Modelling intermittent stream dynamics for a small catchment with a fully distributed model

Background

Intermittent streams are streams that do not always have flowing water. Intermittent streams cover a large fraction of global river networks (Ågren et al., 2015; Caruso and Haynes, 2011; van Meerveld et al., 2019; Levick et. al, 2008). These streams are unique habitats characterised by high biodiversity (Meyer et al., 2007; Stanley et al., 1997; Stubbington et al., 2017).

During dry periods both the streamflow and groundwater level decline. When the groundwater level falls below the elevation of the streambed, streams lose water and might dry up. However, the streams may not dry up completely and isolated pools can persist throughout dry periods. Those pools are important refugia for fish and aquatic invertebrates (Marshall et al., 2016). Sediment and nutrients can accumulate during the dry phase and can be rapidly flushed away at the flow onset. This can lead to high sediment and nutrient fluxes and, therefore, influences water quality (Fortesa et al., 2020). An important question is, thus, how often and how long the streams fall dry and if they fall dry completely.

Even though intermittent streams are important for water availability and quality, they have not been monitored and studied well (Caruso and Haynes, 2011). In fact, these streams are often not even shown on maps. Conventual gauging stations are designed to measure different flows, not to detect zero flows (Zimmer et al., 2020). To describe the possible habitats of fish, aquatic invertebrates and aquatic plants, it is very important to not only be able to assess zero flow, but to further differentiate whether there is standing water in isolated pools or if the streambed is damp or dry. Therefore, a different measuring approach is needed. New sensors have been developed to record the presence of water and sometimes even whether the water is flowing (Bhamjee and Lindsay, 2011; Goulsbra et al., 2014; Gallart et al., 2016; Bhamjee et al., 2016; Assendelft and van Meerveld, 2019; Kaplan et al., 2019). Another approach is the integration of citizens to make observations of the streams' status (Turner and Richter, 2011; Datry et al., 2016; Gallart et al., 2016; Allen et al., 2019; Kampf et al., 2018). Citizen scientists can report if the river bed is dry or wet; in some studies, they have also differentiated between isolated pools of water and trickling flow or flowing conditions. These citizen science projects have the possibility of raising awareness of the importance of these rivers among the general public and collect highly spatially resolved data.

The MSc project

Intermittent streams are highly dynamic, and spatial variation in the stream state can be high. An open question is how many data points are needed to characterise temporary streams in a catchment, and what are the characteristics of measurement points that provide the most information for the calibration of a model?

For this MSc thesis, the spatially distributed model Hill-vi will be applied to the 12ha upper Studibach catchment in the Alptal. The Hill-vi model was first presented by Weiler (2003) and Weiler and McDonnell (2004) for hillslopes. The model was further developed by Stoll and Weiler (2010) to simulate the river network of a small catchment. They used a publicly available river network to calibrate the model for the otherwise ungauged basin. In this study, sensor-based information (Assendelft and van Meerveld 2019) on the state of intermittent streams in the upper Studibach catchment will be used, together with available data on precipitation, streamflow and groundwater levels, for model calibration. Intermittent stream data are available for 30 locations for a three-month period (Assendelft and van Meerveld, 2020).

The calibrated model will then be used in virtual experiments to address questions such as: What combination of observation points provides the best model calibration and lowest model uncertainty? How many observation locations are needed for a sufficient model calibration? What is the required temporal resolution of the data (10 min, daily, weekly)? What are the characteristics of the measurement points with the highest information content for model calibration?

Answering these questions with the calibrated model might provide guidelines for field hydrologists and citizen scientists to know at which spots observations on the state of temporary streams are most valuable for the calibration of a distributed model.

References

Ågren, A., Lidberg, W., Ring, E., 2015. Mapping temporal dynamics in a forest stream network—Implications for riparian forest management. Forests 6, 2982–3001.

Allen, D.C., Kopp, D.A., Costigan, K.H., Datry, T., Hugueny, B., Turner, D.S., Bodner, G.S., Flood, T.J., 2019. Citizen scientists document long-term streamflow declines in intermittent rivers of the desert southwest, USA. Freshw. Sci. 38, 244–256. https://doi.org/10.1086/701483

Assendelft, R.S., van Meerveld, H.J.I., 2020. Spatiotemporal changes in the hydrological state of temporary streams in a pre-alpine headwater catchment, in: EGU General Assembly Conference Abstracts. p. 19965.

Assendelft, R.S., van Meerveld, H.J.I., 2019. A low-cost, multi-sensor system to monitor temporary stream dynamics in mountainous headwater catchments. Sensors (Switzerland) 19. https://doi.org/10.3390/s19214645

Bhamjee, R., Lindsay, J.B., 2011. Ephemeral stream sensor design using state loggers. Hydrol. Earth Syst. Sci. 15, 1009–1021. https://doi.org/10.5194/hess-15-1009-2011

Bhamjee, R., Lindsay, J.B., Cockburn, J., 2016. Monitoring ephemeral headwater streams: A paired-sensor approach. Hydrol. Process. 30, 888–898. https://doi.org/10.1002/hyp.10677

Caruso, B.S., Haynes, J., 2011. Biophysical-Regulatory Classification and Profiling of Streams Across Management Units and Ecoregions. J. Am. Water Resour. Assoc. 47, 386–407. https://doi.org/10.1111/j.1752-1688.2010.00522.x

Datry, T., Pella, H., Leigh, C., Bonada, N., Hugueny, B., 2016. A landscape approach to advance intermittent river ecology. Freshw. Biol. 61, 1200–1213.

Fortesa, J., Ricci, G.F., García-Comendador, J., Gentile, F., Estrany, J., Sauquet, E., Datry, T., De Girolamo, A.M., 2020. Analysing hydrological and sediment transport regime in two Mediterranean intermittent rivers. Catena 196, 104865.

Gallart, F., Llorens, P., Latron, J., Cid, N., Rieradevall, M., Prat, N., 2016. Validating alternative methodologies to estimate the regime of temporary rivers when flow data are unavailable. Sci. Total Environ. 565, 1001–1010.

Goulsbra, C., Evans, M., Lindsay, J., 2014. Temporary streams in a peatland catchment: Pattern, timing, and controls on stream network expansion and contraction. Earth Surf. Process. Landforms 39, 790–803. https://doi.org/10.1002/esp.3533

Kampf, S., Strobl, B., Hammond, J., Anenberg, A., Etter, S., Martin, C., Puntenney-Desmond, K., Seibert, J., van Meerveld, I., 2018. Testing the waters: Mobile apps for crowdsourced streamflow data [WWW Document]. Publ. 12 April 2018. https://doi.org/https://doi.org/10.1029/2018EO096355

Kaplan, N.H., Sohrt, E., Blume, T., Weiler, M., 2019. Monitoring ephemeral, intermittent and perennial streamflow: a dataset from 182 sites in the Attert catchment, Luxembourg. Earth Syst. Sci. Data 11, 1363–1374. https://doi.org/10.5194/essd-11-1363-2019

Levick, L.R., Fonseca, J., Goodrich, D.J., Hernandez, M., Semmens, D.J., Stromberg, J., Tluczek, M., Leidy, R.A., Scianni, M., Guertin, D.P., Kepner, W.G., 2008. The Ecological and Hydrological

Significance of Ephemeral and Intermittent Streams in the Arid and Semi-arid American Southwest.

Marshall, J.C., Menke, N., Crook, D.A., Lobegeiger, J.S., Balcombe, S.R., Huey, J.A., Fawcett, J.H., Bond, N.R., Starkey, A.H., Sternberg, D., Linke, S., Arthington, A.H., 2016. Go with the flow: the movement behaviour of fish from isolated waterhole refugia during connecting flow events in an intermittent dryland river. Freshw. Biol. 61, 1242–1258.

Meyer, J.L., Strayer, D.L., Wallace, J.B., Eggert, S.L., Helfman, G.S., Leonard, N.E., 2007. The contribution of headwater streams to biodiversity in river networks. JAWRA J. Am. Water Resour. Assoc. 43, 86–103.

Stanley, E.H., Fisher, S.G., Grimm, N.B., 1997. Ecosystem expansion and contraction in streams. Bioscience 47, 427–435.

Stoll, S., Weiler, M., 2010. Explicit simulations of stream networks to guide hydrological modelling in ungauged basins. Hydrol. Earth Syst. Sci. 14, 1435–1448. https://doi.org/10.5194/hess-14-1435-2010

Stubbington, R., England, J., Wood, P.J., Sefton, C.E.M., 2017. Temporary streams in temperate zones: recognising, monitoring and restoring transitional aquatic-terrestrial ecosystems. Wiley Interdiscip. Rev. Water 4, e1223.

Turner, D.S., Richter, H.E., 2011. Wet/dry mapping: Using citizen scientists to monitor the extent of perennial surface flow in dryland regions. Environ. Manage. 47, 497–505. https://doi.org/10.1007/s00267-010-9607-y

van Meerveld, H.J.I., Kirchner, J.W., Vis, M.J.P., Assendelft, R.S., Seibert, J., 2019. Expansion and contraction of the flowing stream network alter hillslope flowpath lengths and the shape of the travel time distribution. Hydrol. Earth Syst. Sci. 23, 4825–4834. https://doi.org/10.5194/hess-23-4825-2019

Weiler, M., 2003. Connectivity due to preferential flow controls water flow and solute transport at the hillslope scale. Proc. MODSIM.

Weiler, M., McDonnell, J., 2004. Virtual experiments: A new approach for improving process conceptualisation in hillslope hydrology. J. Hydrol. 285, 3–18. https://doi.org/10.1016/S0022-1694(03)00271-3

Zimmer, M.A., Kaiser, K.E., Blaszczak, J.R., Zipper, S.C., Hammond, J.C., Fritz, K.M., Costigan, K.H., Hosen, J., Godsey, S.E., Allen, G.H., Kampf, S., Burrows, R.M., Krabbenhoft, C.A., Dodds, W., Hale, R., Olden, J.D., Shanafield, M., DelVecchia, A.G., Ward, A.S., Mims, M.C., Datry, T., Bogan, M.T., Boersma, K.S., Busch, M.H., Jones, C.N., Burgin, A.J., Allen, D.C., 2020. Zero or not? Causes and consequences of zero-flow stream gage readings. Wiley Interdiscip. Rev. Water 1–25. https://doi.org/10.1002/wat2.1436