $i = \left(\frac{t}{5}\right)^{1.514}$
- α is equal to $\alpha = 675 * 10 - 9 * I3 - 771 * 10 - 7 * I2 + 179210 - 5 * I$

The $EP_{pot\,nc}$ needs to be corrected with the real length of the month and the value of sunshine hour for the specific latitude with the equation:

$$EP_{pot} = EP_{pot\,nc} * \frac{N * d}{12 * 30}$$

where:

- N is the theoretical sunshine hours for each month;
- d is the number of the days for each month;

Starting from the value of the EP_{pot} and the $P(t)$, the precipitation in function of the time, it is possible to evaluate the evapotranspiration $E(t)$ as:

- whether $P(t)$ or $P(t)$+ $S(t)$ is greater or equal to the potential monthly evapotranspiration EP_{pot}, i.e. if there is no water limit, the potential evapotranspiration can be considered coinciding with the real monthly evapotranspiration: $E(t) = E_{pot}(t)$
- if $P(t)$+ $S(t)$ is smaller than EP_{pot}, the actual evapotranspiration is less than the potential evapotranspiration, and $E(t) = P(t)$+ $S(t)$.

To correctly use the model, a calibration parameter C, which was added. The runoff, calculated in month, is referring to the soil water content S(t), where t is referring to a specific event of precipitation, so the equation is:

$$Q(t) = S(t) * \tanh\left[\frac{S(t)}{SC}\right]$$

where:

- SC is a parameter that represent the field capacity of a basins, with the unit of millimeter.

The quantity of the remaining water in the soil at the beginning of the t-th month is $S(t-1) + P(t) + E(t)$, after loss through evapotranspiration $E(t)$, with $S(t-1)$ being the water content at the end of the $(t-1)$ th month and at the beginning of the t-th month. Equation is then used to calculate the t-th monthly runoff as

$$Q(t) = [S(t-1) + P(t) + E(t)] * \tanh\left\{\frac{[S(t-1) + P(t) + E(t)]}{SC}\right\}$$

where S (0) is the third parameter of the model, whose determination is quite simple because it has no significant incidence, except in the first period of the series analysed. Finally, the water content at the end of the t-th month was calculated according to the water conservation law:

$$S(t) = S(t-1) + P(t) + E(t) - Q(t)$$

To have a correct evaluation of the model, it is necessary to introduce some variable that are:

$$R = \frac{\sum_{i=1}^{N}(Q_{obs}(i) - \bar{Q}_{obs})(Q_{sim}(i) - \bar{Q}_{sim})}{[\sum_{i=1}^{N}(Q_{obs}(i) - \bar{Q}_{obs})^2]^{1/2}[\sum_{i=1}^{N}(Q_{sim}(i) - \bar{Q}_{sim})^2]^{1/2}}$$

$$NSCE = \frac{\sum_{i=1}^{N}(Q_{obs}(i) - Q_{sim}(i))^2}{\sum_{i=1}^{N}(Q_{obs}(i) - \bar{Q}_{obs})^2}$$

$$BIAS = \frac{\sum_{i=1}^{N}(Q_{obs}(i) - Q_{sim}(i))}{\sum_{i=1}^{N} Q_{obs}(i)}$$

where:

- R is the correlation coefficient
- $NSCE$ is Nash-Sutcliffe coefficient
- $BIAS$ is Relative Bias
- N is the number of data points
- $Q_{obs}(i)$ is the observed runoff (millimeter per month) at time step i
- $\bar{Q}_{obs}(i)$ is the mean observed runoff (millimeter per month) at time step i
- $Q_{sim}(i)$ is the simulated runoff (millimeter per month) at time step i

The hydrological model, applied to the time range from the 2005 to the 2019, was separated into three periods, because it is necessary to have a period of calibration (2005-2009), a period of validation (2010-2014) and a period of application (2015-2019).

Chapter 3: Case study

The Misa River flows in Marche Region, in the province of Ancona (Marche Region, central Italy). The source, with an approximate level of 793 m above the sea, is located south of Arcevia, in the “Appennino umbro-marchigiano”, and the river flows in the municipalities of Serra de’ Conti, Ostra and Senigallia, where it enters the Adriatic Sea after 48 km (Figure 23).

Figure 23 Misa River in Senigallia

The watershed extension of the Misa River is $383 km^2$, with discharges of about 400, 450, and 600 $\frac{m^3}{s}$ for return periods of 100, 200, and 500 years, respectively. The Misa River has a marked torrential regime with impetuous floods in the rainy seasons. The Misa River flows in the watershed, where find the end in the city of Senigallia. So, there is an estuary. The Misa River is representative of the majority of the rivers debouching into the Western Adriatic Sea. Following the classical definition of an estuary, the place where the tide overlaps with the current of a stream, the Misa River is characteristic of a salt-wedge estuary , (M., 1986), where the river forcing prevails on both marine and tidal influence. Such an estuary type is usually characterized by a freshwater layer over seawater thinning while flowing seaward. Additionally, the zone around the Misa estuary (Figure 24), within the town of Senigallia (Italy), is heavily engineered having cement walls comparable to a field-scale laboratory flume (Figure 244).

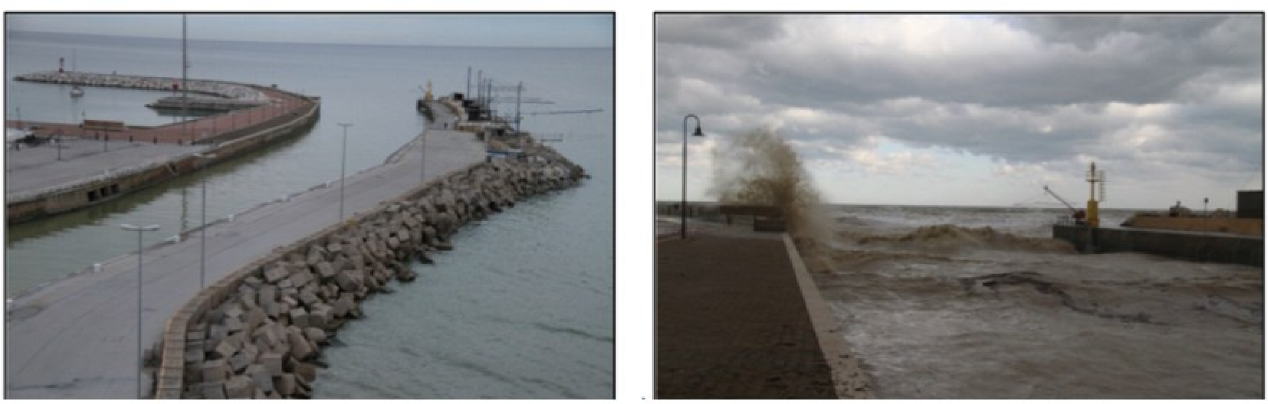


Figure 244 Misa estuary during stormy and calm conditions

The beach to the north of the Misa River estuary is engineered with breakwaters, while the beach to the south is a natural open coast. In the path of the Misa River, there are some instrument, that are located close to the river to collect data for some variable. To have information about the instrument, it is necessary to see the "Annali Idrologici", where it is possible to find information about the watershed.

The "Annali Idrologici" is a hydrographic and hydrological bulletin that is periodically published with information on, among others, rainfall and hydrometry. The "Annali Idrologici" are divided into two parts:

- "Parte I": generally containing results of daily rainfall and hydrometric observations. Daily rain means the height of precipitation, expressed in mm, falling in the 24 hours between 09:00 of the day on which the measurement was made and the 09:00 of the previous day.
- "Parte II" is divided into
    a. Meteoric flux, with the monthly value and the yearly of the meteoric flux
    b. Hydrometry, contain the maps and the index of the station, and the observed hydrometry of the station.
    c. Hydrological balance and discharge: that contain the maps and the station present in the field of interest.

3.1 Precipitation measurement

The data, regarding the precipitation, are collected in the site SIRMIP, and it could be possible to find information about the station and also about the instrument used for the collection of the data. The Table 4, that come from the “Annali Idrologici”, shows in the first column the basin and the station considered, in the second column the type of the instrument, that in this case is the same for all the station considered in the analysis, in the third column the elevation of the station from the sea level, in the fourth column there is the high of the instrument from the ground level and in the last column there is the year when the instrument start to collect data. In the Figure 25 it is possible to see the position of each station considered in the analysis of the precipitation. The instrument used for the precipitation measurement is the pluviometry, as the example in the Figure 26. It is an instrument used to evaluate the high of the water level with a period of data recording of 15 minutes, with a range of analysis shown in the Table 5.

BACINO E STAZIONE	Tipo dell'apparecchio	Quota sul mare	Altezza dell'apparecchio	Anno d'inizio delle osservazioni
Misa				
Arcevia	PP	535	2	2003
Barbara	PP	186	2	2009
Bettolelle	PP	26	2	2007
Colle	PP	350	2	2003
Corinaldo	PP	218	2	2014

Table 4 Example of the "Annali Idrologici" for the precipitation

Figure 25 Precipitation stations

In this study, it was analysed the data of the precipitation in the station and in the time period that are list below, as in the Table 5.

Data	**Station**	**Time period**
Precipitation	*Arcevia*	*01.2005 - 11.2019*
	Barbara	*01.2005 - 11.2019*
	Bettollele	*06.2007 - 11.2019*
	Colle	*01.2005 - 11.2019*
	Corinaldo	*01.2005- 11.2019*

Table 5 Precipitation in the station and in the time period of analysis

Figure 26 Example of pluviometer

3.2 Temperature measurement

Starting from what is written in the “Annali Idrologici”, it could be possible to see in the Table 6, the basin and the station considered, the type of the instrument, that in this case is the same for all the station considered in the analysis, the elevation of the station from the sea level, the high of the instrument from the ground level and the year when the instrument start to collect data. In the Figure 27 it is possible to see the position of each station considered in the analysis of the temperature. The instrument used is a thermometer, an example is shown in the Figure 28, that is an instrument used to evaluate the temperature, that release data every 30 minutes and the period of analysis is shown in the Table 7 . Frequently the thermometer is coupled with the barometer, which record the data pf the atmospheric pressure, the hygrometer, that record the humidity and the anemometer, that recod the wind speed. In fact, as was illustrated in the Figure 3, in the site SIRMIP, there are also information about wind speed, the humidity and the hygrometry.

BACINO E STAZIONE	Tipo dell'apparecchio	Quota sul mare	Altezza dell'apparecchio	Anno d'inizio delle osservazioni
Misa				
Arcevia	TA	535	2	2003
Bettolelle	TA	26	2	2007
Colle	TA	350	2	2003
Corinaldo	TA	218	2	2014

Table 6 Example of the "Annali Idrologici" for the temperature

The station considered for the temperature are shown in the Figure 27 and the time period analysed are show in the Table 7.

Figure 27 Temperature station

Data	Station	Time period
Temperature	*Arcevia*	*01.2005 - 11.2019*
	Bettollele	*06.2007 - 09.2019*
	Colle	*01.2005 - 11.2019*
	Corinaldo	*03.2014 - 11.2019*

Table 7 Temperature station and period

Figure 28 Example of thermometer

3.3 Water-level measurement

The analysis of the water-level measurement in the watershed has been carried out for the period between 2005 and 2019, as reported in the Table 8. In this study, the discharge at Bettolelle station is calculated, starting from the hydrometric level and it is measured by an ultrasonic water gauge (Figure 29).

Data	Station	Time period
Hydrometric level (m)	*Bettollele*	*01.2005 - 11.2019*

Table 8 Hydrometric data, station and period of observation

An ultrasonic flow meter is a type of flow meter that measures the velocity of fluid with ultrasound to calculate volume flow. Using ultrasonic transducers, the flow meter can measure the average velocity along the path of an emitted beam of ultrasound, by averaging the difference in measured transit time between the pulses of ultrasound propagating into and against the direction of the flow or by measuring the frequency shift from the Doppler effect. Ultrasonic flow meters are affected by the acoustic properties of the fluid and can be impacted by temperature, density, viscosity and suspended particulates depending on the exact flow meter

Figure 29 Example of ultrasonic river gauge

Before the ultrasonic water gauge (Figure 29), a manual gauge was used, the so-called “Asta graduata” (Figure 30), which is now used for the calibration of the new instrument. As it is shown in the Figure 30, the graduation line allows one the visual reading of the value and nowadays is not a performed kind of recording of data.

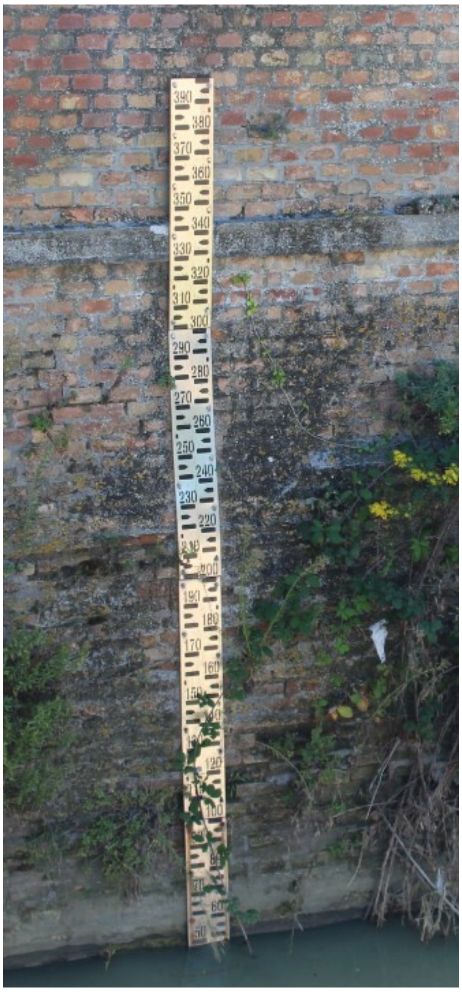


Figure 30 Manual gauge

For the present study in the Misa River, the discharge is calculated at the Bettolelle station, as it was shown in the Figure 5, using the rating curve, although a new instrument has been recently installed at the “Ponte Garibaldi” station, i.e. a Horizontal Acoustic Doppler Current Profiler (H-ADCP).

3.4 Discharge measurement: Horizontal Acoustic Doppler Current Profiler

Since the discharge at Bettolelle is the same as the discharge calculated at the cross section of Ponte Garibaldi due to the conservation law, the data estimated at both locations may be compared. The H-ADCP (Figure 31) was placed horizontally from its mounting structure to measure near-surface water currents and optional multi-directional waves.

Figure 31 H-ADCP gauge

Commonly the H-ADCP is an instrument used for the collection of stream velocity data and also the water surface elevation. The H-ADCP works sending acoustic pulses from their transducer faces into the water column, where they are reflected back by particles and the exact time of their return to the transducer face is measured. The time of the returning signal is affected by the Doppler effect of the moving particles in the water. The time differences measured in the returned signal are used to infer the velocity of the water the particles are travelling with (Figure 32).

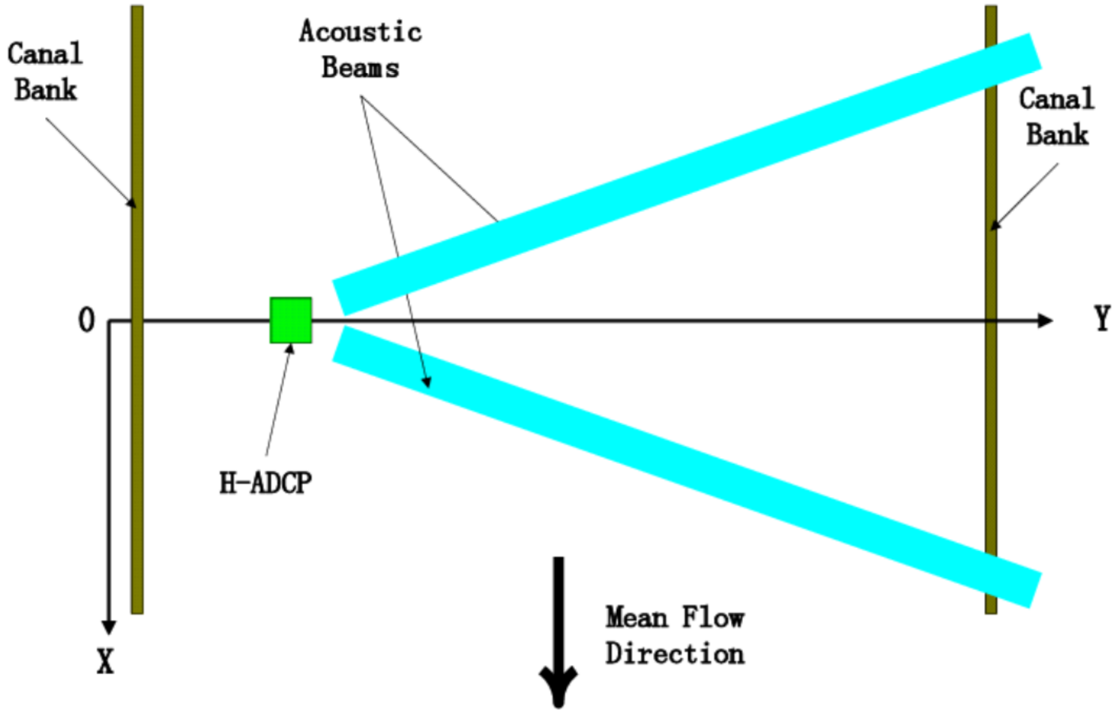


Figure 32 H-ADCP gauge beams influence

A disadvantage of this type of system is that velocity measurements lie completely in a horizontal plane and no information regarding the vertical structure of the velocities is available. In practice, the instrument sends a signal at a given frequency and reads the changes in frequency of the return signal, which are proportional to the relative speed between the ADCP and the reflectors themselves (Doppler effect). The instrument has two inclined transducers, in this case, that point in different directions, which emit pings of acoustic energy at a given working frequency, depending on the characteristics of each tool. Several methods are available to convert H-ADCP data to discharge. In the velocity profile method (VPM), described by (Paquier, 26 November 2008), the total discharge is inferred from theoretical vertical velocity profiles, made dimensional with the H-ADCP velocity measurements across the section, extrapolated over the river width (H. Hidayat, 30 August 2011), and combining elements of both IVM and VPM methods, using a boundary layer model to calculate specific discharge from a point measurement of velocity, and a regression model to relate specific discharge to total discharge.

Chapter 4: Results

4.1 Precipitation analysis

The data was analysed using the MATLAB environment, that allows to have a correct and precise computation. The data, downloaded from the SIRMIP system, were validated using a threshold of 10%, i.e. months with an amount of missing data larger than 10% were discarded. As already mentioned, the precipitation analysis has been done for five stations. In Figure 33, the data about related to the station of Arcevia are illustrated, with the blue line representing the daily precipitation and the orange line the monthly precipitation. Moreover, since all data are collected in the same figure and the range for the daily precipitation is different from the range of the monthly precipitation, a second vertical axis has been used to better visualize the both series. As it could be seen in the Figure 33 for the daily precipitation, there is a peak in the 1st of January of 2015 where the precipitation reaches the value 133,2 mm. There is another peak, that is reach the high of 123,2m in the 23th of the September 2013. The other value of the daily precipitation does not reach the value of 80 mm. So, from the 2005 to the 2019 the trend of the precipitation, excluded the higher peak in the 2015 and in the 2013, the trend of precipitation is not so high. The monthly precipitation is characterized by a range value from the 100mm to 300 mm, but it is present a maximum peak line close to the 23th September 2013. There are also some peak over the 200mm in average in the monthly sum.

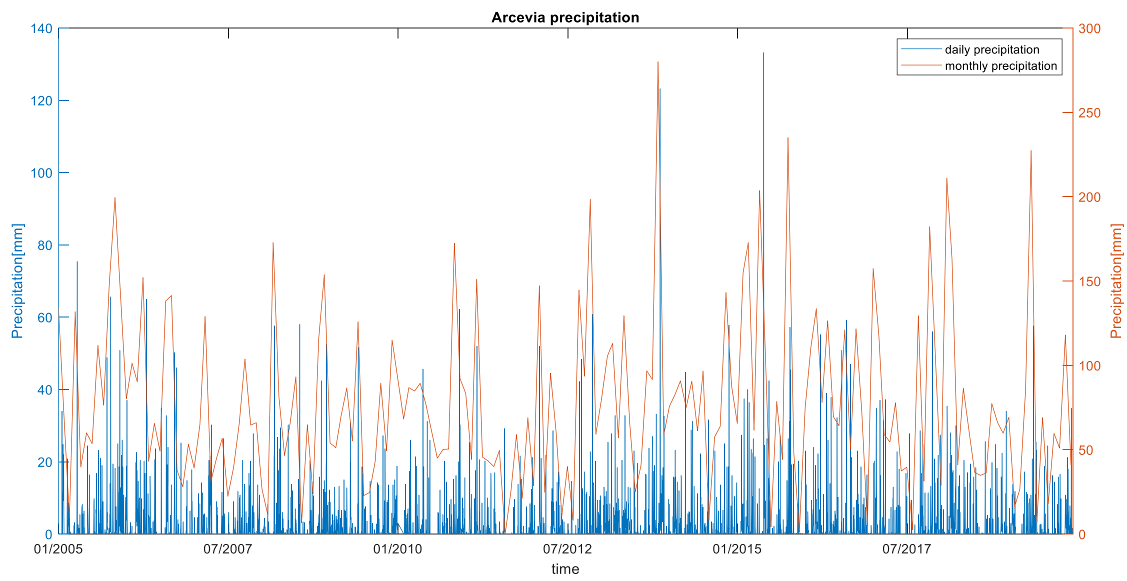


Figure 33 Arcevia:daily and monthly precipitation

The second station is that located at Barbara, whose data are shown in Figure 34. A blank interval can be noted for the daily precipitation during the 2009, due to a large amount of missing data, more than the selected 10% threshold. Starting from the figure the maximum value of precipitation, that fall in the station of Barbara, it is 115 closes to the 2015. The peak of value reaches in the Barbara station are lower than the data, that was collected in the Arcevia station. The monthly average value reaches the peak in the July of the 2012 while the other values are all in the range from 100 mm to the 200mm. The station of Barbara, in the year from the 2005 to the 2019 is characterize almost by single event under the value of precipitation of 20mm.

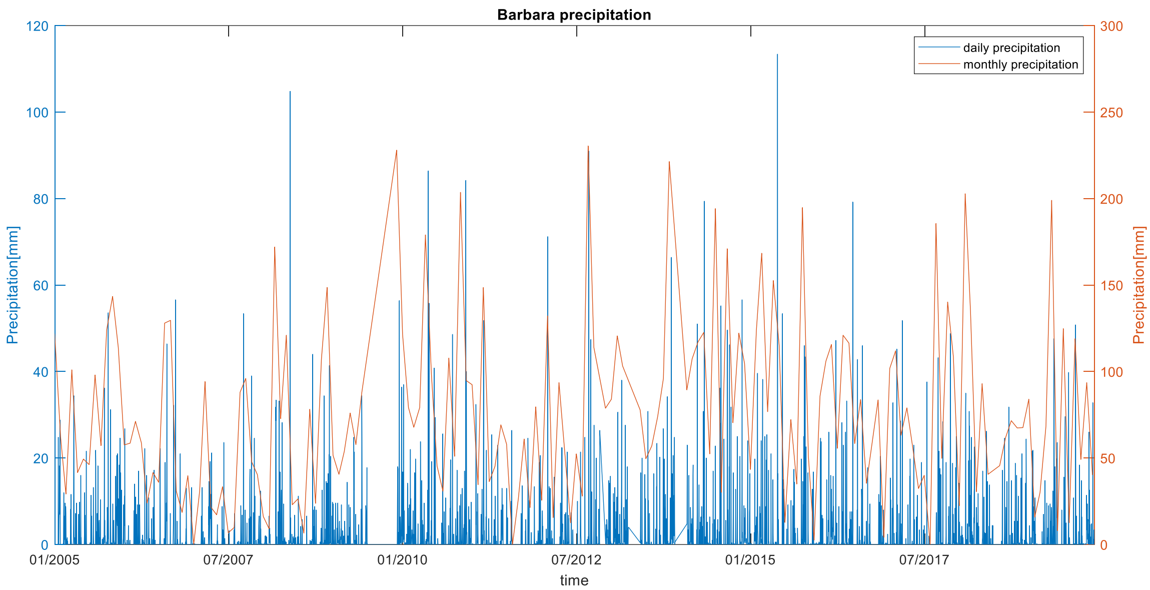


Figure 34 Barbara:daily and monthly precipitation

In the Figure 35, that represents the precipitation data of the station of Bettolelle, it is possible to underline the starting point of the x-axis at the end of 2007, because no data are present before 2007 and between the beginning and the end of 2007, many months are discarded because the amount of missing data is larger than 10%. The daily precipitation is characterized by a peak value of 225m in the January of the 2008. The peak in the daily precipitation, makes that the monthly precipitation reaches close the value of 300 mm. In the monthly precipitation most of the data does not arrive to the value of precipitation of 150mm. Excluded the peak value in the January of 2008, the precipitation that fall in the Betolelle station are not so high, they are under the 50 mm of precipitation.

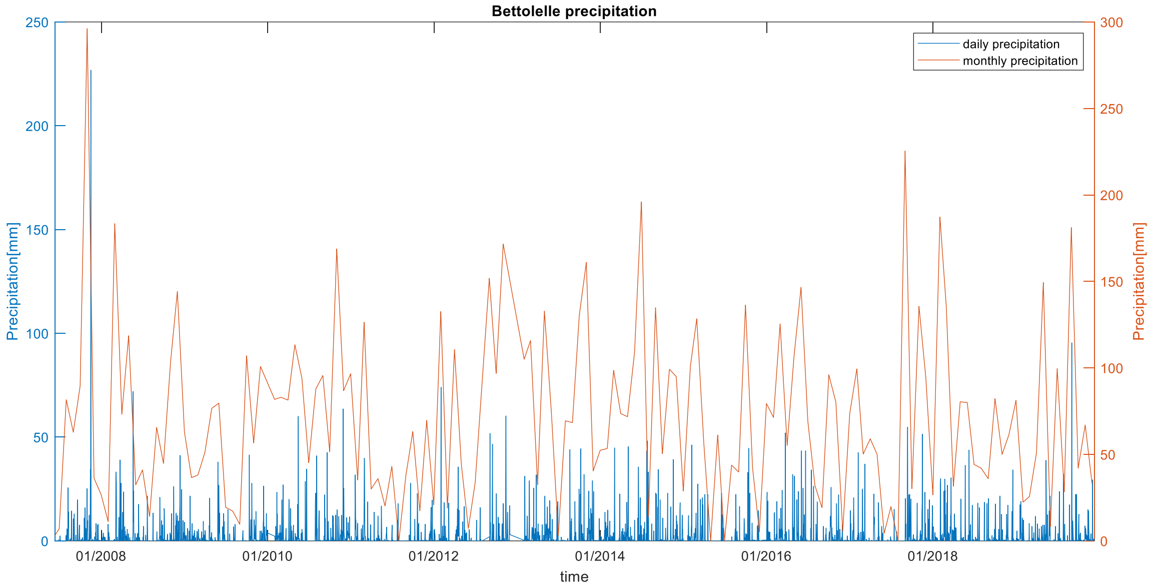


Figure 35 Bettolelle:daily and monthly precipitation

Figure 36, referring to the daily precipitation and the monthly precipitation at Colle station, shows data since the year 2008, because in the period 2005-2008 there are too many missing data and the threshold of missing data is the 10% in a month. There is another period, where the missing data are more than the 10% in a month, in fact there is a blank part in the Figure 36 during the period of 2009 to the 2010. For the daily precipitation, there is a peak value of 97 mm in the 2015, also there are three peaks close to the 80 mm of high of the water. The trend of the precipitation excluded the peak value, the other value is not so high, and are under the value 30mm. The monthly precipitation reaches the maximum value in the peak in the 2012 but it does not arrive to the value of 200m of precipitation. The trend of the monthly precipitation is always under the 150mm of precipitation.

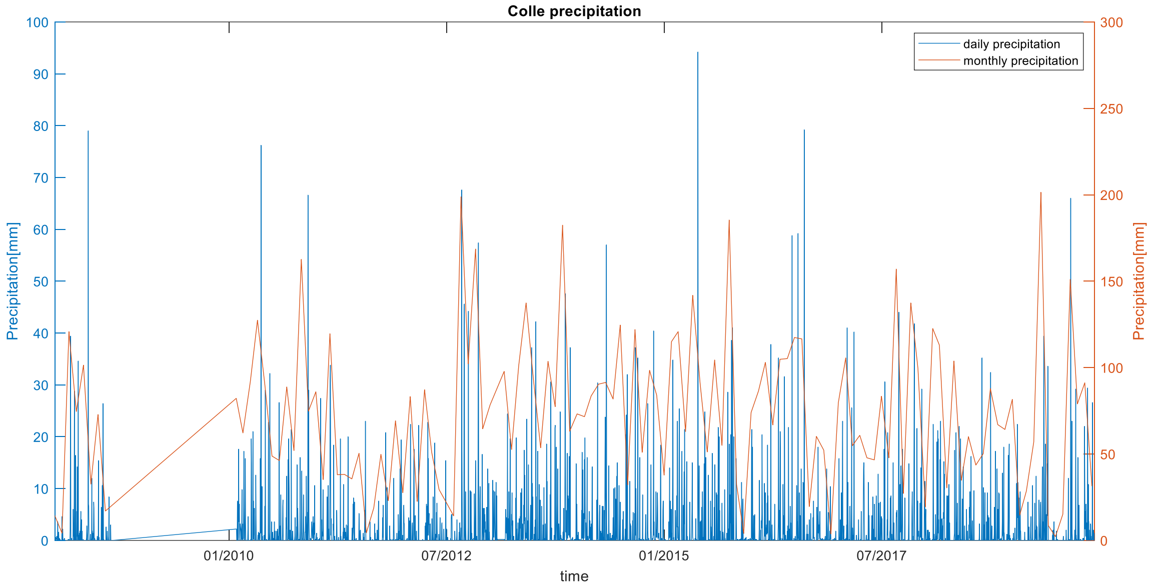


Figure 36 Colle:daily and monthly precipitation

The last pluviometer analysed in the Misa River watershed is located at Corinaldo (Figure 37), where there are all the data from the year 2005 to 2019. The data are completed, and the trend of this station is very similar to the trend of the data of all the other station. In fact, the daily precipitation trend does not reach value over the 40 mm, where the highest value of the trend for the other station is 50mm. The monthly precipitation has a trend that arrive to the value 200mm, with a only one peak at 222mm.

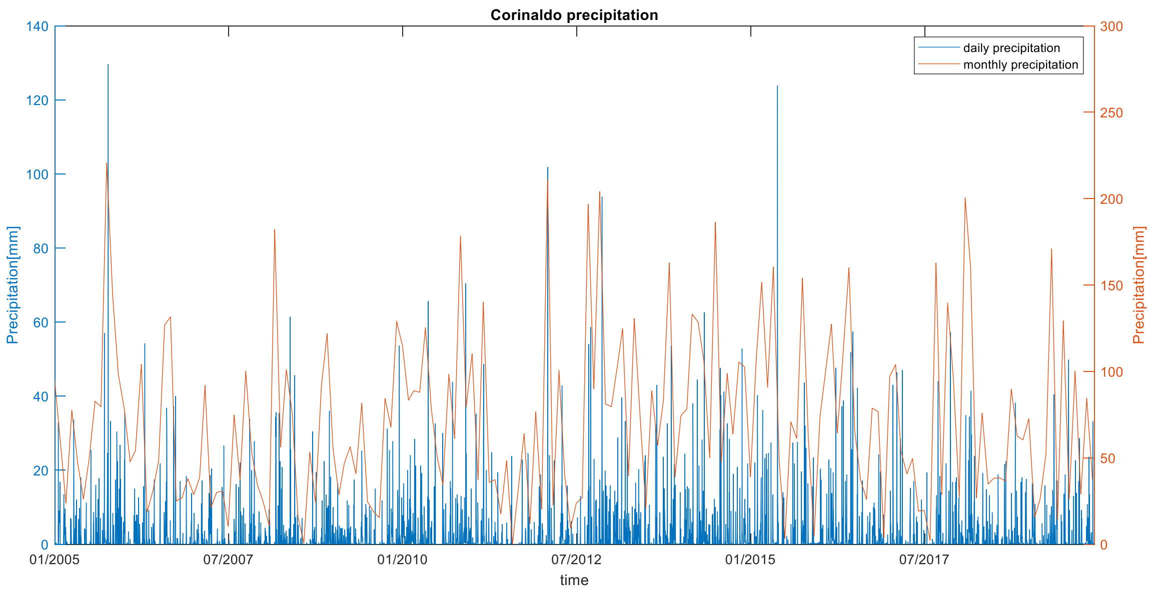


Figure 37 Corinaldo:daily and monthly precipitation

The station analysed are located at different distances from the centroid of the watershed. For this reason, the Inverse Distance Weighted (IDW) method was used to get the average precipitation characterizing the watershed, starting from the value of the distance of each station to the watershed centroid, as it is shown in the Table 9.

Measuring station	Distance from w.c.
Arcevia	13365.4
Barbara	2012.9
Bettolelle	12831.7
Colle	5538.2
Corinaldo	7223.1

Table 9 Distance of each station from the watershed centroid

As it is mentioned in the previous chapter, the IDW method used the distance and these data of the distance is shown in the table below (Table 10).

	Weight											
Arcevia	0.018				0.088	0.126	0.480	0.020	0.022	0.020	0.022	0.019
Barbara	0.796	0.810	0.865	0.976				0.866	0.978	0.889	0.955	0.848
Bettolelle	0.020	0.020	0.021	0.024	0.096	0.137	0.520			0.022	0.023	0.021
Corinaldo	0.105	0.107	0.114		0.514	0.736				0.069		
Colle	0.062	0.063			0.302			0.114				0.112

	Weight									
Arcevia	0.021	0.182		0.147	0.226					
Barbara	0.909		0.907			0.928	0.88			
Bettolelle		0.197	0.022					0.157	0.24	
Corinaldo	0.071	0.622	0.07		0.774	0.072			0.76	0.37
Colle				0.853			0.12	0.843		0.63

Table 10 Weight of each station under different conditions and combinations

So, for each station, there is different weight (IDW method), depending from the distance from the centroid of the watershed and also depends on the presence or the absence of the data. So, in the Table 10 there are shown all the possible combination of coefficient that needs to be multiply for the value of the correspondent station. Considering each case that happens with the presence or the absence of the station and also depends on the distance, it will be find the data average in the watershed. To have an overview of all the station and the mean value that you could find in the watershed, you can see in the Figure 38. The blue line represents the average precipitation calculated for the Misa River watershed in the time interval 2005-2019. As it is possible to see in the Table 9 the station that is close to the watershed centroid is the Barbara station while the furthest is Arcevia station. In fact, in the Figure 38 the red point, that represent the Arcevia station, that are far from the value of the average. To underline the nearest of the Barbara station, it is possible to see, that a lot of the yellow star, that represent the Barbara station, overlap the average mean value. Considering the other station, it is normal to underline that there is some value that are far from the average value. For example, there is a value close to 300mm for the station of Bettolelle, that is the second station further

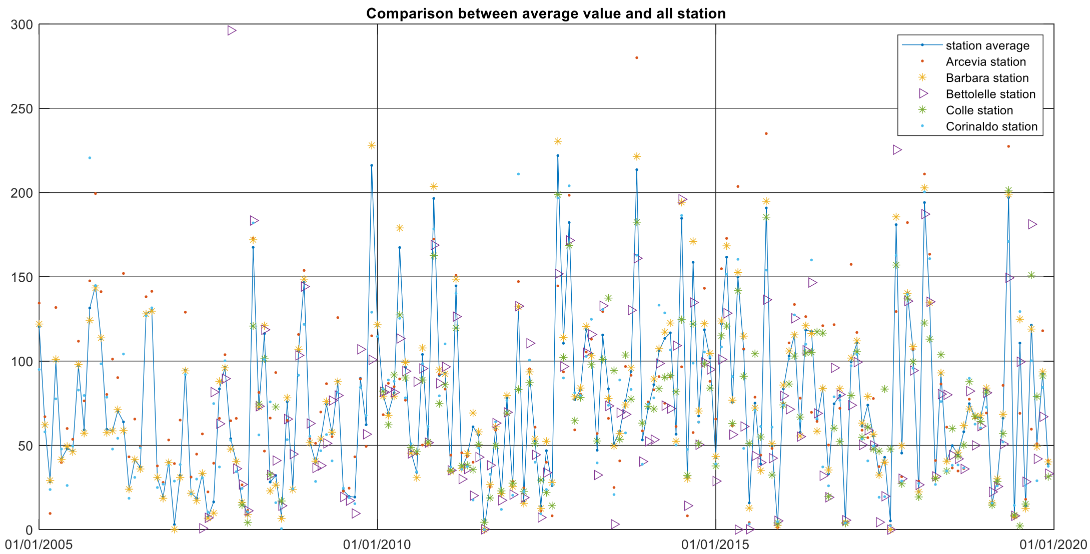


Figure 38 Comparison of the precipitation in all stations with the average precipitation

4.2 Temperature analysis

The analysis of the temperature was done for the station (Arcevia, Bettolelle, Colle, Corinaldo). There is not data for the station Barbara, because of the absence of the thermometer. The data from Arcevia starts in the year 2008 to the year 2019 as shown in Figure 39. So, for the other data there are not missing data, so it is possible to see the trend during the years. The daily temperature and the monthly temeprature has a normal trend, that represent the oscillation of the temperature during the year. The maximum value recorded in the Arcevia station is 31,92°C, while the minimum value is 0°C.

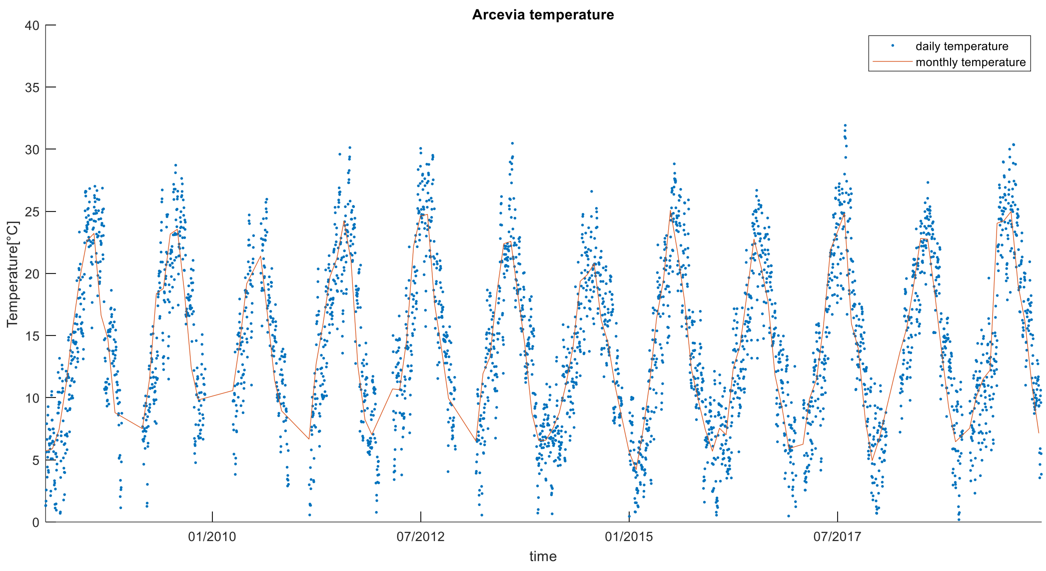


Figure 39 Arcevia temperature with daily and monthly precipitation

The daily and monthly temperature has also been evaluated for the Bettolelle station, as shown in Figure 40.The trend of the daily temperature is characterize by some peak, that corresponding to the summer period of each year, that reach the maximum value of 31,42°C while there are some peak connected to the lower value with the minimum value of 0,7895°C. As it is shown in the Figure 40 there is a superposition of the trend of the monthly temperature and the daily temperature. The station recorded the data from the June of the 2007, so it was calculated all from this date.

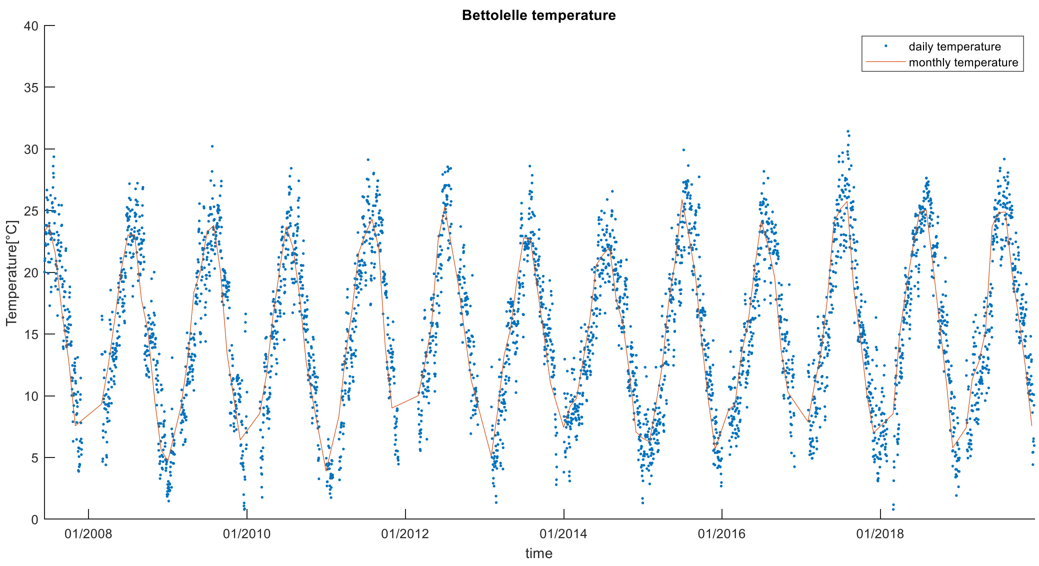


Figure 40 Bettolelle temperature

In the Figure 41 the data of temperature starts from the year 2005, that is the only station, that has the data from the 2005 to the 2019. Not all the data will be used, due to the presence of missing data more than the 10% of missing data for the month. So, there are two blank part in the graph, that corresponding to the 2006 and the period from 2008 to the 2010. Without the blank part the monthly temperature respects the trend of the daily value of temperature. The trend of the daily temperature and the monthly temperature is close to the trend of the other station, in fact there are high peaks for the summer period and low peak for the winter period. The maximum value of the Colle station is 32,3°C, reaches during the July 2017 and the minimum value is 0,31°C during the December 2005.

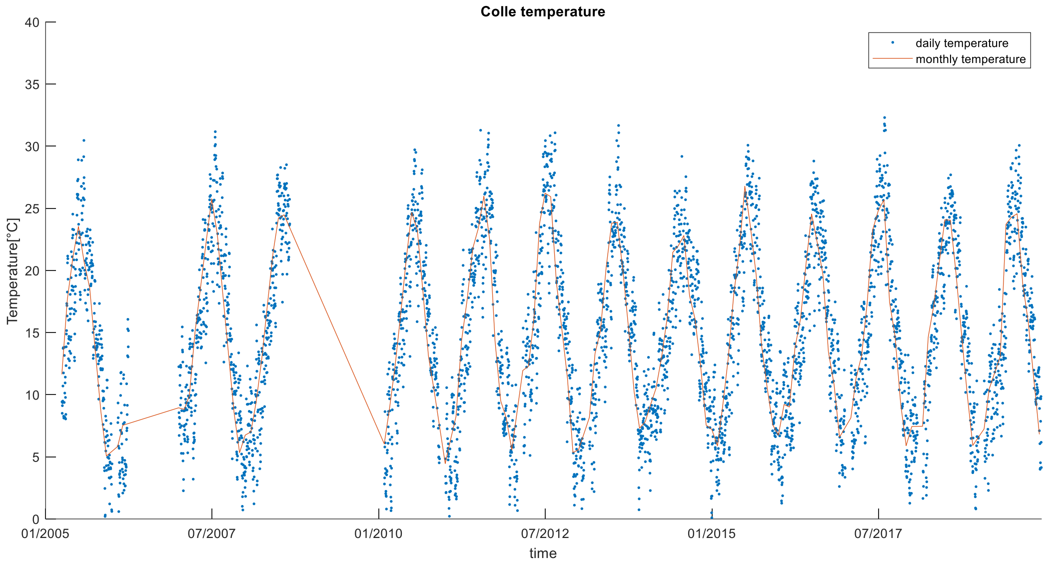


Figure 41 Colle temperature

The analysis of the data for the Corinaldo station starts from the year 2014, because earlier data are missing in the SIRMIP database. It is possible to see, that the data are similar to the other station, because it has some peak value that corresponding to the value reaches during the summer period and some lower peak that corresponding to the data of the winter period. The maximum value reaches with the daily temperature is 34,62°C, while the minimum is 0,1°C.

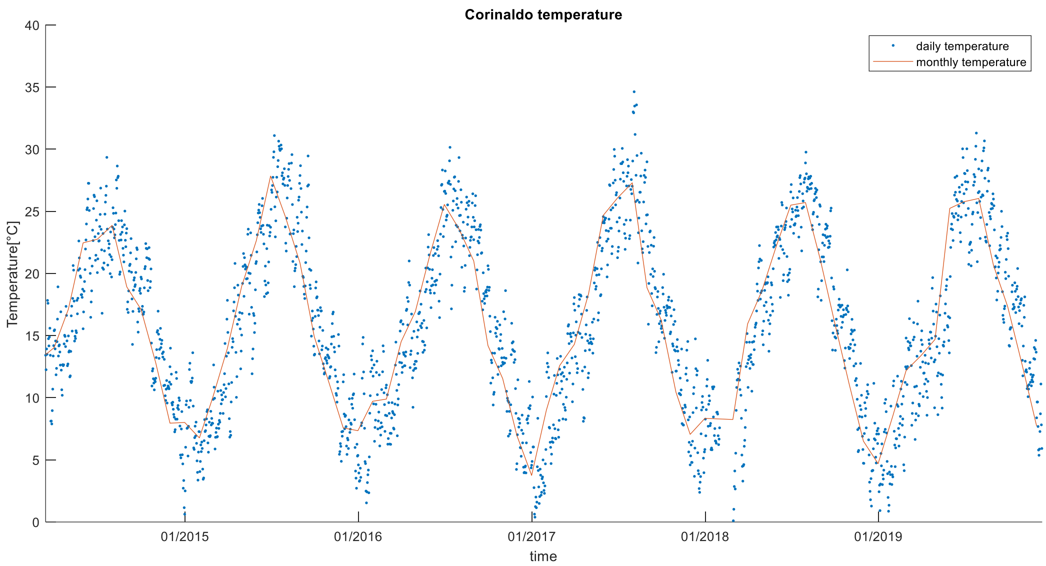


Figure 42 Corinaldo temperature

As it was done for the precipitation, it was analysed all the data with the IDW method so using the value that was list in the Table 10 Weight of each stationTable 11. It necessary to recalculated the IDW value because of the absence of the Barbara station in the analysis of the temperature.

	Weighth						
Arcevia	0.088	0.126	0.480	1.000	0.098	0.147	
Bettolelle	0.096	0.137	0.520				1.000
Corinaldo	0.514				0.568		
Colle	0.302	0.736			0.334	0.853	

	Weight						
Arcevia			0.226				
Bettolelle	0.105	0.157		0.241			
Corinaldo	0.564		0.774	0.759	0.630	1.000	
Colle	0.331	0.843			0.370		1.000

Table 11 Weight for the temperature

The result after the calculation of the data with the IDW method is shown in the Figure 43. All the data are close to the mean average value. There is a kind of superposition of the value of the Bettolelle station with the average value. Almost the data are close to the average value that was calculated. Only for some data of the Corinaldo station, there is a small gap from the average. It is possible to see in the first part of the figure that are not data for almost the station, there are data only from the Colle station, that in this case corrisponded to the average value. The average value respect the trend of the value, that was present in each station.

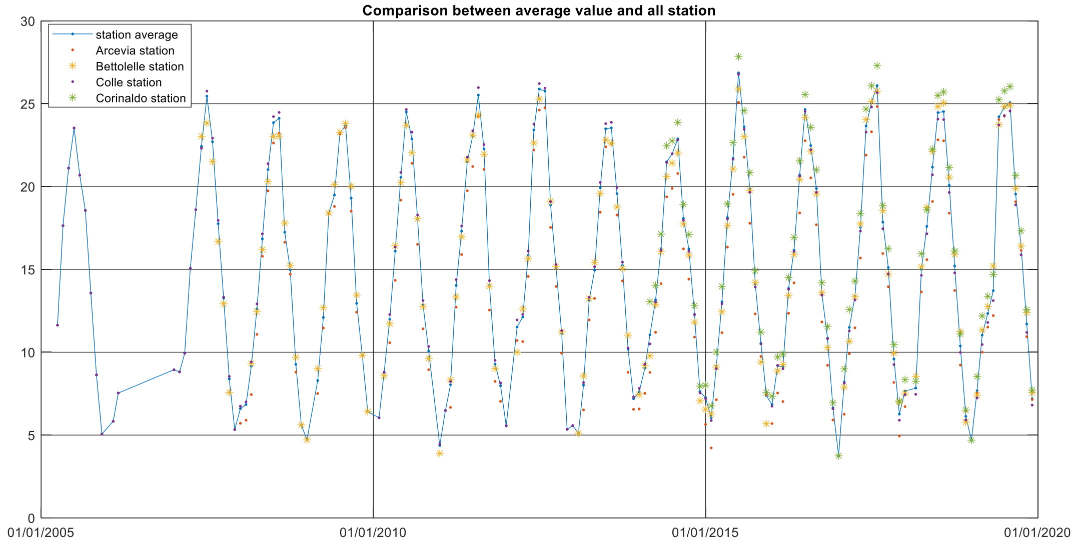


Figure 43 Temperature comparison

4.3 Water-level analysis and discharge estimate

The data of the hydrometric level, with the unit of meters above the datum, have been downloaded from the SIRMIP database. The analysed data start from the year 2005 and end in the year 2019. The rating curve equations valid in this period of time and used to find the water discharge from the hydrometric level, are those illustrated in Table 3. Figure 44 shows in blue all rating curves extracted from the SIRMIP database, while the red curve has been assumed to be that valid in a period of time during which no equation exists in the database. Such curve is based on the assumption of to using the same rating curve of the following period. For the rating curve it was assumed for the plot of the data, the real data, that was used in the analysis. In fact the Figure 44, is characterize by point, because of the real data that are plotted.

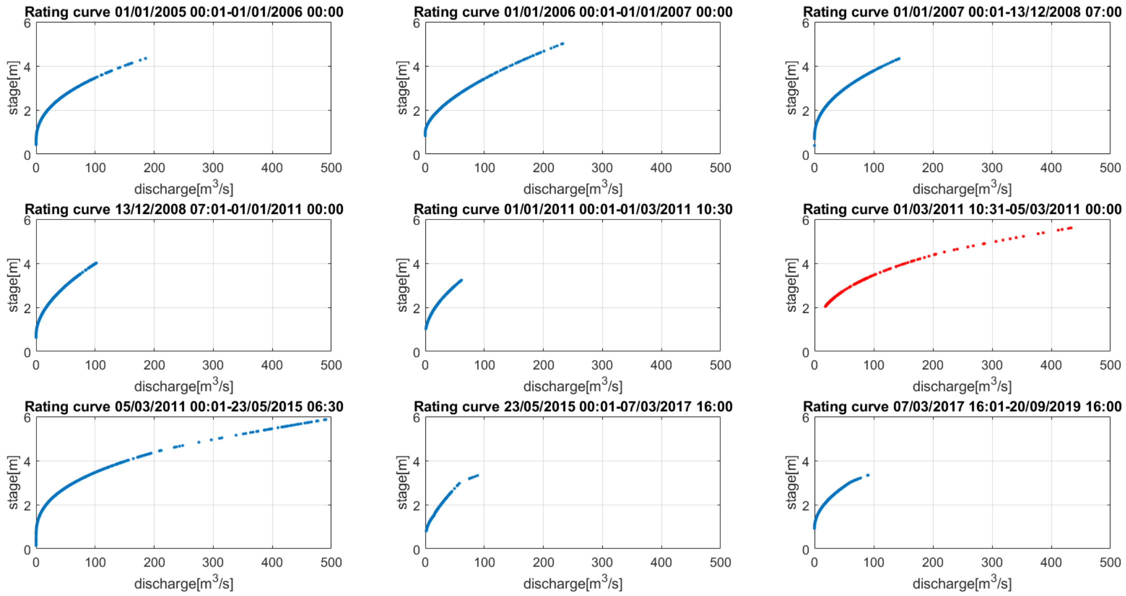


Figure 44 Rating curve at the Bettolelle station

To have a better view of the rating curve, it was decided to plot the data as curves, as it is illustrated in the Figure 45. The reason why, there is a red curve, is the problem connected to the missing rating curve in four day of the March 2011. Some curve does not start from the zero, because it was plotted the curve corresponding to the real data.

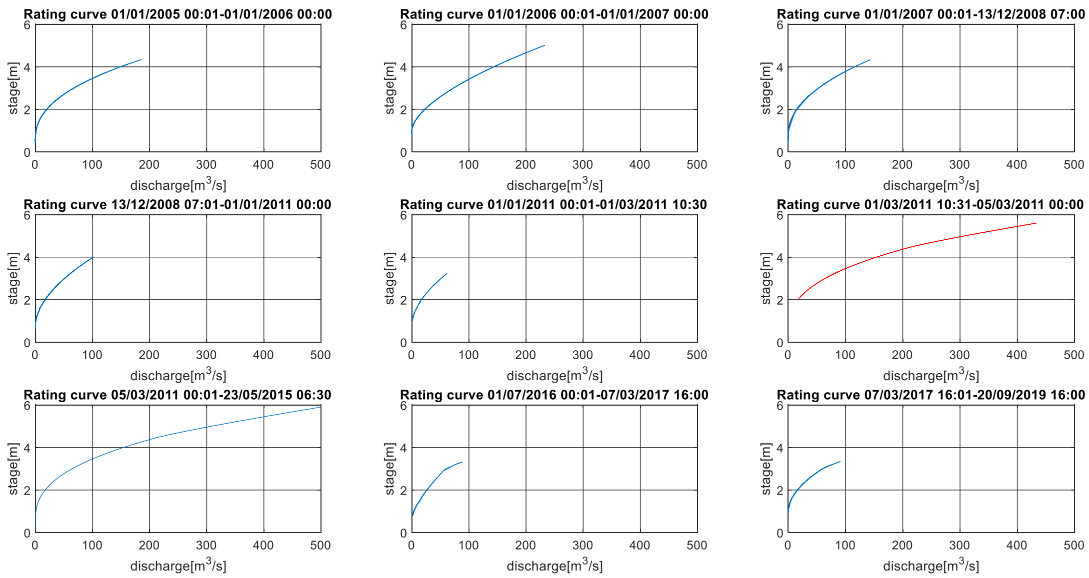


Figure 45 Rating curve

It was also calculated the monthly average discharge and the daily discharge, in the section Bettolelle and the result of the analysis is shown in Figure 46. The daily value of the discharge reaches only in one case a high value. Starting from the data of the discharge, it was decided to analyse the discharge that flow in the river during the period from the 2015 to the July of the 2016 because of the presence of some high data of the discharge. To have a more detail and clear graph of the discharge data, the Y-axis was taken in the logarithmic axis. So, the Figure 46 explain that the data of the discharge during the years does not change too much. There is a blank part during the year from 2015 to the 2016 because of the presence of data, that are not useful in the analysis due to the very different value from the normal trend.

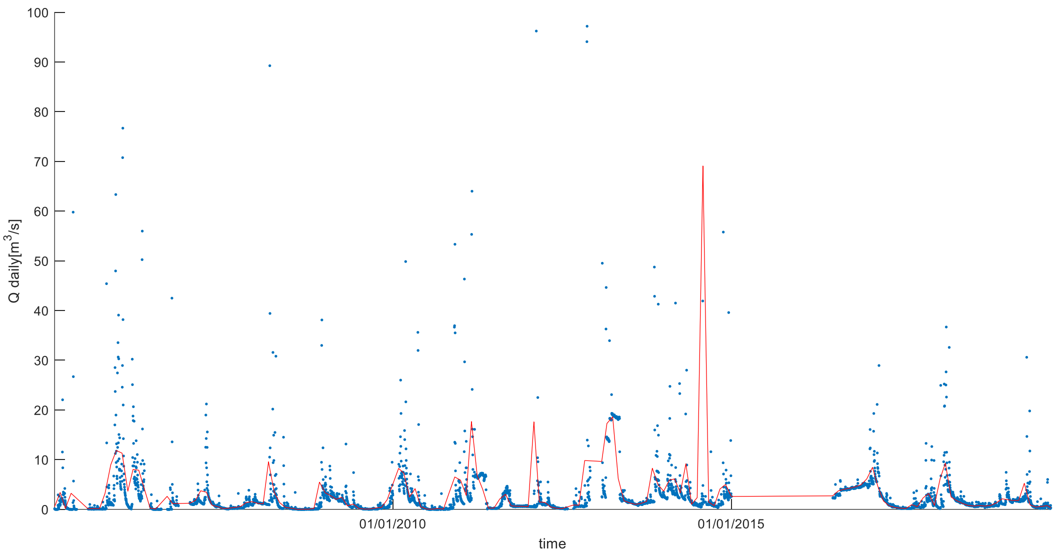


Figure 46 Bettolelle discharge

It was known that the discharge during its own path is constant, so it could be possible to have a comparison, with the data of other station. The comparison of the discharge was done in other two stations, Serra dei Conti and Corinaldo, using the same method, so starting from the rating curve

(Table 12 and Table 13) , it was calculated their own discharge. The two stations are shown in the Figure 47, and it was done the comparison in discharge, because it needs to be the same.

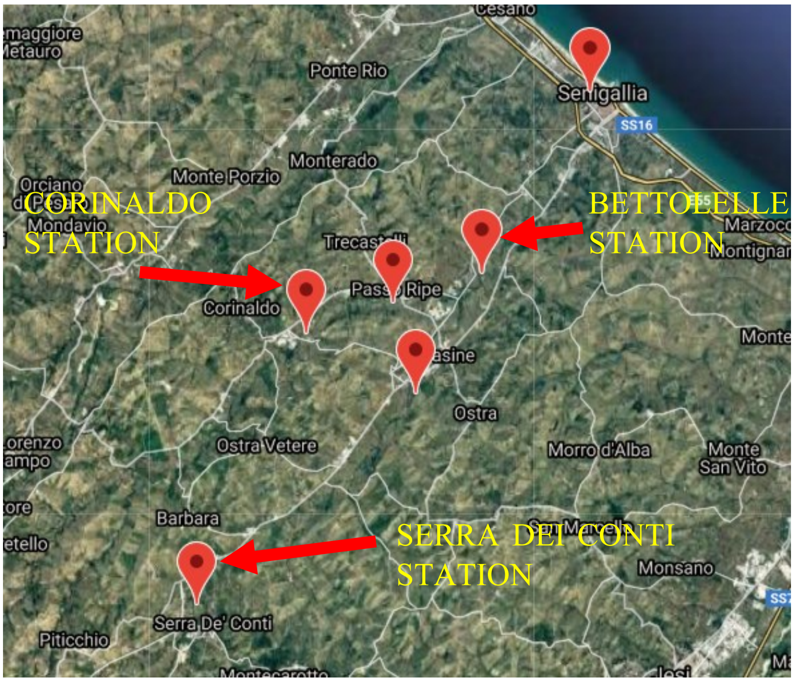


Figure 47 Position of Serra dei Conti, Bettolelle and Corinaldo

Starting validity	**Ending validity**	**Interval stage above the datum**	**Rating curve**
01/01/2011 00:01	28/12/2014 17:30	0,4≤H≤9999	$Q = 12,97 * (H - 0,39)^{1,85} + 0$
28/12/2014 17:31	25/02/2015 09:00	0,41≤H≤0,53	$Q = 11,829 * (H - 0,381)^{1,994} + 0$
28/12/2014 17:31	25/02/2015 09:00	0,54≤H≤ 1,01	$Q = 10,996 * (H - 0,53)^{1,151} + 0,26$
28/12/2014 17:31	25/02/2015 09:00	1,02 ≤H≤ 1,22	$Q = 25,767 * (H - 1,01)^{1,1693} + 4,992$
28/12/2014 17:31	25/02/2015 09:00	1,23 ≤H≤ 100	$Q = 12,97 * (H - 0,39)^{1,85} + 0$
25/02/2015 09:01	01/01/2030 00:00	0 ≤H≤ 0,64	$Q = 2,808 * (H + 0,257)^{5,841} + 0$
25/02/2015 09:01	01/01/2030 00:00	0,65 ≤H≤ 1,56	$Q = 16,399 * (H - 0,64)^{1,492} + 1,492$
25/02/2015 09:01	01/01/2030 00:00	1,57 ≤H≤ 4,5	$Q = 39,465 * (H - 1,56)^{1,238} + 16,53$

Table 12 Serra dei Conti rating curve

Starting validity	Ending validity	Interval stage above the datum	Rating curve
01/01/2011 00:01	17/12/2014 06:00	0,9≤H≤4,2	$Q = 20{,}76 * (H - 0{,}85)^{1{,}9} + 0$
17/12/2014 06:00	27/03/2015 19:30	0,85≤H≤ 1,51	$Q = 21{,}041 * (H - 0{,}837)^{2{,}28} + 0$
17/12/2014 06:00	27/03/2015 19:30	1,52≤H≤ 1,99	$Q = 44{,}368 * (H - 1{,}51)^{1{,}223} + 8{,}528$
17/12/2014 06:00	27/03/2015 19:30	2 ≤H≤ 4,2	$Q = 20{,}76 * (H - 0{,}85)^{1{,}9} + 0$
27/03/2015 19:30	25/03/2016 00:00	0,85 ≤H≤ 1,36	$Q = 16{,}125 * (H - 0{,}847)^{1{,}644} + 0$
27/03/2015 19:30	25/03/2016 00:00	1,37 ≤H≤ 4,3	$Q = 41{,}283 * (H - 1{,}36)^{1{,}48} + 5{,}376$
27/03/2015 19:30	25/03/2016 00:00	4,31 ≤H≤ 7	$Q = 144{,}897 * (H - 4{,}3)^{1{,}091} + 209{,}062$

Table 13 Corinaldo rating curve

In the Figure 48 there are the comparison of the discharges at the three stations, Bettolelle, Serra dei Conti and Corinaldo. The most relevant problem is the upward shift of the Bettolelle data with respect to the Serra dei Conti and Corinaldo data from May of the 2015. Earlier data of all stations seem to be in agreement, with three discharge peaks which are higher at Bettolelle (reaching 100 m^3/s) than at the other two stations. Due to the malfunctioning of the Bettolelle gauge from May 2015, the whole 2015 has been discarded from the analysis.

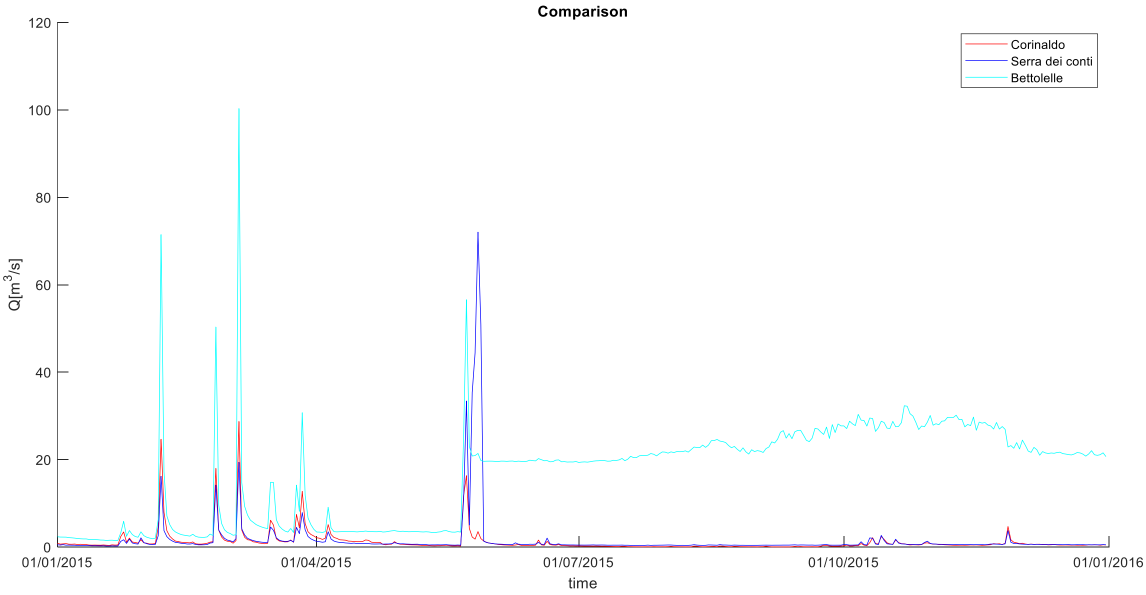


Figure 48 Comparison in the station Bettolelle, Serra dei Conti and Corinaldo

4.4 Model parameters

The analysis of the discharge with the hydrological model is made with the combination of the variable C, that is a calibration parameter, and the field capacity of the basin SC. The variable combination, as shown in the Figure 49. The different simulations show that for low values of the C variable, results are far from the reference value of the discharge, calculated with the rating curve. After a number of coefficient combinations are attempted, the best result was found with a high value of SC and the C parameter close to 1,7. The parameter used in the Figure 49 as a range of value for the C parameter varies from the value 0,7 to 1,9. While for the range of the SC parameter varies in the range of the 1700 mm to the maximum of 2000 mm. It was seen that for vale of C=0,7 correlated to the value SC=1700mm the trend of the data is so far from the discharge reconstructed with the rating curve as it is illustrated in the orange line. For this reason, it was decided to increase the value of the C and the SC. It was necessary to investigate, the result value of the three statistical variable R, NSCE, BIAS. The best result obtains by analysis of the trend of the variable C and SC, with the result of the statistical variable R, NSCE, BIAS.

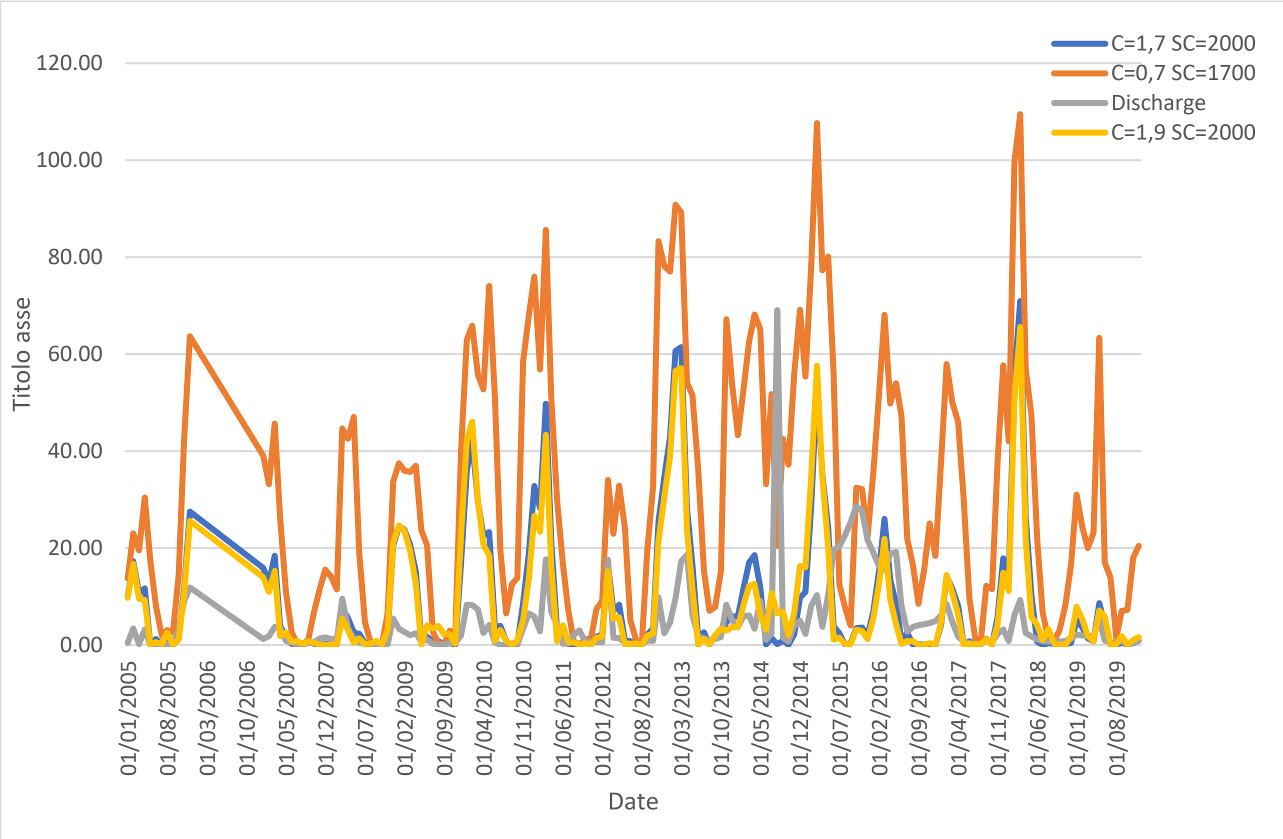


Figure 49 Example of run off with the model

The following combination, that has the best result, for the discharge, is used these parameters:

- Calibration parameter which multiplies EP_{pot}, C=1,7;
- Base runoff $Q_0 = 0$;
- The third parameter, initial water content $S_0 = 50$;
- Field capacity of the basin SC=2000mm.

4.5 Calibration of the model

Using the values for the calibration (period from the 2005 to the 2009), the resulting statistic parameters R, NSCE, and BIAS are:

- R= 0,5994
- NSCE=-2,6011
- BIAS=45,8391

In Figure 50 there is a comparison of the reconstructed (rating curve) runoff and the runoff of the model. The statistical reproduction of the discharge is close to the discharge reconstructed within the rating curve but does not show the same maximum values. In fact, for the runoff of the model there are two peaks that are higher than the discharge reconstructed with the rating curve. The hydrological model is calculated statistically from the data of the temperature and the precipitation, to find the discharge. The result of the model is shown in the Figure 50 and it is possible to underline that some value of the model discharge are far from the trend of the discharge reconstructed using the rating curve. It is possible to see that a small correlation exists between the peak of the discharge of the model whenever there is a peak value of the precipitation. As it is underlined by the statistical values, the discharge of the model, does not overlap the discharge of the river.

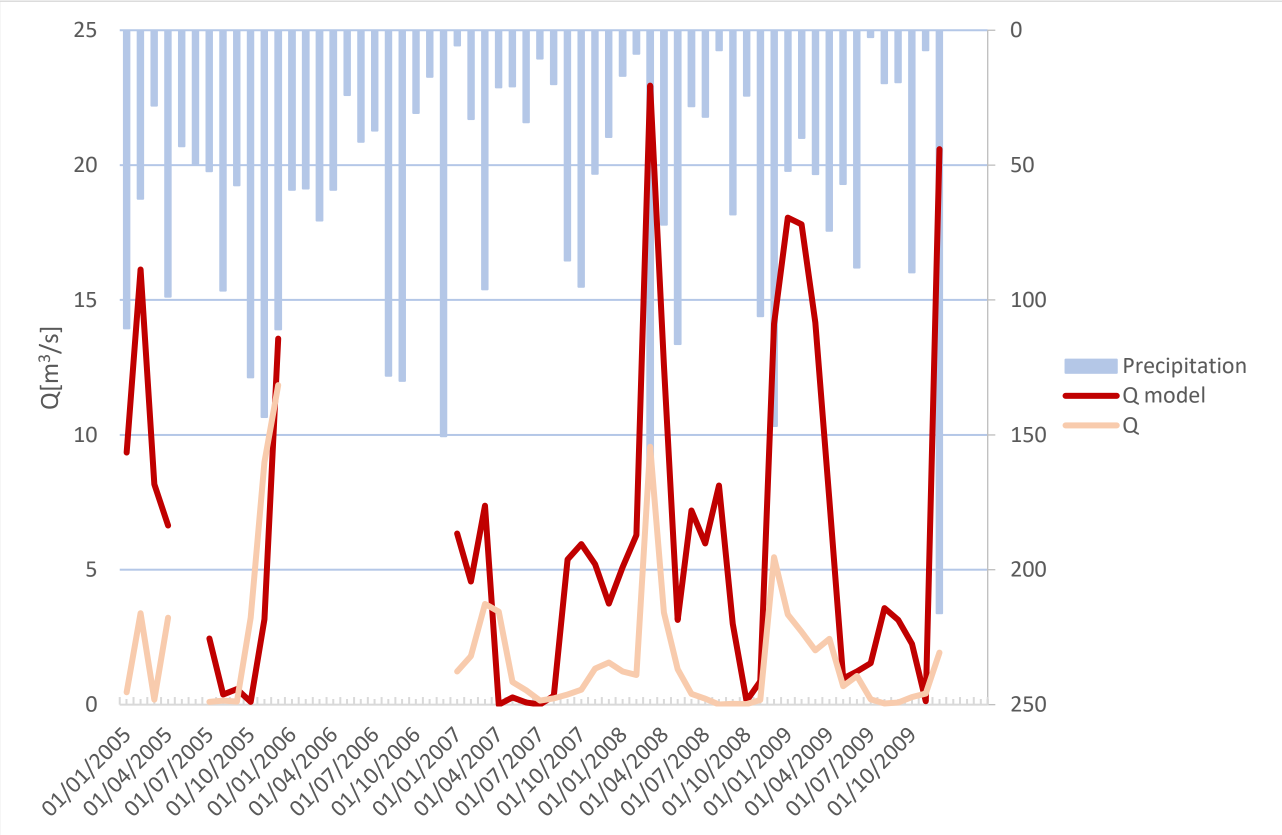


Figure 50 Calibration from the 2005 to the 2009 and the corresponding value of precipitation in the watershed

4.6 Validation of the model

Considering the validation of the model, the combination of the parameters used in the calibration phase has been here applied. Using such values, the validation results (period from the 2010 to the 2015) are described by the statistical parameters R, NSCE, BIAS, i.e.:

- R= 0,4828
- NSCE=-2,0018
- BIAS=37,7542

In Figure 51 there is a comparison between the river discharge reconstructed from the rating curve and the modelled runoff. There are two peaks for the model discharge, that are far from the data the reconstructed curve of the discharge. It is possible to underline that this gap happens close to the precipitation events. There are some blank parts, in both modelled and estimated discharge, because it was decided to exclude months during which a large amount of missing data exist. So, such months are not inserted in the graph. In July 2014 there is a peak in the reconstructed discharge, but the model discharge does not reach the reconstructed discharge.

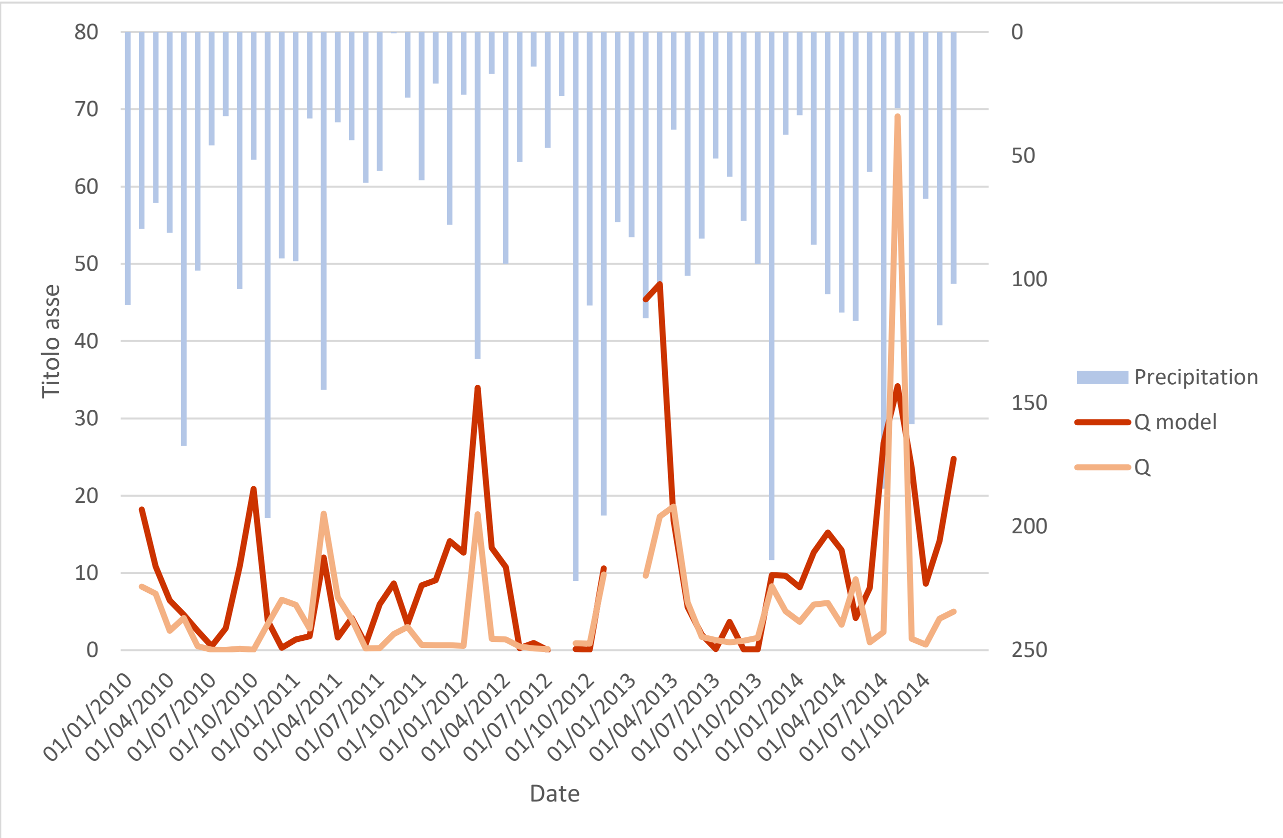


Figure 51 Validation in the period from the 2010 to the 2014 and the corresponding value of precipitation in the watershed

4.7 Application of the model

Considering the application of the model, using the value of the coefficient that are decided to use. The application results (period from the 2015 to the 2019) are shown using R, NSCE, BIAS, i.e.:

- R= 0,4287
- NSCE=-2,1402
- BIAS=16,0499

Figure 52 illustrates a comparison of the reconstructed discharge and the modelled runoff. Only in the first part of the graph there is a difference between the lines, while there is an almost perfect overlap in the period January - May 2018. There is a peak, where the two discharge are almost overlap, and it could be correlated to the precipitation data. The discharge calculated with the hydrological model and the discharge reconstructed with the rating curve are very close, and in some point are the same. These two curves, that are almost overlap, underline the correct choice of the parameter C and SC. The data of the 2015, there are not present in the Figure 52, because it was decide to insert in the graph only the data, that was validated in the analysis of the discharge in Bettolelle station.

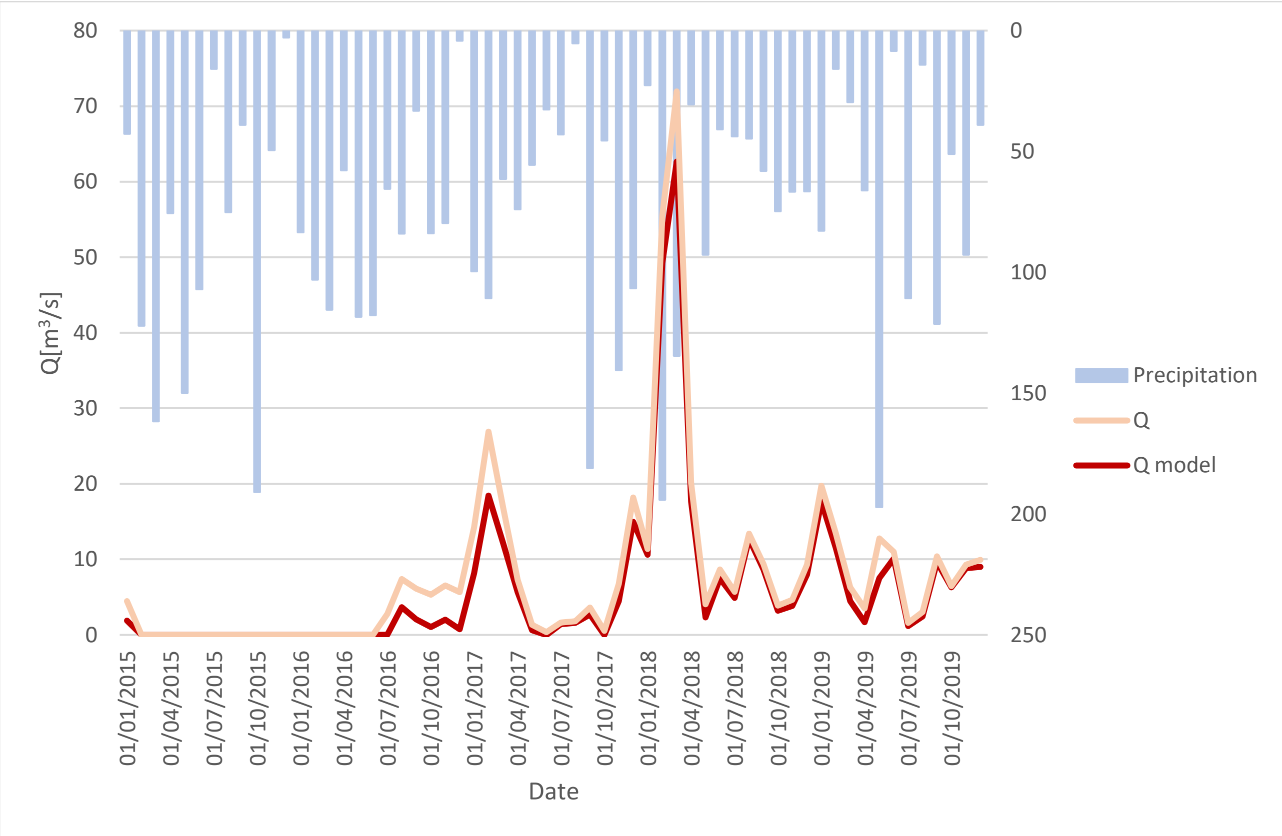


Figure 52 Application of the period from the 2015 to the 2019 and the corresponding value of precipitation in the watershed

4.8 Discharge analysis

At the Ponte Garibaldi location, some meters upstream of the hydrometer, there is the H-ACDP gauge. This acquires discharge data only when a sufficiently high-water level exists. It is possible to download the data from the recorder, as it was shown in the Table 2, where the data from this gauge are not collected every 30 minutes, but every 2 minutes and only when the gauge is submerged, i.e. when the water level is high enough. These data have been analysed using the MATLAB environment. The data of the H-ADCP are shown in the Figure 53 where it possible to underline, from that data, that it is possible to attempt a rating curve. So it was tried to find an equation that could fit the rating curve:

$$Q = 20 * [H - 0{,}1]^{6{,}5} + 0$$

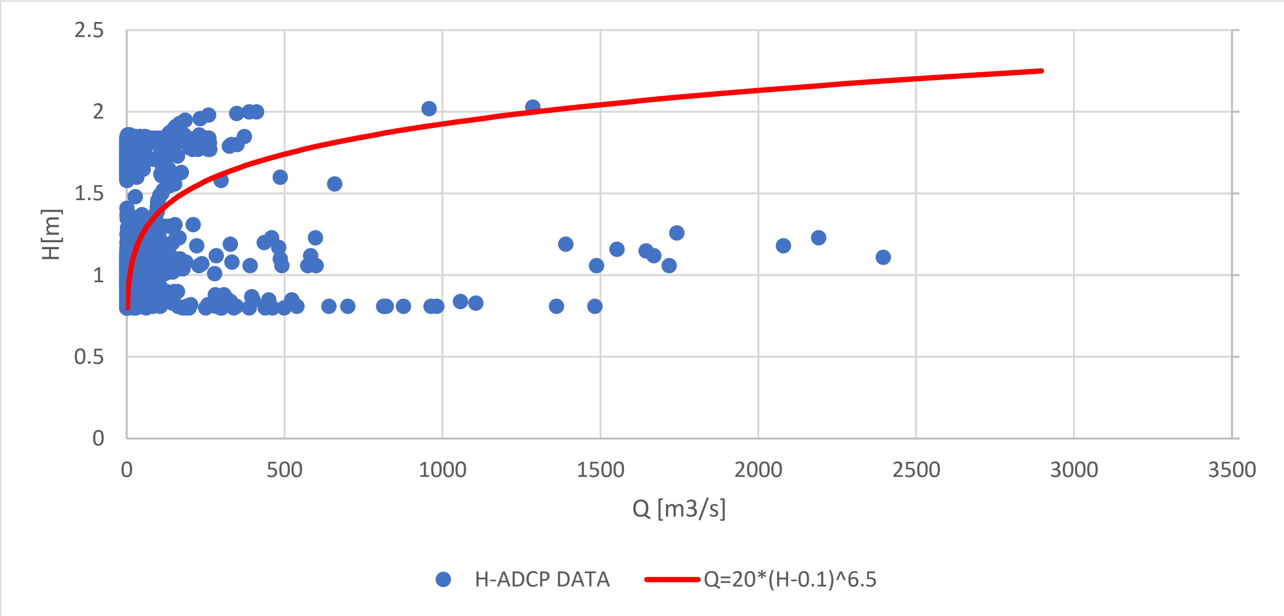


Figure 53 H-ADCP data and possible rating curve

The curve, shown in Figure 53, is representative of not all the data. In the first part the rating curve represent only a part of the data, while in the second part, so after the value of the discharge of 80 $\frac{m^3}{s}$, the curve does not represent the data that are collected by the H-ADCP. The data of the H-ADCP starts from the 1st of January of the 2018. So, in a second time it was decided to evaluate the data of only the November of 2019, when there were some interesting event.

It is known, during the month of November 2019, the H-ADCP gauge, has recorded some data, that are shown in the Figure 54, so the possible rating curve is:

$$Q = 2 * [H - 0,1]^{11,25}$$

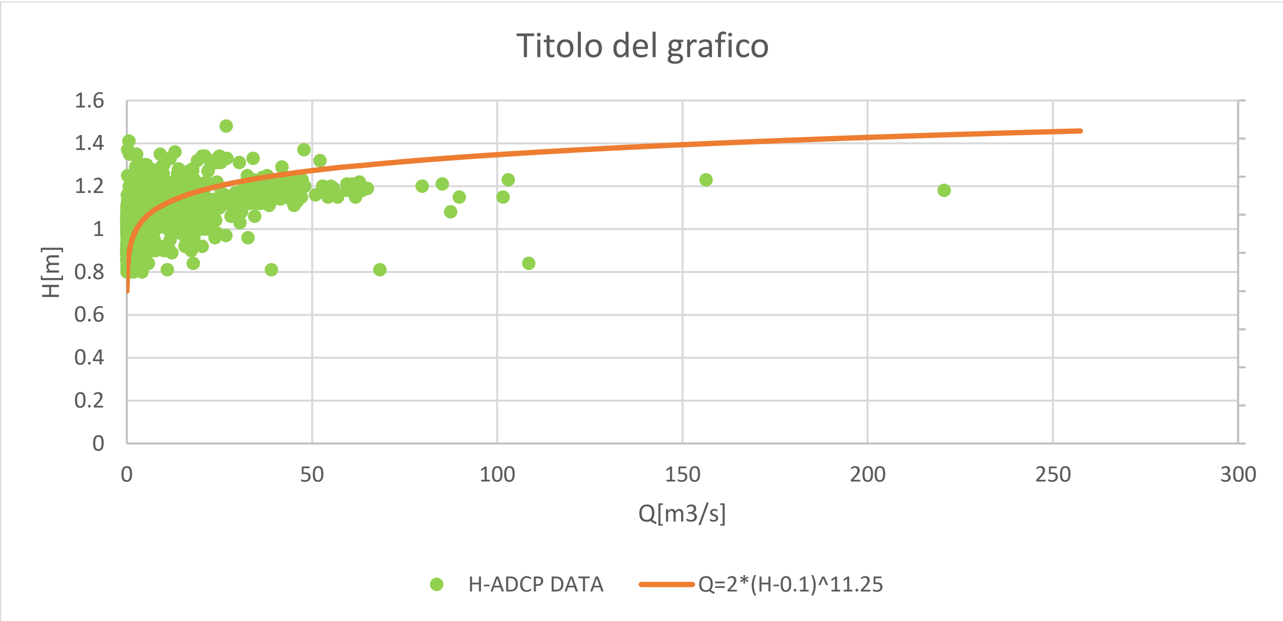


Figure 54 Rating curve for the November 2019 events

The curve is not representative of all the data, in the November event, so it was decided to do a comparison of the H-ADCP data, and the data calculated with HEC-RAS. Starting from the data of the simulation, that was done with the program HEC-RAS, it was tried to do a comparison of the data in Ponte Garibaldi, from HEC-RAS and from the H-ADCP gauge. In the Figure 55 it is possible to underline that the HEC-RAS rating curve has data lower than those coming from the H-ADCP gauge. As it was mentioned in chapter 3 for the data of HEC-RAS, the rating curve is affected by the tide level, that depends on what happens in the estuary. It was decided to analyse the data of the "R.M.N. Rete Mareografica Nazionale" about the hydrometric level during a period from the 2010 to the 2019. It was seen, that the data of the water level, in the estuary, increase during an event of storm. In fact, using the datum, of maximum water level during the 13 November 2019 at the 00:30, the rating curve and the H-ADCP data in the first part are similar. The two-rating curve constructed with the result of the simulations carried out with HEC-RAS show that there is an influence of the sea/estuary condition only for low discharges. While for when the discharge is relatively large, it is not affected by the tidal oscillation and the two lines tend to onverge.

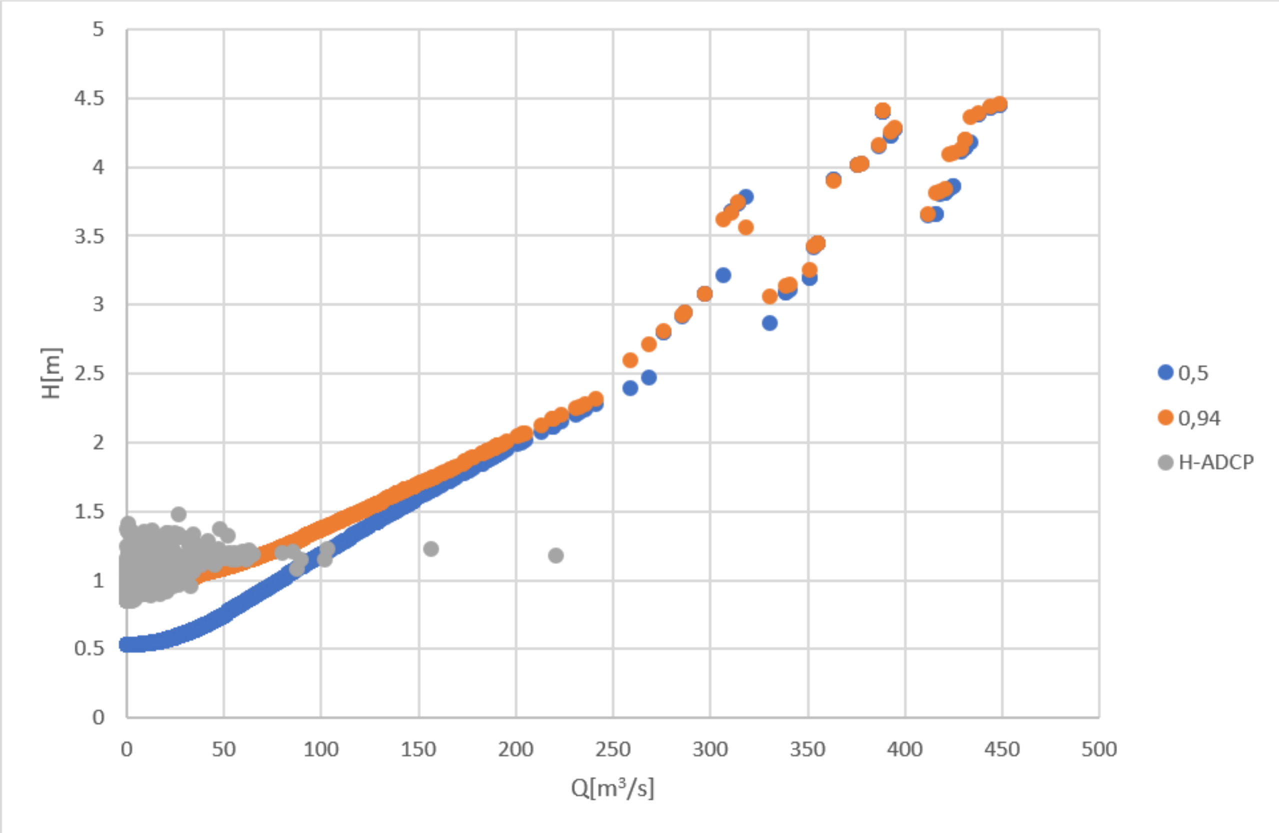


Figure 55 H-ADCP data (grey), rating curve with boundary downstream condition of 0,5m (blue) and 0,94m (orange)

Chapter 5: Conclusion

In the first part of this study, it was analysed the precipitation, the temperature and the discharge in the watershed of the Misa River. The analysis was done in the station: Arcevia, Bettolelle, Barbara, Colle and Corinaldo. It was calculated the precipitation, the temperature and the discharge that is present in this watershed. Also, it was done simulation with the program HEC-RAS, that gives information about the water level, that is calculated passing through the discharge. The simulation with HEC-RAS, was done for all the sections of the river, but in this study, it was decided to focus only on two stations: Bettolelle and Ponte Garibaldi. Close to the Ponte Garibaldi station there is the horizontally acoustic doppler current profile (H-ADCP), that gives information about the high values of the water level, but there is not information about the rating curve, so it was tried to find a curve that could represent the data of the H-ADCP. It was used only the data of the month of November, when some events occurred, that need to be investigated. Starting from the boundary condition about the downstream section of the river, it was seen that the H-ADCP data are far from the HEC-RAS rating curve. Exanimating the data of the sea water level, it was seen that the water level of the sea during the November of the 2019, reaches the maximum value of 0,94m. So, it was decided to change the boundary condition in the downstream section, imposing a value of 0,94m. The result of the comparison of the data from the simulation of the HEC-RAS with a boundary condition in the downstream section, once with the value 0,5 m and in the second time with the value 0,94m, shows that the section of Ponte Garibaldi is affected by the condition of the sea during a stormy condition, with a low discharge in the river. So up to the value of discharge of 200 $\frac{m^3}{s}$, the sea level affects the water level at the Ponte Garibaldi section, while over this value the river is not affected by the sea level, but only by the high discharge that flows in the river. In the comparison between the data of the river gauge (H-ADCP) and the data of the simulation of HEC-RAS with the boundary condition of 0,94m, there is an overlap of the data. In this study, the monthly discharge was also calculated through application of a hydrological model and starting from the data of precipitation and temperature. In a first moment, some combination of unable coefficients have been attempted, with the aim to find the best curve which overlaps to the curve of the reconstructed discharge. To be sure about the value used in the hydrological model, the data was divided into three fields: the first field was used for the model calibration, the second field for the validation and the last field for the application. The statistical parameter used for the hydrological model was decided after several combinations. The best combination of the parameter has as a result, that the curve of the model and the curve of the discharge reconstructed are very close, especially in the most recent time period.

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"Tutto quello che oggi è una realtà, prima era solo parte di un sogno impossibile"