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Perspective

Spatial modelling of discharge and concentration of matter along a stream network

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When using spatial modelling for estimating discharge and concentrations of matter in water along a stream network from local measurements, it is possible to analyse spatial variations, assess yields and loads at any point of the network. The difficulties are due, firstly, to the lack of data that increases the difficulty to infer an adequate spatial model along the network, secondly, to the specificity of tree graphs that do not permit the use of common spatial models. The spatial variations of discharge, functions of the drainage area, are quite continuous. On the contrary, the water quality, including chemical, sediment and biological parameters, is highly variable in space. The variations are mainly due to human activities including point or non-point pollution sources as well as natural characteristics generally structured from the source to the outlet. Many examples are given in the literature [4]. For instance, nitrate concentrations are functions of nitrate excess and denitrification processes that depend on the area of riparian wetlands generally structured from upstream to downstream. The estimates of discharge and concentrations of matter in water along a stream network are discussed from three points of view: (*i*) the representation of a stream network, and more generally the use of a tree graph representation in hydrology; (*ii*) the geostatistical methods to analyse variables distributed on tree graphs; (*iii*) the requirements for applying these methods in hydrology, particularly the availability of the data.

The description of a stream network as a tree graph is classical, based on the concepts proposed by Horton [6], then Shreve [9], who define links and confluences between source and outlet. Analogous objects and variables are defined for river networks and trees, as described by Cudennec et al. [3]. The concepts are similar for two- or three-dimensional objects. In two dimensions, these objects may be linear, as the stream or surfacic networks. Their uses in hydrology are diverse. For instance, they have been used to describe ditch networks [1], fluvisol extent that roughly corresponds to saturated surface runoff [8]. They might be applied to a recently proposed tree graph used to describe flow pathways for surface runoff from field to field [10]. These different flow pathways are not all identical and continuous in time and space and present some particularities from one another.

Two ways to represent a stream network are developed by de Fouquet and Bernard-Michel [5]. The first one describes the tree graph in a simple way as a set of links defined from the sources to the outlet. This tree graph construction presents the difficulty of locating the sources that vary physically during the year for hydrologic systems fed by superficial groundwater or intermittent surface flow. Despite these uncertainties, Crave and Davy [2] showed that interior and exterior link lengths present the same exponential distribution. The other method uses a construction from the outlet to the sources, and requires an exhaustive but fix dis-

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cretization of all the tree graphs that may vary with the availability of data.

As common geostatistical models such as the spherical covariance developed for Euclidean space are not valid for tree graphs, different geostatistical models have recently been proposed in the literature. Two classes of models are generalised by de Fouquet and Bernard-Michel [5]. In the construction from the sources to the outlet, the model considers one-dimensional random functions defined on each path linking one source to the outlet. Going downstream, these functions are linearly combined on each link. The aggregation function differs from link to link. Combining stationary or intrinsic one-dimensional random functions leads to stationary or intrinsic models on links but produces discontinuities at the confluence. This model is well adapted to discharges and loads that increase along the stream. In the construction from the outlet to the sources, the model is based on a conditional independence between the upstream parts of a confluence of the stream network, knowing the function downstream of this confluence. It is demonstrated that this solution provides a linear variogram in a particular case. This construction leads to stationary or intrinsic models on each link, without any discontinuity at the confluence. Multivariate data of discharge and concentrations, or any other context data can be easily used in a coregionalization model.

Available datasets exist to test these methods, particularly in a SAGE (local Water Management Plan), which is the instrument for river management in France. These databases are very heterogeneous in space and in chemical element monitoring. An application of the proposed method to a SAGE would contribute to define which elements in the database, and with which characteristics, can be used to test these methods in terms of sampling density, and what is the outcome.

This article focused on a small domain that concerns the development of geostatistical methods for estimating variables associated with stream networks, such as discharge and concentrations. Applications are still awaited. This article however presents a larger application domain, i.e. the estimation of all the variables associated with objects described by a tree graph. In the new developments, it would be interesting to take into account the temporal dimension. Two aspects may be considered. Firstly, the variables associated with stream networks present specific temporal distributions [7] that may be used for the spatial estimation as in other cases. Secondly, the variables associated with other tree graphs in hydrology often present discontinuities that cut the tree graph. It may be interesting to study these specific situations.

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