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A MICROCOMPUTER-BASED MODEL OF RADIONUCLIDE SPILLS AND DISCHARGE PLUMES

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A MICROCOMPUTER-BASED MODEL OF RADIONUCLIDE SPILLS AND DISCHARGE PLUMES

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ABSTRACT

This report describes the implementation of a spill model for a shore-based contamination source on Lake Ontario. The code was developed on an IBM PC/XT to model the transport of radionuclide contaminants in the wind-driven shore currents. The model requires as inputs the half-day wind direction and speed for the previous thirty half-days and depth contours of the shoreline. The program computes the movements of discrete elements (representing the pollutants) in these shore currents. The simulation has been adapted to the constraints of the computer and the graphics display device in a representative model. Discrete elements, represented by pixels on the screen are released into the coastal zone domain of the lake. Concentrations are calculated by counting pixels in each control volume.

Features of the simulation codes include: reasonable processing speed and medium-resolution visual display, and variations on the mode of wind history input and graphical output display. Comparison of model results with observed heated plume data indicates good potential of the use of the model as a real-time, operational predictive tool required by spill emergency contingency plans.

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INTRODUCTION

Traditionally, lake hydrodynamic models belong to the class of complex models that require large mainframe computers for the numerical solutions of the governing equations. The level of sophistication in terms of both the formulation of the physical processes and the development of advanced computational methods often surpasses other types of models such as water quality models. However, the operation of these models is not easy, particularly for non-experts.

This paper presents an alternative method which is at least valid for coastal regimes with strong shore-parallel currents and is sufficiently simple for implementation in microcomputers. The development of the method and the verification of the results have been discussed in Murthy et al. (1986). This paper focuses on the implementation aspects, with particular emphasis on the input-output design with microcomputer technologies. The program is interactive and requires virtually no modelling experience to run. In addition, there are several options for outputting the simulation results of pollutant transport using the computed currents. These different modes of output are discussed in this paper and are contrasted with a new set of temperature data collected near the Pickering Nuclear Power Generating Station, on the north shore of Lake Ontario.

The use of temperature as a tracer for a heated effluent plume and its relationship to the tritium release from a nuclear power plant such as the one at Pickering has been established by Lam and Durham (1984). The present study is an attempt to apply the simple model to simulate the effluent plume and to display the results dynamically on a microcomputer colour monitor.

THE COASTAL FLOW MODEL

As discussed in Murthy et al. (1986), if the coastal current U at a given station is specified as integer multiples of a chosen time interval Δt and the wind stress τ is given as average values for each interval of Δt, then the currents and winds are staggered in time such that

$$U_i = U(i\Delta t) \qquad \tau_i = \tau\left[(i + \frac{1}{2})\,\Delta t\right] \qquad i = 1,2,3,\ldots \qquad [1]$$

Furthermore, as proposed in Murthy et al. (1986), they can be related through the following linear approximation.

$$U_i = \sum_{n=1}^{N} R_n\,\tau_{i-n} \qquad [2]$$

where $R_n = \Delta t \ R(n\Delta t)$, $n = 1,2,\ldots,N$, are empirical coefficients determined a priori by calibration with observed data at that particular station.

In the case of the coastal area near Pickering, there are a total of ten stations ($j = 1,2,\ldots,10$) aligned along a transect in a direction perpendicular to the shoreline. Each of these stations generates its own set of the empirical coefficients R_{nj} ($n=1,2,\ldots,N$ and $j=1,2,\ldots,10$). Calibration results show that a total of 30 wind records (i.e. N=30) at half-day intervals are able to produce a good approximation of the actual currents to within 75% of the variance. Thus, there are a total of 30x10 = 300 R_{nj}'s which are all that are required to be stored in the computer to generate the currents at these stations. Compared to the storage requirement of conventional hydrodynamic models (e.g. Simons and Lam, 1985), the saving in both computer memory and execution time is substantial for the present model.

In order to extrapolate the currents evaluated at the ten stations to other points in the coastal area, these currents are linearly interpolated at 1 km intervals along the current meter transect and the main circulations are assumed to be confined to movements along the depth contours. That is, the depth contours become the streamlines. This assumption is valid because it has been found that about 97% of the flow energy is stored in the along-shore direction (Murthy et al. 1986). As long as the radius of curvature of the shoreline is large, the along-shore velocity at any point can be computed from mass conservation principles based on its depth as well as its distance from the shoreline in relation to the current meter transect (Murthy et al. 1986).

THE POLLUTANT TRANSPORT MODEL

The computation of the movement of individual particles proceeds as follows. Let x and y be rectangular coordinates with the x-axis along the mean orientation of the shoreline and the y-axis pointing toward the lake. Let U_j be the currents computed from the empirical equation at the location of the current meter transect such that j=0 represents the shore and $j=1,2,\ldots,10$ are offshore points at 1 km intervals. Let $Y_j(x)$ be the y-coordinates of the shoreline (j=0) and the depth contours ($j=1,2,\ldots,10$) which cross the data transect at 1 km intervals. Finally, let Δu, Δv be the turbulent vleocity components and x_0, y_0 the initial coordinates of the particle. The coordinates x_1, y_1 after time sep Δt are then computed as follows.

First, the two depth contours adjacent to the initial point are found, say Y_j (x_0) and Y_{j+1} (x_0). Then the relative distance is defined as

$$r = [y_0 - Y_j(x_0)] / [Y_{j+1}(x_0) - Y_j(x_0)] \quad [3]$$

Since the mean flow is assumed to follow depth contours, r remains constant along a streamline and the current speed changes in proportion to the inverse of the contour spacing. It follows that

$$u_0 = [U_j + r(U_{j+1} - U_j)] / [Y_{j+1}(x_0) - Y_j(x_0)] \quad [4]$$

and hence the alongshore displacement is

$$x_1 = x_0 + (u_0 + \Delta u) \cdot \Delta t \quad [5]$$

From the same assumption the offshore displacement is found to be

$$y_1 = Y_j(x_1) + r\,[Y_{j+1}(x_1) - Y_j(x_1)] + \Delta v \cdot \Delta t \quad [6]$$

Note that while the velocity U_j is based on the coastal flow model, the turbulent velocity components Δu, Δv must be selected as random quantities to simulate the dispersion.

MICROCOMPUTER PROGRAMMING

The programs are currently written for the IBM PC, PC/XT or PC/AT with the colour graphics interface and the arithmetic co-processor (8087 or 28087). The source code has been developed in the "C" Programming Language, with extensive utilization of the "Halo" Graphics Package (Middleton and Swayne, 1985). The programs are divided into three distinct domains: input, process and output.

The Input Phase

The input phase includes both static and dynamic data files. The static data files refer to files that are specific to the geographical location of the chosen site. At present, only those data specific to the Pickering Nuclear Power Generating Station are used and they include the shoreline file, the depth contour file, the normal grid line file and the linear coefficients, R_{nj}'s. The dynamic data, on the other hand, refer to the wind information that varies dynamically in time. While the static files are 'permanently' defined (i.e. the users are prevented from assess to, and modification of, these files), the dynamic files must be provided by the user. Both the wind history and the current wind conditions are required to generate the currents at any time. Thus, at the outset of the program, the user is asked to supply, if it exists, the name of the file which contains the date and the history of 30 wind records (wind speed in km/hr and wind direction in degrees (calculated clockwise from the north) at half-day intervals. If it does not exist, the user is asked to enter such records and assign an appropriate file name when finished. Then, the user is further asked if the current wind information is already contained in an existing file. Again, if such a file exists, the file name must be supplied and the process phase follows immediately. If not, the user is asked to enter the current wind information (wind speed and wind direction) at each time step, one record at a time.

The Process Phase

The process phase is the most important part in the program. At present, two versions are available: the patch version and the plume version. In both cases, pixels with red colour are used to denote the individual particles or pollutant parcels. In the patch version, only a finite number (e.g. 100) of pixels are released from the discharge site over an initial time period. Beyond this initial time period, no new pixels are released and hence the existing pixels form a group or a patch. In the case of the plume version, a continuous suply of (e.g. 4 or 8) pixels is released from the discharge site at each time step (i.e. at every half-day). Thus, a plume shape can be formed, particularly if the wind has been steady in one direction. The process phase maintains a record of the positions of the pixels, calls upon the user to supply the wind information (when the user chooses to enter it at each time step) or reads the current wind file if supplied, calculates the new positions according to Equations (3) and (4) and moves the pixels to the new positions. In the case of the plume, as more new pixels enter into the picture, the number of pixels increases. This increase in pixels will eventually increase the processing time and may lead to slower picture response. On the other hand, some of the pixels may travel sufficiently far to reach the boundary of the domain and could leave out of the picture. In such a case, the position records for the lost pixels must be deleted so that the memory space is made available to the new pixels. Thus, the process phase performs both computational and accounting aspects of the model.

The Output Phase

The output phase is the one that makes the present model different from those designed for conventional mainframe computers. Here, colour graphics are extensively used so that the computed results are instantaneously displayed on the colour monitor. The background output includes the shoreline, the date and time, the wind vector and the interactive question that the user may have to respond (e.g. enter wind records). The actual output of the computed results

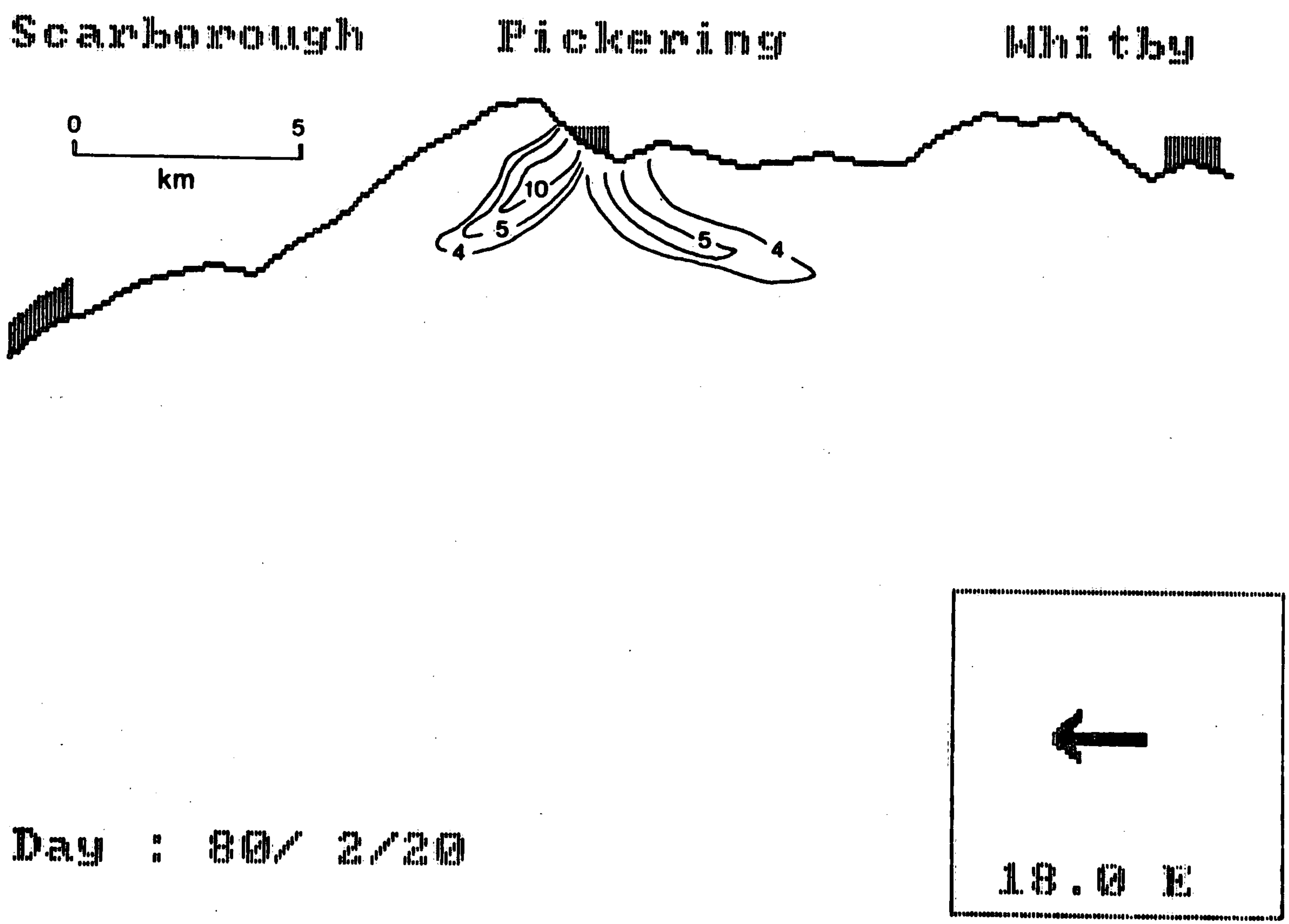

Figure 1. Observed effluent plumes (^{o}C) and wind vector (km/h).

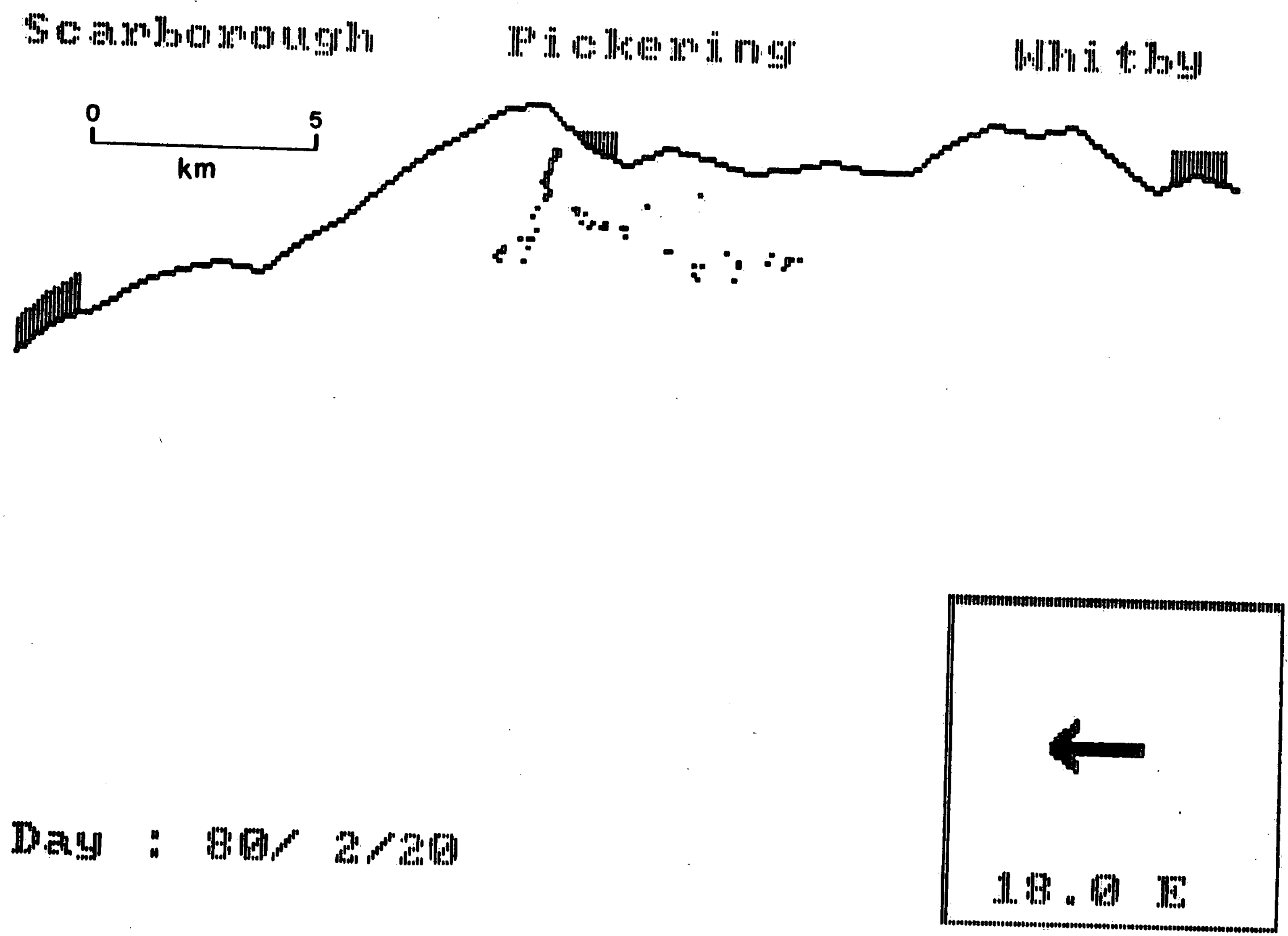

Figure 2. Computed effluent plumes in "points" mode.

can be made in three different modes: points, vector and arc. In the points mode, the computed results are represented by the pixels only.

The density or the sparseness of the pixels provides a qualitative description of the pollutant concentration and the general shape of the patch or plume. At times, however, the pixels may overlap each other and could make the interpretation of the concentration field difficult. The vector mode has been implemented in the plume computation only and is based on the points made with the current and previous position of each pixel connected by a solid colour line to effect a better streamlining of the plume. In the arc mode, which is also implemented for the plume case, the domain is divided into depth contours in the shore-parallel direction and then subdivided into small elements by segmenting these contours in the direction normal to the contours. A rough concentration for each element is then computed by counting the number of pixels in each element. Finally, all these elements will be shown on the colour monitor, with each element coloured by four different shadings to denote the four quartile percentages (0%, 25%, 50%, 75%) of the pixel density. In addition, an arc is drawn to indicate the general direction of movement at the leading edge of the plume.

RESULTS AND DISCUSSIONS

The main results for verification of the model, using the observed currents and temperature, have been presented in the points mode in Murthy et al. (1986). In this paper, the computed results using all three modes of output are presented and compared to a different set of observed temperature data. As discussed in Murthy et al. (1986), the use of the temperature as a tracer of the effluent plume is acceptable within certain limits, and the present results essentially support such an assumption.

Figure 1 shows the observed temperature data for February 10, 1980 at the Pickering Nuclear Power Generating Station. The wind history is such that the wind had prevailed for almost two days from the westerly direction prior to the experiment but shifted to an easterly direction about 15 hours before the experiment. This shift in wind direction caused a bifurcation of the effluent plume, as shown in the data. One branch still contained the remnant plume as marked by lower temperatures lying to the east of Pickering and the other branch was the new plume just emerging from the outfall of the power generating station.

Figure 2 shows the temperature distribution computed by the model equations 1-4 and represented by the pixel positions (i.e. the points mode). The two branches are visible in the pixel distribution. The branch to the east of the Pickering station contains

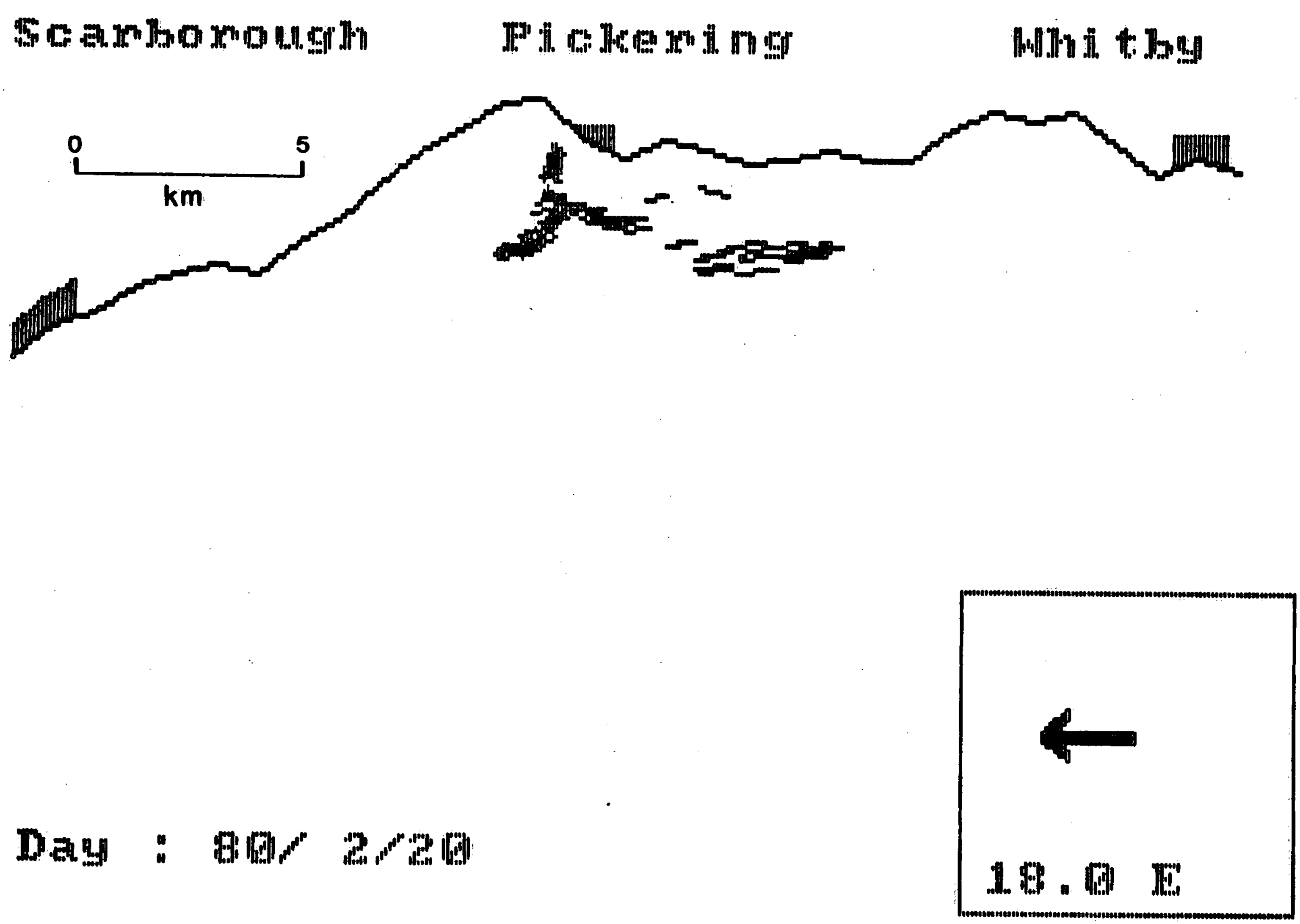

Figure 3. Computed effluent plumes in "vector" mode.

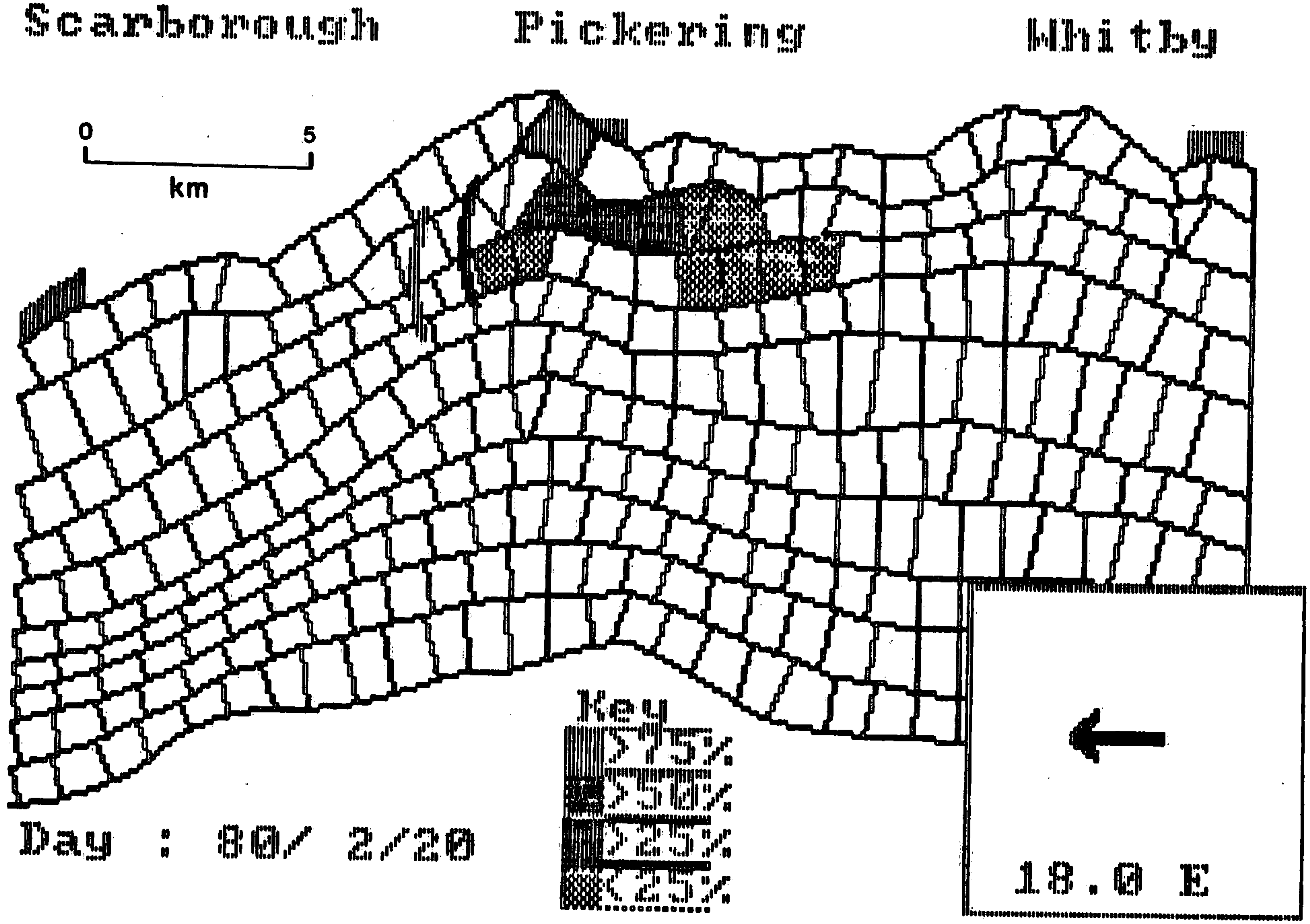

Figure 4. Computed effluent plumes in "arc" mode.

relatively less dense distribution of pixels, indicating lower temperatures, whereas the other branch contains denser pixel points and hence higher temperature.

Figure 3 shows the same computed results but expressed in vector mode. Compared to Fig. 2, this figure provides a better plume shape. Again, the separation of the easterly and westerly plumes is indicated. However, because of the addition of lines between the pixels, it becomes more difficult to discern the pixel density.

Figure 4 also shows the same computed results but presented in shaded and unshaded elements over the entire domain. Note that the elements are subdivided from the belts between different depth contours. The bifurcated plume is not so clearly presented as that shown in Fig. 1. However, the elements containing more pixels (i.e. >75%) are clearly separated from those containing less pixels (e.g. <25%). In a rough sense, therefore, this output mode offers some plume shape as well as a quantification of the computed temperature. Thus, if the inflow temperature is 12°C, then those elements marked by more than 75% pixel density can be assumed to have a temperature of about 9°C and those marked by less than 25%, about 3°C.

While the different forms of outputting have their advantages and disadvantages, the computed results generally conformed to the observed wind shifts very well and hence are able to simulate the observed bifurcation in the thermal plume. Since this is a first attempt to develop an efficient and sufficiently accurate model for implementation in a microcomputer, there is certainly room for improvement. Notably, the extension to nonconservative substances, ranging from those with simple radioactive decay to more complex and inter-reacting species, opens up a new potential of simulation research. Whether they be represented by pixels of different colours or pixels having different luminosity, the computer graphics are definitely essential. The two-dimensional representation used in the present model is valid under a number of assumptions, e.g. strong shore-parallel currents. Difficulties would arise for shorelines having smaller radius of curvature or for shorelines having convex instead of concave curvature with respect to the coastal waters. The ultimate limitation is to extend the model to three-dimensional domains, in which case the requirements for computer memory and time with existing microcomputers could be prohibitive.

CONCLUSION

The use of a simple, linear-response integral function relating the historical and present wind conditions to nearshore circulation has prompted a new application in environmental simulation with microcomputer technologies. It is demonstrated that the presentation by microcomputer graphics is reasonably adequate for a number of alternative outputting designs. Comparison with observed temperature data in the Pickering Nuclear Power Generating Station suggests possible application for predicting a tritium spill on a real-time, instantaneous response basis.

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