14th Congress INTERPRAEVENT 2021
Norway – Paper
www.interpraevent.at

Image-based flow monitoring in a remote alpine catchment

Maxence Carrel[1], Salvador Peña-Haro[2], Beat Lüthi[2], Issa Hansen[3]

Keywords: Flow measurement; real-time monitoring; Flooding; image processing; alpine canyon

Abstract

This paper presents an image-processing based method for measuring water level and volumetric flow rate for a stream located in an alpine catchment. The system is energetically self-sufficient and consists of an IP camera, a floodlight beamer, a processing and a transmission units. It can be accessed in real-time for monitoring the stream. The water level is detected automatically and several thresholds for water level or discharge warning can be implemented. The surface velocity field is measured by means of Surface Structure Image Velocimetry. Using the measured water level and velocity as an input, the flow rate can be computed using a physical model. A rating curve is continuously generated with the measured water level and discharge, thus allowing de-rating detection after extreme events.

Introduction

Flow or discharge data of alpine catchments is key for a wide range of activities spanning from the planning and operation of dams and water intakes, the design of flood protection structures to hydrological modelling. In many cases, access to real-time data is very useful (e.g. dam operational purposes or early warning against floods). In the last decades, image-processing based technologies such as Particle Imaging Velocimetry (PIV) emerged as valuable alternatives for performing flow measurements for many different applications. The idea is to seed the fluid of interest with particles allowing to measure the surface velocity field using cross-correlation methods. Whereas these technologies first were applied to images acquired with high-speed cameras under laboratory conditions (Adrian R.J., 1991), their usage was progressively extended to field experiments (Fujita I. et al., 1999). In recent years, such measurements were also performed using images acquired by consumer-grade devices such as smartphones (Carrel et al., 2019) and drones (Bandini et al., 2019). However, the use of PIV techniques for continuous monitoring of flows under field conditions is hardly feasible as these techniques rely on the addition of tracer particles used to reveal the displacement of the fluid of interest (Muste et al., 2008). This

[1] Dr., Product Manager, Photrack Ltd, Ankerstrasse 16a, Zürich, Switzerland (carrel@photrack.ch)
[2] Photrack Ltd, Ankerstrasse 16a, Zürich, Switzerland
[3] SEBA Hydrometrie GmbH & Co. KG Gewerbestr. 61 A 87600 Kaufbeuren Germany

shortcoming was overcome by another Imaging Velocimetry technique introduced by Leitão et al. (2018) relying on naturally occurring Surface Structures (SSIV) to perform surface velocity measurements. This patented technology was shown to accurately allow the surface velocity measurement under night and day conditions, even for low resolution video recordings, which opens the door to applications in areas where data transmission may be limited by the bandwidth of the internet service as in remote mountainous regions for example. This study introduces an image-based flow measurement system installed in such a remote alpine catchment. Images are acquired with an IP camera and are processed on site using the SSIV technique, delivering water level and volumetric flow rate data, which are required to design the water intake of a hydropower facility under planning.

Methods

The measurement system is installed at 2100 m.a.s.l. in a canyon (see Figure 1), around 500 m below the tongue of a glacier and is used from May to October to monitor water level and volumetric flow rate during the snow and glacier melt season. The system consists of a Vivotek Dom camera allowing precise and repeatable pan, tilt and zoom, a floodlight beamer, a solar panel, a fuel cell as well as processing and transmission units. This system performs water level and flow measurements at hourly intervals over night and day. The power supply of the system is covered by a battery that is recharged by the solar panel and the fuel cell. The floodlight beamer is installed and switched on synchronously with the camera during the night recordings. The camera records 5 seconds movies of a region of the stream that is used for water level detection and surface velocity measurements (8 bit images, 360 x 640 pixels resolution, 30 fps). The recordings are processed on site and the results pushed to a server. The system can be accessed in real-time for monitoring of the stream.

Figure 1. Canyon in which the measurement system is installed (top). Camera located below the bridge (right). Solar panel and box containing the fuel cell, processing and transmission units (bottom).

In order to calibrate the internal and external parameters of the camera, the position of ground control points (GCPs) distributed homogeneously within the field of view are measured with a distance meter (LEICA S910). Figure 2 A presents the position of the camera, the ground control points as well as the cross section of the stream. Figure 2 B shows the detected and computed position of the GCPs, testifying of the accurate calibration of the camera. The dry section of the bathymetry is reconstructed using photogrammetric methods based on images of the region of interest acquired under low-flow conditions. As a portion of the bathymetry remained immerged during the whole melting season, another approach was necessary in order to reconstruct its geometry. In order to obtain the wet section remaining, several possible cross-sections were generated and the discharge was computed using the Surface Structure Imaging Velocimetry approach described below. The results of the discharge measurements were compared with results of several tracer tests performed for different flow rates and the cross-section for which the discharge was best agreeing with the tracer tests was retained as the most plausible one (Figure 2 B). Therefore, the bathymetry considered for the discharge computation is not strictly speaking corresponding to the reality, it is rather an effective bathymetry yielding plausible discharge measurements.

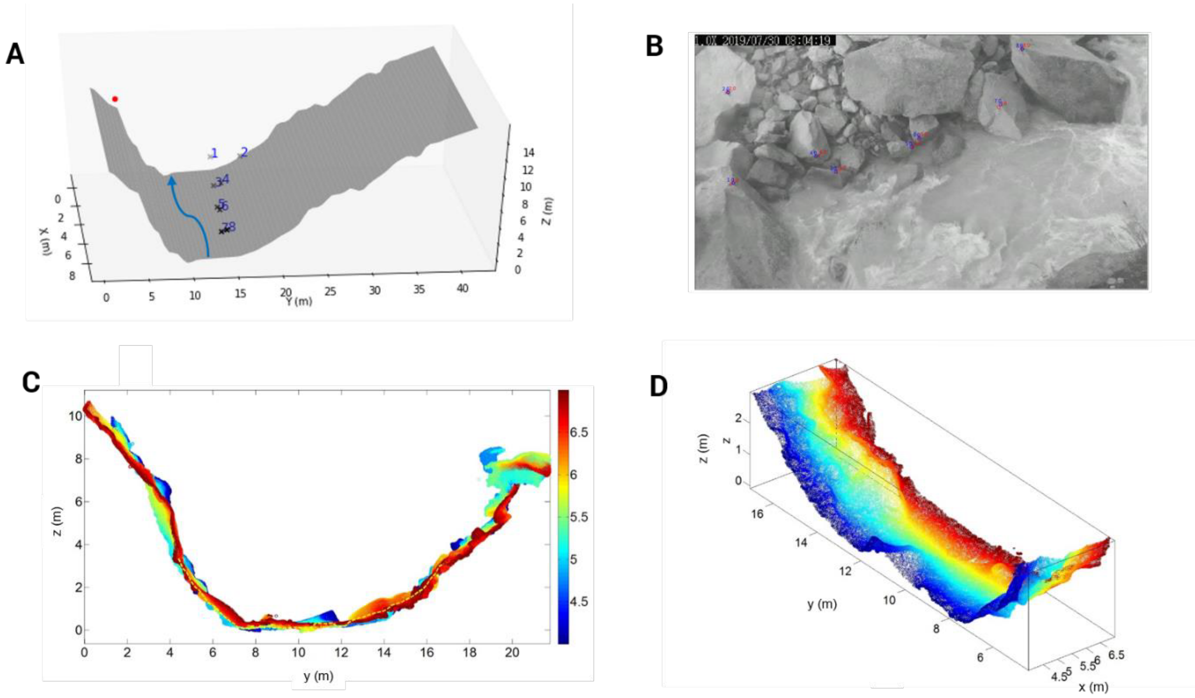

Figure 2. (A) Camera (red) and ground control points (black crosses) with the bathymetry retained for the measurements and the direction of flow (blue arrow). (B) Detected position of the ground control points in image space (blue) and position obtained upon camera calibration (red). (C) 2D projection of the reconstructed canyon geometry (color-coded with the x - position), the yellow dashed-line represents the finally retained bathymetry. (D) Portion of the 3D reconstruction used for the bathymetry generation (color-coded with the x-position).

The water level is automatically measured optically either using a direct segmentation of the 8 bit images or the texture of the flowing water depending on the light conditions. The surface velocity field was computed using the SSIV method for a region of interest of the field of view where the cross-section remained constant. Then, the streamwise surface velocity profile was obtained by applying a fit to the streamwise velocity components measured in the region of interest. Here, the vertical velocity profile was modelled automatically using a model based on Prandtl's mixing length hypothesis, as described by Absi (2006). However, depending on the measurement site, several other approaches for the discharge computation such as methods using alpha values (coefficient relating the depth-averaged velocities to the surface velocity) or the ISO standard 748:2007 (standard expressing the average velocity as a function of the depth, the surface velocity and a Manning roughness coefficient) can be implemented. Finally, the discharge was obtained by integrating the vertical velocity profiles over the width of the stream. The water level, surface velocity field as well as both the horizontal and vertical velocity profiles are presented in Figure 3.

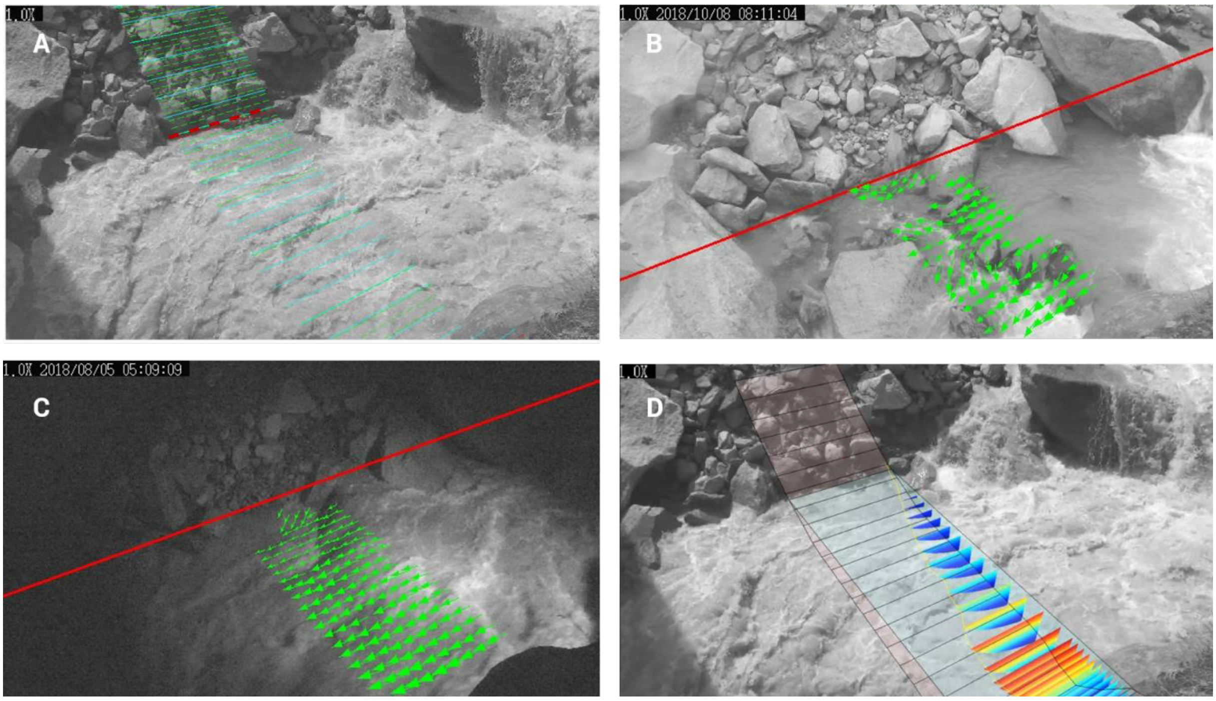

Figure 3. (A) Bathymetry projected on an image of the canyon (green) and optically detected water level (red). (B) Measured water level and flow field under low flow conditions. (C) Water level and flow field obtained for a night measurement. (D) Horizontal and vertical profiles of the streamwise velocity component used for the discharge computation.

Results and discussion

The Figure 4 shows time series of the hourly and daily discharge measured for the melting seasons 2015 to 2018. The hourly data reveal the daily variation in discharge as the flow regime of the catchment considered heavily depends on snow and ice melt, so that the flow rates measured are generally lower at night. High flow rates are then either caused by high temperature and melt rates or subsequent to precipitation events. The night and day high frequency variations are smoothed out in the daily data, where the variations of lower frequencies correspond to temperature variations and responses of the catchment to precipitation events. These time series stretch over different time periods, as the installing and uninstalling dates of the system depended on the presence of snow or not at the measurement location.

In Figure 5, the measured flow rate data obtained for four melting seasons is plotted against the corresponding water level measurements. A possible rating curve or expression of the water level as a function of the discharge is obtained by fitting a power law to the measured data in a least-squares sense is suggested by the dashed line and corresponding 10 percent intervals by the dot-dashed lines. Most of the measured data lies within these intervals. Results of tracer tests are also shown in this Figure and are well corresponding with the possible rating curve.

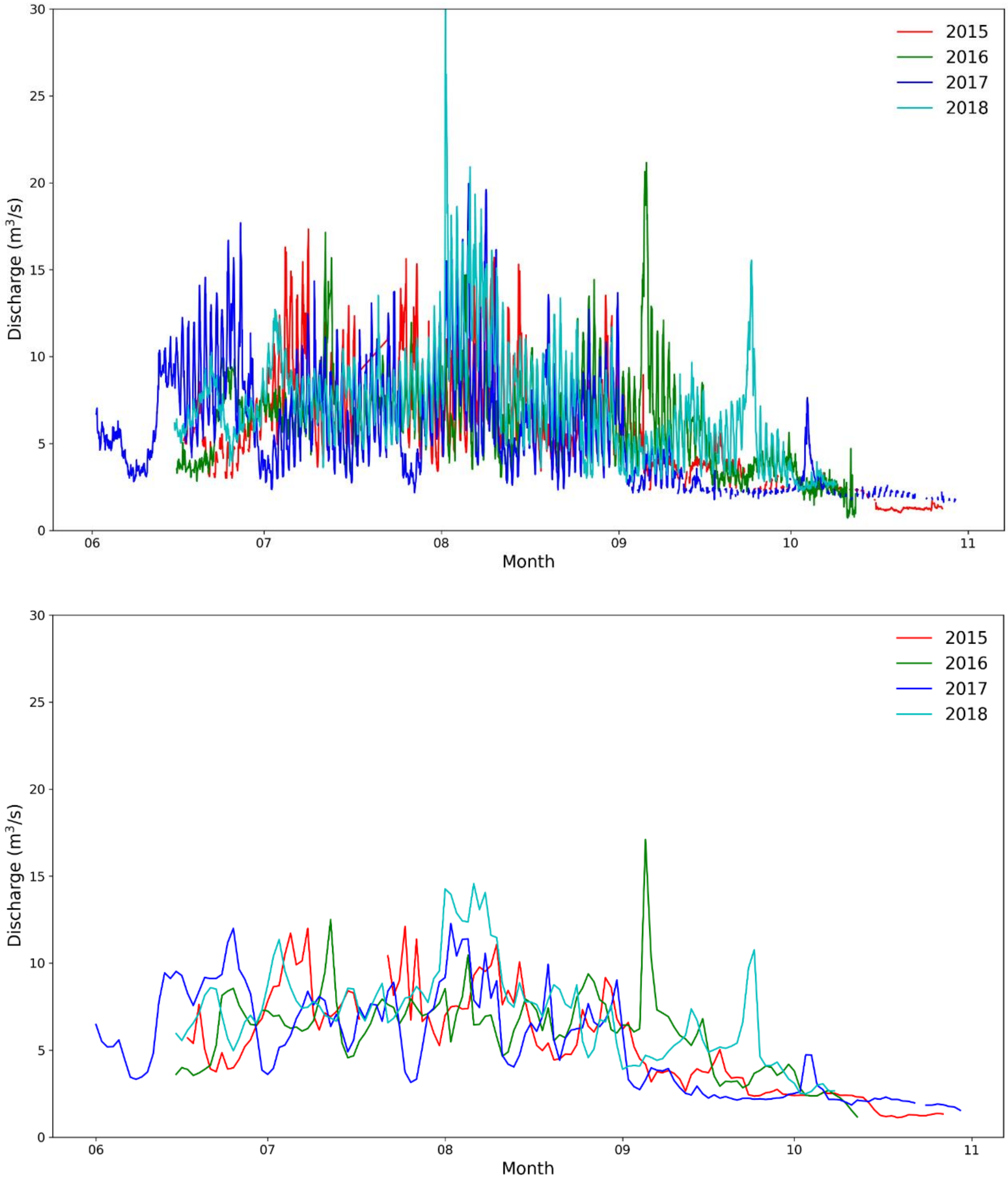

Figure 4. Hourly (top) and daily (bottom) time series of flow data for the melting seasons of 2015 to 2018.

As this measurement system provides simultaneous water level and flow measurements, it allows to detect events upon which the measured data deviates from the rating curve observed previously, so-called de-rating events. Such an event is illutrated on the Figure 6, where the data of the 2018 melting season is shown and color-coded with the calender week corresponding to the date of the measurement. For this season, a flood event occurred during the calendar week 31 (first days of August) and resulted in a de-rating event illustrated by the departure of the measured data from the expected rating curve. In such an event, the cross-section is subject to substantial changes due to the interplay of hydromorphologic processes such as erosion and sedimentation, so that for similar water levels as previously measured, the obtained flow values are significantly different. On Figure 6, note the dashed-line which is the original rating curve on which the data of the season 2018 is falling until the flood event of week 31. The bathymetry of the measurement site was recalibrated upon the de-rating event and the resulting data is the one presented in the Figure 5. With this updated bathymetry, the data is again more similar to the original rating curve measured.

For every measurement performed, a so-called proof image showing the measured water-level and surface-velocity field measured is stored. In the case of the de-rating event mentioned, the proof-image can be assessed a posteriori to ensure that the anomaly detected is in fact the consequence of an extreme event and not the consequence of a measurement error. Warnings can be configured so that the user is informed as soon as such events occur.

An interesting feature of this technology is that the measurements can be performed without having any instrument directly in contact with the water. Such non-contact measurement techniques are particularly of interest in the alpine context where the river bed is subject to important hydromorphological processes, so that material installed in the river bed or its vicinity could be damaged upon extreme events such as floods or landslides. This is particularly true in the present case, as for example the boulder present in Figure 2 B and not visible in any images of Figure 3 attests of the instability of the river bed. Again, real-time access is of interest here as it allows to visually inspect the occurrence of such events.

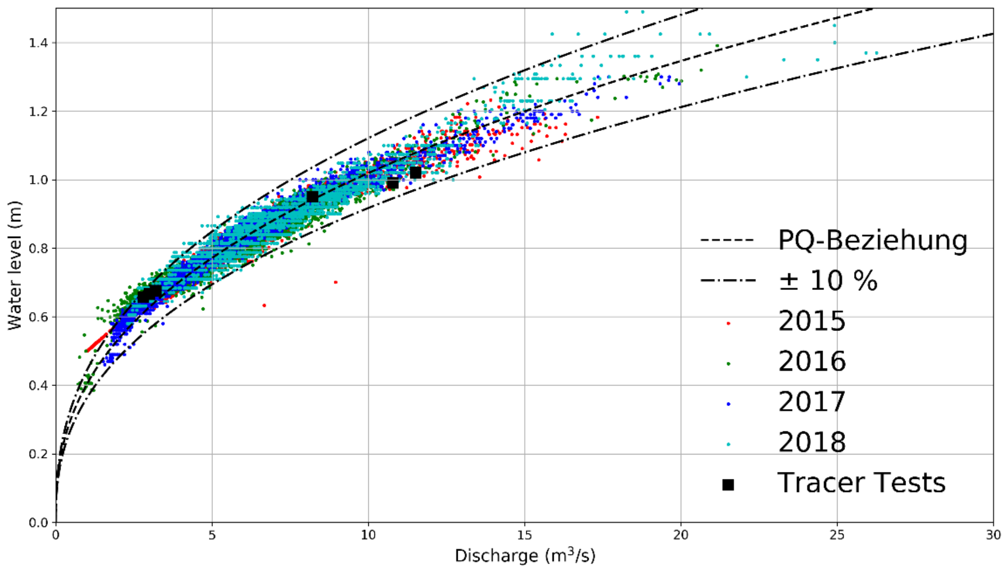

Figure 5. Measured water level plotted as function of the measured discharge for the melting seasons 2015 to 2018, as well as several tracer tests performed (black dots). The black dashed-line presents a possible rating-curve and the dot-dashed lines represent 10 percent intervals.

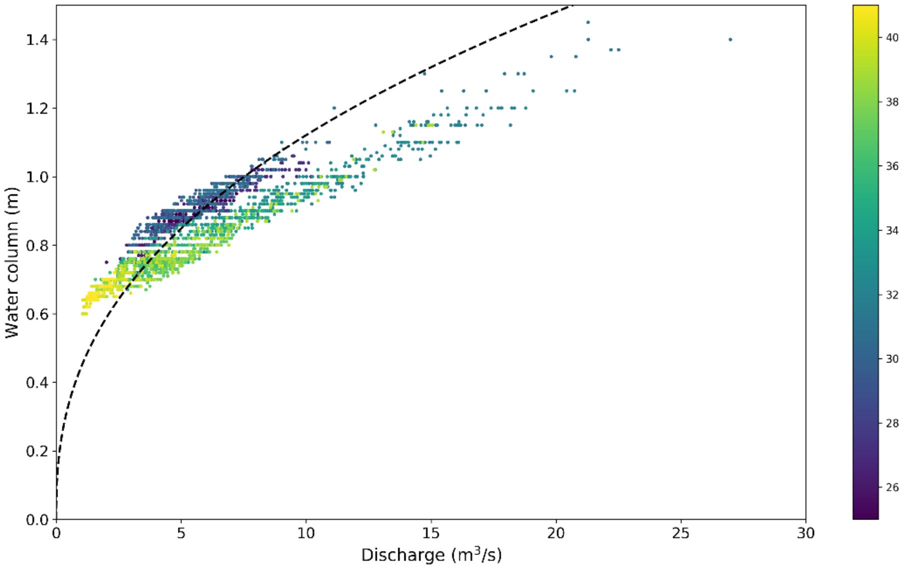

Figure 6. Water level and discharge data measured for the 2018 melting season color-coded with the calendar week before the correction for the de-rating event. Note the de-rating event occurring at the beginning of the calendar week 32.

Conclusions

The results presented in this study underline the potential of non-contact image-based approaches for flow measurements in remote areas. Thereby, one very interesting feature of the technology introduced is that it allows real-time access to the measurement system, providing some interesting information to monitor flow and the vicinity of the river bed. Additionally, early warning can easily be implemented in such measurement system, informing the user in case of extreme events and the plausibility of these early warnings could be checked in real-time.

References

Absi, R. (2006). "A roughness and time dependent mixing length equation." Journal of Hydraulic, Coastal and Environmental Engineering, Japan Society of Civil Engineers 62 (4): 437-446.

Adrian R.J. (1991). Particle-imaging techniques for experimental fluid mechanics. Annual Review of Fluid Mechanics 23.

Bandini F., Lüthi B., Bauer-Gottwein P. (2019). Unmanned aerial systems (UASS) for monitoring water surface elevation, bathymetry, surface velocity and discharge in streams. Drone Special, Hydrolink (1).

Carrel M., Detert M., Peña-Haro S., Lüthi B. (2019). Evaluation of the DischargeApp: a smartphone application for discharge measurements. Hydrosensoft 2019, Madrid, Spain.

Fujita I., Muste M. and Kruger A. (1998). Large-scale particle image velocimetry for flow analysis in hydraulic engineering applications. Journal of Hydraulic Research 36(3).

Leitão J.P., Peña-Haro S., Lüthi B., Scheidegger A., Moy de Vitry M. (2018). Urban overland runoff velocity measurement with consumer-grade surveillance cameras and surface structure imaging velocimetry. Journal of Hydrology (565) 791 – 804.

Muste M., Fujita I., Hauet A. (2008). Large-scale particle image velocimetry for measurements in riverine environments. Water Resour. Res., 44.