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## Technical Briefing Paper (2): Detecting Hydrological Change

**Synopsis** There is evidence of coherent, *global* patterns of change in annual precipitation and runoff with high latitudes experiencing increases consistent with climate model projections. Changes in the timing of snowmelt runoff are also becoming apparent in many areas. However, detection and attribution of precipitation-driven hydrological change at *river basin* scales is not expected for decades to come, due to high variability from year to year and confounding factors. This means that water utilities will have to make some adaptation decisions in advance of formally detected changes in resource availability. This reinforces the case for investment in long-term environmental monitoring.

**Explanation** *Detecting* hydrological change involves demonstrating that water balance terms (such as rainfall, evaporation, runoff, etc.) have changed in some defined statistical sense, without providing the reason(s) for the change. This is distinct from *attribution* which is the process of establishing the most likely cause(s) of any detected changes at a specified level of statistical confidence.

Hydrological change is detected when the likelihood of an observation (such as a sequence of low flows) lies outside the bounds of what might be expected to occur by chance. However, the change need not necessarily occur linearly, as in the case of the dramatic reduction in Sahelian precipitation that occurred in the 1960s. Furthermore, there is always a small chance of spurious detection because data are not homogeneous (see *Application*). Conversely, changes may not be found if the underlying trend is weak compared with the "noise" of climate variability.

The problem for climate change attribution is that there is no physical control. Attribution is typically established if there is consistency between modelled responses to combinations of human and natural factors, and the actual pattern of earth system observations. Modelling accomplishes this by isolating unique "fingerprints" of different external forcings such as greenhouse gas concentrations, variations in solar radiation, or sulphate aerosols from volcanic eruptions. In this way, rising global mean temperatures in the second half of the 20<sup>th</sup> Century can only be explained by combining the human influence on atmospheric composition with natural solar and volcanic forcings.

Evidence of human influences on the climate system has been accumulating steadily over the last two decades. It encompasses changes in seasonal or annual global mean temperatures to other metrics at continental scales (e.g., surface pressure, length of growing season, and some temperature extremes). However, with the possible exception of rainfall reductions over southwest Australia, attribution of rainfall trends to human influence is not yet possible below the scale of the global land area. Nonetheless, as precipitation increases (under the greater water holding capacity of a warmer atmosphere) a greater proportion is expected to fall as heavy and very heavy rainfall events. Thus, changes in moderately extreme precipitation events are, in theory, more robustly detectable than changes in mean precipitation. Disproportionate increases in heavy rainfall records have been widely reported but these patterns seldom agree with models. This is partly due to the inability of climate models to adequately resolve extreme precipitation at sub-grid box scales. It is also due to the scale mismatch between point observations and gridded climate model output, and the difficulty of defining statistically robust "extreme" indices.

Application Trend detection is far from straightforward because the outcome depends on:

- **Chosen indicator**: whether monthly, seasonal, annual, rainfall/river flow, maxima, *N*-day rainfall totals, proportional contributions, counts of peaks over threshold flows, point or area average data, individual records, pooled, or gridded data.
- **Period of record**: When longer rainfall and river flow records are analysed, many trends found in shorter series cease to be significant. This can be due to the influence of outliers (at the start or the end of the record), or simply down to multi-decadal variability.

- **Power of statistical tests**: Widely used methods include (logistic) linear regression, "change point" tests, and the nonparametric Spearman rank correlation and Mann-Kendall tests. Detectability of trends in extreme events can be improved through regional pooling of data.
- Confounding factors: Creeping or sudden changes in meteorological records can arise from changes in site, instrumentation, observing or recording practices, site characteristics, or sampling regime. Discharge records may be biased by many non-climatic influences including land cover and management, urbanization, river regulation, water abstraction and effluent returns, or flood-flows by-passing gauging structures.

Case Study Detection times for hydrological change in UK river basins

The number of years of rainfall or runoff record needed to detect a statistically significant trend depends on four factors: the strength of the trend; the amount of variance about the trend; the probability of erroneous detection (Type I error); and the probability of missing a real trend (Type II error). When plausible values are used for projected changes in summer runoff in UK river basins, the detection times can be of the order of decades from present.

The shortest detection times are found in the summer mean flow of the River Itchen in southern England (Figure 1). This groundwater dominated chalk basin has the lowest coefficient of variation (ratio of variance to mean) of all the river records analyzed. Even so, the detectable trend is a 22-25% reduction by 2025 (i.e., over 35 yrs from 1990), or 16-18% by 2055 (i.e., 65 yrs from 1990), depending on the period of record used to estimate the variance. These reductions are consistent with climate model projections used for water planning. However, in most other rivers climate driven trends that may already be underway will not be *statistically* detectable for many more decades, or even this century. However, the *practical* consequences of such trends may be felt much sooner.





**Figure 1** Detection time (in years from 1990) in relation to the strength of the trend (percent change in mean) and variance of summer flows in the River Itchen, Hampshire, UK. Variance estimates were based on reconstructed runoff records for 1961-1990 (black line) and 1921-1990 (red line).

## Supporting materials and links

- Hegerl., C.C., Zwiers, F.W., Braconnot, P., et al. 2007. Understanding and attributing climate change. In: Climate Change 2007: The Physical Basis. Contribution of Working Group I to the Fourth Assessment of the Intergovernmental Panel on Climate Change. http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter9.pdf
- Jones, P.D., Lister, D.H., Wilby, R.L. et al. 2006. Extended river flow reconstructions for England and Wales, 1865-2002. International Journal of Climatology, **26**, 219-231.
- Timbal, B., Arblaster, J.M. and Power, S. 2005. Attribution of late 20th century rainfall decline in South-West Australia. *Journal* of Climate, **19**, 2046-2062.
- Zhang, X., Zwiers, F.W., Hegerl, G.C., et al. 2007. Detection of human influence on twentieth-century precipitation trends. *Nature*, **448**, 461-465.
- Ziegler, A.D., Maurer, E.P., Sheffield, J., et al. 2005. Detection time for plausible changes in annual precipitation, evapotranspiration, and streamflow in three Mississippi River sub-basins. *Climatic Change*, **72**, 17-36.
- Wilby, R.L. 2006. When and where might climate change be detectable in UK river flows? *Geophysical Research Letters*, **33**, L19407, **doi**: 10.1029/2006GL027552.

See Water Research Foundation Technical Briefing Paper 1 (Climate Variability and Change)