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Visualization and Limnological interpretation of liming treatments in a deep lake, Lake Orta, Italy, using computer generated animations

By:
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MANAGEMENT PERSPECTIVE

This paper presents an application of the visualization program LAKEANIM. The interesting part of this application is two-fold: one is the program has been used to interpret thousands of data (38 cruises at eight stations for four variables, data collected every half metre from the surface to the bottom of a deep lake) collected over two years, the second is that visualization has been performed on a lake with data collected before, during and after a liming treatment. Since the lake is quite deep over 14,000 tons of lime were deposited into the lake over a nine months period. Visualizations of water temperature, pH, dissolved oxygen and conductivity are available both on video tape and on floppy disks.

Visualization and limnological interpretation of liming treatments in a deep lake, Lake Orta, Italy, using computer generated animations

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Lake Orta, in northern Italy, has been acid since the 1960's. Lake Orta is a deep and large lake. The average pH in 1988 was 4.5. As a remedial action, 14,000 tons of calcium carbonate (lime) were added between May 1989 and June 1990. The average pH of the lake increased to 5.52 in 1990. Given the volume of the lake, this is a large increase. A computer generated animation visualizes the change in lake water pH during, and after the treatment.

A colour scale quantifies observed pH values. Data were collected monthly at eight stations, from the water surface to the bottom. Each animation frame is updated weekly. The visualization of over 30,000 data shows that some lime left the lake through the Nigoglia River during the summer months and that liming operations in a large and deep lake have a larger effect in periods of full circulation rather than during periods of thermal stratification.

Animations were created using custom programs written in C, commercial programs (ANIMATOR, DELUXE PAINT II ENHANCED), and shareware programs (VGACAP, GWS) on an MS-DOS platform. The animation is available on floppy disks.

Keyword codes: H 5.1; I 3.3; I 3.6
Keywords:Multimedia Information Systems, Image Generation, Methodology and techniques

1. INTRODUCTION

Located in Northern Italy, Lake Orta has had a persistent low pH in the last 25 years (1963-1988) caused by the ammonium nitrogen discharged over several decades by a rayon factory (Bemberg, S.p.A.), located on its shores (Bonacina et al., 1992). To try to remedy this problem, and to study the effects of direct lake manipulation, starting in 1989, calcium carbonate (lime) was added to the lake (Calderoni et al., 1992). The average pH in 1988 was 4.5 while at the end of the liming treatment, the average pH of the lake had increased to 5.52, a large increase given the large volume of the lake. To verify the effects of this treatment, data were collected at various times, usually monthly, at eight stations.

Computer graphics and computer generated animations (Mahoney, 1992) have been extensively used in many environmental fields, including geology, and oceanography (Katsaros, 1978; Rosenblum, 1989; Miller, 1991). In limnology, however, visualization has not been an area of extensive research (Marshall et al., 1990). The principles of computer generated animations have been presented in a recent textbook by Magnenat-Thalmann and Thalmann (1985).

2. BACKGROUND

Lake Orta, the seventh largest Italian lake by volume and depth, is 12.5 km long (Fig. 1). It is located in a deep long valley at an elevation of 290 m a.s.l. The lake has a maximum depth of 143 m, an average depth of 70 m, an area of 18.2 km^2, and a volume of 1.3 km^3. The watershed area is 116 km^2.

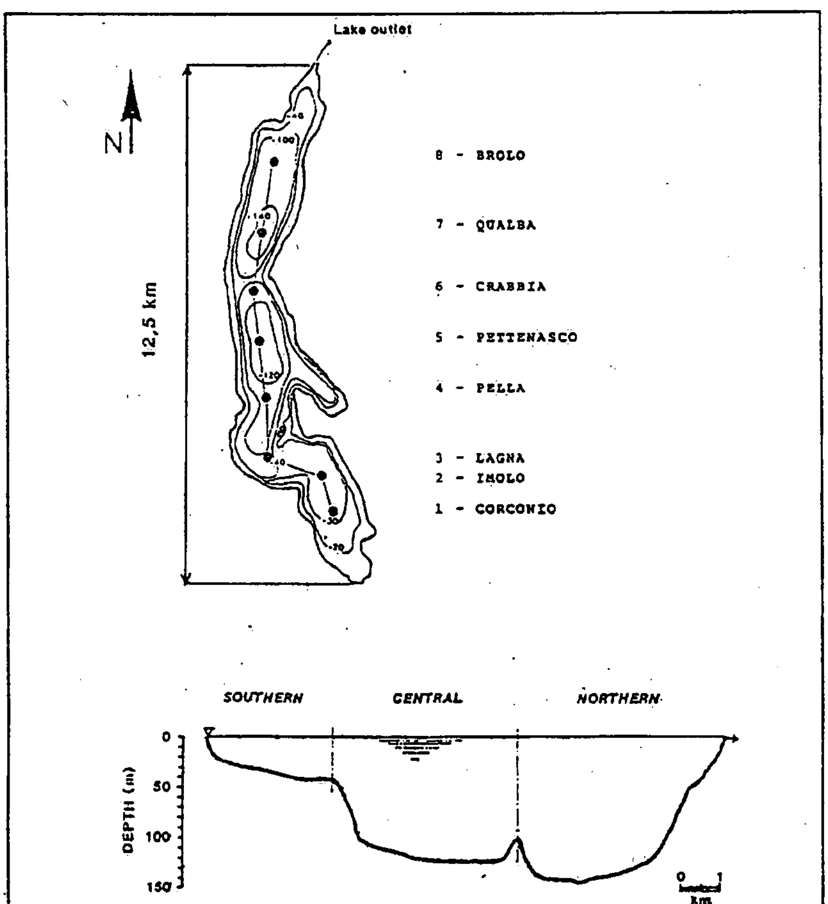

Figure 1. Station locations and a north-south transect

The lake has a shape of a banana, thus, its real length, the "Thalweg", is 14.2 kilometres. Figure 1 shows both the station locations in the lake as well as a north-south transect along the "Thalweg."

The pH in water has changed considerably in the last eight years (1985-1993). In 1985 the water pH was less than 4 (Fig. 2). Following a reduction in ammonium nitrogen loadings since 1981, and a liming treatment starting in 1989, in 1992, the pH had increased to an average epilimnetic value of 6, with a maximum of about 8. Oscillations of epilimnetic pH were evident in 1987-88 (Fig. 2), before liming started. The drastic reduction in ammonium nitrogen loadings 1981, as well as the alkaline surface waters from the watershed, caused these oscillations. The liming treatment, here described, has accelerated the phenomenon of neutralization. In 1989 and 1990 a total of 14,798 tons of calcium carbonate were added with the purpose of increasing the pH in the lake.

During the fourteen months of this project, pH and temperature data were collected at eight stations (Fig. 1) with an electronic probe. Fifteen cruises, approximately every month, but with a larger frequency during the initial stages of treatment, were organized to collect samples while a barge added the lime to the lake. Data were recorded in real time and automatically stored in a spreadsheet.

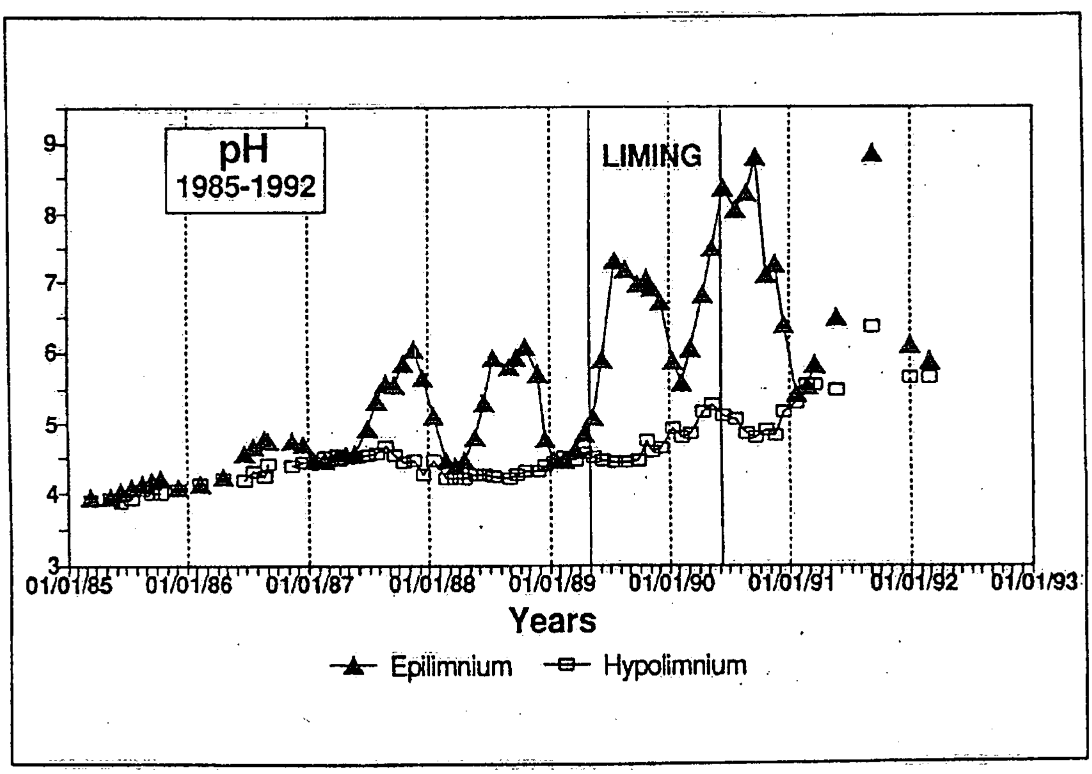

Figure 2. pH trend between 1985 and 1992.

3. PROCEDURE VISUALIZE THE DATA AS ANIMATIONS

Since data were collected at several stations, from the surface to the bottom at one metre intervals, a two-dimensional animation was used to visualize the data collected from 1987 to 1991. The transect covers a north-south section of the lake along the Thalweg.

3.1 Missing data

Data were manipulated for use in a graphical animation environment. An important point was to have a uniform set of data for all 15 sampling periods. One problem was that some data were missing, some were collected at slightly different depths (in different cruises), and to different depths. Missing data were created by linear interpolation.

3.2. Data matrices

The raw data were converted from a matrix of data, 8 x 144, to a matrix of pixels, 144 x 144. One hundred forty four pixels were chosen for several reasons: one is that the lake has a banana shape with an approximate length of 14 kilometres, thus each pixel corresponds to 100 metres. The second reason is that space was required to display on the screen both the pH, and temperature, colour legends. The choice of 144 pixels in the vertical direction was also convenient since the lake has a maximum depth of 143 meters. A total of 15 spreadsheets with dimensions 8 x 144 were created. Eight was the number of stations, and 143 is the maximum depth of Lake Orta. Since not all samples reached the bottom, some of the matrix entries are blank. Data were then exported from the spreadsheet to an ASCII file. In this matrix, the bottom of the lake is indicated by a -1 entry.

3.3. Interpolation

At each sampling period, data were interpolated among all stations. A program was written in C for this purpose. A major problem was to decide how to evaluate the boundary conditions at the shore, and at the bottom of the lake, where data were not collected. This problem was solved with the assumption that the data at the shore and at the bottom had the same values, as sampled at the same depth at the nearest station. This choice was consistent with the knowledge of the limnological characteristics of Lake Orta. Two other procedures could have been followed: one was not to show values at the boundaries, and the second would have been to use other interpolation schemes and extrapolate the data at the boundaries. The first procedure was discarded because the graphic display would not have looked well without the boundaries, and the second procedure was not used because extrapolation might have created data that did not exist and therefore might have confused the viewer.

3.4. Colour palette

Each matrix contained either pH or temperature data. The next step was to convert the data to colour. A program was written to convert each temperature and pH value to a colour. Each shade of colour represents a pH range of 0.11 units. Since we chose to display the data using 128 colours, a new matrix was computed with values between 0 and 127. For temperature, each colour represents a range of three degrees Celsius.

3.5. Key-frames

Frames that display real data are called "key-frames". Key-frames represent real information. Each key-frame represents a monthly picture of the pH: picture created with real data.

3.6. Generation of frames between two key frames: In-between frames

In-between frames visualize the possible evolution of phenomena in the lake each week. Since in-between frames are computed by interpolation in time, and in space, between two key-frames, this visualization might not be completely real. However, it makes it possible to understand how the lake might have changed over time in between observations.

Figure 3 shows an in-between frame (October 16,1989). This frame shows the date, the tons of lime added to the date, a chart of the lake, a pH, and a temperature scale. Figure 4 shows pH isopleths computed with the program SURFER with data collected on October 23, 1989. The two figures are very similar to one another. This confirms the goodness of the in-between image (Fig. 3), when compared with Fig. 4, created by a very different methodology (SURFER).

Generation of in-between frames is the time consuming part of creating an animation. Each in-between frame represents changes that occurred over a week.

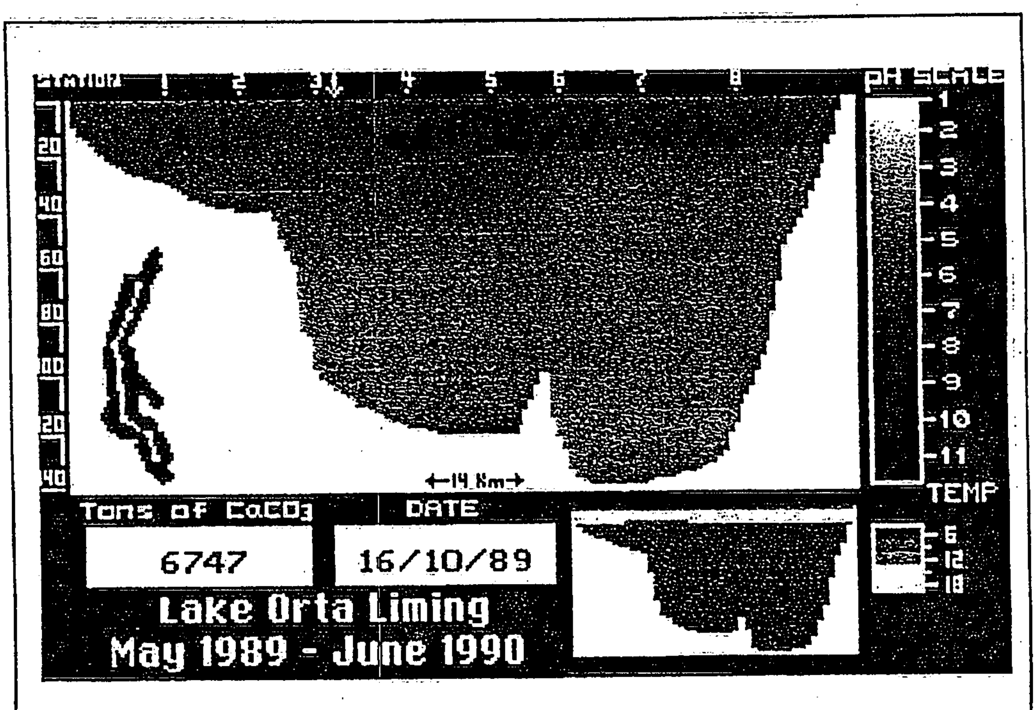

Figure 3.In-between frame that visualizes the possible evolution of pH in the lake.
Top screen, pH; bottom right screen, water temperature.
6747 tons of lime were added from May 1989 to October 1989

3.7. Animations

An animation is produced by creating, and displaying in real time, many frames. Because of limitations of the shareware program VGACAP (Gozüm, 1988), much work had to be done manually and could not be automated. Thus, we decided to create in-between frames with a period of one week. Since the animation lasts 14 months, the total animation has 60 frames, 15 key frames and 45 in-between frames.

The creation of the animation was a time consuming effort: Each frame was created with a custom written program, displayed on the screen, the screen was grabbed by VGACAP, stored on disk, and finally converted to GIF. The GIF files were imported into Autodesk ANIMATOR. VGACAP is a resident utility that captures pictures in 320x200x256 VGA/MCGA mode, any 640x480x256 SVGA mode or any 800x600x256 SVGA mode. The GIF format is a standard graphics file. Graphics Interchange Format and GIF are trademarks (tm) of CompuServe Inc., an H&R Block Company.

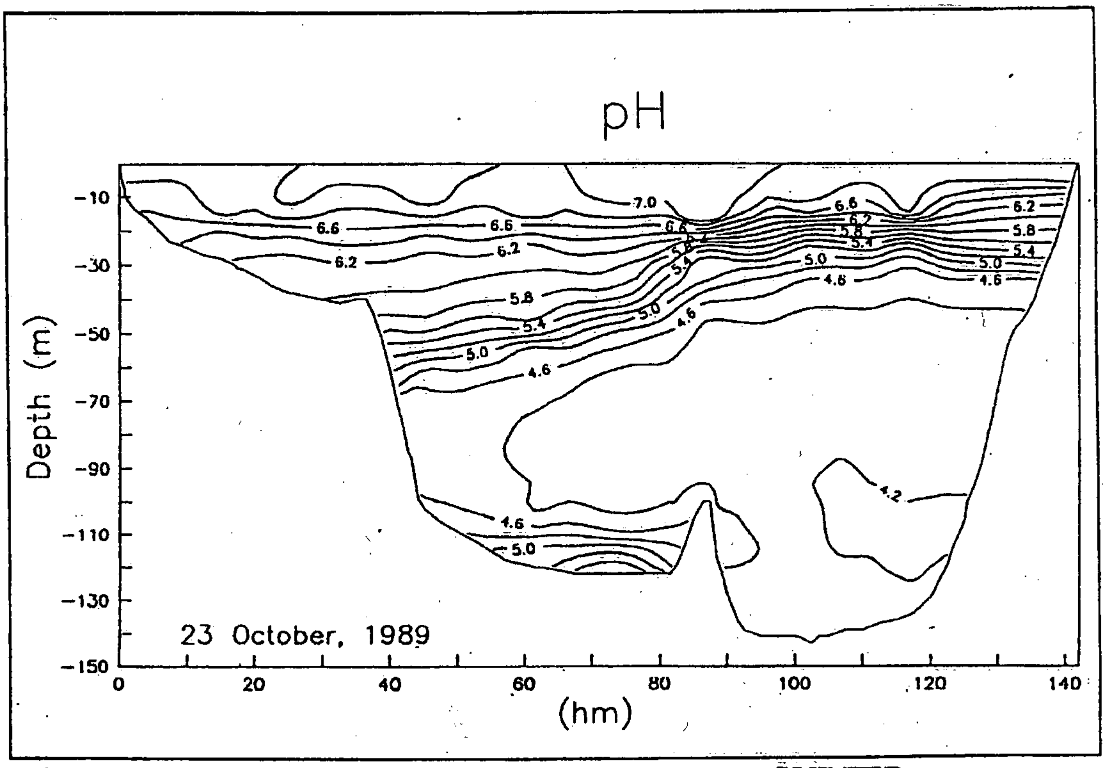

Figure 4. pH isopleths computed with the program SURFER.

3.8. Use of ANIMATOR to create and display the final animations

Autodesk ANIMATOR (The naming of commercial and shareware programs in this paper is for information only. The use of these programs is <u>not</u> endorsed by Environment Canada and by the Istituto di Ricerca sulle Acque) was used display the animation and to edit it. The colour palette was adjusted to make it interesting (Note that it is possible to change the colour palette quite easily, if a user is not satisfied with the one initially chosen). The screen resolution was 320 x 200 with 256 colours. This format is called MCGA since CGA is 320 x

5.1. Year 1989

As liming started in May, in the southern basin, the pH in the epilimnion reached values higher than 8. At the same time, the calcium carbonate sedimented and, in the hypolimnion of the southern basin, quite shallow, the pH increased to between 6 and 7. In the epilimnion of the central and northern zones, the pH did not increase much. In the hypolimnion of these two zones, instead, the pH did not change at all.

Visualization of the thermal structure of the lake and comparison with the variations of pH showed that part of the calcium carbonate had probably left the lake from the Nigoglia River (May - October 1989) due to the high summer thermal stratification.

Since September, all over the lake, pH increased from the surface down to 30-40 metres. At the bottom of the central basin, pH increased due to transport of calcium carbonate from the southern basin.

In November, pH started to become homogeneous (values of 6 to 7 units) both in the epilimnion and in the hypolimnion down to 50 metres.

5.2. Year 1990

Thermal stratification in the lake diminished, until homeothermic conditions were established in February. Liming had been temporarily interrupted in December 1989. In the Spring, liming was resumed. pH increased in the epilimnion but it remained constant in the hypolimnion.

The visualization showed that at the end of the liming treatment in June 1990, the hypolimnion had received small benefits from the liming. This small benefit was caused by in-lake ammonium nitrification (this process leads to acidification of the lake waters). Only in 1992, the potential acidity, due to the high concentrations of ammonium nitrogen, had disappeared (ammonium nitrogen lower than 0.1 mg N/L).

The liming treatment has also influenced the lake chemistry. For example, copper concentration dropped from 35 ug/L to 10 ug/L (Camusso et al., 1992). These artificial changes in the lake chemistry have determined a rapid recovery of the ecosystem, much quicker than the natural one.

6. DISCUSSION

6.1. Animations

This project allowed us the explore the application of animations to display scientific data. As described above, even if the animation only lasts for three minutes, it took much work to develop. The field program had to be organized, data had to be retrieved, analyzed, converted to the proper format, colours had to be chosen, key-frames and in-between frames had to be created and displayed, screens had to be grabbed, colour palettes changed, additional screens added, atlas scanned, etc. The fact that this effort could be completed in just over three weeks could not have been completed without commercial and shareware programs. Even so, a large amount of custom programming had to be developed to integrate these packages.

One of the major drawbacks was the fact that each of the 60 frames had to be displayed on the screen before it could be grabbed by the program VGACAP, saved and converted to GIF. Each step had to be done manually and therefore it was time consuming. VGACAP had to be

manually started (VGACAP is a memory resident program) to store each screen. Since only 60 frames are present the animation is not as smooth as we would have liked it to be. To be smooth, an animation has to be displayed at 30 frames per second.
Thus, a one minute animation would have required 30 x 60 or 1800 frames. To capture 1800 frames manually it would have taken too long. We are now completing a computer program, LAKEANIM. This program renders automatically animations from data and renders a one minute animation in about 15 hours CPU time. This program will be available at the time of publication of this paper.

Animation is an interesting field of research. Organization is needed to collect data in a format suitable for animation. In this effort we used 127 colours. Comments received from individuals that saw the animation indicate that 127 colours are too many. Agreement seems to be that three to 12 colours are enough so that boundaries are easily discerned.

Two-dimensional interpolation is also a major problem. In this effort, we have used linear interpolation. Other two-dimensional interpolation schemes, for example using splines, might give realistic results. The problem of interpolation is also related to the display of events at the boundary where data are not available. This problem is also being investigated.

6.2. Data interpretation through visualization

The animated representation of over 30,000 temperature and pH data has visualized how the neutralization through liming has really taken place in Lake Orta. Some calcium carbonate has left the lake in the summer of 1989 through the River Nigoglia since the lime remained in the epilimnion. Also, the winter overturn has heavily increased the action of liming to the deeper parts of the lake. In other words, the animation visualized how the liming treatment has been heavily influenced by thermal stratification and which water masses have been influenced most by the treatment.

7. CONCLUSIONS

The success of this liming operation on a large (volume, 1.3 km^3) and deep (143 m) lake is due to a good choice of the seasons for the treatment. Often, this choice is not allowed by the rigid winter conditions that preclude technical and barge operations. The success in Lake Orta, observed as increase in water pH, indicates that it is possible to optimize the procedures. Visualization through animation allows interpretation of the data as well as presentation of these results to others.

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