Final Report **Project WFD42**

DEVELOPMENT OF A TECHNIQUE FOR LAKE HABITAT SURVEY (LHS): PHASE 2

June 2006

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This document was produced by:

Rowan, J.S., Soutar, I., Bragg, O.M., Carwardine, J. and Cutler, M.E.J.
Environmental Systems Research Group,
Department of Geography
University of Dundee, Dundee DD1 4HN, UK
Tel 01382 384024, Email j.s.rowan@dundee.ac.uk

SNIFFER's project manager

SNIFFER's project manager for this contract is:
Prof. P.J. Boon
Principal Freshwater Adviser
Scottish Natural Heritage
2 Anderson Place, Edinburgh
EH6 5NP, UK

SNIFFER's project steering group members are:

Stewart Clarke	(English Nature)
Dave Corbelli	(Scottish Environment Protection Agency)
Ian Fozzard	(Scottish Environment Protection Agency)
Tristan Hatton-Ellis	(Countryside Council for Wales)
Mary Hennessy	(Scottish Natural Heritage)
Gina Martin	(SNIFFER Research Manager)
David Smith	(Environment Agency)
Julie Tuck	(Scottish Environment Protection Agency)

SNIFFER
First Floor, Greenside House
25 Greenside Place
EDINBURGH EH1 3AA
www.sniffer.org.uk

EXECUTIVE SUMMARY

WFD42: DEVELOPMENT OF A TECHNIQUE FOR LAKE HABITAT SURVEY (LHS): PHASE 2 (June 2006)

Project funders/partners: SNIFFER

This project was funded by the Scotland and Northern Ireland Forum for Environmental Research (SNIFFER) together with Scottish Natural Heritage. Collaboration, training and field testing was undertaken with a number of partner organisations including the Environment and Heritage Service (EHS) of Northern Ireland, the Scottish Environment Protection Agency (SEPA), the Environment Agency (EA) of England and Wales and Scottish Natural Heritage (SNH).

Background to research

This research project reports the second phase of development of the Lake Habitat Survey (LHS) method, building on the results of the Phase 1 project (SNIFFER Report WFD40, 2004). The need for the work arose from the recognition that within the UK and across Europe more generally, no standard methods existed for assessing the hydromorphological condition of ponds, lakes and reservoirs, or for assessing the physical condition of standing waters in sites designated for conservation. The European Water Framework Directive (WFD), introduced in 2000, has acted as an important driver for LHS, especially because the WFD places a high premium on the development of international standards (e.g. those produced by the European Committee for Standardization). The utility of LHS to provide input data into decision-support systems required for environmental standards was therefore fundamental. However, from its inception, because of the limited choice of available methods, it was recognised that there was scope for this new scheme to be multi-purpose, providing data for management and conservation applications, systematising environmental impact assessment and supporting restoration programmes for degraded lake ecosystems.

Summary of outputs

The protocol underwent some minor revisions following an expert workshop in March 2005, with further amendments made following training workshops held at four lakes across the UK. The final July-2005 versions of the field form and manual were tested both by contractors and partner environmental agencies (EA, EHS and SEPA) during the 2005 field season (available from the SNIFFER website http://www.sniffer.org.uk). Field trials were also conducted in several European countries including Ireland, Finland, France, the Netherlands, Poland and Serbia-Montenegro. Dialogue between surveyors and contractors proved vital for refining the protocol, improving the consistency of field results and improving surveyor confidence.

In terms of methodological development the two main areas considered were the sampling strategy (i.e. the number and siting of Hab-Plots) and further consideration of the role of remote sensing. For selected sites (Loch Lomond, Loch Earn, and Barton Broad) large numbers of Hab-Plots were collected (38, 15 and 18 respectively), allowing surveys of various size to be simulated with the data. It is demonstrated that the uncertainty in Hab-Plot summary data diminishes with sample size, but it was concluded that minor gains in precision do not necessarily outweigh the benefits of a standardised procedure, particularly when considered in tandem with the perimeter survey results. Viewed in the context of a hierarchical monitoring strategy it is concluded that the standard protocol of 10 evenly-spaced Hab-Plots should be the default method. Where surveillance monitoring suggests particular issues or complexities within a system, investigative monitoring can pursue further samples (in increments of 10 and maintaining the principle of even spacing). Further consideration was given to the use of remote sensing and GIS tools. The use of aerial photographs and high resolution digital maps were complemented by an airborne hyperspectral survey of Torside Reservoir. It was concluded that remote sensing is best considered as a complementary method, rather than as an alternative, to a field-based assessment. Analytical and sampling uncertainties, however, are minimised in the field when surveyors have access to high quality maps and appropriately-scaled air photographs.

Following the 2004-05 field seasons the LHS database now contains c. 200 lake surveys (comprising c. 1400 constituent Hab-Plots). Useful summaries relating to engineering practices as well as the range and intensity of specific pressures can inferred, with the caveat that these data do not comply with the statistical requirements of a probability-based, area-weighted sample (though this is desired in future). Summary metrics, such as the Lake Habitat Modification Score (LHMS) and the Lake Habitat Quality Assessment (LHQA) were also derived. LHMS scores of zero were recorded at c. 5 % of sites within the UK, indicating that these would qualify as being at reference condition with respect to hydromorphological quality elements. A useful distinction was made between hydrologically ‘regulated’ and ‘un-regulated’ sites, with the former showing consistently higher LHMS scores and a much wider range of specific pressures. LHQA results were more equivocal, and demonstrated strong scale-dependency, with larger sites such as Loch Lomond having high levels of hydromorphological alteration, but by virtue of their large size they also still contain extensive and diverse natural habitats giving them a higher assimilative capacity with respect to pressures. Analysis of LHS data showed links between macrophyte structure (serving as a proxy for functional groups) and substrate characteristics, which in turn was related to geology and effective fetch. It is concluded that there is considerable potential in analysing the structural data within the database to make inferences about lake habitats. However, further investigations into the linkages between hydromorphological alteration and ecology were constrained by limited access to appropriate biological data.

In terms of the next steps in LHS development, it is concluded that the key challenge remains in more fully exploring the relationships between LHS metrics and comparably scaled biological data. It is noted that integrated field campaigns where macrophyte, macroinvertebrate and fish data have been collected at the same time as LHS surveys offer particular opportunities to advance in this direction. The need for further training and an accreditation programme that will ensure consistency of approach in both field data collection and metric calculation is also recommended. Further innovations relating to the development of electronic field forms, negating database transcription errors and permitting real-time generation of summary metrics inclusive of uncertainty, are further targets for the Phase 3 development of the LHS assessment tool.

Key words: Lake Habitat Survey, Hydromorphology, LHMS, LHQA, Water Framework Directive, Habitats Directive

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1 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). It is expected that LHS can also play an important role in standardising 'condition monitoring' as required for conservation designated sites in the UK, as well as supporting environmental impact assessment and 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). The current version of the LHS protocol has been tested extensively throughout the UK, with limited coverage in the Republic of Ireland. Moreover, several surveys have now been carried out in mainland Europe, and future protocol revisions will acknowledge those surveyors' experiences.

A Joint Nature Conservation Committee (JNCC) scoping study carried out by Rowan *et al.* (2003) involved a literature review, consultations with environmental and lake management experts throughout Europe, and production of a prototype LHS scheme for testing. The Phase 1 report (SNIFFER Report WFD40a, 2004) described the further development of LHS, and included a comprehensive field-testing programme carried out in the UK in the summer of 2004.

The LHS approach is based on combining a standard number of detailed plot observations (n = 10) 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 for 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 the structure and condition of the lake shore zone
>
> *Hydrological regime:* quantity and dynamics of flow, level, residence time, and the resultant connection to groundwater

It is proposed that LHS might be used to describe the hydromorphological reference conditions (HES) for lakes, and 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 potential applications in meeting the regulatory duties imposed by the EC Habitats Directive which include, for example, the management of Special Areas of Conservation (SACs), and the UK's Common Standards Monitoring programme. The latter aims to produce standardised and consistent methods for assessing the condition of habitat features, supporting the designation and maintenance of SACs and SSSIs (Sites of Special Scientific Interest). LHS also has applications 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, attention is given to the development of summary metrics termed the Lake Habitat Modification Score (LHMS) and the Lake Habitat Quality Assessment (LHQA), analogous to the HMS and HQA developed for RHS (cf. Raven *et al.* 1998). The metrics developed in the present study remain provisional because of on-going lack of access to suitable biological data. When such data (e.g. those obtained through WFD-initiated biological sampling) become available, then investigation is required to determine the relationships and thresholds between biology and hydromorphological disruption through calibration with biological data (*cf.* Logan and Furse, 2002).

This Phase 2 study documents the further developments of LHS during 2005/06. These include further field-testing and revision of the survey protocol, a re-examination of the sampling regime, advancement of the LHS database, and analysis of LHS data.

1.2 Aims and objectives

The overall objectives established at the outset of Phase 2 of the LHS project were:

1. To re-examine, and if necessary revise, the LHS protocol as developed during 2004 taking into account recommendations from the Phase 1 final technical workshop (held in Edinburgh, March 2005). In doing so, a revised LHS protocol for deployment during the 2005 field season was to be produced.
2. To provide workshop / training days for relevant environment and conservation field staff (SEPA, EA, and EHS) prior to the main 2005 summer field season. The aims of the workshops were to aid in survey familiarisation, improve consistency of field surveyors, improve surveyor confidence, and contribute further to protocol revisions through practical testing and feedback from experienced field surveyors.
3. To give further consideration to the potential role of remote sensing as a complementary tool in LHS assessments.
4. To complete the analysis of LHS carried out in Phase 1, including preliminary investigations of the links between hydromorphology and biology.
5. To undertake an experimental LHS assessment programme on a series of water bodies varying in geological type (as defined by the UK TAG reporting typology), size, and shoreline complexity in order to explore the number and siting of Hab-Plots for any given water body.

6. To collate and analyse the LHS data collected by SEPA, EA and EHS field teams during the summer of 2005 in conjunction with coincident biological sampling. Subject to the availability of biological data from the 2005 field season, further exploitation of hydromorphology-biology interactions was to be developed.
7. To reflect on the next steps in LHS development, including refinement of the LHS database and associated analytical tools (for application under the WFD and the Habitats Directive, for example), and the establishment of training and accreditation procedures.

These aims are explored in detail throughout the remaining sections of the report. Summaries of the discussions and outcomes of the two LHS ‘expert workshops’ held in March and December 2005 are presented in Appendices 1 and 2.

Figure 1.1 General view of Loch Earn, Perthshire, Scotland during 2005 survey, note evidence of ‘recent logging on north shore.

2 RE-EXAMINATION AND DEVELOPMENT OF THE LHS PROTOCOL

This section summarises the LHS survey approach as developed throughout both phases of the survey's development. An outline and rationale for the original survey design is followed by a summary of the events in 2005, and their roles in forwarding the development of LHS.

2.1 Summary of 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 (SNIFFER Report WFD40b, 2004).

Alternative versions

During the testing and development phase of LHS (Phase 1), some variations in survey technique were investigated by employing different versions of the survey protocol. During Phase 1 analyses, the comprehensiveness of each protocol draft was assessed, and the various survey versions were compared to determine the extent to which they could be used interchangeably (at the discretion of the surveyor). Of fundamental importance was the decision to employ a standard survey size, the rationale for which is described below. Also, based on comparative analysis, it was decided that the survey could be carried out by boat or on foot, depending on resource and access issues, in order to maximise the practicality of the survey. The reasoning behind these decisions are discussed in detail in the SNIFFER Report WFD40a.

Background information

Background information is collated prior to arrival in the field, including morphological data such as depth and surface area, and catchment variables such as area and land-use. Additional relevant information such as the conservation designations (e.g. SSSI, SAC, SPA etc.) in place are noted. For the UK much of this information can be obtained from the UKLakes (formerly GBLakes) database (managed by University College London) some of which is available at http://www.uklakes.net. For lakes outside the UK, entries can be derived from a topographic map. A good quality map is also required in the field to assist in locating sample points, and should be annotated accordingly. Mode of lake formation and lake type can be recorded on arrival at the water body, or else may be established through contact with the land owner/manager, or through consultation with maps or other documentation. Land owners and conservation bodies should also be contacted prior to arrival in the field to ensure access arrangements are in place.

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 water body. Ten Hab-Plots are required for a full 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 an offshore station in the littoral zone, in principle 10 m from the waterline (Figure 2.1). This distance is important to maximise consistency between boat- and foot-based versions. This position is reached either by boat, or by wading from the shore.

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. Testing has shown that it is almost always possible to view the whole plot, including the riparian zone, from this point. Underwater features are viewed using a bathyscope if necessary. If there is insufficient light for this, the characteristics of bottom sediments can be assessed by probing with a ranging pole, and samples of vegetation collected using a rake and/or grapnel. If any littoral features cannot be seen clearly from the offshore station, both boat-based and foot-based surveyors may move around in the Hab-Plot to resolve any uncertainties. Surveyors may also move about in the shore or riparian zone to make recordings of macrophytes and other littoral features. However, this and any other extra measures that are taken must be noted in Section 7 of the form. Such extra measures may increase the overall survey time, particularly if boat-based surveyors opt to moor the boat and land in order to examine the shore and/or riparian zones.

The shore zone, if present, lies between the littoral and riparian zone, and may include a beach and/or a bank face. The junction between these zones is defined by a concave break in slope. A bank is formed by the action of water or waves cutting into the shore, so the bottom of the bank is often at the high waterline or at the height reached by storm wave action. The beach can form either as a consequence of water level regression or may be an erosional or depositional landform resulting from local bank erosion and shoreline sediment transport, and usually has a more gentle gradient. Note that in many natural lakes and in lakes where the water level has been raised, the waterline separates the riparian zone from the littoral zone, i.e., the beach and bank face sub-zones may not be present. In such cases the boundary between riparian and in-lake conditions is often indistinct, especially where reed beds are present (Figure 2.2).

A series of characteristics and features in the riparian zone is recorded. These include a summary of the dominant land cover, the areal extent of various vegetation types, and the presence of some special features (nuisance species, presence of streams or flushes). Areal extent is estimated in bands of % cover, modified from the procedures used in Field Operations Manual for Lakes [FOML] (Kauffman and Whittier, 1997). These are: *0* (0%), ✓ (>0 - 1%), *1* (>1 - 10 %), *2* (>10 – 40 %), *3* (>40 – 75%) and *4* (>75%). The >0 - 1 % category was introduced as a new range category in 2005.

With 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 RHS, as are the % cover of component substrates (bedrock, boulder, cobble, pebble, sand, and silt/mud, using standard Wentworth size grade divisions). Artificial substrates are recorded as concrete, sheet piling, wood piling, gabion baskets, brick/laid stone, rip-rap, tipped debris, fabric, or bio-engineering material. Shore and bank modifications are recorded, again using RHS categories: re-sectioned, reinforced, poached, embankment, and dam. The cover and structure of beach vegetation, signs of geomorphological imbalance, and the distance from the waterline to the trash line (if present) are also recorded.

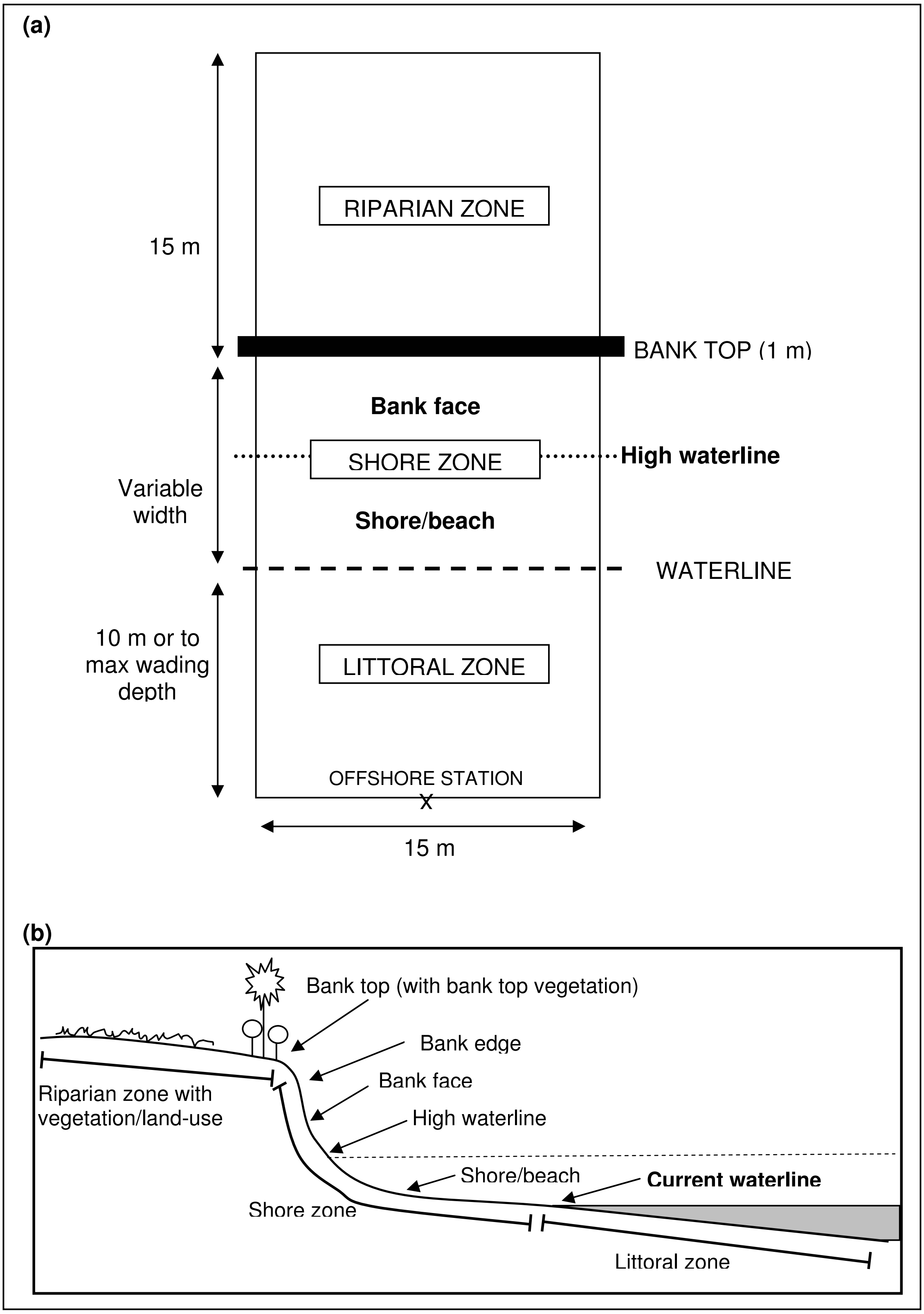


Figure 2.1 Definitions of Hab-Plot zonation: (a) plan view, and (b) cross-section

Figure 2.2 Illustration of heterogeneous shore zone characteristics at Loch Bà, Highland Region, Scotland, spanning from well-defined bank features to hydroseres without the presence of a bank face.

In the littoral zone, the depth and distance from the waterline are recorded at the offshore station. This is ideally 10 m from the waterline, but in practice may be less if this distance exceeds the maximum wading depth (c. 0.75 m) if surveying by foot, or more if the littoral zone is too shallow to approach by boat. The predominant littoral substrate and the composition of substrate components are recorded using the same categories and % cover classes described for the shore zone. The presence of sedimentation over the natural substrate is also noted.

Macrophytes in the littoral zone are recorded with the categories developed for RHS, which assesses the habitat structure they provide at the time of survey, and 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, submerged broad-leaved, submerged short, stiff-leaved, submerged linear-leaved, submerged fine- and dissected-leaved, filamentous algae, phytobenthos and seaweeds. For more detail on the definitions of these categories see the LHS manual.

The aerial cover of each type is estimated using the percentage bands described above for the riparian vegetation. The Percentage Volume Inhabited (PVI) by macrophytes is also estimated using these bands, and it is noted whether growth extends lakewards. Any nuisance species present in the littoral zone is noted. The percentage cover of other littoral habitat features is recorded, including underwater tree roots, woody debris, overhanging vegetation, and rock ledges or drop-offs. The presence and type of any surface films is also noted.

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 developments, roads or railways, unsealed tracks or footpaths, parks and gardens, camping and caravans, docks / marinas / boats / moorings / platforms, walls / dykes / revetments, recreational beaches, litter / dumps / landfills, pasture, other grazed land, coniferous plantations, tilled land, orchards, pipes / outfalls, dredging, riparian vegetation control, and aquatic macrophyte cutting.

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

Shoreline survey

Beyond the detailed Hab-Plot observations, characterisation of the water body perimeter is made through a complementary shoreline survey. 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. Shoreline 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 areas, roads, railways and paths, parks and gardens, camping and caravans, recreational beaches, educational recreation, litter / dump / landfill, quarrying or mining, coniferous plantations, evidence of recent logging, pasture, observed grazing, tilled land, orchards and erosion. Natural habitat types are also recorded, including reedbeds, wet woodland, bogs, fens / marshes, floating vegetation mats, broadleaf and mixed woodland and plantations, coniferous woodland, scrub and shrubs, moorland / heath, open water, rough grassland, tall herbs and rank vegetation, and rock / scree and dunes.

The percentage cover of each pressure and habitat type is estimated for each sector of shoreline in the bands previously described. This process is carried out for two perimeter bands: from 0 - 15 m and >15 - 50 m from the waterline. 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 calculated on the proportion of the lake that was surveyed. However the protocol stipulates that a minimum of 75 % of the shore must be included in the shoreline survey.

Lake site activities/pressures

Information on the presence, extent and intensity of 'in-lake' pressures acting on the whole lake area is recorded. Categories include: bridges, causeways, fish cages, navigation, dredging, dumping, macrophyte control, motorboat sporting activities, non-motor boat activities, angling from boat and shore, non-boat recreation / swimming, litter, nuisance species, fish stocking, wildfowling, military activities, power lines, liming, surface films, and odour.

Hydrology and sedimentology

Basic hydrological information is recorded for the lake where possible. The principal use of the water body (if apparent) 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 geometry and width of the outlet are 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. A series of measurements is taken, relating to:

- The condition of water surface to report any problems such as oil slicks, algal blooms, etc;
- Dissolved oxygen and temperature profiles - these are considered important because most European lakes deeper than 3-5 m display thermal stratification 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 method for determining 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, so their recording clearly depends on the method undertaken by the surveyor. More detailed procedures for the collection of Index Site measurements are provided in the LHS manual.

Rationale for survey design

As described above, 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 collecting useful data on lake and catchment metrics. The use of an OS map or 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; 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 at a system scale. 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. 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. The rationale for the numbers and spacing of the Hab-Plots in LHS was guided by extensive research undertaken for the US EPA's Environment Monitoring and Assessment Program (EMAP). 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. The evenly-spaced 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 2005 events

This section summarizes the main events organised in 2005 regarding the development of LHS. Two SNIFFER workshops were held at either end of the field season to communicate surveyors' experiences of the survey, and to guide protocol design through consensus-led decision-making. A series of training workshops was also held to familiarise UK agency staff with the survey.

2.2.1 Spring workshop

A SNIFFER workshop was held on 30/31 March 2005, prior to the field programmes commencing. The aims of the workshop were:

- To review the physical habitat requirements of lake biota;
- To examine how well these are recorded on the present LHS survey form; and
- To propose changes to the survey form accordingly.

As a response to workshop discussion, several changes to the LHS protocol were agreed upon (See Appendix 1 for minutes and key points for revision).

2.2.2 Training courses

In order to improve surveyor confidence in the protocol and develop familiarity with the form, three one-day training workshops were organised by the contractors at the start of the 2005 field programme. Workshops were held for SEPA and selected members of the Project Steering Group (Loch Leven, Fife), the Environment Agency (Chew Valley Lake, Somerset, and Windermere, Cumbria), and the EHS and EPA (Lough Earne, Republic of Ireland). The days were typically split into a classroom session, where the LHS protocol was discussed, and a field session, where agency staff carried out the full survey. All workshops were well received and proved valuable in providing a platform for discussion and consensus-led decision-making regarding some sections of the survey form.

2.2.3 December workshop

A second workshop was held in Edinburgh on 13/14 December 2005. The meeting was held under the aegis of CEN with a view to further develop the core principles that could contribute to the development of a CEN standard on assessing the hydromorphology of lakes. It provided the opportunity for UK environment and conservation agencies to review their summer 2005 field campaigns and to critique the survey form and sampling protocol. Discussion took place regarding the future applications of LHS (in addition to the WFD), and also concerning the development of a strategy to incorporate LHS into a CEN standard. Full minutes of the workshop are given in Appendix 2.

2.3 LHS form revisions

Several sections of the LHS protocol were revised during the 2005 field season. These changes reflected the experiences expressed by the contractors at the close of the 2004 field season (SNIFFER Report WFD40a), and through feedback from the March workshop. Some sections of the form were revised further following the training sessions with the UK agencies in summer 2005. All amendments made to the survey form are summarised in Table 2.1. Several changes were made to the LHS manual to complement form amendments and also to clarify some points regarding protocol methodology and the definitions of features and pressures. The latest version of the manual and field form (Version 3.1 May 2006) is available from the SNIFFER website http://www.sniffer.org.uk .

Table 2.1 Protocol amendments implemented during 2005

Section	Amendment
General surveying and recording instructions	Some changes to filling boxes (e.g. using “0” instead of “NO” in some cases);
	Nomenclature for cover classes *(None*, *Sparse*, *Moderate*, *Heavy* and *Very Heavy)* removed;
	Additional cover class (“✓”) added for recording presence (< 1 %) of features;
	Consistently use land-cover, substrate and other categories as for RHS;
	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 *(subject to copyright conditions)* to use for annotation rather than a sketch.
2. Physical Attributes	GPS location instructions revised (Eastings precede Northings);
	Additional space to record full 12-digit alphanumeric NGR.
2.1 Riparian Zone	“Pine needles or leaf litter” field removed;
	“Barren” changed to “Bare ground”;
	“Dominant banktop vegetation type” field removed;
	Option of indicating reedbed as dominant land cover added.
2.2 Shore zone	Estimate bank height to nearest metre (rather than categorical);
	Additional information on beach substrate requested - cover for beach components (bedrock, boulders (> 256 mm), cobbles (> 64 mm - 256 mm), pebbles (> 2 - 64 mm), sand (≥ 0.063 - 2 mm) and silt/clay (< 0.063 mm);
	Definition of “beach” made clearer;
	Boulder aprons consistently recorded effectively as “bank face”;
	Information on beach vegetation cover and structure added.
2.3 Littoral zone	Entire section moved from 2.4 to 2.3;
	For sedimentation over natural substrate, sediment type now specified;
	Sediment “colour” and “odour” fields removed;
	“Submerged short, stiff leaved” and “Phytobenthos” cover added;
	“Amphibious” cover category removed;
	% total macrophyte cover changed to Percent Volume Inhabited (PVI) using standard areal cover classes;
	“Total cover for fish” and “Inundated live trees” removed.
2.4 Human pressures	Entire section moved from 2.3 to 2.4;

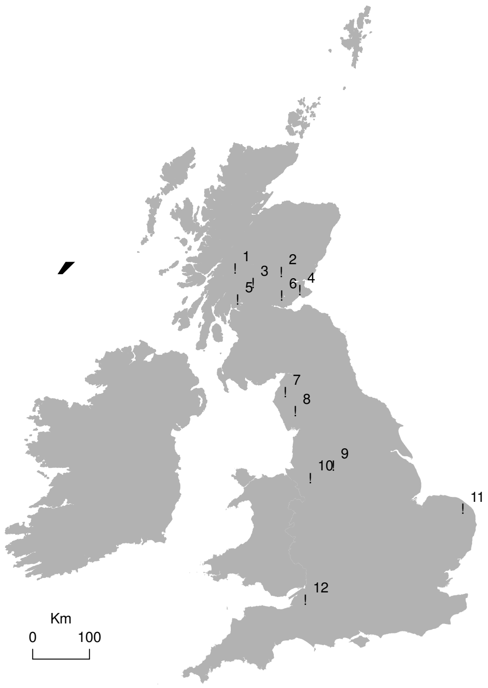
	(continued) Several new pressures to be recorded: “Unsealed tracks and footpaths”, “Educational recreation”, “Other grazed land”, and “Camping and caravans”; Some pressures re-named to remove ambiguity (“Row crops” now “Tilled land”, “Riparian weed control” now “Riparian vegetation control”, “Macrophyte cutting” now “Aquatic macrophyte cutting”).
3.1 Lake Perimeter Characteristics	Section renamed from “Shoreline Pressures”, and includes information on pressures and natural land-cover types within 15m of the shore and between 15 and 50 m of the shore; Instruction to quantify total shoreline pressures removed; “Hard engineering” now classified according to material, with “Closed-type” encompassing any sealed material (e.g. sheet piling, concrete etc.) and “Open-type” any unsealed material (rip-rap, gabion baskets etc.); “Footpaths” added to “Roads and railways” Several natural land-cover types added; “Observed grazing” used instead of “Intensive grazing”.
3.2 Lake site activities / pressures	Lake action/pressure entries amended to record extent and intensity of activities; “Fish farming” changed to “Fish cages”; New fields: “Bridges”, “Causeways”, “Dumping”, “Non-boat recreation/swimming”, “Fish stocking” and “Wildfowling”; “Angling” now divided into “Angling from boat” and “Angling from shore”.
3.3 Landform features	Section 4.2 (sedimentology) now Section 3.3, and categories reworded to remove ambiguity;
3.4 Outlet geometry	Form and width of outlet recorded; Animals no longer recorded in this section, and should instead be noted in Section 6 (‘Further comments’) if they are believed to have an influence on lake morphology or may indicate morphological conditions.
4. Hydrology	Circling of more than one lake use allowed; Date of raising / lowering can now be recorded; Additional category of vertical range of water fluctuation (0.5 - 2 m); Can specify whether control structures are at the inflow or outflow.
5. Lake Profile Information	Alkalinity or pH no longer recorded; Sediment grab sample now taken at Index Site.

3 2005 EXPERIMENTAL PROGRAMME

3.1 Site selection

Testing of the LHS method was carried out by the contractors on 10 water bodies of varying character across Great Britain (Figure 3.1). Summary characteristics for each of the sites are given in Table 3.1. Sites were selected to represent the ranges of physical and geological variation within British lakes, and draws from typological definitions defined by United Kingdom Technical Advisory Group (UK TAG, 2004). The sites also varied with respect to the perceived naturalness of the system (in terms of hydrological and morphological alteration and catchment development pressures) to ensure that the survey can be applied across the continuum of water bodies in the UK. Limited testing was also carried out on the three sites selected for training purposes (Chew Valley Lake, Loch Leven and Windermere), locations and details of which are included in Figure 3.1 and Table 3.1.

Figure 3.1 Locations of lakes involved in 2005 field trials and training



KEY:

1. Loch Bà
2. Loch of Drumellie
3. Loch Earn
4. Cameron Reservoir
5. Loch Lomond
6. Loch Leven
7. Bassenthwaite
8. Windermere
9. Torside Reservoir
10. Budworth Mere
11. Barton Broad
12. Chew Valley Lake

The 2005 test lakes extended the range of geological lake types sampled in 2004 ('HA', 'P' and 'Marl'). Brackish lakes remained unsampled, but this in part reflects their relative rarity in the UK. Surveyed lakes also displayed a variety of morphometric characteristics reflecting different modes of formation, from ice-scoured rock basins (Bassenthwaite Lake) to blanket bog depressions (Loch Bà) and kettle-hole basins (Loch of Drumellie).

Sampling water bodies of varying basin origin ensured that there were a range of lake sizes, and surface areas ranged from 0.4 km^2 (Budworth Mere) to 70.7 km^2 (Loch Lomond), and maximum depths from 3.0 m (Cameron Reservoir) to 189 m (Loch Lomond). As well as considering lakes of varying natural morphologic character, basins with modified physical structure (Cameron Reservoir, Barton Broad, Torside Reservoir) were also surveyed. Lakes also varied according to the extent and intensity of shoreline pressures, from a 'candidate' reference condition Scottish Highland loch (Loch Bà, Figure 3.2) to lakes with higher degrees of development (Loch Lomond, Barton Broad), where multiple uses and local management strategies reflect higher densities of lake users.

Figure 3.2 Typical view of Loch Bà, Scottish Highlands

Loch Bà, Rannoch Moor. Note evidence of grazing of heather-moorland vegetation in foreground and distance, contrasting with semi-natural mixed woodland on island and coniferous plantation behind.

Table 3.1 Summary characteristics of water bodies involved in 2005 field trials and training

Lake Name	Location	Origin (mode of formation)	UK TAG 'Lake Type'	Surface area (km^2)	Max depth (m)	Shoreline development	Index site completed	No. of Hab-Plots surveyed	
								By boat	On foot
Budworth Mere	Cheshire, England	Glacial moraine-dammed*	HA, Sh, Low, S	0.39	4.0	1.3	✓	10	0
Cameron Reservoir	Fife, Scotland	Impounded watercourse	Marl, Sh, Low, S	0.43	3.0	1.5	✓	10	10
Torside Reservoir	Derbyshire, England	Impounded watercourse	LA, Sh, Mid, L	0.55	11.7	2.1	✓	10	0
Barton Broad	Norfolk, England	Flooded peat excavation	HA, VSh, Low, L	0.58	2.3	3.2	✓	18	0
Loch of Drumellie	Angus, Scotland	Kettle-hole basin	Marl, Sh, Low, L	0.70	17.7	1.3	✓	10	14
Loch Bà	Highland, Scotland	Depression in blanket bog	P, VSh, Mid, L	2.49	9.1	4.6	x	13	0
Chew Valley Lake	Avon, England	Impounded watercourse	HA, Sh, Low, L	4.65	27.4	1.9	-	-	-
Bassenthwaite Lake	Cumbria, England	Ice-scored rock basin	LA, Sh, Low, L	5.24	19.0	2.2	✓	10	0
Loch Earn	Stirling, Scotland	Ice-scored rock basin	MA, D, Low, L	9.47	87.5	2.1	✓	15	0
Windermere	Cumbria, England	Ice-scored rock basin	LA, D, Low, L	14.36	64.0	3.9	-	-	-
Loch Lomond (north)	Argyll, Scotland	Ice-scored rock basin	LA, D, Low, L	70.73	189.9	4.6	✓	21	0
Loch Lomond (south)	Argyll, Scotland	Ice-scored rock basin	LA, D, Low, L		64.9		✓	17	0

* - or natural salt subsidence

Key:
Geology: LA = > 90 % Siliceous catchment geology; MA = > 50 % Siliceous; HA = > 50 % Calcareous; Marl = > 65 % Limestone
Mean Depth (Dmv): VSh: Very shallow (Dmv <=3 m); Sh = Shallow (Dmv 3 – 15 m) and D = Deep (Dmv > 15 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 ha)

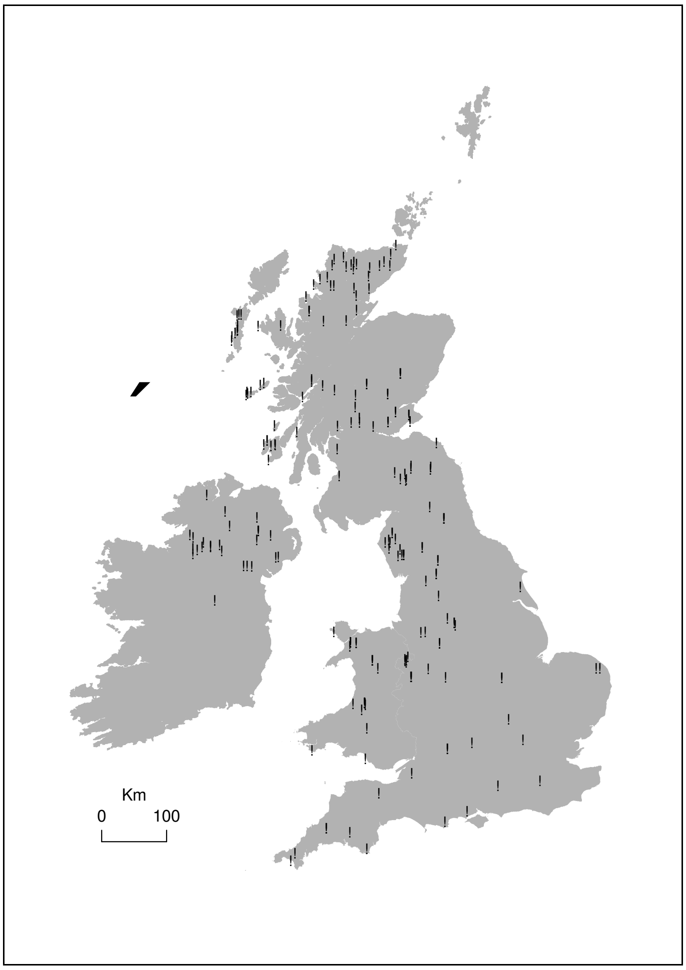
LHS surveys were also carried out by survey teams from environmental agency field teams on lakes that were visited as part of on-going WFD-related biological sampling (SEPA, EA, EHS) and/or for Site Condition Monitoring surveys on lakes with designation status. Additional biological data (macrophyte, diatom and invertebrate surveys) were recorded by EHS (Northern Ireland) at the same time and locations as LHS components. The selection rationales varied between agencies, but were generally chosen to complement existing biological survey schemes. For example, SEPA (49 and 7 Scottish lochs surveyed in 2004 and 2005 respectively) focused primarily on biological sampling on Scottish sites expected to be at 'reference condition'. Table 3.2 summarises the total numbers of surveyed sites, and the number of sites entered into the LHS database at the time of writing (including repeat visits and multiple basins). Of 345 completed surveys, 200 were entered into the database (locations of which are illustrated in Figure 3.3). The remaining surveys were not processed because surveys were returned to the contractors incomplete. Of the surveys entered into the database, over a third (73) contained 10 or more Hab-Plot records (the majority are entries of 4-plot LHS_{core} surveys), with 1497 Hab-Plot records in total.

Table 3.2 Summary of water bodies for which LHS sites have been visited (including repeat visits)

Surveyors' organisation	Region	Number of completed surveys		Number of sites in database		Other data collected
		2004	2005	4-plots	10+ plots	
Environment Agency (EA) of England and Wales	England and Wales	108	23	53	23	Macrophytes, invertebrates
Scottish Natural Heritage (SNH)[1]	Scotland	94	0	9	0	SCM data, macrophytes
Scottish Environment Protection Agency (SEPA)	Scotland	49	5	49	4	Macrophyte, invertebrate, diatom & chemistry data
Environment and Heritage Service (EHS) of Northern Ireland	N. Ireland	7	15	7	15	Macrophyte, invertebrate, diatom & chemistry data
Trinity College Dublin	Republic of Ireland	0	9	0	9	Macrophyte, invertebrate, diatom & chemistry data
Contractors	Scotland, England, Wales	19	14	9	22	N/A
Totals		**277**	**68**	**127**	**73**	
		345		**200**		

[1] Surveys undertaken by the Centre for Ecology & Hydrology

Figure 3.3 Geographical distribution of all 207 surveyed sites



3.2 Index Site data

Index Site measurements are considered an important element in physical habitat characterisation (Kauffman and Whittier, 1997), providing insight into the general structure and functioning of the water body as a whole. Index site measurements were taken in all but one test site (summary data are given in Table 3.3). Loch Bà was surveyed using a shore-based method because it was deemed inaccessible by boat and thus the Index Site could not be sampled. More generally, the Index Site is taken to be the deepest point of the lake, located using a brief sonar survey and bathymetric maps. Measurements were taken relating to:

- The condition of the water surface (presence of slicks, films, algal blooms, etc.)
- Dissolved oxygen and temperature profiles (characterising the pelagic habitat and degree of water column heterogeneity)
- Secchi disc depth (water transparency - affected by colour, algae, and suspended sediment concentrations - as proxies for human impact and productivity)

The set of observations recorded at the Index Site can be used simply as a discrete physico-chemical profile, but also, importantly, to set the context for other LHS observations. The varying degree of mixing within the Index Site water columns is evident from the dissolved oxygen and temperature profiles for selected sites (Figure

3.5), particularly the variable presence and depth of a thermocline. The isothermal profile for the mid-altitude Torside Reservoir attests to its exposed elevated position, the alignment of the valley axis to the prevailing south-westerly winds and artificial mixing/oxgenation by the reservoir operators. Bassenthwaite Lake exhibits limited stratification most probably because of its morphometry, where its low V_d (volume development ratio) indicates that it has a large surface area with extensive areas of relatively shallow water which promotes mixing (cf. SNIFFER Report WFD49a). Deep, steep-sided trough systems such as Lochs Lomond and Earn exhibit well-developed thermoclines, indicating vigorous wind-induced mixing to considerable depths (10 -15 m). By contrast, the Loch of Drumellie displayed a shallow weakly developed thermocline, compatible with the woodland-sheltered, lowland location of the water body.

A range of DO profiles was also obtained from the survey sites (Figure 3.5). Both Bassenthwaite Lake and the Loch of Drumellie display a deficit in dissolved oxygen in the hypolimnion (DO levels of ≤ 4 mg L^{-1}), with the latter in particular having very low DO levels, reaching 0.1 mg L^{-1} at 16 m depth. Both these systems experience very high natural loadings of organic matter. In the case of the low alkalinity Bassenthwaite Lake this is party explained by the exceptionally high catchment area/basin area ratio (ADA/A) and the extensive tree cover within the riparian zone. In the case of the Loch of Drumellie (Figure 3.4), high leaf-litter input from surrounding trees, and concerns over eutrophication pressures boosting autochonous production, may explain the exceptionally low levels of DO as the lake bed is approached. Cultural eutrophication, principally from sewerage is also a significant concern in Bassenthwaite Lake (Winfield *pers com.*).

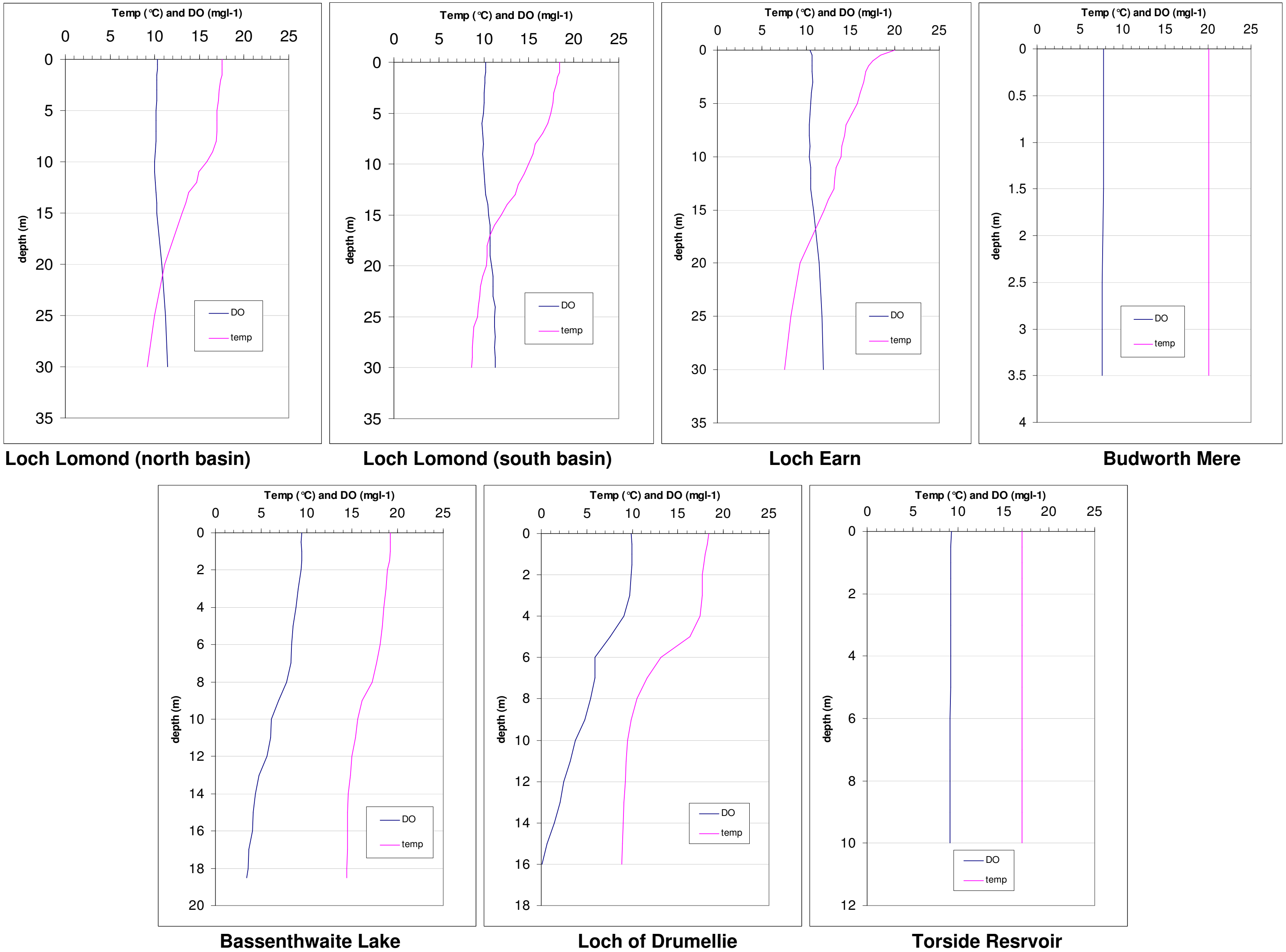
Figure 3.4 General illustration of extensive deciduous woodland within the riparian zone of the Loch of Drumellie, providing high organic matter loading to both littoral and profundal habitats

Table 3.3 Summary results from Index sites surveyed by the contractors in 2005

Lake	Date of survey	Maximum depth observed (m)	Secchi depth (m)	Thermal stratification (Yes/No)	Temperature range (^{O}C)	Hypolimnion dissolved oxygen deficit (< 4 mg L^{-1})	Dissolved oxygen range (mg L^{-1})
Barton Broad	22/07/05	2.3	0.5	No	18.4 – 18.4	No	10.4 – 10.1
Bassenthwaite Lake	01/07/05	19.5	2.9	Yes	19.2 – 14.4	Yes	9.5 – 3.4
Budworth Mere	19/07/05	4	0.6	No	20.1 – 20.1	No	7.8 – 7.6
Cameron Reservoir	07/08/05	3	2.6	No	17.7 – 17.7	No	10.7 – 10.7
Loch of Drumellie	07/07/05	18	3.9	Yes	18.4 – 8.8	Yes	9.9 – 0.1
Loch Earn	11/07/05	83	3.9	Yes	20 – 7.6	No	10.5 – 11.9
Loch Lomond (north)[1]	27/07/05	168	3.5	Yes	17.5 – 9.2	No	10.3 – 11.4
Loch Lomond (south)[1]	28/07/05	64.9	3.2	Yes	18.4 – 8.6	No	10.2 – 11.2
Torside Reservoir	20-07/05	11.6	1.3	No	17 – 17	No	9.3 – 9.1

Note 1 Loch Lomond is sub-divided into two basins in accordance with WFD convention of distinguishing sub-basins on the basis of morphology, in this case essentially distinguishing the glacial trough of the northern basin with the wider and shallower southern basin. Water body boundaries are consistent with those employed by SEPA.

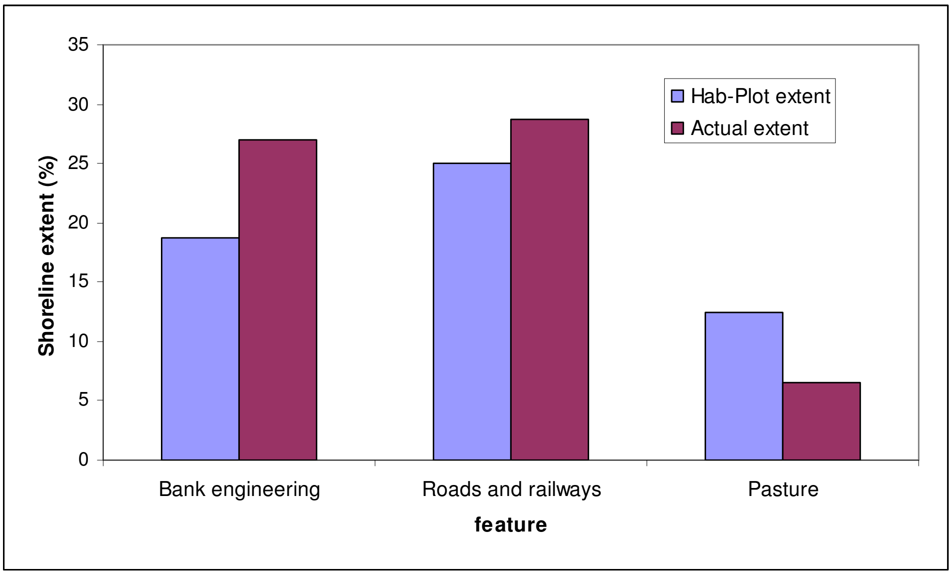
Figure 3.5 Temperature and dissolved oxygen profiles for selected test sites



3.3 Hab-Plots and shoreline surveys

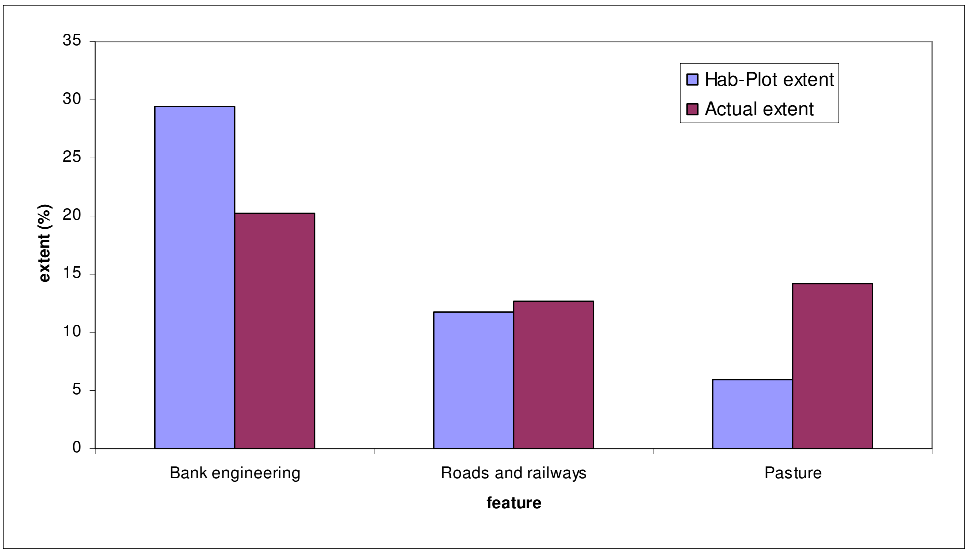
In order to test the effectiveness of Hab-Plots, plot-derived shoreline feature extents were compared with the results directly measured in the field. Using Hab-plots the extent of a given feature (% extent) is obtained from the frequency of its occurrence in a given number of Hab-Plots visited. For example, if a given feature was observed at only one Hab-Plot out of 10, then based on binomial probability theory it can be inferred that such features are likely to have an extent of between 10 - 20 %, providing Hab-Plots are positioned systematically around the perimeter (with an initial random position to minimise bias). The 'definitive' shoreline extent of a feature is calculated from detailed shoreline survey observations. In the case of Loch Lomond, the shoreline surveys were carried out by annotating maps whilst navigating between Hab-Plots. Figures 3.6 and 3.7 compare plot-derived feature extents with definitive extents for three selected features in both of Loch Lomond's sub-basins. These features were selected because they appear in both the Hab-Plot and Shoreline Sections of the LHS form.

Figure 3.6 Comparison of plot-derived and survey-derived feature extents for Loch Lomond (north basin)



The results of the analysis were mixed. In Loch Lomond's north basin, the plot-derived extent of 'roads and railways' correlated well (to within 4 %) with the actual extent, but the other two selected features, 'bank engineering' and 'pasture', featured slightly greater differences of c. 6 %. Analysis of the two methods for Loch Lomond south basin (Figure 3.7) produced similar results, with the estimate for the extent of 'roads and railways' closely matching the true extent. There was no consistency in how estimated values varied with actual values between north and south basins. The disparity between estimated shoreline extent and actual shoreline extents may in part be explained by how the features are arranged spatially along the shoreline. Roads and railways are generally more continuous than pockets of bank engineering or pasture fields (and certainly in the case of Loch Lomond), so it is less likely for a feature such as this to be 'missed' by Hab-Plot observations. Conversely, fields of pasture, and bank engineering in particular, are patchier along the shores of Loch Lomond, meaning that the chance location of Hab-Plots on such features can result in the overestimation of feature extent. However, as long as the features of interest have an aggregated perimeter length exceeding 10 % then all such features have an equal likelihood of being sampled.

Figure 3.7 Comparison of plot-derived and survey-derived feature extents for Loch Lomond (south basin)



It may be assumed that increasing Hab-Plot sampling density will increase the accuracy of Hab-Plot-derived estimates by reducing the chance that relatively small patches of features will be overlooked. Still, given the relatively low sampling density used in Loch Lomond (ca. 1 plot every 4,200 m), shoreline extents for these few features were estimated with an acceptable degree of accuracy (both 'bank engineering' and 'pasture' extent' were estimated to within the same percentage cover class, and never differed by more than 9 % for any feature in both sub-basins).

3.4 Shoreline and riparian pressures and land cover

Summary data for shoreline pressures recorded at each test site are presented in Table 3.4. Loch Earn and Loch Lomond south basin are recorded as having the largest number (calculated as the sum of 0 - 15 and >15 - 50 m perimeter bands) of different pressures (15 each), followed by Loch Lomond north basin (14 pressures) and Bassenthwaite Lake (13 pressures). Barton Broad, Loch Bà, and the Loch of Drumellie had the fewest number of different pressures, with three, four and six recorded respectively. There were relatively few cases where pressures extended into the landward >15 – 50 m band perimeter band. Furthermore, in only one case (one pressure type at one test site) does the lakeward pressure extent exceed the landward extent by more than one category. This indicates that when shoreline pressures exist, they are more likely to extend to within 15 m of the water edge than to be detached by a more natural 'buffer zone' (or at least a zone where the given pressure has a lower areal extent). Table 3.5 summarises data for natural shoreline data for both 0 – 15 m and >15 – 50 m perimeter bands. Loch Lomond south basin is recorded as having the most diverse shoreline with respect to natural land cover types (eight different types), followed by Cameron Reservoir and Loch Earn (seven types each). However, Loch Lomond (south basin) and Cameron Reservoir are also characterised by a relatively low overall degree of natural cover (no land cover type exceeds 40%). Loch Earn, on the other hand, is dominated by broadleaf/mixed woodland in both perimeter bands (cover exceeding 75 % and 40 % for the 0 – 15 and >15 – 50 m bands respectively). At the other end of the scale, Budworth Mere is recorded as being the least diverse site (3 land-cover types) followed by Loch Bà and Loch Lomond north basin (4 types each).

Figure 3.8 Illustration from Loch Earn (Scotland) demonstrating marina and related residential activities being strongly tied to within the littoral and riparian zones, especially within ± 15 m of the water's edge.

Table 3.4 Summary data for shoreline pressures within 15 m and between >15 - 50 m for all lakes expressed as extent of total perimeter length

	Barton		**Bassent.**		**Budworth**		**Cameron**		**Bà**		**Lomond N**		**Lomond S**		**Torside**		**Earn**		**Drumellie**	
Pressure type	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**
Impoundments	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0
Hard (open) eng.	0	0	2	0	0	0	0	0	✓	0	2	0	1	0	✓	0	3	0	0	0
Hard (closed) eng.	0	0	✓	0	0	0	1	0	✓	0	2	0	1	0	4	0	1	0	0	0
Soft engineering	0	0	0	0	0	0	0	0	0	0	✓	0	0	0	0	0	0	0	0	0
Docks, marinas	1	✓	✓	0	✓	0	✓	0	0	0	1	0	2	1	✓	1	2	0	✓	0
Commercial	0	0	0	0	0	0	0	0	0	0	✓	✓	1	1	0	0	1	1	0	0
Residential	✓	✓	✓	✓	0	0	0	✓	0	0	✓	1	1	1	0	✓	1	2	✓	✓
Litter, dump	0	0	0	0	✓	0	0	0	0	✓	1	0	1	0	✓	0	✓	0	0	0
Quarry, mining	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Roads, rail	0	0	2	2	2	2	0	✓	0	✓	2	2	2	1	2	3	3	2	0	0
Parks, gardens	0	0	✓	✓	0	✓	✓	✓	0	0	✓	✓	1	1	0	0	1	1	0	✓
Camping & caravans	0	0	1	0	0	0	0	0	0	0	1	1	1	1	0	0	2	1	0	0
Recreational beach	0	0	1	0	0	0	0	0	0	0	2	0	1	1	0	0	2	0	✓	0
Coniferous. plantation	0	0	✓	✓	0	0	1	1	0	0	0	0	0	0	✓	2	✓	1	✓	0
Logging	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	✓	0	0
Pasture	0	0	2	2	2	2	0	1	0	0	1	1	2	2	1	2	1	1	0	0
Grazing	0	0	0	1	0	2	0	0	0	0	1	1	1	1	1	1	0	✓	0	0
Tilled land	0	0	0	1	1	2	0	1	0	0	0	0	0	✓	0	0	0	0	2	3
Educational recreation	0	0	0	0	✓	0	0	0	0	0	0	0	✓	0	0	0	0	0	0	0
Erosion	2	0	2	0	✓	0	2	0	0	0	1	0	1	0	1	0	1	0	0	0
Number of pressures	**3**		**13**		**9**		**10**		**4**		**14**		**15**		**11**		**15**		**6**	

Table 3.5 Summary data for natural land cover and meso-habitats within 15 m and between 15 - 50 m for all lakes expressed as extent of total shoreline length

	Barton		**Bassenth.**		**Budworth**		**Cameron**		**Bà**		**Lomond (North)**		**Lomond (South)**		**Torside**		**Earn**		**Drumellie**	
Natural land cover and meso-habitat type	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**	**0 - 15 m**	**>15 - 50 m**
Broadleaf / mixed woodland	1	2	3	3	3	2	✓	1	1	✓	2	2	2	3	1	2	4	3	3	2
Broadleaf / mixed plantation	0	0	0	0	0	0	0	0	0	0	0	0	✓	1	0	0	✓	✓	2	2
Coniferous woodland	0	0	0	0	0	0	0	0	0	0	0	0	✓	✓	0	0	✓	1	1	1
Moorland / heath	0	0	0	0	0	0	0	0	0	0	✓	✓	✓	✓	0	0	0	0	0	0
Open water	0	0	0	0	0	0	0	0	✓	✓	0	0	0	1	0	0	0	0	0	0
Scrub and shrubs	0	0	0	0	0	0	✓	✓	0	0	0	0	0	0	0	0	1	1	0	0
Rough grassland	0	0	✓	0	1	1	1	1	0	0	0	0	0	0	0	1	✓	1	0	0
Tall herb - rank vegetation	✓	0	0	0	0	0	1	1	0	0	1	1	0	0	2	1	0	0	0	0
Rock, scree or dunes	0	0	0	0	0	0	0	0	✓	✓	0	0	✓	✓	0	0	✓	0	0	0
Emergent reed-bed	3	2	2	0	2	✓	1	0	0	0	✓	0	0	0	0	0	0	0	2	0
Wet woodland / carr	3	4	2	0	0	0	1	0	0	0	0	0	0	0	✓	0	✓	✓	✓	✓
Bog	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0
Fen / Marsh	0	0	1	1	0	0	✓	0	0	0	0	0	0	0	✓	0	0	0	0	0
Floating vegetation mat	✓	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other wetland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Extent of predominant cover	**3**	**4**	**3**	**3**	**3**	**2**	**1**	**1**	**4**	**4**	**2**	**2**	**2**	**3**	**2**	**2**	**4**	**3**	**3**	**2**
Diversity of land-cover types	**5**		**5**		**3**		**7**		**4**		**4**		**6**		**5**		**7**		**5**	

3.5 Practical difficulties and developments in survey practice

Throughout the 2005 field testing programme, it was evident that data retrieval could be subject to a range of logistical issues. For example, it was not possible survey an Index Site on Loch Bà because the water level was too low to allow the launch and safe operation of a boat. However, the relatively low water level was not apparent until most of the survey had been completed. Other access problems were encountered on Cameron Reservoir, where submerged macrophyte communities were exceptionally dense throughout the whole basin area, making movement difficult. Since the use of petrol outboard engines was restricted at the site, navigation around the water body was time-consuming. The potential issue of resource limitation was experienced at Loch Lomond, where the large, exposed nature of the site meant that a larger and more robust vessel then usual was required to safely and speedily traverse between Hab-Plots. These practical difficulties underlined the necessity for surveyors to be pragmatic, both when confronted with adverse weather conditions and when other logistical issues arise.

3.6 Analysis of the Hab-Plot strategy

Previous testing of the change in data return brought about by increasing the number of Hab-Plots showed that relatively little extra information (with respect to the total number of observed features) is gained beyond 10 plots (SNIFFER Report WFD40a, 2004). It was also illustrated that the number of observed component features (vegetation types, land cover types, etc.) increased at rates consistent with the homogeneity of the site, with relatively simple water bodies (containing only a few different types of each feature) generally requiring fewer Hab-Plots than more complex sites (with many different types of each feature).

An important component of Phase 2 analysis was to explore further the suitability of a 10-plot standard survey for lakes of increased size and complexity. It was also suggested during LHS Phase 1 that testing of the relative merits of stratified sampling (either on the basis of habitat/land-cover composition or by morphological classification of shoreline units) could take place, with a view to acquiring a representative set of observations from a limited number of Hab-Plots.

3.6.1 Number of Hab-Plots

During Phase 1 of LHS development, the data obtained from an abridged version of the LHS (termed LHS_{core}) with four Hab-Plots were compared with those from the full version (10 plots). The average number of features observed from a given number of Hab-Plots was found to be influenced by the size and complexity of the lake, with larger and more complex sites exhibiting a more diverse set of features. However, it was stressed that in substantive terms, e.g. for WFD classification purposes, that relatively little information is gained if more than 10 Hab-Plots are sampled, and in doing so not only increases the time taken to carry out the survey, but also introduces undesirable redundancy in the data collected. Moreover, since the survey also includes observations of the shoreline at a larger scale, it was suggested that a standard Hab-Plot number used at all sites should always be complemented by a comprehensive perimeter survey.

(a) Cameron Reservoir, Fife, Scotland.

(b) Torside Reservoir, Derbyshire, England.

Figure 3.9 Illustration of sampling difficulties encountered in the 2005 field season

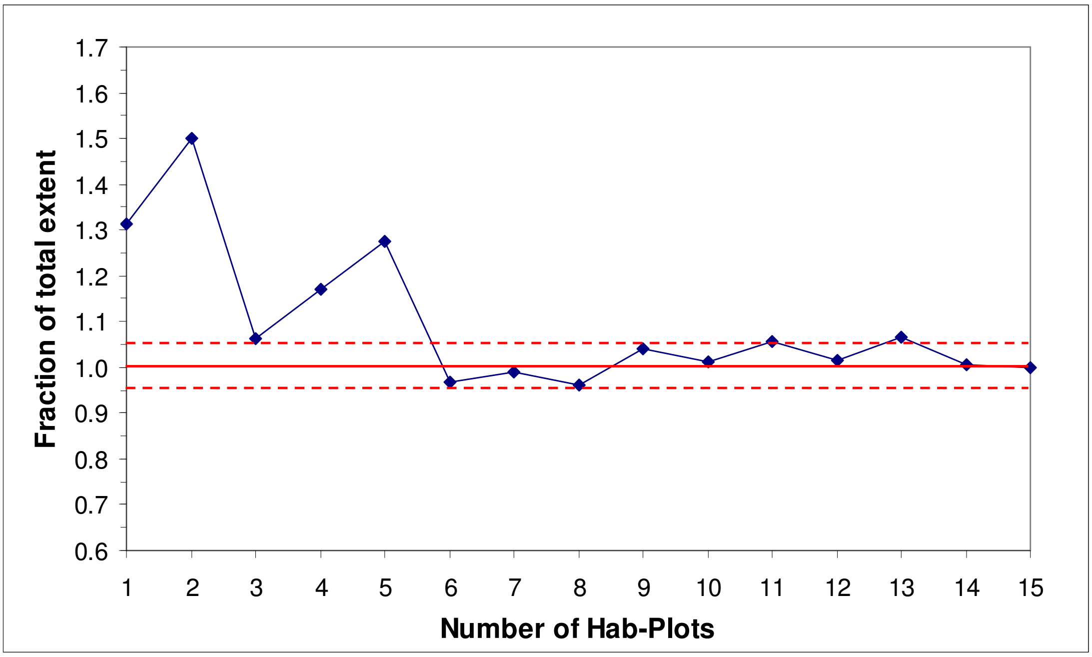
(a) Cameron Reservoir was effectively choked with macrophytes making boat propulsion extremely difficult. (b) Significant water level draw down in Torside Reservoir, presented difficulties in viewing riparian vegetation at Hab-Plots and major differences between remote sensing imagery and field data.

The Phase 1 trials of LHS were carried out on 10 lakes of varying size, with surface areas ranging from 0.28 to 13.70 km^2. However, by European standards, these sites are relatively small, with some lakes on the European mainland encompassing several hundred square kilometres. For this reason, it was decided that for the Phase 2 trials the largest UK lakes should be included. The contractors surveyed Loch Lomond (ca. 70 km^2) collecting data from 38 Hab-Plots, and Lough Neagh (ca. 380 km^2) was sampled by EHS field teams (30 Hab-Plots). It should be noted that for WFD purposes each of these lakes comprise two and three sub-basins (distinct water bodies) respectively. Additional Hab-Plots were also surveyed for other systems, such as Cameron Reservoir, Loch Earn, and Barton Broad.

From all of the sites surveyed by the contractors a series of trials was made on the Hab-Plot arrays by drawing random subsets of Hab-Plots, generated from surveys carried out on Loch Lomond and Loch Earn for the degree of bank modification. Loch Lomond and Loch Earn were selected for their shoreline structural diversity featuring steep cliffs and drop-offs, re-profiled and reinforced sections, and extensive sand-silt deltas. Ten iterations of randomly drawn Hab-Plot sets, increasing in size to the maximum number, were run and mean estimate of feature extent determined for each.

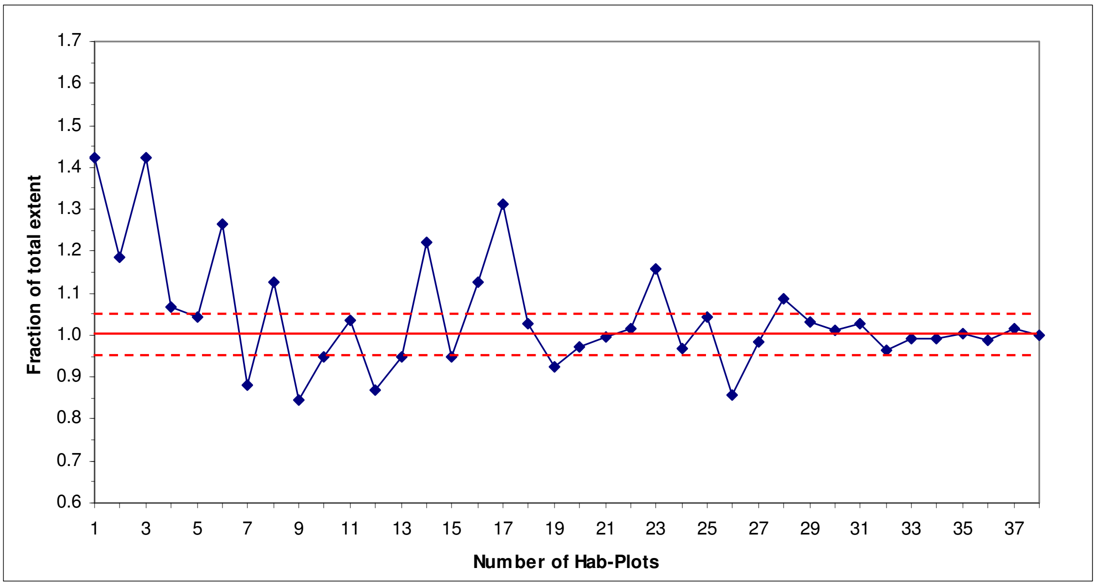
The effect of Hab-Plot number on the estimate of bank modification extent on Loch Earn, Loch Lomond, Loch Leven, and Torside Reservoir is shown in Figures 3.10 3.13. For Loch Earn (Figure 3.10) the estimated extent of bank modification was within 5 % of the true value within approximately six Hab-Plots. This value was varied for the other three lakes analysed, with Loch Lomond (3.11) requiring around 30 plots, Loch Leven 14 plots (Figure 3.12), and Torside Reservoir four plots (Figure 3.13) to reach a comparable accuracy.

Figure 3.10 The extent of bank modifications on Loch Earn estimated on the basis of an increasing number of Hab-Plots



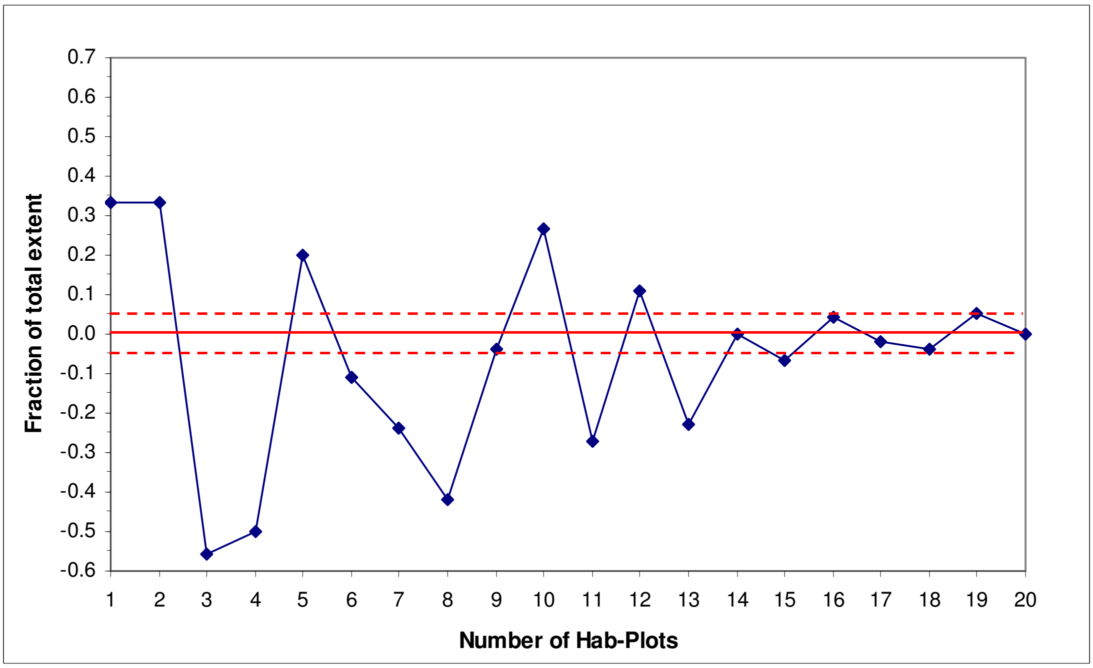
Note: Solid horizontal line represents the estimated extent based on all Hab-Plot observations; dashed lines represents 5 % error.

Figure 3.11 The extent of bank modifications on Loch Lomond estimated on the basis of an increasing number of Hab-Plots



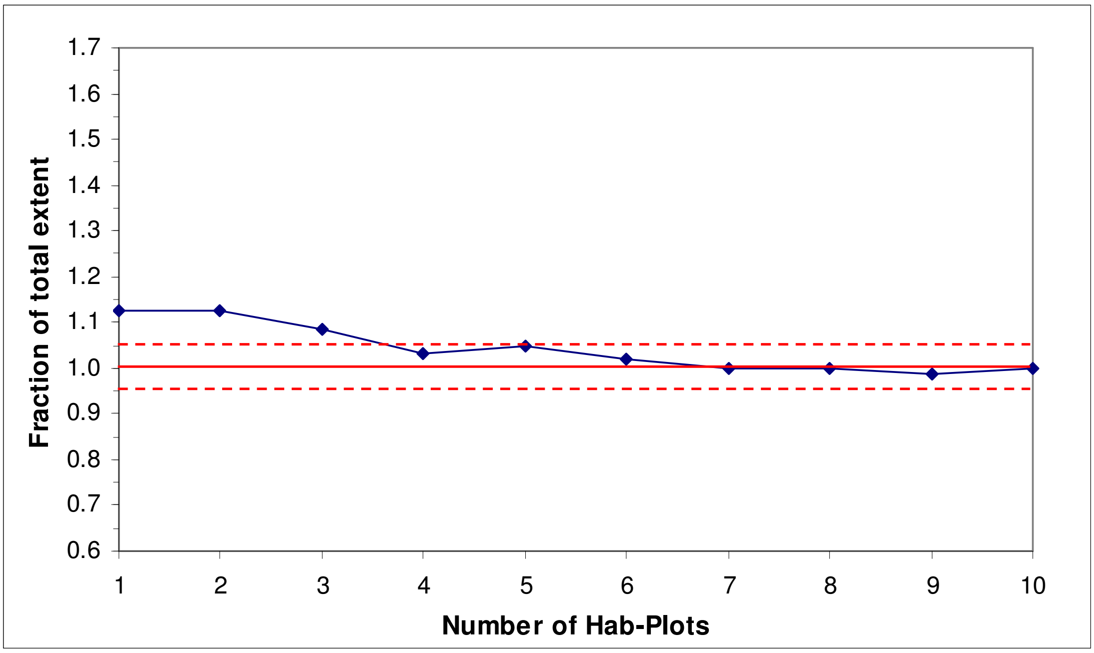
Note: Solid horizontal line represents the estimated extent based on all Hab-Plot observations; Dashed lines represents 5 % error.

Figure 3.12 The extent of bank modifications on Loch Leven estimated on the basis of an increasing number of Hab-Plots



Note: Solid horizontal line represents the estimated extent based on all Hab-Plot observations; Dashed lines represents 5 % error.

Figure 3.13 The extent of bank modifications on Torside Reservoir estimated on the basis of an increasing number of Hab-Plots



Summary data (given in Table 3.6) indicate that when employing only Hab-Plots different amounts of effort are needed to capture the true extent of features (such as bank engineering). The effects both of sampling density (reflecting basin size and perimeter length) and the extent of shorezone features are reflected in the effort needed. Lochs Earn and Leven have similar perimeter lengths, but the limited extent of bank modification in the latter requires more plots to produce a robust estimate. Torside Reservoir, with around 80 % bank modification requires the least number of plots to obtain a representative Hab-Plot estimate.

Table 3.6 Summary data for estimating the extent of bank modification in selected lake/reservoir systems on the basis of varying Hab-Plot numbers

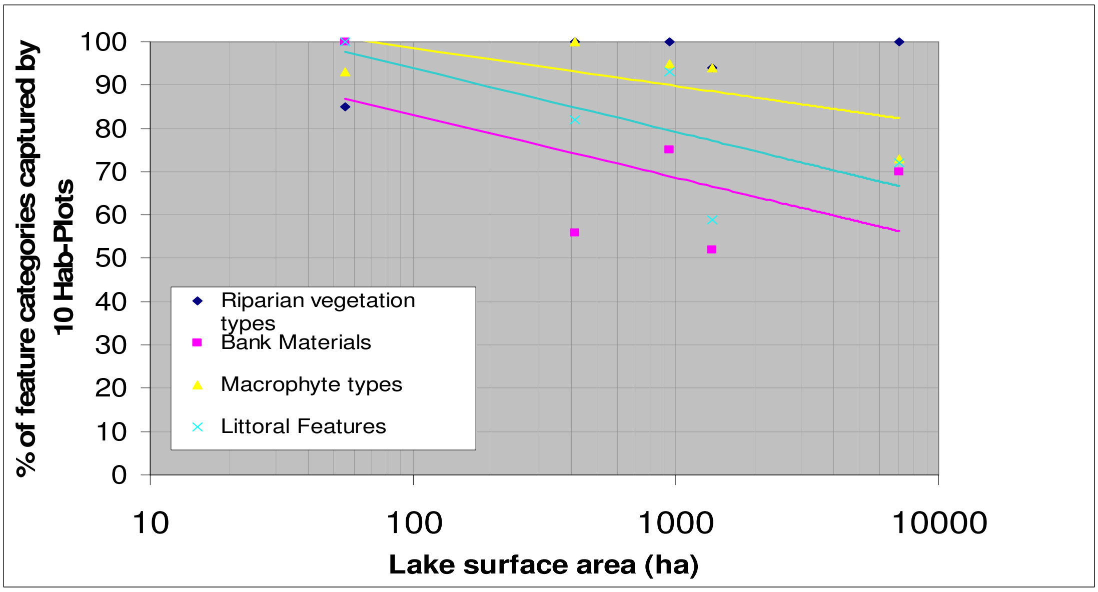
Site	Perimeter length (m)	Approx. sampling density	Degree of bank modification (%)[1]	Plots required[2]
Loch Lomond	138,860	1 in 4,200 m	21	≈ 30
Loch Leven	22,970	1 in 1,150 m	15	14
Loch Earn	22,720	1 in 1,500 m	53	6
Torside Reservoir	5,410	1 in 540 m	80	4

[1] – 'Degree of bank modification' corresponds to the true extent (based on all Hab-Plot observations at the particular site, and confirmed by perimeter survey observations)

[2] - 'Plots required' corresponds to the minimum number of Hab-Plots that can be used as a basis for accurately (within 5 %) estimating the degree of bank modification

Figure 3.14 provides another illustration of the relationship between Hab-Plot number and system size and complexity (where complexity can be represented by large numbers of shore zone features of limited spatial extent), and confirms that the accuracy of features will be determined both by sampling density and their actual extent. Increasing the sampling density (number of Hab-Plots per unit length) should increase the accuracy of feature quantification, but the implications of this result are important in relation to the development of a standard method, where consistency of application and the need to minimise data redundancy are deemed essential.

Figure 3.14 Relationship between lake surface area and the degree of features captured by 10 Hab-Plots



As illustrated in Table 3.6 and Figure 3.14, smaller systems, which are dominant in the UK in general can be satisfactorily characterised using a standard number of 10 evenly spaced (but randomly located) Hab-Plots. A review of the size distribution of UK lakes (SNIFFER Report WFD49a, 2005) indicates that 10 Hab-Plots are probably adequate for characterisation purposes in the majority of the lakes. Thus it can be concluded that a hierarchical monitoring approach should be adopted in relation to LHS application, whereby the standard protocol of 10 Hab-Plots is applied for surveillance monitoring applications. A more site-specific investigative approach, employing additional Hab-Plots, should then be adopted only where there are local conservation interests, or where there are significant hydromorphological problems to be addressed. Similarly, exceptionally large sites may warrant consideration of the requirement for additional samples.

3.6.2 Location of Hab-Plots

Further analysis was undertaken to ascertain the effect of Hab-Plot sampling strategy (positioning) in order to characterise the distribution and extent of shore zone features. Stratifying the sampling effort according to *a priori* defined basin features for land-cover type or morphological characteristics (e.g. headlands, bays and deltas) is another issue that requires some reflection. In practice, a standard number of Hab-Plots could be located in accordance with the proportion of each stratum relative to the entire perimeter length. Stratified sampling is generally used when the population in question is heterogeneous, but where certain homogeneous sub-populations (strata) can be isolated. The advantage is that sampling time and effort can be reduced by sampling each stratum to a degree that is representative with the extent of that stratum.

Analysis was carried out using the data from 38 Hab-Plots on Loch Lomond. The plots were located according to the standard sampling protocol (evenly-spaced and randomly-distributed), and then classified according to two different schemes (land-cover type, and shoreline morphology). Selected Hab-Plot components were then compared within-strata and between-strata for each classification scheme.

For land cover stratification, Hab-Plots were classified into one of three strata ('forestry', 'pasture' and 'urban') by associating plot locations with Digimap images. Within- and between-strata comparisons of Hab-Plot observations for selected LHS components are given in Table 3.7. The features selected for comparison were riparian vegetation cover for the riparian zone, beach substrate and vegetation cover for the shore zone component, and littoral substrate and macrophyte cover for the littoral zone component.

Table 3.7 Number of matching observations within each stratum for land-cover-stratified sampling

	Coefficients of Variance (%)				
Strata	**Riparian zone**	**Shore zone**	**Littoral zone**		**Littoral slope (°)**
			substrates	**macrophytes**	
Forestry (n = 21)	106	173	162	136	112
Pasture (10)	130	140	94	103	69
Urban (7)	148	156	130	215	82
All (38)	116	174	167	273	111

Within the forestry stratum, riparian zone data were relatively consistent with a CV (coefficient of variation) of 106 %. Shore zone and littoral zone substrate and macrophyte components matched less well, with CV values of 173, 162 and 136 % respectively. This is probably a reflection of the relative structural homogeneity of vegetation in those areas defined as 'forestry', and also indicates that the shore and littoral zone of these forestry strata are more heterogeneous. The littoral zone components of shore sections defined as 'pasture' are also relatively homogeneous (CV of 94 and 103 %), indicating that there may be some relationship between areas of pasture (and other grassland) and littoral substrate and vegetation composition. When compared with the total Hab-Plot sample (n = 38), stratification by land-cover did lead to reduced CV, but not significantly and the result confirms that little benefit can be gained by seeking to stratify Hab-Plot location by land-cover.

With regard to shoreline morphology, similar analysis was carried out by stratifying the data according to landforms (but excluding samples obtained on islands). Four shoreline morphology strata ('bay', 'delta / inlet', 'headland' and 'straight shore') were established by associating plot locations with Digimap images. Within- and between-strata comparisons of Hab-Plot observations for selected LHS components are given in Table 3.8.

Table 3.8 Number of matching observations within each stratum for shoreline morphology-stratified sampling

	Coefficients of Variance (%)				
Strata	**Riparian zone**	**Shore zone**	**Littoral zone**		**Littoral slope (°)**
			substrates	**macrophytes**	
Bay (n = 10)	81	149	82	180	87
Delta / inlet (3)	98	80	75	74	86
Headland (4)	82	126	91	34	79
Straight-shore (16)	121	174	145	86	99
All (33)	119	175	147	258	106

Comparing strata variance with within-strata variance, homogeneity generally increased upon stratification by bay, delta, or headland, but the difference was less clear for straight-shore sections. The most significant differences in homogeneity upon stratification were with shore zone substrates in deltas (CV = 80 % from 175 %), littoral zone substrates in deltas (75 % from 147 %) and littoral zone macrophytes in headlands (34 % from 258 %). The increased homogeneity of shore and littoral zone substrates reflects the energetic regime (influenced by fetch and exposure) and the local geomorphological conditions. For example, the predominant shore and littoral substrates of deltas or bays can be expected to be fine grained and well sorted, reflecting the stable, low energy conditions provided by the surrounding shoreline morphology. In contrast, the substrates found in sections of straight shore are likely to be more heterogeneous because of the higher energies involved, and of the local influences of effective fetch and exposure.

Again, although stratification generally increased the similarity between Hab-Plot components, the degree by which homogeneity increased differed between LHS components, and not to any significant degree. This indicates again that the natural heterogeneity of LHS components at the Hab-Plot scale preclude any large-scale stratification on the basis of map-derived features. The Hab-Plot is designed to provide a detailed picture of local habitat structure, and so the components (substrate types, macrophyte communities) recorded therein often vary significantly within a few tens of metres on the basis of local changes in geology, exposure, land use, and basin form. Therefore, it is difficult to classify Hab-Plots for the purpose of ‘scaling up’ to the whole lake, or even to be representative of other, similarly-situated plots in the same basin. It should also be remembered that the shoreline survey is designed to ‘sweep-up’ those important shoreline features related to specific pressures and habitats that are missed through a standard sampling regime, and in doing so provide a complementary assessment of shorezone characteristics in addition to the Hab-Plot observations.

This review, though focusing exclusively on the Loch Lomond case study, provides the basis to make some general comments. Ten evenly spaced but randomly located Hab-Plots provide a standard approach to undertaking LHS. This represents a more practical approach than requiring surveyors to stratify a lake *a priori* into land cover or morphological classes before randomly locating sample plots within these strata. Rather than describing a representative segment of shoreline, Hab-Plots have perhaps more of a role in providing a platform for establishing some important small-scale linkages between shoreline morphology and ecology. This may be achieved by carrying out existing ecological surveys (macrophytes, invertebrates, diatoms) at the same time and at the same location as the Hab-Plots survey.

4 REMOTE SENSING, MAP AND GIS – BASED TECHNIQUES

From the outset of LHS, it was envisaged that remote sensing may have a role in providing a consistent and objective method to complement field studies. Cherrill and McLean (1999) reported that field-based methods (such as LHS) are highly surveyor-dependent with attendant implications for accuracy and reproducibility. Furthermore, the resource-intensive nature of field visits makes automation attractive, provided the remote sensing methodology is sound and can be made available to those involved. Once appropriate methods and algorithms were established, the repeatability of individual surveys would be relatively time- and cost-effective, although would be dependent on data availability and the skills infrastructure of the agency involved.

During Phase 1 of LHS, the potential of remotely sensed and geo-spatial data sets was assessed in terms of their usefulness to LHS. Of the remotely sensed data sets reviewed, aerial photography was deemed the most reliable in supplying estimates of riparian and bank top land-cover type, shoreline characteristics and human pressures. However, aerial photographs provided no useful information regarding the littoral zone and very little information relating to the shore zone. Of the secondary geo-spatial data sets reviewed, both OS Mastermap and LCM2000 appeared 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. However, neither provides any substantial information regarding the littoral or shore zones.

The following recommendations emerged from the review:

- 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 and locating pre-defined Hab-Plots;
- 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 UKLakes;
- 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 so these electronic databases should be used to maximum advantage to the survey team whenever possible (A. Keto, *pers. comm.*)

- At the catchment scale, LCM2000 can be used to derive land-cover types within lake catchments. These data are already available within the UKLakes database and could be used to identify hydrological regime modifications;
- 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.

4.1 Application of multispectral data for LHS

One of the most popular applications of remotely sensed data is to map land cover and land use (Aplin, 2004). For LHS, land cover is an important variable both in the wider catchment and in the riparian zone and shoreline. However, the ability of remote sensing to map land cover in these areas is directly related to the intrinsic scale of variation in surface types present within the scene, and in many cases may be limited by the spatial and spectral resolution of the data acquired.

The spatial and spectral dependence of land cover classification in the riparian zone was investigated at Torside Reservoir, Derbyshire (Figure 4.1). The site was chosen as digital hyperspectral data of the site were available from the BNSC/NERC SAR and Hyperspectral Airborne Campaign (SHAC) that took place in 2000. The data were acquired at both 3 m and 5 m spatial resolution by the HyMap sensor, which has 126 spectral bands located in the visible, near-infrared and short-wave infrared regions of the electromagnetic spectrum. From these data it was possible to simulate data from a number of commercial spaceborne sensors that provide synoptic and relatively low cost imagery at a fine temporal resolution (Table 4.1).

Table 4.1 Spatial and spectral characteristics of simulated multispectral data

Sensor-type simulated	Spatial resolution	Number of wavebands	Spectral regions
IKONOS	4 m	4	Visible and near infrared
Terra ASTER	15 m – 90 m*	15	Visible, near-, shortwave- and thermal infrared
SPOT HRVIR	20 m	4	Visible, near- and middle-infrared

**** Spatial resolution varies with wavelength. 15 m for visible and nIR, 30 for SWIR and 90 in thermal wavelengths.***

Figure 4.1 Aerial colour photograph acquired over Torside Reservoir

The three simulated data sets and the original HyMap data were each classified using a standard supervised maximum likelihood classification approach. The accuracy of each classification result was determined by comparison with ground data obtained during a field visit carried out at the same time of year as the original image acquisition. Finally, the LHS survey form was completed by using the best and worst performing classification.

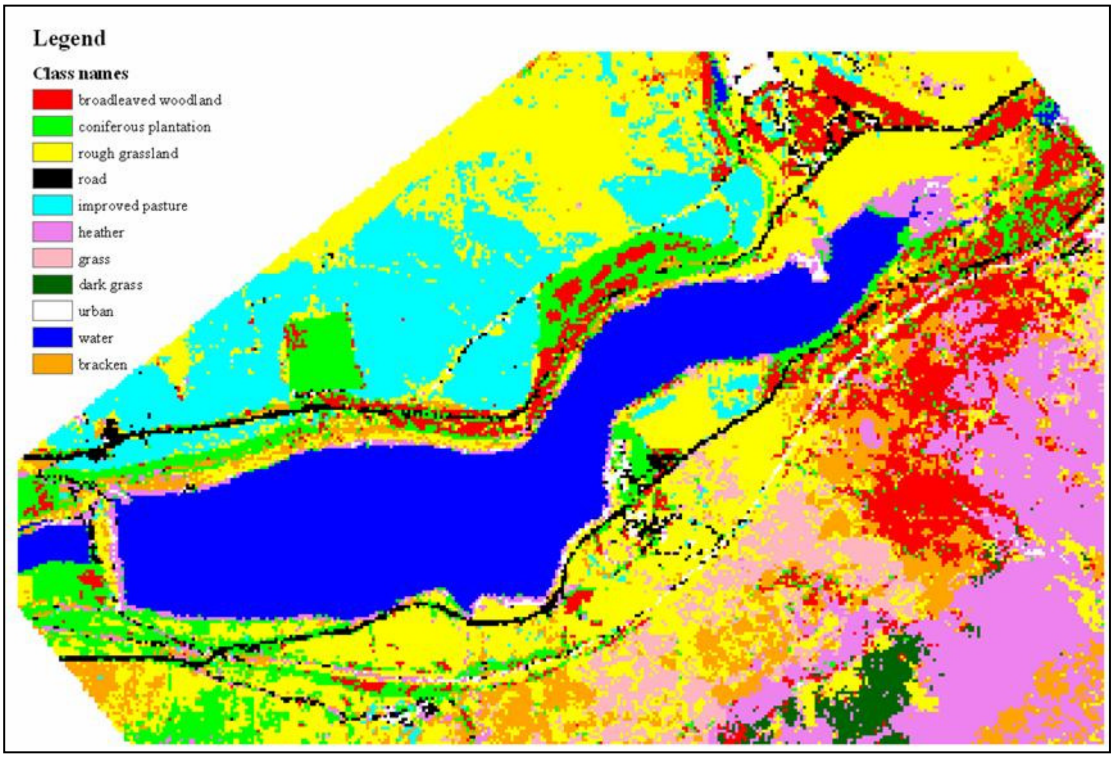
The overall classification accuracy for the 5 m HyMap image (Figure 4.2) was 85.9%. Misclassification and confusion occurred particularly between the two pasture classes and some other vegetation classes, but in general the classification performed well. The presence of mixed pixels (pixels covering more than one land cover type) gave rise to small areas of confusion near to class boundaries but generally these were small in area.

The simulated IKONOS data performed well in comparison to the original hyperspectral data, despite having a much reduced spectral resolution. The overall accuracy was 84.7%. Several vegetation classes, including pasture and grass (60% and 57.1% accuracy respectively), were confused and misclassified, probably as a result of the limited spectral dimensionality of the data. However, in comparison with the results observed from the classification of the other simulated data sets (ASTER: 64.7% and SPOT HVIR 78.8%), the IKONOS data performed well.

The overall accuracy of the IKONOS result was comparable to that observed with the HyMap data that were of a similar spatial resolution but higher spectral resolution. From this, it would appear that the spatial resolution of the remotely sensed data was the controlling factor in being able to accurately map land cover in the riparian zone at Torside Reservoir.

Using a mixture of visual interpretation of raw data and the classified images, the remotely sensed data were used to complete as much of the Torside Reservoir LHS form as possible. The results observed were compared with the form completed in the field.

Figure 4.2 5 m HyMap classified image of Torside Reservoir



There was considerable variability in the agreement between the remotely sensed data and the field observations for riparian zone observations. The HyMap hyperspectral data showed good agreement with the field data for estimating the aerial coverage of trees and tall herbs and grasses (including bracken), while ASTER and IKONOS underestimated the aerial extent of these classes. The presence of herbs, grasses and bryophytes was detected in the field at most of the habitat plots but was not detected within the remotely sensed data, probably due to being obscured by overlying vegetation canopies, or because they were small in extent and, therefore not resolvable given the spatial resolution of the data. The spatial extents of artificial features were generally underestimated by the multispectral data but the presence of such features was detected for all habitat plot sites where they were recorded. Finally, there was considerable disagreement between the multispectral data and ground observations regarding the dominant land cover within the riparian zone and shorezone at each Hab-Plot. This was in some measure due to the significant water level drawdown which occurred between the time of the sensor over-flight and the field survey. Thus the view from the boat anchored 10 m from the active waterline meant that the riparian zone (above the bank top) was in some instances 200 m from the position of the boat. Regarding the littoral zone, the remotely sensed data were only partially successful in identifying the presence of overhanging vegetation, but no other part of this section could be completed using the remotely sensed data.

In summary, it was established that some major land-cover classes and landform features (forestry, urban development, and marinas) could be confidently identified, but the detail of vegetation structure and cover recorded at the Hab-Plot scale was not easily represented. Major landform features such as islands and deltaic bars could also be readily recognised, although the presence and extent of these can be highly dependent on water level, especially where hydrological management is in place. Also, many pressures relevant to LHS (and associated summary metrics) could not be identified, and are likely to change seasonally (such as boating, angling, swimming and related visitor pressures). The results of this study in large measure confirm the findings of Davids *et al.* (2003), which are summarised in Table 4.2 indicating that in stand-alone mode remotely sensed data have only limited application for characterising lake hydromorphology. This fact allied to the significant data acquisition and image processing costs, in terms of both equipment and human resources, shown in Table 4.3 indicate that a field-based survey approach is the only practical way forwards, at least in the immediate future..

Table 4.2 Summary of feasibility study into the use of remotely sensed data to characterise hydromorphological quality elements in standing waters (lakes/lochs).

Hydromorphological quality elements	Summary of feasibility of using remotely sensed data
Quantity and dynamics of water flow	Not possible
Water level	Provides an indication at the time of survey
Residence time	Not possible
Connection to groundwater	Only detectable in thermal imagery where marked upwellings and limited mixing are apparent
Continuity	Not possible
Depth variation	Possible in shallow (< 2 m) non-turbid (e.g < 20 NTU) waters using multi-spectral imagery and aerial photography
Quantity and structure of the substrate	Not generally possible
Structure and condition of lake shore zone	Can characterise riparian land cover using most high spatial resolution image types

(adapted from Davids *et al.,* 2003)

Table 4.3 Estimated costs for data acquisition and image processing analysis associated with established remote sensing platforms

Platform	Acquisition cost (£ per km^2)	Estimation of costs (£ per km^2) associated with storage, image processing and analysis
LIDAR	250 – 350	medium (300)
NEXTMAP (IFAR)	20	medium (300)
Aerial photography	40 – 100	medium (200)
Airborne hyper-spectral	100 – 1000	high (1000)
ORRI	10	low (150)
Radarsat	0.8	low (150)
High spatial resolution satellite imagery e.g. IKONOS	16 – 36	medium (300)

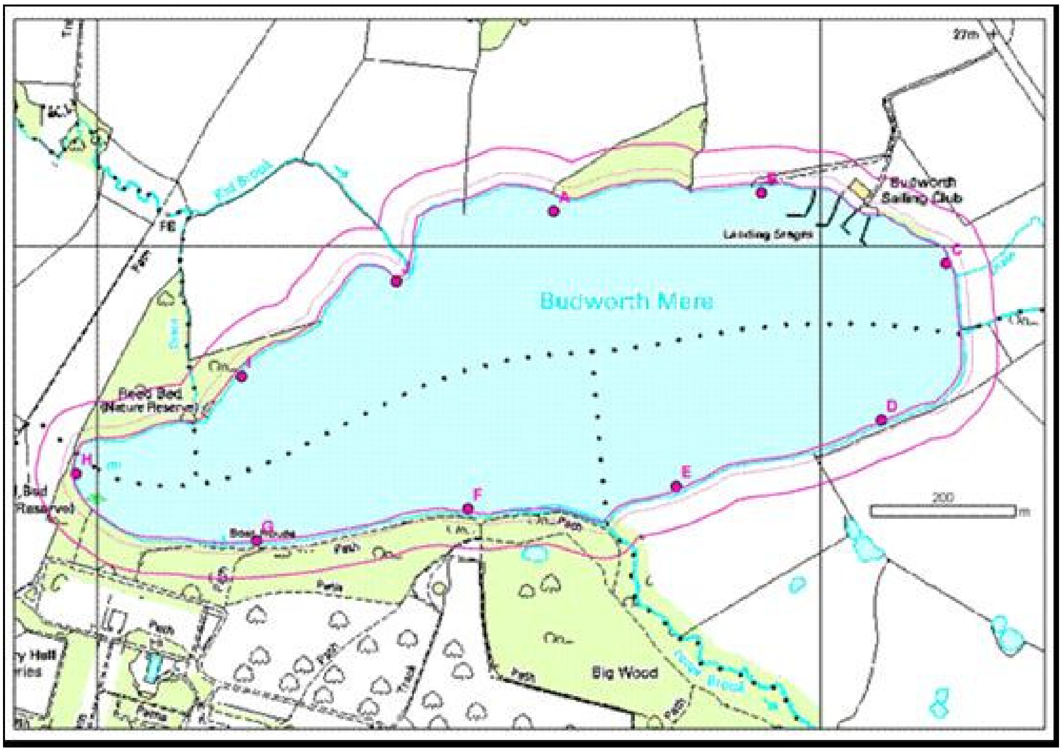
(adapted from Davids *et al.,* 2003)

4.2 Use of GIS for survey planning

For many of the lakes surveyed by the contractors in 2005, maps were prepared beforehand using ArcView GIS software and standard Ordnance Survey (OS) digital raster mapping at scales of 1:10,000, 1:25,000 and 1:50,000, for which all of the UK agencies hold licences. The most suitable OS mapping scale was selected (usually 1:10,000 for small lakes and 1:25,000 for larger ones) and a snippet showing the lake and its immediate surroundings prepared. The GIS software was used to create 15 m and 50 m buffer polygons around the mapped perimeter of the lake, to assist in definition of the two zones described during the whole lake assessment part of LHS. The perimeter of the lake was measured, its total length divided by 10, and the standard 10 evenly-spaced Hab-Plots were laid out as a point theme, starting at a randomly chosen location on the perimeter and then using the GIS measuring tool to measure the requisite distance along the mapped shoreline between points. The resulting map was printed in colour on an A4 sheet for use in the field.

These maps proved to be much easier to use in the field than sketch maps or photocopies of 1:50,000 maps. The technique was especially helpful in planning survey logistics for Loch Lomond, where it was impossible, with the resources available, to complete a full circuit of the 139 km perimeter in a single day, and where traverses between Hab-Plots typically exceeded 2 or 3 km.

Figure 4.3 Example of field map prepared using GIS software



Budworth Mere. The pink points show Hab-Plot locations and the pink lines around the lake perimeter indicate the limits of the 15 m and 50 m zones for the lake perimeter survey. The slight error in registration at the southern side of the lake arises from the fact that the buffer polygons were constructed using 1:25,000 scale mapping before the 1:10,000 scale material became available. Based on © Ordnance Survey data.

4.3 Use of digital mapping and air photography for assisting LHS

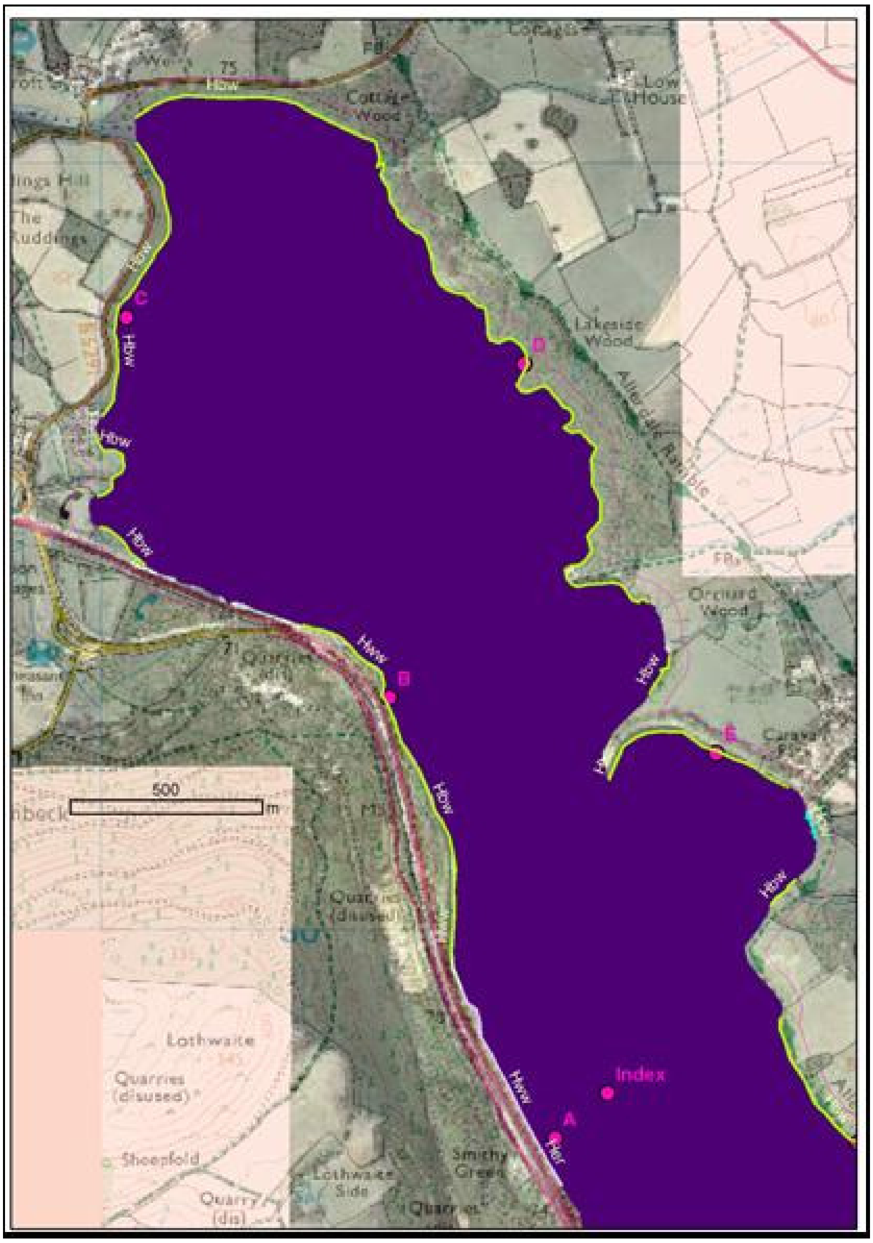
Although the 2004 trials of desk-based air photograph interpretation as a substitute for the lake perimeter survey were unsuccessful, the technique was nonetheless thought to have potential for augmenting and improving the accuracy of the field survey. This aspect was investigated further in conjunction with the Bassenthwaite Lake survey.

Shortly after the Bassenthwaite Lake survey, the extents of bank construction, pressures, land uses and habitats were re-measured in the GIS environment, which allowed reference both to Ordnance Survey mapping and low-resolution air photography. Ideally, this approach would employ standard UK-wide air photography such as the imminent *Get Mapping* coverage. However, at present, *Get Mapping* does not cover the whole of Scotland and licenses are held by only some of the UK Agencies, so the existing coverage of England held by the Environment Agency could not be employed in this project. Therefore, this trial employed the low-resolution sample imagery that is accessible through the *Get Mapping* website.

The aerial photograph of the site was overlain atop the map image (Figure 4.4), and the two perimeter bands defined by placing buffer polygons along the shoreline. The percentage extents of LHS features (both shoreline pressure and habitat features) were then measured by interpreting the map and photograph images for both perimeter bands (0 - 15 and >15 - 50 m). The data for categorised segment lengths were extracted from the GIS database into an Excel spreadsheet and the total length for each pressure and habitat type per zone calculated for the whole lake. These data were compared with estimates for the whole lake obtained by summing and averaging the mid-class values for scores awarded during the survey. In most cases, GIS and field estimates are similar to within 5%. Other features could not be estimated as accurately. Grazing could be observed only in the field, and this would seem an adequate explanation of the apparent under-estimate using GIS. Non-wooded wetlands (reed-bed and fen) may have been under-estimated in the field because they lie in a relatively inaccessible section of shore that could not easily be viewed from the boat.

In consideration of future developments it is likely that universally available systems such as Google Earth®, which provides very high resolution digital aerial photography data for much of Europe will offer scope to ensure that wherever possible teams surveying large sites are supplied with good quality aerial photography.

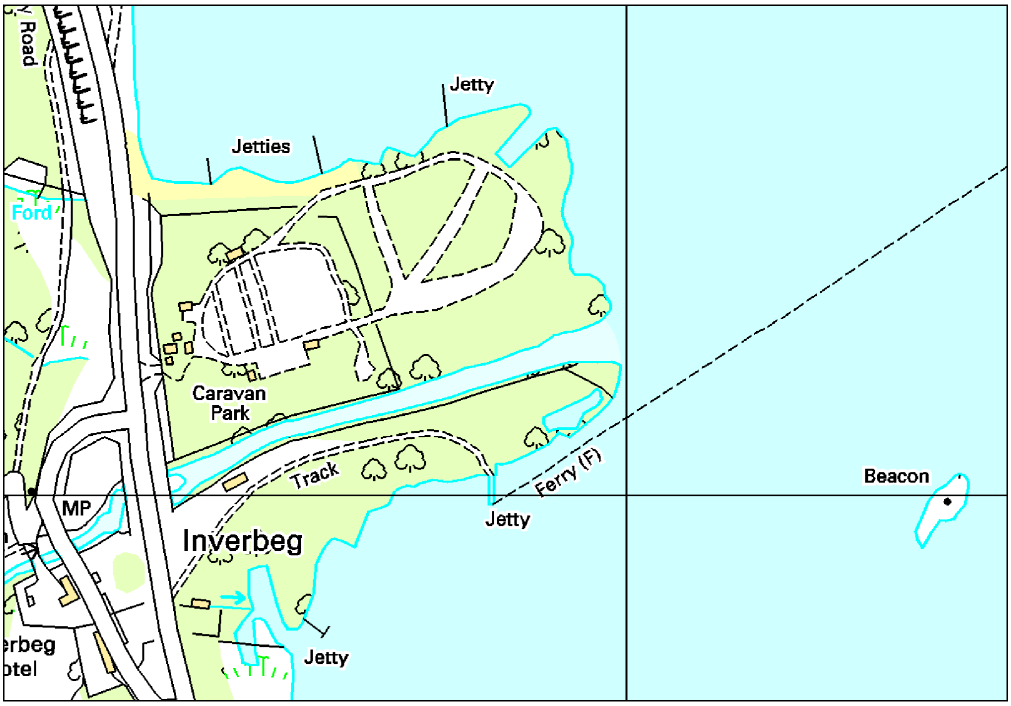
Figure 4.4 Section of Bassenthwaite Lake with Get Mapping overlay, showing location of Hab-Plots and perimeter buffer polygons



4.4 Use of Digimap geo-spatial database

The Digimap online digital mapping resource, hosted by the Edina, Edinburgh University, delivers maps and map data of Great Britain to UK tertiary education institutes. Data from selected Ordnance Survey and Landmark (historic maps) products, with full coverage of Great Britain, can be downloaded for use with appropriate software (GIS or CAD). An illustrative example of a section of the Digimap image of Loch Lomond is shown in Figure 4.5.

Figure 4.5 Digimap extract of selected Loch Lomond shoreline section



The high level of detail available with Digimap images makes them useful for field navigation, and they have potential for supplementing field sketches by annotating hard copies. Many shoreline features (jetties, tracks, roads, buildings) relevant to LHS are visible, as are major land-cover classes (broadleaf woodland, coniferous woodland, agricultural land, beaches). During the shoreline survey section of the protocol, the potential for surveyor error is thought to increase as the length of the section increases, because it becomes more difficult to assess the relative extents of a large number of features over both 0 - 15 and >15 - 50 m perimeter bands. For example, the relatively long (typical shoreline sector of 2.7 km) and heterogeneous shoreline sections on Loch Lomond made it difficult to assess the extent of features over such long distances. However, by using the Loch Lomond Digimap images in the field, it was possible to map the extents of shoreline features definitively for each shoreline section by using a GPS to verify the positions of point features (jetties, field boundaries, deltas), and filling in details by annotating the Digimap printout. The true shoreline extents could then be assigned to the appropriate percentage classes.

For some smaller water bodies (where surveyor error is expected to be comparatively low), shoreline survey data were compared with data obtained from interpretation of Digimap images for selected features. These comparisons were only carried out for the few shoreline features that could be detected (through direct classification or by association) from the image (hard-engineered bankfaces and broadleaf woodland). The correlation between image-derived perimeter extents and field estimations Figure 4.6 and 4.7) were generally close for both bank engineering and woodland cover. Of the nine map-based estimates made, eight features were estimated to within 20 % of the field-based value, and five to within the same percentage cover class. Some error, however, was introduced in estimating the extent of bank engineering at Torside and Lindores from maps, probably because classification could only be carried out by association (the presence of a road or railway within a few metres of the shoreline) in some cases. Similarly, errors in the estimates of woodland arose because the Digimap images do not discriminate between different sizes or densities of trees. It is expected that both errors would be reduced somewhat by using the maps in conjunction with aerial photographs, as discussed in Section 4.3.

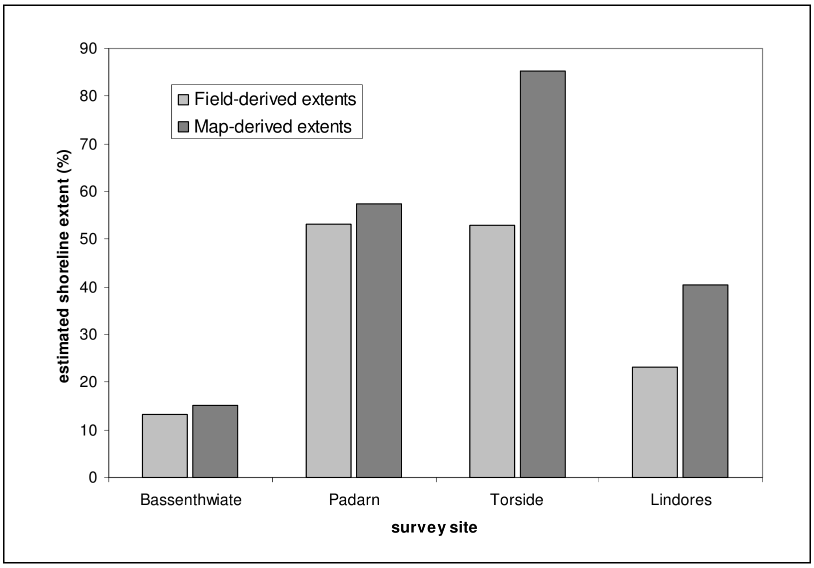


Figure 4.6 Comparison of field- and map-derived perimeter extents of bank engineering on selected water bodies

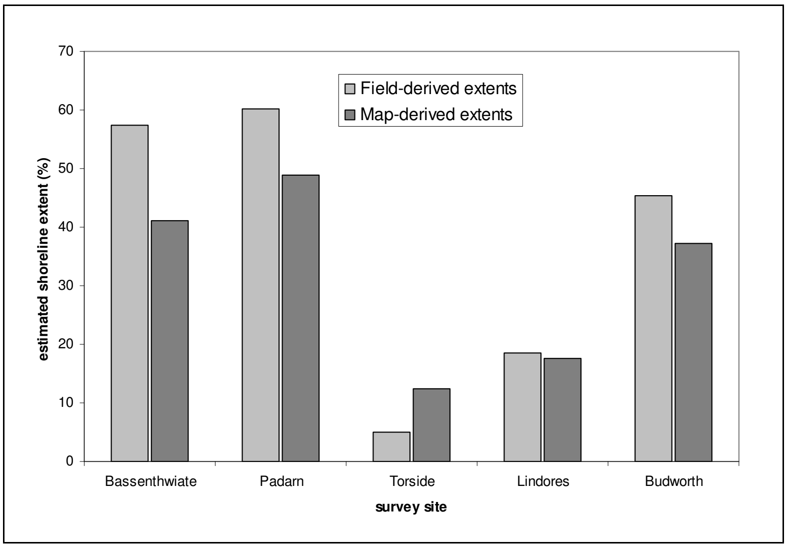


Figure 4.7 Comparison of field- and map-derived perimeter extents of broadleaf/mixed woodland on selected water bodies

The generally close correspondence between these two independent approaches indicates that whilst there is scope to automate this process and retain comparable results to the field method, there remains a considerable benefit from tying the benefits of good map/aerial photograph control with ground truth data carried out by well-trained surveyors.

5 DATABASE DEVELOPMENT AND MANAGEMENT

The LHS database was developed at the end of the 2004 field season in Microsoft Access (2002). It has a user-friendly interface whose layout closely matches that of the field form, allowing efficient data entry. It has the ability to store information on an unlimited number of sites and allows multiple entries (subsequent site visits). Within each record (a record corresponds to a single survey), any number of Hab-Plots can be stored, as can any number of shoreline sections. Surveys are identified by using unique entry numbers, and site locations and characteristics are routinely validated at the time of data entry (through interrogation of the UKLakes database, and map resources) to validate site identification.

As a response to changes in the survey protocol in 2005, the database has been modified to accept data from the updated field form. To allow database interrogation of surveys spanning different field form versions, several database fields offer the option of entering categories from any form version. In other cases, database fields may be redundant (features recorded in previous versions of the form have been omitted from subsequent versions) or are recent additions, meaning that care must be taken during interrogation to make sure the required data reflect the various versions of the survey protocol.

Further development of the user interface has also taken place to improve functionality and allow quick data entry. The interface is set up to look like the survey form so that it is easily navigable by users with survey experience (see Figure 5.1 for two examples of the Access data entry form). Several important fields (e.g. Lake Name) are necessary for Hab-Plot identification and cross-reference purposes and their entries are therefore required before advancing through the data entry procedure. Other fields (e.g. Hab-Plot code) are subject to rules, which prohibit the entry of duplicate values (which compromise the unique identifier of a Hab-Plot). Also, a few fields are automatically checked for validation during data entry – for example, an erroneously entered survey date will be rejected if it postdates the date of entry into the database. With equivalent mistakes the user is automatically alerted and cannot proceed until the error is rectified. Finally, in those field names that may appear ambiguous to an inexperienced user, a description of the information required is provided.

Some quality assurance measures have been taken to minimise error at the time of data entry. For example, it is not possible to enter a value or abbreviation that does not appear for that particular field. In future it may be desirable for users to be obliged to enter records twice (as is the practice in the River Habitat Survey database), or to verify survey form entries by carrying out a coarse re-survey by way of analysing surveyor's Hab-Plot photographs. Clearly, it would not be possible to re-survey Hab-Plots completely, but the process could, for example, be used to challenge potential anomalies (e.g. a beach being recorded as absent, but beach vegetation recorded as present) or the appearance of rare features or conditions in the form (the absence of both a bankface and a beach at a Hab-Plot is possible if the system is in disequilibrium, but the situation is rare).

The database developed for WFD40 and WFD42 (presently > 300 MB in size) was delivered to SNIFFER under the terms of the contract.

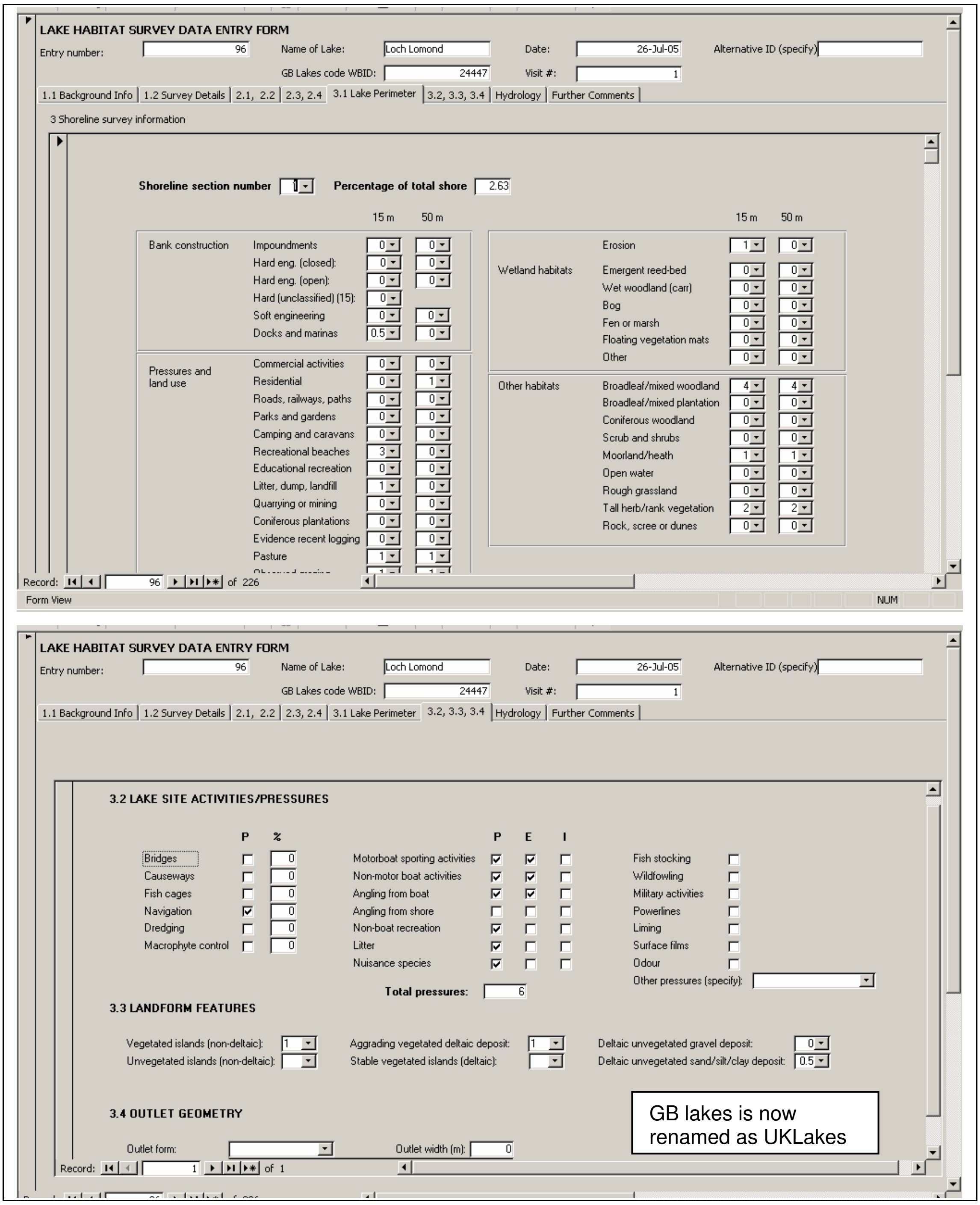


Figure 5.1 Extracted images from the LHS Access database entry form

At present there is no completed protocol in place for archiving Hab-Plot and site photographs into the database, and presently images are filed alongside site records. Digital images are essential for quality assurance purposes, and in due course can provide a catalogue of searchable images for surveyor training purposes. The database is configured to accept images, but the time-consuming and data-hungry nature of uploading graphics files (there are typically a minimum of 12 photographs for a complete site) causes the database file size to increase dramatically, compromising data retrieval and processing operations and so further development of the database will be an important priority for a future Phase 3 study.

6 SUMMARY METRICS USING LHS

A key requirement of the LHS project was to generate summary metrics that synthesise the wide ranging and multivariate data collected and reduce these to meaningful indices. Indices are required to indicate the degree of hydromorphological alteration (a key requirement of the WFD), and to evaluate aspects of lake habitat quality, inclusive of diversity and naturalness of physical structure as well as the presence of habitat features perceived to be of value to wildlife. The Lake Habitat Modification Score (LHMS) is comparable to the HMS used for River Habitat Survey data. A summary of the derivation of the score is provided below.

The contractors also developed an alternative scoring scheme as part of SNIFFER Project WFD49a. One of the key aims of this project was to develop a decision-making framework for assessing the point at which morphological alteration to a lake system is likely to compromise its ecological status. The scheme was required to assess the impact of extant hydromorphological pressures, but also to evaluate the likely consequences of new development proposals. It was designed to take into account the WFD concept of ‘type-specific reference conditions’, where the term ‘reference condition’ refers to a site that is totally, or nearly totally, undisturbed, and incorporated a ‘sensitivity typology’ which acknowledges that the sensitivity and resilience of lake ecosystems is controlled by physical factors such as alkalinity, depth, residence time and morphometry.

A scoring scheme known as ALMS (Alteration of Lake Morphology Score) was formulated, which was based on the concept of ‘thresholds of potential change’ whereby numerical thresholds and criteria of morphological change were established for specific morphological pressures affecting lakes. The ALMS scheme generates two key threshold values; the first which determines whether a site has no or minimal impact and therefore can be classified as being at reference condition (high ecological status), and thereafter higher ALMS scores indicate progressively greater risk that a site will fail to achieve good ecological status. The scheme also indicates when a lake has been ‘significantly changed in character’ to the point that it qualifies as a candidate heavily modified water body (HMWB) – the eventual designation of which being subject to tests outlined in Article 4.3 of the Directive (SNIFFER Project WFD49a, 2005). ALMS scores were designed around the comprehensive data available from LHS and incorporate Hab-Plot and ‘whole-lake’ survey data. Data inputs from map-based analysis, remote sensing analysis and hydrometric records can enhance information obtained otherwise exclusively in the field.

Both the LHMS and ALMS approaches are provisional schemes, which although conceptually sound, need biological data and many worked examples to calibrate and refine both the scoring scheme structure and any revised weightings (e.g. preferential weighting of the significance of changing seasonal water levels against varying the extent of shoreline residential developments). For this reason the remainder of this section will focus on examination of results of the LHMS. The generation of LHMS scores is obtained using a combination of queries from the LHS database followed by some additional spreadsheet calculations (the whole procedure will ultimately be fully automated when the final LHMS scoring scheme is finalised).

6.1.1 Lake Habitat Modification Score (LHMS)

The Lake Habitat Modification Score (LHMS) builds upon the UK TAG guidance risk assessment exercise (UK TAG, 2003), which uses expert opinion to define thresholds of pressures leading to likely impacts on 'ecological status'. The features included in the LHMS scheme developed for LHS Phase 1 (SNIFFER Report WFD40) were:

- % 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 introduced species.

The LHMS can be calculated for lakes with any number of Hab-Plot and perimeter survey observations. The full array of features included in the LHMS scoring system is shown in Table 6.1. The current version of LHMS omits Index Site results (e.g. Secchi disc depths and DO concentrations) and other potentially valuable desk-top insights such as the extent of intensive land-uses within upstream catchments which are likely to influence water, sediment and geochemical fluxes. A number of additional modifications were suggested following the Phase 1 end-of-project expert workshop, including the desire to classify 'in-lake' pressures into extent and intensity classes (cf. Rowan *et al.,* 2006) and these will be discussed in due course.

LHMS scores were calculated for all lakes entered into the database during 2004 and 2005. Results for the lakes surveyed by the contractors are provided in Table 6.2. The spectrum of scores achieved across the test lakes reflects the various degrees of regulation and development that characterise them. Cameron and Torside Reservoirs scored highest with 30 points each, reflecting their artificially constructed shorelines and regulated hydrological regimes. Loch Lomond (both north and south basins) and Loch Earn also score highly due to a combination of large amounts of in-lake pressures, relatively large portions of intensively-managed shoreline, and some shore modification pressures. Bassenthwaite Lake was the highest scoring natural water body (LHMS = 20) mainly because of several in-lake pressures (angling, nuisance species) and the presence of a road within close proximity of the western shore. Barton Broad scores 12 points, most of which are acquired either directly or indirectly through the extensive use by visitors for navigation. At the lower end of the spectrum, Loch Bà scored 0 points, indicating the few pressures experienced at such remote sites.

It should also be noted that in relation to introduced species, the primary focus for LHS is on those introduced species that detract from habitat quality – which hitherto has thus meant plant species and excluded animals and fish. Accordingly, although it is well established that ruffe (*Gymnocephalus cernuus*) have been introduced to Loch Lomond with significant impact on native species this issue is not presently represented in the LHMS score. However, discussions at the LHS-CEN Workshop December 2005 highlighted that some introduced animal species e.g. muskrats *(Ondatra zibethica)* have very significant habitat effects through burrowing etc., and thus this issue should could be revisited in later versions of LHMS.

Table 6.1 LHMS scoring scheme

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)	
Introduced 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)		

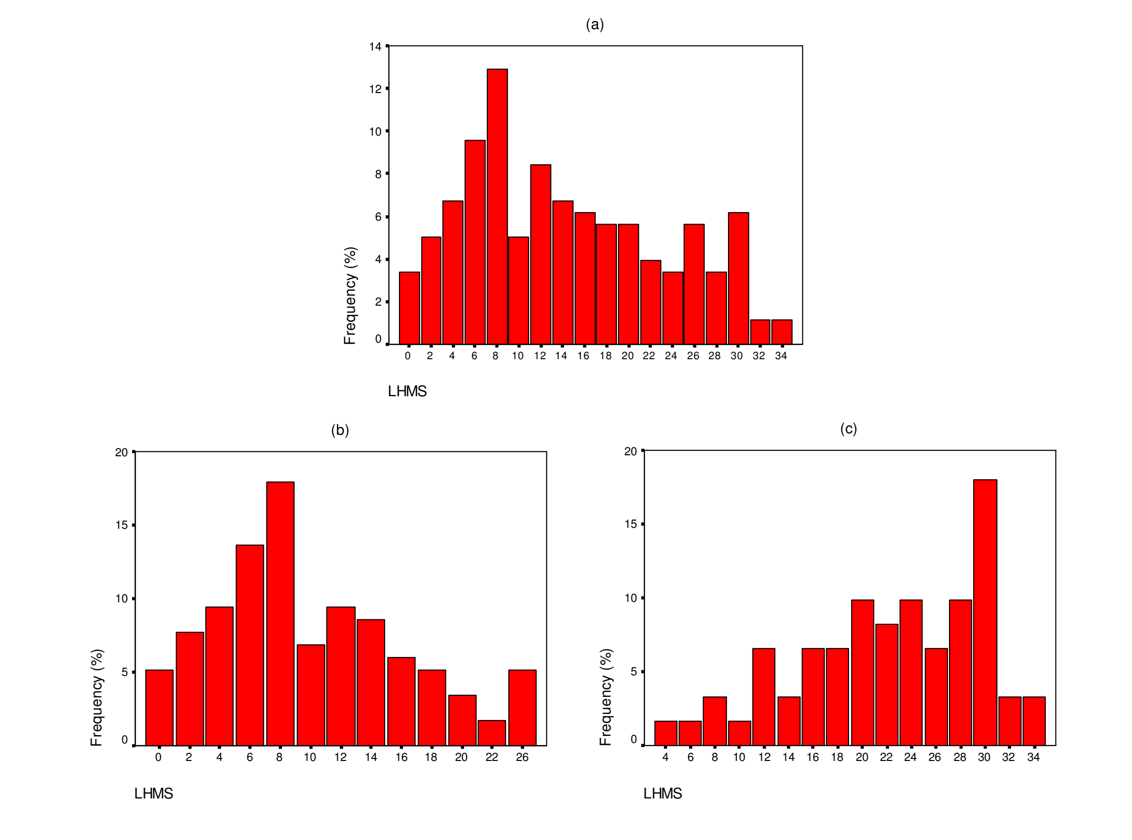
Table 6.2 LHMS scores and component values for all 2005 test sites

Basin	Shore modification	Shore use	Lake pressures	Hydrological structures	Sediment	Introduced species	Number of Hab-Plots	TOTAL SCORE
Loch Bà	0	0	0	0	0	0	12	**0**
Barton Broad	0	4	8	0	0	0	18	**12**
Bassenthwaite Lake	2	6	8	0	2	2	10	**20**
Budworth Mere	0	6	8	0	4	0	10	**18**
Cameron Reservoir	6	6	6	8	4	0	10	**30**
Loch Earn	6	8	8	4	0	0	15	**26**
Loch of Drumellie	0	6	6	0	4	0	10	**16**
Loch Lomond (whole)	4	6	8	8	0	0	38	**26**
Loch Lomond (north)	4	6	8	8	0	0	17	**26**
Loch Lomond (south)	4	6	8	8	0	0	21	**26**
Torside Reservoir	8	6	4	8	4	0	10	**30**

Whilst distinct from the purely morphological metric of ALMS (SNIFFER Report WFD49a, 2005), the LHMS metric is also relevant for classification purposes, especially in relation to identifying lakes at HES and those at risk of not attaining GES due to hydromorphological alteration. LHMS offers a valuable synthesis of morphological and other pressures that have no morphological expression (e.g. boating, angling, camping etc.) and so permits comparison of hydromorphological and related pressures between sites. Figure 6.1 illustrates a series of frequency distributions for LHMS scores obtained from 183 surveys across the UK and stored in the LHS database (see Appendix 3).

The frequency distribution for all surveyed water bodies, as illustrated in Figure 6.1a is skewed to the left. It must be noted, however, that sites were not sampled statistically at random, but were largely the by-product of existing sampling programmes by environment and conservation agencies. Of all sites for which an LHMS has been calculated (n = 178), the majority (n = 118) are classified as ‘natural unmodified’. Those ‘natural’ sites (Figure 6.1b) with LHMS scores of 10 and below generally accrue points through the ‘shore-use’ (presence of intensive land-use within 15 m of the waterline) and ‘lake pressures’ (angling, litter, nuisance species etc.) components’. The highest score (26) within the ‘natural’ subset was reached by predominantly large systems with extensive recreation pressures (and associated catchment development pressures), and includes Loch Lomond (all basins), Loch Earn and Llyn Padarn. The distribution of those water bodies classified as ‘regulated’ (Figure 6.1c) is skewed to the right, with few sites achieving scores of 10 or less. These sites are predominantly made up of remote upland systems with only minor (two or less) hydrological structures, but with no significant management regime in place.

Figure 6.1 Frequency distribution of Lake Habitat Modification Scores (LHMSs) for (a) All surveyed UK standing waters (n = 178), (b) Natural unregulated lakes (n = 118) and (c) Impoundments and regulated standing waters (n = 60)



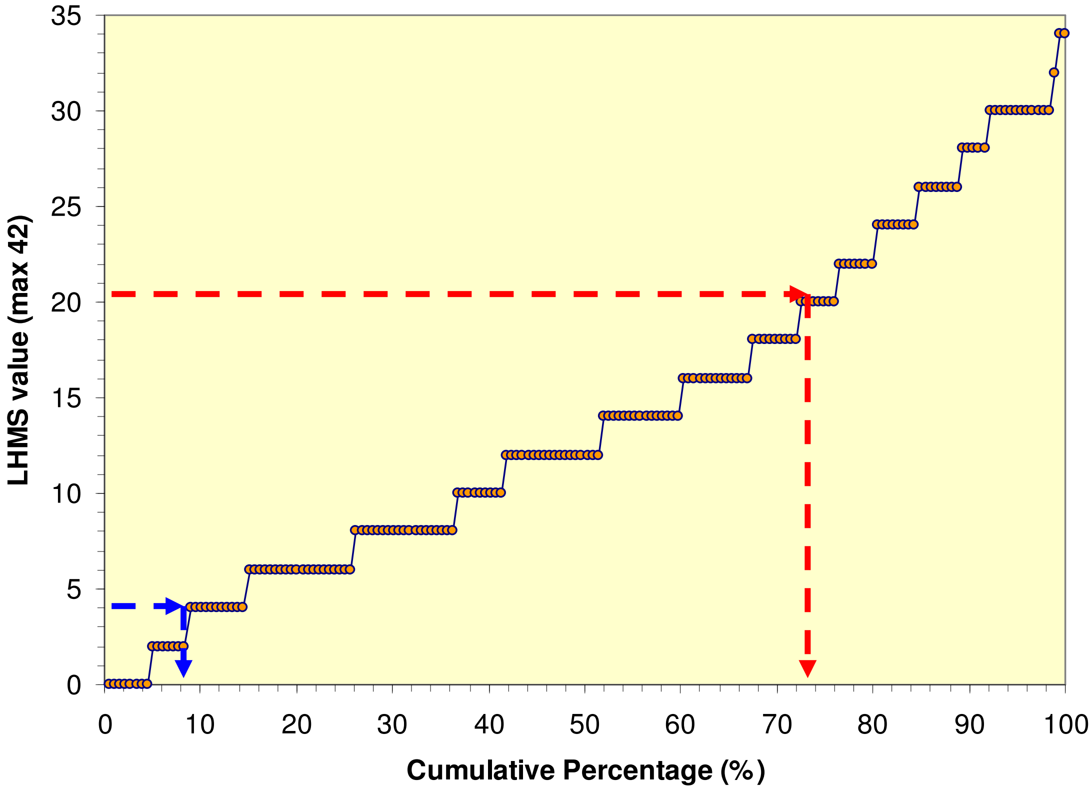
It is clear that some sections of the LHS form are more important than others with respect to deriving summary metrics, and there is a risk of calculating misleadingly low scores if particular sections have been overlooked or neglected, as is sometimes the case. Inaccurate or incomplete surveys may arise from surveyors' time constraints or, more commonly, through unawareness of basin features, especially hydrological regime management. Observing introduced species is also problematic as macrophytes may well be recognised, but surveyors are unlikely to encounter introduced macroinvertebrates or fish (and in any event the latter do not count towards the LHMS). In these instances, it can be difficult and time-consuming to verify form entries. It has been agreed that it would not be desirable to 'flag up' sections of importance as this may deflect surveyors' attention away from other sections of the survey. But, it may be advantageous to have additional quality control practices in place to validate and corroborate those form sections that are used to derive summary metrics. Cross-referencing can be either desk-based (using maps, contact with water regulation authorities / landowners), or may be carried out as sites are re-surveyed and compared with previous surveys.

Steering group members at the final phase 2 workshop held in December 2005 (see Appendix 2) agreed on the value of a generalised summary metric such as LHMS, but it was acknowledged that further refinement of the system was required e.g. ensuring extent and intensity of pressures features in the scoring system and further reflection on weighting within groups of pressures e.g. at present, swimming pressures scores the same amount of component points as motor boating and dredging pressures). Also, it may be appropriate to weight entire pressure categories (such as the 'hydrology' group of component pressures) against those pressures (such as 'in-lake' activities) perceived to cause less disruption to habitat functions. It would also be appropriate to incorporate recently-developed LHS protocol features into the scoring scheme. For example, scores are currently based partly on the shoreline survey section of the form, but only take the 0 - 15 m perimeter band into account. But, if it is likely that pressures cause some (albeit reduced) level of disruption if they are further from the waterline (within the >15 - 50 m perimeter band), it may be appropriate to take them into account. Future revision of this summary metric, however, should if possible be capable of integrating older survey data with newer data, or should at least acknowledge that older data (obtained by using older protocols) may produce a less sophisticated summary metric.

Further considerations may also be made of the importance of the natural condition of the particular water body in question, and the varying degrees of ecological response that can be expected from different lake types. For example, it may be assumed that large lakes have an increased capacity to assimilate small, localised pressures compared with smaller lakes. Similar lake-specific sensitivities to habitat disruption may also be important across the continua of alkalinity, bathymetry, altitude and other characteristics. However, the mechanisms for assigning lake-specific sensitivity are not well known, and are likely to be complex.

Figure 6.2 illustrates the potential of the LHS database and the LHMS score to provide insight to the extent of hydromorphological alteration across the UK's standing water. Of the 200 lakes sampled, less than 10% of LHMS scores (< 4 points), might satisfy reference conditions, even though there are still uncertainties surrounding the extent to which grazing can be considered.

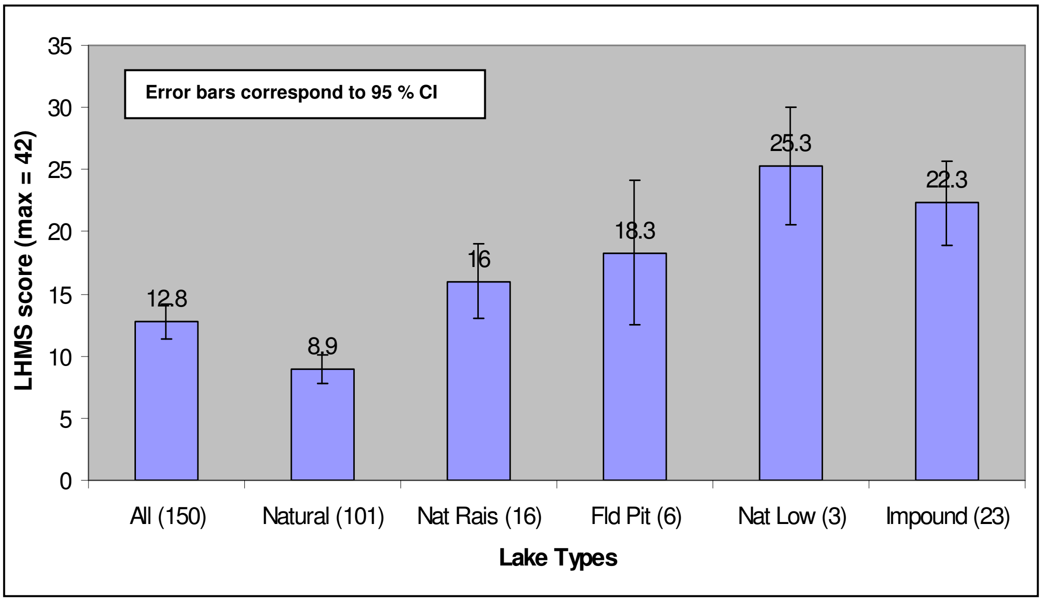
Figure 6.2 Cumulative distribution of UK lakes in LHS database (n= 200)



The second important boundary is around 20 LHMS points, where the degree of hydromorphological disturbance is likely to equate to a 'substantial change in character'; this normative definition flags a site as a candidate heavily modified water bodies [HMWB] (subject to the tests of Article 4.3). If this threshold value were adopted it would flag around 25 % of all sites surveyed as candidate HMWBs.

Figure 6.3 illustrates the range of mean LHMS values obtained when grouping lakes by mode of formation and degree of regulation. Lakes were grouped by returns of the LHS field form and classified into natural and unregulated; natural (but raised or lowered), artificial represented by flooded quarries or impoundments. Accepting the caveat of low sample numbers, naturally formed, but subsequently drawn-down systems such as Loch Leven and Llyn Tegid exhibited the highest overall mean with impoundments scoring next highest as a group. Natural, but raised (e.g. Loch Tummel) and artificial (such as Barton Broad) were the next highest and significantly higher (P > 0.05) than unregulated natural systems.

Figure 6.3 Illustration of LHMS mean values for UK lakes in the LHS database categorised by mode of formation and hydrological alteration



Key Numbers in brackets correspond to lake numbers, **All** - all sites, **Natural** - natural unmodified, **Nat Rais** - pre-existing natural lake but water level raised by a structure, **Fld Pit** - flooded pit, **Nat Low** - natural lake with water level lowered, **Impound** - dam built across river valley)

6.1.2 Lake Habitat Quality Assessment (LHQA)

Lake Habitat Quality Assessment (LHQA) is the second key summarising metric emerging from LHS data and is intended to complement LHMS, but in this case focuses on the naturalness, diversity and special interest features of a lake system. Conceptually, this approach owes much to the Habitat Quality Assessment (HQA) scheme used in RHS (Raven *et al.,* 1998), where points are accumulated through assessment of the extent and diversity of natural habitat features. The following 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).

The basis for the LHQA scoring system is presented in Table 6.3. Minor changes were required from the 2004 procedure because of changes in the field form, but to ensure continuity and maximise the value of the first field season's data these have been kept to a minimum. Figure 6.4 illustrates general views of the lakes receiving the highest (Loch Lomond) and lowest (Derwent Reservoir) LHQA scores respectively.

(a) Loch Lomond (2005)

(b) Derwent Reservoir (2004)

Figure 6.4 Illustration of the lake systems achieving the highest Loch Lomond (96) and lowest Derwent Reservoir LHQA scores for field seasons 2004-2005

Table 6.3 Revised scoring system for LHQA

LAKE ZONE	Characteristic measured	Measurable feature	Scores- full LHS (based on 10)[1]	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	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	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	4
	Diversity of natural land-cover types	Number of natural cover types recorded	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	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	4
		Proportion of Hab-Plots with trash-line	1 for 2-4 2 for 5-6 3 for 7-8 4 for 9-10	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	4
	Diversity of natural bank habitat	Number of natural bank materials recorded	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	4
	Diversity of natural beach habitats	Number of natural beach materials recorded	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	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	4
	Diversity of natural littoral zone types	Number of natural littoral substrate types recorded	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'	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	4
	Diversity of macrophyte structural types	Number of macrophyte cover types recorded (not including filamentous algae)	1 for each type, maximum score of 4	4
	Extent of littoral habitat features	Average of number of littoral habitat features per Hab-Plot[2]	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	4
WHOLE LAKE	Presence and diversity of special habitat features[3]	Number of special habitat features (excl. diseased alders)	5 for each type, maximum score of 20	20
		Number of islands	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	6

Notes
1. Numbers are expressed for standard LHS survey of 10 Hab-Plots, where more Hab-Plots are available scores are assigned on the basis of percentage extents
2. Revised entry from 2004, due to changes in field form
3. Revised entry from 2004, due to availability of extent data for selected natural meso-habitats.

Table 6.4 presents the results from the 2005 test sites surveyed by the contractors, along with comparable data from 2004, and the distribution of LHQA scores is presented in Figure 6.5.

Table 6.4 LHQA scores for 2004 and 2005 contractor test lakes

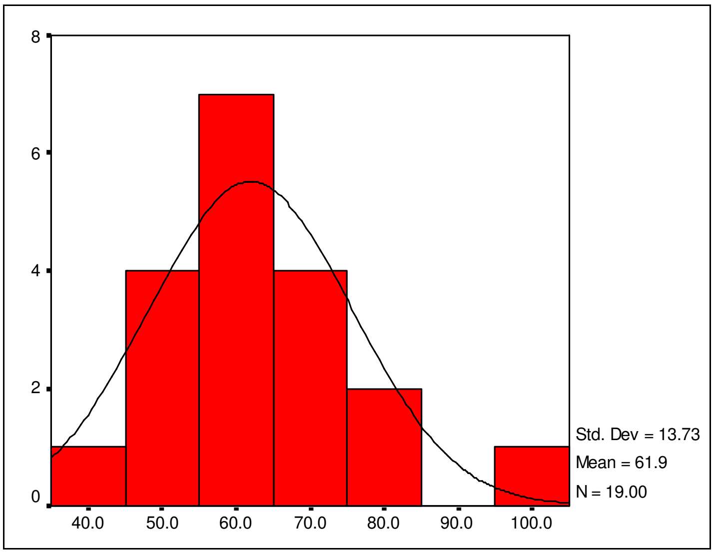
Lake	Riparian	Shore	Littoral	Whole Lake	Total Score
2005 test site results					
Budworth Mere	*14*	*16*	*20*	*15*	65
Loch of Drumellie	*11*	*18*	*25*	*19*	73
Loch Earn	*11*	*11*	*21*	*28*	71
Loch Ba	*14*	*16*	*21*	*25*	76
Torside Reservoir	*9*	*13*	*11*	*17*	50
Bassenthwaite	*7*	*13*	*21*	*24*	65
Loch Lomond	*16*	*20*	*26*	*34*	96
Barton Broad	*11*	*11*	*20*	*17*	59
Cameron Reservoir	*10*	*9*	*26*	*15*	60
2004 test site results[1]					
Llyn Tegid	*10*	*8*	*21*	*7*	47
Loch Brandy	*9*	*13*	*23*	*15*	60
Derwent Reservoir	*6*	*9*	*15*	*7*	37
Kilconquhar Loch	*9*	*5*	*24*	*10*	48
Loch Leven	*6*	*8*	*25*	*20*	59
Loch of Lindores	*10*	*5*	*24*	*17*	56
Loch Maree	*11*	*15*	*23*	*34*	83
Llyn Padarn	*8*	*12*	*24*	*7*	51
Loch Tummel	*8*	*14*	*24*	*15*	61
Windermere	*8*	*12*	*23*	*17*	60

Note 1: Re-calculated values contain minor differences due to error found in 2004 database query

The LHQA scores obtained for the 19 study lakes considered over 2004-2005 had an overall mean value of 61.9, and approximated a normal distribution encompassing a wide range of lake types, morphology and pressure gradients (Figure 6.5). The highest score of 96 was obtained for Loch Lomond from 2005, whilst the lowest of 37 was from Derwent Reservoir surveyed in 2004. It must be noted that these results are drawn from a small and not-statistically robust sample and so caution must be applied in terms of further generalisations.

In the Phase 1 study (SNIFFER Project WFD40a, 2004) a weak negative relationship was established between the LHMS score and the LHQA. With the added information of new sites this relationship was re-investigated; while still weakly negative it was not statistically significant for any of the lake types. The negative relationship is expected because LHMS scores departure from naturalness through engineering activity etc., whereas LHQA captures both naturalness *per se,* and the diversity of natural physical structure.

Figure 6.5 Frequency distribution of LHQA scores for contractor's trial lakes 2004-05



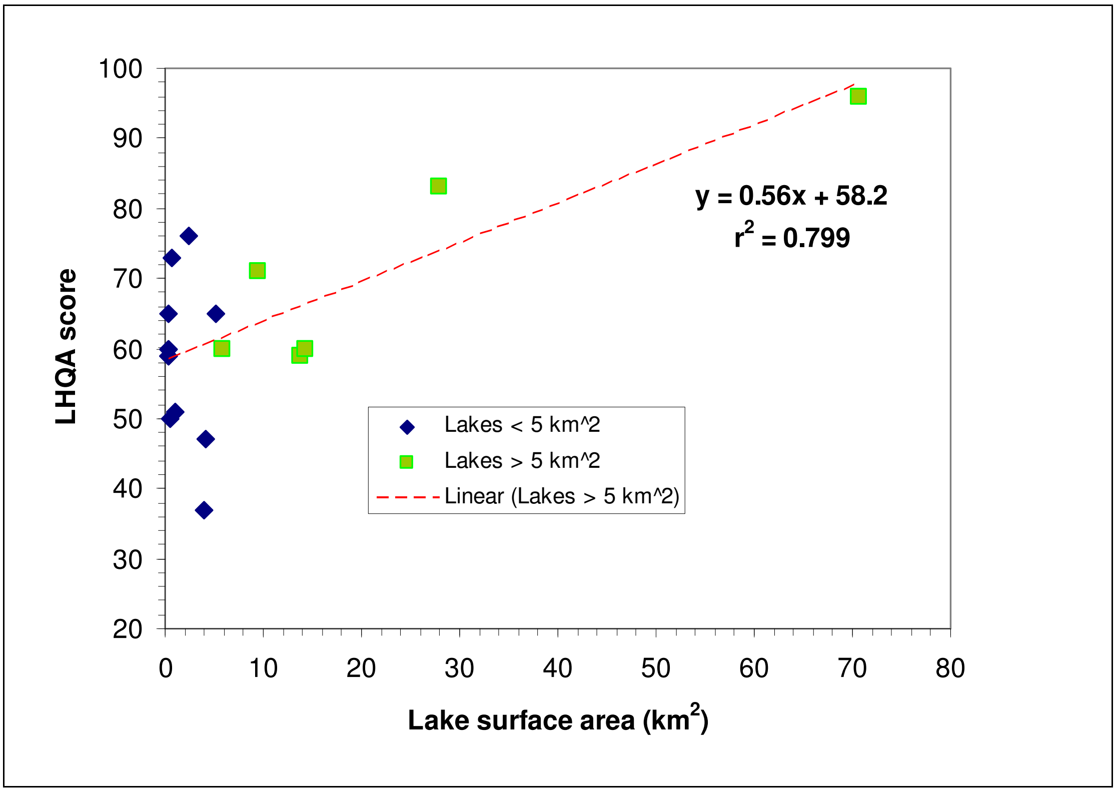
With regard to 'conservation status' an important distinction must be made between the 'quality' of a lake expressed by the range and condition of its physical habitats and the value of that lake system (in terms of flora/fauna species/communities represented or specified designated habitats (as defined in the Habitats Directive) and their relative rarity nationally or internationally (S. Clarke, *pers. comm.*). Thus the present configuration of LHQA provides a proxy of *ecological opportunity* in relation to the number and extent of different natural meso-habitats and niches. However, there is inevitably a scale dependency in the mechanics of LHQA in the sense that larger and morphometrically complex lakes – either in terms of water depth variation or shoreline irregularity (cf. Håkanson, 2005) will feature more combinations of wave environment, substrate type, thermal character, turbidity etc. than smaller and simpler lakes. This effect is demonstrated in Figure 6.6, which indicates that while there is no apparent size-dependency within lakes < 0.5 km^2, the smaller data set of very large lakes (> 5 km^2) suggests considerable size-dependency (accepting the obvious caveat of small sample size).

Table 6.5 provides comparative data for LHQA scores from the contractors test sites. Basic descriptive statistics and the results of t-tests undertaken to compare LHQA scores for all lakes categorised into larger or smaller than 5 km^2 are shown. A subset of LA systems were also analysed in the same way.

Table 6.5 Comparative aspects of LHQA scores for contractor's study lakes

LHQA scores	N	Mean	St.Dev	Min.	Max.	t-test significance (sig. 2 tailed)
All lakes	19	61.9	13.7	37	96	
All lakes < 5 km^2	13	58.5	10.5	37	73	0.000
All lakes > 5 km^2	6	71.5	15.2	59	96	0.000
LA lakes < 5 km^2	5	54.6	7.6	50	60	0.000
LA lakes > 5 km^2	4	75.0	17.6	61	96	0.005

Figure 6.6 LHQA scores versus basin surface area for lakes surveyed by contractors 2004-2005



It was concluded that LHQA, whilst a potentially valuable window into the composition and complexity of lake habitats, needs more biological data to calibrate and guide the future direction of this index. One obvious way forwards is to consider disaggregating the component elements of LHQA into quasi-discrete 'diversity' and 'naturalness' characteristics and to draw more extensively from the whole-lake perimeter study (see Table 6.6). The complexity of automatic query generation meant that a revised working scheme was not ready at time of writing. It is suggested that an important element of any Phase 3 Programme should be to ensure that metric generation is fully automated within the database structure and that this scheme is sufficiently flexible to incorporate inputs from environment and conservation agency staff and European collaborators applying LHS elsewhere (Appendix 2).

Table 6.6 Revised scheme for determination of Lake Habitat Quality Assessment (LHQA)

	Diversity[1]	**Naturalness**[1]
RIPARIAN	Vegetation structural complexity (4)	Vegetation longevity/stability (4)
	Diversity of natural land-cover types (4)	Extent of natural land-cover types (4)
	Diversity of bank-top features (4)	
SHORE	Diversity of natural bank habitat (4)	Extent of bank with cliff line 1 m high[2] (4)
	Diversity of natural beach habitats (4)	% Hab-Plots with trashline[2] (4)
		Bank naturalness (4)
		Beach naturalness (4)
LITTORAL	Hypsographic variation (4)	Extent of natural littoral (4)
	Diversity of natural littoral zones (4)	
	Average of total macrophyte cover (4)	
	Number of Hab-Plots where macrophytes extend lakewards (4)	
	Diversity of macrophyte types (4)	
	Extent of littoral habitat features (4)	
	Diversity of littoral habitat features (4)	
WHOLE LAKE	Number of deltaic deposits (6)	Presence/diversity of special habitat features[3] (20)
		Number of islands (10)
	54 points max	58 points max

Notes:
1. Maximum number of points are given in parentheses
2. These features have elements of naturalness and diversity that yield ecological interest
3. Scope to more fully integrate data from the whole-lake perimeter survey

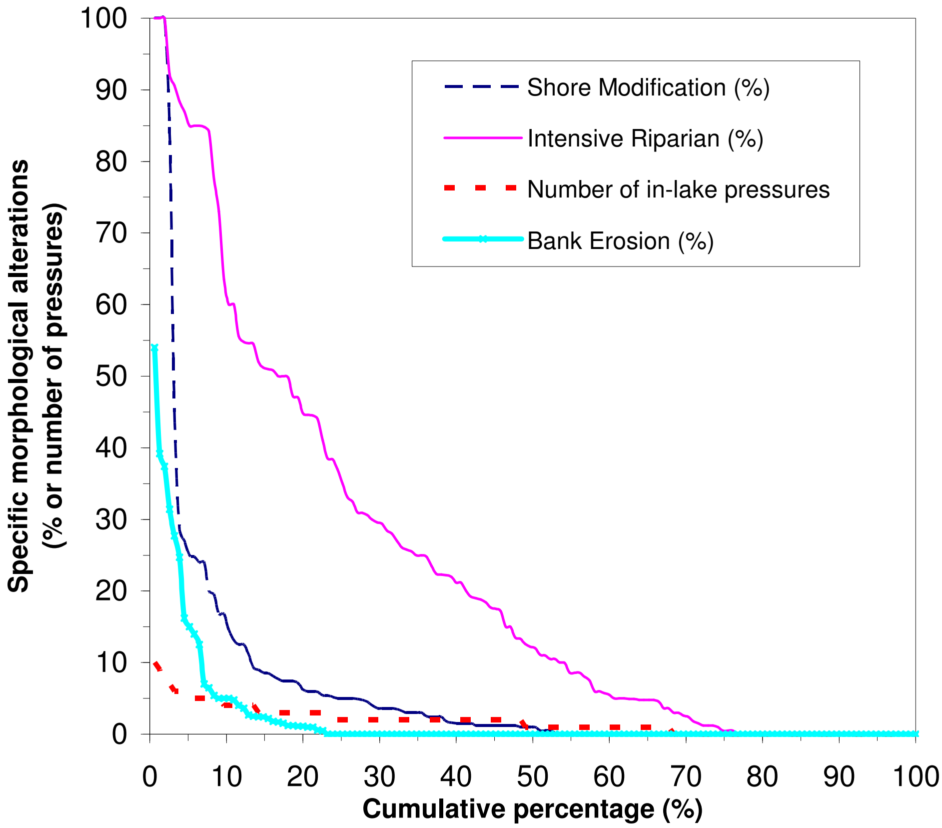
7 ELUCIDATING HABITAT – ECOSYSTEM LINKAGES

A key aim of this study was to use the field data obtained from the LHS surveys undertaken by environment and conservation agency staff during the Phase 1 programme (SNIFFER Report WFD40a, 2004). In particular it was considered important to investigate the insights into the condition of the UK's standing water resource base and to begin the process of elucidating the linkages between physical lake types as defined by the UK's WFD core reporting typology, which broadly reflect geology (Peat, Low Alkalinity, Medium Alkalinity, High Alkalinity, Marl and Brackish), their biology and the responsiveness of the biology in these systems to hydromorphological pressures. Such work is vital for the development of scientifically credible and legally enforceable environmental standards (SNIFFER Report WFD49a, 2005).

7.1 Use of LHS database to characterise status of UK standing waters

As the number and distribution of sites successfully sampled with LHS surveys has grown and the range of different lake types and the profiles of pressures occurring with these becomes clearer, then the LHS database becomes an increasingly important national resource. As an illustration of this statement, Figure 7.1 presents cumulative percentage summary data of various pressures. From this it can be seen that around 20 % of all surveyed lakes have more than half of their perimeter lengths featuring intensive riparian land-uses (urban/residential, tilled land or commercial coniferous plantation). More than 50 % of lakes within the database contained two or more in-lake pressures (including the relatively unintensive recreation pressures of angling and boating). Bank erosion was found to be important in around 10 % of lakes examined, particularly within reservoir systems where water-level variability was more pronounced than in unregulated lakes. Finally, although LHS does not undertake conventional macrophyte surveys, it is worthy to note that approximately 40 % of the sites within the database registered one or more nuisance plant species.

Figure 7.1 Selected cumulative distribution data pertaining to sites within the LHS database (n=150), September 2005



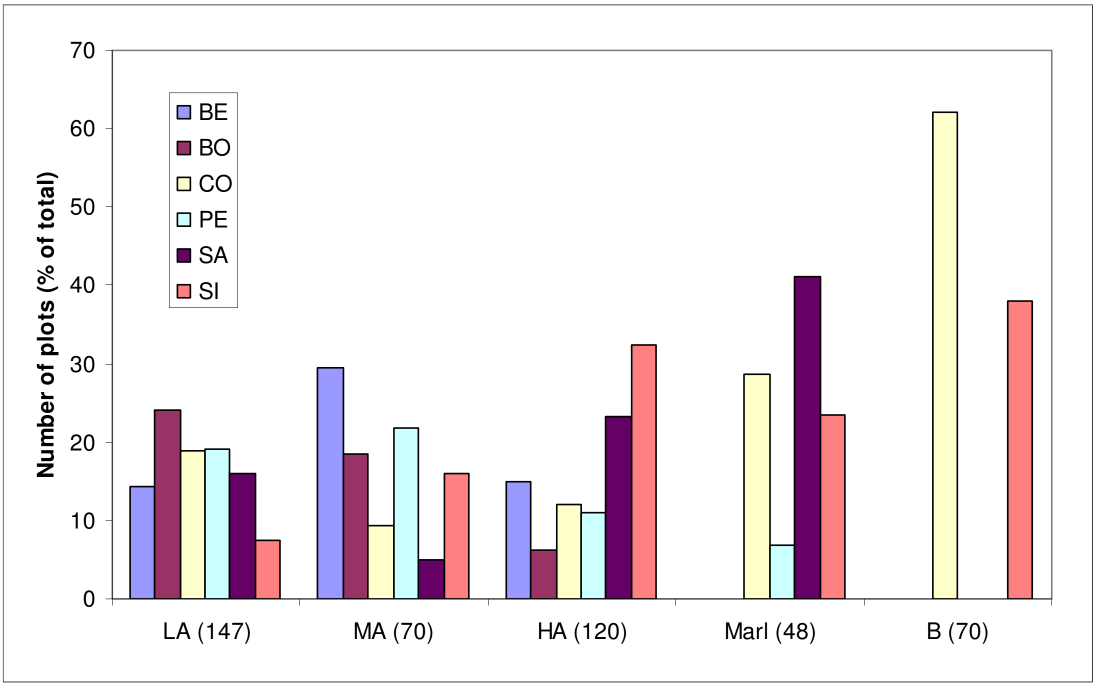
7.2 Analysis of agency data to explore habitat and hydromorphology

In an attempt to establish some linkages between ecology and hydromorphology, analysis was carried out at the Hab-Plot scale with several LHS components. It was reasoned that if fundamental ecological and hydromorphological components (macrophyte and substrate structure of the littoral zone) are recorded during LHS, then there should be some correlation between the two.

7.2.1 Lake type and substrate associations

The littoral substrate composition of 391 Hab-Plots was compared against geological type as defined by UKTAG. Figure 7.2 illustrates the percentage of Hab-Plots for which individual littoral substrate components (bedrock (BE), boulder (BO), cobble (CO), pebble (PE), sand (SA) and silt SI)) exceed 40 % littoral zone cover. The analysis could only be carried out for the limited number of surveys that included detailed substrate texture data following the most recent modifications of the LHS field form.

Figure 7.2 Percentage of Hab-Plots for each lake type for which areal cover of littoral substrate components exceeds 40 %

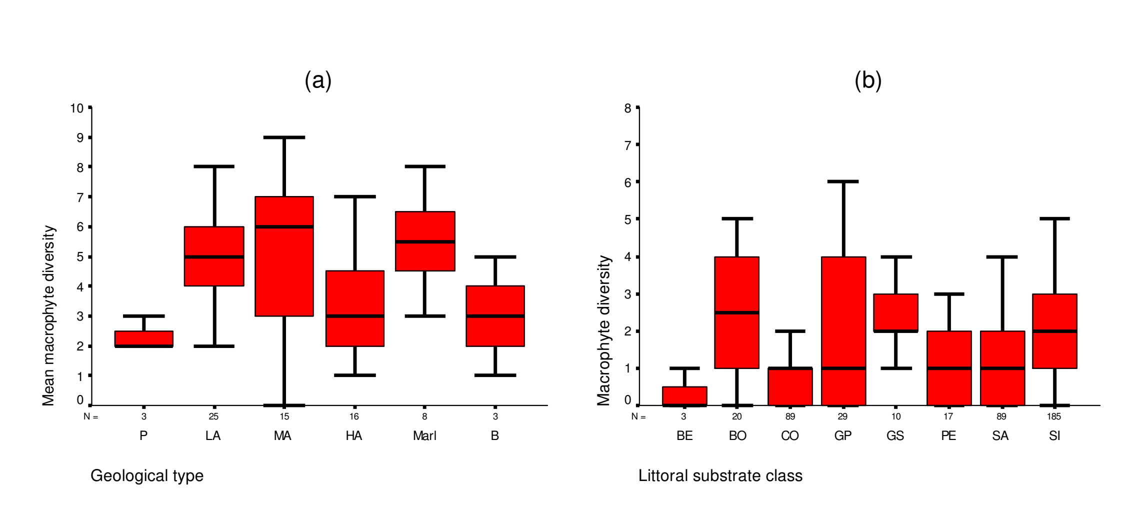


The variation in littoral zone structure between different lake types is clear. The littoral zones of LA lakes are characterised by having a range of substrate classes similar in distribution. This is perhaps an indicator of the large variety of energy conditions that characterise the majority of LA shore zones. The relatively high wind and wave energies of many LA lakes are illustrated by these Hab-Plots containing the highest proportions of both boulder and cobble substrates, and the lowest proportion of silts. Conversely, HA lakes are characterised more by lower wave energies and gentler topology, and this is reflected in the high proportion of small-grained substrates in the littoral zones therein.

7.2.2 ***Substrate and macrophyte associations***

The distribution of macrophyte structural diversity, sorted by lake type and predominant littoral substrate class is given in Figure 7.3 (a) and (b). Here, littoral macrophyte diversity is defined as the number of different structural types that have an areal cover of 10 % or more (with a theoretical maximum of 10). Median values are given by the solid horizontal lines, boxes represent the first and third quartiles, and whiskers represent the largest and smallest values that are less than 1.5 box lengths from either end of the box.

Figure 7.3 Box and whisker plot of (a) mean littoral macrophyte diversity for each geological lake type and (b) macrophyte diversities sorted by littoral substrate class



The differences in littoral macrophyte diversity between lake types are clear, with both the medians and ranges varying between types. Peat lakes have both the smallest median diversity, and the most limited range, while MA lakes have the highest median value, and widest range. Similarly, littoral macrophyte diversities also show variation when sorted by the predominant littoral substrate occurring at a particular Hab-Plot. The highest median values for littoral macrophyte diversity occur for boulder and gravel/sand substrates.

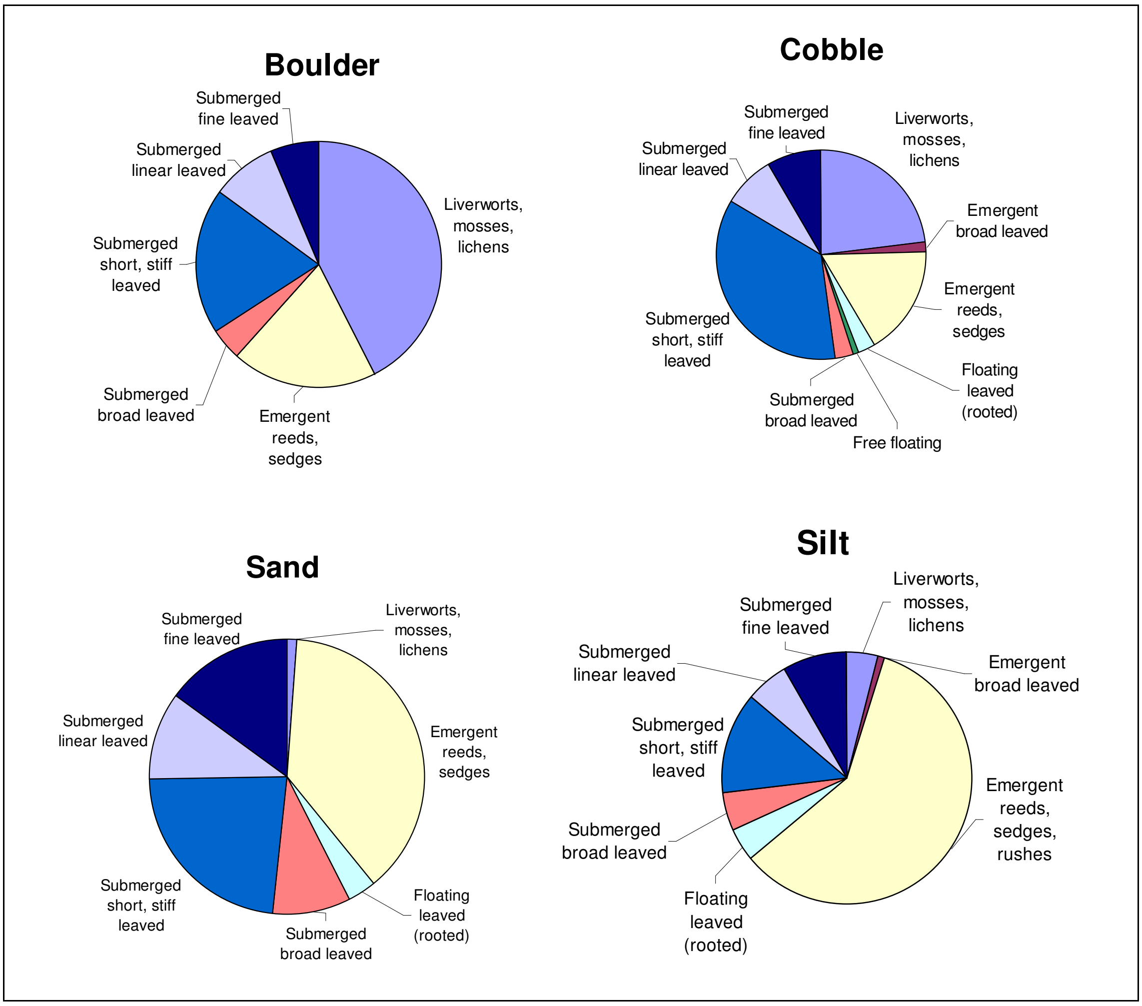
Further analysis was undertaken to associate substrate classes with macrophyte communities within Hab-Plots. Figure 7.4 illustrates the distribution of various littoral macrophyte structural types for selected predominant littoral substrate classes (boulder, cobble, sand and silt in 47, 109, 87 and 122 sites respectively), and indicates that substrate conditions influence the structure and cover of littoral macrophyte communities. In plots where boulders dominated, liverworts, mosses and lichens make up most (have more cover than any other macrophyte structural class) of the littoral zone. Littoral zones with predominantly cobble substrates also have a large proportion of liverworts, mosses and lichens, but are typically dominated by submerged, short, stiff-leaved macrophytes (*Littorella* type). With smaller-grained littoral substrates, emergent reeds, sedges and rushes dominate, with submerged short, stiff leaved types again important.

7.3 Linking LHS with WFD biological quality elements

The availability of complementary biological data is key to this process; however, whilst considerable work is focusing on the development of biological classification tools, access to such data has been very problematic. The only biological data that are available to date are values of macrophyte indices for 52 lakes supplied by N. Willby (Stirling University). The variation of each of these indices with LHMS score was examined across the full sample of lakes, and across four sub-samples distinguished on the basis of geological lake type (P, LA, MA, HA). The sample - and especially some of the sub-samples - was small, and relationships were generally weak. However, some tentative trends indicated by the data (Figure 7.5) are that in

LA lakes, species richness and cover decline with increasing habitat modification. Note also that predominant littoral substrate may well also provide a measure of substrate heterogeneity.

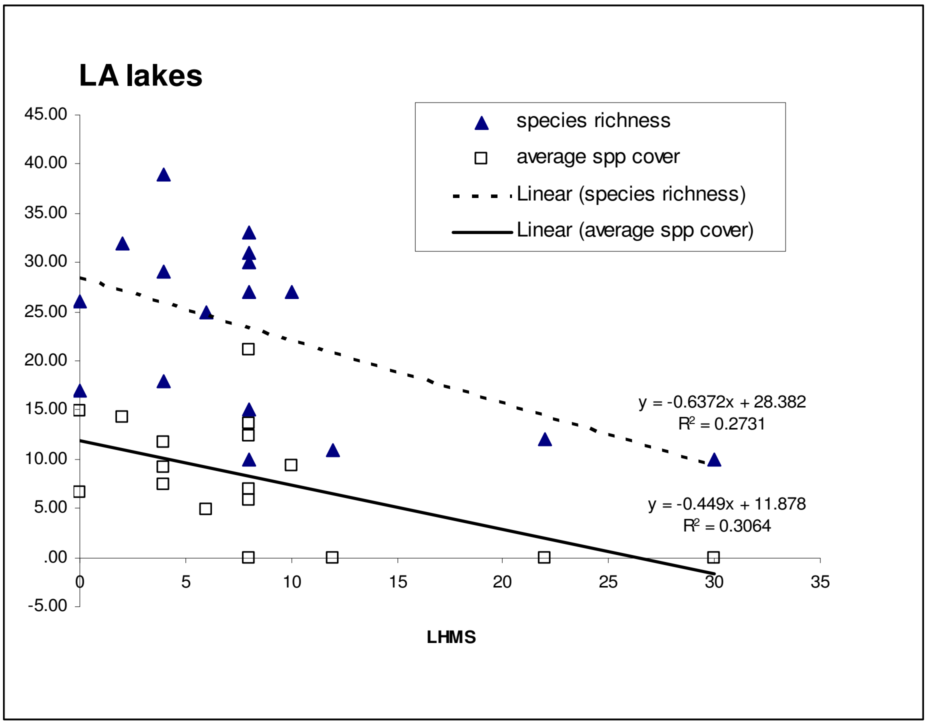
Figure 7.4 Distribution of littoral macrophyte structural types for selected predominant substrate classes

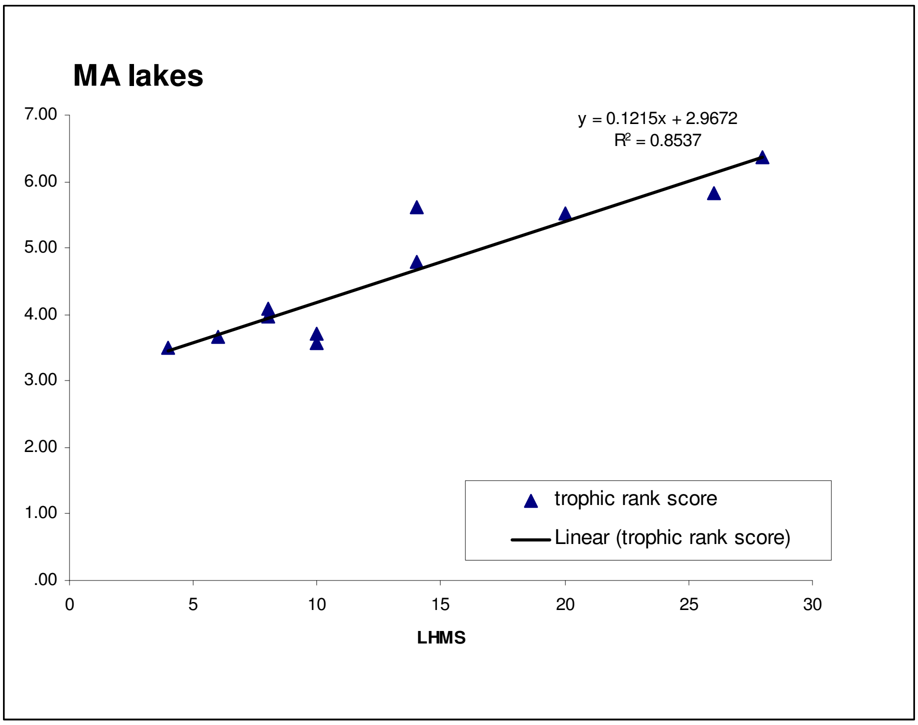


Although species richness shows a similar trend for HA lakes, there is a small tendency for cover to increase with modification in this type. Willby (pers comm.) has developed multiple macrophyte-based indices of environmental disturbance (e.g., “reltol” and “relsens”) and nutrient pressure (e.g. trophic rank) as part of the LEAFPACs Project. The index “reltol”, which reflects tolerance to water level change, increases with increasing habitat modification. The index “relsens” (relative sensitivity to water level change) declines with increasing habitat modification. Finally, trophic rank score tends to increase with LHMS in all lake types except LA, and for illustrative purposes the strong correlation between trophic rank and LHMS (Figure 7.5b) is most likely due to nutrient loadings associated with intensive land-uses within the riparian zones and catchments of these lakes. Willby (pers comm..) observed similarly strong correlation between trophic rank and hydromophology pressures on river systems suggesting nutrient concentrations are the proximate indicator of system pressure when assessed alongside hydromorphology, but in practice many of these effects are inseparable.

This preliminary work in comparing floristic data from macrophyte surveys with LHS metrics is entirely dependent on data availability, and it is proposed that this matter should be pursued vigorously in Phase 3 of the LHS development programme.

Figure 7.5 Relationship between LHMS scores and (a) species richness and species cover in LA lakes and (b) trophic rank in MA lakes





8 FUTURE DEVELOPMENT ISSUES

Significant developments in the LHS method were confirmed by the Phase 2 project. The field protocol and manual underwent considerable revision and iterative upgrade compared with the original Phase 1 procedures (SNIFFER Report WFD40, 2004). Training workshops were held throughout the UK, and involved over 70 environment and conservation agency staff. These workshops were an invaluable two-way exchange and both the instruction given and feedback returned have been vital for strengthening the procedure and its guidelines, and ensuring the highest quality of survey undertaken by environmental and conservation agency field teams. The July 2005 field form (version 3.0) was considered to be highly robust and capable of delivering all the necessary input data for WFD decision-support systems (cf. SNIFFER Report WFD49a, 2005). However, time and storage space constraints mean that further work is needed in terms of the creation of a fully comprehensive photo-gallery to accompany the manual, or indeed some form of web-based platform that could be internationally accessible.

In terms of the future development of the method there are a number of possible directions. Probably the most important element is to demonstrate comprehensively the ecological relevance of the LHS protocol. Both the Phase 1 and Phase 2 LHS projects have been constrained by the limited availability of suitable ecological data. Such data should ideally be drawn from a range of WFD biological quality elements including phytobenthos, macrophytes, benthic macroinvertebrates and fish – along with other biological groups such as amphibians, mammals and birds – which are typically the concern of other national and international regulations (e.g. EU Birds and Habitats Directive). Whilst such data should be more widely available in coming months, it is clear that in Northern Ireland considerable efforts have been made to harmonise biological sampling with LHS survey (C. Armstrong, *pers. comm.*). It would make obvious sense to pursue these data in any Phase 3.

Further work is required to determine relationships between LHMS scores and ecological status. This necessitates calibration against biological data to explore ideas such as the 'limits of acceptable change', linked to thresholds between species and communities and the degree of hydromorphological disruption. As a consequence of the classification and monitoring duties that the WFD places on Member States, access to high quality hydromorphological and biological data will improve, and there is clear potential to utilise the experiences of other European partners adopting the LHS approach (T. Peltier, Agence de L'eu, *pers comm.*). It is envisaged that better calibrated and validated metrics will then be able to contribute to fulfil decision-support functions relevant to regulators, and for the design of the 'programmes of measures' developed for remediation purposes.

In terms of UK applications, there is scope to execute and evaluate the performance of the method within a wider range of lake types. Thus far, relatively rare systems such as brackish lakes are only poorly represented within the database. Since the overall sampling programme for lake selection for LHS survey was typically driven by managerial/agency decisions relating to biological monitoring, a synoptic assessment of the overall condition of UK standing waters would require a spatially-balanced probability sample of lakes. 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).

There is still much to be done in demonstrating the suitability of the LHS approach as a contribution to the development of a CEN standard on the hydromorphological assessment of standing waters. However, present understanding indicates that no standard lake monitoring protocol is available elsewhere in Europe. During 2004 the first trials of LHS outside the UK were undertaken in France, Germany, and Finland. Further work took place in 2005 in Ireland, Finland, France, the Netherlands, Poland and Serbia-Montenegro. The findings of the 2005 trials were reviewed at the December LHS Workshop presented in Appendix 2, and selected results from France, Serbia-Montenegro and Poland (though these data were not presented at the workshop) are presented in Table 8.1. The consensus of this workshop was that LHS is a very promising tool which may be able to fill the vacuum of appropriate tools elsewhere in Europe. Indeed, an extended campaign of LHS application in France, where the procedure has been translated into French (l'hydromorphologie des lacs), will commence in the summer of 2006 (T. Peltier, Agence de L'eu, *pers. comm.*). Translations of the manual are completed or under way in Serbia-Montenegro and Poland. With this broader experience from field trials, it is anticipated that LHS could contribute to the development of a European standard for assessing the hydromorphology of standing waters under the aegis of the CEN. Promoting further exchange with European practitioners is therefore seen as an important element of any Phase 3 development programme.

Training and accreditation remain important issues for any Phase 3 LHS project and the experience of Phase 2 (with the very positive feedback of most surveyors), suggested that though very valuable, a one day training course for LHS is too brief. Whereas the accreditation process for RHS is now five days, it is suggested that LHS accreditation would be optimally served by a training event of three days. The additional days would enable staff to undertake surveys on more than one lake type (e.g. contrasting upland low productivity sites with higher productivity as well as a fuller range of hydromorphological pressures). Persons being trained would be expected to complete surveys of several sites and understand the mechanics of metric collection and the extraction of information from the LHS database. There would also need to be some form of assessment, whereby candidate surveyors undertake an accreditation test – where accreditation (for a period of three to five years) would ultimately be necessary before surveyors' results can be added into the LHS database.

In terms of database development, considerable advances were made in the Phase 2 project including the ability to handle multiple Hab-Plot inputs, and continued evolution of quality assurance process, but there is considerable scope to move this work on. In particular a comprehensive audit of the existing data would be valuable, and there may be considerable advantage in migrating to a double-entry protocol where sites are entered twice, and anomalies flagged before entry into a master data set. It would also be desirable to incorporate photographs and automate the metric generation processes. In principle, with a suitable user-friendly interface, it would be possible for field surveyors to enter data directly into a database format, inclusive of automatic metric generation and protocols for handling digital photographs which would yield immediately diagnostic data profiles for surveyed lakes.

Finally, scope remains to develop further the role of remote sensing, especially in the context of a rapid pressure assessment tool. Such schemes are feasible only with the delivery of new digital mapping products, such as Mastermap® and Digimap®, and the wider availability of digital colour aerial photography and GIS data. SNIFFER project WFD49e (A GIS-based geomorphorphic channel typology) provides an illustration of this complimentary approach.

Table 8.1 Details and characteristics of 12 European surveys carried out during 2005

Country	Name	Surveyor	UK TAG 'Lake type'	Water body type	Surface area (km^2)	Max depth (m)	# of Hab-Plots surveyed	LHMS
France	La mare a Goraiux	Agence de l'eau Artois Picardie (AEAP)	Medium Alkalinity	Natural lowered	0.5	1.3	10	**18**
	L'etang du Vignoble		-	-	-	2.5	10	**20**
	Les etangs d'Ardres		Peat	Natural raised	0.8	-	10	**16**
	Le lac du Val Joly		-	Natural raised	-	5.3	10	**14**
	Etangs Romelaere		Peat		-	2.7	10	14
Poland	Jezioro Malta	ACAV Poznen	High Alkalinity	Impoundment	0.6	5	10	**30**
	Jezioro Rusałka		High Alkalinity	Impoundment	0.4	9	10	**26**
	Jezioro Brdowskie		Medium Alkalinity	Natural unmodified	1.9	4.9	10	**22**
	Jezioro Przedecz		High Alkalinity	Natural raised	0.9	1.8	10	**20**
Montenegro	Crno Jezero (north basin)	University of Novi Sad, Serbia and Montenegro	Low Alkalinity	Natural unmodified	1.4	50	10	**8**
	Crno Jezero (south basin)		Low Alkalinity	Natural unmodified	0.2	25	10	**12**
	Vrazije Jezero		Low Alkalinity	Natural unmodified	0.3	10.6	10	16

Note: 'Lake Type' is the geological class based on the UK TAG Reporting Typology (UK TAG 2004). Future versions of the form will allow entry of the lake type as specified by the EC state in which the survey takes place. Dashes (-) indicates those variables not defined by surveyors.

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APPENDICES

Appendix 1 March 2005 workshop minutes

LAKE HABITAT SURVEY (LHS) AS AN ECOLOGICALLY RELEVANT TOOL

Thistle Hotel, Edinburgh, 30/31 March 2005.

Attendees:

Name (initials)	Affiliation	E-mail
Phil Boon (PB) - *Chairman*	SNH	phil.boon@snh.gov.uk
Angus Tree (AT)	SNH	angus.tree@snh.gov.uk
Gina Martin (GM)	SNIFFER	gina@sniffer.org.uk
Ian Fozzard (IF)	SEPA	ian.fozzard@sepa.org.uk
Dave Corbelli (DC)	SEPA	david.corbelli@sepa.org.uk
Julie Tuck (JT)	SEPA	julie.tuck@sepa.org.uk
June Graham (JG)	SEPA	
Stewart Clarke (SC)	English Nature	stewart.clarke@english-nature.org.uk
Deirdre Quinn (DQ)	EHS	deirdre.quinn@doeni.gov.uk
Colin Armstrong (CA)	EHS	colin.armstrong@doeni.gov.uk
Geoff Phillips (GP)	Environment Agency	geoff.phillips@environment-agency.gov.uk
Jo-Anne Pitt (JP)	Environment Agency	jo-anne.pitt@environment-agency.gov.uk
Ian Winfield (IW)	Centre for Ecology & Hydrology	ijw@ceh.ac.uk
Ken Irvine (KI)	Trinity College, Dublin	kirvine@tcd.ie
Nigel Willby (NW)	University of Stirling	n.j.willby@stir.ac.uk
John Rowan (JR)	University of Dundee	j.s.rowan@dundee.ac.uk
Olivia Bragg (OB)	University of Dundee	o.m.bragg@dundee.ac.uk
Margriet Schoor (MS)	RIZA	m.schoor@riza.rws.minvenw.nl
Iain Malcolm (IM)	Fisheries Research Services	
Margaret Palmer (MP)	Independent Consultant	

EHS Environment and Heritage Service, Northern Ireland
SNH Scottish Natural Heritage
SNIFFER Scotland and Northern Ireland Forum for Environmental Research
SEPA Scottish Environment Protection Agency

INTRODUCTION (PB)

The need to develop LHS arises in the context of the EU Water Framework and Habitats Directives, as well as the wider framework of lake management and restoration.

LHS is envisaged as a multi-functional tool that will both meet the needs of UK conservation and environment agencies, and be relevant to a wider European audience through contributing to the development of a CEN standard.

Initial work involved a literature review and scoping study. A contract for Phase 1 of LHS development was let to Dundee University in March 2004. Surveyors from the Environment Agency, SEPA, CEH and Dundee University used the method at around 300 lakes, and the outcome was presented at a workshop (participants from UK, European partners and USA) in October 2004.

LHS Phase 2 will commence on 01 April 2005. This will involve:

- input from ecological consultants Nigel Willby (macrophytes), Ken Irvine (macroinvertebrates) and Ian Winfield (fish);
- completion of the analysis of 2004 field results;
- new field trials to refine protocol, principally with respect to survey strategy;
- further examination of links between hydromorphology and ecology;
- examination of potential for incorporating remote sensing techniques; and
- possible trials in other European countries.

By the end of the project (February 2006) the following should be in place

- a final version of the LHS protocol
- proposals for creating a national LHS database;
- proposals for developing a training and accreditation scheme; and
- a core method for contributing to a CEN standard.

The European aspects of the work are important, especially in the context of WFD Annex V. Several countries have expressed interest in collaborating on this: Finland, France and Ireland have made fairly firm commitments to involvement this year. There will be a CEN workshop in December 2005 to consider the results from Phase 2.

Aims of the workshop:

- to review the physical habitat requirements of lake biota;
- to examine how well these are recorded on the present LHS survey form; and
- to propose changes to the survey form accordingly.

Session 1 – Physical habitats for lake biota

<u>Lake Habitat Survey and aquatic macrophytes</u> (Margaret Palmer)

1. LHS could contribute to WFD implementation (hydromorphological classification), understanding the JNCC lake classification, using LACON (Lake Assessment for Conservation, partially equivalent to SERCON for rivers), and implementing Common Standards Monitoring of sites designated for nature conservation.

2. The LHS form incorporates all principal habitat features influencing aquatic macrophyte assemblages except salinity. A decision is required as to whether or not LHS should be applicable to brackish lakes.
3. All of the "missing links" (i.e. habitat features that were not taken into account in the multivariate analysis) in the JNCC classification and most of the habitat information required for LACON are covered by the current version of the LHS form. A concern with both the JNCC lake classification and LACON is that neither allows departure from reference condition adequately to be assessed.

<u>Aquatic and wetland plants</u> (Nigel Willby)

1. Work on amalgamated data collected during conservation agency lake surveys, together with results of new surveys, has found there is a shortage of physical habitat data to link with macrophyte data, other than those contained in the UKLakes database. However, much can be deduced from the vegetation itself; e.g. reduced habitat quality might be inferred from the absence of certain combinations of species (functional groups).
2. Regulation generally enhances species richness, and the effect is greatest at moderate to low alkalinity. The differential between sensitive and tolerant species increases as alkalinity declines.

<u>Discussion (macrophytes)</u>

Topics raised were:

- water level regulation – surrogates are recorded by LHS, but there is potential for obtaining real data for reservoirs and in conjunction with future abstraction licensing; some macrophyte species are supported by artificial water level regimes;
- sediment build-up, whether or not promoted by macrophytes, may mask effects of change in water level regime; and
- wind exposure – probably influences cover rather than species complement.

<u>The response of macro-invertebrates to lake hydromorphology</u> (Ken Irvine)

1. Sampling of lake invertebrates is difficult because of the variety of micro/meso-habitats, but samples from different habitats in the same lake appear to be more similar than samples from the same habitat in different lakes.
2. The important WFD hydromorphological quality elements are depth variation because of its influence on stratification and thus on profundal (not littoral) invertebrates; and sediments which are important for food, etc.
3. Slope may not be relevant since macrophytes and sediment structure may provide a surrogate; whilst transitional areas (ecotones) are discussed by neither WFD nor LHS; their boundaries may fluctuate.

<u>Discussion (invertebrates)</u>

- Particle size and presence of plants are the key aspects.
- For LHS, possibilities for recording meso-habitats directly, and for using macrophytes to indicate the distribution of abiotic habitats, were explored.

- The existing protocol was preferred, since it avoids the difficulty of training surveyors to recognise plants or habitats reliably in the field, but nonetheless returns statistically valid information on the range of available habitats.
- Ecological boundary criteria have been discussed recently by the Lakes Task Team.

<u>Physical habitats for lake fish in the littoral zone</u> (Ian Winfield)

1. Fish move between littoral and open water habitats in order to feed, avoid predation and reproduce. Different species use the littoral in different ways, exhibiting different diel, seasonal and ontogenetic patterns.
2. The five major threats to fish are eutrophication, siltation, water level variation, species introductions and shoreline developments.
3. Management approaches may be general to the lake or specific to fish in the littoral zone.

<u>Discussion</u> (fish)

- For calibration of LHS habitat modification scores, fish could be a good choice because they use the whole water body, but an impractical choice because there are many fishless lochs.
- The meso-habitats approach is attractive but would not be useful for fish because they are long-lived, they move, and spawning requirements are species-specific and not comprehensively documented.
- On the other hand, repeat LHS surveys indicating change in sediment and macrophyte habitat quality might be used to infer changes in conditions for fish.
- The relative merits were explored of the current unbiased morphological approach of LHS and a system that would record habitat features chosen to reflect specific requirements of individual fish species (e.g. locations for egg-laying).
- The capability of LHS in flagging catchment problems leading to sediment transport into the lake (e.g. Bassenthwaite Lake) was queried; a tool is needed to improve WFD reporting and LHS might be the appropriate one?

<u>General discussion</u>

<u>*Water quality*</u>

- LHS should be capable of application to brackish/saline lakes; although there are relatively few examples of this type, some are important for conservation reasons.
- LHS could use salinity data from water quality monitoring. Measuring salinity profiles would identify a halocline at some sites, but it is questionable whether this should fall within the remit of habitat survey.
- LHS incorporates the collection of some water quality (and other) data at an index site. The information is needed, but it is difficult to work out whether its collection should be part of habitat survey, which was not originally envisaged as a comprehensive lake survey. Nonetheless, there are strong arguments

for collecting physical, chemical and biological data from a lake at the same time.

Hydrology

- Information on hydrology collected within LHS is useful because water level data are generally lacking, and we need to develop our understanding of the relationships between morphology and hydrology in lakes. Since LHS can deliver information only for the day of survey, records of structures that modify lake hydrology (e.g. dams, sluices) are potentially more useful than water level observations.
- Information on connectivity (reflecting e.g. the ease with which fish can move into side channels) is especially important for lowland lakes.
- In Holland it is considered important to know mean summer and winter water levels.

Habitats

- It was agreed that direct recording of a suite of physical features that can subsequently be grouped in different ways is preferred to an approach that pre-supposes the existence of meso-habitats.
- Analyses to relate LHS data to macrophyte and other biological data should have high priority, since most ecology operates at a finer spatial scale than LHS but habitat quality and modification scores ought nonetheless to be meaningful.
- On the other hand a fairly broad habitat assessment is needed for conservation assessment, since the objective is to show that the physical condition of the site is appropriate for a conservation site.
- A format with a simple core and bolt-on modules was suggested.
- LHS collects just about all of the information that is needed, but it is not clear whether all needs to be collected every time or how often it should be used.
- The question of how far LHS should extend to landward was discussed. Several people were confused about the functional status of the riparian zone (e.g. is it ever flooded?, is there a one-way or two-way hydrological connection between riparian zone and lake?, how much of the riparian is an aquatic transition zone?). Detailed guidance should be included in the manual.
- LHS relies on surveyors recognising signs of abnormal sedimentation (e.g. eroding cliffs, gravel overlain by silt). Land Cover 2000 data might be a helpful (desk-based) source. Also, a possible need to collect a sediment core at the Index Site either within or in addition to LHS was suggested.
- A need was identified to make it clear which elements of the LHS form are necessary because they provide background information but are not surveyed in the field.

Session 2: Ensuring ecological relevance of the lhs survey protocol

LHS form section 1: Lake information and survey details

PAGE	ITEM	ISSUES
1	Catchment geology	Some of the typology data in UKLakes are incorrect, and there is an opportunity to use LHS to check this; suggestion to add a separate page (for UK use only) to record anomalies.
		Information on basin as well as catchment geology desirable but it may be more appropriate to deal with this when describing substrates.
2	Grid Reference	Despite practical difficulties for UK surveyors using paper maps and potential for subsequent conversion in database, locations to be recorded as latitude/longitude rather than OS grid reference (straightforward with GPS).
	Add?	Wind condition and direction.
	Add?	Space for more Hab-Plot locations.

LHS form section 2: Physical attributes

PAGE	ITEM	ISSUES
2-3	Order of sub-sections	Change order to: 2.1 Riparian zone; 2.2 Shore zone; 2.3 Littoral zone; 2.4 Human pressures.
2	2.1 Riparian zone	Vegetation structure to be recorded in 3 height categories, namely: >5m, 2-5m; <2m.
		Discard the terms “canopy layer”, “understorey” and “ground cover”
		Add option for dominant land cover in riparian zone “WL” – circle if reedbed.
	2.2 Shore zone: Bank face	Need definition of “boulder apron” in manual.
		Add proximity to an influent stream? This should cover the connectivity question and include ‘little seeps’ – need to record distance from any major inflow and any minor ‘streams’ that enter the Hab-Plot.
	2.2 Shore zone: Shore/beach	Shore material (discussed at length); only change proposed is to add “circle if compacted”. [the key feature for abnormality is “sedimentation over natural substrate” in Section 2.3; when invertebrate samples are taken, sediment types other than the dominant one will be ticked since the potential for spaces under stones is important; later possibility to develop a lakes equivalent of “geo-RHS” which is the geomorphological version of RHS designed for WFD flood morphology and includes more detail on substrate types].
		Evidence of shore geomorphological imbalance; use the term “active” (not erosion) to indicate that there is movement of sediments due to disequilibrium.
		Try to sort out anthropogenic impacts from natural processes; solution is probably to change wording in Manual.
		Under “shore vegetation structure” add “amphibious”.
		Reinstate recording of position of trashline (see page 5).
3	2.4 Littoral zone	Transpose “depth” and “distance”.
		Insert “natural” before “substrate”; add “circle if compacted”.
		Give more clarification of “sedimentation over natural substrate” in manual (do we mean ‘natural’ or ‘predominant’?); remove “BE” from this list; add “MA” for depositing marl, which doesn’t ‘roll’ and can resemble sediment over another substrate.
		Insert “littoral habitat features” before “odour”; are boulders double-recorded?;
		Insert “water” before “surface film”.

PAGE	ITEM	ISSUES
		Change “macrophytes” to “vegetation structure”; correct spelling of “areal”.
		Vegetation categories (discussed at length): remove “amphibious”; add “submerged short, stiff-leaved” to cover *Littorella*, *Lobelia* and *Isoetes*; add “floating rafts of vegetation (non-rooted emergents e.g. *Menyanthes*, *Phragmites*) or schwingmoor”; add “bacterial tufts”. Charophytes are described in manual as “fine-leaved”; distinguish plants with dissected leaves e.g. *Myriophyllum*; give explanatory line diagrams or photographs in manual.
		“Inundated terrestrial vegetation” is OK, but there are situations where the survey would be senseless when water level 1m too high because the whole Hab-Plot would be located above the banktop; need pragmatic approach, give appropriate advice in manual.
		There is an issue about applicability of LHS to Breckland meres and turloughs; possibly need to exclude non-permanent water bodies from LHS applicability range.
		PVI may be difficult to estimate, bathyscope required; may be implicit in combination of growth forms and areal cover (e.g. *Myriophyllum*/*Lemna* have low/zero PVI and high areal cover; to be trialled this year.
		Nuisance plant species: identification must be covered thoroughly in surveyor training, e.g. using voucher specimens and improved colour illustrations (N.B. *Crassula*), because important for surveyors to recognise and take precautions to avoid spreading these species (risk assessment).

LHS form section 3: Whole lake assessment

PAGE	ITEM	ISSUES
4	Heading	Change “extent of shoreline” to “extent of lake perimeter” because observations should relate to a wider belt than just the shoreline – in fact a zone from the water’s edge to the banktop plus 15 or 50m beyond.
	Bank construction	Hard and soft engineering to be explained more fully in manual; soft engineering includes deliberately planted willow saplings and earthmoving. Use of remote sensing vs. scanning from boat to be explored further this year.
	Pressures and non-natural land use	Change heading to “pressures and land-use”.
		Add “footpaths” to “roads or railways”.
	Erosion	The intention is to capture (and separate) erosion in littoral/banks (15m) and in the near catchment (50m); should include poaching by cattle; additional explanation to be given in manual.
	Wetland habitats	Delete “alders” and change some terms and order to read: emergent reedswamp; wet woodland; bog; fen/marsh; floating vegetation mats (of emergent vegetation attached to shore); other.

page	item	issues
4	Other natural habitats	Change heading to "other habitats".
5	3.2 Lake site activities/pressures	Add: "wildfowling" and "fish stocking" (the latter, for example, deduced from presence of hatchery or chute for releasing fish, or from contact with local anglers, EA, SEPA, etc.).
	3.3 Landform features	Comment that it may be difficult to estimate % cover, but this was reported to be possible in practice.
		Add information on the outlet to indicate why the lake is there – e.g. sill or moraine. Dundee to explore need for recording outlet geometry e.g. width only or cross-section, and report after summer 2005.
	3.4 Animals	Correct spelling of "hand" in heading.
		Suggestion that examples should be removed from form, but more extensive guidance given in manual. [Coot are macrophyte-dependent; presence of large numbers of some birds likely to affect nutrient loading where individuals feed elsewhere and then bring nutrients back to the lake – e.g. Canada geese, black-headed gull colonies should be recorded; also invasives; animals indicative of an important feature or of conservation interest; idea that RSPB impose water level controls for birds]
		Due to lack of time, further consideration of this section was referred to Steering Group. *At the LHS Steering Group meeting it was agreed that this section should be removed, together with the relevant guidance in the manual. Instead, Section 6 ('Further comments') could include notes on anything that may be having a direct or indirect effect on lake morphology, or may indicate morphological conditions - including animal-related features: e.g. presence of Canada geese, large flocks of swans or coots, etc*.

LHS form section 4: Hydrology and sediment regime

PAGE	ITEM	ISSUES
5	General	Leave this section more or less as it is; however, there are unsatisfactory aspects that might be addressed in manual and/or training, detailed below.
		Information on e.g. principal uses and water level fluctuations will probably come from sources other than field survey; consider removing such items from form; SNIFFER Project WFD48 (lakes elements also let to Dundee University) should feed into this.
	Vertical range of water level fluctuation	May not be obvious in the field; one approach is to record conditions (e.g. drawdown) on the day of survey; or flag as a point to be investigated before survey; or provide guidance for on-site estimates.
		Recording position of trashline is useful and should be reinstated in Hab-Plot survey.
	Water management structures	Some fish passes (and whether or not they work) are not obvious in the field; information on hydro-power structures is probably accessible from other sources, so the most important information to record here is "unofficial" activity often associated with fisheries management.

Lake profile information at Index Site

Not discussed due to lack of time. *Following the workshop, the LHS Steering Group agreed the following changes to the LHS survey form:*

(a) Specify that Index Site data MUST be collected between July and September.

(b) Remove alkalinity

(c) Remove pH

(d) Change 'Secchi disk' to 'Secchi disc'

It was also agreed that LHS was applicable to brackish lakes, but that no water chemistry data need be collected; and specifically that conductivity should not be added to the survey form.

Appendix 2 December 2005 workshop minutes

LAKE HABITAT SURVEY, PHASE 2 Workshop

Edinburgh Training Centre, Edinburgh, 23/24th December 2005

Attendees:

Name (initials)	**Affiliation**	**E-mail**
Phil Boon (PB) - *Chairman*	SNH	phil.boon@snh.gov.uk
Mary Hennessy (MH)	SNH	mary.hennessy@snh.gov.uk
Alison Lee (AL)	SNH	alison.lee@snh.gov.uk
Gina Martin (GM)	SNIFFER	gina@sniffer.org.uk
Kirsty Irving (KI)	SNIFFER	kirsty@sniffer.org.uk
Ian Fozzard (IF)	SEPA	ian.fozzard@sepa.org.uk
Dave Corbelli (DC)	SEPA	david.corbelli@sepa.org.uk
Julie Tuck (JT)	SEPA	julie.tuck@sepa.org.uk
Stewart Clarke (SC)	English Nature	stewart.clarke@english-nature.org.uk
David Smith (DS)	Environment Agency	david.c.smith@environment.agency.gov.uk
Colin Armstrong (CA)	EHS	colin.armstrong@doeni.gov.uk
Mary Gallagher (MG)	EHS	mary.gallagher@doeni.gov.uk
Wayne Trodd (WT)	EPA	w.trodd@epa.ie
Catherine Bradley (CB)	EPA	c.bradley@epa.ie
John Rowan (JR)	University of Dundee	j.s.rowan@dundee.ac.uk
Iain Soutar (IS)	University of Dundee	i.soutar@dundee.ac.uk
Margriet Schoor (MS)	RIZA	m.schoor@riza.rws.minvenw.nl
Jean Prygiel (JP)	Agence de l'eau Artois Picardie, France	j.prygiel@eau-artois-picardie.fr
Thomas Pelte (TP)	Agence de l'Eau Rhone Mediterranée & Corse, France	thomas.pelte@eaurmc.fr
Hania Soszka (HS)	Institute of Environmental Protection, Poland	hasoszka@ios.edu.pl
Snezana Radulovic (SR)	University of Novi Sad Serbia and Montenegro	snezar@ib.ns.ac.yu

SNH Scottish Natural Heritage
SNIFFER Scotland and Northern Ireland Forum for Environmental Research
SEPA Scottish Environment Protection Agency
EHS Environment and Heritage Service (NI)
RIZA Institute for Inland Water Management and Waste Water Treatment, The Netherlands
EPA Environment Protection Agency (Republic of Ireland)

Summary of meeting minutes

Note: This document is intended as a summary minute only. Some discussion points have been re-ordered to more appropriate locations to improve the clarity of this document.

Tuesday 13 December

Session 1: Introduction and content

PB, JR and DC gave brief introductions of the workshop agenda, a summary of LHS, links between LHS and the Water Framework Directive, and some other potential applications of LHS data and its associated database.

Session 2: Recent experiences of using LHS in the British Isles

DS, IF and CA gave summaries of the UK agencies' recent experiences with LHS, highlighting some of the problems and issues raised by surveyor teams. These issues were summarised for consideration in Session 5 (proposals for revising LHS protocol and survey form).

Session 3: Recent experiences of using LHS on the mainland of Europe

JP, MS, SR and HS gave overviews of their respective experiences of using LHS in France, The Netherlands, Montenegro, and Poland. AL presented on behalf of Antton Keto (Finnish Environmental Institute).

Principal issues raised were regional access problems, sampling strategies on lakes of varying size / complexity, lack of agreement between surveyors, and concerns about how summary metrics should be applied. PB noted that survey familiarity, achieved through training / accreditation, should overcome some of these problems. It was acknowledged that although flexibility is needed to cope with the natural variation of water bodies throughout Europe, there should be a limit to this flexibility if a European standard is to be produced.

Other more specific issues regarding methodology were summarised for consideration in Session 5 (proposals for revising LHS protocol and survey form).

Session 4: New research and development on the LHS protocol

JR presented the main developments on the LHS protocol in 2005, with particular focus on (a) survey strategy, (b) use of remote sensing data, (c) links between morphology and ecology, and (d) development of metrics. In general, feedback from field practitioners throughout the 2005 field season was positive.

Considerable interest was focused on the issue of survey strategy (size, positioning and number of Hab-Plots). Opinions ranged widely from MS's concerns that 10 Hab-Plots might be excessive in the case of the Netherlands because of the perceived morphological homogeneity of water bodies in that country, to other views (e.g. IF) that 10 Hab-Plots may be insufficient on large complex lakes, or where the conservation/management interest of a site is focused on a small area which might not be sampled in the standard protocol. JR pointed out that the protocol has been applied on several large lochs (Loch Lomond, Lough Neagh), and seems to be robust at that scale. SC believed that if Hab-Plots are regarded as sample locations rather than discrete surveys in their own right, there should be no problem in using additional plots (above a standard of 10) to complement the surveys on larger water bodies. It was concluded that a standard 10-plot survey (regardless of size) is the best option, as it removes the need for *a priori* sampling considerations at the agency / practitioner end and simplifies metric calculation and statistical comparisons between different sites.

On the topic of sub-division of larger lakes, JR stated that division should be made only on the grounds of morphology, and not simply to break up the water body into manageable sub-units.

In relation to remote sensing, it was agreed that whilst the application of remote sensing is desirable, there remain practical limitations in what can be achieved. Also, infrastructural differences in the availability of resources and trained remote sensors between different agencies and different countries mean that remote sensing cannot yet be adopted as a viable stand-alone strategy. However, all delegates acknowledged that maps and aerial photographs can be important aids in the field, particularly in the perimeter survey section of the form.

SC suggested that the links between morphology and ecology in lakes are less direct than in rivers, and that morphology in lakes should be related to functional habitats before these habitats can be linked to particular biological quality elements. JR noted that the appropriate habitat data are recoded in LHS, but that ecological surveys relevant to the Hab-Plot scale of morphological sampling have not been made available from partner agencies in the UK. PB noted that a team from Cardiff University is looking at the interactions between riparian features and invertebrate communities as recorded during application of the River Habitat Survey (RHS), and contact could be made to ascertain if findings are relevant and can be adapted for application with LHS data. CA will also forward biological data from Northern Ireland surveys (collected at Hab-plot locations at time of LHS) to the Dundee team.

On the topic of summary metrics, IF and DS questioned the sensitivity of summary scores such as the Lake Habitat Modification Score (LHMS) and the Alteration of Lake Morphology Score (ALMS), the latter developed in SNIFFER Project WFD49a. JR pointed out that refining all the summary metrics from LHS remains a key priority and will be a focus in the remaining part of the project. Whilst the ALMS score is exclusively morphological, thus WFD compliant and logically a basis for setting environmental standards, the LHMS score is a broader index of environmental quality and better captures the essence of lake systems as a whole. However, all agreed on the need for further development of LHMS to capture issues such as the intensity and extent of different pressures and to re-consider the relative weighting of different component scores within the metric.

Wednesday 14th December

Session 5: Proposals for revising LHS protocol and survey form

Several changes to the survey protocol were suggested / agreed based on agency concerns. These are as follows:

Background data and general approach (Section 1)

The suggestion was made that those sections of the form that are required for derivation of metrics should be highlighted. However, others believed that doing so would encourage surveyors to omit those sections which are not mandatory. However, the manual should alert users to the importance of filling in all sections.

The issue of different national reporting typologies (under the WFD) was raised and it was agreed that guidance in the manual should help surveyors recognise that some aspects of the present LHS form e.g. 'lake type' – based on alkalinity / conductivity /

colour – are GB specific. It was agreed that, where available, additional information can be provided in section 7 of the form, as some countries (MS) have excellent morphometric databases e.g. the Netherlands.

It was agreed that island perimeters should be recorded in the 'lake information' section of the form, and the form / manual will be updated to provide a protocol for this. The term 'Lake perimeter + island perimeters' should be used. JR proposed that if the cumulative island perimeter length exceeds 10 % of the total length (shoreline perimeter length + island perimeter length), a Hab-Plot should be positioned therein.

Most of the surveyors believed that a photograph gallery of possible features / pressures would help in the field, and it was agreed that this will be a feature in future manuals.

Riparian zone (Section 2.1)

Some discussion centred on the issue of nuisance species. It was accepted that a European-wide list of nuisance (introduced) species is not practicable, and instead it was agreed that brief indicative lists should be developed for each Member State, and may even differ regionally. It was believed that surveyors would be aware of any significant nuisance species through familiarity of the area in question, and, if in doubt, should indicate the presence of potential nuisance species in the form.

Shore zone (Section 2.2)

The manual / form will be modified to allow more accurate recording of bank face height, down to 0.1 m, where the bank face is < 1 m. In the case of substrate size classes, it was suggested that size ranges also include a descriptive element (e.g. cobble = greater than size of tennis ball; boulder = greater than size of basketball etc.), as at present the numerical boundaries imply unwarranted precision. The LHS form and manual will change in response to this. Some attendees were also confused with the term 'geomorphological imbalance', and it was agreed to indicate clearly that artificially-induced imbalance is what is meant. Since other types of bank face erosion are seen elsewhere in Europe (muskrats are a problem in France), it was agreed to modify the form to permit the recording of 'biogenic erosion' where this mechanism is locally significant. As a response to confusion over the term 'sedimentation over natural substrate', it was agreed that this be changed to 'deposition', and indicate that this process includes substrates of all size classes (including boulders).

Littoral zone (Section 2.3)

'Depth of gravel/fines boundary' to be changed to 'Water depth of gravel/fines boundary' to remove ambiguity.

Littoral nuisance species are to be defined more clearly (as for riparian nuisance species - Section 2.1) in the manual, with encouragement to record notable animal species (e.g. zebra mussels) which are perceived as likely to be influencing significant habitat change.

SC suggested that there should be room on the form for recording a 'hydrosere' succession since it is an example of a noteworthy habitat type. SC will provide conceptual illustration of a hydrosere to allow identification in the field, and this will be incorporated into the manual. Space for recording on the form will be made, probably along with ‘emergent reeds/sedges/rushes’; i.e. ‘(tick if hydrosere is observed)’.

Concern was raised about the lack of an option for recording organic content along with littoral (and shore zone) substrate. It was agreed to include this in the substrate ‘fines’ categories (‘(Ring if organic mud)’).

Whole lake assessment (Section 3)

For assessing perimeter extents of pressures / habitat features on larger water bodies, it will be stressed in the survey guidance that Hab-Plots are visited before the whole-lake survey is attempted to ensure that no features are omitted by accident.

It was suggested (MG) that ‘pasture’ should be changed to ‘improved grassland’ to remove ambiguity, and this will be defined more clearly in the guidance.

IF suggested that poaching, as a pressure, is more important than several other pressures, but is not included as an option. This category will be reinstated.

Lake site activities / pressures (Section 3.2)

The following changes were agreed:

- Form / manual to be amended to allow for inclusion of chemical applications observed in France. ‘Liming’ to be changed to ‘Liming and other chemical applications’).
- Wildfowling to be defined more clearly to include more general ‘hunting’
- ‘Mortorboat sporting activities’ to be changed to ‘Motorboat activities’
- ‘Fish cages’ to be defined more clearly in manual, and another pressure (fish nets for commercial trapping) to be added.
- Golf courses to fall under ‘parks and gardens’ in manual.

Hydrology (Section 4)

Some features / processes were proposed for inclusion in this section on the basis of mainland Europe experiences (water level change resulting from beaver activity (HS), uncommon water level management regimes (MS)) and it was agreed that they should be recorded as ‘others’.

In some countries detailed physico-chemical data exist for lakes, and it was suggested that these could be used instead of the Index Site survey. JR stressed, however, that independent Index Site surveys should ideally be completed at the same time as other LHS components to ensure that seasonality does not affect data and that a synoptic survey of both littoral and pelagic habitats is achieved. The revised 2006 protocol is also likely to feature guidance on benthic sediment sampling (using either a grab (e.g. Ekmann or van Veen grabs) or a short mud-water interface sampler e.g. Jenkins corer). There was some concern that profiles should be taken at depths greater than 50 m, but the reduced information return (due to the high likelihood of stability by that depth) meant this increased effort would rarely be worthwhile.

Session 6: LHS Applications

This session was concerned with available LHS tools (e.g. LHMS, ALMS) and other LHS applications (e.g. WFD assessment, conservation assessment, and evaluating restoration potential). Discussion concerning the LHMS method centred around the possibility of weighting score components to acknowledge the perceived increased ecological impact that can arise from some pressures (hydrological control, for example). It was agreed that the appropriateness of weighting would be explored in ongoing analysis by the Dundee team. The positioning of thresholds (for use in classifying component scores) was also discussed, with IF noting that any scoring system should be 'ground-truthed' on the basis of macrophyte data. CA agreed to forward the results of biological sampling in Northern Ireland to the Dundee team with a view to developing LHMS and other potential summary metrics.

JR outlined an alternative scoring method (the Alteration to Lake Morphology Score, ALMS) developed in SNIFFER Project WD49a, which is based on morphological change only. IF suggested that this method, along with the complementary 'Sensitivity Typology' which takes the perceived resilience of a system into account, offers the most obvious way in which LHS data can contribute to the development of environmental standards. JR and PB agreed that although the ALMS method had considerable potential, there was insufficient time and resources within the WFD42 LHS project to test further the ALMS scheme.

In relation to applications for the Habitats Directive, PB suggested that an LHMS-type scoring method could be valuable in determining whether or not a site is in 'favourable condition'.

Session 7: The European Dimension

This session was concerned with developing a strategy to incorporate LHS developments into 'standard and best practice' methods embodied within CEN standards. Discussion centred around those 'core' elements of LHS that should be universally applied, optional extras that should be recommended, and consideration of lake types that might require further investigation before a CEN standard can be developed.

JR expressed concern that there was a lack of knowledge about what many EU Member States are doing in relation to the development of hydromorphological assessment protocols equivalent to LHS. PB will contact UK and international hydromorphology project leaders in his capacity as WFD42 Project Manager and Chair of the CEN Working Group on hydromorphology to try to clarify this situation.

Several specific lake types were considered for further testing of the LHS protocol to ensure method robustness, including brackish lakes, semi-arid / Mediterranean type lakes and seasonal systems such as Irish turloughs.

Conclusions

The main concluding points and actions were as follows:

1. Further analysis of data by the Dundee team will focus on survey strategy considerations, with particular attention to the number and spacing of Hab-Plots;

2. The summary metrics (LHMS in particular) need further refinement, especially to take into account issues of extent and intensity in relation to particular component pressures, and the relevant weighting of pressure categories;
3. Further discussion of the scope for a Phase III project (e.g. database development, training and accreditation) should be deferred to the WFD42 Steering Group;
4. PB to investigate the development status of lake hydromorphology assessment across all EU member states and amongst other European countries contributing to CEN standards.

Appendix 3 Summary of LHMS Score for LHS Surveys in the UK (2004-2005)

LAKE	WBID	entry num	Shore modification	Shore use	Lake pressures	Hydrology	Sediment	Invasive spp.	No. Hab-Plots	TOTAL LHMS
Akermoor Loch	**27347**	**51**	**0**	**2**	**2**	**0**	**0**	**2**	**3**	**6**
Aqualate Mere	**35724**	**176**	**2**	**4**	**2**	**0**	**0**	**0**	**4**	**8**
Ardnave Loch	**25899**	**44**	**0**	**4**	**0**	**0**	**0**	**4**	**4**	**8**
Ardnave Loch	**25899**	**224**	**0**	**8**	**0**	**0**	**4**	**0**	**10**	**12**
Ash Lough	**50102**	**16**	**0**	**6**	**2**	**0**	**0**	**0**	**4**	**8**
Ballylough Lake	**50126**	**197**	**8**	**8**	**8**	**0**	**4**	**0**	**10**	**28**
Barton Broad	**35655**	**80**	**0**	**4**	**8**	**0**	**0**	**0**	**18**	**12**
Bassenthwaite Lake	**28847**	**82**	**2**	**6**	**8**	**0**	**2**	**2**	**10**	**20**
Bassenthwaite Lake	**28847**	**179**	**4**	**6**	**8**	**0**	**0**	**0**	**4**	**18**
Betton Pool	**36566**	**133**	**2**	**8**	**6**	**0**	**0**	**0**	**4**	**16**
Blagdon Lake	**43135**	**153**	**2**	**6**	**8**	**8**	**4**	**0**	**10**	**28**
Bomere Pool	**36544**	**127**	**0**	**8**	**6**	**0**	**0**	**2**	**4**	**16**
Bough Beech Reservoir	**43602**	**126**	**2**	**6**	**6**	**8**	**4**	**4**	**4**	**30**
Branxholme Wester Loch	**27501**	**113**	**0**	**0**	**0**	**0**	**2**	**0**	**2**	**2**
Braxholme Easter Loch	**27494**	**118**	**0**	**6**	**2**	**0**	**0**	**4**	**3**	**12**
Broomlee Lough	**28172**	**144**	**0**	**2**	**0**	**0**	**4**	**0**	**10**	**6**
Budworth Mere	**32974**	**92**	**0**	**6**	**8**	**0**	**4**	**0**	**10**	**18**
Burrator Reservoir	**46279**	**136**	**4**	**6**	**0**	**8**	**4**	**2**	**4**	**24**
Buttermere	**29052**	**143**	**2**	**8**	**4**	**8**	**4**	**0**	**10**	**26**
Cameron Reservoir	**24588**	**90**	**6**	**6**	**6**	**8**	**4**	**0**	**10**	**30**
Cameron Reservoir	**24588**	**91**	**6**	**6**	**6**	**8**	**0**	**0**	**14**	**26**
Cashel Lough Upper	**50234**	**160**	**4**	**6**	**2**	**0**	**4**	**2**	**10**	**18**
Caslub	**18305**	**42**	**0**	**0**	**2**	**0**	**0**	**0**	**4**	**2**
Castle Semple Loch	**26392**	**69**	**2**	**6**	**4**	**6**	**4**	**4**	**4**	**26**
Chasewater	**36523**	**120**	**4**	**6**	**8**	**8**	**4**	**0**	**4**	**30**
Coldingham Loch	**26072**	**112**	**0**	**2**	**4**	**0**	**2**	**0**	**3**	**8**
Cole Mere	**35079**	**142**	**0**	**4**	**8**	**0**	**4**	**4**	**10**	**20**
Cole Mere	**35079**	**173**	**0**	**2**	**8**	**0**	**0**	**4**	**4**	**14**
Coniston Water	**29321**	**21**	**2**	**6**	**8**	**0**	**0**	**4**	**4**	**20**
Coolyermer Lough	**50089**	**20**	**0**	**0**	**4**	**0**	**0**	**0**	**4**	**4**
Cotswold Water Park	**41559**	**140**	**2**	**6**	**4**	**2**	**0**	**4**	**4**	**18**
Cotswold Water Park	**41559**	**177**	**2**	**6**	**6**	**2**	**4**	**4**	**10**	**24**
Cropston Reservoir	**36331**	**9**	**2**	**8**	**4**	**8**	**2**	**0**	**4**	**24**
Crosemere	**35211**	**175**	**0**	**6**	**2**	**0**	**0**	**0**	**4**	**8**
Crummock Water	**29000**	**167**	**0**	**6**	**0**	**6**	**0**	**0**	**4**	**12**
Derwent Reservoir	**28519**	**30**	**2**	**6**	**6**	**8**	**2**	**0**	**4**	**24**
Derwent Reservoir	**28519**	**191**	**4**	**8**	**6**	**8**	**2**	**0**	**4**	**28**
Derwent Reservoir	**28519**	**192**	**4**	**8**	**6**	**8**	**4**	**0**	**10**	**30**
Derwent Reservoir	**32359**	**146**	**4**	**8**	**6**	**8**	**4**	**0**	**10**	**30**
Derwent Reservoir	**32359**	**178**	**2**	**8**	**6**	**8**	**6**	**0**	**4**	**30**
Derwent Water	**28965**	**180**	**2**	**4**	**4**	**0**	**0**	**4**	**4**	**14**
Dozmary Pool	**46232**	**135**	**6**	**0**	**2**	**0**	**4**	**0**	**4**	**12**
Dozmary Pool	**46232**	**147**	**6**	**2**	**2**	**0**	**4**	**0**	**10**	**14**
Ellesmere/The mere	**34990**	**11**	**2**	**8**	**4**	**0**	**0**	**0**	**4**	**14**
Elter Water	**29222**	**4**	**0**	**6**	**0**	**0**	**2**	**0**	**4**	**8**
Ennerdale Lake	**29062**	**129**	**0**	**6**	**0**	**8**	**4**	**0**	**4**	**18**
Esthwaite Water	**29328**	**187**	**0**	**8**	**8**	**0**	**0**	**0**	**4**	**16**
Faldonside Loch	**27149**	**111**	**2**	**4**	**0**	**0**	**2**	**4**	**3**	**12**

Farmoor Reservoir	41011	139	8	8	8	6	0	0	4	30
Frensham Great Pond	44031	155	4	2	8	8	4	0	10	26
Gartmorn Dam	25038	1	0	0	4	6	0	0	4	10
Hanmer Mere	34780	3	0	4	0	0	4	0	4	8
Hatchet Pond	45652	101	2	4	4	0	4	0	10	14
Hatchet Pond	45652	138	0	8	4	0	4	2	4	18
Hickling Broad	35640	148	0	0	8	0	4	0	10	12
Hornsea Mere	30244	128	2	2	4	4	4	0	4	16
Hoselaw Loch	27170	53	0	8	0	0	2	0	4	10
Keenaghan Lough	50086	18	2	8	4	0	0	0	4	14
Kenfig Pool	42170	116	0	4	0	0	0	0	4	4
Kilcheran Loch	23675	122	0	0	0	0	0	0	3	0
Kilconquhar Loch	24894	193	4	4	2	0	4	0	10	14
Kilconquhar Loch	24894	194	4	2	2	0	0	2	4	10
Kiltybane Lough	50165	161	0	8	2	0	4	0	10	14
Kingside Loch	27476	54	0	4	2	8	4	0	4	18
Ladybower Reservioir	32459	22	8	6	2	6	2	0	4	24
Lake of Menteith	24919	68	0	8	4	0	0	0	4	12
Lake Vyrnwy	35568	171	6	6	8	6	0	2	4	28
Lattone Lough	50032	48	2	2	0	0	0	2	4	6
Lily Ponds	41602	26	0	0	0	0	0	0	4	0
Lindean Reservoir	27213	70	0	4	2	6	4	0	4	16
Lindores Loch	24422	195	2	6	4	0	0	0	4	12
Lindores Loch	24422	196	2	2	8	2	4	0	10	18
Little Sea	46102	157	0	2	2	0	0	0	9	4
Llyn Berwyn	38907	25	0	8	0	0	0	0	4	8
Llyn Cwellyn	34002	27	0	8	4	6	4	2	4	24
Llyn Egnant	38409	114	0	8	0	8	0	0	4	16
Llyn Eiddwen	38422	24	0	8	0	0	0	0	4	8
Llyn Gynon	38525	154	0	8	0	0	4	0	10	12
Llyn Hîr	38394	23	0	8	0	0	4	0	4	12
Llyn Ogwen	33803	125	0	6	8	8	4	0	4	26
Llyn Ogwen	33803	152	2	6	8	8	4	0	10	28
Llyn Padarn	33730	29	2	6	8	2	4	0	4	22
Llyn Padarn	33730	185	8	8	8	2	0	0	4	26
Llyn Padarn	33730	186	6	8	8	2	0	0	11	24
Llyn Penrhyn	32968	124	0	4	2	0	0	0	4	6
Llyn Tegid	34987	31	4	8	8	6	4	0	4	30
Llyn Tegid	34987	87	2	8	8	6	0	0	15	24
Llyn Tegid	34987	88	2	8	8	6	0	0	4	24
Llyn Teifi	38390	115	2	8	2	8	0	0	4	20
Llyn Teifi	38390	156	0	2	2	8	2	0	10	14
Loch a' Bhuird	15176	76	0	0	0	0	0	2	4	2
Loch à Mhill Aird	22685	123	0	4	0	0	0	0	2	4
Loch a' Mhuilinn	5619	49	0	2	0	0	0	0	3	2
Loch a' Phuill	23618	52	0	6	0	4	0	0	3	10
Loch Achnacloich	14403	35	0	4	0	0	0	0	4	4
Loch Achtriochtan	22893	50	0	6	2	0	0	0	3	8
Loch Ailsh	11338	72	0	4	4	0	0	0	4	8
Loch Aird an Sgairbh	19593	141	0	8	0	0	4	0	4	12
Loch an Lagain	12578	33	0	6	2	0	2	0	4	10
Loch Ascaig	8945	57	0	0	4	0	0	2	4	6
Loch Assynt	8751	61	0	0	2	0	0	4	4	6
Loch Ba	23206	79	0	0	0	0	0	0	12	0
Loch Ballygrant	26178	73	0	0	4	0	0	4	4	8
Loch Ballygrant	26178	228	0	0	2	0	4	0	10	6
Loch Bhasapoll	23445	121	0	4	0	0	0	0	3	4
Loch Borralan	11355	71	0	0	2	0	0	0	4	2
Loch Brandy	22051	32	0	0	0	0	0	0	4	0
Loch Brandy	22051	189	0	0	4	0	4	0	10	8
Loch Brandy	22051	190	0	0	4	0	4	0	10	8

Loch Brora (mid)	**11747**	**43**	**0**	**0**	**4**	**0**	**0**	**0**	**4**	**4**
Loch Coulside	**5307**	**78**	**0**	**0**	**0**	**0**	**0**	**4**	**4**	**4**
Loch Craggie	**11642**	**14**	**0**	**2**	**4**	**0**	**4**	**0**	**4**	**10**
Loch Culag	**9669**	**67**	**0**	**0**	**0**	**0**	**4**	**0**	**4**	**4**
Loch Culaidh	**6234**	**36**	**0**	**0**	**0**	**0**	**0**	**0**	**4**	**0**
Loch Druidibeag	**18682**	**41**	**0**	**0**	**0**	**0**	**0**	**0**	**4**	**0**
Loch Earn	**24132**	**95**	**6**	**8**	**8**	**4**	**0**	**0**	**15**	**26**
Loch Fada	**17329**	**77**	**0**	**8**	**4**	**6**	**2**	**0**	**4**	**20**
Loch Fada East	**25001**	**104**	**0**	**4**	**2**	**0**	**0**	**0**	**2**	**6**
Loch Gorm	**26168**	**63**	**2**	**2**	**4**	**0**	**0**	**0**	**4**	**8**
Loch Gowan	**16530**	**64**	**0**	**8**	**0**	**0**	**0**	**0**	**4**	**8**
Loch Hope	**2490**	**12**	**0**	**2**	**4**	**0**	**0**	**0**	**4**	**6**
Loch Kinnabus	**26944**	**74**	**0**	**4**	**4**	**0**	**0**	**2**	**4**	**10**
Loch Langabhat	**17379**	**109**	**0**	**0**	**4**	**0**	**0**	**0**	**4**	**4**
Loch Leven	**24843**	**83**	**2**	**6**	**8**	**6**	**0**	**2**	**4**	**24**
Loch Leven	**24843**	**84**	**2**	**4**	**8**	**6**	**0**	**0**	**20**	**20**
Loch Lomond	**24447**	**96**	**4**	**6**	**8**	**8**	**0**	**0**	**38**	**26**
Loch Lomond north		**225**	**4**	**6**	**8**	**8**	**0**	**0**	**17**	**26**
Loch Lomond south		**226**	**4**	**6**	**8**	**8**	**0**	**0**	**21**	**26**
Loch Lossit	**26217**	**110**	**0**	**2**	**4**	**6**	**0**	**0**	**4**	**12**
Loch Loyal	**3904**	**46**	**0**	**6**	**2**	**0**	**0**	**0**	**4**	**8**
Loch Mahaick	**24742**	**105**	**0**	**4**	**2**	**0**	**0**	**0**	**3**	**6**
Loch Maree	**14057**	**7**	**2**	**6**	**4**	**0**	**0**	**0**	**4**	**12**
Loch Maree	**14057**	**102**	**0**	**4**	**4**	**0**	**0**	**2**	**4**	**10**
Loch Maree	**14057**	**103**	**0**	**2**	**4**	**0**	**0**	**0**	**11**	**6**
Loch Meadie	**4204**	**37**	**0**	**2**	**6**	**0**	**0**	**0**	**4**	**8**
Loch Meadie	**5222**	**100**	**0**	**0**	**6**	**0**	**0**	**0**	**4**	**6**
Loch Mór	**17514**	**65**	**0**	**8**	**2**	**0**	**0**	**2**	**4**	**12**
Loch Na Beiste	**12733**	**108**	**0**	**0**	**0**	**0**	**0**	**2**	**4**	**2**
Loch na Béiste	**11238**	**60**	**2**	**0**	**0**	**0**	**0**	**0**	**4**	**2**
Loch na Moracha	**15316**	**40**	**0**	**0**	**0**	**0**	**0**	**0**	**4**	**0**
Loch nan Gabhar	**22577**	**28**	**2**	**8**	**0**	**0**	**0**	**0**	**4**	**10**
Loch Naver	**6405**	**66**	**0**	**2**	**4**	**0**	**0**	**0**	**4**	**6**
Loch of Drumellie	**23553**	**93**	**0**	**6**	**6**	**0**	**4**	**0**	**10**	**16**
Loch of Mey	**2088**	**38**	**0**	**0**	**0**	**0**	**0**	**0**	**4**	**0**
Loch Rangag	**5714**	**58**	**0**	**6**	**4**	**0**	**0**	**0**	**4**	**10**
Loch Scarmclate	**2499**	**56**	**0**	**2**	**4**	**0**	**0**	**4**	**4**	**10**
Loch Shnathaid	**18113**	**59**	**0**	**0**	**0**	**8**	**0**	**0**	**4**	**8**
Loch Skerrols	**26257**	**45**	**0**	**2**	**4**	**0**	**4**	**4**	**4**	**14**
Loch Stack	**5350**	**62**	**0**	**2**	**0**	**0**	**0**	**0**	**4**	**2**
Loch Stack	**5350**	**227**	**0**	**6**	**2**	**0**	**4**	**0**	**10**	**12**
Loch Syre	**4974**	**13**	**0**	**0**	**4**	**0**	**0**	**0**	**4**	**4**
Loch Tormasad	**15551**	**81**	**0**	**2**	**4**	**0**	**0**	**0**	**4**	**6**
Loch Tummel	**22725**	**183**	**2**	**6**	**8**	**8**	**4**	**2**	**10**	**30**
Loch Tummel	**22725**	**184**	**0**	**6**	**8**	**8**	**0**	**0**	**4**	**22**
Loch Ussie	**16456**	**34**	**0**	**0**	**2**	**0**	**0**	**0**	**4**	**2**
Loch Ussie	**16456**	**230**	**0**	**0**	**2**	**0**	**4**	**0**	**10**	**6**
Loch Watston	**24933**	**106**	**0**	**6**	**0**	**0**	**0**	**0**	**2**	**6**
Lochan Lùnn Da - Bhra	**22395**	**15**	**0**	**8**	**0**	**0**	**0**	**0**	**4**	**8**
Lochan nan Cat	**23612**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**4**	**0**
Lochan Taynish	**25393**	**107**	**0**	**4**	**2**	**0**	**0**	**0**	**3**	**6**
Lough Beg	**50006**	**198**	**0**	**4**	**8**	**6**	**4**	**0**	**10**	**22**
Lough Carn	**50168**	**17**	**0**	**0**	**0**	**6**	**0**	**0**	**4**	**6**
Lough Skale	**50264**	**164**	**4**	**4**	**0**	**0**	**4**	**4**	**10**	**16**
Macnean Lower Lough	**50007**	**47**	**0**	**2**	**4**	**0**	**0**	**0**	**4**	**6**
MacNean Upper Lough	**50005**	**19**	**0**	**0**	**4**	**0**	**0**	**2**	**4**	**6**
Malham Tarn	**29844**	**8**	**2**	**4**	**4**	**4**	**4**	**0**	**4**	**18**
Malham Tarn	**29844**	**151**	**0**	**6**	**2**	**4**	**4**	**0**	**10**	**16**
Martnaham Loch	**27398**	**39**	**0**	**8**	**2**	**0**	**0**	**2**	**4**	**12**
Rudyard Reservoir	**33784**	**119**	**4**	**4**	**8**	**8**	**4**	**4**	**4**	**32**
Rudyard Reservoir	**33784**	**181**	**6**	**2**	**8**	**8**	**2**	**4**	**10**	**30**

Rutland Water	**36479**	**132**	**2**	**6**	**8**	**8**	**2**	**0**	**4**	**26**
Rutland Water	**36479**	**145**	**4**	**6**	**8**	**8**	**4**	**4**	**10**	**34**
Semer Water	**29479**	**137**	**0**	**8**	**6**	**0**	**4**	**0**	**4**	**18**
Semer Water	**29479**	**150**	**0**	**6**	**6**	**0**	**4**	**0**	**10**	**16**
Slapton Ley	**46472**	**174**	**6**	**4**	**6**	**2**	**4**	**0**	**10**	**22**
St Mary's Loch	**27309**	**55**	**0**	**6**	**6**	**8**	**0**	**2**	**4**	**22**
Stanborough Lake	**40755**	**158**	**6**	**8**	**8**	**4**	**4**	**0**	**10**	**30**
Stewartby Lake	**39450**	**159**	**2**	**4**	**6**	**0**	**4**	**0**	**10**	**16**
Stithians Reservoir	**46501**	**131**	**2**	**2**	**6**	**8**	**4**	**4**	**4**	**26**
Stocks Reservoir	**30030**	**134**	**8**	**6**	**0**	**8**	**0**	**0**	**4**	**22**
Sunbiggin Tarn	**29178**	**5**	**0**	**6**	**8**	**0**	**2**	**0**	**4**	**16**
Sunbiggin Tarn	**29178**	**149**	**0**	**6**	**8**	**0**	**4**	**0**	**10**	**18**
Tabley Mere	**32960**	**182**	**2**	**6**	**4**	**0**	**4**	**0**	**10**	**16**
The Loe	**46556**	**130**	**2**	**6**	**0**	**0**	**2**	**4**	**4**	**14**
Torside Reservoir	**32111**	**89**	**8**	**6**	**4**	**8**	**4**	**0**	**10**	**30**
Usk Reservoir	**39967**	**162**	**2**	**2**	**4**	**8**	**4**	**0**	**4**	**20**
Wast Water	**29183**	**188**	**2**	**6**	**2**	**0**	**4**	**0**	**4**	**14**
West Loch Ollay	**19170**	**75**	**0**	**8**	**2**	**0**	**0**	**2**	**4**	**12**
White Mere	**35091**	**172**	**0**	**2**	**4**	**0**	**0**	**2**	**4**	**8**
Widdop Reservoir	**30604**	**6**	**8**	**2**	**0**	**8**	**4**	**0**	**4**	**22**
Windermere	**29233**	**10**	**4**	**6**	**8**	**6**	**0**	**4**	**4**	**28**
Windermere	**29233**	**85**	**2**	**8**	**8**	**6**	**0**	**2**	**4**	**26**
Windermere	**29233**	**86**	**4**	**8**	**8**	**6**	**4**	**4**	**10**	**34**
Yetholm Loch	**27233**	**117**	**2**	**4**	**2**	**6**	**2**	**4**	**3**	**20**