Time Lapse Photography – A Low-Cost, Low-Tech Alternative for Monitoring Flow Depth

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Abstract

Streamflow information is collected worldwide and used in areas of engineering design, water supply planning, hydrologic and water quality analysis, among others. Available data from intermittent and ephemeral streams in arid regions are sparse because streamflow is highly variable and infrequent. Due to a lower perceived priority to monitor intermittent and ephemeral streams, it is more difficult to justify the economic expense of traditional monitoring equipment. In this study, we demonstrate that time lapse photography can provide a viable, low-cost, low-tech option for measuring stage (water depth) at stream gauging stations. A time lapse camera was set up to record images of a channel and staff gauge in an ephemeral urban catchment in central New Mexico. During flow events, stage can be read from the time lapse images and converted to a discharge time series. In the course of a 2-year test period, 33 runoff events were recorded. For approximately $200 in materials, this method costs only a fraction of conventional gauging stations.

Peer-reviewed accepted manuscript. For published article, please refer to: Schoener, G. (2017). “Time-Lapse Photography: Low-Cost, Low-Tech Alternative for Monitoring Flow Depth.” J. Hydrol. Eng. 23(2). https://doi.org/10.1061/(ASCE)HE.1943-5584.0001616

Introduction

Streamflow information is collected worldwide and used for a wide range of purposes, including:

- Water supply planning (Loucks et al., 2005),
- Flood planning and engineering design (Douglas et al., 2002; Read and Vogel, 2016),
- Tracking the impacts of land/water use and climate change (Ye et al., 2013; Aich et al., 2014),
- Validating hydrologic and water quality models (Daggupati et al., 2015).

The Global Runoff Data Center (GRDC, 2017) maintaines a global runoff database comprising more than 9,300 gauging stations from countries around the world (Fig.1). While this is by no means a comprehensive list of all gauging stations, it illustrates areas that are heavily monitored and, conversely, regions with few or no flow measurements.

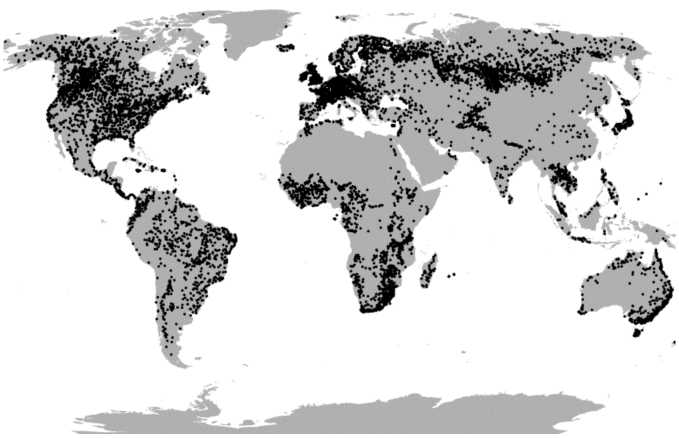

Fig. 1. Map of stream gauging stations around the world (GRCD, 2017).

In the United States, the U.S. Geological Survey maintains a network of nearly 10,000 stream gauging stations (USGS, 2017). Fig. 2 shows stations in the continental U.S.; station density is markedly higher in the eastern half of the country, as well as along the west coast.

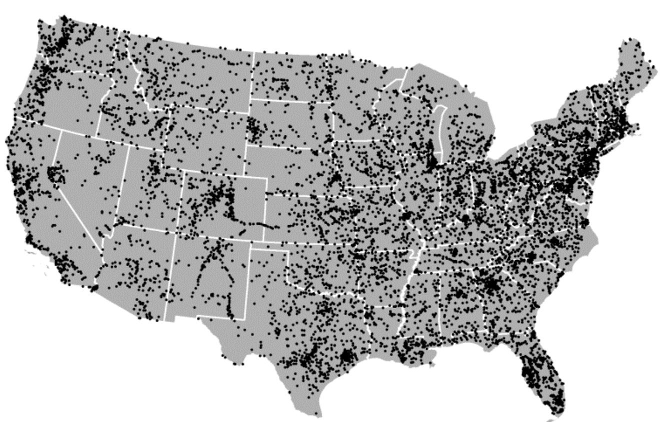

Fig. 2. Map of USGS stream gauging stations in the continental U.S. (USGS, 2017).

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Figs. 1 and 2 illustrate reduced densities of gauging stations in arid and semi-arid regions, both in the US and globally. Streamflow in arid regions is highly variable and infrequent. Due to a lower perceived priority to monitor intermittent and ephemeral streams, it is more difficult to justify the economic expense of traditional monitoring equipment. USGS stream gauging stations that are part of the National Streamflow Information Program (NSIP) cost between $20,000 and $50,000 to install (Babbitt and Groat, 1999) and between $7,000 and $15,000 annually to operate (Norris et al., 2007). Pilgrim et al. (1988) noted that the lack of streamflow data from arid regions is a major challenge for hydrologic analysis.

An inexpensive, low-tech alternative to traditional stream gauges is needed to provide reliable flow data in ephemeral systems where flow events are infrequent and short in duration and in cases where budget is a constraint.

Royem et al. (2012) introduced the concept of a low-cost stream stage monitoring system using time-lapse photography and image post-processing software. Variations of the same concept have been field tested by Gilmore et al. (2013) and Hubble (2016). Lo et al. (2015) tested a method for detection of flooding based on the analysis of images from surveillance cameras. Keys et al. (2016) monitored the dynamics of a river ecosystem based on time lapse imagery.

The objective of this study was to evaluate whether a simple, commercially available time lapse camera can (1) successfully collect time series data of flow depth in an ephemeral channel that can be converted to discharge hydrographs, (2) operate reliably for prolonged periods of time, and (3) substantially lower hardware cost.

Camera

A wide variety of time lapse or trail cameras are offered for purchase in retail stores and through online sellers. Prices range from approximately $50 to more than $200 per camera. For this study, cameras were evaluated based on the following requirements:

- Built-in infrared flash that is invisible to the human eye for night exposures; an invisible flash was deemed desirable so as to not draw attention to the camera and avoid theft or vandalism
- Ability to operate in time lapse mode continuously; although trail cameras are equipped with a motion sensor, field testing revealed that flowing water did not reliably trigger the sensor
- Power jack for connecting an external, rechargeable battery for extended operation
- Low power usage
- Cost

Cameras available at the start of the study in 2014 were evaluated based on the above criteria, and the Stealth Cam G-42NG (GSM, Grand Prairie, TX) was selected.

Setup

The time lapse camera, housed in a lockable steel enclosure, was attached to a road crossing structure spanning a trapezoidal concrete channel (Fig. 3 a and b) located in the city of Rio Rancho, NM. The channel drains a 1.5 km^2 urban catchment that – on average – receives 250 mm of precipitation annually. The camera records images of the channel upstream of the

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crossing (Fig. 3 c). A staff gauge attached to the side of the channel allows calculation of flow depth based on the side slope. Total hardware cost was approximately $200 (camera and SD card: $130; external battery: $30; housing and misc. hardware: $40).

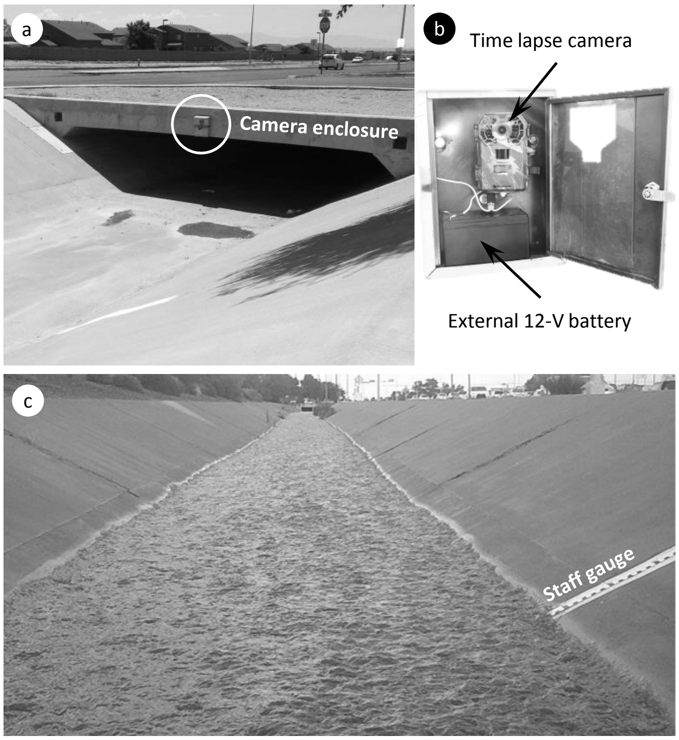

Fig. 3. Time lapse camera installation (a) and detail (b) in a trapezoidal concrete channel, and view recorded by the camera (c) (images by author).

During the 2-year study period (Dec. 2014-Dec. 2016), 33 flow events were recorded. Flow events were "flashy", with hydrographs peaking rapidly and total flow durations ranging from 10 minutes to 6 hours. A short time lapse interval of five minutes was required to capture peak discharges and rapid changes in runoff hydrographs.

Images were saved to a removable SD card. Available image resolutions for the camera used in this study were 0.5, 2, 5, 8 and 10 megapixels. Field testing revealed that a resolution of 2 megapixels provided the best compromise between image quality and storage requirements. At this resolution, each image was approximately 0.6 megabytes in size; based on a 5-minute photo interval (288 images per day), this adds up to 173 megabytes of images per day. A 32 gigabyte SD card would therefore fill up in approximately 180 days.

The camera was powered with an external 12-volt rechargeable lead-acid battery. At a 5-minute time lapse interval, the battery had to be recharged approximately once every 6 weeks. Battery life will depend on a number of variables, including battery age, ambient temperature, and power consumption. Different camera makes and models have unique power use characteristics (Trailcampro, 2016); total power consumption therefore depends on the type of camera, the number of images recorded, and the percentage of day and nighttime photos.

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From Image to Hydrograph

In perennial streams, rating curves are typically developed empirically by plotting measured discharge against stage (Rantz, 1982). In ephemeral systems with infrequent and highly variable flows, rating curves are often developed by indirect methods (Davidian, 1984). For this study, a standard step analysis was performed in HEC-RAS version 4.1 (USACE, 2010). The trapezoidal concrete channel (Fig. 3) has a bottom width of 3m, 2:1 side slopes, a roughness coefficient (Manning's n) of 0.015, and a uniform slope of 2.6%. Flow through the channel is supercritical for the entire range of observed flows. Model results were used to develop a rating curve for the gauging station.

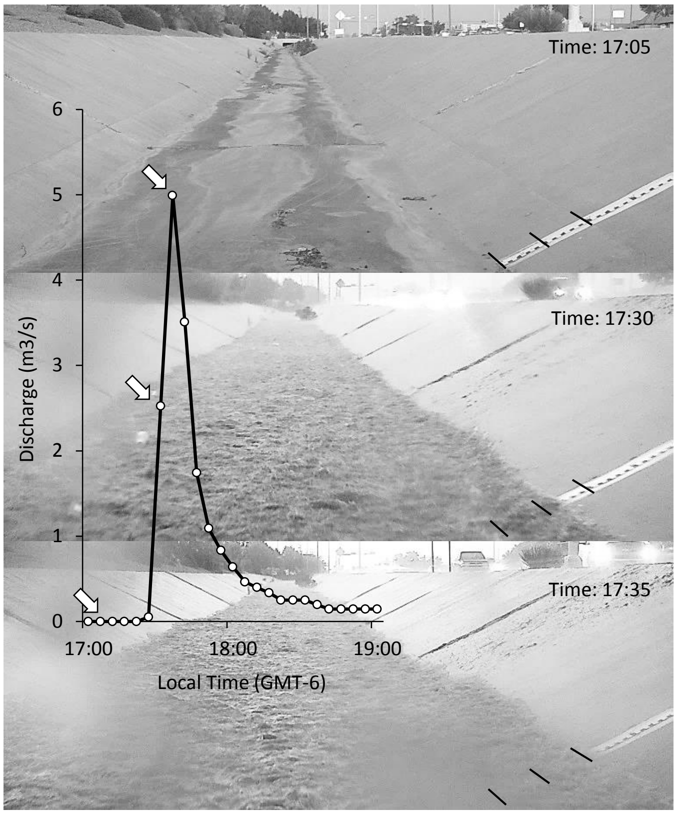

Fig. 4. Time lapse imagery, storm of July 29, 2016, and corresponding hydrograph; blurred areas are caused by rain drops on the camera lens.

Obtaining water level readings from images can be automated using image post-processing software (Royem et al., 2012); this, however, increases the cost and complexity of the system, and introduces the potential for error (Gilmore et al., 2013). Rain and flow events in ephemeral drainage systems are infrequent and often short in duration. For this study, it was decided to post-process time lapse images visually. To speed up the process, start and end dates and times of all 33 storms that occurred during the 2-year study period were obtained from recording rain gauges located near the gauging station, and only corresponding imagery was evaluated. Staff gauge readings for each 5-minute time increment were entered into a spreadsheet and converted to flow depth based on the measured side slope of the trapezoidal channel. Depth values were then converted to discharge using the rating curve. Estimated post-processing time was 16 hours for 33 events (not including rating curve development and initial setup of the spreadsheet). Fig. 4 shows three selected images from a storm event that occurred on July 29, 2016, and

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corresponding points on the discharge hydrograph. The staff gauge can be seen at the right-hand side. Please note that graduation of the staff gauge is 0.1 ft (1 ft = 30.5 cm). Three lines have been added to each image for reference, corresponding to flow depths of 0, 15 and 30 cm, respectively. Discharge data collected as part of this study have been used as the basis of a paper analyzing the impact of urban imperviousness on hydrologic simulations (Schoener, 2017).

Data Uncertainty

Several sources of error can affect discharge estimates at gauging stations, including unsteady flow conditions, rating curve errors, and errors of flow depth measurement (Di Baldassarre and Montanari, 2009). Steady-flow rating curves are considered adequate for channels with slopes exceeding 0.1% (Dottori et al., 2009), as is the case in this study. Rating curve uncertainty has been discussed extensively in the published literature (Le Coz, 2012; Domeneghetti et al., 2012; Di Baldassarre and Montanari, 2009) and will not be addressed further here. Errors of flow depth measurement in this study are influenced by the readability of the staff gauge, and the time lapse interval selected. Fig. 4 illustrates that, particularly under high flow conditions, the water surface is not smooth, and readability is in the range of +/- 3 cm (one mark on the staff gauge) or +/- 1.4 cm of flow depth. Readability can be further reduced due to blurring caused by water droplets on the camera lens (Fig. 4). Night-time images have reduced visibility.

Finally, the time interval between images determines the resolution of data points. Given the “flashy” nature of ephemeral systems, peak discharge may occur between photos; the longer the selected time interval, the higher the likelihood of underestimating peak flows. Images from some of the storms used in this study featured a distinct debris line on the side of the channel. Debris lines may indicate flow depth during peak flow conditions, and could be used to estimate peak discharge. Debris lines, however, could also be impacted by translatory waves that often occur in supercritical channels (Julien et al., 2010).

Other Configurations

Two other examples are included here to illustrate the versatility of using time lapse cameras for stage measurement. Fig. 5 shows a camera attached to a tree that records images of a natural channel. The camera and battery enclosure are well disguised and thus protected from theft and vandalism. Two permanent reference points (rebar and cap) have been installed at the toe and near the top of the channel bank in the camera’s field of view (Fig. 5d, arrows). The elevation difference between the reference points as well as the distance along the slope is known. During a runoff event, stage can be estimated by measuring the distance between the toe of the slope and the water surface from a scaled image, and calculating the corresponding depth. This can be accomplished with the aid of free software such as *ImageJ*. Effects of perspective might have to be taken into consideration under some circumstances, but were found to be negligible in this case. Ideally, the selected site has a bank with a uniform slope and is not subject to large changes in geometry (erosion, sediment deposition) during flow events.

Discharge can be estimated from flow depth values by establishing a stage-discharge rating using the step backwater method (Davidian, 1984). Factors such as varying channel geometry and roughness, as well as moveable beds make natural conveyances more challenging for rating curve development. Confidence in resulting discharge estimates will therefore be lower compared to uniform concrete channels such as the one featured in Fig. 3. Total cost for the setup in Fig. 5 was $170 (camera and SD card: $130; battery and enclosure: $40).

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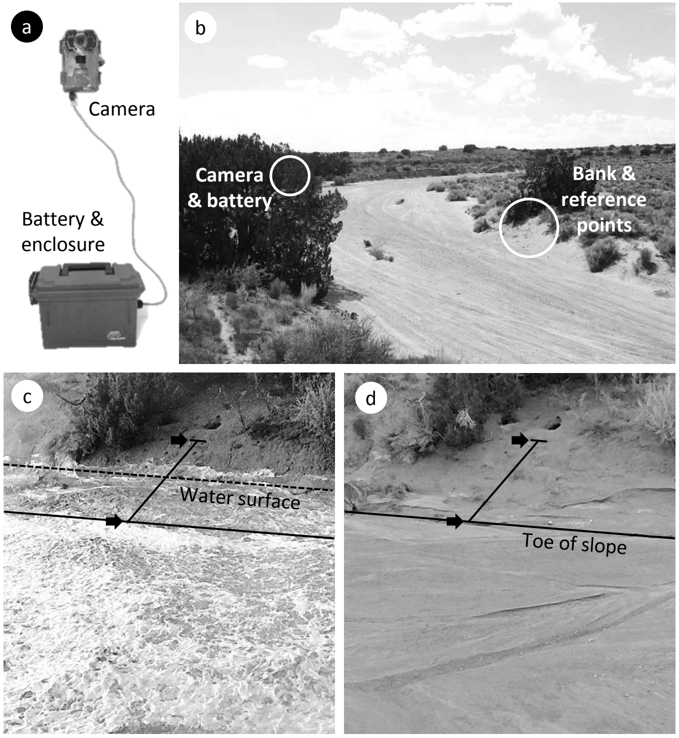

Fig. 5. Example of alternative setup with camera mounted in a tree adjacent to a natural channel (a, b), and view recorded by the camera during flow (c) and dry conditions (d) (images by author).

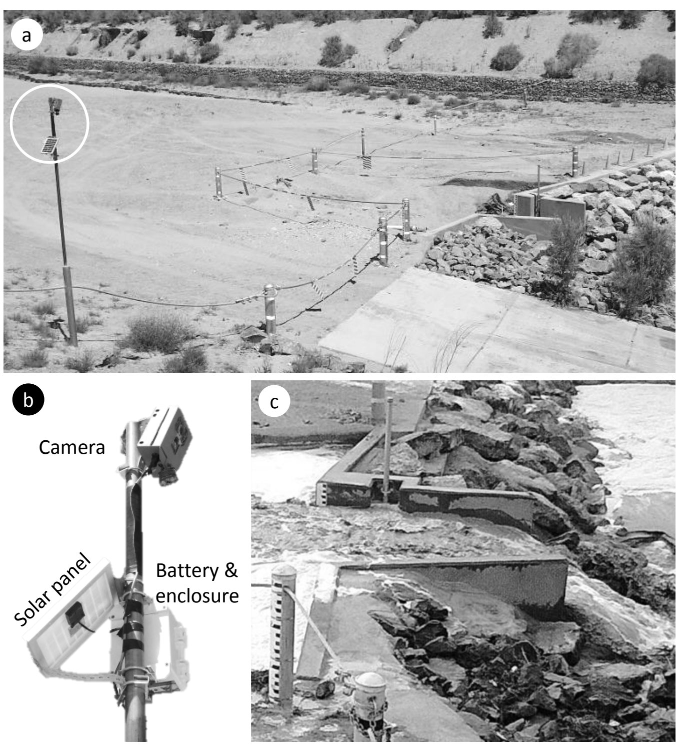

Fig. 6. Example of alternative setup with camera mounted on a pole (a, b) and view recorded by the camera (c) (images by author).

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Fig. 6 features a configuration where the camera is mounted on a pole. A 5-watt solar panel keeps the external battery charged. Solar panel sizing depends on multiple factors, e.g. solar irradiation at the specific site, load, and battery capacity. The camera records images of a flume for measurement of small flows in a natural channel (Fig. 6 c). Flume dimensions and stage discharge rating are based on the U.S. Bureau of Reclamation Water Measurement Manual (USBR, 2001). Total hardware cost was approximately $300 (camera, housing and SD card: $170; battery, enclosure and charge controller: $70; solar panel: $30; pole and misc. hardware: $30).

Time Lapse Cameras – Benefits and Drawbacks

The greatest advantage of time lapse photography compared to other methods of stage measurement is the low cost and portability. Total hardware cost for configurations featured in this study ranged from $170 to $300. This is only a fraction of the cost of traditional gauging stations. Conventional gauging stations require permanent structures, while cameras may be attached to a tree adjacent to a natural channel, or housed in a small enclosure that can easily be moved.

Fig. 7. Dave Gatterman with the Southern Sandoval County Arroyo Flood Control Authority at a stream gauging station clogged with debris and sediment after flow event (image by author).

Visual verifiability is another major benefit of image based stage measurement. Gauge housings are prone to clogging by sediment and debris. Fig. 7 shows a picture of a gauging station in the city of Albuquerque, New Mexico after a flood event in 2013. The galvanized steel pipe (Fig. 7) is approximately 2m tall and houses a pressure transducer. After debris was removed from the outside of the pipe, it was discovered that sediment had clogged the perforations at the bottom of the housing and trapped water in the pipe, thereby affecting transducer readings.

Despite the advantages discussed above, time lapse photography also has some drawbacks. A low-tech, low-cost setup such as the system used in this study requires more maintenance and more post-processing compared to traditional gauging stations. Cameras may be prone to theft and vandalism in populated areas. Furthermore, time lapse photography is likely not suitable for real-time monitoring of streamflow due to high data storage requirements and the necessity of post-processing imagery to obtain stage values.

While time lapse photography should not replace conventional stream gauging stations, it can provide a viable alternative under certain circumstances: in ephemeral systems where flow events are infrequent and short in duration, in cases where budget is a constraint, and for temporary monitoring where the cost of installing a conventional gauging station cannot be justified.

Summary and Conclusions

This study demonstrates that time lapse photography using a commercially available trail camera provides a viable, low-cost, low-tech option for collecting time series data of flow depth at stream gauging stations. A time lapse camera was set up to record images of a channel and staff gauge draining an ephemeral urban catchment in central New Mexico. In the course of a 2-year test period (2014-2016), 33 runoff events were recorded. Images captured during flow events were post-processed visually and converted to discharge time series. For approximately $200 in materials, this method costs only a fraction of conventional gauging stations.

Simplicity and low initial cost make time lapse photography a valuable tool for monitoring stream stage, particularly in ephemeral systems with infrequent flows, for studies with budget constraints, and for temporary monitoring where the cost of installing a conventional gauging station cannot be justified.

Acknowledgements

The author thanks Mr. Charles Thomas, Mr. James Service and Mr. Dave Gatterman for their review and comments.

References

Aich, V., Liersch, S., Vetter, T., Huang, S., Tecklenburg, J., Hoffmann, P., Koch H., Fournet S., Krysanova V., Müller E. N., and Hattermann FF. (2014). "Comparing impacts of climate change on streamflow in four large African river basins." Hydrology and Earth System Sciences, 18(4), 1305-1321.

Babbitt, B., and Groat, C. G. (1999). "Streamflow information for the next century – a plan for the National Streamflow Information Program of the U.S. Geological Survey." USGS Open-File Report 99-456. Reston, VA.

Di Baldassarre, Giuliano, and A. Montanari. (2009). "Uncertainty in river discharge observations: a quantitative analysis." Hydrology and Earth System Sciences 13(6), 913-921.

Daggupati, P., Pai, N., Ale, S., Douglas-Mankin, K. R., Zeckoski, R. W., Jeong, J., Parajuli, P. B., Saraswat, D. and Youssef, M. A. (2015). "A recommended calibration and validation strategy for hydrologic and water quality models." Trans. ASABE, 58(6), 1705-1719.

Davidian, J. (1984). "Computation of water-surface profiles in open channels." U.S. Geological Survey, Alexandria, VA.

Domeneghetti, A., Castellarin, A. and Brath, A. (2012). "Assessing rating-curve uncertainty and its effects on hydraulic model calibration." Hydrology and Earth System Sciences, 16(4), 1191-1202.

Dottori, F., Martina, M. L. V., & Todini, E. (2009). "A dynamic rating curve approach to indirect discharge measurement." Hydrology and Earth System Sciences, 13(6), 847-863.

Douglas, E. M., Vogel, R. M., and Kroll, C. N. (2002). "Impact of streamflow persistence on hydrologic design." J. Hydrol. Eng. 7(3). doi: 10.1061/(ASCE)1084-0699(2002)7:3(220).

Gilmore, T. E., Birgand, F., and Chapman, K. W. (2013). "Source and magnitude of error in an inexpensive image-based water level measurement system." Journal of Hydrology, 496, 178-186.

Global Runoff Data Center (GRDC). (2017). "GRDC station catalogues." http://www.bafg.de/GRDC/EN/02_srvcs/21_tmsrs/211_ctlgs/catalogues_node.html (1/27/2017).

Hubble, M. (2016). "Ephemeral stream-flow monitoring using SRP Flowtography ®." Westcas 2016 Annual Conference, Santa Fe, NM.

ImageJ (Computer software). (https://imagej.nih.gov/ij/index.html).

Julien, P.Y., Friesen, N., Duan, J.G. and Eykholt, R. (2010). "Celerity and amplification of supercritical surface waves." Journal of Hydraulic Engineering, 136(9), 656-661.

Keys, T. A., Jones, C. N., Scott, D. T., and Chuquin, D. (2016). "A cost-effective image processing approach for analyzing the ecohydrology of river corridors." Limnology and Oceanography: Methods 14(6), 359-369. Doi: 10.1002/lom3.10095.

Le Coz, J. (2012). "A literature review of methods for estimating the uncertainty associated with stage-discharge relations." WMO Rep. PO6a.

Lo, S. W., Wu, J. H., Lin, F. P., & Hsu, C. H. (2015). "Cyber surveillance for flood disasters." Sensors, 15(2), 2369-2387. Doi: 10.3390/s150202369.

Peer-reviewed accepted manuscript. For published article, please refer to: Schoener, G. (2017). "Time-Lapse Photography: Low-Cost, Low-Tech Alternative for Monitoring Flow Depth." J. Hydrol. Eng. 23(2). https://doi.org/10.1061/(ASCE)HE.1943-5584.0001616

Loucks, D. P., Van Beek, E., Stedinger, J. R., Dijkman, J. P., & Villars, M. T. (2005). "Water resources systems planning and management: an introduction to methods, models and applications." Paris: UNESCO.

Norris, J. M., Lewis, M., Dorsey, M., Kimbrough, R., Holmes, R. R., and Staubitz, W. (2007). "Qualitative comparison of streamflow information programs of the U.S. Geological Survey and three non-federal agencies." USGS Open-File Report 2007-1426. Reston, VA.

Pilgrim, D. H., Chapman, T. G., and Doran, D. G. (1988). "Problems of rainfall-runoff modelling in arid and semiarid regions." Hydrological Sciences Journal, 33(4), 379-400.

Rantz, S. E. (1982). "Measurement and computation of streamflow: volume 2. Computation of discharge." Geological Survey Water-Supply Paper 2175. Washington, D.C.

Read, L. K., and Vogel, R. M. (2016). "Hazard function analysis for flood planning under nonstationarity." Water Resources Research, 52(5), 4116-4131. doi:10.1002/2015WR018370.

Royem, A. A., Mui, C. K., Fuka, D. R., & Walter, M. T. (2012). "Proposing a low-tech, affordable, accurate stream stage monitoring system." Trans. ASABE, 55(6), 237-242.

Schoener, G. (2017). "Urban Runoff in the U.S. Southwest - The Importance of Impervious Surfaces for Small Storm Hydrology." J. Hydrol. Eng., in press. doi: 10.1061/(ASCE)HE.1943-5584.0001610.

Trailcampro. (2016). "2016 battery consumption test for trail cameras." http://www.trailcampro.com/pages/battery-consumption-test-for-trail-cameras (Jan. 30, 2017).

USACE (U.S. Army Corps of Engineers). (2010). "HEC-RAS river analysis system user's manual version 4.1." Hydrologic Engineering Center, Davis, CA.

USBR (U.S. Bureau of Reclamation). (2001). "Water Measurement Manual." U.S. Government Printing Office, Washington, D.C.

USGS (U.S. Geological Survey). (2017). "National water information system: web interface." https://waterdata.usgs.gov/nwis. (1/27/2017).

Ye, X., Zhang, Q., Liu, J., Li, X., & Xu, C. Y. (2013). "Distinguishing the relative impacts of climate change and human activities on variation of streamflow in the Poyang Lake catchment, China." Journal of Hydrology, 494, 83-95. Doi: 10.1016/j.jhydrol.2

Peer-reviewed accepted manuscript. For published article, please refer to: Schoener, G. (2017). "Time-Lapse Photography: Low-Cost, Low-Tech Alternative for Monitoring Flow Depth." J. Hydrol. Eng. 23(2). https://doi.org/10.1061/(ASCE)HE.1943-5584.0001616