R-00-38

Lake and lake-related drainage area parameters for site investigation program

Peter Blomqvist, Anna-Kristina Brunberg
Department of Limnology, Evolutionary Biology Centre
Uppsala University

Lars Brydsten
Department of Ecology and Environmental Science
University of Umeå

September 2000

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

ISSN 1402-3091
SKB Rapport R-00-38

Lake and lake-related drainage area parameters for site investigation program

Peter Blomqvist, Anna-Kristina Brunberg
Department of Limnology, Evolutionary Biology Centre
Uppsala University

Lars Brydsten
Department of Ecology and Environmental Science
University of Umeå

September 2000

Summary

In this paper, a number of parameters of importance to a preliminary determination of the ecological function of lakes are presented. The choice of parameters have been made with respect to a model for the determination of the nature conservation values of lakes which is currently being developed by the authors of this report, but is also well suited for a general description of the lake type and the functioning of the inherent ecosystem.

The parameters have been divided into five groups: 1) The location of the object relative important gradients in the surrounding nature; 2) The lake catchment area and its major constituents; 3) The lake morphometry; 4) The lake ecosystem; 5) Human-induced damages to the lake ecosystem. The first two groups, principally based on the climate, hydrology, geology and vegetation of the catchment area represent parameters that can be used to establish the rarity and representativity of the lake, and will in the context of site investigation program be used as a basis for generalisation of the results. The third group, the lake morphometry parameters, are standard parameters for the outline of sampling programmes and for calculations of the physical extension of different key habitats in the system. The fourth group, the ecosystem of the lake, includes physical, chemical and biological parameters required for determination of the stratification pattern, light climate, influence from the terrestrial ecosystem of the catchment area, trophic status, distribution of key habitats, and presence of fish and rare fauna and flora in the lake. In the context of site investigation program, the parameters in these two groups will be used for budget calculations of the flow of energy and material in the system. The fifth group, finally, describes the degree on anthropogenic influence on the ecosystem and will in the context of site investigation programmes be used to judge eventual malfunctionings within the entire, or parts of, the lake ecosystem. Altogether, the selected parameters will create a solid basis for determination of the lake type and its representativity of the region where it is located and of the function and eventual malfunction of the inherent ecosystem.

Sammanfattning

I denna rapport redovisas ett antal parametrar som är av betydelse för att ett sjöekosystems basala ekologiska funktion och eventuella skador på denna ska kunna bedömas. Urvalet av parametrar har gjorts utifrån en modell för naturvärdesbedömning av sjöar som är under utveckling av författarna till denna rapport. Parametervalet är också mycket väl lämpat för en allmän beskrivning av olika sjötyper och funktionen hos deras ekosystem, något som är aktuellt i samband med de platsundersökningar som under kommande år ska genomföras av SKB för att skapa ett underlag för bedömning av var utbränt kärnbränsle ska kunna slutförvaras.

Parametrarna har indelats i 5 huvudgrupper. Grupp 1 beskriver sjöns läge relativt olika betydelsefulla gradienter i omgivande natur. Grupp 2 beskriver sjöns eget tillrinningsområde och dess huvudkomponenter i form av andra ekosystemtyper. Grupp 3 utgörs av sjömorfometriska parametrar framräknade på basis av djupkartan. Dessa tre grupper av parametrar ska först och främst användas för att bedöma sjöns raritet respektive representativitet i området så att såväl goda representanter för sjöbeståndet som ovanliga och skyddsvärda typer av sjöar kan identifieras. Parametrarna i grupp 3 ska också användas för utformning av provtagningsprogram och för beräkningar av den fysiska utbredningen av olika huvudhabitat i sjöekosystemet. Grupp 4 innehåller parametrar med vars hjälp sjöekosystemets struktur och basala ekologiska funktioner kan beskrivas och innefattar bland annat fysikaliska parametrar som temperaturfördelning, skiktningsmönster och ljusklimat, samt vattenkemiska och biologiska parametrar nödvändiga för bedömning av sjöns trofinivå samt graden av påverkan från terrestra ekosystem i tillrinningsområdet. Vidare ingår standardiserade provfisken och inventeringar av skyddsvärda och hotade arter. Grupp 5, slutligen, innehåller parametrar med vars hjälp graden av mänsklig påverkan på sjön och dess tillrinningsområde kan bedömas och innefattar fysiska ingrepp, föroreningar, främmande arter samt exploatering av artpopulationer. Tanken bakom parametervalet är att de lokaler som ska beskrivas vid platsundersökningar ska kunna värderas utifrån en samlad kunskap om såväl tillgångar i form av intakt natur som skador. Det är författarnas bedömning att de föreslagna parametrarna tillsammans ger en solid bas för bedömningar av sjötypen, dess representativitet inom den region där den är belägen, samt av den naturliga funktionen hos sjöekosystemet och eventuella skador på detta.

Table of contents

1 Introduction

From a biogeochemical perspective, the water in lakes and streams can be regarded as a transport medium by which the weathered dissolved and particulate components of the continents are slowly brought to the sea. While the turnover of water on earth is typically a cyclic process, the transport of weathered products from the continents can be described as unidirectional. Hence, most of the continents will in the long-term perspective end up as marine sediments. While streams from an abiotic point of view can be described as transport pathways through which material is relatively quickly passed on to the sea, lake basins act as sediment traps for particles as well as for those inorganic nutrients which are assimilated into biota that subsequently settle out in the basin. The establishment of an ecosystem in lakes and streams considerably slows down the transport of material both by assimilatory processes and by direct filtering of the water through dense stands of vegetation. A reduced loss of nutrients and particulate matter from the continents to the sea is a characteristic also of the ecosystems of the catchment area, which together with the aquatic ecosystems, creates the largest functional ecosystem unit of the continents, the drainage area. Most human-induced disturbances of the ecosystems ultimately result in altered transport of material from the continents to the sea. A majority of the disturbances tend to speed up the losses, e.g. drainage of land, channelisation of streams for transportation, agriculture, urbanisation, forestry, and acidification, while others, e.g. construction of dams, typically result in decreased losses of material to the sea.

Investigating the role of lakes as traps for material on its way from the continents to the sea, a large number of internal and external factors must be included, e.g. the climate, geology, vegetation and higher biota of the drainage area as well as the lake basin morphometry and characteristics of the lake ecosystem and its key habitats. It is also essential to have good knowledge of the human-induced damages to the systems. Thus, in all studies aiming at understanding of a lake ecosystem functioning from a biogeochemical perspective the lake must be regarded as an integral part of the drainage area.

SKB, The Swedish Nuclear Fuel and Waste Management Company, is planning to continue the siting program for deep repository of spent nuclear fuel in year 2001 with surveys of at least two potential sites. These sites will be selected from six communities in Sweden: Nyköping, Östhammar, Oskarshamn, Tierp, Hultsfred, or Älvkarleby. Previous studies have been carried out to identify suitable areas in different communities in Sweden based on available data from various disciplines, mainly geology and transport possibilities. By analysing site characteristics it will become possible to point out the most suitable sites for siting program. The sites will be surveyed for data relevant to evaluate the construction and function of a planned deep repository.

There are scientists from several fields of investigation preparing for the siting program. Variables that might be of interest to study from an ecosystem point of view have been compiled by Lindborg and Kautsky /2000/, variables of interest for geological investigations are presented in Andersson et al /1998/, available climatological and oceanographical data are presented in Lindell et al /1999/, and available statistics for site studies in registers and surveys at Statistics Sweden are presented in Haldorson /2000/.

This report describes a selected number of lake and lake-related drainage area parameters required for a preliminary determination of the ecological functioning of the lake ecosystem from a point of view of its nature conservation value and its functioning as a trap for radioactive compounds that may enter the biosphere from the deep repository in case of a leak of the containers holding the nuclear waste.

2 The location of the object relative important gradients in the surrounding nature

The physical, chemical, and biological properties of a lake ecosystem reflect the conditions of the surrounding land area and particularly the catchment area, from which the lake receives its water. The climate of the area determines the drainage regime which, together with lake basin morphometry, determines the turnover time of the water, a parameter which is tightly coupled to the cycling of nutrients in the system. The climate and basin morphometry also determine the mixing regime of the lake, another crucial factor to lake metabolism. The bedrock and soils of the drainage area are the principal sources of many important plant nutrients in the lake water. Hence, the richer and more easily weathered the soils, the more naturally nutrient rich the lake water. The vegetation and size of the drainage area are important determinators of the transport of terrestrial organic carbon to the lake ecosystem, a factor which in turn determines relative importance of bacteria vs primary producers in utilising nutrients and mobilising carbon energy at the base of the lake food-web /Jansson et al, 1999/. During Quaternary, Scandinavia has suffered at least four major periods of glaciation and subsequent meltoff of the glaciers. As a result of these dramatic changes, most geological layers between the Precambrian shield and Quaternary have been lost to the sea and settled there as marine sediments. Areas dominated by the Precambrian shield (bedrock) and its weathering products (soils), respectively, are characterised by scarcity of nutrients and a resulting low productivity of terrestrial as well as aquatic ecosystems. However, as a result of the depression of the peninsula into the crust of the Earth during last glaciation, large parts of Sweden have a substantial land-rise also today and this process brings more easily weathered and nutrient-rich soils back on land. Hence, land areas below the highest shore-line of the sea have a greater production potential than other areas, including also the lakes and streams. The Baltic Sea has altered between being a lake and an estuary four times after the last glaciation; first being a freshwater ice lake, then the Yoldia Sea, the Ancylus lake and, finally, the Littorina Sea – the present stage of which is entitled the Baltic Sea. As a consequence, there are several highest shore-lines of the Baltic “Sea” in the landscape /cf. Påsse, 1996/. Two of these shore-lines are especially important to the distribution of post-glacial sediments on land because the glacier had almost melted off from Sweden when they were formed, that of the Ancylus lake (which is the highest of the four) and that of the Littorina Sea (below which marine sediments were settled). In the context of fertility of the drainage areas and their aquatic systems due to soils being brought up by land-rise, Sweden can be divided into three regions, above the very highest shore-line, between the very highest shore-line and the highest shore-line of the Littorina Sea, and below the highest shore-line of the Littorina Sea.

Although it may be claimed that each lake is unique the similarities between lakes are likely to increase with decreasing distance between systems, due to similarities caused by the factors described above. Hence, in the analysis of the rarity and representativity of lake ecosystems, these factors can be used for sorting the lakes into main categories. As far as the authors know, there are no standardised ways to establish the rarity and representativity. We therefore propose a new method, based on regional non-lake parameters, starting with the large-scale factors described in this chapter. Combined with the catchment area parameters described in chapter three, a model which is currently under construction by the authors of this paper will be used to establish how many lakes in each area of Sweden intended for the site investigation program that have similar characteristics. Below follows a description of the large-scale factors, some of which are already available on the National SKB GIS (Geographical Information System). In the context of using the GIS for calculations of various parameters on the national and regional scales it has been assumed that the programme ArcView is the basis for storage and analysis of the data.

2.1 Location relative major drainage regions

We suggest that the division of Sweden into nine major drainage regions (MDR) presented by Melin /1970/ is used:

MDR 1. The rivers of Nordkalotten: Rivers Torneälven and Kalixälven.

MDR 2. The northern alpine rivers of Norrland: Rivers Lule-, Pite-, Skellefte- and Umeälven.

MDR 3. The central alpine rivers of Norrland: Rivers Ångermanälven and Indalsälven.

MDR 4. The alpine and forest rivers of southern Norrland and northern Svealand: Rivers Ljungan, Ljusnan, Dalälven, and Klarälven.

MDR 5. The forest and coastal rivers of Norrland.

MDR 6. Rivers which represent a transition between northern and southern types: Rivers entering Lake Vänern from the north (except R. Klarälven) and rivers entering Lake Mälaren from Bergslagen.

MDR 7. Rivers in SE Sweden that enter the Baltic Proper.

MDR 8. Rivers in SW Sweden that enter Skagerack or Kattegatt.

MDR 9. The outlet rivers of the large Lakes: Norrström and Göta Älv except those parts that are members of MDR6 or MDR4.

2.1.1 Methods for data collection

The map can be constructed by aggregation of the main river systems of Sweden on the digital drainage area map available from the Swedish Meteorological and Hydrological Institute (SMHI) into nine major drainage regions (MDR). Using the overlay technique in the Regional SKB GIS, each drainage area within the sites intended for the site investigation program can be assigned to a major drainage area.

2.1.2 Costs

The digital drainage area map over Sweden can soon be bought from the Swedish Meteorological and Hydrological Institute (SMHI). The price is yet not available.

2.2 Location relative main river systems of Sweden

We suggest that the division of Sweden into main river systems follows that of the Swedish Meteorological and Hydrological Institute (SMHI), using the label 1 for River Torneälven and 118 for Snodeån.

2.2.1 Methods for data collection

The available digital map of drainage areas of Sweden can with GIS then be aggregated into a map with main river systems.

2.2.2 Costs

See 2.1.2.

2.3 Location relative important terrestrial ecozones (naturgeografiska regioner)

We suggest that the division of the Nordic countries into important terrestrial ecozones (naturgeografiska regioner) by the Nordic meeting of the Ministers /NU, 1977/ is used. Out of a total of 76 such regions, 29 are found in Sweden.

2.3.1 Methods for data collection

A digital map of the ecozones, produced by the National Atlas of Sweden /SNA 1992/, can be included in the National SKB GIS. Alternatively, the map in the paper version of the atlas can be digitised. In those cases when a drainage area extends into several eco-zones, the dominant (by area) zone is used for the classification.

2.3.2 Costs

The digital ecozones map over Sweden can be bought from the National Atlas of Sweden /SNA 1992/. The total cost for all maps (see also sections 2.4.2 and 2.5.2, below) required from the atlas is ca. 3000 SEK.

2.4 Location relative main soil regions of Sweden

We suggest that the division of Sweden into 13 major soil regions established by Persson and presented in the National Atlas of Sweden is used /SNA 1992/.

2.4.1 Methods for data collection

The map can be bought in digital format from the National Atlas of Sweden /SNA 1992/. In those cases when a drainage area extends into several soil regions, the dominant (by area) region is used for the classification.

2.4.2 Costs

The digital soil region map over Sweden can be purchased from the National Atlas of Sweden /SNA 1992/ (see section 2.3.2).

2.5 Location relative marine limits

We suggest that the available digital maps of the very highest shore line of the Baltic Sea (VHS), and the highest shore line of the Littorina Sea (HSL) is used for this classification. These maps are then combined, which gives a map with three areas; above VHS, between VHS and HSL, and below HSL. Using overlay technique in the Regional SKB GIS each local drainage area can be assigned to a particular location relative the marine limits.

2.5.1 Method for data collection

The digital map of the highest shoreline of the Baltic Sea is available at the Department of Ecology and Environmental science, University of Umeå and the digital map of the highest shoreline of the Littorina Sea is available from the National Atlas of Sweden /SNA 1992/.

2.5.2 Costs

The costs for the digital map of the highest shoreline of the Baltic Sea is free of charge and the digital map of the highest shoreline of the Littorina Sea can be purchased from the National Atlas of Sweden /SNA 1992/ (see section 2.3.2).

3 The catchment area and its major constituents

Knowledge about the characteristics of the land area (catchment area) from which water is transported to lakes and streams is of outmost importance for the understanding of the functioning of aquatic ecosystems. The catchment, or drainage, area is defined as the upstream area collecting water that flows out over the lake threshold. Traditionally /cf. Forbes, 1887/, limnologists regarded lake ecosystems as “microcosms” with respect to the production of biota, i.e. although the production of organisms was believed to be based on inorganic nutrients from the catchment area, it was plants growing in the lake that mobilised the carbon energy used by higher trophic levels. However, during the past decade this picture has changed dramatically as it was realised that carbon produced in the drainage area was metabolised during the passage of the lake ecosystem to such an extent that most lakes could be regarded as net heterotrophic systems, i.e. producing carbon dioxide to and consuming oxygen from the atmosphere /Cole et al, 1994/. Particularly in brownwater lakes, i.e. the dominant lake type in the boreal forest region, allochtonous organic carbon was found to constitute the most important basis for the total production of biota /Jansson et al, 1999/. Hence, the catchment area is crucial to the understanding of the natural functioning of lake ecosystems. The same line of reasoning can indeed be applied to understanding of man-made damages to the functioning of lakes and streams, as there are few damages to lake ecosystems that do not have their origin in terrestrial parts of the drainage area. The problems of physical damages, acidification, eutrophication, toxic substances etc., all have their origin in undertakings in the catchment area. Hence, in all studies pertaining to understand the functioning and malfunctioning of lakes, including the aim of the material generated for the site investigation program, good knowledge about the catchment area is crucial.

3.1 Size of the drainage and catchment areas

The size of the drainage and catchment areas, respectively, are the needed basic parameters for determination of all other drainage area parameters described below. The size of the drainage area can be obtained by a variety of methods to determine the size of an area, manual (e.g. through planimetry) as well as automatic (see below). However, before any calculations can be made the location of the watershed must be established which requires manual work on a high-resolution topographic map and which sometimes must be complemented by field studies. Especially in lowland plains, establishment of the watershed may be a difficult task and require field verifications.

3.1.1 Existing data

The Swedish Meteorological and Hydrological Institute (SMHI) has a digital map of the major drainage areas in Sweden, including some 11500 units. This map is already available on the Regional SKB GIS but not nation-wide. Furthermore, Brunberg and Blomqvist /1998/ includes a high-resolution drainage area map of Uppsala County with a total of 277 units, which covers all sites in the communities of Älvkarleby, Tierp, and Östhammar. This map is also available on the Regional SKB GIS. For the remaining areas of interest to the site investigation program, the larger drainage areas of the SMHI map should be further divided into subunits, preferably in the same way as for Uppsala County.

3.1.2 Methods for data collection

Performance

The watershed is tracked and preliminary marked with a pencil on the topographic map (Gröna kartan). In cases where the location of the watershed is not clear on this map, the high resolution topographic map (Ekonomiska kartan) is used as a complement. In cases where it is still not possible to locate the watershed, field studies are used to finally resolve the problem. After the watershed has been established it is finally drawn with a black Indian ink pen on the main topographic map (Gröna kartan). The information from this map is then digitised as described below.

Background data

Background data needed include topographic maps of Sweden (Gröna kartan) and access to the most recent version of the economic map (Ekonomiska kartan) which has also the topographic information.

Time schedule

Establishment of the watershed is done once and for all, unless major changes in river flow or man made disturbances, e.g. channelisation, alters the conditions completely.

Potential resources

Establishment of the location of the watershed can be carried out by hydrologists and limnologists as well as by physical geographers.

Data processing

For the communities of Älvkarleby, Tierp, and Östhammar, the drainage area information from Brunberg and Blomqvist /1998/, already available on the Regional SKB GIS is used. For other sites intended for site investigation program, the digital map of drainage areas available from SMHI is primarily used. Remaining drainage areas are made available from the topography maps, scanned into the computer, and digitised. The area of each sub-catchment is calculated within the GIS and stored as an attribute value in a table linked directly to the map.

Uncertainty-risks

The precision of the parameter size of the drainage area will to a great extent rely on the precision of the location of the watershed, which in turn depends on the type of topographic map used (scaling factor) and whether or not difficult sections have been verified by field studies. Hence, using the main topography map of Sweden alone may result in large errors, whereas by using the entire procedure described above, the precision will be determined by the resolution of the map from which data are scanned and directly proportional to the size of the drainage area.

Costs

Personnel involved in work with location of the watershed on maps and in the field are paid at an hourly or monthly rate.

3.2 Vegetation and land use in the drainage area

Once the size of the drainage area has been established (see 3.1 above), other characteristics of the area can be calculated using overlay techniques in GIS. The vegetation and land use in each drainage area is obtained using a combination of the following digital products already available on the Regional SKB GIS: Landsat satellite images (forest) and the topographic map of Sweden, "Lantmäteriets blå karta" (other kinds of land use). Using overlay technique in the Regional SKB GIS, the area of each kind of land use can be calculated and is then saved as attributes to the drainage area map. The resulting parameters from this step in the procedure include the size of the actual lake and the size and relative contribution of forests, wetland, open land, other lakes, urban area, and major industries within the catchment.

3.3 Bedrock in the drainage area

Once the size of the drainage area has been established (cf. 3.1 above), other characteristics of the area can be calculated using overlay techniques in GIS. The bedrock in the drainage area is obtained from the digital bedrock map, which is available from the National Atlas of Sweden. Using the overlay technique the area of each type of bedrock can be calculated and is then saved as attributes to the drainage area map. The resulting parameters from this step in the procedure include all different types of bedrock on the map.

3.4 Soils in the drainage area

Once the size of the drainage area has been established (cf. 3.1 above), other characteristics of the area can be calculated using overlay technique in GIS. The distribution of soils in the drainage area is obtained from the digital soil map, which is available from the National Atlas of Sweden. Using the overlay technique the area of each type of soil can be calculated and is then saved as attributes to the drainage area map. The resulting parameters from this step in the procedure include all different types of soils on the map.

3.5 Populations of humans and live stock and residences in the drainage area

Once the size of the drainage area has been established (cf. 3.1 above), other characteristics of the area can be calculated using overlay technique in GIS. Data on populations of humans and live stock and residences can be bought from SCB and are available for each km^2 of Sweden. The data are transformed to a digital map in a raster format and using the overlay technique, the number of humans and live stock and residences in each drainage area is calculated. The resulting data are then saved as attributes to the drainage area map.

3.6 Climate

Once the size of the drainage area has been established (cf. 3.1 above), other characteristics of the area can be calculated using overlay technique in GIS. The climate of the area is obtained using digital maps over average temperature, evaporation, and area-specific runoff, which are available from the National Atlas of Sweden. Using the overlay technique, area-weighted averages for each parameter and drainage area are calculated and subsequently saved as attributes to the drainage area map. The resulting parameters include average temperature, evaporation, and area-specific runoff.

3.7 Actual and calculated runoff

Once the size of the drainage area has been established (cf. 3.1 above), other characteristics of the area can be calculated using overlay technique in GIS. For all running waters in each site intended for the site investigation program in which the runoff is continuously measured, monthly average runoff data for the latest 30 year period are bought from SMHI and saved as attributes in the table linked to the drainage area map. For all drainage areas the annual average runoff is calculated using the area-specific runoff maps (cf. 3.6, above) and the resulting data are saved as attributes in the table linked to the drainage area map.

3.8 Drainage area morphometry

Once the size of the drainage area has been established (cf. 3.1 above), other area-related characteristics can be calculated using overlay technique in GIS. The drainage area morphometry, including maximal and average slope of the landscape, is calculated using the digital elevation model (DEM) already available on the Regional SKB GIS for the sites intended for the site investigation program. The resulting data are saved as attributes in the table linked to the drainage area map.

3.9 Origin of lake basin

Lake basins can be formed in many different ways and the formation process has been of considerable interest to physical geographers and limnologists during the first part of the 20th century. Hutchinsson /1975/ summarised this research and concluded that although the total number of ways by which lakes can be formed amounted to 76, these types could be sorted into 11 main categories. The process by which the lake basin is formed initially determines the lake morphometry, and in many cases also the morphometry of the drainage area, thereby being an important factor related to the functioning of the lake ecosystem. It is also a frequently used parameter in the context of nature conservation and is therefore essential for establishment of the rarity and representativity of a particular lake.

3.9.1 Existing data

There are no systematic data about the origin of Swedish lakes. However, descriptions of lakes from inventories for nature conservation purposes frequently include statements about particularly rare types of lakes and are available for all sites intended for the site investigation program.

3.9.2 Methods for data collection

Performance

Most Swedish lake basins are of glacial origin and were formed in connection with the meltoff of the ice at the conclusion of the last glaciation. During visits to the lakes in connection with various other undertakings within the site investigation program, both terrestrial and aquatic, we suggest that an ocular inspection of the lake basin is performed, and that its most probable origin is classified into one of the following classes:

1. Tectonic basins (sprickdalssjöbäcken).
2. Fluviatile basins.
3. Volcanic basins.
4. Basins created by meteorite impact.
5. Landslide basins.
6. Solution basins.
7. Wind-induced basins.
8. Basins associated with coast lines.
9. Lakes formed by organic accumulation or by complex behaviour of higher animals.
10. Glacial basins in the form of kettle lakes (åsgropssjöar).
11. Other basins, origin unknown but most probably glacial.

Time schedule

Identification of the origin of a lake basin is carried out once and for all.

Background data

Background data needed include a topographic map of the area in which the lake is located and a map of the bedrock in the drainage area available on the Regional SKB GIS (cf. 3.3 above).

Potential resources

The analysis requires a well trained physical geographer.

Data processing.

The resulting data (including the 11 categories described above) are saved as attributes in the table linked to the drainage area map (cf. 3.1 above).

Uncertainty-Risks

Since the suggested classification system includes the category "other basins" into which those lake basins for which the formation process is not evident should be put, the risk of an experienced physical geographer to make a mistake seems minimal.

Costs

Since the identification of the origin of the lake basin is carried out in connection to other studies, the costs are most likely minimal and restricted to a maximum of one working hour per lake basin.

4 Lake morphometry parameters

Access to lake morphometry data is an absolute prerequisite for all lake studies included in the site investigation program as well as for a majority of limnological studies in general. The lake morphometry data are for example used to calculate the volume of water in the basin, a parameter which in turn is used to calculate the retention time of the water in the lake. The latter parameter is a key to the understanding of the fate of nutrients and pollutants in the system. Furthermore, lake morphometry data are included in the sampling programme for chemistry of the open water of the lake (cf. 5.3–5.7 below), the description of the area distribution of key habitats in the lake (cf. 5.9 below) and in the planning of the standardised gill net fish surveys (cf. 5.10 below).

4.1 Depth sounding

The depth chart is the key to calculations of all lake morphometry parameters and can be established after careful and systematic measurements of the water depth over the lake. Depth soundings have traditionally been performed either 1) manually (and then usually from ice during winter) or 2) automatically, using an echo-sounding equipment which records the water depths along known transects on a paper echo gram /cf. Håkansson, 1981/. In the description below we suggest a third possibility, an automatic method using a combination of an echo-sounding equipment and a GPS equipment.

4.1.1 Existing data

In comparison with the rather accurate height data for land areas, presented on the topographic maps of Sweden, surprisingly few data exist on water depths in Swedish lakes. As far as the authors know, no systematic surveys of depths in inland waters have been performed by any Swedish authority, except in the largest and deepest lakes used for transportation of cargo on ships. Other depth soundings have been carried out sporadically in connection with various activities in the lakes, activities ranging from private persons describing the basin morphometry for purposes of boating or fishing, over descriptions of volumes of water to be accessed by water level regulation for power supply, to scientific investigations by limnologists and hydrologists. In Uppsala County, many of the lakes have been depth sounded by hydrologists and limnologists at Uppsala University, or by the Uppland Foundation. The resulting depth charts for most of the totally 140 larger lakes in the county have been compiled and presented by Brunberg and Blomqvist /1998/ and are already available on the Regional SKB GIS. For other communities of Sweden which will be subject to the site investigation program, the few existing depth charts are most likely spread on a variety of publications. SMHI (the Swedish Meteorological and Hydrological Institute) has the ambition to gather as many as possible of these charts and to keep a register over depth-sounded lakes /cf. Lindell et al, 1999/. Depth charts over particular lakes may also be found in publications from local and regional water authorities, and registers may be kept by the Regional Administrative Office of the County (Länsstyrelsen).

4.1.2 Methods for data collection

Performance

For those lakes where paper depth charts are available, the depth information (including eventual measurements of the location of the shoreline) should be digitised into xyz-data. Data about the location of the shoreline and the nearest 5 meter contour line on land should then also be added from the economic map of Sweden (scale 1:20000). These two curves should be transformed to data points and added to the data points from the digitised depth chart. A digital depth chart in a raster format should then be constructed using any of the interpolation-techniques available in the GIS-program (preferably the Kriging-technique). Using this rasterised theme as a the basis, all lake morphometry parameters described below can be automatically calculated. The relative hypsographic curve should be presented in the form of a graph. The graph is constructed using a macro in a calculation programme (i.e. Excel) and the spreadsheet should be linked to the “Lake polygon theme” using the “Hot Link tool”.

For those lakes where information about water depths are missing, depth sounding should be performed and a depth chart constructed. The sounding should be carried out from a boat using a combination of a digital echo-sounder and a DGPS-equipment. For each time the position given by the DGPS is updated (every 3 seconds) the co-ordinates X and Y from the DGPS should be stored together with the depth value, Z, given by the echo-sounder. The resulting XYZ-data from the depth sounding procedure should then be transferred to the GIS-application and added to XYZ-data describing the location of the shoreline and the nearest 5 m height curve above water taken from the topographic map. The construction of a digital depth chart and subsequent calculations of lake morphometry parameters is then carried out as described above.

The required precision of the paper version of the depth chart required for planning of composite sampling of water chemistry in connection to the site investigation program (cf. section 5 below) is given in Table 4-1.

Table 4-1. Required precision of the bathymetric map for planning of composite sampling in lakes of different maximum depth.

Maximum depth (m)	Equidistance (m)
0–5	0.5
5–10	1
10–20	2
20–40	4
40–	8

4.2 Maximum length and direction of major axis

These parameters can be calculated directly in the Regional SKB GIS. All lake polygon objects in the Regional SKB GIS areas is copied from the economic map and stored in a new “Lake polygon theme”. The maximum length is measured manually with the “Length tool” and the result is stored in the “Lake polygon theme” attribute table. Since ArcView is the GIS-programme in use, the direction of major axis is calculated using a free Avenue-script named “Joint.ave” (can be downloaded at http://www.esri.com). A new line-theme is created and a line drawn along the major axis, then the joint.ave script is run. The direction of the major axis is stored as an attribute in the new line-theme. The direction value is then copied to a new field in the “Lake polygon theme”.

4.3 Maximum width

Maximum width can be measured directly in the Regional SKB GIS, using the “Length tool”. The resulting parameter is then stored in the “Lake polygon theme” attribute table.

4.4 Mean and maximum depth

These parameters can be calculated directly in the Regional SKB GIS. Both the “Raster lake theme” and the “Lake polygon theme” are used with the “Summarise zones” function where the “Lake polygon theme” is used to define the zones to be summarised. The resulting “Summarise table” is then joined to the “Lake polygon theme table” and the fields “Mean depth” and “Maximum depth” are permanently saved.

4.5 Lake area

The lake area can be calculated directly in the Regional SKB GIS by adding a new numeric field to the “Lake polygon theme” attribute table. The area can be calculated using the Avenue-function “Shape.ReturnArea”. The unit will be the same as the map unit (meter).

4.6 Total shoreline length

This parameter can be calculated directly in the Regional SKB GIS by converting the lake polygon object to a line object, using the Avenue-script “cvtplypl.ave”. The line length is then calculated in a new numeric field using the Avenue-function Shape.ReturnLength”. The resulting parameter is manually stored in the “Lake polygon theme” attribute table.

4.7 Lake irregularity index

Lake irregularity index is calculated as a quotient between the shoreline length if the lake was perfectly circular with the same area and the real total shoreline length. The index varies between 0 and 1 with 1 for a circular lake. The index is calculated in a new field in the "Lake polygon theme" with the equation:

Index = 2 * sqrt(3.14 * lake area)/shoreline length.

4.8 Islands, islets, and rocks ("islands")

These parameters can be counted and their area calculated according to Håkansson /1981/ directly in the Regional SKB GIS. The "Lake polygon theme" holds the extensions of islands and in the attribute table, one field has a code for water and island, respectively, and one field has a code for in what lake each island is located. By summarising the data in the latter field, the number of islands and total island area in each lake is calculated and the summarising table is then joined to the "Lake polygon theme table" and the fields "Number_of_islands", "Number_of_islets", "Number_of_rocks", and "Total_island_area" are permanently added to the table.

4.9 Total lake area

The total lake area can be calculated directly in the Regional SKB GIS. The total lake area is calculated in the "Lake polygon theme table" by summarising the fields "Lake_area" and "Total_island_area".

4.10 Total lake volume

The total lake volume can be calculated indirectly in the Regional SKB GIS, in the "Lake polygon theme table", by multiplying the field "Mean depth" with the field "Lake area".

4.11 Lake volume in different depth intervals and the relative hypsographic curve

The "Lake raster theme" is clipped by the "Lake polygon theme" for each lake. The raster values in the clipped theme is exported to Excel by using the Ascii-grid format. Using the frequency function in Excel, the number of raster cells in each depth interval is calculated and based on these values both water volume in different depth intervals and bottom area at different depth intervals are calculated. Both curves are then displayed in separate X,Y-graphs. The Excel-sheet is finally linked to the "Lake polygon theme" with the "Hot Link Tool".

4.12 Theoretical residence time of the water in the lake basin

The theoretical residence time of water in the lake basin can be calculated in the “Lake polygon theme table” using the size of the drainage area (cf. 3.1, above), the lake volume (cf. 4.10, above), and the theme of area-specific runoff (cf. 3.6, above) . The area-specific runoff theme is converted to raster format. The area weighted mean area-specific runoff ($l\ s^{-1}\ km^{-2}$) for each drainage area is calculated with the “Summarise zones” function and the mean runoff ($m^3\ s^{-1}$) is then calculated by multiplying the mean area-specific runoff with the drainage area. Finally, the theoretical residence time is calculated by dividing the lake volume with the mean runoff.

5 Lake ecosystem parameters

The structure and function of the lake ecosystem can be determined from a large number of parameters, physical and chemical as well as biological. In order to make the sampling effort reasonable, we have reduced the number of parameters in the following description to the minimum number required for a preliminary determination of the ecological functioning of lakes. Especially concerning lake biology, we have restricted the data to three groups, including the fish community, the presence of threatened or rare species of fauna and flora, and the habitat diversity. The habitat diversity is a new parameter and includes an inventory of the geographical distribution of and dominant organisms in, maximally, five key habitats present in lakes.

5.1 Water temperature and thermal stratification

The vertical distribution of temperature gives information about thermal stratification of lakes, which in turn is tightly coupled to a large number of physical, chemical, and biological processes regulating the metabolism of the system. Knowledge about the vertical distribution of temperature and the stratification pattern is fundamental to understand the functioning of the lake ecosystem.

5.1.1 Existing data

Measurements of vertical distribution of temperature in a particular lake are as a rule lacking. However, in connection with research projects and local, regional, and national lake monitoring programmes, vertical measurements of water temperature may have been taken. Such data can be found in reports and scientific papers at the universities and in reports published by the local, regional and national water authorities. As a rule, reports from local and regional authorities should be kept by the Regional Administrative Office of the County (Länsstyrelsen). National data can be accessed by Internet at http://www.ma.slu.se. For Uppsala County, references to data sources with a majority of the data generated up to 1997 are given in Brunberg and Blomqvist /1998/. However, as most of the monitoring programmes only include a single or a few observations per year, the resolution in time is not enough to determine length of the stratified period, just whether or not the system is thermally stratified. Thus, in connection with the site investigation program, new data on these two parameters must be generated.

5.1.2 Methods for data collection

Performance

Vertical distribution of temperature is easily measured with a thermometer inside a water sampler, with a thermistometer, or with recording temperature chains. The required precision of the instrument is ± 0.1 °C. Thermal stratification of the water may be difficult to define, but at high latitudes as those in Scandinavia, thermal stratification can be considered to occur when the difference in temperature in a one meter interval is greater than 2 °C. Secondary discontinuity layers, frequently formed close to the surface during hot periods, should be disregarded.

Background data

Background data needed include a depth chart, in order to locate the deepest part of the lake (cf. 4.1, above). Data on the date of formation of an ice cover and of ice-out are also essential in order to plan the survey.

Time schedule

A normal resolution with depth is measurements every meter from surface to bottom at one station located at the deepest part of the lake. A normal resolution in time is biweekly samplings during the ice-free period, combined with a few measurements from ice in connection with measurements of concentrations of dissolved oxygen (cf. 5.8, below).

Potential resources

A survey of water temperatures can be performed by any person with basic knowledge of aquatic systems. However, such surveys are almost exclusively carried out in connection with other measurements (e.g. water chemistry), which requires trained personnel (cf. 5.3–5.7, below).

Data processing

Temperature data can be directly logged into a computer file from the raw (field) protocol and stored in databases, using date of sampling and depth of sampling as descriptors. The data in the database should then be printed in the form of a primary protocol and checked against the raw protocol for errors. Both protocols should then be signed, using name and date of input, by the person in charge of the inlogging procedure and finally stored in a paper file. Depth of the thermocline should then be judged by examination of the depth series of temperature data and logged into a separate file using date of sampling as a descriptor.

Uncertainty – Risks

The thermometer should be calibrated regularly, using a certified reference thermometer for the appropriate temperature interval. Thermometers placed within water samplers have a tendency to break. Thermistometers must be thoroughly checked for batteries and calibrated before travelling to the field. Automatic thermistor chains must be continuously checked for function and well protected from sabotage.

Costs

Cost in connection with measurements of water temperature are restricted to travel and subsidence expenses and salary at an hourly rate of the person involved in the measurement.

5.2 Light penetration into the water and the effective light climate

Measurements of the light penetration into the water column can be used to determine the thickness of the pelagic layer in the lake in which primary production can proceed and for determination of the extension of the littoral zone (cf. 5.9 below). It is also the basis for calculation of the average epilimnetic light intensity (the effective light climate), a parameter of very high importance for the understanding of the variations in productivity among phytoplankton.

5.2.1 Existing data

Measurements of light penetration into the water column of lakes are as a rule lacking from a particular lake. Only in connection with scientific research projects such measurements might have been performed. Available data are therefore to be sought for in scientific papers and reports from the universities. For Uppsala County, references to data sources with a majority of the data generated up to 1997 are given in Brunberg and Blomqvist /1998/. An older parameter, which to a certain degree also describes the light conditions in lakes, is the Secchi disc visibility. Measurements of the Secchi disc visibility can be found in many routine investigations of lakes (for sources cf. 5.1.1, above). Secchi disc visibility data should be gathered from previous investigations but are not necessary to generate in connection with the site investigation program.

5.2.2 Methods for data collection

Performance

Light penetration into the water column is measured using a quanta meter equipped with an underwater sensor (e.g. Lambda Instruments LI 189 Quanta meter and underwater sensor UWQ 4748). Since the decrease of light with increasing depth follows an exponential equation of the form:

$$I_z=I_0 * e^{-k*z}$$

(where I_z = the light at depth z, I_0 = the light just above the surface, e = the base of the natural logarithms, and k = the attenuation coefficient).

It is essential that measurements are carried out at more narrow intervals close to the surface than deeper down. A common depth scale is: one measurement just above surface followed by measurements at depths of 0.1 m, 0.2 m, 0.4 m, 0.8 m, 1.6 m, 3.2 m, 6.4 m, 12.8 m etc.

Background data

Background data needed include a depth chart to locate the deepest part of the lake (cf. 4.1, above). Data on the date of formation of an ice cover and of ice-out are also essential in order to plan the survey.

Time schedule

A normal resolution with depth is presented under performance above. A normal resolution in time is biweekly samplings during the ice-free period. Light penetration measurements should be co-ordinated with measurements of temperature and samplings for water chemistry.

Potential resources

A survey of vertical distribution of light can be performed by any person with basic knowledge of aquatic systems. However, such surveys are almost exclusively carried out in connection with other measurements (e.g. temperature and water chemistry), which require trained sampling personnel (see chemistry below).

Data processing

Light data can be directly logged into a computer file from the raw (field) protocol and stored in databases, using date of sampling and depth of sampling as descriptors. The data in the database should then be printed in the form of a primary protocol and checked against the raw protocol for errors. Both protocols should then be signed, using name and date of input, by the person in charge of the inlogging procedure and finally stored in a paper file. Calculations of the effective light climate can then be performed according to the following equation:

$$I_{eff} = \frac{1}{V_z} \sum_{i=0}^{n} I_i \frac{1 - e^{-k_i \Delta z_i}}{k_i \Delta z_i} V_i$$

where z is the depth of the mixed layer, divided into n intervals, V_z the volume of the mixed layer, z_i the upper depth of the depth interval i, k_i the attenuation coefficient in the interval i, Δz_i the depth of the interval i, and V_i the volume of the interval i. Hence, lake morphometry data and data about the depth of the thermocline are also needed for the calculation. Data on the effective light climate should then be logged into a separate file using date of sampling as a descriptor.

Uncertainty – Risks

Quantameters must be thoroughly checked for batteries before travelling to the field. It is also very necessary to avoid making the measurements so that the shadow of the boat interferes with the light conditions. Near surface measurements may be difficult to perform in windy situations due to problems with holding the underwater sensor at the required depth. The measurements must be performed quickly in order to avoid changes in cloudiness etc., that may yield erroneous results. Both when measuring above surface irradiance and when measuring subsurface irradiances it is necessary to assure that the sensor is placed horizontally; this is best achieved by always holding the underwater sensor by the cable.

Costs

Cost in connection with measurements of light penetration are restricted to travel and subsidence expenses and to salary at an hourly rate of the person involved in the measurement.

5.3 The pH-value of the water

The pH-value is a standard parameter describing the acidity of the water, which in turn is coupled to the conditions of the bedrock, soils and vegetation of the catchment area. In areas where the soils have a high content of easily weathered substances, the pH-value of the water is generally higher than in areas with more refractory soils. If background levels are known, measurements of the pH-value can also be used to determine human-induced acidification of the system (cf. 6.2, below).

5.3.1 Existing data

Measurements of the pH-value of lake waters have been frequently carried out in connection with monitoring of acidification of surface waters. Hence, both in connection with research projects and local, regional, and national lake monitoring programmes, measurements of the pH-value may have been carried out. Data can be found in reports and scientific papers at the universities and in reports published by the local, regional and national water authorities. As a rule, reports from local and regional authorities should be kept by the Regional Administrative Office of the County (Länsstyrelsen). National data can be accessed by Internet at http://www.ma.slu.se. For Uppsala County, references to data sources with a majority of the data generated up to 1997 are given in Brunberg and Blomqvist /1998/. However, as most of the monitoring programmes only include a single or a few observations per year, the resolution in time may be low. Furthermore, most of the environmental monitoring with respect to pH-value of the water have been carried out in poorly buffered areas in the forested regions of Sweden. From other areas, including the localities chosen for the site investigation program, data from a particular lake may be very sparse. Thus, in connection with the site investigation program new data on the pH-value of the water must be generated.

5.3.2 Methods for data collection

Performance

Sampling for measurements of the pH-value of the water in connection with the site investigation program is best performed by taking vertically and horizontally integrated composite samples representing the open water habitat in its entirety, e.g. by the methodology described by Blomqvist /2000/. Such integrated samples should also be used for the determination of all other water chemistry parameters described below but for concentrations of dissolved oxygen. By using integrated sampling, the number of samples to be analysed at each occasion is reduced to a minimum (one) and, hence, also the costs for the survey are kept minimal. The pH-value of the water should be measured on unpreserved water directly after transportation to the laboratory and preferably on the same day as the samples have been taken. The measurements should be performed according to Swedish Standard SS 02 81 22 mod.

Background data

Background data needed include a bathymetric map with a precision (i.e. equidistance between contour lines) according to table 1 in section 4.1 (above).

Time schedule

A normal resolution in time is biweekly samplings during the ice-free period. Sampling of water for measurements of water chemistry (i.e. pH-value, alkalinity, colour, concentrations of particulate and dissolved organic carbon, concentrations of total phosphorus and soluble reactive phosphorus, concentrations of total nitrogen, ammonium nitrogen and nitrite+nitrate nitrogen, and chlorophyll a) should be co-ordinated with measurements of temperature and light and samplings for measurements of the concentrations of dissolved oxygen.

Potential resources

Composite sampling of water for measurements of water chemistry parameters of the water should be performed by trained personnel which are mostly to be found among limnologists. Measurements of the water chemistry should be performed by an accredited laboratory specialised on analyses of water chemistry on natural, unpolluted waters.

Data processing

Data on the water chemistry can be directly logged into a computer file from the analytical protocol delivered from the accredited laboratory and stored in databases, using date of sampling and thickness of the integrated sample as descriptors. The data in the database should then be printed in the form of a primary protocol and checked against the raw protocol for errors. Both protocols should then be signed, using name and date of input, by the person in charge of the inlogging procedure and finally stored in a paper file.

Uncertainty – Risks

The precision of the measurements of different water chemistry parameters is affected by the precision of the sampling procedure and by the precision of the method of analysis by the accredited laboratory. The latter is given by the manual of standard procedures to be used in the context of the site investigation program (see above).

The main source of error during integrated sampling is the same as during other types of sampling: poorly educated sampling personnel. Among the errors such personnel frequently give rise to, the following can be mentioned:

- Poorly rinsed and dirty sampling equipment is one common source of error. Because composite sampling usually deals with large volumes of water the risk that contamination of the larger containers will lead to erroneous results is reduced, but the risk for contamination due to dirty storage bottles remains. The most common places in which sampling equipment is contaminated is probably in cars during transportation (through contact with petroleum products), on the ground during transfer of the equipment from one vehicle to another (soil) or in the water inside the boat (petroleum products, rotten fish etc.). To avoid this kind of contamination the entire sampling equipment should be kept in separate containers during transportation.

- Sampling is performed during a cold day and the personnel are wearing woollen or other kinds of gloves on their hands. From the gloves, and in particular from woollen gloves, a stream of dirty water runs into the sampling containers. The contamination is not only due to dirty gloves but also due to chemical compounds that have been used to impregnate the gloves or from different kinds of dyes. If warming gloves are needed, they should be covered with plastic gloves to prevent contamination.

- Another frequently occurring source of contamination is that the water sampler has been in contact with the lake sediments. To avoid this the sampled water should be checked before each sample is poured into the container. No visible turbidity is allowed in the lower part of the water sampler.

- An anchor is used to hold the boat in an exact position during sampling, the boat starts to drift, and the anchor stirs up mud from the sediments. Anchoring is not necessary, it is enough if the samples are taken in an area close to the selected station. Starting with the deepest interval to be sampled, the risk of hitting the bottom because the boat drifts to shallower areas is minimised.

- The only source of error that is specific to composite sampling is that the person in charge of the procedure loses count of which samples already have been taken and which samples remain at a particular station. This risk can also be minimised by making careful instructions for sampling and to take samples according to fixed routines each time.

Costs

Costs in connection with sampling of water for measurements of the pH-value include travel and subsidence expenses and salary at an hourly rate of the person involved in the measurement. Costs for analysis of the pH-value of the water by an accredited laboratory amount to ca 50 SEK per analysis.

5.4 The alkalinity of the water

The alkalinity of the water is a standard parameter describing the buffering capacity of the water against acidification, which in turn is coupled to the conditions of the bedrock, soils and vegetation of the catchment area. In areas where the soils have a high content of easily weathered substances, the alkalinity of the water is generally higher than in areas with more refractory soils. If background levels are known, measurements of the alkalinity of the water may also be used to determine human-induced acidification of the system (cf. 6.2, below).

5.4.1 Existing data

Measurements of the alkalinity of the water in lakes have been frequently carried out in connection with monitoring of acidification of surface waters. Hence, both in connection with research projects and local, regional, and national lake monitoring programmes, measurements of the alkalinity may have been carried out. Data can be found in reports and scientific papers at the universities and in reports published by the local, regional and national water authorities. As a rule, reports from local and regional authorities should be kept by the Regional Administrative Office of the County (Länsstyrelsen). National data can be accessed by Internet at www//http.ma.slu.se. For Uppsala County, references to data sources with a majority of the data generated up to 1997 are given in Brunberg and Blomqvist /1998/. However, as most of the monitoring programmes only include a single or a few observations per year, the resolution in time may be low. Furthermore, most of the environmental monitoring with respect to alkalinity of the water have been carried out in poorly buffered areas in the forested regions of Sweden. From other areas, including the localities chosen for the site investigation program, data from a particular lake may be very sparse. Thus, in connection with the site investigation program, new data on the alkalinity of the water must be generated.

5.4.2 Methods for data collection

Performance

Sampling for measurements of the alkalinity of the water in connection with the site investigation program is best performed by taking vertically and horizontally integrated composite samples representing the open water habitat in its entirety, e.g. by the methodology described by Blomqvist /2000/. Such integrated samples should also be used for the determination of all other water chemistry parameters described in this paper but for concentrations of dissolved oxygen. By using integrated sampling, the number of samples to be analysed at each occasion is reduced to a minimum (one) and, hence, also the costs for the survey are kept minimal. The alkalinity of the water should be measured on unpreserved water directly after transportation to the laboratory and preferably on the same day as the samples have been taken. The measurements should be performed according to Swedish Standard SS 02 81 39 mod.

Background data

See 5.3.2.

Time schedule

See 5.3.2.

Potential resources

See 5.3.2.

Data processing

See 5.3.2.

Uncertainty – Risks

See 5.3.2.

Costs

Costs in connection with sampling of water for measurements of the alkalinity include travel and subsidence expenses and salary at an hourly rate of the person involved in the measurement. Costs for analysis of the alkalinity of the water by an accredited laboratory amount to ca 75 SEK per analysis.

5.5 The colour of the water

The colour of the water is a parameter related to the amount of dissolved, coloured, organic substances in the water. These, mainly humic, substances have their origin in the top soils in the catchment area and their amounts can be used as one expression of the influence of the catchment on the lake ecosystem. According to the amount of humic substances, lakes can be divided into clearwater and brownwater systems. The presence of humic substances in the water affects the entire metabolism of the lake ecosystem via e.g. reduction of the depth of the euphotic zone, formation of iron-humus-phosphorus complexes that reduce the availability of P to lake biota, and by keeping various elements and pollutants in suspension instead of allowing them to settle out to the sediments (see 6.2.3, below). Furthermore, the presence of large amounts of organic substances of external origin in the water alters the competition between bacterio- and phytoplankton at the base of the pelagic food-web in favour of the former which may become the dominant mobiliser of carbon energy. Production of bacterioplankton instead of phytoplankton, i.e. a shift from relatively large to very small organisms may then have consequences at all higher trophic levels.

5.5.1 Existing data

Measurements of the lake water colour have been frequently carried out in connection with monitoring of the quality of surface waters. Hence, both in connection with research projects and local, regional, and national lake monitoring programmes, measurements of the water colour may have been carried out. Data can be found in reports and scientific papers at the universities and in reports published by the local, regional and national water authorities. As a rule, reports from local and regional authorities should be kept by the Regional Administrative Office of the County (Länsstyrelsen). National data can be accessed by Internet at http://www.ma.slu.se. For Uppsala County, references to data sources with a majority of the data generated up to 1997 are given in Brunberg and Blomqvist /1998/. However, as most of the monitoring programmes only include a single or a few observations per year, the resolution in time may be low. Furthermore, most of the environmental monitoring with respect to the colour of the water have been carried out in the poorly buffered waters of the forested regions of Sweden. From other areas, including the localities chosen for the site investigation program, data from a particular lake may be very sparse. Thus, in connection with the site investigation program, new data on colour of the water must be generated.

5.5.2 Methods for data collection

Performance

Sampling for measurements of the colour of the water in connection with the site investigation program is best performed by taking vertically and horizontally integrated composite samples representing the open water habitat in its entirety, e.g. by the methodology described by Blomqvist /2000/. Such integrated samples should also be used for the determination of all other water chemistry parameters described in this paper but for concentrations of dissolved oxygen. By using integrated sampling, the number of samples to be analysed at each occasion is reduced to a minimum (one) and, hence, also the costs for the survey are kept minimal. The colour of the water should be measured on unpreserved, filtered water directly after transportation to the laboratory and preferably on the same day as the samples have been taken. The measurements should be performed according to Chalupa /1963/.

Background data

See 5.3.2.

Time schedule

See 5.3.2.

Potential resources

See 5.3.2.

Data processing

See 5.3.2.

Uncertainty – Risks

See 5.3.2.

Costs

Costs in connection with sampling of water for measurements of the water colour include travel and subsidence expenses and salary at an hourly rate of the person involved in the measurement. Costs for analysis of the colour of the water by an accredited laboratory amount to ca 60 SEK per analysis.

5.6 The concentrations of total, particulate, and dissolved organic carbon in the water

The concentrations of dissolved (DOC) and particulate (POC) organic carbon in the water are important measures of the status of the pelagic ecosystem in the lakes since they reflect the total amount of organic carbon (TOC) available in the system, both the part which is produced by the pelagic organisms and that produced in other habitats within the lake and the drainage area. The concentration of POC in the water may be used as a course measure of the total amount of planktonic organisms (i.e. heterotrophic bacterioplankton, phytoplankton, and zooplankton) in the pelagic habitat. The concentration of DOC in the water is a measure of both coloured (cf. water colour in section 5.5, above) and uncoloured organic substances in the water which, together, form the basis for production of heterotrophic bacterioplankton.

5.6.1 Existing data

Measurements of the concentrations of DOC and POC in the lake water may have been carried out in connection with monitoring of the quality of surface waters. Hence, both in connection with research projects and local, regional, and national lake monitoring programmes, measurements of at least DOC but sometimes also POC may have been carried out. Data can be found in reports and scientific papers at the universities and in reports published by the local, regional and national water authorities. As a rule, reports from local and regional authorities should be kept by the Regional Administrative Office of the County (Länsstyrelsen). National data can be accessed by Internet at http://www.ma.slu.se. For Uppsala County, references to data sources with a majority of the data generated up to 1997 are given in Brunberg and Blomqvist /1998/. However, as most of the monitoring programmes only include a single or a few observations per year, the resolution in time may be low. From other areas, including the localities chosen for the site investigation program, data from a particular lake may be very sparse. Thus, in connection with the site investigation program, new data on the concentrations of DOC and POC of the water must be generated.

5.6.2 Methods for data collection

Performance

Sampling for measurements of the concentrations of DOC and POC of the water in connection with the site investigation program is best performed by taking vertically and horizontally integrated composite samples representing the open water habitat in its entirety, e.g. by the methodology described by Blomqvist /2000/. Such integrated samples should also be used for the determination of all other water chemistry parameters described in this paper but for concentrations of dissolved oxygen. By using integrated sampling, the number of samples to be analysed at each occasion is reduced to a minimum (one) and, hence, also the costs for the survey are kept minimal. Filtration of the water in order to separate POC from DOC should be performed directly after transportation to the laboratory and preferably on the same day as the samples have been taken. The measurements should be performed according to Swedish Standard (the same for both analyses) SS-EN 1484.

Background data

See 5.3.2.

Time schedule

See 5.3.2.

Potential resources

See 5.3.2.

Data processing

See 5.3.2.

Uncertainty – Risks

See 5.3.2.

Costs

Costs in connection with sampling of water for measurements of the water colour include travel and subsidence expenses and salary at an hourly rate of the person involved in the measurement. Costs for analysis of the concentrations of DOC and POC of the water by an accredited laboratory together amount to ca 180 SEK.

5.7 The concentrations of total phosphorus and soluble reactive phosphorus of the water

Phosphorus is considered a key nutrient limiting the production of organisms in lake ecosystems. Phosphorus in unpolluted lake ecosystems mainly originates from the soils of the drainage area. The concentration of total phosphorus is a standard parameter describing the nutrient status of the water, which in turn is coupled to the conditions of the bedrock, soils and vegetation of the catchment area. In areas which are characterised by easily weathered and fertile soils, the concentration of total phosphorus in the water is generally higher than in areas with more refractory soils. Phosphorus is also one of the key elements in human-induced eutrophication of surface waters. If background levels are known, measurements of the concentrations of total phosphorus in the water can also be used to determine human-induced eutrophication of the system (cf. 6.2.1, below). The concentration of soluble reactive phosphorus in the water is a course measure of how much phosphorus that is readily available to phytoplankton.

5.7.1 Existing data

Measurements of the concentrations of total phosphorus (TP) and soluble reactive phosphorus (SRP) of the water in a particular lake have been frequently carried out in connection with monitoring of quality of surface waters. Hence, both in connection with research projects and local, regional, and national lake monitoring programmes, measurements of the concentrations of TP and SRP may have been carried out. Data can be found in reports and scientific papers at the universities and in reports published by the local, regional and national water authorities. As a rule, reports from local and regional authorities should be kept by the Regional Administrative Office of the County (Länsstyrelsen). National data can be accessed by Internet at http://www.ma.slu.se. For Uppsala County, references to data sources with a majority of the data generated up to 1997 are given in Brunberg and Blomqvist /1998/. However, as most of the monitoring programmes only include a single or a few observations per year, the resolution in time may be low. Furthermore, most of the environmental monitoring with respect to the concentrations of TP and SRP in the water have been carried out in eutrophicated low-land and urban areas of Sweden. From other areas, including the localities chosen for the site investigation program, data from a particular lake may be very sparse. Thus, in connection with the site investigation program, new data on the concentrations of TP and SRP in the water must be generated.

5.7.2 Methods for data collection

Performance

Sampling for measurements of the concentrations of TP and SRP of the water in connection with the site investigation program is best performed by taking vertically and horizontally integrated composite samples representing the open water habitat in its entirety, e.g. by the methodology described by Blomqvist /2000/. Such integrated samples should also be used for the determination of all other water chemistry parameters described below but for concentrations of dissolved oxygen. By using integrated sampling, the number of samples to be analysed at each occasion is reduced to a minimum (one) and, hence, also the costs for the survey are kept minimal. The concentrations of TP and SRP in the water can be measured on unpreserved water directly after transportation to the laboratory or, but only in the case of TP, after storage in a deep-freezer. The measurements should be performed according to Swedish Standard SS 02 81 27-2 mod., and SS 02 81 26-2 mod., respectively.

Background data

See 5.3.2.

Time schedule

See 5.3.2.

Potential resources

See 5.3.2.

Data processing

See 5.3.2.

Uncertainty – Risks

See 5.3.2.

Costs

Costs in connection with sampling of water for measurements of the concentrations of TP and SRP of the water include travel and subsidence expenses and salary at an hourly rate of the person involved in the measurement. Costs for analysis of the concentrations of TP and SRP of the water by an accredited laboratory amount to ca 125 and 100 SEK per analysis, respectively.

5.8 The concentrations of total nitrogen, ammonium nitrogen, and nitrite+nitrate nitrogen of the water

Nitrogen is another (cf. phosphorus above) key limiting nutrient which determines the carrying capacity of the production of organisms in lake ecosystems. In contrast to P, which has a more or less unidirectional flow from the catchments to the lake ecosystem, nitrogen can also be imported from nitrogen fixation, a process carried out by heterocytous cyanobacteria. The concentration of total nitrogen is a standard parameter describing the nutrient status of the water, which in turn is coupled to the conditions of the bedrock, soils and vegetation of the catchment area. In areas which are characterised by easily weathered and fertile soils, the concentration of total nitrogen in the water is generally higher than in areas with more refractory soils. Nitrogen is also one of the key elements in human-induced eutrophication of surface waters and is, together with phosphorus, an indispensable parameter to judge the consequences of eutrophication on the production of biota. The concentrations of ammonium-N and nitrite+nitrate-N in the water gives a course measure of how much nitrogen that is readily available to phytoplankton.

5.8.1 Existing data

Measurements of the concentrations of total nitrogen (TN), ammonium-nitrogen (NH4-N) and nitrite+nitrate-nitrogen (NO_2+NO_3-N) of the water in a particular lake have been frequently carried out in connection with monitoring of quality of surface waters. Hence, both in connection with research projects and local, regional, and national lake monitoring programmes, measurements of the concentrations of TN, NH_4-N and NO_2+NO_3-N may have been carried out. Data can be found in reports and scientific papers at the universities and in reports published by the local, regional and national water authorities. As a rule, reports from local and regional authorities should be kept by the Regional Administrative Office of the County (Länsstyrelsen). National data can be accessed by Internet at http://www.ma.slu.se. For Uppsala County, references to data sources with a majority of the data generated up to 1997 are given in Brunberg and Blomqvist /1998/. However, as most of the monitoring programmes only include a single or a few observations per year, the resolution in time may be low. Furthermore, most of the environmental monitoring with respect to the concentrations of TN, NH_4-N and NO_2+NO_3-N in the water have been carried out in eutrophicated lowland and urban areas of Sweden. From other areas, including the localities chosen for the site investigation program, data from a particular lake may be very sparse. Thus, in connection with the site investigation program, new data on the concentrations of TN, NH_4-N and NO_2+NO_3-N in the water must be generated.

5.8.2 Methods for data collection

Performance

Sampling for measurements of the concentrations of TN, NH_4-N and NO_2+NO_3-N in the water in connection with the site investigation program is best performed by taking vertically and horizontally integrated composite samples representing the open water habitat in its entirety, e.g. by the methodology described by Blomqvist /2000/. Such integrated samples should also be used for the determination of all other water chemistry parameters described below but for concentrations of dissolved oxygen. By using integrated sampling, the number of samples to be analysed at each occasion is reduced to a minimum (one) and, hence, also the costs for the survey are kept minimal. The concentrations of TN, NH_4-N and NO_2+NO_3-N in the water can be measured on unpreserved water directly after transportation to the laboratory or, but only in the case of TN and NO_2+NO_3-N, after storage in a deep-freezer. The measurements should be performed according to Swedish Standard SIS 02 81 31, SIS 02 81 34, and SIS 02 81 33-2 mod., respectively.

Background data

See 5.3.2.

Time schedule

See 5.3.2.

Potential resources

See 5.3.2.

Data processing

See 5.3.2.

Uncertainty – Risks

See 5.3.2.

Costs

Costs in connection with sampling of water for measurements of the concentrations of TN, NH_4-N and NO_2+NO_3-N of the water include travel and subsidence expenses and salary at an hourly rate of the person involved in the measurement. Costs for analysis of the concentrations of TN, NH_4-N and NO_2+NO_3-N of the water by an accredited laboratory amount to ca 125, 100, and 100 SEK per analysis, respectively.

5.9 The concentrations of chlorophyll a of the water

The concentration of chlorophyll a in the water is a measure of the biomass of phytoplankton. It is a standard descriptive parameter of the productivity of the pelagic ecosystem of the lake and is frequently used in the context of monitoring eutrophication in the system.

5.9.1 Existing data

Measurements of the concentrations of chlorophyll a of the water in a particular lake have been frequently carried out in connection with monitoring of quality of surface waters. Hence, both in connection with research projects and local, regional, and national lake monitoring programmes, measurements of the concentrations of chlorophyll a may have been carried out. Data can be found in reports and scientific papers at the universities and in reports published by the local, regional and national water authorities. As a rule, reports from local and regional authorities should be kept by the Regional Administrative Office of the County (Länsstyrelsen). National data can be accessed by Internet at http://www.ma.slu.se. For Uppsala County, references to data sources with a majority of the data generated up to 1997 are given in Brunberg and Blomqvist /1998/. However, as most of the monitoring programmes only include a single or a few observations per year, the resolution in time may be low. Furthermore, most of the environmental monitoring with respect to the concentrations of chlorophyll a in the water have been carried out in eutrophicated lowland and urban areas of Sweden. From other areas, including the localities chosen for the site investigation program, data from a particular lake may be very sparse. Thus, in connection with the site investigation program, new data on the concentrations of chlorophyll a in the water must be generated.

5.9.2 Methods for data collection

Performance

Sampling for measurements of the concentrations of chlorophyll a in the water in connection with the site investigation program is best performed by taking vertically and horizontally integrated composite samples representing the open water habitat in its entirety, e.g. by the methodology described by Blomqvist /2000/. Such integrated samples should also be used for the determination of all other water chemistry parameters described below but for concentrations of dissolved oxygen. By using integrated sampling, the number of samples to be analysed at each occasion is reduced to a minimum (one) and, hence, also the costs for the survey are kept minimal. Filtration of the water in order to separate particles containing chlorophyll a should be performed directly after transportation to the laboratory. The filters may then be stored in a freezer for analysis later. The measurements should be performed according to Swedish Standard SS 02 81 46.

Background data

See 5.3.2.

Time schedule

See 5.3.2.

Potential resources

See 5.3.2.

Data processing

See 5.3.2.

Uncertainty – Risks

See 5.3.2.

Costs

Costs in connection with sampling of water for measurements of the concentrations of chlorophyll a of the water include travel and subsidence expenses and salary at an hourly rate of the person involved in the measurement. Costs for analysis of the concentrations of chlorophyll a of the water by an accredited laboratory amount to ca 240 SEK per analysis, respectively.

5.10 The concentrations of dissolved oxygen of the water

The concentration of dissolved oxygen in the water is a key parameter related to the total metabolism of the lake ecosystem. It describes the net outcome of the sum of production and import of oxygen to the system and the sum of processes consuming oxygen at respiration of produced and imported organic matter. At periods when respiratory processes are strongly dominant, the entire lake ecosystem or important parts thereof may face anoxia, with dramatic effects on different components of lake fauna. In deep thermally stratified and turbid lakes, anoxia may develop below the thermocline during summer stratification. In both shallow and deep lakes, anoxia may develop in the entire water column during winter, especially if the ice is covered by snow. Anoxia in the sediments is also a key factor regulating the transport of nutrients and other elements (e.g. metals, radionuclides) over the sediment-water interface. Therefore it is a very important factor in connection with the site investigation program.

5.10.1 Existing data

Measurements of the concentrations of dissolved oxygen in the water in a particular lake have been carried out in connection with monitoring of quality of surface waters, especially during the 1970ies. Today this parameter is unfortunately more seldom used, partly as a result of that it should be measured at a period when oxygen stress is maximal (e.g. during winter). Nevertheless, both in connection with research projects and local, regional, and national lake monitoring programmes, measurements of the concentrations of dissolved oxygen may have been carried out. Data can be found in reports and scientific papers at the universities and in reports published by the local, regional and national water authorities. As a rule, reports from local and regional authorities should be kept by the Regional Administrative Office of the County (Länsstyrelsen). National data can be accessed by Internet at http://www.ma.slu.se. For Uppsala County, references to data sources with a majority of the data generated up to 1997, including data from a synoptic study of 107 lakes during the winter of 1988/89, are given in Brunberg and Blomqvist /1998/. However, as most of the monitoring programmes including data on dissolved oxygen are relatively old and since dissolved oxygen is a highly dynamic parameter, the situation may have changed considerably. Furthermore, most of the environmental monitoring with respect to the concentrations of dissolved oxygen in the water have been carried out in eutrophicated lowland and urban areas of Sweden. From other areas, including the localities chosen for the site investigation program, data from a particular lake may be very sparse. Thus, in connection with the site investigation program, new data on the concentrations of dissolved oxygen in the water must be generated.

5.10.2 Methods for data collection

Performance

Data on the concentrations of dissolved oxygen in the water should describe the worst situation in the system. Therefore, the investigation should be performed from ice during winter and preferably as late as possible after formation of ice, but before the first major meltoff event in the area in late winter. A normal timing of the study is mid-February. In deeper, thermally stratified lakes, a second study should be performed at the height of summer stratification and include samples from all layers in the lake. Samples for analysis of the concentration of dissolved oxygen in the water should be taken with a closing sampler (e.g. Ruttner sampler) at one station located close to the deepest point of the lake. During winter sampling, a vertical series of samples should be taken, representing the mid portion of each depth interval given in table 1, section 4.1.2, above. Hence, the deeper the lake, the greater the vertical distance between samples. During summer sampling, the samples should be taken so that the epi-, meta-, and hypolimnion, respectively are covered. Within each layer, samples should be taken in the middle of each depth interval given above. For definition of thermal stratification see section 4.1.2.

The samples for analysis of dissolved oxygen should be preserved directly in the field after sampling. The measurements should be performed according to Swedish Standard SS 02 81 14-2.

Background data

Background data needed include a depth chart to locate the deepest part of the lake and to determine the number of vertical samples (see section 4.1, above). Data on the date of formation of the ice cover and on periods of thaw between formation of ice-cover and time of sampling are also essential for the evaluation.

Time schedule

The sampling should be performed in connection with samplings for vertical distribution of temperature, light, and for composite sampling of other water chemistry parameters (n.b. oxygen samples can **not** be taken from the composite sample!). In shallow lakes one sampling should be performed during winter and in deep, thermally stratified lakes two samplings should be performed, one during winter and one during summer (see performance, above).

Potential resources

A survey of vertical distribution of dissolved oxygen should be performed by well trained personnel which are mostly to be found among limnologists. Measurements of the concentrations of dissolved oxygen in the water should be performed by an accredited laboratory specialised on analyses of water chemistry on natural, unpolluted waters.

Data processing

Data on the concentrations of dissolved oxygen can be directly logged into a computer file from the raw protocol delivered by the accredited laboratory and stored in the database, using date of sampling and depth of sampling as descriptors. Data on the formation of an ice cover on the lake should be stored in a separate file. The data in the database should then be printed in the form of a primary protocol and checked against the raw protocol for errors. Both protocols should then be signed, using name and date of input, by the person in charge of the inlogging procedure and finally stored in a paper file.

Uncertainty – Risks

The precision of the measurement of the concentration of dissolved oxygen in the water is affected by the precision of the sampling procedure and by the precision of the method of analysis used by the accredited laboratory. The latter is given by the manual of standard procedures to be used in the context of the site investigation program (see above). Errors during sampling described in section 5.3.2, above, are also applicable on dissolved oxygen.

Costs

Costs in connection with sampling of water for measurements of the concentrations of dissolved oxygen in the water include travel and subsidence expenses and salary at an hourly rate of the person involved in the measurement. Costs for analysis of the concentrations of dissolved oxygen of the water by an accredited laboratory amount to ca 75 SEK per analysis.

5.11 The habitat diversity of the lake ecosystem

The habitat diversity of the lake ecosystem is a new parameter currently under development of the authors of this report. It describes the area distribution of the maximally five key habitats that can be present in lakes, the pelagic habitat, the profundal habitat, the wind-sheltered (emergent macrophyte-dominated) littoral habitat, the wind-exposed (periphyton-dominated) hard-bottom littoral habitat, and the illuminated soft-bottom littoral habitat /e.g. Blomqvist and Brunberg, 1999; Brunberg and Blomqvist 2000a; 2000b/.

Its use, except for describing the number and area distribution of habitats in the lake, is to create a platform for budget calculations of the metabolism of organic carbon in different parts of the lake ecosystem. In the context of the site investigation program, this is an extremely important parameter, because it can be used to estimate the retention of radionuclides in the lake basin.

In a future project financed by SKB we intend to develop an automatic device by which the measurements on which habitat diversity parameter is based can be directly transferred from the field into the SKB Regional GIS.

5.11.1 Existing data

This parameter is new and as far as the authors know there has be no data generated that can be used in this context. Hence, new data must be generated for each lake included in the site investigation program.

5.11.2 Methods for data collection

Performance

The habitat diversity of the lake ecosystem, i. e. the number of key habitats and their area distribution, is obtained combining information about the basin morphometry (section 4, above), horizontal distribution of emergent and floating-leafed macrophytes, extension of the euphotic zone calculated from the measurements of light penetration (section 5.2, above), and distribution of course and finer sediments in the lake basin. It is obtained using a DGPS equipment (precision 0.5 m) directly coupled to the basin morphometry unit of the Regional SKB GIS and should be performed in mid – late summer in connection with depth sounding of the lake basins. The field work includes the following steps:

a) Measurements of the location of the shore line are performed using the DGPS by walking around the lake along the shore. This step is combined with the search for physical damages to the lake ecosystem described in chapter 6, below.

b) Measurements of the location of the outer edge of the combined emergent and floating-leafed macrophyte belt. This step is combined with the depth sounding of the lake using a digital echo sounder coupled to the DGPS.

c) Measurements of the location of the border between course and fine sediments (gravel and sand). This step is also combined with the depth sounding of the lake.

d) Measurements of the light penetration into the lake water (described in chapter 5.2.2).

e) Measurements of the vertical distribution of water temperature and the location of the thermocline (described in chapter 5.1.2).

Using the information from step a), the outer edge of the lake is defined. Combining the information from a) with that from b), the area of the wind-sheltered littoral zone can be calculated. Combining a) and c) the area of the wind-exposed littoral zone can be calculated. Combining a) and b) with the measurements of the light penetration into the water column, the area of the illuminated soft bottom littoral zone can be calculated. Using the depth of the euphotic zone given by the measurements of light penetration into the water column, the area of the profundal zone can be calculated. Finally, by calculating the total area of the lake and subtracting the area of the wind-sheltered littoral zone, the area of the pelagic zone can be calculated and so can also its volume and division into layers at stratification using the data from e). The calculation procedures can be directly performed in the Regional SKB GIS.

Background data

Background data includes those described for depth sounding in chapter 4.1.

Time schedule

The measurements should be performed at the height of the summer (July-August) in order for the macrophyte vegetation in the lake to have completely established. Measurements can be performed once, in the case of a) – c). Frequency of the light and temperature measurements have already been described (see sections 5.1.2 and 5.2.2).

Potential resources

The measurements require extremely well trained personnel, mostly to be found among limnologists and physical geographers.

Data processing

The resulting areas (and in the case of the pelagic zone also volume) of the different key habitats are calculated within the regional SKB GIS and saved as attributes to the “Lake Polygon Theme”.

Uncertainty – Risks

The precision of the measurements will depend on the precision of the instruments used (i.e. the DGPS and the Echo-sounder). For the total extension of the littoral zone and for the outer edge of the wind-exposed littoral zone, respectively, field verifications of the measurements will increase the precision.

Costs

Costs for measurements of the area distribution of key habitats include travel and subsidence expenses and salary at an hourly rate of the person involved in the measurement. One average size lake can likely be covered in 2–3 days, including sampling for parameters described in previous sections of chapter 5 and inventories of physical damages described in chapter 6, below.

5.12 The fish community of the lake ecosystem

Fish represent the most dominant and long-lived organisms in Scandinavian lake ecosystems, and are therefore excellent bioindicators of water quality and long term stress on the system. With the exception of different forms of whitefish and char, fishes are also possible to identify to the species level by a well educated general limnologist or zoologist, which means that species identifications will be as reliable as possible – something which is not possible at any other level of the ecosystem. Furthermore, as most fish are top-line predators or just below that level in various food chains in the aquatic food-web, they are also excellent indicators of bioaccumulation of toxic substances (see section 6.2.3 Toxic substances – Methods for data collection). For these reasons, we suggest that the species composition of the fish community and the abundance and biomass of each species and of the community in its entirety measured as catch per unit effort (CPUE) is the only biological parameter including taxonomy to be included in the studies within the site investigation program. In order to generate comparable data between lakes, the fish surveys should be performed using the standardised technique described in Appelberg /2000/.

5.12.1 Existing data

Fish surveys using the standardised technique have been performed in lakes all over Sweden and are available from the register kept by the Institute of Freshwater Research, Drottningholm. This register also includes the studies of 82 lakes in Uppsala County presented by Nyberg /1999/ and included in Brunberg and Blomqvist /1998/. During that survey, which was carried out between 1991 and 1993, most of the larger lakes in the communities in Uppsala County intended for the site investigation program were covered. For the few remaining lakes in Uppsala County, as well as for most lakes in the other communities intended for the site investigation program, new data must be generated.

5.12.2 Methods for data collection

Performance

Inventories of species composition of the fish fauna and mean catch per unit effort (CPUE) should be performed using the standardised gillnet fishing method described in Appelberg /2000/. In short, this method is based on a minimum number of gill nets in each lake and more gill nets added the larger and deeper the system is. The catch is then sorted to species and each individual is weighed and its total length is measured, and these parameters together with date of sampling, total number of gill nets and their location in the lake are saved on a raw protocol and the depth chart of the lake, respectively. Calculations of the CPUE in terms of abundance and biomass are then performed in the Regional SKB GIS. Large, (by size presumably piscivorous) individuals of the species pike (Esox lucius), perch (Perca fluviatilis), and pikeperch (Stizostedion lucioperca) should then be sorted out for sampling of muscle tissue for analysis of the content of mercury and radioactive ^{137}Cs (see section 6.2.3, below).

Background data

Background data needed include a bathymetric map for planning of the location of the gill nets (cf. 4.1, above) and preferably a map of the area distribution of different key habitats in the basin (cf. 5.9, above).

Time schedule

Sampling is performed once in each lake during late summer according to the standard procedure.

Potential resources

The fish survey can be performed by a normally trained fisheries person, but the species analysis as well as the selection of individuals from which muscle samples should be taken needs to be supervised by a well trained fisheries biologist. Such personnel is best found at the regional offices of the National Swedish Board of Fisheries.

Data processing

The co-ordinates of the endpoints of each gill net are measured with DGPS. The location of the gill nets are then stored in the Regional SKB GIS as line object using the endpoint co-ordinates. Data on the date and time interval of sampling and the total length and weight of each individual caught in the survey as well as the gill net in which it was caught are taken from the raw protocol and included in "Gill net line theme". The parameters CPUE in terms of abundance and biomass are then calculated in the Regional SKB GIS and stored in new "CPUE table" linked to the "Lake Polygon Theme" by the common field "Lake_Id".

Uncertainty – Risks

As with most other parameters describing large motile biota, the abundance and biomass of the fish community and its constituents (species) will include errors depending on the activity of the organisms during the particular time interval when samples were taken. Nevertheless, by using the standardised technique, such errors should be minimised. Potential errors in the species identification due to varying competence among the personnel are minimised by the suggested leadership of the project by an experienced fisheries biologist.

Costs

Costs for studies of the fish community of the lake ecosystem include travel and subsidence expenses and salary at an hourly rate of the persons (normally 2) involved in the gill net fishing and also salaries for the supervisor for planning of the study and for the personnel measuring and weighing the catch.

5.13 The presence of rare species of fauna and flora in the lake ecosystem

Knowledge about rare fauna and flora is essential in all studies aiming at nature conservation or exploitation of lakes, since such species are most likely the most protectable and vulnerable, respectively. Systematic inventories of rare and threatened species of plants and animals in Swedish lakes are unfortunately lacking and are very expensive to perform since they require a maximum level of expertise. We suggest that in the context of the site investigation program, only the available data from The Swedish Threatened Species Unit (Artdatabanken) at SLU are gathered and included in the Regional SKB GIS.

5.13.1 Existing data and their collection

Available data on rare flora and fauna species in the lakes intended for the site investigation program is gathered from the register at The Swedish Threatened Species Unit at SLU and saved as attributes in a table connected to the section information about the chemistry and biology of each lake in the Regional SKB GIS using the common field "Lake_Id".

6 Damages to the lake ecosystem

Considerations regarding levels of damage

In order to understand the ecological functioning and production capacity of a lake ecosystem and to predict how such a system may evolve in a long-term perspective it is necessary to include also various forms of anthropogenic disturbances to the ecosystem in the study. In the context of the site investigation program, we therefore suggest that surveys of human-induced damages are included. The methodology described below has been applied to the lakes of the County of Uppsala included in Brunberg and Blomqvist /1998/ and the results are currently being evaluated by the scientific community /Brunberg and Blomqvist, 2000c/. The different kinds of anthropogenic threats to freshwater ecosystems treated in that study follows the list compiled by Sandlund and Viken /1997/ which is presented in Table 6-1.

Table 6-1. Anthropogenic threats to the structure and function of freshwater lake ecosystems, compiled from Sandlund and Viken /1997/.

I. Technical encroachments
   a. Construction of dams
   b. Constructions to facilitate flood control, navigation, and transportation of timber
   c. Drainage of land

II. Pollution
   a. Eutrophication
   b. Acidification
   c. Toxic substances
   d. Thermal pollution

III. Introduction of non-native organisms

IV. Exploitation of species populations
   a. Overexploitation
   b. Aquaculture

To asses the total anthropogenic impact on a lake ecosystem, Brunberg and Blomqvist /2000c/ constructed a classification system including four levels of damage for each kind of disturbance. Absence of a particular type of disturbance was classified as "0", minor damage was classified as "1", moderate damage as class "2", and severe damage was classified as "3". In this chapter, the classification system is presented and defined for each of the 10 different kinds of disturbances given in Table 6-1.

6.1 Technical encroachments

Technical encroachments include various forms of man-made physical disturbances to the lake ecosystem such as construction of dams, constructions to facilitate flood control, constructions to facilitate transportation of timber, fill-outs to create harbours or for construction of buildings, and drainage of land. In the following description we have used three main groups of technical encroachments: dams, constructions along the shore-line, and drainage of land. All these forms of physical disturbances to lake eco-systems must be proceeded by a permit from the Environmental Courts handling the water law (formerly the Water Rights Courts, Vattendomstolarna). However, especially regarding drainage of land, also many illegal projects have been performed.

6.1.1 Dams

Construction of dams, and particularly dams for regulation of the water level, is a major threat to lake ecosystems world-wide. Among the many damages, partial or complete loss of the littoral habitat, loss of migratory populations of fish, lowering of the water temperatures during summer with effects on stratification and bioproduction, and increased trapping of nutrients in the basin due to sedimentation are among the most threatening to whole-lake ecosystem functioning /e.g. Brittain and Nilsson, 1996 and papers therein). According to the scale constructed by Brunberg and Blomqvist /2000c/ the following classification system for the levels of impact should be used:

No damage (class 0) is defined as when the water level in the lake is not maintained by a dam.

A minor damage (class 1) is considered to have occurred when there is presence of a dam in the outlet but no evident signs of effects from water level regulation on the littoral habitat.

A moderate damage (class 2) is defined as the presence of a dam with regulation of the water level, which has resulted in partial loss of the littoral habitat or transition of the littoral habitat into a floating mat of macrophytes.

A severe damage (class 3) is defined as when the water regulation has resulted in extinction of major components of the littoral habitat e.g. emergent plants.

Existing data

Construction of dams must be proceeded by a permit from the Environmental Courts (formerly the Water Rights Courts, vattendomstolarna) and these permits can be found in the files at each such Court . However, many of the dams in Sweden are much older than the water laws and are not regulated by any permit. To get hold of the number of dams in each area and their condition, inventories of dams have been carried out in many Communities and Counties in Sweden. Data can be found in reports published by the local, regional and national water authorities. As a rule, reports from local and regional authorities should be kept by the Regional Administrative Office of the County (Länsstyrelsen). For Uppsala County, references to data sources with a majority of the data generated up to 1997 are given in Brunberg and Blomqvist /1998/. However, in the context of the site investigation program, the outlet of all lakes should be inspected for the presence/absence of dams holding the water level which means that complementary studies are necessary. Furthermore, an inspection of each lake is necessary in order to determine the degree of damage to the system.

Methods for data collection

Performance

Inventories of dams include a description of the location of the dam, the type of construction (fixed or regulated) its height and length, the kind of material it is made of, its ownership and the number of the permit by which it has been constructed.

A drawing and preferably also a photograph of the dam should also be included. A reasonable methodology is presented by Syrén and Åse /1987/. Inventories regarding level of damage to the lake ecosystem can be performed in connection with measurements of the habitat diversity of the ecosystem (cf. 5.9, above).

Background data

Background data needed include a topographic map over the outlet section of the lake (either Gröna Kartan or Ekonomiska kartan).

Time schedule

Inventories of dams are carried out at one occasion and can then be complemented with new information in the case of changes within a particular system.

Potential resources

Inventories of dams can be carried out by well trained physical geographers and limnologists. Inventories of degree of damage should be performed by an experienced limnologist.

Data processing

Location of the dams are measured with DGPS. Data from the dam inventory should be logged into the Regional SKB GIS as a point-object theme. Measurements and statements about the condition is stored as attributes to the "Dam theme table" and drawings and photographs are linked to the "Dam theme" with the "Hot Link Tool". The degree of damage can then be calculated within the GIS and saved in a new "Damage table" linked to the "Lake Polygon Theme" by the common filed "Lake_Id".

Uncertainty – Risks

The physical measurements and judgements of the conditions of a dam should involve small problems. To judge the effects of water level regulation according to the four degree scale presented above should neither present any major problem.

Costs

Costs in connection with dam inventories include travel and subsidence expenses and salary at an hourly rate of the person involved in the measurement.

6.1.2 Constructions to facilitate flood control etc.

Constructions to facilitate flood control, to facilitate transportation of timber or navigation are a major threat to ecosystem functioning in running waters, but also lakes may be encompassed by different kinds of dikes. The damages include a decrease in the lake area and a loss of wetland/littoral ecosystems, which in turn affect flood storage, elimination of nutrients from surface and ground water, processing of pollutants, and the production of biomass and oxygen /Sandlund and Viken, 1997/. According to the scale constructed by Brunberg and Blomqvist /2000c/ the following classification system for the levels of impact should be used:

No damage (class 0) is defined as when less than 10% of the shoreline length has been subject to installation of dikes.

A minor damage (class 1) is considered to have occurred when 10–30% of the shoreline length has been subject to installation of dikes in attempts to control flooding of surrounding land.

At moderate damage (class 2), between 30 and 50% of the length has been subject to installation of dikes.

When more than 50% of the shoreline consist of dikes, the damage is considered as severe (class 3).

Existing data

Construction of dikes must be proceeded by a permit from the Environmental Courts (formerly the Water Rights Courts, vattendomstolarna) and these permits can be found in the files at each such Court . However, some of the dikes or similar constructions in Sweden are older than the water laws and are not regulated by any permit. Inventories of dikes may have been carried out in some communities and counties in Sweden. Data can be found in reports published by the local, regional and national water authorities. As a rule, reports from local and regional authorities should be kept by the Regional Administrative Office of the County (Länsstyrelsen). For Uppsala County, references to data sources with a majority of the data generated up to 1997 are given in Brunberg and Blomqvist /1998/. However, in the context of the site investigation program, all lakes should be inspected for the presence/absence of dikes along the shores which means that complementary studies are necessary. Furthermore, an inspection of each lake is necessary in order to determine the degree of damage to the system. Inventories of constructions along the shore can be performed in connection with measurements of the habitat diversity of the ecosystem (cf. 5.9, above).

Methods for data collection

Performance

Inventories of constructions along the shores are carried out by examination of the economic maps, and by visits to the lake. When constructions have been identified their length, width, and height are measured and the reasons for their construction is sought by interviewing the landowner and by searching for the court permit regulating their construction.

Background data

Background data include economic maps covering the entire lake and its nearby surroundings.

Time schedule

Inventories of dikes are carried out at one occasion and can then be complemented with new information in the case of changes within a particular system.

Potential resources

Inventories of dikes and other constructions along the shore can be carried out by well trained physical geographers and limnologists.

Data processing

Location of the constructions are measured with DGPS. Data from the inventory should be logged into the Regional SKB GIS as a line-object theme; “Construction Theme”. Measurements and statements about the condition is stored as attributes to the “Construction theme table” and drawings and photographs are linked to the “Construction theme” with the “Hot Link Tool”. The degree of damage can then be calculated within the GIS and saved in the “Damage table” (cf. 6.1.1 Dams – Existing data, above) linked to the “Lake Polygon Theme” by the common filed “Lake_Id”.

Uncertainty – Risks

The physical measurements and judgements of the conditions of a dike should involve small problems. The effects of their presence on the littoral ecosystem according to the four degree scale presented above can be carried out within the Regional SKB GIS and should neither present any major problem.

Costs

Costs in connection with inventories of dikes include travel and subsidence expenses and salary at an hourly rate of the person involved in the measurement.

6.1.3 Drainage projects

Drainage of land including lowering of the water table of lakes by deepening of the lake threshold is one of the most serious threats to lake ecosystems in Swedish lowlands /Wolf, 1960; Brunberg and Blomqvist, 2000c/. Damages to lakes due to drainage of land typically include expansion of aquatic macrophytes, decreases in the concentrations of dissolved oxygen during critical periods (i.e. during winter under the ice), and subsequent loss of oxygen-demanding organisms (fish-kills). Anoxia may also result in reduced functioning of the lake as a trap for nutrients and various pollutants and is therefore of great interest in the systems to be included in the site investigation program. According to the scale constructed by Brunberg and Blomqvist /2000c/ the following classification system for the levels of impact should be used:

No damage (class 0) is defined as when the lake threshold is in its natural state, undamaged by diggings.

A minor damage caused by drainage (class 1) is defined as documented lowering of the water table, but after which the ecosystem has stabilised without any visible changes of the littoral zone.

A moderate damage (class 2) is defined as the situation when drainage has caused an increase of the vegetation in the lake, forming a characteristic dense belt of *Phragmites* along the shoreline.

A severe damage(class 3) is defined as substantial increase of the vegetation, more or less completely covering the lake area. This does not necessarily imply that the area has lost all nature values – wetlands may have potential value from other than limnological aspects – but the conversion is *de facto* a threat to the lake ecosystem.

Existing data

Drainage of land must be proceeded by a permit from the Environmental Courts (formerly the Water Rights Courts, vattendomstolarna) and these permits can be found in the files at each such Court . However, many of the drainage projects in Sweden are much older than the water laws and are not regulated by any permit. To get hold of the number of drainage projects in each area and their effects on the systems, inventories have been carried out in some Communities and Counties in Sweden. Data can be found in reports published by the local, regional and national water authorities. As a rule, reports from local and regional authorities should be kept by the Regional Administrative Office of the County (Länsstyrelsen). For Uppsala County, in which the inventory is almost complete, references to data sources with all data generated up to 1997 are given in Brunberg and Blomqvist /1998/. Hence, only minor complementary studies are needed in the Communities of this County intended for the site investigation program. However, in the other communities studies of drainage of land including lowering of lake water tables must be carried out. Furthermore, an inspection of each lake is necessary in order to determine the degree of damage to the system.

Methods for data collection

Performance

Lowering of the water tables has occurred both legally (registered at the Regional Administrative Office of the County, Länsstyrelsen) and illegally (can be assessed from field observations of old shore lines and analyses of discrepancies between registered threshold levels and field measurements). We suggest that the methodology presented by Syrén and Åse /1987/ and applied in Uppsala County is followed. Inventories regarding drainage of land can be performed in connection with inventories regarding dams in the outlet (cf. 6.1.1 Dams – Methods for data collection, above).

Background data

Background data needed include topographic maps of the lake ecosystem in its entirety and access to existing court permits describing legal drainage projects.

Time schedule

Inventories of drainage of land and resulting lowering of lake water tables are carried out at one occasion and can then be complemented with new information in the case of changes within a particular system.

Potential resources

Inventories of drainage of land and resulting lowering of lake water tables can be carried out by well trained physical geographers and limnologists.

Data processing

Location of the former shore-lines are measured with DGPS. Data from the inventory of drainage of land and resulting lowering of lake water tables should be logged into the Regional SKB GIS as a line-object theme; "Drainage Theme". Measurements and statements about the condition is stored as attributes to the "Drainage theme table" and drawings and photographs are linked to the "Drainage theme" with the "Hot Link Tool". The degree of damage can then be calculated within the GIS and saved in the "Damage table" (cf. 6.1.1 Dams – Existing data, above) linked to the "Lake Polygon Theme" by the common filed "Lake_Id".

Uncertainty – Risks

The physical measurements of lowering of the lake water table should involve small problems. The effects of drainage on the littoral ecosystem according to the four degree scale presented above should neither present any major problem.

Costs

Costs in connection with inventories of drainage of land and resulting lowering of lake water tables include travel and subsidence expenses and salary at an hourly rate of the person involved in the measurement.

6.2 Pollution

Pollution of lake ecosystems may be caused by hundreds of substances but has conveniently by the scientists behind the document of Sandlund and Viken /1997, table 2/ been divided into four major groups: eutrophication (pollution caused by excess input of plant nutrients), acidification (pollution by excess input of acid), pollution by toxic substances (including inorganic and organic compounds as well as radionuclides), and pollution by heat.

6.2.1 Eutrophication

Pollution of lakes by plant nutrients (eutrophication) has been a major concern in limnological research as well as in practical environmental management for several decades. High external loading of nutrients may result in high biomasses of bloom-forming and potentially toxic cyanobacteria within the phytoplankton, excessive growth of macrophytes in the littoral zone and anoxia in the water and subsequent fish-kills during critical periods (i.e. during winter). As a result of anoxia the capacity of the lake to serve as a trap for nutrients and pollutants may be altered. As a result of eutrophication, the capacity of the ecosystem to produce organisms may be greatly overestimated and so will its ontogeny assuming that eutrophication is stopped. Thus, in the context of the site investigation program, damages to the lakes due to excessive input of plant nutrients are important to analyse. According to the scale constructed by Brunberg and Blomqvist /2000c/ the following classification system for the levels of impact should be used:

No damage (class 0) is defined as when the concentrations of total phosphorus in the water do not exceed the estimated or calculated natural background levels.

A minor eutrophication damage (class 1) is defined as a nutrient level higher than the estimated or calculated natural background levels but below 50 µg P l^{-1}.

Nutrient concentrations higher than the estimated or calculated natural background levels and ranging between 50 and 100 µg P l^{-1} is classified as a moderate damage (class 2).

A severe eutrophication damage (class 3) is defined as the situation when the concentrations of phosphorus in the lake water are higher than the estimated or calculated natural background levels and exceeded 100 µg P l^{-1}.

Existing data

Measurements of the concentrations of total phosphorus of the water in a particular lake have been frequently carried out in connection with monitoring of quality of surface waters. Hence, both in connection with research projects and local, regional, and national lake monitoring programmes, measurements of the concentrations of total phosphorus may have been carried out. Data can be found in reports and scientific papers at the universities and in reports published by the local, regional and national water authorities. As a rule, reports from local and regional authorities should be kept by the Regional Administrative Office of the County (Länsstyrelsen). National data can be accessed by Internet at http://www.ma.slu.se. For Uppsala County, references to data sources with a majority of the data generated up to 1997 are given in Brunberg and Blomqvist /1998/. However, as most of the monitoring programmes only include a single or a few observations per year, the resolution in time may be low. Furthermore, most of the environmental monitoring with respect to the concentrations of total phosphorus in the water have been carried out in eutrophicated lowland and urban areas of Sweden. From other areas, including the localities chosen for the site investigation program, data from a particular lake may be very sparse. Thus, in connection with the site investigation program, new data on the concentrations of total phosphorus in the water must be generated.

Methods for data collection

Performance

See total phosphorus in section 5.7.2.

Background data

See total phosphorus in section 5.7.2.

Time schedule

See total phosphorus in section 5.7.2.

Potential resources

See total phosphorus in section 5.7.2.

Data processing

The degree of damage due to pollution by plant nutrients can be calculated directly in the Regional SKB GIS and the resulting classification is then saved as attributes to the "Damage table" (cf. 6.1.1 Dams – Existing data, above) including all classifications of damages.

Uncertainty – Risks

The classification system described above is enough detailed to give a meaningful distinction between degrees of damage without being difficult to apply.

Costs

Apart for costs in connection with sampling and analysis of samples for concentrations of total phosphorus, the costs are minimal.

6.2.2 Acidification

Acidification of lakes and streams is one of the most serious threats to lake ecosystems in poorly buffered areas of Sweden, particularly in the SW part and has received massive attention during the past decades. Consequences of acidification of lakes and their drainage areas include mobilisation of toxic compounds, loss of sensitive fauna and flora, and potentially also altered retention capacity for contaminants (e.g. in the form of radionuclides) in the system. Therefore, damages due to acidification should be of great interest in the studies to be included in the site investigation program. According to the scale constructed by Brunberg and Blomqvist /2000c/ the following classification system for the levels of impact should be used:

No damage due to acidification (class 0) is defined as when deposition of acidifying substances on the drainage area is less than twice the calculated background levels /Ahl, 1994; SMHI, 1999/.

A minor damage by acidification (class 1) is defined as deposition of acidifying substances on the drainage area amounting to at least twice the calculated background levels despite lack of effects on the alkalinity and pH-value of the lake water. This definition is more stringent than if the concept of critical loading is used /Nilsson and Grennfelt, 1998/. Using the enhanced deposition as a criterion for damage takes into account the long-term perspective that the soils are slowly depleted of buffering capacity and important plant nutrients /e.g. Ca and Mg; Ripl, 1995/.

A moderate damage(class 2) is considered to occur if the deposition has caused documented reduced alkalinity and fluctuations in the pH values.

A severe damage (class 3) is considered to occur with documented loss of alkalinity and decreased pH in the lake water.

Existing data

Measurements of the pH-value and alkalinity of the water a particular lake have been frequently carried out in connection with monitoring of acidification of surface waters (cf. 5.3.1, above). Hence, both in connection with research projects and local, regional, and national lake monitoring programmes, measurements of the pH-value may have been carried out. Data can be found in reports and scientific papers at the universities and in reports published by the local, regional and national water authorities. As a rule, reports from local and regional authorities should be kept by the Regional Administrative Office of the County (Länsstyrelsen). National data can be accessed by Internet at www//http.ma.slu.se. For Uppsala County, references to data sources with a majority of the data generated up to 1997 are given in Brunberg and Blomqvist /1998/. However, as most of the monitoring programmes only include a single or a few observations per year, the resolution in time may be low. Furthermore, most of the environmental monitoring with respect to pH-value of the water have been carried out in poorly buffered areas in the forested regions of Sweden. From other areas, including the localities chosen for the site investigation program, data from a particular lake may be very sparse. Thus, in connection with the site investigation program, new data on the pH-value of the water must be generated.

Methods for data collection

Performance

See sections 5.3.2 and 5.4.2, above.

Background data

See sections 5.3.2 and 5.4.2, above.

Time schedule

See sections 5.3.2 and 5.4.2, above.

Potential resources

See sections 5.3.2 and 5.4.2, above.

Data processing

The degree of damage due to pollution by acidifying substances can be calculated directly in the Regional SKB GIS and the resulting classification is then saved as attributes to the “Damage table” (cf. 6.1.1 Dams – Existing data, above) including all classifications of damages.

Uncertainty – Risks

The classification system described above is course enough to give a meaningful distinction between degrees of damage without being difficult to apply. Access to relevant background data is a key factor to the analysis. Hence, it is very important to gather all previous data from the lakes.

Costs

Apart for costs in connection with sampling and analysis of samples for the pH-value and the alkalinity of the water, the costs are minimal.

6.2.3 Toxic substances

The Swedish "Observation List" , published by the Swedish National Chemicals Inspectorate (Kemikalieinspektionen) gives examples of ca. 250 substances or groups of substances that require particular attention and which are used to a large extent. Heavy metals and radioactive compounds are examples of pollutants which may reach levels that are harmful also to the human population, due to bioaccumulation in fish /e.g. Sonesten, 2000/. We suggest that analysis of the concentrations of radioactive caesium and mercury in the muscle tissue of fish are used in connection with the site investigation program as measures of the general situation regarding pollutants in the systems. According to the scale constructed by Brunberg and Blomqvist /2000c/ the following classification system for the levels of impact should be used:

No damage (class 0) is defined as when the concentrations do not exceed 0.5 mg Hg kg^{-1} or 800 Bq ^{137}Cs kg^{-1} in fish muscle, respectively, which corresponds to lowest limit for clearly elevated levels compared to the natural background.

A minor damage (class 1) is defined as concentrations exceeding 0.5 mg Hg kg^{-1} or 800 Bq ^{137}Cs kg^{-1} in fish muscle, respectively, which corresponds to clearly elevated levels compared to the natural background.

A moderate damage (class 2) is considered as concentrations ranging between 1.0–3.0 mg Hg kg^{-1} or 1500–10 000 Bq ^{137}Cs kg^{-1} in fish muscle, the lower levels corresponding to limits for marketing of fish in Sweden.

Concentrations exceeding 3.0 mg Hg kg^{-1} or 10 000 Bq ^{137}Cs kg^{-1} are denoted as severe damage (class 3).

Existing data

Measurements of the concentrations of radioactive caesium and mercury in fish tissue in a particular lake may have been carried out in connection with monitoring of quality of surface waters. Hence, both in connection with research projects and local, regional, and national lake monitoring programmes, measurements of the concentrations of radioactive caesium and mercury may have been carried out. Data can be found in reports and scientific papers at the universities and in reports published by the local, regional and national water authorities. As a rule, reports from local and regional authorities should be kept by the Regional Administrative Office of the County (Länsstyrelsen). National data can be accessed by Internet at http://www.ma.slu.se. For Uppsala County, references to data sources with a majority of the data generated up to 1997, and including a systematic study of 82 lakes /Sonesten, 2000/ are given in Brunberg and Blomqvist /1998/. From other areas, including the localities chosen for the site investigation program outside Uppsala County, data from a particular lake may be very sparse. Thus, in connection with the site investigation program, new data on the concentrations radioactive caesium and mercury in tissue of fish must be generated.

Methods for data collection

Performance

Muscle tissue from consumption size fish are sampled from the fish material caught in the investigation described in section 5.12.2. The fresh fish material is immediately after sampling brought to the laboratory and muscle tissue is sampled. The tissue is then analysed with respect to the concentrations of radioactive Cs and Hg according to the procedures described by Sonesten /2000/.

Background data

See section 5.12.2.

Time schedule

See section 5.12.2.

Potential resources

Sampling of fish see section 5.12.2. The analyses of ^{137}Cs and Hg in the tissue of fish should be performed by an accredited laboratory specialised on measurements on fish.

Data processing

Data on the concentrations of ^{137}Cs and Hg in the tissue of fish should be linked to the table describing the entire fish material presented in section 5. 12. 2. The degree of damage due to pollution by toxic substances can be calculated directly in the Regional SKB GIS and the resulting classification is then saved as attributes to the "Damage table" (cf. 6.1.1 Dams – Existing data, above) including all classifications of damages.

Uncertainty –- Risks

The precision of the measurements of the concentration of ^{137}Cs and Hg in fish will be given by the manual of analysis used by the accredited laboratory. The classification system described above is course enough to give a meaningful distinction between degrees of damage without being difficult to apply.

Costs

The costs per sample for analysis of ^{137}Cs and Hg in fish tissue and amount to ca 250 and 300 SEK/sample, respectively.

6.2.4 Thermal pollution

Thermal pollution is a relatively new environmental problem occurring in connection with industrial uses of water. Its main consequences on lake ecosystems include undesired shifts in species composition and ecosystem functioning. The shifts in species composition include establishment of populations of warm-water species, often mediated via deliberate or accidental introductions of non-native organisms. Since thermal pollution was not found in any lake in Uppsala County, Brunberg and Blomqvist /2000c/ did not construct any scale for determination of the degree of damage. We nevertheless suggest an inventory of thermal pollution (based on permits to pump warm-water into lakes and streams) to be included in the site investigation program. In the case of presence of such a source of pollution we suggest the following classification to be used:

No damage (class 0) is defined as when the calculated elevation of the water temperature given in the permit is less than 1 °C.

A minor eutrophication damage (class 1) is defined as when the calculated elevation of the water temperature given in the permit is more than 1 °C.

A moderate damage (class 2) is defined as when the calculated elevation of the water temperature given in the permit is more than 1 °C and occurrence of previously unknown organisms in the system has been documented.

A severe damage (class 3) is defined as when the calculated elevation of the water temperature given in the permit is more than 1 °C and when previously unknown organisms in the system have established a strong and reproducing population.

Existing data and methods for their collection

Permits to use lakes and their tributaries as recipients for warm-water from different types of industries as well as reports on the occurrence of previously unknown species are gathered from the local, regional and national authorities. As a rule, permits should be kept by the Regional Administrative Office of the County (Länsstyrelsen).

The resulting data are classified using the system described above and saved as attributes to the "Damage table" (cf. 6.1.1 Dams – Existing data, above) including all classifications of damages.

Data processing

The resulting data on the presence of thermal pollution in the lakes are classified using the system described above and saved as attributes to the "Damage table" (see section 6.1.1 Dams – Existing data, above) including all classifications of damages.

Costs

Costs in connection with search for data regarding thermal pollution include travel and subsidence expenses and salary at an hourly rate of the person involved in the studies.

6.3 Introduction of non-native organisms

As a rule, attempts to introduce non-native organisms to intact ecosystems are bound to fail because that niche in the ecosystem is already occupied by a more efficient native organism /Sandlund and Viken, 1997/. However, in a minority of cases the introduction is successful and, almost without exception the development of the new organism takes place on the expense of existing fauna and flora. The damages caused by introduction of non-native organisms varies from reduction in abundance of one or a few native species to catastrophic collapse complex and diverse ecosystems into simpler and less well functioning ones /Sandlund and Viken, 1997/. In order to facilitate for non-native species to establish, and particularly in connection with introduction of top-line predatory fish, treatment of the lake ecosystem with an organic poison, rotenone, has been widely used. Both introduction of non-native organisms and rotenone treatment must be proceeded by a permit from the Regional Fisheries Authorities (Länsstyrelsen) to be carried out. However, regarding non-native organisms a large number of illegal introductions have also been performed. Damages to the lake ecosystems due to introduction of alien species may lead to misjudgements of the ecological functioning of the systems. We therefore suggest that in the systems intended for the site investigation program, introductions of non-native fish and crayfish are included as a parameter describing the total damage to the system. According to the scale constructed by Brunberg and Blomqvist /2000c/ the following classification system for the levels of impact should be used:

No damage (class 0) is defined as when the lake ecosystems lacks introduced species.

Lakes in which new species have established weak populations, or lakes which have previously been subject to rotenone treatments but in which the natural fish community has been able to recolonise, are classified as having minor damage (class 1).

Lakes in which introduced species have established a strong population, or those which have been subject to rotenone treatment and in which the natural fish community has not been able to recolonise, are classified as being moderately damaged (class 2). Introduction of non-native crayfish shall always be considered a moderate damage, because it usually coincides with introduction of the fungus causing a plaque on native crayfish.

A severe damage (class 3) is defined as when rotenone treatment is currently and repeatedly used in order to maintain a strong population of a non-native species.

6.3.1 Existing data

Data on both introductions of non-native organisms and rotenone treatment must be proceeded by a permit from the Regional Administrative Office of the County (Länsstyrelsen) and these permits can be obtained from the files of each such office. In the case of freshwater fish and crayfish also the files at the Institute of Freshwater Research at Drottningholm should be consulted. For Uppsala County, references to data sources with a majority of the data about non-native organisms in the lakes generated up to 1997, and including a systematic study of the fish communities in 82 lakes are given in Brunberg and Blomqvist /1998/. However, introduction of non-native organisms have been and is currently being carried out illegally. For the communities in Uppsala County the list needs to be updated at least by searching the registers at the Regional and national offices, and for the other communities intended for the site investigation program inventories have to be carried out.

6.3.2 Methods for data collection

We suggest that a study of presence of non-native organisms in the lakes should include at least a check of the National and Regional registers for introductions of fish and crayfish and an analysis of the catch from the inventory of the fish community (cf. 5.10.2) for non-native species.

Performance

See section 5.12.2.

Background data

See section 5.12.2.

Time schedule

See section 5.12.2.

Potential resources

See section 5.12.2.

Data processing

The resulting data on the presence of non-native organisms in the lakes are classified using the system described above and saved as attributes to the “Damage table” (see section 6.1.1 Dams – Existing data, above) including all classifications of damages.

Uncertainty – Risks

See section 5.12.2.

Costs

See section 5.12.2.

6.4 Exploitation of species populations

Exploitation of species populations due to overexploitation or aquaculture installations represent a major threat to the sustainable use of components of biological diversity world-wide. Overexploitation may result severe reduction or even reproductive failure of population of target species as well as by-catches in those cases non-selective methods for harvest are used /Sandlund and Viken, 1997/. A selective pressure on target populations, especially of top-line predators, may also result in imbalances in the ecosystem with consequences at lower trophic levels via trophic cascades /Sandlund and Viken, 1997/. Aquaculture installations and subsequent feeding of enclosed populations with imported food may lead to eutrophication. Furthermore, aquaculture using non-native as well as native species may lead to spreading of diseases on wild stock and, in the latter case also, to inbreeding if the cultured material includes a limited genetic diversity.

6.4.1 Overexploitation

Overexploitation of fish populations is mostly a problem in coastal and marine sites but may also occur in lakes, especially those with native stocks of salmonids.

Overexploitation of macrophytes is a more common problem in lakes an may occur due to overexploitation of the shores by private houses, docks, and swimming sites. Over-exploitation of fish species populations may lead to excessive growth of prey populations and cascading effects to lower trophic levels /Sandlund and Viken, 1997/. Overexploitation of aquatic macrophytes may lead to a reduced function of the littoral zone regarding retention of nutrients in the lake ecosystem and hence, to misjudgements of their natural functioning. Thus, in the context of the site investigation program damages due to overexploitation of species populations should at least be briefly invented. According to the scale constructed by Brunberg and Blomqvist /2000c/ the following classification system for the levels of impact should be used:

No damage due to overexploitation of fish populations (class 0) is considered as when only sport fishing and fishing with gill nets for personal consumption takes place in the lakes and when no special regulations have been issued by the authorities. The corresponding classification (class 0) applied to emergent aquatic plants includes minor removal of plants, e.g. outside private docks and swimming sites, along less than 10% of the shore.

A minor damage due to overexploitation of fish populations (class 1) is considered to occur when the population is lacking old individuals, but still have reproductive capacity. The corresponding classification applied to emergent aquatic plants defined minor damage (class 1) as when plants have been removed along 10 to 30% of the shoreline, including removal of roots.

A moderate damage due to overexploitation of fish populations (class 2) is considered to exist when reproducing individuals are lacking. Applied to emergent aquatic plants, moderate damage denotes that the population has been removed along between 30 and 50% of the shoreline.

A severe damage due to overexploitation of fish populations (class 3) represent a situation when the population is extinct or very close to extinction. The corresponding damage applied to aquatic plants is when removal has occurred along more than 50% of the shoreline.

Existing data

Data on overexploitation of fish populations, in the form of restrictions regarding fishing, should be present at the Regional Administrative Office of the County (Länsstyrelsen) or in the files at the Institute of Freshwater Research at Drottningholm and these files should be consulted. Data regarding overexploitation of aquatic macrophytes need to be generated.

Methods for data collection

Performance

Data on the removal of aquatic macrophytes along the shore-line can be generated in connection with the description of the habitat diversity of the lakes (see section 5.11.2).

Background data

See section 5.11.2.

Time schedule

See section 5.11.2.

Potential resources

See section 5.11.2.

Data processing

The resulting data on overexploitation of species populations in the lakes are classified using the system described above and saved as attributes to the "Damage table" (cf. 6.1.1 Dams – Existing data, above) including all classifications of damages.

Uncertainty – Risks

See section 5.11.2.

Costs

Costs in connection with search for data regarding overexploitation of species populations include travel and subsidence expenses and salary at an hourly rate of the person involved in the studies.

6.4.2 Aquaculture

Aquaculture installations represent a major threat to lake ecosystems via eutrophication, spreading of diseases, and inbreeding with native stock and may lead to misjudgements of the capacity of the system to produce organisms. Hence, in the context of the site investigation program, aquaculture installations and their effects on the lake ecosystem are necessary to describe at least briefly. In the following description we have focused on the effects of aquaculture of the spreading of diseases and genetic variability of wild stock. Damages by additions of nutrients due to aquaculture are considered to be covered by the criteria applied for eutrophication (cf. 6.2.1, above). According to the scale constructed by Brunberg and Blomqvist /2000c/, the following classification system for the levels of impact should be used:

No damage due to aquaculture (class 0) is defined as the absence in the lake of aquaculture installations.

A minor damage due to aquaculture (class 1) is defined as the presence in the lake of an aquaculture installation using native stock, without registered infections by epidemic fish diseases, and without major events of fish escaping from the enclosures.

A moderate damage (class 2) signifies when non-native stock is grown in the enclosures or when large amounts of native stock has escaped due to collapse of the enclosures.

A severe damage(class 3) is defined as when the installations has become infected by epidemic fish diseases then spreading to the wild fish, or when non-native fish has escaped from the enclosures and established populations in the lake.

Existing data and methods for their collection

Aquaculture installations must be proceeded by a permit from the Regional Administrative Office of the County (Länsstyrelsen) and these permits can be obtained from the files of each such office. In the case of freshwater fish and crayfish also the files at the Institute of Freshwater Research at Drottningholm should be consulted. For Uppsala County, references to data sources with a majority of the data about aquaculture in the lakes generated up to 1997, are given in Brunberg and Blomqvist /1998/. For the communities of Uppsala County the list needs to be updated at least by searching the registers at the Regional and National offices and for the other communities intended for the site investigation program inventories of the files over longer time perspectives are needed.

Data processing

The resulting data on the presence of aquaculture installations in the lakes and reports of diseases on wild stocks are classified using the system described above and saved as attributes to the “Damage table” (see section 6.1.1 Dams – Existing data, above) including all classifications of damages.

Costs

Costs in connection with search for data regarding aquaculture installations include travel and subsidence expenses and salary at an hourly rate of the person involved in the studies.

7 References

Ahl T, 1994. Regression statistics as a tool to evaluate excess (anthropogenic) phosphorus, nitrogen, and organic matter in classification of Swedish fresh water quality. – Water, Air and Soil Pollution 74: 169–187.

Andersson J, Almén K-E, Ericsson L O, Fredriksson A, Karlsson F, Stanfors R, Ström A, 1998. Parameters of importance to determine during geoscientific site investigation. SKB TR-98-02, Swedish Nuclear Fuel and Waste Management Co.

Appelberg M (ed.), 2000. Swedish standard methods for sampling freshwater fish with multi-mesh gillnets. Fiskeriverket information 2000(1): 27 pp.

Blomqvist P, 2000. A proposed standard method for composite sampling of water chemistry and plankton in small lakes. – Ecological and Environmental Statistics (in press).

Blomqvist P, Brunberg A-K, 1999. Lakes. Origin, ontogeny and natural functions. – In: Lundin L-C (editor) Sustainable Water Management in the Baltic Sea Basin. 1. Water in Nature. The Baltic University Programme, Uppsala University, pp. 93–108.

Brittain J E, Nilsson C (eds.), 1996. Remedial strategies in regulated rivers. Regulated rivers. Research and Management, 12:4-5, 345–561.

Brunberg A-K, Blomqvist P, 1998. Vatten i Uppsala län 1997. Beskrivning, utvärdering, åtgärdsförslag. Upplandsstiftelsen, Rapport nr 8/1998, 944 pp.

Brunberg A-K, Blomqvist P, 2000a. Characteristics and ontogeny of oligotrophic hardwater lakes in the Forsmark area, central Sweden. SKB R-99-68, Swedish Nuclear Fuel and Waste Management Co, 48 pp.

Brunberg A-K, Blomqvist P, 2000b. Post-glacial, land-rise induced formation and development of lakes in he Forsmark area, central Sweden. SKB TR-00-02, Swedish Nuclear Fuel and Waste Management Co, 86 pp.

Brunberg A-K, Blomqvist P, 2000c. Quantification of anthropogenic threats to lakes in a lowland county of central Sweden. – Ambio (in press).

Chalupa J, 1963. Humic acids in water. 1 Methods of preparation and determination. Sbornik Vysoké Skoly chemicko-technologické v. Praze. Technologie vody 7(1), 17–47.

Cole J J, Caraco N F, Kling G W, Kratz T, 1994. Carbon dioxide supersaturation in the surface water of lakes. Science 265: 1568–1570.

Forbes S A, 1887. The lake as a microcosm. Bull. Peoria (Ill.) Sci. Assoc. 1887. Reprinted in Bull. Ill. Nat. Hist. Surv., 15: 537–550 (1925).

Haldorson M, 2000. Statistics available for site studies in registers and surveys at Statistics Sweden. SKB R-00-25, Swedish Nuclear Fuel and Waste Management Co.

Hutchinsson G E, 1975. A treatise on Limnology. Volume I. Geography, physics, and chemistry. John Wiley & Sons, New York, 540 pp.

Håkansson L, 1981. A manual of lake morphometry. Springer Verlag, Berlin, 78 p.

Jansson M, Bergström A-K, Blomqvist P, Isaksson A, Jonsson A, 1999. Impact of allochtonous organic carbon on microbial food web carbon dynamics and structure in Lake Örträsket. – Arch. Hydrobiol. 144: 409–428.

Lindborg T, Kautsky U, 2000. Variabler och parametrar för att beskriva ytnära ekosystem vid platsundersökningar. SKB R-00-19, Swedish Nuclear Fuel and Waste Management Co.

Lindell S, Ambjörn C, Juhlin B, Larsson-McCann S, Lindquist K, 1999. Available climatological and oceanographical data for site investigations of surface ecosystems. SKB R-99-70, Swedish Nuclear Fuel and Waste Management Co, 98 pp.

Melin R, 1970. Hydrologi i Norden. Utbildningsförlaget, p 207. (In Swedish).

Nilsson J, Grennfelt P (eds.), 1998. Critical loads for sulphur and nitrogen. – Nordic Council of Ministers, Miljörapport 1988:15, 418 pp.

NU, 1977. Naturgeografisk regionindelning av Norden. NU B 1977:34, 137 p, ISBN 91-7052-339-8. (In Swedish).

Nyberg P, 1999. Fiskfaunan i Uppsala läns sjöar. En provfiskeinventering i 82 sjöar 1991–93. Upplandsstiftelsen, stencil nr 14, 1997. (In Swedish).

Påsse T, 1996. A mathematical model for the shore-line displacement in Fennoscandia. SKB TR 96-26, 92 pp.

Ripl W, 1995. Management of water cycle and energy flow for ecosystem control: the energy-transport-reaction (ETR) model. Ecological Modelling 78, 61–76.

Sandlund O T, Viken Å, 1997. Workshop on freshwater biodiversity Selbu, Norway 5–7 June 1997. Report. The Trondheim Conferences on Biodiversity. Directorate for Nature Management/Norwegian Institute for Nature Research.

SMHI, 1999. Klimat, miljö och data. Luft och marknära data, atmosfärskemiska variabler. Online 00-01-26 http://www.SMHI.se/sgn0102/n0202/index.htm

SNA, 1992. National Atlas of Sweden. The Environment (1st ed.). Almqvist & Wiksell International, Stockholm. ISBN 91-87760-10-X.

SNAS, 1994. National Atlas of Sweden. The Geology. Almqvist & Wiksell International, Stockholm. ISBN 91-87760-44-4.

Sonesten L, 2000. Environmental influence on Hg and 137Cs levels in perch (Perca fluviatilis L.) and roach (Rutilus rutilus L.) from circumneutral lakes. PhD-thesis, Uppsala University. Acta Universitatis Upsaliensis 525, 41 pp.

Syrén P, Åse L-E, 1987. Trösklar till sjöar och vattendrag i Uppsala län. Meddelanden från länsstyrelsen 1987: 3, 192 pp. (In Swedish).

Wolf P, 1960. Land drainage and its dangers as experienced in Sweden. A study in soil erosion with particular reference to agriculture and fisheries. John Sherratt & Son Publisher, Altrincham.