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Spatio-temporal development of streamflow droughts in north-west Europe

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Abstract. This paper examines the spatial and temporal development of streamflow droughts in Europe over the last 40 years, differentiating the climatic factors that drive drought formation from catchment controls on drought manifestation. A novel approach for quantifying and comparing streamflow and precipitation depletion is presented. This approach considers atypical flow or rainfall events, as well as more severe droughts, regardless of the season in which they occur (although unlikely to constitute drought in an operational sense, sustained atypical flows are important with regard to understanding how droughts arise and develop). The amount of flow depletion is quantified at daily resolution based on the standardised departure from the mean day *d* flow, or *flow anomaly*. The index was derived for 2780 gauging points within north-west Europe using data from the FRIEND European Water Archive for the 1960-1995 period. Using a simple interpolation procedure these data were used to produce a time-series of grids, with a cell size of 18 km^2, showing the spatial distribution of flow anomaly over the study area. A similar approach was used to characterise monthly precipitation anomalies, based on existing grid data (see New *et al.*, 2000). The grids were analysed chronologically to examine the spatial and temporal coherency of areas showing large flow and/or precipitation anomalies, focussing on drought development during the 1975-1976 and 1989-1990 periods. Using a threshold approach, in which an anomaly of 2 standard deviations represents the onset of drought conditions, indices were developed to describe the time-varying extent and areal-severity (flow deficit) of streamflow and precipitation drought. Similar indices were used to describe how the magnitude and temporal variation of flow depletion varied spatially.
In terms of streamflow depletion, the 1976 drought was found to be a highly coherent event, having a well defined start (in January 1976) and end (in September 1976). The worst and most persistent streamflow droughts occurred in southern England and northern France. Central parts of Europe experienced only severe streamflow depletion during the 'height' of the drought in June, July and August when there was negligible precipitation across large areas of Europe. In contrast, the 1989/90 period was characterised by a series of shorter and less severe droughts, with much greater variability over time. The relationship between precipitation drought and streamflow drought was less clear, which might have resulted

from periods of precipitation depletion occurring randomly in time. Particularly high levels of streamflow drought were again observed in southern England and northern France.
Several possible explanations for the increased drought occurrence over southern England and northern France were investigated using data from the 1976 event. However, immediately antecedent precipitation deficits could not explain the level of streamflow depletion which appears to have been enhanced by decreased discharge of groundwater into the river networks in this region. This can probably be attributed to large precipitation deficits during autumn 1975 and spring 1976: the consequent reduction in groundwater recharge ultimately led to depressed groundwater levels.

Keywords: drought, streamflow depletion, streamflow drought, low-flow regimes, Drought Index

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