Final Report Project WFD40

DEVELOPMENT OF A TECHNIQUE FOR LAKE HABITAT SURVEY (LHS): PHASE 1

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Executive Summary

The importance of European lakes for conservation and resource use is widely recognised, yet a systematic procedure for classifying lake characteristics and habitat quality is lacking. The Water Framework Directive (WFD) requires the assessment of 'ecological status', in which the hydromorphological (or physical) features of standing waters is a key management consideration. The WFD has acted as an important driver for the development of a Lake Habitat Survey (LHS) method that can systematically characterise and assess the physical habitat of lakes and reservoirs. This report describes Phase 1 of the project titled "Development of a technique for Lake Habitat Survey (LHS)" (project code WFD40). Funding was provided primarily by Scotland and Northern Ireland Forum for Environmental Research (SNIFFER) and Scottish Natural Heritage (SNH). This project was carried out by the Environmental Systems Research Group, University of Dundee, hereafter referred to as the contractors.

Beyond immediate WFD applications, LHS has a potentially valuable role in systematising the monitoring and management of conservation interests, e.g. monitoring internationally significant habitats, such as Special Areas of Conservation, assessing the condition of sites notified as Sites of Special Scientific Interest and wider applications in environmental impact assessment and restoration programmes. From the outset of the project it was envisaged that the LHS protocol could contribute to the work of a CEN (Comité Européen de Normalisation) Task Group on the development of a guidance standard for assessing the hydromorphology of standing waters.

A scoping study carried out by Rowan *et al.* (2003) involved a literature review, consultations with environmental and lake management experts throughout Europe, and produced a prototype LHS scheme to be tested. This Phase 1 study reports the further development of LHS, including a comprehensive field testing programme carried out in the UK during the summer of 2004. As part of the development process, the aim was to restrict field data collection to those data that cannot readily be obtained from desk-based resources. Detailed information on physical habitat (e.g. substrate types and riparian vegetation), is recorded at a number of sampling plots around the lake shore. Shoreline and in-lake characteristics and pressures, such as angling, erosion, and grazing, are recorded over the entire lake. Data on hydrological regime are obtained where possible.

Two levels of LHS were developed. The full version (LHS) involves a boat-based deployment with 10 sampling plots (Hab-Plots) located around the perimeter of the lake and profiling of temperature, oxygen and light penetration at the deepest point of the lake (Index Site). An abridged version (LHS_{core}), designed for rapid deployment, is foot-based, uses only four Hab-Plots and omits the Index Site measurements. The contractors tested both full LHS and LHS_{core} surveys at 10 principal test sites across Great Britain while, through collaboration with UK environment and conservation agencies (SEPA, EA, SNH and EHS), LHS_{core} was deployed on a total of approximately 300 lakes in Scotland, England, Wales and Northern Ireland. 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) were also developed. Methods of data interpretation for the WFD, Habitats Directive, and general ecological assessment were also investigated using results from the 2004 surveys.

The potential of remote sensing and geo-spatial databases (collectively desk-based data sources) in meeting LHS survey requirements was also reviewed. It was concluded that some desk-based data sources could provide useful metrics for LHS, in particular the Great Britain Lakes database (GBLakes), and that previewing an aerial photo prior to arrival at the lake was useful to orient surveyors in the field. Aerial photography and satellite imagery was able to provide useful catchment and riparian information, but shore and littoral information and human pressures were less confidently observed. The present inconsistencies in data availability between agencies and other potential surveyors may prevent further desk-based sources from being used extensively in LHS.

The results of the survey indicated that a high degree of reproducibility (70 - 90 %) can be achieved between different surveyors examining the same features. The introduction of a comprehensive training and accreditation programme should further ensure high quality in the data recorded. Comparison of the boat-based versus shore-based approaches indicated that the former was preferable overall owing to ease of access, speed of deployment, and the ability to gain Index Site information. Analysis also confirmed that a minimum of 8-10 Hab-Plots are required to capture habitat variation on heterogeneous lakes. LHMS and LHQA scores were obtained for the 10 principal test sites, and LHMS scores were also derived for a sample of 34 environment and conservation agency sites. The LHMS has clear applications as a WFD screening tool, for identifying hydromorphological quality elements at reference condition lakes and for identifying physical measures for the improvement of lake ecology (programmes of measures). The LHQA provides a measure of site naturalness and habitat complexity (which may be associated with biodiversity), and has wider applications for site management.

Following the inaugural field season of LHS a workshop was held to review the protocol, with expertise drawn from participants from the UK, Europe and the US. Revisions are discussed in this report, and the field form has been amended and is included in the appendices. The next phase in LHS development requires the following: (i) establishment of a training program to improve surveyor confidence and data quality, (ii) deployment of the revised LHS, including wider geographical application across European regions (eventually this should encompass the full range of biomes), (iii) further testing of quality indices for the WFD and other requirements, in particular exploring the linkages between ecological function and hydromorphological alteration, and (iv) the continued development of an LHS database which can be queried to extract information and which is accessible to relevant stakeholders.

Keywords: Lake Habitat Survey, Hydromorphology, Water Framework Directive, Lake Habitat Modification Score, Lake Habitat Quality Assessment

PART ONE: INTRODUCTION

1.1 Overview

The Water Framework Directive (WFD) has acted as an important driver for the development of a Lake Habitat Survey (LHS) method that can systematically characterise and assess the physical habitat of lakes and reservoirs (collectively known as standing waters). The LHS can also play an important role in 'condition monitoring' for designated sites in the UK, as well as systematising environmental impact assessment and supporting restoration programmes for degraded lake ecosystems.

From the outset of the project it was envisaged that the LHS protocols developed could contribute to the foundations of a European standard for assessing the hydromorphology of standing waters under the aegis of CEN (Comité Européen de Normalisation). However, in the current version of LHS reported here, many aspects are exclusively UK-oriented, such as references to existing UK data sources. This approach was taken for ease in testing the survey in the United Kingdom, but LHS is designed such that it can be modified for use elsewhere.

A scoping study carried out by Rowan *et al.* (2003) involved a literature review, consultations with environmental and lake management experts throughout Europe, and produced a prototype LHS scheme to be tested. This Phase 1 study reports the further development of LHS, including a comprehensive field-testing programme carried out in the UK during the summer of 2004. As part of the development process, the aim was to restrict field data collection to those data that cannot readily be obtained from desk-based resources, such as conventional maps, electronic databases and remote sensing. The LHS approach is based on a combination of a small number of detailed plot observations along with a collection of whole-lake metrics. The scheme builds upon lake habitat characterisation techniques developed in the United States by the Environmental Mapping and Assessment Program (EMAP) (Baker *et al.,* 1997) as well as those developed in the River Habitat Survey (RHS) in the UK (Fox *et al.,* 1998).

The WFD stipulates that surface water bodies, including lakes, should achieve good ecological and chemical status (pollutant levels) by 2015. Good Ecological Status (GES) requires hydromorphological conditions supporting <u>at worst</u> 'slight changes' in the composition and abundance of key biological quality elements (phytoplankton, macrophytes and phytobenthos, benthic macroinvertebrates and fish fauna) relative to the appropriate natural reference condition termed High Ecological Status(HES). Hydromorphological quality elements comprise morphology and hydrology, and are described in Annex V of the WFD as follows:

Morphological conditions: lake depth variation, quantity and structure of the substrate, and both the structure and condition of the lake shore zone, correspond totally or nearly totally to undisturbed conditions.

Hydrological regime: quantity and dynamics of flow, level, residence time, and the resultant connection to groundwater reflect totally or nearly totally undisturbed conditions.

It is proposed that LHS might be used to describe the hydromorphological reference conditions (HES) for lakes, and to determine the characteristics of hydromorphology that support the biological elements for varying levels of ecological status (Good, Moderate, Poor and Bad). It may also aid in the identification of remediation needs in WFD programmes of measures where the ecological status is less than good. Beyond the WFD, LHS has potentially important applications in legislation such as the EC Habitats Directive which, for example, targets the management of Special

Areas of Conservation (SACs), and in the UK's Common Standards Monitoring programme. The latter aims to produce standardised and consistent methods for assessing the condition of features that SACs and SSSIs (Sites of Special Scientific Interest) are designated for. LHS is also required for general water resources management and environmental impact assessment.

For LHS to be widely adopted as an operational tool, the method needs to be of value to the user community. Accordingly, it was necessary to develop summary metrics termed the Lake Habitat Modification Score (LHMS) and the Lake Habitat Quality Assessment (LHQA) analogous to the HMS and HQA used in RHS. The metrics developed in the present study are provisional and subject to change and further investigation is required to determine the relationships and thresholds between biology and hydromorphological disruption. This will require calibration with biological data (*cf.* Logan and Furse, 2002).

1.2 Review of existing methods

The LHS drew significant guidance from lake monitoring protocols in the United States (US). No strategic monitoring programme for lakes was present in the US prior to the introduction of the Federal Clean Water Act of 1972. This legislation imposed similar requirements in America to that which the WFD requires in Europe, i.e. the assessment and monitoring of the condition of standing waters. However, the variety of methods subsequently introduced and the variable quality of the resulting data necessitated a more coordinated response (Johnson, 1989). Accordingly, the US Environmental Protection Agency developed the Environmental Monitoring Assessment Program (EMAP), within which the Surface Waters Program (responsible for both rivers and lakes) produced the Field Operations Manual for Lakes (FOML). This was the product of a four-year development and testing programme (1991-1994) involving both state level and federal agencies (Baker *et al*., 1997).

The FOML provides protocols and sampling strategies for a comprehensive range of biological, water quality and hydromorphological data. With regard to biological data, field and data management procedures are described for variables such as chlorophyll *a*, water chemistry, diatoms, zooplankton, macro-benthos, fish assemblages and birds. Paulsen *et al.* (1997) suggest that physical habitat alterations cause more degradation to aquatic ecosystems in the United States than other human activities. Habitat data provide three important functions in terms of managing lake resources. Firstly, habitat information is essential for defining what pristine (or near pristine) biological assemblages should look like in the absence of various forms of human activity (analogous to HES in WFD). Secondly, habitat evaluation is a reproducible, quantified estimate of habitat condition, providing a benchmark against which to compare future habitat changes. Thirdly, metrics obtained from the survey process aid in the diagnosis of probable causes of ecological impairment in lakes. Kaufmann and Whittier (1997) advocate three key elements to lake habitat assessment including i) characterising the water body through measurement of temperature and dissolved oxygen profiles at a single, nominally representative, location; ii) measurements of the physical structure of riparian, shore and littoral habitats are made at 10 predetermined stations evenly spaced around the perimeter of the lake; iii) finally, macro-scale riparian and littoral habitats are classified and mapped at the whole-lake level.

In Europe there is no equivalent assessment scheme for lakes (Rowan *et al.* 2003). However, the River Habitat Survey (RHS) programme designed by the Environment Agency of England and Wales as a strategic tool for surveying and analysing river habitat quality (Raven *et al.,* 1998) provides a model framework for the development of LHS. The RHS is carried out on foot, with surveyors traversing a 500 m length of a river channel, and detailed observations are taken at 10 equally spaced plots (spot-checks) along the stretch. As part of a 'sweep-up' survey to provide additional information, records of artificial features, special habitats, valley form and land-use are taken along the corridor (Raven *et al.,* 1998).

RHS has become a key tool for UK statutory conservation bodies undertaking site inspections, site condition and feature monitoring within Sites (and Areas) of Special Scientific Interest (SSSIs/ASSIs), Special Areas of Conservation (SACs) and for more general management applications by UK environment and conservation agencies including environmental impact assessment and river restoration programmes. Over 16,000 UK sites now exist within the sophisticated relational geodatabase maintained and updated centrally by the EA's RHS Team in Warrington, NW England. RHS has received further development impetus and international attention due to the regulatory requirements of the WFD. While RHS continues to undergo new refinements (e.g. new survey handbook issued 2003), it has become a central element in the CEN guidance standard for assessing the hydromorphological features of rivers. In the absence of such established methods for lake monitoring, it is anticipated that LHS will contribute to the development of a CEN standard method for assessing the hydromorphology of standing waters.

1.3 Aims and objectives

The overall objectives established at the outset of Phase 1 of the LHS project were:

(a) To design a protocol for LHS based on a combination of data from maps, remote sensing and field survey. This protocol is likely to comprise at least two levels of complexity – a simple version for rapid and extensive use, and a more comprehensive version for intensive use on a limited number of lakes.

(b) To ensure that the framework of LHS is capable of serving a range of operational needs, incorporating suites of lake habitat features for survey and assessment that meet the requirements of the WFD, the Habitats Directive, and monitoring programmes for SSSIs/ASSIs.

(c) With respect to the WFD, to ensure that the survey protocol provides a tool for:

- recording and assessing the hydromorphological characteristics of lakes at high status (reference conditions) and at the good/moderate ecological status boundary;
- effective monitoring of the hydromorphological quality elements for lakes;
- assessing significant impacts on lake hydromorphology;
- enabling the identification of heavily modified water bodies; and
- structuring the sampling and assessment of WFD biological elements.

(d) To test the protocol on a range of lakes of different types in England, Scotland and Wales.

(e) To participate in a European workshop (held in the UK, under the auspices of CEN) to bring together the preliminary findings of Phase 1 and to discuss them in the light of wider European experience.

(f) To revise the protocol on the basis of the field trials and the workshop, and to outline the scope of a second phase of the project. This will include, potentially, refinement of the protocol for wider European use, full development of an LHS database and analytical tools, and establishment of training and accreditation procedures.

The requirement under (d) was to assess the ability of the full LHS survey and reduced version (LHS_{core}) to adequately characterise the physical habitat of standing waters, over a range of lake types and covering a broad spectrum of pressures and impacts. The following specific aims were identified for the field testing exercise:

- To determine the repeatability of LHS in terms of the consistency of entries between surveyors;
- To determine the level of consistency between the boat and foot versions and to highlight the advantages and disadvantages of each;
- To determine the level of consistency between the full and core versions and to highlight the advantages and disadvantages of each, at the same time investigating the optimum number of Hab-Plots;
- To appraise surveyors' perceptions of LHS in terms of confidence in carrying out the survey, the adequacy of the survey, and any aspects that could be improved; and
- To investigate the potential role of remote sensing and other desk-top sourced data for complementing or replacing field survey techniques in LHS.

PART TWO: METHODS

This section summarises the LHS survey approach as used in Phase 1, and provides an outline of the site selection, experimental design, field programme and data analyses that were undertaken between May and September 2004. An overview of the summary metrics developed (LHMS and LHQA) is included along with an explanation of the review process.

2.1 Summary of the survey approach

This section provides an overview of the LHS prototype that was proposed for summer field surveys in 2004. For further details on the methodology, or on the categories used for recording, the reader is referred to the LHS user manual (Rowan *et al.* 2004). The LHS_{core} field form is reproduced in Appendix 2 (Rowan *et al.*, 2004), and the full survey form is shown in Appendix 3. Appendix 5 shows the field survey guidance sheets that were provided with the field forms in Rowan *et al.* (2004). While the protocol has been revised, the instructions here and in the manual concur with those used in Phase 1 of testing in 2004. Amendments were discussed at the final workshop and are described in Appendix 1.

Alternative versions

During the testing and development phase of LHS, some variations in survey comprehensiveness and technique were investigated. Firstly, in the draft LHS protocol, options are given for surveyors to carry out either a boat-based or a foot-based survey, thus dictating the procedures for completing the survey. Secondly, the cut-down version (LHS_{core}) was tested against the full version, the latter involving more sample plots and the collection of additional information. The differences between each of these versions are described in relevant sections of the methodology below.

Background information

Background information should be collated prior to arrival in the field, including morphological data such as depth, surface area, altitude and catchment area. Additional relevant information such as the conservation status (e.g. SSSI, SAC, SPA etc.) is also noted. For most lakes in the UK (with the exception of Northern Ireland), much of this information can be obtained from the GBLakes database (managed by University College London) at http://ecrc.geog.ucl.ac.uk/gblakes. For lakes not included in this database, entries can be derived from a topographic map (the protocol recommends Ordnance Survey (OS) Landranger Series at a scale of 1:50,000). An original OS map is also required to create a sketch of the lake by tracing from the map onto the survey form, which is annotated with information such as the location of sampling plots. Catchment land-use and mode of lake formation are recorded on arrival at the catchment and lake area. Land owners and conservation bodies should also be contacted prior to arrival in the field to ensure access arrangements can be agreed.

Physical attributes at sampling plots (Hab-Plots)

Detailed habitat characteristics are recorded at a number of habitat observation plots (Hab-Plots) evenly spaced around the lake. In LHS_{core} four Hab-Plots are used, while 10 are required for the full LHS survey (see section on ‘rationale for survey design’ at the end of this section for details on the selection of these numbers). Observations for the entire plot are made from the littoral zone, in principle 10 m from the waterline

(Figure 2.1). This can be either from a boat, or by standing at maximum wading depth (0.75 m). This measure is enforced for maximum consistency between boat- and foot-based versions.

The plots are 15 m wide and extend 15 m into the riparian zone from the bank top, and 10 m into the littoral zone from the waterline. The shore zone, if present, lies between the littoral and riparian zone, and may include a beach and/or a bank face. These are separated in most cases by the high waterline. Bank structures can vary from a wave-cut notch to a high vertical cliff.

Riparian zone information is collected, including the extent of each vegetation layer (canopy, understorey, groundcover), and of bare and artificial surfaces. Extent is estimated in categories of % cover consistent with the procedures used in FOML (Kauffman and Whittier, 1997). These are: *NO=None, 1=Sparse (<10%), 2=Moderate (10-40%), 3=Heavy (>40-75%), 4=Very heavy (>75%).*

The overall dominant land-cover in the riparian zone is also recorded in one of several broad types developed for RHS (Environment Agency, 2003). The same categories were used where possible to avoid confusion. These are: broadleaved/mixed woodland (includes coniferous woodland), coniferous plantation, scrub and shrubs, tall herb/rank vegetation, orchard, wetland, moorland heath, rough grass, improved pasture, rock/scree/sand dunes, tilled land, parks and gardens, open water and built (see Appendix 5 “Field survey guidance sheets” for a table of these categories with their abbreviated codes). Differences from the RHS categories are as follows:

- All broadleaved woodland or plantation and natural or semi-natural coniferous were combined for simplicity;
- Built was used in place of ‘suburban/urban development’ as other types of built land-cover were observed; and
- Natural and artificial open water were combined (differentiation between the two can be derived from the human pressures section).

The structure of the vegetation on the bank top is recorded, along with any bank top habitat features and nuisance species (invasive alien species) observed in the riparian plot.

On the shore zone, the presence of a bank face and/or beach is noted, and their respective heights, widths and slopes are recorded. The predominant material is also recorded using the categories of material developed for the RHS. These are: bedrock, boulder, cobble, gravel/pebble, sand, silt, clay, peat, and earth. Artificial substrates are recorded as either: concrete, sheet piling, wood piling, gabion, brick/laid stone, rip-rap, tipped debris, fabric, or bio-engineering material (see Appendix 5 “Field survey guidance sheets” for a table of these categories with their abbreviated codes). Shore and bank modifications are also recorded, using the RHS categories: re-sectioned, reinforced, poached, embankment, dam, and evidence of erosion, deposition and trash-lines are noted.

In the littoral zone, the depth and distance from the waterline are recorded at the observation point. This is ideally 10 m from the waterline, but may not be in cases where this distance exceeds the maximum wading depth if carrying out the survey by foot (0.75 m), or if it is too shallow or inaccessible by boat. The predominant substrate is recorded using the same categories as listed above for the shore zone. Any sedimentation over the natural substrate is also noted.

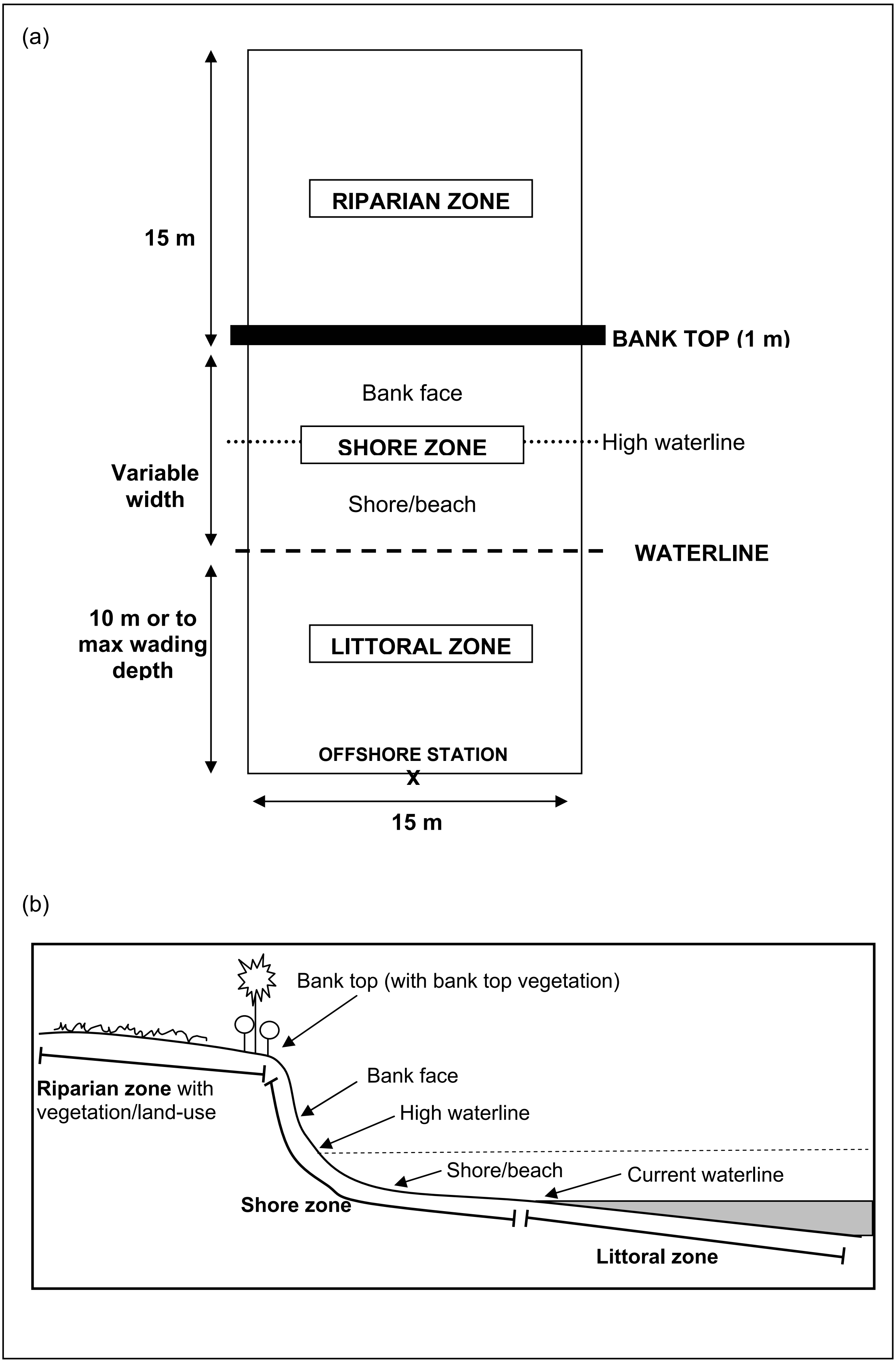


Figure 2.1 Definitions of Hab-Plot zonation: (a) plan view, and (b) cross-section

Macrophytes in the littoral zone are recorded in the categories developed for RHS, which assess the habitat structure they provide at the time of survey, not their morphological character as described in botanical flora guides. These are: liverworts/mosses/lichens, emergent broad leaved herbs, emergent reeds/sedges/rushes, floating-leaved (rooted), free-floating, amphibious, submerged broad-leaved, submerged linear-leaved, submerged fine-leaved and filamentous algae. For more detail on defining these categories see the LHS manual.

The aerial cover of each type is estimated in the percentage bands described above for the riparian vegetation. Total macrophyte cover is also estimated using these bands and it is noted whether growth extends lakewards. Any nuisance species present in the littoral zone are noted. The percentage cover of other littoral habitat features are also recorded, including underwater tree roots, woody debris, inundated live trees, overhanging vegetation, rock ledges or drop-offs, and boulders. Total cover for fish is estimated, as an attempt to integrate all the types of habitat features recorded in this section.

Finally, human and associated pressures are recorded over the entire Hab-Plot, and are also noted if they occur within a 50 m radius of the edge of the plot. The following are recorded: commercial activities, residential buildings, walls, dykes or revetments, litter, dump or landfill, quarrying or mining, roads or railways, parks and gardens, recreational beaches, docks/marinas/boats/platforms, coniferous plantations, pasture, row crops, orchard, pipes/outfalls, dredging, riparian weed control and macrophyte cutting.

A photograph should be taken of each Hab-Plot, and of other interesting or unusual features and in cases where observations are difficult. Further photographs can also be taken to illustrate the lake's character in general.

Whole lake assessment

Beyond the detailed observations made at the selected number of Hab-Plots, a method is also presented to acquire data on shore developments and pressures over the lake as a whole. This is an approach analogous to the macro-habitat characterisation of FOML (Kaufmann and Whittier, 1997) and the "sweep-up" assessment within RHS (Fox *et al.,* 1998). The entire lake perimeter is audited through a number of sections, which are observed either from the boat when cruising between Hab-Plots, or by viewing the opposite shore with binoculars if carrying out the foot-based survey. Pressure types recorded are: bank modification, (including impoundments, hard engineering, soft engineering, docks and marinas), intensive riparian and shore zone use (including commercial activities, residential, litter/ dump/ landfill, quarrying or mining, roads or railways, parks and gardens, recreational beaches, coniferous plantation, evidence of recent logging, pasture, intensive grazing, row crops, orchard), and erosion.

The percentage cover of each section of shoreline that is affected is estimated in the bands previously described. The length of each sector observed is determined from the map, and overall percentages of shoreline features then calculated. If the entire lake cannot be surveyed percentages are to be calculated on the proportion of the lake that was surveyed. However the method stipulates that a minimum of 75 % of the shore should be included in the shoreline survey. Other activities not necessarily associated with the shore are also noted, including: motorboats, non-motor boats, angling, macrophyte control, navigation, dredging, liming, odour, fish farming, military activities, power lines, litter and surface scums/slicks.

Habitat features of special interest are recorded if observed during the survey. These include fringing reed banks, fen, bog, marsh, flush, wet woodland (carr), water meadows, deltas, quaking banks and alders. It is noted if alder trees show signs of

Phytophthora disease. Observations of certain animals of special interest are recorded, e.g. otter, mink, vole, kingfisher, sand martin, heron, osprey and dragonflies as illustrative, but not exclusive examples.

Hydrology and sedimentology

Basic hydrological information is recorded for the lake where possible. The principal use of the water body is noted, from the categories of hydropower, water supply, flood control, navigation and amenity. The water body type is recorded in relation to whether the lake is natural, artificial, raised or lowered. The height of raising or lowering and of the principal retaining structure is recorded if applicable. The presence of upstream impoundments, flow diversion, and tidal influence is noted. The daily and annual water level fluctuation is estimated, and a list of all hydrological structures is tallied. As a proxy for the extent of upstream geomorphological disturbance, the extent of emergent depositional landforms in deltaic areas is recorded. The maximum height of eroded bank is also noted.

Index Site: water column characterisation

In the FOML protocol Baker *et al.* (1997) use the concept of an Index Site to provide a single measure representative of the physical characteristics of the water body. The Index Site is taken to be the deepest point of the lake and is located using a brief sonar survey. At the Index Site a series of measurements are taken relating to:

- the condition of water surface to report any problems such as oil slicks, algal blooms, etc;
- alkalinity - expressed as equivalent mg L^{-1} $CaCO_3$;
- dissolved oxygen and temperature profiles - these are considered important because most European lakes deeper than 3-5 m thermally stratify during the summer, so that the vertical distribution of temperature and dissolved oxygen (DO) characterises the pelagic habitat;
- Secchi disk depth - this is a standard and simple means to determine water transparency, which is affected by colour, algae and suspended sediment concentrations. Transparency is a powerful indicator of human impact and can be used as a means to determine the widely reported Carlson's Trophic State Index (TSI) (Carlson, 1977).

Index Site measurements depend upon the availability of a boat and have therefore been omitted from LHS_{core}. Detailed procedures for the collection of Index Site measurements will be provided in the revised LHS manual. However, the survey form and associated instructions are given in Appendix 3. The metalimnion (thermocline) is located where the rate of change in temperature exceeds 1°C m^{-1}.

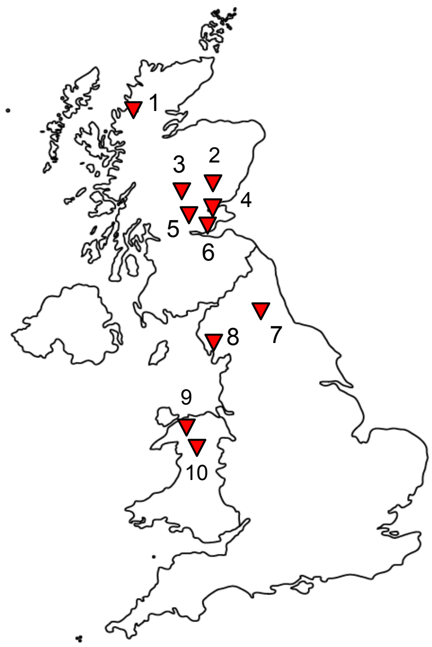
Rationale for survey design

As described above, the LHS involves a number of component survey sections. The first, background information, is designed to familiarise the surveyor with the characteristics of the site prior to arrival in the field, whilst also collecting useful data on lake and catchment metrics. The use of an OS map and a sketch map is intended to help surveyors with orientation upon arrival at the site. Characterisation of lake habitats is conducted at two spatial scales and levels of detail; the Hab-Plots being intensively surveyed at multiple locations on a small scale, and the whole-lake survey detecting the presence of special habitats and features such as wetlands on a broader scale but in less detail. Pressures at the lake are similarly recorded at these two scales, at the Hab-Plots, around the lake shore between the Hab-Plots, and over the in-lake area. Collecting habitat and human use data over two scales provides complementary data in that the shoreline and whole-lake survey records information between the Hab-Plots. Some data are collected on both scales, such as the presence of hard engineering and other human modifications. This enables exploration of relationships at the localised scale of the Hab-Plots, such as between human pressures and habitat types, as well as providing overall estimations of the extent of such pressures over the entire lake. Additional details are also recorded at the Hab-Plots, such as the dimensions and material of hard engineering structures.

Ten Hab-Plots feature in the full version of LHS, however four plots are used LHS$_{core}$ as a shorter method was required for rapid deployment. The rationale for the numbers and spacing of the Hab-Plots in LHS was guided by extensive research undertaken for the US EMAP FOML. The 10 plots used in the FOML is based on binomial theory, which suggests that a feature comprising 10% or more of the shoreline will, on average, be detected when using 10 sample locations. This theory is based on the assumption that the feature is always observed if it is present (Kaufmann *pers. comm.*). The stratified randomised design for the location of the plots is integral to this probability theory, in that the likelihood of detecting features in proportion to their occurrence significantly declines if plots are not evenly spaced (Kaufmann, *pers.comm.)*. The randomised starting point (or location of the first plot) ensures an unbiased site selection regime.

2.2 Site selection for LHS trials

Rigorous testing of both the full version of LHS and LHS$_{core}$ was carried out by the contractors over 10 principal test lakes of varying character drawn from locations across Great Britain (Figure 2.2). Summary data for each of the sites are shown in Table 2.1, including the lake typology as proposed for reporting purposes by the United Kingdom Technical Advisory Group (UK TAG) for the WFD. This typology considers the geology, depth, altitude and size of the lake (see draft guidance report TAG, 2004).



KEY:

1. Loch Maree
2. Loch Brandy
3. Loch Tummel
4. Loch of Lindores
5. Loch Leven
6. Kilconquhar Loch
7. Derwent Reservoir
8. Windermere
9. Llyn Padarn
10. Llyn Tegid

Figure 2.2 Location of the 10 test lakes used for LHS development

Table 2.1 Details of the 10 principal lakes used for comparative testing of LHS versions

Name	Location	Max. depth (m)	Altitude (m)	Lake size (ha)	Catchment area (km^2)	Shoreline Perimeter (km)	Water body type	Designation Status	Pressures	Agency surveys	UK TAG 'Lake Type'
Loch Maree	Highland, Scotland	110	6	2,796	440.1	95.5	Natural	SSSI, SAC, Ramsar, SPA	Light recreation	SNH/ SEPA	LA, D, Low, L
Loch Brandy	Angus, Scotland	**56***	638	28	1.2	2.5	Natural	SSSI	Light grazing	SEPA	LA, D, Mid, S
Loch Tummel	Perth, Scotland	42	142	580	818.2	27.2	Natural raised	NONE	Hydropower, recreation	None	LA, D, Low, L
Lindores Loch	Fife, Scotland	3	68	41	5.1	3.5	Natural	SSSI	Fishing, recreation	SNH	MA, Sh, Low, S
Loch Leven	Perth, Scotland	25	106	1,371	158.7	23	Natural lowered	SSSI, NNR, Ramsar, SPA	Fishing, recreation	SNH	HA, D, Low, L
Kilconquhar Loch	Fife, Scotland	1.8	17	37	1.3	2.3	Flooded pit*	SSSI	Residential	SNH	Marl, Sh, Low, S
Derwent Reservoir	NE England	64	222	1,436	249.7	52.1	Impoun-dment	NONE	Water supply, recreation	EA	MA, D, Mid, L
Windermere	NW England	40	37	390	86.4	14.2	Natural	SSSI	Urban, intensive recreation	EA	LA, D, Low, L
Llyn Padarn	North Wales	20	105	98	49	7.7	Natural	SSSI	Urban, recreation, mining/landfill	EA	LA, D, Low, L
Llyn Tegid	North Wales	43	158	415	149.2	15	Natural lowered	SSSI, Ramsar	Flood control, recreation	EA	LA, D, Low, L

*indicates a correction or addition to GBLakes values

Key: For UK TAG Lake Type Abbreviations (TAG, 2004)
Geology: LA= >90% Siliceous, MA= >50% Siliceous, HA= >50% Calcareous, Marl = >65% Limestone
Depth: Sh= Shallow (<=3 m), D= Deep (>3 m)
Altitude: Low <200 m a.s.l., Mid= 200-800 m a.s.l., High= >800 m a.s.l.
Size: VS= Very small (1-9 ha), S= Small (10-49 ha), L= Large (50-10,000 ha)

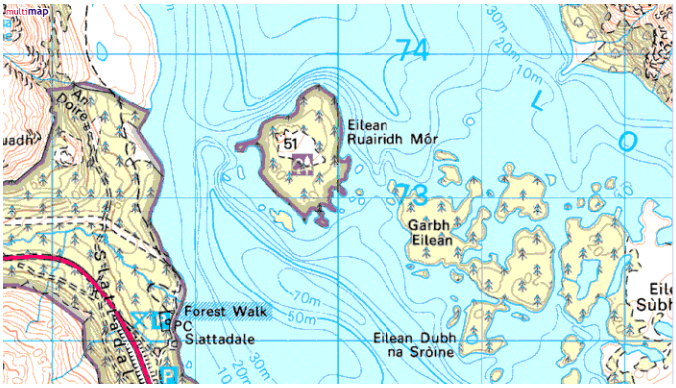
The lakes are representative of a range of geological types (from siliceous to marl), though a high proportion are siliceous systems, which are widespread across the UK. They also cover a variety of structural types, from deep trough-shaped systems such as Loch Maree, reaching depths of 110 m, to shallow near circular forms such as Kilconquhar Loch with a maximum depth of 1.8 m. A range of altitude and size classes is also featured and the selection spans the continuum of lake pressures ranging from near-pristine candidate reference conditions at Loch Brandy to highly altered and developed sites such as Llyn Padarn; see Figure 2.3 for representation of selected lakes in OS map format. The sites also exhibit different levels of hydromorphological alteration. Derwent Reservoir is an impounded pre-existing river valley, whereas water levels in Llyn Tegid and Loch Tummel are regulated by sluice gates and a dam, respectively. Kilconquhar Loch is the legacy of medieval peat diggings and is therefore analogous to comparable shallow water bodies termed ‘broads’ in England.

LHS_{core} surveys were also carried out by survey teams from the environmental and conservation agency field teams on lakes that were visited as part of on-going WFD-related biological sampling (SEPA, EA, EHS) and/or for macrophyte and Site Condition Monitoring surveys on lakes with designated status (SNH). The selection rationales varied between agencies, but were based on requirements other than LHS. For example, the SEPA programme (*ca.* 50 lochs) focused on biological sampling on Scottish sites expected to be at ‘reference condition’. In England and Wales, the EA surveyed *ca.* 120 lakes for biological elements along with LHS for hydromorphology. SNH planned to survey *ca.* 190 lochs as part of the Site Condition Monitoring Programme. Consequently at the start of the 2004 summer field season it was expected that more than 300 lakes would be surveyed for LHS_{core}. A summary of the numbers of forms received from each of the agencies at the time of finalising this report is shown in Table 2.2.

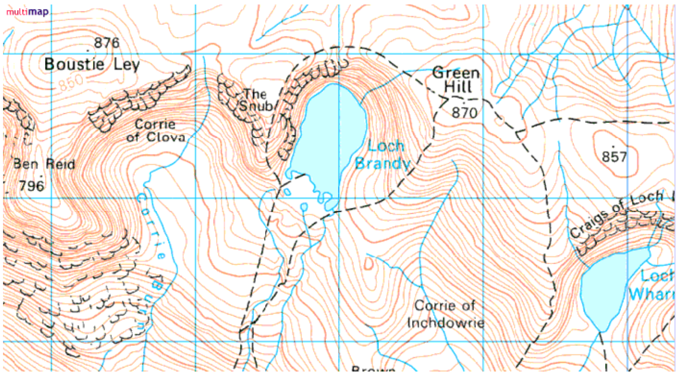
Table 2.2 Summary of lakes for which LHS_{core} forms have been received

Agency	**Number of LHS sites**	**Region**	**Lake types**	**Other survey data collected**
Environment Agency (EA) of England and Wales	116	England and Wales	Broad range of types	Biological data, macrophytes, invertebrates
Scottish Natural Heritage (SNH) (surveys undertaken by Centre for Ecology and Hydrology)	57	Scotland	Mostly reference condition sites	Site condition monitoring data, macrophytes
Scottish Environment Protection Agency (SEPA)	44	Scotland	Mostly reference condition sites	Ecological surveys, risk assessment
Environment and Heritage Service (EHS) of Northern Ireland	7	N. Ireland	Mostly reference condition sites	N/A

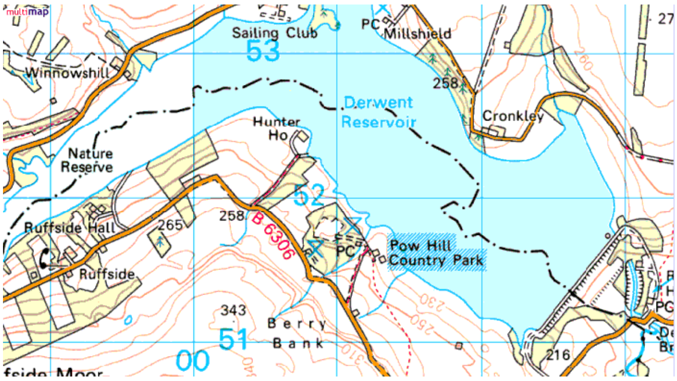
With the exception of Loch Tummel, selected to represent the important hydro-power lochs in Scotland, all the lakes surveyed by the contractors were also sampled by partner environment and conservation agency staff.



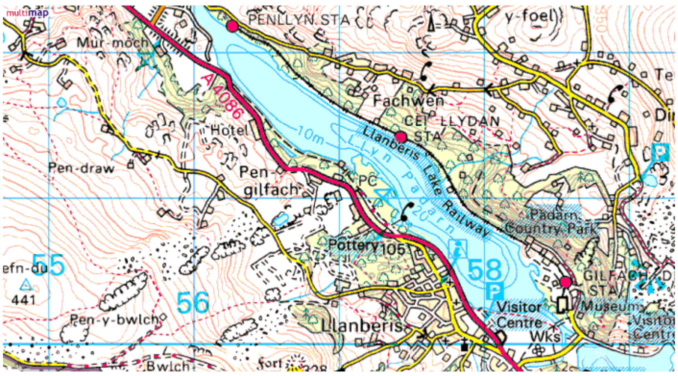
Loch Maree, Highland, Scotland (NG930716)



Loch Brandy, Angus, Scotland (NO339753)



Derwent Res., Durham, England (NZ011522)



Llyn Padarn, Gwynedd, Wales (SH569614)

Figure 2.3 Selected map extracts of study lakes (source: 1:50,000 OS Landranger Series, Crown Copyright protected)

2.3 Field survey experimental design

Surveys were carried out to test the LHS methodology between May and September 2004. Table 2.3 summarises the survey work carried out on each of the 10 principal lakes. At each site both a full boat-based LHS and an abbreviated shore-based LHS_{core} (based on four Hab-Plots) were deployed. Routinely, the core version was completed prior to undertaking the full survey. To ensure direct comparability between the methods the same Hab-Plots used in LHS_{core} were re-sampled from the boat as part of the complete LHS survey. This framework also permitted results to be obtained equivalent to a boat-based LHS_{core}, which enables added comparison of the boat and foot methods. At Loch Brandy a total of 10 shore-based Hab-Plots were collected to be equivalent to the full survey (excluding the Index Site).

Table 2.3 Summary of LHS survey work at the 10 principal lakes

Name	LHS_{core}		Full LHS survey		Total Number of Hab-Plots		50 m land-cover & natural habitats	Other
	Boat	Foot	Boat	Foot	Boat	Foot		
Loch Maree	✔	✔	✔	✖	11	4	✔	
Loch Brandy	✔	✔	✔	✔	10	10	✔	
Loch Tummel	✔	✔	✔	✖	10	4	✔	Water level DHRAM
Loch of Lindores	✔	✔	✔	✖	10	4	✔	Surveyor comparisons
Loch Leven	✔	✔	✔	✖	20	4	✔	
Kilconquhar Loch	✔	✔	✔	✖	10	4	✔	
Derwent Reservoir	✔	✔	✔	✖	10	4	✔	
Windermere	✔	✔	✔	✖	10	4	✔	
Llyn Padarn	✔	✔	✔	✖	11	4	✔	
Llyn Tegid	✔	✔	✔	✖	15	4	✔	Water level DHRAM
Total	**9**	**10**	**10**	**1**	**117**	**46**	**10**	

At Loch Leven, an extra 10 Hab-Plots were carried out from the boat, which were spaced evenly between the first 10 Hab-Plots. An extra five Hab-Plots were also surveyed at Llyn Tegid, and one extra at both Loch Maree and Llyn Padarn. These sites with 20 and 15 Hab-Plots were used to determine whether 10 is an appropriate number of plots for LHS. Some further survey work was undertaken to investigate alternative possibilities to the proposed survey. At all lochs, shoreline estimates were made to within 50 m as well as within 15 m. In addition, estimates were made of natural shoreline habitat cover within 50 m, using the same categories as used for ‘dominant land-cover’ in the riparian zone Hab-Plot sections. These extra survey data were collected in anticipation of possible changes to the shoreline survey, particularly as there was some uncertainty as to whether it was more appropriate to record land-use within 15 m or 50 m. It was also suspected that while immediate pressures within 15 m of a water body are likely to have a direct effect, pressures within 50 m may also be important. When surveying the percentage of the shore exposed to pressures and different natural land-cover occurring within 50 m of the shore this included land-cover within 15 m. However the two bands could be separated in the database.

Surveyor comparability was tested at Lindores Loch at the end of the survey season by eight surveyors, three of whom had previous experience carrying out LHS over the summer (two had extensive experience); the remainder were post-doctoral researchers or postgraduates. Two Hab-Plot and two shoreline sections were chosen, each with different habitats, structural features and pressures. Each surveyor carried out the Hab-Plots and shoreline sections independently.

2.4 Summary metrics using LHS data

A key requirement of the LHS project was to generate summary metrics which synthesise the wide ranging and multivariate data collected and reduce these to meaningful indices. Indices were to be developed to indicate the degree of hydromorphological alteration (a key requirement of the WFD), and to measure the lake habitat quality based on diversity and naturalness of physical structure and the presence of habitat features perceived to be of value to wildlife. The Lake Habitat Modification Score (LHMS) and the Lake Habitat Quality Assessment (LHQA) are comparable to the HMS and HQA used for the River Habitat Survey data (though both are under review at present, Dr Helena Parsons, EA, *pers. comm.*). A summary of the derivation of each of the scores is provided below. Both LHQA and LHMS are reported for the 10 principal lakes, and the LHMS is reported for an additional 34 of the agency survey lakes.

Lake Habitat Modification Score

The Lake Habitat Modification Score (LHMS) builds upon the UK TAG guidance risk assessment exercise (with thresholds reviewed 25/11/03, TAG, 2003), which uses expert opinion to define thresholds of pressures leading to likely impacts on ‘ecological status’. The following types of features are included in the new LHMS:

- % shoreline construction and reinforcement;
- % shore zone subject to intensive use;
- Severity of in-lake pressures and uses;
- Degree of hydrological alteration;
- Extent of non-natural sedimentation; and
- Presence of invasive species.

This version can be applied to lakes using both the LHS_{core} full version of the survey. The full array of features included in the LHMS scoring system is shown in Table 2.4. The current version of LHMS omits Index Site results and other potentially valuable desk-top information. Table 2.4 includes some suggestions in this respect which might include Secchi depth and DO (although both are highly type-specific), and desk-top data such as the percentage of catchment under intensive land-use which will influence water, sediment and geochemical fluxes.

Lake Habitat Quality Assessment

The Lake Habitat Quality Assessment (LHQA) provides a measure of the naturalness, diversity and special interest of the lake. It is a similar system to the HQA used in RHS, where points are gained for the extent and diversity of natural habitat features. The following types of features are measured:

- Extent of natural features, riparian zone structural complexity, stability and diversity;
- Shore zone structural habitat diversity and extent of natural features;
- Hypsographic variation and diversity of natural littoral substrates;
- Extent of macrophyte cover and diversity of structural types;
- Extent and structural diversity of littoral habitat features (e.g. fish cover);
- Presence and diversity of special habitat features (e.g. wetlands); and
- In-lake landform complexity (e.g. number of islands).

For a full account of the scoring system for LHQA see Table 2.5.

Table 2.4 Scoring system for LHMS

PRESSURE	SCORES 0	SCORES 2	SCORES 4	SCORES 6	SCORES 8
Shore zone modification	<10% shoreline affected by hard engineering AND Shore re-enforcement recorded at 0-1 Hab-Plots (0 for core)	≥ 10%, < 30% shoreline affected by hard engineering OR Shore re-enforcement recorded at 2 Hab-Plots (1 for core) OR Poaching recorded at 3 or more Hab-Plots (2 for core)	≥ 30%, < 50% shoreline affected by hard engineering OR Shore modification recorded at 3-4 Hab-Plots (2 for core)	≥ 50%, < 75 % shoreline affected by hard engineering OR Shore modification recorded at 5-7 Hab-Plots (3 for core)	≥ 75% shoreline affected by hard engineering OR Shore modification recorded at 8 or more Hab-Plots (4 for core)
Shore zone intensive use	< 10% shoreline non-natural land-cover AND Non-natural land-cover recorded at 0-1 Hab-Plots (0 for core)	≥ 10%, < 30% shoreline non-natural land-cover OR Non-natural land-cover recorded at 2 Hab-Plots (1 for core)	≥ 30%, < 50% shoreline non-natural land-cover OR Non-natural land-cover recorded at 3-4 Hab-Plots (2 for core)	≥ 50%, < 75% shoreline non-natural land-cover OR Non-natural land-cover recorded at 5-7 Hab-Plots (3 for core)	≥ 75% shoreline non-natural land-cover OR Non-natural land-cover recorded at 8 or more Hab-Plots (4 for core)
In-lake use	No in-lake pressures (excl. litter or odour)	1 in-lake pressure (excl. litter or odour)	2 in-lake pressures (excl. litter or odour)	3 in-lake pressures	> 3 in-lake pressures
Hydrology	0-1 hydrological structures	2 hydrological structures OR Presence of an upstream impoundment	3 or more hydrological structures	Principal use hydropower, flood control, water supply OR Raised or lowered by > ± 1 m	1 dam (no fish pass) OR Principal use hydropower, flood control, water supply AND Annual fluctuation > 5m or < 0.5m
Sediment regime	< 25% shore affected by erosion AND < 25% in-lake area affected by deposition (excl. veg islands)	≥ 25%, < 50% affected by erosion OR ≥ 25%, < 50% lake area affected by deposition (excl. veg islands) OR Sedimentation over natural substrate recorded at 3-4 Hab-Plots (2 for core)	≥ 50%, < 70% shore affected by erosion OR ≥ 50%, < 70% lake area affected by deposition (excl. veg islands) OR Sedimentation over natural substrate recorded at 5-6 Hab-Plots (3 for core)	≥ 70% shore affected by erosion OR ≥ 70% lake area affected by deposition (excl. veg islands)	
Nuisance Species	0-1 recordings (not 2 recordings of 1 species)	2 -3 recordings (may be 1 or more species)	≥ 4 recordings (may be 1 or more species)		

Measures below not included in presently configured LHMS, but could feature in revised versions

Index Site condition	Secchi depth ≥ 3m AND DO > 6 mg L^{-1}	Secchi depth ≥ 1.5, < 3m OR DO ≥ 4-6 mg L^{-1}	Secchi depth < 1.5 OR DO < 4 mg L^{-1}		
Catchment pressures	< 3% Urban AND < 20% Total non-natural land-use	≥ 3%, < 5% Urban OR ≥ 20%, < 25% Total non-natural land-use	≥ 5%, < 8% Urban OR ≥ 25%, < 40% Total non-natural land-use	≥ 8%, < 10% Urban OR ≥ 40%, < 50% Total non-natural land-use	≥ 10% Urban OR ≥ 50% Total non-natural land-use

Table 2.5 Scoring system for LHQA

LAKE ZONE	Characteristic measured	Measurable feature	Scores- full LHS	Scores- LHS_{core}	Max
RIPARIAN	Vegetation structural complexity	Proportion of Hab-Plots with complex or simple riparian vegetation structure	1 for 1-3 2 for 4-6 3 for 7-8 4 for 9-10	1 for each plot	4
	Vegetation longevity/stability	Proportion of Hab-Plots with >10% cover of trees with DBH > 0.3m	1 for 1-3 2 for 4-6 3 for 7-8 4 for 9-10	1 for each plot	4
	Extent of natural land-cover types	Proportion of Hab-Plots with either natural/semi-natural woodland, wetland, moorland heath or rock, scree and dunes	1 for 1-3 2 for 4-6 3 for 7-8 4 for 9-10	1 for each plot	4
	Diversity of natural land-cover types	Number of natural cover types recorded	1 for each type, maximum score of 4	1 for each type, maximum score of 4	4
	Diversity of bank-top features	Number of bank-top features recorded	1 for each type, maximum score of 4	1 for each type, maximum score of 4	4
SHORE	Shore structural habitat diversity	Proportion of Hab-Plots with an earth or sand bank >1m	1 for 2-4 2 for 5-6 3 for 7-8 4 for 9-10	1 for each plot	4
		Proportion of Hab-Plots with trash-line	1 for 2-4 2 for 5-6 3 for 7-8 4 for 9-10	1 for each plot	4
	Bank naturalness	Proportion of Hab-Plots with natural bank material	1 for 1-3 2 for 4-6 3 for 7-8 4 for 9-10	1 for each plot	4
	Diversity of natural bank habitat	Number of natural bank materials recorded	1 for each type, maximum score of 4	1 for each type, maximum score of 4	4
	Beach naturalness	Proportion of Hab-Plots with natural beach material	1 for 1-3 2 for 4-6 3 for 7-8 4 for 9-10	1 for each plot	4
	Diversity of natural beach habitats	Number of natural beach materials recorded	1 for each type, maximum score of 4	1 for each type, maximum score of 4	4
LITTORAL	Hypsographic variation	Coefficient of variation for depth at 10 m from shore over all plots	1 for >25 2 for >50 4 for >75	1 for >25 2 for >50 4 for >75	4
	Extent of natural littoral zones	Proportion of Hab-Plots with natural littoral substrate	1 for 1-3 2 for 4-6 3 for 7-8 4 for 9-10	1 for each plot	4
	Diversity of natural littoral zone types	Number of natural littoral substrate types recorded	1 for each type, maximum score of 4	1 for each type, maximum score of 4	4
	Extent of macrophyte cover	Average of total macrophyte cover over all plots	1 for a ‘1’ 2 for a ‘2’ 3 for a ‘3’ 4 for a ‘4’	1 for a ‘1’ 2 for a ‘2’ 3 for a ‘3’ 4 for a ‘4’	4
		Number of Hab-Plots where macrophyte cover extends lakewards	1 for 1-3 2 for 4-6 3 for 7-8 4 for 9-10	1 for each plot	4
	Diversity of macrophyte structural types	Number of macrophyte cover types recorded (not including filamentous algae)	1 for each type, maximum score of 4	1 for each type, maximum score of 4	4
	Extent of littoral habitat features	Average of total cover for fish over all plots	1 for a ‘1’ 2 for a ‘2’ 3 for a ‘3’ 4 for a ‘4’	1 for a ‘1’ 2 for a ‘2’ 3 for a ‘3’ 4 for a ‘4’	4
	Diversity of littoral habitat features	Number of littoral habitat feature types recorded	1 for each type, maximum score of 4	1 for each type, maximum score of 4	4
WHOLE LAKE	Diversity of special habitat features	Number of special habitat features (excl. diseased alders)	5 for each type, maximum score of 20	5 for each type, maximum score of 20	20
		Number of islands	2 for 1 5 for 2-4 10 for 5 or more	2 for 1 5 for 2-4 10 for 5 or more	10
		Number of deltaic depositional features recorded (excl. unvegetated sand and silt deposits)	2 each type	2 each type	6

2.5 Data analysis

General survey interpretations

Because shoreline segment locations could differ between each survey version, overall estimations of % of shoreline affected by each pressure type were generated. These were calculated by initially allocating each % extent category, as observed in each shoreline section, the approximate value of the midpoint of that category (1= 5%, 2= 25%, 3=60%, 4=85%). The midpoint values for each segment were multiplied by the proportion of the shoreline made up by that segment. These values were added to give the total shoreline % of each pressure. These values were then converted back into the categories of 0-4 to enable comparisons. The same was done for shoreline pressures within 50 m and for natural habitat types within 50 m.

Surveyor comparability

Surveyor comparability was tested at Lindores Loch using eight surveyors carrying out two Hab-Plots and two shoreline surveys. The percentages of entries that were matching for all surveyors were calculated for each plot and shoreline section. The percentages of entries that were matching to within one category for all surveyors were also determined. These calculations were also carried out allowing one surveyor to disagree, then two and then three surveyors to disagree.

Foot vs. boat version

Survey entries for the four Hab-Plots common to both the foot and the boat survey at each lake were compared. In all cases at least one surveyor was present during both surveys to ensure consistency. For Derwent Reservoir, only six boat-based Hab-Plots were completed (none of which was common to the four foot Hab-Plots), owing to extreme weather conditions during the time available for fieldwork, so it was not included in this category of comparison. Otherwise, the percentage of entries that were matching for both surveys was calculated for each Hab-Plot, and then averaged for the four Hab-Plots at each lake. An overall percentage of matching entries was then calculated for all lakes.

The percentage of entries requiring the estimation of '% cover' that were matching to within one category was also calculated (e.g. if the boat survey estimated 10-40% of large trees and the foot survey estimated 40-75%). The percentage of matching entries was then recalculated for each lake and averaged for all lakes, allowing the % cover entries to differ by one category.

The shoreline surveys carried out by boat were also compared with those carried out by foot (with binoculars). The overall percentages of the shoreline affected by each pressure (values in the categories of 0-4) were used. The percentage of matching categories for boat and foot versions for each pressure was calculated for each lake and then averaged over all lakes. The process was repeated, allowing categories to differ by one.

The LHS_{core} boat survey and foot survey were also compared by their LHMS and LHQA values to determine whether differences in matching answers would alter these scores. The foot and boat methods were also compared subjectively using advantages and disadvantages of each as experienced during summer surveys, including feedback from agency staff.

Core vs. full version

The principal differences between the core and full versions are the number of Hab-Plots and the Index Site. Hence, the comparison between these two versions was firstly undertaken by an analysis of the differences in survey outcomes with varying numbers of Hab-Plots. A selection of features was chosen with which to compare the difference in information with varying numbers of Hab-Plots. These are:

- The number of vegetation structural types;
- The number of dominant land-cover types recorded in the riparian zone;
- The presence of a bank;
- The presence of a beach;
- The number of bank, beach and littoral materials recorded (each material scored separately for each zone);
- The number of macrophyte structural types; and
- The number of littoral features.

For each lake, the total number of features recorded in the core and full versions was calculated. The difference between these overall scores was investigated using a paired t-test to determine whether scores were significantly different.

The number of features that were recorded with increasing numbers of Hab-Plots was determined using data from the full boat surveys. The full spectrum of plot numbers was used where available (1-15 plots for Llyn Tegid and 1-20 plots for Loch Leven), to determine the relevance of using 10 Hab-Plots. Figures were constructed showing the cumulative number of total features as each Hab-Plot was added. For selected lakes – Loch Brandy, Llyn Tegid and Loch Leven – more detailed analysis was undertaken using multiple iterations of randomly selecting 1, 2, 4, 6, 8, 10, 12, 15, 18, 20 Hab-Plots where available. For each number of Hab-Plots, 10 iterations were run and the resultant averages of number of each type of feature were plotted.

The core and full boat versions were also compared using their LHMS and LHQA scores to determine whether the number of Hab-Plots could affect this outcome.

Processing and analysis of agency data

At the time of writing this report a total of 224 LHS_{core} forms had been received from the environment and conservation agencies. Of these, 175 were complete with four Hab-Plots. The remainder were only partially completed due to expressed time constraints on behalf of some of the teams. To date 34 of these lakes have been entered into the LHS database for analysis for this report. These were selected to cover a range of types, geographical extents and to capture a range of lake uses, and are listed in Section 3.9.

Analysis of the agency data included the processing of LHMS scores. LHQA scores were not obtained due to time constraints for building this into the database. The database was also used for generating summary statistics on these lakes, which are presented in Section 3.9.

2.6 Deployment of a 'surveyor experience' questionnaire

In order to obtain surveyors' views on LHS a questionnaire was sent to the surveyors from all agency teams, as shown in Table 2.6. Feedback from surveyors was used in the method development process, which is discussed later.

Table 2.6 Key questions asked of environment and conservation agency staff conducting LHS_{core} survey work during summer 2004

1. How well did the LHS_{core} manual prepare you for carrying out the survey in the field? Include suggestions for improvements.
2. How many lakes have you surveyed using LHS_{core} ?
3. Give comments on how sites were selected for Hab-Plots and on accessing these plots.
4. Time frames:
    a. *How long did a typical Hab-Plot take to complete?*
    b. *What were the shortest and longest Hab-Plot completion times?*
    c. *How long did the total of all LHS_{core} components typically take to complete?*
    d. *What were the shortest and longest completion times for the entire survey?*
5. The LHS_{core} is a cut down version using only 4 Hab-Plots, whereas the full version uses 10. Do 4 Hab-Plots seem to adequately capture most shoreline and littoral habitats?
6. Have you carried out LHS by foot, boat or both? If both, which was preferable and why?
7. Were you confident in your survey entries, particularly for estimating % cover and % extents? If not, state which sections were difficult (e.g. difficult to estimate extent of shoreline pressures from opposite bank).
8. Give any other issues or difficulties you have had with carrying out LHS_{core}. Please give suggestions for improvement. Include any information that you feel LHS does not capture (e.g. things that have been recorded under 'Other' such as recreational camping areas).
9. Do you feel LHS adequately captures the overall characteristics and quality of a lake?

2.7 Role of desk-top information to complement field survey

A key concern at the outset of the development of any new field survey approach (with its attendant resource costs) is whether data could more efficiently collected, or improved (in terms of quality, coverage or in elapsed times between repeat surveys) through remote sensing or access to alternative datasets (e.g. maps, GIS-linked electronic databases and other forms of electronic meta-data). Section 3.7 reviews these issues with particular reference to remote sensing and GIS. Because of the desire to develop a hydromorphological assessment including both morphological alterations and hydrological alterations, some additional analysis was also conducted on water levels using the DHRAM approach (Black *et al.*, 2000) in Section 3.8.

PART THREE: RESULTS AND INTERPETATIONS

3.1 Surveyor comparability

Results from the Hab-Plots and shoreline sections that were tested on a visit to Lindores Loch by eight LHS surveyors are shown in Table 3.1. Consistency between surveyors was generally good, with all surveyors recording matching entries at least 70% of the time for both Hab-Plots and the shoreline sections. Over 80% of entries were always matching to within one category between all surveyors. Results were least consistent for Hab-Plot B, but for all other trials, entries were always matching to within one category for at least seven of the eight surveyors. For Hab-Plot B, five of the eight always recorded entries matching to within one.

Though limited in extent, this trial indicates the survey has good internal reproducibility, crucial for quality assurance purposes. In addition, further investigation revealed that entries by the two surveyors who had extensive LHS experience almost always concurred exactly. It is further expected, therefore, that the degree of surveyor comparability, and hence data consistency, would benefit considerably by an appropriate training and accreditation programme.

Table 3.1 The percentages of entries matching for sample plots carried out by multiple surveyors (Loch of Lindores, September 2004)

	All surveyors		All surveyors with one exception		All surveyors with two exceptions		All surveyors with three exceptions	
	Matching	Within one category	Matching	Within one category	Matching	Within one category	Matching	Within one category
Hab-Plot A	77	96	85	100	95	100	96	100
Hab-Plot B	70	82	81	88	92	96	95	100
Shoreline A	89	100	94	100	94	100	100	100
Shoreline B	78	100	83	100	100	100	100	100

3.2 Comparison of boat and foot version

The advantages and disadvantages of the boat and foot versions were apparent over a range of lake types. Table 3.2 summarises this information, which includes feedback from environmental and conservation agency survey teams via the surveyor questionnaire and direct discussion.

Table 3.2 Analysis of the relative merits of the boat vs. foot version of LHS

LHS component	Preferable version	Explanation
Survey duration	Boat	Boat generally faster, especially for large lakes. Accessing Hab-Plots can be time consuming on foot, and can require driving from plot to plot.
Logistics	Foot	Foot version negates the need for boat hire or purchase and licensing. A boat is unavailable or very difficult to take to some sites.
Hab-Plot selection	Boat	Boat version minimises bias for selecting plots in areas easily accessible by foot/vehicle. It also minimises the reliance upon access permission from land owners to access sites.
Viewing riparian/ shore zone	Foot	From the boat, visibility of the riparian zone can be obscured by vegetation making it difficult to estimate percentage cover of lower levels of vegetation and to observe pressures in and within 50m of the plot. However, this is only applicable to certain lake types, such as Kilconquhar which has extensive fringing reeds.
Viewing littoral zone	Boat	Conversely to the above, visibility of the littoral zone can be obscured by fringing reeds when attempting to view from the shore. Again this is applicable only on certain lake types.
Viewing whole shoreline	Boat	It can be difficult to view the opposite shore on foot, especially on large lakes and in rainy or foggy conditions. In particular, hard engineering structures can be difficult to determine. Estimations of how far roads, etc, are from the lake shore can also be difficult.
Whole lake assessment	Boat	Boat is preferable overall for accessing all areas to record special habitats and hydrological features.
Index Site	Boat	The Index Site is not possible without a boat.

The percentages of matching entries given for each lake (averaged over all Hab-Plots) are shown for the riparian, shore and littoral zones in Figure 3.1. The percentage of entries that were matching to within one category (for % cover estimate entries only) is shown for each lake in Figure 3.2. Both of these figures illustrate some variation in consistency between versions between lakes and between different zones within lakes. However, for all lakes between 55 and 95% of entries were exactly matching in each zone, and for most lakes entries were matching to greater than 80% to within one category for all zones.

The poorest concurrences were obtained for Kilconquhar Loch in the littoral survey, which can be explained by the difficulty in observing the littoral zone from the shore due to extensive fringing reeds. Further investigation revealed the majority of the littoral entries were 'NV' for two of the four Hab-Plots for the foot-based survey at this loch, while the littoral zone was viewed easily from the boat. Notably, while the converse effect may be expected for the riparian zone (i.e. a low level of agreement between boat and foot surveys due to inability to view the riparian zone from the boat), this did not occur. This suggests that inability to view the riparian zone from the boat may be a lesser concern than inability to view the littoral zone from the shore, particularly where fringing reeds are the obstructing form of vegetation.

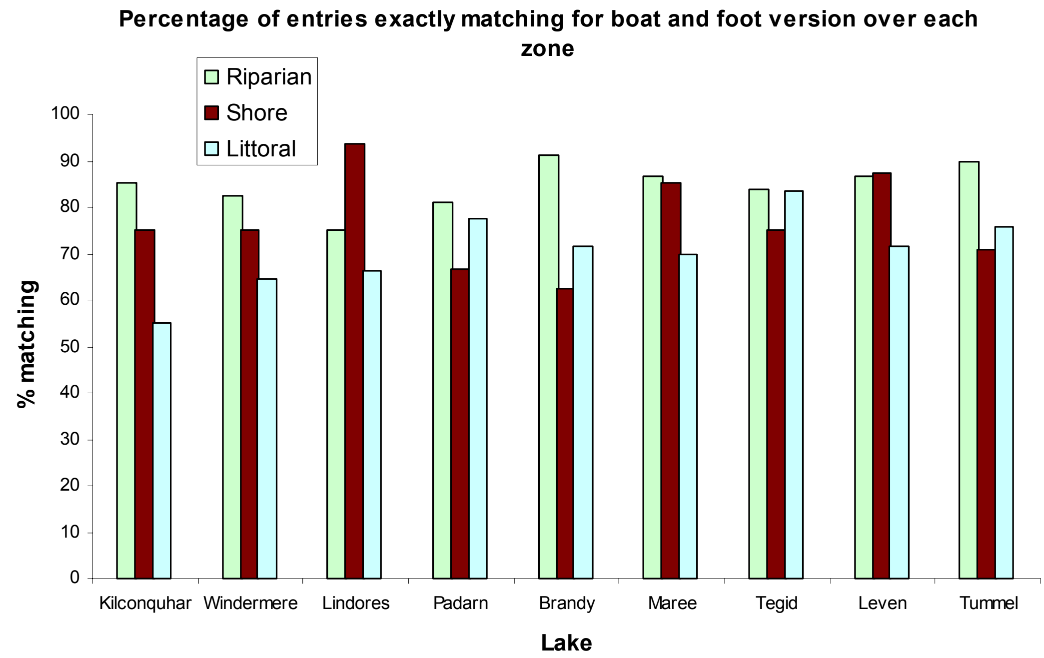


Figure 3.1 The percentage of entries for each Hab-Plot zone that were exactly matching for the boat and foot surveys for each lake

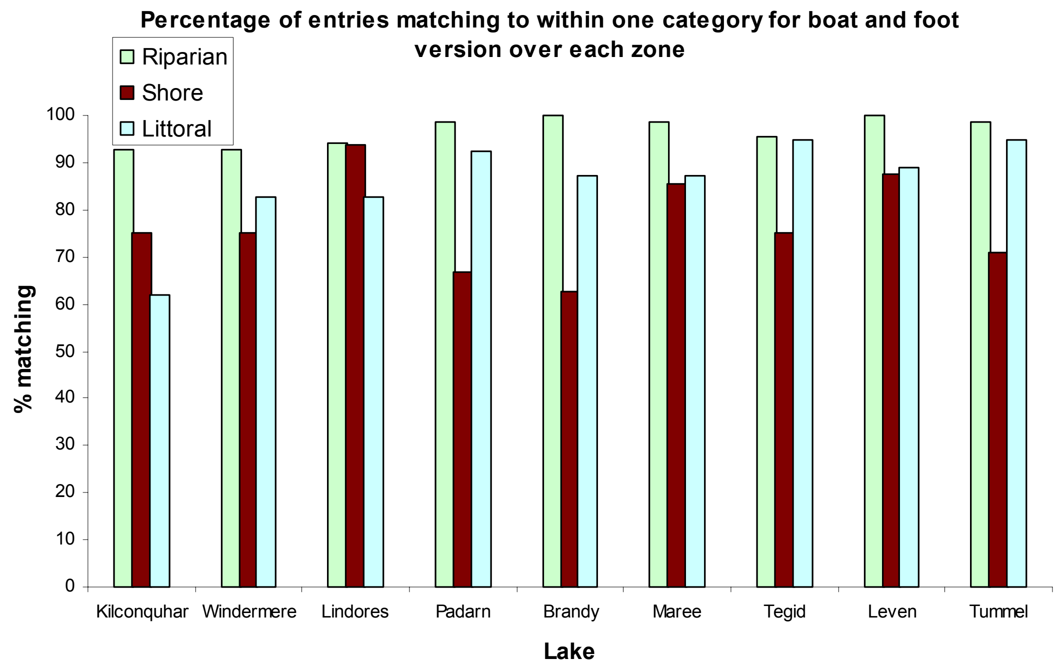


Figure 3.2 The percentage of entries for each Hab-Plot zone that were matching to within one category for the boat and foot surveys for each lake

Shore zone entries were in poor agreement for some sites, particularly Llyn Padarn, Loch Brandy, and to a lesser extent Loch Tummel and Llyn Tegid. Further investigation of the data showed that this was often due to differences in interpretations of the shore zonation, i.e. whether a bank and/or beach was present. If a bank was recorded as present from the boat, but not from the shore, this resulted in a particularly low score as all entries for the bank details would be different. This inconsistency is more likely a legacy of the ambiguity in defining these zones, rather than an issue of boat vs. foot survey. However, it is possible that perspective can change interpretations of the shore zone particularly in difficult cases, and at some plots at Loch Brandy surveyors carried out shore based surveys from within the riparian plot as it was unsafe to wade. The unvegetated ‘boulder apron’ surrounding Loch Brandy and some other highland lochs can be difficult to assign to the beach and bank categories under the current definition of zones. This highlights the need for a more robust definition of the beach and bank face.

The overall percentage of matching entries and entries matching to within one category for each lake is shown in Figure 3.3, which includes the riparian, shore and littoral zones and pressures observed in and within 50 m of the plot. When averaged, entries always matched to at least 75% for all sites, and above 80% were matching to within one category. Sites are in order of increasing consistency from left to right in the plot. Notably, there did not appear to be any trends evident in site complexity and level of consistency between versions, nor between consistency and the order that sites were surveyed, the latter of which could indicate an improvement due to surveyors gaining experience.

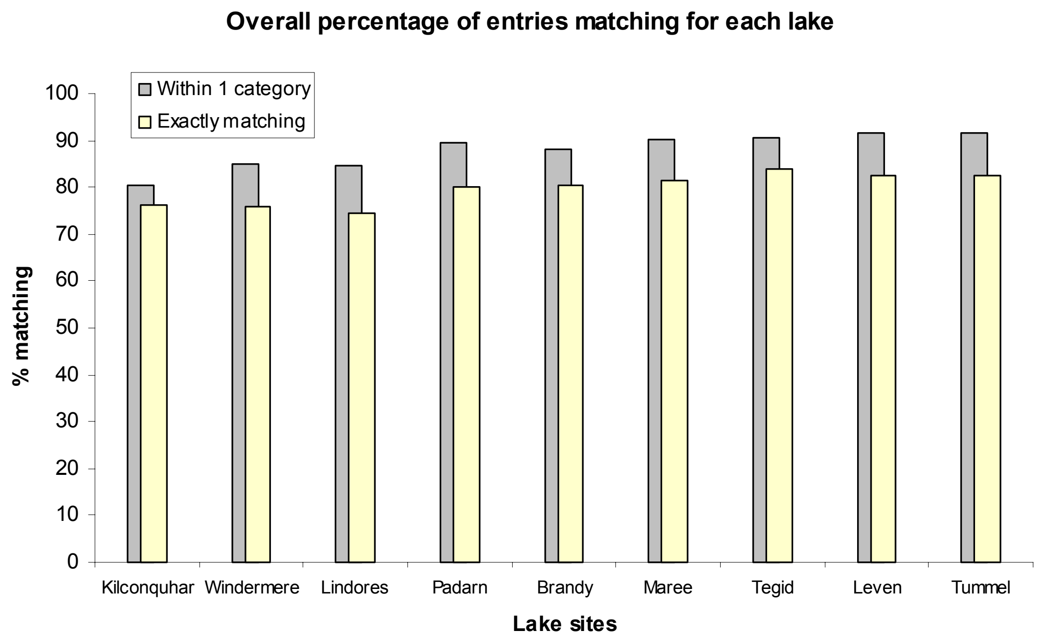


Figure 3.3 The overall percentage of entries for the Hab-Plot survey that were matching, and matching to within one category, for the boat and foot surveys for each lake

Figure 3.4 illustrates the percentage of matching entries, and matching to one category, for each of these sections of the Hab-Plot survey, which is averaged over all lakes. Note that for pressures and shore zone sections percentage matching is always equal to percentage matching within one category as these sections do not include any percentage cover estimate entries. These results indicate that the riparian zone was most consistently surveyed with matching entries in the boat and foot versions. The shore zone was the most poorly surveyed, which is likely to be due to the zonation difficulties as previously discussed. The littoral zone was also less consistently surveyed, which is probably due to differences in visibility between the boat and foot versions. Overall, the average of all entries for all sites over all zones was above 80% exactly matching and above 85% matching to within 1 category. This suggests fairly high consistency between boat and foot versions for the Hab-Plot section of LHS, although there is room for improvement.

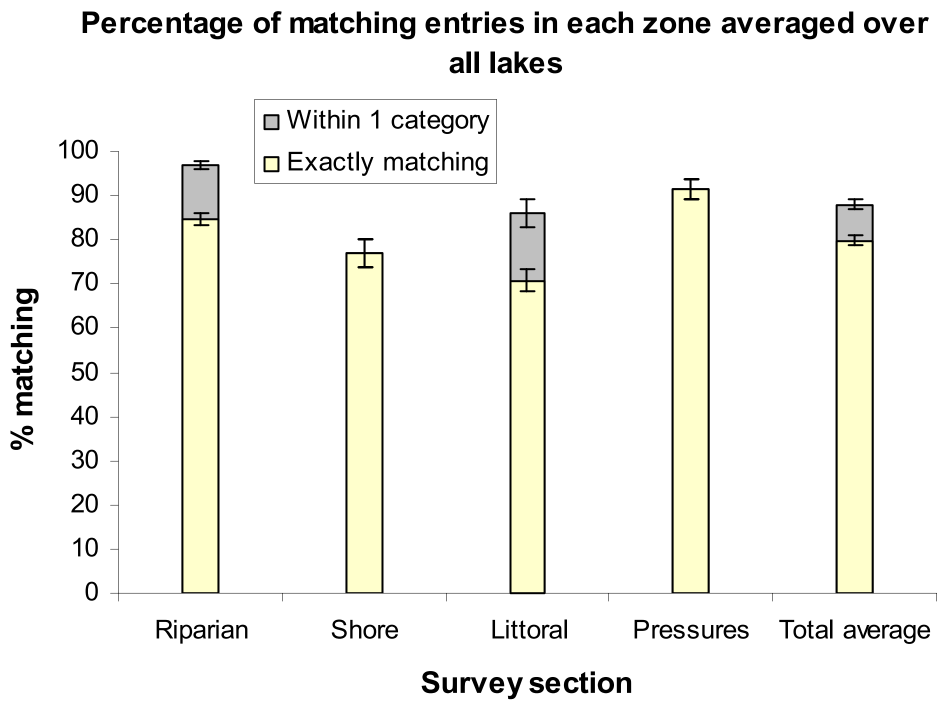


Figure 3.4 The overall percentage of entries for each section of the Hab-Plot survey that were matching, and matching to within one category, for the boat and foot surveys

The percentage of shoreline estimates matching, and matching to within one category, for each shoreline pressure averaged over all lakes, is compared for the boat and foot surveys in Figure 3.5. The shoreline pressure types are in order from left to right as the percentage of entries exactly matching increased. There was some variation in the level of agreement between boat and foot surveys for different shoreline pressures, with recreational beaches and intensive grazing pressure apparently the most difficult to detect consistently between the methods. Soft engineering was only recorded for the shoreline survey at one lake (Lindores Loch) and in this case was exactly matching in the two methods. However, quarrying, mining and orchards were never actually observed within 15 m of the shore of any lake. Therefore, results from this analysis should not be interpreted for these pressures.

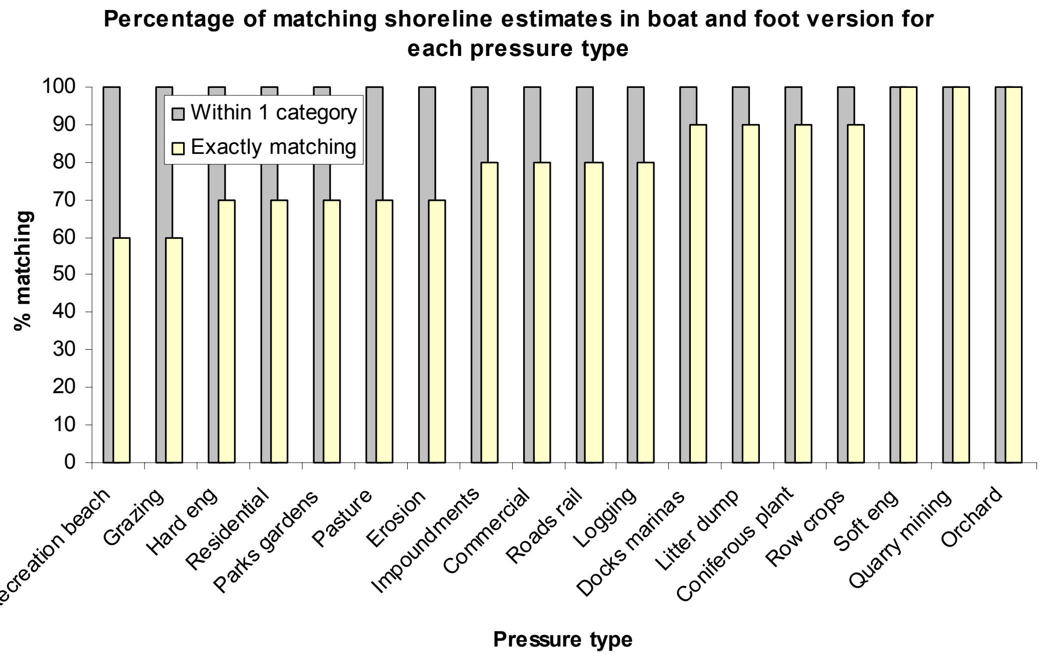


Figure 3.5 The percentage of shoreline estimates matching, and matching to within one category, for each shoreline pressure averaged over all lakes for boat and foot surveys

It is likely that the commonly occurring pressures that were more consistently observed between the boat and foot versions, such as docks and marinas and coniferous plantations, were simply more easily observed. The foot survey involved the use of binoculars often over long distances, and recreational beaches and the presence of grazing animals were difficult to detect. This is somewhat supported by the results shown in Figure 3.6, which depicts the percentage of shoreline estimates matching, and matching to within one category, in the boat and foot surveys, averaged over all pressures. The two smaller lakes, Brandy and Kilconquhar, showed very high agreement between the boat and foot shoreline surveys. The most poorly matched results were for Windermere, which may be in part explained by foggy conditions. In addition, the Windermere shoreline proved difficult to view from the opposite shore as it is very long, narrow and convoluted.

While the entries exactly matching were as low as 60% for some lakes and some shoreline pressure types, all entries were matching to within one category 100% of the time. This means that for a particular lake with a shoreline estimate of 10-40% (a 2 in the scoring category used in LHS) for the boat survey, the estimate from the shore survey was always at least a 1 or a 3. Overall, therefore, high consistency was found between the boat and foot versions; however, this too would be likely to improve with surveyor training and experience.

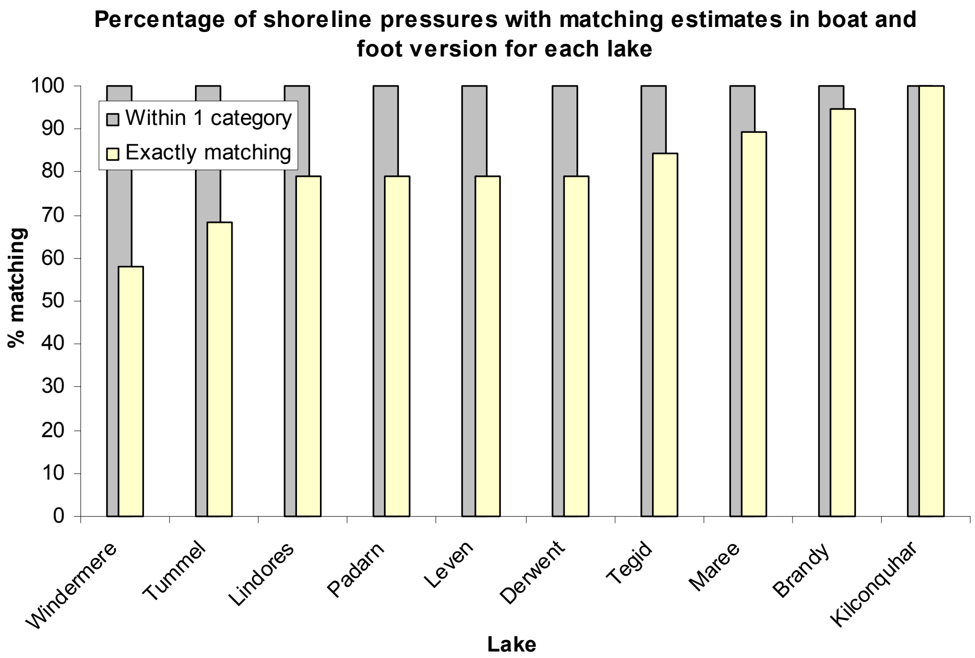


Figure 3.6 The percentage of shoreline estimates matching, and matching to within one category, for the boat and foot survey for each lake averaged over all pressures

3.3 Comparison of core and full version

The fully comprehensive and LHS_{core} versions were compared by looking at the number of features recorded in each. Based on the number of possible entries drawn from selected sections of the survey form, the total number of features recorded using each version is shown in Figure 3.7. In all cases the full version resulted in more features being observed (plotting above the equiline) and a paired t-test confirmed that the two methods were significantly different (P<0.0001). While these results are using a small number of lakes, this does suggest some level of incompatibility between the core and full versions.

Figure 3.8 illustrates the cumulative numbers of features recorded with increasing numbers of Hab-Plots for each of the 10 study lakes. There is no discrimination between natural and artificial features, thus cumulative number is a proxy of feature diversity. The range of curve forms clearly distinguishes sites of relatively low diversity such as Loch Brandy from more complex sites such as Llyn Padarn and Lindores Loch. For most lakes there was a slight inflection at around three Hab-Plots, but generally more features were observed up until the seventh or eighth Hab-Plots, where curves were typically much flatter. However, the occasional extra feature was observed at the ninth or tenth Hab-Plot.

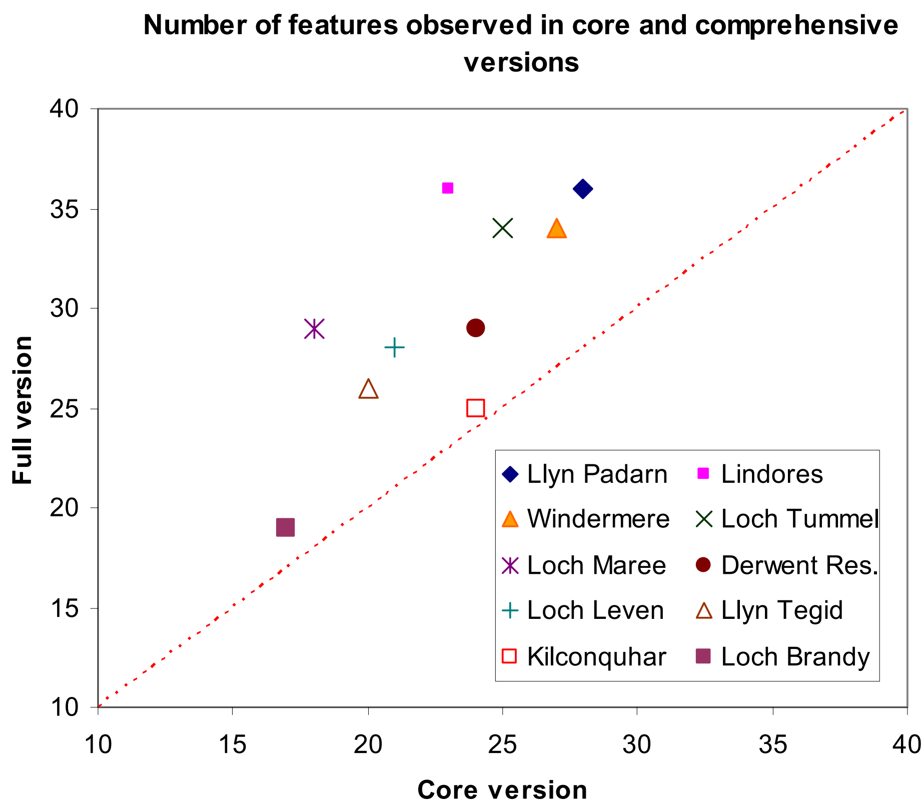


Figure 3.7 Total number of features observed in core vs. full versions of LHS

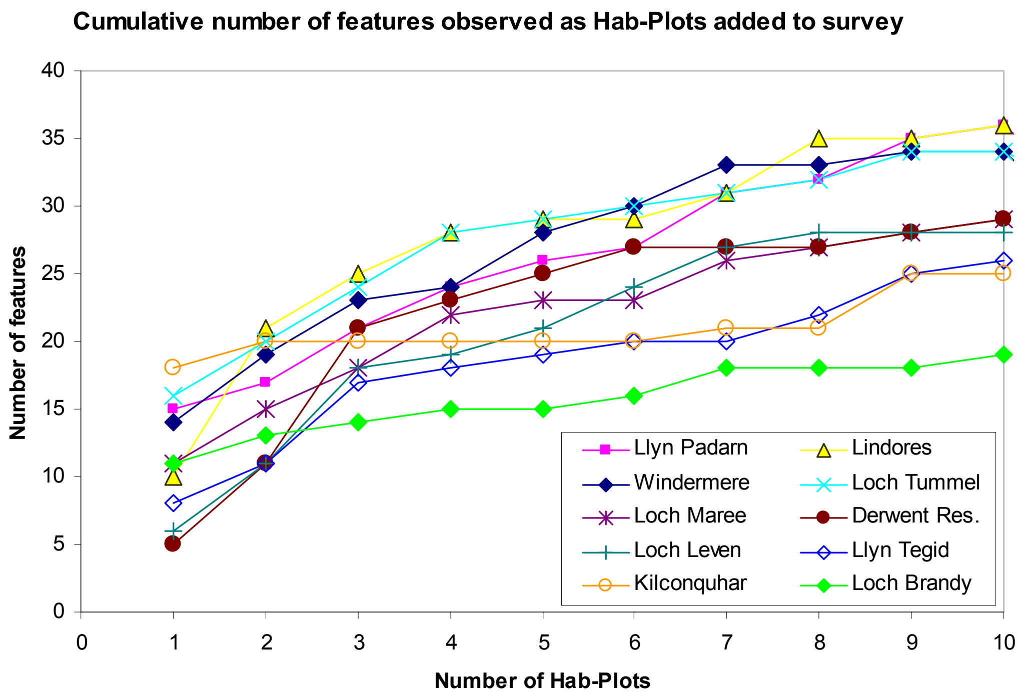


Figure 3.8 Cumulative number of features observed as Hab-Plots are added to the survey for each lake up to a maximum of 10 Hab-Plots

The cumulative number of different features observed with increasing numbers of Hab-Plots is shown for three lakes – Loch Leven, Llyn Tegid and Loch Brandy – in Figures 3.9-3.11, respectively. In this case, 10 random iterations of different combinations of plots were used at each interval, i.e. for Loch Leven 10 different combinations of 1, 2, 4, 6.... Hab-Plots were averaged to give the number of features in each category at 6 Hab-Plots on the graph. This produced smoother curves. For two of these sites, the total number of Hab-Plots surveyed exceeded the usual 10 (Loch Leven: 20, Llyn Tegid: 15).

Trends for Loch Leven and Llyn Tegid were similar (Figures 3.9-3.10). Both clearly demonstrate a sharp rise in the number of features observed up to a critical inflection point of between six to eight Hab-Plots. Beyond this number of Hab-Plots key variables such as beach material, littoral material and diversity of vegetation types were stable. However, some features – e.g. littoral features, dominant land-cover and diversity of macrophyte types – continued to rise before the curve flattened out between nine and 12 Hab-Plots. For Loch Brandy (Figure 3.11), curves were much flatter, again highlighting its less diverse nature. Few extra features were gained beyond four Hab-Plots, and there was particularly low diversity in cases such as beach material, where only boulders were observed.

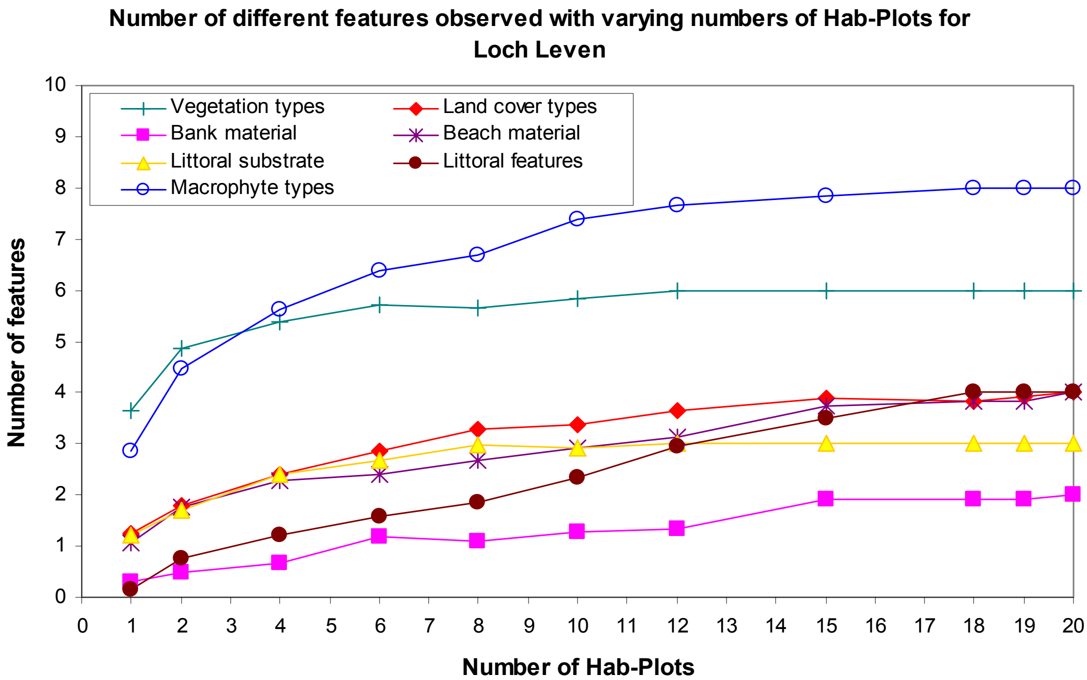


Figure 3.9 Number of features observed in each feature category with increasing numbers of Hab-Plots from 1 to 20 for Loch Leven

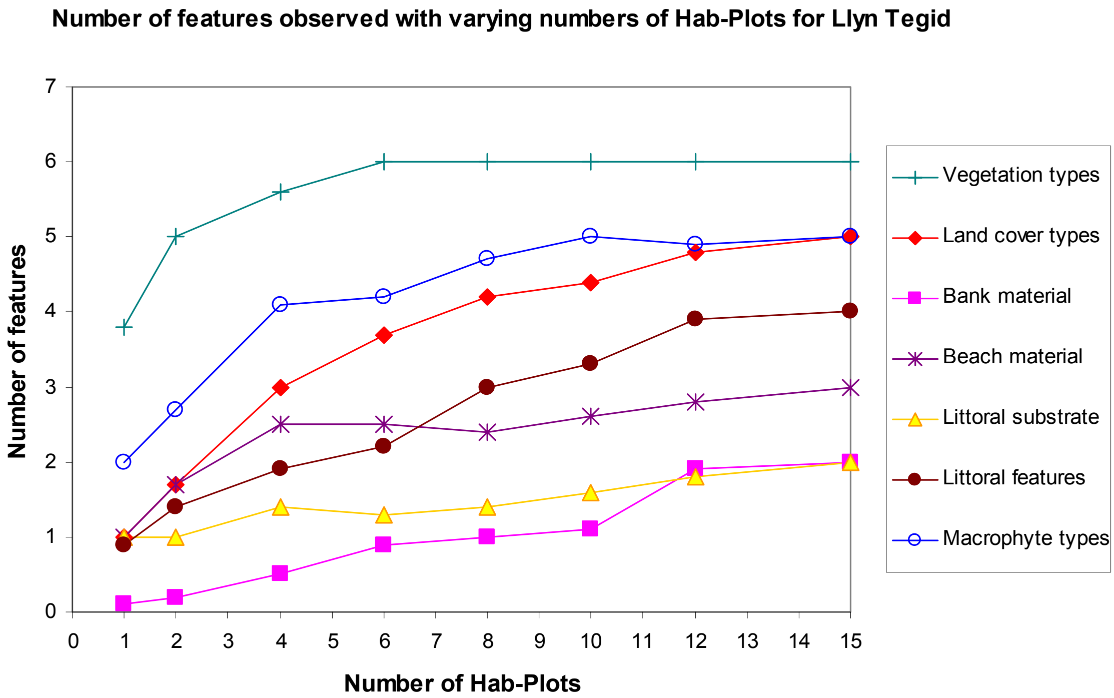


Figure 3.10 Number of features observed in each feature category with increasing numbers of Hab-Plots from 1 to 15 for Llyn Tegid

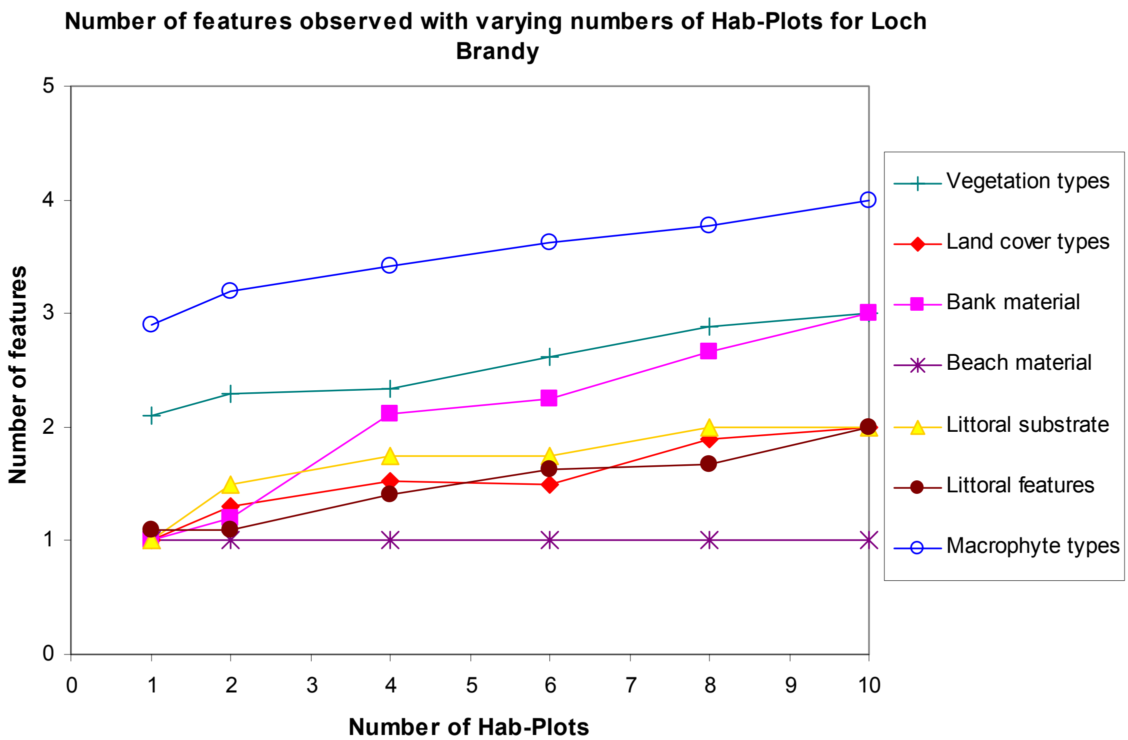


Figure 3.11 Number of features observed in each feature category with increasing numbers of Hab-Plots from 1 to 10 for Loch Brandy

The cumulative total number of features observed as a function of increasing the number of Hab-Plots surveyed is shown for these three lakes in Figure 3.12. The results indicate that the shape of the feature curves is a reflection of the habitat diversity along with the size and complexity of the lake under investigation, i.e. in Figure 3.12 there is a clear divergence between the results for Loch Leven and Loch Brandy, reflecting a large, productive, naturally-eutrophic system situated within an agricultural catchment, versus a small upland oligotrophic system with a montane moorland-heath vegetation cover. These results also show that the overall feature accumulation curves for Loch Leven and Llyn Tegid do not necessarily 'plateau' before 10 Hab-Plots. However, relatively little extra information is gained beyond 10 Hab-Plots. In addition, these sites are both extremely diverse, and conducting more than 10 Hab-Plots for LHS is likely to be time consuming and inefficient in terms of extra information gained for most lakes.

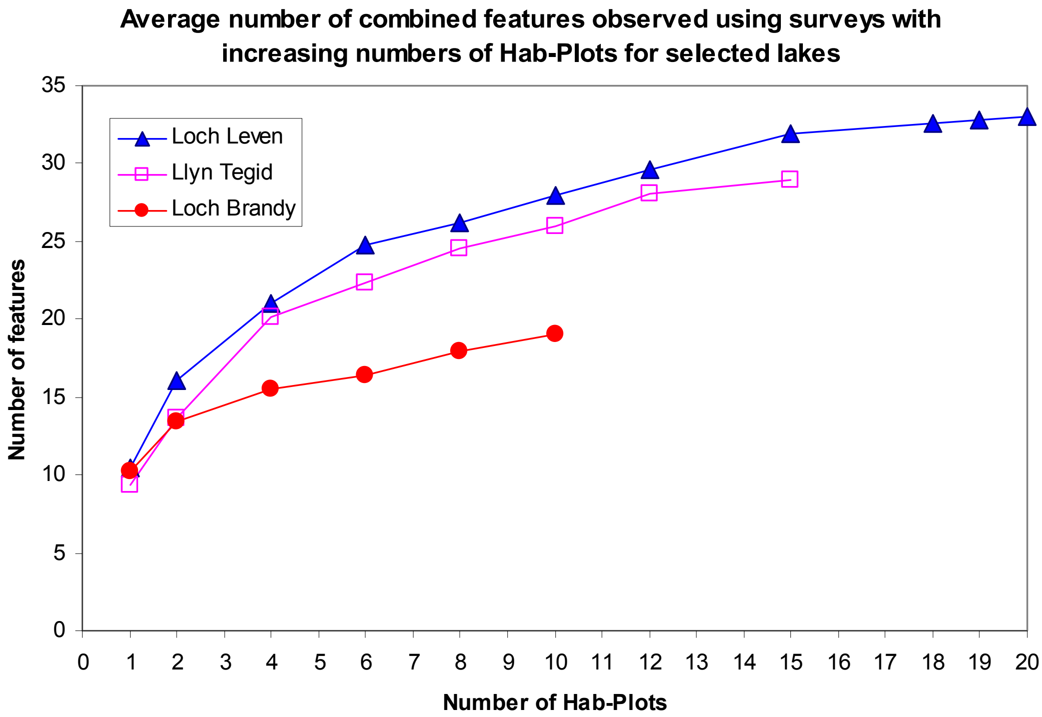


Figure 3.12 Cumulative total number of features observed with increasing number of Hab-Plots from for Loch Leven, Llyn Tegid and Loch Brandy

3.4 Characterising shore pressures and natural land-cover

The 10 principal lakes used to test different LHS versions were subject to a range of pressures and impacts, and exhibited a variation of habitat types. The lake shore pressures and habitats can be well represented and summarised by the shoreline data collected on each lake. Table 3.2 details the pressures affecting each lake, and the extent of the shoreline that appears to be subject to each pressure, where 0=*Zero, 1=Sparse (<10%), 2=Moderate (10-40%), 3=Heavy (>40-75%), 4=Very heavy (>75%).* Estimations are given to within 15 m and 50 m of the shoreline. Estimations of the extent of natural habitat types present at the site (within 50 m) are also given in Table 3.3, using the same percentage bands.

The data presented in Table 3.2 demonstrate a high degree of discrimination between the 10 sites, both in terms of the number of shoreline pressures present and their intensity. Loch Brandy featured only grazing as a sparse pressure, whereas Llyn Padarn was subject to 11 out 18 recognised pressures and intensity scores reaching 4 (> 75 % of the shoreline length). Note that for some lakes, extending the survey to a 50 m observation limit identified pressures not captured within 15 m. For example at Derwent Reservoir four additional pressures were added: residential, roads, parks/gardens and coniferous plantation. This is even more significant in the case of Llyn Padarn, whereby quarrying, a defining characteristic of the lake, was not observed within 15 m of the shore, but was recorded as moderate (10-40 %) within 50 m. Similarly, roads and railways increased by a class of one or more in seven out of the 10 lakes when observations were extended to 50 m. Nevertheless, in 90 % of the cases, there was not a range difference between the two data sets. The key issue here is to capture the ecologically relevant pressures. As distance from the shoreline increases so does the area over which these pressures need to be observed. There are also likely to be a mixture of pressures / land-cover types / habitats, etc., which may not be captured in sufficient detail or recognised, due to the semi-quantitative nature of field survey techniques. An alternative approach may be to use remote sensing and secondary geo-spatial data sets which can provide a less subjective and synoptic view of the area. This is investigated further in Section 3.7.

In the LHS_{core} protocol tested by agency teams in 2004 natural land-cover types within the riparian zone are recorded only within Hab-Plots. For development purposes additional data summarising nine natural land-cover types within 50 m of the shoreline were also collected (Table 3.3). Some sites, such as Kilconquhar, have a high degree of natural land-cover in the riparian zone, but exhibit a low diversity of land-cover types (where broadleaf/mixed woodland exceeds 75 %). Loch Brandy is similarly dominated by one land-cover type (moorland heath), but features a greater diversity of types. Such observations permit a qualitative grouping of these sites into low diversity and low natural cover (Derwent Reservoir) to high diversity and high natural cover (such as Lindores). Lochs Brandy and Kilconquhar are grouped by having high natural cover values, but dominated by only one or two land-cover types.

Table 3.2 Summary data for shoreline pressures within 15 m and 50 m for all lakes expressed as extent of total shoreline length

Pressure type	Derwent		Brandy		Windermere		Llyn Tegid		Kilconquhar		Leven		Lindores		Maree		Padarn		Tummel	
	15 m	50 m	15 m	50 m	15 m	50 m	15 m	50 m	15 m	50 m	15 m	50 m	15 m	50 m	15 m	50 m	15 m	50 m	15 m	50 m
Impoundments	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1
Hard engineering	2	2	0	0	2	2	2	2	2	2	1	1	2	2	1	1	3	3	1	1
Soft engineering	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0
Docks, marinas	1	1	0	0	2	2	2	2	1	1	1	1	1	1	1	1	2	2	1	1
Commercial	0	0	0	0	2	2	0	0	0	0	1	1	1	1	1	1	2	2	0	0
Residential	0	**1**	0	0	2	2	1	1	2	2	1	1	1	1	1	1	2	2	1	1
Litter, dump	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2	2	0	0
Quarry, mining	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**	0	0
Roads, rail	0	**1**	0	0	1	**2**	2	**3**	0	0	1	1	3	**4**	1	**3**	3	**4**	1	**2**
Parks, gardens	1	**2**	0	0	2	2	2	2	1	1	1	1	1	1	1	1	2	2	0	0
Recreation beach	1	1	0	0	1	1	2	2	0	0	1	1	0	0	1	1	2	2	0	0
Coniferous plantation	1	**2**	0	0	1	1	0	0	0	0	1	1	0	0	1	**2**	0	0	1	**2**
Logging	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	**1**	0	0	0	0
Pasture	3	3	0	0	2	2	2	**3**	0	0	2	2	2	**3**	1	1	1	1	2	2
Grazing	0	0	1	1	0	0	1	1	0	**1**	0	0	0	0	0	0	0	**1**	1	1
Row crops	0	0	0	0	0	0	0	0	0	2	2	2	2	**3**	0	0	0	0	1	1
Orchard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Erosion	2	2	0	0	0	0	0	0	0	0	1	1	0	0	1	1	0	0	2	2

NB Emboldened numbers denote an increase in the extent of pressure observed within 50 m of the shoreline compared with 15 m
Key for extent of shoreline pressures: 0 (0-1%), 1 (>1-10%), 2 (>10-40%), 3 (>40-75%), 4 (>75%)

Table 3.3 Summary data for natural shoreline land-cover within 50m for all lakes expressed as extent of total shoreline length

Land-cover type	Derwent	Brandy	Windermere	Llyn Tegid	Kilconquhar	Leven	Lindores	Maree	Padarn	Tummel
Broadleaf/mixed woodland	0	0	**3**	**3**	**4**	**3**	2	**3**	**3**	**3**
Broadleaf/mixed plantation	1	0	1	0	0	0	0	0	1	1
Scrub and shrubs	1	0	0	1	0	1	1	1	1	0
Wetland	1	1	1	0	1	0	1	0	1	1
Moorland/heath	0	**4**	0	0	0	0	0	**3**	0	0
Open water	0	1	0	0	0	0	0	0	0	0
Rough grassland	1	0	1	2	0	2	**3**	0	1	1
Tall herb/rank vegetation	0	0	0	0	0	0	0	0	0	0
Rock, scree or dunes	0	1	0	0	0	0	0	1	0	0
Diversity of land-cover types	4	4	4	3	2	4	5	4	5	5

NB Emboldened numbers denote natural land-cover types exceeding 40 % of the total shoreline length.
Key for extent of land-cover types: 0 (0-1%), 1 (>1-10%), 2 (>10-40%), 3 (>40-75%), 4 (>75%)

3.5 Summary metrics using LHS data

LHMS and LHQA metrics were generated for each of the 10 principal test lakes using each LHS version, i.e. LHS_{core} (boat and foot) and the full boat-based version. Table 3.4 presents the results for LHMS showing how the final score is generated, and the LHQA data are given in Table 3.5.

In its present configuration LHMS has a full potential range from 0 to 42. Derwent Reservoir scored the highest total of 28 reflecting the construction of its impoundment, highly regulated water levels, modified shoreline and recreational pressures. Of the natural lakes, Llyn Padarn scored highest because of the range and intensity of impacts, e.g. downstream of a hydro-scheme, highly modified shore zone with road and railway embankments, significant infilling and land-take from dumped quarry spoil and a position within Snowdonia National Park which makes the lake a honey-pot for tourists visiting the lake-side resort town of Llanberis. By contrast, systems like lochs Brandy and Maree achieved much lower scores. Situated at over 600 m in the southern Grampian Mountains, Loch Brandy experiences relatively few pressures, excepting managed grazing (grouse, deer and sheep) on the heather moorland. Grazing pressures and heather burning prohibit colonisation by trees, but otherwise the system can be considered semi-natural. Loch Maree has more modification because, common to many large UK lakes, it has roads running at least part way along the valley floor. The access thus afforded is also often associated with recreational facilities (car parking, picnic sites and walking trails) and engineering modifications also occur. An intermediate level of disturbance is shown for sites such as Kilconquhar, Lindores and Leven.

Considering only the full version LHS, the LHQA values ranged from a minimum of 42 for Derwent Reservoir to a maximum of 86 for Loch Maree. The LHQA is configured to express naturalness and diversity as proxies for the conservation value of a site. Unlike the LHMS, which provides a measure of alteration from pristine, the LHQA does not have a comparable single starting point and must therefore be qualified in relation to the type of lake under consideration. This issue has been previously identified in the equivalent HQA developed for rivers within the RHS programme (Raven *et al.* 1998), and in the context of the WFD indicates the need to utilise type-specific reference conditions. The UK's Technical Advisory Group Article 5 Report WP2a(01) (TAG, 2004), will report 12 lake types for the UK spanning six geological types (variants of siliceous, calcareous and organic) and two depths (deep/shallow). Further divisions, but not used for reporting purposes, include altitude and area. For these 12 lake types, there is a need to define 'type-specific reference conditions' with respect to both biological quality elements and hydromorphological quality elements including hydrological regime and morphological condition.

Table 3.4 LHMS scores for each of the 10 lakes generated by each survey version

Lake	Method	Shore modification	Shore use	Lake pressures	Hydrology	Sediment regime	Nuisance species	TOTAL SCORE
Llyn Tegid	LHS_{core} boat	2	6	8	6	0	0	22
	LHS_{core} foot	2	6	8	6	0	0	22
	Full LHS boat	2	8	8	6	0	0	24
Brandy	LHS_{core} boat	0	0	0	0	0	0	0
	LHS_{core} foot	0	0	0	0	0	0	0
	Full LHS boat	0	0	0	0	0	0	0
	Full LHS foot	0	0	0	0	0	0	0
Derwent	LHS_{core} foot	4	8	6	8	2	0	28
	Full LHS boat	4	8	6	8	2	0	28
Kilconquhar	LHS_{core} boat	4	4	2	0	0	0	10
	LHS_{core} foot	4	4	2	0	0	0	10
	Full LHS boat	4	4	2	0	0	0	10
Leven	LHS_{core} boat	2	4	4	6	0	0	16
	LHS_{core} foot	2	4	4	6	0	0	16
	LHS_{core} (random)	2	4	4	6	0	0	16
	Full boat (1-10)*	2	4	4	6	0	0	16
	Full boat (11-20)*	2	4	4	6	2	0	18
	Full boat (random)	2	4	4	6	0	0	16
Lindores	LHS_{core} boat	2	4	4	0	0	0	10
	LHS_{core} foot	2	6	4	0	0	0	12
	Full LHS boat	2	8	4	0	0	0	14
Maree	LHS_{core} boat	0	4	4	0	0	0	8
	LHS_{core} foot	0	2	2	0	0	0	4
	Full LHS boat	0	2	4	0	0	0	6
Padarn	LHS_{core} boat	8	8	6	2	0	0	24
	LHS_{core} foot	8	8	6	2	0	0	24
	Full LHS boat	8	8	6	2	0	0	24
Tummel	LHS_{core} boat	0	4	8	8	0	0	20
	LHS_{core} foot	0	8	8	8	0	0	24
	Full LHS boat	2	6	8	8	0	0	24
Windermere	LHS_{core} boat	4	8	6	4	2	2	26
	LHS_{core} foot	2	8	6	4	0	2	22
	Full LHS boat	2	8	6	4	4	2	26

*1-10 indicates that the first 10 Hab-Plots were used, while 11-20 indicates the second 10 which were evenly spaced between the first around the lake

Table 3.5 LHQA scores for each of the 10 lakes generated by each survey version

Lake	Method	Riparian	Shore	Littoral	Whole Lake	Total Score
Llyn Tegid	LHS_{core} boat	10	8	18	7	43
	LHS_{core} foot	9	9	20	7	45
	Full LHS boat	10	8	23	7	48
Brandy	LHS_{core} boat	7	11	22	15	55
	LHS_{core} foot	6	11	15	15	47
	Full LHS boat	9	13	25	15	62
	Full foot	7	14	20	15	56
Derwent	LHS_{core} foot	5	9	16	7	37
	Full LHS boat	6	9	20	7	42
Kilconquhar	LHS_{core} boat	9	6	22	10	47
	LHS_{core} foot	9	6	23	10	48
	Full LHS boat	9	5	27	10	51
Leven	LHS_{core} boat	3	5	23	20	51
	LHS_{core} foot	4	9	21	20	54
	LHS_{core} boat (random)	7	4	25	20	56
	Full LHS boat (1-10)*	6	8	28	20	62
	Full LHS boat11-20)	9	10	25	15	59
	Full LHS boat (random)	6	10	24	20	60
Lindores	LHS_{core} boat	7	6	21	17	51
	LHS_{core} foot	7	10	24	17	58
	Full LHS boat	10	5	27	17	59
Maree	LHS_{core} boat	9	6	20	34	69
	LHS_{core} foot	13	8	14	34	69
	Full LHS boat	11	15	26	34	86
Padarn	LHS_{core} boat	9	13	23	7	52
	LHS_{core} foot	9	9	19	7	44
	Full LHS boat	8	12	26	7	53
Tummel	LHS_{core} boat	7	16	20	15	58
	LHS_{core} foot	9	16	20	15	60
	Full LHS boat	8	14	27	15	64
Windermere	LHS_{core} boat	8	9	23	17	57
	LHS_{core} foot	7	11	20	17	55
	Full LHS boat	8	12	24	17	61

*1-10 indicates that the first 10 Hab-Plots were used, while 11-20 indicates the second 10 which were evenly spaced between the first around the lake

Comparisons of LHMS and LHQA in the core and full survey versions are shown in Figures 3.13 and 3.14 respectively. Values for the scores obtained between the boat and foot versions (using core data) are shown in Figures 3.15 and 3.16.

With respect to LHMS there is a high degree of consistency between the different versions of LHS. In terms of LHS_{core} boat and foot-based surveys, six out of the 10 case-studies produced identical results. Where results differed it was generally because the boat version provided a more comprehensive view of the shoreline; consequently 'shore modification' values were higher. A high degree of consistency was also observed between LHS_{core} and the full survey (Figure 3.13). This might seem surprising considering the different numbers of Hab-Plots involved in each (four versus 10), but reflects the fact that the scoring system also draws heavily on whole-lake metrics such as shore modifications, hydrological data and nuisance species. Again, where differences occur, the full-boat LHMS generally scores higher by virtue of having a better view of the shoreline and a greater likelihood of observing modifications and pressures.

In the case of LHQA there is a greater variety of outcomes depending on the survey method used. The foot and boat versions of LHS_{core} are the most consistent, with the difference varying by up to 8 points (Loch Brandy and Llyn Padarn). These differences principally result from the foot-based survey producing higher scores in the riparian categories and lower in the littoral. These differences became more exaggerated in the comparison of LHS_{core} and the full version of LHS (Figure 3.14). In this case the full version consistently scored higher than the foot-based LHS_{core} by 3-15 points; again riparian and littoral totals differed, but the LHQA is also sensitive to the number of Hab-Plots surveyed.

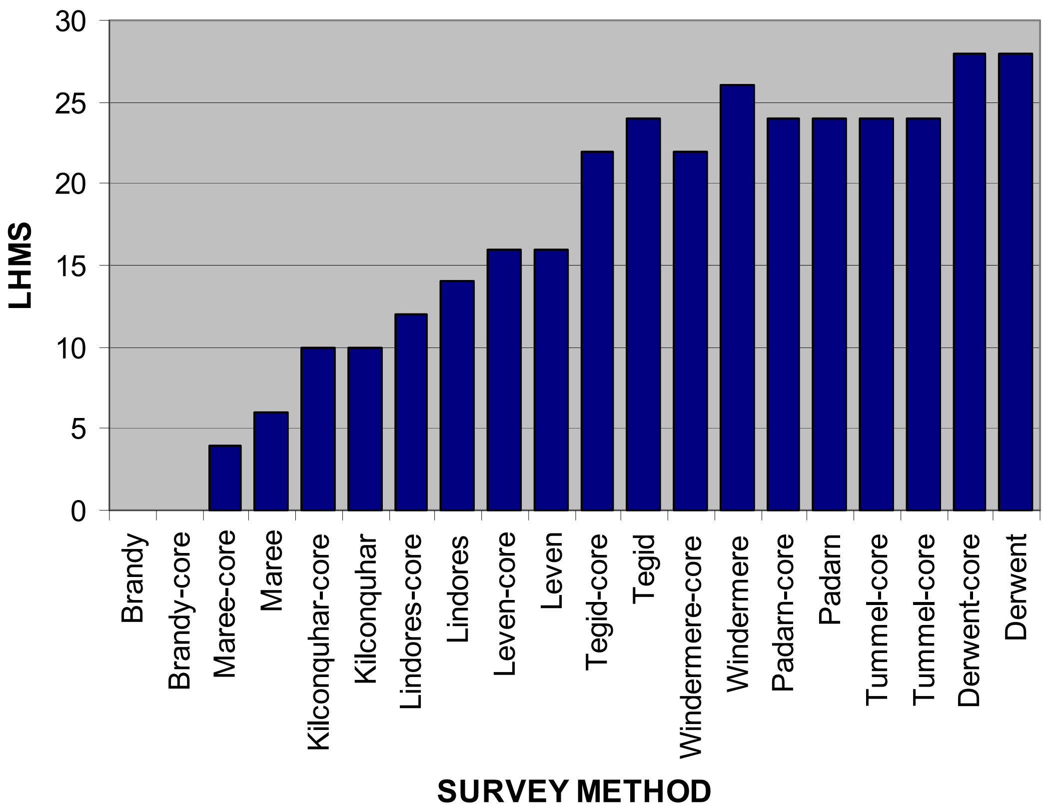


Figure 3.13 LHMS results for 10 lakes illustrating both full LHS and LHS_{core} results

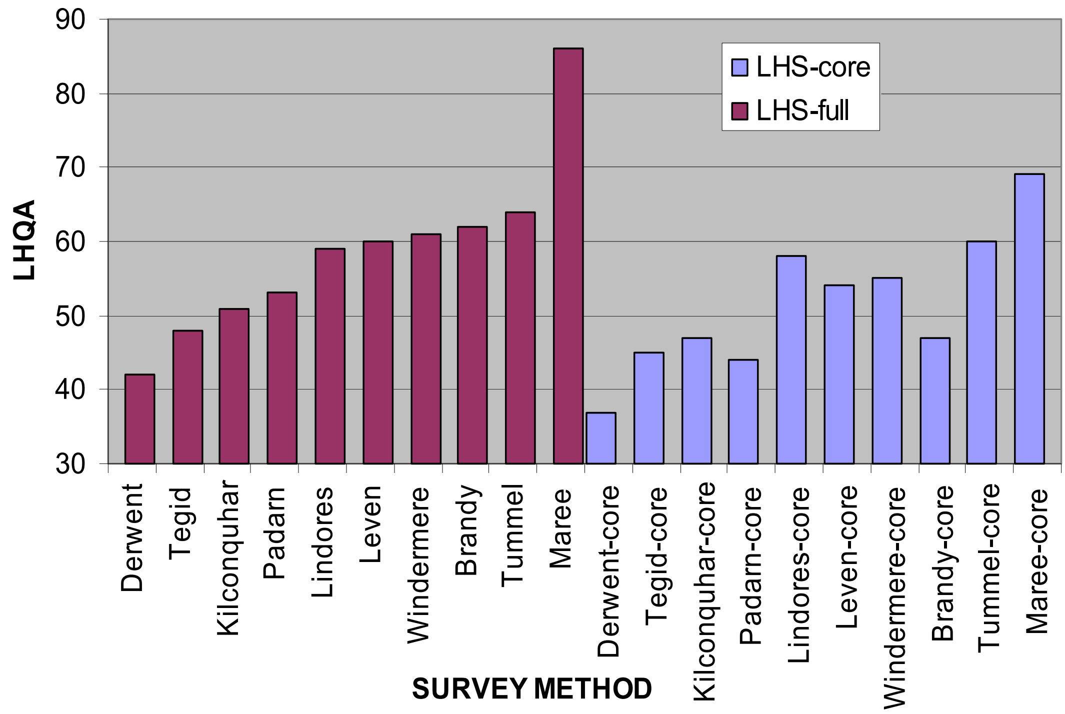


Figure 3.14 LHQA results for 10 lakes illustrating both full LHS and LHS_{core} results

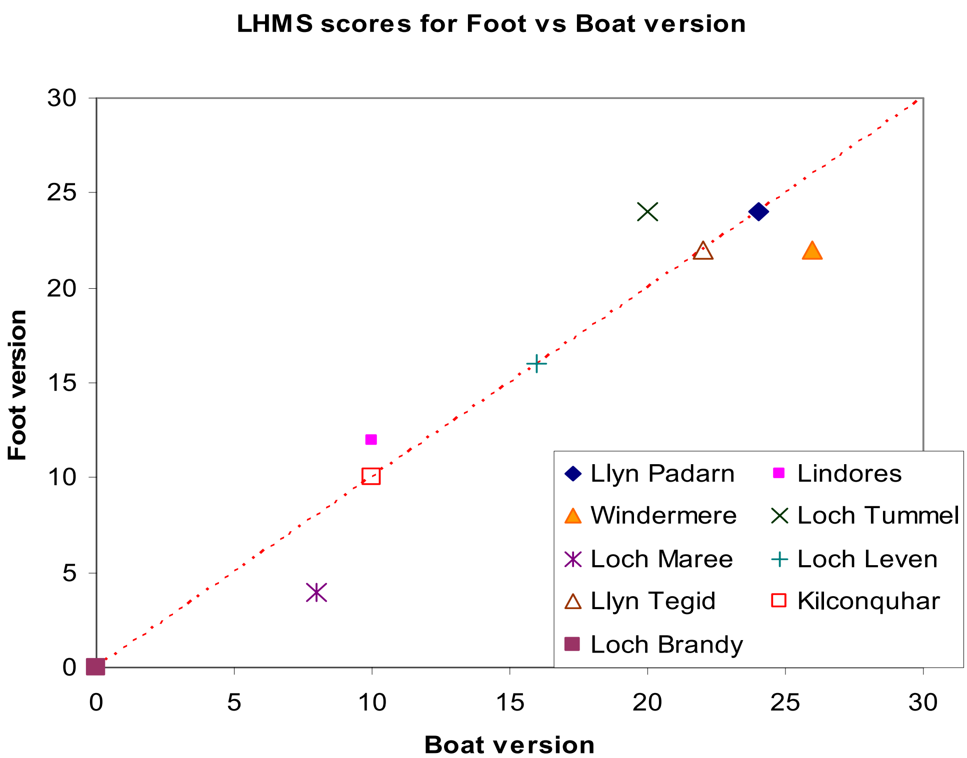


Figure 3.15 LHMS results for 10 lakes illustrating boat and foot LHS_{core} results

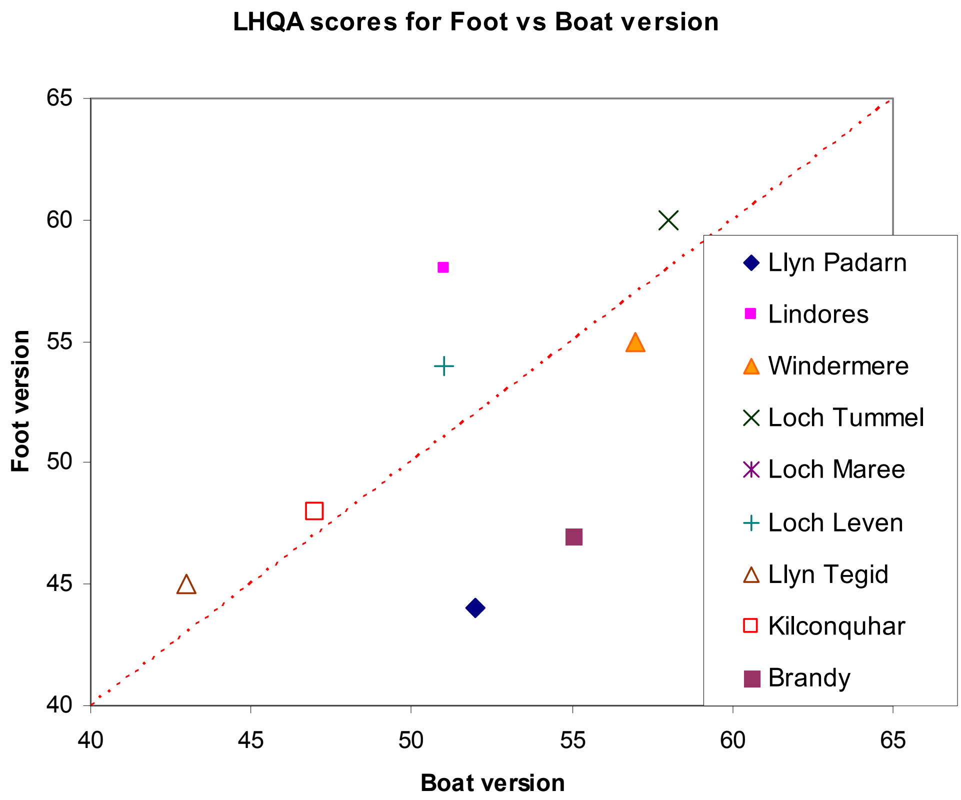
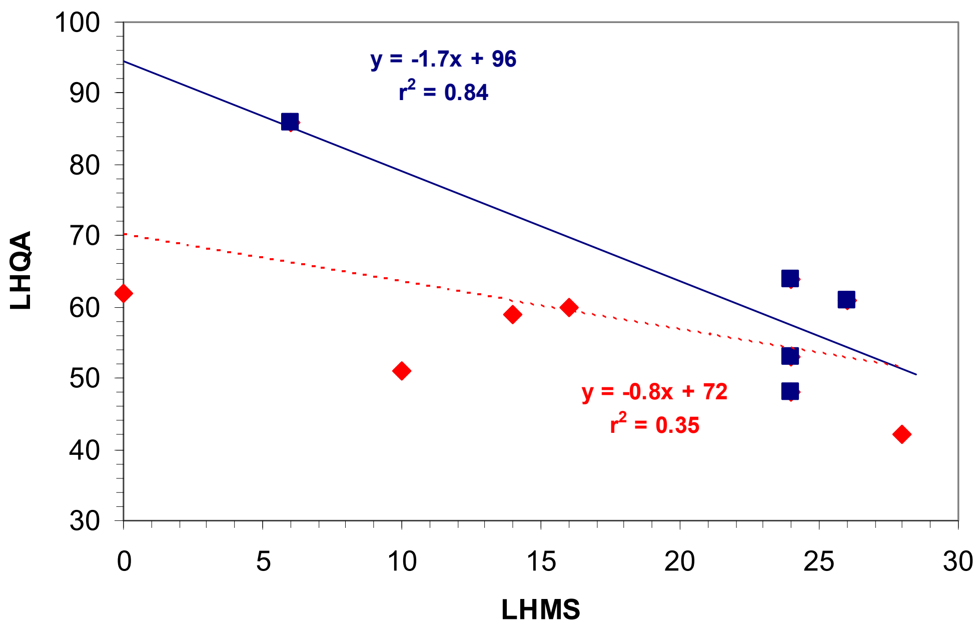


Figure 3.16 LHQA results for 10 lakes illustrating boat and foot LHS_{core} results

Summary metrics such as LHMS and LHQA have obvious potential for classification purposes, especially in the context of identifying lakes at HES and those at risk of not attaining GES due to hydromorphological alteration. The relationship between LHMS and LHQA for the 10 principal lakes is shown in Figure 3.17 (using data from the full LHS survey). This demonstrates a negative, but statistically insignificant trend, between the two metrics. However, when only the same lake type (siliceous, deep, lowland and large) is considered, the negative relationship becomes stronger and statistically significant ($p < 0.05$). As more data become available (i.e. from surveys undertaken by SNH, EA, SEPA, EHS) it should be possible to better define a geographically representative baseline dataset identifying the diversity and extent of habitat features encapsulating the lake-type reference conditions. This point is best illustrated with reference to Loch Brandy, because although the LHMS confirms it to be in near-pristine condition, it has a relatively low LHQA. However, this result is consistent with the fact that in near-pristine condition, oligotrophic upland systems such as Loch Brandy should naturally feature a low diversity of habitat forms.
In relation to the equivalent problem in river assessment studies, Buffagni and Erba (2002) introduced the concept of a 'Benchmark Distance Score (BCD), which indicates the extent of difference between a site and a pristine analogue, and a River Habitat Quality (RHQ) score derived from combining the other indices, which provides an overall evaluation. It is recommended that in Phase 2 of the development programme, on the basis of the anticipated greatly enlarged dataset, corresponding scores for LHS will be derived. This is seen as the key route towards the contribution that LHS can make in defining HES for lakes and the delimitation of the GES/less than good boundary. In this way LHS will become integrated into implementation of the WFD in terms of the identification, prevention and reduction of ecological impacts in lakes.



Key:

....	Least-squares regression fitted through all 10 points
■	Sub-set of lakes within a single UK typology (*siliceous, deep, lowland and large*)
——	Regression of single typology sub-set
◆	Remaining lakes (other typologies)

Figure 3.17 Plot of LHMS vs. LHQA for the 10 principal test lakes

3.6 Index Site results

Index Site measurements are considered an important element in physical habitat characterisation (Kaufmann and Whittier, 1997). Key results reporting maximum depths observed, light penetration (Secchi depths), alkalinity, thermal stratification and dissolved oxygen concentrations are summarised in Table 3.6. Alkalinity data are a simple surrogate for catchment geology (central to the WFD lake typology) and clearly differentiate base-poor, low productivity systems such as Loch Maree from naturally eutrophic and highly productive systems exemplified by Loch Leven. Secchi depths reflect both levels of production and lake-type and exhibit non-linear dependency on alkalinity with the relation $y = 407x^{-1.3}$ ($r^2 = 0.65$), varying from > 7 m in deep oligotrophic systems such as Loch Brandy, to depths of less than 0.5 m in eutrophic broad-lakes such as Kilconquhar which additionally experience regular bed sediment re-suspension events (OECD classification data are shown in Table 3.7).

Examples of thermal and dissolved oxygen profiles observed on selected lakes are shown in Figure 3.18. Shallow lakes such as Kilconquhar and Lindores, by virtue of limited depth and full-water column mixing, do not develop any thermal structure (isothermal). Some larger and 'deeper' systems, such as Loch Leven, also fail to stratify because their convex hypsographic forms (*cf.* Håkanson, 1981) promote mixing between extensive shallows and deeper areas of more limited extent. All the other lakes exhibited well defined stratification with the top of the metalimnion (thermocline) commencing as shallow as 4 m in the case of Llyn Padarn to a depth of 22 m in the case of Loch Brandy. Surface temperatures reflect location factors (latitude, longitude and altitude) as well as lake morphology and the co-dependent epilimnion volume. In the study lakes examined oxygen stress was not a widespread problem, though in the case of the Lindores commercial trout fishery, oxygen levels were maintained by an artificial aeration system. Microbial decomposition of organic matter falling from relatively productive epilimnions led to significant dissolved oxygen hypolimnion deficits in two lakes e.g., 3.8 mg L^{-1} in Llyn Padarn and effectively zero in the basal layers of Derwent Reservoir. It is widely accepted that DO levels below 4 mg L^{-1} cause acute mortality of early life stage fishes as well as macro and micro-invertebrates. Furthermore, deoxygenation of bottom waters and consequent changes to the redox status of the sediment-water interface can lead to rapid release of nutrients and contaminants resulting in significant water quality deterioration.

Because Index Site data are not collected in LHS_{core}, in order to permit foot-based application of the survey method LHMS and LHQA scores do not include these data. However, it is recommended that these data are routinely collected. In the absence of more comprehensive data it is recommended that LHS should determine the maximum depth, which has powerful explanatory value in a range of limnological models (*cf.* Håkanson, 1997). Indeed, in the case of Loch Brandy the maximum water depth of > 56 m was previously unknown and is exceptionally deep for a corrie lochan. In possible future refinements of the HMS (see Table 2.4) it is clear that Secchi depths and DO levels could be additionally incorporated into measures of habitat modification and habitat quality.

Table 3.6 Summary data for Index Site for the 10 principal survey lakes

Lake	Index Site survey date	Maximum depth observed (m)	Secchi depth (m)	Alkalinity (mg L^{-1} $CaCO_3$)	Thermal stratification (Yes/No)	Temperature range (^{O}C)	Hypolimnion dissolved oxygen deficit (< 4 mg L^{-1})	Dissolved oxygen range (mg L^{-1})
Loch Maree	24/08/04	100	7.4	25	Yes	14.6 - 12.3	No	9.9 - 9.9
Loch Brandy	06/07/04	57	7.6	25	Yes	10.3 - 4.9	No	n/a
Loch Tummel	29/07/04	40	1.5	50	Yes	15.4 - 7.4	No	9.3 - 7.4
Loch of Lindores	27/05/04	4	0.9	100	No	14.8 - 14.6	No	10.7 - 9.4
Loch Leven	30/06/04	26	2.9	100	No	14.7 - 14.2	No	10.6 - 9.9
Kilconquhar Loch	21/07/04	2	0.5	125	No	19.5 - 18.7	No	n/a
Derwent Reservoir	12/08/04	20	1.0	50	Yes	18.7 - 15.1	Yes	10.2 - 0.0
Windermere	09/08/04	80	2.8	50	Yes	21.8 - 6.8	No	10.8 - 8.1
Llyn Padarn	05/08/04	24	2.5	50	Yes	18.3 - 9.1	Yes	13.9 - 3.8
Llyn Tegid	02/08/04	35	2.9	50	Yes	19.5 - 8.7	No	10.9 - 9.2

Note n/a represents malfunctioning temperature/oxygen meter.

Table 3.7 OECD criteria for trophic status of lakes (after OECD, 1982)

Trophic Status	Total P	Chlorophyll *a*		Secchi disc depth	
	Mean (μg L^{-1})	Mean (μg L^{-1})	Max. (μg L^{-1})	Mean (m)	Min. (m)
Ultra-oligotrophic	< 4	< 1.0	< 2.5	> 12	> 6
Oligotrophic	< 10	< 2.5	< 8.0	> 6	> 3
Mesotrophic	10 - 35	2.5 - 8.0	8.25	6 - 3	3 - 1.5
Eutrophic	35 - 100	8.25	25 - 75	3 - 1.5	1.5 - 0.7
Hypertrophic	> 100	> 25	> 75	< 1.5	< 0.7

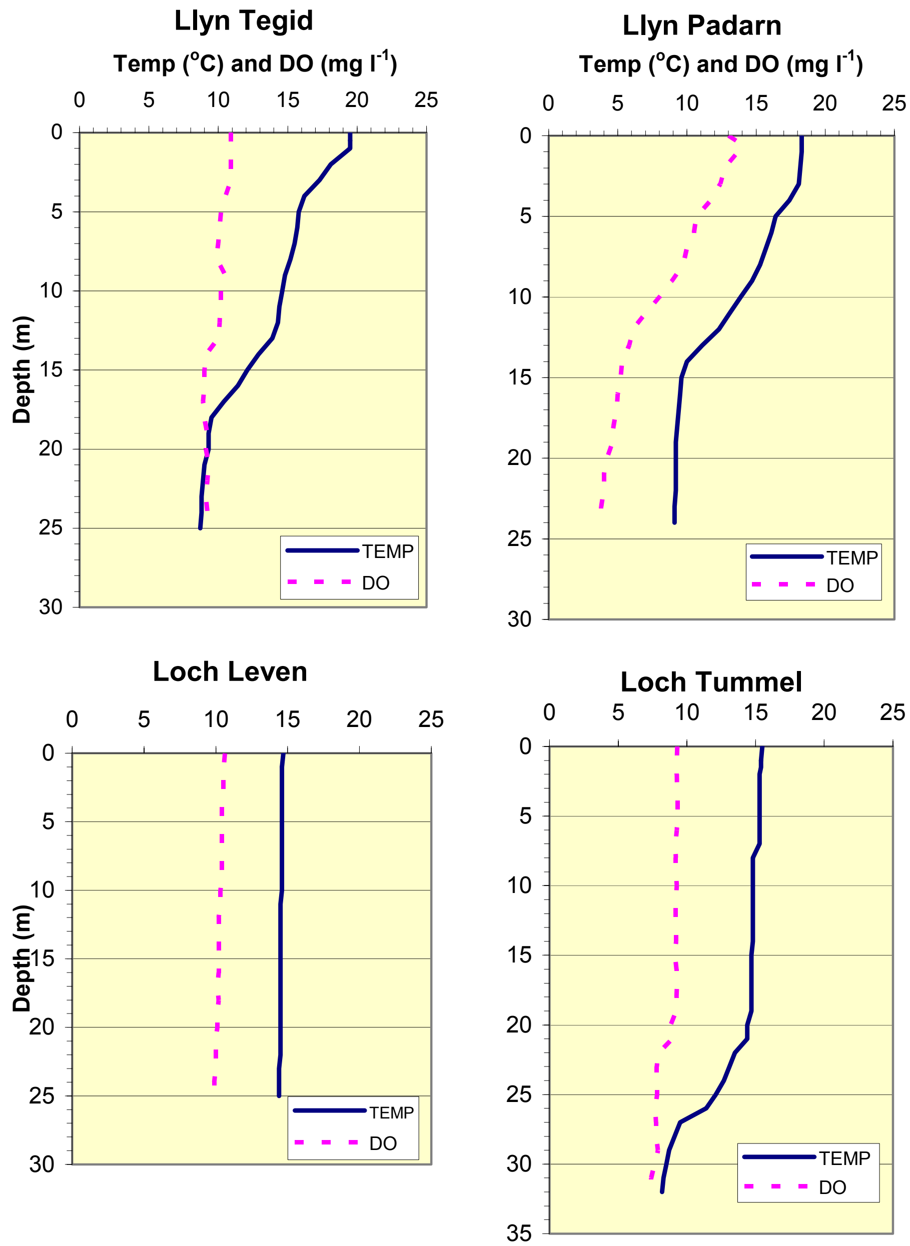


Figure 3.18 Temperature and dissolved oxygen profiles for four selected study lakes.

3.7 Remote sensing and geo-spatial databases

Remote sensing uses electromagnetic radiation (EMR) sensors to record images of the environment that can be interpreted to yield useful information (Curran, 1985). Remotely sensed data can take the form of photographs or digital images, usually acquired from sensors carried on aircraft or satellite platforms that can be manipulated and interrogated to provide information relating to the properties, location and status of objects on the ground. A detailed review of remote sensing technology is not within the remit of this study. This section will therefore concentrate on the use of remotely sensed data and other forms of geo-spatial data with specific reference to LHS.

Table 3.8 compares several commonly available remote sensing platforms in relation to the spatial, spectral and temporal resolution of their data. Spatial resolution refers to the size on the ground that is covered by one pixel in the image. A fine spatial resolution (e.g. 2 - 10 m) will allow small features on the ground to be resolved or distinguished, while medium to coarse spatial resolution sensors (20 - 5,000 m) give a synoptic view across large areas (regional to continental scales). Spectral resolution usually refers to the wavelength range of the sensor, i.e. the number of bands, and the band width. This may be an important factor in detecting ground features that may only be distinguishable in certain regions of the electromagnetic spectrum or in narrow ranges of wavelengths. Temporal resolution refers to the frequency with which data are acquired by a particular sensor.

Table 3.8 Comparison of the spatial, spectral and temporal resolution of common remote sensing systems

Platform	**Sensor**	**Spatial resolution**	**Temporal resolution**	**Spectral resolution**
Aircraft	Wild RC10 aerial camera	Variable (> 200 mm)	Requires aircraft deployment	1 B & W or colour photographs (400-700 nm)
Aircraft	Compact Airborne Spectrographic Imager (CASI)	2 m to 10 m (dependent upon altitude)	Requires aircraft deployment	15 / 288 bands between 450-950 nm
Satellite *(IKONOS)*	IKONOS	4 m	3 days (maximum)	450-520, 520-600, 630-690, 760-900 nm
Satellite *(SPOT)*	High Resolution Visible	20 m	26 days	500-590, 610-680, 790-890 nm
Satellite *(Landsat)*	Thematic Mapper	30 m	16 days	450-520, 520-600, 630-700, 750-900, 1550-1750, 2080-2350, 10400-12500 nm

3.7.1 The potential role of remote sensing in LHS

Cherrill and Mclean (1999) report that field-based survey methods, such as Phase 1 Habitat Survey, are highly surveyor-dependent with attendant implications for accuracy and reproducibility; moreover, because they are labour-intensive and costly this militates against repeat survey. Remote sensing offers scope for the application of a more consistent mapping scheme, independent of people, time and geographical extent (Mehner *et al.*, 2004). In addition, remotely sensed data typically provide a view over a large area and are captured within a short space of time; provide continuous digital data rather than point-based observations; and can be more cost effective in time and financial terms.

To date, remote sensing applications in the study of standing waters have mostly focused on mapping water quality parameters, such as chlorophyll *a* and suspended sediment concentrations (Dekker *et al.* 1996). 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. Acornley *et al*. (1995) demonstrated that the morphological characteristics of chalk streams can be mapped, but that this requires shallow, clear conditions because suspended sediment inhibits the ability of radiation to penetrate through the water column. Such conditions are rarely found in lakes pointing to limited applications in characterising littoral zone and sub-surface features.

Davids *et al.* (2003) reviewed the utility of remote sensing in assessing groundwater and surface water bodies for WFD applications. It was concluded that the approach can yield some information on hydromorphology elements, but the greatest confidence was achieved in estimating land-cover types. Both manual and automated classification of aerial photographs were considered the most effective for characterisation and monitoring applications. Multi-spectral remotely sensed data were reported to have only limited potential.

It is concluded that remotely sensed data could contribute to LHS in the following ways:

- Placing the lake in context with its surroundings and wider catchment, allowing the type of lake and potential pressures to be observed;
- Providing information directly to the LHS survey form, which although requiring some field verification, may benefit from some of the advantages listed above; and
- Provide a means of detecting change after the survey has been completed.

Remote sensing of land-cover

Mapping land-cover is considered the most effective application of remote sensing to LHS. Remote sensing has a long history of mapping land-cover, whether from aerial photography or multispectral images. Mapping objects on the ground from a single aerial photograph relies upon the recognition elements of size, shape, tone, pattern, site and association, shadows and texture. For example, an orchard will appear as a series of regular shapes (trees) in a repeated pattern, with a tone that is likely to either be green (in the case of colour photography) or dark grey (for black and white photography). Using such elements it is possible to map large areas relatively quickly. However, aerial photographs should not be used to trace information directly; rather, the interpreted information should be transferred to a base map acquired from other sources. This is because aerial photographs are not geometrically robust due to variation in scale across the field of view and with topography. Only after significant correction (orthorectification) can aerial photographs be used to map planimetry with confidence. The use of multiple stereo photographs can aid interpretation when viewed through an appropriate stereo viewing device. An impression of topography is given by the stereo model which helps to locate and recognise objects and cover types within the landscape.

The way in which EMR is reflected from the Earth's surface is object specific, with different objects reflecting light at different intensities at different wavelengths. The amount of radiation reflected at each wavelength is known as spectral response and is used for distinguishing between objects, as well as providing other information such as biochemical and biophysical status (Jago *et al.*, 1999). Typically, land-cover is mapped by associating features within remotely sensed imagery (e.g. pixels) with specific land-cover classes and then comparing all other pixels to those that have been linked and assigning them to a class they most resemble. The process of image classification can be completely manual (as in the case of applying photogrammetric interpretation to multispectral images), semi-automated (supervised classification) and fully automated (unsupervised classification). Of these, supervised classification, which relies on user input to make the link between specific pixels and land-cover types, is the most common and generally accepted technique for mapping land-cover from multispectral images. While land-cover classification has been widely used for over 20 years, there continues to be much interest in developing new classification techniques, accuracy measures and algorithms (Aplin, 2004).

3.7.2 Evaluating aerial photography and the existing LHS protocol

Aerial photography was obtained for all the Scottish lochs surveyed by the contractors in 2004 from SNH (the only agency able to supply national coverage of air photos in Scotland). No digital aerial photography was made available restricting the analysis to manual interpretation, nevertheless it was possible to explore the relative performance of black and white photography versus colour photography and to consider scale. Photographs were investigated in relation to helping set context, providing input to the LHS form and in relation to monitoring applications. An experienced remote sensor (M. Cutler) undertook a blind interpretation prior to comparison with field-based results.

A sample of aerial photographs is shown in Figure 3.19. Figure 3.19a illustrates a typical small-scale aerial photograph invaluable for context setting and enabling the surveyor to view all or large parts of a lake within its wider environment. It is highly desirable for surveyors to have access to aerial photography prior to visiting each lake in the field. Photographs provide a stimulating overview of the site and greatly aid pattern recognition as well as navigation. A comparative assessment between the observations made from the photographs versus direct field observation is provided in Tables 3.8 and 3.9, commencing at section 2 of the LHS form (Annex A). In summary it was found that aerial photography estimates of riparian land-cover, dominant bank top vegetation, human pressures and shoreline characteristics agreed well with the estimates made from the LHS field survey. Less reliable were the estimates of lake activities and pressures. Aerial photography was deemed unreliable to complete any of the sections that dealt with the littoral zone, most of the sections in the shore zone and those sections that dealt with individual species of vegetation and animals. The amount of information available from the colour image (Figure 3.19b) was not significantly better. Again it is those sections that require information on land-cover that showed good agreement with the field survey, and those that deal with individual species and fine-scale features that show the poorest relationship between the two surveys.

(a) 1:24,000 scale air photo, Loch of Lindores (1988) and detailed extract

(b) 1:24,000 colour air photo, Kilconquhar Loch (1988) and detail extract.

(c) 1:5,000 scale colour image of Loch Leven.

Figure 3.19 Illustrative aerial photographs: Lochs Lindores, Kilconquhar and Leven

This comparative study suggests no particular advantage of colour photography over black and white. However, the land-cover surrounding both lochs was relatively homogeneous and at sites with more heterogeneous land-cover types, a colour photograph will have distinct advantages over black and white photography. By contrast the scale issue was explored through an analysis of recent 1:5,000 photographs (2000) obtained for Loch Leven (Figure 3.19c). It was assumed that those features observed on 1:24000 scale photographs could still be observed and so only those not observable in the coarse scale photography were investigated. A key distinction was that the higher resolution photographs enabled recognition of many shore zone features, including bank face engineering activity, beach materials and vegetation and evidence of geomorphological activity. Some submerged macrophytes were visible but identification proved difficult.

While small features may be observable on fine scale photography, a limitation is that to cover large water bodies it may be necessary to interpret many photographs (e.g. *ca.* 72 to cover Loch Leven). The ability to view the lake within its wider catchment and context is clearly lost in this situation, as well as leading to problems when trying to orthorectify and map planimetry from large numbers of photographs. It would be inappropriate to recommend a particular scale of aerial photography that should be used for LHS as this will depend upon the diversity of hydromorphological features and land-cover at a site. In general, however, it is recommended that photography of the finest scale possible is used that ideally includes the whole lake, or is contained within as few photographs as possible.

Overall, the analysis confirms that aerial photography can provide useful information to the LHS as input directly to the survey form. There are also clear limitations in terms of identifying features in the shore and littoral zones. The fact that land-cover within the riparian zone could be mapped reliably, suggests that aerial photography could be employed to map land-cover within the extended 50 m shoreline / lake pressures part of the survey (Section 3.5). Digital aerial photography was not provided but if available could have been used to test semi-automated image segmentation routines to provide a less subjective assessment of land-cover types. However, it is unlikely that further additional information could have been extracted from digital versus hard copy photography, although with the increasing availability of digital aerial photography, this area is suitable for further investigation.

Most agencies and local authorities will have access to aerial photography in digital or print form. The currency of these data, however, may well preclude their use on lakes where modification has since taken place or in highly dynamic lake environments and catchments. For large systems such as Windermere it may well be cost effective to commission an aerial survey but this is rarely feasible. More recent photography may well be available from a number of new vendors (e.g. Getmapping) or as part of the soon to be released image layer of the Ordnance Survey (OS) Mastermap. Getmapping provide prints and digital aerial photography for virtually the whole of the UK at a spatial resolution of 25 cm. The exception is for most of rural and upland Scotland where no data are yet available but these will become available in time. Cost is based upon the aerial coverage and is quoted at £40.81 per km^2 (Getmapping, 2004). The frequency with which these data will be updated is not given but for rural areas this is likely to be between 5 and 10 years.

Table 3.9 Comparison of black and white aerial photography and LHS form field observations for Loch of Lindores

Sect No.	Feature	Measured from AP	Explanation	Field survey results	Potential reliability/usefulness of remote sensing for this attribute
2.1	Riparian zone				
	Canopy layer (>5 m)	Variable	Crowns of large trees observable	Yes	Unreliable, cannot recognise GBD classes
	Understorey	Variable	Obscured mostly by upper canopy	Yes	Cannot resolve height classes / limited use
	Ground cover	No	Not visible/observable at available scale	Yes	Unreliable / not useful.
	Dominant land-cover	Variable	Most land-cover types easily observable	Yes	Reliable (small differences), potentially useful
	Nuisance species	No	Not observable due to scale/type of photos	Yes	Unreliable / not useful
	Bank top vegetation	Yes	Bank top vegetation observable	Yes	Reliable and potentially of use
	Bank top features	No	None observed at this site	No	Undetermined, but very unlikely to be reliable
2.2	Shore zone				
	Bank face	No	Bank features not observable at given scale	Yes	Unreliable / not useful
	Shore / beach present	No	None observed	Yes	Unreliable (field survey suggest presence of shore covered by vegetation) / not useful
	Shore modifications	Variable	Not directly observable, embankment assumed due to roads/railway but hard engineering not observed	Yes- embankment and hard eng.	Unreliable (not directly observed) / potentially of limited use.
	Geomorphology	No	None observed	No	Undetermined, but unlikely to be reliable
2.3	Human Pressures				
	Pressures over plot		All human pressures except riparian weed control and macrophyte cutting observable	Yes	Reliable / of potential use
2.4	Littoral zone	No	No parts of the littoral zone observable	Yes	Unreliable / of no use
3.	Whole lake				
	Shoreline characteristics	Variable	Many shoreline characteristics observable	Yes	Mostly reliable (only SE missed) / of potential use
	Lake activities / pressure	Variable	Activities inferred by association. Fish farming included but incorrect.	Yes	Mostly reliable (Fish farming included but incorrect) / of potential use.
	Special interest	Variable	Fringing reed banks easily observable	Yes	Unreliable (carr and marsh missed)/ little use.
	Animals	No	Not detected due to scale of photography	Yes	Unreliable / of no use.

Table 3.10 Comparison of 1:24000 colour aerial photography and LHS field survey form for Kilconquhar Loch

Sect No.	Feature	Measured from AP	Explanation	Field survey results	Potential reliability/usefulness
2.1	Riparian zone				
	Canopy layer (>5 m)	Variable	Crowns of large trees observable	Yes	Unreliable, cannot recognise GBD classes
	Understorey	Variable	Obscured mostly by upper canopy	Yes	Cannot resolve height classes / limited use
	Ground cover	No	Not visible/observable at available scale	Yes	Unreliable / not useful.
	Dominant land-cover	Variable	Land-cover types easily observable	Yes	Reliable (mostly correct), potentially useful
	Nuisance species	No	Not observable due to scale/type of photos	Yes	Unreliable / not useful
	Bank top vegetation	Yes	Bank top vegetation observable	Yes	Reliable and potentially of use
	Bank top features	No	None observed at this site	No	Undetermined
2.2	Shore zone				
	Bank face	No	Bank features not observable at given scale	Yes	Unreliable / not useful
	Shore / beach present	No	None observed	Yes	Unreliable (field survey suggest presence of shore covered by vegetation) / not useful
	Shore modifications	No	Hard engineering may be assumed due to residential gardens	Yes - hard engineering	Unreliable / potentially of limited use.
	Geomorphology	No	None observed	No	Undetermined
2.3	Human Pressures				
	Pressures over plot	Variable	All human pressures except riparian weed control and macrophyte cutting observable	Yes	Reliable / of potential use
2.4	Littoral zone	No	No parts of the littoral zone observable	Yes	Unreliable / of no use
3.	Whole lake				
	Shoreline characteristics	Variable	Many shoreline characteristics observable	Yes	Mostly reliable (only RC different) / of potential use
	Lake activities / pressure	No	None observed	Yes	Unreliable / of limited use.
	Special interest	Variable	Fringing reed banks easily observable	Yes	Unreliable (omitted carr) / of little use.
	Animals	No	Not detected due to scale of photography	Yes	Unreliable / of no use.

3.7.3 Multispectral remotely sensed data

Multispectral data were not provided for any of the lakes visited and so could not be assessed directly for their applicability and reliability of information extraction for LHS. Davids *et al*. (2003) previously suggested that while multispectral data can detect many land-cover types and hydromorphological structures, its use is limited by data availability and the spatial resolution of most multispectral remote sensing systems. Recent satellite-based systems, such as IKONOS, that have a spatial resolution of less than 4 m, may hold promise for the future but are limited in their spectral resolution, which will affect the ability to discriminate between spectrally similar land-cover types. New classification strategies are being developed constantly and this may be an area for further research as finer spatial resolution data from satellite sensors become increasingly available.

One area in which satellite-based sensors may prove useful is mapping land-cover in large catchments and where change is taking place rapidly. With the repeat visit time of most satellites ranging between 3 and 15 days there exists the possibility of monitoring change on a frequent basis. However, in reality, cloud cover in the UK is generally high and the chances of a cloud free day and satellite overpass being coincident are low. Acquisition costs for airborne multispectral and hyperspectral sensors remains high (£100-1000 per km^2) in comparison to satellite-based sensors (£16-36 per km^2) and so they are unlikely to be cost effective in the short term, despite being able to take advantage of fine weather conditions. Again, this is an area for further investigation given appropriate access to data.

3.7.4 Geo-spatial databases (OS Mastermap and LCM2000)

Conventional topographic and geological maps can provide rich insights into land-use patterns, hydrogeology and hydromorphological pressures. However, the availability of specialised maps developed by national agencies such as the Ordnance Survey offers exciting new opportunities obviating the need to undertake primary field mapping. The applications of these databases offer the greatest potential at large lakes for characterising catchment land-cover and land management practices. In terms of UK datasets, two commercially available products of particular relevance are Mastermap and LCM2000.

OS Mastermap

OS Mastermap is a digital database of mapped landscape features. It is provided as a series of layers, the most relevant of which is a topography layer that includes nine themes: roads, tracks and paths, land, buildings, water, rail, height, heritage, structures and administrative boundaries. Of particular use to LHS is the land theme, which provides a vector / parcel-based land-cover map (Figure 3.20). These data are acquired from standard OS mapping practices, such as field survey and aerial photograph interpretation. They provide a non-subjective assessment of land-cover in that the percentages of land-cover around a shoreline / catchment may be easily determined using standard GIS packages. Typically, a buffer can be placed at a set distance (e.g. 15 m for the riparian zone) and the total percentage of land-cover for each class within the buffer calculated. No interpretation from the analyst is required and the buffer can be set at a variety of distances and so could provide information to the extended 50 m shoreline / pressures part of the survey.

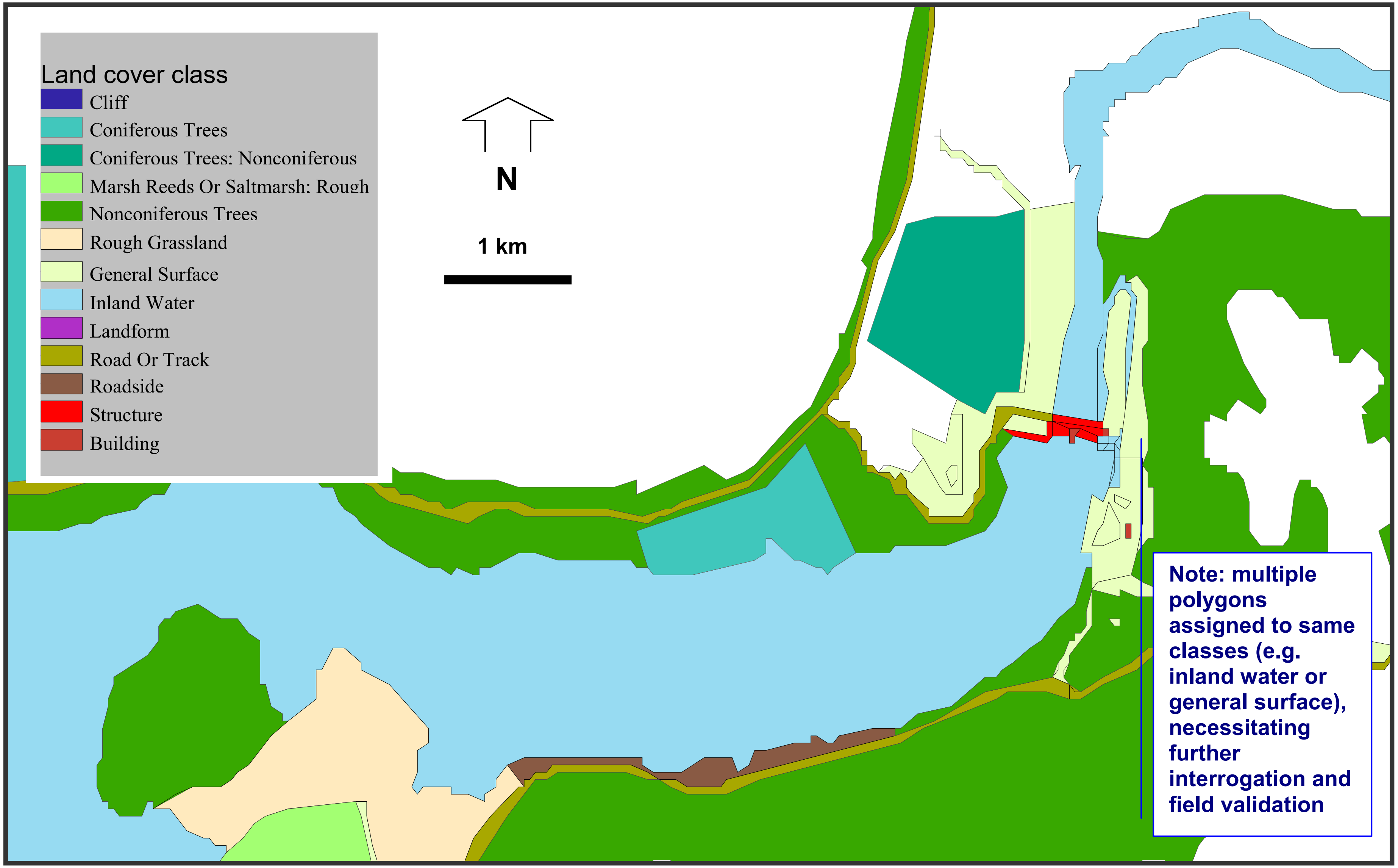


Figure 3.20 Example of OS Mastermap land theme for Loch Tummel

As part of the OS Mastermap product, a new imagery layer is being made available. This provides 25 cm spatial resolution aerial photography which has been orthorectified and matches precisely the topography and other layers present within Mastermap. Photography for the entire country will be available from March 2006, with update periods of three years in urban and semi-rural areas, and five years for more sparsely populated areas. The pricing of these data is dependent upon the licence / pricing agreement which agencies have in place with the OS. A limitation of OS Mastermap is that the land-cover classes provided do not always map directly onto the land-cover classes in LHS, a problem that could be overcome by adopting the OS Mastermap land-cover classification scheme. However, even if this were done, the land-cover layer also includes some classes which are poorly defined or ambiguous, e.g. the class 'General Surface' (see Figure 3.20). In such cases the use of an aerial photograph and field verification may be necessary.

Land-cover Map 2000

The national Land-cover Map 2000 (LCM2000) is a product derived from the classification of land-cover from remotely sensed satellite imagery. It is a vector database containing 16 target classes (mapped at 90% accuracy) and subdivided into 27 subclasses, allowing the construction of 22 broad habitat classes (Fuller *et al.*, 2002). The data are available as vector coverages, raster (grid) data sets or 1 km summary products, and range in cost from £20,000 for the entire UK (commercial rate) to £4,500 per 100 km^2 (CEH, 2004). Information on catchment land-use that has been generated using LCM2000 data is available from GBLakes (Table 3.11). This is proposed as a potentially useful and manageable addition to LHS to capture catchment information, particularly as it is readily available. The percentage of catchment under intensive non-natural land-use for each lake is proposed as an additional component of the LHMS. Such data could readily be incorporated into a relatively simple hydrological routing model to assess the likely degree of hydrological alteration due to catchment land-use change.

Table 3.11 Summary land-cover percentages for 10 lake catchments

Lake Name	***Suburban/ urban (%)***	***Coniferous (%)***	***Arable (%)***	***Combined total % of high intensity land-uses***
Loch Brandy	0	0.21	0	0.21
Loch Maree	0.21	1.22	0.01	1.44
Llyn Padarn	1.17	0.58	1.3	3.05
Llyn Tegid	0.61	6.26	0.56	7.43
Loch Tummel	0.17	7.63	0.39	8.19
Windermere	1.73	2.91	4.8	9.44
Derwent Reservoir	1.15	4.26	8.19	13.6
Loch Leven	2.03	3.68	35.29	41
Lindores Loch	2.84	1.04	38.4	42.28
Kilconquhar Loch	0.15	2.56	58.53	61.24

(data obtained from GBLakes)

3.7.5 Remote sensing summary and recommendations

The use of remotely sensed and secondary geo-spatial data sets has been assessed in terms of their usefulness to LHS. Of the remotely sensed data sets reviewed, aerial photography is deemed the most reliable in supplying estimates of riparian and bank top land-cover type, shoreline characteristics and human pressures. By contrast, aerial photographs provide no information regarding the littoral zone and little information relating to the shore zone. Of the secondary geo-spatial data sets reviewed both OS Mastermap and LCM2000 appear to be of significant value. OS Mastermap provides a non-subjective assessment of riparian land-cover, while LCM2000 can provide information on the dominant land-cover types within a catchment. Neither provides any substantial information regarding the littoral or shore zones.

The following recommendations emerge from the review overall:

- Surveyors greatly benefit from having access to colour aerial photography to gain an overview of lake and catchment characteristics and help with executing the survey, particularly through greater confidence in navigation;
- Digital aerial photography and multispectral data should be investigated in the future as to their potential for providing non-subjective and semi-automated assessments of riparian and shoreline habitats and land-cover;
- Colour aerial photography can be used to provide systematic and less subjective assessment of selected riparian and shore zone characteristics. Land-cover within both 15 and 50 m from the shoreline are readily obtained subject to data accessibility;
- Geo-spatial databases offer the way forward in terms of collecting information on lake-side and catchment land-use and land management practices. In terms of short- to medium-term implementation of LHS , a nested-scale approach is envisaged where OS Mastermap and equivalents generate data on shore zone and riparian land-covers, and LCM2000 (and equivalents) provide aggregated data on catchment land-cover (critical because of data processing costs) and already available with GBLakes;
- At the lake (water body) scale, OS Mastermap offers the most promising method to quantify shore zone pressures and riparian land-cover types (buffer strips of 15 and 50 m). There are considerable resource implications in terms of access to data sets and having GIS staff capable of undertaking analysis. Digital products similar to OS Mastermap are unlikely to be available in many European countries, but near-equivalent systems are under development elsewhere and represent a generic approach to be enshrined within a European standard on assessing lake hydromorphology;
- At the catchment scale, LCM2000 can be used to derive land-cover types within lake catchments. These data are already available within the GBLakes database and could be used to identify hydrological regime modifications; and
- Satellite-based remote sensing and OS Mastermap image layer data could be investigated for monitoring change in catchments that require frequent updating. Specially commissioned aerial photography should be required only where rapid large-scale hydromorphological alterations are under way.

3.8 Hydrological regime alteration

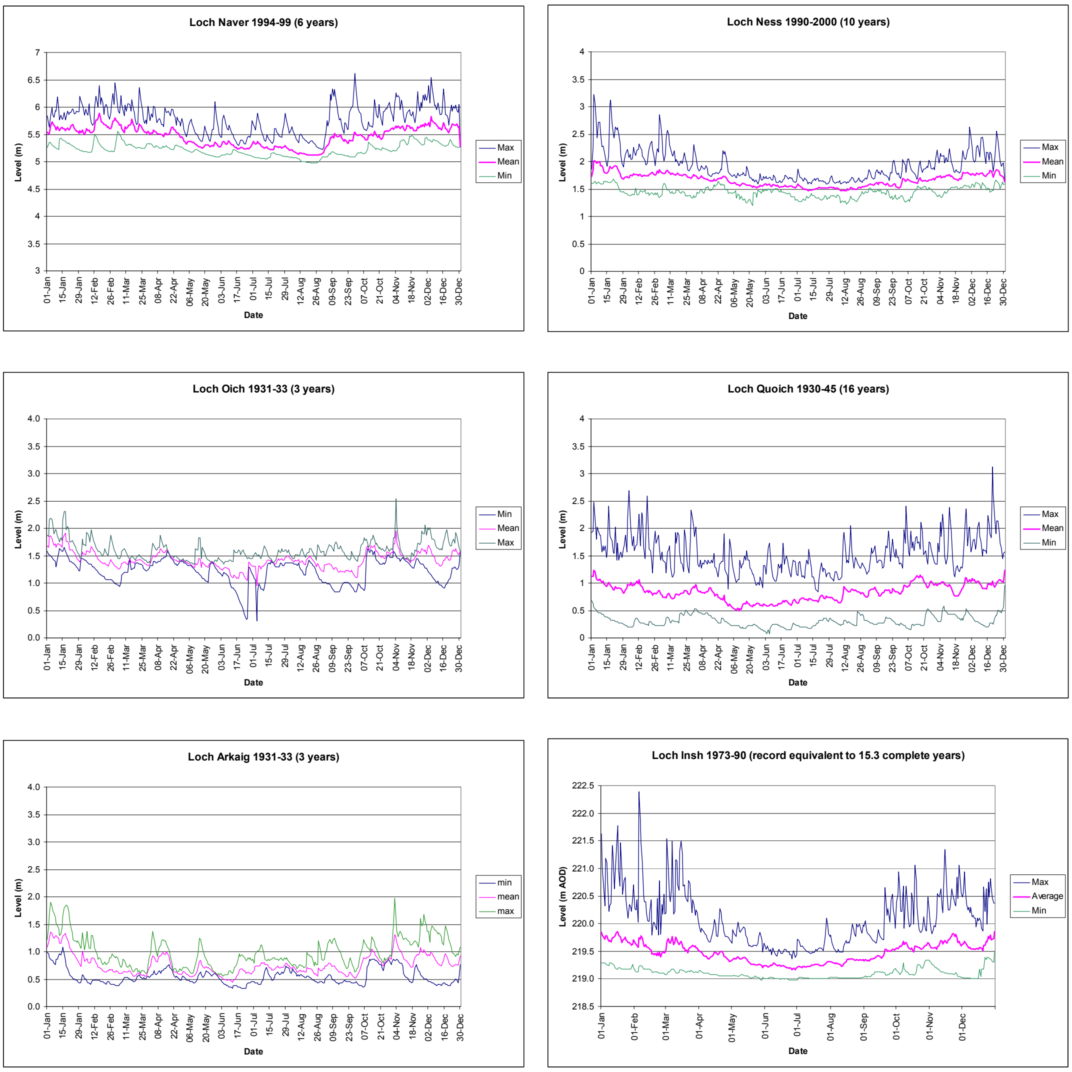
Lake water levels and residence times can be altered by changing the quality and timing of catchment runoff, altering water volumes through impoundment, drainage, abstraction or augmentation, all of which are common in recreational, water supply and hydro-power lakes and reservoirs. Whereas the field-based LHS assessment can comprehensively tackle the extent of lake morphological alteration, it is much more difficult to observe modification to hydrological quality elements on-site. The LHS field form seeks answers to a series of questions relating to the existence of physical structures (e.g. dams and sluices) as well as specific questions pertaining to water range dynamics where the surveyors have access to published statistics or water body managers. The questions regarding water level variation attempt some quantification of the regime, although such data will typically not be available in the case of unregulated lakes, and field estimation may indeed be difficult if water level is high at the time of survey. Thus where only proxy data are available, such as the dominant use of a water body or maximum height of retaining structures, insights into the nature of hydrological alteration and consequent ecological impact are likely to be limited.

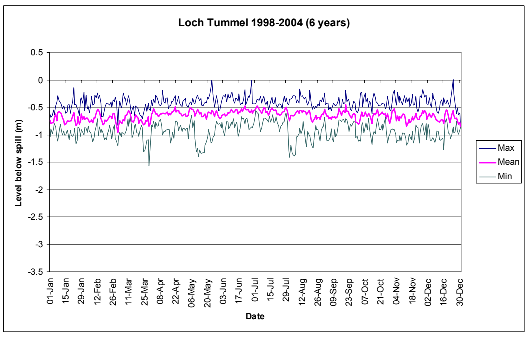
Water level data could in many cases be modeled; however, this is almost always expected to be complex. The lake outflow control would require surveillance, along with modelling of the inflows and of the lake storage. The amount of work required is incompatible with the requirement for LHS to be a quick, convenient methodology. The 'Further Comments' box of the form could be used to indicate the approximate proportion of the catchment draining into a lake which is affected by impoundments or other important water uses such as a major abstraction. This information may help establish the severity of any human impact on the hydrology of the lake of interest. However, such information can be used only in a qualitative way only.

There is a paucity of long-term water level records for natural lakes in the UK, indeed data for only seven relatively natural Scottish lochs (i.e. not impounded for storage) are known to the authors. Annual average hydrographs are shown for six of these, as well as for Loch Tummel, (hydro-power reservoir surveyed in the current LHS) in Figure 3.21. This illustrates broad similarities of seasonality, but differences in flashiness reflecting lake morphology, hydrogeology, capacity: inflow ratios and land-use practices. The Tummel hydrograph illustrates restricted seasonal variation in the average daily levels, thought largely to be as a result of an amenity concern to keep summer levels within a narrow, prescribed range. Figure 3.22 presents sample hydrographs for two lakes in northern Scotland before and after development of hydro schemes, illustrating the effects of (a) impoundment and (b) regime change downstream of a number of reservoirs. Daily water level recording is a feature of reservoirs covered by the Reservoirs Safety Act, but this does little to enhance the knowledge of water level behaviour for reference conditions.

DHRAM (Dundee Hydrological Regime Assessment Method)

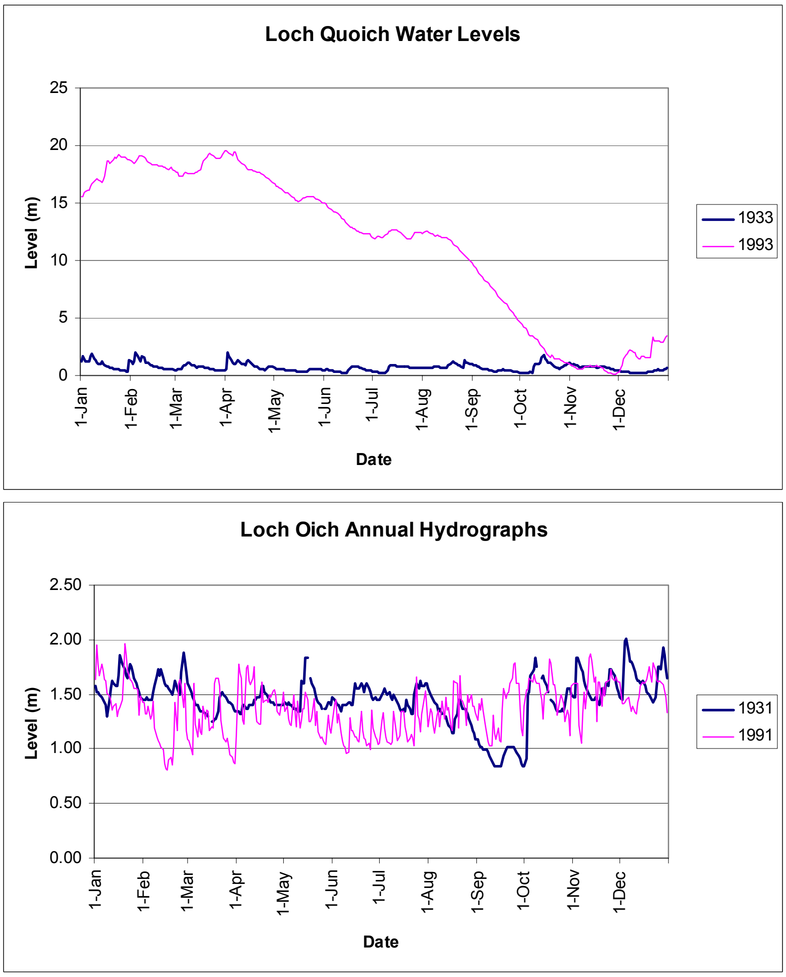
Black *et al.* (2000) introduced the DHRAM methodology (for rivers and lakes) to provide a measure of hydrological regime modification measured against assumed natural reference conditions, and thus provides a measure of risk to the aquatic ecosystems contained. The DHRAM method for lakes drew heavily from the available literature (e.g. Smith *et al.* 1987) and is shown in outline in Figure 3.23.





Data obtained from: *SEPA, †McClean archive, University of Dundee, ‡RSPB, §Scottish & Southern Energy plc.

Figure 3.21 Daily minimum, mean and maximum water levels for periods of available record for six broadly natural lochs: Naver*, Ness*, Oich†, Quoich†, Arkaig† and Insh‡. Loch Tummel§ is impounded for hydro-power generation



Data from McClean archive, Scottish & Southern Energy plc and SEPA

Figure 3.22 Comparison of sample annual hydrographs before and after hydro impoundment: (a) Loch Quoich, (b) Loch Oich

Water level data was obtained for the six natural Scottish lakes shown in Figure 3.21, and for Loch Tummel and Llyn Tegid. DHRAM analysis was run for these eight lakes, and the results are shown in Table 3.12. Lochs without outflow weirs and with no major structural controls on the inflows (Naver, Quoich (pre-hydro) and Arkaig) are by default allocated to Class 1 ("un-impacted condition").

Black *et al.* (2000) acknowledged the need to calibrate risk-based assessments against biological data and to further refine the threshold values used to define classes. In this spirit, the analysis was undertaken both including, and by-passing, the first question of naturalness. Whilst Naver and Arkaig gained no more points, the pre-hydro Quoich regime failed Step 2 suggesting an *apparent* moderate risk of impact. Those lochs with outflow controls (Oich and Ness) and upstream impoundments (Oich, Ness and Insh) were also classified. Loch Oich was classified a Class 5 (severely impacted condition) due to a large number of the regime assessment criteria not being met, while lochs Insh and Ness were found to be Class 2 (low risk of impact). While both of these latter lochs experience substantial alterations to their inflows principally as a result of hydro impoundments, diversions and/or generation, the low severity assessments may result from (a) the large surface area of Loch Ness providing it with a relative insensitivity to upstream influences and (b) the relatively small proportion of total catchment area affected by upstream impoundments in the case of Loch Insh. By contrast, *ca.* 90% of the catchment draining to Loch Oich is controlled for hydropower generation.

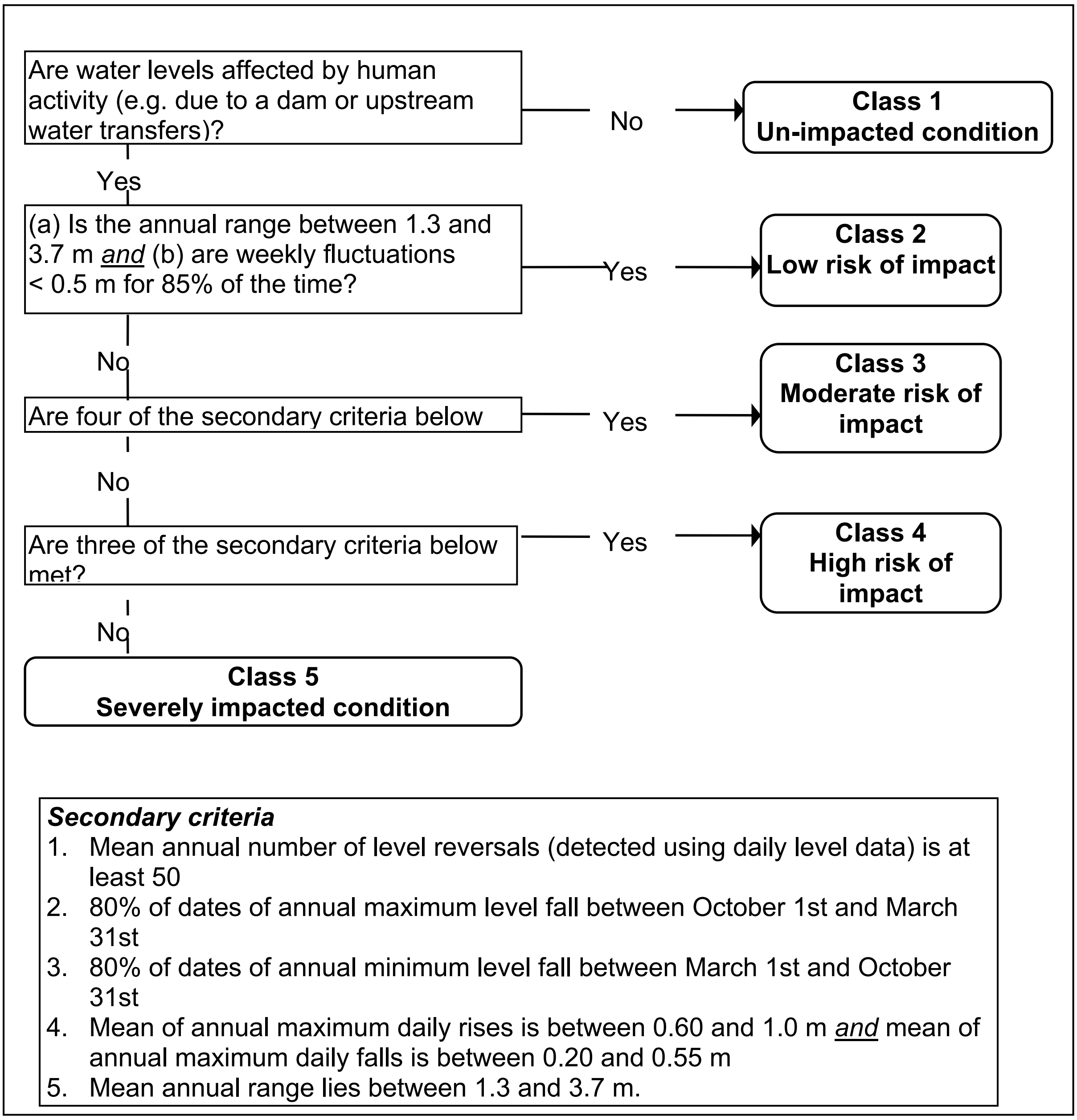


Figure 3.23 DHRAM method for standing waters (after Black *et al.,* 2000)

The Welsh lake Llyn Tegid is a highly managed system that has been controlled by sluice gates at the outflow since the beginning of the 19th century. Water levels in the lake are controlled as part of the River Dee Regulation Scheme, which regulates flow in the River Dee for the dual purposes of flood alleviation and flow maintenance for river abstractions downstream. Water levels were reduced by 2 m in the 1950s and during the summer months the level is maintained within a narrow ‘summer bandwidth’ to optimise recreational (and conservation) targets (Mayall, 1999). Llyn Tegid thus scores a Class 4 (High Risk) because weekly and annual oscillations are greater than the threshold values, and the seasonality of annual minima is also unusually outside the summer season.

Table 3.12 Results of DHRAM loch/reservoir investigations

	Naver *(natural)*	Arkaig *(natural)*	Quoich (pre-hydro) *(outflow controlled)*	Ness (post-hydro) *(outflow controlled & upstream dam)*	Insh *(upstream dam)*	Oich (post-hydro) *(outflow control & upstream dam)*	Tummel *(reservoir & upstream dams)*	Llyn *Tegid (sluice regulated & upstream impoundment)*
Years of water level data	6	3	16	9	12	9	5	25
Step 1: Are levels affected by human activity?	No*	No*	No*	Yes	Yes	Yes	Yes	Yes
Step 2a. Annual range between 1.3-3.7 m	Yes: 1.36	Yes: 1.30	Yes: 2.04	Yes: 1.36	Yes: 1.99	No: 1.18	No: 0.88	Yes: 2.37 m
Step 2b 85% of weekly fluctuations <0.5 m	Yes: 0.43	Yes: 0.41	No: only 75%	Yes: 0.30	Yes: 0.40	Yes: 0.41	No: only 81%	No: only 77%
Step 2: Are 2a and 2b true?	Yes**	Yes**	No	Yes*	Yes*	No	No	No
Step 3: Are four secondary criteria met?			Yes**			No	No	No
Step 4: Are three secondary criteria met?						No	No	Yes*
					s			
Step 5: Are less than three secondary criteria met?						Yes*	Yes*	
Secondary criteria								
1. Mean annual number of reversals >50			Yes: 150			Yes: 201	Yes: 201	Yes: 111
2. >80% of annual maxima 1-Oct - 31 Mar			Yes: 88%			Yes: 100%	No: 50%	Yes: 84%
3. >80% of annual minima 1 Mar - 31 Oct			Yes: 88%			No: 78%	No: 25%	No: 32%
4a. Mean annual max daily rise between 0.6-1.0 m			Yes: 1.0			No: 0.55	No: 0.55	No: 1.12m
4b. Mean annual max daily fall between 0.2-0.55 m			Yes: 0.54			Yes: 0.39	Yes: 0.50	No: 0.71m
4. 4a and 4b both true?			Yes			No	No	No
5. Mean annual range between 1.3-3.7 m			Yes: 2.04			No: 1.18	No: 1.07	Yes: 2.37
DHRAM Class	1	1	1	2	2	5	5	4

Note *DHRAM score determined with inclusion of step 1
**DHRAM score determined with the by-pass of step 1 (if this results in different score)

In all these cases there is therefore good behavioural correspondence between the management regimes and the DHRAM scores obtained. Nevertheless, a more extensive compilation of standing water level data from around the UK (beyond the scope of this project) and an extension of the monitoring of un-impacted lakes would allow refinement of the DHRAM lake method and produce more ecologically relevant impact classifications.

Considering the two lakes that were part of the LHS survey (Lochs Tummel and Llyn Tegid) the hydrological data collected during the survey work did provide a reasonable measure of hydrological alteration. Loch Tummel was assigned to DHRAM Class 5 because it had a high altered water level regime and due to impoundment of a pre-existing lake experienced a significant increase in surface area and volume (residence time). These factors were recognised by LHMS as it received a hydrological sub-component score of 8, even though Loch Tummel's regime is atypical for hydro-power lakes because the water level range is restricted for visual aesthetics (compared with water level ranges more typical of hydropower systems as shown in Table 3.13). In the case of Llyn Tegid the DHRAM Class of 4 was again broadly matched with the LHMS component score of 6 (due to upstream impoundment, reduced water level and recognition of the sluice gates controlling the outflow).

Table 3.13 Details of mean annual water level range and derived DHRAM scores for reservoirs in the Galloway Dee hydro-power scheme, Scotland

Reservoir	Catchment area (km^2)	Reservoir area (ha)	Annual water level range (m)	DHRAM score
Loch Doon	130	874	9.1	4
Kendoon Loch	393	60	2.0	4
Carsfad Loch	442	41	2.6	3
Earlstoun Loch	502	54	3.5	4
Clatteringshaws Loch	123	413	9.2	5
Loch Ken	940	846	1.9	3
Tongland Loch	1023	43	3.9	5

(after Black *et al.,* 2002)

It is logical and highly desirable that any future European Standard dealing with lake hydromorphology should include both hydrological regime and morphological conditions. Future work must be directed towards fuller examination of the ecological relevance of regime regulation (Hellsten *et al.,* 1996; 2002). Allied to this is the need for a better understanding of the ecological sensitivities of different lake types (*cf.* Bragg *et al.* 2003) and to develop new water resource regulations to implement the requirements of the WFD (e.g. Water Environment and Water Services (Scotland) Act 2001). Type-specific reference conditions will need to take factors such as location and geology into account because effective precipitation totals decline north to south and east to west, locally modified by topography and altitude, and geology affects infiltration and runoff characteristics, groundwater connectivity and lake morphology. These natural factors, modified by catchment land management practices together influence the regime, especially water level variations and seasonal residence times.

1.9 Results of environment and conservation agency data

Data for LHS_{core} were processed for 34 of the agency test sites. These were entered into the LHS database (development of the database itself is described in section 4.3). The lakes spanned a range of lake types, geographic locations, and pressures and impacts.

As an illustration of the potential of the LHS database to provide insights into overall condition of the UK standing water resources a sample of queries were run through the database. These produced summary statistics indicating that bank reinforcement was recorded at five lakes, and water control structures were identified at 12. Four lakes had been raised or lowered by 1 m or more. A total of 19 lakes had one or more pressures recorded in the Hab-Plot survey. One or more in-lake pressure was also recorded at 19 lakes; many, but not all, of these were overlapping, which highlights the need to record pressures in both of these sections. Less than 10% of lakes were free of shoreline intensive use, half of the lakes had at least 25% shoreline use, and more than 10% of lakes showed more than 75% of intensive shore use.

Table 3.14 shows the values obtained for LHMS scores using the agency data for 34 lakes. Where available, LHMS scores using data collected by the contractors for the same lakes are shown in the right-hand column. A range of scores were generated, from zero for potential reference condition sites such as Loch Brandy and Lochan Nan Cat, to values of 28 and 30 for highly modified sites such as Llyn Tegid and Cropston Reservoir. Scores using contractors' data were similar if not exactly the same as scores obtained using agency data. This further supports the LHMS (and indeed the LHS) in terms of its robustness, as it provides comparable scores using data collected by different surveyors and using different Hab-Plot locations.

Table 3.14: LHMS scores for agency sites

Lake Name	Region	Shore modification	Shore use	Lake pressures	Hydrology	Sediment regime	Nuisance species	TOTAL SCORE	Contractor data total scores (for core, full versions)
Lochan Nan Cat	Perthshire	0	0	0	0	0	0	0	-
Loch Brandy	SE Scotland	0	0	0	0	0	0	0	0,0
Botherston Central Arm	South Wales	0	0	0	0	0	0	0	-
Loch Syre	Highland	0	0	4	0	0	0	4	-
MacNean Upper	Northern Ireland	0	0	4	0	0	0	4	-
Lough Coolyermer	Northern Ireland	0	0	4	0	0	0	4	-
Hammer Mere	North Wales	0	2	0	0	4	0	6	-
Loch Hope	Highland	0	2	4	0	0	0	6	-
Lough Carn	Northern Ireland	0	0	0	6	0	0	6	-
Elter Water	NW England	0	6	0	0	2	0	8	-
Loch Maree	Highland	0	6	2	0	0	0	8	4,6
Lochan Lunn Da Bhra	Highland	0	8	0	0	0	0	8	-
Lough Ash	Northern Ireland	0	6	2	0	0	0	8	-
Llyn Eiddwen	South Wales	0	8	0	0	0	0	8	-
Llyn Berwyn	South Wales	0	8	0	0	0	0	8	-
Nan Gabhar	Highland	0	8	0	0	0	0	8	-
Sunbiggin Tarn	NW England	0	6	2	0	2	0	10	-
Craggie	Highland	0	2	4	0	4	0	10	-
Gartmorn Dam	SE Scotland	0	0	6	6	0	0	12	-
Llyn Hir	S Wales	0	8	0	0	4	0	12	-
Ellesmere/The mere	Midland England	2	8	4	0	0	0	14	-
Keenaghan Lough	Northern Ireland	2	8	4	0	0	0	14	-
Kingside Loch	Scottish Borders	0	0	2	8	4	0	14	-
Malham Tarn	NE England	0	6	2	4	4	0	16	-
Coniston	NW England	2	6	8	0	0	4	20	-
St Mary's Loch	Scottish Borders	2	6	4	8	0	0	20	-
Llyn Padarn	North Wales	2	6	6	2	4	0	20	24,24
Llyn Cwellyn	North Wales	0	8	4	6	4	0	22	-
Windermere	NW England	4	6	6	4	0	4	24	22,26
Ladybower Reservioir	Midlands	8	6	2	6	2	0	24	-
Derwent Reservoir	NE England	2	6	6	8	2	0	24	28,28
Widdop Reservoir	NE England	8	8	0	8	4	0	28	-
Llyn Tegid	North Wales	4	8	6	6	4	0	28	22,24
Cropston Reservoir	Midlands	8	8	4	8	2	0	30	-

3.10 Review of LHS approach and recommended revisions

During the summer field season a number of areas within the methodology were identified as needing clarification and in some cases modification. A number of surveyor questionnaires were also received (11 responses, though most were completed by groups of surveyors). A summary of surveyor comments on these issues and action needed is shown in Table 3.15.

Table 3.15 Review of LHS_{core} and full LHS procedures based on field trials and feedback from environment and conservation agency staff

Issue / comment	Action / response
It was felt that the LHS_{core} manual was good, but that it would be improved by the inclusion of a photo-gallery.	Will be included in 2005 manual
Agency staff requested more training prior to undertaking field campaigns	Recommended for Phase 2 development
In LHS_{core} Hab-Plot selection was often driven by access to sites for the foot version, creating a bias towards accessible areas.	Must follow procedure, subject to time, boat-based survey avoids these problems
Survey not considered overly time consuming; a typical Hab-Plot took about 10-25 minutes and an entire survey could be completed in 1-4 hours.	Contractors completed Hab-Plots in 5-15 minutes and full LHS in 3-7 hours
The boat version was quicker than foot-based version.	Agreed
Four Hab-Plots were sufficient on simple lakes, but may not be on more complex sites	Agreed and confirmed by data
Surveyor confidence in estimating percentage cover was generally good, but shoreline percentages were sometimes difficult to estimate on large lakes and in foggy conditions.	Visibility issues of less concern surveying from a boat
Amendments suggested by agency survey teams:	
• Categories should be more consistent with RHS	• Agreed
• Request for improved definition of shore zones	• New diagrams and definition for 2005 manual
• The addition of information about islands	• Added in updated version
• Comments that hydrological data are very rarely available to field teams, low confidence in completing hydrology sections	• Acknowledged but agreed at workshop to retain for cases when data are known
• Other minor corrections that will be amended, such as revising the order of National Grid References.	• Updated for 2005 form
Many surveyors felt that LHS does adequately capture the overall characteristics and quality of a lake, but some felt that not enough information on natural shoreline habitat is collected. Some felt that this question was difficult to answer without knowing how the data will be used.	This was undertaken by the contractors during 2004 (Table 3.3), updated forms address this issue

Overall the comments received from the environment and conservation agency field teams were positive. Surveyors with experience and training in RHS procedures generally found the approach familiar and readily managed.

A list of recommendations for amendments to the LHS survey (suggested by the contractors in response to their own and other surveyors' experiences) was distributed prior to the final workshop in October 2004, where the possibilities for revision were discussed. Full details of the discussions are provided in Appendix 1, and a summarised list of the amendments to be introduced into a revised LHS field survey form is provided in Table 3.16.

Table 3.16 Amendments to be implemented for 2005 LHS field form

LHS section	Amendment
General surveying and recording instructions	Revise GPS location instructions (Eastings precede Northings)
	Some changes to filling boxes (e.g. using "0" instead of "NO" in some cases), and removing nomenclature for cover classes, i.e. *0=None, 1=Sparse(<10%), 2=Moderate(10-40%), 3=Heavy(>40-75%), 4=Very heavy(>75%)* will become *0=None, 1=<10%, 2=10-40%, 3=>40-75%, 4=>75%* Consistently use land-cover, substrate and other categories as for RHS Percentage cover must be at least 1 % to be registered as 'present' in cover entries
	Allow surveyors to expend extra efforts, such as snorkelling for macrophytes and going on shore from the boat to view riparian zones, as long as these are documented.
1.1 Background information	Allow option of attaching a photocopy of an OS map to use for annotation rather than a sketch.
2.2 Shore zone	Definition of shore zones above the waterline needs revising (i.e. bank face, shore/beach)
	Boulder aprons are to be consistently recorded as having a 'bank face'
	Estimate bank height to nearest metre (rather than as categorical)
	Add information on vegetation on shore zone
2.4 Littoral zone	For sedimentation over natural substrate, specify sediment type
	Remove reference to sediment colour and odour, but retain odour as a general descriptor
	Change % total macrophyte cover to a measure of the three-dimensional density of macrophytes, i.e. Percent Volume Inhabited (PVI)
	Remove 'fish cover' (or add clarification)
3.1 Shoreline Pressures	This will become "Shoreline characteristics" and include information on pressures and natural land-cover types within 15 and 50 m of the shore, including some details on special habitats, such as wetlands.
	Add recreational/education activity as a pressure for Hab-Plot and shoreline
	Remove instruction to quantify total shoreline pressures, this will be calculated in the database
	Define intensive grazing, or simply use observed grazing
	'Residential' includes residential lawns, but 'Parks and Gardens' are public areas

	Islands must be included in the shoreline assessments if their shore length $\geq$ 10% of the total shoreline
3.2 Lake site activities / pressures	Lake action/pressure entries amended to record extent and intensity of activities
	Change “fish farms” to “fish cages” and add “swimming”
3.3-3.4 Special Habitat Features and Animals	Most special habitats moved to shoreline survey and section 3.3 changed to “Landform features”. Information on non-deltaic islands and deltaic deposits are recorded here.
	Animal list will be changed to suit geographic regions, and grouped into functional groups, such as piscivores, macrophyte-dependent species, pest species, and species of conservation interest.
4. Hydrology	Allow circling of more than one lake use
	Specify whether control structures are at the inflow or outflow

The field form was updated in light of these suggested amendments, and is provided in Appendix 4. The manual will also be updated. This version of LHS will be known as “Version 2”, and is the revised version at the end of Phase 1. Further changes may be made before the commencement of Phase 2.

PART FOUR: DISCUSSION

4.1 Comparative review of alternative LHS versions

A key element in the project brief was to develop two versions of LHS, which might serve two separate needs. The 'simple' version was envisaged to be capable of rapid and extensive deployment, while the fuller version would be less frequently used because of the greater time and resources involved. It was also a requirement of the project brief that the survey could be either boat- or foot-based. Meeting these requirements naturally proved difficult because of the tension between speed of deployment versus comprehensiveness and usefulness of the data produced.

Considerable attention was given to the prospect that remote sensing and other associated desk-top data could provide the basis for LHS_{core} with the consequence that only the full LHS would require field work. Though desirable in principle this option was not explored further because of the need to issue agency field teams with survey instructions at the beginning of the summer field season. It was also considered necessary that field survey methods were trialled by independent surveyors to provide feedback on the protocol. Moreover it is clear that major institutional and ontological barriers remain between the desire to use remote sensing and electronic databases (reaping the potential efficiencies they are widely championed to bring) with the ability of UK environmental and conservation agencies to put these methods into practice. At present, there are great differences between agencies, and indeed within agencies, in terms of the availability and use made of data streams such as digital aerial photography, OS Mastermap and LCM2000 due to different levels of geographical cover, data costs, data management and licensing issues, as well as having appropriately qualified staff that can be deployed to undertake such specialist analysis. The gap between aspiration and practical application will diminish with time, but in view of the implementation milestones imposed by WFD for LHS this point has not yet been reached.

Because remote sensing and geo-spatial databases were unlikely to deliver results within the time available to the project, two field-based versions of LHS were developed. The results from the various field trials undertaken indicate that with practice and experience a high degree of reproducibility can be achieved with the survey. Anecdotal evidence from the agency field teams undertaking LHS_{core} also supports this contention. This suggests that there is the potential for maintaining good quality within the resulting database, particularly allied to a comprehensive training and accreditation programme and appropriate revision of the method and manual.

Comparing boat versus bank versions of LHS_{core} produced some differences particularly relating to the foot-based version allowing a better view of the riparian zone at the expense of littoral zone and vice versa for the boat-based version. More generally the boat-based version is superior, particularly in relation to the assessment of whole-lake pressures, and it is concluded that the boat-based survey should be the preferred method. However, for sites where a boat cannot practically be obtained (e.g. five surveyors were required to transport a boat to Loch Brandy), then the foot-based method can be used without seriously compromising the survey. However, this may prevent the collection of Index Site information.

The full version of LHS is boat-based, involves the deployment of 10 Hab-Plots located around the perimeter of the lake, and profiling of temperature, oxygen and light penetration at the deepest point of the lake (Index Site). LHS_{core}, can be deployed from either foot or boat, uses four Hab-Plots and omits the Index Site. Considering that both versions require survey teams to visit the field site, the true time difference between both methods is small (2-3 hours). However, it is accepted that even modest time differences can be important considering the number of lakes involved, e.g. there are over 4,300 lakes in the GBLakes database and Bailey-Watts *et al.* (2000) report there to be *ca.* 8,900 lakes with surface area > 2 ha.

Comparing the full and core versions of the survey confirmed that the former consistently recorded more features, and also demonstrated that 10 Hab-Plots were needed to capture variability at high diversity sites. Thus, the full version of LHS produces a more complete sample of lake character, especially taking into account the data from the Index Site. While it is reasonable to expect that complementary field campaigns could collect such data, e.g. as part of biological or water quality sampling programmes, it is preferable and probably most time-effective to gain a synoptic view of all three key habitat components (riparian, littoral and profundal) during a single site visit. In relation to the summary metrics (LHMS and LHQA) it was found that the full and core versions were broadly consistent. It can thus be concluded that the method is capable of delivering a consistent and systematic set of habitat metrics for lakes.

4.2 Application of LHS in WFD and site condition monitoring

Water Framework Directive

Bragg e*t al*. (2003) identified the following aspects of WFD implementation where lake hydromorphological data would be required:

- Defining lake types, and subsequently for assigning surveyed lakes to the appropriate types (Article 5 and Annex II, 1.3);
- Identification and assessment of pressures and impacts (Annex II, 1.4/5), which in turn would provide information for one of the early stages of screening for HMWB (Heavily Modified Water Body) status;
- Environmental objectives: preventing deterioration and restoring morphology to support good ecological status (Articles 1, 4 / Annex V); measures to ensure morphological conditions are consistent with the required ecological status (Article 11(i)); and
- Monitoring, especially surveillance monitoring (Article 8).

Hydromorphology is thus important not only for defining water bodies at high status, and for investigating possible reasons for water bodies failing to reach GES, but also has an important role in designating and establishing appropriate monitoring strategies for HMWBs and Artificial Water Bodies. However, it is acknowledged that the links between specific morphological features and their associated biota are generally poorly understood (Håkanson and Boulion, 2002; Logan and Furse, 2002). An important application of the emergent LHS database will therefore be to use the accumulated data from surveillance, operational and, where necessary, investigative monitoring programmes to explore and model linkages between different types and levels of pressures and the ecological data. Such analysis will help elucidate the linkages between lake hydromorphology and ecology. Crucially, such information is also needed for developing transparent and defendable ‘programmes of measures’ to raise ecological awareness of the status of water bodies failing to meet WFD environmental objectives (Rowan *et al.,* 2003).

Condition monitoring for designated sites

Beyond the immediate needs of the WFD, LHS has many conservation applications. The Habitats Directive aims to maintain and enhance European biodiversity through the conservation of natural habitats and targeting specific threatened populations. It requires specified natural lake habitats (either in their own right or for the presence of particular species of fauna and flora) designated as Special Areas of Conservation (SACs) to be maintained or restored to *favourable conservation status.* Seven lake types qualify as Annex I habitats, including oligotrophic, oligo- to mesotrophic, hard oligo-mesotrophic, natural eutrophic, dystrophic waters, turloughs and Breckland meres, and many lakes have been designated as candidate SACs on the basis of the species contained. For example Llyn Tegid features the gwyniad (a rare whitefish, *Coregonus lavaretus*) and the UK's only known population of the glutinous snail, *Myxas glutinosa*).

Each habitat and species requires a Favourable Condition Table (FCT) and a monitoring protocol, the former to define the attributes for monitoring, and the latter to describe the method used. The two-part approach is considered necessary because the FCT cannot provide the necessary detail on monitoring (Gilmour, *pers. comm.*). Clearly there is scope for LHS to provide a systematic basis for monitoring the integrity of habitat form and function. The statutory conservation agencies in the UK already have duties in terms of site condition assessment and monitoring within SSSIs and ASSIs. During the 2004 field season SNH commissioned the Centre for Ecology and Hydrology (CEH) to undertake site condition surveys of 120 lake SSSIs/SACs which required surveyors to evaluate the effects of lake pressures on the condition of features for which the sites were designated. LHS played an important role in this process by formalising hydromorphological site assessment. With further development, there is also clear scope for the LHQA to be employed in site management applications and as part of national inventory studies designed to explore the extent and condition of habitats of particular interest, e.g. extent of dunes, quaking banks, fringing reed beds, etc.

4.3 Database development and management

The LHS database was developed at the end of the field season. It is an Access (2002) relational database, which has a user friendly interface for entering data from the LHS forms (see Figure 4.1 for examples of two of the input tabs). It has the ability to store information for multiple lakes, multiple survey data for each lake, and multiple Hab-Plot and shoreline data within each survey. The database can be interrogated for information on the location of certain habitats or lake types, and can generate a multitude of summary statistics (a sample of these is reported in section 3.9).

The opportunity also exists to explore spatial patterns and temporal trends in lake habitat quality serving both strategic and reactive survey needs. A clear distinction can be made between reactive survey, collected in response to proposed developments that requires assessment of specific site conditions and features of conservation value, and strategic survey, which requires systematically collected spatial data at scales from individual catchments up to the national level. Such data allow appraisal of the quality of the resource base, and the establishment of trends (i.e. degradation or enhancement), and provide the foundation for setting national and regional management priorities (Larsen *et al.*, 1994).

Measures are required for data quality assurance. To date, data have been checked manually, but in future measures can be put in place to enter forms twice and run a macro to auto-check entries. This method of quality assurance is used in the current RHS database to check at least 10% of rivers.

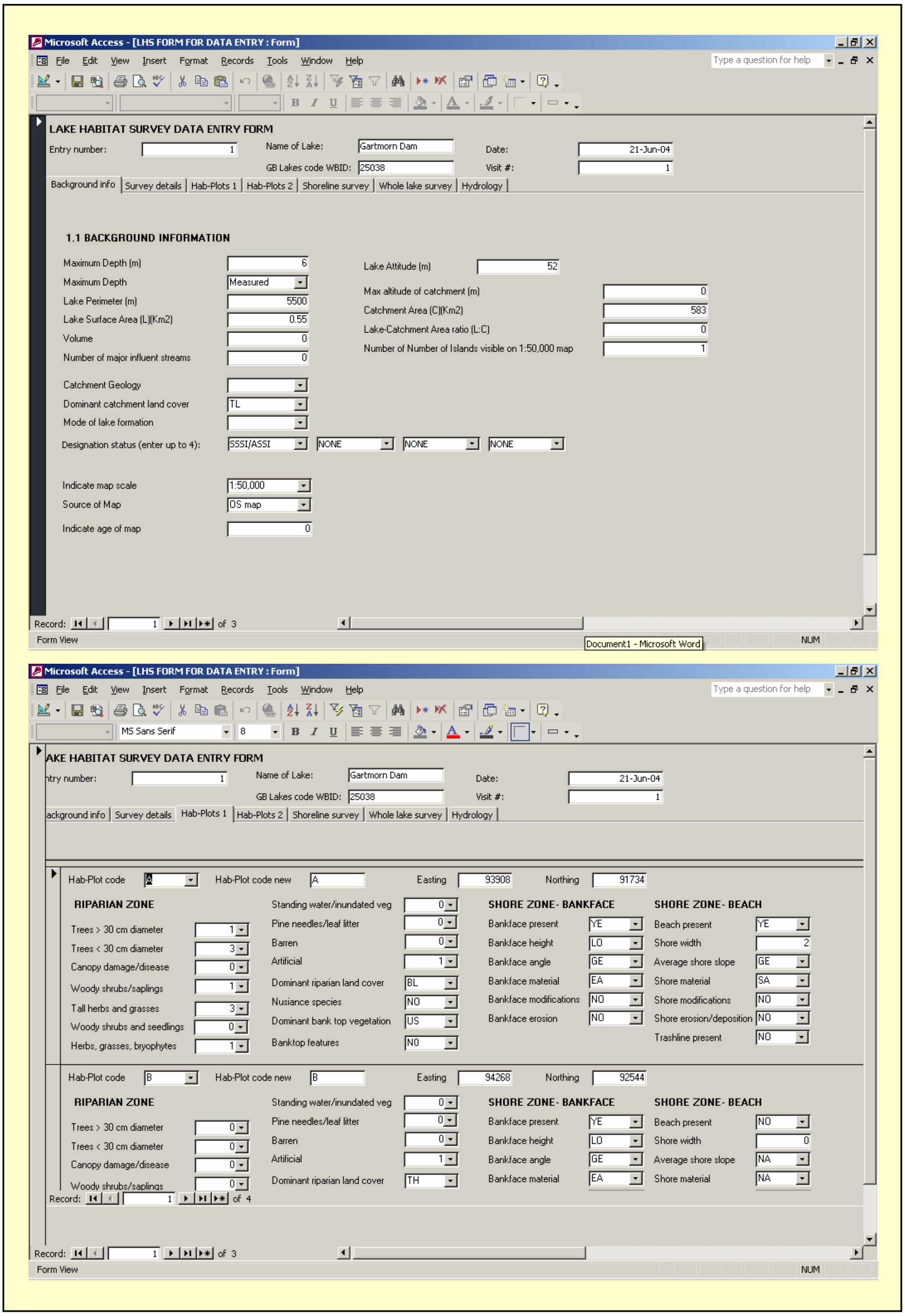


Figure 4.1 Extracted images from the LHS Access database

PART FIVE: PHASE 2 DEVELOPMENT OF LHS

Phase 1 of the LHS project has produced a working survey protocol that can systematically describe the physical characteristics and habitat structure of lakes and reservoirs. LHS can also play an important role in condition monitoring of designated sites, as well as inform restoration programmes required for degraded lake ecosystems. The Phase 1 study culminated with a 'Technical Workshop to Review the Development of Lake Habitat Survey (LHS)' held in Edinburgh (26-27 October 2004). This workshop brought together the preliminary Phase 1 findings from UK-based field teams, critique from UK environment and conservation agency managers, along with an international perspective provided by academics, regulators and practitioners drawn from northern Europe and the United States. Amendments to the protocol agreed in the light of review and discussion are summarised in Section 3.10, and full details are provided as part of the 'workshop minute' in Appendix 1. The field recording form was updated and is presented in Appendix 4, and the revised version of the manual will be completed as part of the Phase 2 development process.

The key aspects required in Phase 2 of the development process are summarised as follows:

- Revision of the Phase 1 Field Survey manual, taking into account the feedback obtained from the 2004 field season and the agreements made at the Edinburgh Workshop;
- Scope also exists for further methodological developments. Lake surveys are clearly contingent on system complexity and scale. The full version of LHS with 10 Hab-Plots captured more variability than LHS_{core}, but both versions combined meso-scale Hab-Plot observations, with a whole-lake 'sweep-up' of shore zone modifications (updated to include natural riparian land-covers). Some testing of the relative merits of randomised versus habitat-stratified sampling could be undertaken, however alternative approaches must be very carefully designed to ensure between-site data compatibility and to permit strategic survey allowing analysis of regional, national and international patterns and trends;
- Further analysis of the role of remote sensing and electronic data sources to complement the field-based LHS approach;
- Further consideration of how the LHS protocol can be used to meet the statutory duties of the WFD (e.g. see section 4.2) in terms of assessing the type-specific hydromorphological characteristics of lakes at high status and at the good/moderate boundary, effective monitoring (surveillance, operational and investigative), and contributing to the designation process for HMWBs. An important factor here is to further consider the role that LHS can play in terms of structuring the sampling and assessment of WFD biological quality elements. More informed guidance should be possible in Phase 2 because results from the ecological surveys carried out by SEPA, EA, EHS and SNH will be available in early 2005;
- Fundamental gaps remain in understanding the linkages between ecology and hydromorphology. An important element of the Phase 2 survey will be to collate and analyse the full database of results obtained from the 2004 field survey, which was outside the scope of Phase 1 due to timing issues. Considerable scope exists in Phase 2 to explore the linkages between impaired ecosystems and the nature and extent of hydromorphological alteration (morphology and hydrological regime). Establishing the sensitivity

of different lake types to different forms and intensities of pressures is clearly a key need for maintaining and enhancing lake quality. Testing of empirical relationships and expert judgement is critical to develop the underlying science and ensure that all stakeholders and user groups accept designations and management options;

- Allied to the above point is the need for further work on the summary metrics LHMS and LHQA. As discussed in Section 3.5 LHMS appears to offer a useful classification tool and provide a basis for developing possible remediation strategies. More work is required on LHQA, particularly in relation to type-specific reference conditions and to further consider the components driving the score (i.e., naturalness, diversity and features of interest). A number of options exist such as building on the 'Benchmark Distance Score' approach proposed by Buffagni and Erba (2002) or normalising the LHQA based on type-specific reference values, e.g. analogous to the Environmental Quality Ratio (EQR) outlined in WFD;
- The Edinburgh Workshop confirmed that LHS is viewed as a viable approach to characterising lake hydromorphology in several European countries. It is thus proposed that efforts should be made to build on the partnerships established during the Phase 1 development project. It was provisionally agreed that Finnish, French, Irish and possibly German collaborators would further test the method, particularly involving the full LHS approach (10 Hab-Plots) and the amended field form in the summer field season of 2005. LHS SNIFFER Project Manager Dr Phil Boon will review progress made and propose further collaboration at the Bratislava meeting (May 2005) of the CEN Task Group developing standards for assessing the hydromorphology of standing waters;
- The Phase 2 development project should include provision for a formal training programme. The 2004 field season raised issues in the manual requiring clarification and a significant number of field forms were only partially completed. With a revised manual it is anticipated that a 2-day training course (involving theory and field practice) could be designed. Accreditation could be based on both field and theory tests, e.g. a multiple choice competency test with an associated pass mark of *ca.* 90 %. Furthermore restricting the training to accredited trainers is considered best practice;
- In terms of database development it is suggested that the database developed for the Phase 1 programme can be updated to accommodate the changes proposed for Phase 2 and to enable further analysis of data. Migration of data to Oracle format for spatial use and for compatibility with the RHS database is not anticipated until a later phase.

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Appendix 1: Minute of the LHS final workshop

A TECHNICAL WORKSHOP TO REVIEW THE DEVELOPMENT OF LAKE HABITAT SURVEY (LHS)

Thistle Hotel, Edinburgh, 26/27th October 2004

Attendees:

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SNH	Scottish Natural Heritage
EN	English Nature
CCW	Countryside Council for Wales
EHS	Environment and Heritage Service (Northern Ireland)
EA	Environment Agency
SEPA	Scottish Environment Protection Agency
EPA	Environment Protection Agency (Republic of Ireland)
SNIFFER	Scottish and Northern Ireland Forum for Environmental Research
CEH	Centre for Ecology and Hydrology
USEPA	United States Environment Protection Agency

Summary of meeting minutes

The authors intend the following details to provide an accurate account of the final LHS workshop. Some discussion points have been re-arranged to more appropriate locations within the structure of the agenda to improve the clarity of this document. Due to time limitations not all participants were able to comment on these minutes.

DAY 1: TUESDAY 26TH OCTOBER

Session 1 – Introduction and overview of LHS; preliminary results of field trials

Part A: Workshop introduction & setting LHS in context (Phil Boon)

PB gave an overview of the workshop structure and the background and rationale for the development of LHS. The workshop structure was described as per the agenda. The purposes of LHS development are multiple, and include the fulfilment of the Water Framework Directive requirements. LHS can also play a valuable role in systematising the monitoring and management of conservation interests, e.g. monitoring internationally significant habitats, such as Special Areas of Conservation, assessing the condition of sites notified as Sites of Special Scientific Interest and wider applications in environmental impact assessment and restoration programmes.

PB described the paucity of standard lake habitat surveying methodology in the UK and Europe-wide, and the vision of a European standard under the CEN (Comité Européen de Normalisation) Task Group on standing waters. It is hoped that the LHS protocols developed can form the basis for the development of such a standard.

PB described the primary aims of the workshop as:

- To present and discuss the results of LHS
- To present and discuss the experiences of testing LHS and other lake hydromorphology methods in Europe and Worldwide (including USA)
- To agree on amendments to the current LHS methodology
- To discuss future needs and directions for the project

Part B: Overview of LHS protocol (John Rowan)

JR gave a 30 minute summary of the LHS protocol, including reiteration of the background and purpose of its development. LHS is envisaged as a method to systematically and consistently record physical habitat for lakes and to evaluate data sources from maps, remote sensing and field survey. It is proposed as a modular scheme, with a meso-habitat focus supplemented with whole lake data. Two versions have been produced: (i) a core version, LHS_{core} for rapid and extensive deployment, and (ii) the full version of LHS, which is more intensive but less frequently applied. Each of these can be carried out either by foot or by boat (although the full version requires a boat to collect the Index Site data). JR stressed the importance of the River Habitat Survey (RHS) and the USEPA Field Operations Manual for Lakes (FOML) in providing the foundations for LHS. Well tested lake survey protocols from the FOML were combined with the UK specific nomenclature and acronyms of RHS.

JR summarised the LHS procedures as follows (for more detail on carrying out procedures see the main body of the manual):

- ➢ Background information and survey details
  - Background data, some desk-based
  - Survey details: name, date, times, conditions
- ➢ Physical Habitat (Hab-Plot sampling survey)
  - 10 plots (or four in LHS_{core})
  - Vegetation and macrophyte types, shore and littoral structure and materials

    - Human pressures over all zones
- Whole lake assessment
    - Shoreline survey (% shore affected by pressures)
    - Occurrences of in-lake pressures, special habitats and animals
- Hydrology and sedimentology
    - Water body use, water level fluctuations, water control structures, erosion and deltaic deposition
- Index Site information
    - Depth, water clarity, alkalinity and temperature and DO profiles

JR summarised the expected outputs from the project, which were to include (i) summary metrics, and (ii) a database of lake habitat information available for interrogation. Two lake summary metrics have been developed. The first, Lake Habitat Modification Score (LHMS) measures the extent of human induced modification at the lake and can be used for classification, interpretation and trend analysis. The second, Lake Habitat Quality Assessment (LHQA) gives an index of the naturalness and habitat diversity of the site, but the values are type-specific. This is similar to the HQA developed for measuring river habitat quality. The database has been built in Microsoft Access (2002), and is capable of storing all LHS data, including multiple entries, and can generate summary metrics and be interrogated for information. It is also robust to changes to the LHS methodology.

JR gave an overview of site selection for summer field testing. Ten lakes were tested by the Dundee contractors: Loch Maree, Loch Brandy, Loch Tummel, Lindores Loch, Loch Leven, Kilconquhar Loch, Derwent Reservoir, Windermere, Llyn Padarn and Llyn Tegid. These cover a range of types and geographic distribution and are subject to a range of pressures. At the time of finalising this report forms had been received for a total of 224 lakes that were surveyed for LHS_{core} by the environment and conservation agencies. The table below summarises the numbers for each agency and the other survey data that were collected at the lakes at this time. For more detail see the main body of the report.

Agency	Number of LHS sites	Region	Lake types	Other survey data collected
Environment Agency (EA) of England and Wales	116	England and Wales	Broad range of types	Biological data, macrophytes, invertebrates
Scottish Natural Heritage (SNH) (surveys undertaken by Centre for Ecology and Hydrology)	57	Scotland	Mostly reference condition sites	Site condition monitoring data, macrophytes
Scottish Environment Protection Agency (SEPA)	44	Scotland	Mostly reference condition sites	Ecological surveys, risk assessment
Environment and Heritage Service (EHS) of Northern Ireland	7	N. Ireland	Mostly reference condition sites	N/A

Part C: UK field trials – description of work, summary of results (Josie Carwardine)

JC gave overview of the field work that was carried out by the contractors and the agencies, and a summary of the results from data analysis. Both full and core versions of LHS were carried out using both boat and foot approaches. Results from the following were summarised:

(i) Tests for surveyor comparability

This was tested at Lindores Loch with 8 surveyors (3 experienced in LHS). Entries from surveyors were generally well matched, although some differences depending upon complexity of site. Overall ca. 80% entries were matching for all surveyors.

(ii) Analysis of differences between boat vs foot versions

Boat version was preferable in terms of ease of carrying out the survey; JC summarised the advantages and disadvantages of each as follows:

LHS component	Preferable version	Explanation
Survey duration	Boat	Boat generally faster, esp. for large lakes
Logistics	Foot	No boat hire/purchase/licence necessary, boat unavailable at some sites
Hab-Plot selection	Boat	Minimises bias towards sites that are easily accessible by foot/vehicle
Viewing riparian/ shore zone	Foot	Visibility can be obscured by vegetation
Viewing littoral zone	Boat	Visibility can be obscured by fringing reeds
Viewing whole shoreline	Boat	Difficult to view opposite shore on foot, esp. in large lakes and if foggy
Whole lake assessment	Boat	Boat preferable for accessing all areas
Index Site	Boat	Not possible without a boat

The consistency in results between boat and foot versions was variable. The Hab-Plot surveys were more comparable between versions, while the shoreline survey was more variable, with some activities/pressures more difficult to observe. Consistency tended to be higher for simpler lakes.

(iii) Analysis of differences between core vs full versions

JC summarised the differences between the versions, principally the full method has 10 Hab-Plots compared with four in the core version, and the full method includes the Index Site. When comparing the number of features recorded using the Hab-Plot survey, more features were always recorded in the full version. However, there was less disparity between versions on simple lakes. The cumulative number of features recorded as Hab-Plots were added to the survey from 1-10 (up to 15 and 20 for selected lakes), suggests that four plots are generally insufficient. There is not necessarily a plateau before 10 plots, but little extra information is gained beyond this point.

(iv) Investigation of desk-based and remote sensing options

JC summarised the comparison of low and high resolution aerial photography and Mastermap, with field survey techniques. The following table reviews the potential use of each remote sensing/desk-based data source in providing LHS information.

LHS component	1:24 000 APs	1:5 000 APs	Mastermap
Background data	Catchment info	Catchment info	Catchment info
Riparian zone	Limited	Limited	Limited
Shore zone	No	Limited	No
Littoral zone	No	No	No
Bank modifications	Limited	Limited	Limited
Constructions (e.g. dams)	Limited	Limited	Yes
Intensive land-use	Yes	Yes	Yes
Lake activities	Limited	Limited	No
Special habitats	Limited	Yes	Yes
General shoreline land-cover types	Yes	Yes	Yes

(v) Results from agency data

Approximately 200 forms have been received from agency teams. However a significant number of these are incomplete due to time constraints expressed by some of the teams. To date 30 lakes are in the database, and values for LHMS have been generated (discussed below).

JC stressed the importance of agency field teams for providing independent feedback from the field experiences. A summary of the questionnaires completed by agency field teams is as follows:

- It was felt that the LHS_{core} manual was good, but that it would be improved by the inclusion of a photo-gallery
- Agency staff requested more training prior to undertaking field campaigns
- Hab-Plot selection was often driven by access to sites for the foot version, creating a bias towards accessible areas
- Survey not considered overly time consuming; a typical Hab-Plot took about 10-25 minutes and an entire survey could be completed in 1-4 hrs.
- The boat version was quicker than foot-based version
- Four Hab-Plots were sufficient on simple lakes, but not on complex sites
- Surveyor confidence was generally good, but shoreline percentages were sometimes difficult to estimate on large lakes and in foggy conditions
- Amendments suggested by agency survey teams:
  - Categories should be more consistent with RHS
  - Request for improved definition of shore zones
  - The addition of information about islands
  - Hydrological data rarely available, low confidence in completing
  - Other minor suggestions, such as the format for recording revising National Grid References
- Not enough information on natural shoreline habitat is collected

(vi) Results from first iteration of summary metrics LHMS and LHQA

A range of values for LHMS has emerged for the 10 principal test lakes and 30 of the agency lakes that have been processed to date, from potential reference condition sites such as Loch Brandy to highly modified artificial sites such as Derwent reservoir. Generally the LHMS scores are in agreement with subjective judgements of the lakes. In additional, similar values are achieved regardless of method (core or full) or approach (boat or foot).

LHQA scores have been derived for the 10 principal test sites only. These span a range of values to reflect the naturalness and also the habitat diversity of each site. It was stressed that simple but natural sites such as Loch Brandy could have lower LHQA scores than complex but modified sites, such as Llyn Padarn. This highlights the need for type specificity in LHQA interpretation, perhaps derived using benchmark distance scores from reference condition lakes in each typology group.

In summary, JC emphasised that the Phase 1 experiences suggest that LHS can provide a useful method to systematically collect lake habitat data, and that LHMS and LHQA are essential in using these data to characterise lakes. However, both of these are subject to revision, especially in the light of the workshop conclusions. Issues to consider in the revision include: (i) European experiences and the potential for CEN standard (ii) possibilities of including more desk-based and remote sensing data sources (iii) viability/usefulness of twin track version: core and full (iv) appropriateness of boat vs. foot options.

Part D: Experience of LHS in Finland (Antton Keto)
AK opened with some statistics on Finnish lakes:

- The total number of lakes and ponds 188,000 (with area > 0.05 ha)
- About 4,500 lakes, which are larger than 0.5 km^2 (WFD threshold)
- The total area of Finnish lakes is 32 600 km^2, which is 10% of total surface area of the country
- Most lakes are shallow (mean depth 7 m)

There is an extensive history on lake research in Finland, involving some method developments (e.g. REGCEL), and RHS and DHRAM have been partly imported (for rivers). Emphasis has been on hydrological pressures, and morphological pressures are poorly documented.

LHS was tested on eight lakes, two with urban pressures and the remainder with hydrological pressures. The lakes covered a range of water quality values, and some stratified while others did not. AK showed summary results for the Hab-Plots over all lakes; ground cover was the most extensive riparian vegetation cover, but broadleaved woodland was the dominant vegetation type overall. Quaking banks were often observed as bank top features. The most common Hab-Plot pressures were residential buildings, followed by recreational beaches and roads and railways. Most macrophyte types and littoral habitat features were observed, although reeds and sedges were dominant. The most common shoreline pressure was also residential development. Scores for LHMS were varied and in agreement with surveyors' impressions of the lakes. There was less confidence in LHQA values obtained.

Overall impressions were that LHS is a systematic and fast method for data collection, and that currently data on lake morphology is poorly documented and not collected systematically in Finland. Regional Environment Centres have suitable staff to conduct this field survey. There is also support for the international aspect of the project, and LHS should be useful for assessing hydromorphological pressures in the WFD context. Further comments were that not all data collected are suitable for a Finnish assessment and, in particular, four Hab-Plots are not enough for most Finnish Lakes.

Part E: Surveying lake hydromorphology in Germany (Wolfgang Ostendorp)
WO opened with some statistics regarding the area and shoreline lengths of lakes:

- About 0.5 % of the earth's surface is covered with lakes whose surface areas range from 0.01 km^2 (by definition) to 374 400 km^2 (Caspian Sea).

- Three out of the 25 largest lakes in the world lie in Europe. The largest of them is Lake Ladoga with 18 400 km^2.
- The number of lakes in the world is estimated to be about 8.5 $x10^6$, and in Europe more than $5x10^5$ natural lakes exist.
- The total shoreline length of lakes in Germany amounts to approximately 11000 km in total, and 6000 km for natural lakes larger than 0.5 km^2, respectively.
- Lakes in Germany are concentrated in formerly glaciated areas in northern Germany and in southern Germany as a consequence of alpine glaciation

LHS has not been tested in Germany. Instead, two alternative methods of hydromorphological assessment for lakes are being developed and tested. These are being developed by "LUNG Mecklenburg-Vorpommern", and "International Commission for the Protection of Lake Constance (IGKB)". The first is sophisticated and technical, using only air photos, maps and other written data. It is desktop-based and works exclusively with GIS. The other method is more suitable for field biologists; air photos and GIS are also used, but the main focus is on field survey. Hence these two methods are different, but it is hoped a combination of the strengths of each would produce a method to meet all requirements

Both methods measure the morphology of the lake shore zone (including some aspects of biotic structures such as macrophytes, dead wood, etc). The approaches do not include basin morphology or hydrology (shore zone, basin), nor do they consider artificial and heavily modified standing water bodies.

Further potential issues for consideration include:

- limnological lake typology is weakly linked to lake and lakeshore morphology
- too many purely descriptive variables of limited value for the indication of human pressure(s)
- weak links to nature conservation and species protection
- no facilities yet for quality assurance
- no plans yet for the scientific and/or applied use of the data

The methods are being tested on Lake Constance and some lakes in MeckPomm over winter 04/05. Upon receiving results from these, methods will be further evaluated. Potential tasks for improvement include:

- take the best ideas from both approaches (best = scientifically sound, simple, cost-efficient, indicative for distinct impacts)
- add strategies for the development of aggregation rules
- add modules for basin morphology and hydrological impacts on pelagic water bodies and lake shores
- add links to nature conservation (EU Habitats Directive, National legislation)
- add strategies for data handling, storage and processing, and strategies for quality assurance

Further consideration may be given to LHS once results from these methods are received and assessed.

Part F: Experience of LHS in France (Thomas Pelte)
TP gave a summary of LHS testing in France. This was carried out over three lakes, one artificial, one natural, and one natural and raised. Size ranged from 72-230 ha, and depth from 18-45 m. Background data were available, and surveys were carried out by boat in 1-2 hrs. No major difficulties were encountered when completing the form and the LHS could easily be added to other survey requirements.

Habitats and conditions observed at various Hab-Plots were discussed. Of particular importance was the distinction between naturalness and habitat complexity; some sites were simple but natural while others were diverse but modified by human activity. This needs to be considered when using scoring systems, etc. TP also expressed the concern from the French trials of using a fixed number of Hab-Plots, as the quality of information may decrease with an increasing lake perimeter. Possible solutions were suggested: to make Hab-Plot number a function of lake size or to make plot width a function of lake size. Generally the French group felt the former was preferable.

In general, 4 Hab-Plots were insufficient, although they were enough to highlight many pressures. In additional, the whole lake assessment was found to be lacking in the recording of habitat quality, and the French group felt that some important functional metrics are missing (e.g. shoreline development index). They also highlighted a need for additional data to pass from a descriptive system to an assessment system. This could be achieved by establishing links between physical descriptors (e.g. width of beach, angle, substrate), and functional metrics (e.g. macrophyte cover, cover for fish).

Overall impressions of the LHS were positive in that it is a simple, practical system that focuses on the most important metrics. Some further thought may be needed as to its purpose and ultimate aims.

Part G: Surveying lake hydromorphology in the USA (Phil Kaufmann)
PK gave an overview of the Lakeshore and Littoral Physical Habitat approach used in EMAP (the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program). The EMAP is a comprehensive lake and river survey program, involving the collection of data for a variety of disciplines. The theory is that data collected at a snap-shot in time can be more easily linked together, and that coordinating multiple survey needs into a single trip is very efficient. Under EMAP the Field Operations Manual for Lakes (FOML) was developed to provide instruction for collecting these variables for lakes.

The variables include: physical habitat (which is most relevant in the context of the LHS), water chemistry, clarity, temperature, lake assessment and site characteristics, riparian bird assemblage, fish assemblage, fish tissue contaminants, benthic invertebrate assemblages, zooplankton, sediment diatoms (current & paleo).
The data collected under the physical habitat section include:

- Habitat Structure and Living Space*
- Substrate: Shoreline*, Littoral*, Profundal
- Hydrologic Regime & Hydraulic Characteristics (rough indicators* + fetch & calculated residence time)
- Temperature and Light (*mid-lake profile)
- Riparian Vegetation* and Disturbance*
- Landscape and Catchment Characteristics (obtained from GIS)

(NB: *indicates inclusion in shoreline habitat survey)

Since the physical habitat section of the FOML was used as a basis for LHS there are many similarities. As per the full version of LHS, the deepest point of the lake is surveyed for chemistry + profile and 10 randomized, evenly-spaced plots are used for habitat plots. Plot dimensions are as for LHS with the exception of the shore zone; this is defined as a 1 m strip above the waterline. PK suggested that this might be brought in line with LHS if the FOML was revised. Field observations are made from a boat. Field observations made are very similar to LHS, so these are not summarized in this minute.

For the pilot test of the FOML a spatially-balanced probability sample of lakes (n=350) was surveyed. This was taken to represent 11,088 lakes in the Northeastern U.S.A.

PK presented some results of data analysis. Data precision was measured by looking at a "Signal:Noise" Variance Ratio, which measures the variation for a suite of habitat metrics recorded among lakes and between visits to the same lake. Larger values therefore indicate lower precision in recording features. Values varied between 1 and 10 for all features and composites of features presented. By this ratio, water level fluctuations and surface scums were the most imprecise measures, however these are subject to change over time. For variables expected to be largely time independent (e.g. mean substrate size and canopy cover), values were lower.

Summary metrics were developed within the EMAP scheme, and made use of basic data, such as "Riparian Development "(which measures the extent and intensity of human activities), "Riparian Vegetation Quality" (which measures the complexity of the canopy and other vegetation layers), and "Littoral Cover" (which sums the littoral habitat features).

Investigations were made into the associations between habitat and human disturbances. For example, (the square root of) road density within the catchment was positively correlated with the riparian alteration index, and was more likely to be high on lowland sites. Natural fish cover was weakly but negatively associated with the riparian alteration index, and tended to be higher in highland sites. Habitat associations with biota were also investigated. Riparian habitat quality index was positively associated with the presence of intolerant bird species, which tended to be more abundant in highland and mountainous sites. Conversely, intolerant bird species were negatively associated with the riparian development index. There was a strong positive association between fish species richness and drainage basin size (catchment size). Intolerant fish were favoured by littoral-riparian habitat quality index, while the more tolerant fish were more common in lower habitat quality sites.

In terms of overall lake shore modification, PK presented survey results showing that *ca*. 23% of lakes were not affected by human activities. The moderately stressed boundary was drawn at just over 20% shoreline modification, which encompassed over 50% of lakes (i.e. less than 50% of lakes escaped this boundary). The high stress boundary was drawn where almost half the lake shore was affected by human activities, and this encompassed just under 25% of sites. The extent of shoreline alteration was associated with regions, with lowland and north-eastern lakes suffering higher alteration than lakes in upland and mountainous areas. (This type of analysis may be relevant to TAG guidance in the UK and specifically to LHMS for the present study.)

These studies and results were carried out from 1991-94. PK suggested some changes that might improve the protocol:

- Improved GPS precision

- Linking GPS to SONAR
- Use of SONAR for substrate and aquatic macrophytes
- Increased use of remote imagery

Over 50 publications were produced as a result of EMAP data. Lists and copies can be obtained from:
John Stoddard, U.S. EPA National Health and Ecological Effects Research Laboratory, Western Ecology Division, 200 SW 35th Street, Corvallis, OR, U.S.A. 97333 Stoddard.John@epamail.epa.gov, or
Thom Whittier, Dynamac, 200 SW 35th Street, Corvallis, OR, U.S.A. 97333
Whittier.Thom@epa.gov

Session 2 – Detailed review of the LHS protocol: what works and what doesn't?

This session comprised a section-by-section review of LHS, with brief introduction of each part by the contractors, followed by group discussion.

Part A. Background data and general approach to survey (Rob Duck)

- Collecting and collating background data

RD summarised the approach to filling in Section 1.1 of the form using GBLakes, and an OS map. Issues for consideration were:

  - Are there European equivalents to GBLakes?
  - Should data be directly input to database?
  - Some entries not so easily derived were often left blank
  - Potential additional data sources available (more remote sensing or other desk-based data, e.g. LCM2000 catchment cover data)

Points made in discussion:
WO suggested finding a word (in English) to encompass the lake edge, which includes the riparian, shore and littoral zones. Group suggested 'edge' was probably the best word but agreed to revisit this if anybody found a preferable descriptor.
LH suggested that many variables collected in Section 1.1 were less useful than many alternative variables. The following variables were agreed to be useful:

Fetch
Mean depth
Shoreline irregularity
Total shoreline length (at stated scale)
Latitude and longitude
Distance from sea
Basin geology
Mean annual rainfall

GP suggested that geological metrics could be replaced with alkalinity, colour and conductivity, however IF warned of possible problems of using variables that reflect pressures. PK proposed the division of variables into 'base data', i.e. raw variables that can be obtained from a database, and 'derived data', which can be calculated using the base data variables. There was agreement on this distinction; only base data need be required by the form and further calculations can be generated in the database. Hence the above list of new variables will be referred to in the manual but need not be collected by surveyors.

There was general discussion regarding terminology and definitions. For a pan European approach these will need to conform to EU standards. LS pointed out that definitions are possibly more important than terminology on the form.

LS and IG felt strongly that background data need not be collected by field teams, and this was generally agreed upon by the group, although most agreed that looking at background data prior to arrival in the field is useful for giving surveyors an overview of the lake and surrounding area, and for detecting pressures and special habitats. There was a lack of resolution on this issue, however the contractors felt that some metrics should be included on the form to aid field work, e.g. knowledge of maximum depth before arrival in the field will aid in locating the Index Site.

- Role of remote sensing

RD summarised the findings from the remote sensing investigation carried out by the contractors as described by JC earlier. These results were similar to those described in the SEPA report by Davids *et al.* (2003). Issues for consideration in further use of remote sensing/desk-based data are:

- Variability in type and quality of data available for each lake
- Variability in access to data between agencies
- Need for field based verification

Suggestions for further use of remote sensing:

- Use of APs for orientation in the field and getting an idea of catchment as a whole
- Use of LCM2000 to quantify catchment pressures (GBLakes)
- Possible use of Mastermap for natural land-cover types around the lake

Points made in discussion:
GP stressed that we should keep LHS as a lake hydromorphology method, and not broaden the scope to the collection of catchment data. KI suggested the use of a lake 'health check' using remote sensing data, which could direct the efforts of the actual lake visit. JR emphasised the gap between the desire to use remote sensing and our ability to acquire and utilise the data. PB agreed that at present remote sensing may not provide what is needed from LHS, but that further investigation may be required. The scope for inclusion of remote sensing remained open and was recommended as an issue for further consideration in Phase 2.

- Surveys on foot compared with surveys by boat

RD summarised the advantages and disadvantages of each, as described by JC. RD stated that the boat version is generally preferable, but it may be necessary to use the foot version in some cases. He also pointed out that results from each were generally comparable.

Points made in discussion:
The group agreed that the use of a boat is generally preferable but since there was little difference apparent in scores the two can be used comparably.

CA questioned the standardised approach to the boat based survey which states that surveyors should not go onshore for better riparian observations. This was often frustrating for surveyors (was reported to AT and others as well), but is in place for standardisation purposes. The group agreed on the importance of this, but also of striking a balance. The conclusion was to allow surveyors to leave the boat and gain access to the shore if needed. The option of other methods, such as snorkelling and searching in the lake was also discussed. The group agreed these approaches could be used but if so they will need to be documented. This will provide some confidence in the detail (i.e. 'catch per unit effort' indicator). The manual will be amended to include this.

JC pointed out that the Index Site also requires a boat (although this is discussed in next section it is also an important boat-based consideration).

- Numbers and location of ‘Hab-Plots’ – includes Index Site discussion

RD summarised the suggestions from the results of the 10 test lakes, i.e. that four Hab-Plots may be insufficient, and that 10 may provide a good sample size.

Points made in discussion:
LH suggested that the number of plots should be dependent upon lake size and possibly on complexity. PK described the rationale for 10 plots used in the FOML, which is based on the binomial probability of detecting a habitat that comprises at least 10% of the lake. During the FOML development the use of 20 plots was investigated, but a standardised number of 10 plots was decided upon to measure the number of features/habitat types that are captured when deploying a standard effort on each lake.

GP felt that there is a need to link physical data with biological elements, which requires specific plots to be linked with biotic data, especially for non-mobile taxa and to establish relationships at localised scales.

DC suggested that the 10 plots in RHS should not be used to justify 10 plots in LHS, as multiple stretches of a river are surveyed for RHS, and hence the actual plot size is >>10.

CA commented that many Irish lakes have a high percentage of agricultural land surrounding them, apart from very small pockets of important wetlands which comprise <<10% of the lake, that could easily be missed by using 10 plots. PK pointed out that the ‘sweep up’ covers the whole lake and should detect important features that the Hab-Plots miss.

PB summarised the group’s views in suggesting that more is needed to compare the results derived from a variable number of Hab-Plots with the ‘true situation’, which could be found by conducting a comprehensive shoreline survey on selected lakes. This would be part of a Phase 2 investigation.

RD summarised the information collected at the Index Site, which provides essential data on the physico-chemical character of the water body, such as maximum depth, temperature, dissolved oxygen and water clarity. It is logically collected at the same time as the hydromorphology survey (from boat).

Points made in discussion:
GP expressed support for the Index Site approach, in that it is a key to understanding lake habitat and ecological linkages, particularly in understanding stratification patterns. LH stressed that the Index Site measurements should be used with caution, being largely dependent upon weather, season, etc. He conceded, however, that the index data are essential for modelling functions such as mass balance and outflow. LH suggested adding the ‘depth to wave base’ as an indicator of stratification patterns.
MH suggested alkalinity should be measured in meq L^{-1} for consistency with WFD requirements.

Part B. Recording features at survey sites (John Rowan)
JR described proposed changes to the approach to GPS recording. These will be a 12 figure alphanumeric code, as displayed by a GPS, which is the standard EA reporting method. GP suggested that UTMs may be a better standard under the EU. However, CA stressed the importance of being able to located positions on a grid.

The group decided that each country could have a unique recording code as long as all these can be converted to UTMs for any inter-European comparisons.

- Riparian zone

JR summarised the content on the form for the riparian zone section. There was agreement within the group that the protocol does not require any changes.

- Shore zone

JR summarised the content on the form for the shore zone section. LS expressed difficulties surveyors had with defining the zones of the beach and bank face, which had been reported by other surveyors. This difficulty was recognised by the contractors, in particular difficulties were encountered in defining zones when vegetation was present on the shore zone, where two banks were present (such as the drawn down water level bank and flood storage bank encountered at Llyn Tegid), and for 'boulder aprons' (such as in many pristine Scottish lochs, e.g. Loch Brandy). JR summarised proposed changes: boulder aprons will be defined in the new form as a type of 'bank face', and vegetation on the shore zone will be recorded. Some discussion was initiated by GF regarding fringing reed banks. It was confirmed that these are recorded in both the shore and littoral zones. For lakes with two banks formed by fluctuation between two water levels, a rule is required to define how often water bodies must reach high water banks for these to be used as zones for recording (e.g. if water reaches higher bank annually then this bank should be used for recording in LHS). PK suggested that shore width should be recorded, perhaps using a range finder for drawn down lakes with extensive exposed beach zones. This is already specified on the current form.

- Littoral zone

JR summarised the content on the form for the littoral zone section, and the changes proposed by the contractors. These include the removal of sediment odour and colour, but retention of odour as a general descriptor. The new form also requires specification of type of sediment, if sedimentation over natural substrate is present. Some discussion followed regarding 'cover for fish', which has been reported to cause confusion. It was decided to remove cover for fish as it can be derived from the other variables in littoral habitat features. SC suggested that macrophyte information could be lost if water level was raised and the littoral zone for LHS purposes covered the area usually exposed during summer drawdown. On vegetated shorelines this also leads to submerged terrestrial vegetation, which can still be recorded structurally as 'macrophytes'. However, it was recommended that a separate entry was included to record whether submerged terrestrial cover is present in the littoral zone.
The remainder of the littoral zone section was agreed upon with the exception of changing total macrophyte cover to a measurement of PVI (percent volume infested) as suggested by GP. This estimates the percentage of the three dimensional space in the littoral zone that is occupied by macrophytes.

- Human pressures

JR summarised the human pressures recorded for LHS. A short discussion followed led by GP and KI regarding the need for recording these pressures in the plots as well as in the shoreline survey. JR pointed out the need to link localised Hab-Plot information with pressures at the scale of the plot. There was general agreement within the group on the list of pressures recorded, although it was suggested that some of the more general pressures could be added if these are not incorporated in the whole-lake survey. However, all pressure types will be covered at the two "complementary" scales of Hab Plot and whole lake assessment. The current list does not prevent further development of LHS.

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Session 2 – cont.

Part C. Whole-lake assessment (Rob Duck)

- Shoreline pressures and lake site activities
- Habitat features of special interest

RD summarised suggested changes to the form, which include a major re-arrangement of the alignment of the shoreline survey table (see new proposed form), the addition of land-use within 50 m, the addition of natural land-cover, and the addition of special habitats (e.g. wetlands).

PB suggested changing terminology for % cover estimates from 'sparse', 'moderate', 'heavy', 'very heavy' etc, but to avoid the term 'extensive'. After group discussion it was agreed that categories of pressures could simply be reduced to a numerical scale, i.e. '10-40', '>40-75', etc.

SC expressed doubt in the ability of many surveyors to differentiate between many wetland types, particularly if viewing from a boat as part of a shoreline survey. IF pointed out that in RHS surveyors actually walk through the wetlands making identification easier. After some discussion, it was agreed to reduce the number of terms for wetland habitat to 'bogs', 'wet woodlands', 'reedbanks' and 'other wetlands'. Later in the session it was agreed to include 'poaching' as a shoreline pressure at the suggestion of JT.

AT and GF both expressed concern as to surveyors' abilities to estimate land-cover within 15 and 50 m. JR and JC maintained that this was not difficult in practice, and took an insignificant amount of extra time, but training may be required to demonstrate this. JR also pointed out that there did appear to be a critical distinction between land-cover types at around 15 m, where often a buffer strip around the lake (15 m) was composed of very different land-cover than the area beyond it within 50 m. PK, TP and IG supported the idea of recording both closer and further pressures to give an indication of directness of impacts. PB suggested that aerial photographs could be used for detecting land-cover outside 15m, but concluded that further work needed to resolve the distance of recording the inner strip inland. AK suggested using 100 m rather than 50, but JR pointed out that as the distance from the shore increases the complexity and uncertainty also increase; in addition the value of using remote sensing rather than field survey would increase for larger land strips. PB concluded that further testing is required, looking at land-cover within 15, 50 and 100 m.

RD summarised changes for the non-shoreline part of the whole lake survey, which primarily include the estimation of presence, extent and intensity for the lake site pressures.

Changes to pressures recorded here were agreed upon. These included IF's suggestion to specify 'fish cages' rather than 'fish farm', and SC suggested 'swimming' should be included. IF questioned the need to separate shore-based fishing from boat-based fishing; however, JR pointed out that these have differing effects on the lake (e.g. shore based can cause major disturbance to nesting birds in wetland areas) and should be differentiated. It was also agreed that headings for in-lake pressures should be removed.

PB expressed concern in general over the subjective judgement for measuring intensity; JC agreed that instructions for defining these could be difficult. JR suggested simply ticking boxes to indicate whether the pressures were extensive or intensive. LH stressed the variability and seasonality in measuring pressures, particularly intensity (e.g. whether a fishing rally was observed or missed makes major difference to intensity recorded). The group agreed that simple definitions were needed but that some indication of the intensity and extent of these pressures is desirable.

There was general agreement on the new subsection for 'landform features'. JT suggested the addition of archaeological features such as crannogs; however, it was decided that these should be recorded as 'other' where observed.

Under the recording of animals it was recognised that the list provided is regionally specific. To allow more general adoption of the LHS, generic categories should be added: i.e. piscivores, macrophyte-dependent species, pest species, and species of conservation interest. Examples should be provided, and can be adapted for regional differences. It was agreed that the recording of animals was really supplementary information and it will be noted in the manual that a full faunal survey is not the intention of this section.

Part D. Hydrology and sediment regime

- Hydrology
- Sediment regime

RD summarised changes, which include the relocation of the sediment regime section to the previous section as discussed. Water level fluctuation categories have also changed (0-0.5 m, >0.5-2 m, >2-5 m etc). PB also pointed out that category boundaries need to be checked. JC emphasised that many questions in the hydrology section were not well answered; IG in particular expressed concerns over the difficulties of answering this section. However, it was agreed that these questions should be retained to allow answers to be given where possible. PB highlighted that raising or lowering does not only refer to recent water level changes, but WO suggested that we may need a threshold before which these changes should not be recorded. The group agreed to use 1850 for consistency with the threshold for diatom palaeolimnology, which is linked to the beginnings of intensive agriculture.

It was agreed that specifying whether control structures are inflow or outflow would be useful. PB and AT highlighted the need for harmonising control structure definition with CEN guidelines. IF suggested recording the level of water control in adjustable sluices.

RD also summarised the approach of DHRAM (Dundee Hydrological Regime Assessment Method) in providing a measure of hydrological regime modification against assumed natural reference conditions, and thus giving a measure of risk to the aquatic ecosystems contained. However, while water level data are available for many reservoirs, data are scarce for natural lakes (e.g. only six in Scotland). The group agreed on the need for improved linkages between water level fluctuations and ecological impact, which could be improved by modelling reservoir data and relating to unmanaged lakes. PB highlighted that DHRAM should not be used out of context and may be inappropriate outside Scotland or the UK.

AK believes good water level data to exist in Finland; generally this was the response from other European delegates. LH described models available that can process water level data for specific scenarios, which can be linked to sedimentation, oxygen concentration and differences in lake hypsographic form. For example, when water level is lowered, wave base is lowered, which can cause increased sediment re-suspension.

E. Lake Habitat Metrics (John Rowan)

- Classification Tools: Benchmark Scores and Habitat Modification

JR summarised the system developed by the contractors for classifying the habitat modification (LHMS) and habitat quality of lakes (LHQA). LHMS values were well matched to subjective appraisal of sites. LHQA numbers were less consistent and more dependent on survey versions (boat, foot, core, full). Because LHQA is a measure of diversity as well as naturalness, type specific reference conditions are needed such that LHQA values can be used in conjunction with 'benchmark distance scores' from the reference condition values within each type. JR reiterated the point from TP's presentation that low diversity is not a negative trait of many natural lakes. JR described the theory for using LHMS to generate boundaries for High Ecological Status (HES), Good Ecological Status (GES), and Heavily Modified Water Bodies (HMWB), although for the latter this will require additional information and 'economic tests'. It was emphasised that feedback on these metrics is welcome and necessary.

Suggestions for Lake Habitat Modification Score

- PB suggested the removal of nuisance species from the score generations as these are not hydromorphological elements. SC pointed out that macrophytes can have profound effect on physical lake structure, and KI agreed that invasive macrophytes can have a particularly negative effect on habitat structure. After some discussion it was agreed to remove macrophytes for consistency, but that scores will be subject to development;
- GP not in favour of including Index Site measurements in the scores (GP not present on day 2; this point was made on the previous day but has been noted here);
- May need to change how individual metrics are weighted;
- Needs clear definition of 'hard' and 'soft' engineering, may need to include information on resilience and extent of structures (AT and JT). JC to follow this up with Jim Walker and Lindsay Syme;
- Under WFD, the hydromorphology supports the biology: this point needs to be considered when translating scores to thresholds for GES, HES etc;
- PB emphasised that there are some aspects that are independent of lake-type, and that LHMS component data should be considered in this way.

Suggestions for Lake Habitat Quality Assessment

- MH suggested nuisance species could be included here as a negative score (i.e. lack of naturalness)?;
- PB suggested separating 'naturalness' and 'diversity' values. JC wondered whether simply scoring naturalness would merely result in inverse scores to LHMS, although agreed that this requires further testing. If time, JC to investigate this in coming weeks;
- Also needs to take account of 'special features'- current version does this, although not necessarily separated into lake type specific features.

PK emphasised that it is more important to ensure LHS involves collection of the appropriate data to generate the scores, but the scoring systems themselves can evolve. KI agreed that these scores need not be finalised at the current workshop and further investigation may be required including field testing and validation.

<u>Session 3 – Future prospects</u>

Resumé of points agreed in Session 2 (Ken Irvine)
KI provided a concise summary of the points agreed in Session 2. In this minute these have been incorporated into the relevant sections of Session 2 above.

Discussion involving:

- Refinement of LHS

Further discussion on the recording of special features
IF suggested the need for defining specific habitat features that are known to be important for biota, and setting out the form to highlight these more intuitively. However a literature review may be required first to define these specific features. The contractors suggested that as long as features are being recorded they may not need to be explicitly stated on the form, and hence it is more important to decide if information is missing from the form. This point was strongly supported by PB, but no additions were suggested. It was agreed that key features should be identified and described in the manual as an aide memoire to surveyors.

Further discussions on the number and location of Hab-Plots
IF led further discussion on the locations of Hab-Plots, and expressed concern over missing key features using a randomised design. He proposed a stratified approach involving strategic placement of Hab-Plots over different habitats. KI pointed out that this becomes problematic when our ideas change regarding what a special habitat is, and which should be surveyed. PK agreed field testing could be used to determine whether these 'important habitats' are captured, but also emphasised the need for defining a consistent sampling strategy, as data using different approaches may not always be combined. JC agreed, especially in that LHMS and LHQA scores would not work under a stratified design. PB suggested that rather than discussing this theoretically, further testing may be required, including surveying the entire lake perimeter and looking into more remote sensing options.

An important point made by PB was the differentiation between a method and a protocol; a different protocol could be applied using the same methodology to answer a different question. PK agreed and illustrated the following example: if LHS is to be for routine application to permit comparisons between sites a systematic random approach is needed (in this way an unbiased estimate of the extents of different habitat types over a lake will be recorded). However, if the purpose is to sample the condition of special habitat features and link biotic and physical data on a localised scale, then systematically placed plots may be preferable to cover these habitat features and/or to be located within collection zones for biological data.

CA posed the question of whether Hab-Plots were ever required on islands. JC explained the contractors' rationale that island perimeter must make up at least 10% of total perimeter to have a Hab-Plot placed on it, although bonus plots were sometimes carried out on islands and can provide useful information on lake conditions prior to human disturbances. JT suggested that a different approach could be taken, such as in line with RHS where 25% of the river is aimed to be surveyed. This could translate to 25% of the lake shore being sampled in detail.

It was agreed overall that further research is needed in this area.

- Development of databases

It was decided that the database requires further attention as well as the field work, however PB suggested keeping this for Phase 2. Until the method is finalised there is little point in attempting to combine LHS with other databases. AT emphasised the importance of quality control; each RHS form is input twice and a macro run to identify differences. As a minimum, 10% of forms should be checked, and photographs provide a useful check for misclassifications.

- Training and accreditation

Due to time constraints no training was available during the past summer; this will need to be rectified for subsequent field seasons. A suggestion was made for a 2 day training session, involving at least some time in the field.

- Wider European involvement, integration/ alternative approaches, CEN standards

PB will discuss further involvement with CEN at next meeting in Bratislava in May 2005. Overall feedback from European delegates at the workshop was very positive and there is promising scope for European involvement to work towards a CEN standard.

Appendix 2: Version 1: Field survey form LHS_{core}

The following form was distributed for 2004 fieldwork to complete the LHS_{core} survey.

LAKE HABITAT SURVEY (LHS_{core})

Name of Lake:	GBLakes code: WBID ________	Date:	Visit #

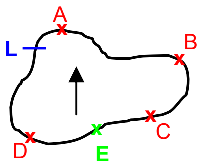
1. LAKE INFORMATION AND SURVEY DETAILS

1.1 BACKGROUND INFORMATION (use GBLakes database and recent OS 1:50,000 topographic map)

Maximum Depth (m) *[if known]*	*Circle method* Modelled / Measured	Lake Altitude (m)	
Lake Perimeter (m)		Max altitude of catchment (m)	
Lake Surface Area [L] (km^2)		Catchment Area [C] (km^2)	
Volume (m^3 x 10^3) *[if known]*		Lake:Catchment Area ratio [L:C]	
Number of major influent streams		Number of islands visible on 1:50,000 map	

Catchment Geology [circle]:	Siliceous/Calcareous/Organic/Mixed
Dominant catchment land-cover [circle]:	NV, BL, BP, CW, CP, SH, WL, MH, RP, IG, TH, TL, IL, PG, BT
Mode of lake formation *[if known]* [circle]:	RV, RC, KL, KH, GD, DP, FV, WW, BS, CW, IW, EH, ED, BP, OT
Designation Status [circle]:	SAC, SPA, NNR, SSSI/ASSI, LNR or Ramsar Site

MARK ON MAP
Arrow indicating North and scale bar
L = Launch site (if using boat)
A,B,C,D = location each Hab-Plot
E,F…= any additional viewing sites



Trace lake outline into space provided below (from map)

Trace from topographic base map (circle scale) [1:10,000, 1:25,000, 1:50,000, other specify]:
Indicate source of Map (e.g. Mastermap, OS Map, Other):
Indicate age of map:

1.2 SURVEY DETAILS (fill in when commencing field survey)

Surveyors name(s):		Time at start of survey:	
Organisation and code:		Time at end of survey:	
Survey method (circle):	Boat/ Foot	Estimated time to complete LHScore components:	

Adverse conditions affecting survey? (☐ ✓ tick if none, otherwise specify):

LAKE IDENTITY VERIFIED BY (✓ all that apply) GPS ☐ Local contact ☐ Signs ☐ Topo. Map ☐

1.3 PHOTOGRAPHS (Take two to illustrate the lake's characteristics and one of each Hab-Plot)

LAKE HABITAT SURVEY (LHS_{core})

Name of Lake:	GBLakes code: WBID ________	Date:	Visit #

Using GPS record six figure National Grid Easting and Northing of Launch site (L) and each Hab-Plot

Site	*National Grid Northing*	*National Grid Easting*
Launch (L)		
Hab-Plot A		
Hab-Plot B		
Hab-Plot C		
Hab-Plot D		

Any additional sites used for viewing

Site	*National Grid Northing*	*National Grid Easting*

2. PHYSICAL ATTRIBUTES *(to be assessed across four 15 m wide observation plots)*

New station ID (if needed):				
(STATION ID):	**A**	**B**	**C**	**D**

2.1 RIPARIAN ZONE (15 m x 15 m plot landwards from bank top)

Areal coverage to be assessed over plot *NO=None, 1=Sparse(<10%), 2=Moderate(10-40%), 3=Heavy(>40-75%), 4=Very heavy(>75%)*

		A	B	C	D
CANOPY LAYER (> 5 m)	Trees ≥ 0.3 m diameter				
	Trees < 0.3 m diameter				
	Evidence of canopy damage/disease				
UNDERSTOREY (0.5 – 5 m)	Woody shrubs & saplings				
	Tall herbs & grasses				
GROUND COVER (< 0.5 m)	Woody shrubs & seedlings				
	Herbs, grasses, bryophytes				
OTHER	Standing water or inundated vegetation				
	Pine needles or leaf litter				
	Barren				
	Artificial				

	A	B	C	D
Dominant land-cover within riparian zone (NV, BL, BP, CW, CP, SH, OR, WL, MH, OW, RP, IG, TH, RD, TL, IL, PG, BT)				
Notable nuisance plant species (NO=None, GH=Giant hogweed, RH= Rhododendron, HB=Himalayan balsam, JK=Japanese knotweed, OT=Other)				
Dominant bank top (1m wide) vegetation type (NO=None, CL=Canopy layer (>5 m), US=Understorey (0.5-5m), GC=Ground cover (<0.5m). MI=Mixed)				
Bank top features (BK=Bedrock, BO=Boulders, BR=Beach ridges, DU=Dunes, QB=Quaking bank, OT=Other)				

2.2 SHORE ZONE (15 m wide plot of variable length between bank top and waterline)

		A	B	C	D
BANK FACE (if present)	Bank face present (NO=None, YE=Yes)				
	Bank face height (m): (LO < 1, ME = 1-2, TA >2)				
	Bank face angle: (HO < 5°, GE = 5-30°, SL > 30-75°, VE > 75°, UN = Undercut)				
	Bank face material (NV, BE, BO, CO, GP, SA, SI, EA, PE, CL, CC, SP, WP, GA, BR, RR, TD, FA, BI, OT)				
	Bank face modification(s) (NO, NV, RS, RI, PC, EM, DM)				
	Evidence of bank face erosion (NO=None, ER=Eroding)				
SHORE/BEACH (if present or if bank face absent)	Beach Present (NO=None, YE=Yes)				
	Shore width (m) (estimate to nearest metre by pacing shore)				
	Average shore slope (HO < 5°, GE = 5-30°, SL > 30-75°, VE > 75°)				
	Shore material (NV, BE, BO, CO, GP, SA, SI, EA, PE, CL, CC, SP, WP, GA, BR, RR, TD, FA, BI, OT)				
	Shore modification(s) (NO, NV, RS, RI, PC, EM, DM)				
	Evidence of shore geomorphological activity: (NO=None, ER = Eroding, DS = Depositional)				
	Presence of shore organic debris/trash-lines (NO=None, YE=Yes)				

LAKE HABITAT SURVEY (LHS$_{core}$)

Name of Lake:	GBLakes code: WBID _________	Date:	Visit #

New station ID (if needed):				
(STATION ID):				

2.3 HUMAN PRESSURES (to be assessed over entire plot)

✓*(tick) if present, B = behind or adjacent to plot (within 50m radius)*

Any other pressures or comments for this section (indicate which Hab-Plots affected):

Commercial activities				
Residential buildings				
Walls, dykes or revetments				
Litter, dump or landfill				
Quarrying or mining				
Roads or railways				
Lawns, parks, gardens				
Recreational beaches				
Docks, marinas, boats, platforms				
Coniferous plantations (ring if evidence of logging)				
Pasture (ring if observed grazing)				
Row crops				
Orchard				
Pipes, outfalls				
Dredging				
Riparian weed control				
Macrophyte cutting				

2.4 LITTORAL ZONE (15 m wide plot extending to offshore station)

Depth (m) at offshore station (10 m offshore or maximum wading point)				
Distance (m) of offshore station from waterline (10 m or maximum wading point)				
Predominant substrate (NV, BE, BO, CO, GP, SA, SI, EA, PE, CL, CC, SP, WP, GA, BR, RR, TD, FA, BI, OT)				
Any sedimentation over natural substrate (NO=None, YE = Yes)				
Colour of sediment *(NS=No sediment, BL = Black, GY = Grey, BR = Brown, RD = Red, OT= Other)*				
Odour of sediment *(NS=No sediment, NO = None, HS = H_2S, SW = Sewage, OI = Oil, CH = Chemical, OT= Other)*				
Surface film type *(NO = None, SC= Scum, AM = Algal Mat, OI = Oily, OT=Other)*				

MACROPHYTES *NO=None, 1=Sparse(<10%), 2=Moderate(10-40%), 3=Heavy(>40-75%), 4=Very heavy(>75%)*

Liverworts/mosses/lichens				
Emergent broad leaved herbs				
Emergent reeds/sedges/rushes				
Floating-leaved (rooted)				
Free-floating				
Amphibious				
Submerged broad-leaved				
Submerged linear-leaved				
Submerged fine-leaved				
Filamentous algae				
Total macrophyte cover				

Do macrophytes extend lakewards (NV=Not Visible, NO=None, YE=Yes)				
Notable nuisance plant species (NO=None, NP=Nuttalls pondweed, WF=Water fern, AS=Australian swamp stonecrop, PF=Parrots feather, FP=Floating pennywort, OT=Other)				

LITTORAL HABITAT FEATURES *NO=None, 1=Sparse(<10%), 2=Moderate(10-40%), 3=Heavy(>40-75%), 4=Very heavy(>75%)*

Underwater tree roots				
Woody debris (ring if predominantly ≥ 0.3 m diameter)				
Inundated live trees (ring if predominantly ≥ 0.3 m diameter)				
Overhanging vegetation close to water surface (< 1 m above)				
Rock ledges or sharp drop-offs				
Boulders				
Total cover for fish				

LAKE HABITAT SURVEY (LHS$_{core}$)

Name of Lake:	GBLakes code: WBID ________	Date:	Visit #

3. WHOLE LAKE ASSESSMENT (carry out in consultation with recent OS 1:50,000 topographic map)

3.1 SHORELINE PRESSURES

Complete table from either a boat-based survey (cruising and observing between Hab-Plots) ***OR*** *by viewing visible shoreline sections from each Hab-Plot (these must be shown on sketch map). Observe progressively from Hab-Plots A, B, C, D (or add more appropriate viewing locations) until at least 75% of shoreline is observed (observe 100% if possible).*

Delete option not used (line through column), fill extra boxes as required

EXTENT OF SHORELINE SECTION AFFECTED

NO=None, 1=Sparse(<10%), 2=Moderate(10-40%), 3=Heavy(>40-75%), 4=Very heavy(>75%)

(ring entry if known that impact is affecting 'critical' area)

Boat	**Foot**			Bank construction				Intensive riparian and shore zone land-use (within 15m shore)													
Shoreline section observed between Hab- Plots	Shoreline section observed by viewing from Hab-Plot	Shoreline section number	Shoreline section as % of total shore	Impoundments	Hard engineering	Soft engineering	Docks and marinas	Commercial activities	Residential	Litter, dump, landfill	Quarrying or mining	Roads or railways	Lawns, parks, gardens	Recreational beaches	Coniferous plantation	Evidence recent logging	Pasture	Intensive grazing	Row crops	Orchard	Erosion
A-B	A	1																			
B-C	B	2																			
C-D	C	3																			
D-A	D	4																			
Totals			*																		

*total shoreline sections must be ≥ 75 % of entire shore

3.2 LAKE SITE ACTIVITIES/PRESSURES OBSERVED *✓(tick) if observed*

Motorboat sporting activities (e.g. jetski, waterski) ☐ Non-motor boat activities (e.g. sailing, rowing) ☐ Angling ☐

Macrophyte control ☐ Navigation ☐ Dredging ☐ Liming ☐ Odour ☐

Fish farming ☐ Military activities ☐ Powerlines ☐ Litter ☐ Surface scums/slicks ☐

Other (specify): ☐

3.3 HABITAT FEATURES OF SPECIAL INTEREST *✓(tick) if observed*

Fringing reed-bank(s) ☐ Fen(s) ☐ Quaking bank(s) ☐ Flush(es) ☐ Wet woodland(s)- carr ☐

Water meadow(s) ☐ Bog(s) ☐ Marsh(es) ☐ Delta(s) ☐ Alders (circle box if diseased) ☐

Others (specify): ☐

3.4 ANIMALS (circle if observed)

otter – mink – water vole – kingfisher – dipper – grey wagtail – sand martin – heron – osprey – dragonflies/damselflies – large bottom-feeding fish

Other (specify):

LAKE HABITAT SURVEY (LHS$_{core}$)

Name of Lake:	GBLakes code: WBID _________	Date:	Visit #

4. HYDROLOGY AND SEDIMENT REGIME (to be assessed over entire lake)

4.1 HYDROLOGY

Principal use (if any) *(circle)*	HydroPower / Water Supply / Flood Control / Navigation / Amenity
Water body type *(circle)*	Natural$_{(unmodified)}$ / Natural$_{(raised)}$ /Natural$_{(lowered)}$ / Impoundment / Flooded pit

If raised or lowered, state height difference of water level relative to natural condition (m) *[if known]*	(m)
Maximum height of principal retaining structure (m) *[if known]*	(m)

Are there any upstream impoundments? (circle)	No / Yes / Unsure
Any evidence of significant flow diversion into/out of catchment? (circle)	None / Into / Out of / Unsure
Does water level experience tidal influence? (circle)	No / Yes / Unsure

Vertical range of water level fluctuation (m) *(✓tick appropriate box)*

Daily$_{max}$	0 ☐	>0, < 2 ☐	2 – 5 ☐	5 – 20 ☐	> 20 ☐	Unsure ☐	**This question answered by:**
Annual$_{max}$	0 ☐	>0, < 2 ☐	2 – 5 ☐	5 – 20 ☐	> 20 ☐	Unsure ☐	On-site estimation ☐ Data ☐

Hydrological structures observed (total the number of each type in boxes provided below)

Dam without fish pass		Barrage		Weir	
Dam with fish pass		Sluice		Outfall	
Channelised channel		Lock		Intakes	
Other (specify):		Specify other here :			

4.2 SEDIMENTOLOGY

If possible, estimate maximum height (m) of any areas of eroded bank:	(m)

Emergent depositional landforms in deltaic areas

Extent of Lake area: NO=None, 1=Sparse(<10%), 2=Moderate(10-40%), 3=Heavy(>40-75%), 4=Very heavy(>75%)

Stable vegetated island(s)	☐	Unvegetated sand deposit(s)	☐
Aggrading vegetated deltaic deposit(s)	☐	Unvegetated silt/clay deposit(s)	☐
Unvegetated gravel deposit(s)	☐		

★ **Remember to fill in 'time at end of survey' and 'estimated LHScore time' in section 1**
Have you taken photographs to illustrate the lake's characteristics?

5. FURTHER COMMENTS

Use this section to describe any incidences of 'OT= Other' used in the survey, where insufficient room was provided within the section. Also include general comments, problems and suggested improvements for parts of the survey (continue over page if necessary).

Appendix 3: Version 1: Field survey form full LHS

The following form was used by the contractors in 2004 to complete the full LHS survey.

LAKE HABITAT SURVEY (LHS)

Name of Lake:	GBLakes code: WBID _________	Date:	Visit #

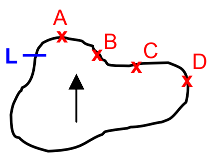
1. LAKE INFORMATION AND SURVEY DETAILS

1.1 BACKGROUND INFORMATION (use GBLakes database and recent OS 1:50,000 topographic map)

Maximum Depth (m) *[if known]*	*Circle method* Modelled / Measured	Lake Altitude (m)	
Lake Perimeter (m)		Max altitude of catchment (m)	
Lake Surface Area [L] (km^2)		Catchment Area [C] (km^2)	
Volume (m^3 x 10^3) *[if known]*		Lake:Catchment Area ratio [L:C]	
Number of major influent streams		Number of islands visible on 1:50,000 map	

Catchment Geology [circle]:	Siliceous/Calcareous/Organic/Mixed
Dominant catchment land-cover [circle]:	NV, BL, BP, CW, CP, SH, WL, MH, RP, IG, TH, TL, IL, PG, BT
Mode of lake formation *[if known]* [circle]:	RV, RC, KL, KH, GD, DP, FV, WW, BS, CW, IW, EH, ED, BP, OT
Designation Status [circle]:	SAC, SPA, NNR, SSSI/ASSI, LNR or Ramsar Site

MARK ON MAP
Arrow indicating North and scale bar
L = Launch site (if using boat)
A,B,C,D…etc = location each Hab-Plot



Trace lake outline into space provided below (from map)

Trace from topographic base map (circle scale) [1:10,000, 1:25,000, 1:50,000, other specify]:
Indicate source of Map (e.g. Mastermap, OS Map, Other):
Indicate age of map:

1.2 SURVEY DETAILS (fill in when commencing field survey)

Surveyors name(s):		Time at start of survey:	
Organisation and code:		Time at end of survey:	
Survey method (circle):	Boat/ Foot	Estimated time to complete LHScore components:	

Adverse conditions affecting survey? (☐ ✓ tick if none, otherwise specify):

LAKE IDENTITY VERIFIED BY (✓ all that apply) GPS ☐ Local contact ☐ Signs ☐ Topo. Map ☐

1.3 PHOTOGRAPHS (Take two to illustrate the lake's characteristics and one of each Hab-Plot)

LAKE HABITAT SURVEY (LHS)

Name of Lake:	GBLakes code: WBID __________	Date:	Visit #

Using GPS record National Grid Easting and Northing of Launch site (L) and each Hab-Plot

Site	*National Grid Northing*	*National Grid Easting*	***Hab-Plot***	*National Grid Northing*	*National Grid Easting*
Launch (L)			E		
Hab-Plot			F		
A			G		
B			H		
C			I		
D			J		

2. PHYSICAL ATTRIBUTES *(to be assessed across 10 15 m wide observation plots)*

	New station ID (if needed):										
	(STATION ID):	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**

2.1 RIPARIAN ZONE (15 m x 15 m plot landwards from bank top)

Areal coverage to be assessed over plot *NO=None, 1=Sparse(<10%), 2=Moderate(10-40%), 3=Heavy(>40-75%), 4=Very heavy(>75%)*

		A	B	C	D	E	F	G	H	I	J
CANOPY LAYER (> 5 m)	Trees ≥ 0.3 m diameter										
	Trees < 0.3 m diameter										
	Evidence of canopy damage/disease										
UNDERSTOREY (0.5 – 5 m)	Woody shrubs & saplings										
	Tall herbs & grasses										
GROUND COVER (< 0.5 m)	Woody shrubs & seedlings										
	Herbs, grasses & bryophytes										
OTHER	Standing water or inundated vegetation										
	Pine needles or leaf litter										
	Barren										
	Artificial										
Dominant land-cover within riparian zone (NV, BL, BP, CW, CP, SH, OR, WL, MH, OW, RP, IG, TH, RD, TL, IL, PG, BT)											
Notable nuisance plant species (NO=None, GH=Giant hogweed, RH= Rhododendron, HB=Himalayan balsam, JK=Japanese knotweed, OT=Other)											
Dominant bank top (1m wide) vegetation type (NO=None, CL=Canopy layer (>5 m), US=Understorey (0.5-5m), GC=Ground cover (<0.5m). MI=Mixed)											
Bank top features (BK=Bedrock, BO=Boulders, BR=Beach ridges, DU=Dunes, QB=Quaking bank, OT=Other)											

2.2 SHORE ZONE (15 m wide plot of variable length between bank top and waterline)

		A	B	C	D	E	F	G	H	I	J
BANK FACE (if present)	Bank face present (NO=None, YE=Yes)										
	Bank face height (m): (LO < 1, ME = 1-2, TA >2)										
	Bank face angle: (HO = near Horizontal, GE = 5-30°, SL = 30-75°, VE = near Vertical, UN = Undercut)										
	Bank face material (NV, BE, BO, CO, GP, SA, SI, EA, PE, CL, CC, SP, WP, GA, BR, RR, TD, FA, BI, OT)										
	Bank face modification(s) (NO, NV, RS, RI, PC, EM, DM)										
	Evidence of bank face erosion (NO=None, ER=Eroding)										
SHORE/BEACH (if present or bank face absent)	Beach Present (NO=None, YE=Yes)										
	Shore width (m) (estimate to nearest metre by pacing shore)										
	Average shore slope (HO = near Horizontal, GE = 5-30°, SL = 30-75°, VE = near Vertical)										
	Shore material (NV, BE, BO, CO, GP, SA, SI, EA, PE, CL, CC, SP, WP, GA, BR, RR, TD, FA, BI, OT)										
	Shore modification(s) (NO, NV, RS, RI, PC, EM, DM)										
	Evidence shore geomorphological activity: (NO=None, ER=Eroding, DS=Depositional)										
	Presence of shore organic debris/trash-lines (NO=None, YE=Yes)										

LAKE HABITAT SURVEY (LHS)

Name of Lake:	GBLakes code: WBID _________	Date:	Visit #

New station ID (if needed):										
(STATION ID):	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**

2.3 HUMAN PRESSURES (to be assessed over entire plot)

✓(tick) if present, B = behind or adjacent to plot (within 50m radius)

Any other pressures or comments for this section (indicate which Hab-Plots affected):

	A	B	C	D	E	F	G	H	I	J
Commercial activities										
Residential buildings										
Walls, dykes or revetments										
Litter, dump or landfill										
Quarrying or mining										
Roads or railways										
Lawns, parks, gardens										
Recreational beaches										
Docks, marinas, jetties or boats										
Coniferous plantations (ring if evidence logging)										
Pasture (ring if observed grazing)										
Row crops										
Orchard										
Pipes, outfalls										
Dredging										
Riparian weed control										
Macrophyte cutting										

2.4 LITTORAL ZONE (15 m wide plot extending to offshore station)

	A	B	C	D	E	F	G	H	I	J
Depth (m) at offshore station (10 m offshore or maximum wading point)										
Distance (m) of offshore station from waterline (10 m or maximum wading point)										
Predominant substrate (NV, BE, BO, CO, GP, SA, SI, EA, PE, CL, CC, SP, WP, GA, BR, RR, TD, FA, BI, OT)										
Any sedimentation over natural substrate (NO=None, YE = Yes)										
Colour of sediment *(NS=No sediment, BL = Black, GY = Grey, BR = Brown, RD = Red, OT= Other)*										
Odour of sediment *(NS=No sediment, NO = None, HS = H_2S, SW = Sewage, OI = Oil, CH = Chemical, OT= Other)*										
Surface film type *(NO = None, SC= Scum, AM = Algal Mat, OI = Oily, OT=Other)*										

MACROPHYTES *NO=None, 1=Sparse(<10%), 2=Moderate(10-40%), 3=Heavy(>40-75%), 4=Very heavy(>75%)*

	A	B	C	D	E	F	G	H	I	J
Liverworts/mosses/lichens										
Emergent broad leaved herbs										
Emergent reeds/sedges/rushes										
Floating-leaved (rooted)										
Free-floating										
Amphibious										
Submerged broad-leaved										
Submerged linear-leaved										
Submerged fine-leaved										
Filamentous algae										
Total macrophyte cover										

	A	B	C	D	E	F	G	H	I	J
Do macrophytes extend lakeward (NV=Not Visible, NO=None, YE=Yes)										
Notable nuisance plant species (NO=None, NP=Nuttalls pondweed, AS=Australian Swamp Stonecrop, PF=Parrots Feather, FP=Floating Pennywort, OT=Other)										

LITTORAL HABITAT FEATURES *NO=None, 1=Sparse(<10%), 2=Moderate(10-40%), 3=Heavy(>40-75%), 4=Very heavy(>75%)*

	A	B	C	D	E	F	G	H	I	J
Underwater tree roots										
Woody debris (ring if predominantly > 0.3 m diameter)										
Inundated live trees (ring if predominantly > 0.3 m diameter)										
Overhanging vegetation close to water surface (< 1 m above)										
Rock ledges or sharp drop offs										
Boulders										
Total cover for fish										

LAKE HABITAT SURVEY (LHS)

Name of Lake:	GBLakes code: WBID ________	Date:	Visit #

3. WHOLE LAKE ASSESSMENT (carry out in consultation with recent OS 1:50,000 topographic map)

3.1 SHORELINE PRESSURES

Complete table from either a boat-based survey (cruising and observing between Hab-Plots) ***OR*** *by viewing visible shoreline sections from each Hab-Plot (these must be shown on sketch map). Observe progressively from Hab-Plots A, B, C, D (or add more appropriate viewing locations) until at least 75% of shoreline is observed (observe 100% if possible).*

Delete option not used (line through column), fill extra boxes as required

EXTENT OF SHORELINE SECTION AFFECTED

NO=None, 1=Sparse(<10%), 2=Moderate(10-40%), 3=Heavy(>40-75%), 4=Very heavy(>75%)

(ring entry if known that impact is affecting 'critical' area)

Boat	Foot			Bank construction				Intensive riparian and shore zone land-use (within 15m shore)														
Shoreline section observed between Hab- Plots	Shoreline section observed by viewing from Hab-Plot	Shoreline section number	Shoreline section as % of total shore	Impoundments	Hard engineering	Soft engineering	Docks and marinas	Commercial activities	Residential	Litter, dump, landfill	Quarrying or mining	Roads or railways	Lawns, parks, gardens	Recreational beaches	Coniferous plantation	Evidence recent logging	Pasture	Intensive grazing	Row crops	Orchard	Erosion
A-B	A	1																			
B-C	B	2																			
C-D	C	3																			
D-E	D	4																			
E-F	E	5																			
F-G	F	6																			
G-H	G																				
H-I																					
I-J																					
J-A	J	10																			
Totals			*																		

*total shoreline sections must be ≥ 75 % of entire shore

3.2 LAKE SITE ACTIVITIES/PRESSURES OBSERVED ✓*(tick) if observed*

Motorboat sporting activities (e.g. jetski, waterski) ☐ Non-motor boat activities (e.g. sailing, rowing) ☐ Angling ☐
Macrophyte control ☐ Navigation ☐ Dredging ☐ Liming ☐ Odour ☐
Fish farming ☐ Military activities ☐ Powerlines ☐ Litter ☐ Surface scums/slicks ☐
Other (specify): ☐

3.3 HABITAT FEATURES OF SPECIAL INTEREST ✓*(tick) if observed*

Fringing reed-bank(s) ☐ Fen(s) ☐ Quaking bank(s) ☐ Flush(es) ☐ Wet woodland(s)- carr ☐
Water meadow(s) ☐ Bog(s) ☐ Marsh(es) ☐ Delta(s) ☐ Alders (circle box if diseased) ☐
Others (specify): ☐

3.4 ANIMALS (circle if observed)

otter – mink – water vole – kingfisher – dipper – grey wagtail – sand martin – heron – osprey – dragonflies/damselflies – large bottom-feeding fish
Other (specify):

LAKE HABITAT SURVEY (LHS)

Name of Lake:	GBLakes code: WBID ________	Date:	Visit #

4. HYDROLOGY AND SEDIMENT REGIME (to be assessed over entire lake)

4.1 HYDROLOGY

Principal use (if any) *(circle)*	HydroPower / Water Supply / Flood Control / Navigation / Amenity
Water body type *(circle)*	Natural(unmodified) / Natural(raised) /Natural(lowered) / Impoundment / Flooded pit

If raised or lowered, state height difference of water level relative to natural condition (m) *[if known]*	(m)
Maximum height of principal retaining structure (m) *[if known]*	(m)

Are there any upstream impoundments? (circle)	No / Yes / Unsure
Any evidence of significant flow diversion into/out of catchment? (circle)	None / Into / Out of / Unsure
Does water level experience tidal influence? (circle)	No / Yes / Unsure

Vertical range of water level fluctuation (m) *(✓tick appropriate box)*

							This question answered by:
Daily$_{max}$	0 ☐	>0, < 2 ☐	2 – 5 ☐	5 – 20 ☐	> 20 ☐	Unsure ☐	On-site estimation ☐
Annual$_{max}$	0 ☐	>0, < 2 ☐	2 – 5 ☐	5 – 20 ☐	> 20 ☐	Unsure ☐	Data ☐

Hydrological structures observed (total the number of each type in boxes provided below)

Dam without fish pass		Barrage		[illegible]	
Dam with fish pass		[illegible]		[illegible]	
[illegible]		[illegible]		Intakes	
[illegible]		Specify other here :			

4.2 SEDIMENTOLOGY

If possible, estimate maximum height (m) of any areas of eroded bank:	(m)

Emergent depositional landforms in deltaic areas

Extent of Lake area: NO=None, 1=Sparse(<10%), 2=Moderate(10-40%), 3=Heavy(>40-75%), 4=Very heavy(>75%)

Stable vegetated island(s)	☐	Unvegetated sand deposit(s)	☐
Aggrading vegetated deltaic deposit(s)	☐	Unvegetated silt/clay deposit(s)	☐
Unvegetated gravel deposit(s)	☐		

5. LAKE PROFILE INFORMATION AT INDEX SITE (to be measured at deepest point of lake)

Using GPS record National Grid Easting and Northing of Index Site	*National Grid Northing*	*National Grid Easting*

5.1 INDEX SITE AND WATER CONDITIONS

Surface conditions (circle):	Flat / Ripple / Choppy / Breaking Waves
Surface films (circle):	Scum / Algal mat / Oil / Other (specify)
Odour (circle):	None / H_2S / Sewage / Oil / Chemical / None / Other (specify)

MEASUREMENTS AT INDEX SITE		SECCHI DISK TRANSPARENCY	
Index Site water depth (m)		Clear to bottom (circle):	Yes / No
Alkalinity (mg/l CaCO3)		Depth disk disappears (m)	
pH		Depth disk reappears (m)	

LAKE HABITAT SURVEY (LHS)

Name of Lake:	GBLakes code: WBID _________	Date:	Visit #

5.2 DISSOLVED OXYGEN AND TEMPERATURE PROFILE

Depth of measurement (m) surface, 1.5, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 25, 30, 35, 40 and 50 m
(include readings at 1 m above lake bottom)

Calibration check confirmed (circle) Yes / No

Comments	**Depth (m)**	**O_2 (mg L^{-1})**	**Temp**	**M/T (°C)**
	Surface			
	Surface (duplicate)			

Confirm that duplicate O_2 reading is within ± 0.5 mg L^{-1} of initial surface reading **(Yes / No)**

If the site depth ≤ 3 m, take readings at the surface, every 0.5 m, and 1 m above the bottom

M/T located the position of the metalimnion = region of the water temperature profile where the temperature changes at a rate of 1°C or greater per metre of depth. Indicate the depth of the top of the metalimnion with a "T", and the bottom of the metalimnion (when the rate of change becomes less than 1°C per metre) with a "B". After the metalimnion is encountered, take readings every 1 m until bottom of the metalimnion is reached.

Remember to fill in 'time at end of survey' and 'estimated LHScore time' in section 1
Have you taken two or more photographs of the site?

6. FURTHER COMMENTS

Use this section to describe any incidences of 'OT= Other' used in the survey, where insufficient room was provided within the section. Also include general comments, problems and suggested improvements for parts of the survey (continue over page if necessary).

Appendix 4: Version 2: Revised LHS field survey form

The following form is the version revised after the final workshop and recommended for future use.

LAKE HABITAT SURVEY (LHS)

Name of Lake:	GBLakes code: WBID _________	Date:	Visit #

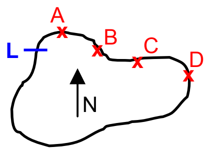
1. LAKE INFORMATION AND SURVEY DETAILS

1.1 BACKGROUND INFORMATION (use GBLakes database and recent OS 1:50,000 topographic map)

Maximum depth (m) *[if known]*		*Circle method by which depth was determined*	Modelled / Measured
Lake perimeter (m)		Lake altitude (m)	
Lake surface area [L] (km^2)		Catchment area [C] (km^2)	

Catchment geology [circle]:	Siliceous/Calcareous/Organic/Mixed
Dominant catchment land-cover [circle]:	NV, BL, BP, CW, CP, SH, WL, MH, RP, IG, TH, TL, IL, PG, SU
Mode of lake formation *[if known]* [circle]:	RV, RC, KL, KH, GD, DP, FV, WW, BS, CW, IW, EH, ED, BP, OT
Designation status [circle]:	SAC, SPA, NNR, SSSI/ASSI, LNR, Ramsar Site, or OTHER (specify section 6)

MARK ON MAP
Arrow indicating North and scale bar
L = Launch site (if using boat)
A,B,C,D…etc = location each Hab-Plot



Trace lake outline into space provided below (from map). Or attach a photocopy of an appropriately scaled topographic base-map for annotation.

Trace from topographic base map (circle scale) [1:10,000, 1:25,000, 1:50,000, other specify]:
Indicate source of map (e.g. Mastermap, OS Map, Other):
Indicate age of map:

1.2 SURVEY DETAILS (fill in when commencing field survey)

Surveyor name(s):		Time at start of survey:	
Organisation:		Time at end of survey:	
Survey method (circle):	Boat/ Foot	Estimated time to complete LHS components:	

Adverse conditions affecting survey? (☐ ✓ tick if none, otherwise specify):

LAKE IDENTITY VERIFIED BY (✓ all that apply) GPS ☐ Local contact ☐ Signs ☐ Topo. Map ☐

1.3 PHOTOGRAPHS (Take two to illustrate the lake's characteristics and one of each Hab-Plot)

LAKE HABITAT SURVEY (LHS)

Name of Lake:	GBLakes code: WBID ________	Date:	Visit #

Using GPS record 12 figure Ordnance Survey Grid Reference for launch site (if using boat) and Hab-Plots (Two letters, and 10 digit eastings & northings e.g. NO 14729 34834)

Launch (L)													E											
Hab-Plots													F											
A													G											
B													H											
C													I											
D													J											

2. PHYSICAL ATTRIBUTES *(to be assessed across TEN 15 m wide observation plots)*

	New Hab-Plot ID (if needed):										
	Hab-Plot ID:	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**

2.1 RIPARIAN ZONE (15 m x 15 m plot landwards from bank top)

Estimate aerial cover over plot *(0 (0-1%), 1 (>1-10%), 2 (>10-40%), 3 (>40-75%), 4 (>75%))*

		A	B	C	D	E	F	G	H	I	J
CANOPY LAYER (> 5 m)	Trees ≥ 0.3 m diameter										
	Trees < 0.3 m diameter										
	Evidence of canopy damage/disease										
UNDERSTOREY (0.5 – 5 m)	Woody shrubs & saplings										
	Tall herbs & grasses										
GROUND COVER (< 0.5 m)	Woody shrubs & seedlings										
	Herbs, grasses, bryophytes										
OTHER	Standing water or inundated vegetation										
	Pine needles or leaf litter										
	Bare ground										
	Artificial										
	Dominant land-cover within riparian zone (NV, BL, BP, CW, CP, SH, OR, WL, MH, AW, OW, RP, IG, TH, RD, TL, IL, PG, SU)										
	Notable nuisance plant species (NO=No, GH=Giant hogweed, RH= Rhododendron, HB=Himalayan balsam, JK=Japanese knotweed, OT=Other)										
	Dominant bank top (1 m wide) vegetation type (NO=No, CL=Canopy layer (>5 m), US=Understorey (0.5-5 m), GC=Ground cover (<0.5 m). MI=Mixed)										
	Bank top features (NO= None, BE=Bedrock, BO=Boulders, BC=Beach ridges, DU=Dunes, QB=Quaking bank, OT=Other)										

2.2 SHORE ZONE (15 m wide plot of variable length between bank top and waterline)

		A	B	C	D	E	F	G	H	I	J
BANK FACE (if present- includes boulder aprons)	Bank face present (NO=No, YE=Yes)										
	Bank face height (m) (estimate to nearest metre)										
	Angle (GE=Gentle (5 -30°), SL=Sloped (>30-75°), VE=near Vertical (>75°), UN=Undercut)										
	Bank material (NV, BE, BO, CO, GP, GS, SA, SI, EA, PE, CL, CC, SP, WP, GA, BR, RR, TD, FA, BI, OT)										
	Bank face modification(s) (NO, NV, RS, RI, PC, EM, DM, OT)										
	Bank face vegetation cover (*0 (0-1%), 1 (>1-10%), 2 (>10-40%), 3 (>40-75%), 4 (>75%)*)										
	Bank face vegetation structure (NO=No, CL=Canopy layer (>5 m), US=Understorey (0.5-5 m), GC=Ground cover (<0.5 m). MI=Mixed)										
	Evidence of bank face erosion (NO=No, ER=Eroding)										
SHORE/BEACH (if present)	Beach present (NO=No, YE=Yes)										
	Shore width (m) (estimate to nearest metre)										
	Slope (HO=near Horizontal, GE=Gentle (5 -30°), SL=Sloped (>30-75°), VE=near Vertical (>75°)										
	Shore material (NV, BE, BO, CO, GP, GS, SA, SI, EA, PE, CL, CC, SP, WP, GA, BR, RR, TD, FA, BI, OT)										
	Shore modification(s) (NO, NV, RS, RI, PC, EM, DM, OT)										
	Shore vegetation cover (*0 (0-1%), 1 (>1-10%), 2 (>10-40%), 3 (>40-75%), 4 (>75%)*)										
	Shore vegetation structure (NO=No, CL=Canopy layer (>5 m), US=Understorey (0.5-5 m), GC=Ground cover (<0.5 m). MI=Mixed)										
	Evidence of shore geomorphological activity: (NO=No, ER=Eroding, DS=Depositional)										
	Presence of shore organic debris/trash-lines (NO=No, YE=Yes)										

LAKE HABITAT SURVEY (LHS)

Name of Lake:	GBLakes code: WBID _________	Date:	Visit #

New Hab-Plot ID (if needed):										
Hab-Plot ID:	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**

2.3 HUMAN PRESSURES (to be assessed over entire plot)

✓*(tick) if present, B = behind or adjacent to plot (within 50m radius)*

Any other pressures or comments for this section (indicate which Hab-Plots affected):

	A	B	C	D	E	F	G	H	I	J
Commercial activities										
Residential areas										
Roads or railways										
Parks and gardens										
Docks, marinas, jetties or boats										
Walls, dykes or revetments										
Recreational beaches										
Educational recreation										
Litter, dump or landfill										
Quarrying or mining										
Coniferous plantation (ring if evidence logging)										
Pasture (ring if observed grazing)										
Tilled land										
Orchard										
Pipes, outfalls										
Dredging										
Riparian vegetation control										
Macrophyte cutting										

2.4 LITTORAL ZONE (15 m x 10 m plot extending from waterline to offshore station)

	A	B	C	D	E	F	G	H	I	J
Depth (m) at offshore station (10 m offshore or maximum wading point)										
Distance (m) of offshore station from waterline (10 m or maximum wading point)										
Substrate (NV, BE, BO, CO, GP, GS, SA, SI, EA, PE, CL, CC, SP, WP, GA, BR, RR, TD, FA, BI, OT)										
Any sedimentation over natural substrate? (NV, NO, BE, BO, CO, GP, SA, SI, EA, PE, CL)										
Odour *(NO = No, HS = H_2S, SW = Sewage, OI = Oil, CH = Chemical, OT= Other)*										
Surface film *(NO = No, SC= Scum, AM = Algal Mat, OI = Oily, OT=Other)*										

MACROPHYTES ***Estimate aerial cover*** *(0 (0-1%), 1 (>1-10%), 2 (>10-40%), 3 (>40-75%), 4 (>75%))*

	A	B	C	D	E	F	G	H	I	J
Liverworts/mosses/lichens										
Emergent broad leaved herbs										
Emergent reeds/sedges/rushes										
Floating-leaved (rooted)										
Free-floating										
Amphibious										
Submerged broad-leaved										
Submerged linear-leaved										
Submerged fine-leaved										
Filamentous algae										
Cover of inundated terrestrial vegetation in littoral zone										
Total macrophyte percent volume inhabited (PVI) ***Estimate volume of macrophytes within littoral plot*** *(0 (0-1%), 1 (>1-10%), 2 (>10-40%), 3 (>40-75%), 4 (>75%))*										
Do macrophytes extend lakewards? (NV=Not Visible, NO=No, YE=Yes)										
Notable nuisance plant species (NO=No, NP=Nuttall's pondweed, AS=Australian swamp stonecrop, PF=Parrots feather, FP=Floating pennywort, OT=Other)										

LITTORAL HABITAT FEATURES *Estimate aerial cover (0 (0-1%), 1 (>1-10%), 2 (>10-40%), 3 (>40-75%), 4 (>75%))*

	A	B	C	D	E	F	G	H	I	J
Underwater tree roots										
Woody debris (ring if predominantly > 0.3 m diameter)										
Inundated live trees (ring if predominantly > 0.3 m diameter)										
Overhanging vegetation close to water surface (< 1 m above)										
Rock ledges or sharp drop offs										
Boulders										

LAKE HABITAT SURVEY (LHS)

Name of Lake: | GBLakes code: WBID _________ | Date: | Visit #

3. WHOLE LAKE ASSESSMENT (carry out in consultation with recent OS 1:50,000 topographic map)

3.1 SHORELINE CHARACTERISTICS

Complete table from either a boat-based survey (cruising and observing between Hab-Plots) ***OR*** *by viewing visible shoreline sections from each Hab-Plot (these must be shown on sketch map). Observe progressively from Hab-Plots A, B, C, etc (or add more appropriate viewing locations) until at least 75% of shoreline is observed (observe 100% if possible).* ***If shoreline can be viewed from one location, do so; this will minimise uncertainty in estimations of overall % for the entire shoreline.***

EXTENT OF SHORELINE SECTION AFFECTED BY (OR COMPRISED OF) EACH PRESSURE OR LAND-COVER TYPE

Estimate extent (0 (0-1%), 1 (>1-10%), 2 (>10-40%), 3 (>40-75%), 4 (>75%)). Ring entry if known to affect 'critical' area.

	Shoreline section number	1		2		3		4		5		6		7		8		9		10	
Circle option used	Boat: viewed between Hab-Plots	A-B		B-C		C-D		D-E		E-F		F-G		G-H		H-I		I-J		J-A	
	Shore: viewed from Hab-Plots	A		B		C		D		E		F		G		H		I		J	
	New viewing locations (if req.)																				
	Section as % of total shore																				
	% shoreline at 15 and 50 m	15	50	15	50	15	50	15	50	15	50	15	50	15	50	15	50	15	50	15	50
Bank construction	Water control structures																				
Bank construction	Hard engineering																				
Bank construction	Soft engineering																				
Bank construction	Docks and marinas																				
Pressures and non-natural land-use	Commercial activities																				
Pressures and non-natural land-use	Residential areas																				
Pressures and non-natural land-use	Roads or railways																				
Pressures and non-natural land-use	Parks and gardens																				
Pressures and non-natural land-use	Recreational beaches																				
Pressures and non-natural land-use	Educational activities																				
Pressures and non-natural land-use	Litter, dump, landfill																				
Pressures and non-natural land-use	Quarrying or mining																				
Pressures and non-natural land-use	Coniferous plantation																				
Pressures and non-natural land-use	Evidence recent logging																				
Pressures and non-natural land-use	Pasture																				
Pressures and non-natural land-use	Observed grazing																				
Pressures and non-natural land-use	Tilled land																				
Pressures and non-natural land-use	Orchard																				
	Erosion																				
Wetland habitats	Fringing reed banks																				
Wetland habitats	Wet woodlands																				
Wetland habitats	Alders (ring if diseased)																				
Wetland habitats	Bogs																				
Wetland habitats	Quaking banks																				
Wetland habitats	Other (e.g. fen, marsh)																				
Other natural habitats	Broadleaf/mixed woodland																				
Other natural habitats	Broadleaf/mixed plantation																				
Other natural habitats	Coniferous woodland																				
Other natural habitats	Scrub and shrubs																				
Other natural habitats	Moorland/heath																				
Other natural habitats	Open water																				
Other natural habitats	Rough grassland																				
Other natural habitats	Tall herb/rank vegetation																				
Other natural habitats	Rock, scree or dunes																				

LAKE HABITAT SURVEY (LHS)

Name of Lake:	GBLakes code: WBID ________	Date:	Visit #

3.2 LAKE SITE ACTIVITIES/PRESSURES

*✓ (tick) box (**P**) if known to be present, and ring entry if actually observed*
If possible to estimate, ✓ (tick) boxes (E) and/or (I) if the pressure appears to be Extensive or Intensive, where specified

	P	E	I		P	E	I		P	E
Motorboat sporting activities				Causeways (in-lake barrier)				Fish cages		
Non-motor boat activities				Bridges				Dredging		
Navigation				Military activities				Liming		
Angling from boat				Macrophyte control				Litter		
Angling from shore				Surface films				Odour		
Swimming/wading				Nuisance sp (specify section 6)				Powerlines		

Others (add in spaces above and/or specify in Section 6)

3.3 LANDFORM FEATURES

Estimate extent as % lake surface area (0 (0-1%), 1 (>1-10%), 2 (>10-40%), 3 (>40-75%), 4 (>75%))

Vegetated islands (non deltaic)		Stable vegetated islands (deltaic)		Deltaic gravel deposit	
Unvegetated islands (non deltaic)		Aggrading vegetated deltaic deposit		Deltaic sand/silt/clay deposit	
Others (add here or specify in Section 6)					

3.4 ANIMALS *(tick if observed, and specify in right had column)*

Piscivores		*e.g. Cormorant, Kingfisher*
Macrophyte dependent species		*e.g. Swan, Grebe*
Non-native invasive species		*e.g. Mink*
Species of conservation interest		*e.g. Dragonflies, Osprey*

4. HYDROLOGY (to be assessed over entire lake)

Principal use(s) *(circle)*	None / Hydro-power / Water supply / Flood control / Navigation / Amenity / Other (specify)
Water body type *(circle)*	Natural(unmodified) / Natural(raised) /Natural(lowered) / Impoundment / Flooded pit

If raised or lowered, state height difference of water level relative to natural condition (m) *[if known]*	(m)
If raised or lowered, state when this occurred *[if known]*	
Estimate maximum height from lake bed of principal retaining structure (m)	(m)

Number of significant influent streams (stream catchment >10% total catchment)	
Are there any upstream impoundments? (circle)	No / Yes / Unsure
Evidence of significant flow diversion (i.e. may affect residence time) into/out of catchment? (circle)	No / Into / Out of / Unsure
Does water level experience tidal influence? (circle)	No / Yes / Unsure

Vertical range of water level fluctuation (m) *(✓tick appropriate box)*

Daily$_{max}$	< 0.5 ☐	> 0.5 – 2 ☐	>2 – 5 ☐	> 5 – 20 ☐	> 20 ☐	Unsure ☐	**This question answered by:**
Annual$_{max}$	< 0.5 ☐	> 0.5 – 2 ☐	>2 – 5 ☐	> 5 – 20 ☐	> 20 ☐	Unsure ☐	On-site estimation ☐ Data ☐

Water management structures observed (total each type in boxes provided). Where possible, indicate if critical areas are affected. Mark the location of any structures on the sketch map or photocopy of OS map.

Inflow	Dam without fish pass		Barrage		Weir	
	Dam with fish pass		Sluice		Outfall	
	Channelised channel		Lock		Intake	
Outflow	Dam without fish pass		Barrage		Weir	
	Dam with fish pass		Sluice		Outfall	
	Channelised channel		Lock		Intake	
Other (specify here or section 6):						

LAKE HABITAT SURVEY (LHS)

Name of Lake:	GBLakes code: WBID _________	Date:	Visit #

5. LAKE PROFILE INFORMATION AT INDEX SITE (to be measured at deepest point of lake)

Using GPS record 12 figure Ordnance Survey Grid Reference at the Index site (Two letters, and 10 digit eastings & northings)

5.1 INDEX SITE AND WATER CONDITIONS

Surface conditions (circle):	Flat / Ripple / Choppy / Breaking waves
Surface films (circle):	None / Scum / Algal mat / Oil / Other (specify)
Odour (circle):	None / H_2S / Sewage / Oil / Chemical / Other (specify)

MEASUREMENTS AT INDEX SITE		SECCHI DISK TRANSPARENCY	
Index Site water depth (m)		Clear to bottom (circle):	Yes / No
Alkalinity (meq L^{-1})		Depth disk disappears (m)	
pH		Depth disk reappears (m)	

5.2 DISSOLVED OXYGEN AND TEMPERATURE PROFILE

Measure at depths of (m) surface, 0.5, 1, 1.5, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 25, 30, 35, 40 and 50 m. Include readings at 1 m above lake bottom). If depth ≤ 3 m, take readings at the surface, every 0.5 m, and 0.5 m above the bottom.

Calibration check confirmed (circle) Yes / No

Comments	Depth (m)	O_2 (mg L^{-1})	Temp (^{o}C)	Metalimnion (T,B)
	Surface			
	Surface (duplicate)			

Confirm that duplicate O_2 reading is within ± 0.5 mg L^{-1} of initial surface reading (Yes / No)

Metalimnion (T, B): locate the position of the metalimnion, i.e. region of the water temperature profile where the temperature changes at a rate of 1^{o}C or greater per metre of depth. Indicate the depth of the top of the metalimnion with a "T", and the bottom of the metalimnion (when the rate of change becomes less than 1^{o}C per metre) with a "B". After the metalimnion is encountered, take readings every 1 m until bottom of the metalimnion is reached.

LAKE HABITAT SURVEY (LHS)			7 of 7
Name of Lake:	GBLakes code: WBID _________	Date:	Visit #

FIELD SURVEY QUALITY CONTROL (*✓tick boxes to confirm checks, explain in section 6 if necessary)*

- ★ Have you taken two or more photographs of the site and one of each Hab-Plot? ☐
- ★ Have you filled in the lake's name, GBLakes WBID, date and visit number on each page? ☐
- ★ Have you sketched the lake on page 1 (or provided photocopy of OS map), and annotated it? ☐
- ★ Have you completed the background data (from GBLakes) on page 1? ☐
- ★ Have you filled in 'time at end of survey' and 'estimated LHS time' (Section 1.2) on page 1? ☐
- ★ Have you completed 10 Hab-Plots, including GPS locations (Section 2) on pages 2 and 3? ☐
- ★ Have you surveyed at least 75% of the lake shoreline (Section 3) on page 4? ☐
- ★ Have you completed the whole lake survey (Section 3), activities, special habitats, and animals on page 5? ☐
- ★ Have you completed the hydrology section (Section 4) on page 5 answering all questions possible? ☐
- ★ If a boat is available, have you completed the Index Site (Section 5)? ☐

6. FURTHER COMMENTS

Use this section to describe any incidences of 'OT= Other' used in the survey, where insufficient room was provided within the section. Also include general comments and problems encountered during the survey.

Appendix 5: Field survey guidance sheets

LAKE HABITAT SURVEY (LHS) : FIELD GUIDANCE SHEET

CODES FOR ABBREVIATIONS (SECTIONS 1 AND 2)

LAND-COVER TYPES SECTION 1.1 & SECTION 2.1	
NV	Not visible
BL	Broadleaf/mixed woodland (semi-natural)
BP	Broadleaf/mixed plantation
CW	Coniferous woodland (semi-natural)
CP	Coniferous plantation
SH	Scrub and shrubs
OR	Orchard
WL	Wetland (e.g. bog, marsh, fen)
MH	Moorland/heath
AW	Artificial open water
OW	Natural open water
RP	Rough/unimproved grassland/pasture
IG	Improved/semi-improved grassland
TH	Tall herb/rank vegetation
RD	Rock, scree or sand dunes
TL	Tilled land
IL	Irrigated land
PG	Park, lawn or gardens
SU	Suburban/urban

MODE OF LAKE FORMATION SECTION 1.1: LAKE FORMATION	
Natural glaciated	
RV	Ice-scoured rock basin (valley floor)
RC	Ice-scoured rock basin (corrie)
KL	Knock and lochan (glacial scour)
KH	Kettlehole basin (detached ice block)
GD	Glacial drift (moraine or outwash dam)
Natural non-glaciated	
DP	Depression in blanket bog
FV	Fluvial processes on valley floor
WW	Wind/wave driven sand-blocked valley
BS	Depression in coastal windblown sand
CW	Chemical weathering
Artificial	
IW	Impounded watercourse (reservoir)
EH	Flooded excavation in hard rock
ED	Flooded excavation in drift
BP	Bunded completely artificial concrete bowl
OT	Others (specify in comments at end of survey)

PHYSICAL ATTRIBUTES SECTION 2

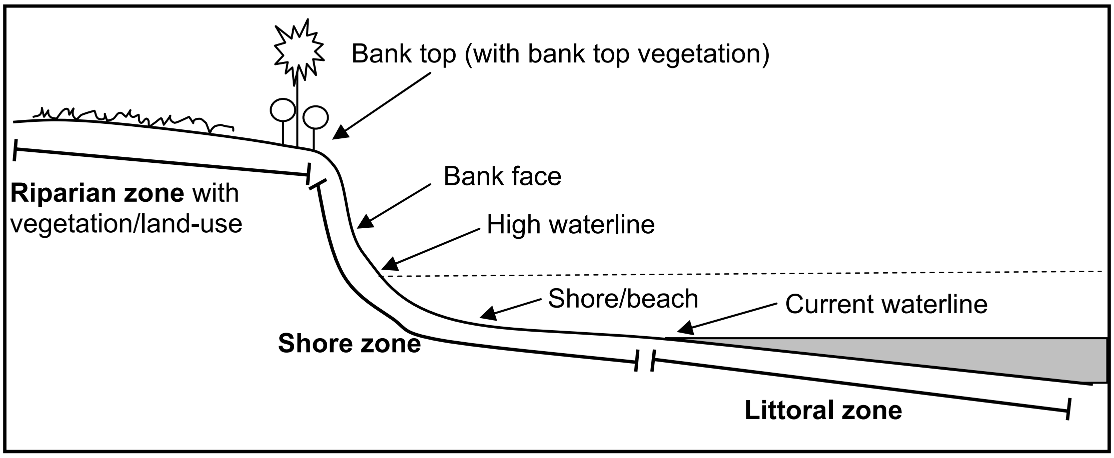
Materials and substrates 2.2 SHORE ZONE & 2.4 LITTORAL ZONE

NV	Not visible	
BE	Bedrock	Underlying, *in situ*
BO	Boulder	≥ 256 mm
CO	Cobble	≥ 64, < 256 mm
GP	Gravel/pebble	≥ 2, < 64 mm
GS	Gravel/sand mix	≥ 0.06, < 64 mm
SA	Sand	≥ 0.06, < 2 mm
SI	Silt	< 0.06 mm
EA	Earth	Crumbly
PE	Peat	Organic
CL	Clay	Sticky
OT	Other	

Artificial types	
CC	Concrete
SP	Sheet piling
WP	Wood piling
GA	Gabion
BR	Brick/laid stone
RR	Rip-rap
TD	Tipped debris
FA	Fabric
BI	Bio-engineering materials

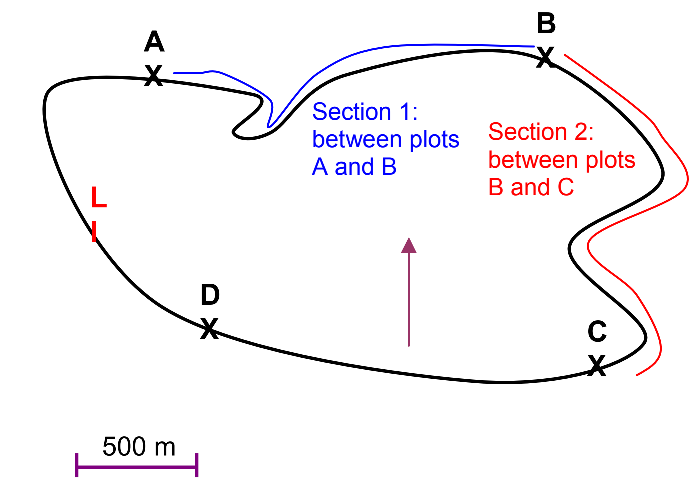
Modifications 2.2 SHORE ZONE	
NV	Not visible
NO	None
RS	Re-sectioned
RI	Reinforced
PC	Poached
EM	Embankment
DM	Dam
OT	Other

LAKE SHORE PROFILE (CROSS SECTION OF HAB-PLOT)

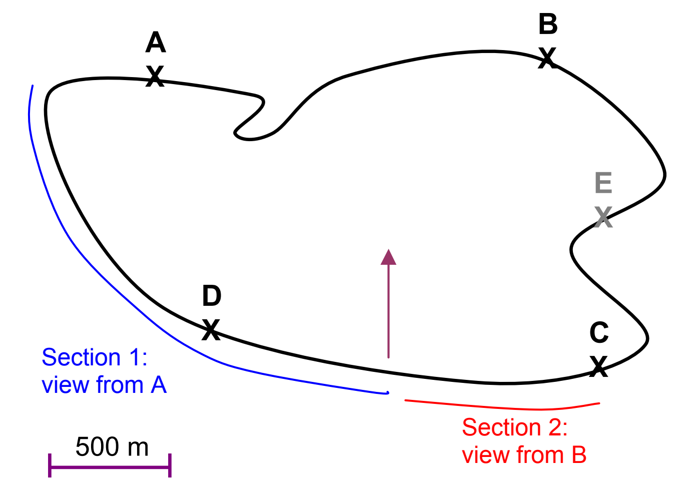


SKETCH MAP (FOR SECTION 1)

Option 1: Boat-based survey (sketch arrow indicating North, estimated scale bar, and location of launch site (L) and Hab-Plots (A-D). Observe and sketch sections of shore between each pair of Hab-Plots for section 3.1 (as shown for 1.2)



Option 2: Foot-based survey (sketch arrow indicating North, estimated scale bar, the location of Hab-Plots (A-D) and extra viewing points if required (e.g. E, F). Observe and sketch sections of shoreline observed for section 3.1 (as shown for 1.2)

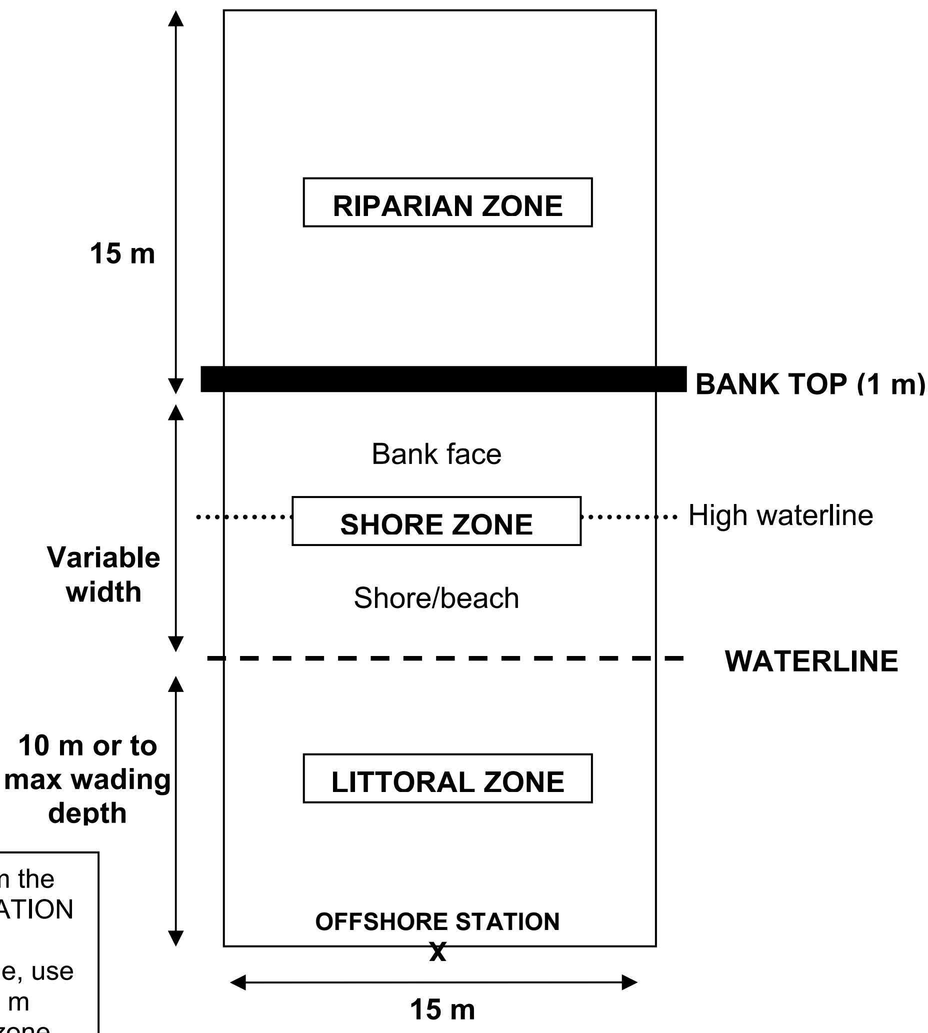


IN SECTION 2, USE 10 **15 m WIDE HAB-PLOTS** TO CHARACTERISE LAKE HABITAT

HABITAT PLOT OBSERVATION STATION (HAB-PLOT)

The **riparian zone** (section 2.1) begins at the top of the bank face, indicated by change in slope. It includes the **'bank top'**, which is an area 1m from the edge of the bank.

The **shore zone** is of variable width, and is the region between the edge of the bank and the current waterline. The **edge of the bank** is defined by a distinct change in slope and/or the junction between inlake and riparian conditions.
The shore zone includes the **bank face** and the **shore** (or beach), which are separated by the high waterline. Both the bank face and the shore may or may not be present.

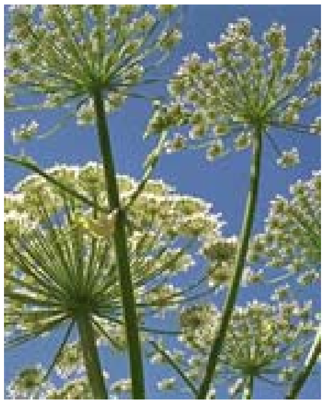


The **littoral zone** is the area from the waterline to the OFFSHORE STATION which is ideally 10 m from the waterline. If a boat is not available, use maximum wading depth up to 10 m from the waterline to define this zone.

SPECIES TO IDENTIFY IN THE RIPARIAN ZONE – NUISANCE SPECIES AND ALDERS

Giant hogweed (GH) – *Heracleum mantegazzianum*

Large growth (right) and close view of flowers (far right)



Rhododendron (RH) – *Rhododendron ponticum*

Large growth (below) and close view of flowers (right)

Himalayan balsam (HB) – *Impatiens glandulifera*

Large growth (right) and close view of flowers (below)

Japanese knotweed (JK) – *Fallopia japonica*

Large growth (left) and close view of distinctive seed pods (right)

Alders -*Alnus glutinosa*

Close view of healthy leaves

Dead trees as a result of *phytopthora* disease lining a river bank with live trees visible behind

Close view of diseased alder trunk showing lesions

SPECIES TO IDENTIFY IN THE LITTORAL ZONE – NUISANCE MACROPHYTES

Nuttall's pondweed (NP) - *Elodea nuttallii*
Close view of plant growths and leaves. Left shows size of leaves.

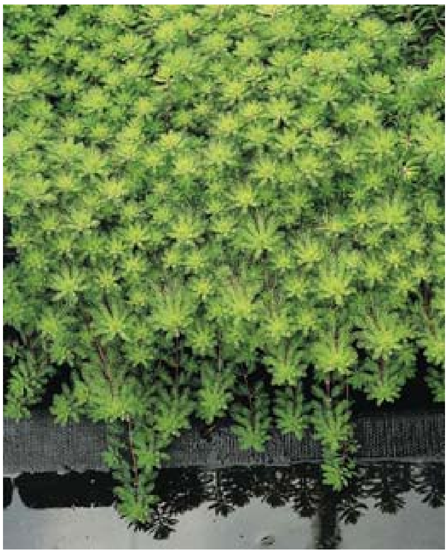
Water fern (WF) – *Azolla filiculoides*

Close view of floating leaves

Australian swamp stonecrop (AS) – *Crassula helmsii*
Two growth forms – floating mat and submerged plants rooted to substrate (above). Yellowing well-established mat (below)

Parrot's feather (PF) – *Myriophyllum aquaticum*

Large growth (left) and close view of featherlike leaves (below)



Floating pennywort (FP) – *Hydrocotyle ranunculoides*

Large growth (right) and close view of leaves (left)