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Water quality — Guidance standard on assessing the hydromorphological features of lakes

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National foreword

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Foreword

This document (EN 16039:2011) has been prepared by Technical Committee CEN/TC 230 “Water analysis”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2012, and conflicting national standards shall be withdrawn at the latest by March 2012.

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WARNING — Working in or around water is inherently dangerous. Surveyors should conform to EU and national health and safety legislation, and any additional guidelines appropriate for working in or near lakes.

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Introduction

This European Standard contains lists of lake features and guidance on how to record, analyse and interpret the data obtained from desk-top, remote sensing and field surveys. In this document the word ‘lake’ is used as a generic term for standing waters including natural and modified lakes, reservoirs and excavated pits.

The physical character of a lake is defined by its morphometry (size and shape) and by its hydrological regime, both of which are contingent on the landscape setting of the lake-catchment system and its environmental history. Ensuring that the key features and associated physical processes operating within lakes are consistently recognised enables legitimate comparisons to be made among different lake types. This is required for a range of purposes, including the EC Water Framework Directive (WFD), the EC Habitats Directive, and lake management and restoration. The WFD requires physical features of surface waters to be considered when assessing ’ecological status’ and refers to these features as hydromorphological. Annex V of the WFD lists two categories of hydromorphological ‘quality elements’ for assessing lakes – ‘hydrological regime’ and ‘morphological conditions’ – each sub-divided into a number of specified ‘quality elements’. Those in the hydrological category comprise the quantity and dynamics of flow, level, residence time and connection to groundwaters, whilst those in the morphological category are lake depth variation, quantity and structure of the substrate and the structure and condition of the lake shore zone.

The Habitats Directive applies to a wide range of terrestrial, freshwater and marine habitats and species. The Directive requires Member States to maintain or restore these to ‘favourable conservation status’, partly by designating Special Areas of Conservation (SACs). For lakes, the process of selection and monitoring SACs involves recording and regularly assessing a suite of physical, chemical and biological features. A standard approach to hydromorphological assessment, while not specifically required by the Directive, thus enables the contribution of physical structure and hydrology to favourable conservation status to be assessed, and allows comparisons to be made between Member States.

NOTE In this document, ‘assessment’ is used as a broad term referring to the general description and characterization of lake features and the pressures that impinge upon them. It is not used to imply particular levels of ‘quality’ or ‘value’, whether related to ecological status under the WFD or more generally.

1 Scope

This European Standard is applicable to lakes, which are water bodies occupying one or more basins with surface areas greater than 1 ha (0,01 km^2) and maximum depths (at mean water level) greater than 1 m. All types of permanent lakes, including natural, modified and artificial, freshwater and brackish, except for those systems which regularly connect to the sea, are included in this European Standard, though canals are excluded.

Based on these criteria, it can be estimated that there are at least 500 000 natural lakes across Europe, most of which are located in the glaciated landscapes in northern and western provinces and in Scandinavia. Lakeland districts also occur locally in areas such as the Danubian plain and around the Alps. Elsewhere, naturally occurring lakes are relatively sparse and in such areas reservoirs or pits are more common.

This European Standard is designed to:

a) support environmental and conservation agencies in meeting the monitoring requirements of the WFD (Article 8, Annex II and Annex V);

b) generate data sets appropriate for monitoring and reporting of *Natura* 2000 sites designated under the Habitats Directive and the Birds Directive;

c) provide information supporting other environmental reporting requirements (e.g. in relation to biodiversity or environmental impact assessment);

d) support lake management and restoration initiatives.

This European Standard:

e) defines the key term of ‘hydromorphology’ and other terms relating to the physical characteristics of lakes and their hydrological regimes;

f) details essential features and processes of lakes that should be characterised as part of a hydromorphological survey and for determining the hydromorphological condition of a lake;

g) identifies and defines the key pressures affecting European lakes;

h) provides guidance on strategies for collecting hydromorphological data depending on resources available and the anticipated use of the assessment; a hierarchy of approaches is recognised from the ‘overview method’ utilising existing databases, maps and remote sensing data through to recognised field-based survey techniques such as Lake Habitat Survey (LHS);

i) offers guidance on data presentation;

j) establishes guidance on data quality assurance issues.

This European Standard does not deal with biological assessments in lakes such as the presence or absence of individual species or community composition, nor does it attempt to link specific hydromorphological features with their associated biological communities or to create a classification based on such links. However, it is relevant where plants or other organisms form significant structural elements of the habitat (e.g. a gradation from riparian to littoral vegetation).

With respect to the WFD, the hydromorphological condition of a lake only contributes to its status classification at high ecological status (HES). Hydromorphological conditions are not defined for good and moderate status but shall be sufficient to support the biological elements.

2 Normative references

EN 14614, *Water Quality — Guidance standard for assessing the hydromorphological features of rivers*

3 Terms and definitions

For the purpose of this document, the following terms and definitions apply.

3.1
aquatic macrophyte
larger plant of fresh water which is easily seen with the naked eye, including all aquatic vascular plants, bryophytes, stoneworts (Characeae) and macro-algal growths

NOTE This definition includes plants associated with open water or wetlands with shallow water.

3.2
attribute
specific recorded elements of a hydromorphological feature

EXAMPLE 'Silt' and 'boulders' are natural substrate texture attributes, 'sheet piling' and 'gabions' are attributes of engineered banks.

3.3
bank
physical edge of the lake shore, or of the island(s) within

NOTE Generally defined by a wave-cut break in slope at or near the water's edge of the lake, but can also be defined as the line along which riparian (terrestrial or land) conditions change to littoral in-lake conditions.

3.4
basin
defined hollows which are permanently or temporarily filled with water

NOTE Basin size and shape (morphometry) strongly control the fluxes of substances in lakes and the structure and function of lake food webs.

3.5
bathymetry
systematic survey of size, shape and water depth distribution in a lake

NOTE Bathymetry is the basis of deriving morphometric parameters and to predict thermal stratification, residence time and sediment redistribution processes.

3.6
bay
indent of the lake shore which can span from metres to many kilometres in size

NOTE Bays are normally protected by a promontory (or headland) projecting from the shore which reduces exposure. Bays often contain beach deposits.

3.7
bedform patterns
topography of the lake bed may be simple or complex depending on the size and shape of the system and the nature of local sediment transport processes

NOTE Deposition produces bedforms such as sand and gravel bars, whilst erosion results in scour features such as troughs.

3.8
bedrock
in situ naturally consolidated rock either underlying drift deposits such as glacial till or exposed by past or current erosion processes

3.9
beach
sub-zone of the exposed shore above the water line of a lake defined by the accumulation of sediment (texturally will range in grain size from clays and silts through to boulders) depending on the energetics of the wave environment and the geomorphological history of the site

3.10
catchment
drainage basin contributing water and sediment into a lake

NOTE Also recognised as drainage area.

3.11
continuity
uninterrupted movement of water, sediment and organisms into, out of and within a lake system

3.12
delta deposits
sediment deposits formed where an inflowing stream enters the lake

NOTE The size and style of the deposits depends on upstream catchment characteristics and reworking of the sediments by wave and current action in the lake. At least some of the delta sediments are expected to be above water.

3.13
direction of the main axis
compass bearing along the axis of the maximum length of a lake, e.g. NW-SE

3.14
ecological potential
set out in Annex V of the WFD the environmental objective of heavily modified water bodies (HMWBs) or artificial water bodies (AWBs) is to achieve good ecological potential, rather than good ecological status

NOTE This means that the system is managed to optimise biological quality accepting its altered hydromorphological condition that cannot be mitigated without significant adverse effect on specified uses.

3.15
ecological status
expression of the quality of the structure and functioning of aquatic ecosystems, by comparing the prevailing conditions with reference conditions

NOTE As classified in accordance with Annex V of the EC Water Framework Directive.

3.16
epilimnion
warm upper layer of lake water column vertically mixed by wind driven forces in a thermally stratified lake

3.17
eulittoral zone
area of the lake shore spanning the mean annual high and mean annual low water level

3.18
exposure
measure of the energetics of a shoreline segment obtained from various fetch calculations

3.19
fetch
distance of open water over which the wind can blow and generate wind-driven waves

3.20
headland
promontory of land projecting into water

3.21
hydrological connectivity
degree of coupling (natural or impeded) between the lake basin and surrounding/underlying groundwater and surface water bodies

3.22
hydromorphology
physical and hydrological characteristics of lakes including the underlying physical processes from which they result

3.23
hypolimnion
dense, bottom layer of water in a thermally stratified lake

NOTE Being at depth, it is isolated from surface wind-mixing during summer.

3.24
hypsographic curve
depth–area curve describing the form of the basin

3.25
ice phenology
description of the duration and the timing (dates) of formation (freeze-up) and melting (break-up) of the ice cover

3.26
island
landform protruding from the surface of the lake

NOTE A useful size-based classification for island features is as follows:

— Outcrop: < 0,001 km^2;

— Islet: 0,001 km^2 to < 0,01 km^2;

— Island: 0,01 km^2 to 1 km^2;

— Large island: > 1 km^2.

3.27
lake altitude
elevation of a reference height such as lake mean annual water surface level above reference sea level datum

3.28
lake hydrological type
generalised scheme to describe the water balance of a lake water body according to factors such as the relative importance of surface water compared with groundwater, and flushing rates and seasonal characteristics (water level variability over annual time series)

3.29
lake perimeter
equivalent to the shoreline length measured at a reference level such as the mean annual water level

3.30
lake stratification
variations in water column structure with respect to temperature and density

3.31
lake surface area
planimetric surface area of the lake water body

3.32
lake type
group of lakes that can be broadly differentiated from other groups on the basis of their physical and chemical characteristics

3.33
littoral zone
habitat extending from the water's edge to the lakeward limit of rooted macrophytes or algae on the lake bed

3.34
longshore drift
process of sediment transport along the lake shore (coast) driven by shore-wise currents and wave action

3.35
maximum effective length
length of a straight line connecting the two most distant points on the perimeter of the lake over which winds and waves may act without interruptions from islands and land

NOTE This is distinct from the maximum length which is any line connecting the two most distant points on the shoreline. It must not cross land, but can cross islands. In regular shaped basins, this will approximate to a straight line, but in irregular lakes (such as oxbows) the maximum length may be curved.

3.36
metalimnion
medial region of the water temperature profile separating the epilimnion from the hypolimnion in a thermally stratified lake where the temperature declines at a rate of 1 °C or greater per metre of depth

3.37
morphometry
basin shape, or form, which expresses how water depth varies with surface area (hypsographic curve) and includes both mean and maximum water depth

NOTE Basis for deriving indices used for morphometric analysis of important lake functions.

3.38
near-shore sub-system
includes all shore features typically associated with the littoral zone as well as islands and shallow water features such as sand bars or shoals

3.39
open water (off-shore) sub-system
includes circulatory basins and major embayments extending to either the silt–sand sediment boundary or the attached plant boundary, typically linked to the pelagic zone

3.40
outflow condition
character of the outflow which may be natural or modified by raising or lowering and which may involve engineering structures

3.41
pelagic zone
open water zone extending from the littoral zone to the centre of a lake

NOTE In the deeper parts of the pelagic zone (known as the profundal zone) light does not penetrate and there is no photosynthetic activity.

3.42
planform
view of lake shape from above

EXAMPLE Elongate, circular, etc., and also relevant in relation to the shoreline development index which expresses the degree of irregularity of a lake compared with a circular form of the same area.

3.43
reference conditions
conditions which are totally, or nearly totally undisturbed by human activity

3.44
riparian vegetation structure
physical character of the vegetation that creates habitat in the riparian zone

3.45
riparian zone
area of land adjoining the lake capable of directly influencing the condition of the aquatic ecosystem (e.g. by shading and leaf litter input)

3.46
shoreline length
length of the lake perimeter at mean annual water level

NOTE In practice, lake perimeter is derived from a relevant scaled topographic map.

3.47
shore reinforcement
work undertaken to prevent or mitigate erosion on the banks and shore of a lake

NOTE Hard engineering uses materials such as concrete walls, gabion baskets and sheet piling, whilst soft engineering uses natural materials such as basket-work and planted vegetation such as willow saplings to stabilise banks.

3.48
shore zone
comprises riparian, eulittoral and littoral zones around the perimeter of a lake

3.49
substrate (substratum)
natural sediment or engineered surfaces comprising the shore and bed of a lake

NOTE Natural sediments are generally characterised by texture and organic matter content, while artificial substrates are described by their construction materials (see Annex B).

3.50
water level regime
range, frequency and timing of water level fluctuations

3.51
wave base
water depth to which wind-driven waves penetrate, thus separating areas of the lake bottom where wave action erodes and transports sediments from the zone below where sedimentation is continuous without resuspension

3.52
wetlands
transitional zones between permanently inundated, and generally dry, environments, e.g. marshes (wet ground without peat), fens (groundwater fed peats) and bogs (rain-fed peat systems)

4 Principle

This standard describes a protocol for recording the physical features of lake systems, including both their gross morphometry (size and shape of the lake basin and its upstream catchment relations) as well as characterising morphological and hydrological attributes which control the behaviour and functioning of the system. The range of features surveyed, and the methods used for the survey, may vary according to lake type and the objectives of the study. This European Standard provides a common framework recognising the strengths and limitations of different methods and provides guidance on selecting the most appropriate approaches depending on lake size and on the purpose of the exercise. Guidance is given on the hydromorphological features that should be used for characterising lake types and for subsequent assessment of morphological integrity through comparison with reference conditions.

5 Survey requirements

5.1 Lake ‘types’

Every lake is unique, each with a particular genesis, morphometry, catchment/landscape relationship, biogeography and environmental history. Lakes exist within a continuum of size, depth, form, altitude, geology, climate, hydrological regime and catchment characteristics. However, describing and identifying lake ’types’ enables the results of hydromorphological surveys from different types to be compared. In addition, defining ’high status’, type-specific, reference conditions in lakes is a requirement of the WFD, with the aim of comparing the quality of lakes in an equitable and ecologically meaningful way. Some hydromorphological assessment methods are not linked to lake types but can still provide useful information for better lake management; this European Standard therefore includes consideration of such methods. Information required to define lake types can often be derived from maps or catchment-wide databases. Types may be refined by using information gathered during field surveys, or through input from expert opinion. It is recommended that the following factors should be considered in the definition of lake types:

Size: Surface area of the lake, catchment area;

Depth: Maximum and mean depth, with the latter expressed as three categories - very shallow, shallow and deep (see Table 1);

Basin form: Shape of basin (hypsographic form) represented by three categories - convex, concave or linear;

Geology: A minimum of three lithological categories, preferably more – e.g. siliceous, calcareous, organic, (or mixed); this principally applies to the catchment because rock type strongly influences hydrological pathways e.g. contrasts surface water supplied versus groundwater fed systems, but also provides a surrogate for alkalinity;

Geographical location: Latitude and longitude;

Altitude: Altitude of lake, altitude of source within the catchment;

Hydrological regime: Quantity and dynamics of the flow expressed especially through water level variability (daily, seasonally and annually) and residence time dynamics.

Table 1 provides an example of the way in which physical and chemical features are used to derive lake types in the legislative context of the WFD. In this example, lakes are ‘typed’ either according to geographic location (ecoregions) together with a set of obligatory ‘descriptors’ (System A), or using an equivalent approach based on ’obligatory and optional factors’ (System B).

Table 1 — The two systems for determining 'lake type' provided in the Water Framework Directive

KEY FACTORS	DESCRIPTORS
System A	
Ecoregion	Ecoregions shown on Map A in Annex XI
Altitude typology	high: > 800 m mid-altitude: 200 m to 800 m lowland: < 200 m
Depth typology based on mean depth	< 3 m 3 m to 15 m > 15 m
Size typology based on surface area	0,5 km^2 to 1 km^2 1 km^2 to 10 km^2 10 km^2 to 100 km^2 > 100 km^2
Geology	calcareous siliceous organic
System B	
Alternative characterisation	Physical and chemical factors that determine the characteristics of the lake and hence the biological population structure and composition
Obligatory factors	altitude latitude longitude depth geology size
Optional factors	mean water depth lake shape residence time mean air temperature air temperature range mixing characteristics (e.g. monomictic, dimictic, polymictic) acid neutralising capacity background nutrient status mean substratum composition water level fluctuation

5.2 Scale

5.2.1 General

Scale is important in lake hydromorphological assessment owing to the large numbers of lakes involved and their size range, e.g. the largest lake in the EU is Lake Vänern in Sweden at 5,670 km^2. Different applications also require different levels of detail, e.g. SAC condition monitoring for *Natura* 2000 sites may require analysis of the entire lake-catchment system, whilst analysis of the linkages between hydromorphological alteration and ecological response may be most appropriate at the scale of habitat patches. Along with lake size, other factors determining the appropriate scale of survey will include access to the lake and availability of maps, aerial photos or satellite images. To illustrate this point further, it can be shown that a lake shoreline measurement (by map measurer or digitising) varies significantly as a function of map scale. In such instances the optimum map factor (SF) can be determined from the expression $SF \approx 5\ 500\ \sqrt{A_{itot}}$ where A_{itot} is the total surface area (km^2) of the lake, including islands.

The consideration of scale in assessing the severity of impacts is also important; i.e. a small-scale pressure may be insignificant on a large lake but have significant impacts on a small lake. Different survey techniques are scale-dependent. For example, catchment and riparian zone pressures may be best analysed using geospatial databases and remote sensing techniques, whilst characterising the quantity and structure of the substrate can generally only be tackled using field survey techniques.

5.2.2 Dividing the lake system into zones for hydromorphological assessment

Small to medium lakes are generally considered as single units. In large and morphologically complex lakes with discrete and only partially interconnected sub-basins different reference conditions may apply. Whilst many schemes exist to classify lakes into functional zones the key for the present purposes is simplicity and general applicability across Europe. Within large deep lakes the most useful distinction is between the shore zone and the open water sub-systems found off-shore. The latter include circulatory basins and major embayments extending to either the silt–sand sediment boundary or the attached plant boundary. Seasonal stratification is likely where water depth is sufficient which in turn influences mixing, dissolved oxygen profiles and hydraulic residence times. Below the wave base the lake bed is typically composed of fine sediment with a low diversity of habitat types and the profundal zone is free of any rooted macrophytes. The shore zone extends from the lakeward limit of rooted vegetation through the littoral, exposed shore and riparian zone beyond. It is typically more diverse in terms of morphometry, energy regime and substrate characteristics with assorted macrophyte and macroinvertebrate assemblages and provides important spawning and nursery habitats for fish. In very shallow lakes (and some shallow systems) the entire lake bed is likely to be colonised by macrophytes. In such cases, the term ‘near-shore’ still usefully constrains attention to pressures most strongly associated with shore and land-based activities.

5.2.3 Catchment scale

The catchment area is also considered a relevant zone because of the coupling of lake systems to water, mineral sediment and organic matter inputs from the catchment. The relationship between the lake and its catchment can be strong or weak depending on lake type, catchment size, landscape setting, ground water connectivity and degree of catchment alteration and so should be explicitly addressed in the hydromorphological assessment process. Human pressures cause a range of responses including water quality changes (e.g. increased phosphorus loading which can indirectly lead to enhanced organic sediment accumulation on the lake bed), but hydrological regime alteration and land use/land management pressures leading to increased soil erosion and accelerated sedimentation are particularly important from a hydromorphological perspective.

5.3 Reference conditions

5.3.1 General

The identification of hydromorphological ‘reference conditions’ is an essential pre-requisite for assessing the condition, or degree of hydromorphological modification present in a lake which has been affected by human activity (pressures). It is also a specific requirement of the WFD as part of the water body classification process. Reference conditions should be identified within each lake type reflecting totally, or near totally, undisturbed conditions.

The hydromorphological quality elements listed in Annex V of the WFD distinguish between hydrological regime represented by the quantity and dynamics of flow, level, residence time and connection to groundwaters and morphology represented by lake depth variation, quantity and structure of the substrate and the structure and condition of the lake shore zone. The criteria for reference conditions given below are intended to give a general indication, not a detailed description. Within any given national typology of lake types, each type should have its distinctive features characterised and thus hydromorphological modification is assessed as the degree of departure from reference conditions that a site exhibits.

The key ecological objective for substantially altered natural lakes, reservoirs and artificial water bodies, which qualify under the WFD as either heavily modified water bodies (HMWBs) or artificial water bodies (AWBs), is to be set at a less stringent level, termed good ecological potential (GEP). GEP is defined as a 'slight' deviation from the reference condition for the closest comparable natural water body type, termed maximum ecological potential (MEP). MEP seeks to describe the best approximation to a natural aquatic ecosystem and so should be managed to optimise the biological quality of the system accepting that its altered hydromorphological condition cannot be mitigated without significant adverse effects on the specified uses that have led to the hydromorphological alteration, or the wider environment. Specified uses include hydropower generation, flood defence, water supply, navigation, irrigation and mineral extraction. Mitigation measures must be applied where feasible.

5.3.2 Lake water balance and hydrological regime

Inflow and outflow volumes and dynamics are minimally altered and no obvious catchment or lake structures exist to affect the natural water balance, lake level, stratification and mixing processes or the hydraulic residence time of the system. Water level fluctuations must therefore be within the envelope of natural variability (either observed or modelled).

5.3.3 Lake morphometry

Size and shape of the basin is effectively unaltered from the natural condition so there are minimal engineering pressures such as land claim or aggregate extraction affecting natural lake depth variation. The rate and location of erosion and sedimentation processes is also consistent with natural rates within the lake basin and associated catchment.

5.3.4 Shore and lake bed character

Corresponds to the condition where the shore and lake bed are composed of natural materials. No artificial or in-lake or lake shore structures disrupt natural hydromorphological processes such as longshore sediment transport or wave generation which govern the quantity and structure of the substrate. Free from human disturbance to sediment supply from the catchment, lake shore or autochthonous sediment production.

5.3.5 Hydromorphological connectivity and biological continuity

There are no structural impediments or significant abstraction pressures that prevent the natural sediment transfers and exchange with ground water or surface water. Similarly, there should be no physical impediments to the movements of biota, such as impassable dams or grilles, which prevent the passage of migratory species such as salmonids.

5.3.6 Terrestrial and aquatic vegetation

Riparian vegetation and aquatic macrophytes appropriate to the type and geographical location of the lake. By implication urban development, intensive agricultural activities or plantation coniferous forestry are absent or negligible within the riparian zone. In suitable conditions, hydroseres may be expected to occur.

6 Features for survey and assessment

6.1 Features and attributes

Table 2 provides a standard check-list of hydromorphological features for survey and assessment. These are grouped within 11 categories and cover the two main zones of lake environments:

a) the open water system;

b) the shore zone.

6.2 Feature recording related to purpose and method of data gathering

Assessment categories and groups of features (as defined in Table 2) may be selected for survey according to purpose. For example, for a comprehensive characterization of lake hydromorphology, it is recommended that all categories and features should be assessed. On the other hand, where a hydromorphological survey is required to assist in lake management and restoration, only those features should be selected that are likely to be the most sensitive to the prevailing pressures on hydromorphology (e.g. shore-based marina developments or off-shore aggregate harvesting). (Pressure assessments are described in 6.4.)

Other combinations of features may be selected for purposes such as defining high ecological status (where the degree of hydromorphological alteration should be minimal relative to the type-specific reference condition) or for assessments of lakes important for conservation. It is important also that the approach adopted is tailored to the scale of the system under investigation.

6.3 A framework for acquiring lake hydromorphology data

European Standards should be both robust and parsimonious and produce consistent outcomes with a known level of confidence. Where available, existing reliable data should be used before deciding to start a new data collection campaign. Similarly, because of the large number of lakes that require hydromorphological assessment, geospatial databases, geographical information systems and remote sensing data capture systems should be used where possible. However, remote sensing methods cannot directly quantify the full range of hydromorphological impacts (such as aggregate harvesting, macrophyte clearance, tourism and amenity impacts) and in such cases a systematic field survey protocol should be used.

Table 2 — Categories, features and attributes comprising a standard hydromorphological assessment for lakes

No	Assessment Categories	Generic Features	Examples of Attributes Assessed
OPEN WATER PELAGIC/ PROFUNDAL ZONE			
1	HYDRAULICS *Describes the quantity and dynamics of flow, mixing behaviour and residence time*	Catchment hydrology	Quantity and dynamics of inflows
		Stratification/mixing	The seasonality and stability of thermal stratification as well as salinity-driven mixing within brackish waters. Water column characteristics at the Index Site (transparency, temperature and oxygen profiles) should also be considered against type-specific reference conditions.
		Residence time	Hydraulic retention equates to time for water in a lake to be replaced, variously calculated.
2	MORPHOMETRY *Describes the size and shape of the lake basin*	Planform	Spatial pattern (size and shape) of lake surface area, relevant to wave generation and heterogeneity of habitats
		Morphometry	Basin shape, or form, which expresses how water depth varies with surface area (hypsographic curve) and includes both mean and maximum water depth
3	BEDFORMS AND SUBSTRATE *Describes the size, structure and sorting of profundal sediments or off-shore lake bottom sediments in large very shallow lakes*	Bedform patterns	Topography and landform features of the lake bottom
		Natural substrate size range	Size distribution and spatial variability of sediment patches (structure, porosity, organic matter content)
4	CONNECTIVITY AND CONTINUITY *Assess artificial barriers to flow, sediment and migratory movement*	Natural exchange with groundwater and surface waters	Connectivity of the water column and bed sediments to groundwater, and disconnection of the water column from the atmosphere by seasonal ice.
		Migratory movement	Ability of aquatic organisms to migrate freely into, out of and within the lake system
		Sediment transmission through the lake and natural erosion/deposition patterns	Erosion and sediment transport patterns within the profundal zone in deep water or offshore littoral sediments in shallow lakes
5	AQUATIC VEGETATION *Describes the presence and distribution of vegetation features*	Structure and extent of aquatic vegetation	Character and density of aquatic vegetation offshore in shallow systems; in deep systems profundal zone is free of vegetation.
SHORE ZONE (RIPARIAN/ LITTORAL ZONES) AND ADJACENT AREA			
6	HYDRAULICS *Describes water level variability and implications for wind generated wave wash*	Water level regime	Range of water level, timing and duration of different levels, ramping rate and periodicity
7	MORPHOMETRY *Describes the shape of banks, beaches and littoral zone*	Profile of shore and/or littoral zone	Slope of the bank and littoral zone resulting from natural erosion/deposition processes.

Table 2 (*continued*)

No	Assessment Categories	Generic Features	Examples of Attributes Assessed
8	LANDFORMS AND SUBSTRATE *Describes the landform character, sediment dynamics and composition*	Bank-forming materials	Structure, texture and composition
		Presence and extent of geomorphic landforms	Nature and rate of sediment deposition to create features such as delta deposits, dunes, berms and bars.
		Natural substrate size, range of littoral zone sediments	Size distribution of naturally occurring sediments within the eulittoral zone
		Embeddedness of littoral gravels	Extent to which fines infiltrate or cover gravels
9	CONNECTIVITY AND CONTINUITY *Assess artificial barriers to flow, sediment and migratory movement*	Natural erosion/deposition patterns	Both natural onshore and offshore sediment fluxes, together with longshore transport
		Migratory movement	Ability of organisms to migrate freely into, out of and within a lake system
		Natural exchange with groundwater	Connectivity of lake with adjacent riparian groundwaters
10	VEGETATION *Describes the presence and distribution of vegetation features*	Structure and extent of riparian vegetation	Character and density of terrestrial vegetation
		Structure and extent of littoral vegetation	Character and density of aquatic macrophyte vegetation
11	LAND COVER	Land cover beyond the riparian zone	Character and composition

The following list provides a general guide to the data sources appropriate for characterising lake systems and hydromorphological conditions.

a) topographic maps or digital geospatial databases;

b) aerial photographs used in geodesy and cartography by the national land surveying authorities along with commercial imagery;

c) bathymetric, hydrological and limnological data collected by the competent authorities or by scientific or private institutions;

d) historical maps, descriptions and reports on a site from the scientific literature, useful when comparison with the present-day situation is necessary;

e) newly commissioned digital aerial photography and remote sensing products;

f) lake and catchment databases containing details of the distribution of hydromorphological pressures within a catchment;

g) field survey.

Field survey and remote data sources are complementary approaches in the assessment of lake hydromorphology. The application of the assessment, the number of lakes under consideration and the resources available will dictate the importance of one approach over another. As with all types of environmental monitoring the integration of lake hydromorphology assessments with existing biological or water quality sampling should be encouraged, in order to minimise expenditure. Different data sources will produce varied levels of data quality in terms of accuracy and reliability.

Three sources of data can be distinguished as follows:

- measured and observed data based on a satisfactory number of measurements, counts or observations;
- modelled data;
- data resulting from expert judgement.

In many situations measured data are limited for historical, practical or financial reasons and in such situations alternative data sources should be used. An example of this might be where bathymetric surveys have yet to be completed; then map-based modelling can be used as a first approximation using statistical relationships as shown in Annex C.

Assessors are encouraged to acknowledge the quality of data used in the assessment process and report precision in either statistical terms (95 % confidence intervals) or at least ‘low’, ‘medium’ or ‘high’.

6.4 Hydromorphological pressure assessment

6.4.1 General

Hydromorphological pressures affect the physical structure and functioning of lake systems in many ways. An important factor determining the significance of an impact is whether it is restricted to a local area or whether the effects propagate through the system as a whole. Raising natural water levels using dams, sluices or weirs, or lowering by outlet modification represent examples of the latter, which through the DPSIR (Driver, Pressure, State, Impact, and Response) framework can be shown to generate widespread biotic consequences. These include changing feeding and nursery areas for fish or changing water depth and light conditions for macrophytes. More localised impacts occur where specific pressures are introduced that affect only parts of the system. For example, hard bank reinforcement will directly affect wave behaviour and sediment transport in the immediate vicinity, but its influence will rapidly diminish along the direction of longshore drift.

6.4.2 Classes of engineering and activity pressures

Because of the variety of lake environments and specific cultural uses of catchment and lake systems across Europe it is necessary to consider both engineering and non-structural ‘activity-related’ pressures in relation to hydromorphological assessment. Pressures on both the lake basin and upstream catchment area are considered, e.g. the extent of intensive land–use in the upstream catchment (where alterations to runoff and sediment yields rather than nutrient pressures are relevant). Similarly, activities such as recreation and boating do not necessarily result in engineering interventions, but may still induce wave wash and re-suspension of bed sediments with potentially important ecological consequences.

Table 3 describes the list of specific pressures which have been grouped into broad categories. Use of broad categories means that multi-faceted developments such as harbours or marinas do not require their many different forms to be described. The definitions of the engineering activities and hydromorphological pressures presented here are consistent and compatible with desk-top, remote sensing and field data collection with recognised survey methods such as Lake Habitat Survey (Annex F) and with wider European efforts on standardisation through CEN.

Table 3 — Hydromorphological pressures and lake features likely to be affected

Pressure type	Specific Pressures	Description	Lake features likely to be affected (Table 2)
Water level control and regulation	Water level adjustment (active)	Active raising or lowering of water level through outflow control structures such as dams, sluices and weirs or by water abstraction outlets or augmentation from inter-basin transfers of water. In active schemes water levels are further manipulated for hydropower, flood control, water supply, amenity use, irrigation, fish production, etc.	1,2, 3, 4, 5, 6, 7, 8, 9, 10
	Raising or lowering (passive)	Describes the situation where water levels are changed by either raising or lowering of the water level relative to the natural condition as a result of the imposition of a control structure or outflow channel but without further manipulation through active control.	1,2, 3, 4, 5, 6, 7, 8, 9, 10
Structural shore zone alteration	Shore reinforcement – hard bank engineering	Consolidated materials such as concrete and steel sheet piling to stabilise shorelines (does not include water control structures, but does include docks and marinas made of hard engineering materials). Does not include use of rip-rap for bank-toe protection.	2, 7, 8, 9, 10
	Shore reinforcement – soft bank engineering	Stabilisation of the shoreline using 'soft' materials including basket-work, planted saplings and live willow, dumped natural debris (to renourish sediment supply) and degradable synthetic materials. Also includes earth-moving where re-sectioning and re-profiling takes place. This category can also be used to represent slipways and informal boat launching sites.	2, 7, 8, 9, 10
	Flow and sediment control structures	Range of engineering structures, which may be composed from various consolidated materials designed to afford shelter for ports, harbours, marinas and anchorage sites. Structures may be aligned to the shore in different ways depending on the fetch conditions at each site. Groynes are specifically introduced to counter the effects of longshore drift and promote the retention of beach sediments (especially sand). Farm walls projecting into the lake for cattle management typically do not perform this function.	2, 3, 4, 7, 8, 9, 10
	Piled structures	Range of constructions raised on one or more foundation structures extending out into the lake, e.g. bridges, piers, jetties and fishing platforms. Piles typically support platform structures.	3, 5, 7, 8, 9, 10
	Outfalls and off-takes	Outfalls are artificial discharge structures, e.g. turbine releases from hydropower stations or cooling releases, whereas off-takes are installations for abstracting water from a lake or reservoir. They may be shore-based or constructed in the lake bed as with reservoir water release towers.	1, 3, 5, 6, 8, 10
	Flood embankments	Artificial bank of earth or stone created to prevent inundation of riparian areas and valuable infrastructure.	1, 6, 9, 10

Table 3 *(continued)*

Pressure type	Specific Pressures	Description	Eco-geomorphic features likely to be affected (Table 2)
Within-lake structures and activities	Land claim	Engineering activities enclosing shore and littoral areas with impermeable banks followed by infilling for use by agriculture, housing and other infrastructural activities.	1, 2, 3, 5, 7, 8, 9, 10
	Dumping	Dumping of materials, e.g. rock and soil debris, construction materials, landfill waste.	1, 2, 3, 5, 7, 8, 9, 10
	Sediment extraction	Extraction of substrates, most commonly associated with dredging to facilitate navigation, or aggregate extraction or habitat management.	1, 2, 3, 5, 7, 8, 10
	Causeway	Physical barrier projecting from the shore lakewards whose foundations extend to the lake bed and where gaps in the structure represent < 20% of the total length. Typically used to support infrastructure such as roads, railways and pipelines.	1, 2, 3, 4, 5, 7, 8, 9, 10
	Floating and tethered structures	Multiple forms including pontoons, floating platforms, aeration systems and cages/structures used for commercial fish farming.	3, 5, 10
	Macrophyte manipulation	Macrophyte management can be commercial harvesting of reeds, or removal of vegetation growth to clear water for recreational activities e.g. sailing, swimming and fishing.	3, 5, 8, 10
	Dense concentrations of boat moorings	Anchorage sites, typically concrete or metallic mooring blocks positioned in the littoral zone to which boats are attached. Often associated with marina and harbour developments and sheltered bays or leeward of headlands.	3, 5, 7, 8, 10
Lakeside pressures	Riparian vegetation loss	Loss of natural vegetation cover and structure with implications for shading, sediment, carbon fluxes, etc.	3, 7, 8, 9, 10
	Recreation and navigation	Pressures associated with formal or informal recreation; in the shore zone these include walking, use of recreational beaches, swimming, bank fishing and hunting. Increased lake bank and bed sediment disturbance also associated with boat wash from commercial, ferry and recreational craft, along with increased sediment resuspension. Open water can also be affected by boat fishing, jet ski, waterskiing and pleasure cruising craft, as well as non-motor activities such as sailing.	3, 5, 7, 8, 9, 10, 11
Catchment hydromor-phology	Catchment hydrological regime alteration	Changes to the quantity and dynamics of inflow resulting from water resource development in the catchment including impounding, abstraction, etc.	1, 2, 3, 4, 6, 7, 8, 9, 11
	Alteration to catchment land-use	Percentage of catchment with intensive land-use (e.g. urban, arable or plantation coniferous forestry).	1, 2, 3, 6, 7, 8, 9, 10, 11

6.5 Timing and frequency of hydromorphological assessments

Timing and frequency of a survey will vary among ecoregions, and will depend upon the reason for assessment. Hydrological elements (e.g. water level fluctuations) should generally be recorded at a higher frequency than morphological elements. The timing of a survey will depend upon the technique used. For example, the summer months are more appropriate for field surveys when the full range of vegetation types are present and the seasonally low water level conditions generally means that all features within the shore zone can be described with confidence. By contrast, more information may be gathered from remote sensing images during winter months when, for example, the trees are not in leaf. Some key limnological processes, such as winter turnover in large deep lakes, require a survey at the appropriate time of year.

The frequency of a survey should ideally be linked with the rate of hydromorphological change; this in turn is partly related to the resistance to change and the resilience of the system in terms of recovery from a specific set of pressures. Other survey frequencies may be dictated by specific monitoring requirements, e.g. WFD surveillance monitoring, *Natura* 2000 site monitoring. As a general rule, the interval between surveys should be no longer than 10 years. Where it is clear that there are no pressures, this period may be extended.

6.6 Lake characterisation

6.6.1 General

Background morphological data should be collected as far as possible from reliable existing sources of information. Key data are surface area, lake shoreline length (and hence shoreline development, see Annex C); lake bathymetry and riparian land–cover patterns, all of which are likely to vary according to lake type. Additional relevant information such as the conservation designations (e.g. SAC status) should be noted. Mode of lake formation (if known or inferred) can be recorded on arrival at the water body, or else may be established through contact with the land owner/manager, or through consultation with maps or other documents. Where a field visit is deemed necessary, land owners or the relevant competent authority should also be contacted in advance to ensure access arrangements are in place.

6.6.2 Field sampling

Most hydromorphological assessment will require use of a boat. Bank based surveys are possible but boats provide much greater speed and potential to cover the entire perimeter. A summary of recommended field equipment required to undertake a field-based survey is provided in Annex D.

Technology offers the potential for automated data capture, e.g. using specifically commissioned flights and plane- or helicopter-mounted digital photography systems (stills and video) capable of capturing swaths of shoreline. In principle it is possible to geo-reference these data acquisition systems automatically and apply unsupervised classification systems to quantify the amount and distribution of many shoreline pressures, such as engineering structures or land-cover change.

6.6.3 Bathymetry

The basic building block of lake morphological analysis is the bathymetric survey. Such surveys can be carried out with equipment ranging from the most basic such as ‘weighted-lines’ to sophisticated multi-channel digital acoustic systems linked to GPS (global positioning systems) depending on the specific needs of the survey and the resources available. For maximum utility, a bathymetric map should show the position of the shoreline (depending on seasonality), the positions of islands and bars, and a sufficient coverage of the water area to locate and record depth soundings accurately. The survey design should account for the physical size of the system under investigation.

6.6.4 Water column and lake bed characterisation at an Index Site

At least one determination of water transparency, thermal structure and dissolved oxygen profile should be made at an Index Site. This is important for determinations of mixing volume and residence time and to characterise lake bottom sediments. The Index Site should be positioned over the deepest part of the lake, located from an existing bathymetric map or by a brief sonar survey.

The measurements that should be taken include:

a) dissolved oxygen and temperature profiles - these are considered important because many European lakes with mean depths greater than 3 m to 5 m display thermal stratification during the summer, so that the vertical distribution of temperature and dissolved oxygen (DO) characterises the pelagic habitat;

b) water transparency - depends on the amount of dissolved and particulate substances, algae and suspended sediment concentrations in the water and can be estimated using the Secchi disc method;

c) lake bed sediment character in the profundal (or off-shore) zone; sampling strategy will depend on the level of detail required but could be either a grab or core sample, used to describe profundal sediment character.

Index Site measurements usually require the use of a boat.

6.6.5 Shore zone assessments

Shore zone hydromorphological assessments can be conducted at a broad or fine scale. GIS and remote sensing approaches are conducive to continuously survey around the lake perimeter and can help with the development of an effective asset register of hydromorphological pressures (especially engineering structures) distributed along the shore zone. However, remote sensing of the shore zone is not always possible where a tree canopy obscures shoreline features. Field methods can undertake similar assessments as demonstrated in the ‘whole-lake’ perimeter survey of LHS, which quantifies the extent of a broad range of pressures and natural habitats. In LHS this is complemented by the addition of 10 randomly located, but evenly spaced quadrats (termed Hab-Plots) which are sampled around the perimeter of the lake yielding very detailed information on morphology, vegetation structural characteristics, nature and condition of the substrate and proximal human pressures.

6.6.6 Lake site activities/pressures

Information on the presence, extent and intensity of pressures acting within the lake should be recorded. Categories include: bridges, causeways, fish cages, navigation, dredging, dumping, macrophyte control, motorboat sporting activities, non-motor boat activities, angling from boat and shore, non-boat recreation/ swimming, litter, nuisance species, fish stocking, wildfowling, military activities, power lines, liming and surface films (see Table 3).

6.6.7 Hydrology

Data on lake hydrological regime are fundamental to the characterisation process through the construction of water balances but are often lacking. Some countries have comprehensive monitoring networks and sophisticated archives of hydrological data, while others have sparse long-term water level records and data management systems which are difficult to access (though the situation is much better for reservoirs).

In the absence of adequate hydrometric data basic hydrological information can still be inferred. The principal use of the water body may be identified as belonging to one of the groups: hydropower, domestic, industrial and agricultural water supply, flood control, navigation and amenity. The water body type is recorded in relation to whether the lake is natural, artificial or modified (Annex A). The height of raising or lowering and of the principal retaining structure is recorded if applicable. The presence of upstream impoundments, flow diversions into or abstraction from the lake and any tidal influence should be noted. The daily and annual water level fluctuation should be estimated, and a list of all hydrological structures tallied. The geometry and width of the outlet are also noted. A summary of these basic attributes is provided in Annex E. For hydrological assessment, daily records of water levels are recommended.

6.6.8 Sedimentology

Most lakes in geological terms are transient systems undergoing a natural process of infilling from sediments derived from catchment and bank erosion sources (allochthonous) or supplied from chemical and biological processes (autochthonous).

From a hydromorphological perspective it is important to establish the natural sediment budget of a lake system and to determine the extent to which patterns of erosion and sedimentation are affected by human activity. There are well-established palaeolimnological techniques available for doing this. Catchment land-use changes are commonly linked to increased sediment supply, whilst pressures such as increased water level fluctuations are likely to result in increased rates of bank erosion.

7 Reporting hydromorphological assessment and classification

7.1 General

The procedure for assessing hydromorphological survey data will vary according to the purpose of the assessment, e.g. assisting with local lake management, guiding the rehabilitation of degraded sections of the shoreline or lake basin, or for identifying lakes with minimal alterations and meeting the requirements of high ecological status under the WFD.

This European Standard takes account of the present level of sophistication of national hydromorphological assessment methods and provides guidance to enable a basic assessment of the extent of deviation from reference conditions. It is intended that further development of national methods and inter-comparison of the results that they produce will lead to harmonised assessments based on type-specific occurrence of physical features within a lake.

The extent of deviation from reference condition is used to place a lake water body into one of five classes according to its degree of modification (Table 4). This is achieved by assessing data from maps, remote sensing data or field survey methods to determine how far the five criteria in 5.3 are met.

7.2 Data presentation

For strategic reporting purposes, a single composite assessment of a lake is likely to be a necessity. However, for operational or monitoring purposes it will be essential to keep elements of the assessment (i.e. riparian, shore zone and pelagic/profundal zones) separate. An ability to map these separate components and specific segments of the shore zone or sub-basins within the open-water zone will be important to maximise use of the information. With the use of GIS 'layering' technology, it is possible to present information at different scales and levels of integration, including the relationship between hydromorphological features and artificial modifications.

Although the WFD does not require hydromorphology to be reported in five classes, this European Standard recommends the use of an equivalent five-band condition class classification system in which reference conditions or near reference conditions (high status) are defined as Class 1, and the remaining classes as 2 to 5. For the purposes of this standard, use of the WFD terms such as ‘good status’ and ‘moderate status’ should be avoided as they are linked entirely to the WFD assessments of biological conditions (except at HES). Where maps of hydromorphological quality are produced, it is recommended that the terminology and colours shown in Table 4 are used as recommended in EN 14614.

Table 4 — Hydromorphological condition (modification) classes recommended for reporting purposes

Score (Class)	Name	Map colour
1	Near-natural	Blue
2	Slightly altered	Green
3	Moderately altered	Yellow
4	Extensively altered	Orange
5	Severely altered	Red

The names used to describe each class have been deliberately chosen to be different from terms used in the WFD to emphasise that classifications made using this standard are unrelated to classifications of ecological status made for the WFD. Although the five colours recommended in Table 4 are the same as those used in the WFD, they are also used routinely for reporting other (non-WFD) aspects of environmental quality.

8 Training and quality assurance for survey and assessment

8.1 General

Surveyor training is essential to ensure consistency in recording the hydromorphological attributes of lakes and their associated pressures. Surveyors should have a background in environmental science, but they should not normally be expected to have specialist knowledge of plant identification or geomorphology.

Training should be structured to cover aspects such as:

— safety issues;

— planning surveys, including issues of access and permission;

— recognising features and pressures;

— accurate completion of recording forms;

— how to compile a series of reference photographs;

— how to collect and interpret non-survey data – historical maps, aerial photos;

— for use of digital databases, GIS systems and remotely sensed data sources, operating staff must be suitably experienced and skilled in data handling protocols and familiar with appropriately up to date software.

Training should:

— incorporate a certification system;

— include regular refresher courses;

— be carried out over a wide range of lake types (in the absence of this, certification may in some instances only be valid for the range of lake types experienced during the training);

— be fully supported by manuals and other teaching aids (e.g. videos).

Procedures should be put in place to test the results obtained by different surveyors on the same lakes and on particular stretches of shoreline. If a surveyor consistently records results which vary from those recorded by others, the problem should be rectified by additional training.

8.2 Training manuals

Manuals should present basic information on hydromorphological principles, general background on the development of the method, and unambiguous information on how to carry out the survey, with accurate descriptions of the features to be recorded. Text should be supported by illustrative material (e.g. photographs, videos, DVDs, CDs) to illustrate what features look like (not just the typical, but the full forms which might be encountered). Photographs and other illustrations must not be used without full copyright permission.

Manuals should include guidance on:

— how to transfer information from field sheets to databases;

— how to obtain and interpret information from maps;

— how to apply the results to assessments of hydromorphological quality;

— how to apply quality assurance systems;

— issues of Health and Safety;

— matters relating to access to lakes.

8.3 Data entry and validation

It is important that no errors occur when transferring data from field sheets to databases. Suitable quality assurance methods should be used, such as double entry of data onto databases by two different operators, followed by tests to ensure the results are identical. Random testing should also be carried out on hydromorphological quality assessments and other applications to ensure that consistent results are obtained from the same data. Data corruption can occur when systems are up-dated or during information transfer; some form of checking procedure is required following such changes.

Technologies enabling field survey data to be directly entered into database systems should be regularly reviewed and adopted as appropriate.

Annex A
(informative)

Common European lake types defined by mode of formation

Table A.1 — Common European lake types

Lake formation types	Characteristic features
Natural glaciated	
Ice-scoured rock basin (valley floor)	Long, narrow and straight sided, reflecting the form of a valley glacier
Ice-scoured rock basin (corrie / cirque)	Typically small, circular and located at higher altitudes (variously known as tarn or cirque lakes)
Glacial-scoured bedrock (knock and lochan)	Low-lying, occupying rock basins of irregular form
Kettlehole basin (detached ice block)	Generally circular depressions left on level surfaces when ice, formerly covered by drift, melts
Glacial drift (moraine or outwash dam)	Formed by cross-valley moraine or drift deposits reworked by rivers draining from melting ice
Natural non-glaciated	
Depression in blanket bog	Often irregular planform, and often dry during summer months
Fluvial processes on valley floor	Created by natural fluvial processes e.g. valley-floor ox-bow lakes
Naturally blocked valley	Lake created by natural dam built up by wind, waves or landslides
Depression in coastal windblown sand	Depression in sand in coastal areas
Chemical weathering	Formed in limestone terrain by solution
Volcanic lake	Variety of forms such as a crater lake
Others	Specify e.g. beaver dams
Artificial and Modified	
Impoundment	Reservoir created by damming a river valley, or dammed transitional / coastal waters
Flooded excavation in hard rock	Flooded quarry
Flooded excavation in drift	Flooded sand, gravel or peat-cut excavation
Bunded	Artificial bowl
Modified	This category applies to natural lakes significantly altered by addition of structure (dam, barrage, etc.) raising the lake by more than 1 m or by outflow engineering works resulting in significant lake draw-down (water level lowering e.g. for land claim).

Annex B
(informative)

Lake shore and bottom natural and artificial substrates

Table B.1 — Lake shore and bottom natural and artificial substrates

Natural substrates	
Material/substrate	**Description**
Bedrock	Underlying solid rock, *in situ*
Boulder	Large rocks ≥ 256 mm in diameter
Cobble	Loose medium gravels ≥ 64, < 256 mm
Pebble	Loose small gravels ≥ 2, < 64 mm
Sand	Fine grained particles ≥ 0,06, <2 mm in diameter (gritty when rubbed)
Silt	Very fine, smooth material > 0,004 , <0,06 mm in diameter
Clay	Sticky cohesive clay material < 0,004 mm (can be rolled without crumbling)
Earth	Crumbly soil, rare as a predominant in lake substrate, may occur on poached banks
Peat	Lake bed formed of organic matter derived from decayed vegetation, rare, usually dark brown or black
Marl	Fine calcareous material deposited in hard-water lakes (crumbles when rolled)
Artificial substrates	
Material/substrate	**Description**
Concrete	Cemented revetment, possible on bank face for reinforcement
Sheet piling	Vertical, interlocking steel sheets (e.g. corrugated iron), possible on bank face for reinforcement
Wood piling	Wooden poles, or vertical or horizontal planks, usually protecting bank face
Gabion	Stones in wire baskets, to protect banks from erosion
Brick/laid stone	Bank protection that includes cemented walls (e.g. brick walls) or uncemented laid stones
Rip-rap	Boulders (normally quarried, square and of similar size) purposely tipped or laid along bank face for erosion protection. Includes uncemented block stone/boulders compacted into soil banks.
Tipped debris	Discarded material, e.g. rubble, metal, wood, old cars and excavated soils and other minerals. May be intentional or un-intentional.
Fabric	Synthetic (usually permeable geotextile) bank protection fabric, often used in conjunction with soil back-fill; always non-biodegradable, e.g. plastic
Bio-engineering materials	Live or dead plants or non-synthetic materials used to protect banks from erosion and/or to restore bankside habitat (e.g. willow stakes, biodegradable matting and planted reeds)

Annex C
(informative)

Definitions and formulae for lake morphometric parameters

Table C.1 — Definitions and formulae for lake morphometric parameters

Parameter (units)	Code	Derivation
Maximum length (m)	l	From topographic map
Maximum width (m)	w	From topographic map
Shoreline length (km)	L_o	From topographic map
Lake area (km^2)	A	From topographic map
Lake volume (km^3)	V	From bathymetric survey, or Log(1 000*V) = 0,134 + 1,224*log(A) + 0,332*log(RDA)
Mean depth (m)	D_{mv}	From bathymetric survey, or D_{mv} = 1 000 * V/A
Maximum depth (m)	D_{max}	From bathymetric survey, or Log(D_{max}) = -4,202 + 4,558*(1 000*V)^{0,1} – 1,008*log(A)
Altitudinal range of drainage area (m)	dh	From topographic map
Drainage area (km^2)	ADA	From topographic map
Volume to drainage area ratio (dimensionless)	VDA	VDA = V / ADA
Catchment to lake volume ratio (Schindler's Ratio) (dimensionless)	Sr	Sr = V / (ADA + A)
Relief of drainage area (dimensionless)	RDA	RDA = dh / (√ADA)
Relative depth (dimensionless)	D_{rel}	$D_{rel} = (D_{max} * \sqrt{\pi}) / (20 * \sqrt{A})$
Depth of wave base (m)	D_{wb}	$D_{wb} = (45,7 * \sqrt{A}) / (21,4 + \sqrt{A})$
Dynamic ratio (dimensionless)	D_R	$D_R = (\sqrt{A}) / D_{mv}$
Volume development (dimensionless)	V_d	$V_d = 3 * D_{mv} / D_{max}$
Shoreline development (dimensionless)	L_d	$L_d = L_0 / (2 * \sqrt{(\pi * A)})$
Specific runoff (m^3 m^{-2} per year)	SR	From hydrological measurements/topographical maps
Theoretical water discharge (m^3 yr^{-1})	Q	Q = ADA*SR
Theoretical retention time (yr)	T	T = V/Q
Areas of erosion and transportation (fraction, %)	BET*	BET = 0,25 * D_R * $41^{0,061/DR}$ (if A>1 km^2)
Areas of accumulation (fraction %)	BA	BA = 100 – BET

If A<1 km^2, then BET = 1-(A((D_{max}-D_{wb})/(D_{max}+D_{wb}*EXP(3-$V_d^{1,5}$)))$^{(0,5/Vd)}$)/A

Three groups of morphometric parameters (size, form and special) can be recognised in lake morphometry studies. Size factors equate to the basic dimensions of a lake and include area, water depth and shoreline length. Form factors are second-order metrics e.g. mean water depth and shoreline development. Finally, special factors are those from which behavioural characteristics of the system can be inferred – examples include volume development (V_d), and the dynamic ratio (D_R). Morphometric analysis can also provide the basis to model key aspects of lake ecosystem functioning and predicting whole-system response. Based on Hakanson (2004).

Annex D
(informative)

Equipment required for a field-based hydromorphological survey

Table D.1 —Field equipment

Equipment	Details	Mode of surveying the lake perimeter	
		Boat based	Shore based
Field survey forms, guidance sheet, pencils	If available, coloured pencils are ideal for sketching onto diagram	✓	✓
Access to national/regional lake database	Electronic repository of bathymetric survey, land cover, morphological inventory	✓	✓
Topographic base map and/or recent aerial photograph	Most recent edition at the appropriate scale	✓	✓
GPS	For recording locations of various sites, e.g. Hab-Plots	✓	✓
Binoculars	For identifying habitats and pressures from a distance	✓	✓
Camera	For taking photographs of the site	✓	✓
Tape measure (or rangefinder)	For measuring distance to shore	✓	✓
2 m ranging pole	For identifying underwater substrates by probing, especially when water is turbid; also useful for measuring shallow water depths	✓	✓
Bathyscope	For examining underwater substrates and vegetation; especially useful when estimating vegetation structure and Percent Volume Inhabited (PVI)	✓	✓
Rake and grapnel	For collecting samples of underwater vegetation when water depth and/or turbidity make it impossible to view the lake bed	✓	✓
Boat with anchor and suitable safety equipment	Use a boat for the survey if possible	✓	×
Echo-sounder or weighted cord	For measuring water depth in different situations	✓	×
Secchi disc	For measuring water clarity and light transmission	✓	×
Dissolved oxygen/ temperature meter, or water sampler capable of taking samples at discrete depths	For measuring profiles of dissolved oxygen and temperature at the Index Site	✓	×
Grab / coring device	Used to characterise profundal zone sediments or the ‘offshore’ sediment character in the case of shallow lakes	✓	×

NOTE Ensure that adequate measures are taken to prevent transmission of pathogens/invasive species (e.g. zebra mussels) between water bodies.

Annex E
(informative)

Checklist of factors relevant to assessing hydrological regime

Table E.1 — Checklist of factors

This checklist of factors is part of a risk assessment framework that operates in the absence of medium to long-term hydrometric (water level) records that would capture the alteration of a lake's hydrological regime.

Factors	Explanatory description
Natural hydrological type	*European lakes will generally fit into the following natural hydrological types (broadly related to their water balances):* permanent lakes; endorheic (terminal) lakes; flow-through lakes (dominated by surface runoff); groundwater-fed lakes; precipitation-fed lakes
Hydrological modification	Natural (unmodified); natural (raised); natural (lowered)
Principal use(s)	Hydropower; water supply (domestic, industrial and agricultural); flood control; navigation; amenity or none
Water balance change	Vertical range of water level fluctuation (m), change in storage volume and change in residence time and stratification behaviour
Inflow structures	Barrage, weir, sluice, lock, channelised watercourse, outfall, intake, by-pass channel, sediment lodge (for all of these a fish pass may or may not be present).
Outflow structures	Dam, barrage, weir, sluice, lock, channelised watercourse, intake (for all of these a fish pass may or may not be present).
Catchment hydrological regime alteration	Changes to the quantity and dynamics of inflow resulting from water resource development in the catchment including impounding, abstraction, etc.
Alteration to catchment land–use	Percentage of catchment with intensive land–use (e.g. urban, arable or plantation coniferous forestry)

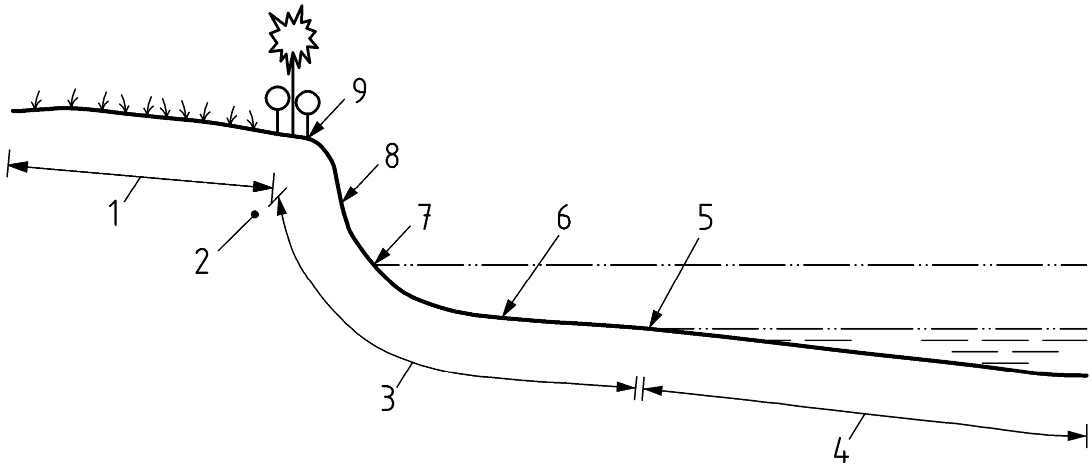
Annex F
(informative)

Explanatory account of the Lake Habitat Survey (LHS) method

Lake Habitat Survey (LHS) is a systematic protocol for characterising the physical condition of lakes extending the habitat assessment approach pioneered in the Environmental Monitoring and Assessment Program (EMAP) of the US Environmental Protection Agency and the River Habitat Survey (RHS) of the Environment Agency in the UK. The protocol has been extensively tested in a range of European countries including the UK, France, Poland, Ireland, the Netherlands, Serbia, Montenegro, Italy and Finland. A training and accreditation scheme was completed in 2008 to maximise quality assurance in data collection and data management.

The LHS approach is principally field-based, although it takes advantage of remote sensing and map-based information wherever these are appropriately scaled and suitably up-to-date. The survey fundamentally comprises two scales of investigation. The first provides detailed observations on the physical nature of the riparian, shore and littoral zones at a minimum of 10 large quadrats (Hab-Plots) evenly spaced, but randomly located around the perimeter of the lake (Figure F.1). Vegetation and macrophyte structure, morphology, shore and littoral substrate types are all recorded along with information on the nature of any alterations and other pressures present. The second set of observations occurs over the whole lake and provides information on riparian land–cover, shore zone engineering and the presence of natural meso-habitats and features of ecological interest such as wetlands. The extent and intensity of pressures such as sediment dredging or dumping are recorded over the entire lake. Water body use, hydrological regime and the type and operational characteristics of any water control structures are also recorded as far as possible. Whilst the survey can be conducted either from the shore or by boat, the boat method is strongly encouraged because it permits the collection of water column data at the Index Site (maximum depth, water clarity, temperature and DO profiles).

Data collection is structured through the provision of a formal survey protocol with extensive supporting documentation and photographic gallery. Survey data are archived and manipulated through a comprehensive relational LHS database. Key outputs from the survey include summary metrics relating to the degree of site modification, the Lake Habitat Modification Score (LHMS), and a measure of diversity and naturalness of physical structure through the Lake Habitat Quality Assessment (LHQA). The survey method also provides the input data required for WFD characterisation and classification decision-support tools.



Key

1 riparian zone with vegetation/land use
2 bank edge
3 shore zone
4 littoral zone
5 current waterline
6 beach
7 high waterline
8 bank face
9 bank top (with bank top vegetation)

NOTE In LHS the term ‘littoral zone’ has been standardised to a 10 m observation length.

Figure F.1 — Definitional illustration of LHS Hab-Plot components

Annex G
(informative)

Remote sensing and GIS for lake hydromorphology data capture

Survey and mapping using remote sensing (aerial photographs, satellite images, etc.) offers an alternative, or at least complementary, approach to hydromorphological characterisation based on field survey. Remote sensing based surveys lend themselves to automation, especially when combined with geographical information systems, because whilst the initial investment in data capture and data management systems may be expensive and technically challenging, repeat surveys can be updated in a relatively timely and cost-effective manner (depending on the tools and skills available in the agency involved).

Remote sensing typically provides data over large areas, involves data capture within a relatively short space of time and yields continuous rather than point-based observations, all of which may offer logistical advantages over field-based surveys. However, as with all surveying techniques there is a trade-off between the spatial resolution of data capture and its cost and transferability. It must also be recognised that some hydromorphological features (such as bank reinforcement) are much more easily identified and mapped (manually or using automated classification methods) than others, such as changes in the quantity and nature of littoral substrates. Reflectance from water is typically very low, with most of the incident radiation being absorbed rather than reflected to a remote sensor. Consequently, bathymetric information, substrate type and macrophyte coverage in the littoral zone are problematic. The greatest confidence for mapping hydromorphological alteration is associated with estimating land-cover types and identifying engineering structures.

In relation to the use of remote sensing data and GIS databases the following can be concluded:

— remote sensing (especially digital aerial photography and multispectral data) provides valuable information on geomorphology, engineering pressures, shore zone habitats and land cover; these data also help to set a lake in context with its catchment and wider landscape setting;

— geo-spatial databases offer a framework for data storage and for mapping both present hydromorphological conditions and patterns of change (in time and space); the advantages of using such systems are greatest where there are many lakes to be surveyed and the individual systems are large;

— care should be taken to extract the maximum value from existing information (maps, databases, etc.), new field survey and specifically commissioned remote sensing surveys should be required only where rapid large-scale hydromorphological alterations are under way;

— the specific objectives, scale of the investigation and resources available should guide the selection of particular approaches, and the complementarities of desk-top/remote sensing techniques and field survey control should always be considered.

There are already several established methods for hydromorphological survey primarily based on remote sensing, e.g. the method developed for Landesamt für Umwelt, Naturschutz und Geologie Mecklenburg-Vorpommern (Germany).

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