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Research article

New tools for the hydromorphological assessment and monitoring of European streams

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ABSTRACT

Hydromorphological stream assessment has significantly expanded over the last years, but a need has emerged from recent reviews for more comprehensive, process-based methods that consider the character and dynamics of the river with greater accuracy. With this as a focus, a series of hydromorphological tools have been developed and/or further extended in Europe within the context of the REFORM (REstoring rivers FOR effective catchment Management) project. The aim of this paper is to present the set of REFORM hydromorphological assessment methods and, based on some examples of their application, to illustrate and discuss their synergic use, specific features, limitations and strengths.

This assessment and monitoring includes three tools: the Morphological Quality Index (MQI), the Morphological Quality Index for monitoring (MQIm), and the Geomorphic Units survey and classification System (GUS). These tools constitute the assessment phase of an overall multi-scale, process-based hydromorphological framework developed in REFORM. The MQI is aimed at an assessment, classification and monitoring of the current morphological state; the MQIm aims at monitoring the tendency of morphological conditions (enhancement or deterioration); the GUS provides a characterization, classification and monitoring of geomorphic units.

A series of examples are used to illustrate the potential range of application, including: (i) an assessment of morphological conditions; (ii) an assessment of the morphological effects of restoration projects; (iii) an evaluation of the geomorphic impacts of interventions for risk mitigation; and (iv) an integrated use of MQI and GUS to assess and characterise morphological conditions. Finally, some of the main features, strengths and peculiarities of the three hydromorphological tools are discussed with the support of examples of their application.

1. Introduction

The integration of information on hydrology and fluvial geomorphology (termed hydromorphology) aimed at promoting river management has seen a significant increase over the last years. In European countries, this process has been accelerated by the implementation of the EU Water Framework Directive (WFD; European Commission, 2000), which recognises hydromorphology as an important component in supporting the assessment and integrated management of river ecosystems. Following the introduction of the WFD, numerous methodologies have been proposed to assess and monitor the hydromorphology of fluvial water bodies, which vary widely in terms of their concepts, aims, spatial scales, collected data and therefore their applicability (e.g., Fernández et al., 2011; Belletti et al., 2015). Initially, hydromorphological assessment was seen to be synonymous of a physical habitat survey (e.g. Platts et al., 1983; Raven et al., 1997), used to rapidly assess the status of a river (Fryirs, 2015). A series of limitations were identified in the use of physical habitat assessment methods, including among others (Fryirs et al., 2008; Belletti et al., 2015): (i) the limited spatial scale of investigation (i.e. the 'site' scale with a fixed length of a few hundred meters) is usually inadequate to fully

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contextualise river condition and to perform an accurate diagnosis of the causes of alteration; (ii) the use of reference conditions based on the statistical analysis of empirical data is questionable for hydromorphology; (iii) the terminology used to describe geomorphic units in most habitat surveys is neither comprehensive nor updated when compared to the present state-of-the-art classifications in fluvial geomorphology.

In contrast with the physical habitat survey procedures, over the last few years an evident trend has emerged in increasing the scientific development of geomorphologically based approaches, methods, and frameworks of geomorphic condition assessment, in the attempt to understand river functioning and evolution as a basis for interpreting current conditions (e.g., Brierley and Fryirs, 2005; Ollero et al., 2007, 2011; Rinaldi et al., 2013; Fryirs, 2015; Gurnell et al., 2016a). Process-based methods can be defined as those methods that (i) emphasize the consideration of the occurrence of expected geomorphic processes (e.g., the continuity of sediment and wood fluxes, lateral connectivity, bank erosion, and armouring) rather than just classifying physical habitats and channel forms; and (ii) include the explicit consideration of temporal changes and dynamics.

The review by Belletti et al. (2015) emphasizes that some of the previous features could also to some degree be interpreted as being limitations. For example, physical processes are more difficult to assess than a simple inventory of existing forms; indicators of whether processes have taken place or not are thus often generated from a visual assessment of the occurrence or not of that processes (observed in the field or based on remotely sensed information) or else they are indirectly based on the presence of artificial elements which are inferred to have a significant impact on some processes. Furthermore, a morphological method is not just a field sampling methodology, but it requires integration with remote sensing – GIS, and therefore requires an operator with training and an appropriate background knowledge of the underlying geomorphic principles. These factors in part explain why, in most EU member states, a gap still exists between the development of new approaches and their application and use for the assessment, monitoring and identification of possible management actions. The implementation of these approaches is still quite limited, whereas methods not based on physical processes remain the most widely applied to assess hydromorphology (Belletti et al., 2015). Therefore, a need still exists to promote a more comprehensive, process-based hydromorphological assessment that considers the character and dynamics of river reaches and how these are affected by present and past natural and human-induced changes within the catchment as well as within the reach.

In response to this need, new methodologies have been developed and/or extended within the REFORM (REstoring rivers FOR effective catchment Management) project (2011–2015), funded by the European Union's FP7 Programme. Specifically, two complementary approaches have been proposed for hydromorphological assessment: (i) an open-ended approach - the REFORM hydromorphological framework (Gurnell et al., 2014, 2016b), and (ii) a set of more specific hydromorphological assessment procedures which incorporates a set of clearly defined stages and steps – the REFORM hydromorphological assessment methods.

The objective of this paper is to present the set of REFORM hydromorphological assessment methods and, based on some examples of their application, to illustrate and discuss their synergic use, specific features, limitations and strengths.

2. The overall assessment and monitoring framework

The REFORM hydromorphological analysis (Gurnell et al., 2014, 2016b) is based on previous hierarchical frameworks (e.g., Frissell et al., 1986; Montgomery and Buffington, 1998; Habersack, 2000; Brierley and Fryirs, 2005; Rinaldi et al., 2013), but has several properties that reflect the European context for which it was developed. The framework is open-ended, i.e. European member states can incorporate their own data sets, methods and modelling tools. A multi-scale hierarchical approach provides the spatial framework, including spatial units at region, catchment, landscape unit, segment, reach, geomorphic unit, hydraulic unit and river element scales. The temporal context of the framework is linked to the key concept of evolutionary trajectory (Brierley et al., 2008; Dufour and Piégay, 2009), emphasising that fluvial systems are dynamic and follow a complex trajectory of changes with time in response to a series of driving variables acting at various spatial and temporal scales. Each river may have specific characteristics determined by its historical evolution, including climatic variations, human interventions, and unique sequences of large flood events, so the interpretation of temporal adjustments in morphology is essential for assessing current conditions and possible future adjustments and scenarios.

A more prescriptive version of the framework was proposed by Rinaldi et al. (2015a). This version is still flexible and open-ended, but incorporates a set of specific tools – the REFORM hydromorphological assessment methods – with which some of the components of the overall framework can be assessed. Four stages are defined, in accordance with existing frameworks with a similar structure (Brierley and Fryirs, 2005; Rinaldi et al., 2015b), each one containing a series of procedural steps that support the assessment of river conditions in a consistent manner. During Stage I (Catchment-wide delineation and spatial characterization of the fluvial system), the catchment and the river system in their current conditions are delineated, characterised, and analysed. Stage II (Assessment of temporal changes and current conditions) involves reconstructing the history and evolutionary trajectories of morphological changes that have resulted in the current river conditions. Stage III (Assessment of scenario-based future trends) identifies possible future scenarios of hydromorphological modification. Stage IV (Management) identifies possible hydromorphological restoration or management actions.

The three methods illustrated in this paper are mainly a part of Stage 2 (assessment and monitoring phase), but they can also be used to support Stages 3 and 4.

3. The Morphological Quality Index (MQI)

The Morphological Quality Index is the key tool of the REFORM assessment methods. It derives from an original version developed for application in Italy, described in detail in Rinaldi et al. (2013). The MQI can be classified as a 'process-based' method because it presents the following features:

(1) It explicitly considers processes which go beyond basic channel forms, i.e. it includes a series of indicators directly linked to the functioning of a series of basic processes expected in natural rivers (e.g., continuity in sediment and wood fluxes, bank erosion, lateral channel mobility);
(2) The temporal component is explicitly accounted for, i.e. channel form is not limited to being considered in a static way, but its adjustments through time are addressed by a series of specific indicators;
(3) Reference conditions are defined in terms of dynamic processes and functions that are expected to normally occur in a given physical context. This differs substantially from most current hydromorphological methods which define reference conditions in terms of a precise channel configuration or a set of channel characteristics. In fact, reference