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Christine Argillier, Alexandra Carriere, Sandra Poikane, Wouter van de Bund

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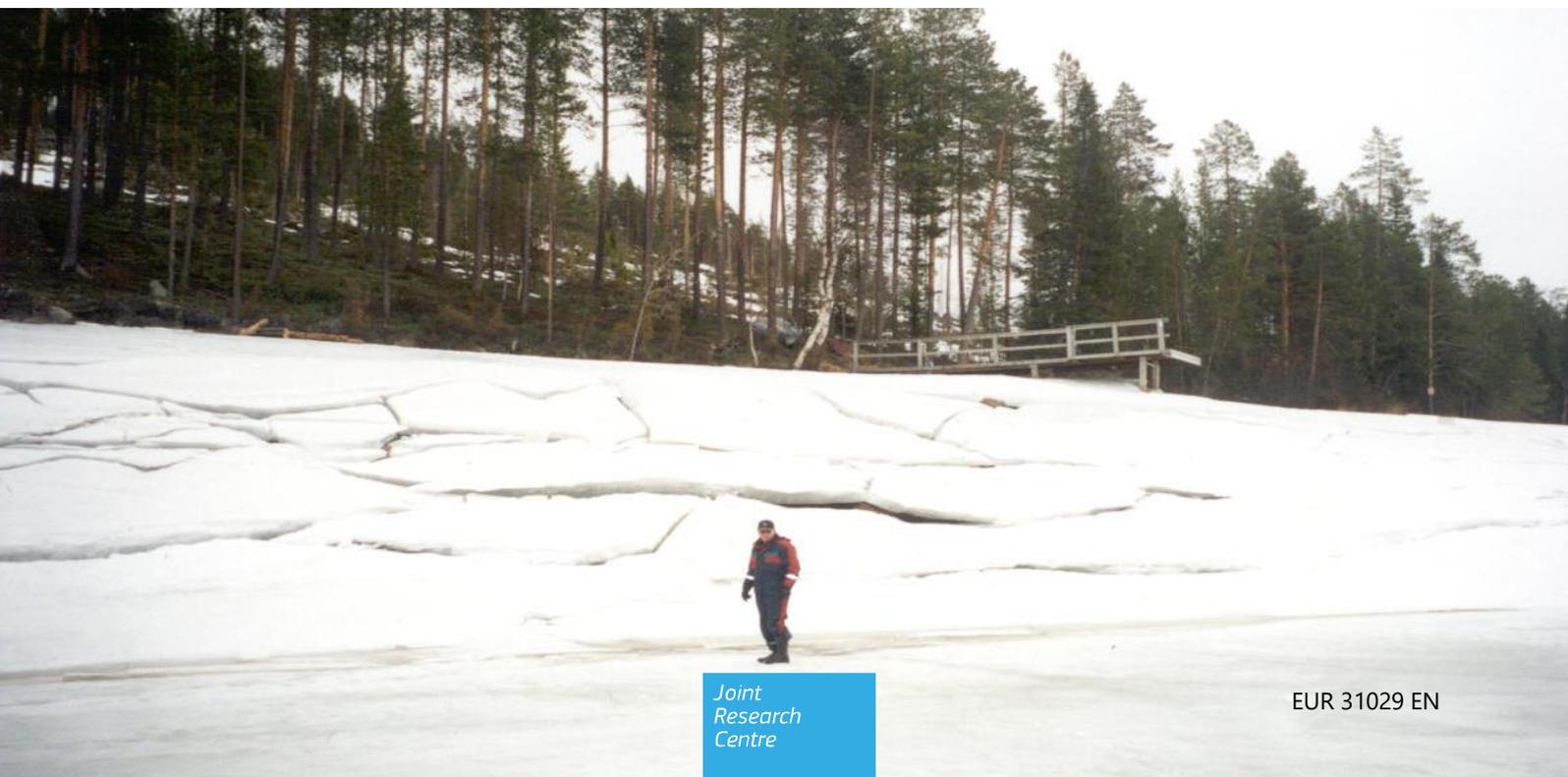
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JRC TECHNICAL REPORT

Lake Hydromorphological Assessment and Monitoring Methodologies – European survey

**Christine Argillier, Alexandra Carriere,
Sandra Poikane, Wouter van de Bund
2022**



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Authors

Report written by Christine Argillier, Alexandra Carriere, Sandra Poikane and Wouter van de Bund.

Abstract

The assessment of lake status in Europe has evolved during the last few decades from physico-chemical focused assessment to a more comprehensive ecological approach. The EC Water Framework Directive (WFD) requires the assessment of hydromorphological and physico-chemical conditions of lakes considered as supporting elements of the biological communities. The WFD describes the hydromorphology of lakes using quality elements belonging to the hydrological regime on the one hand and to morphological conditions on the other hand. A lake can achieve good ecological status only if the aforementioned quality elements correspond to natural conditions or deviate from them very slightly. Therefore, hydromorphological assessment is crucial for ecological status assessment. During summer 2020, an inventory of the HYMO assessment and monitoring methods currently implemented or under development in the different European countries for WFD implementation was conducted. This study summarises key information reported through the aforementioned inventory in order to get a comprehensive overview of the hydromorphological methods at the present time and to contribute to more common understanding of how hydromorphological conditions are defined and hydromorphological changes are characterised in different national contexts in Europe. The high response rate of the European survey makes it possible to provide a comprehensive overview of lake hydromorphological assessment and monitoring methods implemented or under development in the different European countries.

Currently, 33 methods are applied or in development in 20 countries, 20 are currently assessment methods, 10 are monitoring methods and 3 methods will be replaced by new protocols. This report gives also a basis to carry out future relevant good practices suitable with standards such as the water quality guidance standard on assessing the hydromorphological features of lakes – EN 16039:2011 and the water quality guidance standard on determining the degree of modification of lake hydromorphology – EN 16870:2017. Hydrological characteristics are relatively well taken into account by the different countries except the residence time although its evaluation is recommended in the EN 16039:2011 standard. Surface-groundwater interactions and stratification/mixing are also poorly taken into account in the different countries even though the interactions between surface water and groundwater are characterised in a majority of countries but not used to assess lake conditions. Morphological characteristics are also relatively well taken into account by the different countries, in particular lake depth variation, shape of the littoral zone and shore zone aquatic vegetation. Nevertheless, the planform pattern, substrate and aquatic vegetation in the open water are still poorly used to evaluate lake conditions although their evaluation is recommended in the EN 16039:2011 standard. All of the 20 current assessment methods use a scoring system which are mostly quantitative although the degree of confidence is still poorly included in the methods. However, the scoring system and the way in which class thresholds are defined remain to be specified by the different countries.

Finally, two main hurdles remain; a methodological hurdle with the determination of reference conditions which is not clearly defined for many countries although this is essential when assessing lake conditions and a scientific hurdle with regard to the link with biology of the different hydromorphological assessment methods. In order to improve best practices and write recommendations further information is needed on how reference conditions and classification are undertaken at Member State level for assessing lake hydromorphology.

1 Introduction

The assessment of lake quality in Europe has evolved since last decades from its physico-chemical focused assessment to a more comprehensive ecological approach. The EC Water Framework Directive (WFD) requires the assessment of hydromorphological and physico-chemical conditions of lakes considered as supporting elements of the biological communities. The WFD describes the hydromorphology of lakes using quality elements belonging to the hydrological regime on the one hand (quantity and dynamics of water flow, residence time, connection to the groundwater body), to morphological conditions on the other hand (lake depth variation, quantity, structure and substrate of the lake bed, structure of the lake shore). A lake can achieve the status of good ecological status only if the aforementioned elements correspond to natural conditions or deviate from them very slightly.

Therefore, in application of the WFD directive, hydromorphological assessment is crucial for the ecological status assessment. However it can be useful in other situations such as for example to investigate the risk of alterations, for the monitoring of mitigation measures or simply to assess the quality of habitats in the perspective of biodiversity conservation.

Many models and methods have been developed around the world to measure or estimate the hydrological and morphological characteristics of water bodies (Donohue *et al.*, 2005) or even to assess the deterioration caused by humans (Acreman *et al.*, 2006; Ostendorp *et al.*, 2004; Ostendorp, 2004) However, in Europe, the implementation of the WFD has been a driving force for the development of new methods.

A questionnaire on hydromorphological assessment and monitoring methods used or under development in European countries for WFD implementation was conducted in summer 2020 in order to get a comprehensive overview of the hydromorphological methods used at present time by the member states for WFD assessment. The aim of this study was to make an inventory of these HYMO assessment and monitoring methods developed in European countries. The present report sum key information reported through this questionnaire.

The aim of this exercise is also to contribute to more common understanding on how hydromorphological conditions are defined in different national contexts and how hydromorphological changes are characterized.

Finally this report will give a basis to carry out future relevant good practices suitable with standards such as the water quality guidance standard on assessing the hydromorphological features of lakes – EN 16039:2011 (BSI, 2011) and the water quality guidance standard on determining the degree of modification of lake hydromorphology – EN 16870:2017 (BSI, 2017).

The information collection exercise has been set-up in 2020 with the support of the sub-group consisting of mMember States (MS) hydromorphology experts within ECOSTAT.

This report is structured around ten chapters, the first of which consists of this introduction. Chapter 2 describes the questionnaire on lake hydromorphological assessment and monitoring methods sent to the European countries. The seven following chapters synthetize the results of the survey. Chapter 3 presents general information such as the use of the reported methods for different purposes within the WFD planning process as well as beyond the WFD. Chapter 4 reports the general description of the methods.

Chapters 5, 6 and 7 deal respectively with hydrological, morphological components and physical processes that are considered by the methods. Then, chapter 8 reports the kind of assessment outputs provided by the methods. Chapter 9 draws feedbacks on the use of the methods such as the lessons learned as well as the strengths and the weaknesses of the methods. Chapters 10 and 11 expose, respectively, the outcomes of the virtual ECOSTAT workshop conducted in order to present, discuss and share feedbacks about the hydromorphological (HYMO) methods, and the future perspectives that emerge from this workshop. Finally, chapter 12 concludes with an overall assessment of the information collection exercise and key conclusions.

2 European countries Questionnaire on Lake Hydromorphological Assessment and Monitoring Methods

A questionnaire was built in 2019 on the same format as the questionnaire used for river HYMO assessment methods but adapted to lake HYMO. It was then distributed to national experts of 28 countries implementing the WFD in order to gather information about lake hydromorphological assessment and monitoring methods.

The aim of this information collection exercise was to record hydromorphological and monitoring methodologies which are used in the implementation of WFD on a structured basis.

The questionnaire is organized around seven headings:

- 1) General information about the method;
- 2) General characteristics of the method;
- 3) Recorded hydrological features;
- 4) Recorded morphological features;
- 5) Alteration of hydromorphological features and consideration of processes;
- 6) Assessment output;
- 7) Lessons learned.

The morphological and hydrological terms are used according to two standards:

- Water quality – Guidance standard on assessing the hydromorphological features of lakes – EN 16039:2011

- Water quality – Guidance standard on determining the degree of modification of lake hydro-morphology – EN 16870:2017.

Due to the technical nature of the questionnaire and the possible different interpretation of the questions and the terms across countries, a detailed guide (see Annex 3) was distributed together with the questionnaire. The specific questions covered in the seven different sections of the questionnaire are outlined in the table below.

Table 1. Items included in the questionnaire on lake hydromorphological assessment and monitoring methods.

1 – General Information	
ID	Question
1.1	Name of the method
1.2	Country
1.3	Contact person
1.4	Use of the method
1.5	Use of the method for the WFD planning process
1.6	Use for other Directives (except WFD)
1.7	Status of the method

1.8	Level of application
1.9	Extent of application
1.10	Inclusion in legislation
1.11	Key reference
1.12	Available supporting material
1.13	Users' qualification
1.14	Requirement for accreditation
1.15	Resource intensity
2 – General Characteristics	
ID	Question
2.1	Components covered by the method
2.2	Biological considerations
2.3	Source of information/data collection
2.4	General temporal scale
2.5	General spatial extent of the monitoring
2.6	Criteria for selection of sections
2.7	Extent of the sections
2.8	Approach used by the method to define reference conditions
2.9	Use of HYMO types
2.10	Criteria/parameters for definition of HYMO types
2.11	Extent of application according to lake types
2.12	Temporal dimension
2.13	Severity of hydromorphological pressures
3 – Recorded Hydrological Features	
ID	Question
3.1	Inflows
3.2	Outflows
3.3	Stratification/mixing
3.4	Water level regime
3.5	Residence time
3.6	Surface – groundwater interactions
4 – Recorded Morphological Features	
ID	Question
4.1	Lake – Planform pattern
4.2	Lake – Depth variation/bathymetry
4.3	Open water – Bedform substrate
4.4	Open water – Aquatic vegetation
4.5	Morphometry – Shape and characteristics of banks and beaches
4.6	Substrate – Shore zone
4.7	Aquatic vegetation – Shore zone
5 – Alteration of hydromorphological features and consideration of processes	
ID	Question
5.1	Off-site pressures
5.1.1	Non-natural land cover in the catchment

5.1.2	Non-natural land cover in the riparian zone/buffer zone
5.1.3	Longitudinal continuity in the catchment
5.2	Alteration of the hydromorphology and/or processes occurring in the lake
5.2.1	Adjustments in shape
5.2.2	Presence of a dam
5.2.3	Outfalls and off-takes installations impacting flow and/or sediment discharge in the lake
5.2.4	Residence time modification
5.2.5	Current
5.2.6	In lake sedimentology
5.2.7	Hydrology, lateral continuity of flow
5.2.8	Bank protection, flood embankment (impacting habitat and lateral connectivity)
5.2.9	Alteration of bed sediment structure/ substrate composition/ vertical continuity
5.2.10	Occurrence of bank erosion processes
5.2.11	Floating and tethered structure
5.2.12	Trampling of shorelines and the littoral zone
5.2.13	Artificial waves
5.3	Management interventions
5.3.1	Sediment management
5.3.2	Water level management
5.3.3	Vegetation management
5.3.4	Land use in the surrounding area
5.4	Uses, others (aquaculture, touristic activities, etc.)
6 – Assessment output	
ID	Question
6.1	Type of output of the assessment
6.2	Type of scoring
6.3	Scoring information
6.4	Degree of confidence
7 – Lessons learned	

3 General information

We received 32 questionnaires describing 33 methods applied or in development in 20 countries.

In addition, the following information were collected by email:

- Denmark: no method currently implemented;
- Luxembourg: a method is under development (adaptation to an existing one) for its application to two reservoirs;
- Slovakia: no special HYMO assessment method for lakes was developed - Until now the HYMO assessment method developed for river reaches has been also used for these “artificial lakes” but special part of this method focusing the HYMO assessment in reservoirs is currently under development.

Therefore, finally, the questionnaires generated information from 23 European countries. We got no response from Belgium, Bulgaria, Malta, the Netherlands and Slovenia. .

Table 2. Summary of the questionnaire received.

Country	Number of questionnaires	Additional information
Austria	2	Information at different spatial scale
Croatia	1	
Cyprus	2	Monitoring methods
Czechia	1	Monitoring of reservoirs
Denmark	0	
Estonia	1	
France	7	Six monitoring methods and one assessment method under development
Finland	1	
Germany	3	Different details and information collected
Greece	1	
Hungary	1	
Ireland	1	
Italia	1	
Latvia	1	
Lithuania	1	
Luxembourg	0	
Norway	3	Two classification systems and one monitoring method
Poland	1	
Portugal	1	Method used in the Azores only. Another in development but not described
Romania	1	
Slovakia	0	
Spain	2	One currently used and another one in development
Sweden	1	

When several methods were described in a country, the following information allows the reader to understand better their respective use:

- In **Austria**, one method is a quick screening method (for whole lake use), the second one is a detailed method (for lake sections of special interest).
- In **Cyprus**, one method was dedicated to the monitoring of natural lakes, the other one to the monitoring of reservoirs.

- In **France**, among the seven methods described, 6 are implemented in order to collect information that will feed the HYMO assessment system described in the seventh one.
- In **Germany**, three methods are used. Two of them are “overview” methods (one focusing on hydrological regime), the last one is a “detailed” method.
- In **Norway**, one method is the HYMO lake classification system that has been developed in the period 2018-2020. During the first phase (described in the SINTEF report 2018:00768) a pilot version of a lake classification was developed, taking an “all inclusive” approach, meaning that all HYMO parameters considered relevant for Norwegian lakes and reservoirs were included in the HYMO system. In the second phase (reported in SINTEF report 2019:01365), the pilot version was tested, and a revised system with fewer parameters was proposed. Another method is a hydromorphological pressures classification system used in the characterization/pressure analysis that was carried out in the first phase of the implementation of the EU WFD in Norway. The third one is a hydrological monitoring system managed by the Norwegian Water Resources and Energy Directorate (NVE). This is first of all a hydrological monitoring system that would provide input to the calculation of hydrological indices, such as the hydrological parameters described in the HYMO lake classification system above (point 1) and not a classification system as such.
- In **Spain**: two methods are described, one which is currently used and another one that will be used in the future. This new method will include the same criteria than the first one and additional information.

Four countries: Poland, Italia, Latvia and Czechia use more or less the same method derived from the Lake Habitat Survey.

To summarize, among the 33 methods described in the questionnaires:

- **Three are methods which will be replaced by new protocols (Portugal) or which will evolve to integrate new criteria (Spain and Norway). In that last two cases, the new method was also described;**
- **Three methods (two implemented in Cyprus and one in Czechia) were supporting lake typology only;**
- **Seven methods are used to collect HYMO information but do not lead to a HYMO status assessment. This is the case of six French methods and one in Norway that are used to collect information that will feed the assessment method;**
- **20 methods seems currently implemented in the assessment of the lake HYMO status of 17 countries.**

3.1 Use of the methods

Table 3 presents the responses to the first general question on the use of the method for the 33 methods described.

Table 3. Use of the 33 methods of lake hydromorphological assessment and monitoring.

Country	Method	Hydromorphological classification (WFD-related)	Supporting ecological classification	Proxy of biological quality elements	Hydromorphological monitoring	Hydromorphological assessment (non-WFD)	Diagnosis for designing measures (e.g. rehabilitation, mitigation, etc.)	Assessment of the effectiveness of measure(s)	Prognostic tool (e.g. for environmental impact assessment)	Other
Austria	HYMO screen	1	1		1	1	1	1	1	
Austria	HYMO screen +	1	1		1	1	1	1	1	
Croatia	Proposal of methodology for hydromorphological status assessment in standing water bodies	1	1		1					
Cyprus	Cyprus natural lakes hymo monitoring		1			1				1
Cyprus	Cyprus water reservoirs hymo monitoring		1			1	1			1
Czechia	Methodology for assessing ecological potential of heavily modified and artificial water bodies - category lake									1
Estonia	Estonian hydromorphological assessment method for lakes	1	1		1	1	1	1	1	
Finland	Finnish regulated lakes	1	1		1	1	1	1		
France 1	ALBER		1		1	1	1	1		
France 2	Bathymétrie (Bathymetry)		1		1	1				
France 3	BAVELA		1		1	1				
France 4	CHARLI		1		1	1	1	1		
France 5	CORILA		1		1	1				
France 6	LHYMO	1	1		1	1	1	1	1	
France 7	SEDILAC		1			1				
Germany 1	LAWA: overview - method	1	1							
Germany 2	HML - Hydromorphologie der Seen	1	1		1	1	1	1	1	1
Germany 3	LAWA Biota									
Germany 3	Klassifizierung des Wasserhaushalts von Einzugsgebieten und Wasserkörpern – Verfahrensempfehlung (LAWA)	1	1		1	1	1	1	1	
Greece	Guidance on Hydromorphological Assessment in surface water bodies	1	1		1					
Hungary	HU RBMP3 method on hydromorphology	1	1		1		1			
Ireland	Lake MImAS	1	1		1					
Italia	Lake Habitat Survey - LHS	1	1					1		
Latvia	Lake Habitat Survey (LHS)	1	1	1	1		1	1		
Lithuania	HMLe	1	1							
Norway 1 (revised)	Hydromorphological classification system, Norway, Revised 2019/2020	1	1			1	1			1
Norway 2	Pressures analysis and simple hymo classification	1	1							
Norway 3	Norwegian Water and Energy Directorate (NVE) - National hydrological monitoring program		1		1	1	1	1	1	
Poland	Lake Habitat Suvey PL (LHS_PL)	1	1		1	1	1			
Portugal	Photointerpretation and streamflow and limnometric evaluation				1		1	1		
Romania	Methodology for hydromorphological assessment of lakes (natural and heavily modified water bodies-lakes and reservoirs)	1	1				1			
Spain current			1							
Spain future		1	1		1	1	1	1	1	
Sweden		1	1	1	1	1	1	1	1	
	Total	21	31	2	21	20	19	15	9	5

The results are illustrated on the following figure with a distinction between the 33 methods described in the questionnaires and excluding those that will no longer be used or that are monitoring methods.

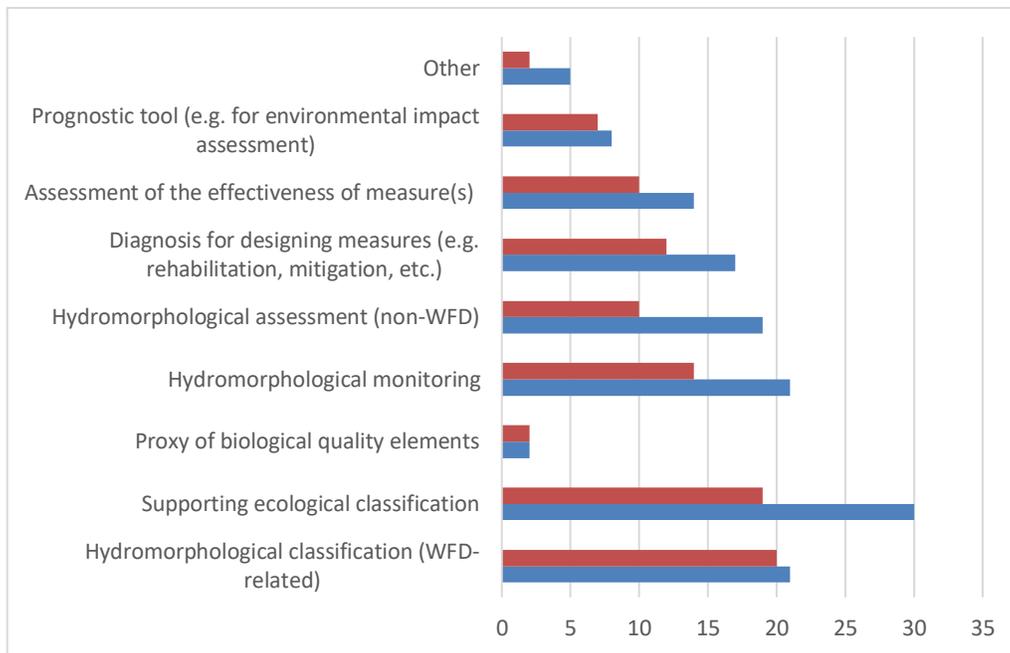


Figure 1. Use of the methods: responses collected in the 33 questionnaires (blue) or limited to the 20 assessment methods (red).

All the methods except those of Czechia, Portugal and Romania (i.e. 30 out of 33) were used to support ecological classification but considering that some of them are only monitoring methods, we can consider that the response to this question has different meanings. Indeed, the methods can directly assess the HYMO status in two or five classes (21 methods including one no longer used in Norway) or indirectly by HYMO data collection analyzed in addition to biological and physico-chemical elements (Figure 1).

Only half of the 20 methods used currently to support HYMO classification in the WFD context are also used to assess hydromorphology in another context than the WFD purpose. This proportion is higher when we consider the whole dataset of methods. Therefore, these methods appear to be rarely used to achieve a prognosis of the problem in other contexts. However, this proportion is higher when we consider the whole dataset of methods.

Seventeen and 14 methods out of the 33 methods are used respectively to design restoration measure or to evaluate the impact of these restoration measure in the implementation of the WFD.

The possible use of the method as a proxy of biological elements was noted only from Latvia and Sweden methods. Indeed, considering some additional information, some positive responses were corresponding to methods that include metrics selected for their impact on biology; it does not mean that the method was used to indirectly assess or replace biological quality as explained in the guide.

The other uses correspond to long term monitoring (Cyprus, both methods), typology (Czechia), habitat assessment for nature protection purposes (Germany HMS) and on-going revision of the terms of the hydropower regulations (Norway 1).

3.2 Focus on the WFD process

All the methods are used at least for one of the listed options of the questionnaire.

Pressures/impacts analyses then status classification and risk analyses are the most often cited uses as we can see in figure 2. When status classification is assessed, it is most often for the 5 classes than only for the high status.

HYMO methods were less used for exemptions and typology, these steps being done probably before the development and implementation of the HYMO methods.

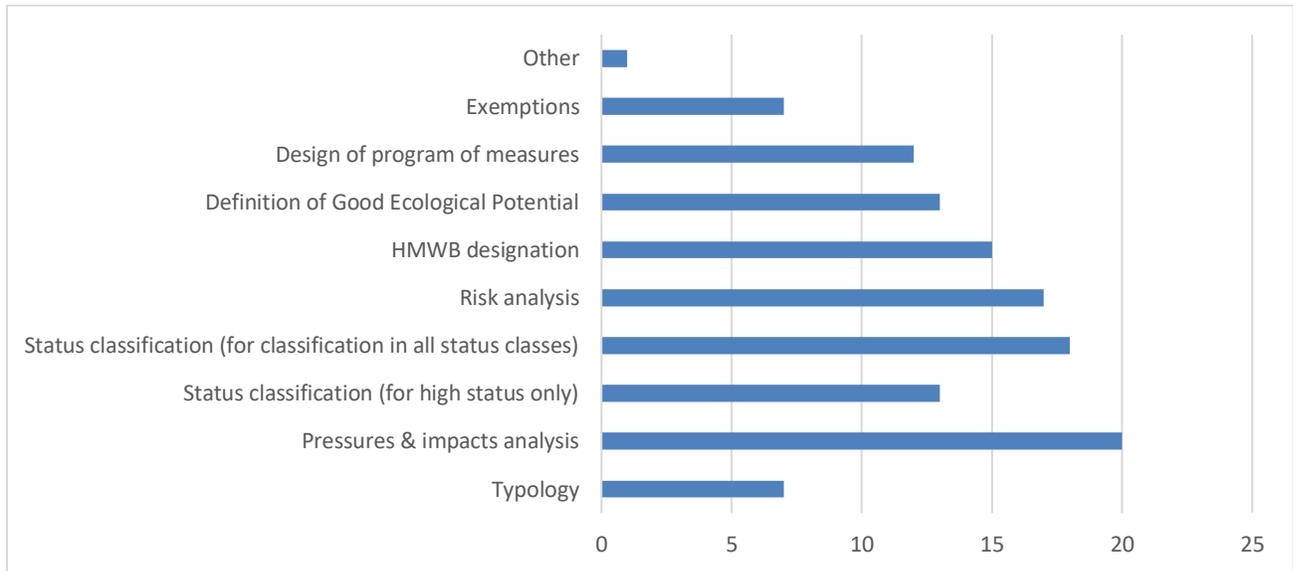


Figure 2. Use of methods in the WFD process.

In addition, seven of the methods are used for Habitat Directive and four for Flood Directive.

In figure 3, the use of HYMO methods is increasing between the 1st and the second River Basin Management Plans (RBMPs) from 6 to 22 methods. In the 3rd RBMPs, four new methods were implemented and a total of 20 methods was noted. However, a lot of 3rd RBMPs have still to be developed when the questionnaire was launched and the responses are maybe not complete.

We have also to note that the two Austrian methods and one of the French methods were recently developed but not yet practically applied and that five methods (Croatia, France, Norway 1 and 3, Spain) were under development at the time the survey was conducted.

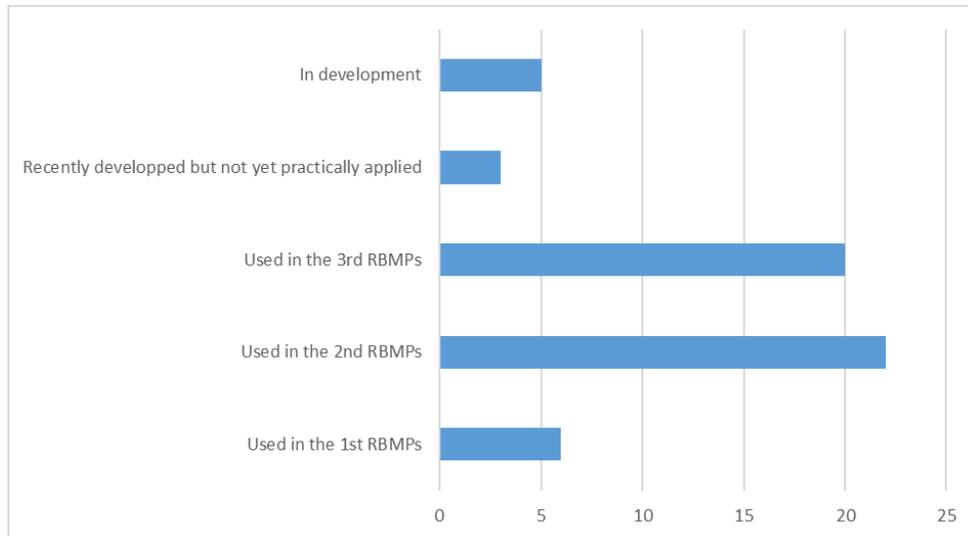


Figure 3. Evolution of the use of the methods.

3.3 Level and extent of application

Most of the methods (29/33) are applied at the national level, three only at regional level - HMS in Germany and Portuguese method applied only in the Azores(Figure 4).

Twenty five methods are applied to all the types of lakes whereas one method is dedicated to the assessments of lakes that are significantly affected by hydromorphological pressures (Norway 2), one Cyprus method is dedicated to natural lakes and the other one to reservoirs; another one (Austria HYMO screen +) focus on some lakes but no detail was given.

The percentage of lakes where the methods have been applied varied between 5% (Austria and Germany LAWA) and 100% (Croatia, Finland). The information on types where the methods are applied is often not available.

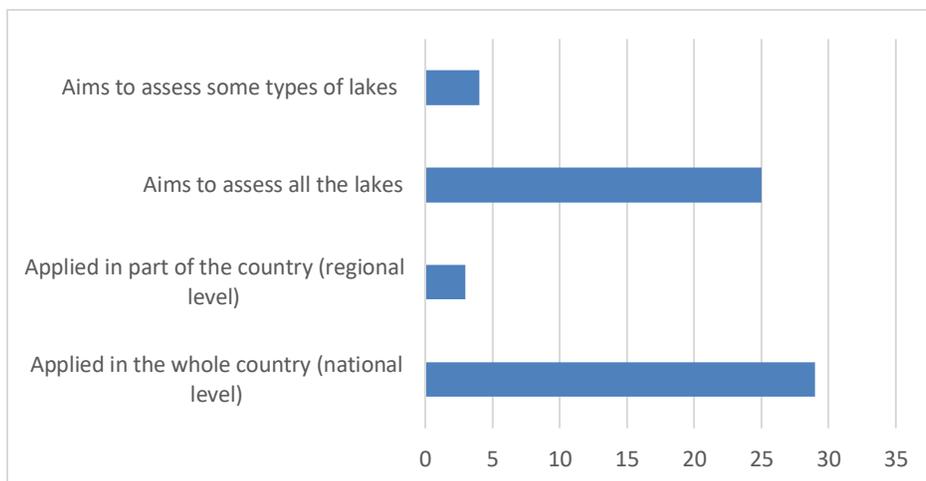


Figure 4. Level and extent of application.

3.4 Inclusion in legislation

In general, the methods are included in national guideline (20 methods) and/or national legislation (9 methods). The two German methods are also included in regional guidelines but this number to be might be underestimated (Italy).

3.5 Available supporting material

The methods are generally described in guidebooks (20 out of 33) and field forms are also often provided to improve the quality and homogeneity of the collected data (Figure 5). In general, these collected data are included in free access databases from where information are extracted for the assessment.

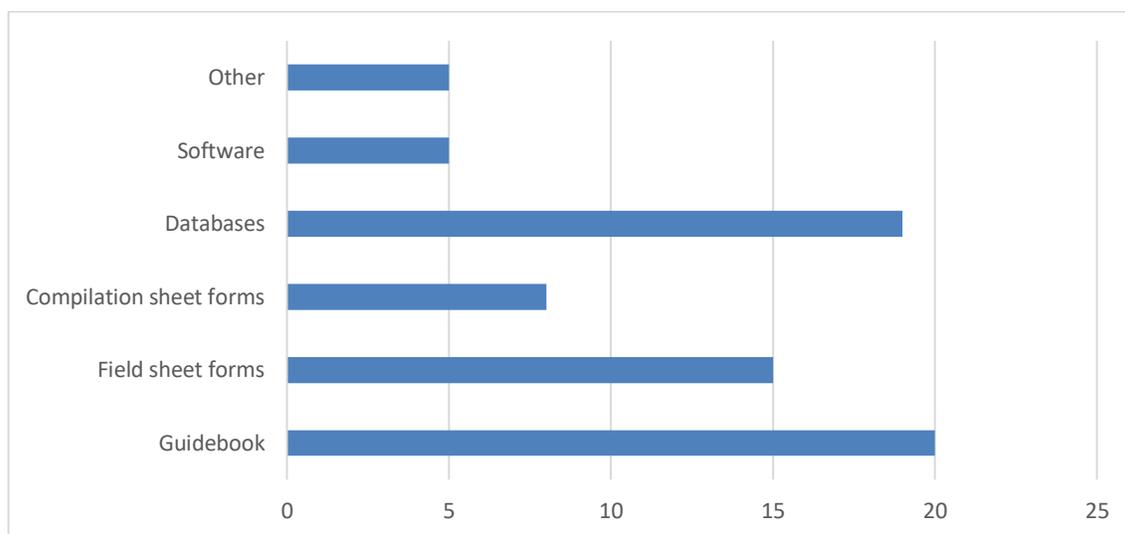


Figure 5. Available supporting material linked to the methods.

Among the supporting material not listed we have “national standard” for two of the French methods and video tutorial for one of the French method, general literature in Finland, and historical information in Latvia (database).

In general, the methods have to be applied by a person with a Master degree or similar level of expertise by training. The implementation of the methods require knowledge in geomorphology, hydrology, nature/biology/ecology/limnology; Skills in GIS and aerial photography interpretation are also often necessary as well as in hydrological modelling.

Application of the method generally not required accreditation except in Poland.

3.6 Resource intensity

We got no response from Portugal, and Germany mentions two possible levels of desk task intensity: high or medium. No general tendency was observed in terms of resource intensity (Figure 6). The resources required are very different from one method to another but field work rarely mobilizes a lot of resources. We are however aware that these assessments can involve a great deal of subjectivity. We have also to note a rather high proportion of methods that do not require any field work.

It is important to emphasize that the number of lakes varies extensively between the countries. Some have just a few ones and could allow more detailed and manual work, while countries like Norway, Sweden and Finland have very many lakes (for instance, in Norway there are around 6500 lake water bodies).

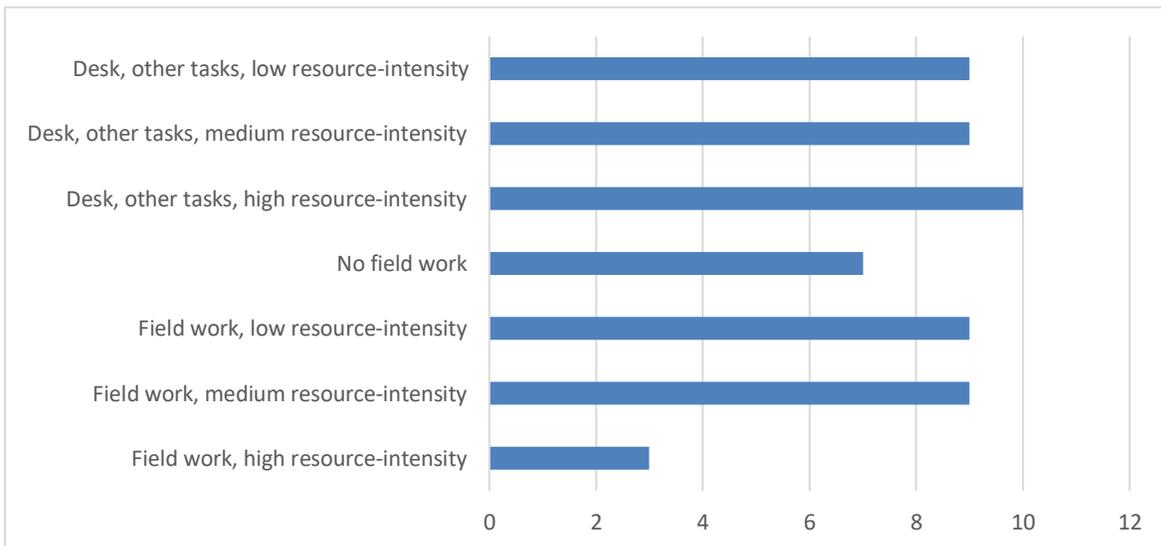


Figure 6. Resources required.

4 General description of the methods

4.1 Components covered

The main component covered is alteration of hydrology (27 methods). Generally, both alterations of hydrology and morphology are considered by the methods (24 out of 33).

We observe that alterations of hydrology and morphology are taken into account in the 17 countries having an assessment method.

There are only five methods covering the four components (hydrology, morphology and their alterations).

Directly or indirectly, assessment of ecological continuity for fish is included in 17 methods; 16 methods include biological considerations different from fish. For most of them (10 methods), it concerns aquatic or riparian vegetation. No precision is given for six methods.

Table 4. Components covered by the methods – cells in grey represent monitoring methods and methods no more used in the future.

Country	Name of the method	Components covered					
		Hydrology	Morphology	Alteration of hydrology	Alteration of morphology	Fish continuity	Other biological elements
Austria	HYMO-screen			X	X	X	X vegetation
	HYMO-screen+			X	X	X	X vegetation
Croatia				X	X	X	X riparian vegetation
Cyprus	Natural lakes	X	X				
	Reservoirs	X	X				
Czechia		X	X				
Estonia				X	X	X	X algae and plants in the littoral zone
Finland				X	X	X	X macrophytes and macroinvertebrates
France	Alber			X	X	X	
	Bathymetry		X				
	BAVELA			X	X		
	Charli	X	X			X	X aquatic vegetation
	CORILA	X		X	X		X riparian vegetation
	LHYMO			X	X	X	X riparian and aquatic vegetation
	SEDILAC		X				
Germany	LAWA - overview		X	X			X
	HMS			X	X	X	X
	LAWA BIOTA	X		X	X	X	
Greece		X	X	X	X		
Hungary		X	X	X	X	X	
Ireland	Lake MIMAS			X	X	X	X
Latvia	LHS	X		X	X		
Italy	LHS			X	X	X	X
Lithuania	HMIe			X	X		
Norway	Hydromorphological classification system	X	X	X	X	X	
	Pressures analysis and simple hymo classification			X	X		
	National hydrological monitoring program	X		X			
Poland	LHS_PL	X	X	X	X	X	X
Portugal				X*		X*	
Romania				X	X		
Spain	Current	X	X	X	X		X riparian vegetation
Spain	Under development	X	X	X	X		X riparian vegetation
Sweden				X	X	X	X
TOTAL	Out of 33 methods	14	13	27	24	17	16
	Out of 20 methods	7	6	20	19	14	13

4.2 Sources of information

Generally, the methods use different sources of information. Most of them required field survey and/or different existing data. Aerial photography maps resulting of topographic surveys and parameters resulting of GIS surveys are also often exploited. The specific use of new technologies (satellites, LiDAR, drone) seems still rare (Figure 7).



Figure 7. Sources of information

4.3 Temporal extent of the method use

Considering temporal scale, most of the methods are applied once per management plan (Table 5). Field surveys can be done during the vegetative period when vegetation is considered (ES, FR-Charli, GR). Some methods refer also to the mean water level of the lake (AU screen and screen +, FR-Alber, Charli, Sedilac and Bathy) whereas others refer to summer and low water level (IT, LV, LT).

Table 5. Temporal scale of application of the method.

	When the method is applied?	Once per river basin management plan
Austria HYMO Screen	Mean water level	X
Austria HYMOScreen+	Mean water level	X
Croatia	Use since 2018/2019	?
Cyprus Natural lakes	Once per month during period when there is water in the lake	X
Cyprus Reservoirs	Four times per year (March, June, September, December)	X
Czechia		X
Estonia	During vegetation period	X
Finland		X
France 1 Alber	As close as possible to the mean water level of the lake	X
France 2 Bathy	Close to or above the mean water level of the lake, gentle wind to avoid wrong measurements caused by waves	X (but rarely done)
France 3 - Bavela	Following the update of the datasets used in the method	X
France 4 Charli	Period of plants development, as close as possible to the mean water level	X
France 5 Corila	Following the update of datasets used in the method	X
France 6 Lhymo	The method includes existing data collected by others methods with their own requirements	X
France 7 SEDILAC	Close to or above the mean water level of the lake, gentle wind to avoid wrong measurements caused by waves	
Germany LAWA overview	NA	NA
Germany 2 HMS	In the Federal State of Brandenburg: first basic survey (about 100 lakes); repetition currently not planned	
Germany 3	No fixed starting/ending time within the course of the year.	X
Greece	Depends on the features: Hydrological features are monitored yearly at a monthly time step. With regard to morphological features, lake bathymetry is done once, aquatic vegetation and shore zone substrate in natural lakes is monitored during vegetative period every 3 years	
Hungary	Desk study is done continuously while field survey depends on hydromorphological type	X
Ireland	Desk study carried out when new earth observation data are available and field verification when biological element monitoring is scheduled.	X
Italy	During summer, when is present lake thermal stratification	X
Latvia	During low flow period (summer-autumn), if possible	?
Lithuania	In the july-october	X
Norway1 HYMO Class	For the HYMO classification of lakes, the conditions are considered constant over time (years/decades), i.e. the hydromorphological alterations have been made and is a constant deviation from reference conditions (over the planning period). Parameters that describe e.g. hydro-peaking operations and the effect in lakes/reservoirs shall be given as "typical fluctuations" within the time span assessed. As the HYMO classification would be revised every planning cycle (6 years), possible changes in hydromorphological state would be tracked when a new HYMO classification is made.	X
Norway2 Pressure analyses	Applied for characterisation of lakes in 2013-2014 for the first RBMP and then for updating the characterisation in 2018/2019	X
Norway3 NVE	Flow is typically measured hourly/daily and sometimes even finer time resolution than 1 hour	?
Poland		X
Romania		X
Spain future		X
Sweden	Also when ever appropriate	X

4.4 Spatial extent of the methods

Among the 33 methods, 10 are considering the whole water body and its catchment and 12 are considering the whole water body without its catchment.

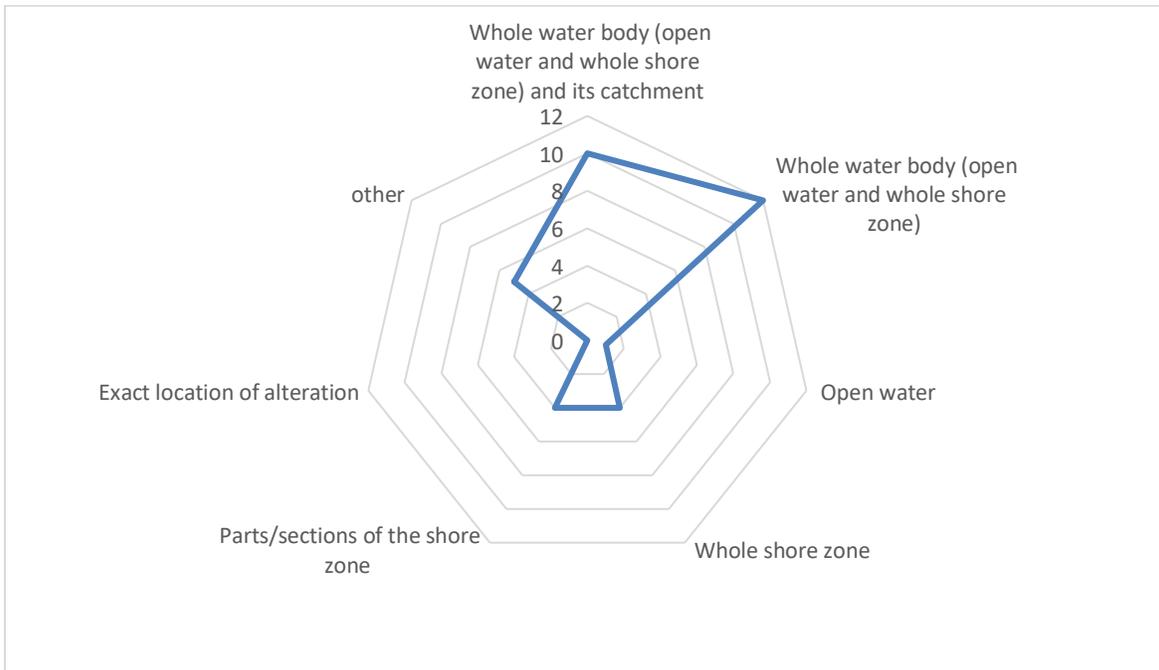


Figure 8. Spatial extent of the methods

Many methods are also dedicated to the description of some parameters in parts of the lake (section of the littoral zone, deeper point etc.) as we can observe in figure 8. These descriptions can be done in addition of the whole lake survey or not.

The case “Other” refers to different types of information including precisions on the spatial scale or process of section selection:

- littoral zone from visibility depth to landward end of azonal vegetation (AU, screen);
- in selected sections (reaches): littoral zone from depth limit of the macrophyte vegetation to landward end of azonal vegetation (AU, screen+);
- all catchment basin (FR, Bavela);
- multiple buffer zones of different size surrounding the lake (FR, Bavela).

When sections are chosen, several criteria can be used including « homogeneity » (5 cases) and accessibility (4 cases), randomly (2), representability (1), special interest (1) (Figure 9).

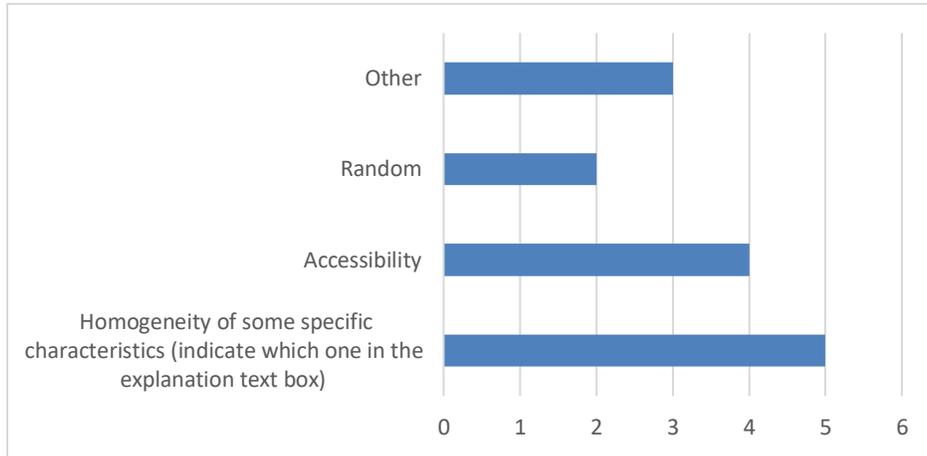


Figure 9. Criteria for selection of sections

If we consider only the spatial scale of the 20 assessment methods, half of them cover the whole water body and its catchment but catchment information is often lacking. Four of the 20 methods focus on the shore zone.

4.5 Extent of the sections

The sections generally include the bank, the riparian zone, the littoral zone and to a lesser extent floodplain (Figure 10). Floodplain is also often considered. When sections are part of these zones, it seems that the length of the part described can be variable or fixed. No clear tendency can be observed.

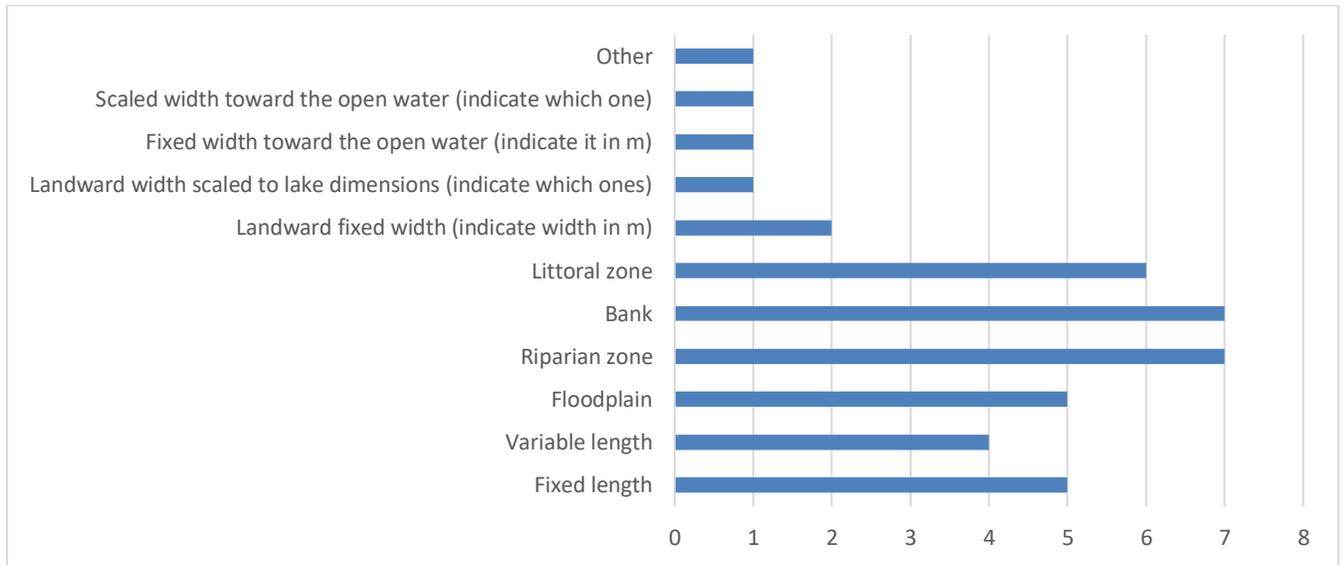


Figure 10. Extent of the sections

4.6 Approach used by the methods to define the reference conditions

For 16 out of 33 methods, the reference is not measured or required (Figure 11). When considering the 20 assessment methods, the reference is noted as not required only for the methods implemented in Greece, Italy and Poland (in that last two cases, it refers to LHS method).

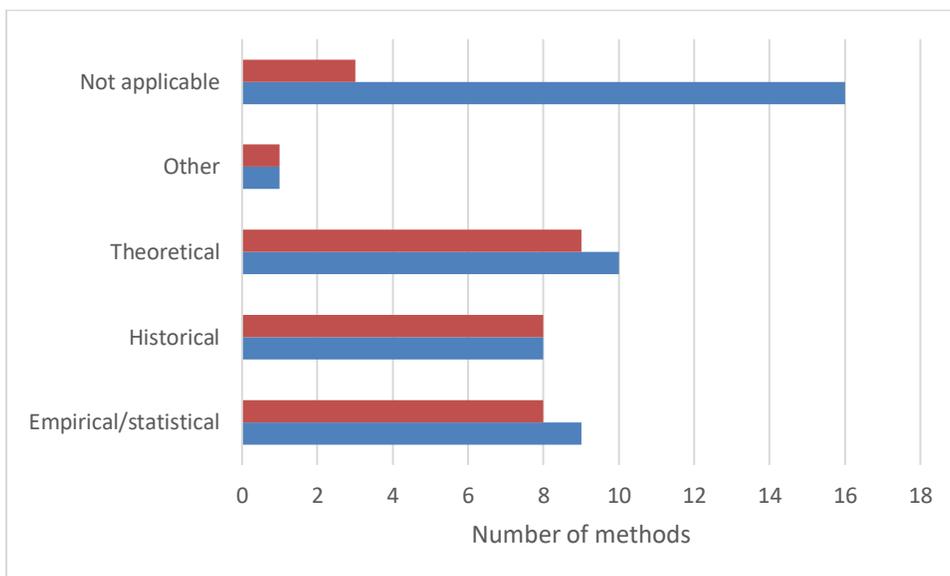


Figure 11. Approach employed to define the reference conditions in the 33 HYMO methods (blue) and 20 assessment methods (red)

When it is defined, the conditions are those prior to human impacts i.e. no land use, bank fixation, no physical modification, etc. A combination of two or three criteria (empirical/statistical and historical or empirical/historical and theoretical information) is often given.

Table 6. The different types of approach employed to define the reference conditions.

Country	Empirical/statistical	Historical	Theoretical
Austria 1	in natural situation no land use, bank fixation or human induced alteration of zonation of the riparian vegetation	comparison with data of natural situations	As soon as possible but definitely before lake-specific human induced alterations.
Austria 2	comparison with data of natural situations	as early as possible but definitely before lake-specific human induced alterations	In natural situation no land use, bank fixation or human induced alteration of zonation of the riparian vegetation.
Croatia	X	X	
Finland	water level fluctuation includes reference condition		
France Bavela	low non natural use		
France LHYMO			Reference conditions are assessed for each lake and each parameter (= best reachable state when considering no alteration).
Germany LAWA			Very complex in detail.
Germany HMS			Yes (pre-industrial situation).
Hungary			On natural lakes no human usage, planform and cross-section: before regulation (large lakes, oxbows and salinic lakes), for vegetation: type specific. For AWBs and reservoirs together with GEP/GES identification.
Ireland		x	
Latvia			"Theoretical assumption&Expert judgement (for example, the maximum score corresponds to undisturbed or nearly undisturbed conditions of each indicator or <10% scores difference corresponds to a lake in natural conditions (high class)). Reference conditions are directly taken from Great Britain, but there is to less data to compare them to specific Latvian conditions."
Lituania	X		
Norway 1	In order to find the hydrological conditions prior to regulations, a hydrological model must be used. A range of different models could be used for this purpose, including the well-known HBV, used extensively in Scandinavia, or the SMHI model HYPE, developed on the concept of HBV. Other alternatives could be ENKI	Historical information can be used directly for some parameters. The reference conditions are for some parameters simply defined as prior to any human interventions (e.g. no physical modifications (embankments) along the shoreline).	A hydrological model applied to assess the reference (hydrological) conditions can be considered a theoretical approach.
Romania		The reference period has been established based on year of commissioning of hydrotechnical works but also taken into account the reanaturalization of the lakes; For reservoirs, the reference period correspond to the designed parameters related to natural operation regime at the first filling the lake at NRL. Therefore, the values of the hydrological and morphological parameters corresponding to the normal operation regime represent reference values to which the degree of alteration of the hydromorphological characteristics for the accumulation lakes will be analyzed	No significant pressure are in place affecting the natural water balance and the water level, the erosion natural processes and sediment formation, biological cycles of aquatic organisms as well as riparian vegetation.
Spain future	X		X
Sweden	X	X	

4.7 HYMO types and parameters used in the typology

Most of the methods do not use any typology (23 out of 33 responses to this question). When a typology is done, origin, geology and altitude are the three parameters most often considered (Figure 12).

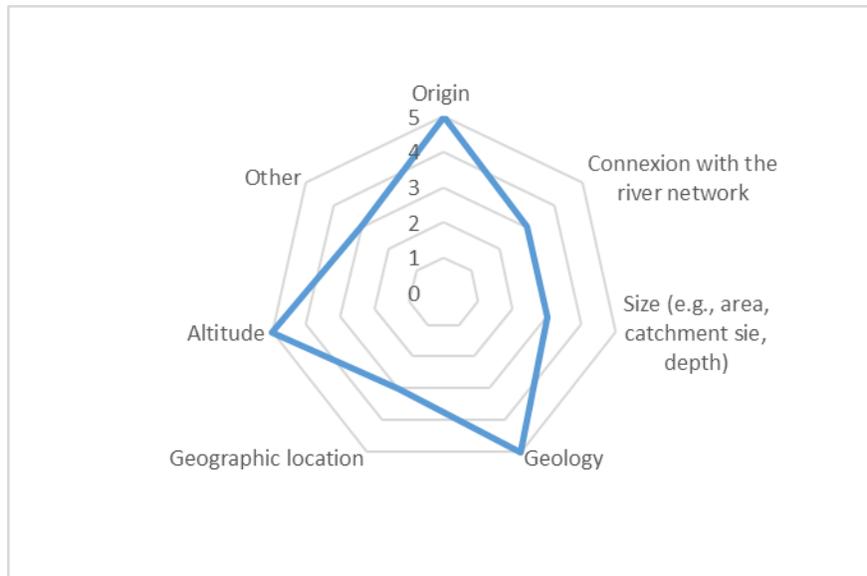


Figure 12. Criteria used for the definition of HYMO types

4.8 Extent of application

Surprisingly, we have the same number of methods applied to natural lakes and applied to reservoirs and in a same way. In addition, a lot of them are also applicable to artificial water bodies (Figure 13).

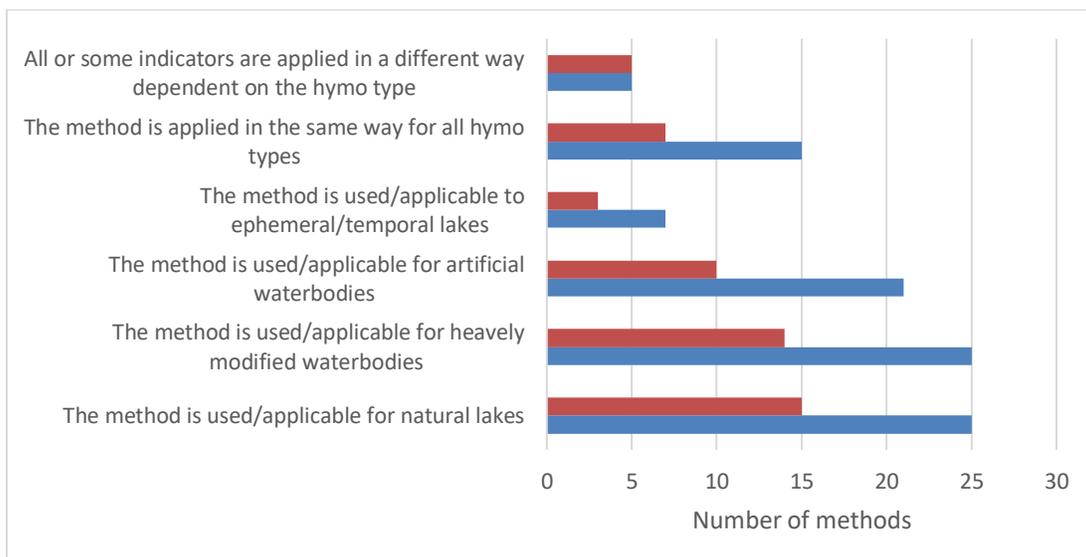


Figure 13. Extent of application of the 33 HYMO methods (blue) and 20 assessment methods (red)

4.9 Severity of hydromorphological pressures

Hydromorphological stressors are quantified in a third of all the methods described and in half of the assessment methods (Figure 14). In addition, even if there is no quantification of the stress, another large part of the methods attempts to evaluate the severity of the stressors. If we consider only the 20 assessment methods, only one (LHS Italy) was not considering given information on the severity of HYMO pressures.

In addition, half of the methods include parameters known to influence biology. This number is probably higher but responses are maybe given in reference to pressure/impact analyses not necessary yet done.

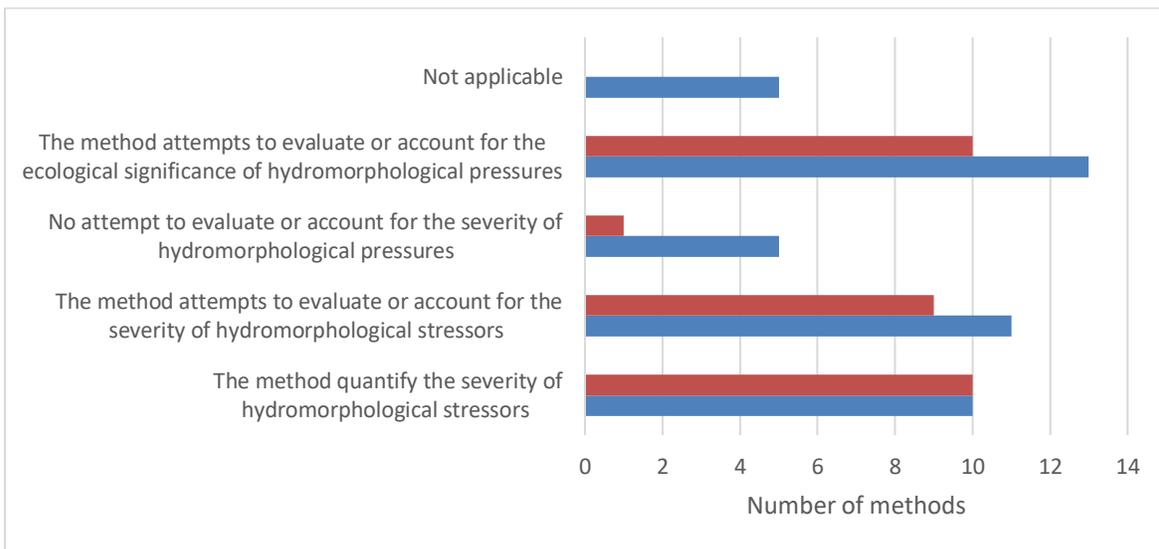


Figure 14. Severity of hydromorphological pressures measured by the 33 methods (blue) and by the 20 assessment methods (red)

5 Hydrology

This section mainly includes features that are normally accounted by methods specifically used for hydrology and assessing its characteristics such as (i) the quantity and dynamics of flows, (ii) residence time and (iii) connection to the groundwater body.

“Quantity and dynamics of flows” is a HYMO parameter considered through four variables: inflows and outflows, stratification/mixing and water level regime. The parameters “residence time” and “connection to the groundwater” are each described by a single variable.

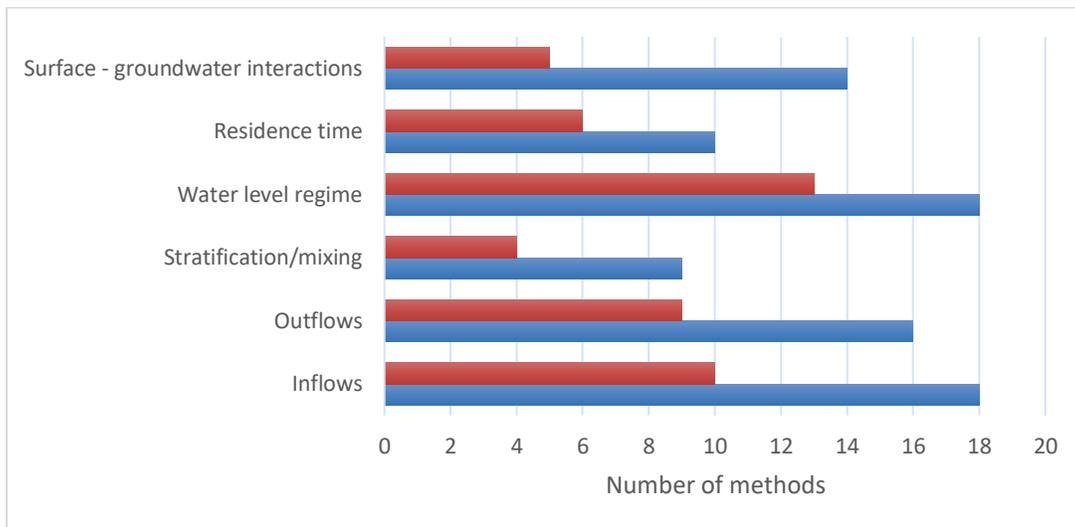


Figure 15. Hydrological features included in the 33 HYMO methods (blue) and 20 assessment methods (red)

The parameter quantity and dynamics of flows is taken into account by more countries and methodologies than the residence time and the connection to the groundwater (Figure 15). In general most of the methods include the characterization of the inflows as well as the water level regime (18 methods out of 33 methods for both features) (except Austria, Croatia, Czechia, Finland, Lithuania, Poland, Portugal, Romania for the inflows and Czechia, Estonia, Lithuania, Poland, Portugal, Romania for water level regime) while stratification and mixing and residence time are poorly informed (Figure 15, blue bands). When we focus on the 20 methods dedicated to the assessment of lake condition, water level regime is the most widely used feature (Figure 15, red bands) followed by inflows and outflows.

Stratification/mixing feature and residence time are the least employed features for evaluating the degree of hydrology alteration (Figure 15, red bands). The low consideration of stratification can be a consequence of the types of water bodies covered by the methods (e.g. no stratification in shallow lakes) and/or of the availability of data for estimating reference conditions. In addition, it is probably not obvious whether the stratification is modified or not. Considering its importance for biology, the low consideration of residence time is more surprising since it can be easily approximate knowing inflow and outflow.

Although the surface-groundwater interactions are fairly well included in the methods to characterize the hydrology, it is relatively poorly used to assess lake condition. The surface-groundwater interactions are difficult to assess directly (note that this is also a problem to measure the residence time). However some methods indirectly address this connection between surface and groundwater by measuring morphological characteristics of the lakes (e.g. waterproofing of the banks or the lake basin).

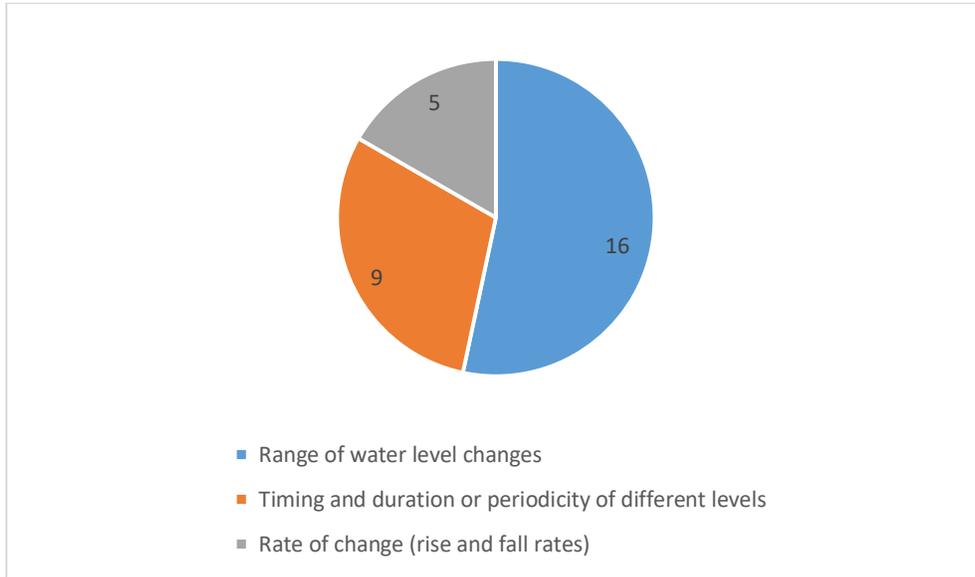


Figure 16. Criteria included in water level regime assessment

As mentioned above water level regime is the most widely used feature for assessing lake condition. This former feature is evaluated mainly according to the magnitude/range of water level changes (16 methods, knowing that Austria and Norway have both of their respectively two and three methods assessing this attribute), then according to timing and duration or periodicity of different water levels considered (nine methods) and finally by how fast are water level changes (five methods knowing that Norway has two methods) (Figure 16).

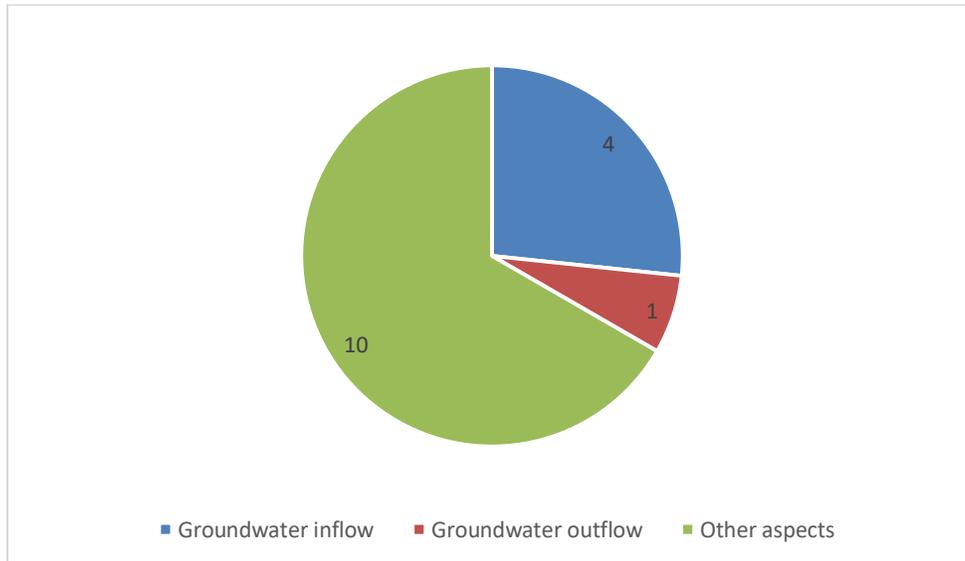


Figure 17. Surface/groundwater interactions integration

Four methods are including groundwater inflow to take into account surface-groundwater interactions (one method, Spain). Greece and Sweden are taking into account groundwater inflow thanks to modelling,

Spain establishes quantitative status of groundwater and Hungary did not specify (Figure 17). Greece is the only country that assess groundwater outflow by modelling. Some other aspects of the interaction between surface waters and groundwaters are considered, e.g. groundwater and lake water connectivity is supported by two methods (Estonia and one of the French methods), quantity of abstraction/discharge of groundwater within the catchment area and its effects on the mean (low) water flow of the waterbody is taken into consideration by one method (Germany), impact of groundwater inflow on lake water quality and temperature in one method (Sweden) and these other aspects of the interaction between surface water and groundwater are not explained for four methods (two Austria, Croatia, Hungary). Norway is not including surface-groundwater interactions in the assessment of hydrology as groundwater inflow are considered very low (dominated by surface flow) in most parts of Norway with limited soil depths.

In conclusion, with regard to the hydrology the various characteristics are relatively well taken into account by the different countries (in particular the water level regime) except for the residence time although its evaluation is recommended in the water quality guidance standard on assessing the hydromorphological features of lakes – EN 16039:2011. Surface-groundwater interactions and stratification/mixing are also poorly taken into account in the different countries even though the interactions between the surface water and groundwater are characterized in a majority of countries but not used to assess lake condition.

6 Morphology

This section concerns the morphological characteristics that are considered by the methods. Morphological elements are describing three spatial areas of the lake: the whole water body, the central part of the lake corresponding to the “open water” area and the littoral part of the lakes.

The morphological characteristics are evaluated under five main components:

- the aquatic vegetation (i.e. aquatic macrophytes) of the shore zone and of the open water both in terms of their potential effect on morphology;
- the characterization of the substrate (i.e. type of the substrate and texture or size) in the shore zone and the open water;
- the morphometry of the littoral area (i.e. banks and beaches);
- the bathymetry of the lake and
- the planform pattern of the lake.

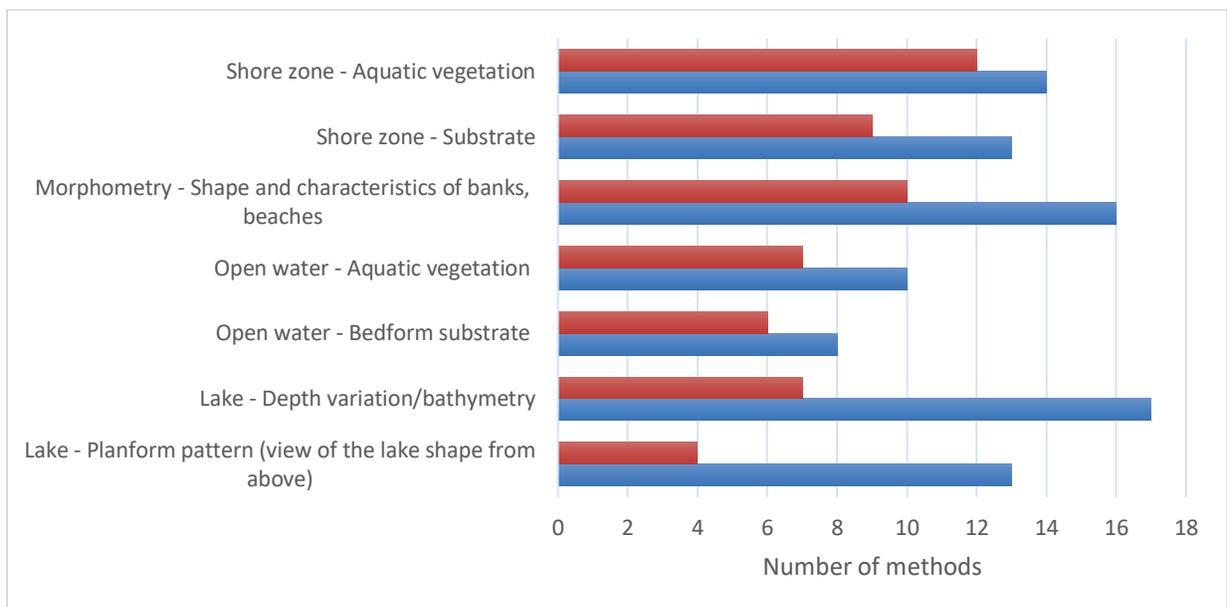


Figure 18. Morphological features included in the 33 HYMO methods (blue) and in the 20 assessment methods (red)

We first note that most methods of characterizing morphology take into account the properties of the shore zone. The characteristics of open water are much less taken into account.

If we consider the 33 methods, the bathymetry of the lake and the shape of the littoral zone are the most often measured parameters (respectively 17 and 16 methods) following by the shore zone aquatic vegetation parameter considered by 14 methods (Figure 18). When the analysis is limited to the 20 assessment methods, the most used variables are those characterizing the shore zone (aquatic vegetation, substrate and characteristics of the banks and beaches).

To the question of taking aquatic vegetation into account, among all present attributes (vegetation type or/and density or/and extent) by default we currently consider that as soon as the attribute “extent (depth, area, coverage...)” is filled, it informs us if the aquatic vegetation is characterized or not into the method.

The lake depth variation and planform pattern are often measured but generally not recorded periodically (respectively 4/17 and 4/13) and rarely or not necessary included in the lake condition assessment (respectively 7/17 and 4/13). Conversely, the parameters related to shore zone are often measured and generally used to define lake condition (Figure 18). Lake depth variation and planform pattern is less employed for assessing lake condition. This can be explained by the difficulty to measure the rate of filling and knowing if the filling is either natural or altered. Indeed, the changes in shore zone/planforms can then be extensive. This factor, plus the operational regime of the lake (if used for hydropower), possible transform of water and a few other factors, will affect the timing of filling and emptying of the lake, and how extensive the water level variations are. It can, however, sometimes be difficult to assess the alterations on shore zone/planform and filling/emptying, as it can be difficult to find data about the situation prior to the hydropower regulation, as this might have happened more than 100 years back for some lakes.

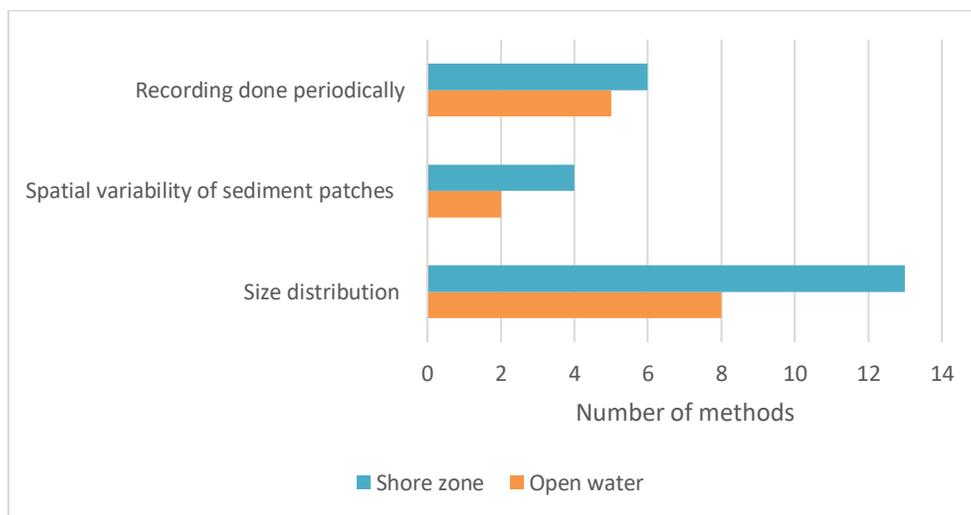


Figure 19. Substrate of the shore zone and the open water.

In figure 19, substrate of the open water is the less monitored and the assessment is made periodically in slightly more than half of the methods (5/8). This can result of difficulties in assessing this feature in deep lakes. Substrate occurring in the shore zone is often characterized but temporal variation is generally not considered (6/13). Indeed, this is a very slow process, so it would not be expected to see very much of a temporal variation, for e.g. changes more over decades. Description of spatial variability of the sediment patches are scarce.

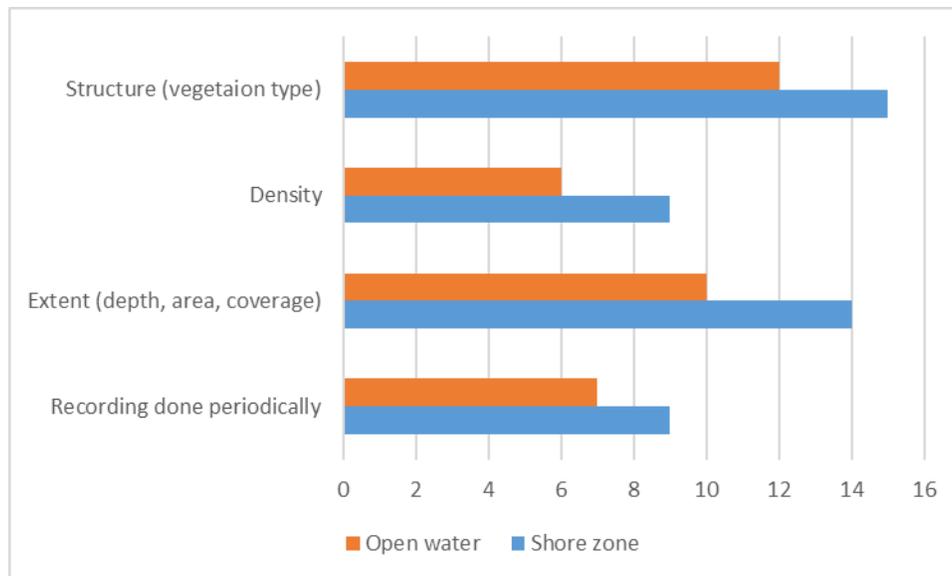


Figure 20. Number of methods including the features of aquatic vegetation of the shore zone and the open water.

Aquatic vegetation is one of the most often included parameter in the HYMO methods, in particular in the littoral area even if aquatic vegetation is sometimes monitored in the open water (Figure 20). The features used are structure and extent of the vegetation; density is less considered in particular in open water probably due to technical limitations. The recording is also often done periodically compare to the monitoring of the other features (shape, substrate, etc.).

In summary, with regard to the morphology the various characteristics are relatively well taken into account by the different countries, in particular the lake depth variation, the shape of the littoral zone and the shore zone aquatic vegetation. Nevertheless, the planform pattern, the substrate in the open water, and the open water aquatic vegetation are still poorly used to evaluate lake conditions although their evaluation is recommended in the water quality guidance standard on assessing the hydromorphological features of lakes – EN 16039:2011. The lack of use of these three latter features might be first explained by the difficulty to measure the rate of filling and knowing if the filling is either natural or either altered for the planform pattern. Technical constraints (lack of methodology, not enough precision in the measurements, lack of reference, etc.) can limit the use of substrate and aquatic vegetation in the open water for assessing lake conditions.

7 Alteration of HYMO features and consideration of processes

This specific section concerns the consideration of physical processes and focus on whether or not the processes responsible for the correct functioning of the lake are prevented or altered by some type of artificial element or by human disturbances. It is important to consider that the same type of pressure may result in different responses for different lakes (depending on their shape, size, morphology, and therefore their sensitivity to pressures etc.), so consideration of processes and temporal changes can provide information on the response to a given pressure. In other terms, together with hydrological and morphological features, processes can provide a full understanding of the response of the lake to hydromorphological pressures.

This part is built in 3 blocks corresponding respectively to off-site stressors, alteration of the hydromorphology and/or processes occurring in lake resulting most of the time of lake uses and management interventions which represents the last block.

No response has been given by Cyprus and Czechia on this part since they only have monitoring methods. Indeed, generally speaking, if this part is not completed, it is a monitoring method. Nevertheless, monitoring methods can fill in this part when there is a measure of the degree of alteration, as for the Alber, BAVELA and CORILA French monitoring methods.

Table 7. Number of methods considering the off-sites stressors, alteration of the hydromorphology and/or processes occurring in the lake and management interventions.

	Number of methods considering the parameters
Off-site stressors	23
Alteration of the hydromorphology and/or processes occurring in the lake	26
Management interventions	24

Alteration of the hydromorphology and/or processes occurring in the lake is the most often considered (26/33 and the 20 current assessment methods) (Table 8). However, the methods include generally also at least one type of management interventions (24/33 and the 20 current assessment methods) and off-site pressures (23/33 methods and 19 out of the 20 current assessment methods). No off-site pressures are included in the current assessment method developed in Finland.

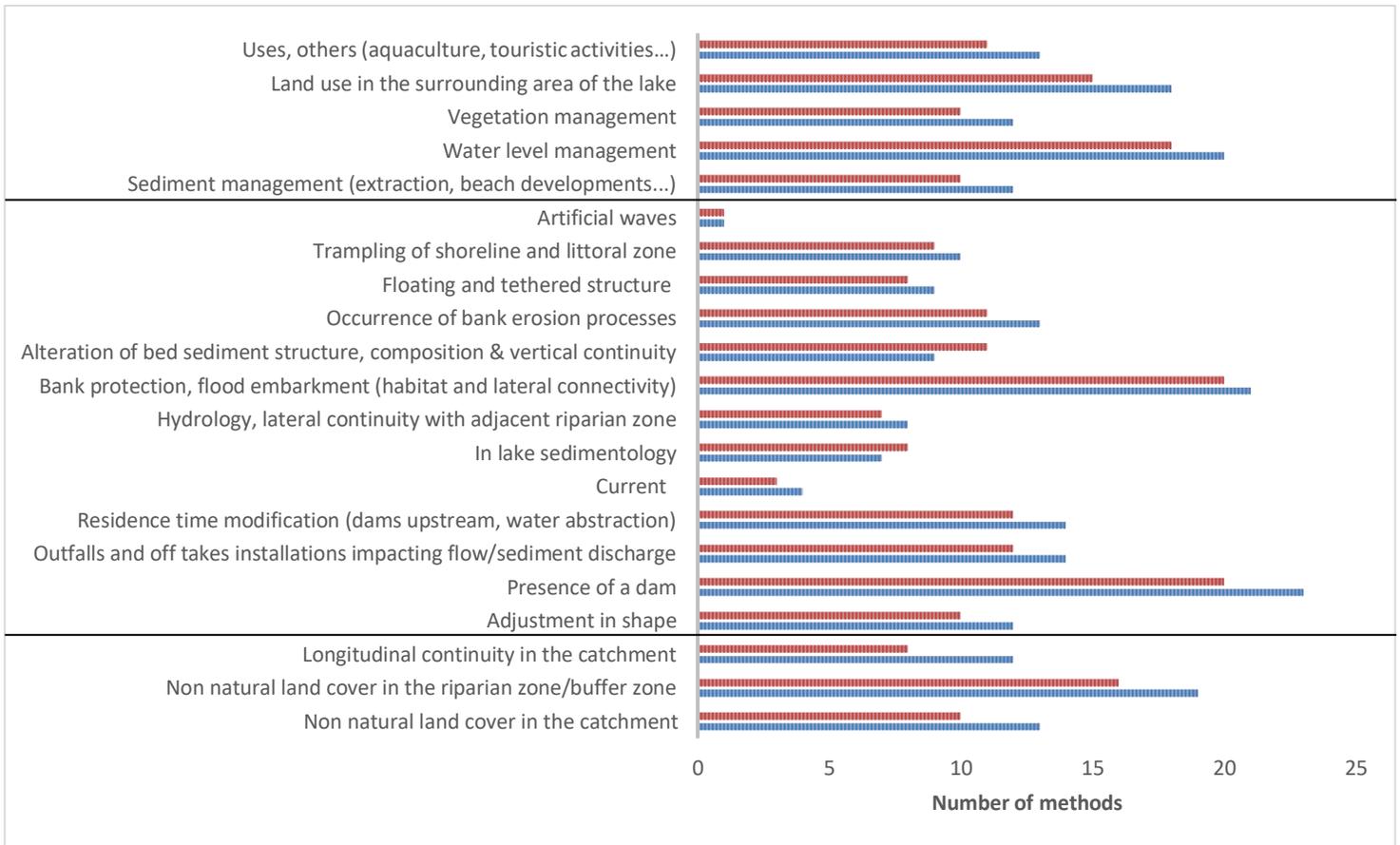


Figure 21. Hydromorphological features and processes included in the 33 HYMO methods (blue) and in the 20 assessment methods (red)

In Figure 21, the first three parameters depict the off-site pressures. The parameter related to non-natural land cover in the riparian/buffer zone is measured in all methods including off-site pressures (19/19) as well as widely used in the assessment of lake conditions (16 out of 20 current assessment methods). Nonetheless, longitudinal continuity is less measured and even less used to assess lake condition (8 out of 20 current assessment methods). This poor consideration of longitudinal continuity is maybe due to the fact that this is a criteria mainly considered to alter river conditions rather than lake condition even if some alteration of the continuity can impact hydrology or that this parameter is informed through others hydrological parameters (e.g. inflow alteration).

The second part of the Figure 21 (from the adjustment in shape parameter to artificial wave's parameter) is related to the alteration of hydromorphology and/or processes occurring in the lake. The bank protection, flood embankment parameter, which underlines habitat and lateral connectivity alterations, is widely measured and used to assess lake conditions (18 out of 20 current assessment methods) as well as the presence or not of a dam which is largely employed for assessing lake condition (18 out of 20 current assessment methods). The impact of artificial waves (1 out of 20 current assessment methods) on banks and the current of the lake (4 out of 20 current assessment methods) are very rarely measured. The unique method that takes into account the impact of artificial waves is the Austria HYMO Screen + method.

Finally, the third part of the Figure 21 represents the management interventions that can occur on the sediment, the water level or vegetation. Vegetation management (selective cutting, total removal of living vegetation in the channel and riparian zones including cutting and/or dredging aquatic vegetation) is the

least measured management intervention parameter (12/33 or 11 out of 20 current assessment methods) maybe because it is not relevant in a large number of lakes. Land use in the surrounding area of the lake, related to purification processes, and water level management are widely measured and used for assessing lake conditions (respectively 18/33 or 15 out of 20 current assessment methods and 20/33 or 18 out of 20 current assessment methods).

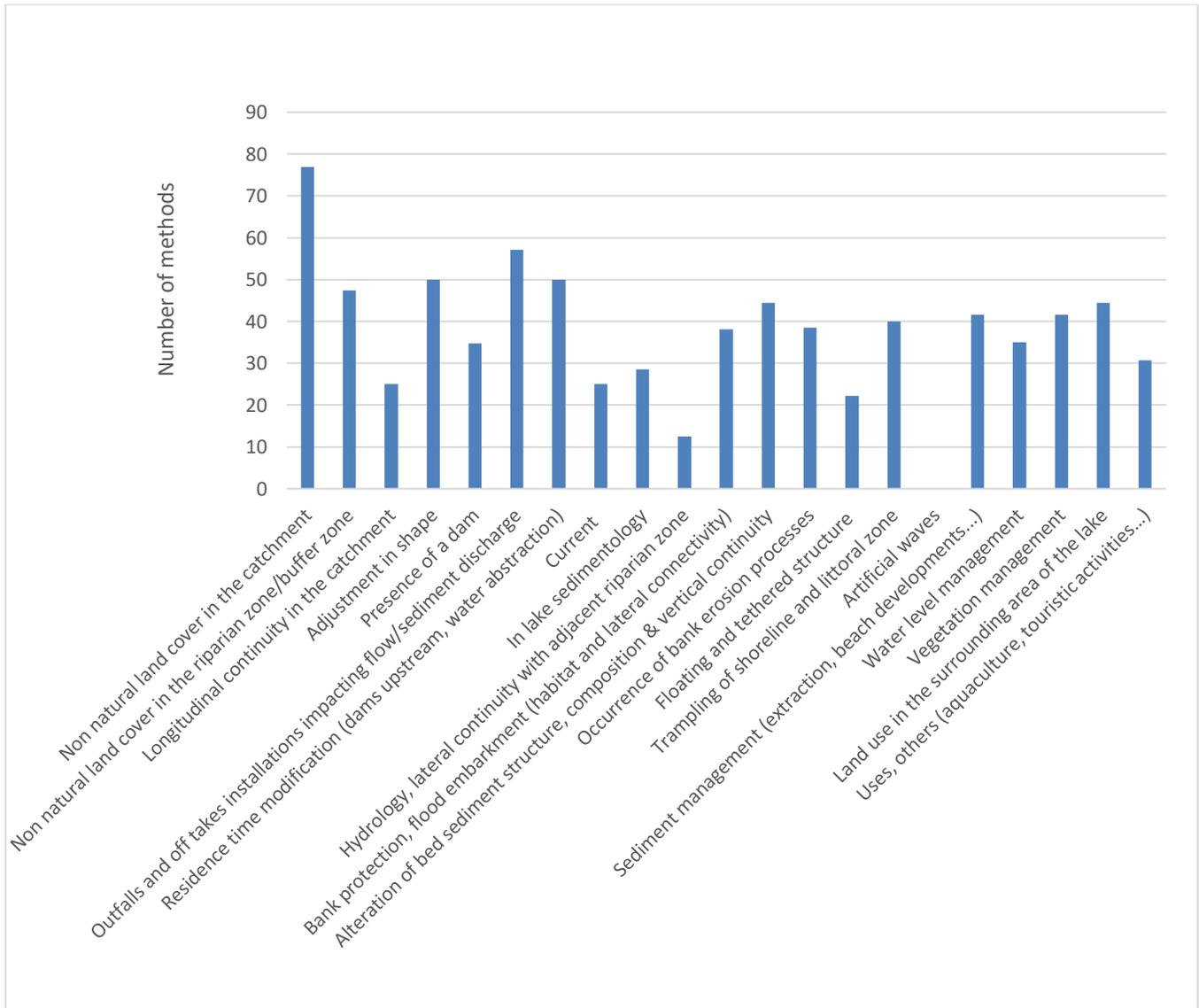


Figure 22. Periodic assessment of the parameters (%).

The periodic assessment of the parameters represents the ratio between the number of methods including a periodic measurement and the number of methods including a measurement. Most of the parameters depicted in Figure 21 have at least one out of five methods that make periodic measurements (i.e. at least 20%) (Figure 22) except from the artificial wave's parameter which is measured only for one method and the lateral continuity of flow parameter which is rarely measured periodically.

The non-natural land cover off-site pressure in the catchment and the outfalls and off takes installations impacting flow and/or sediment discharge in the lake are periodically measured for a large proportion of methods (respectively 77% and 57% of the methods).

Finally we focus on the alteration of bed structure parameter which evaluates the presence of alteration processes of the natural bed structure, potentially affecting vertical continuity. The nature and composition of the bed sediment structure is very important and its alteration can impact many aquatic species, since it can notably constitute a cache and zone of shelter but also impacts the connection to groundwater. Indeed, the main processes of alteration of bed structure are: (i) armouring, i.e. presence of a surface layer in which bed material size is significantly coarser than the sub-layer; (ii) clogging, i.e. excess of fine sediments causing interstitial filling of the coarse sediment matrix and potentially smothering the lake bed; (iii) burial or siltation, i.e. where finer sediments (e.g. silt and sand) are deposited in a sufficiently thick layer to bury a coarser (e.g. gravel) lake bed; (iv) presence of blocks or anchorage sites.

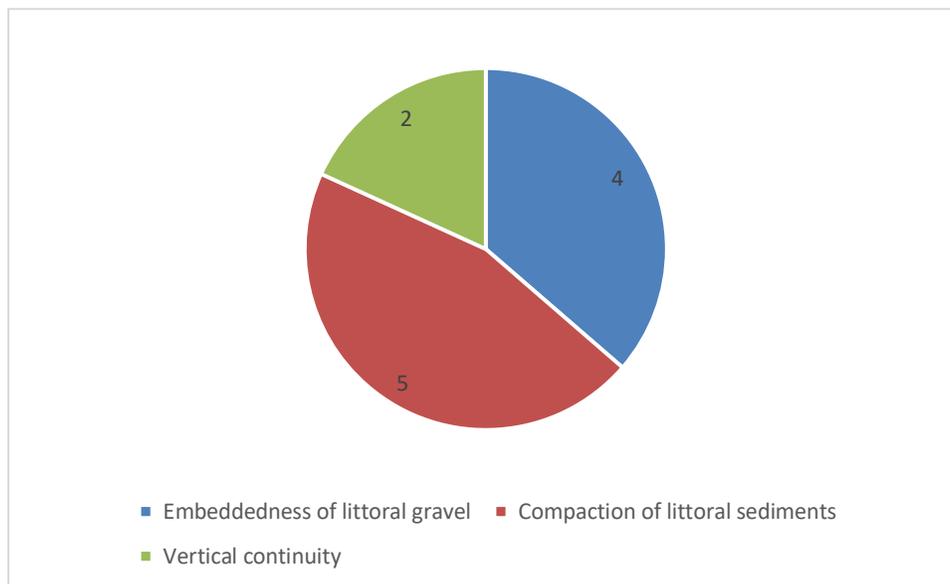


Figure 23. Processes covered by the alteration of bed sediment structure parameter.

More than half of the current assessment methods (11 out of 20) are using the alteration of bed sediment structure and composition to assess lake condition. In Figure 23 we observe that most of them (5/11) are assessing the compaction of littoral sediments. Then, the embeddedness of littoral gravel is the most informed process (4/11) followed by the information on vertical continuity (2/11).

In conclusion, the different alterations of the hydromorphology and/or processes occurring in the lake are rather well taken into account in the different methods as well as the off-site pressures. Nonetheless, longitudinal continuity off-site pressure is still used by less than half of the current assessment methods to assess lake condition.

8 Output of the methods

This section is reserved to some basic information about the scoring system providing the final result of the method.

8.1 Type of output

The application of the assessment method can produce a series of outputs, such as scoring, establishment of a typology, maps summarising results, report, etc.

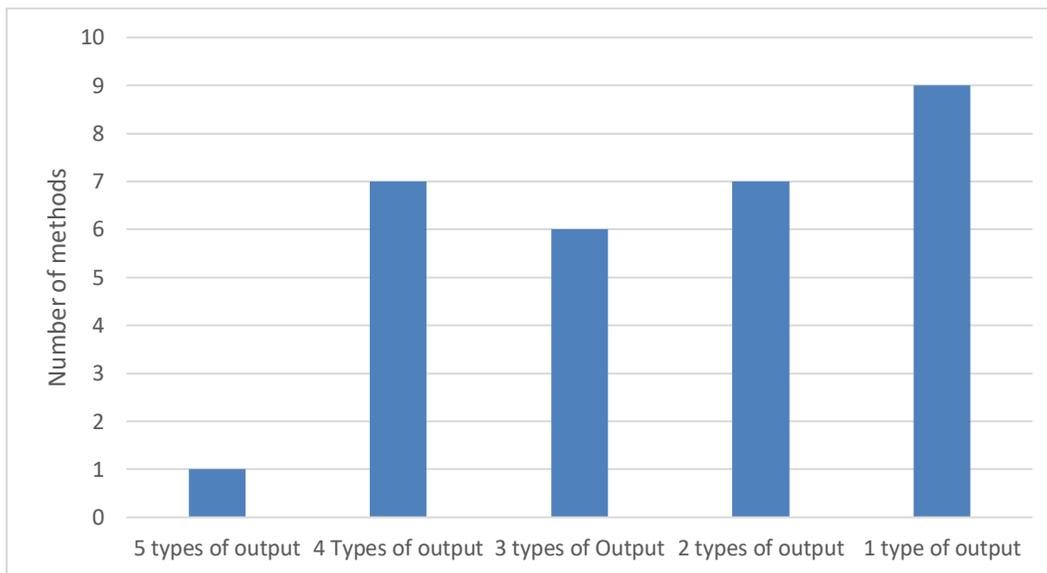


Figure 24. Number of output provided by the method

In Figure 24, nine methods (9/33) provide only one output; eight of them provide a scoring and a single one delivers a map. Eighteen methods (18/33) combine several types of output. The first method used by Germany gives five outputs (Germany 1).

No output was provided for the method developed in Portugal out of 33 methods.

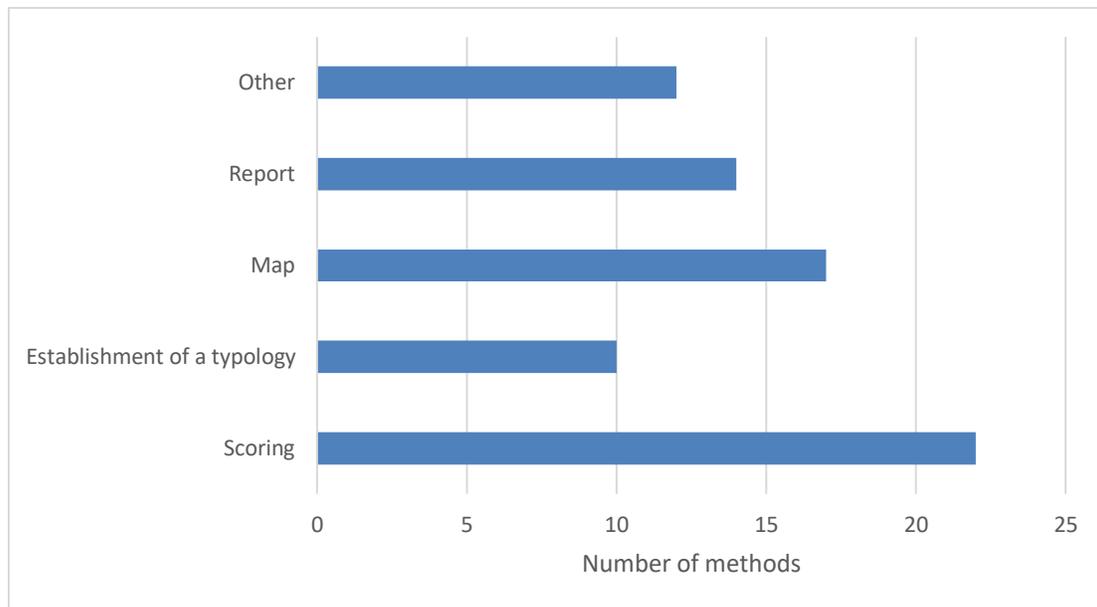


Figure 25. Type of output of the assessment

In figure 25, the majority of assessment methods provide outputs in the form of scoring (22 methods), followed by maps (17 methods) and outputs in the form of reports (14 methods). The outputs produced in the form of typologies are the least widespread (10 methods).

Some other type of output are supported by 12 methods, e.g. one method of assessment provides georeferenced photo database (Croatia), one method offers a webpage of RBMP (Finland), eight methods provide metrics included in a database (2, Cyprus and 6, France) and a database and a GIS project is delivered by two methods (2, Germany).

Databases are also probably available for other methods.

8.2 Scoring information and degree of confidence

The scoring information concerns the type of data processing that the method uses to deliver the final result. Also in application of the method, some uncertainties are possible. The degree of confidence reflects the presence or absence of attempts to consider these uncertainties.

Scoring is available for 22 methods (out of 33). It is a quantitative assessment for 17 methods and a qualitative assessment in Czechia, Estonia, Latvia, Norway (Norway-2), and Poland. It should be pointed out that all the current 20 assessment methods are using a scoring system.

Scores and algorithms are transparent for almost all the methods except from Cyprus (both methods) as Cyprus' methods don't provide scores and algorithms (just a collection of data), an English version of the indicator calculation algorithm is under review for a publication for Poland and no response was given from Portugal. The two Norwegian methods can deliver some assessment criteria that not easy to determine thanks to information from public databases, in other words public data are not easily available.

Degree of confidence is lacking for 23 methods whereas some indications about the degree of confidence are given for eight methods. Note that in Germany, HMS method allows the calculation but it is not used.

To sum up, most assessment methods result in a scoring (including all the current 20 assessment methods), and a little less commonly in a map. Most scoring methods are quantitative, however the degree of

confidence is still poorly included in the methods. Most methods provide transparent scores and algorithms. In addition, further information will be needed about the procedure of the scoring system of the different countries to examine if the scoring system employed fits with the scoring system for assessing the degree of modification of lake hydromorphology described in EN 16870:2017 - the water quality guidance on determining the degree of modification of lake hydromorphology.

9 Feedback on the use of the methods

9.1 Lessons learned

In a very schematic way, the responses received fall into three categories. The idea most often put forward is that of a satisfaction linked to the use of the method e.g. “help identifying the gap to good status”, “valuable information”, “useful”, “practical and efficient” etc.

A second group of responses are in relation with the development or the necessary evolution of the methods. This can refer to a better response to the expectations of the WFD (Portugal, Spain), to a more applicable method in order to generalize its application on a large number of lakes (Norway), to a new definition of the classification system (Poland, Norway) and/or to the necessity to link HYMO and biology (Germany, Poland, Romania).

Finally, even if the method is considered as the result of a long tradition in lake monitoring in Finland, difficulties related to the lack of data are often highlighted (Croatia, Italy, Latvia, France). On the other hand, it is also recognized that the WFD has been a great way to stimulate the collection of new information.

Table 8. Lessons learn in application of the methods. Cells in grey refer to monitoring methods; cells in blue in methods that will be replaced by new methods.

Name of the method	Country	Lessons learn
Proposal of methodology for hydromorphological status assessment in standing water bodies	Croatia	<i>Beginning of the HYMO assessment of lakes in Croatia. Building of lakes database. Lack of specific data is a large limiting factor in evaluation process. Some projects (e.g. bathymetry of lakes) are undergoing and will help better HYMO assessment in the future. Need for human capacity building including more natural scientists, e.g. fluvial geomorphologists, hydrologists, remote sensing and GIS experts.</i>
Estonian hydromorphological assessment method for lakes	Estonia	<i>Help identify the gap to good status and results from application of this method are used as valuable information in the third River Basin Management Plan and Programs of Measures.</i>
Finnish regulated lakes assessment method	Finland	<i>Finland has a long tradition of management of regulated lakes, because almost 60% of lake area is somehow regulated. It was relatively easy to apply in WFD contexts.</i>
Lake HYdroMORphological conditions / LHYMO	France	<i>The method was currently not applied. Some metrics included in the final index are still under development. Then the scoring will have to be define as well as the thresholds between at least the High and Good status.</i>
Hydromorphological classification of whole lake shores (LAWA: overview - method)	Germany	<i>In essence, the procedure involves the derivation of a typology of semi-natural lake shores (reference status) for the purpose of a type-specific assessment of the hydromorphological status of the shores using the WFD quality component zoobenthos (Macroinvertebrates; AESHNA procedure of LAWA with habitat-specific sampling). The overview procedure is mainly based on already available geoinformation, which is naturally richest in the terrestrial area, while the underwater structures that are actually relevant for the macroinvertebrates can only be recorded very inadequately in this way.</i>
HMS - Hydromorphology of Lakes)	Germany	<i>The HML protocol has proven to be practical and efficient. It is used to prepare programs of measures and specific measures at the respective lakes and shore sections. The basic principles of the procedure are intuitively understandable and can therefore also be communicated in dialogue with stakeholders. The procedure was developed with several stages of detail and effort</i>

		<i>(overview procedure, detailed procedure, point procedure), each of which is downward compatible.</i>
Classification of the hydrological regime for catchment areas and water bodies - Classification of hydrological regime [CHR-Germany; non official acronym] by LAWA	Germany	<i>There is a significant deficit in reliable, homogeneous (digital) data, especially concerning water rights (abstraction/discharge of water). As a result of the application of the method it is strongly recommended, that corresponding databases are maintained and constantly updated by the respective authorities/agencies in charge. A further recommendation is the implementation of a legal basis in order to oblige the collection of data on pressures relevant for the WFD and other directives.</i>
Guidance on Hydromorphological Assessment in surface water bodies	Greece	<i>It is a useful and necessary component of lakes ecosystem structure and functioning</i>
Lake MImAS	Ireland	<i>Earth observation data are extremely useful and can be used to identify a wide range of lake modifications.</i>
Lake Habitat Survey - LHS	Italy	<i>Thanks to the LHS has been possible to collect numerous information on natural habitat, artificial features, vegetation on riparian and littoral zone, land use and water body uses. It teaches to look at single features or alteration and to relate them with the whole lake and its hydromorphological quality.</i>
Lake Habitat Survey (LHS)	Latvia	<i>The Water Framework Directive (WFD) has acted as an important driver for the development of a Lake Habitat Survey (LHS) method that allows us to systematically characterize and assess the physical habitat of lakes and reservoirs (collectively known as standing waters)</i>
Hydromorphological classification system, Norway, Revised 2019/2020	Norway	<i>The method was revised based on testing of a first version developed in 2018. The 2019/2020 version assessed in this Excel sheet is closer to an operational classification tool, but given the fact that it should be applied to around 6500 lake water bodies in Norway, where manual work on each lake should be avoided, the system probably still needs to be tested and adjusted accordingly. The concept of the system (dividing the system to be classified into zones, i.e. upstream, lake internal and downstream) and other methodological choices have been well</i>

		<i>received and are most likely to stay firm even though parameters and parameter values (class boundaries) are adjusted.</i>
Lake Habitat Suvey PL (LHS_PL)	Poland	<i>The method works well until recently. The need to refine classification system, which is not really related to the BQEs conditions.</i>
Cyprus natural lakes HYMO monitoring	Cyprus	<i>Even simple methods need thorough planning, continuously available resources (budget, human) and an organized way of storing data.</i>
Cyprus water reservoirs HYMO monitoring	Cyprus	<i>Even simple methods need thorough planning, continuously available resources (budget, human) and an organized way of storing data.</i>
Altération des BERges (Lake shore alteration) / ALBER	France	<i>The method was applied on most of the lakes included in the WFD monitoring programs. It is generally applied at the same time that the CHARLI method.</i>
Bathymétrie (Bathymetry)	France	<i>Used for the typology.</i>
Catchment basin of lakes) / BAVELA	France	<i>This method was used to define the reference conditions of the lakes.</i>
Charaterizing habitats for lakes shores and littoral zone / CHARLI	France	<i>The method was applied on most of the lakes included in the WFD monitoring programs. It is generally applied at the same time that the ALBER method.</i>
Riparian buffer zone of lakes / CORILA	France	<i>This method was used to define the reference conditions of the lakes.</i>
Sediments of lakes / SEDILAC	France	<i>Data are collected but not necessary used to define the ecological status.</i>
Pressures analysis and simple HYMO classification	Norway	<i>We plan to implement a more sophisticated method to further improve the precision of our assessment of status and pressures in lakes with hydromorphological pressures.</i>

<p>Photointerpretation and streamflow and limnometric evaluation</p>	<p>Portugal</p>	<p><i>As mentioned in section “6. Assessment output”, at the 3rd cycle, PT RH9 foresees the development of a comprehensive hydromorphological assessment method, accordingly to the guidelines established in PT mainland, this method should be an adaptation of the Lake Habitat Survey.</i></p>
<p>Spain current – CEDEX-L-HMF-2010</p>	<p>Spain</p>	<p><i>Current method being applied in Spain is based on pressures that are assessed in a qualitative way. Approach useful at first to learn the type of pressures affecting Spanish lakes and to obtain information on the attributes that need to be considered in a more quantitative way.</i></p> <p><i>The new method being developed will consider all the lessons learned from the application of the initial method in order to improve the hydromorphological assessment and to obtain all the data considered necessary to assess hydromorphological status, develop measures and assess the effectiveness of those measures.</i></p>

9.2 Strengths of the methods

We analyze first the 18 methods dedicated to HYMO assessment for which we got information. The advantages of the methods most often put forward are their simplicity, robustness and effectiveness in measuring the hydromorphological characteristics of lakes (Austria, Estonia, France, Norway, Cyprus, Italy, Lithuania, and Germany). Related to this strength of the methods, the rapidity and low cost of implementation are also sometimes emphasized (Croatia, Italy, Lithuania, Poland).

It is also sometimes specified that the method used follows the recommendations of the WFD in terms of parameters considered (Austria, France, Germany, Romania, Norway). However, it is not possible to say if it is not the case when this information is not given.

Some other more specific strengths are also noted:

- **The definition of lake specific reference conditions (Austria, Croatia, France)**
- **The possibility to be updated (Germany, Ireland)**
- **Clarity and transparency of the evaluation process (Latvia, Germany)**
- **Assessment of suitable habitat for semi aquatic and terrestrial organisms (Germany)**
- **Known relationship with biota (Finland).**

The main advantage of the 9 monitoring methods is their simplicity of use and the quality of the data collected.

9.3 Weaknesses of the methods

A lot of weakness were reported in relation to the implementation or to the assessment. Regarding difficulties in the implementation, we noted:

- Rarity of morphological data (Finland, Romania);
- Lack of data (France, Germany);
- Time consuming (Austria);
- Data intensive (Greece);
- No automatic tool (France).

If we consider now the weakness and challenges in relation with the assessment, the following information are reported:

- An improvement of the link or a measure of the link with biology is required (Germany, Italy, Romania, Poland);
- Lack of information on the reference of some parameters or on how to define the boundaries and thresholds (Latvia, Norway, Romania);
- Evaluation is dependent on the quality of the data (Austria);
- The method does not consider groundwater (Italy, Romania);
- The assessment is limited to the most important HYMO pressures (Austria); reflect better large scale changes (Lithuania);
- The method provides many quality scores (Croatia);
- The classification system has to be developed (Estonia);
- The improvement of the new method proposed has to be checked (Germany);
- Provide relevant information for planning and monitoring the success of measures to achieve GES (Good Ecological Status) (Germany).

Table 9. Strength and weakness of the methods.

Name of the method	Country	Strengths of method	Weakness & challenges of the method
Screen	Austria	<i>Pressure-specific analysis of whole lake, separately for homogeneous sections; efficiency; (most often) lake-specific defined references; gives a good picture of the overall hydromorphological situation.</i>	<i>Digital assessment of studied area, land use and vegetation highly dependent on quality of data (e.g. aerial photographs), respectively on digitizing agent; focus on most important hydromorphological pressures in Austria.</i>
Screen +	Austria	<i>Pressure-specific analysis of selected sections; length of analyzed shoreline can be defined individually; (most often) lake-specific defined references.</i>	<i>Digital assessment of studied area, land use and vegetation highly dependent on quality of data (e.g. aerial photographs), respectively on digitizing agent; focus on most important hydromorphological pressures in Austria; if applied for a whole lake very time consuming.</i>
Hydromorphological status assessment in standing water bodies	Croatia	<i>Low cost and not very time consuming. Individual approach to each lake.</i>	<i>Many qualitative scores.</i>
Hydromorphological assessment method for lakes	Estonia	<i>Robust and suitable for all lake types.</i>	<i>Precise status classification system still has to be developed for the method.</i>
Finnish regulated lakes assessment method	Finland	<i>Very extensive hydrological data is available from Finnish lakes. Known relationships between biota is available.</i>	<i>In general, morphological data is scarce, because it is not playing a big role in natural lakes.</i>
LAKe HYdroMORphological conditions / LHYMO	France	<i>It is very complete to assess deviation between impacted and non-impacted situations; reference are defined for the different metrics. It is applicable whatever the type of lakes is.</i>	<i>Calculation of some metrics is not easy due to the lack of data or because they required a lot of data. No automatic tool available for these calculations.</i>

<p>Hydromorphological classification of whole lake shores (LAWA: overview - method)</p>	<p>Germany</p>		<p><i>The evaluation provides for a "calculation method" with a fixed algorithm and for most criteria alternatively a simple "expert evaluation". It must therefore be left open whether the LAWA review procedure is superior to older, already tested procedures in terms of the relevance of the data collected and the reliability of the evaluation. It is not to be expected that the procedure will provide the relevant information necessary for planning and monitoring the success of measures to achieve good ecological (littoral) status.</i></p>
<p>HMS - Hydromorphology of Lakes)</p>	<p>Germany</p>	<p><i>All relevant hydromorphological characteristics are recorded. For natural lakes, the assessment principle is whether and to what extent anthropogenic influences have led to a change in natural conditions (pre-industrial state, reference state). Therefore no typification of lakes is necessary. The procedure can be used to simulate future intervention or improvement measures. The procedure is not specifically directed at certain taxa of the WFD (macro-invertebrates, fish, macrophytes), but also includes habitat suitability for semi-aquatic and terrestrial organisms. Inevitably, the algorithm used to calculate the index automatically contains subjective expert assessments in addition to objective operations. However, the subjective parts are transparent and narrowly localized. The algorithm is therefore open to revision and can be learned.</i></p>	<p><i>In many aspects, the method does not allow direct conclusions to be drawn on the structure of aquatic biocoenoses. This requires separate investigations based on characterizing case studies. Some case studies have already been carried out (and are published). Further case studies are in progress.</i></p>

Classification of the hydrological regime for catchment areas and water bodies - Classification of hydrological regime [CHR-Germany; non official acronym] by LAWA	Germany	<i>Method considers several classification criteria based on WFD pressure types covering a wide range of pressures on the hydrological regime. All classification criteria (14 in total) belong to one out of five pressure groups. A missing classification of a single criterion within a pressure group (e.g. due to a lack of valid data) can be compensated by other criteria within the respective group. Method is applicable to lakes and running waters. Method is applicable independent from the size of the research area (workload does not grow proportionally with area size). Primarily data based and therefore objective method. Method is still applicable without a valid data basis for all classification criteria as the quantitative approach (GIS based) can be substituted or supplemented by the qualitative method (expert review). Expert review can be used to validate the results of the quantitative method in order to reach a higher level of resilience.</i>	<i>Reliable data on respective pressures are not always available. 'A lack of reliable data can be compensated by the qualitative approach of the method (expert review). However, a high proportion of classification results obtained by the qualitative approach may lead to higher workload and weaker objectivity.</i>
Guidance on Hydromorphological Assessment in surface water bodies	Greece	<i>Assessment of lake's hydromorphology in relation with climate, land uses and water use at catchment scale</i>	<i>Data intensive.</i>
HU RBMP3 method on hydromorphology	Hungary	<i>The method uses hydromorphological types of lakes, the parameters are evaluated with regard to their hydromorphological lake type.</i>	<i>First trial of the method is for the 3 RBMP.</i>
Lake MImAS	Ireland	<i>The modular structure of the calculations means that the tool can be modified and updated with new information or understanding.</i>	<i>Buried within the LHS data and approach, which is much more time consuming. Does not address all of the elements of lake hydromorphology listed in the Directive.</i>

Lake Habitat Survey - LHS	Italy	<i>It is simple to learn and to apply, it collects a lot of information and it elaborates them in a robust way. Its application not required a lot of time.</i>	<i>Not consider groundwater and it is not so simple to extrapolate single information on single habplot to possible elaboration with biological punctual information.</i>
HMle	Lithuania	<i>Fast and simple evaluation</i>	<i>Better reflects larger-scale changes.</i>
Lake Habitat Survey (LHS)	Latvia	<i>The LHS method uses scoring system for the Lake Habitat Modification Score (LHMS) that allows us to assess pressures and impacts on a lake water body. The scoring system seems clear and transparent. Another advantage that the method also includes Field Protocol that may be filled in during the survey (e.g. at Sampling Plots or Hab-Plots). Conversely, topographical and orthophoto maps, existing GIS data and databases in the office gives an opportunity to evaluate lake conditions in case of difficulties in measurements of some features during the survey (especially hydrological regime, catchment pressures).</i>	<i>The LHS doesn't supply any information on reference boundaries or thresholds for some features of hydrological regime, e.g. for a residence time the classification hasn't been developed to define if the lake is classified as a water body with good HYMO class (status) or poor status. The other problem is that the assessment of water level regime by DHRAM method is used for all lake types but the area, depth and flow (is it a lake with inflow/-s and outflow, or a lake with only outflow, or a lake without any flow) should be taken into account at first.</i>
Hydromorphological classification system, Norway, Revised 2019/2020	Norway	<i>The method follows closely the principles of the EU WFD (definition of parameters and 5 classes, alterations from reference conditions, grouping of hydrological, morphological and continuity parameters) and seems to capture all major hydromorphological alterations of ecological relevance. The system is designed to basically be applied based on existing data (limited new data collection should needed).</i>	<i>Some of the parameters (that are easy to calculate) describe the severity of the regulation and not alterations from natural state. It can be difficult to find data/calculate all parameters for the situation both before and after regulation. In particular, it can be difficult to find data on the hydrology after regulation, unless these are available as observed data (difficult to model the effect of regulation as this is often given as a result of optimization of revenue of the power production in a European electricity market).</i>

Lake Habitat Survey PL (LHS_PL)	Poland	<i>Fast survey time (about 4 hours per lake on average); the method is based on, hence compliant with, the well-known LHS method</i>	<i>Actual boundary values are derived on a small amount of data and in relation to the macrophyte community conditions only. Need for better link between hydromorphological assessment and biological assessment.</i>
Methodology for hydro-morphological assessment of lakes (natural and heavily modified water bodies-lakes and reservoirs)	Romania	<i>The Methodology considered the requirements of WFD, CEN Standard SR EN 16039 / 2011, current activity of lake monitoring national program for hydro morphology. The classification system includes 5 classes - according to WFD. The methodology is used for natural lakes, heavily modified natural lakes and reservoirs.</i>	<i>Difficulties in measurement the morphological conditions (shoreline/bank /lake bed structure represent a gap in morphological assessment). Fully correlation with relevant BQE. There is also need for development of an indicator which reflects and interprets the connectivity of the lake with groundwater especially of the alteration due to the changes from reference conditions The establishment of reference conditions represents a challenge the approach being different for natural lakes (including heavily modified natural lakes) comparing to reservoirs.</i>
Cyprus natural lakes HYMO monitoring	Cyprus	<i>The method's simplicity.</i>	
Cyprus water reservoirs HYMO monitoring	Cyprus	<i>The method's simplicity.</i>	
Lake shore alteration / ALBER	France	<i>It provides very precise information on the littoral HYMO elements able to influence biology with spatial information (GPS position of the alterations)</i>	<i>It can be long to apply on large lake. Some operator bias were noted in the description of some metrics.</i>
Bathymetry	France		<i>Littoral area is not well described due to technical limitation. Interpolation required.</i>

Catchment basin of lakes / BAVELA	France	<i>It is simple to apply, whatever the lake.</i>	<i>Difficult to define what is a level of low or absence of impacts on the lakes. In addition, spatial data are not frequently updated. Difficult to translate in "RISK assessment".</i>
Characterizing habitats for lakes shores and littoral zone / CHARLI	France	<i>It provides very precise information on the littoral habitats with spatial information (where are the different habitats, their length along the shoreline etc).</i>	<i>It can be long to apply on large lakes. Some operator bias were noted in the description of some metrics.</i>
Riparian buffer zone of lakes / CORILA	France	<i>It is simple to apply, whatever the lake.</i>	<i>Difficult to define what is a level of low or absence of impacts on the lake ecosystems. Difficult to translate in "RISK assessment".</i>
SEDiments LACustres (Sediments of lakes) / SEDILAC	France	<i>This method provide good maps of the different substrates occurring in a lake. Its interest is in the long term monitoring of this bottom characteristics.</i>	<i>Difficult to find a reference and therefore to measure a deviation from "natural conditions" in most of the lakes. Does not allow to measure the sedimentology process.</i>
National hydrological monitoring program	Norway	<i>Very good monitoring network managed by very competent persons. Data is easily accessible.</i>	
Pressures analysis and simple HYMO classification	Norway	<i>Some of the data needed to use the method is easily found in public databases. The method is simple, it can be performed as a desk study and may can easily be checked by stakeholders or others for some of the criteria.</i>	<i>The method does not provide the level of information needed to assess status and pressures with satisfactory degree of precision and confidence.</i>

10 Outcomes of the workshop

The virtual ECOSTAT Hydromorphological Assessment and Monitoring of Lakes workshop took place on May 20, 2021 with the aim of presenting what was understood about the HYMO methods implemented in Europe as part of the implementation of the WFD, after collecting information from the Member States national experts. The purpose of this workshop was also to present these methods and to discuss them with European national experts in order to share feedbacks, to extract some questions/lessons and the remaining hurdles, and to agree on the next steps to take (Agenda in Annex 2).

We reported here a summary of the lessons/questions and remaining hurdles discussed during this meeting.

Most of them were discussed during ‘Knowledge and experience sharing: feedbacks on indicators’ and ‘Find the gaps’ sessions.

10.1 ‘Knowledge and experience sharing: feedbacks on indicators’ session

During the ‘Knowledge and experience sharing: feedbacks on indicators’ session three main subjects were discussed: the hydrological features included in the methods, the morphological features included in the methods and the hydromorphological processes and their alterations included in the assessment methods.

Concerning hydrological features, the parameters required to define the hydromorphological quality of water bodies in application of the WFD are the following three parameters: (i) the quantity and dynamics of flows (4 features are generally considered and included in the standard: inflows, outflows, stratification/mixing and water level regime), (ii) residence time, and (iii) connection to groundwater.

The various hydrological characteristics are relatively well taken into account by the different methods in particular water level regime; however assessments of residence time and stratification/mixing are scarce. Surface-groundwater interactions are also fairly included in the methods even though poorly used to assess lake conditions (Figure 15).

Key questions were raised:

- **Why is there less information on stratification/mixing feature and residence time? Is it linked to the types of water bodies or to the availability of data or even to difficulties in estimating reference conditions?**

The low consideration of stratification can be a consequence of the types of water bodies covered by the methods (e.g. no stratification in shallow lakes) or/and of the availability of data for estimating reference conditions. Indeed, it is probably not obvious if whether the stratification is modified or not. Considering its importance for biology, the low consideration of residence time is more surprising since it can be easily approximated knowing inflow and outflow.

- **Should changes in water temperature be incorporated into the assessment methods and if so, how?**

In response to this question, temperature is not considered as a HYMO criteria but it is useful to monitor this criteria. Furthermore, the question of the water temperature monitoring has not been explicitly asked, although in a certain way it is impacted by the alteration of the stratification/mixing of the lakes which has been asked in the way hydrological characteristics are recorded.

- **Surface-groundwater interactions are generally assessed by modelling. Is there any common approach? Why are these interactions generally included in the methods but remain poorly used to assess lake condition?**

Although the surface-groundwater interactions is fairly well included in the methods to characterize the hydrology, it is relatively poorly used to assess lake condition. The surface-groundwater interactions are difficult to assess directly. However some methods indirectly address this connection between surface and groundwater by measuring morphological characteristics of the lakes (e.g. waterproofing of the banks or the lake basin).

- **Which criteria are most relevant to characterize water level regime (which metrics?): Range of water level change (the most often used), timing and duration or periodicity of different levels? Rate of change?**

This key question remains open as no comment and no clear answer were given to this question during the workshop.

Concerning morphological features, the choice was to focus on the attributes defined for different spatial entities and recommended in the standard EN 16039:2011 (water quality – guidance standard on assessing the hydromorphological features of lakes). The morphological features are considered under five main features: aquatic vegetation of the shore zone and the open water (i), morphometry of the littoral area (i.e. banks and beaches) (ii), characterization of the substrate in the shore zone and the open water (i.e. type of substrate, texture or size) (iii), bathymetry/depth variations of the lake (iv), planform pattern of the lake (v).

The various morphological characteristics are relatively well taken into account by the different countries in particular shore zone aquatic vegetation, shape of the littoral zone and lake depth variations. Most methods of characterising morphology first take into account the properties of the shore zone. The characteristics of open water are much less taken into account. Analysis of the questionnaires highlighted that the most measured variables were those characterising the shore zone (aquatic vegetation, substrate and characteristics of the banks and beaches) and that they were often used to define lake condition. Conversely, planform pattern, substrate in the open water and the open water aquatic vegetation were less employed to evaluate lake conditions (Figure 18).

From these observations, key questions were raised:

- **Why are open water characteristics of the lakes (planform pattern, substrate and aquatic vegetation) less employed to evaluate lake conditions? Are they not relevant (e.g. no vegetation)? Or are they generally not impacted? Is it due to technical constraints (method, cost...) or to the lack of reference?**

The lack of use of planform pattern, substrate in the open water and the open water aquatic vegetation for assessing lake conditions might be first explained by technical constraints for the last two features, including the lack of methodology and not enough precision in the measurements were reported. In addition, the lack of reference, to define the reference conditions, can also limit the use of metrics linked to substrate and aquatic vegetation in the open water for assessing lake conditions.

- **Why is lake depth variation, even though very widely registered, poorly used to assess lake conditions? Are they generally not impacted? Or is it difficult to find data about the situation prior the hydropower regulations for example?**

Concerning lake depth variations and planform pattern which are less employed for assessing lake condition, the difficulty to measure the rate of filling and knowing if the filling is either natural or either altered is mentioned. Indeed, the changes in shore zone/planform can then be extensive. These changes, plus the operational regime of the lake (if used for hydropower), thus possible transfer of water, will affect the timing of filling and emptying of the lake, and how extensive the water level variations are. It can, however, sometimes be difficult to assess the alterations on shore zone/planform and filling/emptying, as it can be difficult to find data about the situation prior to the hydropower regulation, as this might have happened more than 100 years back for some lakes in Norway for example.

In addition, substrate of the open water is the less monitored. This may be due to methodological difficulties assessing this feature in deep lakes. Substrate occurring in the shore zone is often characterised but temporal variation is generally not considered probably for the same reason (methodological constraints due to low precision of the measures compare to low variability). Indeed, this is a very slow process, so it would not be expected to see very much of a temporal variation, for e.g. decades.

- **Why are shore zone characteristics not always included in the assessment methods?**

This key question remains open as no comment and no clear answer were given to this question during the workshop.

Finally, the section on hydromorphological processes and their alterations included in the assessment methods is built in three blocks corresponding respectively to off-site stressors, alteration of the hydromorphology and/or processes occurring in lake resulting most of the time from lake uses and management interventions which represents the last block. Generally speaking, if this part was not completed, it was a monitoring method. Nevertheless, monitoring methods can fill in this part when there is a measure of the degree of alteration, as for the Alber, BAVELA and CORILA French monitoring methods.

The different alterations of the hydromorphology and/or processes occurring in the lake were rather well taken into account in the different methods as well as the off-site pressures. Nonetheless, longitudinal continuity off-site pressure was used by less than half of the current assessment methods to assess lake condition (Figure 21).

Key questions were raised:

- **Why is longitudinal continuity (off-site pressure) used by less than half of the current assessment methods? Is it not relevant in some cases (no connection with the river)? Are the other metrics taking into account this off-site pressure (e.g. inflow alteration)?**

In answer to this question, concerning the longitudinal continuity off-site pressure used by less than half of the current assessment methods, it is surprising considering that the presence or not of a dam is informed in all the assessment methods. This poor consideration of longitudinal continuity is maybe due to the fact that this is a criterion mainly considered to alter river conditions rather than lake conditions even if some alteration of the continuity can impact hydrology.

- **How are the different management activities taken into account in the assessment methods? In calculation of some metrics and the definition of the reference conditions? In addition to the HYMO metrics? (Q1)**
- **Why artificial waves are not often considered? Is it not relevant? (Q2)**
- **Why lateral continuity is poorly considered? Is it not relevant in many cases? Or is it due to a lack of method? (Q3)**
- **How is in lake sedimentology assessed? (Q4)**

- **Which metrics are used to define the adjustment in shape? (Q5)**
- **Is there a consistency between the types of hydromorphological alterations/processes occurring in the lake and used in the assessment methods and the type of management interventions occurring in the lakes? (Q6)**

All these questions remain open.

10.2 'Find the gaps' session

During the 'Find the gaps' session three main topics were discussed: the reference conditions/classification, the link between HYMO and biology and other various subjects that were already reported as key questions in the questionnaires.

Reference conditions (Norway, Romania) and Classification system still needs to be developed (Croatia, Estonia, France) or improved (Poland, Latvia, Romania, Norway) in many countries.

To do this, the following avenues of reflection have been identified:

- **How to define the reference conditions? Less impacted site, historical knowledge, use of modeled data, other...? What is the acceptable degradation limit for the reference?**

It was pointed out that the reference conditions were very complicated to define for both hydrological and morphological characteristics at the same time (Italy). It was also highlighted that we might need to use modelling in order to define reference conditions in the context of climate change (Finland).

- **How is the High/Good threshold defined?**

Link between HYMO and biology is known (numerous case study in the literature) but not often used to define threshold of the quality classes in the assessment system. This lead to the question: How to interpret the "support to biology" included in the directive?

In addition, the debate remains open concerning the use of the HYMO methods possibly as a proxy of biology in some countries. Indeed, this can be a very fundamental difference between some countries as some argue that HYMO shall be a proxy for biology, while others think HYMO should be something independent of biology. For example among researchers in Norway there are diverging views regarding the role of the HYMO system as a proxy to ecological status. In other words, should HYMO act independently of ecology, or as a support/proxy to ecological classification?

We agreed during the workshop on the fact that the HYMO is in support of biology. In particular, it was agreed that we should try to find relationships between the different BQEs and the assessment of HYMO status in order to set the thresholds for the five classes required by the WFD. Nevertheless, **more precise questions were raised such as:**

- **Which biological quality element(s) should be considered? One or several?**

It was recommended that several BQEs should be employed in order to help to set up boundary conditions for the five HYMO assessment classes. Indeed, several countries are already using macrophytes to link HYMO assessment to biology. However, in case several BQEs are used, it was not clear how to deal with different thresholds if the responses to HYMO alterations are different for each BQE?

- **How to establish the link? By statistical relationship between HYMO status and biological status? Relationship between the different parameters of the HYMO classification systems and some specific biological metrics? Should we start at a more upstream level of information, at the level**

of metrics? In other words should we compare HYMO metrics and some specific biological metrics?

- **How to use qualitative information?**
- **HYMO assessment should be used only to distinguish between High/Good status or more?**
- **How are the other boundaries defined?**

These key questions remain open.

Various topics raising many questions were also highlighted:

- **Should changes in sediment continuity be incorporated in the assessment system and if so, how?**

It might be risky to include sediment continuity in the HYMO assessment of lakes as it may also include the connection between the rivers and lakes (Spain). Moreover, this issue is more linked to river issues (Italy).

- **Should the importance of the different hydromorphological criteria be weighted?**

In Norway, they do use different weights between the different criteria however the weight for each criteria is given based on expert judgment and not according to a scientific approach. Nevertheless, it was agreed during the workshop that there are no general rules on how metrics should be aggregated.

- **There are 2 standards in relation with lake HYMO. Are they well/easy to apply in the WFD context?**

The first standard (EN 16039: 2011) is included in the WFD and is consistent to the use for implementing WFD. Nevertheless, the second standard (EN 16870: 2017) is not included in the WFD and was not set up specifically for that purpose. However it can be a good support to the HYMO assessment.

However some questions have not been answered and it will be necessary to answer them later. They are listed below:

- **How the information on the different hydromorphological parameters is aggregated (average, one out all out)? Has the impact of these aggregation methods been evaluated on the classification?**
- **Is there an interest in harmonizing the procedures for assessing hydromorphological status? For example in terms of: data collection (panel of methods, spatial and temporal considerations)? Characterization of metrics to be included (more precise than parameters), aggregation method (and possibly weighting) and definition of the boundaries?**

11 Future perspectives

Following the discussions during the workshop the different next steps have been identified:

- improve the definition of reference conditions;
- improve the development of studies on the links between biology and hydromorphology.

In order to rise up best practices and write recommendations we need to collect further information from European Member State countries on how reference conditions and classification are undertaken (if classification is made) in the national context for assessing lake hydromorphology.

Finally, a challenge highlighted during the workshop is to deal with current climate change.

12 Conclusions

The high response rate of the European survey makes it possible to provide a comprehensive overview of lake hydromorphological assessment and monitoring methods applied in member states.

Among the 32 questionnaires received describing 33 methods applied or in development in 20 countries, 20 are currently assessment methods, 10 are monitoring methods (two method of Cyprus, one of Czechia, six of France, and one of Norway) and three methods will be replaced by new protocols (Portugal, Norway, Spain).

Application or development of these methods seems to have been motivated by the WFD, and it is noticed that a few of them are used in other contexts. Even if some of them seem to be used for the habitat directive and to a lesser extent for the flood directive, cases remain very rare. Likewise, few methods have been used for purposes other than monitoring or classifying the condition. Perhaps this is simply a result of the fact that these are recently developed methods as evidenced by the increase in their use between the 1st and the 2nd RBMP.

On the other hand, the methods described are generally included in the national guideline or regulation for some of them, applicable to all types of lakes, natural or man-made and on a national scale, once by RBMP. These methods seem to mobilize field data gathered with low or medium resource intensity but also spatial data and / or data recorded in existing databases.

With regard to the hydrology the various characteristics are relatively well taken into account by the different countries (in particular the water level regime) except for the residence time although its evaluation is recommended in the water quality guidance standard on assessing the hydromorphological features of lakes – EN 16039:2011. Surface-groundwater interactions and stratification/mixing are also poorly taken into account in the different countries even though the interactions between the surface water and groundwater are characterized in a majority of countries but not used to assess lake condition.

With regard to the morphology the various characteristics are also relatively well taken into account by the different countries, in particular lake depth variation, shape of the littoral zone and shore zone aquatic vegetation. Nevertheless, the planform pattern, substrate in the open water, and the open water aquatic vegetation are still poorly used to evaluate lake conditions although their evaluation are recommended in the water quality guidance standard on assessing the hydromorphological features of lakes – EN 16039:2011. The lack of use of these three latter features might be first explained by the difficulty to measure the rate of filling and knowing if the filling is either natural or either altered for the planform pattern. Technical constraints (lack of methodology, not enough precision in the measurements and lack of reference) can limit the use of substrate and aquatic vegetation in the open water for assessing lake conditions.

In addition, the different alterations of the hydromorphology and/or processes occurring in the lake are rather well taken into account in the 20 current assessment methods as well as the off-site pressures. Nonetheless, longitudinal continuity off-site pressure is still used by less than half of the current assessment methods to assess lake condition.

All of the 20 current assessment methods are using a scoring system which are mostly quantitative although the degree of confidence is still poorly included in the methods. However, the scoring system and the way in which class thresholds were defined (if there is a classification) remain to be specified since the questionnaire did not go to that level of detail. Thus, further information will be required about the procedure of the scoring system of the different methods to examine if it fits with the scoring system required in application of the WFD (based on biology).

Finally, evaluation is still limited: only 17 countries seem to have an evaluation system or at least the basis of a system that is still being developed, even among these 17 countries (for example, Croatia, France and Spain).

The way in which reference conditions are determined and the link with biology, especially if class thresholds are defined for classification status, are the main points into the methods that need to be improved/tested. As illustrations, some methods do not provide the level of information needed to assess status as there is a lack of information on the reference conditions of some parameters or on how to define boundaries and thresholds according to Latvia, Norway and Romania. There is also a need for improving the link between hydromorphological assessment and biological assessment report Germany, Italy, Romania and Poland.

Thus two main hurdles remain; a methodological hurdle with the determination of reference conditions which is not clearly defined for many countries although this is essential when assessing lake conditions and a scientific hurdle with regard to the link with biology of the different hydromorphological assessment methods.

An improvement in the consideration of HYMO in application of the WFD is still in progress: evolution might arise between the 1st and the 3rd RBMP.

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List of abbreviations and definitions

AWB	Artificial Water Bodies
BQE	Biological Quality Element
RBMP	River Basin Management Plans
WFD	Water Framework Directive

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Annexes

Annex 1. Key references for the reported methods

Country	Name of the method	Key reference
Austria	HYMO-screen	<p>Pall, K. & Plachy, B., 2020: Hydromorphologie-Aufnahmeverfahren - Stillgewässer.- Studie im Auftrag des Bundesministeriums für Landwirtschaft, Regionen und Tourismus, 63pp.</p> <p>Pall, K. & Plachy, B., 2020: Hydromorphologie-Bewertungsverfahren - Stillgewässer.- Studie im Auftrag des Bundesministeriums für Landwirtschaft, Regionen und Tourismus, in prep.</p> <p>ÖNORM M6231</p>
	HYMO-screen+	<p>Pall, K. & Plachy, B., 2020: Hydromorphologie-Aufnahmeverfahren - Stillgewässer.- Studie im Auftrag des Bundesministeriums für Landwirtschaft, Regionen und Tourismus, 63pp.</p> <p>Pall, K. & Plachy, B., 2020: Hydromorphologie-Bewertungsverfahren - Stillgewässer.- Studie im Auftrag des Bundesministeriums für Landwirtschaft, Regionen und Tourismus, in prep.</p> <p>ÖNORM M6231</p>
Croatia		<p>Reports/Studies: 1. Proposal of methodology for hydromorphological status assessment in standing water bodies 2. Development of methodology for hydromorphological status assessment in standing water bodies and hydromorphological monitoring.</p>
Cyprus	Natural lakes	X
	Reservoirs	X
Czechia		<p>Methodology accepted by the Ministry of the Environment of the Czech Republic: BOROVEC, J. a kol. Metodika pro hodnocení ekologického potenciálu silně ovlivněných a umělých vodních útvarů – kategorie jezero. Biologické centrum AV ČR, v. v. i., 2014.</p> <p>https://www.mzp.cz/prehled_akceptovanych_metodik_vod/\$FILE/OOV-Metodika_hodnoceni_%20ekologicky%20potencial_%20kategorie_jezero-20140301.pdf</p>
Estonia		<p>Report (in Estonian with summary in English):</p> <p>Ott, I., Saar, K., Ott, K., Sepp, M., Laarma, R., Rakko, A., Teppo, T., Lasn, R., Konoplitski, J. & Eist, A. 2014. Pinnavee ökoloogilise seisundi hindamine hüdro-morfoloogiliste kvaliteedielementide alusel. Estonian University of Life Sciences, contract nr 4-1.1/14/70. Report</p> <p>https://www.envir.ee/sites/default/files/hymo_jarved_2014_11_24.pdf</p>
Finland		<p>There are several scientific papers describing relationship between water level regulation and ecology. However, method itself is developed for implementation of WFD and therefore available only in Finnish.</p>
France	Alber	<p>Qualité de l'eau - Qualité des milieux - Caractérisation des altérations des berges de plans d'eau – XP T90-714:2016</p>

	Bathymetry	Alleaume S. et al. (2010). Bathymétrie des plans d'eau - Protocole d'échantillonnage et descripteurs morphométriques. Rapport d'étude Convention Onema-Cemagref, Cemagref, Aix-en-Provence.
	BAVELA	Heyd C. et al. (2012). BAVELA Bassin Versant Lacustre - Méthode de délimitation et extraction des données spatiales. Rapport d'étude Convention Onema-Irstea, Irstea, Aix-en-Provence.
	Charli	Qualité de l'eau - Qualité des milieux - Caractérisation des habitats des rives et du littoral des plans d'eau – XP T90-718:2016
	CORILA	Alleaume S. & C. Argillier (2012). Corila : Corridors Rivulaires Lacustres. Rapport d'étude Convention Onema-Irstea, Irstea, Aix-en-Provence.
	LHYMO	X
	SEDILAC	Mouget A. et al. (2017). Protocole d'utilisation du système RoxAnn® pour la classification des fonds lacustres. Rapport d'étude, INRA, Thonon-les-Bains.
Germany	LAWA	MEHL, D., EBERTS, J., BÖX, S. und KRAUß, D. (2015a): Verfahrensanleitung für eine uferstrukturelle Gesamtseeklassifizierung (Übersichtsverfahren). – 2. überarbeitete und erweiterte Fassung (2015) im Rahmen des LAWA-Projektes O5.13. – 78 S. hg. von der Bund/Länder-Arbeitsgemeinschaft Wasser (LAWA). MEHL, D., EBERTS, J., BÖX, S. und KRAUß, D. (2015b): Verfahrensanleitung für eine uferstrukturelle Gesamtseeklassifizierung (Übersichtsverfahren). Anlage: Bearbeitungsalgorithmen und -verfahrensweisen. – 2. überarbeitete und erweiterte Fassung (2015) im Rahmen des LAWA-Projektes O5.13. – 47 S. hg. von der Bund/Länder-Arbeitsgemeinschaft Wasser (LAWA).
	HMS	Ostendorp, W. & Ostendorp, J. (2014): Hydromorphologie der Seen. – Band 2: Erfassung und Klassifikation der hydromorphologischen Veränderungen von Seen nach dem HMS-Verfahren (Anwenderhandbuch). - Fachbeiträge des LUGV, Heft 141, 236 S., hg. vom Landesamt für Umwelt, Gesundheit und Verbraucherschutz (LUGV) Brandenburg, Potsdam Ostendorp, W. & Ostendorp, J. (2015): Analysis of hydromorphological alterations of lakeshores for the implementation of the European Water Framework Directive (WFD) in Brandenburg (Germany). – Fundam. Appl. Limnol. 186/4 (2015), 333–352.
	LAWA BIOTA LAWA	MEHL et al. (2014a) [method guidance] MEHL, D., HOFFMANN, T. G. & MIEGEL, K. (2014): Klassifizierung des Wasserhaushalts von Einzugsgebieten und Wasserkörpern – Verfahrensempfehlung. a) Handlungsanleitung. – Bund-/Länderarbeitsgemeinschaft Wasser [Hrsg.], Ständiger Ausschuss „Oberirdische Gewässer und Küstengewässer (LAWA-AO), Sächsisches Staatsministerium für Umwelt und Landwirtschaft, Dresden. https://www.gewaesserbewertung.de/files/lawa_wh_verfahrensempfehlung.pdf
Greece		http://wfdver.ypeka.gr/el/management-plans-gr/methodologies-gr/
Hungary		X The reference will be given by the closing of the 3rd RBMP of HU, method and data.
Ireland	Lake MImAS	Rowan et al., 2008 https://www.sniffer.org.uk/wfd49f-final-report-web-pdf
Latvia	LHS	Methodology for assessment of hydromorphological pressures and impact on lake water bodies is included in the 2nd RBMPs. The guidelines are not placed in accessible web page yet.

Italy	LHS	http://www.life-inhabit.it/en http://www.ise.cnr.it/products/report http://www.ise.cnr.it/wfd-en
Lithuania	HMIe	X
Norway	Hydromorphological classification system	The first version of the Norwegian system for hydromorphological classification was included in the following report (See Chapter 8): Bakken, Tor Haakon; Schönfelder, Lennart Hagen; Charmasson, Julie; Alfredsen, Knut; Adera, Abebe Girmay. Outlining a hydromorphological classification system for lakes: data availability, modelling tools and comparable assessment approaches. Trondheim: SINTEF Energi 2018 (ISBN 978-82-14-06906-8) 70 s. SINTEF Rapport(2018:00768). ENERGISINT NTNU. This system was in the next phase tested/demonstrated on 9 selected lakes in Norway, and a revised HYMO classification system was proposed (in Chapter 7). The demonstration and the revised system is available in the following report: Bakken, Tor Haakon; Beck, Valerie; Schönfelder, Lennart Hagen; Charmasson, Julie; Thrane, Jan-Erik; Lindholm, Markus; Brabrand, Åge. Testing and evaluation of a HYMO classification system for lakes and reservoirs - Proposed new and modified hydromorphological (HYMO) classification system. : SINTEF Energi 2019 (ISBN 978-82-14-06234-2) 103 s. SINTEF Rapport(2019:01365) ENERGISINT NTNU RSH UiO. We have recently also started writing a scientific paper based on the work carried out.
	Pressures analysis and simple hymo classification	The method is described in our national guidelines, Appendix II: http://www.vannportalen.no/globalassets/nasjonalt/dokumenter/veiledere-direktoratsgruppa/veiledere-1-2018-karakterisering.pdf
	National hydrological monitoring program	https://www.nve.no/hydrology/?ref=mainmenu
Poland	LHS_PL	http://www.gios.gov.pl/images/dokumenty/pms/monitoring_wod/Observacje_Hydromorfologiczne_Jezior.pdf (only in Polish)
Portugal		X
Romania		Research study for development of hydro-morphological indicators for natural and heavily modified water bodies-lakes and reservoirs (National Institute of Hydrology and Water Management, 2015).
Spain	CURRENT METHOD – CEDEX – L – HMF 2010	Establecimiento de condiciones físicoquímicas e hidromorfológicas específicas de cada tipo ecológico en masas de agua de la categoría lagos en aplicación de la Directiva Marco del Agua. Noviembre 2010.
Spain	Under development – M – L- HMF	
Sweden		http://www.havochvatten.se/download/18.4705beb516f0bcf57ce1c145/1576576601249/HVMFS_2019-25-ev.pdf

Annex 2. Agenda of the virtual ECOSTAT Hydromorphological Assessment and Monitoring of Lakes workshop

Agenda

ECOSTAT Hydromorphological Assessment and Monitoring of Lakes workshop

20th May 2021

10:00 – 12:00 Hydromorphological Assessment and Monitoring of Lakes in Europe

- 10.00 Welcome and introduction to the workshop *Wouter Van de Bund*
- 10.10 Aims of the meeting/Presentation of the Lake Hydromorphological Assessment and Monitoring Methodologies report in Europe *Alexandra Carriere, Christine Argillier*
- 10.35 HymoLake feedbacks from the report, overview of comments when reading the report *Alexandra Carriere/Discussion open to all*
- 10.55 Country of thousands lake monitoring sites - presentation of Finnish hydrology based lake assessment method *Seppo Hellsten*
- 11.15 Hydromorphological Assessment of Lakes: Procedures used in Germany *Wolfgang Ostendorp and Ralf Köhler*
- 11.35 Development of a Hydromorphological classification system for lakes in Norway *Tor Haakon Bakken*
- 11.55 End of the morning session - lunch

13:30 – 16:30 Feedback, discussions and future plans (What are the positive issues and difficult issues and how to solve them?)

- 13.30 Knowledge and experience sharing: feedbacks on indicators
- Hydrology (15 min)
 - Morphology (15 min)
 - Alteration processes (15 min)
- Discussion open to all*
- 14.15 15 min break
- 14.30 Find the gaps:
- Reference conditions/classification (30 min)
 - Link between hydromorphology and biology (30 min)
 - Others: opening (30 min)
- Discussion open to all*
- 16.00 Future work (next steps for 2021 and next work program) *Sandra Poikane/Discussion open to all*

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