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**A Manual for Analysis and Display of Lake Habitat and Fish
Position Information using GIS: physical and hydraulic habitat,
draw down, and acoustic telemetry**

by

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Preface

The integration of Geographic Information Systems (GIS) into the process of decision making for aquatic environmental management has been slow. This is mostly due to the relative youth of GIS and the lack of assessment and modeling techniques needed to provide the data for effective decision making, rather than its inapplicability. Although GIS offers potential for improved decision making in aquatic Environmental Impact Assessment (EIA), the lack of techniques and their standardization indicates that this potential is mostly unrealized.

The need for conservation and management of aquatic resources over many spatial or temporal scales poses a significant problem for EIA's. In the real world of finite time and money, efforts to assess change must be efficient, well placed, and consistent. This is particularly true for large-scale development projects common to northern Canada. Although the assessment of resources is a vital and necessary component of environmental screenings to which GIS is ideally suited, the strongest contribution of GIS to the process of aquatic EIA will lie in the ability to use maps as models. The use of map models by EIA's on large or remote lakes may extend the assessment of change from a limited number of sites to entire systems.

GIS offers a rapidly growing set of tools for environmental management, but few members of EIA panels are aquatic GIS analysts or software application developers. It is important therefore, that those who manage or focus the direction of EIA's still need to understand the basic functionality and applications of aquatic GIS in order to evaluate proposals from the GIS community. The purpose of this manual is to provide to those involved in aquatic research and environmental assessment a document that includes a basic but directed primer for the use of GIS in lakes. The manual also hopes to suggest potential directions for the use of GIS in lakes, particularly in the area of process modeling and fish tracking.

This manual uses Idrisi for Windows®GIS (version 2.0) software for the Personal Computer. It is the most widely used raster GIS available, and is relatively simple to operate. Idrisi integrates raster, vector, and tabular data and user supplied programs. Idrisi for Windows®offers a strong set of analytical routines, and the low cost makes the system available to more users.

Scope and Structure of the Manual

This manual targets the novice Idrisi for Windows® user. This manual, hereafter referred to as *the manual*, provides introductory information to demonstrate the basics of the Idrisi GIS software system, and also the functionality necessary to operate specific aspects of the enclosed digital GIS database. The manual assumes that all users are familiar with the Idrisi for Windows system manual sections named introduction and system basics, and the fundamentals covered in the system tutorials. The manual is intended as an application specific companion to the Idrisi software manual, not a stand-alone replacement.

The manual is divided into two parts. The first begins with a general and brief introduction to Idrisi for Windows software, including simple aspects of display and Idrisi's database management system, Database Workshop. Part 2 introduces selected aquatic GIS techniques in 5 areas of application in a tutorial format: 1) substratum classification, 2) modeling water level change and effects on substratum habitat availability, 3) modeling physical processes in lakes, 4) the paradox of habitat replacement and enhancement, and 5) integration of physical and biological data. The manual can be used in two ways: 1) an overview tool for the display of the GIS data (all GIS files are provided), or as a tutorial for users wishing to use Idrisi for Windows by completing simple query and modeling analyses.

Although results are produced in the manual applications, the emphasis here is to introduce aquatic GIS techniques. Due to the introductory nature of the manual and the youth of some of the techniques used in the applications, the manual adopts a simple non-statistical approach. The analyses are not intended to be full and exhaustive, but merely to provide pointers to developing GIS methods and areas of needed research.

The digital data on the CD-ROM which accompanies the manual requires approximately 200 Mb of hard disk space. Idrisi for Windows is best suited for operation on MS Windows 98®, or preferably Windows NT®. A list of the digital data files on the CD-ROM is appended.

Data use policy

Source data are available on compact disc from the author, email: pcooley@cc.umanitoba.ca. Each request for data from the author registers the user as a data recipient to which the data are on loan.

Permission to use the digital data that accompanies this workbook is granted for and is limited to individual and non-commercial use of the information that is enclosed. Permission is not granted for unauthorized reproduction, redistribution, publication, or presentation of the CD-ROM data, or results of any analyses using the data contained on or derived from the CD-ROM.

All requests for use of data are welcome.

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Abstract

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The analysis and display of lake habitat and fish position information using Geographic Information Systems (GIS) is investigated on a Boreal lake. Using companion digital data, five display and modeling analyses are reviewed in a GIS tutorial format: I) Substratum classification, ii) cartographic modeling of water level draw down, iii) integrating spatial process models, iv) the paradox of habitat replacement and enhancement, v) integrating physical and biological data.

Key words: draw down, fetch, GIS, habitat, habitat enhancement, habitat replacement, lakes, lake whitefish, wave energy, spawning, substratum, telemetry.

Résumé

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L'analyse et la visualisation de l'information sur l'habitat lacustre et la position des poissons à l'aide du Système d'information géographique (SIG) a été examinée dans un lac boréal. À l'aide de données numériques complémentaires, cinq analyses de visualisation et de modélisation sont examinées sous la forme d'un didacticiel pour le SIG : i) classification des substrats ; ii) modélisation cartographique de l'abaissement du niveau de l'eau ; iii) intégration des modèles des processus spatiaux ; iv) le paradoxe du remplacement et de la mise en valeur de l'habitat ; v) intégration des données physiques et biologiques.

Mots clés : abaissement du niveau de l'eau, fetch, SIG, habitat, mise en valeur de l'habitat, remplacement de l'habitat, lacs, grand corégone, hydrodynamisme, fraye, substrat, télémétrie.

1. Introduction

The effective implementation of Environmental Impact Assessment (EIA) in aquatic ecosystems is a step-wise process which probably has a minimum of three primary requisites: 1) an understanding of distribution and function of fish habitat, 2) the formulation of this research into protocols to guide decision making, and 3) development of policy to legislate and enact resource management decisions.

Efforts in this regard have focused mostly on the development of protocols and policy. For example, prototype frameworks have been developed for EIA implementation regarding the Department of Fisheries and Oceans (DFO) guiding principle "no net loss of the productive capacity of habitats" (DFO 1986), and the development of protocols to assess change of productivity for fish habitats (Minns 1995). Such protocols, however, must assume that an understanding of the relationships between fish and habitat does exist, when in fact these associations are not well known for most species of freshwater fish. The frameworks which assess the productive capacity of fish habitats, or implement replacement/enhancement strategies do provide important links to no net loss policy, but the science which underpins the concepts of productive capacity remains mostly unstudied.

The limited understanding of the associations of fish to habitat in the nearshore area of lakes is not surprising given the physical heterogeneity of these areas within and between lakes, and the varied habitat requirements of fishes during their ontological development. Indeed, the physical processes and variables which maintain the form of aquatic habitats have been known for decades, but because habitat predictions are unavailable it is clear that the spatial consequences of these processes are not. Habitat managers do not yet have a firm grasp on the distribution of physical variables that form and maintain the structure of aquatic habitats because most inventory methods are best suited to deliver site-specific information, at local spatial scales. While important and widely used, local scale habitat mapping techniques often do not capture the heterogeneity of habitat attributes, or habitat boundaries that form in

response to forcing variables like wave energy or slope (Cooley 1997). In addition, few lakes can be inventoried completely using local scale techniques. The understanding of incremental habitat loss is unclear in lakes with incomplete map databases.

To improve the understanding of lake habitats, survey techniques are needed that observe natural substratum boundaries like rock, sand, and mud transitions, or similarly but over larger areas, the zones of erosion, transport, and deposition (Hakanson 1981) that form the most general habitat zones in lakes. Many process based lake models are available, but few have been implemented in a spatial context. For example, empirical models are available to estimate the properties of surface waves (Airy 1845), and the redistribution of materials into areas of erosion, transport, and accumulation, using fetch distance (Hakanson 1983, Rowan et al. 1992). Such point models were developed from data acquired at select locations in lakes, so the validity of their spatial expression is unknown because they have yet to be implemented within a Geographic Information System (GIS).

Mapping studies indicate a need to reconstruct the habitat forcing and response variables using spatial models. Jensen et al. (1992) and Minns et al. (1995) used a GIS to predict macrophyte distribution using wave energy derived from fetch estimation and slope data. Substratum boundary, depth, and slope surveys were conducted in six boreal lakes by Cooley (1997) to compare habitat availability between lakes. In one of these lakes, the role of wave energy as a control on the upper limit to the distribution of mud was investigated, and demonstrated a close spatial correspondence between predicted erosive and observed depositional boundaries.

If simple process models can predict the spatial distribution of the most general elements of physical habitat for entire lakes, we may be able to better understand the distribution and maintenance of habitat. Using a combination of site and system scale habitat data then, the more available but incomplete local scale inventory information that is common to research and environmental assessments can be put into a more appropriate context. Habitat boundary validation surveys need to move beyond the

arbitrary depth limits of two or three meters that are common to most nearshore habitat surveys. Once process oriented mapping techniques become operational, comparisons of results from process models among lakes can be considered. This will facilitate the validation of spatial process models that can be used operationally in research and environmental assessment.

The integration of data on substratum, slope, wave energy, depth, and telemetry positions of fish movements in a GIS is an ideal vehicle to delimit and understand habitat maintenance processes, and the relationships of fishes to habitats. Where change in a lake is planned, spatial models are needed to predict lake surface hydrodynamics, sediment, and macrophyte distribution to aid planning and assessment before development occurs. Pre- and post estimate maps of erosion, transport, and deposition can quantify these changes (i.e. the distribution, number, and scale of the more general habitat zones) and be used to recommend lake management regimes. Habitat partitioning by fishes in natural lakes can be used to develop suitability models by combining physical habitat mapping with advanced telemetry tracking techniques (e.g. Begout Anras et al. 1999). When the behavior of fishes revealed by detailed telemetry studies in unmanipulated lakes becomes better known, only then will comparisons to tracking patterns of species in lakes under environmental change be meaningful. Although GIS offers much potential to the study of lakes, Jao and Fonseca (1996) recognized that GIS has been under utilized in environmental assessment.

While local scale inventory techniques can be used to assess physical change at sites, complete habitat assessment on large lakes using the same methods is generally infeasible. Accordingly, there is a need for the development of GIS models to predict the patterns of habitat attributes in lakes. The development and validation of spatial process models is data intensive because many of the processes that develop and maintain habitats, like wave energy, can not be effectively modeled using only local area data. The development of prototype lacustrine process models must therefore recognize the initial importance of small lakes, or nearly closed back bays on larger lakes as

locations where both physical and biological data requirements can be met.

The purpose of this manual is to demonstrate the application of GIS as a tool to improve the understanding of physical habitats, lacustrine hydraulic processes, habitat replacement techniques, and fish movements in lakes. To do this, we will review simple display and modeling analyses in a GIS tutorial format on experimental Lake 226, northwest Ontario. A recent study on water level draw down, habitat availability, and the swimming behavior of lake whitefish (*Coregonus clupeaformis*) in Lake 226, a small and deep dimictic Boreal lake, by the Government of Canada, Department of Fisheries and Oceans provides a unique opportunity to demonstrate the application of new habitat mapping, modeling and telemetry tracking techniques. Lake 226 is an ideal case study because its small size facilitated complete mapping of habitats, wave properties, and tracking of spawning lake whitefish throughout the entire lake basin.

1.1 Getting Started

The manual assumes you have Idrisi for Windows® version 2.0, or later, installed on your personal computer, and the software manuals are accessible. Before starting ensure the hard disk intended for the CD ROM data is fully defragmented. If your intent is to use the manual as an aquatic GIS tutorial, copy the 226 directory on the CD-ROM and all of the contents to your hard disk as close to the root of the drive as possible. Next, using a file management program, such as file manager or explorer, select the properties option for the folder and deselect the check box which indicates the copied files are read-only. Your work will overwrite some of the maps that are provided. If the manual is intended only for display purposes you can display directly from the CD-ROM. All data files are provided, and are listed in appendix A.

The typographic conventions used to describe the Idrisi system commands and files are as follows: 1) Idrisi system commands are UPPER CASE, the GIS map filenames are ***bold and italic*** lower case, other file types are **bold**

lowercase and are identified by their file type. Specific GIS instructions are indented from the body of text.

Consult the section entitled scope and structure of the manual for the policy regarding use of digital data.

For a detailed description of the Idrisi for Windows GIS, refer to sections 1 and 2 of the Idrisi for Windows GIS manual provided with the software.

1.2 Simple Display using Idrisi for Windows®

Idrisi operates from a single directory. To set the working directory, i.e. the environment, press the left most radio button on the Idrisi menu bar, and set the directory to the 226 directory, or the directory to which you have copied the data.

1.2.1 File types, Raster and Vector Data File Documentation

Many file types are used or are created by Idrisi during GIS analyses. It is much easier to manage your files within Idrisi. Under the FILE pull down menu (PDM), the LIST, DESCRIBE, DOCUMENT, and FILE MAINTENANCE programs are available.

The files in the working environment are viewed with the LIST module. The LIST module calls a dialogue box which indicates the types of files which can be viewed in the current directory. The data files of interest in the manual are: 1) image (raster grid data), 2) vector (points, lines, and polygons), 3) values/database (attribute information), 4) symbol (vector display), and 5) palette (raster display). Open the LIST module and review the files that are available in image, and vector format. You will notice that map titles are displayed to assist in identifying files.

The specific details of any map files can be viewed with the DESCRIBE module, or modified using the DOCUMENT module. Each raster or vector map in the system has an accompanying

documentation file " *.doc " which allows the system to check details about: the files geographic location, the data type of the file (e.g. real, or integer), the file type (e.g. ASCII, or binary), and the maximum and minimum values of the file, among others. The DESCRIBE module is for view of the *.doc file only, and does not provide access to file components. The documentation files have all been created for the manual, so you will not have to create or modify them. Review the dialogue box for this command by selecting an image file of your choice.

Also on the FILE PDM are system programs for data FILE MAINTENANCE. Using these functions you can delete, copy and rename files. Data file maintenance is preferable from within the system to limit deletion of essential files that are created by the system and are transparent to the user. Do not delete files that have extensions that you do not recognize. Become familiar with this program; it is the routine you will be using most frequently.

Keep a log book handy while working. Record the names of the files you create. At the end of each of the five tutorials in section 2 make sure you delete your unwanted or temporary files to keep your directory clean.

1.2.2 The Display System

Lake 226 is a small lake found in the Experimental Lakes Area of the Canada Department of Fisheries and Oceans, in the Precambrian Shield of northwestern Ontario, Canada (figure 1). Lake 226 is a deep-dimictic two-basin lake with a maximum length of about 1.1 km, a depth of 15 metres, and a surface area of 16.3 hectares. Lake 226 is shown in figure 2.

To gain familiarity with aspects of display we will review the Lake 226 physical habitat databases, including: 1) depth, 2) a digital elevation model of the lake bottom surface, 3) slope, 4) substratum, and 5) wave energy estimated from measurement of fetch distance.

Idrisi is primarily a raster system, but supports both vector and raster data formats. One raster image with up to 15 additional vector layers can be displayed simultaneously. The individual elements of the maps can be saved together as

map compositions. This prevents the need to rebuild files with many layers for display. First we will open a map composition, then we will build individual maps by adding vector data to a single raster base map.

Select the DISPLAY LAUNCHER radio button, or the F5 key, or from the FILE PDM. Select the option to open a map composition, then double-click your mouse on the empty pick box and select **compos_1** (figure 2).

The display of files automatically calls a companion function, the COMPOSER. We can see a list of vector map names which indicates that other source map layers have been combined for display.

Map compositions simplify the process of displaying maps made of several different files by saving the names of all files that should be opened. The composition also records how to display the colors and symbols in each map. Note that map COMPOSITION's are merely linked files. Do not delete each of the source layers or that information will be lost to the composition also. From COMPOSER, vector layers, scale bars, logos, and text can be added to a raster base map, edited, and arranged.

The next two map compositions contain information about the substratum distribution, and also acoustic telemetry tracking positions. We will investigate these data in more detail in section two of the manual.

Select the DISPLAY LAUNCHER radio button, or the F5 key, or from the FILE PDM. Select the option to open a map composition, then double-click your mouse on the empty pick box and select **compos_2**.

Select the DISPLAY LAUNCHER radio button, or the F5 key, or from the FILE PDM. Select the option to open a map composition, then double-click your mouse on the empty pick box and select **compos_3** (figure 3).

Next, we will display an individual image file named **226depth** with 16 colors, and ask for only the title to be displayed. This raster image

shows the distribution of depth, as integer values, in metres.

Select the image option, then double click the cursor in the empty file name box in the box which indicates name of file to display. From the list of available image files, select **226depth**.

In the group of check boxes located at the bottom of DISPLAY LAUNCHER, Select title, and then select idris16 from the palette options box. This will assign pre set colors to the numbers in the raster image. Select OK.

The PROPERTIES option in COMPOSER enables editing image details. This includes on screen text, relative locations of the map objects, map grid lines, and others (see system manual for details).

Select ADD LAYER in COMPOSER, then from the vector file dialogue box select **presshore**. Next, select the **whitelin** symbol file (which automatically assigns white to all object entities in the vector file) by double clicking the empty pick box located at the bottom of the palette options list. This file displays the lake shoreline before draw down. Once displayed, this file can be removed by selecting the file name displayed near the top of COMPOSER, then select remove layer. Any displayed layer can be hidden by deselecting the red check mark to the left of the layer name. To the right of each map layer name in COMPOSER is a small icon that identifies the layer is one of raster, point, line, or polygon file types. Close the open map window by double clicking the minus sign in the upper left hand corner.

Again select ADD LAYER in COMPOSER, then from the vector file dialogue box select **226contr**. This vector file shows the depth contours for the lake. Do not close the map window.

The addition of the vector contours to the map has covered the shorelines from the previous vector file. To change the order of the vector files, select the **presshore** title in COMPOSER and drag the title below the **226contr** title.

Next we will open the Lake 226 digital elevation model (DEM) (Figure 4). This raster image depicts a continuous surface in which the depth values have been interpolated from the **226contr** file. This interpolation produces a floating-point data type with many more values than can be displayed by super VGA systems. As a result, we will use a feature called autoscaling in DISPLAY LAUNCHER to linearly scale the values in the image from 0 to 255 to facilitate color display.

Open the raster image file **226dem** (figure 4) and complete the steps above but substitute the palette idris256. Note that autoscale, located in the lower right hand corner of the DISPLAY LAUNCHER, is invoked automatically when images of real data are opened. Do not close the map.

Let's inspect the documentation file for **226dem**. Select DESCRIBE, and review the image details available. Note that the number of rows and columns of the image are shown, as are the bounding coordinates for the vector data to the right of min and max x and y. Image overlay analysis and the superimposition of vector data on raster base layers require that these coordinates are identical in all layers. The map type is referenced as plane, but the values are Universal Transverse Mercator (UTM). Close DESCRIBE.

Next, open the same file with DOCUMENT, but do not change any of the values. If you ever experience problems with the display of vector data on raster images, you will want to start here and ensure the information is consistent between all map files. Note: the boxes with down pointing arrows allow the user to select a different object type, or file type. These changes do not occur to the source file, but only change the way the system uses the file. If, for example, you wanted to change a new file from ASCII to binary format to save valuable disk space, you would have to use the CONVERT module.

Next, using COMPOSER we will change the symbol file for **226contr** to improve the visibility of the vector display by using a

custom made palette file that assigns all values associated with vector features to white. To do this, select PROPERTIES from COMPOSER, then double click the symbol file pick box, and select the file named **whitelin**, then OK. See the system manual for details on palette and symbol file creation.

Now, we will inspect individual values in the raster map by invoking cursor inquiry mode.

Select the **226dem** map window to ensure it is active, then select the question mark ("?") icon in the radio button bar. Move the cursor over the map and left click your mouse on individual cells. The value of the cell and its location in x and y and rows and columns, is shown along the bottom information bar from right to left.

Let's magnify a part of the image using two different techniques.

First, using the magnifying glass tool on the active map window, click and drag the mouse to the direction of the opposite corner of the region you would like to inspect. You may have to readjust the slide bars to see the area of interest. To restore the original magnification, again select the magnification tool icon, then right click the mouse over the active map window.

The second method, using the WINDOW command is much quicker, but does not allow the magnification to be restored to the original because only the area selected is maintained in computer memory.

Select the WINDOW radio button (ninth radio button from left), and proceed as above. Close the active map window.

Display the raster image, **226slope**, using the grey256 palette (figure 5). This image is also floating point data, so autoscaling is in effect. Remove the grey scale palette and try the idris256 palette.

Using cursor inquiry mode we may observe that Lake 226 has a diversity of slope environments. What are the units of measurement in this image (check DESCRIBE for this)? Low gradient areas

are found mostly in the offshore areas of the lake. In the nearshore area, low gradient areas exist along the western shoreline, and in three isolated pockets in the east basin. High gradient areas, are found mostly in the east basin on the north shoreline of the island, the linear reach of shoreline on the lakes southeast shoreline, and along the east side of the south shore of the narrows.

Now we will open the substratum distribution map, **226subcd** (figure 6), using the qualitative 256 palette. While the classification system is described later in section 2.1.1, it is sufficient to observe for now that Lake 226 offers a diversity of substratum habitat types.

Using cursor inquiry mode, we can observe that a common class code (i.e. 200) is found among all substratum areas in the east basin with slopes greater than 40 degrees. The class code 200 represents bedrock areas. Most other areas of the lake have boulder/cobble combination shorelines with varied slopes. The offshore area of the lake is depositional due to refocusing of fine materials by waves and slope around the lake margin. In the east basin, three secluded pocket embayments with low slope are areas of detrital deposition. These nearshore areas of deposition are protected usually from wave action.

Wave energy in lakes can exert a strong control on the type and distribution of nearshore substratum. Maximum fetch (Figure 7) and mean fetch (Figure 8) have been used to predict wave properties or a sites exposure to wave action, respectively.

Let's review the raster map of the values of maximum fetch distance, **maxf_km** which can be used to predict the size of, or energy available from, surface waves (Figure 7). Next, with the mouse look at the fetch map in areas of the east basin which correspond to the nearshore areas of deposition in the substratum map.

Each of the pocket embayments that have similar substratum characteristics also have a similar range of maximum fetch values. The distances, in kilometres, in such areas range from 0.42 to 0.49. From this we may expect

that shorelines with a maximum fetch greater than 0.5 km have enough energy to redistribute fine materials.

Explore the remaining image and vector database using DISPLAY LAUNCHER and COMPOSER. The palette and symbol files for each map have been given the same name as the map. If a map name does not exist in the palette or symbol file list, use the defaults.

Review the digital photos of the lake and a lake whitefish. These images are named **img0041**, **img0042**, **img0064**, **img0065**. Open each file using a custom palette that indicates the image name.

Close all files.

1.3 Database Workshop

An advance in Idrisi GIS includes the integration of tabular data and map data. Most GIS projects require the collation of data from many sources; some data may be thematic maps, while other data may be archived in the form of data tables. The ability to handle both in an integrated fashion offers many advantages to the GIS analyst.

The linkage between maps and attribute tables enables the exploration of spatial patterns in map data through the use of database queries using Structured Query Language (SQL). SQL statements manipulate the database using a set of command instructions that are defined within the software. The results of the database query are then displayed in map form, which allows a tabular database to be viewed in a spatial context. The linkage of maps and tables also offers tremendous flexibility to the analyst because the location of a GIS analysis can be performed within the GIS in map form, or outside the GIS in a separate software application in tabular format. Generally, most spatial queries are performed using a GIS. Within a spatial context, GIS has yet to provide robust parametric or non-parametric statistical functionality. Consequently, to perform many types of statistical analyses it may be preferable to extract spatial data from maps into data tables

for processing with statistical software (figure 9). Another advantage to tabular statistical analysis outside of the GIS is that the processing of data tables usually is much faster than is the same process conducted on a large raster image.

We will review the linkage of maps and tables in subsequent sections that describe physical habitat and acoustic telemetry techniques. For now, we will review the structure of the DATABASE WORKSHOP PDM's.

Idrisi's database workshop uses the database engine developed for Microsoft Access. Consequently, Access files are the native format for DATABASE WORKSHOP. Import and export routines are provided and are described in the Idrisi for Windows system manual.

Open the database file **226atrib**.

We will review the fields in the table and their characteristics using the DESCRIBE DATABASE routine under the FILE PDM.

Select the DATABASE WORKSHOP icon, the 18th from left, or invoke the program name from the Data Entry PDM.

This dialogue box indicates the number of fields and records in the database. The DOWN ARROW in the selection box can be used to describe each field separately. When a file is open, three other menu's (in addition to HELP) can be invoked: 1) MODIFY, 2) QUERY, and 3) LINK. The MODIFY PDM is used to change the values within fields or to create new values in new fields based on existing records in the database. The QUERY menu performs searches for records, filters the database for records using SQL, and restores the filtered database to its original state. Results of queries can also be converted to Boolean results (i.e. 0 or 1) for simple display. The LINK menu is used to construct a link, known as a "hot link" between the map and table, to update the map display so as to contain only the results of database queries. It is also used to assign tabular data to maps, or to extract map data into tables.

Close files and database workshop

2. Selected Aquatic GIS Techniques and Analyses

Five selected aquatic GIS applications are used to demonstrate the utility of map databases for improving the understanding of habitat distributions, and the relationships of fishes to habitats. The applications are listed below.

- 2.1.1 Substratum habitat classification and assessment using the Nearshore Substratum Classification System
- 2.2 Lake water level draw down and substratum availability
- 2.3.1 Estimating the physical properties of surface waves using fetch distance
- 2.3.2 Predicting and evaluating nearshore sediment dynamics
- 2.4 The paradox of habitat replacement and enhancement
- 2.5 Assessing the distribution and habitat utilization of lake whitefish during spawning
- 2.6 Developing information for spawning habitat suitability models

In this section, we will use a variety of simple GIS techniques that are presented as explicitly described tutorials. Beginner Idrisi users should follow the sequence of exercises.

We will conduct numerous GIS operations which are performed on a single image or using two images. On single images two types of simple queries (by location and attribute) will be performed. The analyses will include the use of scalar mathematics, extended neighborhood context operators, image reclassification, and image crosstabulation. Image overlay is performed using two raster images.

Using vector data we will establish and perform links between maps and attribute tables and use Structured Query Language requests of tabular databases with graphical display of the results in map form. We also will move data bi-directionally between maps and tables.

Consult the two introductory sections in the Idrisi for Windows manual for definitions, and an overview of GIS techniques.

2.1 The Lake 226 Substratum Distribution Database

The geology and geomorphology of the study region have been described by Cleugh and Hauser (1971).

2.1.1 Substratum Classification

Maps of substratum have several potential uses. They can be used to develop spawning habitat suitability models, or to perform comparisons between wave energy and sediment particle size, or to compare substratum availability in lakes where water levels are controlled. Substratum maps which are sufficiently detailed for use in spawning suitability or water level studies are not widely available due to difficulties in making direct and system-wide observations. This is especially true in mid to large sized lakes. Consequently, predictive substratum models are needed for spawning suitability assessments. A GIS can be used to develop such models by documenting, for example, the slope and wave energy that correspond to substratum classes.

The experimental draw down study of Lake 226 conducted by Government of Canada Department of Fisheries and Oceans provided several substratum mapping opportunities: i) to map completely all of the nearshore and offshore habitats in the lake and follow habitat availability during draw down, ii) to evaluate the role of wave energy in determining the upper boundary of the distribution of fine sediments, and iii) to compare lake whitefish (*Coregonus clupeaformis*) tracking patterns at different water levels. With such detailed requirements, the Nearshore Substratum Classification System was a useful technique to meet these objectives in this lake.

Most substratum mapping methods are best suited for contrasting major habitat classes (like boulder, sand, and mud) because nominal classification systems tend to generalize habitat attributes. While suited for such inter-habitat comparisons, these methods inadequately describe intra-habitat class variation, like boulder, cobble, and gravel combinations that are often present in habitat distributions. Most nominal habitat maps, then, take complex habitat mosaics and partition these into very few classes. They are very simple and are often unsuitable for detailed description of fish spawning site characteristics. For example, a fish species may be studied using telemetry tracking techniques during spawning. Results may show that boulder coasts are preferred to sand and mud areas. In the context of environmental assessment, does this mean all rocky shores are critical spawning habitat? While the spawning requirements will vary among species, and some species will be more specific than others, it is unlikely that all rocky shores are critical. To better understand the range of substratum types selected for spawning a more detailed approach is merited.

The Nearshore Substratum Classification System is a substratum mapping technique designed to capture the heterogeneity of substratum materials and the patterns of substratum which result from wave or slope processes (Cooley 1997). The nearshore substratum classification system differs from most other nominal substratum classifications mostly in two ways: 1) one to three nominal material size classes can be nested within a single polygon, and 2) substratum material size boundaries are captured. Such a monopartite, bipartite, or tripartite classification system captures the variability of materials that most single class nominal systems do not. To simplify classifications in the field, the nearshore substratum classification system assigns numbers to classes. An example of a bipartite and tripartite classification using the nearshore substratum classification system would be, for example, 71/61 or 61/52/51. This coding indicates the first substratum area of interest has approximately 66% depositional characteristics with 33% being small boulder. Each of the three classes present in the second area (i.e. small boulder, large cobble and small cobble) represents 33% of the polygon, respectively.

The boundaries of the nearshore substratum polygons and station numbers surrounding the lake are shown in figure 10. The class numbers that reference material size classes are found in Appendix B. The nearshore substratum classification system and the comparison of habitats among six lakes are described in Cooley (1997).

Using the Lake 226 substratum database as an example, we start the tutorial by learning that GIS databases are often complex in spatial pattern, so it is useful to explore fully the data before relationships are investigated. Often, significant amounts of time and effort are needed in the data exploration stage, so it is important that the most efficient means for querying the data be employed.

Recall in Section 1, query by location was performed which asked the question: "what substratum attribute is at this location". Below, a second type of database query, known as query by attribute, is used to ask a related question "where are the substratum areas that have the attribute of bedrock". Two approaches will be used to do this. The first is to use image reclassification, and the second involves linking a tabular database to a vector polygon map. Both methods produce the same results (i.e. delineate areas that satisfy the criteria of the query), but reclassification operates on raster image data, whereas the results of tabular database queries are displayed using vector polygon data.

Objectives:

1) to delineate the substratum areas of Lake 226 which have a specific attribute (e.g. bedrock) using image reclassification, and display of vector polygon information using tabular database queries.

Raster Data Reclassification

Open the raster image **226subbcd** using the qualitative 256 palette. Using cursor inquiry mode we can observe the integer values indicated in the substratum map. The interpretation of these numeric codes as nearshore substratum classes (as shown

above) is described in appendix B. For now, we will identify the areas of the lake as homogeneous bedrock. The bedrock nearshore substratum classification system code number is 200 and corresponds to the value of 20 in this map. Open the RECLASS module from the ANALYSIS—DATABASE QUERY PDM's, or select the radio button 19th from the left.

The result we wish to produce is a map which indicates areas of bedrock and all other areas combined as non bedrock. The output map we produce in this step is known as a Boolean map because it contains only values 1 and 0, for the areas which do or do not satisfy the bedrock criteria, respectively.

Using the first two defaults, specify **226subcd** as the source image and name the output image bedrock with an appropriate title. To change the values from the many integer codes to a Boolean result we will assign the class 20 to 1, and reassign all other values 0. To do this follow these steps: assign a new value of 1 to all values from 20 to just less than 21, then select the right pointing arrow, and assign a new class of 0 to all values from 0 to just less than 20. Again select the right arrow, then assign 0 to all values from 21 to just less than 256. Select OK, then display the map using the Boolean palette. Add the vector layer **preshore** to provide a reference for the lakes shoreline.

Vector Polygon Attribute Query

Perform the same query using a link between the vector substratum data **226subid** and the attribute table **226attrib**.

Open the vector file **226subid** with the qualitative 256 symbol file. Next, open DATABASE WORKSHOP and the table **226attrib** using the FILE PDM.

We will now construct the linkage between the map and the table. This a two step process which indicates to the system that a link is requested, and which values in the database correspond to the values in the map, and how those values will be displayed. Databases and

maps can only be linked if the values in the leftmost field in the table correspond to the entity codes for the corresponding vector polygons. Thus, if a single substratum area in the map had an entity identifier value of 163, the database would also have a record with the ID value of 163. The other fields in the same record describe the other attributes for that substratum area.

Select the map window to make it active, then select properties on COMPOSER and indicate the use of a values file named **dbwlink** file by selecting the values file option and double clicking next to the values file box. Now, using DATABASE WORKSHOP, we will specify the link parameters using the LINK PDM. Select the set display link parameters option. In the upper left corner of the dialogue box indicate the name of the map window for the link, **226subid**, the vector layer and object type which will be used for the display of the tabular attributes, **226subid** (polygon). Next, specify that **idr_id** is to be used as the link variable (this indicates to the GIS which field contains the feature identifier values in the table which correspond to those in the map). We must also specify that the field which contains the attributes we wish to display is named **classcode**. Select OK. Ensure the display of data is Boolean by ensuring the grid-like radio button, i.e. 5th from the left is only two colors. If not, press the display radio button once.

The vector display of polygons should now disappear from view, and the area above the DATABASE WORKSHOP menus should indicate that the map window is linked to the **226subid** file. We are now ready to query the tabular database using SQL and have those results displayed in map form.

Add the vector layer **preshore** to the map to provide a reference of the lakes shoreline, then select the QUERY PDM. Select create filter and enter the following simple SQL statement to the right of the last text entry: the result should read "where classname = 20". Select OK, then review the active map window. When finished, remove the SQL filter using the QUERY PDM. The entire substratum coverage should reappear. If

not, select the update display option under the LINK menu.

This interactive form of query can provide an efficient means to explore the spatial patterns in data, and can also provide a precursor step to image reclassification. In this example, we learned quickly that bedrock areas are available only on the lakes southern shores. If these results confirmed suspicions about, e.g. fish distribution relationships, we would then perform image reclassification and continue with more detailed raster data analyses.

Perform other queries of the database to gain familiarity of the substratum distribution patterns. Start with a SQL that queries the location of purely depositional sites; i.e. where classname = 71 or classname = 72 (appendix C). This query requests only the area of offshore deposition and the nearshore area's that also show deposition.

By reviewing other attribute fields on the queried database, like mean_slope for example, we find that the nearshore area polygons that show deposition are all areas of low slope; most areas are less than 10 degrees. Repeat the bedrock query (completed above) and review the mean_slope field after the query is performed.

Close all files.

Overview

Using reclassification and query techniques we have learned, based on slope alone, that sites where deposition occurs are likely to have slopes less than about 13 degrees, and that bedrock areas have slopes greater than this threshold. Therefore, substratum areas with slopes greater than about 13 degrees in Lake 226 are probably geological. Detailed substratum classifications are an essential tool for describing the relationships of material size to slope.

The production of reclassified raster maps is often a necessary step because, in Idrisi, most programs operate only on raster data. However, the use of linked vector polygon information and

attribute tables using SQL provides an efficient initial means to explore the spatial patterns in the database, and review tabular attribute summaries. In addition, vector polygon query relieves the need to create many images which simplifies the management of hard disk space. Another reclassification technique is available which integrates tabular query and image data directly. This is done using the ASSIGN option of DATABASE WORKSHOP which is introduced in section 2.5.

2.2 Cartographic Modeling of Water Level Draw Down and Effects on Substratum Availability

Water level regulation and draw down in temperate lakes provides valuable hydroelectric generation potential to most temperate communities. In general, the magnitude and season of draw down are determined by hydroelectric demand. In Canada, most regulated lake systems have a period of water retention during the fall season, in anticipation of the winter draw down period when demands for electricity are highest. Such draw down regimes may not reflect the natural hydrologic cycle, and have unknown effects during the critical spawning periods of many fish species. This is particularly true for the fishes that have reproduction and rearing requirements in nearshore areas.

The inclusion of substratum information into a GIS can delineate substratum areas and their corresponding physical attributes, like slope, or geological material combinations. When substratum data are combined with fisheries distribution information, habitat suitability models can be developed to indicate the relative use (i.e. importance) of habitats. This topic is explored in more detail in section 2.6. When such requirements are known, a GIS can also assist in the development of draw down regimes that include also the habitat requirements of fish species. A GIS is suitable for this because new water levels can be prescribed effectively using digital elevation models. As demonstrated

below, the effects of water level change on substratum availability, or loss, can be assessed rapidly in a GIS.

During the winter months of 1995, 1996, and 1997, the water level of Lake 226 was drawn down experimentally as part of an ecosystem manipulation experiment by the Department of Fisheries and Oceans. The purpose was to determine the effects of draw down on the physical characteristics and biological communities of the lake. In particular, the effects of draw down on spawning success of lake whitefish (*Coregonus clupeaformis*) were studied. Lake whitefish tend to spawn in littoral areas (Bodaly 1986) late in the open water season. Lake whitefish reproduction therefore, may be vulnerable to fall and winter draw down because the eggs remain dormant in the shallows during winter and are susceptible to desiccation during and after winter draw down.

A reference lake stage datum was established at 9.2 m on September 13, 1994. The water level draw down regime during 1994 – 1997 is shown in Figure 11. Water levels were manipulated using large gravity-fed siphons directed into the lakes natural outflow during late fall and winter.

Objective: to simulate the change in water level of Lake 226 at three lake stages, and to assess the corresponding availability of substratum areas.

To do this we will use RECLASS on the raster image **226DEM_F** to prescribe lake level changes. Using the lake level Boolean maps which result from the reclassification and the map of substratum, an image OVERLAY will be used to delineate the wetted substratum areas. We will then quantify the substratum availability using the AREA module. The results of the substratum availability can be output to a software spreadsheet in ASCII text form for summary purposes.

To simulate the change in lake stage, use RECLASS on **226dem** three times separately to convert the image to three Boolean water level maps (i.e. at -1.7, - 3.1 and at a depth of your choice below the lakes water level datum of 9.2 m). In figure 10, these prescribed lake levels correspond

to 7.5 and 6.1 metres. Next, use each of the Boolean lake stage maps (which must have a lake value of 1 and land value of 0) in a multiplication OVERLAY with the **226subcd** raster map. In this manner, we exclude desiccated areas from the area summaries, as product of any value multiplied by zero remains zero.

The three final output maps show the reduced lake area and the available substratum. Use the AREA module on each map and indicate that tabular data in hectares is the desired output. The maps produced from the RECLASS and OVERLAY operations are provided. They are named **dd17** and **dd31**, and **sa_dd17** and **sa_dd31**, respectively. The ascii text outputs from the analysis are also available on disk using the same filenames with a "txt" extension.

Using a spreadsheet program like MS Excel®, we can parse the ASCII space delimited results from the AREA module and graph the change in habitat availability. Although it is beyond the scope of this exercise, it should be clear that it is often necessary to move data from the GIS to other software environments to access additional analytical and graphical applications.

Close all files.

Overview

The use of GIS to inventory habitat and model water level provides a tool to assess the availability or change of the amount and distribution of physical habitat. Limitations of such methods include that all areas estimated represent the horizontal lake surface area (which corresponds to the substratum zone), not the actual area of the basin surface. Also, any changes noted in substratum availability in natural lakes due to draw down only represent conditions immediately after draw down. Improvements to draw down analyses in natural lakes, therefore, should attempt to account for basin surface area, and the dynamic redistribution of fine substratum areas that continue to be sorted due to wave energy only at lower lake stages.

2.3 Integrating Physical Process Models in GIS

The integration of physical process models in GIS is needed to better understand the spatial dynamics of sediment redistribution, and how these processes are controlled by wave energy and slope.

2.3.1 Mapping wave properties using fetch distance

Estimates of the physical properties of surface waves are essential for effective modeling of shoreline erosion, and to model the mechanics of material redistribution in lakes. Estimates of deep water wave properties (i.e. wave height, length, and the depth to the subsurface wave base) can be estimated empirically using fetch distance measurement and deep water wave theory (Airy 1845). Spatial modeling of these properties in a GIS can allow the areal delineation of the depth to the sub surface wave base and the upper limit of fine sediment deposits, known as the mud energy boundary depth and mud deposition boundary depths (Rowan et al. 1992), respectively. Wave energy models have been demonstrated as useful for point models of lake sediment dynamics (Hakanson 1983), Coastal Processes (Bartlett 1989), and predictive mapping of macrophyte distribution (Jensen et al. 1992).

The physical properties of surface waves can vary due to the interaction of the variables that control their form. This includes water depth, water temperature, lake size, and the effects of watershed relief on the transfer of wind energy to the lake. Most in situ measurements of wave properties have been developed in large temperate lakes (e.g. Schwab et al. 1984). As such, measurements that can validate predicted wave properties are still lacking in small and mid-sized lakes.

In this exercise we will implement a maximum fetch model to predict the mud energy boundary depth in Lake 226. We will learn that in areas unaffected by slope, the lower limit of the mud energy boundary depth in Lake 226

corresponded closely to the upper limit of the distribution of fine sediments. This suggests that the deep water wave theory (Airy 1845) may be valid for predicting the properties of waves in small lakes. A description of the GIS maximum fetch distance program and the method of measuring fetch is described by Cooley (1997). Deep water wave theory has been simplified and summarized by Rowan et al. (1992).

In this exercise our aim is four fold:

- 1) to predict the spatial distribution of the depth to the sub surface wave base,
- 2) to delineate the mud energy boundary depth for Lake 226,
- 3) to assess the similarity between the lower limit of the mud energy boundary depth and the upper limit of the mud depositional boundary depth
- 4) to predict the areas of Lake 226 which represent areas of erosion, transport, and deposition.

To do this, we will first predict spatially the depth at which the sub surface orbital velocity of waves ceases for the entire lake area. Next, to delineate where the subsurface wave base contacts the substratum of the nearshore area, we will use the DEM and the wave base map in a subtraction OVERLAY. This pair-wise map overlay simply is a superimposition of the two maps that allows algebraic operations to be performed among values in cells that correspond in each image. Thus, the zone of erosion will be represented where water depth is less than the predicted depth to the wave base (as negative values in the third output image which results from the overlay process). To investigate the relationship between wave energy and sediment distribution, we will conduct an analysis using information from the mud energy boundary depth, substratum distribution, and slope.

First, we will use the system module called IMAGE CALCULATOR to convert maximum fetch values to estimate the depth to the sub-surface wave base. To do this we will use equation 5 from Rowan et al. (1992):

$$h > 1.66F^{0.5}$$

where h = water depth (metres), and F = maximum fetch (kilometers)

Select the image file *maxf_km* and review the fetch values. We see that the maximum fetch is approximately 1 kilometer. Now select the IMAGE CALCULATOR icon, 22nd from the left, or from the ANALYSIS—MATHEMATICAL OPERATORS PDM's.

IMAGE CALCULATOR provides the functionality of the RECLASS, OVERLAY, SCALAR, and TRANSFORM system modules. In this example, we will use this program to perform scalar mathematics indicated in the equation noted above. IMAGE CALCULATOR is an efficient and flexible way to perform manipulations on images using text scripts. Although these scripts are built within the module we will implement a script which is already saved on the hard disk.

First, in IMAGE CALCULATOR ensure that the mathematical expression option is selected. For the output filename enter *wvbtmp1* (we will produce a few temporary files before the final result is created so it is helpful to indicate they are temporary files to simplify data management). Select the open expression selection radio button and select the file *wvbase* from the pick menu. This script should read as follows:

$$[\text{max_fkm}]^{0.5} * 1.66$$

Select the radio button which indicates process expression. The resulting map indicates the depth to the wave base for the entire lake. Name the file *226wvbase*. Inspect the values of the image at the two opposite ends of the lake. The maximum depth to the wave base is about 1.68 meters below the water surface.

Next we will use an image overlay to delineate the area of the lake bed which is cleansed mechanically by surface waves.

Select the OVERLAY icon, 21st from the left or from the ANALYSIS- MATHEMATICAL OPERATORS menus. The first input image file is *226dem_F* and the second input image is *wvbase*. Select the option that indicates first image minus second, and call the output image *mdebdtmp*, then give the image an appropriate title. Select OK.

Open the file produced by the overlay using the Idrisi 256 palette.

It is evident that the area of the mud energy boundary depth has the smallest values in the map and is scaled to black for display. In the next two sections, we first produce the mud energy boundary depth map, then compare it to the mud depositional boundary depth on the substratum map. For this we will want an image that contains only the mud energy boundary depth for Lake 226. To do this we will use RECLASS.

2.3.2 Predicting the mud energy boundary depth

To delineate the mud energy boundary depth we will implement image reclassification. Most often reclassification is used to generalize ratio data to nominal classes. Below we will convert all negative values in the *mdebdtmp* map to a single integer that represents the mud energy boundary depth. The map that results from the reclassification is available for display, and is called *mdebd*. The steps to produce this map are found below.

Select the RECLASS radio button, 20th from left, or from the ANALYSIS—DATABASE QUERY PDM's. In this image we want the background values to be zero, and the mud energy boundary depth to have a value of 1. Using the first two defaults, we will specify *mdebdtmp* as the input file and the output file, *mdebd*. Assign a new value of 1 to all values from -2 to just less than zero, then select the right pointing arrow to specify details required to reclass the background to zero. Enter as above 0,0,17, respectively. Give the image the title "Lake 226 Mud Energy Boundary Depth". Select OK.

Open the raster file *mdebd* with a user defined palette named *mdebd*. Also select the title, north arrow, and scale bar. Using COMPOSER, add the vector layer *presshore* with the default symbol file. This map predicts the maximum area of the Lake 226 substratum that can be eroded or cleansed by surface waves.

It is good practice to confirm results are as expected before proceeding too far into an analysis. Confirm the calculations performed thus far are correct using one image cell in the fetch image, the equation from Rowan et al. (1992) above, and a calculator.

Using the file maintenance utilities, delete all temporary files before proceeding.

Note that the lower limit of the mud energy boundary depth also delineates the region of the lake where shallow water changes the form of surface waves. Estimates of deep water wave properties are only valid for the area of the lake that is at depths greater than the mud energy boundary depth.

2.3.3 Comparing the mud energy boundary depth and mud depositional boundary depth

Now that the mud energy boundary depth has been delineated for the entire lake, we will compare the distribution of depositional substratum types in relation to this modelled wave energy zone. Although we would expect that wave energy and sediment distribution would be related, the spatial correspondence of the lower limit of the mud energy boundary depth and the upper limit of the distribution of sediment is unknown. Consequently, we will conduct a preliminary analysis to assess the feasibility of a more detailed and quantitative analysis. To do this, we will use a forward link to superimpose on the raster mud energy boundary depth map only the vector substratum polygons with depositional characteristics to visually review the correspondence of energy and depositional boundaries (figure 13).

Add the vector polygon layer **226subid** with the qualitative 256 symbol file to the **mudebd** base image. Open DATABASE WORKSHOP and the table file **226attrib**. Establish a forward link to the vector polygon layer using "idrid" as the field containing feature identifiers, and "class_code" as the field containing the attribute codes for display.

The "deposition" field of the tabular substratum database has been preprocessed to indicate only the classes which are depositional. This Boolean field indicates deposition as value 1 and non deposition as value 0.

Construct the SQL query: deposition = 1. On the DATABASE WORKSHOP interface, confirm the 5th icon from the left displays only a 2 colored array, then select the execute radio button.

We can make three qualitative observations from this map (refer to figure 10 for station numbers):

- 1) The mud depositional boundary depth exceeds the mud energy boundary depth in much of the nearshore area of Lake 226.
- 2) The mud energy boundary depth and mud depositional boundary depth correspond very closely in 5 areas of the lake: the western end of the lake (station range 1250-1400), around station 1700, and also in east basin in the two small embayments immediately to the northeast of the island in the east basin (around station 2600), and the northern shoreline (the shoreline reach containing station 2300).
- 3) In seven shoreline areas (i.e. the reaches including station #470, 800, 1600, 1800, 1970, 2550, 2750) the mud depositional boundary depth is much shallower than the predicted mud energy boundary depth.

The areas of Lake 226 where the predicted mud energy boundary depth was more shallow than the mud depositional boundary depth can be explained due to the effects of slope on sediment redistribution (Rowan 1992). This is likely because, in terms of site depth, the areas where the mud depositional boundary depth was greater than the predicted mud energy boundary depth, were areas of moderate to high slope. The substratum classes of such areas tended to have bedrock or boulder and cobble combination shorelines lacking material size gradients due to sorting. The shorelines that show a close correspondence between the mud energy boundary depth and mud depositional boundary depth tend to be in lower slopes with sand and/or gravel combinations, and on boulder shorelines that show evidence of material sorting with increased water depth.

A zone of erosion was predicted in seven sites that showed deposition in the substratum map. These discrepancies can be readily clarified in three of these sites (near stations 1600, 1800, and 2750). Each of these areas showed deposition due to reduced wave energy, probably, from forest windfall in the littoral area, sheltering behind large boulders, or from activity by beaver (*Castor canadensis*), respectively. For the remaining four sites which were predicted to have an erosive shoreline but were depositional, it is likely that the fetch program overestimated the wave energy because it does not account for variation in wind direction. The maximum fetch model assumes that the wind direction and velocity are equal about the 360 wind directions that are measured. The sites for which wave energy is overestimated have fetch axes that are sufficiently long to produce a margin of erosion, but these sites are depositional because they are sheltered from prevailing winds. Apparently, the aspect of the maximum fetch at these sites is an infrequent wind angle.

We will now investigate the approximate slope threshold that produces a mud depositional boundary depth at depths below the mud energy boundary depth.

Superimpose the polygons of deposition, as above, on to the map *ebdslope*, using the *idris256* palette. Using cursor inquiry mode, inspect the values of the slope map which correspond to the deposition substratum polygons. Most slope values in the sites of deposition in the nearshore area are less than 6 degrees. Few depositional sites have slopes > 10 degrees. Recall that our use of SQL in the first application (section 2.1.1) described the relationship between slope and deposition was described statistically (grand mean slope of 8.4 degrees +/- 4.4 degrees). Thus, the selection of a 10 degree threshold is conservative, and explains greater than 80% of the observed depositional data.

2.3.4 Estimating areas of erosion, transport, and deposition

We will now estimate the area of the lake occupied by erosion, transport, and deposition. As we are aware that the predicted mud energy boundary depth is an overestimate we will quantify this error.

Use the AREA module on the *mudebd* image to determine the area of erosion in Lake 226. Output the results in tabular form in hectares.

Now, we will use the ASSIGN operation in DATABASE WORKSHOP to produce a raster map of the areas of deposition shown in the query above.

Assign the values of the deposition field to a new map called *deposit* using *226subid* as the template image. Use CONVERT to truncate the real values to integer, then RECLASS the mud energy boundary depth area to value 2.

Next, perform an addition overlay using the *mudebd* and *deposit* images. Name the output image *overest*. The areas with overestimated mechanical energy is delineated as value 3. Run the AREA module and save the results.

To determine the area of sediment transport, perform a cover OVERLAY using *overest* and *226lake*. The output map, *eta*, will indicate the mud energy boundary depth (value 1), area of deposition (value 2), overestimated wave energy (value 3) and zone of transport (value 4). Now perform the cover OVERLAY *226lake* with *overest*. Run AREA on *ebd*, record the results, and calculate the areas relative to the entire lake area. Review the spatial pattern of zones delineated in the *ebd* raster map.

The areas of Lake 226 occupied by erosion transport and deposition (ha) for the lake and Nearshore Area (nearshore area) are found below. Values indicate horizontal lake area occupied. Bracketed values are %.

	Erosion	Transport	Deposition
Lake Area	1.18 (7)	2.57 (15)	12.46 (76)
nearshore area	1.18 (23.6)	2.57 (51.2)	

From this map we can determine that deposition occurs in about 76% of Lake 226. The total area of transport (found in depths between the mud energy boundary depth and mud depositional boundary depth) is about 15% of the lake area, and is about half of the nearshore area. Wave energy only contacts about 7% of the lake bottom, or nearly one-quarter of the nearshore area. Clearly, sediment redistribution in Lake 226 is controlled mostly by slope. Because the predicted mud energy boundary depth and depositional boundary depth corresponded closely in areas with slopes \leq to about 10 degrees, these low slope environments do not exhibit a clearly definable zone of transport.

In Lake 226 three general types of shorelines can be distinguished based on the patterns of material redistribution. Shorelines with boulder cobble combinations have aquatic slopes that tend to exceed 10 degrees. In such shorelines there is a narrow zone of wave action from the surface extending to a maximum depth of 1.68 m. Below this erosive zone, material redistribution continues to greater depths due to the effects of gravity. Two other types of shorelines, beaches and depositional embayments, are low slope (< 10 degrees). Beaches do not exhibit a zone of transport because the mud energy boundary depth and mud depositional boundary depth are coincident. Depositional sites do not show frequent erosion or transport.

Close all files.

Overview

The implementation of map models in EIA's for prediction of areas of erosion, transport, and deposition in lakes proposed for hydroelectric

regulation would be valuable tool for assessing large scale changes in their physical and mechanical properties. In such lakes GIS models of lake dynamics would provide a mitigation protocol to define the water level regime apriori, based on predicted habitat characteristics.

Maps of erosion, transport, and deposition can aid in general habitat assessment at different levels of draw down to indicate the change in each of these areas. Although the specific substratum types in this estimated zone of erosion will be unknown in lakes without littoral maps, the change in the zone of erosion at different lake stages can be used as simple indicator to document the change in areas of the lake with mechanically cleansed shorelines. The estimated zone of erosion can serve as a proxy for delineating the littoral area in lakes at different water levels, in an attempt to minimize areal losses at lower lake stages.

Mapping wave energy for use in modeling of lake dynamics requires the documentation of wave properties in small to mid sized lakes. Multi-lake observed substratum distributions are needed to refine fetch models so they can accommodate the effects of wind angle frequency. The estimation of surface wave properties for modeling spatial lake dynamics, therefore, must be considered developmental, and requires more research before their use can be operational.

In large systems where the complete collection of habitat data is unlikely in environmental assessments, GIS models can be also be used to predict the general characteristics of substratum (e.g. bedrock, rocky, sand, and deposition) and their spatial distribution. Such predictions are feasible, and only require a minimum set of information which would include a bathymetric map (i.e. a DEM), a fetch distance program, and a statistical model relating slope and wave energy to the general substratum classes. Multi-lake databases are needed to compile the data for model development and validation.

2.4 The Paradox of Habitat Replacement and Enhancement

Effective habitat replacement or enhancement protocols probably have two primary considerations: 1) to simulate the structure of the lost or desired habitat, 2) and to choose locations that have mechanical and slope conditions similar to the area of lost habitat to ensure its long term quality is maintained.

The selection of sites for habitat replacements can be somewhat arbitrary. To maintain the desired quality of a replaced or enhanced substratum, areas selected for habitat replacements probably should have mechanical and slope conditions that are similar to the site where habitat losses are anticipated. In this regard, the processes that maintain the habitats of the lake can also be used for the long-term maintenance of the replaced habitat. However, this introduces a paradox. Shorelines in a steady state condition (Selby 1990) develop an equilibrium between the available wave energy, substratum material size, and the resultant nearshore slope. In other words, when a shoreline becomes stable it has achieved a particular slope because the wave energy distribution at that site has previously removed the fine materials to the point where erosion and transport of the remaining larger material sizes only occurs during infrequent but high magnitude storm events. According to the contention of shoreline equilibrium theory then, all other candidate littoral sites with wave and slope conditions like that of the site of habitat loss may also already have developed a generally similar substratum character. Replacements at such sites would only constitute habitat superimposition (i.e. covering of similar or different habitats), not a habitat replacement or addition.

Perhaps the only other opportunity to develop additional habitat is to construct new habitat in areas of the lake other than along the lakes shoreline. For example, the design of rocky shoals or headlands in areas just offshore in the

nearshore area will have greater wave energy that can be exploited to maintain the quality of the habitat. However, as shown below, the tapping of surface wave energy in one location will reduce the ability of the lake to maintain the desired habitat structure in areas surrounding the site of replacement.

Objective: to identify the areas of Lake 226 which may be suitable for habitat replacement based on the wave energy and slope characteristics of a site proposed for development.

To develop the environmental criteria, we will sample values from wave and slope thematic maps in the proposed site where habitat will be lost. These values will then be used to identify other similar sites in the lake where habitat replacement may be feasible. In this analysis we will learn that replacement or enhancement strategies will always cause direct or indirect changes to the availability and distribution of aquatic habitat though superimposition or mechanical sheltering.

Open the raster images, **226subcd**, **226slope**, **maxf_km**, **mnfetch**, the substratum, maximum, and mean fetch images, respectively. Position the windows so they all are visible, then make the maximum fetch image active. Add the polygon layer **hab_loss** (using the Idris 16 symbol file) to identify the area where the habitat is to be lost due to development.

To identify all sites in the lake that have similar wave energy we will document the values for both maximum and mean fetch in this area and combine the Boolean maps of the areas that satisfy the criteria. Although we could use a statistical approach to gather the values for criteria, we will use a more simple method, i.e. cursor inquiry mode to determine the maximum and minimum values.

Because the area of habitat loss is defined as a polygon and we can not see through it, we will change the display from polygon to line so we can interpret the values of the fetch map located within this area.

Select the FILE and DOCUMENT PDM's. Select the vector option and the *hab_loss* vector polygon file. In the DOCUMENT dialogue box, change the object type from polygon to line by selecting the down arrow. Select OK.

After making these changes you may need to remove this layer from the map composition, then add it again. Only the boundary of the area proposed for change should be visible.

Add the *hab_loss* layer to each fetch and the slope map with the *whitelin* symbol file. Review the maximum and minimum values using cursor inquiry mode (use WINDOW to magnify). The maximum and minimum fetch and slope values associated with the location of habitat loss for the maximum (km), mean (m), and slope (degrees) maps are listed below.

	Minimum	Maximum
mxf_km	0.85	0.90
mnfetch	35.51	39.98
slope	11.73	42.09

RECLASS each of the fetch distance maps to a Boolean coverage (areas of interest value 1, other areas value 0) using the measurement thresholds above. Display each of the maps using the qualitative 16 palette and the *presore* layer using the *whitelin* symbol file. Name the files *mxf_crit* and *mnf_crit* for the maximum and mean criteria images, respectively.

Each fetch model produces a criteria map with a different spatial pattern (figure 12). Maximum fetch produces areas that satisfy the criteria at opposite ends of the lake, whereas mean fetch forms a criteria pattern that loosely follows the lake perimeter. As we are aware that maximum fetch can overestimate wave energy, in this analysis we will produce a conservative estimate that also integrates the results of mean fetch.

To determine only the areas that satisfy both wave energy criteria, perform a multiplication OVERLAY among *mxf_crit* and *mnf_crit* fetch criterion images, and

view the result with the boolean palette. Name the image file *fcritria*.

The results of the multiplication overlay produce several zones that meet the combined wave energy criteria. While a few are relatively large, several are quite small. We now need to calculate the areas for each of these zones to satisfy the requirement of replacing an area about the size that was lost. First, we have to determine the clusters of contiguous pixels as groups. As each group of pixels is assigned a unique integer, it is then possible to sum each of the cells in a group to determine the area.

To identify the number of groups of contiguous cells use the GROUP module (located under the ANALYSIS—CONTEXT PDM's) on the *fcritria* map. Select the option to include diagonals, and name the map *st_group*.

The results of the GROUP program display each of the areas with contiguous image cells that satisfy the criteria with unique and sequential integers. To quickly determine the number of groups in the map (without having to use cursor inquiry mode), double click on the *st_group* filename in COMPOSER to invoke DESCRIBE. The maximum number on this map is 8. Some of the 8 sites appear too small to replace the area of lost habitat (i.e. 0.03145 ha or 314.5 m²). To determine sites that meet the similar size criteria in addition to wave energy, we will compute the area of the sites, and reclass those that are too small to zero to eliminate them.

Next, run AREA on *st_group* with output in hectares and output the name of *cr_areas*. Then RECLASS *cr_areas* to Boolean using a value of 1 for all areas greater than 0.03145 and less than 57.6922 (the background area), and reclass all other values to 0. Name this map *wvcritria*. Press OK.

The eight areas which satisfy the environmental criteria are reduced to 1 when the original site and size of the areas are considered. This area, along the southern shore of the east basin, is bedrock. If this site was found to be unsuitable for habitat replacement, we may also consider the next largest site, group number 1 in

st_group found on the north side of the island, which is about 90% of the minimum size.

To demonstrate the techniques for habitat loss in offshore areas we will assume that the primary site identified for replacement is unsuitable. If the primary site was geological and of similar slope, replacement of similar materials would only constitute a superimposition of habitat (not a habitat addition). In fact, the primary site may be a suitable location because the replacement site is bedrock which could be augmented with a boulder and cobble deposit similar to the site of loss.

Open the maximum and mean fetch images that represent the lake after the offshore habitat addition, i.e. *mx_f_repl*, and *mn_f_repl* respectively.

Observe the changes in the fetch maps using cursor inquiry mode.

When compared to the source fetch distributions, the secondary site for replacement reduces the potential wave energy. Mechanical sheltering showed by maximum fetch is only to the east of the replacement site, with little effect on surrounding areas. Mean fetch, however, indicates that the entire shallow bay area to the east of the site is likely to have reduced wave energy. As the site is already a depositional environment, the changes in wave energy will have little effect on the depositional boundaries in this area, and are unlikely to cause changes in other areas of the lake.

Close all maps and delete your temporary files.

Overview

Two different mechanical energy estimates have been combined to identify areas that satisfy both wave energy and slope criteria. Although this approach may provide a reasonable stop-gap, the technique can be improved with the use of a single and more robust fetch distance model that can account for periodicity in wind direction.

The addition of habitat to the primary site would provide the smaller amount of change in mechanical energy in the area surrounding both sites. The smaller and secondary site changes the mechanical energy, particularly on the lee side of the habitat structure, and produces a sheltering effect on the natural habitats located along the shoreline in that area. In this case, the effect of sheltering would not likely change the composition of the habitat because this area was already a depositional site. If other sites of the lake were suitable and had good quality geological shorelines, this sheltering effect may reduce the surrounding habitat quality indirectly. In such situations the addition of habitat in the offshore area would only provide a shift, not an addition of new habitat due to the losses it might create. Such a shift could not be recommended to mitigate habitat loss.

A limitation of replacement techniques similar to the example provided here is that only the habitat structure which is directly affected by development is considered. The technique does not consider the issues of habitat scale (i.e. habitat loss is part of a larger habitat unit and only part of that unit is being replaced) or entropy (i.e. patchiness or diversity of area surrounding the original site). These characteristics could be important variables that fish use in site selection.

2.5 Integrating Physical and Biological Data Using GIS

Impact assessments in lakes proposed for development require an understanding of the habitat requirements of fishes to identify and mitigate any negative physical changes that may affect the productive capacity of habitats. The linkage of telemetry and habitat data is one way to better understand the use of habitat by fishes in natural systems, and to document changes in habitat use in systems under environmental change.

The degree of opportunism or site fidelity that fish exhibit in spawning site selection is not well known for most inland fish species. If fish exhibit site fidelity through highly selective habitat preference it may be possible to replace that habitat in a proximate location without

compromising productive capacity. However, if the preferred site is visited due to learned behavior from older cohorts it may be determined that habitat rehabilitation, not replacement, is the only valid option to mitigate negative effects for that species.

Small systems are ideal for the experimental manipulation to link cause and effect. As such, relatively small lakes are likely to be the types of systems that first produce integrated GIS databases that can be used to develop spawning habitat suitability models, and can test habitat replacement initiatives.

2.5.1 Assessing the distribution and habitat use of lake whitefish during spawning

In Canada, lake whitefish are a valuable commercial species and many populations inhabit large northern lakes which have regulated hydrologic regimes. Lake whitefish spawn in the fall and deposit their eggs in shallow areas until they develop in spring. This makes the eggs vulnerable to water level draw down. Although the biology of the lake whitefish is not completely known, it is suspected that draw down may cause year class failure.

This exercise is presented in two parts. First we will briefly review the general patterns of lake whitefish distribution as shown by acoustic telemetry data, then we will use some techniques to characterize the behavior and habitat use for one lake whitefish in section 2.5.2.

In this last section of the manual we will use the system modules called CROSSTAB, ASSIGN, and EXTRACT. You may wish to consult the Idrisi for windows system manual to learn about these programs.

Two general patterns of distribution were apparent in Lake 226 during the 1995 spawning period. To start let's look at two representative data sets to demonstrate this.

To delineate the water level at time of study and also the boundary for the profundal zone, open the vector line file **226pnp** using

the default symbol file. Add the vector bathymetric depth map, **226contr**, using the default symbol file. Next, add the vector point file **fc_lwf3** using the **2pt_bcir** symbol file. This name indicates a 2 point black circle will be used for display. Select the title for display.

Fish no. 3 showed a distribution limited to the East basin of the lake, mostly in the offshore area. This fish shows a highly repetitive tracking pattern which followed the lake contours closely. As the data are redrawn (select manual redraw in COMPOSER) we can observe that the depth of the fish increased during the study. Let us make the display of the data easier to interpret by color coding the fixes into four time periods. To do this, we will link the point distribution pattern to the corresponding attribute table using DATABASE WORKSHOP.

Select the title bar for the vector point file **fc_lwf3** in COMPOSER, then Link the database **fa_lwf3** to the map using a forward link in DATABASE WORKSHOP. The vector point file **fc_lwf3** should be listed in the map window for link area of the link dialogue. If not, then reopen the three files mentioned above with the **fc_lwf3** file opened first. Specify the field 'N' as the link field, and the attribute field for display to be "day". Next we will again specify the symbol file because we wish to distinguish the movements of the fish in 4 periods of time using colors. To change the symbol file select the file title in COMPOSER, then PROPERTIES and select the **date** symbol file. This symbol file indicates the dates for each position fix using four colors: red, green, yellow, and black to indicate the dates which span the period October 19 to November 7. You may have to select the multicoloured array found below the LINK PDM to display the fish positions in colour.

The offshore distribution of Lake Whitefish no. 3 indicates that it is an unlikely candidate for spawning. During most of the study period fish no. 3 occupied areas of the basin with deep flocculent sediments. The repetitive nature of the tracks which increased in depth during the study was a strategy to avoid the colder surface waters which increased in depth during the study (Begout Anras et al. 1999).

Close all windows. Do not save any changes to the database.

We will now look at a distribution pattern that is much more likely to represent spawning behavior for lake whitefish.

Open the point file *fc_lwf2* to the display using the *2pt_bcir* symbol file. As above, add the two files: *226pnp*, *226contr*. Reconstruct the link to the table database using the same link field with the *date* symbol file.

The distribution pattern of fish no. 2 probably represents spawning behavior due to the inshore movements and the long shore tracks which appear as "shoreline cruises". In fact, the data of Begout Anras et al. (1999) show that the nearshore area's with highest activity among individuals in Lake 226 is limited mostly to two reaches of shoreline. The south shoreline of the west basin is the most frequently visited habitat. In the next section we will investigate lake whitefish behavior and quantify the physical attributes of habitat areas with high activity.

2.5.2 Developing information for spawning habitat suitability models

The techniques used to develop habitat suitability all have a common need for describing the behavior of fishes through habitat partitioning and selection. In this exercise our objective is not to produce a suitability model, but to introduce GIS techniques that can provide combined geographic and behavioral information.

We will investigate the lake whitefish data first by reviewing the general tracking patterns for the whole lake basin. We will then look in more detail at specific attributes of those patterns to identify how the lakes' habitats are partitioned by lake whitefish. We will also develop some techniques to identify site selection by lake whitefish.

When integrated in a GIS with physical habitat maps, results from acoustic telemetry tracking

techniques can provide an ideal method to document habitat partitioning, and site selection. However, the large number of positions that can be produced during an acoustic telemetry study requires that analytical techniques identify and isolate the relevant data. The approach used here is to implement a step-wise series of techniques to identify the behavior of one lake whitefish using spatial patterns in the tracking data and behavioral attributes to identify key data.

First, using all positions for fish no. 2 collected during a 20 day period, we will describe the total amount of nearshore and offshore habitat use. Next we will determine on what dates of the tracking study spawning would be likely to occur in the nearshore area by describing the inshore movement by study date. After a period of peak activity in the nearshore area has been identified, we will use swimming speed of the fish to characterize and separate moving and stationary tracking patterns. Finally, we will determine what substratum classes and slopes are found in the locations where hot spots of activity occurred. These tasks are listed as objectives 1 through 5 below.

Objective 1: To determine the total frequency of positions (called "fixes") found in each of the offshore and nearshore areas; to do this we will use image crosstabulation.

Let's begin by creating the two input images that are required for the crosstabulation. To delineate the nearshore and offshore areas we will use an addition overlay on the *226pre* and *profund* images. Next, we will convert the vector point data file *fc_lwf2* to a raster image that contains the telemetry positions for Lake Whitefish no. 2.

Review the data values in the *226pre* and *profund* images using cursor inquiry mode, then perform the instructions below. Both of these maps are Boolean (the area of interest is value 1), so an addition OVERLAY analysis will produce a map with values for the nearshore area and profundal of 1 and 2 respectively. Call the result *nsaprof*. Close all files.

The second task at hand is to convert the positions in the vector file to raster so we may use the image crosstabulation module.

To do this, open INITIAL under the DATA ENTRY PDM. We will copy the parameters (which indicate number of rows and columns and coordinate margins for the vector data from **226dem_f**) so we don't have to enter them manually. Name the output image **lwf2_fix** and enter the title: positions from lake whitefish no. 2. Use all other defaults which includes assigning the value 0 to all cells in the image.

We now have a blank image with the appropriate cell resolution and vector coordinates with a 0 background.

Using the POINTRAS program (located under the REFORMAT RASTER/VECTOR CONVERSION PDM's), convert the file to raster using the vector file **fc_lwf2** and the raster image **lwf2_fix**. We will select the option that records the frequency of points because several vector points may fall within a single 0.5 x 0.5 m cell. Numerous fixes at a single cell may indicate areas of increased whitefish activity or may indicate spawning behavior (depending whether the points were created during a short time, or are superimposed from different days). Using this single raster image we can not resolve this. However, we will separate these two forms of behavior using SQL's of swimming speed using the vector data set in objective 3, below.

Use CROSSTAB (from the ANALYSIS—DATABASE QUERY PDM's) with the images **lwf2_fix** and **nsaprof** to determine the frequency of occurrence in each the nearshore area and profundal areas as a tabular result.

The results of the crosstabulation indicate that we are interested in the data which intersects column and row headings greater than zero (since these are the background values in each raster image). As the table has rows with a maximum value of 5, we know that some image cells had a frequency of five.

When the values for columns 1 and 2, which represent the nearshore area and offshore area respectively, are summed we can later calculate that about 34% of the total fixes for fish no. 2

were located in the nearshore area. Close all files.

Objective 2: to document the distribution of inshore movement by date of study

To characterize the pattern of nearshore area habitat use and to identify on what dates spawning may have occurred, we will again use image crosstabulation to determine the frequency of fixes on each date in the Profundal and nearshore area's.

We will use the ASSIGN module in DATABASE WORKSHOP to assign the date on which each position was collected into the corresponding raster cell in the image.

Open DATABASE WORKSHOP and the attribute table **fa_lwf2**. Select the LINK menu, then select the ASSIGN option.

In the ASSIGN dialogue box we are prompted for four pieces of information. Because we want to create an image that indicates the date on which each fix was collected, we must move the date values from the attribute table and ASSIGN them to the appropriate cells in the image. To do this we must meet the requirement of having an image with the feature identifiers indicated for each cell. Each of these identifiers corresponds to an identical link value in the tabular database.

As the feature identifier image **lwf2_id** already exists, enter this name as the feature definition image. Name the output image **lwf2date**. Specify that the feature definition field as "N", and the data field from current database as "DAY". Select OK, review the map window when complete to validate operations were indicated correctly, then close DATABASE WORKSHOP.

As above, use CROSSTAB on the **nsaprof** and the image **lwf2date** using tabular results. Save the results to a disk file, **lwf2txt**. Open this ASCII file in a spreadsheet such as MS Excel. Delete the row and column data corresponding to the heading of zero (each is a background value). Plot a frequency histogram using these data to indicate frequency in the

nearshore area and profundal areas (see figure 11).

The distribution of nearshore area and profundal habitat use by fish no. 2 indicates that peak activity occurred early in the study with a bimodal distribution between October 20 and 24. Before and after this period most activity was located in the offshore zone.

Objective 3: To investigate the distribution of nearshore area activity during the period of inshore movement from October 20 - 24.

To observe the spatial patterns of tracking data, link the vector point data file *fc_lwf2* to the associated attribute table *fa_lwf2* using the default symbol file, and "day" as the display field. Add the vector layer *226pre*, and *226pnp*. These files show the pre draw down shoreline and the -1.7 m draw down shoreline during the time of telemetry surveys. In COMPOSER, select the title bar that indicates *fc_lwf2*, then select the PROPERTIES radio button and indicate the symbol file "date" should be used. On the 5th radio button from the left on the DATABASE WORKSHOP menu bar indicate a multicolored array is desired.

Change the Redraw option on COMPOSER from "auto" to "manual". Select the redraw radio button to reveal the tracking pattern of fish no. 2 in the sequence the data were collected.

Although it is important to explore the entire spatial pattern of the tracks during this period, let us display the fixes only for the nearshore area to better indicate the area of highest activity.

Construct the following SQL query: WHERE ns_pro = 2.

Using the date symbol file, it is clear that early during the study period the southern rocky shore of the west basin was the preferred nearshore area. Although we observe that fish no. 2 partitioned the lakes' habitats with a preference for activity along this shoreline, it is difficult to characterize the use of this habitat still due to abundant data that contains different types of fish movement. To discriminate these data

further we will use SQL to isolate two types of tracking patterns from the data.

Remove the previous filter.

Construct the following SQL query: WHERE day > 19 and day < 25. Select execute. Now we have only the data displayed for the period from 20 - 24 of November. To better display these data select PROPERTIES on COMPOSER (after highlighting the point distribution map name in the COMPOSER list). Select the symbol file *spwn_2* from the pick list. This symbol file color codes the days for this period. Select OK.

Remove the filter.

Construct the following SQL query: WHERE day = 20. Update the display. Next, repeat this query for day 21 to 25. Note the daily pattern of movements for each day. These movements are summarized below.

On October 20, fish no. 2 repeatedly swam along the length of the southern shoreline of the west basin; we will call this form of longshore movement a shoreline cruise. Few fixes are found in the nearshore area on the 21st. The tracking pattern starts to become patchy with two areas in the offshore zone and another cluster in the nearshore area on the 22nd. On the 23rd, most fixes occur in the nearshore area and are localized in three sites; two of these areas also are visited on the 24th. Fish no. 2 moved to the offshore zone near the areas with increased activity on the 25th. Most of the positions from this fish during the rest of the study remained in the offshore area.

Lets look at the same 5 day period but we will use swimming speed as the attribute for display.

Open the Link dialogue box on DATABASE WORKSHOP and select Display_spd as the field for attribute display. Next, change the symbol file from date to speed. Select OK.

Repeat the SQL queries for each date during the period from November 19-26, after reviewing the symbol file speed using SYMBOL WORKSHOP. The speed symbol file shows attribute values using three colors

from slower to faster speeds, in the order of red, blue, black.

As noted above, on November 23rd and 24th the tracking pattern of fish no. 2 changed from a "shoreline cruise" to activity that centered on specific sites along the same shoreline. Using SQL queries with the speed attribute symbol file, we can also see that the rate of movement at such locations decreased (e.g. November 23 and 24 at coordinates 446172.7,5504234.0). Close all files.

Objective 4: To describe the substratum classes and slope characteristics of the nearshore area along the shoreline with the highest levels of activity during the inshore movement of fish no. 2.

To statistically describe the slopes of the shoreline, we will use the EXTRACT system module found in DATABASE WORKSHOP to summarize and move the slope map data to *subatrib*, the substratum attribute table.

EXTRACT uses two images. The first, called a feature definition image, defines the features for which we want to collect statistics. The second image is the raster file we wish to collect the data from. In essence, the feature definition image is a template that determines the number of statistics we will gather, and defines the area from which each statistic is collected. Because our interest is in the slope values which correspond to each of the substratum areas, we will use the substratum image *226subid* as the feature definition image with *226slope*.

Before we perform the extraction process, we must first create a field for the slope data in the *subatrib* database file.

Open DATABASE WORKSHOP and the database file *subatrib*. Under the MODIFY PDM select ADD FIELD. The data type of this field will be integer, and specify a field name of *slopetmp*. Under the LINK PDM select the extract statistical summary from image option. Enter the map names for use by the program, then specify that the feature ID field is *idr_id*. The field for statistical summary is *slopetmp*. Select the option that which indicates the average will be determined. Press OK.

To reduce the time required to perform the extractions that describe the maximum, minimum, mean, and standard deviation they have been provided in the database file. The same methods were used to also load the database with substratum information.

Delete the *slopetmp* field from the database using the MODIFY PDM.

Next we must identify which substratum polygons were used during the inshore movement of fish no. 2. Because there are relatively few areas cursor inquiry was used with the file *fc_lwf2* to determine the identifiers. They are listed below:

119, 126, 127, 128, 138, 140, 142, 143, 149, 150, 151

Run an SQL filter on the *subatrib* database file, using the *lwf2shor* SQL file. Save the query results to a new database file named *lwf2shor* using the save to new database option under the MODIFY PDM. These data are found in Table 1.

Objective 5: To determine the frequency of fish positions for lake whitefish no. 2 in the zones of erosion, transport, and deposition.

Many lakes proposed for hydroelectric regulation may not have detailed habitat data available to assist in environmental assessments. This is especially true for larger and more remote systems. While detailed predictions of specific habitats are not yet possible, a proxy approach for setting hydroelectric draw down regimes might be to estimate the zones of erosion, transport, and deposition, and then compare the areas of these zones at different proposed lake stages. While these zones are general, their simplicity means that such predictions are more readily developed. To fulfil data requirements for models of erosion, transport, and deposition, may require only a wave energy model, a slope threshold model, and precise in situ bathymetric data. The production of good depth maps today, even on large lakes, is facilitated by digital sonar linked to Global Positioning Systems.

The use of erosion, transport, and deposition models in a hydroelectric assessment would be

meaningful if an understanding could be learned regarding the importance of these general zones to fish. The importance of the littoral zone, as a habitat unit, is well known as it contains high species numbers, and provides important habitats for most species in lakes (Wetzel 1983). A first approximation using the erosion, transport, and deposition approach could be a coarse but effective way to ensure that water level changes not do pose marked shifts in the ratio of the littoral to profundal zones.

To demonstrate the relative importance of these zones to a single lake whitefish, we will use an existing image of the telemetry positions of fish no. 2 from file *lwf2spwn*, and crosstabulate the frequency of positions with the zones of the *eta* image. Recall that this image contains the positions that showed the inshore movement on October 20-24, shown in figure 15.

Use CROSSTAB to quantify the frequency of occurrence of the positions during the inshore movement of lake whitefish no. 2 using the raster image *eta*. The results are shown below.

Energy Zone	Frequency
Erosion	25
Transport	1169
shallow Deposition	0
Deposition	1711

The inshore movement of lake whitefish no. 2 traveled mostly in the zone of transport, suggesting that the upper 1 metre or so of water in this lake was not that critical (that is about equal to the depth of ice during lake whitefish egg incubation in this lake). The data also show about half of the positions are found in the offshore areas, and that shallow depositional sites are not frequented. When the entire data set for this fish is considered (i.e. figure 15), it is clear that relatively few nearshore positions probably carry the majority of the biological interest in terms determining of spawning site selection requirements. During this period of peak nearshore activity, the zone of transport was the zone with highest activity.

Close all files.

Overview

Two types of swimming behavior, nearshore and offshore, have been demonstrated for lake whitefish during the pre-ice spawning season in Lake 226. These patterns may be interpreted to indicate spawning behavior and thermal preference, respectively. The whitefish that exhibited inshore movements partitioned the lakes available substratum first by selecting a reach of shoreline. This activity centered mostly in the zone of transport on a shoreline which contained boulder/cobble/gravel combinations; mean slopes ranged from 15 to about 26 degrees.

Repetitive movements occurred in shallow water along the length of a shoreline for a few days. The shoreline oriented tracking pattern then changed to one that shows centers of focused activity, and a reduced rate of movement. Whitefish exhibit fidelity to these places as repeat visits occurred to the same sites over several days. After 5 days of increased nearshore activity, the nearshore pattern of distribution shifted to the offshore area where activity was reduced.

The combination of physical and biological data as an integrated GIS database can provide an improved method for the production of spawning suitability models, and the construction of predictive physical habitat models to assess physical habitat change. The merit of using a GIS for such tasks is that assessments can move from site scale measurements with detailed data to those that are implemented at a lake wide scale using more general assessment approaches that are not currently available.

3. Conclusions

GIS process models for lakes require the continued development of techniques to describe habitat boundaries and patterns that respond to lake forcing variables. Wave energy model validation can be gained by inter-lake comparisons using observed substratum distributions. Small lakes are the most ideal systems to develop prototype models.

The integration of physical and biological information in a GIS can provide a database and set of tools that habitat managers and researchers can use for classification, assessment, and research into fish habitat utilization. While GIS has been recognized for its potential in this regard, few databases are available that integrate physical and biological data. More research is merited for the multi-year study of natural range in spawning depth and substratum types of fishes in nearshore areas, and the effects of draw down on substratum availability, and the depth of spawning and success of year class recruitment.

GIS can play a strong role in the development of lake and reservoir research by improving the ability to handle and analyze complex littoral data. GIS can also serve as a valuable, apriori, decision making tool in hydroelectric projects.

4. Acknowledgments

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5. References

- Airy, G.B. 1845. Tides and Waves. *Encycl. Metropol. Art* 192: 241-396.
- Bartlett, D. J. 1989. Spatial data structures and coastal information systems. *Proceedings EGIS'90 - First European conference on Geographic Information Systems*. 30-39 p.
- Begout-Anras, M. L., P. M. Cooley, R. A. Bodaly, L. Anras and R. J. P. Fudge. 1999. Movement and habitat use by lake whitefish during spawning in a boreal lake: integrating acoustic telemetry and G.I.S. *Transactions of the American Fisheries Society* (in press).
- Bodaly R.A. 1986. Biology, exploitation and culture of coregonid fishes in Canada. *Archive fur Hydrobiologia, Supplement Ergebnisse der Limnologie* 22: 1-30.
- Cleugh, T.R. and B. W. Hauser. 1971. Results of the initial survey of the Experimental Lakes Area, northwestern Ontario. *J. Fish. Res. Board Can.* 28: 129 -137.
- Cooley, P. M. 1997. Mapping nearshore and hydraulic habitats in lakes (Masters thesis). University of Manitoba, Department of Geography, Canada. 164 p.
- Department of Fisheries and Oceans, 1986. The Department of Fisheries and Oceans policy for the management of fish habitat. The Department of Fisheries and Oceans, Ottawa, Ontario. 30 p.
- Jao, E. and A. Fonseca. 1996. Current use of Geographical Information systems for Environmental Assessment: a discussion document. *Research papers in Environmental and Spatial analysis*. London School of Economics. No. 36. 20 p.
- Hakanson, L. 1981. On lake bottom dynamics-the energy topography factor. *Can. J. Earth Sci.* Vol 18, 899-909.
- Hakanson, L. and M. Jansson. 1983. *Principles of lake sedimentology*. Springer-Verlag, Heidelberg. 316 p.
- Jensen, J. R., S. Narumalani, O. Weatherbee, K. S. Morris, Jr., H. E. Mackey, Jr. 1992. Predictive modeling of cattail and waterlily distribution in a South Carolina reservoir using GIS. *Photogramm. Eng. and Remote Sens.*, Vol. 58, no. 11. 1561-1568 p.

- Minns, C.K. 1995. Calculating the net change of productivity of fish habitats. Can. Ms. Rep. Fish Aquat. Sci. 2282: vi + 37 p.
- Minns, C.K., J. D. Meisner, J.E. Moore, L. A. Grieg, and R.G. Randal. 1995. Defensible methods for Pre-and post development assessment of fish habitat in the Great Lakes. I. A prototype methodology for headlands and offshore structures. Can. Ms. Rep. Fish Aquat. Sci. 2328: xiii + 65 p.
- Rowan, D. J., J. Kalff, and J. B. Rasmussen. 1992. Estimating the mud deposition boundary in lakes from wave theory. Can. J. Fish. Aquat. Sci. 49: 2490-2497.
- Selby, M.J. 1990. Earth's changing surface. Clarendon Press. Oxford. 607 p.
- Schwab, D.J., J. R. Bennett, and P.C. Liu. 1984. Application of a simple numerical wave prediction model to Lake Erie. Journal of Geophysical Research. Vol. 89, No. C3, 3586-3592.
- Wetzel, R.G. 1983. Limnology. Saunders college Publishers. Philadelphia. 767 p.

Table 1. Database workshop attribute table subatrib.mdb describing nearshore substratum attributes where lake whitefish no. 2 was active during an inshore movement.

ID	CL _c	CL _n	Description	A (m ²)	P (m)	S _{min} (degrees)	S _{mx} (degrees)	S _{mn} (degrees)	S _{sd} (degree s)
119	206	2052	bedrock/cobble	858.23	121.65	2.14	44.51	15.15	7.25
126	70	615271	boulder/cobble	1088.88	219.81	7.09	50.09	22.36	8.69
127	206	2052	bedrock/cobble	118.58	91.97	9.34	37.93	20.40	6.98
128	200	20	bedrock	223.45	97.09	9.32	30.18	19.14	5.57
138	107	525171	cobble/deposition	103.63	82.48	6.87	27.13	15.53	3.77
140	113	524271	cobble/gravel/deposition	496.01	116.25	4.62	43.72	25.74	9.17
142	200	20	bedrock	61.77	90.29	8.18	32.52	20.05	7.77
143	113	524271	cobble/gravel/deposition	1087.04	301.72	3.20	43.77	21.38	8.69
149	60	6152	boulder/cobble	392.49	114.53	4.44	36.06	23.58	5.38
150	70	615271	boulder/cobble/deposition	36.95	78.97	16.76	31.56	26.32	3.51
151	200	20	bedrock	129.50	76.12	15.94	32.20	23.62	4.69

- ID = geographic identifier (corresponds to raster image 226subid)
- CL_c = class codes (corresponds to raster image 226subcd)
- CL_n = class number
- Description = text description
- A = the area occupied by the substratum polygon
- P = Perimeter occupied by the substratum polygon
- S_{min} = minimum slope in substratum area of geographic identifier
- S_{mx} = maximum slope in substratum area of geographic identifier
- S_{mn} = mean slope in substratum area of geographic identifier
- S_{sd} = standard deviation of slope in substratum area of geographic identifier



Figure 1. The location of Experimental Lakes Area (ELA) in North America, Northwest Ontario, and the location of Lake 226 in the centre of a sub-region of ELA.

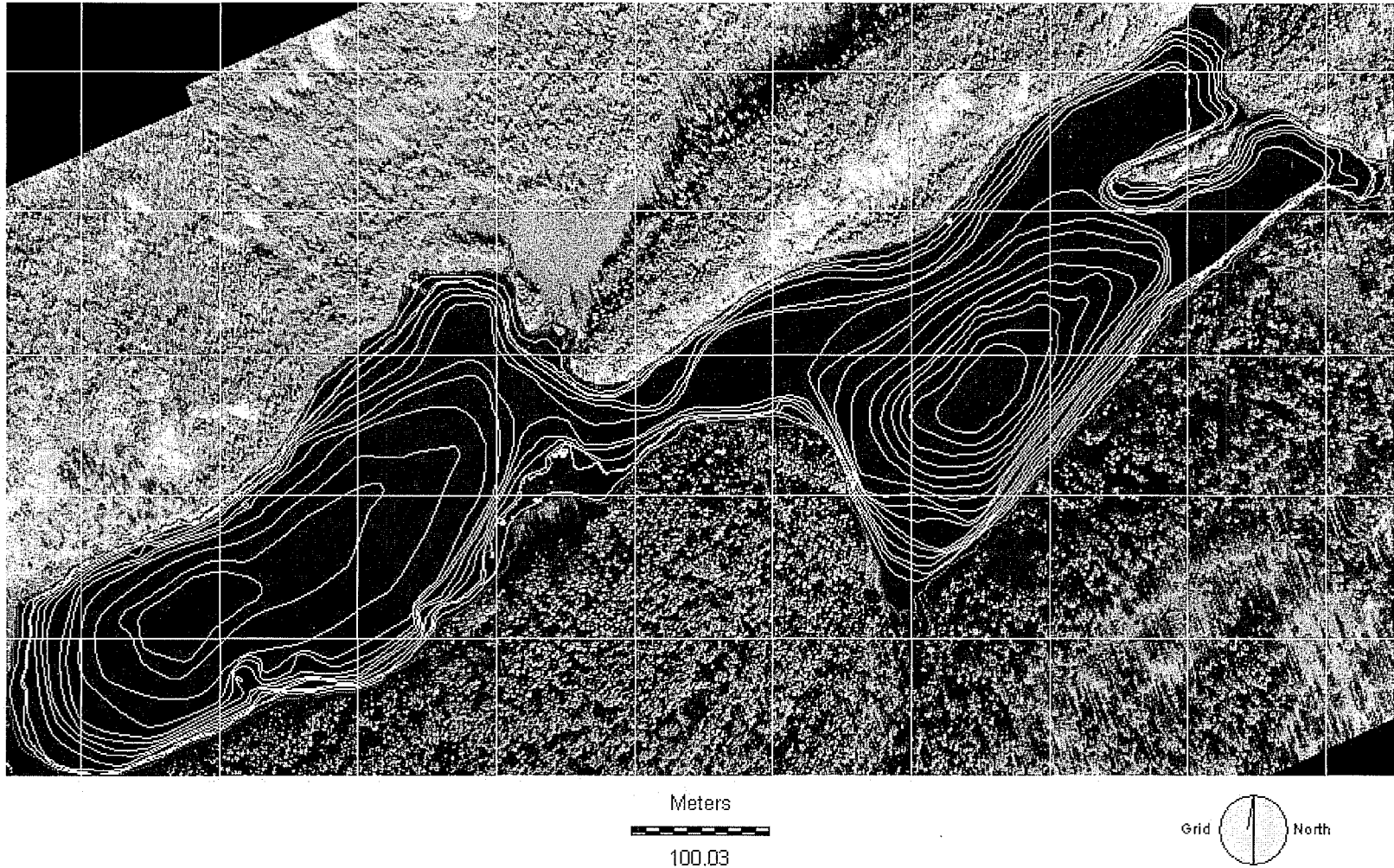


Figure 2. Lake 226, Experimental Lakes Area, northwest Ontario. Lake bathymetry and shoreline vector files on georectified panchromatic photos of the lake at pre draw down water levels. Map composition filename: compos_1.

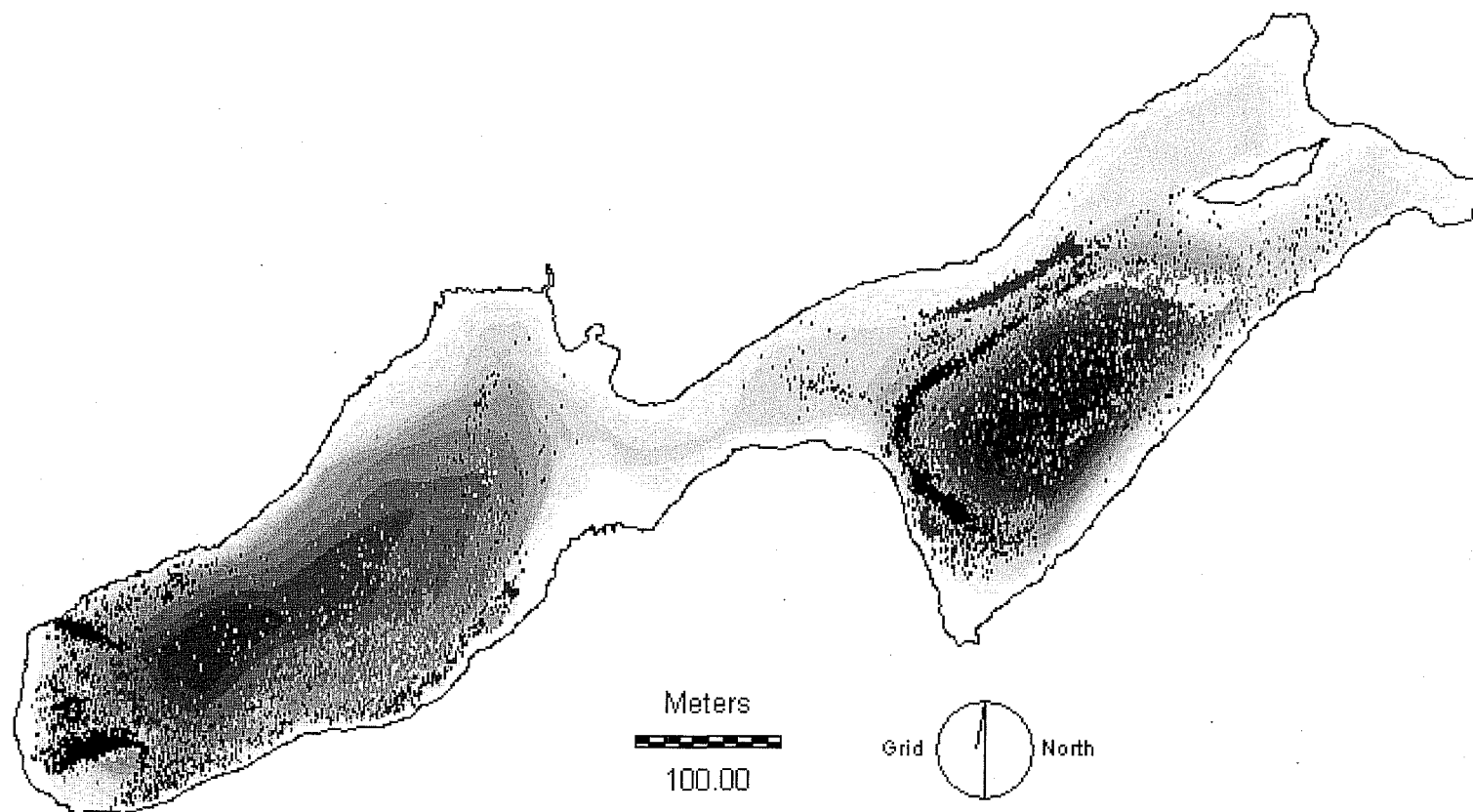


Figure 3. Two lake whitefish acoustic telemetry tracking patterns captured during spawning, 1995. Lake whitefish no. 2 (west basin) showed nearshore movements characteristic of nearshore spawning. Lake whitefish no. 3 (east basin) showed an offshore and repetitive tracking pattern. The digital data show colors in the order of red, green, yellow, and black, indicating consecutive four day periods. Filename of map composition: *compos_3*.

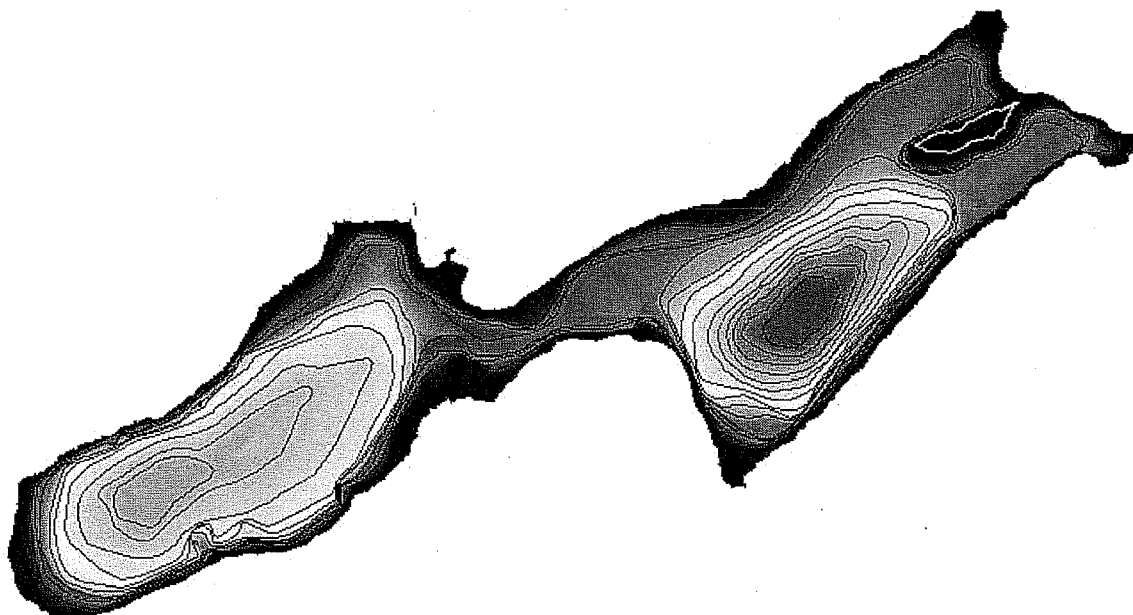


Figure 4. Experimental Lake 226 Digital Elevation Model (metres). Filename 226DEM displayed using Idrisi 256 palette. Maximum depth in the west basin is 12 m, and 15 m in the east basin.

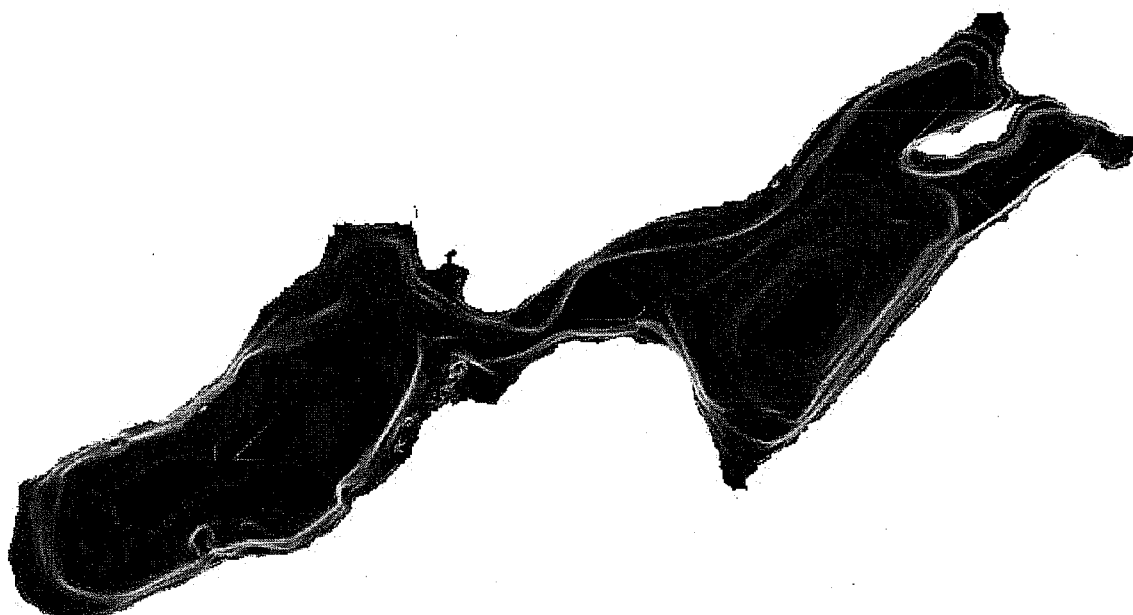


Figure 5. Experimental Lake 226 slope model (degrees). Filename 226slope displayed using grey scale values ranging from 0 (black)-59 degrees (white).

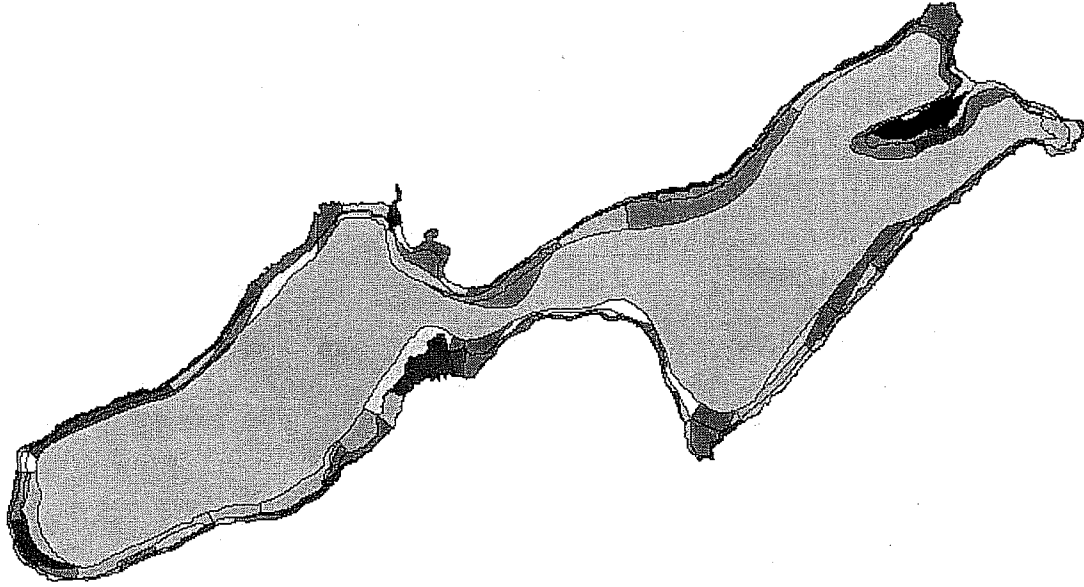


Figure 6. Experimental Lake 226 substratum distribution. Filename 226sbcd displayed using qualitative 256 palette. Thirty-four types of material classes exist in the lake including the offshore zone of deposition.

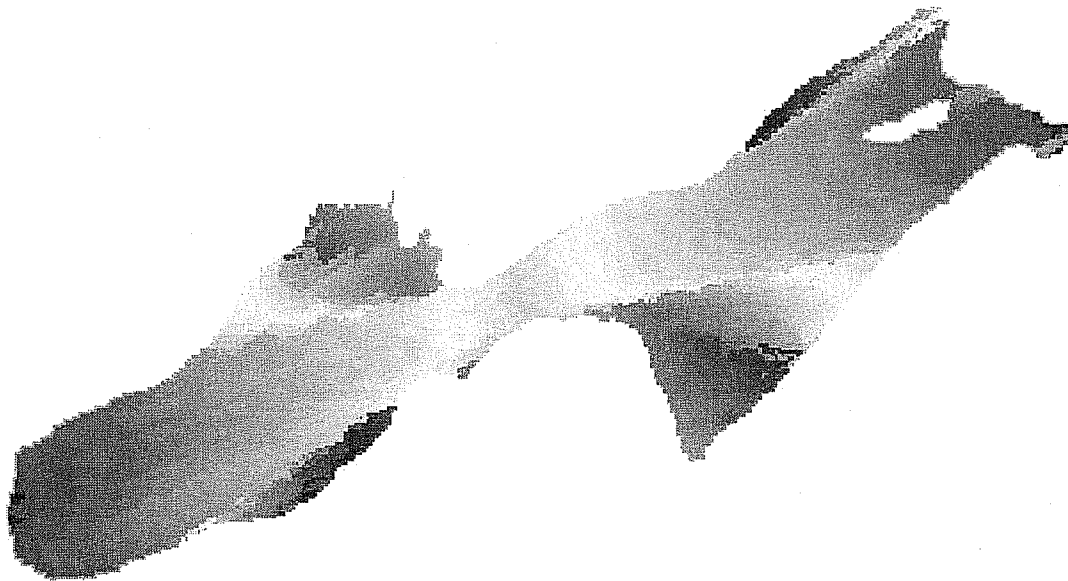


Figure 7. Experimental Lake 226 maximum fetch distance distribution. Image mxfet_km.

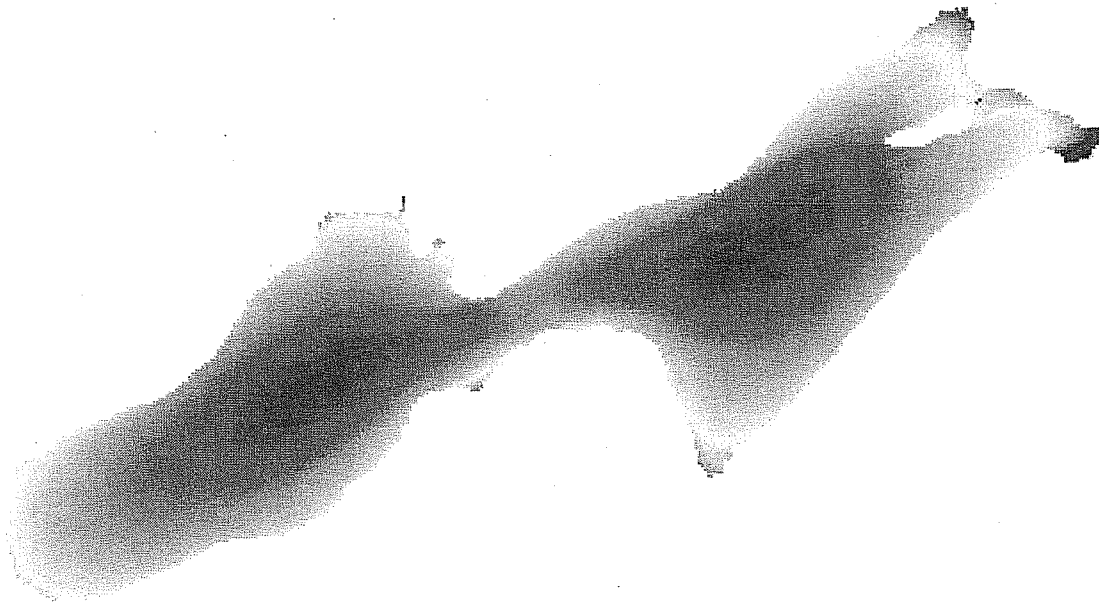


Figure 8. Experimental Lake 226 mean fetch distance distribution. Image mfetch displayed using autoscaled values and the Idrisi 256 palette.

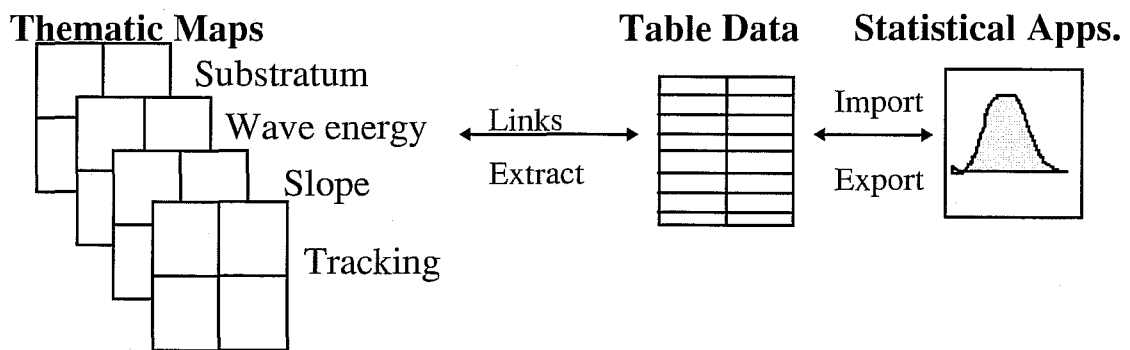


Figure 9. Linking of thematic maps and attribute tables and export of tabular data to statistical software applications.

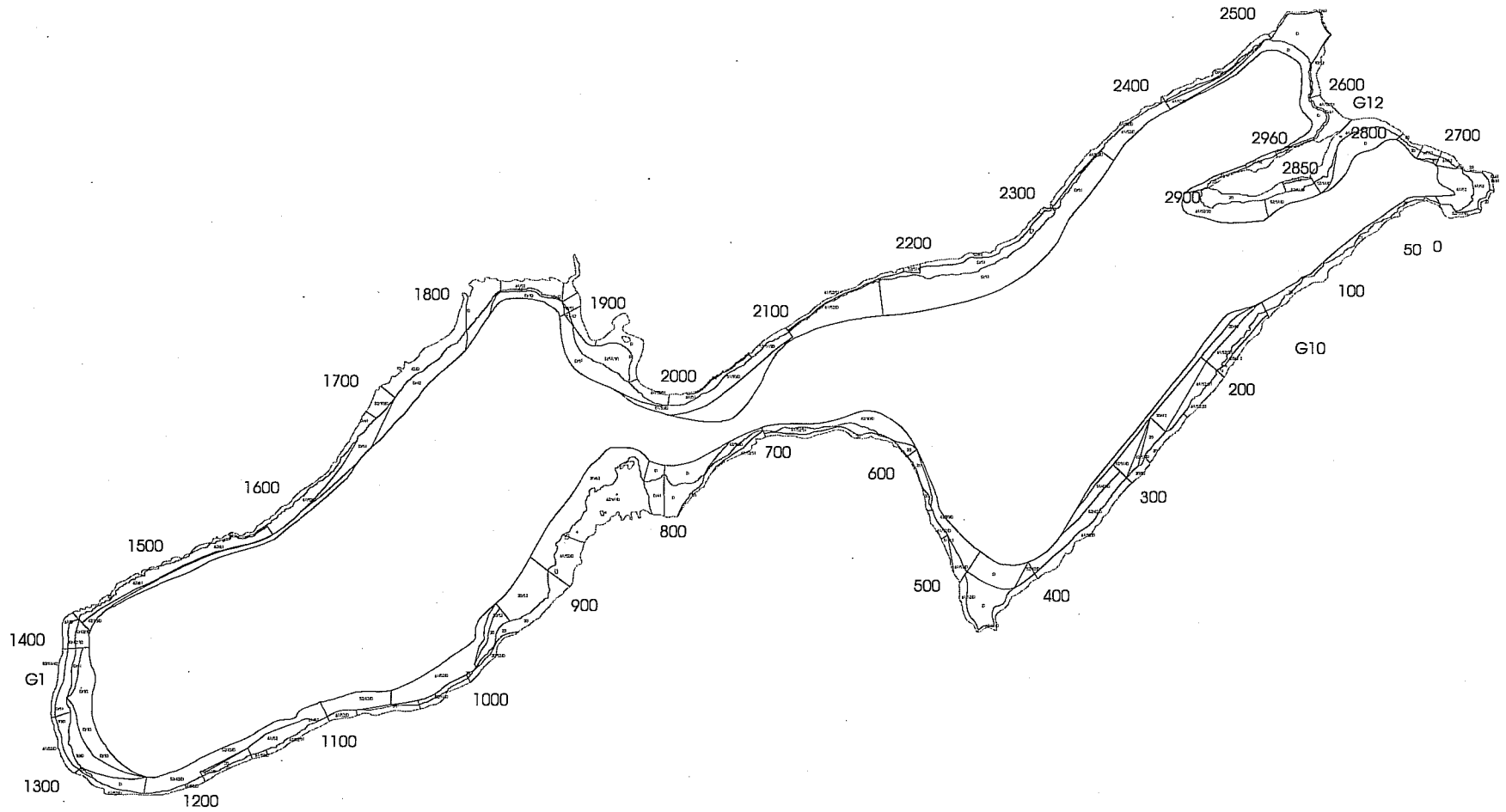


Figure 10. Vector database showing substratum polygons, station numbers, and class codes at natural lake stage. The large central polygon is the profundal zone of perennial deposition.

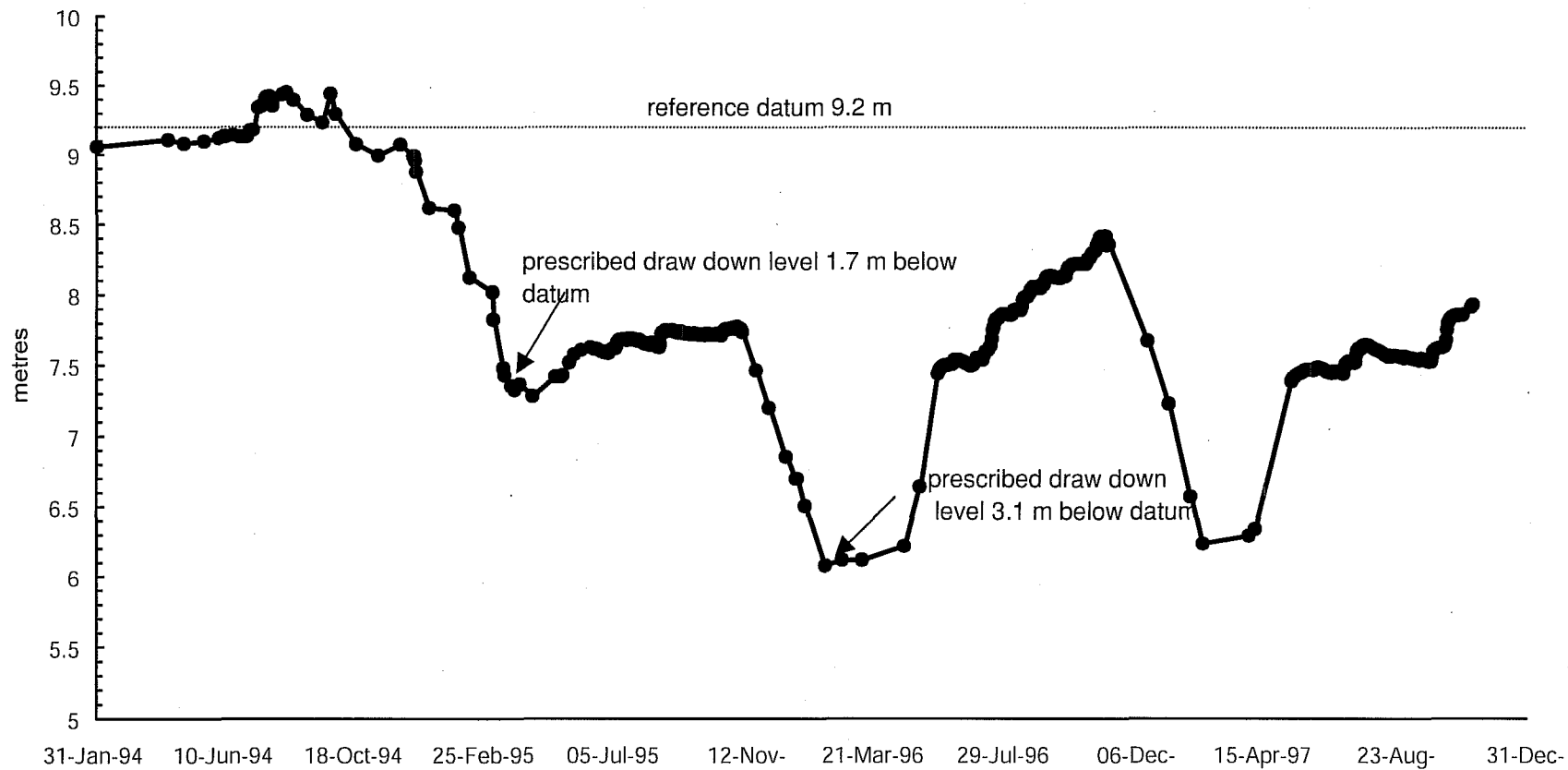


Figure 11. Water draw down levels relative to a reference lake stage datum, for the period January, 1994 to December, 1997. The two water levels prescribed in the GIS substratum model (indicated with arrows) correspond to annual minima observed during draw down in 1995, and 1996.

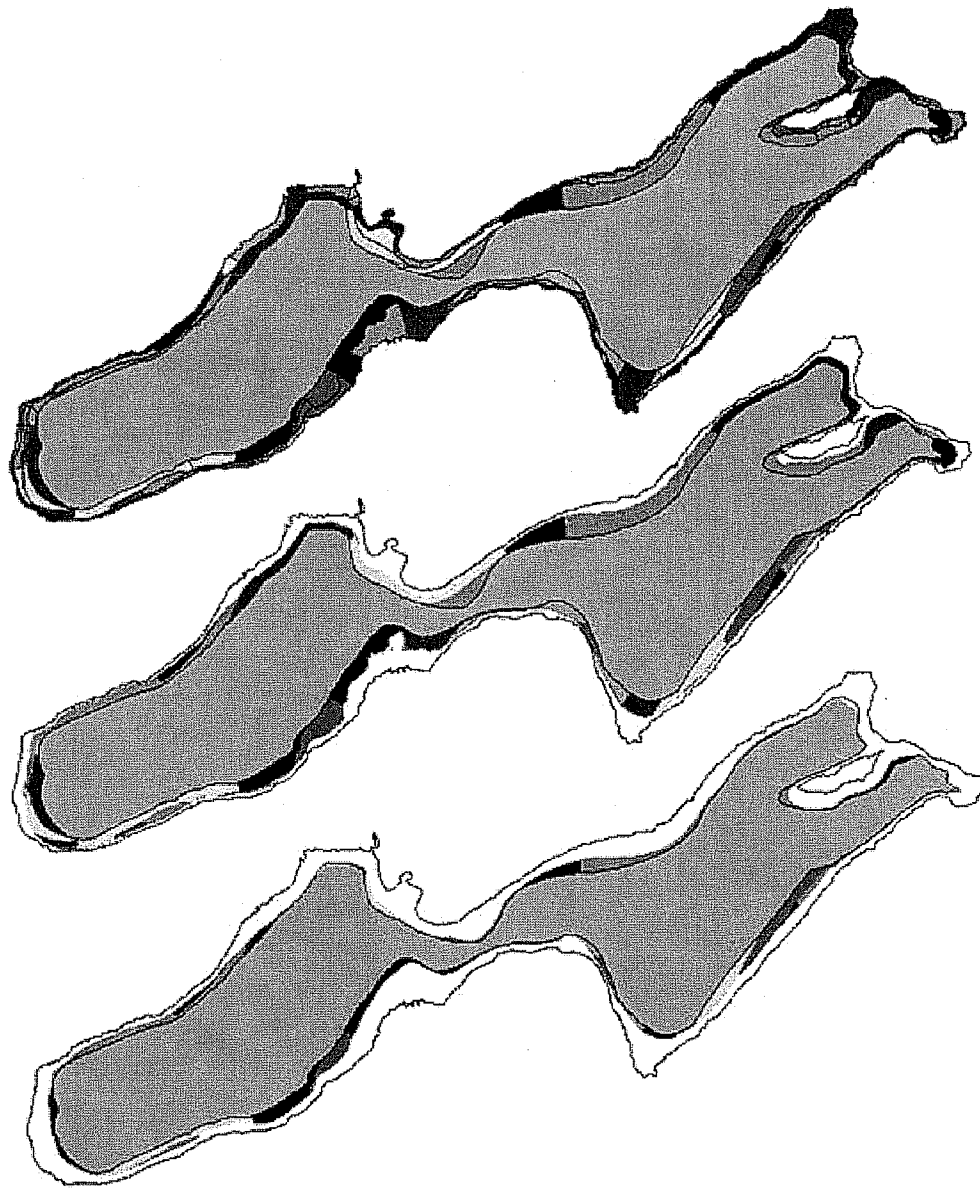


Figure 12. Lake 226 substratum distribution at the natural lake stage (top), and at 1.7 m (middle) and 3.1 m (lower) below lake datum, the annual minimum draw down levels in 1995, and 1996. At three metres draw down, most of the littoral area is desiccated, and some areas of profundal sediments are exposed. The middle and lower panels show the pre draw down shoreline as a reference.

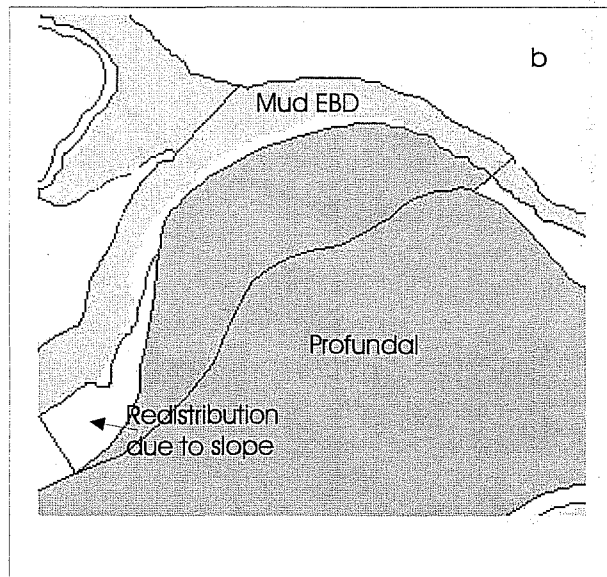
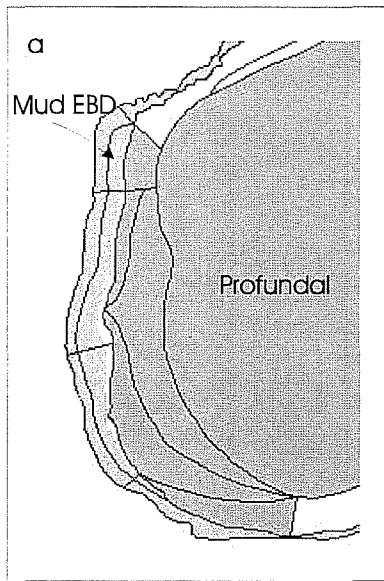
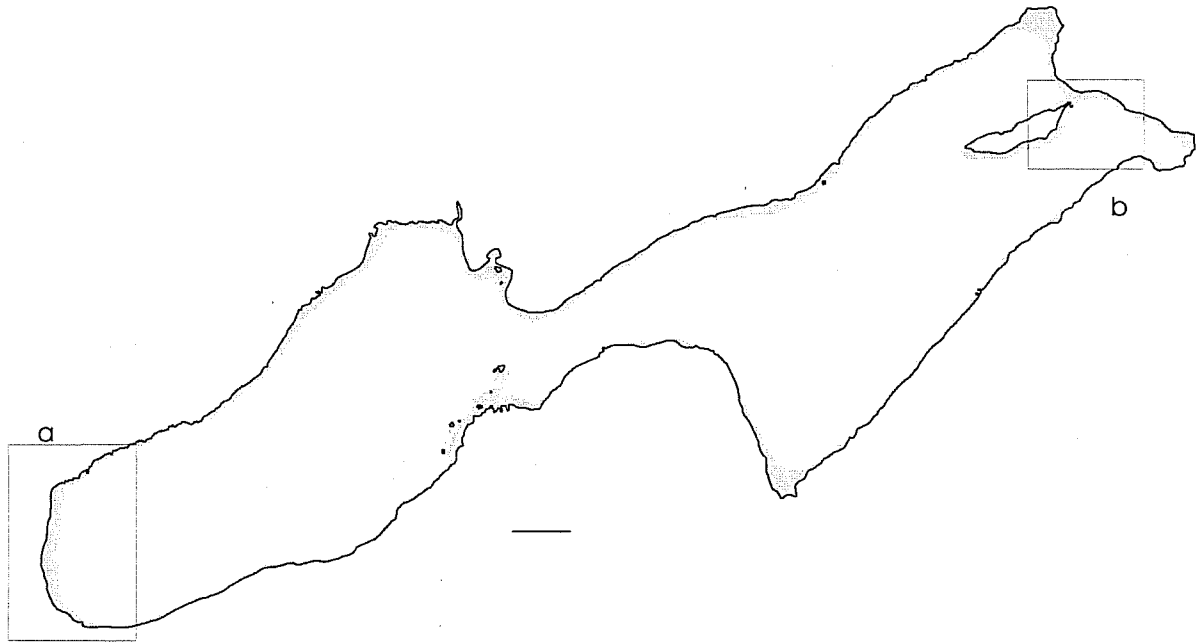


Figure 13. The mud energy boundary depth zone predicted by maximum fetch for the shallow water region of Lake 226. Lower insets, a and b, show examples of high spatial correspondence between the mud energy boundary depth (mud EBD- the lower limit of predicted wave energy), and the observed zone of deposition (mud DBD mud depositional boundary depth).

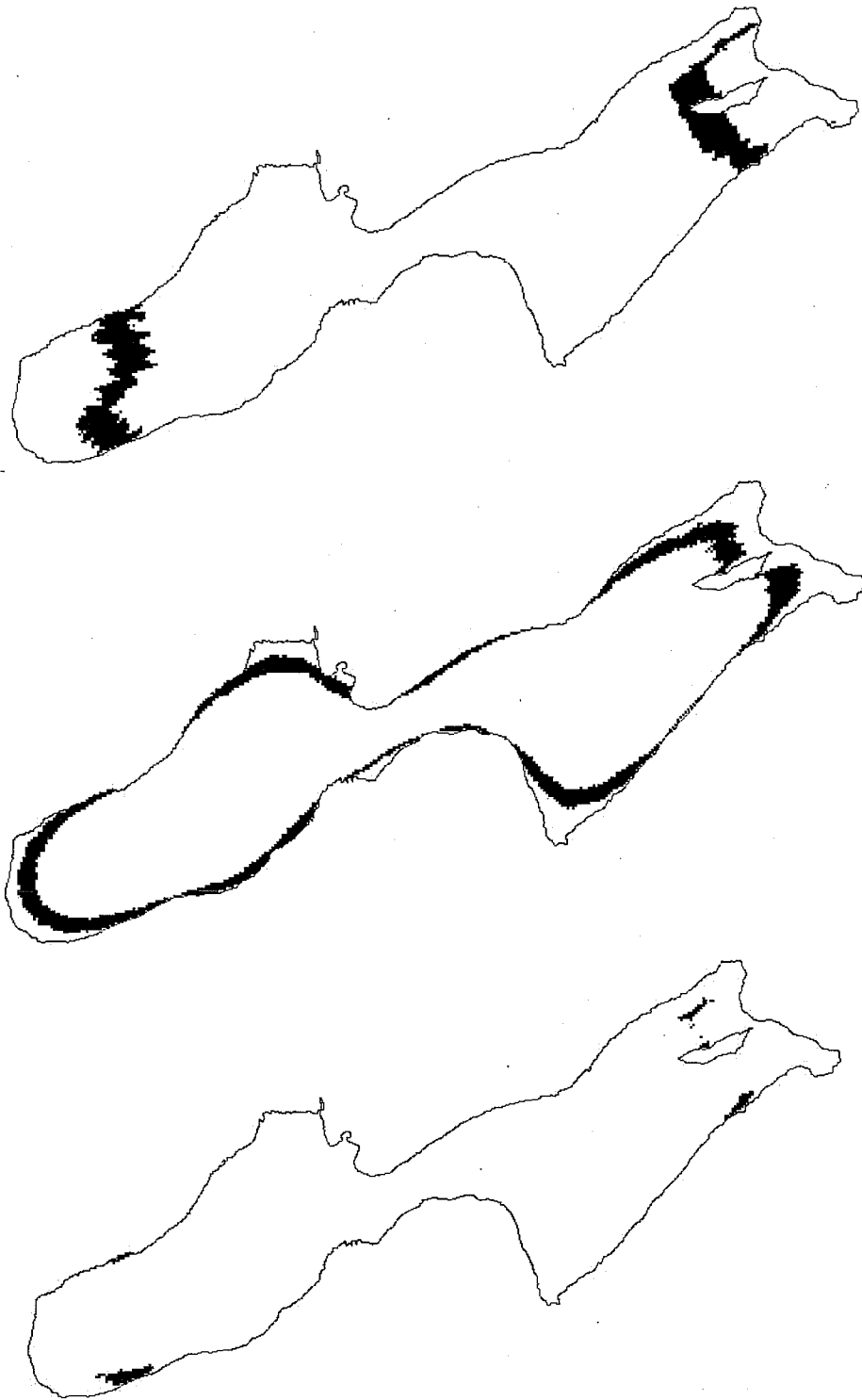


Figure 14. Boolean maps showing areas of the lake that satisfy the wave energy criteria extracted from the site where habitat losses are expected due to development. Maximum fetch (top), mean fetch (middle), and the areas that satisfy both criteria (lower) in black are candidate sites for habitat replacements with wave energy similar to the site of anticipated habitat loss.

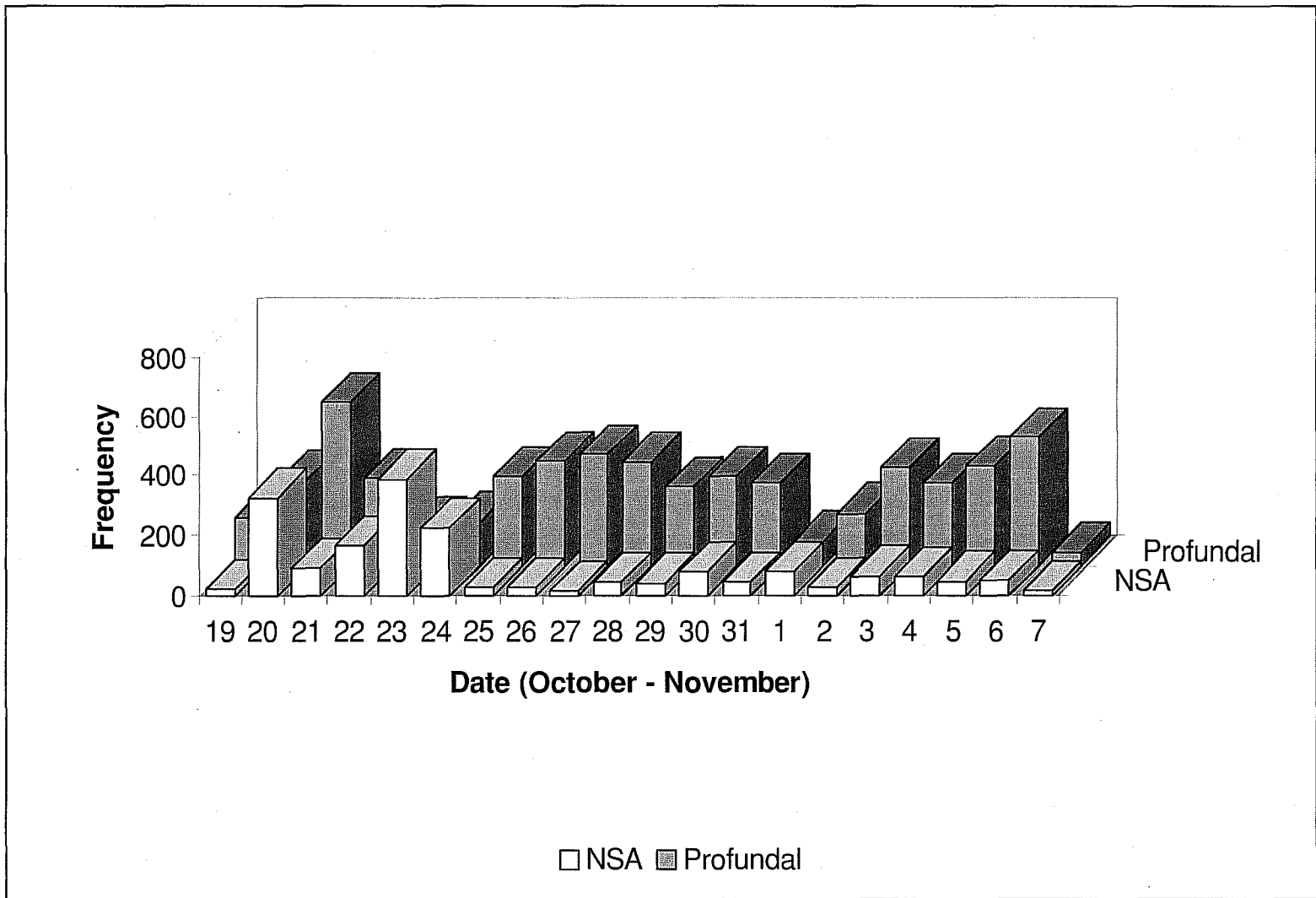


Figure 15. The frequency of nearshore area (NSA) and profundal area positions from lake whitefish no. 2 during the spawning period, from October 19 to November 7, 1995.

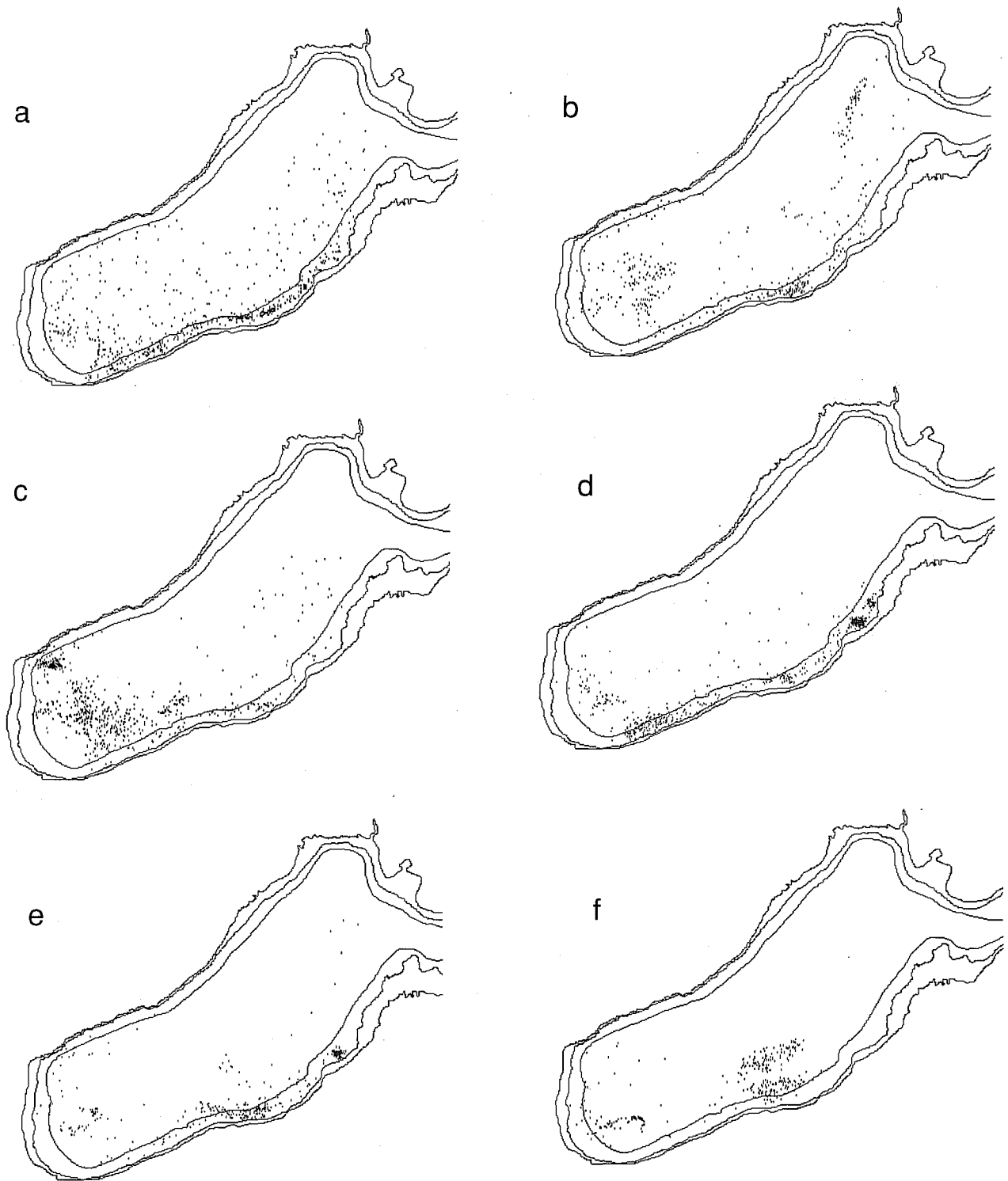


Figure 16. Daily acoustic telemetry positions for lake whitefish no. 2 showing an inshore movement for the period October 20 (a), 21 (b), 22 (c), 23 (d), 24 (e), and 25 (f), a subset of data shown in figure 15. Site fidelity in the nearshore area is apparent among days (a, b, d, e), prior to an offshore movement where activity was much reduced. For each inset the positions are bounded by the pre draw down shoreline (outer polygon), the shoreline during telemetry survey (middle polygon; -1.7 meters below reference datum), and the profundal zone of perennial deposition (innermost polygon).

6. Appendices

6.1 Appendix A: data files contained on the companion compact disc

File ID	Name	Type	File ID	Name	Type
1	226ATRIb	Microsoft Access Record-Locking	51	Concat	Idrisi Documentation file
2	226atrib	Microsoft Access Database	52	Concat.img	IMG File
3	226codes.dvl	DVL File	53	Cr_areas	Idrisi Documentation file
4	226codes.val	VAL File	54	Cr_areas.img	IMG File
5	226contr.dvc	DVC File	55	Date.sm0	SM0 File
6	226contr.vec	VEC File	56	Date1pt.sm0	SM0 File
7	226dem_f	Idrisi Documentation file	57	Day.sql	SQL File
8	226dem_f.img	IMG File	58	Dbwlink.dvl	DVL File
9	226depth	Idrisi Documentation file	59	Dbwlink.val	VAL File
10	226depth.img	IMG File	60	Dd17	Idrisi Documentation file
11	226lake	Idrisi Documentation file	61	Dd17.img	IMG File
12	226lake.img	IMG File	62	Dd17m	Text Document
13	226nsasb	Idrisi Documentation file	63	Dd31	Idrisi Documentation file
14	226nsasb.img	IMG File	64	Dd31.img	IMG File
15	226pnp	Idrisi Documentation file	65	Dd31m	Text Document
16	226pnp.dvc	DVC File	66	Ddlv1	Idrisi Documentation file
17	226pnp.smp	SMP File	67	Ddlv1.img	IMG File
18	226pnp.vec	VEC File	68	Depth.sm0	SM0 File
19	226sim.smp	SMP File	69	Depth.smp	SMP File
20	226slope	Idrisi Documentation file	70	Depthlgt.smp	SMP File
21	226slope.img	IMG File	71	Ebdslope	Idrisi Documentation file
22	226sub	Text Document	72	Ebdslope.img	IMG File
23	226sub.dvl	DVL File	73	Eta	Idrisi Documentation file
24	226subcd	Idrisi Documentation file	74	Eta.img	IMG File
25	226subcd.img	IMG File	75	FA_LWF2	Microsoft Access Record-Locking
26	226subid	Idrisi Documentation file	76	Fa_lwf2	Microsoft Access Database
27	226subid.dvc	DVC File	77	Fa_lwf2.dvl	DVL File
28	226subid.img	IMG File	78	FA_LWF3	Microsoft Access Record-Locking
29	226subid.vec	VEC File	79	Fa_lwf3	Microsoft Access Database
30	226wbase	Idrisi Documentation file	80	Fa_lwf3.dvl	DVL File
31	226wbase.img	IMG File	81	Fc_lwf2.dvc	DVC File
32	2pt_bcir.sm0	SM0 File	82	Fc_lwf2.dvl	DVL File
33	Area17	Text Document	83	Fc_lwf2.val	VAL File
34	Area31	Text Document	84	Fc_lwf2.vec	VEC File
35	Areapre draw down	Text Document	85	Fc_lwf3.dvc	DVC File
36	Bathy.smp	SMP File	86	Fc_lwf3.dvl	DVL File
37	Bedrck	Idrisi Documentation file	87	Fc_lwf3.val	VAL File
38	Bedrck.img	IMG File	88	Fc_lwf3.vec	VEC File
39	Bedrock	Idrisi Documentation file	89	Fcritria	Idrisi Documentation file
40	Bedrock.img	IMG File	90	Fcritria.img	IMG File
41	Bluline.sm1	SM1 File	91	Hab_loss.dvc	DVC File
42	Boolean.smp	SMP File	92	Hab_loss.vec	VEC File
43	Bouys.sm0	SM0 File	93	Lake 226 ELA	Text Document
44	Buoy95.dvc	DVC File	94	Logo_bw	WMF File
45	Buoy95.vec	VEC File	95	Lwf2_fix	Idrisi Documentation file
46	compos1	Text Document	96	Lwf2_fix.img	IMG File
47	compos1.ans	ANS File	97	Lwf2_id	Idrisi Documentation file
48	Compos_1.map	MAP File	98	Lwf2_id.img	IMG File
49	Compos_2.map	MAP File	99	Lwf2bool	Idrisi Documentation file
50	Compos_3.map	MAP File	100	Lwf2bool.img	IMG File

Appendix A: Data files contained on the companion compact disc, continued.

File ID	Name	Type	File ID	Name	Type
101	Lwf2date	Idrisi Documentation file	150	Repl_mxf	Idrisi Documentation file
102	lwf2date	Text Document	151	Repl_mxf.img	IMG File
103	lwf2DATE	Microsoft Excel Worksheet	152	Replace	Idrisi Documentation file
104	Lwf2date.img	IMG File	153	Replace.img	IMG File
105	Lwf2sbcd	Idrisi Documentation file	154	Replsite	Idrisi Documentation file
106	Lwf2sbcd.img	IMG File	155	Replsite.img	IMG File
107	Lwf2shor	Microsoft Access Database	156	Sa_dd17	Idrisi Documentation file
108	LWF2SHOR	Microsoft Access Record-Locking	157	Sa_dd17.img	IMG File
109	Lwf2shor	File	158	Sa_dd31	Idrisi Documentation file
110	Lwf2shor.dvl	DVL File	159	Sa_dd31.img	IMG File
111	lwf2shor.sql	SQL File	160	SLOPE%	Idrisi Documentation file
112	Lwf2spwn	Idrisi Documentation file	161	SLOPE%.img	IMG File
113	Lwf2spwn.img	IMG File	162	Slpgt9	Idrisi Documentation file
114	Maxf_km	Idrisi Documentation file	163	Slpgt9.img	IMG File
115	Maxf_km.img	IMG File	164	Speed.sm0	SM0 File
116	Mn_areas	Idrisi Documentation file	165	Speed.smp	SMP File
117	Mn_areas.img	IMG File	166	Spwn_2.sm0	SM0 File
118	Mnf_crit	Idrisi Documentation file	167	St_group	Idrisi Documentation file
119	Mnf_crit.img	IMG File	168	St_group.img	IMG File
120	Mnf_repl	Idrisi Documentation file	169	SUBATRIB	Microsoft Access Record-Locking
121	Mnf_repl.img	IMG File	170	Subatrib	Microsoft Access Database
122	Mnfetch	Idrisi Documentation file	171	Subatrib.dvl	DVL File
123	Mnfetch.img	IMG File	172	Whitelin.sm1	SM1 File
124	Mud_prof	Idrisi Documentation file	173	Wvbase.exp	EXP File
125	Mud_prof.img	IMG File	174	Img0041.img	IMG File
126	Mudebd	Idrisi Documentation file	175	Img0041.doc	Idrisi Documentation file
127	Mudebd.img	IMG File	176	Img0041.smp	SMP File
128	Mudebd.smp	SMP File	177	Img0042.img	IMG File
129	Mudebd2	Idrisi Documentation file	178	Img0042.doc	Idrisi Documentation file
130	Mudebd2.img	IMG File	179	Img0042.smp	SMP File
131	Mx_areas.rcl	RCL File	180	Img0064.img	IMG File
132	Mxf_crit	Idrisi Documentation file	181	Img0064.doc	Idrisi Documentation file
133	Mxf_crit.img	IMG File	182	Img0064.smp	SMP File
134	Mxf_repl	Idrisi Documentation file	183	Img0064.img	IMG File
135	Mxf_repl.img	IMG File	184	Img0064.doc	Idrisi Documentation file
136	N_twlght.sql	SQL File	185	Img0064.smp	SMP File
137	Ns_pro.sm0	SM0 File			
138	Nsaprof	Idrisi Documentation file			
139	Nsaprof.img	IMG File			
140	Overest	Idrisi Documentation file			
141	Overest.img	IMG File			
142	Preshore.dvc	DVC File			
143	Preshore.vec	VEC File			
144	Prof_ebd.smp	SMP File			
145	Profund	Idrisi Documentation file			
146	Profund.dvc	DVC File			
147	Profund.img	IMG File			
148	Profund.vec	VEC File			
149	Redline.sm1	SM1 File			

6.2 Appendix B: numeric class codes and material size ranges used in the Nearshore Substratum Classification System

Class Name	Class	Size (mm)	
		(min.)	(max.)
Silt/Clay	10	Texture	
Bedrock	20	> 4096	
Sand	30	0.062	4
Gravel			
fine	41	4	8
coarse	42	8	64
Cobble			
fine	51	64	128
coarse	52	128	256
Boulder			
	61	256	1024
	62	1024	4096
Detritus	71	Texture	
Flocculent (Profundal)	72	Texture	

6.3 Appendix C: Nearshore Classification System Integer codes assigned to substratum class number combinations for substratum materials present in Lake 226.

Integer code	Class number combinations	Description
1	72	profundal flocculent sediment
2	71	detritus
4	7161	detritus/small boulder
6	7151	detritus/small cobble
7	7142	detritus/large gravel
9	7130	detritus/sand
14	6261	large boulder/small boulder
24	626171	large boulder/small boulder/detritus
33	625251	large boulder/large cobble/detritus
60	6152	small boulder/large cobble
61	6151	small boulder/small cobble
68	6171	small boulder/detritus
70	615271	small boulder/large cobble/detritus
71	615251	small boulder/large cobble/small cobble
75	615220	small boulder/large cobble/bedrock
97	5251	large cobble/small cobble
107	525171	large cobble/small cobble/detritus
108	525142	large cobble/small cobble/large gravel
110	525130	large cobble/small cobble/sand
111	525120	large cobble/small cobble/bedrock
113	524271	large cobble/large gravel/detritus
122	523071	large cobble/sand/detritus
125	522071	large cobble/bedrock/detritus
128	5142	small cobble/large gravel
136	5171	small cobble/detritus
138	514271	small cobble/large gravel/detritus
147	513071	small cobble/sand/detritus
161	4271	large gravel/detritus
167	423071	large gravel/sand/detritus
188	30	sand
197	3071	sand/detritus
200	20	bedrock
201	2010	bedrock/silt-clay
204	2042	bedrock/large gravel
206	2052	bedrock/large cobble