

94-79 c,

NATIONAL
WATER
RESEARCH
INSTITUTE

INSTITUT
NATIONAL
de RECHERCHE
sur les
EAUX

CCIW

SEP 21 1994

LIBRARY

**VISUALIZATION OF TEMPERATURE
AND OXYGEN CONCENTRATIONS IN
HAMILTON HARBOUR,
LAKE ONTARIO**

E. Halfon

NWRI Contribution No. 94-79

TD
226
N87
No. 94-
79
c.1

**VISUALIZATION OF TEMPERATURE AND OXYGEN
CONCENTRATIONS IN HAMILTON HARBOUR, LAKE ONTARIO**

Efraim Halfon

**National Water Research Institute
Canada Centre for Inland Waters
Burlington, Ontario
Canada L7R 4A6**

NWRI Contribution No. 94-79

MANAGEMENT PERSPECTIVE

The goal of this project is implementation of a system whereby researchers can access, analyze, and visualize water quality data collected in three dimensions (geographical coordinates and depth). Another objective of this research is to develop software that not only enables but encourages ecologists to more fully utilize time-varying, multi-dimensional data from Hamilton Harbour and other areas of concern. A literature review has failed to identify volume visualization applications in limnology, thus this effort of combining visualization algorithms and research in lakes might be the first to be published.

The Hamilton Harbour Research project will have archived over a gigabyte of heterogeneous image data by the end of this year. Other RAP sites are similarly amassing large, complicated data sets. Ecologists want to transform this raw data into useful information to provide new insight into long-term ecological phenomena. Unfortunately, the procedures, software tools, and user friendly interfaces necessary to facilitate access to these data sets are currently lacking. This precludes analysis and subsequent visualization by ecologists. Visualization provides efficient and powerful means of comprehending complex numeric data. This project investigates approaches to visualization of sampled volumetric data collected in Hamilton Harbour, Lake Ontario. An aspect of this research is to carefully compare different approaches to certain aspects of visualization, particularly, the interpolation of 3D data, the mapping from numeric data to visual parameters such as colour and transparency, and methods of efficient volume traversal.

SOMMAIRE À L'INTENTION DE LA DIRECTION

L'objectif de ce projet est la mise en place d'un système qui permettra aux chercheurs d'avoir accès à des données sur la qualité de l'eau recueillies en trois dimensions (coordonnées géographiques et profondeur), de les analyser et de les visualiser, ainsi que d'élaborer un logiciel qui non seulement autorise mais aussi encourage les écologistes à utiliser pleinement les données pluridimensionnelles à variation temporelle recueillies dans le port de Hamilton et d'autres secteurs préoccupants. Une étude de la littérature n'a pas révélé d'applications de visualisation en volume pour ce qui est de la limnologie; cette tentative de combinaison des algorithmes de visualisation et de la recherche sur les lacs pourrait donc être la première à être publiée.

Le projet de recherche sur le port de Hamilton aura archivé plus d'un gigabyte de données d'images hétérogènes d'ici la fin de l'année. D'autres sites de plans d'assainissement amassent des ensembles de données vastes et complexes, que les écologistes veulent transformer en informations qui serviront à jeter un nouvel éclairage sur des phénomènes écologiques à long terme. Malheureusement, on manque encore de méthodes, d'outils logiciels et d'interfaces simples pour faciliter l'accès aux données, ce qui empêche les écologistes de les analyser, puis de les visualiser. La visualisation est un moyen efficace et puissant pour comprendre des données numériques complexes. Ce projet examine les approches à la visualisation de données volumétriques échantillonnées dans le port de Hamilton, sur le lac Ontario. Un des volets de la recherche est de comparer soigneusement diverses approches à certains aspects de la visualisation, en particulier l'interpolation des données tridimensionnelles, la cartographie de données numériques en paramètres visuels tels que la couleur et la transparence, et les méthodes efficaces de coupe transversale du volume.

ABSTRACT

The inner structures of lakes can be revealed using volume visualization algorithms. Lakes are three dimensional objects that are explored by taking samples at various stations and at different depths. The data are sparse in space but contain much information that can be extracted using computer graphics. These algorithms did not exist twenty years ago, could be run on supercomputers ten years ago, on workstations three years ago, and now on personal computers. It is now possible to combine data, their three dimensional location and lake topography to create images of water quality patterns. These visualizations supersede conventional surface, two dimensional, graphics (GIS). Through solid modelling, data are mapped into voxels and visualized on a two dimensional screen. Oxygen and temperature data collected on May 28, 1990 and August 8, 1990 in Hamilton Harbour are visualized. Various three dimensional representation of temperature and oxygen data including water masses with temperatures of less than 12°C, 13 to 14°C, 16°C to 17°C, and greater than 23°C, and oxygen concentrations of less than 4 mg/L, 6 to 8 mg/L and 10 to 12 mg/L are visualized.

RÉSUMÉ

La structure interne des lacs peut être révélée au moyen d'algorithmes de visualisation des volumes. Les lacs sont en effet des objets tridimensionnels, qu'on explore en prélevant des échantillons en divers sites et à diverses profondeurs. Les données, bien que rares dans l'espace, contiennent une profusion d'information qu'on peut extraire par infographie. Ces algorithmes n'existaient pas il y a 20 ans, et tournaient sur des super-ordinateurs il y a 10 ans, sur des postes de travail il y a 3 ans et maintenant sur des micro-ordinateurs. Il est maintenant possible de combiner les données, leur emplacement dans l'espace et la topographie du lac pour créer des images des configurations de la qualité de l'eau. Ces visualisations surclassent les graphiques classiques bidimensionnels (SIG). Grâce à la modélisation en volume, les données sont cartographiées en voxels et visualisées sur un écran à deux dimensions. On peut visualiser les données d'oxygène et de température recueillies le 28 mai 1990 et le 8 août 1990 dans le port de Hamilton. On peut aussi visualiser diverses représentations tridimensionnelles des données de température et d'oxygène, dont les masses d'eau de température inférieure à 12 °C, comprise entre 13 °C et 14 °C, comprise entre 16 °C et 17 °C, et supérieure à 23 °C, et présentant une concentration d'oxygène inférieure à 4 mg/L, comprise entre 6 et 8 mg/L et entre 10 et 12 mg/L.

INTRODUCTION

In traditional (pre 1970) computer graphics, polygons and lines (e.g., a wireframe) represent three dimensional (3D) volumetric objects. Conversely, some 3D data sets, e.g., the volumetric water quality patterns collected in a lake, might not consist of surfaces and edges at all. Greenleaf et al. (1970) were the first to introduce new methods of visualization to extract information from volume data: this process called volume visualization is defined by Kaufmann (1992) as "a **direct** technique for visualizing volume primitives without any intermediate conversion of the volumetric data set to surface representation."

The first applications were in medical imaging and they are still dominant (e.g., Adams et al., 1990; Rhodes et al., 1987). McCormick et al. (1987) stated that volume visualization was emerging as a new visualization environment in scientific computing; for example Hibbard and Santek (1989) presented interesting uses in the earth sciences.

Kaufmann (1991a) provided an insight into this technology stating that "the objective of volume visualization is to peer inside the volumetric objects to view that which is not ordinarily viewable and to probe into the voluminous and complex structures and their dynamics to comprehend that which is not ordinarily comprehensible."

A literature review has failed to identify volume visualization applications in limnology. Several reasons might have caused this delay: One is that since a lake is bounded by land from all sides, shoreline and bathymetry must be available in digitized form. Second, water quality data in lakes are usually collected at sparse locations while volume visualization algorithms need the data organized in a uniform grid with no missing values, thus extensive data preparation is necessary. Finally, as late as 1991 figures similar to those presented in this paper were created using a supercomputer (Shirley and Neeman, 1989; Mercurio, 1991) and displayed using workstations. Indeed, Kaufmann (1991a) lists special-purpose hardware for volume

visualization, whereas only three years later this entire paper was produced on a 486/50 personal computer.

Hamilton Harbour (also called Burlington Bay) is located at the western end of Lake Ontario, it has a triangular shape with maximum dimensions eight kilometres from east to west and five kilometres from north to south; the maximum depth in the middle of the bay is about 26 metres and an additional deep area is located at the east end (Fig. 1). A ten metre deep channel connects it to Lake Ontario. Hamilton Harbour has been widely studied in the past ten years (Charlton, pers. comm.) since it is one of the 42 areas of concern within the Great Lakes and furthermore the International Council for Local Environmental Initiatives has designated the city of Hamilton as Canada's model city under the United Nations Agenda 21 program (ICLEI, 1990).

Here, a framework is described to visualize and interpret 3D data. This outline is specific for lakes. For general applications consult Kaufmann (1991b) and Foley et al. (1991). In this framework there are three steps: data collection, solid modelling or transformation of the data in a specific volumetric format, and finally volume rendering or the visualization process.

THE VISUALIZATION PROCESS

Data

Water quality data (water temperature, oxygen concentration, conductivity, pH, etc.) have been collected by Charlton (pers. comm.) every year since 1985 at 26 stations (the number of stations has slightly increased or decreased over the years). Figure 2 shows the station locations; eight cruises took place in 1990 and since samples were collected with an electronic probe data are available at all depths every few centimetres.

Solid modelling

This area of computer graphics has arisen following the need for modelling objects as solids (Foley et al., 1991). A lake is also a volumetric object; associated with each point in

the lake there is a water quality variable of interest. The "point", or cell, in the lake is of course related to the resolution used in the computer representation and the cells are a collection of adjoining nonintersecting solids. When the cells are equal and arranged in a fixed, regular grid, they are called **voxels** (volume elements), analogous to pixels. Each voxel is a quantum unit of volume and has a numeric value (or values) associated with it that represents some measurable properties (e.g., temperature, pH, conductivity, Secchi disk values, oxygen concentration, toxic contaminants concentrations, etc.). The 3D volumetric data set resides in an **integer** grid of voxels called a cubic frame buffer.

The visualization process consists of several steps necessary to organize the data in the proper voxel format: A first step is to divide the area of interest into a grid; the grid chosen for Hamilton Harbour is 50 x 50 metres. Over 2,500 bathymetry data and 14,000 shoreline data are available from the Canadian Hydrographic Service. The depth value in each grid unit was obtained by interpolation using the SAS contouring program and the bathymetric data, which were originally in sparse form, were organized into a fixed grid.

Following the grid pattern, each voxel was defined as a rectangular parallelepiped with dimensions 50 metres x 50 metres by 0.5 metres and the cube frame buffer has dimensions of 200 x 127 x 52 for a total of 1,320,800 voxels. Note that the choice and of number of voxels and their size is left to the user for several reasons: As the number of cells increases, grid size diminishes, the ambiguity between land and water voxels decreases, but it does not disappear, unless the lake is a perfect cube (unlikely). However, the larger the number of voxels the larger is the computer memory requirement and the computing time. The rectangular parallelepiped form allows for resolution in the different axes.

The second step was to identify which voxels represent land (depth value of zero) and which water (grid depth value greater than zero). Out of the 1,320,880 voxels only 204,034 are water given the conical shape of the harbour. A 3D array was created where each land voxel was assigned a value of zero and each water voxel a value of one. A similar procedure was

followed with the water quality data. Since voxels have dimensions of cubic metres and data collected along the depth axis have already a metric dimension associated with them (data collected at .1, .2, ..., etc. metres), station locations were converted from geographical to UTM coordinates [metres] before the interpolation was performed.

The interpolation problem, that is fitting the data collected at arbitrarily located positions to a uniform grid is complex. While this problem has not been fully solved, Foley et al. (1993) have reviewed past work and proposed solutions. Interpolation of the water quality data from scattered stations to a uniform grid was performed using an algorithm that computed the water quality parameter using data collected at the nearest three stations. Weight factors were inversely proportional to the square of the distance from the three closest stations. Interpolation was performed in two dimensions, one layer at the time. Interpolation in the vertical axis was performed using the IMSL (1987) subroutine SCAKM. This subroutine uses a spline function to interpolate the data. A spline interpolation could not be used in the horizontal plane since the IMSL subroutine SURFER could not be constrained to have the interpolated data stay within the observed range.

The third step was to join the voxels with their water quality values through Boolean algebra. The solid modelling of the data into voxels was now completed for the visualization step.

Volume rendering

Kaufmann (1991) states that "to visualize the volume data set, the voxels can be projected into 2D pixel space and stored as a raster image frame in a frame buffer. This process, which is termed volume rendering (Drebin et al., 1988; Frenkel, 1989; Levoy, 1988; Upson and Keeler, 1988), involves both the viewing and the shading of the volume image." The definition of Foley et al. (1991) is that "volume rendering is the process of displaying scalar fields," where a scalar field is a collection of all the numbers associated with each point in a volume. In summary "volume rendering is a direct display of volume primitives without any intermediate

conversion of volume data to surface representation." (Kaufmann, 1991a). There is no a priori assumption that "the data consist of tangible surfaces that can be extracted and visualized." Specialized algorithms have been developed to render clouds, humans and living objects (Blinn, 1982; Herman and Udupa, 1983). The application of volume rendering techniques to limnology is therefore not complex, but it requires the data preparation explained above.

Volume viewing and shading

Kaufmann's (1991b) book can be consulted for a comprehensive review to create 2D projections from the 3D volumetric data as well as volume rendering and shading. For this application the Hamilton Harbour voxel values were stored in ASCII format and the data set was read into memory by the Spyglass® Slicer¹ program (Spyglass, 1994). Slicer is a volume visualization software that can be used for scientific visualization; while the program focuses on the 3D primitives, Slicer can also visualize the data using more traditional 2D primitives, such as surface rendering as slices and isosurfaces.

Surface rendering is defined as "an indirect technique used for visualizing volume primitives by first converting them into intermediate surface representation and then employing conventional computer graphics techniques to render them to the screen." (Kaufmann, 1992). An isosurface (Levoy, 1988) is a surface where the data with the same values are interpolated together, for example a thermocline can be considered a three dimensional temperature isosurface. The surface can be rendered as a transparent or solid surface. The isosurface can also be coloured according to the values of the scalar field at the surface points (Mercurio, 1991).

¹Spyglass is a registered trademark of Spyglass, Inc.

RESULTS

Figure 3 shows temperature and oxygen concentration data collected on May 28 and August 8, 1990. Depth scale is exaggerated 200 times and land is assumed to be completely transparent. The irregular bathymetry of the lake is clearly visible. These images were created with Spyglass Slicer with a proprietary ray-tracing algorithm. Water temperature on May 28 ranged from 10.6 to 18°C and oxygen concentrations ranged between 6 and 15.5 mg/L; water temperature on August 8 ranged from 12 to 24°C and oxygen concentrations ranged between 0 and 11 mg/L. Figures 3 to 7 show visualization of the temperature data collected on May 28, 1990 under different rendering options. Figure 4 shows temperature data in Hamilton Harbour from two different viewpoints, from the north, and from the bottom and the north-west, respectively. The bay is heating from the west while temperature at depth is still cold, about 11°C. These views allow an understanding of the 3D bathymetry of the lake from different viewpoints and also of the temperature field at the surface, along the shore and at the bottom, but they do not allow a view of inner parts of the lake.

Figure 5 is a cutout view from the south: The northern part of the water surface is visible together with an east to west transect; this view augments the information not provided by Fig. 2 since water temperature inside the harbour is now visible. Figure 6 shows a complementary cutout view: most water masses are transparent and three water masses, those with temperature of less than 12°C, 13 to 14°C and 16°C to 17°C are specifically visualized. The water mass of 13 to 14°C is located at an average depth of 10 metres, but also at the surface near the north shore of the bay. This information about the water masses is not evident from any other previous figures of the water temperature on May 28. At the surface, water is warmer (about 18°C) in the western part of the bay while at the bottom the colder temperatures are near the eastern side, possibly some lake water. Figure 7 shows additional information on water temperature in the form of slices, contours, at two different depths, surface and 15 metres. As additional information note that conductivity values in May 1990 ranged between 550 and 760

with most of the water in the range 655-680 while Lake Ontario waters have an average value of about 300 (Charlton, pers. comm.).

Figures 8 and 9 show oxygen concentrations in May and August 1990, respectively, as a cutout similar to Fig. 6; as an example, three water masses are identified, those with oxygen levels less than 4 mg/L, 6 to 8 mg/L and 10 to 12 mg/L. In May oxygen is abundant everywhere while in August the oxygen concentration pattern (Fig. 8) shows anoxic, < 4 mg/L, conditions below ten metres. Nevertheless, in August 1990, there was enough oxygen near the surface and on the east side of the lake to support fish growth. Volume visualization algorithms can also be used to compute volumetric properties of the data and classify them; for example in August 1990, 34% of the harbour voxels has oxygen levels below 4 mg/L and conversely, 66% of the harbour had waters suitable for fish growth. This calculation is quite simple since each voxel has water quality values associated with it and these values can be summed or elaborated numerically as needs arise.

In August 1990 (Fig. 10) the 13 to 14°C and 16 to 17°C water masses are found at lower depths than in May (Fig. 6), at about 15 and 10 metres, respectively. The water mass at the east end of the bay, > 23°C, has the same surface temperature as the western part of Lake Ontario. In summer conductivity values had decreased to a range of 460 to 670 and two water masses could be distinguished, one at the surface with conductivity 582 to 600 and one at the bottom of 503 to 514. Thus, from May to August, some Lake Ontario water entered Hamilton Harbour, mixed with the harbour water and settled at the bottom.

DISCUSSION

With the development of faster personal computers and properly designed software, it is possible to visualize limnological data on a personal computer quickly (on average about 30 seconds are needed to render each figure presented in this paper) once the data have been

interpolated and saved in a format suitable for volume visualization. This time frame compares well with the months needed to collect a proper data set.

Charlton (pers. comm.) has collected water quality data in Hamilton Harbour since 1985: After nine years of sampling, the amount of data available for analysis is quite extensive, since data are collected seven or eight times a year at over twenty-five stations at over fifty depths. The visualization tool permits a clear understanding of these data at a glance.

Visualization showed three dimensional patterns not visible otherwise. Temperature data, for example, show the water masses present in the lake and their movement to the bay. A floppy disk with figures presented in this paper is available for distribution at cost.

ACKNOWLEDGEMENTS

Murray Charlton provided his unpublished data collected in Hamilton Harbour. Jackie Dowell prepared the FORTRAN program to convert the data to the volume visualization format and create the appropriate masks. Robert Coker gave useful suggestions, helped with the editing and gave creative assistance in the rendering process. Spyglass corporation provided a beta version of their program Slicer.

REFERENCES

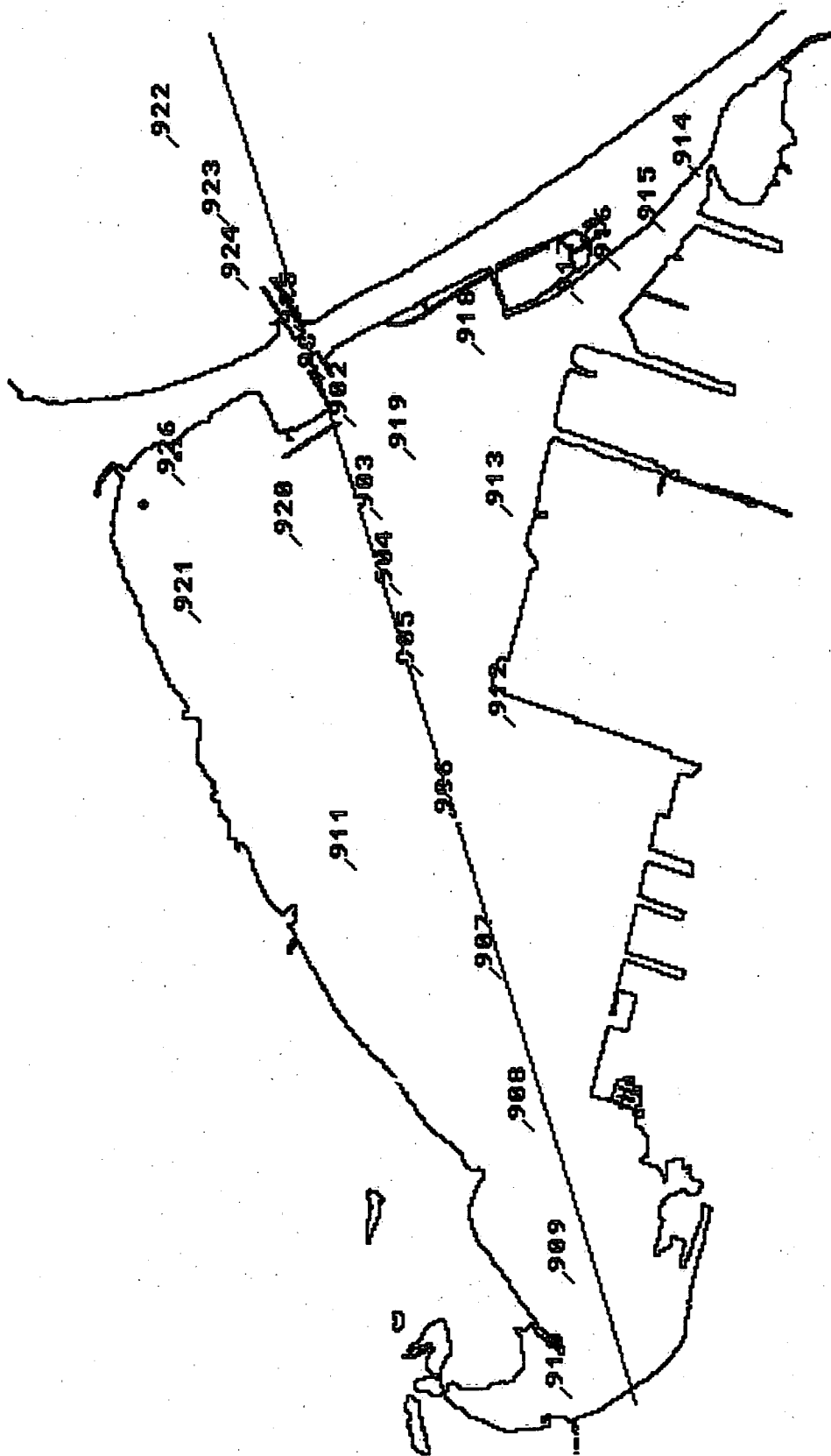
- Adams, L., Gilsback, J.M., Krybus, W., Meyer-Ebrecht, D., Mosges, R. and Schlondorff, G., 1990. CAS-A navigation support for surgery. In K.H. Hoehne, H. Fuchs and S.M. Pzier (Eds.) 3D Imaging in Medicine: Algorithms, Systems, Applications, Springer Verlag, Berlin, 411-423.
- Blinn, J.F. 1982. Light reflection functions for simulation of clouds and dusty surfaces. *Computer Graphics*, 16: 21-29.
- Charlton, M. 1994. Pers. Comm. National Water Research Institute, Canada Centre for Inland Waters, Burlington, Ontario, Canada.
- Drebin, R.A., Carpenter, L., and Hanrahan, P. 1988. Volume rendering, *Computer Graphics*, 22: 64-75.
- Foley, J.D., van Dam, A., Feiner, S.K. and Hughes, J.F. 1991. Computer Graphics: Principles and Practice, Addison-Wesley Publishing Co., Reading, Mass., 1177 pp.
- Foley, T.A., Hagen, H. and Nielson, G.M. 1993. Visualizing and modelling unstructured data. *The Visual Computer*, 9: 439-449.
- Frenkel, K.A. 1989. Volume rendering. *Communications of the ACM*, 32: 426-435.
- Greenleaf, J.F., Tu, T.S. and Wood, E.H. 1970. Computer-generated oscilloscopic images and associated techniques for display and study of the pulmonary blood flow, *IEEE Trans. Nucl. Sci.*, NS-17: 353-359.
- Herman, G. T. and Udupa, J.K. 1983. Display of 3D digital images: computational foundations and medical applications. *Proc. Medcomp '82*, IEEE Computer Society Press, 308-314.
- Hibbard, W and Santek, D. 1989. Visualizing large data sets in the Earth Sciences. *IEEE Computer*, 22: 53-57.
- ICLEI, 1990. World Congress of Local Governments for a Sustainable Future, New York, 1990. International Council for Local Environmental Initiatives, World Secretariat, City Hall, East Tower, 8th Floor, Toronto, Ontario, Canada M5H 2N2.

- IMSL. 1987. Math/LibraryTM. User's manual. FORTRAN subroutines for mathematical applications. IMSL, 2500 ParkWest Tower One, 2500 CityWest Blvd., Houston, Texas 77042-3020, U.S.A.
- Kaufmann, A. 1991b. Volume visualization. Los Alamitos, California: IEEE Computer Society Press, 477 pp.
- Kaufmann, A. 1991a. Introduction to Volume Visualization in A. Kaufmann (ED.) Volume visualization, IEEE Computer Society Press, Los Alamitos, California, pp. 1-18.
- Kaufmann, A. 1992. Introduction to volume visualization. ACM Siggraph '92, Course Notes, 285 pp.
- Levoy, M. 1988. Display of surfaces from volume data. IEEE Computer Graphics and Applications, 8:29-37.
- McCormick, B.H., DeFanti, T.A., and Brown, M.D. 1987. Visualization in scientific computing, Computer Graphics, 21 (special issue).
- Mercurio, P.J. 1991. The data visualizer, Pixel, July/August: 31-35.
- Rhodes, M.L., Kuo, Y., and Rothman, S.L.G.. 1987. An application of computer graphics and networks to anatomic model and prosthesis manufacturing. IEEE Computer Graphics, 7: 12-25.
- Shirley, P. and Neeman, H. 1989. Volume visualization at the center for supercomputing research and development. Proc. Chapel Hill Workshop on Volume Visualization, Univ. of North Carolina Press, Chapel Hill, N.C., pp. 17-20.
- Spyglass 1994. Slice, Spyglass Inc. 1800 Woodfield Dr., Savoy, Illinois.
- Upton, C and Keeler, M. 1988. V-BUFFER: Visible volume rendering, Computer Graphics, 22:59-64.

FIGURE LEGENDS

- Figure 1: Three dimensional bathymetry of Hamilton Harbour, Lake Ontario, viewed from the south. The south shore has been artificially modified in the last century by the presence of steel mills that required the creation of docks.
- Figure 2: Station locations in Hamilton Harbour in 1990.
- Figure 3: Oxygen concentration (a and b) and temperature (c and d) data collected on May 28 and August 8, 1990, respectively. Depth scale is exaggerated 200 times and land is assumed to be completely transparent.
- Figure 4: Temperature data collected on May 28, 1990. Fig. 3a, view from the north, Fig. 3b, view from and from the bottom and the north-west.
- Figure 5: Temperature data, cutout view from the south. Land is not transparent.
- Figure 6: Temperature data, cutout view from the south; most water masses are transparent and three water masses are specifically visualized, those with temperature of less than 12°C, 13 to 14°C and 16°C to 17°C.
- Figure 7: Temperature contours at two different depths, surface and 10 metres.
- Figure 8: Oxygen concentrations on May 28, 1990 as a cutout similar to Fig. 5; three water masses are identified, those with oxygen levels 6 to 8 mg/L and 10 to 12 mg/L.
- Figure 9: Oxygen concentrations on August 8, 1990 as a cutout similar to Fig. 5; three water masses are identified, those with oxygen levels less than 4 mg/L, 6 to 8 mg/L and 10 to 12 mg/L.
- Figure 10: Temperature data, August 8, 1990. The 13 to 14°C and 16 to 17°C water masses are displayed.

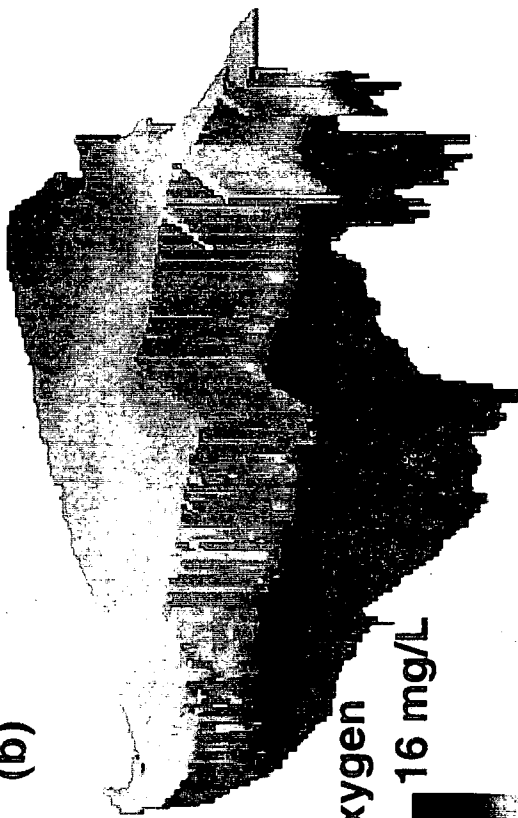




(a)



(b)



Oxygen
16 mg/L



0

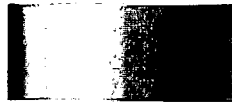
(c)



(d)



Temperature
24°C

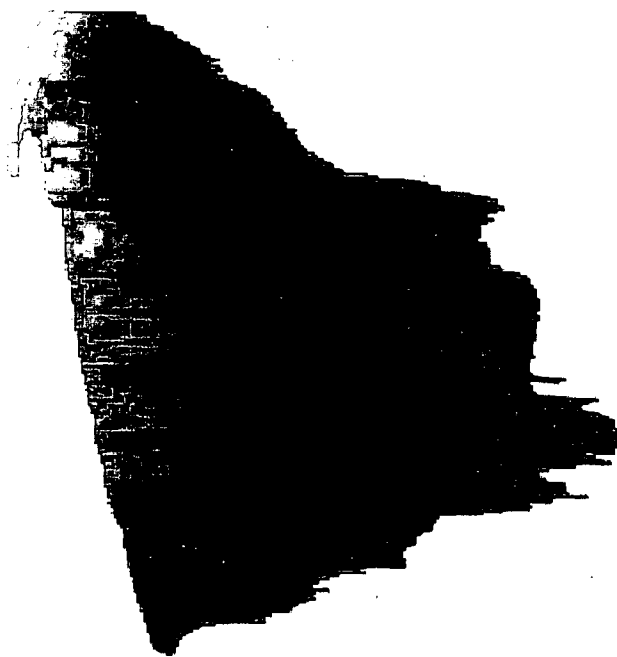


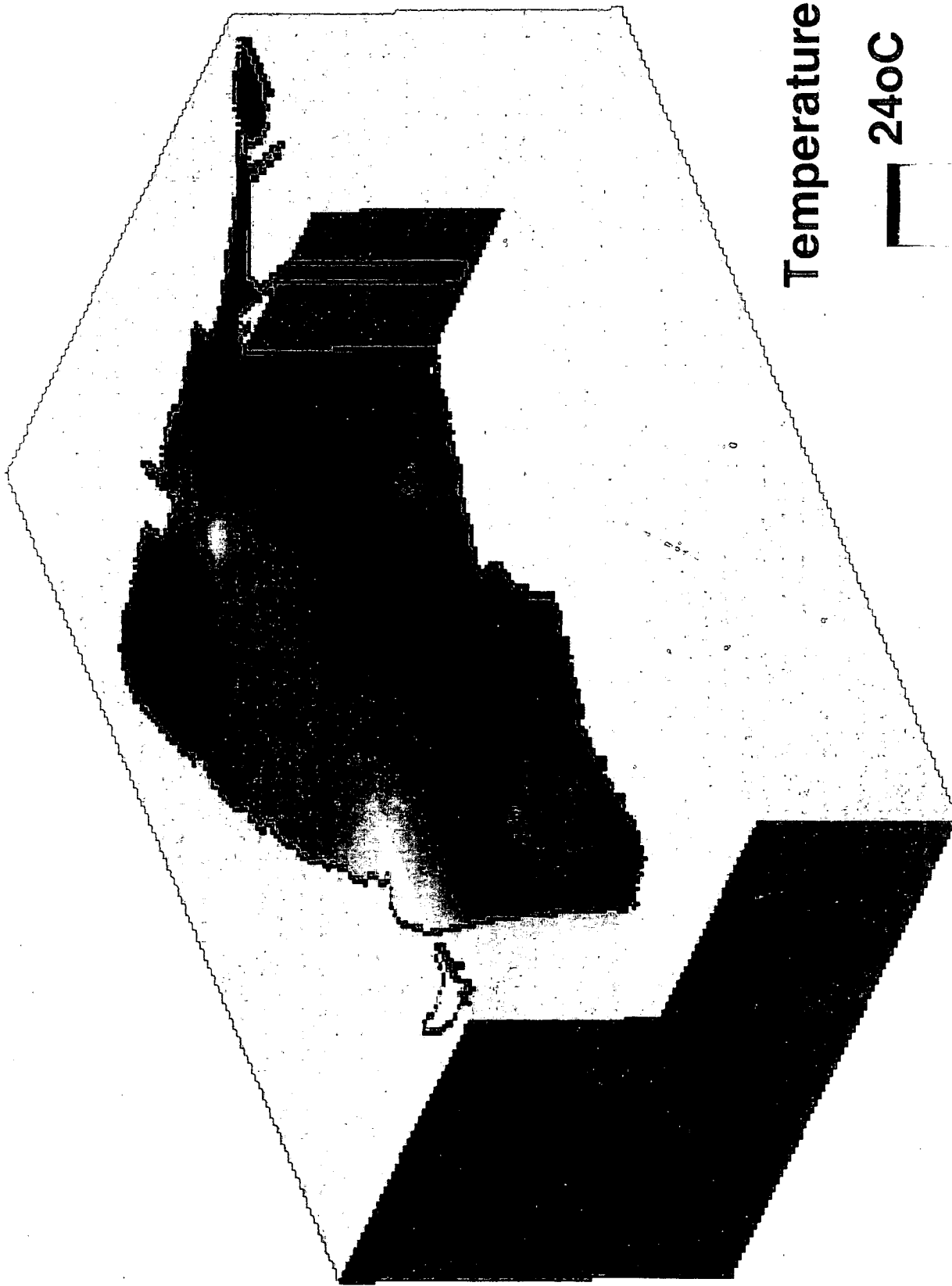
0°C

Temperature

24°C

0°C

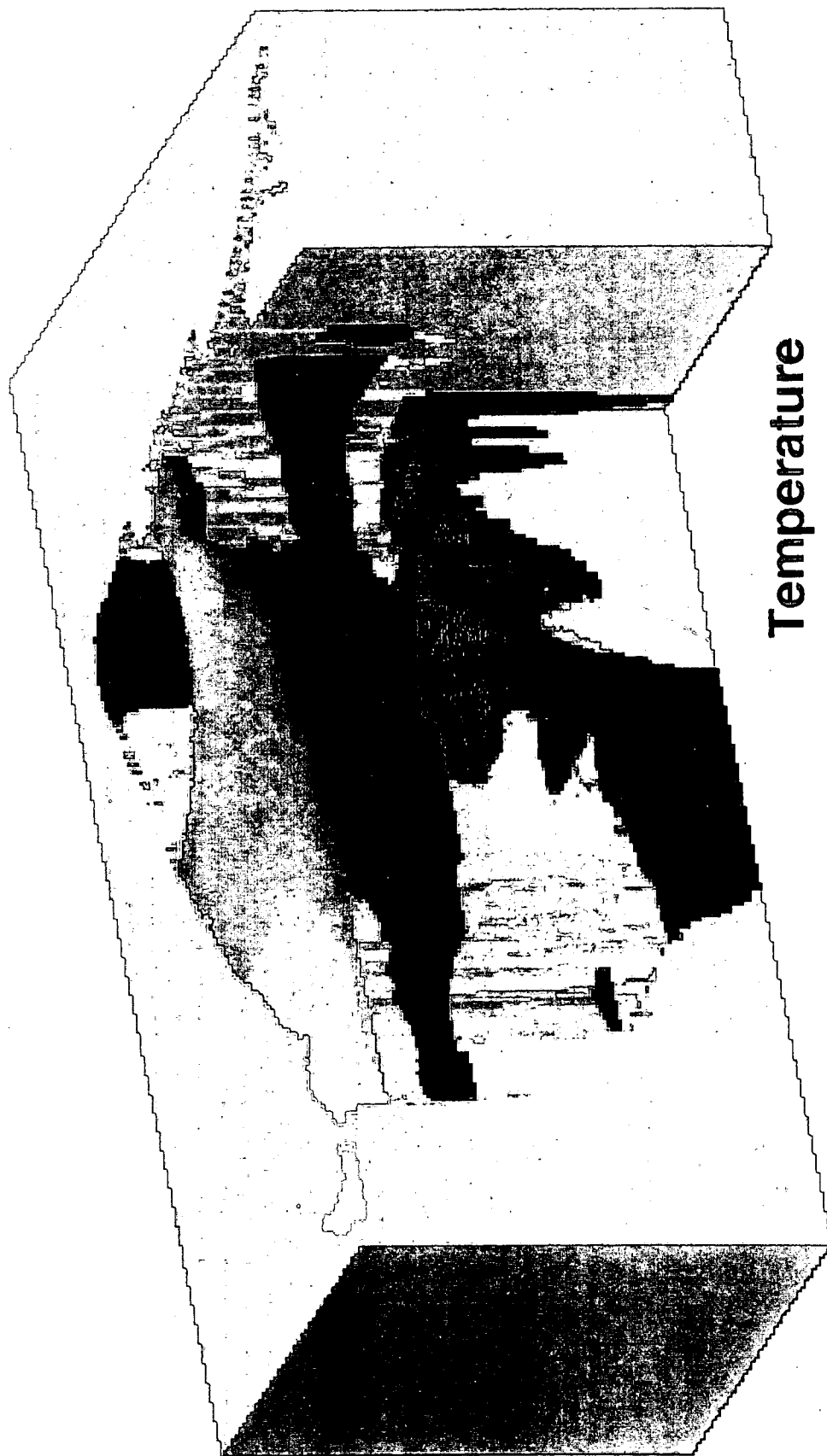




Temperature

24oC

0oC



Temperature

24oC



0oC



24oC



Temperature

0oC



Oxygen

16 mg/L

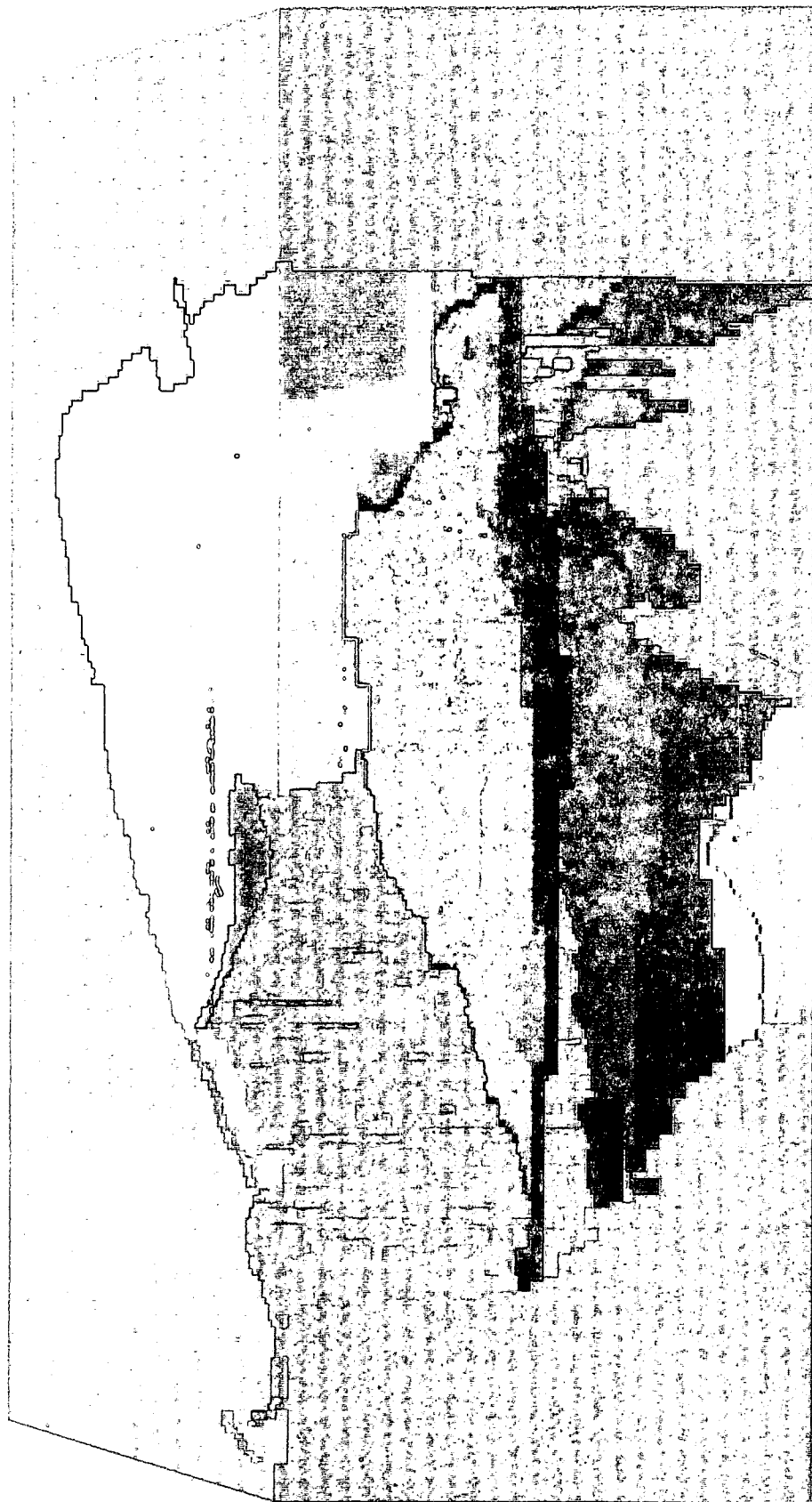




Oxygen
16 mg/L



0



Temperature

24oC

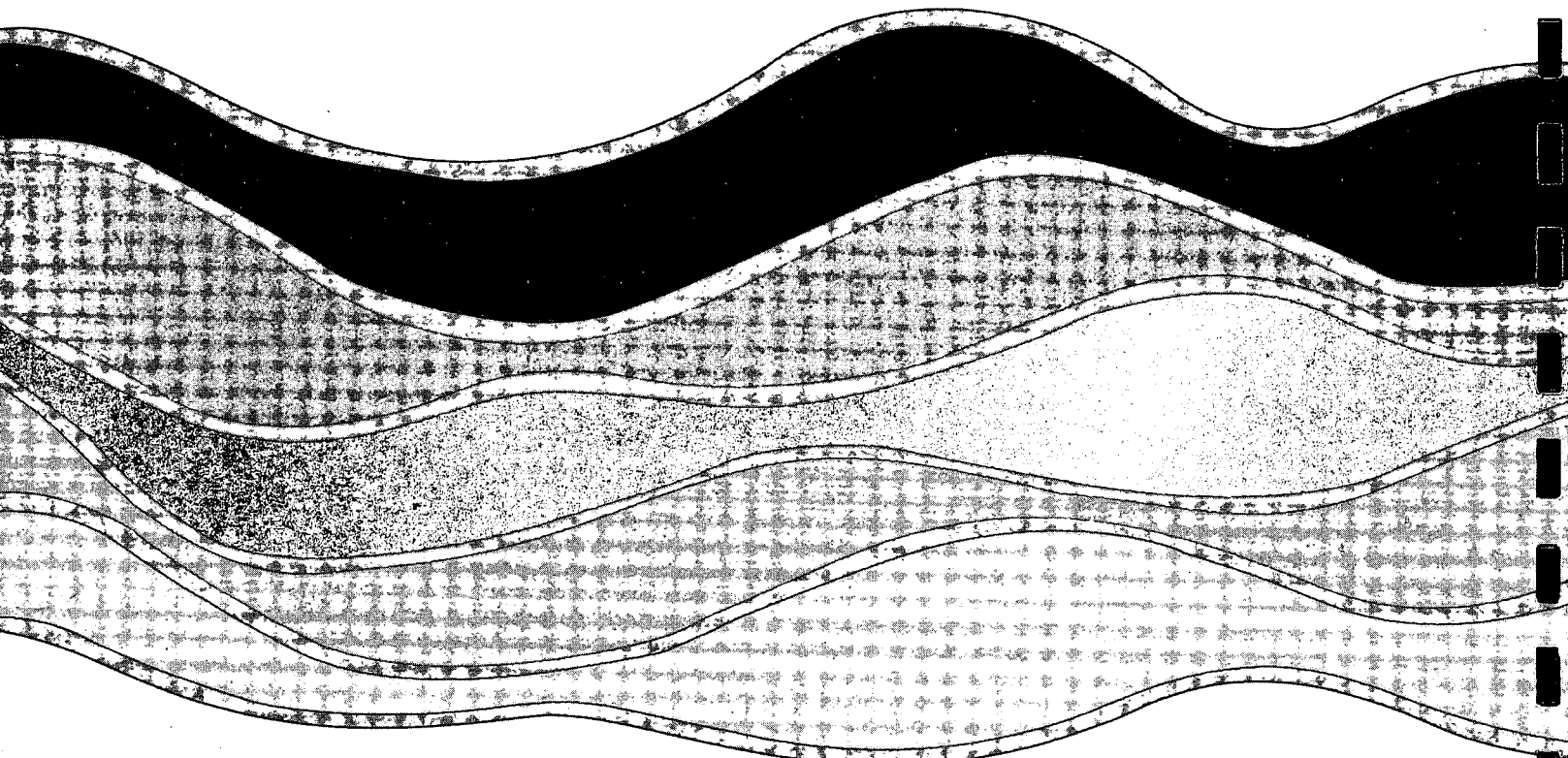
0oC



ENVIRONMENT CANADA LIBRARY, BURLINGTON



3 9055 1016 4717 9



NATIONAL WATER RESEARCH INSTITUTE
P.O. BOX 5050, BURLINGTON, ONTARIO L7R 4A6



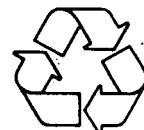
Environnement
Canada

Environnement
Canada

Canada

INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX
C.P. 5050, BURLINGTON (ONTARIO) L7R 4A6

Think Recycling!



Pensez à recycler!