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Abstract

An aspect correlated with climate change is certainly represented by the alternation of severe floods and relevant drought periods. In 2020, European Commission's Joint Research Centre assessed that: (a) global warming will progressively increase flood frequency and severity in most of Europe, (b) direct damages from flooding could become six times present losses by the end of the century in case of no climate mitigation and adaptation and (c) more than 170,000 people every year are exposed to river flooding in the EU and UK. Moreover, in 2021 the European Environment Agency emphasized how between 1980 and 2017, floods have taken some 4,300 lives and cost Europe's economy nearly a third of the total damage from natural hazards; despite this, a tenth of Europe's urban population is currently living in flood-risk zones. It is known that besides heavy precipitation events, a dangerous flood can also be triggered by non-climatic factors, such as land use, changes to river basins and natural characteristics of water flow (dams, river bed changes, sealing surfaces) and urban planning.

There is indeed evidence that changes in climate and land cover are inducing changes in stream channel cross sections altering local channel capacity. A direct consequence of a significant change in local channel capacity is that the relationship between the amount of water flowing at a given point in a river or stream (usually at gauging stations) and the corresponding stage in that section, known as stage-discharge relationship or rating curve, is changed.

Key messages deriving from the present work are:

(a) The more frequent and extreme the floods become, the more rapid the changes in stream channel cross section become.

(b) From an operational point of view, the collection and processing of field measurements of stage and corresponding discharge at a given section to quickly and frequently update the rating curve becomes a priority.

(c) It is important to increase the number of control stations to be installed on rivers and to understand where there is a higher priority.

Therefore, it is necessary to define a control system for acquiring hydrological data capable of keeping river levels and discharges under control to support flood early warning and water management. The proposed stage-discharge management system is used by the Civil Protection Service of the Marche Region (east-central Italy) for the monitoring of river runoff in the regional watersheds. Civil Protection Service staff performs stage-discharge field measurements using water level sensors and recorders (e.g., staff gauges, submersible pressure transducers, ultrasound, and

radar sensors), acoustic doppler velocimeter, acoustic doppler current profilers, portable mobile radar profilers and salt dilution method equipment, respectively.

Power functions are fitted to the stage-discharge field data. Furthermore, extrapolation is performed to cover the full range of flow measurements. Generally, extrapolation is not an easy task because of sharp changes in the stream cross- section geometry for very high or very low stages. In the present work, we focused attention on the application problems that occur in practice and on the software developed to analyze, monitor, and update data relating to sensors, measurements, and rating curves.

Introduction

The traditional method to obtain current information on discharge is to measure the water level with gauges and use the stage-discharge relationship to estimate the discharge, which is less expensive than direct and continuous discharge measurements. Many problems may afflict such measurements:

1. The costs and human resources required for regular discharge measurements to develop and maintain the calibration of the rating curve.
2. The rating curve is limited to the range of measured data.
3. The rating is invalid if the cross-section changes.
4. The discharge measurements typically scatter and do not show a unique relationship with the stage.

Loops and discontinuities in ratings may result from physical factors that affect any term of the equation describing the momentum of the flow that is not accounted for in the rating [1].

Stage-discharge rating curves for flow in rivers and channels are established by concurrent measurements of the stage h (direct measurement) and discharge Q (indirect measurement obtained from velocity acquisitions). The results are fitted to yield the rating curves [1]. When the rating curve is defined, it must be controlled to remain constant during the period. If the measured values substantially deviate from the rating curve currently used, they must be revised. The main problem of rivers is related to the fact that they are time-varying dynamic systems, consequently, also the developed models must be continuously updated in relation to the variations of the riverbed. For this reason, a validity range of the relationship consisting of a start date and an end date must be defined. This represents a very important information for the hydrologist and for Civil Protection. The end date will initially be unknown but will be defined when a significant shift in the curve occurs and thus there is the need to define a new curve. Updates are especially needed after relevant flood events that could change the river bed and banks drastically.

Thus, an automated system is needed that primarily allows the definition of the rating curves. Then, in a graph, the discharge time-trend can be compared to understand whether the stage-discharge relationship is still valid or whether a rating shift occurs. We can put together three types of discharges to compare:

- Discharge measurements acquired on the field.
- Discharges estimated with the current rating scale.
- Discharges estimated with the new rating scale calculated, starting from the new measurements carried out on the field.

If a shift is present, then the exact point in time at which the curves merge must be evaluated: it represents the valid end date-time of the current rating scale and the valid start date-time of the newly calculated rating curve. The evaluation of the end of a scale and the beginning of a new scale must therefore be evaluated on a graph in which we find the time on the abscissa axis and the discharge Q on the ordinate axis. In this graph the three curves will be super- imposed: one simply contains the discrete points of Q measured in the field, one contains the continuous curve Q(t) obtained with the current scale and the last the Q'(t) obtained with the new scale.

We evaluated methods and models to improve the data fitting between the discrete values derived from real measurements in the field (input) and the continuous data extrapolated from hydraulic models (output). A large portion of the modern practices used worldwide were developed by the United States Geological Survey (USGS) [2, 3, 4, 5, 6, 7] and widely described over time by other scientific researchers [8], also using artificial neural networks [9, 10, 11], World Meteorological Organization (WMO) [12, 13], and ISO standards [14, 15, 16, 17, 18, 19, 20]. In Europe, hydrological data are collected by the Copernicus Emergency Management Service (CEMS) Hydrological Data Collection Centre (HDCC) and made available online at European Flood Aware- ness System (EFAS) website (https://www.efas.eu). In 2011 EFAS became part of the CEMS initial operations in support of European Civil Protection. The operational components have been outsourced to Member State organizations. EFAS is running fully operational since autumn 2012. In October 2021, there were 68 data providers with 3949 registered stations in the dataset. HDCC data are representative of more than 50% of all the European water basins spread over 32 countries; approximately 20% of the stations deliver exclusively dis- charge data, another 20% only water level data and the rest provide discharge and water level data.

In Italy, since the second half of the 1800s academics and the community of hydraulic engineers and practitioners had noted the need for a national service to be established to survey the characteristics of water courses; the Italian National Hydrographic and Mareographic Service (SIMN) was indeed established in 1917. Over time, the hydrogeological risk map has been developed and up- dated by ISPRA (Institute for Environmental Protection and Research).

In the present work, we focused on Marche Region territory (east-central Italy, Fig. 1) whose meteo-hydro-pluviometric monitoring network has been managed until 2001 by the SIMN and then by the Functional Center of Regional Civil Protection Service.

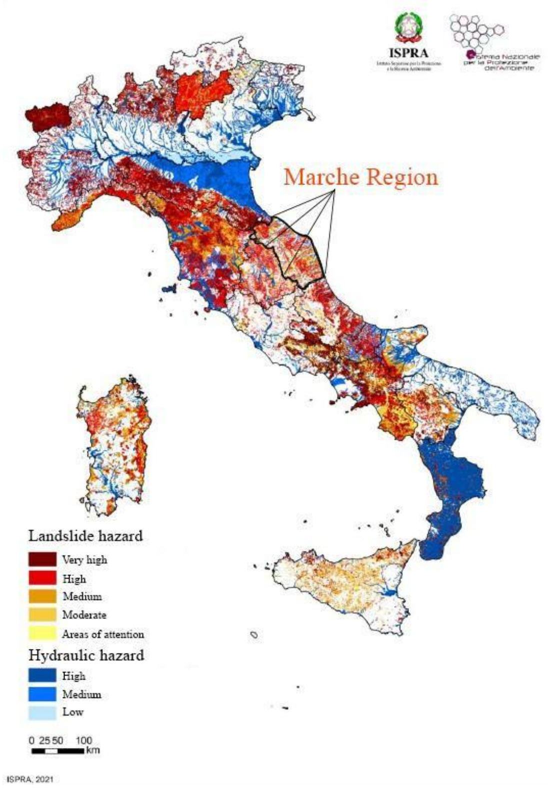


Figure 1: Map of hydrogeological risk in Italy, referred to the ISPRA report 2021, with landslide and hydraulic hazard

The whole monitoring network consists of two distinct networks: one mechanical (RM) and one telemetry (RT). The mechanical network that started working in 1916 was managed by the SIMN. The available sensors were thermometers, rain gauges, and hydrometers. The number, type (thermometric and/or pluviometric, and hydrometric), location, and period of operation of the stations have considerably changed over the years. The Civil Protection Ser- vice has been appointed since 2002 to perform the functions transferred from the SIMN. The activities related to data validation, processing, and publication are handled by the Marche Region Functional Center. The Marche Region is equipped with a telemetry monitoring system that was activated in June 2000. Starting from 2005, the discharges from some hydrometric sections have also been continuously estimated. The RT network, which definitively replaced the RM, in December 2022, mainly consists of 135 rain gauges, 121 thermometers, 107 hydrometers, 30 anemometers, 17 barometers, 113 hygrometers, 13 snow gauges, 18 sensors of incoming solar irradiation, and 6 soil moisture sensors. Flow measurement campaigns are also underway for estimating the discharge of the main regional rivers to define and update the rating curves in correspondence with important hydrometric sections.

To date, the most-used software programs for collecting, storing, managing, validating, analyzing, and reporting water data are proprietary, file-based Hydstra and Water Information System (WISKI) produced by KISTERS [21]. To optimize data acquisition and update the rating curves based on field measurements, a nonproprietary web-based solution was developed for the Marche Region Civil Protection Service in the framework of the STREAM Project (Strategic Development of Flood Management).

From an operational point of view, quick and frequent updating of the rating curve at a given cross-section is becoming a priority; in this context, the software proposed in this work aims to provide an efficient stage-discharge management system.

Materials and methods

The national and regional Civil Protection Services use different applications for monitoring flood risk. These applications have been modified over time with advances in software and hardware technologies for data measurement, management, and transmission. All the stations that record the hydrometric level are displayed in the operations center. In Fig. 4, are reported all the hydrometric sensors currently installed in the control stations of the Marche Region. Hydrometric rods (Fig. 3), placed in the river, are used to verify that the electronic devices (gauge sensors) are always correctly calibrated. Having a redundant stage acquisition system is important; when both gauges provide a correct measurement, the rod value is typically taken as a reference due to its higher accuracy. Therefore, there are two distinct stage level fields in the database: one contains the river stage information of the hydrometric rods while the other contains gauge sensor stage information. The software first evaluates if the hydrometric rod value is present; if the field contains an incorrect value (identified by the code -9999) the gauge sensor is taken as a reference value.

The hydrometric rod is positioned so that the zero value coincides with the gauge datum [22]

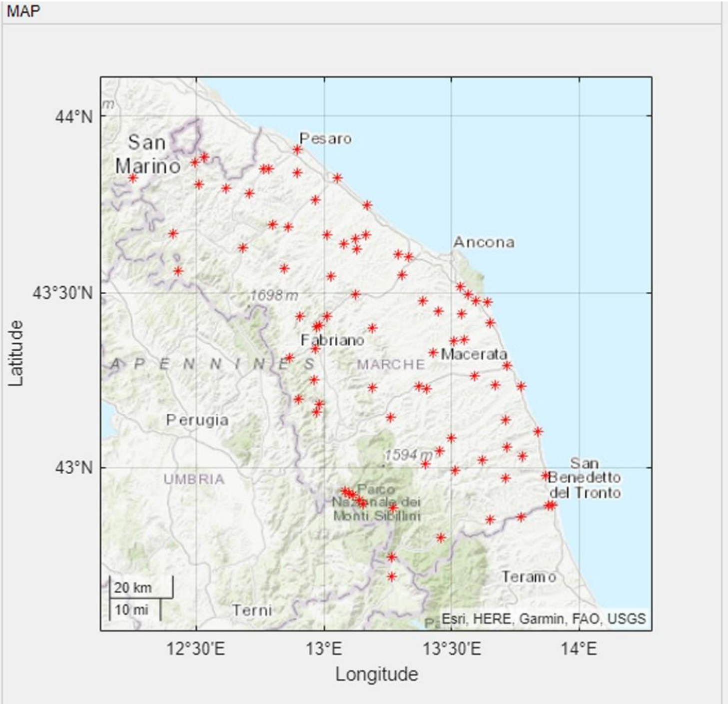


Figure 2 Marche Region with the red dots which are the sensors (radar and ultrasonic) installed by Civil Protection

Figure 3: Example of hydrometric rod installed by the Civil Protection in each river

The rating curves may be simple or complex depending on the river dis- charge, flow regime, riverbank, and bed geometry. These relations are typically empirically developed from periodic measurements of stage-discharge using a hydrometric model with fitting algorithms. To verify the rating scale and monitor riverbed changes, periodic in situ flow measurements with acoustic Doppler current profilers (ADCPs) or velocimeters are required to control and keep the stage-discharge relationship updated. Moreover, hydrometers provide measurements of instantaneous values that may be affected by variations caused by local turbulence, waves, or obstacles under the sensors, so periodic surveys must be planned.

The fundamental assumption in stage-discharge analysis is that a unique discharge can be identified for any given stage [23]. The relationship between stage and discharge is defined by plotting discharge measurements (arranged on the abscissa axis) with the corresponding observation of stage (arranged on the ordinate axis), considering whether the discharge is steady, increasing, or decreasing, and noting the range of change [17]. The plotting scale can be arithmetic or logarithmic. First, data validation is required to ensure that the recorded stages refer to the gauge data and that the calculated discharges are accurate. The number of direct flow measurements needed to develop a rating curve is defined by an ISO standard [17]: at least 15 or more measurements (for each defined segment) are needed, and they must be distributed over the entire range of the gauge height (also including the lower and higher extremes, which are useful in defining the correct shape). In theory 15 or more measurements, in practice there are far fewer measurements available for each segment therefore there will be less precision in the estimation of the model.

As the number of stage-discharge measurements in the field increases, the ac- curacy of the hydrometric model used to determine the rating curve increases. The main problem is caused by the lack of stationary conditions on a river, which causes variations in the stage-discharge relationship.

Three categories of rating curves can be defined:

- Old rating curves: used in the past but that are no longer valid due to riverbed changes over time.
- Current rating curves: currently used by the system to estimate the flow rate.
- New rating curve: created from the last new measurements determining the update of the curve if a substantial shift occurred.

The term uniform flow refers to the hydraulic condition in which the dis- charge, width, depth, cross-sectional area, and velocity are constant throughout the length of a channel. Perfectly uniform flow is rare in natural channels, but the condition is nearly true when the geometry of the channel cross-section is relatively constant throughout the course [24]. For an open channel, additional assumptions include:

- The depth of flow must be constant (that is, the hydraulic grade line must be parallel to the channel bed); this depth of flow is called normal depth.
- Because the velocity is constant, the velocity head does not change through the length of the section; therefore, the energy grade line is parallel to both the hydraulic grade line and the channel bed.

The physical structure of the channel control is linked to the shape of the rating curve through the hydraulic stage-discharge equation expressed by the Eq. (1) [5, 6, 7, 14].

$$Q = C * (h - e)^{\beta}$$

The parameters that define the relationship between the estimated discharge Q and the measured stage h (which represents the gauge height of the water surface referred to as the gage datum) are:

- e (sometimes defined in the literature as h0) is the effective gauge height of zero flow (or sometimes referred to as the cease-to-flow value [17]). This is an adjustment, sometimes called offset, which converts the stage level to the depth of water over the control.
- (h-e) is the effective depth of water on the control, sometimes called a hydraulic head.
- Coefficient C (sometimes defined in the literature as Q1) is a scale factor numerically equal to the discharge when the effective depth of flow (h-e) is equal to 1, representing the product of the scale factor in the stage–area relationship and a flow resistance factor that includes channel slope and the friction factor.
- Exponent β represents the sum of the shape exponent and the friction loss assumption exponent, being the slope of the rating curve when plotted on a logarithmic scale.

The conceptual model for the open channel has three prismatic geometries: a parabola, deep rectangle, and deep trapezoid. For each conceptualized shape, an offset must be estimated, where the offset is the elevation that contains all of the water within that specific shape. This conceptualization allows for the estimation of an exponent for each segment based on the geometric shape [23]. It must be estimated, to have a known parameter, using appropriate software, which, based on how the cross-section is created, provides the e parameters for the defined segments. When this extrapolation is not possible, then e is an un- known parameter that must be calculated (using fitting methods). Generally, we have the information about e only for the first segment so the values of e for the other segments must be evaluated.

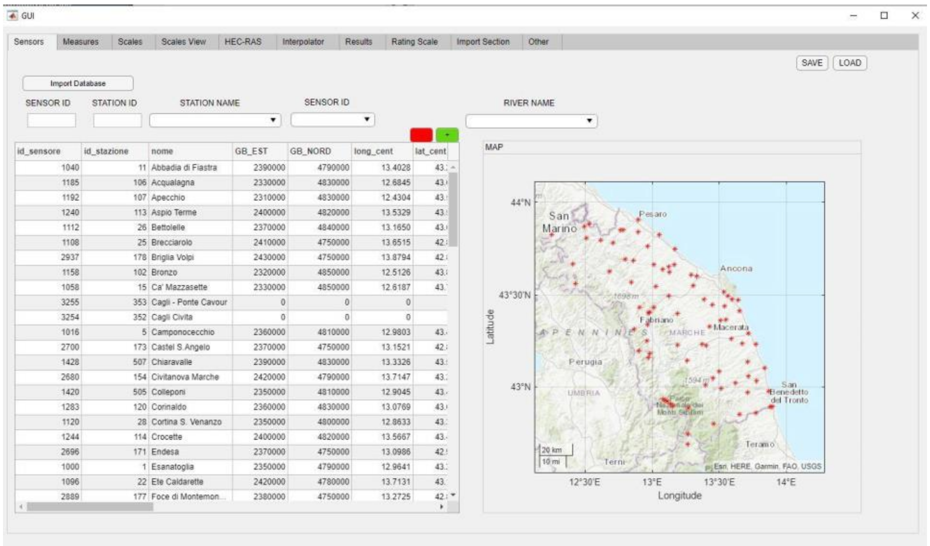
The rating curve calibration is an iterative process of the conceptual model using gauging measurements from the field. Knowing the shape of the cross- section the offset e is defined, but it can vary with the stage increase. Thus, the number of segments needed to evaluate a reliable rating curve must be de- fined. For regular-shaped section controls, the effective gauge height of zero flow is nearly the same as the actual gauge height of zero flow, so it can be measured for the first segment of the rating scale by measuring the river depth at the deepest place in the control section as compared to the gauge datum, and then subtracting it from the gauge height h at the time of measurement [17]). At points where the control shape considerably changes, or where the control changes from section to channel control, the effective gauge height of zero flow usually changes. This results in the need to analyze rating curves in segments to properly define the correct hydraulic shape for each control condition. With our software, it’s possible to superimpose the rating curve with the cross-section of the river in analysis to understand better the change points of the segments.

To ensure the congruence of the measures over time, the measures must re- fer to a single immovable benchmark. However, the bottom of the river bed, by nature, undergoes continuous transformation. For example, during a flood, both the deposit of alluvial material with the relative raising of the bed of the riverbed and erosion with the consequent lowering of the bottom can be observed. For this reason, referring the measurements to a fixed quota is prefer- able to maintain the congruence and comparability of the values measured over time. The values displayed in the hydrometric level graphs do not indicate the real height of the water with respect to the bottom of the section considered, but the distance between the free surface of the water and the gauge. This measure is called gauge height, which is represented in Eq. 1, as h. In general, a datum (also called gauge datum or gage datum) is a point, plane, or surface by which systems of measurement are referred or related to one another. A vertical datum is a level surface to which elevations are referred, usually the mean sea level. On the control station it is possible to identify different heights indicated with:

- hGD indicates the elevation between the mean sea level and the gauge datum chosen for the control station.
- hm represents the height between the sensor position and the river water level.
- hs is the height between the sensor position and the gauge datum (a known constant measured during the installation of the station); e is the previously described gauge height of zero flow.
- (h-e) is the effective depth (or effective gauge height) used in the model of Eq. (1) [22].

Graphic User Interface and Discussion

We have developed the software to acquire data reported by Civil Protection on the field, view the collected data, create, and display rating scales, and update all the information about each river. In Fig. 4, is reported the main window where are shown all the sensors of the control stations located in the Marche Region. In this window, it is possible to import the database that is composed by three tables: sensors table, measures table and rating scales table.



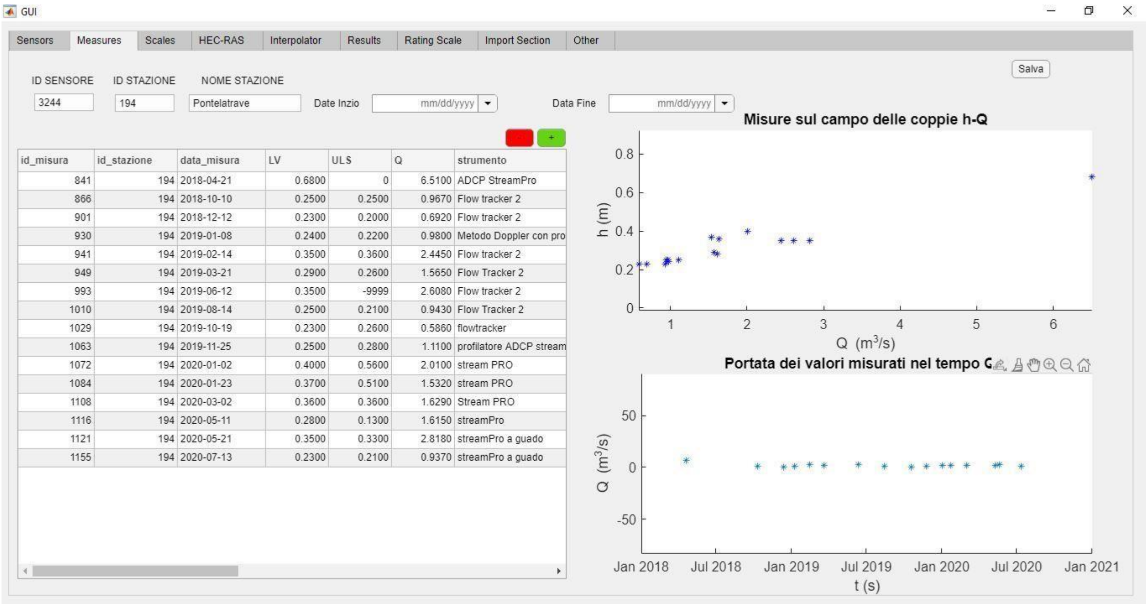
id_sensore	id_stazione	nome	GB_EST	GB_NORD	long_cent	lat_cent
1040	11	Abbadia di Fiastra	2390000	4790000	13.4028	43.
1185	106	Acqualagna	2330000	4830000	12.6845	43.
1192	107	Apecchio	2310000	4830000	12.4304	43.
1240	113	Aspio Terme	2400000	4820000	13.5329	43.
1112	26	Bettolelle	2370000	4840000	13.1650	43.
1108	25	Brecciarolo	2410000	4750000	13.6515	42.
2937	178	Briglia Volpi	2430000	4750000	13.8794	42.
1158	102	Bronzo	2320000	4850000	12.5126	43.
1058	15	Ca' Mazzasette	2330000	4850000	12.6187	43.
3255	353	Cagli - Ponte Cavour	0	0	0	
3254	352	Cagli Civita	0	0	0	
1016	5	Camponocecchio	2360000	4810000	12.9803	43.
2700	173	Castel S.Angelo	2370000	4750000	13.1521	42.
1428	507	Chiaravalle	2390000	4830000	13.3326	43.
2680	154	Civitanova Marche	2420000	4790000	13.7147	43.
1420	505	Colleponi	2350000	4810000	12.9045	43.
1283	120	Corinaldo	2360000	4830000	13.0769	43.
1120	28	Cortina S. Venanzo	2350000	4800000	12.8633	43.
1244	114	Crocette	2400000	4820000	13.5667	43.
2696	171	Endesa	2370000	4750000	13.0986	42.
1000	1	Esanatoglia	2350000	4790000	12.9641	43.
1096	22	Ete Caldarette	2420000	4780000	13.7131	43.
2889	177	Foce di Montemon...	2380000	4750000	13.2725	42.

Figure 4: Graphic user interface: sensors window

The window relating to the sensors shows the most important fields that characterize them:

- Sensor id: uniquely identifies the sensor located in the station
- Station id: uniquely identifies the control station
- Location name: identifies where the station is located
- Gauge G.B. east: Gauss Boaga - Rome 40 (EPSG: 3004) east coordinate
- Gauge G.B. north: Gauss Boaga - Rome 40 (EPSG: 3004) north coordinate
- Gauge longitude (EPSG: 4326)
- Gauge latitude (EPSG: 4326)
- Gauge elevation: sensor position referred to the gage datum
- Gage datum elevation: gage datum position referred to the mean sea level
- Basin name
- River name
- Typical max value for low, medium, and high level: identifies typical stages range in the cross-section of the river for different operating situations; useful for the operator to understand when taking measurements according to the current height
- Various notes

So, when a new sensor is added, a new row must be completed. The control station of interest to be analyzed is selected from the drop-down menu and then the operator moves on to the next window where all the measurements performed are shown (an example is reported in Fig. 5).



ID SENSORE: 3244
ID STAZIONE: 194
NOME STAZIONE: Pontelatrave
Date Inzio: mm/dd/yyyy
Data Fine: mm/dd/yyyy

id_misura	id_stazione	data_misura	LV	ULS	Q	strumento
841	194	2018-04-21	0.6800	0	6.5100	ADCP StreamPro
866	194	2018-10-10	0.2500	0.2500	0.9670	Flow tracker 2
901	194	2018-12-12	0.2300	0.2000	0.6920	Flow tracker 2
930	194	2019-01-08	0.2400	0.2200	0.9800	Metodo Doppler con pro
941	194	2019-02-14	0.3500	0.3600	2.4450	Flow tracker 2
949	194	2019-03-21	0.2900	0.2600	1.5650	Flow Tracker 2
993	194	2019-06-12	0.3500	-9999	2.6080	Flow tracker 2
1010	194	2019-08-14	0.2500	0.2100	0.9430	Flow Tracker 2
1029	194	2019-10-19	0.2300	0.2600	0.5860	flowtracker
1063	194	2019-11-25	0.2500	0.2800	1.1100	profilatore ADCP stream
1072	194	2020-01-02	0.4000	0.5600	2.0100	stream PRO
1084	194	2020-01-23	0.3700	0.5100	1.5320	stream PRO
1108	194	2020-03-02	0.3600	0.3600	1.6290	Stream PRO
1116	194	2020-05-11	0.2800	0.1300	1.6150	streamPro
1121	194	2020-05-21	0.3500	0.3300	2.8180	streamPro a guado
1155	194	2020-07-13	0.2300	0.2100	0.9370	streamPro a guado

Figure 5: Graphic user interface - measures window

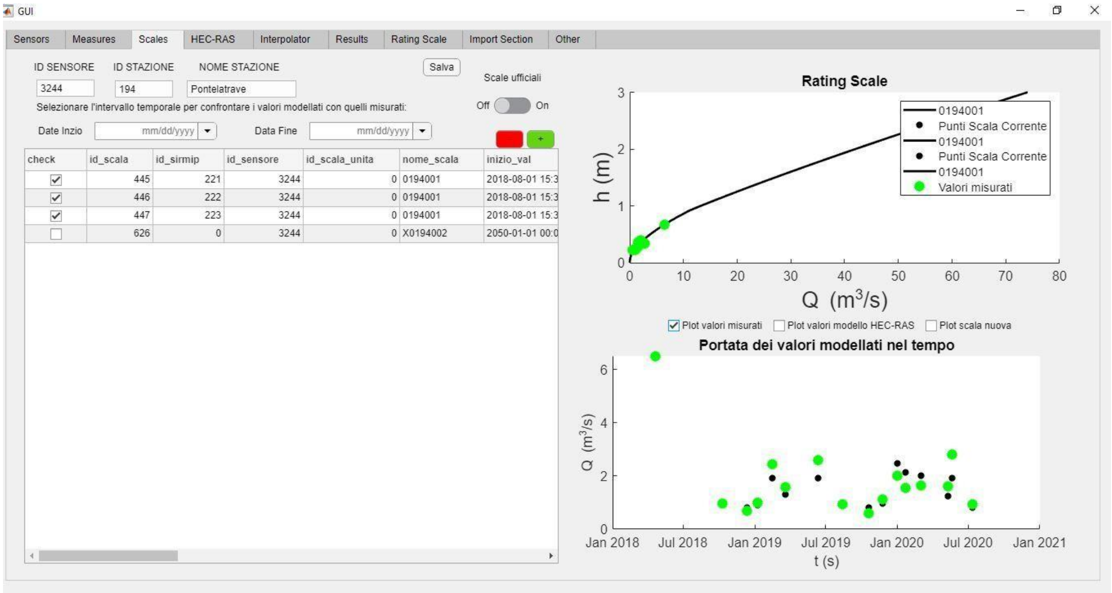
The window relating to the measures shows the most important fields that characterize them:

- Measure id: uniquely identifies the measure.
- Station id: uniquely identifies the station.
- Measure date: the day of the measurement acquisition.
- Rod gauge height: hydrometric rod measurement.
- Sensor gauge height: ultrasound or radar sensor measurement.
- Discharge: discharge estimation on the field (Q).
- Instrument: type of appliance used to indirectly measure the discharge.
- Operator name.
- Measurements notes.
- Link of photos.

In Fig. 5, is shown a table with all the measures recorded for the specific sensor and two graphs. The upper graph shows all the couple of the discrete measures h (stage) and Q (discharge). It allows you to observe the distribution of the measurements made of the levels with respect to the discharges.

The lower graph shows the discharge trend measured over the various years in relation to that specific sensor being analysed. In this window is also possible to reduce the range of measures by changing the “begin date” and “end date”. This allows to analyse in a particular time range which are the associated curves.

Once the range of interest to be analysed has been selected, the operator passes to the next window, that of the rating scales, as reported in Fig. 6.



ID SENSORE: 3244
ID STAZIONE: 194
NOME STAZIONE: Pontelatrave

Selezionare l'intervallo temporale per confrontare i valori modellati con quelli misurati:

Date Inzio: mm/dd/yyyy
Data Fine: mm/dd/yyyy

check	id_scala	id_sirmip	id_sensore	id_scala_unita	nome_scala	inizio_val
☑	445	221	3244	0	0194001	2018-08-01 15:3
☑	446	222	3244	0	0194001	2018-08-01 15:3
☑	447	223	3244	0	0194001	2018-08-01 15:3
☐	626	0	3244	0	X0194002	2050-01-01 00:0

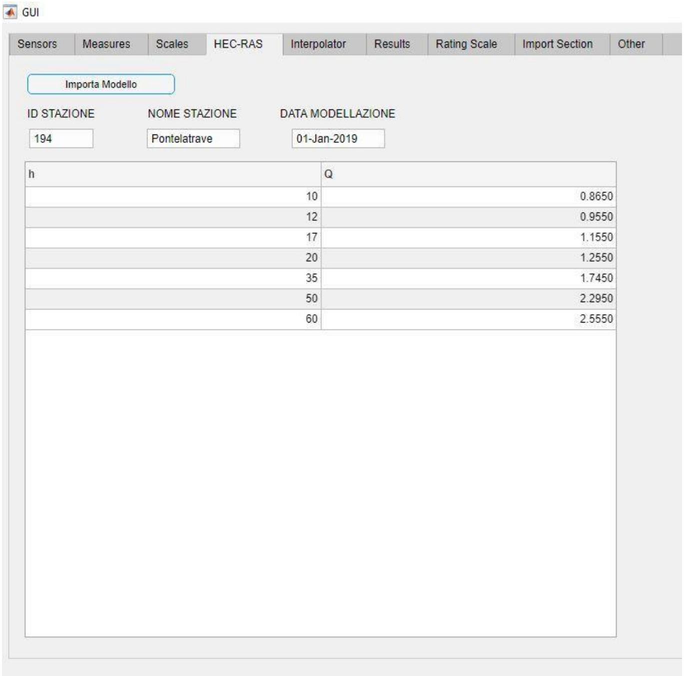
Figure 6: Graphic user interface - rating scales window - an example of view

In this window is possible to see all the rating scales that are saved in the database. Using a check is possible to select only the rating scale that we want to see. The scales memorized are saved in different segments. So, if we want to see the complete scale, we need to enable all the checks associated with a row with the same field “scale name”. The “scale name” field identifies the family of the scale of a cross-section, in a river. Then, each segment is uniquely identified with the identification number. The upper graph in Fig. 6 represents, for example, the entire rating scale composed of three segments and each dot is the measured value on the field. In the lower part is represented the comparison between the discharge points measured on the field and the discharge points estimated from the rating scales selected. So, the operator can directly compare the difference between the real output and the estimated output.

In the subsequent tab of Fig. 7 there is an import window for the HEC-RAS data extracted from HEC-RAS [25]. By means of the modeling of the river and the section through HEC-RAS the extraction of the measurements is carried out when it is not possible to make a direct measurement on the field. Specifically, this software is typically used for data extrapolation towards high discharges where it is difficult to make field measurements with the appropriate instrumentation. In this window, the data field used are:

- Station id
- Station name
- Date of modeling
- The stage values h
- The discharge values Q.

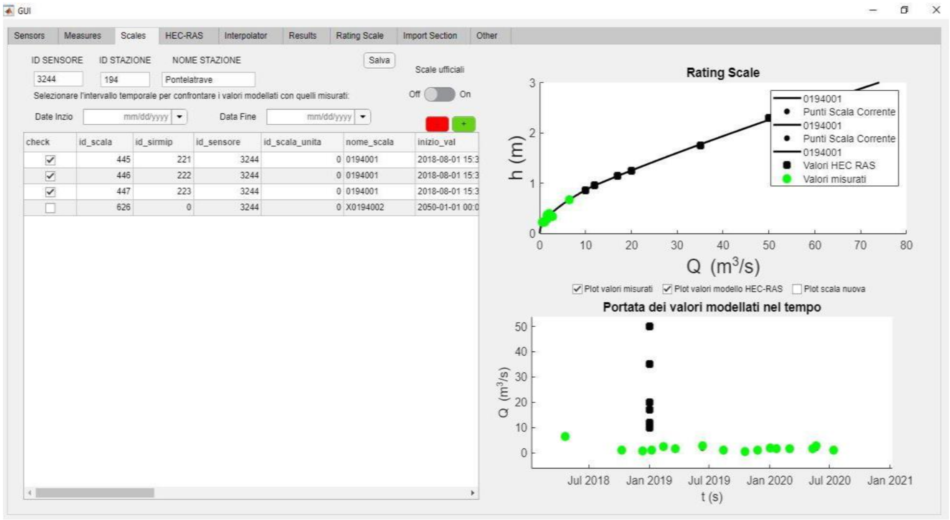
Once imported, these points will be added to the measured data to have a complete representation of the h-Q value pairs over the entire range of interests (as reported in Fig. 7). Then, they can be visible in the rating scale view (as reported in Fig. 8).



ID STAZIONE: 194
NOME STAZIONE: Pontelatrave
DATA MODELLAZIONE: 01-Jan-2019

h	Q
10	0.8650
12	0.9550
17	1.1550
20	1.2550
35	1.7450
50	2.2950
60	2.5550

Figure 7: Grafic user interface – HEC-RAS window – an example of view



ID SENSORE: 3244
ID STAZIONE: 194
NOME STAZIONE: Pontelatrave

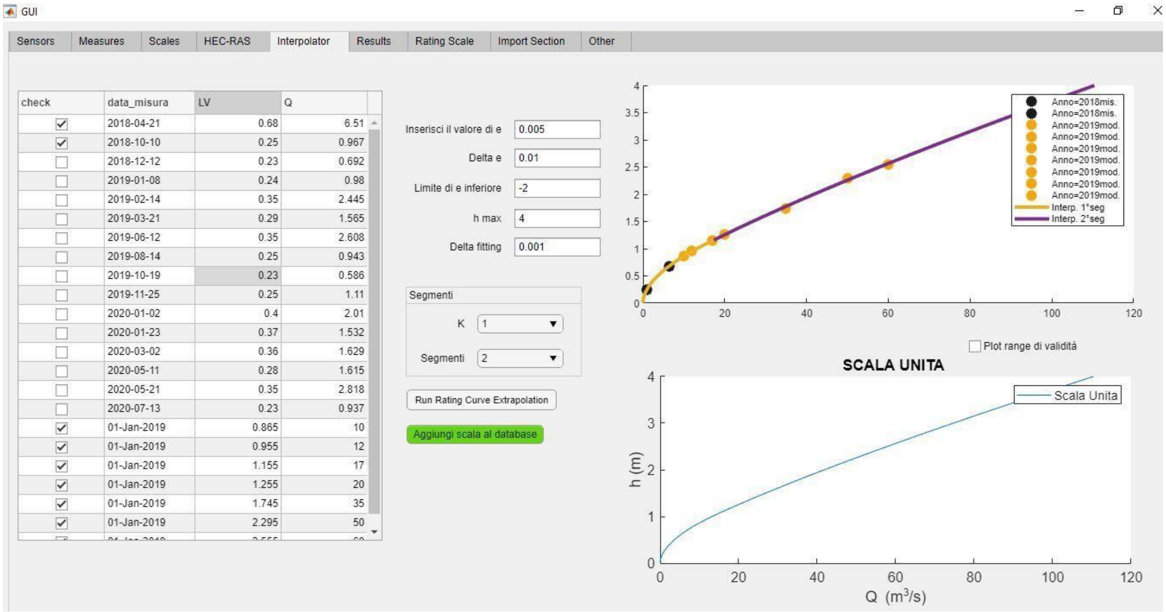
Selezionare l'intervallo temporale per confrontare i valori modellati con quelli misurati:

Date Inzio: mm/dd/yyyy
Data Fine: mm/dd/yyyy

check	id_scala	id_sirmip	id_sensore	id_scala_unita	nome_scala	inizio_val
☑	445	221	3244	0	0194001	2018-08-01 15:3
☑	446	222	3244	0	0194001	2018-08-01 15:3
☑	447	223	3244	0	0194001	2018-08-01 15:3
☐	626	0	3244	0	X0194002	2050-01-01 00:0

Figure 8: Graphic user interface - rating scales with HEC-RAS data - an example of view

On the next tab of the interface, there is the Interpolator window. Here, using the measures acquired on the field and measures modeled by HEC-RAS, is possible to create the rating scale (for example Fig. 9).



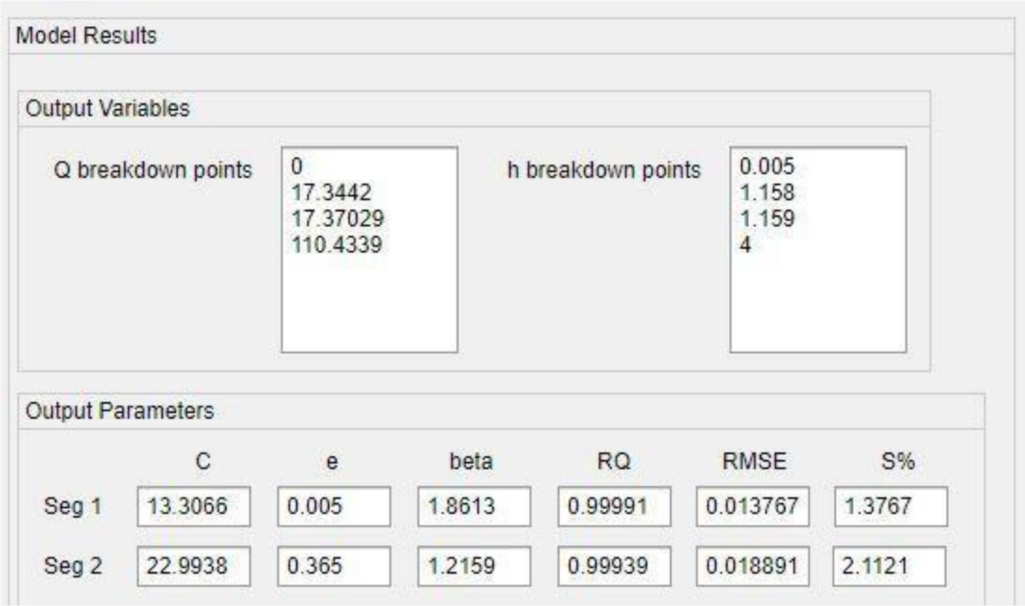
check	data_misura	LV	Q
☑	2018-04-21	0.68	6.51
☑	2018-10-10	0.25	0.967
☐	2018-12-12	0.23	0.692
☐	2019-01-08	0.24	0.98
☐	2019-02-14	0.35	2.445
☐	2019-03-21	0.29	1.565
☐	2019-06-12	0.35	2.608
☐	2019-08-14	0.25	0.943
☐	2019-10-19	0.23	0.586
☐	2019-11-25	0.25	1.11
☐	2020-01-02	0.4	2.01
☐	2020-01-23	0.37	1.532
☐	2020-03-02	0.36	1.629
☐	2020-05-11	0.28	1.615
☐	2020-05-21	0.35	2.818
☐	2020-07-13	0.23	0.937
☑	01-Jan-2019	0.865	10
☑	01-Jan-2019	0.955	12
☑	01-Jan-2019	1.155	17
☑	01-Jan-2019	1.255	20
☑	01-Jan-2019	1.745	35
☑	01-Jan-2019	2.295	50

Inserisci il valore di e: 0.005
Delta e: 0.01
Limite di e inferiore: -2
h max: 4
Delta fitting: 0.001

K: 1
Segmenti: 2

Figure 9: Graphic user interface - rating scales interpolator - an example of view

In this window, the operator can enable or disable the checks to select the measures used to create the rating scales. Some parameters must be inserted in input to the model. For example, the value of e (also known as h_0), the fitting resolution, the max value of the stage, a parameter k used to adjust how curves join each other (to avoid steps), and the number of segments of which the rating scales will be composed. In results window are reported the values of the model used for the fitting of the data (Fig. 10).



Model Results

Output Variables

Q breakdown points
0
17.3442
17.37029
110.4339

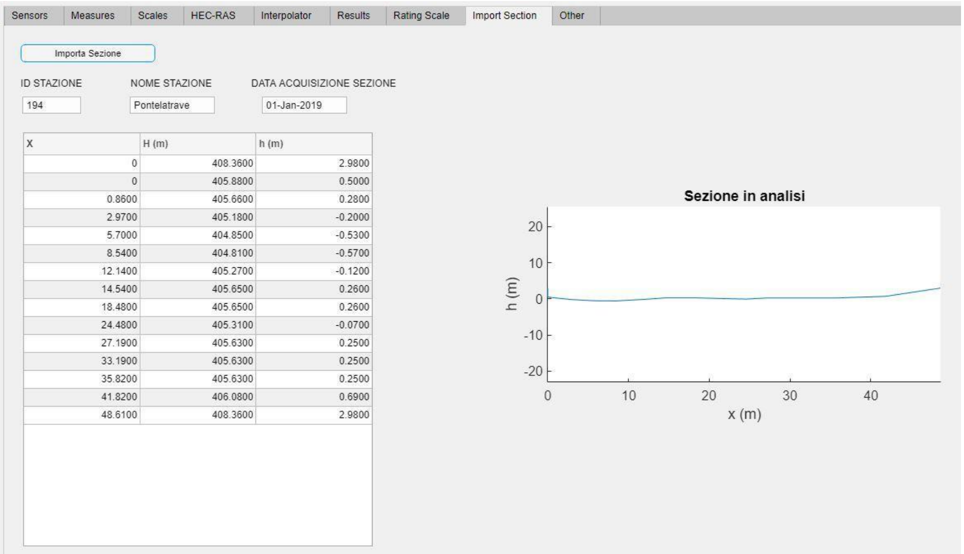
h breakdown points
0.005
1.158
1.159
4

Output Parameters

	C	e	beta	RQ	RMSE	S%
Seg 1	13.3066	0.005	1.8613	0.99991	0.013767	1.3767
Seg 2	22.9938	0.365	1.2159	0.99939	0.018891	2.1121

Figure 10: Graphic user interface – results - an example of view

The breakdown points of h and Q are the values where begin and end the segments of the rating scales. The output parameters will be saved on the scales table if the old rating scales must be updated. Another graph that can be useful when the operator is studying the rating curve is the cross-section which can help the operator to understand when there is a change in the rating curve (example in Fig. 11).



ID STAZIONE: 194

NOME STAZIONE: Pontelatrave

DATA ACQUISIZIONE SEZIONE: 01-Jan-2019

X	H (m)	h (m)
0	408.3600	2.9800
0	405.8800	0.5000
0.8600	405.6600	0.2800
2.9700	405.1800	-0.2000
5.7000	404.8500	-0.5300
8.5400	404.8100	-0.5700
12.1400	405.2700	-0.1200
14.5400	405.6500	0.2600
18.4800	405.6500	0.2600
24.4800	405.3100	-0.0700
27.1900	405.6300	0.2500
33.1900	405.6300	0.2500
35.8200	405.6300	0.2500
41.8200	406.0800	0.6900
48.6100	408.3600	2.9800

Figure 11: Graphic user interface - cross-section of a river - an example of view

In parallel with this application used by hydrologists to manage data and rating scales, a web application has also been developed which is used by operators to enter data acquired in the field (shown in Fig. 12, Fig. 13, Fig. 14, Fig. 15, Fig. 16). The data saved in the web application are then downloaded and imported into the previous interface for managing the rating scales. Once processed the data through queries are imported from the local application on the Meteo-Hydro-Pluviometric Regional Information System (SIRMIP, http://app.protezionecivile.marche.it/sol/indexjs.sol?lang=it). This information system deals with the weather-climatic aspects affecting the Region. Having to enter the data within the regional system, maximum security must be guaranteed to avoid unwanted access. We can therefore identify 3 macro blocks in the infrastructure: the web application located on a server, the software for the rating scales located locally, the SIRMIP platform located on the region's servers.

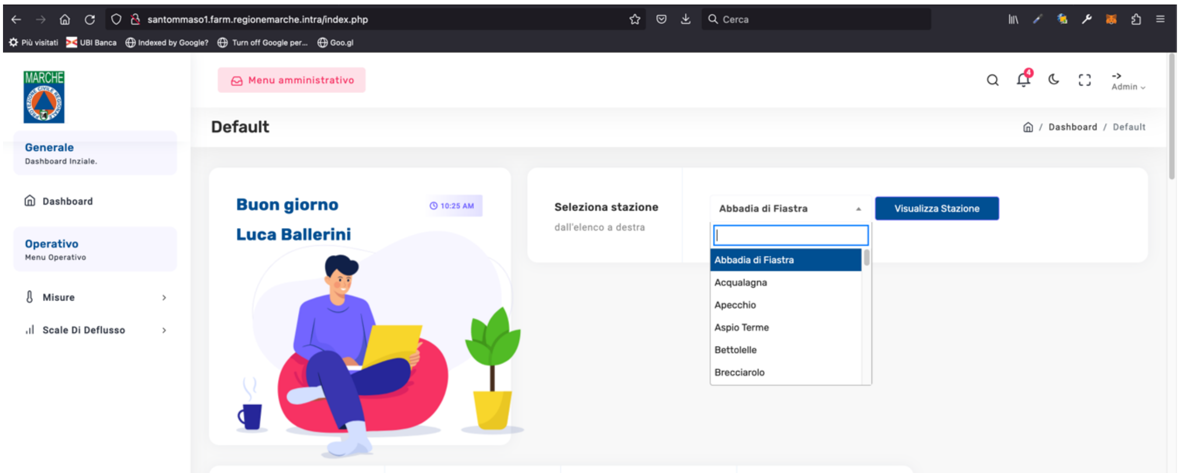
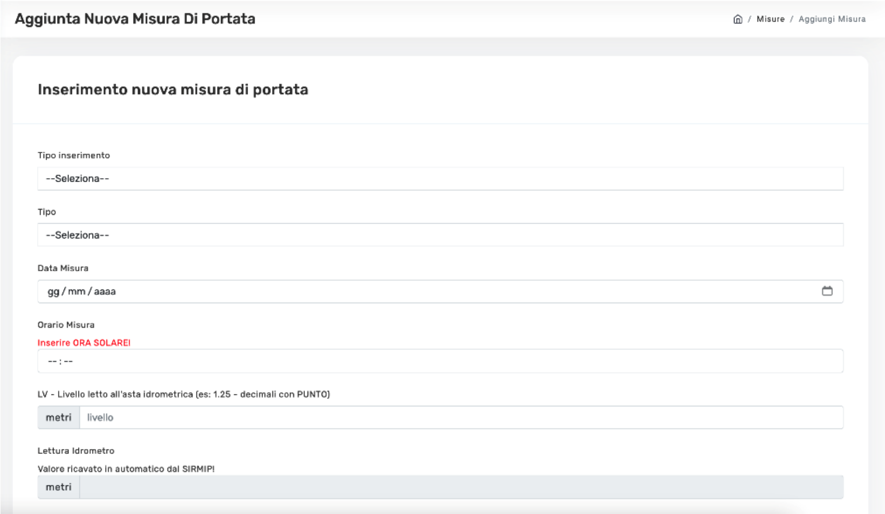


Figure 12: Dashboard



Tipo inserimento
--Seleziona--

Tipo
--Seleziona--

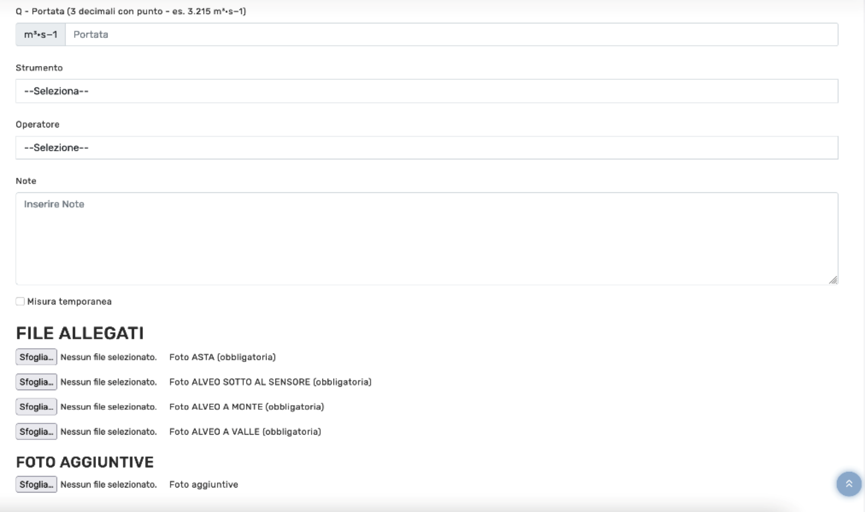
Data Misura
gg / mm / aaaa

Orario Misura
Inserire ORA SOLARE!
-- : --

LV - Livello letto all'asta idrometrica (es: 1.25 - decimali con PUNTO)
metri livello

Lettura Idrometro
Valore ricavato in automatico dal SIRMIP!
metri

Figure 13: Entering a new discharge measurement: type, date, measure time, rod level



Q - Portata (3 decimali con punto - es. 3.215 m^3•s−1)

m^3•s−1 Portata

Strumento

--Seleziona--

Operatore

--Selezione--

Note

Inserire Note

☐ Misura temporanea

FILE ALLEGATI

Sfoglia... Nessun file selezionato. Foto ASTA (obbligatoria)

Sfoglia... Nessun file selezionato. Foto ALVEO SOTTO AL SENSORE (obbligatoria)

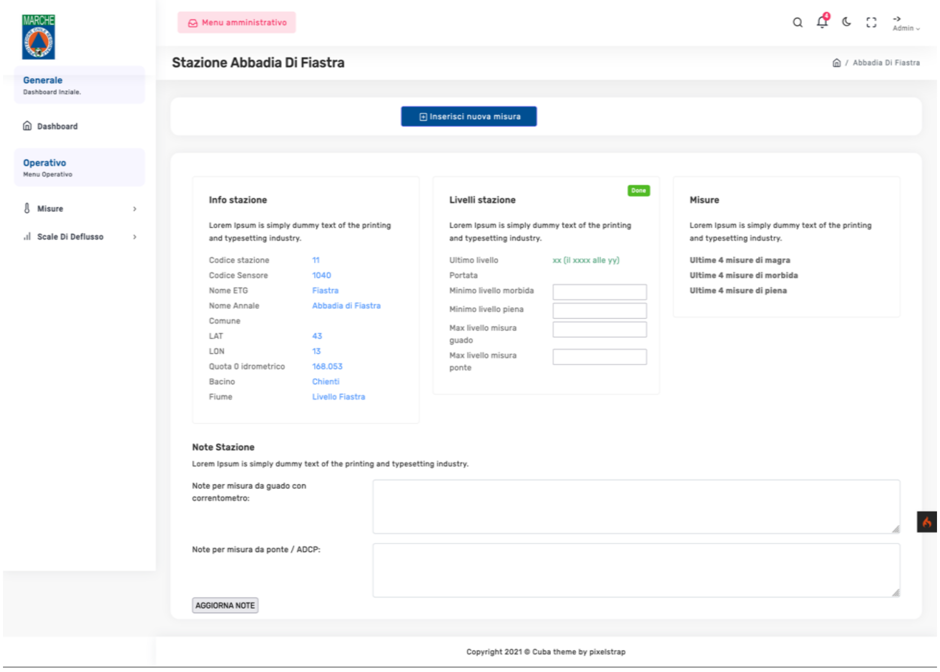
Sfoglia... Nessun file selezionato. Foto ALVEO A MONTE (obbligatoria)

Sfoglia... Nessun file selezionato. Foto ALVEO A VALLE (obbligatoria)

FOTO AGGIUNTIVE

Sfoglia... Nessun file selezionato. Foto aggiuntive

Figure 14: Entering a new discharge measurement: discharge, instrument used, operator name, note, photo files



Stazione Abbadia Di Fiastra

Info stazione

Lorem Ipsum is simply dummy text of the printing and typesetting industry.

Codice stazione	11
Codice Sensore	1040
Nome ETG	Fiastra
Nome Annale	Abbadia di Fiastra
Comune	
LAT	43
LON	13
Quota 0 idrometrico	168.053
Bacino	Chienti
Fiume	Livello Fiastra

Livelli stazione

Lorem Ipsum is simply dummy text of the printing and typesetting industry.

Ultimo livello	xx (il xxxx alle yy)
Portata	
Minimo livello morbida	
Minimo livello piena	
Max livello misura guado	
Max livello misura ponte	

Misure

Lorem Ipsum is simply dummy text of the printing and typesetting industry.

Ultime 4 misure di magra

Ultime 4 misure di morbida

Ultime 4 misure di piena

Note Stazione

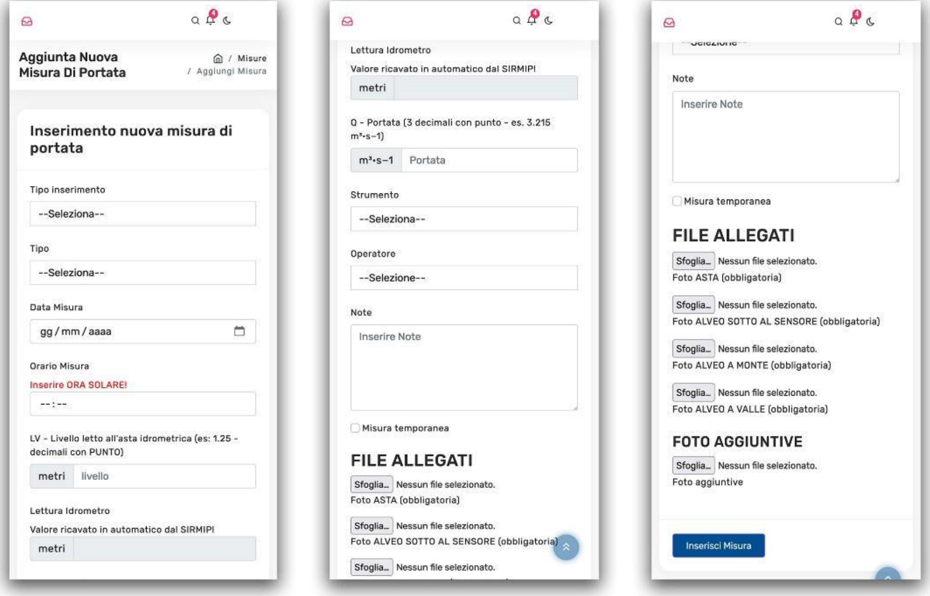
Lorem Ipsum is simply dummy text of the printing and typesetting industry.

Note per misura da guado con correntometro:

Note per misura da ponte / ADCP:

Copyright 2021 © Cuba theme by pixelstrap

Figure 15: Focus on each site



Aggiunta Nuova Misura Di Portata

Misure / Aggiungi Misura

Inserimento nuova misura di portata

Tipo inserimento
--Seleziona--

Tipo
--Seleziona--

Data Misura
gg / mm / aaaa

Orario Misura
Inserire ORA SOLARE!
-- : --

LV - Livello letto all'asta idrometrica (es: 1.25 - decimali con PUNTO)
metri livello

Lettura Idrometro
Valore ricavato in automatico dal SIRMIPI
metri

Q - Portata (3 decimali con punto - es. 3.215 m³•s−1)
m³•s−1 Portata

Strumento
--Seleziona--

Operatore
--Selezione--

Note
Inserire Note

☐ Misura temporanea

FILE ALLEGATI

Sfoglia… Nessun file selezionato.
Foto ASTA (obbligatoria)

Sfoglia… Nessun file selezionato.
Foto ALVEO SOTTO AL SENSORE (obbligatoria)

Sfoglia… Nessun file selezionato.
Foto ALVEO A MONTE (obbligatoria)

Sfoglia… Nessun file selezionato.
Foto ALVEO A VALLE (obbligatoria)

FOTO AGGIUNTIVE

Sfoglia… Nessun file selezionato.
Foto aggiuntive

Figure 16: Compact view of data loading windows using a smartphone

Conclusion

Having a rating scale is essential to estimating the discharge through a section of a watercourse at any time, knowing the water level. The validity of the discharge-water level relationship must be frequently checked and, if necessary, updated as soon as possible to obtain coherent flow data series.

Owing to the knowledge of the estimated discharge, the Functional Centre of Civil Protection can calibrate the numerical model with the historical data series, monitoring the river flow through water-level sensors in telemetry, promptly issuing the necessary warnings in the forecasting phase and sup- porting emergency managers during a flood event.

Data preprocessing is a fundamental step because, if the input data measured in the field and extrapolated from HEC-RAS are updated over time and have a negligible error, the model will produce a more accurate estimate. The flow rate values are also fundamental for both determining the hydrological balance of a basin and estimating return periods from the historical series, essential for designing hydraulic works. The complexity of determining an adequate scale is caused by the need for the knowledge of hydraulics, river dynamics, banks and riverbed geometry, statistics, and geomatics. The discharge data indirectly measured from the riverbed to extrapolate the rating scale are sometimes lacking or technically difficult to obtain. With appropriate settings and surveys of river sections that are updated, the watercourse can be reconstructed, sometimes quite faithfully. With these new data, together with the available measurements, the rating scale can be determined, extrapolating the highest values that are more difficult to measure. The proposed procedure allows us to automatically derive the model used to estimate the discharge, contributing to a faster and easier updating of the rating curve with the management tool [22].

List of abbreviations and terms

The following abbreviations are used in this manuscript:

ADCP Acoustic Doppler Current Profilers
CEMS Copernicus Emergency Management Service EFAS European Flood Awareness System
EPSG European Petroleum Survey Group
G.D. (or GD) Gage Datum
HDCC Hydrological Data Collection Centre
HEC-RAS Hydrologic Engineering Center's - River Analysis System ISPRA Institute for Environmental Protection and Research SIMN National Hydrographic and Mareographic Service
SIRMIP Meteo-Hydro-Pluviometric Regional Information System
STREAM Strategic development of flood management
ULS Ultrasonic sensor
USGS United States Geological Survey WMO World Meteorological Organization

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