Proc. IAHS, 385, 489–497, 2024
https://doi.org/10.5194/piahs-385-489-2024

The International Commission on Continental Erosion (ICCE): a brief overview of its scientific focus and example outputs

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Published: 13 May 2024

Abstract. Erosion and sediment-related problems are well documented globally and continue to warrant further scientific investigation, as well as improved policies and management strategies to protect soil and water resources. The International Commission on Continental Erosion (ICCE) has long been a very active commission of the International Association of Hydrological Sciences (IAHS) focussing on progressing scientific understanding of erosion and sediment systems. This paper provides a brief overview of its main scientific foci, examples of previous contributions to scientific conferences and finally, concludes by paying tribute to two key former members of the international scientific community engaged with its remit.

Keywords. Erosion; sedimentation; sediment budget; sediment source fingerprinting; river basin; connectivity

1 Introduction

Environmental problems associated with accelerated erosion (land and river channel), sediment redistribution, storage and transport, sediment-associated transfers of nutrients and contaminants, and the role of fine-grained sediment in degrading aquatic habitats have attracted increasing attention over the past 30 years (e.g., Hinderer, 2012). Whereas in the past, interest in erosion and sediment delivery focused primarily on those areas of the world with documented high rates of soil erosion and high sediment yields, sediment-associated problems have now frequently been shown to be equally important in other regions where erosion rates and sediment yields are relatively low. These regions are often very sensitive to human impact, since, for example, small shifts in sediment response can result in significant impacts on aquatic habitats. Furthermore, through advances in sediment budget techniques, including sediment fingerprinting and remote-sensed imagery (e.g., Lidar), the relative importance of channel sources versus soil erosion has been established. Globally, land use and climate change, along with commensurate channel readjustments and the construction of large dams, are exerting an important influence on erosion and sediment yields of the world's rivers (e.g., Verstraeten et al., 2009). Rivers are a key source of sediment supplied to deltas and the coastal seas and changes in their sediment flux can have wide-ranging implications, such as the alteration of the global carbon and nutrient cycles (e.g., Horowitz, 2008). More generally, human impact on erosion and sedi-

ment transport is clearly evident across a range of scales, and the role of fine sediment in diffuse or distributed source pollution has resulted in it being described as the world's most pervasive pollutant both currently and historically. These important environmental and societal problems are central to the interests of the International Commission on Continental Erosion (ICCE) and the work of the Commission has therefore gained a growing relevance in recent years. The Commission has responded by directing its attention to these important issues which are forecast to become more severe under projected near- and far-future climates.

2 Focus themes for the ICCE

The work of the ICCE has focused on a number of themes, aimed at emphasizing the sensitivity of sediment cascades and systems to human impact and global change (including changing climate), which, in turn, is directed at improving our understanding of sediment processes with a view to supporting targeted management strategies.

3 Sediment budgets

The first area reflects the need to develop an improved understanding of the mobilization, transfer and redistribution of sediment within the landscape across different spatial and temporal scales. This has, in turn, highlighted the importance of establishing sediment budgets, which link erosion and sediment mobilization to sediment transfer and storage and ultimately sediment output at the outlet of a river basin. Here, particular emphasis is commonly placed on identifying key sediment sources and sinks. Sediment sources are a key influence on sediment quality with associated biological and infrastructure impacts, whereas sediment sinks can exert a very important control on the transit and residence time of sediment fluxes, since much of the sediment mobilized from the surface and channel sources may reach the basin outlet over differing time periods. Sediment budgets are therefore adopted widely as a basic framework for understanding sediment systems and for providing system-wide data for supporting sediment management. ICCE can be seen as being ahead of its time in directing attention to this research theme, by organizing a symposium on "Sediment Budgets" in 1988 in Porto Alegre, Brazil. This was followed up by the Moscow symposium on "Sediment Transfer through the Fluvial System" in 2004 and a second symposium on "Sediment Budgets" held in Foz do Iguacu, Brazil in 2005. The symposium on "Erosion and Sediment Yields in the Changing Environment" in Chengdu, China, in October 2012, also featured work on sediment budgeting (Minella et al., 2012). Even when sediment budgets have not been an explicit focus of ICCE meetings, attendees have always presented on various aspects of the sediment cascade including at the symposium on "Sediment Dynamics from the Summit to the Sea" in New Orleans, USA, in December 2014, where papers were presented on hillslope erosion, channel erosion (e.g., Kuhnle et al., 2015), stream and river sediment transport, catchment and river basin sediment yield (e.g., Zhang et al., 2015) and sediment dynamics in coastal systems.

4 Development and application of measurement and monitoring technique

The development of improved measurement and monitoring techniques has also been an important focus for ICCE activity for many years. This reflects both the need to obtain more reliable information on river sediment loads and the need to develop the new techniques required to quantify the various components of sediment budgets. A major symposium on "Sediment Transport Monitoring in River Basins" was organized by ICCE in Oslo, Norway in 1992, and this was followed up by the Oslo Workshop on "Erosion and Sediment Transport in Rivers – Technical and Methodological Advances" in 2002. The Moscow Symposium on "Sediment Transfer through the Fluvial System" in 2004 emphasized the progress achieved in this research field by the application of different methods and techniques, providing detailed quantitative information on sediment behaviour and sediment transfer in small first order catchments (Porto et al., 2004), as well as in large river basins and their individual components (Walling and Zhang, 2004).

A specialized workshop focused on "Sediment Tracing", held in Melbourne in 2011, provided further thoughts on the need to assemble reliable information to characterize the sources in sediment budget investigations. In that workshop, ICCE scientists focused on the opportunity to combine direct observations of soil erosion/deposition with results obtained using sediment tracing techniques as an essentially unique strategy of assembling the required information on sediment sources, sediment sinks and spatially distributed sediment redistribution rates (Porto et al., 2013; Walling, 2006). Given the increasing drive towards integration of research methods and techniques, the symposium at Okehampton in England in July 2016, focused on "Integrating Monitoring and Modelling for Understanding, Predicting and Managing Sediment Dynamics". Regardless of any specific focus of individual meetings, ICCE scientists have always presented studies using a range of individual or integrated methods for understanding various components of sediment systems, including remote sensing for soil erosion by water (e.g., Fitrzyk, 2012), terrestrial laser scanning for gravel-bed morphology (Moretto et al., 2012), fallout radionuclide measurements combined with sediment load monitoring for catchment sediment response (Porto et al., 2015), fallout radionuclides for estimating overbank sedimentation rates (Golosov and Walling, 2015), acoustic sensor deployment for bedload transport monitoring (Rickenmann et al., 2017), the use of bed sediment sampling for water quality studies and moni-

toring programmes (Horowitz and Elrick, 2017) and the combined use of field walking and digital elevation model information to assess field-to-river connectivity (Favis-Mortlock et al., 2022).

5 Sediment source fingerprinting

One method which has featured strongly in many ICCE meetings over the years is sediment source fingerprinting. This direct method for quantifying the relative contributions from individual sediment sources to various types of target sediment including suspended, bed, floodplain or lake sediment, has experienced growing uptake globally over the past 25 years (Collins et al., 2020) and several ICCE scientists are now seen as being established experts in this specific field. This latter fact is evidenced by their co-authorship of a recent review of the approach and remaining challenges of sediment source fingerprinting, published in the Journal of Soils and Sediments (Collins et al., 2020). ICCE papers on this topic have covered a wide range of issues associated with source fingerprinting procedures and their applications, including the use of frequentist un-mixing models (Walling et al., 1993) and uncertainty analysis (Martinez-Carreras et al., 2008), combining source fingerprinting with artificial tracers to improve the resolution of source data (Collins et al., 2010) and demonstrating applications of different types of tracers including colour (Martinez-Carreras et al., 2008). The focus on sediment sourcing methods was again a feature of one session convened by the ICCE at the 27th IUGG meeting in Montreal, Canada, in 2019. This very successful session resulted in a special issue in the international journal Catena entitled Using Fingerprinting, Monitoring and Modelling to Explore Erosion, Connectivity and Transfers in Catchment Sediment Systems. This special issue includes papers on sediment fingerprinting using elemental geochemistry (Li et al., 2020; Laceby et al., 2021; Shi et al., 2021; Tsyplenkov et al., 2021; Nosrati et al., 2021a), spectroscopy, magnetism and geochemistry (Ramon et al., 2020), magnetic and colour fingerprints (Nosrati et al., 2021b) and optical properties (Amorim et al., 2021).

6 Human impacts on sediment systems

The importance of human impact on erosion and sediment transport has also been a recurring theme for ICCE, as illustrated by the symposia on "The Impact of Environmental Change on Sediment Sources and Sediment Delivery" held in Perugia, Italy in 2007, "Sediment Dynamics in a Changing Environment" held in Christchurch, New Zealand in 2008, and on "Sediment Dynamics for a Changing Future" held in Warsaw, Poland in 2010, as well as the symposium on "Erosion and Sediment Yields in the Changing Environment" held in Chengdu, China in October 2012. In those symposia, the potential impact of environmental change, including both land use change and climate change on sediment fluxes in catchments and river basins, was emphasized (Porto et al., 2009; Bogen, 2009; Zhang et al., 2009).

Wildfires are seen as an increasing threat to many of the world's forests and such fires can cause greatly increased sediment mobilisation and transport, causing both extensive damage within the area and major problems in rivers and reservoirs downstream due to increased sediment loads. Given the growing wildfire threat globally, ICCE organized a Symposium on "Wildfire and Water Quality: Process Impacts and Challenges", in Banff, Alberta, Canada in June 2012. This meeting included papers on a broad range of wildfire related topics including impacts on sediment yields (Jordan, 2012) and sediment accumulation (Southwell and Thoms, 2012).

The recent Fukushima disaster in Japan has clear parallels with the Chernobyl disaster of 1986 and has again directed attention to the fundamental role of erosion and sediment transport in controlling the redistribution and fate of human-induced radionuclide contamination. Attention was directed to this topic by a workshop held at the International Association of Hydrological Sciences (IAHS) Scientific Assembly in Gothenburg, Sweden, 2014. The important role played by sediment in river channel morphology and development and the many detrimental impacts of sediment within river basins, which include degradation of water quality and aquatic habitats and siltation of reservoirs and other infrastructure for water resource development, have necessarily highlighted the need for sediment management strategies. ICCE has addressed this theme through the symposium on "The Structure, Function and Management of Fluvial Sedimentary Systems" held in Alice Springs, Australia in 2002, the symposium on "Sediment Dynamics and the Hydromorphology of Fluvial Systems" held in Dundee, Scotland in 2006 and the workshop on "Sediment Problems and Sediment Management in Asian River Basins", which formed part of the Hyderabad Scientific Assembly in 2009. Together, these various ICCE symposia and workshops have generated a valuable set of IAHS Publications which are an important resource for those working in the field of managing the global sediment problem. The full archive of the publications and/or special issues is available at: https://iahs.info/Commissions--W-Groups/ICCE-Continental-Erosion/ICCE-Publications.do (last access: 7 May 2024).

Another widely discussed topic is related to research on mining-affected rivers, which continues to pose challenges because plans exist in many regions worldwide to develop opencast mines (e.g., Bartley et al., 2004; Chalov, 2014). Metal mining and mineral processing operations often produce substantial quantities of solid waste which are delivered to river systems due to erosion processes, and this material often results in substantial detrimental impacts on fluvial habitats. Responsible catchment management and mining impact control requires an understanding of contempo-

Figure 1. Case studies for erosion research on mining-impacted sites: 19th century abandoned gold-mining site (Sherlock creek, Montana, USA) (left) and ongoing platinum placer mining site (Kamchatka peninsula, Russia) (right) (photos by Sergey Chalov).

raneous catchment baseline conditions of sediment redistribution. Environments, which have historically suffered from mining operations (e.g., the Rocky Mountains in the USA, Fig. 1), or such regions as the Kamchatka Peninsula and the island of Madagascar, which are new frontiers for the mining industry, have been the key focus of the recent research activities related to erosion and sediment transport.

7 River hydromorphology and sediment yield

Another special issue which also included topics associated with human impacts but also comprised studies on interactions between river processes and sediment transport was published as a follow-up to the stand-alone conference hosted by the ICCE which was held in August 2018, in Moscow (Chalov et al., 2019). This particular special issue emphasized that links between sediment yield and channel patterns have been used as a key tool for channel management in many regional studies (e.g., Golovlyov et al., 2019). Estimating the total global suspended sediment flux from the land to the oceans for establishing the global pattern of sediment yields and its major controls has been another key focus of the ICCE (e.g., Walling and Webb, 1996). At the 2004 ICCE symposium "Sediment Transfer through the Fluvial System" a contribution by Dedkov (2004) argued that deposition very often prevails over erosion in the lower reaches of rivers. Analysis of available long-term records and sediment archives has provided an important means of assessing the sensitivity of sediment yields to environmental change; for example, in relation to the contribution of catchment and in-channel erosion to sediment transport.

8 Modelling of sediment dynamics

Whilst the ICCE has undoubtedly attracted more empirical scientists over the years, as opposed to modellers, modelling studies have frequently featured at ICCE symposia in recognition that statistical or process-based tools and frameworks can scale out and up the results generated by the more resource intensive methods used by most of the ICCE community. Examples include the MOSES (Modular soil Erosion System) model for predicting soil erosion at small scales (de Figueiredo and Davi, 2006), the Silsoe model for hillslope soil erosion (Matthews and Neave, 2008), the SWAT (Soil and Water Assessment Tool) model for predicting the impact of different land use scenarios on discharge and sediment transport (Dos Santos et al., 2010), the ADAS (referring to the former UK Agricultural Development and Advisory Service) Pollutant Transport (APT) model for sediment delivery to rivers (Collins et al., 2012), and an integrated sediment production and supply model (Fujita et al., 2015). In other cases, modellers have made a comparison between field observations and Digital Elevation Model (DEM)-based field-to-river routing, using for example, a steepest-descent-with-overtopping model (Favis-Mortlock et al., 2022).

9 Wider contributions of ICCE to international sediment initiatives and programmes

ICCE is active in promoting the contribution of IAHS to international activity in the field of erosion and sediment transport, through involvement in international activities and collaboration with other international bodies. These include the European SedNet initiative, UNESCO International Sediment Initiative (ISI), the World Association for Sedimentation and Erosion Research (WASER), the International Research and Training Centre in Erosion and Sedi-

mentation (IRTCES), the International Geosphere-Biosphere Programme (IGBP), the International Geographical Union (IGU), the International Coordinating Committee on Reservoir Sedimentation (ICCORES), the International Commission on Large Dams (ICOLD), the International Association of Sediment–Water Science (IASWS), the International Soil Conservation Organization (ISCO) and the International Atomic Energy Agency (IAEA). ICCE has been an active participant in UNESCO's International Hydrological Programme for many years and this involvement has increased through its contributions to the UNESCO ISI. Several ICCE members have played a very active role in a number of Collaborative Research Projects organized by IAEA, where the application of new isotopic and radionuclide tracer techniques for documenting erosion and sediment redistribution rates and fingerprinting sediment sources has been progressed. ICCE has also been a major contributor to the Global Geochemical Mapping programme, coordinated by Norwegian scientists, which aims to exploit the sediment archives provided by river floodplains and deltas to document both global patterns of sediment geochemistry and recent changes associated with human impacts in upstream river basins.

During the COVID-19 pandemic, ICCE organised online educational activities. Here, the most wide ranging online seminar series was held online for Young Scientists under the topic "Pollutant and Sediment Mobility in River Systems: Monitoring Studies to Identify Human Impacts" (25–27 November 2020). The programme included lectures by leading experts from Russia, USA, Germany, France, Belgium, Netherlands, Brazil and the UK on the problems of sediment and water quality and geochemistry of river systems: Adrian Collins (Rothamsted Research, North Wyke, Okehampton, United Kingdom); Caroline Clason (University of Plymouth, Plymouth, United Kingdom); Sagy Cohen (Department of Geography, University of Alabama, Tuscaloosa, Alabama, United States); Sergey Chalov (Lomonosov Moscow State University, Moscow, Russia); Bjoern Helm (Dresden University of Technology, Dresden, Germany); Jeff Nittrouer (Department of Earth, Environmental and Planetary Sciences, Rice University, Houston, United States); Edgardo Latrubesse (Federal University of Goiás-Brazil, Goiânia, Brazil); Martina Flörke (Institute of Engineering Hydrology and Water Resources Management, Ruhr University Bochum, Bochum, Germany); Matthias Vanmaercke (Liège University, Liège, Belgium); Salomon Kroonenberg (Delft University of Technology, Delft, the Netherlands), and Daniel Karthe (German-Mongolian Institute for Resources and Technology, Ulaanbaatar city, Mongolia). Almost 400 participants attended the online lectures from almost 50 countries. The full archive of the lectures is available at: https://www.youtube.com/channel/UCCXZNFdglOzGczmnAisb1vg (last access: 7 May 2024).

Figure 2. Wayne Erskine (© IAHS, https://iahs.info/Commissions--W-Groups/ICCE-Continental-Erosion/Past-Information/, last access: 7 May 2024).

10 Notable former members of the ICCE community

10.1 Wayne Erskine

Professor Wayne Erskine (Fig. 2) passed away in Darwin in late July 2017. Wayne graduated with a Doctor of Philosophy in Fluvial Geomorphology (1987) from the University of New South Wales, Australia. He held academic positions at the University of New South Wales, University of Newcastle – Ourimbah Campus and Charles Darwin University and, also, research scientist positions with New South Wales Department of Water Resources, New South Wales State Forest, Office of the Supervising Scientist (OSS), and the Environmental Institute of the Supervising Scientist (ERISS). He had recently been appointed as the sub-editor of Geographical Research. Wayne was a keen fisherman and spoke often of his obsession for everything related to freshwater science.

Wayne was an exceptionally productive and influential fluvial geomorphologist publishing over 230 peer reviewed international and national journal manuscripts, conference papers and book chapters. He supervised 35 post graduate students. Wayne had been a strong supporter of, and contributor to, ICCE activities since the mid-1980s and will be warmly remembered for his in depth and wide readership of the scientific literature which permitted him to engage in detail with all scientists on their work, his ability to produce high quality papers for the Red Book series, his extremely engaging and word perfect presentations on diverse subjects and increasingly on work bridging pure and applied science, and his capacity to ask incisive questions at conferences backed up by his broad, but in-depth, knowledge and understanding. He had recently been discussing the possibility of hosting a future ICCE meeting with the current committee.

10.2 Arthur J. Horowitz

Art Horowitz (Fig. 3) passed away on 26 February 2021, after a relatively short battle with cancer. Art graduated in 1967 from Queens College, New York, with a BA in Chemistry and Geology. Between 1967–1971 he studied for a Master of Science in Marine Geology at the University of Miami, Florida, USA. Thereafter, he studied for a PhD in Geology (1971–1974) at the University of London, UK and

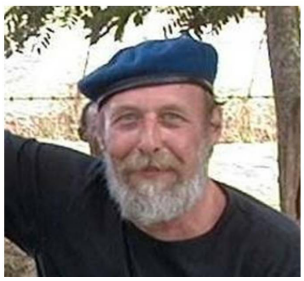

Figure 3. Art Horowitz (© IAHS, https://iahs.info/Commissions--W-Groups/ICCE-Continental-Erosion/Past-Information/).

a DIC in Applied Geochemistry (1971–1974) at Imperial College of Science and Technology, London, UK. His PhD furthered his interests in marine geology and involved research on the geochemistry of sediments associated with the mid-Atlantic Ridge. From 1975–1976 he worked as Assistant Professor in the Department of Earth and Environmental Sciences, Queens College, New York. He then worked as an oceanographer in the Environmental Studies Section, New York Outer Continental Shelf Office, where he served as a Contracting Officer's Representative for developing and monitoring the performance of both government and non-government contractors tasked with establishing baseline environmental levels at potential offshore oil and gas leasing sites.

Art's career changed direction towards things more hydrological when he joined the US Department of the Interior in 1976; first, with the Bureau of Land Management and then with the USGS Water Resources Division in 1978 as a Supervisory Chemist at the Atlanta National Water Quality Lab (ANWQL) in Doraville, Georgia. Between 1978–1983, he was Chief of the Automated Wet-chemistry Section for the ANWQL, responsible for analyses of filtered water, whole-water and bed sediment samples as well as the development of novel analytical techniques for use with these sample matrices. When the Atlanta NWQL closed in 1983, he relocated to the Georgia District Office, Atlanta (USGS-WRD) and began his long tenure as Chief Research Chemist of the Sediment Partitioning Research Project. Over the next 33 years, Art pioneered many of the laboratory analytical techniques used to partition sediment into its chemical components, with a primary focus on indicators of anthropogenic contamination. He developed and tested many of the field-sampling and processing techniques used daily across the US and internationally by the hydrological community. He undertook important work on evaluating de-watering devices for suspended sediment samples in preparation for chemical analyses and was responsible for the development of protocols for the collection and processing of water samples for subsequent trace element analyses. Other key work included testing the effects of membrane filtration on dissolved trace element concentrations, and an evaluation of short-term spatial and temporal variability in suspended sediment and associated trace element concentrations. From 1997 until his retirement, Art continued as Chief for the Sediment Partitioning Project, within the Georgia Water Science Center, Atlanta, where he was responsible for the sediment and sediment-associated chemistry work for the City of Atlanta Water Quality Monitoring Program and for the separation, trace element analyses, and data interpretation for all suspended and bed sediment samples collected for the national NASQAN program.

As well as work in the laboratory and field-testing sampling equipment and sampling protocols and strategies linked to sediment geochemistry, Art was also involved in a number of important field investigations of contaminant transport and fate and water-sediment interactions. These included investigations of mining-related impacts on the Belle Fourche, Cheyenne and Whitewood Creek rivers in South Dakota and high profile geochemical investigations of Lake Coeur d'Alene, the floodplains of the Coeur d'Alene River, and Terrace Reservoir in Idaho. Another nationwide field-based study undertaken by Art in the years before his retirement merits mention as indicative of his dedication to his research. In this, he undertook a nationwide sampling campaign, personally visiting sites as far downstream as practicable on 131 sizeable US rivers located around the coast of the entire country, to collect samples of fine bed sediment to provide ground truth for a national assessment of annual land-sea fluxes of sediment-associated trace and major elements and nutrients that he was undertaking. The sampling campaigns extended over a whole year during 2010–2011. This was followed up in late 2011 by revisiting and resampling 41 of these rivers located between the North Carolina / South Carolina border and the US Canadian border, to investigate the impact of extreme events Hurricane Irene and Tropical Storm Lee, which hit the Atlantic coast of the USA in late August and early September 2011, on the bed sediment chemistry of US Atlantic Coast rivers. Contrary to what might have been expected, these changes were limited. Art also had a long-standing research interest in the changing sediment load of the Mississippi River and demonstrated the importance of the disastrous 1993 flood in influencing such changes. His interests also extended beyond the US; he had a long-term collaboration with French scientists working on the River Seine basin, contributing to their work on sediment geochemistry and sediment-associated contaminants. He also collaborated with Brazilian hydrologists in exploring the problems of obtaining reliable estimates of suspended sediment loads based on infrequent samples and on designing effective sampling strategies.

Art was strongly committed to the need for rigour in the design of hydrological investigations, in their effective implementation and in the interpretation and communication of their results and many will have benefited from this guidance and constructive criticism. He was always available for dis-

cussions and enjoyed being a mentor on sediment chemistry and fluvial geomorphology. As a result of his long and focussed career on sediment and contaminant transport in river systems, Art leaves the international science community with a substantial body of more than 100 published outputs. These include the widely cited "Primer on Sediment-Trace Element Chemistry", which has been an important influence on sediment fingerprinting science. This was originally published as USGS Water Supply Paper 2277 in 1985 and a second edition was published by Lewis Publishers in 1991. Several of his key papers on fluvial sediment and sediment-associated contaminant fluxes can be found in the journal Hydrological Processes. His most recent co-authored publication appeared in December 2020 (Collins et al., 2020). Art was an active member of IAHS from 1992 and will be remembered for his fun presence, challenging questions and raucous laugh at many IAHS meetings including the 2005 IAHS General Assembly in Foz do Iguacu, Brazil, for which Art and Des Walling co-edited the notable twin volume Red Book on Sediment Budgets, containing a total of 80 papers. Throughout his IAHS membership, Art was a strong supporter of ICCE stand-alone meetings and during this phase developed friendships with many sediment researchers globally on the basis of his expert knowledge and advice and enthusiasm for high quality sediment and contaminant science. Art was Vice President of ICCE between 2003–2007. In addition to IAHS, Art was an active member of several additional professional societies including the Geological Society of America, the American Geophysical Union, the American Society for Testing and Materials and the International Association of Geochemistry and Cosmochemistry.

Data availability. No data sets were used in this article.

Author contributions. ALC: conceptualization, writing – original draft; all authors: writing – review & editing.

Competing interests. The contact author has declared that none of the authors has any competing interests.

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Special issue statement. This article is part of the special issue "IAHS2022 – Hydrological sciences in the Anthropocene: Past and future of open, inclusive, innovative, and society-interfacing approaches". It is a result of the XIth Scientific Assembly of the International Association of Hydrological Sciences (IAHS 2022), Montpellier, France, 29 May–3 June 2022.

Review statement. This paper was edited by Christophe Cudennec.

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