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Editorial

Searching for change in hydrological data

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Welcome to the second special section ever published in *Hydrological Sciences Journal* (*HSJ*). The positive response to the Special Section on Ecohydrology published in October 2002, and considerable interest in that special section, prompted the preparation of the present material, devoted to another challenging research topic—the pursuit of evidence for change in long time series of hydrological data.

Detection of abrupt or gradual changes in hydrological records, and river discharge in particular, is of considerable scientific and practical importance, being fundamental for planning of future water resources and flood protection. Traditionally, design rules are based on the assumption of stationary hydrology, resulting in the principle that the Past is the key to the Future, which has a limited validity in the era of global change. If the stationarity assumption is not correct then the existing procedures for designing water-related infrastructures: dams, dikes, etc. will have to be revised. Otherwise, systems would be over- or under-designed and might either not serve their purpose adequately, or be overly costly.

River discharge may have changed due to a range of human activities. Dams and manmade reservoirs dramatically change the natural flow regime. Land-use changes, which induce land-cover changes, control the rainfall–runoff relationships. Deforestation, urbanization and reduction of wetlands reduce the available water storage capacity and increase the runoff coefficient. The timing of water conveyance in rivers is being altered by river regulation measures (such as channel straightening and shortening, construction of embankments). Water withdrawal from rivers is a process of considerable importance in the low flow context—some rivers run dry due to excessive water abstraction.

Yet, climate is the most important driver of the hydrological cycle. Since climate system and water cycle are intimately linked, any change in one of these systems induces a change in another. The Earth's climate system has changed considerably since the pre-industrial era (cf. IPCC, 2001). The global surface temperature rise of 0.6 ± 0.2°C over the 20th century was greater than during any other century in the last 1000 years. The 1990s are likely to be the warmest decade of the millennium and ten (globally) warmest years in the last 140 years have occurred since 1990. A global map of temperature changes over the last quarter of this century (IPCC, 2001) shows substantial warming in the overwhelming majority of grid cells, and slight cooling in a few cells. According to IPCC (2001), there is now new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities (therein, most notably, to emissions of greenhouse gases, land-use and land-cover changes).

Apart from a significant temperature rise, there has been a statistically significant (though neither spatially nor temporally uniform) increase in global precipitation over the 20th century (IPCC, 2001). The warming world has, generally, become wetter. Instrumental records have shown a growth of land-surface precipitation in much of the Northern Hemisphere mid- and high latitudes. Where data are available, changes in mean streamflow usually relate well to changes in total precipitation (IPCC, 2001).

Extreme hydrological events—floods and droughts—have become more destructive in many regions of the globe. Part of the explanation can be linked to changes in socio-economic and terrestrial systems, but climatic factors certainly play an important role. According to the physical law of Clausius-Clapeyron, there is more room for water vapour in the warmer atmosphere, hence the potential for intense precipitation grows with temperature. Indeed, an increase in intense precipitation has been observed already over many areas (IPCC, 2001). Changes in flood frequency depend on the generating mechanism, e.g. rainfall *vs* snowmelt. Results of documented studies demonstrate an increase in rain-caused flood flows in some locations and a decrease in snowmelt- and ice-jam-related floods, where the snow cover is less abundant, snowmelt is earlier and so is high river flow in spring. This leads to a decrease in summer flow.

The hypothesis that climate change leads to the acceleration of the hydrological cycle and may cause increases in the frequency and severity of extreme hydrological events has resulted in growing recent interest in change detection in flow data. Yet, to date, there is not much concrete evidence of significant large-scale climate-induced change for floods and droughts. There are problems with the availability of appropriate data to use, with the methods to apply and, finally, with the interpretation of results. The search for (possibly) weak changes in time series of hydrological data, which are subject to (certainly) strong natural variability, is a difficult task, and the use of adequate baseline data (being in short supply) and of good methodology is essential.

Recently, a paper by Mudelsee *et al.* (2003) reported “no upward trends in the occurrence of extreme floods in Central Europe”. Such a title was surprising to some, since, typically, negative results of change detection do not occur in the literature. However, this particular case demonstrated the lack of continuity between the observations of no increase (Mudelsee *et al.*, 2003) and model projections for the future (Christensen & Christensen, 2003), showing an increase in intense precipitation, despite a decrease in the mean summer rainfall.

As noted by Radziejewski & Kundzewicz (2004), tests are not able to detect a weak trend or a change which has not lasted sufficiently long, but this cannot be interpreted as a demonstration of the absence of change. With the enhanced climate change, the changes in hydrological processes may be stronger and last longer, so that the likelihood of change detection may grow. This is a rationale for the examination of updated time series of hydrological data as a permanent exercise.

This Special Section consists of seven contributions. The first three focus on methodology, while the next four provide information on the hydrology of particular regions. The case studies originate from four continents and include the baseline basins in Canada, a national overview of flood flows in Sweden, and analyses of large rivers of great importance to big nations and to ecosystems—the Yangtze and the Amazon.

Kundzewicz & Robson (2004) provide general guidance to the methodology of change detection in time series of hydrological records, giving an overview of preparation of a suitable data set, exploratory analysis, application of adequate statistical tests and interpretation of results. Particular emphasis is made on the use of distribution-free testing, particularly resampling methods, which are well suited to hydrological data (skewed, seasonal and serially correlated).

Yue & Pilon (2004) offer guidance as to the selection of a test (from slope-based, rank-based, parametric, non-parametric and bootstrap-based approaches) for non-normally distributed data—by comparison of test power. Sensitivity of the power of the tests to the shape of trend (linear *vs* nonlinear) has also been examined. The analysis is extended to discharges of 30 baseline Canadian river basins.

Other facets of detectability of trends are dealt with by Radziejewski & Kundzewicz (2004), who examine how strong a change (gradual trend or abrupt jump) must be and how long it must take in order to be detected by different tests. A new concept of visualization of the comprehensive change detection exercise (for different moving data windows within the overall set) demonstrates very strong interdecadal variability of the flow of the River Warta at Poznań, Poland.

Burn *et al.* (2004) examine the trends and variability of river flow in climate-sensitive northern Canada, where local anthropogenic effects are negligible. The relationships between trends in hydrological variables and both meteorological variables and a large-scale oceanic and atmospheric process are investigated. Among the detection results are: increasing winter and spring flows, and earlier dates of spring freshets and spring maximum discharges.

In a national-scale study carried out for Sweden, Lindström & Bergström (2004) analyse river flow for 61 stations over a century. A substantial recent increase in both annual discharge and flood magnitude has been found, but it is not exceptional in the context of high flows experienced earlier. A novel discharge–temperature diagram illustrates the complexity of the climate–hydrology link.

Callède *et al.* (2004) examine the flow of the Amazon at Óbidos, where available information is scarce and loaded with high uncertainty. A slight increase has been found in the nearly century-long series of flow. The increase in the flow is stronger than in the rainfall, which could be a consequence of the Amazonian deforestation. The rupture tests indicate a break in 1970, as in other rivers of South America. According to Callède *et al.* (2004), this upward jump looks like a counterpart of a negative jump change observed in Africa at about the same time (cf. L'Hôte *et al.*, 2002; Sambou, 2004). Since the issue as to whether the Sahelian drought ended during the 1990s, or is still ongoing, is of high practical importance for the region, it has raised vigorous debate (e.g. Ozer *et al.*, 2003; L'Hôte *et al.*, 2003).

Xiong & Guo (2004) examine the Yangtze flow at Yichang in 1882–2001. No significant trend in the annual maximum flood series is detected, but minimum and mean discharges show decreasing trends. These findings are of substantial practical importance, but cannot serve as an illustration of climate change impact due to considerable interference by strong directly anthropogenic factors.

An observation, resulting from this Special Section, is that combined detection and attribution studies are a challenging research need. This would require undertaking joint examination of elements of water balance in catchments (runoff *vs* precipitation and temperature) in order to confirm, or to reject, the hypothesis of climate link.

In order to be able to predict what is going on in ungauged basins (cf. Sivapalan *et al.*, 2003), one has to draw as much information as possible from the available long time series of data for gauged basins. This is the rationale behind this present Special Section and a number of other recent studies of various aspects of change in hydrological records (e.g. Ayenew, 2002; Callède *et al*., 2002; Coudrain *et al*., 2002; Krasovskaia & Gottschalk, 2002; Yue *et al*., 2003). Beyond contributing to the development of methodology, such works enrich the factual information about the hydrology of particular regions. It is expected that some of the *HSJ* papers referred to here will be considered by the authors of the Fourth Assessment Report (AR4) of the IPCC.

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