GUIDELINES

ENVIRONMENTAL QUALITY GUIDELINES FOR VICTORIAN LAKES

Publication 1302 February 2010

EXECUTIVE SUMMARY

These *Environmental quality guidelines for Victorian lakes* ('the Guidelines') identify indicators and their values for assessing the ambient condition of Victorian lakes. This will assist management decisions to improve or protect the health of Victorian lakes where previously information on the condition of the resource has been lacking.

EPA encourages lake managers to use the monitoring and assessment methods outlined in these Guidelines. We welcome feedback which may assist us to further develop these methods.

The Guidelines are designed to complement other lake assessment programs (such as the Index of Wetland Condition) and do not exclude the use of other, perhaps more intensive methods, as appropriate.

The Guidelines have been developed for natural lakes that are free of tidal influence. The Guidelines should not be applied to artificial waterbodies or marine-dominated systems. A lake for these Guidelines is defined as a type of wetland greater than one hectare in size, dominated by open water.

This publication discusses the range of lake types in Victoria and typical threats facing lakes. It presents the pros and cons of using potential indicators – phytoplankton (algae), diatoms, zooplankton, macroinvertebrates, aquatic plants, sediments, habitat features and water quality.

Data collected on potential indicators from five lakes in the Western District over three years was important in assessing the viability of each indicator. This information, as well as data collected by EPA from other lakes across Victoria, was used to set guideline values for biological (macroinvertebrates and chlorophyll-*a*) and water quality (nutrients and physicochemical) measures.

Although not set as guideline values, measures of habitat features are included as being useful to help interpret condition. Guideline values are set for most lake types found in Victoria.

A monitoring program is described in detail, with field sheets provided to facilitate the practical implementation of the monitoring.

EPA intends the guideline values to be used as triggers in a risk-assessment framework, as is done for assessment of rivers, streams and estuaries. The guideline values have also been set assuming measurements are taken as described in these Guidelines.

This is the first time biological and water quality guidelines have been presented specifically for Victorian lakes. These Guidelines can be refined as further information becomes available.

1 INTRODUCTION

1.1 The purpose of the Guidelines

The purpose of the Guidelines is to support the sustainable management of Victorian lakes. They provide indicators of the environmental condition for lakes and the levels of these indicators that represent a potential risk to the ecosystem. Under the *Environment Protection Act 1970* and *State Environment Protection Policy (Waters of Victoria)* [SEPP(WoV)] (Government of Victoria 2003), EPA is responsible for developing environmental guidelines that help protect the environment.

1.2 The need for the Guidelines

The protection of the ecosystem values and services provided by Victorian lakes has previously been hampered by a lack of knowledge of their structure and functioning. This knowledge gap is the principal reason that environmental quality objectives for lakes are not included in the SEPP(WoV)).

While the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000) contain default guideline values for freshwater lakes and reservoirs in south-east Australia, those values cannot be applied to the majority of Victoria's lakes. For example, many of Victoria's lakes are naturally saline and would not meet the default guideline value range for electrical conductivity (20–30 $\mu S\ cm^{-1}$).

These Guidelines address this knowledge gap by providing a framework for selecting indicators to assess the environmental condition of different lake types and describing levels of these indicators that, if not met, indicate a potential risk to the ecosystem. Assessments should be applied within a risk assessment framework, where failure to attain an indicator may trigger further investigations. The levels of the recommended indicators set out in the Guidelines replace the default guideline values for lakes in ANZECC & ARMCANZ (2000). Recommended components for a monitoring program are also included in these Guidelines.

1.3 The scope of the Guidelines

These Guidelines have been developed for natural lakes in Victoria that are free of tidal influence and should not be applied to man-made systems (such as dams and reservoirs) or marine-dominated systems (such as the Gippsland Lakes).

A lake is defined as a type of wetland greater than one hectare in size where emergent plants and trees represent no more than 30 per cent of the total wetted area. Open-water processes dominate productivity in lakes (although the shallower zones of lakes may still be important contributors to energy and nutrient cycling). Typically these systems are permanent and only dry out during drought periods. Wetlands that are not within the scope of the Guidelines include systems where greater than 30 per cent of the total wetted area is vegetated or are typically ephemeral (they dry out seasonally).

1.4 Protection of Victorian lakes and policy context

Victoria's lakes and wetlands are the focus of increasing attention. They are recognised as vulnerable systems, particularly in the light of climate change. A number of mechanisms are currently in place to ensure the protection of Victorian lakes. The major ones are discussed below.

A number of Victoria's lakes are listed as sites of international significance under the Ramsar Convention. This convention provides a framework for the conservation and use of wetlands.

The listing of a site under the Ramsar Convention involves a commitment to establish and monitor the 'ecological character' of the listed wetlands. 'Ecological character' is the combination of the ecosystem components, processes and benefits, and services that characterise the wetlands (Ramsar 2005). Victorian inland lakes listed under the Ramsar Convention include the Hattah–Kulkyne lakes, the Kerang Wetlands, Lake Albacutya and the Western District lakes.

A number of Victoria's lakes are also listed in the *Directory of Important Wetlands in Australia*. While this does not provide for the protection of lakes, it helps to raise awareness of the importance of Victoria's lakes. The information on individual lakes in the Directory also provides a database for resource managers to assess the values and ecosystem services provided.

At the national level, the National Water Commission is developing high-level indicators for wetland extent and condition as outlined in the *Framework of Assessment of River and Wetland Health* (FARWH) (National Water Commission 2007).

At the state level, the Victorian Government has committed to developing a sustainable wetland strategy through *Our Environment Our Future – Sustainability Action Statement 2006*.

Victoria's catchment management authorities (CMAs) have developed, or are developing, wetland management strategies. These strategies establish broad management objectives for wetlands, with targets and priority actions to achieve these. The basis for these targets is the national natural resource management (NRM) monitoring and evaluation framework, which has identified wetland extent and condition as high-level indicators (Australian Government 2003).

The Victorian Index of Wetland Condition (IWC), developed by the Department of Sustainability and

Environment (DSE 2005a, 2005b and 2008), is designed to assist CMAs to measure against the high-level national indicators. DSE has also developed 'RiVERS', which is an asset inventory that documents the social, economic and environmental assets – and the threats to these assets – associated with waterways across the State. It is currently being improved and extended to apply to wetlands and estuaries.

State legislation such as the *Environment Protection Act 1970* and the *Flora and Fauna Guarantee Act 1988* has provisions relevant to the protection of lake ecosystems. The Commonwealth's *Environment Protection and Biodiversity Act 1999* also aids the protection of lake ecosystems, particularly in regard to Ramsar wetlands and nationally threatened species.

The *Environmental quality guidelines for Victorian lakes* are designed to complement the above by providing indicators for assessing lake condition that are not being developed in the state or national programs. The indicators and values contained in these Guidelines can be directly incorporated into state and national programs where assessment of lake condition is important.

The Guidelines provide a direct measure of condition for a specific subset of wetlands – open-water lakes – by providing guidance on water quality and biotic conditions considered to represent good-quality ecosystems. In addition, the monitoring program outlined in these Guidelines can be used in conjunction with IWC assessments to identify lakes of high environmental value, as well as potential threats to lake condition. Table 1 shows how the Guidelines fit with the IWC and RiVERS tool in a policy context.

Natural resource managers can use the table to select the most appropriate method or methods based on their information needs.

1.5 Defining a healthy lake

A healthy lake should support a diverse community of organisms and be able to withstand and recover from environmental stress (natural and human-induced). While the individual processes, functions and attributes of a healthy lake may be maintained in an effectively natural state, a healthy lake is not necessarily pristine. Broader assessments of lake health could also take into account human values, uses and amenities.

Blue-green algal blooms can be a symptom of stress in a lake. However, shallow lakes in particular can be highly productive systems and blue-green algal blooms may be a natural occurrence. This possibility illustrates the importance of understanding the ecosystem and knowing when a lake has shifted significantly from a defined 'reference' condition.

Table 1: How the guidelines are to be used within the context of Victorian wetlands policy

Wetland information requirements	Method		
	IWC	**EPA guidelines**	**RiVERS Tool**
Wetlands considered	All wetlands	Lakes only	All wetlands
Threats	✓ – supplementary information to inform RiVERS tool	✓ – supplementary information to inform threats	✓
Values	X	X	✓
Condition	✓	✓ – systematic data for assessing water quality and macroinvertebrates (as bioindicators) – supplementary information about habitat features	X

2 TYPES OF VICTORIAN LAKE

There is a wide variety of natural inland lake types in Victoria. They range from freshwater alpine and coastal dune lakes to the saline and hypersaline lakes of western Victoria. Lake depth can vary from much less than one metre to over 40 metres. Victoria has a relatively high abundance and diversity of shallow lakes, predominantly in the west of the state. In contrast, deep lakes are relatively scarce.

Victorian lakes have a variety of origins. Some are associated with river systems. Others resulted from volcanic activity, wind action or the movement of coastal sand dunes. Their origin is important since it helps determine their hydrological connectivity, a major driver of ecosystem processes.

All these lake types are included in the scope of these Guidelines.

2.1 Lakes associated with river systems

Flow-through lakes

These lakes are effectively 'bulges' in river systems. The dominant water source for these lakes is the river system and water quality is largely reflective of the upstream catchment. The size of the lake influences how long river water takes to flow from one end to the other (the 'residence' time). Examples are Lake Elizabeth in the Great Otway National Park, formed by a landslide in 1952, and Lake Tali Karng near Mount Wellington (Figure 1).

Floodplain lakes

Floodplain lakes usually occur in lowlands and are associated with low-lying areas and meanders of major river channels. They include anabranches and abandoned river channels ('billabongs'). These lakes fill periodically and rely on overflows from the main river channel. The first flush of water from the river channel triggers a burst of productivity as dormant seeds and the resting stages of zooplankton are reactivated.

As these lakes dry up, constituents such as nutrients and salt concentrate. The lakes may become stagnant with low dissolved oxygen levels. Major floodplain lake systems are associated with the River Murray and its tributaries, and include the Hattah–Kulkyne lakes (Figure 1).

Terminal lakes

These lakes lie at the end of river systems. They are naturally dry during drought periods and accumulate salt, nutrients and contaminants that are carried in the river system. As with floodplain lakes, the first flush of water to these systems often leads to a burst of productivity. Examples are lakes Hindmarsh and Albacutya in the Wimmera River system and lakes Cullen and Elizabeth, which are part of the Kerang lakes region in northern Victoria (Figure 1).

2.2 Volcanic lakes

Volcanic lakes consist of caldera and maar lakes. Caldera lakes form when an empty chamber below a volcano summit collapses to produce a steep-sided crater. If sufficient water collects within the caldera, a lake forms. These lakes are usually steep-sided and have a very narrow littoral (edge habitat) zone.

Since these lakes lie in steep-sided craters, input and output streams are relatively minor contributors to hydrology. In contrast, groundwater connections can be important in maintaining lake levels.

Caldera lakes are relatively unusual in Victoria. Lake Surprise in Mount Eccles National Park is an example of a caldera lake (Figure 1).

Maar lakes are formed by volcanic explosion. These explosions tend to produce large, round and deep lakes with flat bottoms. Rainfall and groundwater input are usually the major influences on hydrology. These lakes include some of the very few deep lakes in Victoria.

Maar lakes are restricted to the Western District of Victoria and include Lake Purrumbete (Figure 1).

2.3 Coastal dune lakes

Wind action in coastal areas can form natural depressions between sand dunes where water collects. Wind can also move sand to form natural dams in drainage lines, leading to the formation of lakes. Variations in rainfall, loss through seepage and changing water table levels mean that these lakes can fluctuate markedly in water level.

Coastal dune lakes are mostly found in the far east and west of the state. In the east they include Lake Elusive (originally a blocked river valley), Lake Barracouta and Dock Inlet. In the west they include the Bridgewater lakes and Lake Monibeong (Figure 1).

2.4 Shallow inland lakes

Victoria contains a large number of shallow inland lakes. Because they are shallow their salinity can vary greatly according to the amount of rainfall and run-off received and their connection with saline groundwater aquifers.

Some of these lakes have an outflow that allows some flushing of the system when rainfall and run-off are sufficient. Others, such as 'pink lakes' in western Victoria, have no outflow, resulting in accumulation of salts, and salinities can be higher than those of seawater (Figure 1).

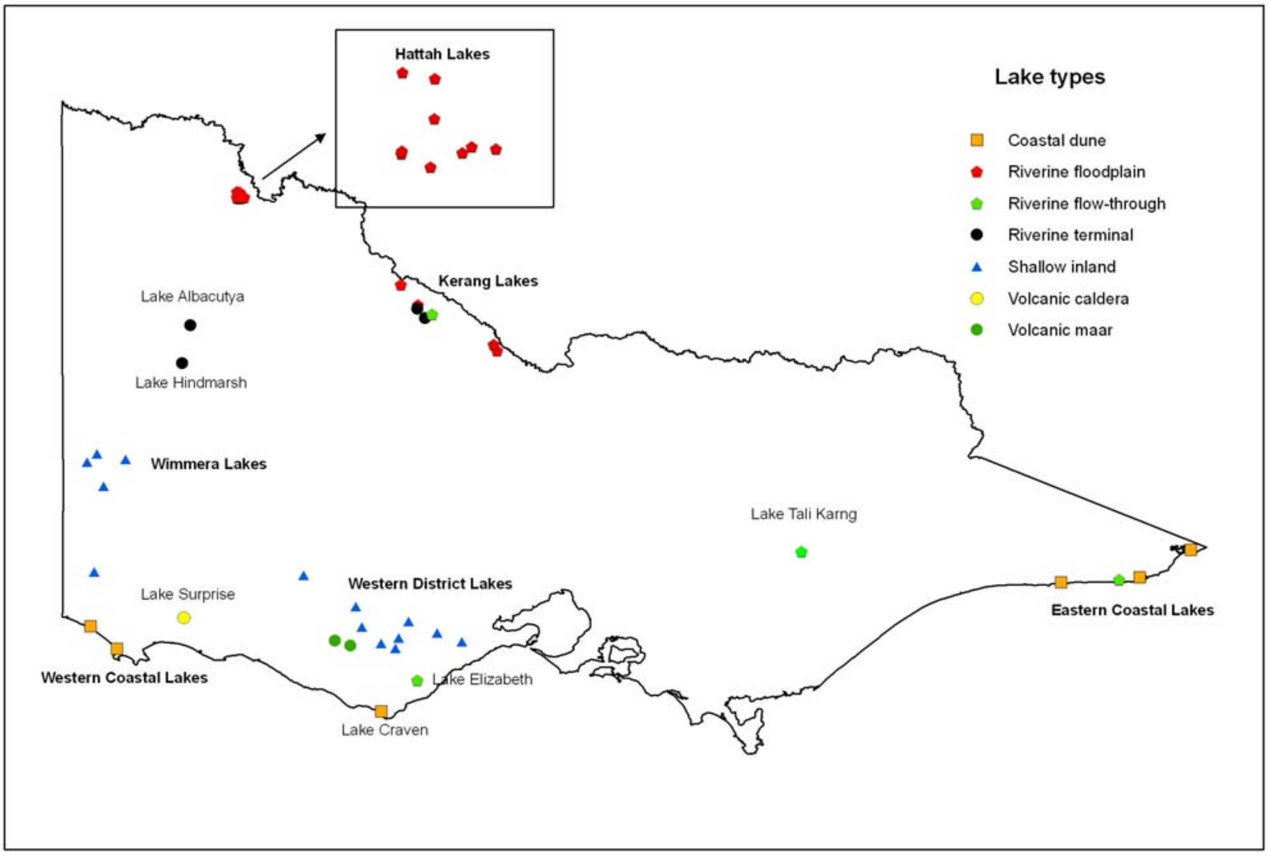

Figure 1: Location of major lakes and lake regions in Victoria

3 THREATS AND IMPACTS ON VICTORIAN LAKES

3.1 Climate change

Victoria's climate is changing. Some of these changes are already being seen in our waterways. Reduced rainfall and increased temperatures in the last decade have led to a number of Victorian lakes drying out, becoming more saline and causing large fish deaths (EPA 2007).

By 2070 Victoria is projected to warm by between 0.6 and 5 °C, with the greatest increases predicted for the north of the state. The largest increases are expected in the spring and summer months. In addition to a general trend of warming, the frequency of extreme temperatures is also likely to increase (State of Victoria 2006).

Average rainfall will also be affected. The largest decreases are predicted for the north-west of the state while East Gippsland and the far south of the state may be least affected. The biggest decreases are projected to be in winter and spring. The effect of these changes is likely to be exacerbated by increased evaporation rates that are also projected as a result of climate change.

These changes, if they occur, will have significant consequences for lakes and are discussed in more detail in *How will climate change affect Victorian lakes?* (EPA 2008).

3.2 Eutrophication

One of the ecosystem services provided by lakes is the dilution, decomposition and transformation of organic wastes and inorganic nutrients. Once this capacity is exceeded, an excess of nutrients builds up. This process is called 'eutrophication'. Such conditions promote the growth of nuisance plants and eventually lead to algal blooms.

Generally, phosphorus is the major nutrient limiting algal growth in Victorian lakes but this is not always the case. For example, Lake Purrumbete is believed to be nitrogen-limited (Herpich 2002). The majority of phosphorus enters lakes attached to particles, while nitrogen is more common in dissolved form. Sources of nitrogen and phosphorus include surface run-off from agricultural and fire-affected landscapes and sewage effluent. Even after these sources are removed or reduced, algal blooms may still occur as a result of nutrients, particularly phosphorus, stored in lake sediments.

Although nitrogen and phosphorus are the main nutrients controlling algal growth, others may also be important. For example, silica is a key nutrient for the growth of diatoms. These algae can also bloom but are not toxic to aquatic life.

While eutrophication is a threat to many lakes, particularly those in agricultural catchments, shallow lakes, particularly those that do not have an outflow, and terminal lakes may be at highest risk. The inability of nutrients to be flushed through these lake types means that the lakes act as nutrient 'sinks'. Nutrient inputs from the catchment need to be carefully managed to ensure these lakes do not become algae-dominated systems.

3.3 Altered water regimes

Many Victorian lakes have a reduced water level or have even disappeared altogether in recent years as a result of drought. The alteration of natural water regimes has also played a role in some lakes shrinking in area or drying up completely. For example, the historic diversion of surface water inflows from Lake Corangamite has caused this lake to shrink significantly. The reduction in inflow has also led to a marked increase in salinity, which in turn has led to reduced biodiversity (Timms 2005).

The over-extraction of groundwater can also lead to lakes drying up. For example, it is believed that the Red Rock lakes near Colac have remained dry since 1997 largely due to the extraction of groundwater for irrigation (Timms 2005). This illustrates the importance of developing a clear understanding of the relationship between a lake and the inflows that maintain its water quality and biodiversity.

In the north of the state, some lakes are used for water storage and salt disposal as part of larger irrigation systems. This has led to significant changes in the functioning and biodiversity of these ecosystems.

3.4 Salinisation

Salinisation is usually a secondary threat associated with threats such as climate change and changes in natural water regimes. For example, many lakes in the Western District have become increasingly saline with declining water levels, which has led to significant losses in biodiversity (EPA 2007).

Recent unpublished work by EPA has shown that major shifts in macroinvertebrate community structure occur at electrical conductivities of 3000, 10,000 and 35,000 $\mu S\ cm^{-1}$. Similar shifts in ecosystem structure may also occur at these levels. This could include the loss of fish (including some pest species) and the simplification and eventual loss of the aquatic plant community.

3.5 Catchment erosion

Catchment erosion is a major source of suspended material in lakes. Sediment material can be harmful to aquatic life. It reduces the amount of light available for plants and phytoplankton and can clog the gills and smother the bodies and eggs of aquatic animals. Suspended sediment can also carries high loads of attached nutrients, particularly phosphorus, and is a significant contributor to eutrophication.

Many crater lakes are particularly vulnerable to this threat since their catchment is relatively small and soils are friable. The build-up of large amounts of suspended sediment in lakes can also significantly reduce their depth and eventually convert them to more of a marsh environment. It may also reduce substrate diversity in the littoral zone, reducing habitat diversity for aquatic life.

3.6 Fish stocking

The stocking of large numbers of introduced and native fish in Victorian lakes adds important recreational values to many of these lakes. However, introduced fish may be significant consumers of zooplankton, macroinvertebrates and native fish (Caldwallader & Eden 1981) and overstocking can lead to significant, but potentially reversible, ecosystem changes (Knapp et al. 2005).

3.7 Contaminants

A large range of contaminants have the potential to enter lakes, primarily from agricultural, urban and industrial sources. Most Victorian lakes are not situated in or near industrial or urban areas. An exception is Lake Colac, which receives a number of inputs, including dairy and sewage effluent and urban stormwater. Potential contaminants from agricultural catchments include pesticides, herbicides, suspended solids and nutrients.

Bushfires can also be a significant source of contaminants to lakes in forested catchments. Run-off from burnt catchments can transport large quantities of suspended sediment, nutrient, ash and woody debris to lakes.

3.8 Recreation

Victorian lakes provide a wide variety of recreational opportunities, including fishing, hiking and boating.

While recreation is an important ecosystem service provided by lakes, there are also a number of threats associated with it. These include the leakage of oil and petrol from boating activities, the introduction of pest plants and animals, and sediment and nutrient inputs from shore erosion caused by backwash from boats, intensive use of hiking trails and so on. Other threats include litter, disturbance to breeding colonies of wading birds, trampling of riparian zones and microorganism contamination.

4 INDICATORS OF LAKE HEALTH

4.1 Biological Indicators

4.1.1 Macroinvertebrates

Macroinvertebrates are accepted indicators of environmental condition in rivers, and protocols have been established for their use (EPA Victoria 2003). There is now considerable data available on the response of invertebrates to various forms of pollution, to changes in catchment use (for example, agriculture, forestry, urbanisation), and of their general habitat preferences and ecology. Some types are known to be sensitive to changes in environmental factors such as temperature, dissolved oxygen or nutrient status. Being of limited mobility, the presence or absence of invertebrate families reflects conditions at a site over time, allowing an assessment of intermittent stresses, which are often missed in water quality monitoring programs.

The usefulness of macroinvertebrates in assessing the environmental condition of lakes and wetlands is subject to debate, due to the reduced diversity in these environments compared with streams and a perception that macroinvertebrate community variability is very high between different wetlands. Lakes addressed in these Guidelines may, as a result of their greater hydrological stability, prove to be less variable systems than other wetlands in their macroinvertebrate composition.

A number of researchers, both in Australia and overseas, have found macroinvertebrates to be appropriate indicators of wetland condition. Biological indices (SWAMPS – Chessman et al. 2002) and predictive models (e.g. AUSRIVAS type – Davies et al. 2006; Knapp et al. 2005) have been constructed and tested successfully. Macroinvertebrate metrics have also been calculated for depressional wetlands in the US and combined into an Index of Biological Integrity (IBI), which was found to be highly significantly correlated with human disturbance scores (Gernes & Helgen 2002).

The use of macroinvertebrates to assess lakes is supported by ANZECC and ARMCANZ (2000) and macroinvertebrates are recognised as potential indicators for reporting on wetland condition at national level (National Land & Water Resources Audit 2006).

Given the considerable potential of macroinvertebrates as an indicator for assessing lake health, a number of existing metrics were evaluated using data collected by EPA from over 30 Victorian lakes between 2004 and 2007. The metrics trialled included those commonly used in river health assessment (EPT, SIGNAL and number of families; see EPA 2003), the SWAMPS index (Chessman et al. 2002), species-level EPT and richness. Predictive macroinvertebrate models were not trialled, due to a lack of suitable reference sites for each of the different lake types.

Lakes used in the development of the Guidelines were assigned a habitat quality score and a modification score (each between one and ten), as determined by an expert panel. The performance of each metric was assessed through correlation with these modification and habitat quality scores.

Both family and species richness performed well, while other indices performed poorly. In particular, the SWAMPS index did not perform well because many of the taxa collected in Victoria were different from those in south-west Australia where the index was derived.

Consequently, EPA developed and tested an index similar to SWAMPS specifically for Victorian macroinvertebrate families, called 'VLAKES'.

The development of VLAKES followed a similar process to development of the SWAMPS index to derive sensitivity scores for each macroinvertebrate family (see Chessman et al. 2003 for this process).

The VLAKES index performed well, showing significant correlation with the habitat quality and modification measures. Both VLAKES and family richness also showed relatively low variation across the seasons, indicating that a single season would be indicative of a longer period.

Overall, macroinvertebrates show considerable potential as an indicator for monitoring and assessing lake health.

4.1.2 Microinvertebrates (zooplankton)

Microinvertebrates are key components of wetland ecosystems and may account for 50 per cent of total invertebrate biodiversity. Therefore they have significant potential in the development of environmental condition indicators. For example, SWAMPS, a biotic index designed for wetlands in south-west Australia (Chessman et al. 2002) incorporates microinvertebrate diversity.

The life cycles of microinvertebrates tend to be shorter than those of macroinvertebrates, so they reflect conditions on shorter time-scales. One obstacle to their widespread use for monitoring lakes is a lack of microinvertebrate specialists trained to identify microinvertebrates at species level. In addition, knowledge of their water quality tolerance and habitat preferences is lacking, although they have been used in biotic indices overseas with some success (Lougheed & Chow-Fraser 2002).

Microinvertebrates are currently not proposed as an indicator for monitoring and assessing lake health because of the lack of understanding and expertise. Also, analyses of EPA data showed that microinvertebrate abundance and community composition were quite variable in space and time.

4.1.3 Diatoms

Diatoms may be a useful indicator because of their greater sensitivity to certain stressors (such as nutrients) when compared to macroinvertebrates. The shorter life cycles of diatoms compared to macroinvertebrates means that they reflect shorter-term changes and impacts. The comparison of current diatom assemblages with those from palaeoecological studies is also helpful in describing 'reference' conditions for Victorian lakes and in determining their response to stressors such as climate change (Gell et al. 2005).

The use of diatoms to monitor and assess freshwaters is widespread in the northern hemisphere but their potential in Australia has not been fully explored, partly as a result of taxonomical knowledge gaps. In the last few years diatom indices have been developed at the level of both genus (Chessman et al. 1999) and species (Chessman et al. 2007). Correlations of these scores with independent measures of river health have been promising, although they are yet to be incorporated into routine, large-scale bioassessments and their use in wetlands and lakes has not been explored.

EPA data showed that lake diatoms were highly variable in abundance and community composition over time and therefore not a reliable indicator. Due to the lack of understanding and application of diatoms in Australia, they are not an ideal indicator for monitoring and assessing lake health.

4.1.4 Aquatic plants

Aquatic plants are obvious components of lakes, especially the shallower zones (although charophytes can grow at much greater depths). Aquatic plants are particularly responsive to hydrological changes. Apart from being important in their own right as components of biodiversity, aquatic plants are important carbon sources and nutrient cyclers and provide important habitat for fish, macroinvertebrates, microinvertebrates and other aquatic life.

In New Zealand, the 'LakeSPI' (Lake Submerged Plant Indicators) (NIWA 2008) method for evaluating the ecological condition of lakes has been developed. Scoring for LakeSPI is based on assessment of the status of native and invasive submerged plant communities.

This method has potential but requires suitably qualified diving personnel and so will not deliver 'rapid bioassessment'. In addition, Victoria has a number of saline lakes with limited aquatic plant communities, which is likely to mean that aquatic plants are not reliable indicators for these lake types.

While important in lakes, aquatic plants are not currently proposed as an indicator for monitoring and assessing lake health.

4.1.5 Phytoplankton ('algae')

Phytoplankton have been used extensively in the past, creating a large body of knowledge about their requirements and the impacts they can cause. They are therefore a suitable indicator for monitoring and assessing lake health.

Rapid changes in phytoplankton abundance and diversity in lakes means that a very high frequency of sampling is required for this indicator to reliably assess ecological condition.

Some attributes of the phytoplankton community are important for the monitoring of lakes. Phytoplankton biomass is an important measure of the trophic status of lakes. More productive, 'eutrophic' lakes have higher phytoplankton biomasses than intermediately productive 'renotrophic' and low-productivity 'oligotrophic' lakes.

Chlorophyll-a, the dominant pigment in phytoplankton, is commonly used as a surrogate measure of phytoplankton biomass. It is also one of the parameters commonly used to assign trophic status to a lake (Carlson 1977).

The presence and abundance of blue-green algae (cyanobacteria) is also important as an indicator of potentially toxic blue-green algal blooms.

4.2 Water quality

The effects of poor water quality on aquatic life are significant and well known, making it an important indicator for assessing lake condition. The major indicators include dissolved oxygen (DO), electrical conductivity (salinity), pH, light, nutrients, major ions, suspended particulate matter, turbidity and toxicants.

Profiles of *in-situ* measures such as temperature, dissolved oxygen and electrical conductivity allow identification of important physical and chemical boundaries in lake systems, including the thermocline (where temperature changes rapidly with depth), halocline (where salinity changes rapidly with depth) and oxycline (where DO changes rapidly with depth).

Assessing the light climate of a lake is important, since light availability determines the composition and size of algal and aquatic macrophyte populations.

Nitrogen and phosphorus are direct measures of the nutrient status of a lake. Although phosphorus is commonly thought to be the limiting nutrient in lakes, this is not always the case.

Silica is also an important nutrient, as diatoms rely on silica availability for their growth (diatom shells or 'frustules' are composed of silica).

Major-ion analysis identifies and quantifies the dominant ions contributing to the salinity of lakes. The proportions of the various cation concentrations in particular are important because they affect the metabolism of many aquatic organisms.

Suspended particulate matter (SPM) has both direct and indirect effects on aquatic life and habitat through smothering, abrasion and reduction in light. Turbidity is a measure of the cloudiness of the water, one of the major consequences of SPM.

Metals and other toxicants are potentially harmful to aquatic life. Their toxicity is well understood and the objectives used in the SEPP(WoV) are suitable for lakes. The need to monitor and assess toxicant levels will depend on the potential local threats; monitoring would not normally be undertaken unless a threat was identified.

4.3 Sediment quality

The sediments of lakes act as sites of microbial degradation of organic matter and nutrient recycling zones. They also act as sinks for suspended particulate matter and constituents that tend to adsorb to particulate matter such as nutrients, metals, microorganisms and other contaminants. There is the potential for these to be released to the water column under some conditions. The organic content of sediment also indicates the potential for the sediment to draw oxygen from the overlying water.

The toxicity of metals and organic chemicals in sediments is well understood and the objectives in the SEPP(WOV) are suitable for lakes. The need to monitor and assess toxicant levels will depend on the potential local threats and would not normally be undertaken unless a threat was identified.

4.4 Habitat quality and potential threats

The availability of good-quality habitat for aquatic life is essential to the functioning of ecosystems and the maintenance of aquatic biodiversity. Similarly, identification of catchment threats is critical for targeting management strategies to improve lake condition.

Two established methods of assessing habitat quality and catchment threats are the Lake Habitat Survey (LHS) (Rowan et al. 2006) and the IWC (DSE 2005a, 2005b and 2008). The total IWC score and the summary metrics generated by the LHS method provide comparable results (EPA, unpublished data). Depending on the type of lake being assessed, either of these methods will inform and aid interpretation of biological or water quality indicator assessments.

The IWC method surveys the whole wetland by walking around the wetland (where possible), mapping features, documenting observations and assessing threats, impacts and wetland habitat features. A desktop assessment of salinity risk is performed prior to the field visit. Six sub-indices are generated from the IWC assessment: wetland catchment, physical form, hydrology, water oroperties, soils and biota. An IWC assessment does not require a boat (the assessment can be performed when the wetland is dry), but can be time-consuming for large lakes. The wetland vegetation assessment (biota), detailed in DSE 2005 requires botanical knowledge of wetland plants (identification to at least genus level) and knowledge of ecological vegetation classes. The background and rationale for IWC is outlined in the *Conceptual framework and selection of feasures* (DSE 2005a).

The LHS method assesses physical habitat and threats at a range of scales. While the LHS has many features in common with the IWC methodology, the key difference is that it does not require knowledge of the wetland ecological vegetation class to assess wetland vegetation. For specific details on how to conduct the LHS see appendices A (field sheets) and B (procedures for collecting the data).

The LHS method does not require specialised botanical knowledge and is particularly practical for larger lakes but may require a boat. In LHS assessments, habitat characteristics and threats are recorded in at least four habitat plots ('habplots'), evenly spaced around the lake from a random starting point. Within these habplots, assessments are made within the riparian, shore and littoral zones (see Appendix B). Observations recorded include structure, diversity and naturalness of the riparian vegetation, structure and diversity of substrate types in the shore and littoral zones, and the diversity and extent of aquatic plants in the littoral zone. Any human pressures present within or adjacent to the habplots are also recorded, along with an estimate of their extent.

Lake threats and significant habitat features are also recorded at the whole-lake scale by dividing the lake into sections — usually quarters. This enables pressures and features that happened to fall outside habplots to be included in the assessment. The human pressure or significant habitat feature is recorded along with an estimate of its extent.

A key feature of the Lake Habitat Survey is the ability to generate two summary metrics from the recorded data:

- Lake Habitat Modification Score (LHMS)
- Lake Habitat Quality Assessment (LHQA).

The LHMS (adapted from Rowan et al. 2006) is a qualitative measure of human pressures on the lake ecosystem and includes assessments of the following threats:

- exotic vegetation
- alteration to natural land cover
- shore zone modification
- artificial bank construction
- catchment pressures
- in-lake pressures
- shore erosion
- catchment erosion.

Full details of the LHMS scoring system can be found in Appendix C. This uses data collected in the LHS.

The LHQA (adapted from Rowan et al. 2006) provides a measure of the naturalness and diversity of habitat features for aquatic life in the lake. It includes assessment of the following features:

- riparian vegetation structural complexity
- riparian vegetation stability
- extent of natural cover in the riparian zone
- shore structural habitat diversity
- shore naturalness
- diversity of natural substrate types in the littoral zone
- extent of aquatic plant cover
- diversity of aquatic plant cover
- diversity and extent of littoral habitat features for fish and macroinvertebrates
- Special habitat features (e.g. fringeing reed beds, wet woodland or other wetland habitats).

Full details of the LHQA scoring system can be found in Appendix D. This also uses data collected in the LHS.

4.5 Selected indicators of Victorian lake health

A number of criteria were considered to select the most appropriate suite of indicators for the Guidelines. Considerations included the repeatability of measurement, knowledge of the spatial and temporal variation, responsiveness to stressors, biological relevance, cost effectiveness and ease of application.

Table 2 outlines the recommended biological and water quality indicators. Assessment of habitat quality and catchment threats using either the LHS or IWC methods should be carried out to aid interpretation of assessments of these indicators.

Table 2: Indicators for environmental quality in Victorian lakes

Ecosystem component	Group	Indicator
Biological	Macroinvertebrates	VLAKES score
		Family richness
	Primary production	Chlorophyll-a
Water quality	Nutrients	Total Nitrogen (TN)
		Total Phosphorus (TP)
	Physicochemical	Electrical conductivity (EC)
		Dissolved oxygen (DO)
		pH
		Turbidity
	Toxicants (not routine – only if potential threat identified)	Toxicants

5 DEVELOPMENT OF THE GUIDELINES

5.1 Risk-based approach

The Guidelines follow the principle of risk-based assessment of ecosystems adopted in the National Water Quality Management Strategy – *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC and ARMCANZ 2000). This approach has been implemented in *State Environment Protection Ppolicy (Waters of Victoria)* (Government of Victoria 2003). Figure 2 outlines the framework for risk-based assessment.

Under this approach, environmental quality objectives are not a simple pass/fail number. The environmental quality objectives now represent trigger levels at which there is a potential risk that adverse ecological effects may occur. Lakes that meet all environmental quality objectives have a low risk. Where the environmental quality objectives are not met, a risk-based investigation may be conducted to ascertain if there is an adverse risk to the ecosystem. The risk-based investigation framework can be considered a process for evaluating the likelihood of adverse effects to the ecosystem.

This risk-based approach has been adopted for the development of these Guidelines. It takes into account spatial and temporal variability and the complexity of aquatic ecosystems. For more information on the risk-based approach and risk-based investigations see *Risk-based assessment of ecosystem protection in ambient waters* (EPA Victoria 2004).

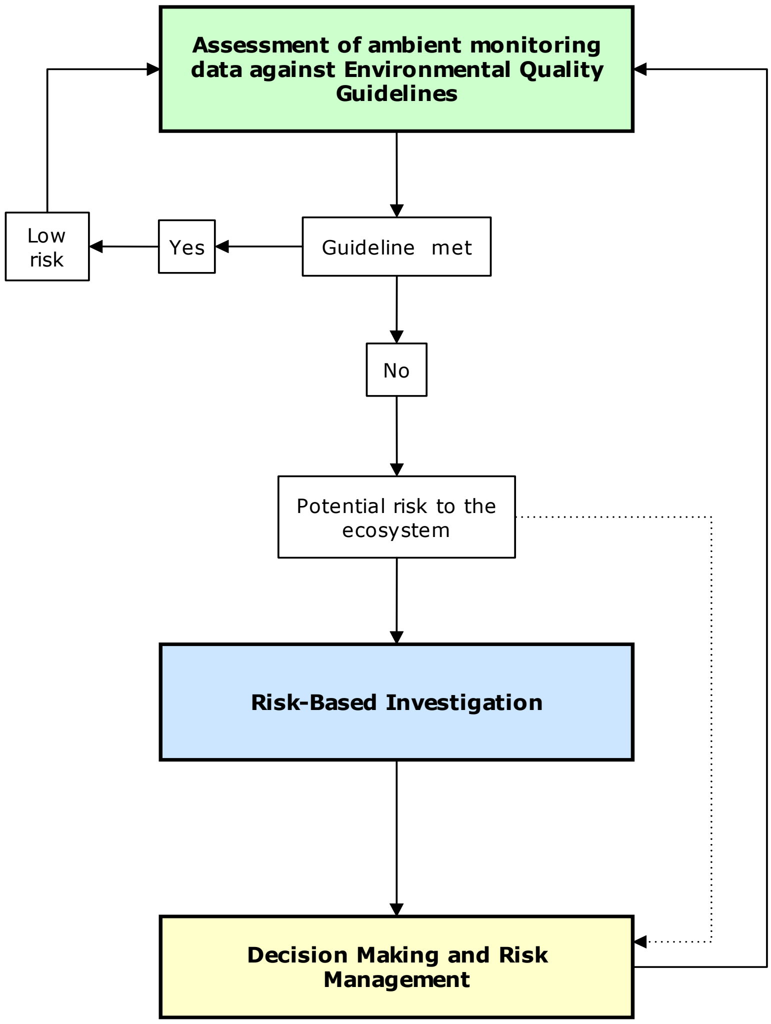

Figure 2: Framework for risk-based assessment

5.2 Derivation of Guideline values

The Guideline values were principally derived from data collected from extensive sampling of five lakes in Victoria's Western District between 2004 and 2007. The study lakes were chosen on the basis that they represented a range of environmental conditions and quality, enabling their application across many lakes in Victoria (see Table 3).

Sampling was undertaken four times a year (seasonally). Water quality samples and *in-situ* profiles were taken at two sites ('index sites') and at depths between 0 and 40 metres. For lakes shallower than 40 metres, the deepest sampling point was the maximum depth of the lake only.

We collected microinvertebrate (zooplankton), diatom and phytoplankton samples from three depths between 0 and 10 metres at the index site located at the deepest point in the lake. Macroinvertebrate samples were collected from five sites situated at approximately regular intervals around the lake edge.

We collected samples following the rapid bioassessment (RBA) method for rivers and streams (EPA Victoria 2003). Habitat assessments were carried out at six habplots situated at regular intervals around the lake from a randomly chosen point using the LHS method (Rowen et al. 2006). Habitat features were also recorded at the whole-lake scale and by dividing the lake into quarters.

The sampling program generated a large amount of data for each of the potential indicators of lake condition.

A key finding of the trial program was that diatoms, phytoplankton and microinvertebrate populations were extremely variable in abundance and community composition over time. This might be expected, since these communities have rapid turnover rates and go through 'boom and bust' cycles. For this reason, reliable guideline values can not be set for these potential indicators at this stage. This should not preclude their use in monitoring programs where appropriate. For example, monitoring phytoplankton populations is important in establishing the presence and abundance of potentially toxic blue-green algae.

This sampling program demonstrated that there was little variability in macroinvertebrates and water quality measurements over the four seasonal samples. A single sample is thus sufficient to represent lake quality for these indicators.

In addition to the trial sampling program we carried out a 'snapshot' sampling program of over 30 Victorian lakes in summer 2007 (EPA 2010). This snapshot sampling program enabled us to assess the performance of the indicators of environmental condition on a wider range of lake types.

The data collected during the snapshot sampling program was also useful in providing a limited baseline dataset for lakes across Victoria. Each lake was sampled once. The sampling included all lake types listed in section 2, except for shallow inland lakes without an outflow ('closed' basins). These were not sampled because most were dry due to the recent dry conditions, or for logistical reasons. As a result, guideline values have not been set for this lake type.

A common approach to assessing environmental condition is to compare the condition of a particular test site with a reference site or set of reference sites. Reference condition is usually defined as the condition of an unimpaired, minimally impacted or best available lake. The relatively small number of reference-quality lakes present in Victoria meant it was not possible to use this approach for all lake types.

The assessment of whether a lake met the requirements of reference condition was based on the professional judgement of experienced EPA limnologists who ranked all the sampled lakes on a scale of 1 (highly modified) to 10 (unmodified or minimally impacted). This assessment was based on the predominant land-use in the catchment (e.g. Is the lake in a national park or surrounded by farmland?) and the presence and extent of threats to condition.

It was also not possible to calculate 25th or 75th percentile values from the data in order to set guideline values.

Where reference sites could be identified for a lake type, initial guideline values were assigned based on the approximate median value for these sites. Where reference sites could not be identified for a lake type, the initial guideline values were based on those from similar lake types where reference sites were available. For example, initial guideline values for shallow inland lakes and riverine terminal lakes were based on those from riverine floodplain lakes. Although these lakes differ, particularly in terms of their hydrological connection with the landscape, they are all shallow, relatively productive systems that might be expected to have similar values of many of the key indicators. A full list of the reference lakes used for each lake type is given in Table 4.

We then refined the initial guideline values using expert opinion. An expert panel was formed and asked to assess the initial guideline values based on their knowledge and understanding of what constituted a healthy lake ecosystem.

A preliminary assessment of Victorian lakes based on the initial guideline values was also provided to the expert panel. This assessment was based on data collected during the 'snapshot' sampling program and provided an indication of how many lakes would 'trigger' when assessed against the initial guideline values.

Based on the opinion of the expert panel, we adjusted the guideline values. The recommended guideline values are shown in Tables 5, 6 and 7. It is important to recognise that these are the first attempt at guideline values, which may be revised in the future as more data and information on Victoria's lakes become available.

Table 3: Characteristics of the lakes sampled in the trial program

Lake	Lake type	Maximum depth (m)	Lake area (km^2)	Catchment area (km^2)	EC (µS/cm)	Main land use	Other significant pressures
Bullen Merri	Deep inland – saline	66	4.9	8.7	15,000	Grazing	Artificially stocked with game fish
Colac	Shallow inland – outflow	2.4	29.7	217	19,000*	Residential, industrial, grazing	Sewage treatment plant discharge
Modewarre	Shallow inland – outflow	4.5	3.2	70	76,000*	Grazing	A recreational and commercial fishery, drought effects
Purrumbete	Deep inland – fresh	45	5.7	9.6	700	Grazing	Artificially stocked with game fish
Surprise	Deep inland – fresh	13	0.1	0.06	750	Recreation	Algal blooms

* EC levels recorded under drought conditions

Table 4: Reference lakes for each lake type

Type	Sub-type	Reference sites
Riverine	Flow-through Terminal Floodplain	Lake Elizabeth (Otways National Park), Thurra Swamp Reference condition assumed to be similar to that for riverine floodplain lakes. Hattah-Kulkyne lakes
Coastal dune	Eastern Western	Lake Elusive, Dock Inlet, Lake Barracouta Lake Monibeong
Deep (>5m) inland		Lake Surprise
Shallow (<5m) inland	With an outflow	Reference condition assumed to be similar to that for riverine floodplain lakes.

* Reference condition assumed to be similar to that for riverine floodplain lakes.

5.3 The Guidelines

Not all of the potential indicators discussed have been assigned environmental quality guideline values. The focus has been on those indicators considered most sensitive to the threats Victorian lakes face. Threat-based monitoring programs (such as the IWC) will, however, incorporate additional indicators relevant to the particular threat.

The guideline values have been set assuming samples have been taken as described in the monitoring and assessment section (Section 6). Any indicator is considered to be triggered if any one of the samples taken for that indicator does not meet the value in Tables 5 to 7. VLAKES is the exception to this, as it requires aggregated data from the macroinvertebrate samples to make an assessment against the Guidelines.

The guideline values have been set by lake type. Lakes of volcanic origin have been categorised as either deep (more than five metres) inland or shallow (less than five metres), as the preliminary sampling program indicated shallow lakes of volcanic origin were similar ecologically to other shallow inland lakes.

Guideline values have been developed for macroinvertebrates as the main biological indicator of ecosystem condition. Guideline values have not been developed at this stage for diatoms, phytoplankton or microinvertebrates, as the sampling program suggested that these potential indicators were too variable in time and space.

Guideline values have not been set for habitat quality. To assess habitat quality and potential threats the LHS rating system is used (see Table 8). The LHS ratings assess physical habitat and threats, providing contextual information to help interpret the water quality and biological indicator values.

Table 5: Environmental quality guideline values for biological indicators

Type	Sub-type	Number of macroinvertebrate families[1]	VLAKES[2]	Chlorophyll a (µg/L)
Riverine	Flow-through Terminal Floodplain	15 15 15	4.7 4.3 4.3	5 10 10
Coastal dune	Eastern Western	15 15	4.7 4.7	5 5
Deep (>5m) inland	Fresh Saline	15 See Table 5	4.3 NA	5 5
Shallow (<5m) inland	With an outflow Closed	15 NA	4.3 NA	10 NA

1 The number of macroinvertebrate families collected in one sweep sample. The guideline values should be adjusted as in Table 6 if background electrical conductivity exceeds 3000 μScm^{-1}.

2 VLAKES is a biotic index developed by EPA Victoria. This requires macroinvertebrate samples to be aggregated for assessment against the guideline values. Details of the scoring system for VLAKES are shown in Appendix E.

NA – not available.

Table 6: Electrical conductivity guideline value adjustments for number of macroinvertebrate families

Electrical conductivity (μScm^{-1})	Number of families
>3000	13
>10,000	12
>35,000	5

Table 7: Environmental quality guideline values for water quality indicators

Type	Sub-type	pH range	Dissolved oxygen range (% saturation)	Electrical conductivity (μScm^{-1})	Turbidity (NTU)	Total Nitrogen (µg/L)	Total Phosphorus (µg/L)	Toxicants[1]
Riverine	Flow-through	6.5–8.5	80–120	1500	5	500	30	T99%
	Terminal	6.5–8.5	80–120	NA	15	1500	100	
	Floodplain	6.5–8.5	80–120	NA	15	1500	100	
Coastal dune	Eastern	6–7.5	80–120	1500	5	500	30	T99%
	Western	6.5–8.5	80–120	1500	5	500	30	
Deep inland	Fresh	6.5–8.5	80–120	1500	5	500	30	T99%
	Saline	6.5–8.5	80–120	NA	5	500	30	
Shallow inland	With an outflow	6.5–8.5	80–120	NA	15	1500	100	T99%
	Closed	NA	NA	NA	NA	NA	NA	

NA = not applicable due to the wide range of natural salinities of these lake types and natural fluctuations over seasonal cycles. Instead, a value of 10,000μScm^{-1} is suggested as the threshold value at which significant and possibly irreversible ecological change may occur.

1. 'T'refers to per cent species protection. For detailed guidelines see ANZECC/ARMCANZ 2000, Table 3.4.1.

Table 8: Ratings of habitat quality and potential threats (applies to all lake types)

Rating	Lake Habitat Quality Assessment	Lake Habitat Modification Score
Good	>45	0–15
Moderate	30–45	15–30
Poor	15–30	30–45
Very poor	0–15	>45

Details of the aggregate scoring system for LHQA and LHMS are shown in Appendices C and D.

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6 MONITORING AND ASSESSMENT

A summary of the monitoring program recommended for the assessment of Victorian lakes against the Guidelines is shown in Table 9. Monitoring requirements are described in detail below.

The monitoring program is designed for ambient monitoring for the purposes of assessing overall environmental condition. If the management question differs from this, not all the elements described here need to be performed. Alternatively, more detailed investigations should be carried out if required.

6.1 Aquatic macroinvertebrates

Typically, at least two sites should be sampled for aquatic macroinvertebrates. For large lakes it is recommended that four sites, spread at about 90° intervals, should be sampled. These sites should coincide with the LHS sites. Sweep samples should be collected following the *Rapid bioassessment methodology for rivers and streams* (EPA 2003).

All sites should be photographed and GPS measurements taken so that they can be easily identified for future sampling.

Aquatic macroinvertebrates should be sampled at least once per year. For all lake types except floodplain lakes, this should be done during autumn, spring or summer. For floodplain lakes, where macroinvertebrates communities may change seasonally, sampling should occur in summer, when potential stress to these ecosystems may be higher than during other times of the year.

6.2 Water quality

Standard *in situ* measurements should be taken at the same time as the aquatic macroinvertebrate sampling. These measurements should include, but are not limited to, temperature, dissolved oxygen, electrical conductivity (relative to 25 °C), and pH. If practical, turbidity should also be measured. These measurements are important when it comes to interpretation of aquatic macroinvertebrate data.

More detailed water quality sampling should take place at the 'index' site. This is a site that will be revisited so that changes over time can be examined. This site will normally be located at the deepest part of the lake and should be marked with a buoy. For deep lakes (more than five metres) consideration should be given to establishing a second site in a shallower part of the lake. Water quality in the shallows may differ considerably from that in deeper areas of the lake and a second site can be important in understanding spatial variations in water quality.

At the 'index' site *in situ* measurements should be taken not only at the surface but also along depth profiles. In general, measurement should be taken at one-metre intervals, but may be increased to two or even five metres in deeper lakes.

Water samples should be collected from the surface at the 'index' site and analysed for:

- turbidity
- chlorophyll-a
- total nitrogen
- total phosphorus.

In addition, at least one algal sample should be taken from the surface and preserved in Lugol's iodine. This sample should be retained for analysis in case the chlorophyll-a guideline level is triggered and further investigation, including examination of the types of phytoplankton present, is required.

When depth profiles indicate that the lake is stratified, additional total nitrogen and total phosphorus samples should be taken from the hypolimnion (bottom waters), since nutrients may accumulate there. When the lake mixes this may result in elevated nutrient levels in the surface layer and possible algal blooms.

Water quality samples should be collected seasonally (four times a year) as a minimum. In order to minimise the effect of diurnal differences, samples and measurements should be taken at approximately the same time of day on each occasion.

6.3 Habitat quality and catchment threats

An assessment of habitat quality and catchment threats should be carried out either using IWC or LHS to aid interpretation of water quality and biological assessments.

The LHS method requires at least four habitat plots to be set up for detailed analysis of the littoral, shore and riparian zones. The first of these sites should be selected randomly and the remainder spaced at regular intervals (if four sites are used, they would be spaced at 90° intervals) around the perimeter of the lake. For large lakes or lakes with a large diversity of habitat types or potential threats, consideration should be given to increasing the number of habitat plots surveyed.

Where possible, the rest of the LHS should be undertaken by walking the perimeter of the lake. Where this is not practicable, surveys should be carried out from a boat ensuring that all four quarters of the lake can be adequately viewed. All sites should be photographed and GPS measurements taken, so that they can be easily identified for future sampling. Where gross changes in habitat quality and threats are not expected, the LHS may be carried out on an annual basis.

The IWC method is a whole-wetland approach to assessment that incorporates some desktop analysis and a field assessment by walking the entirety of the wetland, if practical (in other words, if it is small enough to walk around in less than one hour). The latest methods manual for the IWC is an unpublished document. For current information, visit DSE's IWC website www.dse.vic.gov.au/iwc.

Table 9: Summary of recommendations for monitoring and assessment of Victorian lakes

Measurement type	Minimum sampling frequency	Minimum number of sites
Aquatic macroinvertebrates	Yearly (taken in summer for floodplain lakes, in summer autumn or spring for other lake types)	2
Water quality (macroinvertebrate sites)	Yearly (summer, autumn or spring to coincide with macroinvertebrate sampling)	2
Water quality (index site)	Seasonally (winter, spring, summer, autumn)	1 (2 in deep lakes (over 5 m))
Lake Habitat Survey	Yearly	At least 4 habitat plots
IWC	Five yearly, although preferably yearly to coincide with macroinvertebrate sampling.	Whole wetland

7 SUMMARY

These Guidelines have been developed to provide a framework for assessing the environmental condition of Victorian lakes and to assist in management decisions to improve or protect the health of Victorian lakes.

Many lakes are vulnerable ecosystems, particularly in the light of climate change, and there are few remaining lakes in natural or near-natural condition.

This is the first time that biological and water quality guidelines have been presented specifically for Victorian lakes. These Guidelines can be refined as further monitoring information becomes available, particularly to inform the development of guideline values. Further monitoring will increase our understanding of lakes and their processes and provide a basis for the sustainable management of lake environments.

We encourage lake managers to use the monitoring and assessment methods outlined in these Guidelines. EPA welcomes feedback which may assist us to further develop these methods.

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APPENDIX A: FIELD SHEETS FOR LAKE HABITAT SURVEY METHOD

LAKE .... DATE..........................

LAKE HABITAT SURVEY AND SITE OBSERVATIONS

Record eastings and northings for each hab-plot

Hab-plots

							E								**N**								**E**								**N**
							E								**N**								**E**								**N**
							E								**N**								**E**								**N**

Enter descriptions of each hab-plot here

☐ .... ☐...

☐ .... ☐...

☐ .... ☐...

Enter description of nuisance species here

☐ .... ☐...

☐ .... ☐...

☐ .... ☐...

2. PHYSICAL ATTRIBUTES

2.1 RIPARIAN ZONE (30 m long x 15 m wide plots – from bank top backwards)

Hab-Plot ID							
CANOPY COVER	Trees (>5m)						
	Evidence of canopy damage/disease						
UNDERSTOREY	Small trees and large woody shrubs						
(0.5–5m)	Tall grasses, ferns, blackberries						
GROUND COVER	Small Shrubs, and small ferns						
(<0.5m)	Grasses/ground cover						
OTHER	Standing water or inundated vegetation						
	Leaf litter						
	Bare Ground						
	Artificial						

Length of lakeside zone (m) (when woody veg. changes in land use)						
Gaps in over or understorey longitudinally						
Dominant land cover within the riparian zZone (BA, RR, DS, WS, CT, PP, EP, SH, FB, GL, WL, HE, GR, CR, IL, PG, AW, OW, RS, UR, RE)						
Notable nuisance plant species (NO = None, SN = Stinging Nettle, BL = Blackberries, WI = Willows OT = Other)						
Percentage cover of exotic tree layer						
Percentage cover of exotic shrub layer						
Percentage cover of exotic ground layer						
Slope from the waterline to the top of the crater (°)						

ESTIMATE AERIAL COVER OVER PLOT 0=(0–1%) 1=(>1–10%) 2=(>10–40%) 3=(>40–75%) 4=(>75%)

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LAKE .... DATE...........................

2.2 SHORE ZONE (15 m wide plot of variable length between the actual waterline and the high waterline)

Hab-Plot ID						
SHORE/BEACH (if present) Beach present (NO =no, YE = yes)						
Shore width (m) (estimate to nearest metre)						
Slope (HO = near horizontal, GE = gentle (5–30°) SL = Sloped (30–75°), VE = near vertical (>75°)						
Shore material (write yes or no depending on whether the substrate type is present or absent)						
Boulder						
Cobble						
Gravel						
Pebble						
Sand						
Silt						
Clay						
Concrete						
Other						
Shore Modification(s) (YE = yes or NO = no)						
Shore vegetation cover [0=(0–1%) 1=(>1–10%) 2=(>10–40%) 3=(>40–75%) 4=(>75%)]						
Shore vegetation structure (NO=no, CL=canopy Layer, US=understorey, GC=groundcover, MI=mixed)						
Evidence of shore geomorphological activity (NO=no, ER = eroding, DS = depositional)						
Presence of shore organic debris/trash-lines (NO=no, YE=yes)						

2.3 LITTORAL ZONE (15m x 10m plot extending from waterline to the middle of the lake)

Hab-Plot ID						
DEPTH (M) @ 10M OR MAXIMUM WADING POINT						
Distance (m) from waterline to the maximum wading point if present						
Substrate ≥ 10%						
Boulder						
Cobble						
Gravel						
Pebble						
Sand						
Silt						
Clay						
Concrete						
Other						
Sedimentation over natural substrate [0=(0-1%) 1=(>1-10%) 2=(>10-40%) 3=(>40-75%) 4=(>75%)]						
Odour (NO=no, AN=anaerobic, SW=sewerage, OI=oil, CH=chemical, OT=other)						
Surface film (NO=no, SC=scum, AM=algal mat, OI=oily, OT=other)						
MACROPHYTES						
Estimate aerial cover 0=(0-1%) 1=(>1-10%) 2=(>10-40%) 3=(>40-75%) 4=(>75%)						
LIVERWORTS/MOSSES/LICHENS						
Submerged feather like						
Submerged broad strap like						
Submerged grass like						
Submerged branched						
Floating leaved rooted						
Free floating						
Emergent reed like						
Emergent grass like						
Emergent rush like						
Emergent branched						
Emergent unbranched						
Filamentous algae						
Cover of inundated terrestrial vegetation						
Total macrophyte percentage cover (See above for categories)						
Do macrophytes extend lakewards? (NO=No, YE=Yes)						
If so, in (m) estimate their extent lakewards						
Notable nuisance plant species (NO=None, OT=Other)						
LITTORAL HABITAT FEATURES						
Estimate aerial cover 0=(0-1%) 1=(>1-10%) 2=(>10-40%) 3=(>40-75%) 4=(>75%)						
Underwater tree roots						
Woody debris (>0.1 m diameter)						
Course particulate organic matter (CPOM)						
Inundated live trees (>0.3 m diameter)						
Overhanging vegetation close to water surface (<1 m above)						
Rock ledges or sharp drop-offs						
Boulders						

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LAKE .... DATE...........................

2.4 HUMAN PRESSURES (assessed over entire plot) ✓if present, B= behind or adjacent to plot (within 50m radius)

Hab-Plot ID						
COMMERCIAL ACTIVITIES						
RESIDENTIAL AREAS						
ROADS, RAILWAYS OR GRAVEL TRACKS						
PARKS AND GARDENS						
DOCKS, MARINAS, JETTIES OR BOATS						
WALLS, DYKES OR REVETMENTS						
RECREATIONAL BEACHES						
EDUCATIONAL RECREATION						
LITTER, DUMP OR LANDFILL						
QUARRYING OR MINING						
PLANTATION (PINE OR EUCALYPTUS)						
GRAZING						
CROPPING						
ORCHARD						
PIPES, OUTFALLS						
DREDGING						
RIPARIAN VEGETATION CONTROL						
MACROPHYTE CUTTING						
OTHER PLEASE SPECIFY						

Have you TAKEN PHOTOS of all of the Hab-plots?	
X	**X**
X	**X**
X	**X**

LAKE .... DATE...........................

3. WHOLE LAKE ASSESSMENT

3.1 SHORELINE CHARACTERISTICS

Complete table from a boat-based survey or if visible from the bank. Divide the lake into quarters and observe 50m back from the shoreline. If the shoreline can be observed from one location, do so; this will minimise uncertainty in estimations of overall percent for the entire shoreline.

EXTENT OF SHORELINE SECTION AFFECTED BY (OR COMPRISED OF) EACH PRESSURE OR LAND-COVER TYPE
Estimate extent 0=(0%) 1=(<20%) 2=(20–50%) 3=(50–80%) 4=(>80%)

	Characteristics	SE quarter	SW Quarter	NE quarter	NW quarter
Bank construction	Water control structures				
	Hard engineering				
	Soft engineering				
	Docks and marinas				
Pressures and non-natural land use	STP				
	Commercial/industrial activities				
	Residential areas				
	Roads or railways				
	Parks and gardens				
	Recreational beaches				
	Litter, dump, landfill				
	Quarrying or mining				
	Pine plantation				
	Gum plantation				
	Evidence of recent logging				
	Cropping				
	Grazing				
	Irrigation				
	Erosion				
Wetland habitats	Fringing reed beds				
	Fens, marshes				
	Bogs				
	Wet grassland and floodplain				
	Wet woodland				
Other natural habitats	Dry sclerophyll forest				
	Wet sclerophyll forest				
	Scrub and shrubs				
	Grassland				
	Heath land				
	Natural open water (other than lake)				
	Rock, scree or sand dunes				

LAKE .... DATE...........................

3.2 LAKE SITE PRESSURES/ACTIVITIES										
✓ box (P) if known to be present, and ring if actually observed. If possible to estimate, ✓ boxes (E) and/or (I) if the pressure appears to be Extensive or Intensive where specified										
	P	**E**	**I**		**P**	**E**	**I**		**P**	**E**
MOTORBOAT SPORTING ACTIVITIES				BARRIERS				FISH CAGES		
NON-MOTOR BOAT ACTIVITIES				BRIDGES				Dredging		
ANGLING FROM BOAT				Military activities				Litter		
Angling from shore				Macrophyte control				Water odour		
Swimming/wading				Surface films				Powerlines		
Stock access				Algal blooms						
Other										

ANIMALS *(Tick if observed and specify in the right hand column)*		
Piscivores		E.G. PELICANS
Macrophyte dependent species		E.G. SWANS
Species of conservation interest		E.G. OSPREY

4. HYDROLOGY **(to be assessed over the entire lake)**	
PRINCIPLE USE(S) (CIRCLE)	None/hydro-power/water supply/flood control/navigation/amenity/other (specify)
WATER BODY TYPE (CIRCLE)	Natural (unmodified)/natural (raised)/natural (lowered)/impoundment/flooded pit
If raised or lowered, state height difference of water level relative to natural condition (m) *(if known)*	
If raised or lowered, state when this occurred *(if known)*	
Estimate maximum height from lake bed of principle retaining structure (m)	
NUMBER OF SIGNIFICANT INFLUENT STREAMS (STREAM CATCHMENT >10% TOTAL CATCHMENT)	
Are there any upstream impoundments? *(circle)* Evidence of significant flow diversion (i.e. may affect residence time) into/out of catchment? *(circle)*	No/yes/unsure No/into/out of/ unsure
Vertical range of water level fluctuation (m) ✓ tick appropriate box	
DAILY MAX <0.5 ☐ 0.5–2 ☐ 2–5 ☐ 5–20 ☐ >20 ☐ UNSURE ☐ ANNUAL MAX <0.5 ☐ 0.5–2 ☐ 2–5 ☐ 5–20 ☐ >20 ☐ UNSURE ☐	THIS QUESTION ANSWERED BY: ON-SITE ESTIMATION ☐ DATA☐

APPENDIX B: EPA VICTORIA PROCEDURE FOR LAKE HABITAT SURVEY (LHS) METHOD.

The text marked in **bold** is the type of information to be recorded on the field sheet. For an explanation of how to score this information see the end of Appendix B. The section numbers and headings (eg. 2.1 RIPARIAN ZONE) refer to sections in the LHS field sheets (see Appendix A).

PHYSICAL ATTRIBUTES

B2.1 RIPARIAN ZONE (see end of Appendix B for zone definition)

Measure out a 30 m long x 15 m wide plot – from bank top backwards – write a description of each hab-plot in the space provided.

Complete your assessment of cover for each group (trees, understorey etc) over the entire plot. All estimates are expressed as a **percentage** from the predefined categories.

Use a range finder or tape measure to measure in **metres** the extent of the lakeside zone (riparian zone). This zone is defined where a change in land use occurs; for example, when a road forces an obvious break in the lakeside zone. Where there is no visible break, estimate.

Take note of the dominant land cover using the following **abbreviations:**

BA	Bare	WL	Wetland
RR	River red gums	HE	Heathland
DS	Dry sclerophyll forest	GR	Grazing
WS	Wet sclerophyll forest	CR	Cropping
CT	Cool temperate forest	IL	Irrigated land
PP	Pine plantation	PG	Park, lawn or gardens
EP	Eucalypt plantation	AW	Artificial open water
SH	Scrub and shrub	OW	Natural open water
FB	Ferns/bracken	RS	Rock, scree or sand dunes
NG	Native grassland	UR	Suburban/urban
GL	Grassland	RE	Residential

Note the presence of notable nuisance plant species using the **abbreviations** provided. If you select the other category, there is space provided to specify.

Estimate the cover of native trees, shrubs and ground cover using the predefined **percentage** categories.

Note the slope of the shore using the **abbreviations** supplied.

B2.2 SHORE ZONE (see end of Appendix B for zone definition)

The shore zone is defined as the area between the actual waterline and the high waterline. Measure out a 15 m wide plot of variable length (each lake will be different).

Measure the shore length in **metres** from the actual waterline to the high waterline.

Note the slope of the shore using the **abbreviations** supplied.

Note the presence and absence using **yes** or **no** for each of the listed substrate types.

Note whether the shore has been modified in any way using **yes** or **no**.

Estimate how much of the shore is covered with vegetation within your hab-plot. Use the predefined **percentage** categories.

Define the vegetation structure of the shore using the **abbreviations** provided.

Note any geomorphological activity of the shore zone using the **abbreviations** provided.

Note the presence or absence of organic debris/trash lines with **yes** or **no**.

B2.3 LITTORAL ZONE (see end of Appendix B for zone definition)

Measure out a 15 m wide x 10 m (or maximum wading depth) long plot extending from the waterline towards the middle of the lake.

Measure the depth at 10 m or the max wading point in **metres**.

Measure the distance from waterline to the maximum wading depth in **metres** if present.

Indicate whether a particular substrate type from the list represents >10% of the substrate of your plot with **yes** or **no**.

Estimate how much sedimentation is covering the natural substrate using the predefined **percentage** categories.

Note the presence of any odours occurring at the site using the **abbreviations** provided.

Note the presence of any surface film within the hab-plot using the **abbreviations** provided.

MACROPHYTES

Estimate the cover of each class of macrophytes listed (including filamentous algae and inundated terrestrial vegetation) using the predefined **percentage** categories.

Estimate the total macrophyte cover (not including algae or inundated veg) using the predefined **percentage** categories.

Indicate whether the macrophytes extend lakewards (past your plot boundaries for the zone) with **yes** or **no**.

If macrophytes extend lakewards, then estimate to the best of your ability their extent in **metres**.

Note the presence of notable nuisance aquatic plant species using the **abbreviations provided**. If you select the other category, there is space provided to specify.

LITTORAL HABITAT FEATURES

Estimate the cover of all of the habitat features listed using the predefined **percentage** categories.

B2.4 HUMAN PRESSURES

The human pressures are to be assessed over the entire hab-plot.

The field sheets contain an array of different human pressures. You must indicate whether each pressure is directly present within the plot using the letter **P**, or behind or adjacent to the plot (within a 50m radius) using the letter **B**. If the pressure is not present use an **X**.

B3 WHOLE LAKE ASSESSMENT

B3.1 SHORELINE CHARACTERISTICS

For the whole lake assessment, the lake is divided into quarters, i.e. a SE, SW, NE and NW quarter. Observations are made concerning the shoreline and 50 metres back from the shore. These observations are made from either a boat or from the shore. If you can observe all quarters from the one vantage point this is desirable, as it minimises uncertainty in estimations.

All shoreline characteristics are estimated using the predefined **percentages** for each quarter.

B3.2 LAKE SITE PRESSURES/ACTIVITIES

These pressures/activities are assessed over the whole lake not quarters.

Tick the **P** box if a listed pressure/activity is known to be present and place a **circle** in the **P** box if it is actually being observed. If it is possible to estimate, place a **tick** in the **'E'** box if the pressure/activity occurs extensively throughout the lake, and place a **tick** in the **'I'** box if the pressure/activity is intensive. If you choose the other option, please specify the activity/pressure in the space provided. If listed pressures/activities do not occur in the lake, leave the boxes blank.

ANIMALS

Place a **tick** in the space provided next to a specific category of bird if it is observed. Write a description of the types of birds that you see.

B4 HYDROLOGY

Circle the most appropriate principle use of the lake from the options provided. If you choose the other option, please specify.

Circle the appropriate water body type from the options provided.

If the lake's water level has been raised or lowered from its natural state, please estimate the drop or rise in **metres** only if known.

If the water level has been raised or lowered please specify when this occurred with a **date** if known.

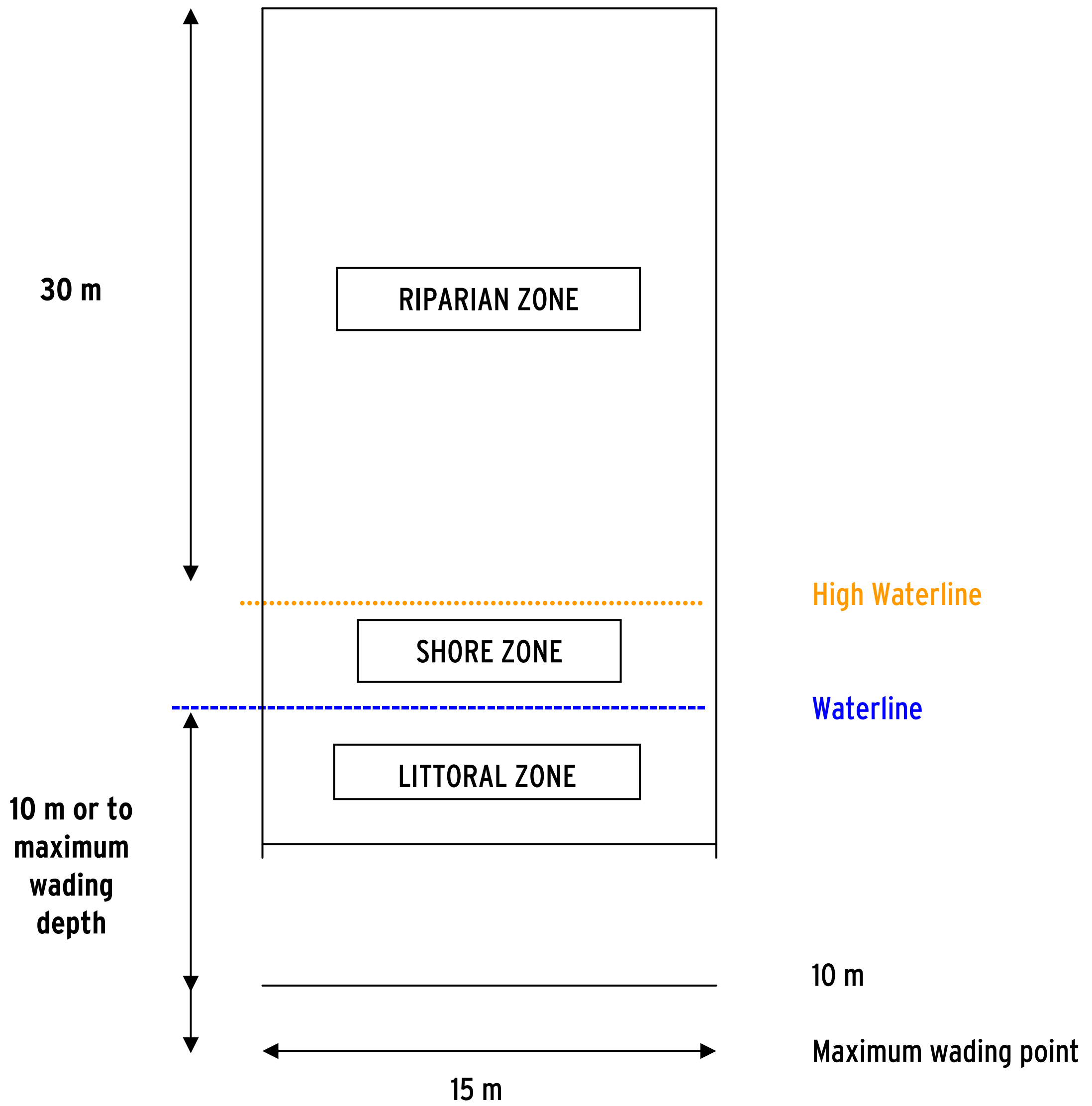
If the lake has a principal retaining structure, estimate the max. height in **metres** from the lakebed.

The number of streams that contribute to >10% of the total catchment is recorded as a **number** value.

Indicate to your knowledge whether there are any upstream impoundments by **circling** the appropriate answer.

Indicate whether there is evidence of significant flow diversion into/out of the catchment by **circling** the appropriate answer.

Definition of lake zones



APPENDIX C: SCORING SYSTEM FOR LAKE HABITAT MODIFICATION SCORE (LHMS)

The section numbers and headings (e.g. 2.1 RIPARIAN ZONE) refer to sections in the LHS field sheets (see Appendix A).

PRESSURE	**Scores 0**	**Scores 2**	**Scores 4**	**Scores 6**	Scores 8
Exotic vegetation in riparian zone (2.1)	% exotic vegetation = 0 for all categories	At least 1 exotic veg category = 1	At least 1 exotic veg category = 2	At least 1 exotic veg category = 3	At least 1 exotic veg category = 4
	(AVERAGE OVER HABPLOTS)				
Riparian zone intensive use (2.1)	Dominant land cover = non-natural at 0 hab-plots	Dominant land cover = non-natural at >10% hab-plots	Dominant land cover = non-natural at >30% hab-plots	Dominant land cover = non-natural at >50% hab-plots	Dominant land cover = non-natural at >70% hab-plots
	(NON-NATURAL LAND COVERS = BA, PP, EP, GR, CR, IL, PG, AW, UR, RE, WI)				
Shore zone modification (2.2)	Shore modification at 0 hab-plots	Shore modification at >10% of hab-plots	Shore modification at >30% of hab-plots	Shore modification at >50% of hab-plots	Shore modification at >70% of hab-plots
Artificial bank construction (3.1)	No artificial bank construction	At least 1 artificial bank construction feature	At least 2 artificial bank construction features	At least 3 artificial bank construction features	4 artificial bank construction features
Catchment pressures (3.1)	No human pressures	At least1 human pressure	At least 2 human pressures	At least 3 human pressures	>3 human pressures
Extent of Catchment Pressures (2.4)	No human pressures	Human pressures recorded at >10% of hab-plots	Human pressures recorded at >30% of hab-plots	Human pressures recorded at >50% of hab-plots	Human pressures recorded at >70% of hab-plots
In-lake use (3.2)	No in-lake pressures	1 in-lake pressure	2 in-lake pressures	3 in-lake pressures	>3 in-lake pressures
	(IGNORE LITTER & ODOUR)				
Shore erosion (2.2)	No shore erosion	Shore erosion recorded at >10% of hab-plots	Shore erosion recorded at >30% of hab-plots	Shore erosion recorded at >50% of hab-plots	Shore erosion recorded at >70% of hab-plots
Catchment erosion (3.1)	Erosion not recorded in any lake quarter	Average erosion = category 1	Average erosion = category 2	Average erosion = category 3	Average erosion = category 4

APPENDIX D: SCORING SYSTEM FOR LAKE HABITAT QUALITY ASSESSMENT

The section numbers and headings (eg. 2.1 RIPARIAN ZONE) refer to sections in the LHS field sheets (see Appendix A).

Lake zone	Characteristic	Measurable feature	Scores	Maximum
RIPARIAN (section 2.1)	Vegetation structural complexity	Number of categories >10% cover	0: **0** 1: **1** 2: **2** 3: **3** 4: **4** 5: **5**	5 per hab-plot (Average value)
	Vegetation stability	Maximum category value of trees or small trees/woody shrubs	Sum of category scores for each hab-plot	Average hab-plot value to a maximum of 6
	Extent of natural cover	% exotic species in each category	Average of category scores (ignoring categories not present) Use inverse of % cover of exotics category, i.e. 0 becomes 4, 1 becomes 3 etc	8 per hab-plot (Average value multiplied by 2)
SHORE (section 2.2)	Shore structural habitat diversity	Number of natural substrate types	1 each	Maximum of 7
	Shore naturalness	No shore modification	% of hab-plots with natural shoreline: **0** for <15 **1** for >15 **2** for >30 **3** for >45 **4** for >60 **5** for >75 **6** for >90	Maximum of 6
LITTORAL (section 2.3)	Diversity of natural substrate types	Number of natural substrate types	1 each	Maximum of 7 per lake
	Extent of macrophyte cover (section 2.3)	Average total macrophyte cover	0: **0** 1: **1** 2: **2** 3: **3** 4: **4**	4 per hab-plot (Average value)
	Diversity of macrophyte cover	Number of transects where macrophyte cover extends lakewards	% of plots where macrophytes extend lakewards **0** for <15 **1** for >15 **2** for >30 **3** for >45 **4** for >60 **5** for >75 **6** for >90	Maximum of 6 per lake
		Total number of macrophyte types (excluding filamentous algae)	0: **0** 1-2: **1** 3-4: **2** 5-6: **3** 7-8: **4** 9-10: **5** 11-12: **6**	Maximum of 6 per lake
	Diversity of littoral habitat features for fish	Number of habitat types	0: **0** 1: **1** 2: **2** 3: **3** 4: **4** 5: **5** 6: **6** 7: **7**	Maximum of 7 per lake
	Extent of littoral habitat features for fish	Maximum category of % cover	Sum of category scores for each hab-plot	Average hab-plot value to a maximum of 6
	Special habitat features	Number of wetland habitats	1 each	5 per lake
WHOLE LAKE (section 3.1)		Number of other natural habitat features	1 each	7 per lake
TOTAL LHQA				**80**

APPENDIX E: SCORING SYSTEM FOR THE VLAKES INDEX

Family	Grade	Family	Grade
Aeshnidae	6	Hydroptilidae	6
Ancylidae	3	Hygrobiidae	5
Atriplectididae	8	Hymenostomatidae	5
Atyidae	5	Isostictidae	5
Baetidae	7	Leptoceridae	3
Belostomatidae	5	Leptophlebiidae	10
Caenidae	5	Lestidae	6
Calamoceratidae	7	Libellulidae	6
Ceinidae	3	Lymnaeidae	6
Ceratopogonidae	4	Naucoridae	5
Chironominae	3	Nepidae	3
Clavidae	2	Noteridae	5
Coenagrionidae	3	Notonectidae	3
Cordulephyidae	7	Notonemouridae	7
Corixidae	2	Odontoceridae	8
Culicidae	3	Orthocladiinae	4
Curculionidae	4	Palaemonidae	5
Dolichopodidae	5	Paramelitidae	6
Dugesiidae	4	Parastacidae	5
Dytiscidae	5	Physidae	4
Ecnomidae	6	Planorbidae	4
Elmidae	7	Pleidae	5
Empididae	6	Psephenidae	7
Erpobdellidae	6	Ptilodactylidae	7
Glossiphoniidae	4	Pyralidae	7
Gomphidae	7	Scirtidae	8
Gripopterygiidae	9	Sialidae	7
Gyrinidae	7	Sphaeriidae	6
Hemicorduliidae	5	Stratiomyidae	3
Hydraenidae	4	Syrphidae	1
Hydridae	4	Tabanidae	5
Hydrobiidae	4	Tanypodinae	5
Hydrochidae	4	Tipulidae	7
Hydrophilidae	5	Veliidae	4