



Threshold-based interpretation of morphological pressures in hydromorphological river assessment: a comparison of River-MImAS, SYRAH-CE and a landscape-hydrological model in the context of the EU Water Framework Directive

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METHODOLOGY REVIEW ARTICLE

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Abstract: The paper provides a comparative analysis of the morphological component embedded in three hydromorphological assessment approaches for rivers—River-MImAS (United Kingdom), SYRAH-CE (France), and the landscape–hydrological model of the river basin geosystem by Yushchenko Y.S. (Ukraine)—within the shared framework of the EU Water Framework Directive (WFD) requirements for supporting hydromorphological quality elements and their role in achieving and maintaining the target ecological status of river water bodies. The aim is to compare how each method “translates” morphological alterations of the channel and floodplain into a formalized management judgement, with a specific focus on the choice of spatial assessment unit, the set of morphological indicators/descriptors, the way mapping/GIS support is organized, and the presence of threshold boundaries used for interpretation. The analysis shows that River-MImAS offers the most rigid formalization of cumulative engineering pressures through the concepts of system “capacity” and the share of capacity used, which enables its application as a threshold-based screening tool for project proposals on short reaches and supports upscaling conclusions to the water-body level. In contrast, SYRAH-CE is designed for national-scale GIS auditing and risk mapping, where segmentation of the river network into homogeneous sections is driven by natural controlling variables (stream order, slope, substrate, valley/floodplain attributes), and outputs are expressed as probabilistic categories of hydromorphological degradation risk. The landscape–hydrological approach, in turn, most explicitly preserves the morphodynamical meaning of disturbances through multi-temporal reconstruction and mapping of the young river landscape and homogeneous channel–floodplain reaches (ODRZ), supported by morphometric indicators and thresholds of significant change (including those related to anthropogenic channel incision and transformation of the multi-year channel-forming belt). Synthesizing the differences and “best-use domains” of these approaches substantiates the value of their combined use in basin management practice: risk screening to rank the network and select priority reaches, detailed landscape–morphological diagnostics to



identify mechanisms and feasible restoration boundaries, and capacity/threshold checks to evaluate the acceptability of specific engineering scenarios and their cumulative effects.).

1. INTRODUCTION

During the 2000s, as part of the reform of the water sector in accordance with the requirements of the EU Water Framework Directive ([WFD, 2000](#)), hydromorphological monitoring was established as one of the mandatory components of the ecological assessment of water bodies. At the same time, a wide range of national approaches to defining hydromorphological status emerged across Europe, leading to the development of dozens of different methodologies and, consequently, complicating the comparability of results and the harmonisation of management decisions between states ([Rinaldi M., Surian N., Comiti F., 2013](#); [Belletti B., Rinaldi M., Buijse A. D., Gurnell A. M., Mosselman E., 2015](#); [Kampa E., Bussetini M., 2018](#); [Pasichnyk M.D. & Buzei O.V., 2025](#)). These differences are largely explained by the historical development of water management practice and monitoring priorities in individual countries: the United Kingdom adopted the detailed field-based River Habitat Survey (RHS) protocol; Italy developed the geomorphologically oriented Morphological Quality Index (MQI); Ireland employs the simplified indicator-based River Hydromorphology Assessment Technique (RHAT); France developed the national audit system SYRAH-CE (Système Relationnel d'Audit de l'Hydromorphologie des Cours d'Eau); and the British technical group UKTAG proposed criteria for high morphological status and the instrumental approach known as the Morphological Impact Assessment System (MImAS) ([Rinaldi et al., 2015](#)). Differences in indicator sets, aggregation approaches, and interpretation logic can yield different conclusions about the status of the same river, especially near quality class boundaries where the choice of thresholds and weighting coefficients becomes critical. Against this backdrop, it is particularly significant that hydromorphological transformations — channel straightening, floodplain disconnection, flow regulation, and other disruptions of natural dynamics — are recognised as one of the principal causes of ecological degradation of watercourses in Europe ([WFD, 2000](#)). This underscores the need for the unification and mutual "readability" of hydromorphological assessment results, in order to ensure their compatibility with WFD objectives and their accurate representation of the role of morphological changes in the functioning of river ecosystems. For Ukraine, this issue is especially important in the context of European integration, as the implementation of European water monitoring standards requires the adaptation of national procedures to EU approaches. Although Ukraine has adopted its own Methodology for Hydromorphological Monitoring of Surface Water Bodies ([2019](#)), the question of its conformity with best European practices and WFD requirements remains open.

In the United Kingdom, the River MImAS (Morphological Impact Assessment System) methodology has been introduced — a tool that calculates the percentage loss of the morphological "capacity" of a channel due to anthropogenic changes relative to a reference state ([UKTAG, 2008](#)). Exceedance of threshold values of this indicator signals a risk of the watercourse failing to meet WFD ecological status requirements. In France, the SYRAH-CE (Système Relationnel d'Audit de l'Hydromorphologie des Cours d'Eau) system has been implemented at the national level — a relational, multi-level methodology for auditing the hydromorphological characteristics of rivers ([Valette L. et al., 2008](#)). SYRAH-CE is a GIS-oriented tool covering the entire national territory and enabling the mapping of physical channel alteration risks for management purposes.

In Ukraine, the Landscape-Hydrological Model of the River Basin Geosystem (hereinafter the Landscape-Hydrological Model) was proposed under the supervision of Professor Yushchenko Yu.S. of the Faculty of Geography at Yuriy Fedkovych Chernivtsi National University. This model is grounded in a landscape-basin approach to the analysis of river morphology ([Yushchenko et al., 2023](#); [Pasichnyk et al., 2025](#); [Zaiachuk et al., 2025](#); [Yushchenko et al., 2026](#)). The methodology involves a comprehensive investigation of the channel and valley (river landscape) using quantitative hydromorphological

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indicators and cartographic methods to assess the current state of a river. Despite the development of various approaches, current research points to the need to integrate quantitative indices, geoinformation mapping, and landscape-based (multi-scale) analysis into the process of river morphology assessment. A comparative analysis of the aforementioned methodologies is thus both timely and valuable with respect to the implementation of WFD standards for the assessment of the morphological status of watercourses.

2. AIM AND OBJECTIVES OF THE STUDY.

The aim of this paper is to compare the morphological component of three hydromorphological river assessment methodologies — River-MImAS, SYRAH-CE, and the Landscape-Hydrological Model — within the context of WFD requirements for the assessment of watercourse morphology. To achieve this aim, the following objectives are set:

- to analyse which morphological indicators and criteria are used in each of the selected methodologies;
- to compare the approaches of the stated methodologies with respect to spatial coverage (local, river basin) and the use of cartographic data;
- to assess the extent to which each methodology integrates quantitative indicators and the landscape-geographic context in determining river status.

3. MATERIALS AND METHODS.

3.1. First M&M section. The River MImAS (Morphological Impact Assessment System) methodology is a system for assessing morphological impacts on rivers, developed within the framework of the UK Technical Advisory Group (UKTAG) — an inter-agency expert body established to provide scientific and methodological support for the implementation of EU Water Framework Directive requirements in the United Kingdom. It is founded on the premise that each river reach has a certain "capacity" to accommodate physical interventions without deterioration of ecological status. Changes in morphological conditions (e.g., bank revetment, bed clearance, artificial channel regulation, etc.) consume part of this capacity, and the degree of capacity consumed is measured as a percentage. The aim of River MImAS is to quantify the risk that proposed anthropogenic changes may cause the acceptable threshold to be exceeded and thereby threaten the achievement of ecological objectives (e.g., maintenance of high ecological status). The methodology specifies "morphological condition boundaries" — threshold magnitudes of change, expressed as the percentage of capacity used, beyond which a risk of status deterioration is indicated.

River MImAS consists of five interrelated modules. Each module operates relatively independently and can, if necessary, be updated independently. The modules and their functions according to UKTAG (2006) are as follows:

- **Attributes Module:** a list of river morphological attributes (cross-section, longitudinal gradient, alluvial deposit grain size, planform and cross-sectional channel diversity, presence of aquatic and riparian vegetation, constraining factors in channel development, etc.). These attributes were selected on the basis of their relevance to supporting river biocoenoses and their contribution to maintaining the ecological function of the system.
- **Typology Module:** defines six river type classes (A–F) based on river energy and form. The typology accounts for characteristics such as river energy, bed type, longitudinal gradient, and morphological dynamics.
- **Sensitivity Module:** assesses two components of river system sensitivity — morphological and ecological. Morphological sensitivity reflects the resistance and resilience of each attribute to physical interventions. Ecological sensitivity assesses the likelihood of degradation of fish, invertebrate, or plant ecological elements in response to disturbance of a given attribute.

- Pressures Module: contains a set of categories of anthropogenic morphological impacts (morphological "pressures"). The original UKTAG description identifies 15 pressure groups (see below), while later updates list up to 25 types of operations. The module assesses two components: (i) the likelihood that a given pressure will affect each attribute (its correlation with the attribute) and (ii) the zone of influence — whether the effect is local or reaches (from site-specific to channel-wide).
- Scoring Module: combines the results of the preceding modules into a numerical Impact Rating. The formula accounts for: the relevance of the attribute to the river type (typology), its morphological and ecological sensitivity, and the likelihood and zone of influence of the pressure.

River MImAS distinguishes 6 main river types (classes A–F), spanning from highly energetic mountain to slow-flowing lowland environments. These are:

Type A — Bedrock channels: very steep banks; channel bed predominantly bedrock/rocky with little sand-gravel cover; high stream energy; limited longitudinal and lateral channel dynamics.

Type B — Cascade and step-pool channels, and plane-bed channels: mountain watercourses with steep gradients and significant elevation drop; bed predominantly cobble-boulder; banks/slopes mostly rocky; active erosion and deposition processes.

Type C — Plane-bed riffle and pool-riffle channels, and braided (multi-thread) channels: mid-mountain category with mixed gravel-cobble bed and moderate gradient; within these, channel anabranches and bars/shoals actively form.

Type D — Channels with low longitudinal gradient (actively meandering): low longitudinal gradient, predominantly meandering planform; mixed-grain bed (from gravel to pebble); relatively high stream energy drives continuous lateral channel migration.

Type E — Channel with significant groundwater input: low longitudinal gradient; bed typically composed of gravel and pebble; frequently stabilised/regulated baseflow; characteristically calmer flow regime, but with cold water and elevated natural clarity.

Type F — Channels with low longitudinal gradient, passively meandering: wide cross-sectional profile and low gradient; bed may be sandy-gravelly; channel processes relatively calm, often with development of floodplain alluvial deposits; low hydraulic resistance (low channel roughness).

Each type is characterised by a "typical" morphological landscape (valley configuration, longitudinal gradient, sediment structure, floodplain character, etc.) and characteristic bedload transport processes. The typology allows the assessment to be calibrated: only attributes relevant to the given type are considered, and their sensitivity is initially assigned by expert judgement.

The methodology identifies 15 types of anthropogenic pressures regularly analysed within MImAS (e.g., bank revetment, culverting, extraction of alluvial deposits, etc.).

The key step is converting observed anthropogenic changes into quantitative impact indices. First, for each identified pressure on a reach, an Impact Rating is determined using the UKTAG formula:

Impact Rating = Relevance × Ecological Sensitivity × Morphological Sensitivity × Likelihood of Impact × Zone of Impact

where Relevance (attribute relevance) is set by the typology module; Ecological and Morphological Sensitivity are taken from the sensitivity module; Likelihood and Zone of Impact are taken from the pressures module.

After the Impact Rating is calculated, it is multiplied by the impact footprint — the geometric magnitude of the intervention (length of revetted reach, area of sediment dispersal, extent of impounded stretch, etc.). The resulting individual "capacity costs" are summed across all pressures within the reach. The calculation is formally expressed as:

$$\% \text{ Capacity Used} = \sum (\text{Impact Rating}_i \times \text{Footprint}_i) / L \times 100\%$$

where L is the length of the assessed reach (as channel length or total bank length). This approach accounts for both the location and scale of the intervention: small localised changes (unique minor

impacts) may yield a low percentage of capacity, whereas serial or spatially extensive interventions (removal/alteration of a large channel reach) rapidly "exhaust" the threshold.

Summing all pressures yields the total capacity used for a 500-metre or longer reach. If the sum approaches or exceeds the established "morphological condition boundaries" (see below), this indicates a high risk of status deterioration.

The concept of system capacity is central to MImAS. It defines how much morphological change a river can sustain before its ecological status is impaired. Capacity is described as the ability of a water body to "absorb" changes in channel form, banks, or embankment without loss of biological integrity. Once cumulative intervention exceeds a certain percentage of this capacity, the ecological status is considered at risk of deterioration. This concept does not encourage degradation (even a 5% impact is a significant proportion), but acknowledges that beyond absolutely pristine conditions, "moderate" amounts of change may be tolerated.

In practice, capacity calculation is used as follows: first, the current balance of "capacity used" from all existing anthropogenic pressures is determined. Then, for each new proposed intervention, the additional percentage of capacity that would be consumed is calculated (in detail, via Impact Rating and footprint). This approach allows the relative risk of any proposal to be assessed: the higher the percentage of capacity used, the greater the risk of water body status deterioration.

UKTAG defines thresholds corresponding to ecological status class boundaries in terms of capacity used. For example, river reaches using up to 5% of system capacity are considered to meet the conditions for High ecological status. The "Good status" boundary is $\leq 25\%$. That is, if a proposed set of interventions within a studied reach would consume more than 5% of capacity, this raises concern that "High status" may be unattainable. For deployment at the regional level, "morphological condition boundaries" have been developed (see Table 1 below):

Table 1. Proposed condition boundaries for river morphology (Rinaldi et al., 2015):

Morphological Component	High status	Good Status	Moderate status	Poor status
Channel	$\leq 5\%$	$\leq 25\%$	$\leq 50\%$	$\leq 75\%$
Banks and Riparian Zone	$\leq 5\%$	$\leq 25\%$	$\leq 50\%$	$\leq 75\%$

It is emphasised that these values are conditional: they refer to the percentage of capacity used, not simply the percentage of affected area or length. Thus, "5%" does not literally mean "5% of the bankline is revetted," but rather a composite indicator derived via the MImAS formula. Additional verification or refinement of values is recommended for instrument validation.

The practical application of MImAS involves a two-stage project screening procedure:

- Screening Assessment: local screening on a short reach (~500 m). Here, the method is applied to rapidly identify low-risk projects that do not threaten ecological status. If the cumulative percentage of capacity used does not exceed the thresholds (5–25%), the project is deemed safe or permissible without further review.
- Detailed Assessment: for projects with potential risk (exceedance of the Screening threshold), a more comprehensive assessment is conducted at the level of the entire water body. The assessment area is expanded; additional data (catchment condition, landscape, etc.) may be incorporated. A determination is made as to whether the intervention could overall cause exceedance of the condition boundaries for any status class within the water body.

It should be noted that MImAS is not applied to very short river reaches (less than 5 km of water body), as their capacity is difficult to assess at such a small length.

River MImAS is included in UKTAG guidance as a tool for regulating engineering interventions and supporting river status classification. UKTAG recommends using MImAS at the permitting stage: if a project may lead to exceedance of morphological condition boundaries, additional mitigation measures or alternative decisions are required. MImAS can also reflect the

status of existing infrastructure. The method thus serves to implement the WFD (assessing the compliance of actions with the requirements for status maintenance).

In the context of national consistency, UKTAG (High Status Features) emphasises that MImAS and related methods provide a "confident" assessment of morphological pressures and their impacts, which is directly used in high status classification. In particular, UKTAG guidance states that methods for assessing morphological condition (including MImAS) may be applied to provide final confirmation of High Status based on abiotic indicators.

River MImAS is widely applied, in particular in Scotland (SEPA) — it is the officially approved tool for river morphology classification in catchment planning. For example, in Scottish mountain (A, B) and foothill (C, D) rivers, MImAS has been used to assess the impact of protective structures and channelisation (channel reconfigurations) on biocoenoses, distinguishing low- and high-risk projects. In England and Wales, UKTAG considered MImAS when developing national morphological criteria; although channel biota analyses are more commonly used there, the MImAS approach is conceptually incorporated. A similar approach (TraC MImAS) has also been developed in Northern Ireland for transitional waters.

Overall, this tool operates across river types from class A to F and is used as a supporting expert assessment in each type. Thanks to the universality of its modules (typology accounts for type differences), MImAS allows the assessment to be adapted to a mountain stream with a rocky bed or to a calm, full-flowing lowland river, maintaining the necessary adjustments for sensitivity

3.2. Second M&M section

The *Système Relationnel d'Audit de l'Hydromorphologie des Cours d'Eau* (SYRAH-CE) methodology is a multi-level hierarchical system for assessing the hydromorphological status of French rivers. It is implemented on a "top-down" principle: the main physical structure of the catchment is described first, followed by the delineation of finer segments. The French hydrographic network is divided into approximately 70,000 homogeneous "morphological" sections (*tronçons*). Each *tronçon* (homogeneous reach) is defined as a section with shared geomorphological, hydrological, and geological characteristics. At the *tronçon* level, cartographic data on human pressures (structures, land use, etc.) are collected and systematised, while at the Directive water body level (via elemental parameters), an integrated risk of degradation is assessed. The system thus combines two data groups: geospatial data on pressures (from national GIS databases) and statistically probabilistic risk calculations (based on these pressures). This approach corresponds to the DPSIR concept — the "Pressure-State-Impact-Response" framework (the pressure of anthropogenic factors and the corresponding hydromorphological consequences). The methodology ultimately enables a river audit: the hydromorphological degradation risk map overlays the pressures map, enabling monitoring and restoration efforts to be directed toward reaches with the highest risk.

The first step is sectorisation — dividing the network into homogeneous segments according to a set of controlling variables. The main variables are: water and sediment inputs (catchment size and area, often ranked using the Strahler scheme), relative floodplain width, valley confinement (degree of valley "encasement" by the channel), dominant valley substrate, and mean channel gradient. For example, a change in stream order (e.g., upon the confluence of a significant tributary) defines a segment boundary (the channel becomes substantially larger). Floodplain width is assessed from a digital elevation model as discontinuities in valley width. Based on these variables, each segment receives typological designations: e.g., a narrow or wide valley, a channel in limestone bedrock or in alluvium, etc. It is worth noting that anthropogenic pressures ("bank smoothing," embankments, irrigation, etc.) are generally not treated as independent variables in SYRAH-CE sectorisation — the approach focuses on natural controlling characteristics (Table 2).

The SYRAH-CE methodology focuses on the characteristics of hydromorphological alterations and the likelihood of their occurrence under anthropogenic influence. Typical

disturbances include the construction of dams and weirs, channel channelisation (straightening), bank revetment, sand and gravel extraction, intensive land use (agriculture, urbanisation), etc. These pressures lead to characteristic river changes: for example, fine sediment clogging (colmation) of the bed under cultivated banks, flow straightening (reduction in channel feature diversity), and channel shallowing (reduction in flow depths at low discharge). Table 3 presents a classification of the main types of hydromorphological disturbances and their consequences..

Table 2. Sectorisation controlling variables (Valette L. et al., 2008)

Control Variable	Variable Description
Water and alluvial fluxes (Strahler rank)	Water and sediment volumes (assessed by stream order; changes at large tributary confluences).
Floodplain width (valley floor)	Maximum valley width (from digital elevation model), compared to channel width.
Valley confinement	Ratio of valley width to channel width: distinguishes confined (narrow) from unconfined valleys.
Dominant substrate	Primary valley floor material — alluvial deposits or bedrock/colluvial layer.
Longitudinal channel gradient	Mean longitudinal gradient (steep mountain or gentle), determining hydraulic stream power.
(Climate) Hydrogeography	HER, (Not directly used for segment sectorisation, but employed for large-scale regional typology).

Table 3. Classification of the main types of hydromorphological disturbances and their consequences (Valette L. et al., 2008)

Disturbance Type	Examples of Pressures	Consequences (Alterations)
Engineering structures	Dams, reservoirs, flow releases	Changes in discharge regime (abrupt fluctuations), sediment accumulation/loss, creation of impounded reaches
Channel channelisation	Flow straightening, levelling, drainage	Reduction in sinuosity, increased flow velocity, reduced habitat diversity
Bank revetment	Bank protection (embankments, rip-rap)	Loss of lateral dynamics, channel narrowing, loss of riparian woodland
Sand/gravel extraction	In-channel and floodplain quarrying	Intensive bed incision, channel shallowing downstream, overall lowering of water levels
Land-use change	Urbanisation, intensive agriculture	Increased runoff velocity, fine sediment input (colmation), water quality deterioration
Water abstraction	Irrigation, water intake	Reduced levels during summer, channel incision and widening (at higher abrasive flows)
Other anthropogenic pressures	Vehicle access to floodplains, small dams, etc.	Local loss of mobility, disconnection of floodplain water bodies and tributaries

The above examples generally correspond to the descriptions in the SYRAH-CE conceptual framework. Importantly, the methodology assesses the likelihood of such alterations through a "pressure → probability of damage" model, rather than direct measurements of change (given the absence of comprehensive monitoring). In SYRAH-CE, each tronçon is assigned a set of hydromorphological descriptors (parameters), probabilistically classified into 5 risk levels.

Hydromorphological degradation risk calculations are performed using statistical models. The principal tool is a Bayesian Belief Network: multiple discretised pressure variables (engineering infrastructure, land use, abstractions, etc.) are combined in conditional probability tables describing the relationship between pressure and the potential degree of damage. For example, the variables "reduction in low-flow depth" and "increase in flood depth" are treated as latent indicators; their alteration classes are determined by the intersection of pressure factors. The model outputs, for each hydromorphological parameter (discharge, flow, channel structure, etc.), a probability distribution across risk categories. The most probable class and the magnitude of its uncertainty are interpreted as the risk assessment for the tronçon. This approach reflects SYRAH-CE's aim of working with incomplete information: it yields probabilistic, rather than binary, conclusions.

SYRAH-CE is a purely geospatial methodology: all input data — land-use maps, hydrography, geology, digital elevation models, registries of structures (dams, water intakes, bridges, etc.) — are sourced from national GIS databases. Key variables are computed via GIS: floodplain width and valley confinement, longitudinal channel gradient from elevation data, deposit type from geological data layers, presence of built structures on floodplains, etc. For example, the project notes that "through digital cartographic tools and powerful GIS information databases, SYRAH provides the capability for spatial modelling of pressure-alteration chains." In practice, the initial segmentation (in accordance with sectorisation principles) is often carried out with expert input, while subsequent calculations (dam density assessment, distances between drainage structures, tributary statistics, etc.) are fully automated through GIS macros and scripts. A recent development is the PRHYMO platform (Pressions et risques d'impacts hydromorphologiques): an interactive web-GIS that integrates SYRAH-CE results with additional data and provides risk map visualisation tools. All SYRAH-CE calculations are completed as geospatial datasets, enabling rapid updating of assessments and their integration into planning systems.

3.3. Third M&M section

According to the Landscape-Hydrological Model of the River Basin Geosystem (hereinafter the Landscape-Hydrological Model), developed by Yushchenko Yu.S. and researchers at the Faculty of Geography of Yuriy Fedkovych Chernivtsi National University, the young river landscape (YRL) is equated with units based on Homogeneous Channel-Floodplain Reaches (HCFR) — Holocene landscape complexes of river valleys with a well-defined structure. HCFRs, or "channel-floodplain complexes," form primarily during the Holocene and possess a unique combination of characteristics. They are proposed as the principal "young" river landscape units, convenient for integrated basin management. The delineation and mapping of the territorial structure of the YRL is carried out using GIS technologies and the formation of a corresponding hydromorphological database for the basin. It is important to account for the historical dynamics of landscape units: comparative analysis of cartographic materials from different years and satellite/aerial photographs (i.e., multi-temporal GIS imagery) is used to delineate contemporary HCFRs.

The methodology employs a three-level taxonomic system for delineating territorial units of the river valley. The following are distinguished: Homogeneous Valley Reaches (HVR) — large structural fragments of the valley (e.g., alluvial lowlands, basins); Homogeneous Valley Bottom Reaches (HVBRs) — sections without significant change in the planimetric outline of the valley floor; and HCFRs (channel and floodplain) — the channel reaches proper with their adjacent floodplain. The criteria for delineating such units are geomorphological features (constriction of the left/right bank, presence of meanders, oxbow lakes, etc.) and hydromorphological processes explaining their genesis and development.

A particular indicator of the character of channel-forming processes and HCFR structure is the Multi-Year Channel-Forming Belt (MYCFB). According to the methodology, it is reconstructed primarily from historical materials: topographic maps from the 19th to mid-20th century reflecting the previous channel and floodplain boundaries. The resulting belt is mapped together with the HCFRs — on the scheme it clearly shows the spatial "trough" of the formational process in each reach. On the Prut River, for example, the MYCFB has been constructed for the entire river reach within Ukraine using these maps. Comparison of the MYCFB with the contemporary channel reveals locations of overall bed incision or change in channel process.

For examples on the Prut River, a wide variety of data were used: morphometric (digital elevation models, 1:25,000 topographic maps, orthophotomaps), cartographic (archival general maps, 1:50,000–1:100,000 topographic maps from various periods, contemporary cadastral and hydrographic maps), and hydrological (long-term discharge observations and water management bed profiles). Geophysical methods (e.g., depth measurements) were also employed, as were field methods — detailed GPS surveys of the longitudinal channel profile, bed trenching, and alluvial sample collection. As noted in the study, it is precisely the combination of official and archival

information, hydrological observations, contemporary maps and imagery, and field (GPS) surveys that underpins the analysis of the natural state of the YRL. GPS measurements were compared with bank waterline elevations from mid-20th century topographic maps, enabling assessment of vertical channel changes.

Anthropogenic disturbances to the structure of the young river landscape (YRL) encompass primarily the processes of artificial channel regulation and active intervention in the natural alluvial regime. The principal degradation factors include engineering bank revetment, the construction of hydraulic structures and obstacles, and the extraction of channel and floodplain alluvium.

Detection methods for such disturbances are based on observations of changes in river forms and processes: these are sometimes formalised in hydromorphological assessment indicators. In particular, anthropogenic incision is detected through GPS geodetic surveys by comparing contemporary and historical elevation differentials to the water surface. Changes in floodplain area are established through multi-temporal analysis of maps and aerial photographs — reaches built over by humans show a reduction in floodplain landscapes. Alluvium losses are tracked both through quarrying operation data (technical documentation) and through changes in channel width and depth: noticeable bed lowering and an increase in bedrock banks signal degradation of the infill material. Overall, anthropogenic hydromorphological changes are noted to result in significant disruption of the YRL (deterioration of landscape quality by hydromorphological indicators) and require continuous monitoring.

The key approach is the combination of spatial (GIS) analysis with temporal (historical data) analysis. In practice, this entails the creation of a geodatabase in which attributes and indicators are accumulated for each HVBR/HCFR: section lengths, average and minimum/maximum channel and floodplain widths, bed gradients, presence of meanders, etc. These data are then "anchored" in time: contemporary maps and satellite imagery are overlaid on archival topographic maps, revealing landscape dynamics. This has enabled spatiotemporal assessment of YRL changes — identifying where units have "migrated," narrowed, or lost hydromorphological connectivity with the former floodplain.

Following HCFR delineation, hydromorphological assessment of the degree of anthropogenic impact on each reach is carried out. For this purpose, morphometric indicators are employed that visibly reflect human intervention in channel processes. Two principal indicators are primarily considered:

- Depth of anthropogenic channel incision (h_{inc}) — the lowering (sinking) of the contemporary river level below the natural terrace level or historical channel, caused by bed clearance, deepening, or other intervention.
- MYCFB coefficient (K_{MYCFB}) — the ratio of the width of the contemporary engineered floodplain belt (or the width of the multi-year channel-forming belt) to its natural width. For example, if engineering works have narrowed the protective floodplain belt by half, $K_{MYCFB} \approx 0.5$.

According to the methodology, a significant anthropogenic load is considered to be present when $h_{inc} > 1$ m or $K_{MYCFB} < 0.5$. These threshold values are derived from hydromorphological monitoring practice: if the mean incision depth exceeds 1 m and the contemporary MYCFB width is less than half its natural width, the changes are considered substantial. Reaches with lesser deviations are classified as moderately altered, while larger values indicate significant anthropogenic transformation.

In addition to quantitative indicators, qualitative signs of morphological change are also incorporated in the assessment. Critical signs include: deformation of the channel profile, asymmetric bank asymmetry, disappearance of meanders or transition from a multi-thread to a single-thread channel, changes in channel bedload composition, floodplain overgrowth, destruction of natural drainage vegetation, etc. In particular, narrowing of the MYCFB (e.g., by a

factor of 2 or more) sharply alters flow conditions and the type of channel process, which is a sign of severe transformation. The principal anthropogenic factors affecting HCFRs are engineering structures (dams, bank revetment, canals) and alluvium extraction (sand and gravel quarrying), which lead to channel incision and floodplain narrowing. It is precisely these factors that typically form the basis of quantitative assessment of anthropogenic loading.

The degree of change in each HCFR is determined by comparing these indicators against critical thresholds. In the given example (Siret River), when $K_MYCFB > 0.5$ and $h_inc \leq 1$ m, the condition is considered "moderately altered" (i.e., closer to natural). If at least one indicator exceeds the boundaries ($h_inc > 1$ m or $K_MYCFB < 0.5$), the reach is assigned the category of "significantly altered." For example, an HCFR with $K_MYCFB \leq 0.5$ and $h_inc > 1$ m is recorded as exhibiting a high degree of transformation. The value 0.5 here signifies "50% preservation" of the floodplain belt: when the contemporary floodplain is half as wide, this is the threshold of substantial impact. Thus, the 0.5 indicator serves as a critical threshold in classification — below this level, the reach belongs to severely degraded; above it, to moderately disturbed. This is effectively not a "share of damage" relative to its natural state; understanding this indicator provides a clear distinction between "moderate" and "significant" anthropogenic transformation conditions.

It is important to emphasise that exceedance of the K_MYCFB and/or h_inc thresholds due to anthropogenic "compression" of the channel and floodplain manifests not only in a reduction in the area (width) of the multi-year channel-forming belt, but also in a restructuring of the spatial organisation of homogeneous reaches: new morphological discontinuities form, causing the boundaries of HCFRs to shift relative to their natural position. In effect, anthropogenic intervention alters not only the "scale" of the MYCFB, but also the "organisation" of rivers into homogeneous reaches.

Under this methodology, the results of hydromorphological assessment of HCFRs become the basis for spatially targeted basin management. It is recognised that a river basin is a synthesis of hydrological, geomorphological, and landscape components, and therefore management must be integrated. In accordance with the principles of integrated basin management, it is necessary to coordinate the balanced use, conservation, restoration, and protection of all geosystems of the river basin (aquatic, floodplain, adjacent forest, soil, etc.). In particular, HCFRs with the lowest degree of alteration should be maximally preserved in their natural state, using them as reference zones for natural processes. On reaches with moderate degradation, new interventions are restricted: for example, water abstraction and bank revetment are regulated, and natural floodplain inundation is restored to support ecosystems. In severely disturbed HCFRs, management should be oriented towards the restoration of hydromorphological functions: widening of the multi-year channel-forming belt to its natural limits, "correction of excessive incision," prohibition of illegal sand and gravel extraction, and strengthening of nature conservation control.

In the broader context, assessment results are incorporated into the River Basin Management Plan: they define ecological objectives for each sectoral reach of the basin and prescribe restoration measures. The preservation of the integrity of the young river landscape as a functional whole of aquatic-geosystems is important. Thus, within the hydro-ecological interpretation framework, the methodology proposes to optimise the management of the hydromorphological quality of rivers, accounting for zones with different degrees of anthropogenic pressure. This may include zoning — the creation of "sensitive areas" (geosystems) based on HCFRs, where restorative or protective actions will be prioritised. In this way, basin management is conducted in accordance with the spatial results of assessment: each HCFR receives a set of measures (from monitoring to rehabilitation) corresponding to its morphological condition and role in the basin structure.

4. PRACTICAL SIGNIFICANCE

The practical significance of this paper lies in its provision of an operational example of the "translation" of morphological diagnostics into management decisions: from the description/mapping of forms and processes — to the selection of permits, restrictions, and restoration measures for specific homogeneous reaches. The comparison of River-MImAS, SYRAH-CE, and the Landscape-Hydrological Model demonstrates how the same problem (morphological pressures and their risk to the achievement of WFD objectives) can be addressed through different tools — "threshold screening," national GIS audit, and landscape-taxonomic zoning. In applied terms, this enables water management authorities and planners to rapidly "filter" risky interventions and identify situations requiring mitigation decisions or project redesign: MImAS explicitly describes a two-stage scheme with local screening on ~500 m reaches and subsequent assessment at the water body level if there is risk of threshold exceedance, effectively "embedding" morphological analysis into the permitting and approval procedure.

The second practical line involves the unification of thresholds and criteria for engineering works and the control of their cumulative effect. The text presents conditional "morphological condition boundaries" for status classes in terms of percentage capacity use (specifically 5%, 25%, 50%, 75% for channel and bank/riparian zone), and emphasises their interpretation as a combined indicator derived via the MImAS formula, rather than simply the proportion of revetted length; an additional stricter variant (15% instead of 25% at the Good–Moderate boundary) is also noted as a management precaution against "missing" risky proposals. This provides practitioners with clear logic: what precisely to calculate, how to aggregate different interventions, and where to set a "stop signal" when reviewing projects in the channel and floodplain.

The third practical dimension concerns the upscaling of assessment and spatial planning. In the paper, SYRAH-CE is presented as a purely geospatial approach in which key variables are computed from national GIS layers and results can be integrated into planning systems; the PRHYMO web-GIS platform is cited as an example for risk visualisation, important for the regular updating of pressure maps and the transparent justification of priorities in basin management.

In the domestic context, the Landscape-Hydrological Model demonstrates how morphological information can be translated into zoning and a package of measures for different transformation categories: proposed quantitative indicators (h_{inc} and K_{MYCFB}) with clear thresholds for substantial change ($h_{inc} > 1$ m or $K_{MYCFB} < 0.5$) and the direct "attachment" of assessment results to the River Basin Management Plan through the setting of ecological objectives and restoration/conservation measures for each homogeneous reach.

5. SCIENTIFIC NOVELTY

This paper presents, for the first time, a targeted comparison of the morphological component specifically of three methodologically and scale-wise distinct hydromorphological river assessment frameworks — River-MImAS, SYRAH-CE, and the Landscape-Hydrological Model — within a shared framework of WFD requirements for supporting hydromorphological quality elements (channel morphology, continuity, flow regime). The novelty lies in the identification and formalised description of equivalences and incommensurabilities between the three approaches at the level of: (1) the spatial unit of analysis (the 500-m reach with "capacity used" thresholds in River-MImAS; national sectorisation into homogeneous tronçons in SYRAH-CE; the three-level taxonomy HVR–HVBR–HCFR in the Landscape-Hydrological Model); (2) the mode of representing morphological changes (the integral "system capacity" and percentage threshold boundaries in River-MImAS; risk-oriented probabilistic interpretation of morphological alterations in SYRAH-CE; landscape-genetic interpretation of the young river landscape using anthropogenic incision indicators (h_{inc}) and the MYCFB coefficient (K_{MYCFB}) with thresholds for significant change); (3) the role of GIS and multi-temporal mapping in reproducing "referentiality" and tracking changes

(from the modular impact scoring scheme to national GIS audit and historical-cartographic MYCFB reconstruction). In summary, a scientific-methodological basis is substantiated for harmonising the "pressure/risk/capacity" approaches with landscape-morphological units and indicators, creating prerequisites for the correct transposition of WFD logic into domestic practice of morphological diagnostics and the prioritisation of restoration measures at the level of homogeneous channel and floodplain reaches.

6. CONCLUSIONS

Synthesising the morphological component of the stated methodologies, it can be asserted that all of them proceed from the same WFD logic: morphology (together with flow regime and continuity) is regarded as a "supporting" quality element, and therefore changes in it must be interpreted not descriptively, but in the format of a management conclusion about the risk/acceptability of interventions or the degree of deviation from reference conditions. A further commonality is that the "unit of analysis" is a spatially homogeneous river reach, but each system defines this homogeneity differently: in UKTAG/River-MImAS the practical basis is a short screening reach (~500 m) and subsequent upscaling to the water body level; in SYRAH-CE — top-down sectorisation of the network into a large number of homogeneous tronçons with naturally controlled characteristics; in the Landscape-Hydrological approach — a hierarchy of valley and young river landscapes (HVR/HVBR/HCFR) anchored to valley structure and the development of young river landscapes during the Holocene. In other words, the difference lies not in "whether segmentation is needed," but in precisely which boundaries are considered morphologically justified and sufficient for decision-making.

The key difference between the approaches is manifest in the type of output and in how morphological changes are "translated" into a status/risk scale. River-MImAS most effectively formalises the cumulative nature and manageability of engineering actions: heterogeneous interventions are reduced to an integral indicator of "percentage capacity used" and compared with conditional boundaries linked to High/Good/Moderate/Poor transitions (approximately 5/25/50/75% for channel and bank/riparian zone), and these boundaries are interpreted as a combined risk indicator, rather than as a "proportion of revetted length." This is why MImAS best "captures" situations where it is necessary to assess project proposals (or a package thereof) and quickly determine whether the morphological resource of the reach is being depleted; conversely, it is less sensitive to situations where the primary cause of degradation is a long-term restructuring of the channel process, requiring historical-morphological reconstruction rather than merely accounting for current intervention "footprints." SYRAH-CE, by contrast, is stronger in large-scale "geospatial auditing": it relies on available pressure registries/maps and natural sectorisation controlling variables (including changes in stream order, floodplain width, valley confinement, alluvial deposits, gradient) to obtain probabilistic/risk categories and prioritisation maps of reaches where monitoring and restoration measures are most appropriate; in this sense, SYRAH-CE works better where field surveys are currently impossible or too costly, but rapid network ranking by expected morphological problematicity is needed.

The Landscape-Hydrological methodology most precisely "illuminates" the morphodynamic meaning of disturbances (incision, narrowing of the active channel-forming belt, loss of floodplain function), since it combines GIS analysis with a temporal axis (maps/imagery from different years) and introduces threshold morphometric criteria for the significance of changes (specifically $h_{inc} > 1$ m or $K_{MYCFB} < 0.5$), which are directly linked to the geomorphological mechanism of degradation, rather than merely to the presence of engineering structures. Consequently, when it is necessary to justify the restoration of channel-floodplain processes (rather than merely "the acceptability of works"), this approach is often more informative; at the same time, it is more demanding in terms of input data requirements and more reliant on historical materials and field verification.

It is important to note that these approaches are not so much competing as complementing each other, addressing different management "windows" of morphological diagnostics. If the task is to make a decision regarding a specific intervention or package of works and to demonstrate its compatibility with status objectives, this is most transparently accomplished through the capacity/threshold logic and two-stage screening, where a short reach (~500 m) provides a rapid filter and the water body level provides context for cumulative effects and possible exceptions/compensations. If the task is to "see the network" and correctly select where to invest resources in field surveys and restoration design, the risk audit with sectorisation by natural controls and pressure mapping is more powerful, as it enables prioritisation without comprehensive field surveys. If the task is to establish a cause-and-effect morphological picture of degradation and define the spatial boundaries of rehabilitation (where to expand/restore the channel-forming belt, how to interpret incision and floodplain narrowing), then the most demonstrative approach is one that directly reconstructs the trajectory of channel-floodplain changes over time and operates with thresholds anchored to morphodynamics. In conclusion, the most reliable strategy for basin management (and the strongest interpretation in the paper's conclusions) is a combination: large-scale risk screening for reach selection and network ranking, detailed landscape-morphological diagnostics for identifying mechanisms and feasible restoration boundaries, and "capacity" verification for assessing the acceptability of specific engineering scenarios and their cumulative effects.

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Порогова інтерпретація морфологічних тисків у гідроморфологічній оцінці річок: зіставлення River-MImAS, SYRAH-CE та ландшафтно-гідрологічної моделі в контексті Водної рамкової директиви ЄС

Ключові слова: гідроморфологічна оцінка; морфологічні тиски; River-MImAS; SYRAH-CE; однорідні ділянки русла та заплави.

Анотація: У статті виконано порівняльний аналіз морфологічної складової трьох підходів до гідроморфологічного оцінювання річок — River-MImAS (Велика Британія), SYRAH-CE (Франція) та ландшафтно-гідрологічної моделі річкових басейнової геосистеми (Україна) — у спільному контексті вимог Водної рамкової директиви ЄС щодо підтримувальних гідроморфологічних елементів якості та їх ролі в досягненні/утриманні цільового екологічного статусу водотоків. Метою роботи є зіставлення того, як кожна методика «перекладає» морфологічні зміни русла й заплави у формалізований управлінський висновок, зосереджуючись на виборі просторової одиниці аналізу, наборі морфологічних показників/дескрипторів, способі картографічної підтримки й наявності порогових меж інтерпретації. River-MImAS найжорсткіше формалізує кумулятивність інженерних втручань через концепцію «ємності системи» та відсотка її використання, що дає змогу застосовувати метод як інструмент порогового скринінгу пропозицій на коротких відрізках і масштабувати висновок до рівня водного тіла; натомість SYRAH-CE орієнтована на національний ГІС-аудит і ризик-картографування, де сегментація річкової мережі на однорідні відтинки ґрунтується на природних контролювальних змінних (порядок водотоку, ухил, субстрат, параметри долини/заплави), а результат подається як імовірнісні категорії ризику гідроморфологічної деградації; ландшафтно-гідрологічний підхід, у свою чергу, найвиразніше відтворює морфодинамічний зміст порушень через багаточасову реконструкцію та картографування молодого річкового ландшафту й однорідних ділянок русла та заплави, а також через використання морфометричних індикаторів і порогів істотності змін (зокрема щодо антропогенного врізання та трансформації багаторічної смуги руслоформування).

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