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Research and Development

Applications of Computer Graphics to Integrated Environmental Assessments of Energy Systems

Interagency Energy/Environment R&D Program Report

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APPLICATIONS OF COMPUTER GRAPHICS TO INTEGRATED ENVIRONMENTAL ASSESSMENTS OF ENERGY SYSTEMS

by

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ABSTRACT

This report summarizes the first two years of research designed to demonstrate applications of computer graphics to environmental analyses associated with the evaluation of impacts from development of conventional energy systems. The work emphasizes the use of storage-tube computer graphics technology as a means for improving the interaction between the engineer-scientist and the power of the computer. Computer graphics is also shown to be an effective medium for summarizing and communicating information about the environment and pollution control alternatives to technical specialists, managers, and the public. The research has resulted in a saving of time and cost for many analysis. Also, many techniques of analysis previously considered impractical can now be conducted on a routine basis. Applications to several fields of analysis are described in detail, including air quality, water quality, radiological hygiene, industrial hygiene, socioeconomics, and data facilities siting with the use of geographically referenced data.

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SECTION 1

INTRODUCTION

INTEGRATED ASSESSMENT RESEARCH

The energy crisis has reemphasized the importance of electric power in maintaining a vigorous economy. However, because the quality of the environment must be protected, extensive planning and assessment are necessary before power generating capabilities can be expanded responsibly. To meet these objectives, activities involved in system planning and impact assessment have intensified to the point that significant, costly delay occurs between the time the need for an electric power generating facility is first identified and the time the facility actually becomes operational. For the typical nuclear plant, environmental analysis occupies a significant portion of the present lead time of more than ten years. Procedures for expediting these activities and for improving their reliability are essential in assuring adequate electrical power in a cost-effective, timely manner with adequate assurances of environmental quality.

When new generating capacity is delayed, the only alternative rapidly available is the use of combustion turbines. The cost per delivered kilowatt-hour for these oil-fired turbines is more than thirty times that for hydroelectric power and seven times that for nuclear power at current fuel and operating costs.

The Tennessee Valley Authority (TVA) is conducting an Integrated Assessment Program, with funds administered by the Environmental Protection Agency (EPA), that is designed to develop methodologies for speeding the planning and environmental assessment of existing and proposed power generating facilities. Integration of activities consist of (1) improving lines of communications among specialists in planning, engineering design, and impact assessment, (2) developing a unified data base containing information for use in a variety of planning and impact assessment activities, and (3) using more efficient techniques for data display, analysis, and management decision making. The work described in this report concentrates on the third activity and specifically emphasizes the exploitation of computer graphics.

EVOLUTION OF ENVIRONMENTAL ANALYSIS THROUGH THE USE OF COMPUTER TECHNIQUES

For more than a decade, aeronautical, civil, mechanical, and architect-engineers have benefited from analytical applications of computer graphics, often termed "computer-aided design." However, a surprisingly small amount of program funding and technical ingenuity has been applied over this same period to nonstructural engineering applications. The need for recasting many analyses that supply input to the preparation of comprehensive environmental impact statements (such as for nuclear power plants) has provided a focus for developing environmental applications of computer graphics. Most efforts to apply computer graphics to environmental analysis in the past have been limited to geographic or mapping applications; techniques of direct benefit to environmental engineers or scientists have hardly been exploited. The intent of this project is to investigate and develop applications of computer graphics that can contribute directly to reducing delays in designing and assessing environmental impacts of power generating systems.

This work is being performed against the backdrop of practical analysis applications experienced during the planning, design, and operation of energy systems by TVA, the Nation's largest producer of electric power. Techniques that have been developed are general enough to be applicable to organizations other than TVA that are involved with impact analysis of energy systems.

An integrated approach to the assessment of environmental impacts of power generating systems requires the timely consideration of alternative pollutant controls, dispersal of pollutants in the environment, impacts on human health and ecosystems, and the attendant costs and benefits. Many analyses involved in the assessment process can be conveniently performed with the use of computational and data management capabilities of the computer. The full potential of the computer has not been realized because a sizable delay was and still is involved between the time an analysis is requested and the time the processed information is presented in suitable form to the engineer, scientist, or manager. This delay resulted from two causes. First, computer job processing was commonly conducted in a batch mode: Computer programs and data were keypunched and then submitted to the computer for processing; the output was returned to the user at some later time, completing only a single iteration. A second cause for delay was the need for various transformations of the computer output before an analysis could be accomplished: Results from computer processing were commonly presented in a tabular or graphical form selected before the analysis was begun; if the results of the analysis suggested presentation of the data in some format (graphic or tabular) other than the one selected, the analysis was repeated, or the data display was revised manually.

Time-sharing systems have greatly reduced some of the delay involved in running many computer programs. However, interactive graphics terminals make available even more possibilities in accessing the power of the computer. Engineering analysis results can be viewed immediately in graph, picture, or map form on a cathode ray tube (CRT).

The type of display, its orientation on the screen, and particular data sets can be selected readily. A hard copy of the information on the screen that is suitable for many reports can be obtained at the touch of a button. For camera-ready copy, a display can be produced immediately by means of various interactive digital plotters. Hardware capabilities already surpass the available software. Also, achieving the full benefits of such capabilities is hampered by the present lack of manpower to implement imaginative applications.

INTERACTIVE COMPUTER GRAPHICS

Computer graphics encompasses any visual medium through which man and computer can communicate. The computer can be instructed to carry out tedious calculations and data management tasks, and it can process results into a meaningful form, such as graphs, maps, or pictures. A user can then respond to this information by (1) slightly modifying specific parameters and rerunning the analysis, (2) changing the type of analysis entirely, or (3) drawing conclusions and making decisions based on the results of the analysis.

Figure 1 depicts the spectrum of currently available devices for computer graphics output. True graphics output devices are those that can be used to draw straight or curved vectors such as graphics terminals and pen plotters. Quasi-graphic devices, such as line printers and alphanumeric terminals, have the capability of drawing alphanumeric characters at specific locations.

Another distinction between devices for graphic output is based on the computing environment in which they are used; that is, whether the work is predominantly batch or interactive. Batch mode is the process by which a job is submitted to the computing system for processing, and after relatively long periods of time, the output is returned to the user. Pen plotters and line printers are commonly used in this manner. Output from the computer is often stored temporarily before being processed into final form off-line.

The term "interactive" implies rapid response to commands that enables "conversation" with the computer. Some output devices, such as graphics terminals, some electrostatic plotters, and teletypes, can be termed interactive. The working definition of the terms batch and interactive depend greatly on the experience of the user and the nature of the particular response requested. A person who commonly waits a week to obtain a copy of printed output from a computer job might view a system as interactive if the job cycle time were reduced to one day. On the other hand, a person who is accustomed to computer responses of less than one second to simple commands from some input device such as a keyboard would begin to question the interactivity of the system if this response were lengthened to ten seconds. If the user feels that a particular task is difficult (e.g., program processing, calculations, display presentation), a longer response time will be tolerated. Tasks that the user views as simple (e.g., computer response to selections from a menu of commands or editing) must take a much shorter time to be considered interactive.

An effective dialog between user and computer depends not only on the availability of suitable output devices but also on the use of hardware that facilitates information input to the computer system. Typical batch-oriented input devices include punched cards, paper, and magnetic tapes. Devices that promote an interactive environment include an alphanumeric keyboard, CRT, function switches, joystick, light pen, graphics tablet, digitizer, trackball, and touch panels. Even direct verbal communication is possible.

	BATCH	INTERACTIVE
TRUE GRAPHIC	FLAT-BED PLOTTERS COMPUTER ON MICROFILM (COM)	GRAPHICS TERMINALS ELECTROSTATIC PLOTTERS
QUASI-GRAPHIC	LINE PRINTER	ALPHANUMERIC CRT TERMINALS TELETYPE

Figure 1. Spectrum of currently available devices for computer graphics output.

SECTION 2

CONCLUSIONS

1. Computer graphics is an important means for enhancing and expediting many types of environmental analyses.

2. Computer graphics can improve the interaction between the technical specialist and the power of the computer.

3. Computer graphics is an effective medium through which complex information can be communicated to managers, planners, and the public.

4. Computer graphics can be applied to techniques for data display, interactive analysis, and mathematical modeling.

5. Computer graphics can result in a savings of analysis time and cost. Analyses previously considered impractical can be readily accomplished.

6. Although some problems can be anticipated in implementing practical applications of computer graphics on conventional time-sharing computer systems, hardware and software capabilities exist which offer effective solutions to these difficulties.

SECTION 3

SCOPE OF RESEARCH

RESEARCH OBJECTIVES AND GOALS

Although this investigation encompassed nearly the entire spectrum of computer graphics devices, initial work emphasized (1) development of an interactive analysis capability with graphics terminals and various input devices and (2) exploration of potential applications for environmental analysis.

Interactive computer graphics provides the potential for almost immediate analysis. Although computing costs will increase as analyses become more ambitious, savings in the overall cost of analysis can be achieved. More sophisticated (and otherwise impractical or impossible) analysis procedures can be accomplished quickly and inexpensively as projects move toward completion. An overall analysis methodology can be adapted logically and dynamically as intermediate results suggest the application of other specific procedures or data displays. Various design alternatives and system constraints can be evaluated. The engineer, scientist, or manager can concentrate on the meaning of an analysis rather than on manual processing of computer output data or preparation of sketches for a draftsman.

During the first two years of work, efforts were directed toward accomplishing four specific objectives:

1. To develop methods that would use computer graphics to expedite critical environmental analyses of electric power generating facilities.

2. To demonstrate to potential users the range of graphics hardware and software techniques that can be practically applied to environmental analysis.

3. To demonstrate the range of environmental analyses to which computer graphics can be applied.

4. To demonstrate the manner in which environmental analysis, through computer graphics, can improve the planning, design, and operation of energy systems.

At the onset, it was apparent that successful implementation of practical demonstrations of computer graphics depends on three factors:

1. Identification of critical activities in environmental analysis that could be markedly improved through computer graphics.

2. Ready availability of suitable graphics hardware and software to potential users as a prelude to the purchase of commercially available software.

3. Identification and correction of a number of problems in computer systems.

To stimulate the identification of potential applications, seminars illustrating the capabilities of computer graphics were provided to TVA employees involved in activities of environmental analysis. Two videotapes illustrating graphics analysis systems were shown to over 300 people throughout TVA. In response to a questionnaire requesting suggestions for valuable applications, TVA's Division of Environmental Planning identified more than 65 specific potential applications related to environmental analysis. These applications are generically summarized in Appendix A.

SELECTION AND DISTRIBUTION OF COMPUTER HARDWARE AND SOFTWARE

The events leading to certain configurations of computer hardware and software are detailed here to provide a guide to others who may attempt to implement similar graphics capabilities. During late 1975 and early 1976 commercially available computer graphics terminals were reviewed. Although some details are omitted and professionals in the field will note certain exceptions, the discussion suggests the available choices among hardware in common use for engineering analysis. On a practical level, there are basically three possibilities, each with its advantages and disadvantages: the raster scan (video), random beam (stroke writing), and storage tube systems.

Raster scan systems have a CRT display similar to that of a television set. Vector graphics are formed by activating a phosphor dot at the appropriate time while an electron beam continuously scans the screen along lines called rasters. Generally inexpensive, these units possess capabilities of color and shading. However, the raster-type display may not be as pleasing to the eye as one generated with continuous lines. Programming such a system may impose burdens. Light pen interaction introduces more complications with raster scan systems than with other systems.

In random beam graphics systems, the display is composed of lines that are redrawn rapidly on the CRT so that the eye sees a constant display. As more information is displayed, the rate at which the display is redrawn (refresh rate) is reduced, resulting in an undesirable flickering effect. Random beam systems tend to be expensive ($30,000 or more) because they require electronics for storing and refreshing a given display. Light pen interaction and displays involving dynamic motion can be readily accomplished. Software for these systems tend to depend more on the specific application and therefore are less available for general use.

Storage tube display systems, which have become quite popular recently, have (1) the capability of unlimited display without flicker, (2) low cost, (3) excellent resolution, and (4) compatibility with numerous software packages. However, storage tube systems sacrifice brightness (contrast) and offer no shading capability, color, or selective screen erase.

The graphics capabilities needed initially to accomplish the research objectives were reviewed. Capabilities for color, shading, animation, and light pen interaction were not judged to be necessary for many initial demonstrations. We also wished to make graphic terminals available to a large number of different potential users, partly through project funds and partly through the responsiveness of other TVA programs to the needs expressed by users. As a result of these factors, storage tube displays were selected for initial graphics implementation. The terminal selected was a Tektronix 4014-1 featuring a 19-inch (diagonal) screen, four character sizes, upper and lower case letters, and 780 x 1024 addressable points (enhanced mode 3120 x 4096).[1] Programming of this equipment is similar to other types of graphics software (e.g., CALCOMP) with which many users are already familiar. A complete graphics station, including a flexible-disc memory unit, graphics tablet (digitizer), and hard-copy device (digital plotter), was obtained for about $25,000.

Several graphics software packages were available that would make possible the demonstration of a broad range of graphics capabilities when implemented on TVA's IBM 370/165 computer system with the time-sharing option (TSO).

As a result of our inventory of applications, direct assistance was provided to establish five graphics hardware stations in TVA. Table 1 shows the location of each station, the distribution of equipment, and funding arrangements. In several cases, project funds were used to purchase equipment to supplement existing graphic hardware purchased by other means. In one case, project funds were used to purchase the entire graphics station. In another case, no project funds were expended, but assistance was provided in preparing the necessary justification for obtaining the equipment. New graphics software was purchased by TVA's Computer Services Branch from other TVA funds.

Figure 2 shows relationships among the various graphic software packages that have been used to develop demonstrations. All routines are callable by the user in FORTRAN IV. Tektronix Plot-10 Terminal Control System (TCS) contains the basic graphics software, including routines for windowing, clipping, moving the graphics beam, drawing vectors, and initiating input and output operations. A user's application program whose output is to be viewed on the CRT is processed through this group of routines. The Plot-10 Advanced Graphing Package, AG-II, allows ready generation of conventional line, point, and bar graphs that can be tailored to a particular need.

Graphics station location and organization	Computer equipment[a] Tektronix 4014 graphics terminal	Tektronix flexible disc memory 4921	Tektronix flexible disc memory 4922	Tektronix graphics tablet 4953	Tektronix graphics digitizer 4954	Tektronix hard-copy device 4632	Tektronix digital plotter 4662	Texas instrument portable terminal MOD 745
Water Quality and Ecology Branch Division of Environmental Planning 401 Building Chattanooga, Tennessee	0	X		X		0	0	X
Air Quality Branch Radiological Hygiene Branch Division of Environmental Planning River Oaks Building, Muscle Shoals Alabama	0		X		X	X		
Regional Studies Branch Division of Navigational Development Regional Studies, Liberty Building Knoxville, Tennessee	X	X				X		
Forest and Wildlife Resources Branch Division of Forestries, Fisheries and Wildlife Development Norris, Tennessee	0		X		X	0		
Water Quality and Ecology Branch Division of Environmental Planning E&D Building Muscle Shoals, Alabama	0					0		

[a]Symbols: X--purchased or leased with the use of research project funds; 0--obtained by other funding arrangements.

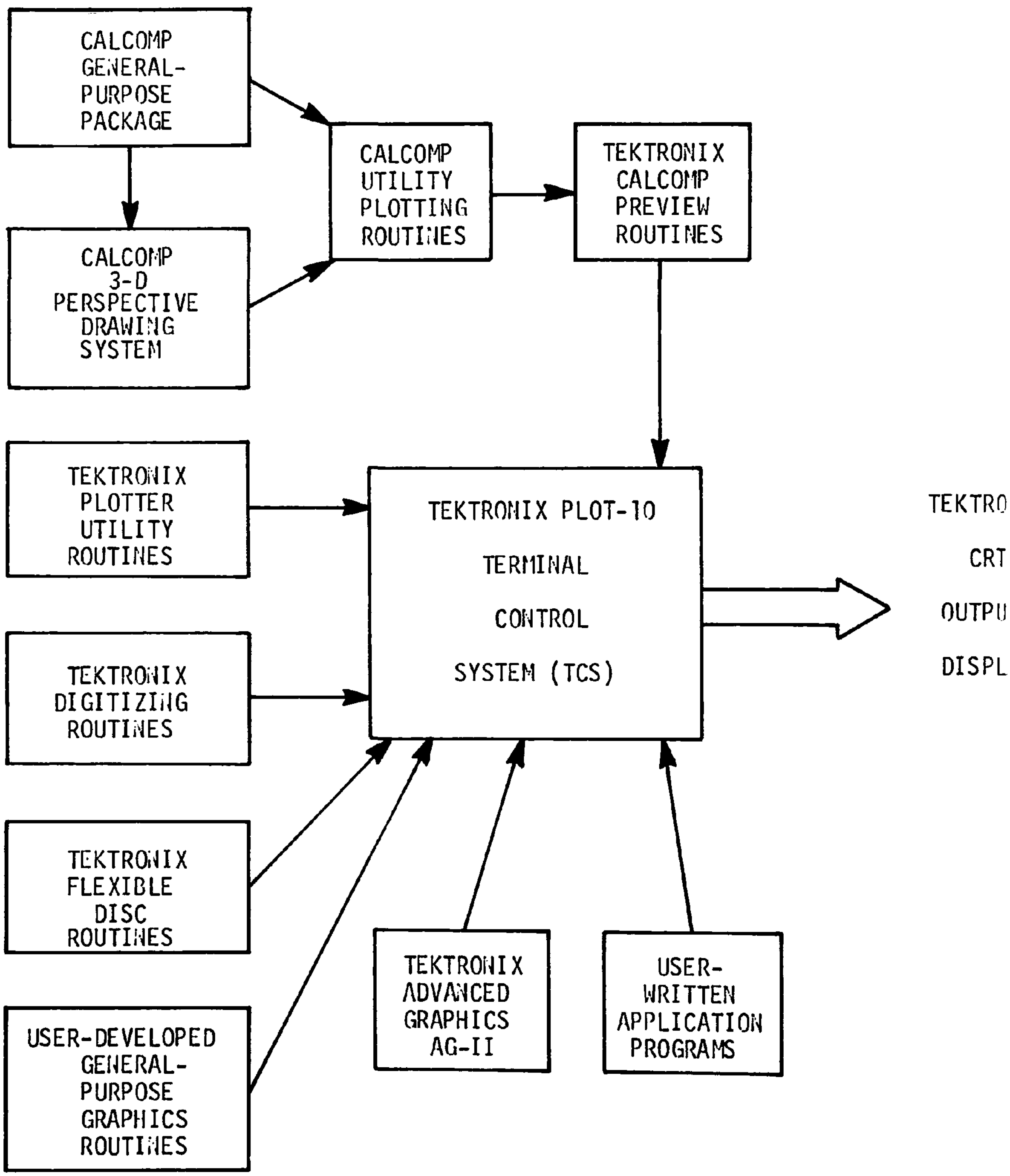


Figure 2. Relationship between TVA's graphic software packages.

The Plot-10 Graphics Tablet (Digitizer) and Plot-10 Flexible Disc Utility Routines allow the user to communicate readily with this hardware and exercise its various operational modes. Tektronix Plot-10 CALCOMP Preview Routine permits programs written with CALCOMP's utility plotting routines[2] to be viewed on a Tektronix graphics terminal with few, if any, program changes. TVA has available two other CALCOMP graphics software products, a general-purpose contouring package (GPCP), and 3-D perspective drawing software.

SECTION 4

DEVELOPMENT OF GENERAL-PURPOSE GRAPHICS

One group of computer programs that operates in this software environment deserves particular mention. Some of these routines were developed to make graphics easier to use. Other routines were formulated to preclude the development of similar graphics routines by individual users. These routines and their capabilities are described below.

The computer-generated displays presented throughout this report represent either a copy of the CRT display shown to the user or a composite made up of several CRT displays and combined manually. In most cases annotation for the figures was added by manual methods (computer-generated text cut and pasted into position). Programming the annotation required for publication by using the currently available low-level software is a rather tedious and time-consuming activity. This fact represents a prime limitation for providing "complete," computer-generated, camera-ready report figures. However, more sophisticated graphics software to facilitate figure annotation is beginning to be offered commercially. The use of these capabilities will be explored in the near future.

INTERACTIVE GRAPHICS DISPLAY PACKAGE (IGDP)

Although computer graphics can often shorten the time required for analysis, the overall cost for the analysis may not be reduced. Although requirements for manpower and elapsed time are reduced, computer processing cost may increase. To keep computer time charges at the lowest possible level, an interactive graphics software package that is simple, inexpensive, and easy to use was developed to display three-dimensional data (i.e., one variable as a function of two others) with (1) a minimum of program development time, (2) a minimum amount of data manipulation to generate the required input format, and (3) a maximum degree of flexibility for generating a display of the required complexity to convey technical meaning and thus minimize the amount of computer processing required. This work was deemed necessary to stimulate interest in applications using this display capability before the purchase of more flexible, but expensive, graphics software was justified.

The IGDP is made up of five basic graphics routines: (1) numeric data presentation routine; (2) partitioned contour plotting routine; (3) conventional line contour routine; (4) three-dimensional surface plotting routine; and (5) two-dimensional sectioning routine.

Overall control of the programs and file allocations are accomplished for the user automatically through a command language program (CLIST). Selection of any or all of the various graphics modules is made by answering yes-and-no questions. Instructions explain the various graphics options available within a particular routine.

Input to this package consists of a regular, rectangular (X,Y) array of data corresponding to vertical coordinate (Z) values. Array sizes (X,Y) up to 250 x 250 have been used. Interpolation of values for missing data and selection of regular increments for X and Y data are intentionally left to the user because the particular technique for interpolation depends on the particular application. Including routines for interpolation and incrementation in the graphics package would have complicated the problem (e.g., delayed the provision of some early capabilities and increased programming complexity) and added little to the graphics output.

The user may also alter his input data format to illustrate a particular feature of the data more effectively. This is particularly true for three-dimensional displays. For example, the user may find that, by surrounding the array of data with some meaningful reference value, he can make relationships of various points of the generated surface clearer as compared with those on an arbitrary surface in space with no points of reference.

Use of the specific graphics routines is illustrated below. As an example, a data set was created that contained the concentration of a chemical dye measured at a particular time in the surface water near a series of waste discharges and water intakes along a reach of the Tennessee River.

1. The Numeric Data Presentation Routine is used to display the complete array of input data in an orderly format selected by the user. The user can also store this reformatted array as a data set on the flexible-disc memory unit or as a member of his TSO library. Figure 3 shows an annotated copy of the CRT display of input data for the example. The arrangement shown can be considered as a plan view of the data.

2. After the Partitioned Contour Plotting Routine calculates maximum and minimum values of the data, it prompts the user for the desired number of intervals into which this range of data is to be divided. The data values are then partitioned into these intervals, and a letter or symbol can be plotted at each corresponding data location. A key for interpreting the plot is also given. Figure 4 shows the sample data presented in this form; ten intervals were selected.

3. After the Line Contouring Routine calculates minimum and maximum values of the data, it prompts the user for the number and values of the contour intervals to be plotted. For a rectangle composed of data values at each corner, a simple calculation determines whether each of the specified contours crosses through or is contained inside the figure. Intersections of a contour with the rectangle's boundaries are then connected by straight lines. Figure 5 illustrates this procedure for the sample data.

RIVERBANK (0.1 mi. INCREMENTS)

DISTANCE OUT FROM BANK (10 FT INCREMENTS)

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	0.6	0.0	7.0	1.8	2.6	11.0	31.0	25.0	18.0	49.0	0.0	0.0	0.0	0.0
0.5	1.6	1.9	6.8	1.0	0.8	11.0	29.0	19.0	3.6	95.0	0.0	0.0	0.0	0.0
1.0	2.7	2.2	6.4	0.5	0.7	1.2	16.4	14.2	0.8	2.4	0.0	0.0	0.0	0.0
2.0	2.7	2.5	9.0	0.0	0.0	0.8	0.6	9.9	0.2	0.2	0.0	0.0	0.0	0.0
2.3	2.8	2.7	11.6	0.0	0.0	0.5	0.2	5.6	0.2	0.0	0.0	0.0	0.0	0.0
2.6	2.9	2.9	14.5	0.0	0.0	0.2	0.2	1.3	0.1	0.0	0.0	0.0	0.0	0.0
2.9	3.1	3.5	14.4	0.0	0.0	0.0	0.1	1.0	0.1	0.0	0.0	0.0	0.0	0.0
3.0	3.3	4.1	14.3	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0
3.8	3.5	4.9	14.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
3.2	3.6	5.4	7.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.5	3.8	5.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.5	3.8	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.5	3.8	4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CONCENTRATION (mg/l)

Figure 3. Formatted tabulation of concentrations of dye in surface water, as generated by IGDP software.

RIVERBANK (0.1 Mile)

DISTANCE OUT FROM BANK (10ft)

A	A	A	A	A	A	A	A	A	A	B	A	A	A	A
A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
A	A	A	A	A	A	B	D	C	B	F	A	A	A	A
A	A	A	A	A	A	B	D	C	A	K	A	A	A	A
A	A	A	A	A	A	A	B	B	A	A	A	A	A	A
A	A	A	A	A	A	A	A	B	A	A	A	A	A	A
A	A	A	B	A	A	A	A	A	A	A	A	A	A	A
A	A	A	B	A	A	A	A	A	A	A	A	A	A	A
A	A	A	B	A	A	A	A	A	A	A	A	A	A	A
A	A	A	B	A	A	A	A	A	A	A	A	A	A	A
A	A	A	B	A	A	A	A	A	A	A	A	A	A	A
A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

KEY-mg/l

0.0	-	9.500	A
9.500	-	19.000	B
19.000	-	28.500	C
28.500	-	38.000	D
38.000	-	47.500	E
47.500	-	57.000	F
57.000	-	66.500	H
66.500	-	76.000	I
76.000	-	85.500	J
85.500	-	95.000	K

Figure 4. Partitioned contour plot (ten intervals) of concentrations of dye in surface water, as generated by IGDP software.

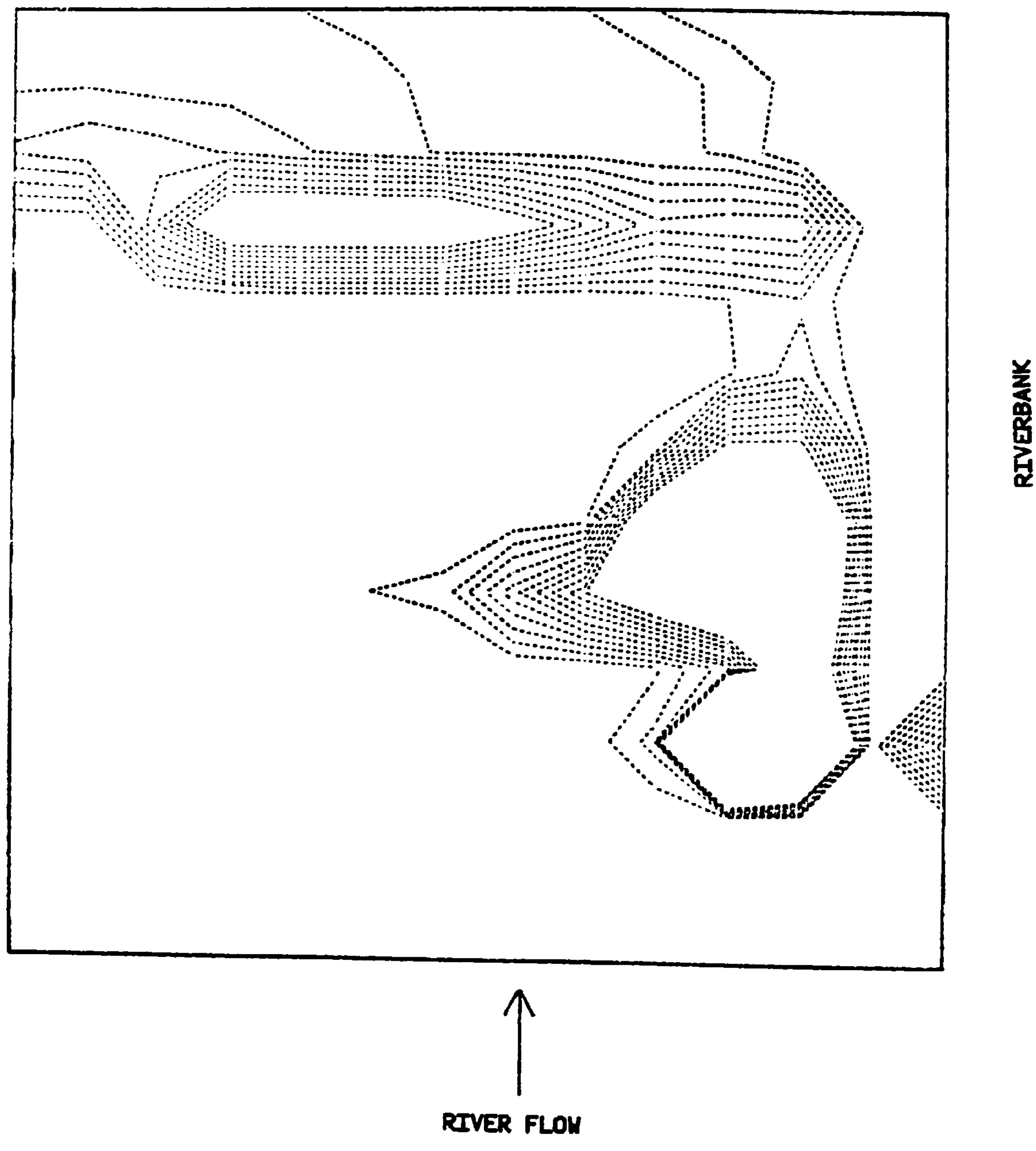


Figure 5. Line contour plot of concentrations of dye in surface water, generated by IGDP software.

4. The 3-D Perspective Routine plots the data viewed as a continuous surface. The user then has numerous options for manipulating the display, including figure rotation, surface tilt, distance of eye from figure, position and size of figure on screen, exaggeration of Z axis (expansion around mean data value), automatic or manual scaling of data by the drawing routine, and degree to which the X,Y directions are scaled with respect to the Z data values. Figure 6 shows a three-dimensional view of the sample data.

5. The 2-D Cross-Section Routine allows the user to interactively obtain cross sections of the surface orthogonal to either the X or Y axis. Profiles may be overlaid on each other for comparison. Figure 7 shows cross sections at several stations perpendicular to the river bank.

KIVIAT DIAGRAM PLOTTING ROUTINE

Many scientific and engineering problems involve the study of complex systems. Analysis of systems impacted by man is now receiving considerable attention. The objective of a typical analysis is to determine and evaluate changes in the states of the systems with respect to time and space. To accomplish this task, many variables must be considered simultaneously. For example, to access changes in the eutrophic conditions of a body of water, the physical, chemical, and biological characteristics are used to describe the state of the system. To assess the impacts of a power generating facility on local socioeconomic conditions, the state of that system might be represented by variables quantifying the availability of facilities for education, health care, recreation, transportation, housing, and community services such as garbage collection, police and fire protection, water supply, and sewage disposal. Social attitude and political and sociopsychological factors may also be important in some analyses.

Many statistical and mathematical techniques have been used to quantify and visualize sets of multivariate data.[3] Diversity indices and clustering techniques are numerical methods commonly used by biologists. Various graphics displays have also been developed. Anderson[4] has suggested the use of circular glyphs to represent multivariate data. Chernoff and Rizvi[5] have described the formulation of a cartoon face for simultaneously displaying as many as 18 variables; the quality of the resulting face communicates information about a system.

Morris[6,7] has described the use of a graphical configuration (Kiviat diagram) in which variables are scaled and plotted along axes oriented as spokes of a wheel; when the data points are connected, a characteristic polygon results. A similar technique has been applied to medical research,[8,9] to aquatic chemistry,[10] and in the presentation of sensitivity analysis results generated with an aquatic systems model.[11] In the latter case, 365 axes, representing days of the year, were distributed in a circular configuration.

At the top of Figure 8 is shown one form of the Kiviat diagram adapted to socioeconomic impact analysis. Six variable axes, each representing a different indicator of socioeconomic conditions, and two

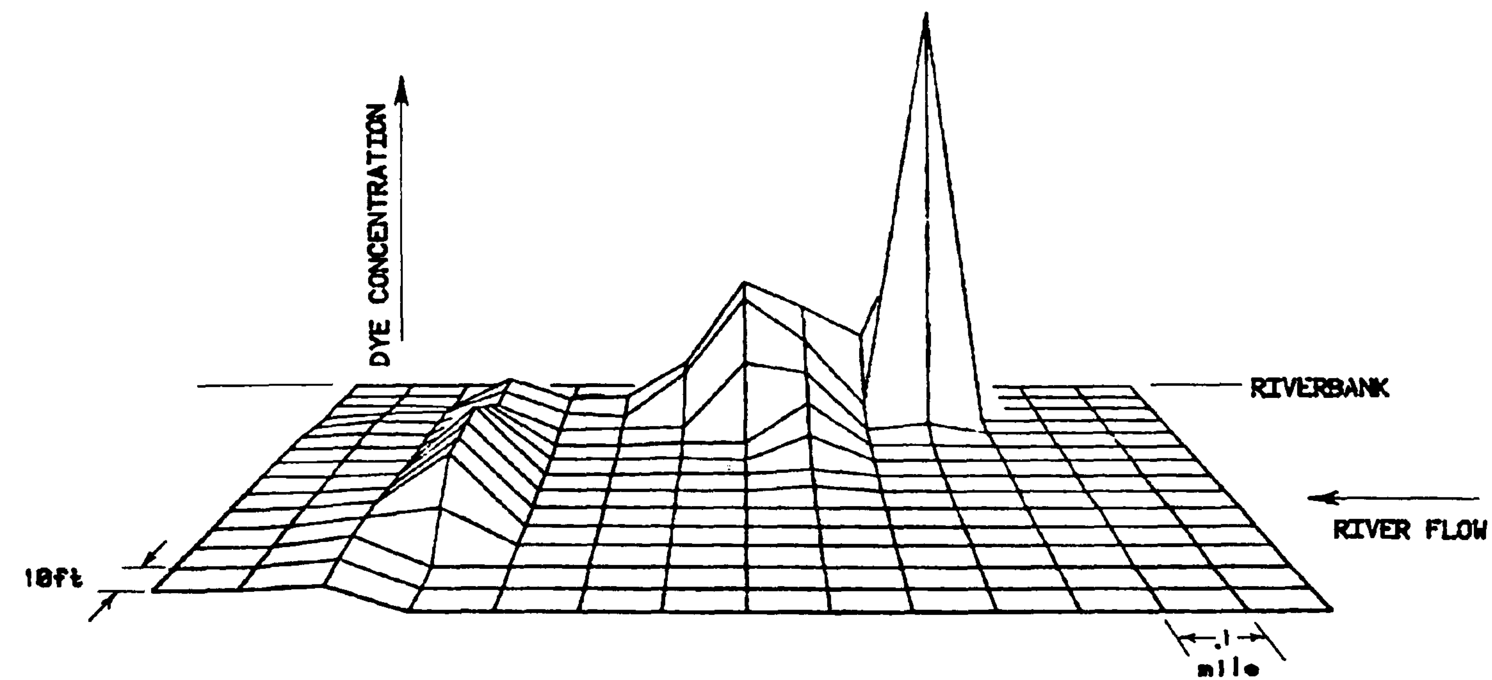


Figure 6. Three-dimensional display of concentrations of dye in surface water, as generated by IGDP software.

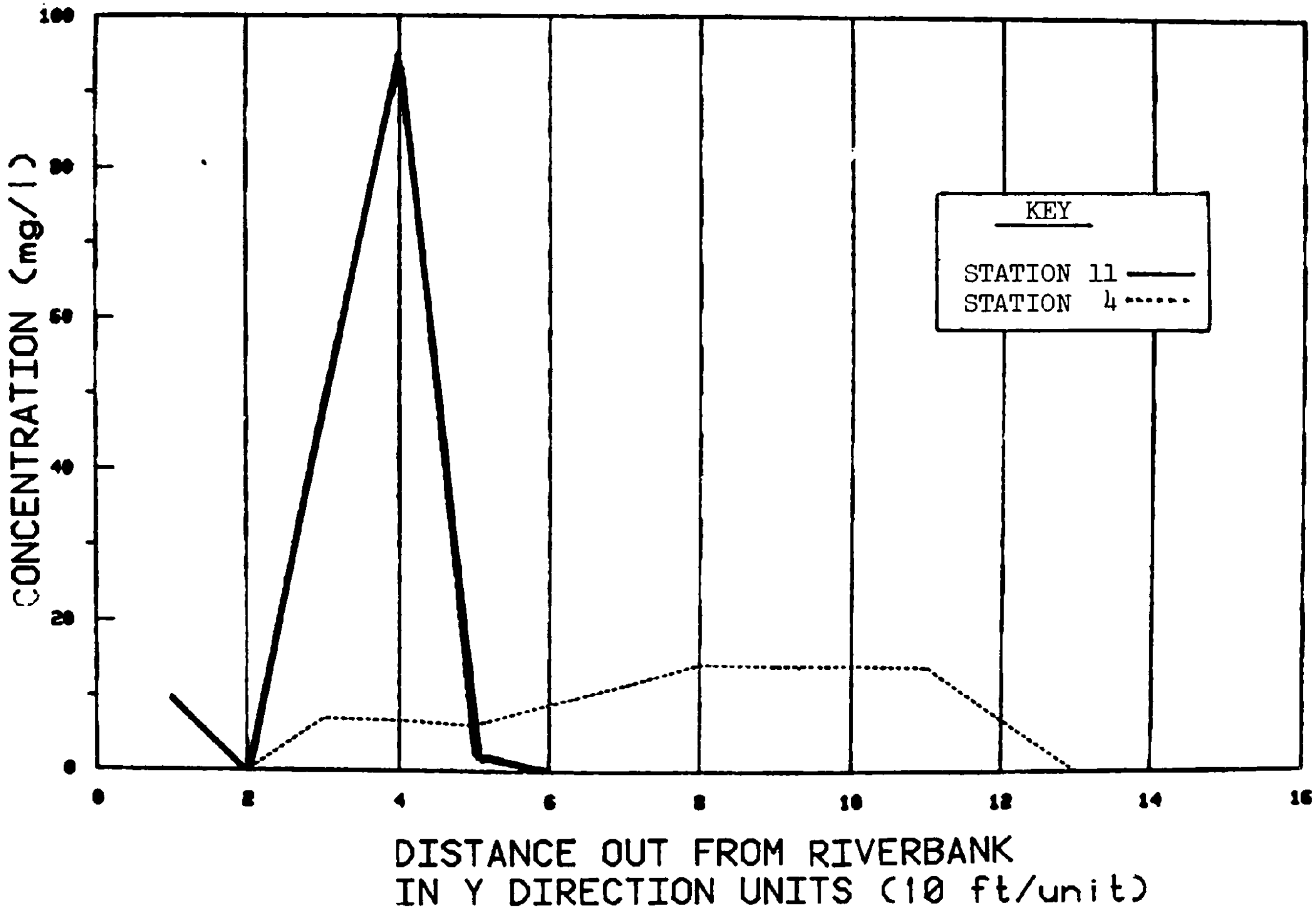


Figure 7. User-selected profiles of dye concentrations perpendicular to the river bank, as generated by IGDP software.

vertical dummy axes were used. The six county-wide variables selected here might be used to measure the desirability for establishing family residences, which may, in turn, be important to an industry or government considering relocation or expansion of activities. The six indicators selected are (1) average teacher's salary, (2) average family income, (3) police expenditure per capita, (4) unemployment rate, (5) percent on welfare, and (6) housing vacancy rate. Another group of variables tailored to siting situations for other facilities could have been used just as easily.

Inspection of the selected indicators in this sample case revealed that the display could benefit from logical grouping into two categories. The first three indicators might be termed "desirable" county features, whereas the last three indicators might be termed "undesirable." County ratings for these two categories of variables were grouped on the left and right sides of the diagram. On the left side, indicators (1) through (3) were plotted so that a rank of one (highest-ranked county) was plotted along the particular axis at a distance equal to the radius. A county with average rank was plotted at a distance equal to one-half the radius. The county with the lowest ranking was plotted at the circle's center.

Indicators (4) through (6) were plotted differently, since high rank indicates a relatively undesirable condition; for these the plotting scheme is inverted. The county with the lowest percentage of its population on welfare, for example, was plotted at a distance equal to the radius. The county with the highest welfare rate was plotted at the center of the circle. Thus, when all the points are connected, including points arbitrarily near the two central vertical axes, a closed polygon results. The resulting figure resembles a butterfly for a county that rates high in all categories. Stated another way, the better the county's overall ratings, the more the figure will achieve a well-developed butterfly shape. Other characteristic images can be constructed by reclassifying and rearranging variables and by using other plotting schemes.

At the bottom of Figure 8, the results of the analysis for eight actual counties (ranked among 22 East Tennessee counties) are shown. Numerical results of this are shown in Table 2. Note that the data are more difficult to interpret from the numeric listing than from the graphic display. It is readily apparent from the figures that counties A and B are more desirable places to live than are counties E and H. County C rates very low on the "desirable" indicators and average on the "undesirable" indicators. County D is average with respect to both sets of indicators. The utility realized by this graphical technique depends on the user's ability to develop an arrangement of the display that conveys meaning. Flexibility can be achieved by varying the number and type of variables, spatial relationship of the axes, and the location and number of dummy axes. Actual scaled numerical values, variances, or residuals can be plotted instead of rank. Other figures, ranging from arbitrary polygons to highly structured figures such as multipointed stars, can be formed.

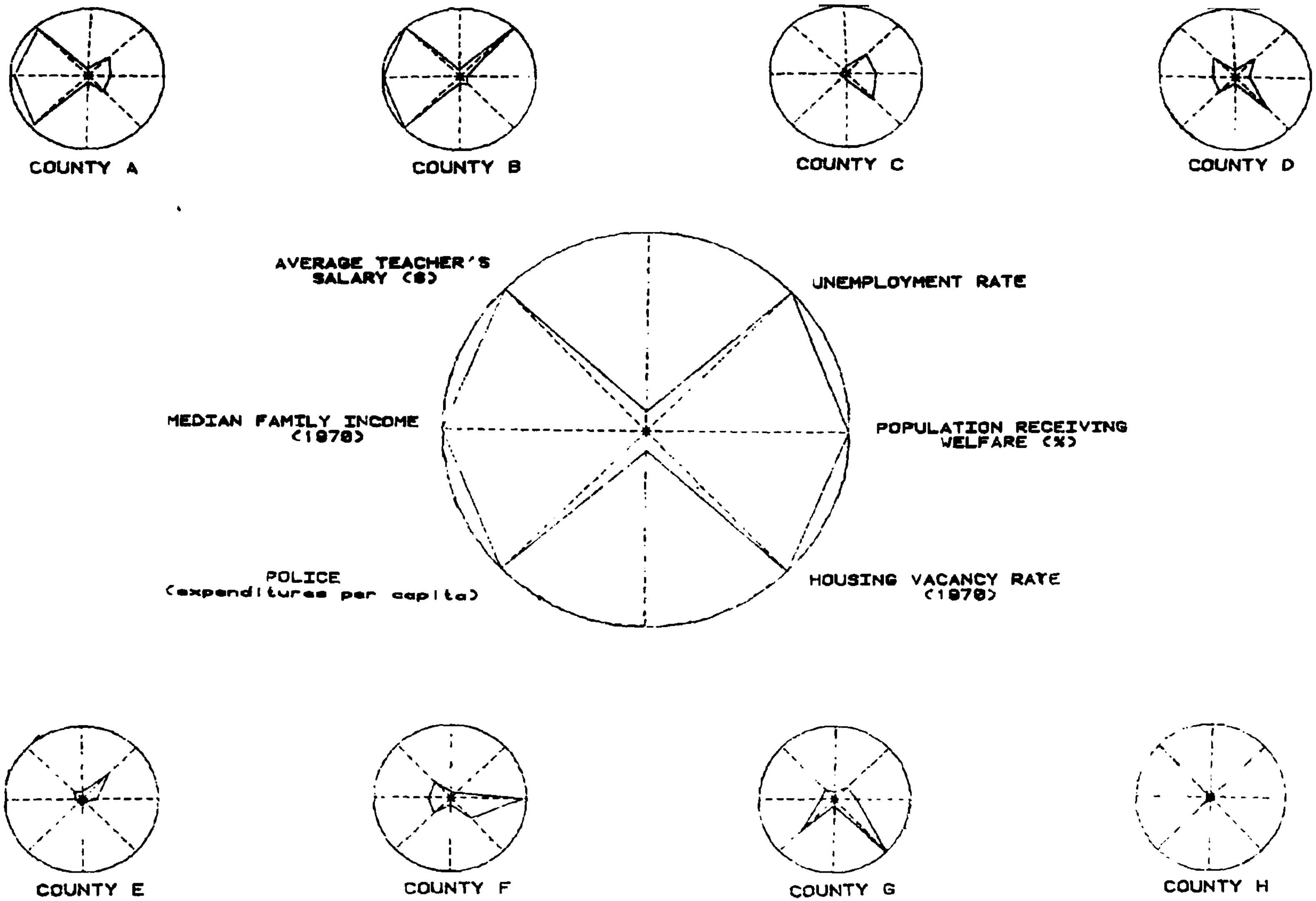


Figure 8. Butterfly configuration of a Kiviat diagram applied to the description of a socioeconomic system.

TABLE 2. NUMERIC RANKINGS AMONG 22 COUNTIES FOR SIX SOCIOECONOMIC INDICATORS

Name	Percent on welfare	Percent unemployment rate	Average teacher's income	Average personal income	Police expenditures per person	House vacancy rate
A	7	10	2	2	2	8
B	3	22	1	1	4	4
C	11	11	21	19	22	14
D	4	12	12	16	13	15
E	5	15	18	20	21	2
F	21	4	13	14	14	9
G	8	6	16	18	7	22
H	1	1	20	22	17	1

Figure 9 shows an example of a star shape that can be used to illustrate the condition of an education system. Information about the system can be inferred from the degree to which the resulting polygon has achieved a given shape and from the symmetry, area, or centroid location of each figure. A series of figures can be used to represent progression of the system in time or space.

To explore the use of various types of diagrams, an interactive computer graphics routine was developed. The user conversationally enters the necessary display information at a computer terminal. The resulting display is shown immediately on a graphics CRT. An experimental plotting variation can then be studied. The user can also interface this display routine with the results of numeric computation routines, allowing complex data manipulation to drive each new display.

Although the examples discussed above used socioeconomic data, other types of data common to environmental and management analysis have been displayed by means of the Kiviat diagram programming routine:

1. The variance of monthly samples of benthic insects at six sample locations (one figure per month).

2. Chlorophyll composition in field water samples (one figure per depth).

3. The measured concentrations of sulfur dioxide leaking around the circumference of a stack (one figure per elevation level).

4. Economic, environmental, and engineering factors relevant to implementing air pollution control alternatives (one figure per generating facility).

5. Five metallic elements obtained from core drillings (one figure per sample depth).

6. Nine physical and chemical variables of water quality (one figure per sampling station and time).

7. The variation in the predictions of a water quality model after a small perturbation in input (one figure per year's simulation).

8. Managerial skills of project personnel (one figure per person).

9. Elements of costs at a given coal-fired steam plant.

One sample of each display is shown in Figure 10.

Experience has shown this technique to be more useful for some applications than for others. Usefulness depends on the nature of the data itself, the level of efforts applied to develop a suitable display scheme, and judgment in the selection of variables. Nevertheless, this simple graphical technique can lead to new and valuable insights into the meaning of a given set of data.

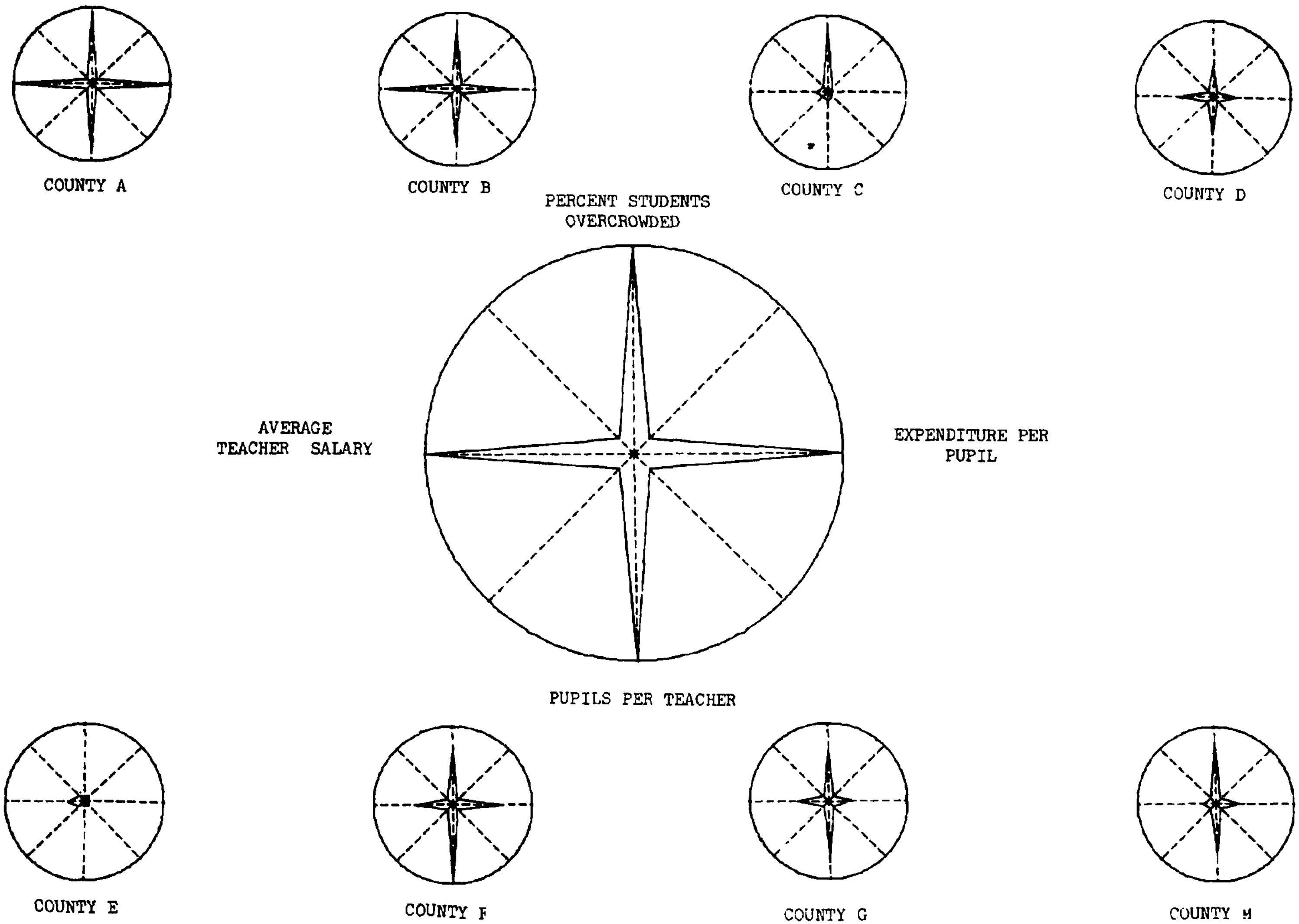


Figure 9. Star configuration of a Kiviat diagram depicting county-level educational indicators.

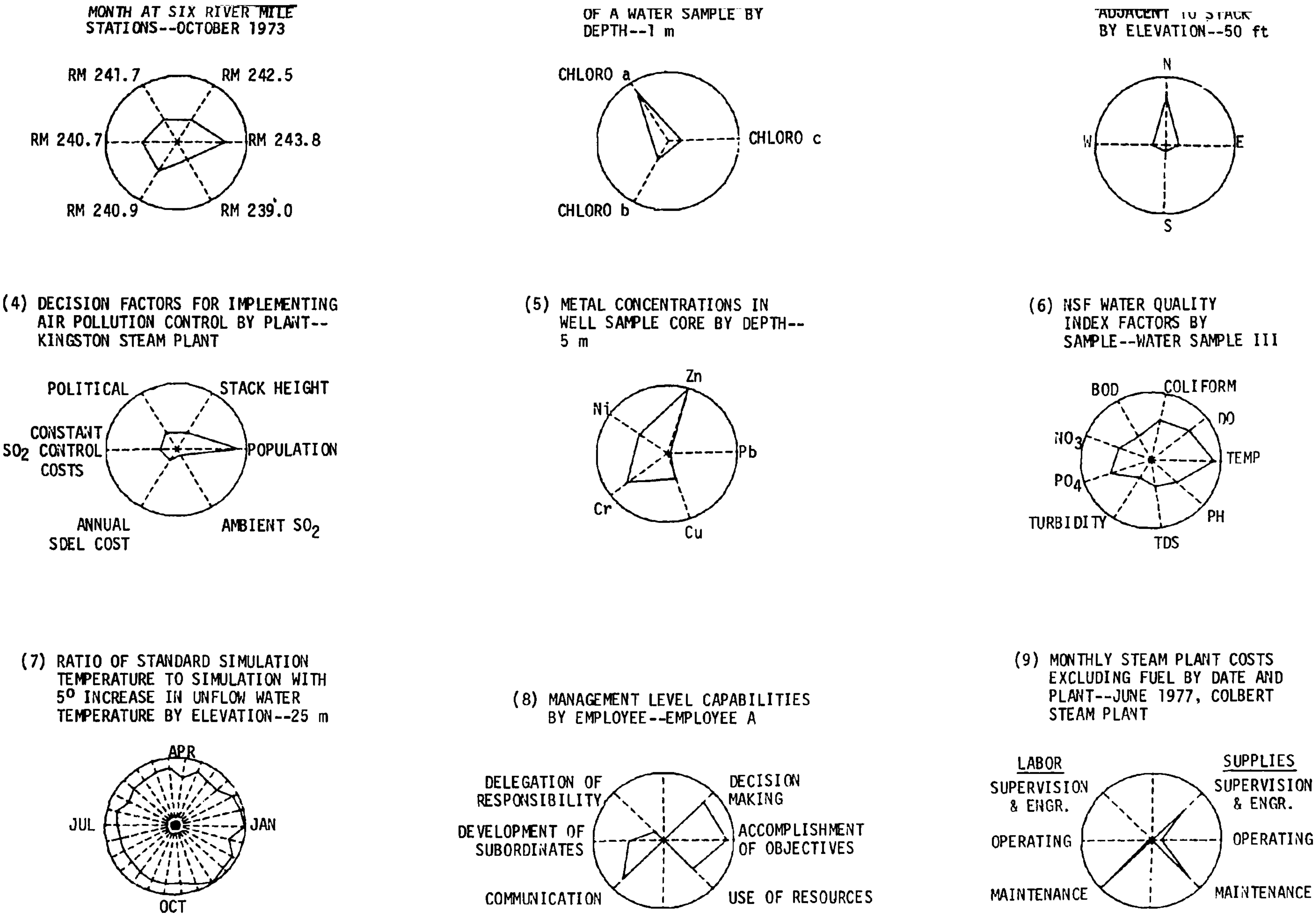


Figure 10. Nine examples of the use of the Kiviat diagram for engineering and management analyses.

INTERACTIVE AG-II PLOTTING ROUTINE

A general-purpose program for plotting data was developed that allows the user to interactively generate a conventional plot of data that is tailored to a particular need. The program is intended for use by individuals familiar with TSO and plotting options with Tektronix Plot-10, AG-II Software. Figure 11 shows two plots of three sets of data displayed first as a bar chart and then as a line plot. Data to be plotted can be input to the program from either the terminal or a data set in the user's library. Data can be specified as X,Y pairs or as X and Y arrays. Several sets of data can be read to create overlays of different data. Fourteen basic options are avaiable to alter and label the figure (Table 3). This program has found wide application because it provides for rapid viewing of data, eliminating the need for developing special programs.

TABLE 3. USER-DEFINED OPTIONS FOR GENERAL-PURPOSE PLOTTING PACKAGE

Parameter	Option
Character size for labeling plot	4 sizes
Size (type) of major tick marks on X and Y axes	6 types
Size (type) of minor tick marks on X and Y axes	6 types
Type of scale along X and Y axes (linear, log, etc.)	8 types
Suppression of zero value labeling	2 levels
Type of symbol plotted for each data value (including bar chart shading)	11 types (15 bar shades)
Size of data symbol	Continuous
Type of connection line through data (including bar chart selection)	9 levels plus any user-defined line type
Missing data value designators	Variable
Draw frame around plot	2 levels
Width of individual bars	Continuous
Labels for X and Y axes	20-character maximum
Scaling minimum and maximum X and Y axes	Calculated from data or user-defined
Screen minimum and maximum coordinates in X and Y directions	0-1024 (X) 0-780 (Y)

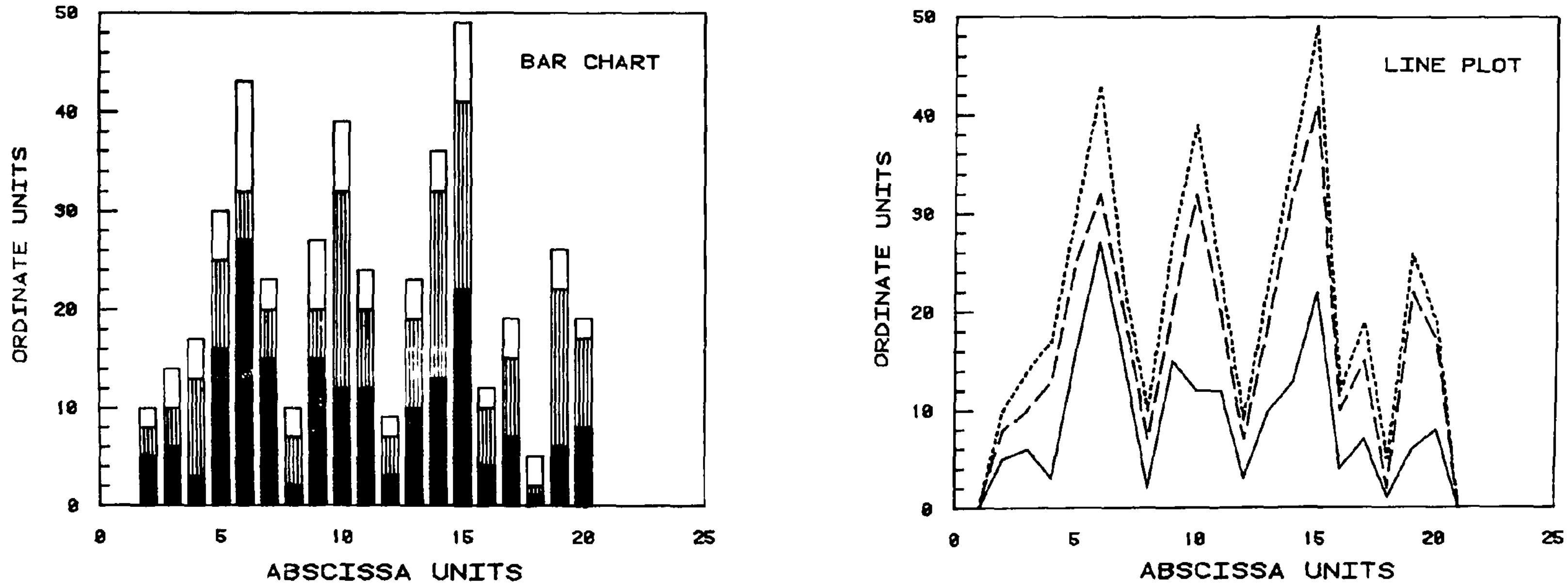


Figure 11. Sample plots of data using the interactive AG-II plotting routine.

DIFFICULTIES INVOLVED IN IMPLEMENTING GRAPHICS HARDWARE AND SOFTWARE

At the onset of this project, several difficulties were encountered that could potentially inhibit practical implementation of certain demonstrations. Later, some difficulties arose as the result of the demands placed on TVA's computer system by rapid increase in use of interactive computing. Other difficulties resulted from problems in the Tektronix software as implemented on TVA's computer system. Finally, as user interest intensified, there were problems in meeting the specific demands of certain applications by means of the existing combinations of hardware and software. Appendix B lists these difficulties and describes approaches to solutions.

SECTION 5

APPLICATIONS AND DEMONSTRATIONS OF COMPUTER GRAPHICS

This section details representative types of applications that have been developed for various aspects of environmental analysis of energy systems. Data display, interactive analysis, and interactive modeling are discussed.

It should be reemphasized that the graphic displays shown in Section 5 represent either a copy of the CRT display shown to the user or a composite made up of several CRT displays and combined manually. In most cases, annotation for the figures was added after the graphics were produced to meet specific requirements for publication. Text was computer-generated and then affixed to the basic figure in an appropriate location.

AIR QUALITY ANALYSIS

Display of Data

Many types of data are used to analyze air quality. Figure 12 shows a display of measured ground elevation and, below it, the measured depth to bedrock. The data were gathered by actual field measurements to investigate the reason for wide variations in growth of soybeans on adjacent test plots that received identical care. These plots formed the test area to (1) study the effects of sulfur dioxide from coal-fired steam plants on crops and (2) determine the effectiveness of a local air cleaning system for controlling crop exposures.[12] Using the three-dimensional data displays made soil depth in the vicinity of the experimental plots easy to visualize. Those test plots with shallow soil depths produced less soybean growth than those with greater soil depth, as might be expected. This analysis was useful for designing future experiments.

A second application arose for the same research project on air quality effects--a study of dose-response kinetics through controlled concentrations of sulfur dioxide, nitrite, nitrate, and ozone in a vegetation growth chamber. To "calibrate" the chamber, representative environmental variables--illumination, relative humidity, temperature, and ozone concentrations--were measured at several locations in the enclosure. Figure 13 shows a sample of the illumination data. The figure clearly illustrates that illumination is not uniform, but slightly higher at one end of the chamber than at the other and slightly higher along the centerline than along the sides. This graphic display can guide readjustments of the lighting arrangement and suggest the magnitude of this source of variation (illumination) in the statistical treatment of data.

Many analyses of air quality require the simultaneous consideration of different variables measured in the field. Computer graphics provides the means for rapidly combining this data in a format suitable for analysis.

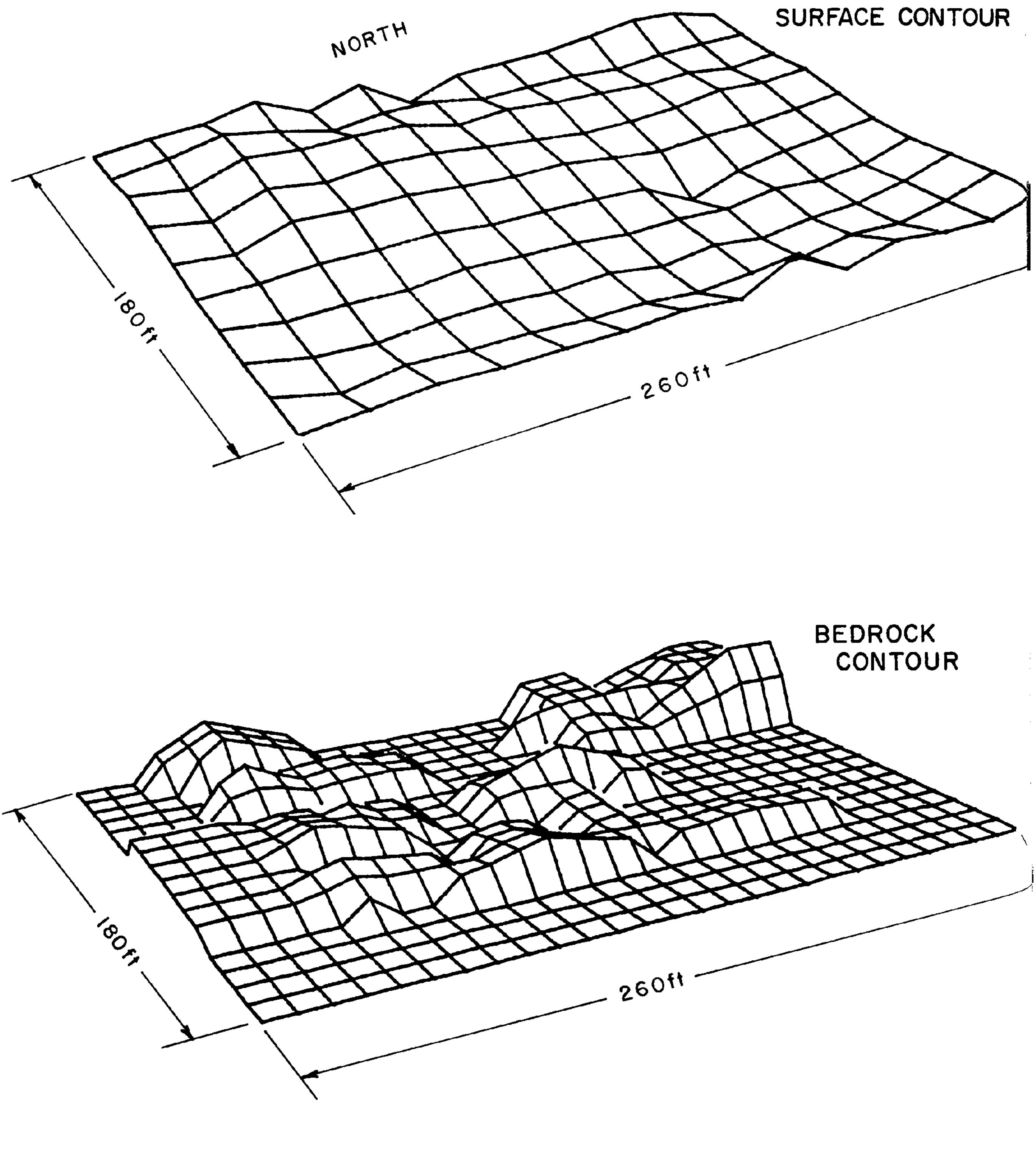


Figure 12. Profile of measured ground elevation and bedrock in the vicinity of soybean test plots.

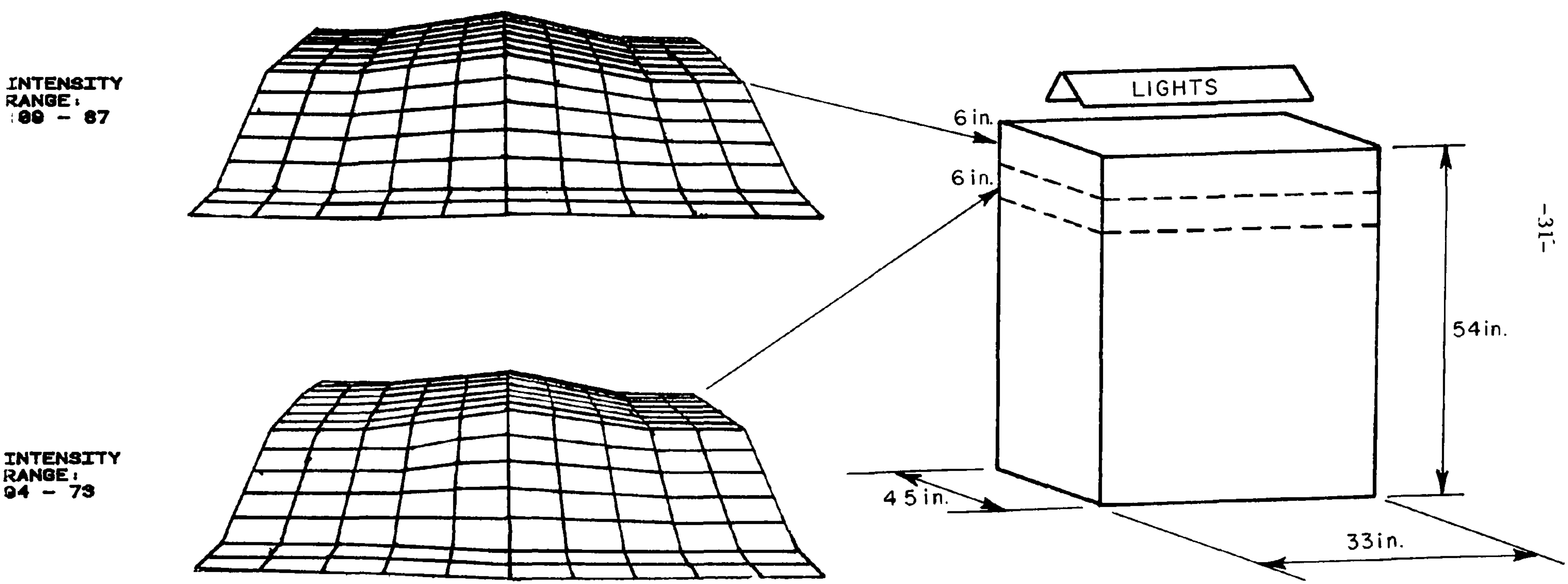


Figure 13. Measured illumination levels at two elevations in a vegetation growth chamber.

Figure 14 shows a complex plot for measured data at a particular time at TVA's coal-fired Johnsonville Steam Plant. At the top is a bar chart that relates which of the plant's ten generator units are operating and at what particular capacity. The main portion of the plot consists of various variables, including potential temperature (a thermodynamic temperature parameter), epsilon (a measure of turbulence), wind speed, and wind direction, plotted against height above ground. Also shown in Figure 14 is a plot of the visible plume boundaries and the plume's centerline. Such display routines have greatly reduced the time needed to present the air quality engineer with field data and to prepare a report after completion of the analysis.

Interactive Analysis of the Effects of Mobile Point Sources

Computer graphics can improve the decision-making process by providing a means for establishing a rapid, meaningful interaction between the scientist or engineer conducting an environmental analysis and the power of the computer. That is, interactive computer graphics allows technical expertise to focus on the meaning of a particular analysis or on an evaluation of different alternatives while the computer generates the necessary computations and manages the data and output display. Figures 15 and 16 show two steps in analyzing distributions of air pollutants from mobile point sources. The situation simulated in the analysis might be encountered during the construction of a power-generating facility. Various types of equipment (vehicles, machinery) that generate gaseous pollutants can be distributed over the construction site in a given pattern. A typical analysis entails several steps:

1. The user is presented with a grid (100 m on a side) on the CRT. If needed, a digitized map of the construction area can be overlaid on the grid as a reference.

2. The user then dynamically positions any number of sources on the grid with the terminal's cross-hair cursor. The characteristics of each source (strength, height) and the meteorological conditions are then entered from the keyboard. Figure 15 shows a completed source grid.

3. The computer then calculates the pollutant concentration at each point on a downwind receptor grid (1600 m on a side). Output from the analysis is available in tabular, contour, or three-dimensional format using IGDP. Figure 16 shows a three-dimensional representation of resultant distributions of pollutants for specified conditions of Figure 15.

4. The user then can repeat the initial step, change the input variables, and again view the output. Patterns of pollutant dispersion from this analysis can be linked to mapping routines, which could overlay patterns of land use, land cover, or environmentally sensitive areas. Models that predict receptor impacts could be invoked, and the results displayed.

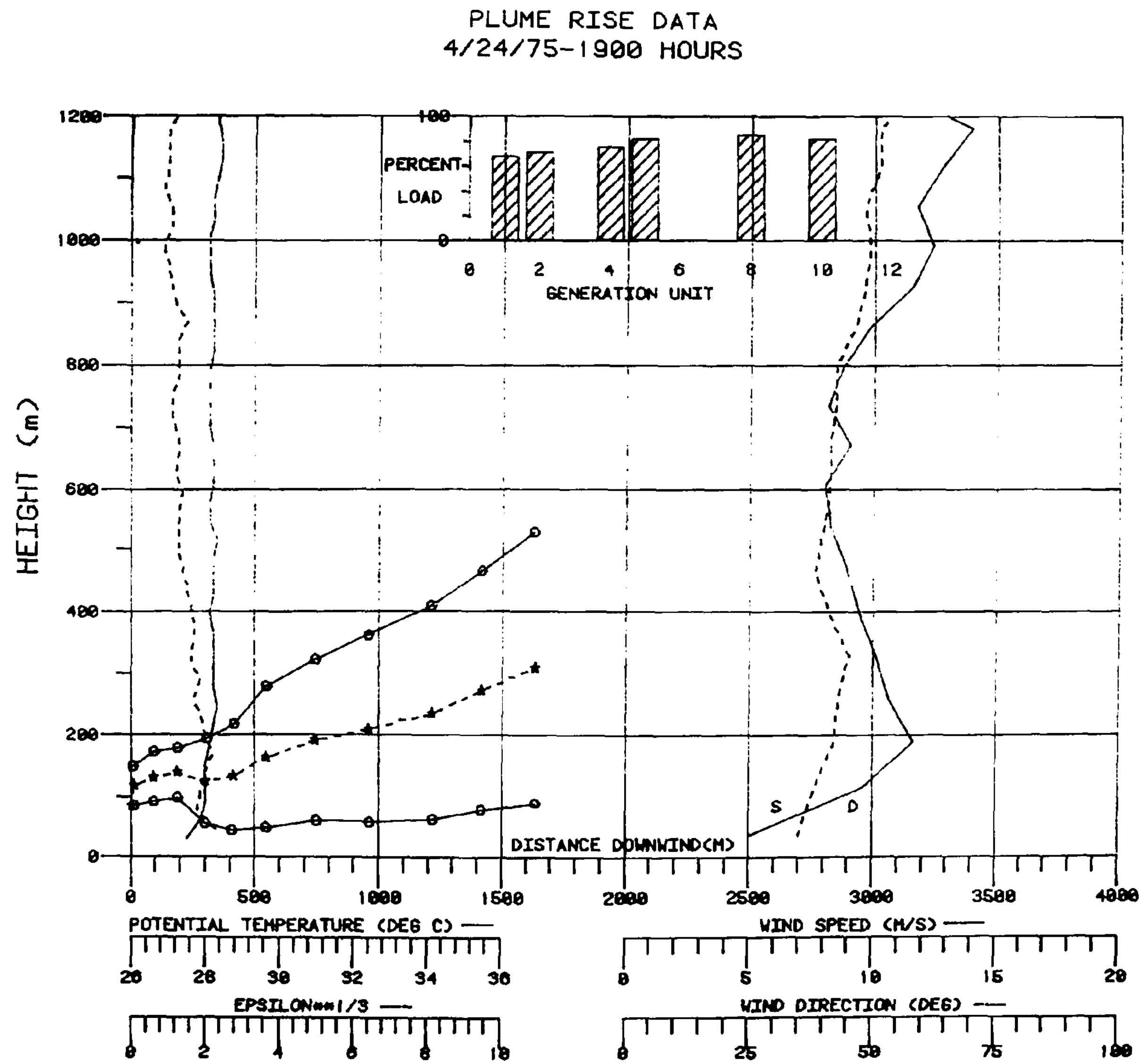
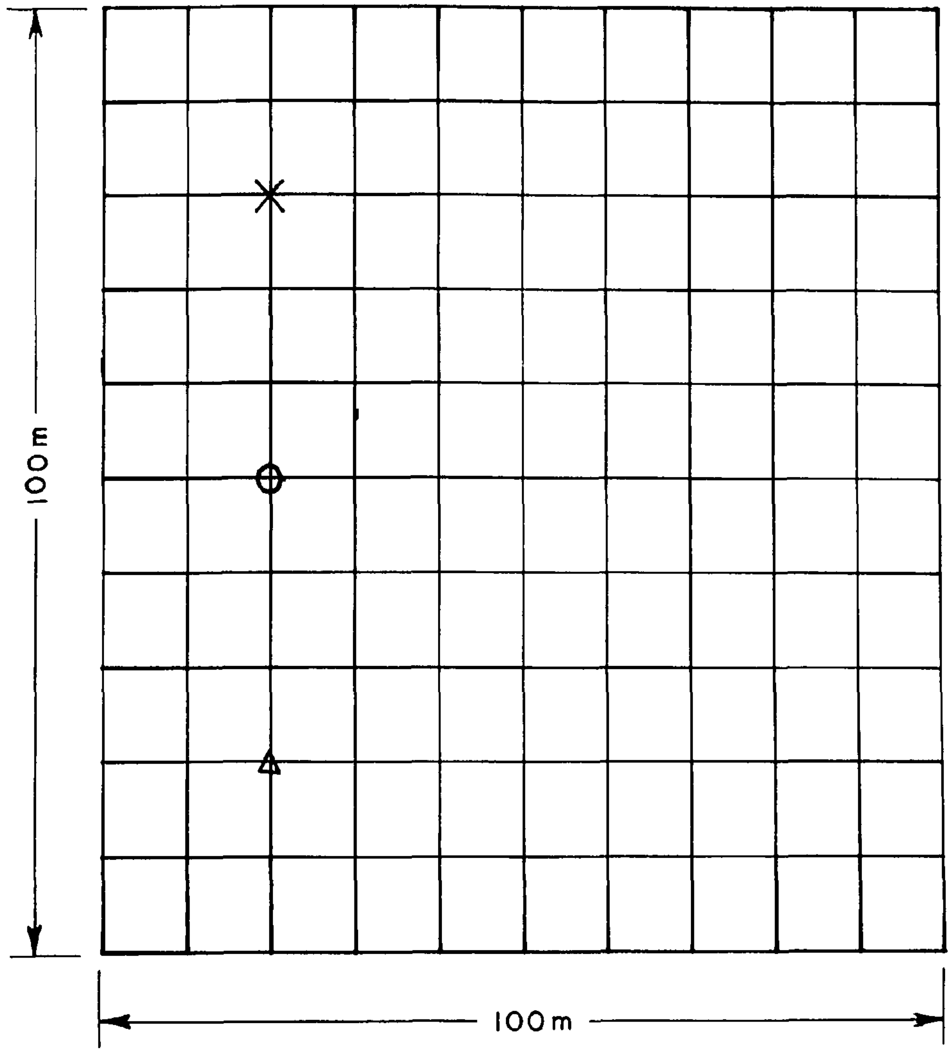


Figure 14. Display of air quality data in the vicinity of a steam plant.

EFFLUENT SOURCE LOCATIONS, POLLUTANT BEING EMITTED, AND METEOROLOGICAL ASSUMPTIONS

SOURCE	STRENGTH (g/sec)	WIND SPEED (m/sec)	STACK HEIGHT (m)	STABILITY CLASS (A-F)	SYMBOL
1	1000	1	10	F	○
2	1000	1	10	F	X
3	1000	1	10	F	△



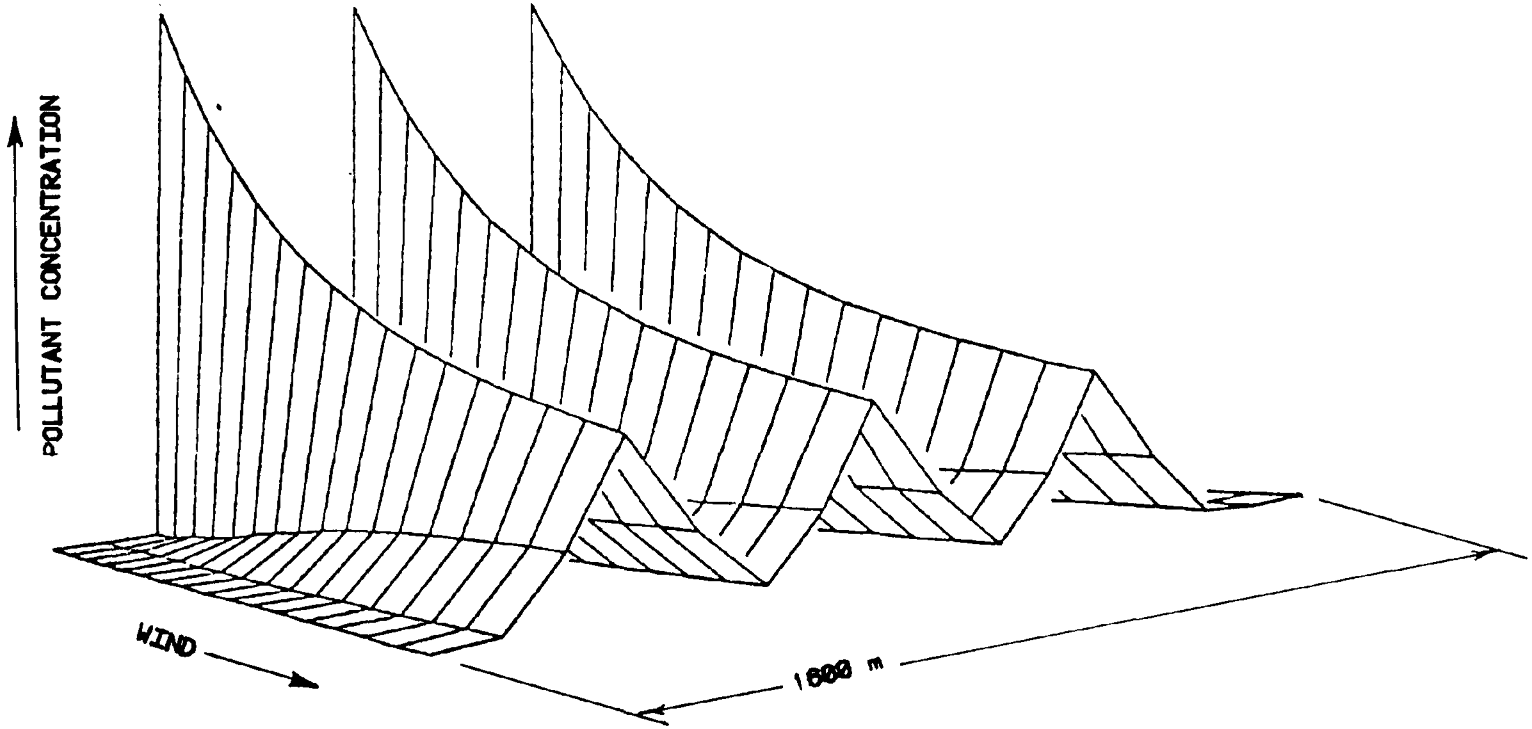


Figure 16. Three-dimensional display of downwind pollutant distribution pattern for a linear array of three gaseous emissions sources.

Previously, this analysis procedure was conducted with the use of a hand calculator; only a limited number of source configurations could be tested and manually plotted in a reasonable amount of time. Interactive graphics has made possible more rapid and accurate identification of potentially adverse situations and has provided analytical results on a more timely basis for court hearings involving potential impacts during construction phases.

Analysis of Output from the Drift, Vapor, and Dry Plume Model

To study the environmental impact of heat released from power plants, models simulating the behavior of buoyant plumes from cooling towers and combustion stacks are used. Effluent species include gases, water vapor, and water droplets containing soluble and insoluble material and particulate drift, which remains after evaporation of the water. The model simulates dynamic phenomena that describe plume trajectory, dilution, concentration, and receptor deposition as functions of elevation and distance from the source, source design parameters, and atmospheric conditions. Such models are adaptable to specific sources such as dry stack-gas plumes; a wet scrubbed stack-gas plume; and vapor and drift plumes from mechanical- and natural-draft cooling towers. For example, to estimate the ground-level deposition of salt or other suspended or dissolved species from cooling tower drift plumes, one must recognize that the time scale of interest, and therefore the meteorological data sets, differs from that for the prediction of length of the visible plume. The latter is commonly considered, if for no other reason, because of aesthetic impact.

Two vapor plume models (developed by Envirodyne Limited, Waterloo, Ontario) were supplied to the TVA's Division of Environmental Planning, Air Quality Branch. These vapor plume models are applicable to mechanical- and natural-draft cooling towers and to dry and scrubbed stack-gas plumes.

An extension of this application was the development of a simple model for drift plumes that may be applied to cooling tower plumes and scrubbed stack-gas plumes, provided sufficient information on the source of the effluent is available. To economize on computer costs and to approach interactive iteration, the model was made as uncomplicated as possible while retaining the necessary and important physics and impact dynamics of drift plume behavior. The principal output of the model is in the form of drift deposition rate (mass per unit area and time) as a function of radial distance from the source. However, one may obtain estimates of excess humidity, temperature, visible plume length, and other variables, if needed. The graphics interface with these models is described in the following section. Specific details of the simulation models and associated computer documentation are provided in separate reports.[13,14]

For the vapor or drift plume model, a simulation run can be accomplished in about 1 to 2 seconds of computation (CPU) time on TVA's computer system. This allows rapid interaction between user and model. For purposes of this demonstration, an interactive routine for input and output display was developed for the plume behavior model. The user is prompted for wind speed, temperature, relative humidity, and stability class. Other variables (cooling tower design information) have specified default values that the user may change. The model then simulates the behavior of the plume and presents the results (Figure 17). Downwind plume behavior is shown for both the near-field (0 to 300 m) and the far-field (300 to 10,000 m) because plume behavior over these two approximate ranges are modeled differently. The addition to the relative humidity at ground level is also shown as a function of distance. This indicates the possibility of predicting local fogging for the meteorological conditions specified. The user can easily make repeated runs using other conditions.

To obtain yearly average conditions around the source, the joint frequency distribution for the four input meteorological variables must be determined. For example, when the drift model is used, a total of 1024 simulations must be run to account for the different probabilities of occurrence of combinations of four classes of wind speed, four classes of temperature, four classes of relative humidity, and sixteen classes of wind direction. A series of computer programs was developed by TVA's Division of Environmental Planning, Air Quality Branch, to determine a representative value for each class variable and to estimate the probability of occurrence based on observed weather data. The drift model was then run for all 1024 cases. Because of the amount of computation, these calculations were not run interactively. The downwind deposition rates were summed with those of previous runs for each of the sixteen wind directions.

An interface routine was developed to format these data for input to the CALCOMP General-Purpose Contouring Package. This graphics package fits a surface to the given data, calculates a regular, rectangular grid, and plots contours. Manual techniques, although somewhat tedious, were also explored for generating a regular grid. The resulting grid serves as input into a previously described Interactive Graphics Display Package (IGDP) with three-dimensional plotting capabilities. Figure 18 shows a contour plot of a sample drift pattern; Figure 19 shows the same data plotted in three dimensions; and Figure 20 shows deposition rate along several sectors.

Although output data from this simulation can be manipulated interactively, a direct, interactive interface with the model itself would be highly desirable for meeting anticipated analysis requirements. A sensitivity analysis to evaluate the influence of terrain, number and type of sources, and source arrangement at the site could be accomplished more rapidly. Also, interactive model-to-graphics capability would be valuable for theoretical model development and the calibration of a model for specific operational use. For example, in the simple model now used for drift plumes, the effect of drift water solute concentration on the rate of evaporation from droplets has been neglected. Incorporation of this effect requires a numerical solution of the drop evaporation equation and increased charges for computer use, which may or may not be justified. With model-to-graphics interaction, only a few iterations would be required to display deposition flux rate vs. distance, with and without evaporation assumptions, in enough cases to assess the significance of the proposed improvement to the model.

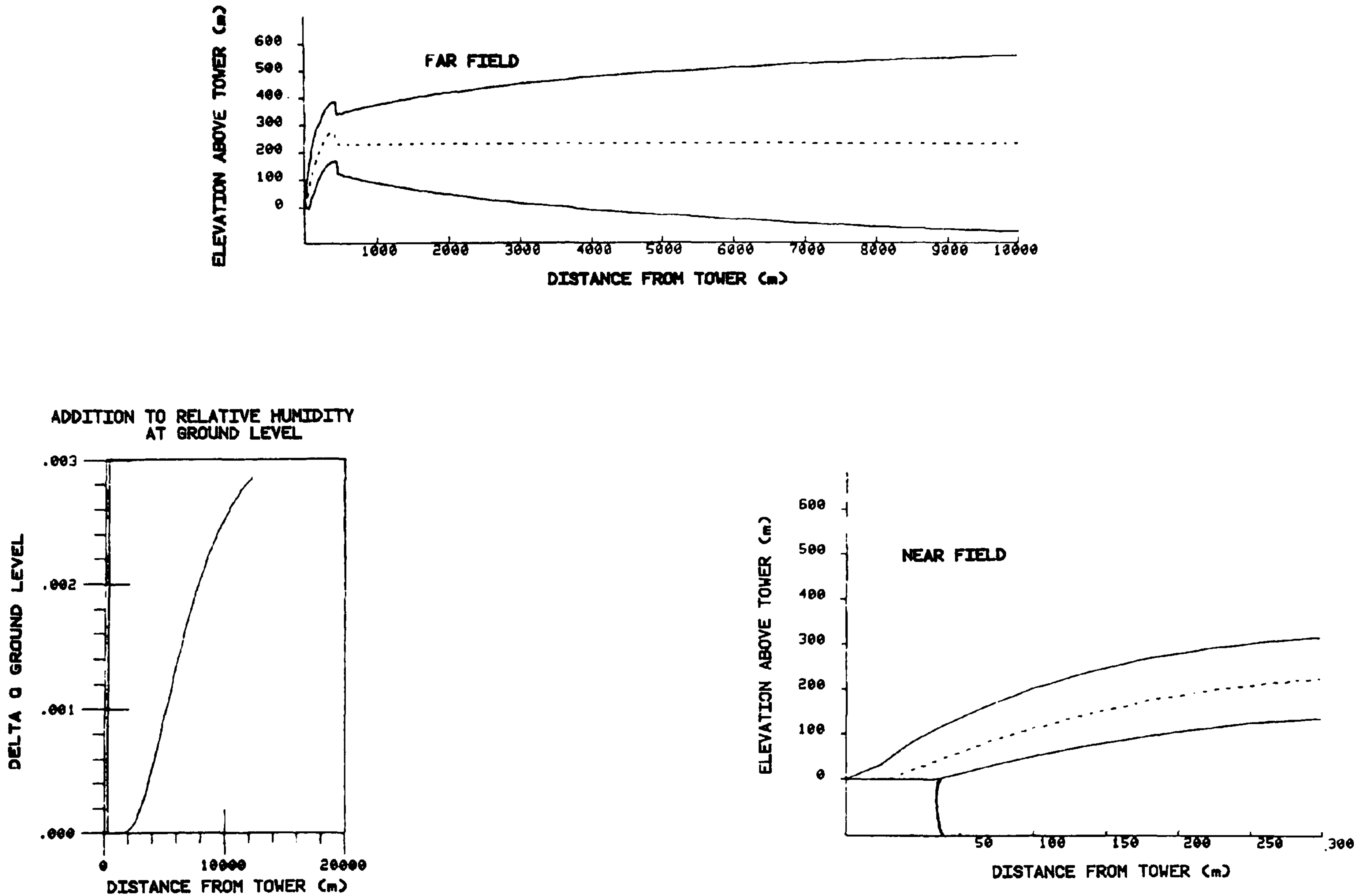


Figure 17. Simulated behavior of a vapor plume for a natural-draft cooling tower, typical

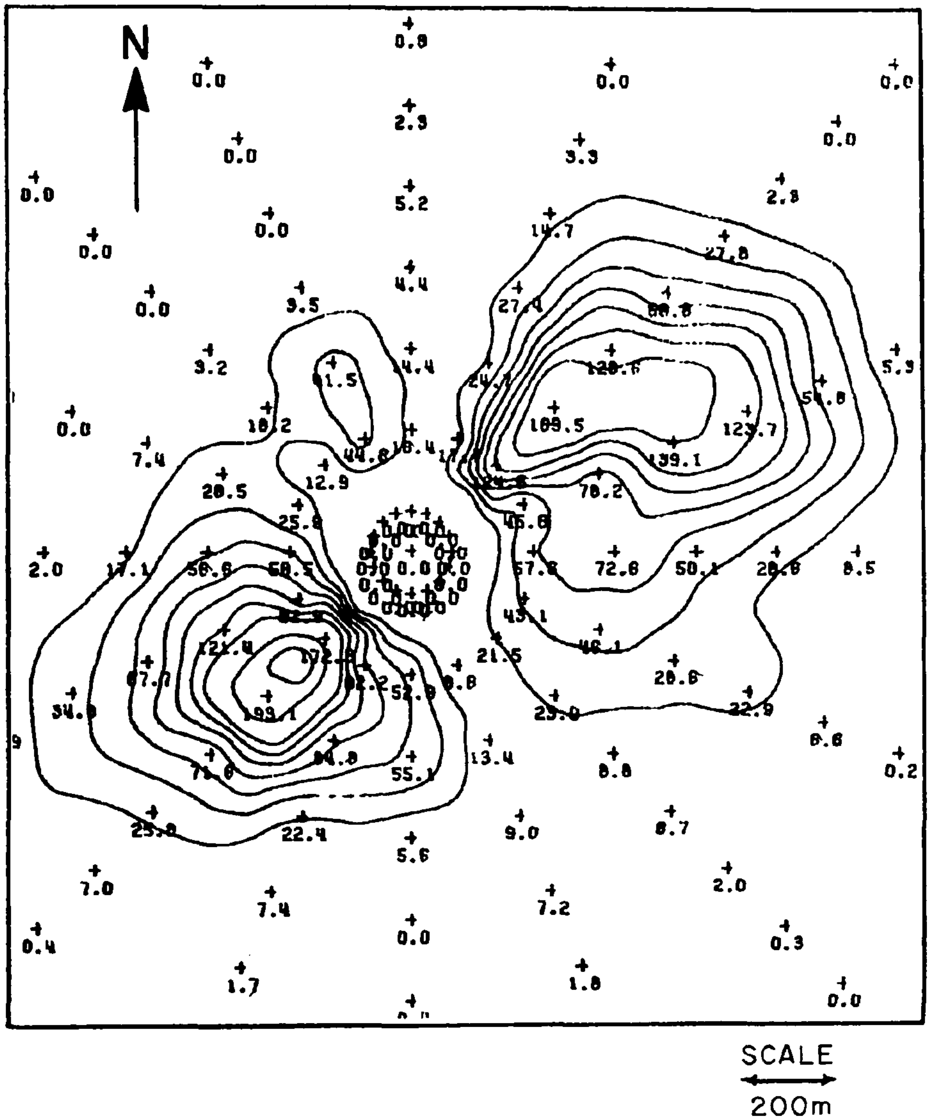


Figure 18. Sample contours of yearly drift deposition in the vicinity of two natural-draft cooling towers.

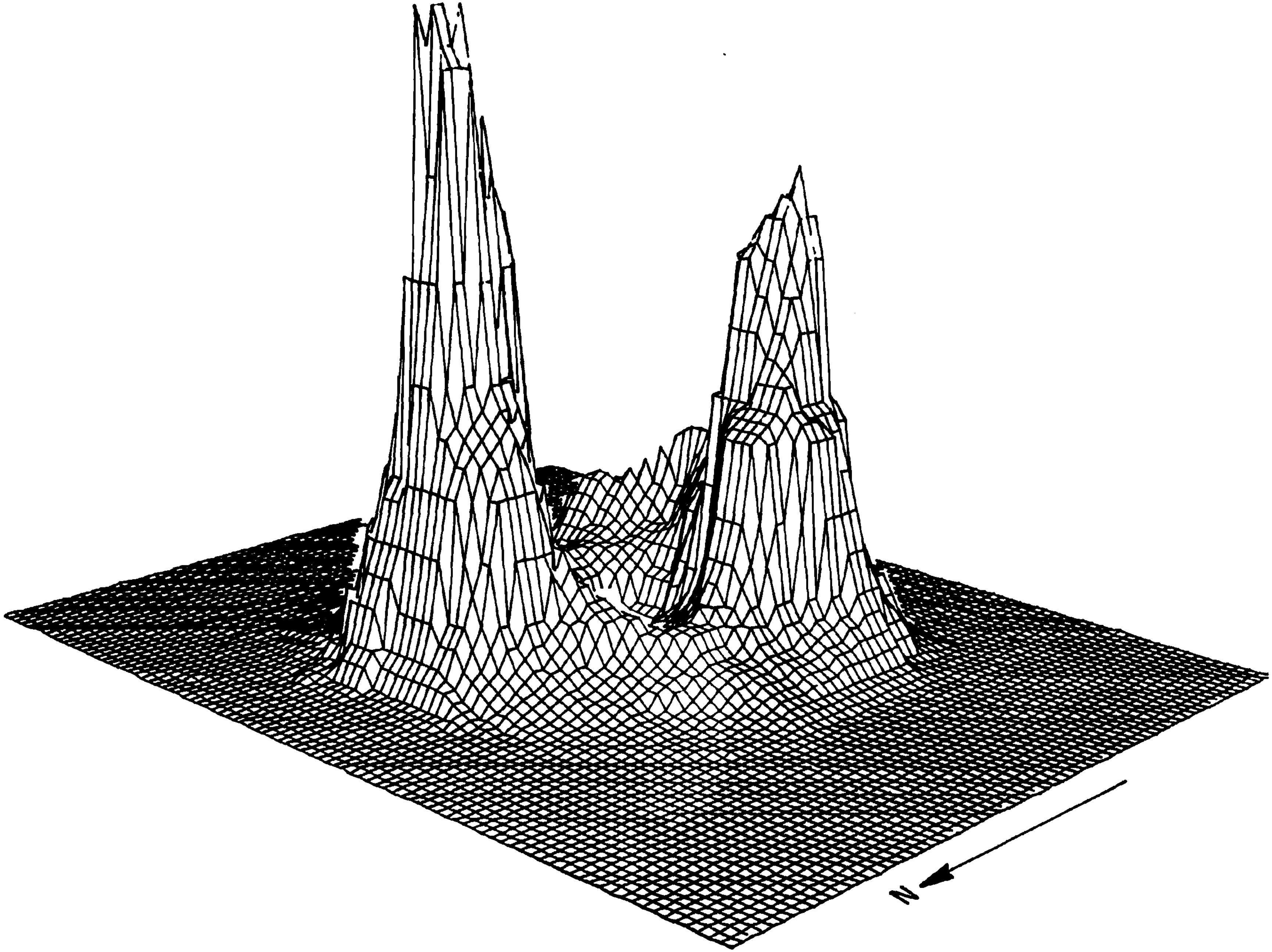


Figure 19. Three-dimensional representation of yearly drift deposition in the vicinity of two natural-draft cooling towers.

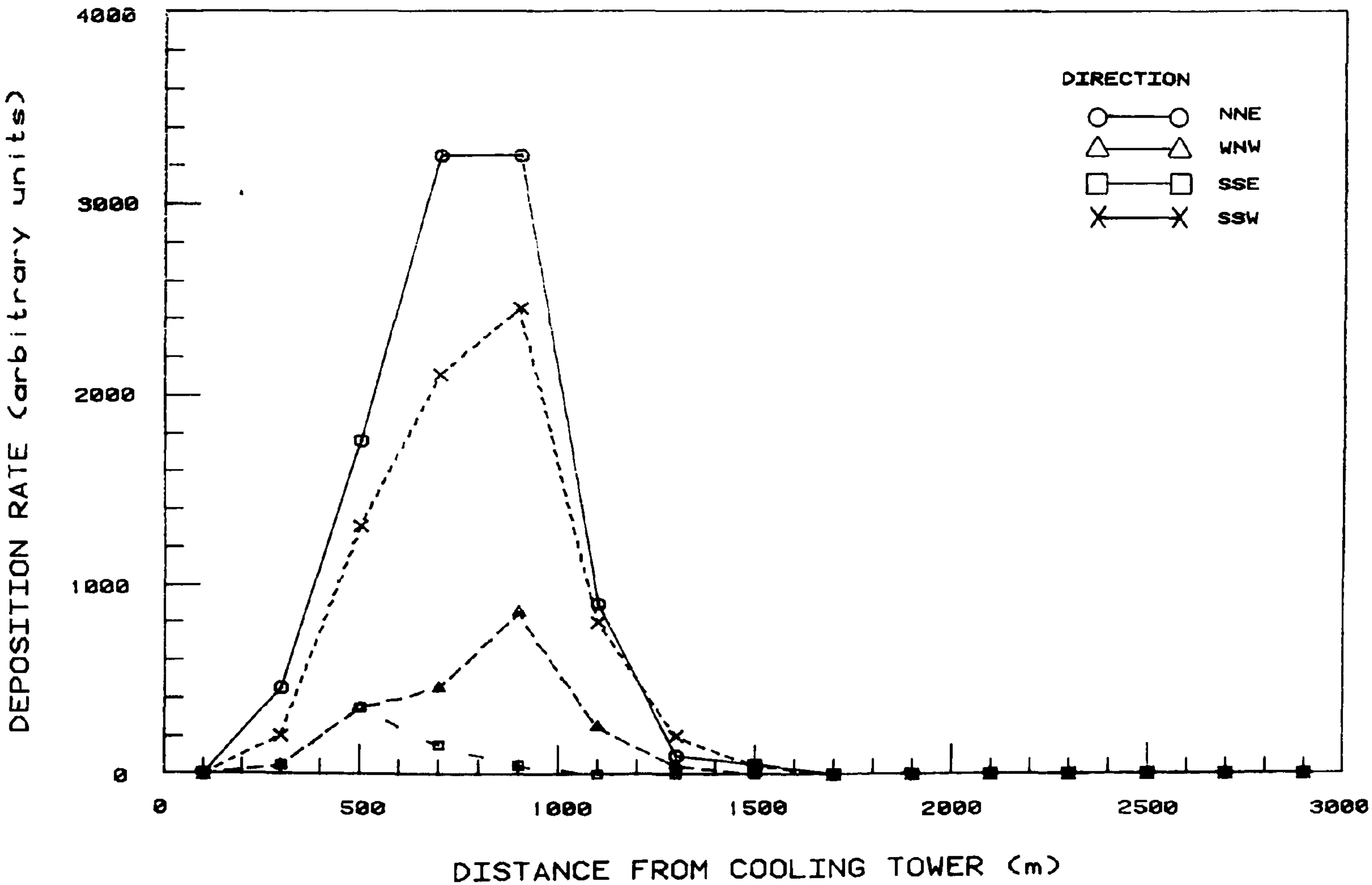


Figure 20. Plot of yearly drift deposition vs. distance from two natural-draft cooling towers.

Air Flow Behavior Patterns

Other types of model predictions can be depicted by computer graphics. Figure 21 shows the predicted pattern of air flow around a building by using a computer model and graphics developed by Dr. T. J. Crawford, Air Quality Branch, Division of Environmental Planning. Flow is shown in the vertical plane. The numerical model that was used is based on the Navier-Stokes equations, which balance the shear pressure forces with momentum in combination with conservation of mass. Each arrow is a vector, with its length proportional to air velocity and its direction the same as the direction of air flow at that particular point. Note the "cavity" recirculation region that forms on the downwind side. This region may be enlarged on the CRT as shown in Figure 22. Because the building is about 100 feet high, a point of gaseous emission must be at an elevation of at least 150 feet to preclude entrainment in this "cavity." Figure 23 shows the simulation of flow patterns around two mechanical-draft cooling towers; various planes and cross sections are shown. Obviously, numerical tabulations of the same results would be much more difficult to interpret.

Future Demonstrations

There is great potential for numerous future applications of computer graphics to analyze air quality. Some of the demonstrations planned will use other types of computer graphics hardware. Refresh graphics will be used to dynamically manipulate a display on the CRT. For example, a series of computer simulations of plume behavior with hourly variations in meteorological conditions can be conveniently condensed into a brief, meaningful, animated sequence. This type of use is expected to increase. Software development will stress the practicality of interactive analysis to permit integrated assessment (e.g., consideration of the costs related to pollution control alternatives and either simple or complex environmental consequences). One system that has been considered would use existing capabilities of TVA, EPA, and others to model fixed and variable costs of pollution control processes, residual generation, transport of atmospheric pollutants, and ecosystem impacts. Once collected, these models could be incorporated into a flexible data base and analysis system that would permit rapid exploration of alternatives for siting, process design, and state of exogenous system (i.e., meteorology to evaluate environmental consequences). Where the state-of-the-art of modeling is not fully developed (e.g., impact damage functions), empirical or assumed relations could be used. The analysis scheme would be sufficiently general as to be able to incorporate future models readily. (Although institutional problems will probably delay development of broad-spectrum, integrated environmental assessment indefinitely, reductions in computer costs do make such ambitious models more feasible now than ever believed possible.)

A typical analysis session would be conducted interactively with the computer. During each step, various analysis options would be presented to the engineer. These options might include the ability to (1) select alternative analysis procedures and graphic displays, (2) apply increasingly complex models, or (3) input different exogenous conditions or design variables. Output of the results would be displayed in tabular.

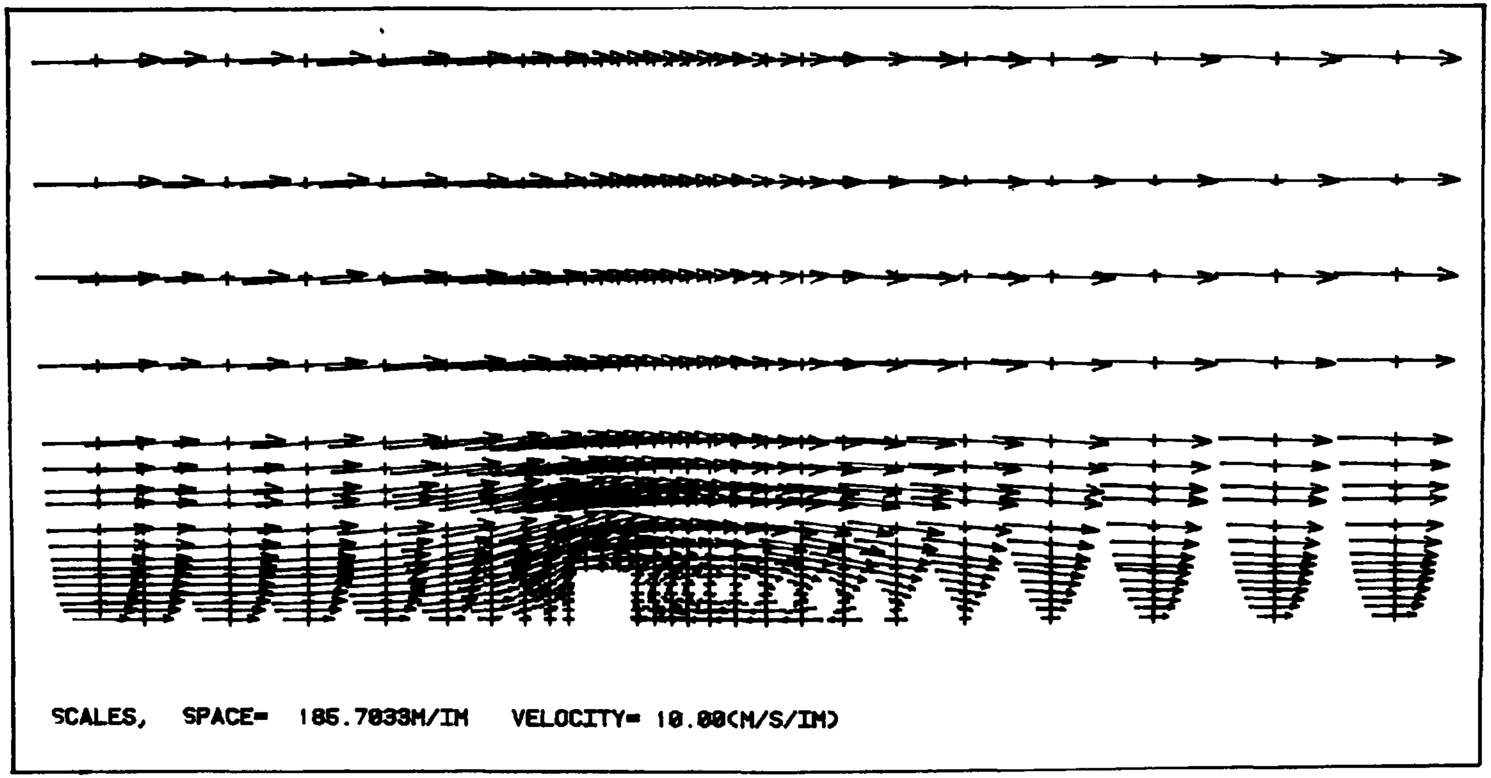


Figure 21. Simulated pattern of simulated air flow in the vicinity of a building.

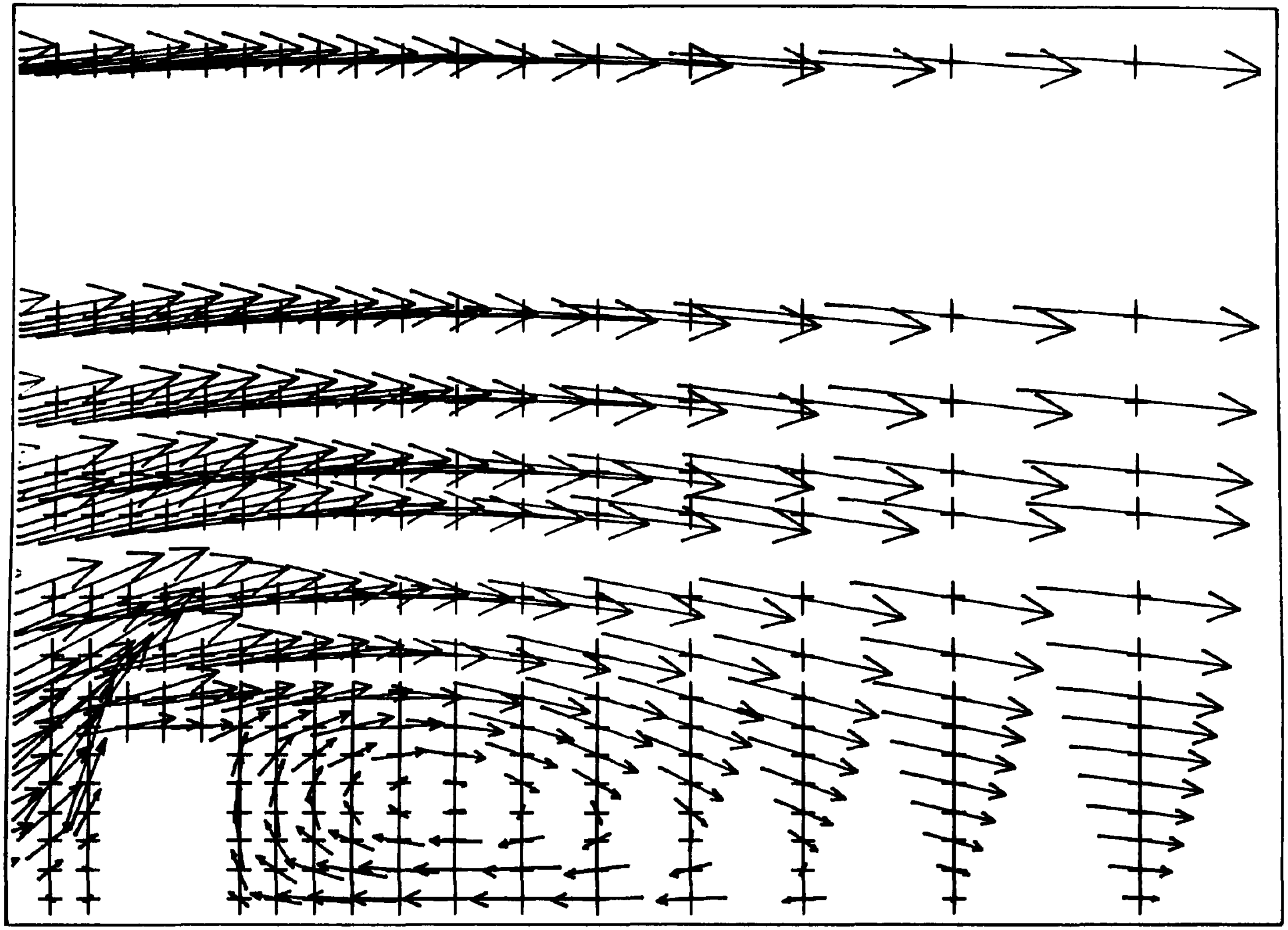


Figure 22. Enlarged view of simulated entrainment cavity on downwind side of building.

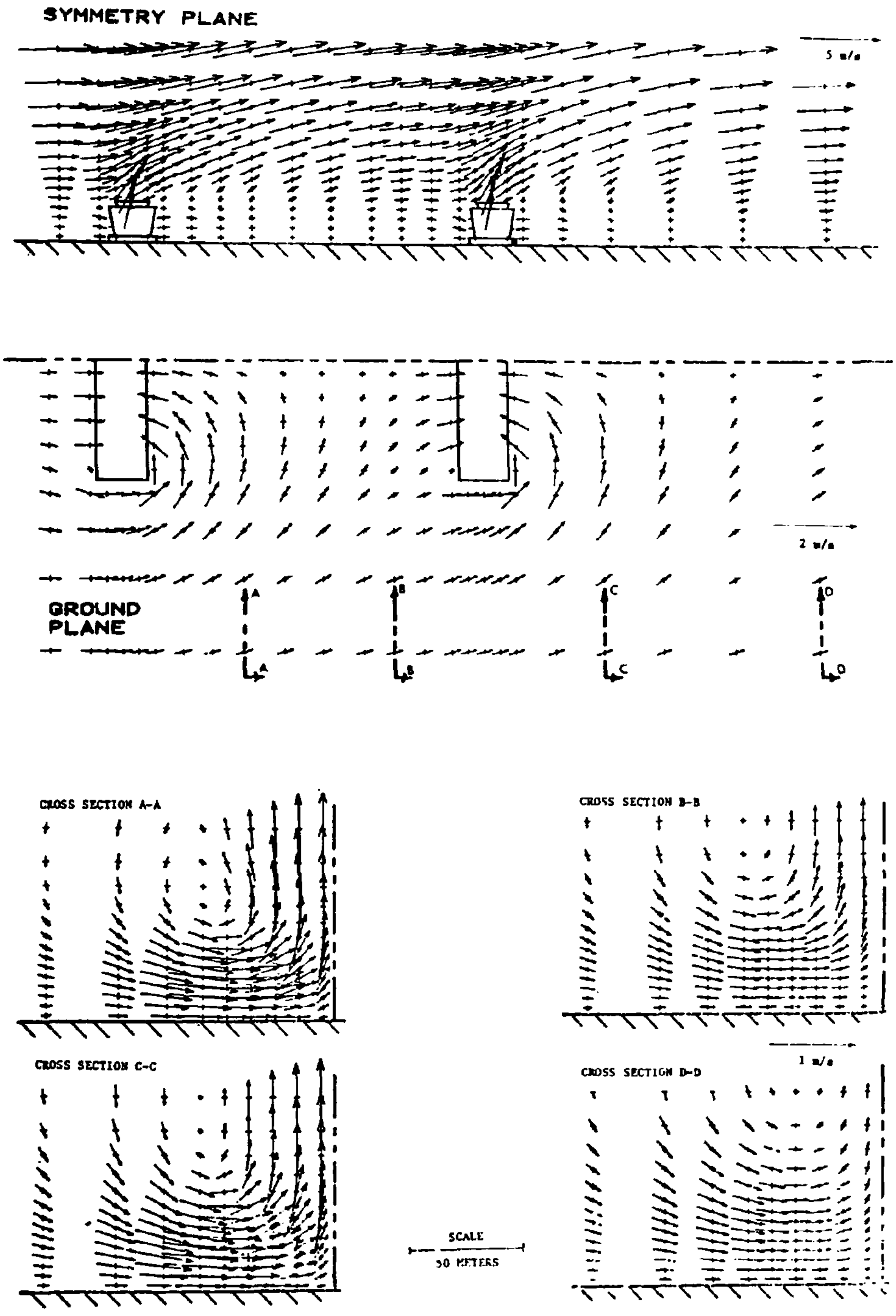


Figure 23. Various views of simulated air flow in the vicinity of two mechanical-draft cooling towers.

map, or graphical format on a CRT or, at the user's option, directed to a computer plotter. Statistical operations (e.g., ranges, confidence intervals, regression analysis) may be advantageous for some analyses.

The data base structure for such a system could include several features:

1. A data base containing a set of default variables necessary to run the various models for residual generation, environmental transport, and impact. Any of these variables could be changed interactively through input programs.

2. A regular, gridded, spatial data base for source location, land use, and topographic information.

3. A costing data base relating to economics and performance models for control technology.

WATER QUALITY ANALYSIS

Data Display

Figures 24 and 25 show typical plots of aquatic data used in reports for TVA's Thermal Effects Studies for the Federal Water Pollution Control Act, Amendments of 1972, Section 316(a). The total time to produce figures of this type alone over the life of TVA's "316" studies was reduced from an estimated 176 man-days, if manual techniques had continued, to 8 man-days with the use of interactive computer graphics.

Three-dimensional (one variable as a function of two others) presentations of water quality data can be valuable. Demonstrations developed to date can be grouped into three categories: (1) horizontal spatial distribution of a particular biological, chemical, or physical variable (Figure 26), (2) variation of a water quality with distance and depth (Figure 27), and (3) variation of a variable with location and time (Figure 28).

In the future, other types of three-dimensional representations of complex relationships will be used increasingly. For example, De Angelis and Thorp[15] recently published computer program documentation for visualizing multiple surfaces in space. They report applications to ecosystem studies such as three-level food chain systems, niche theory, and optimization strategies.

Interactive Analysis of a Water Quality Data Base

A combined package of graphics and analysis routines was developed in association with this project by TVA's Division of Environmental Planning, Water Quality and Ecology Branch, to evaluate trends in the quality of discharged water for TVA's reservoir system. Weekly average values for the volume of water discharged, reservoir depth, concentration of dissolved oxygen, and temperature of the discharge are stored on the computer for each of TVA's reservoirs during the last 16 years. The user can request a display of the weekly data for the entire period of

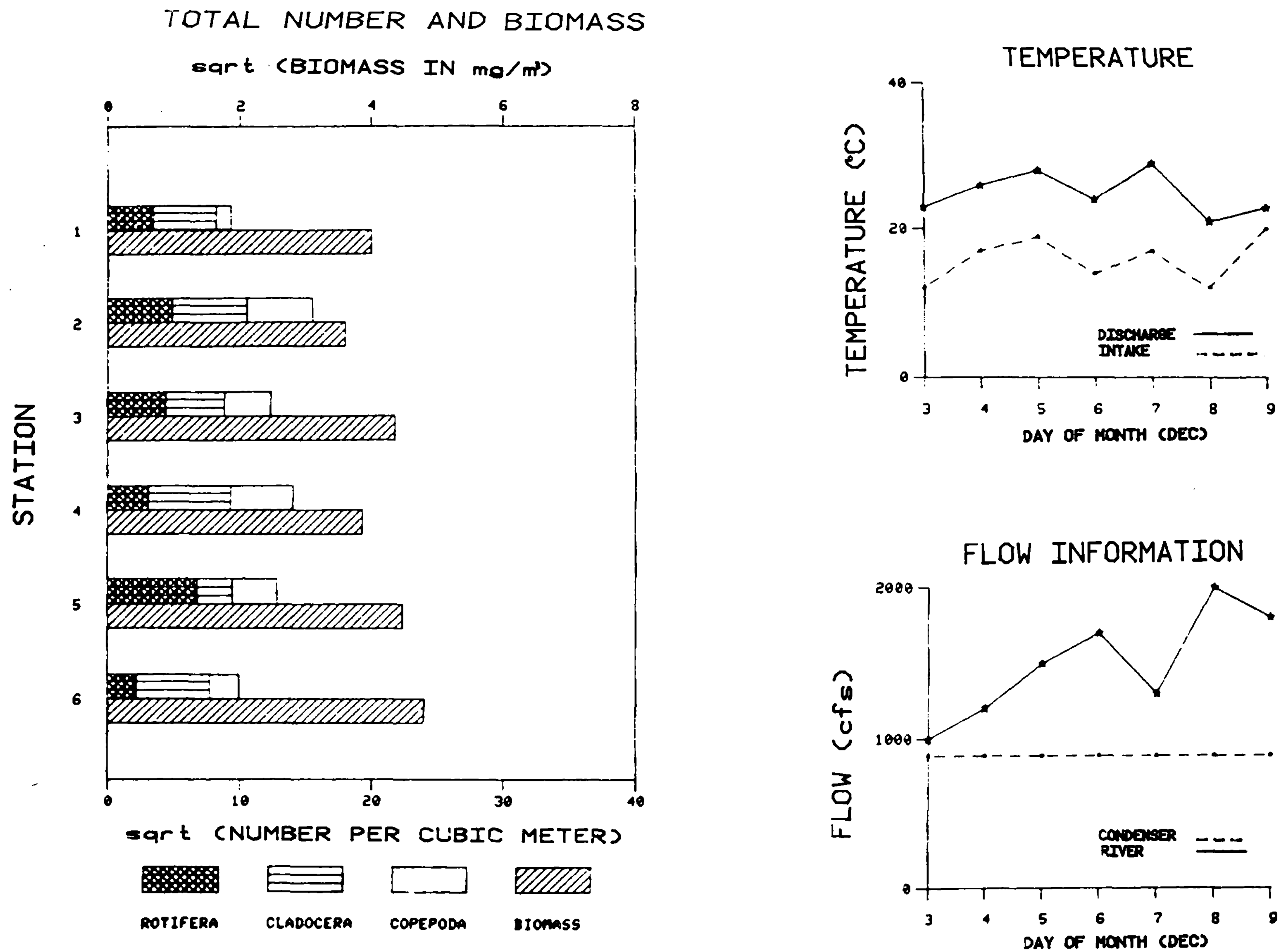
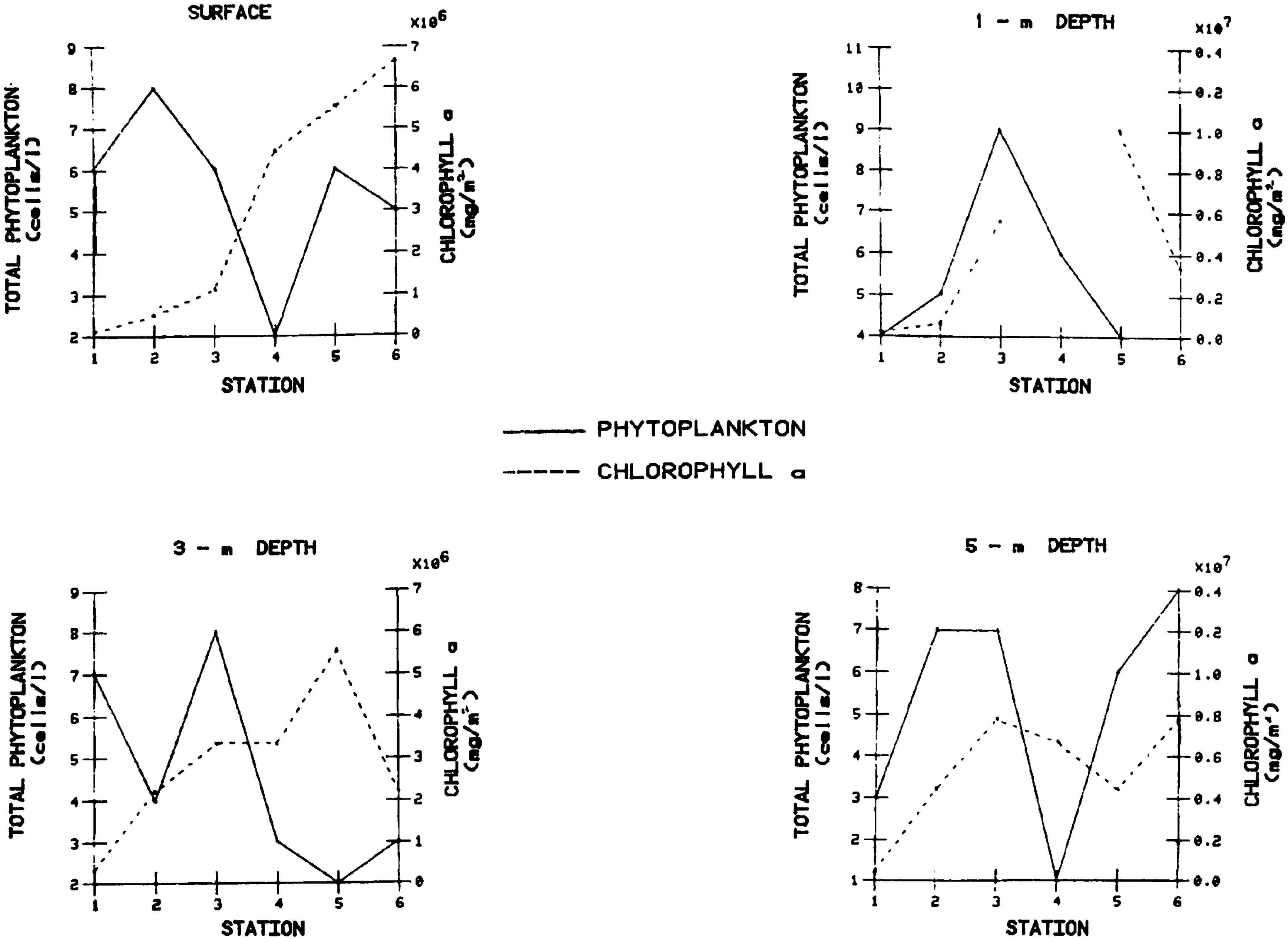


Figure 24. Typical display of biological and physical water quality data for TVA-EPA Thermal Effects Studies.


SURFACE
1 - m DEPTH
3 - m DEPTH
5 - m DEPTH
TOTAL PHYTOPLANKTON (cells/l)
CHLOROPHYLL a (mg/m²)
x10⁶
x10⁷
STATION
PHYTOPLANKTON
CHLOROPHYLL a

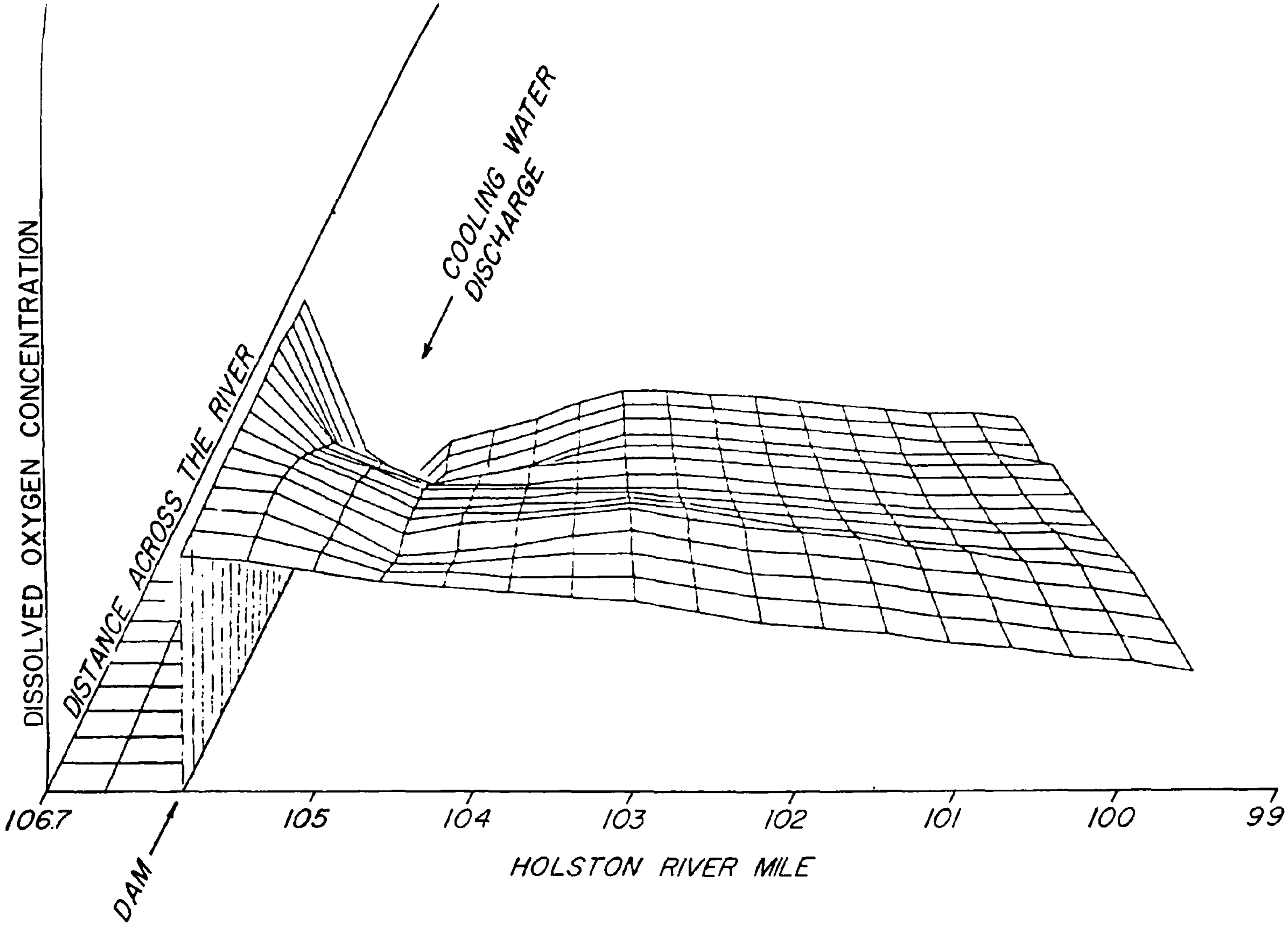


Figure 26. Three-dimensional representation of distribution of dissolved oxygen in the vicinity of a dam and a thermal discharge.

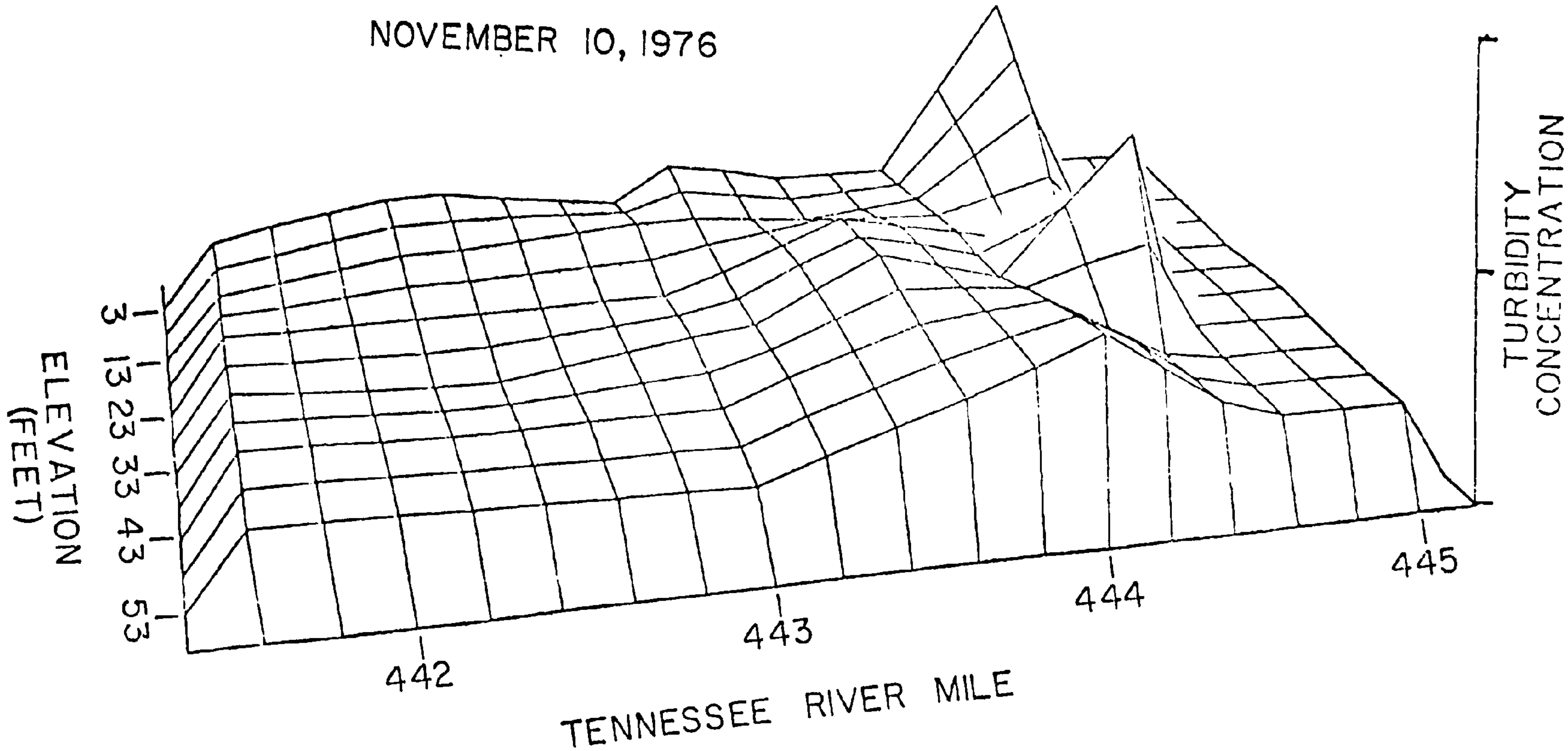


Figure 27. Three-dimensional representation of turbidity as a function of river mile and depth.

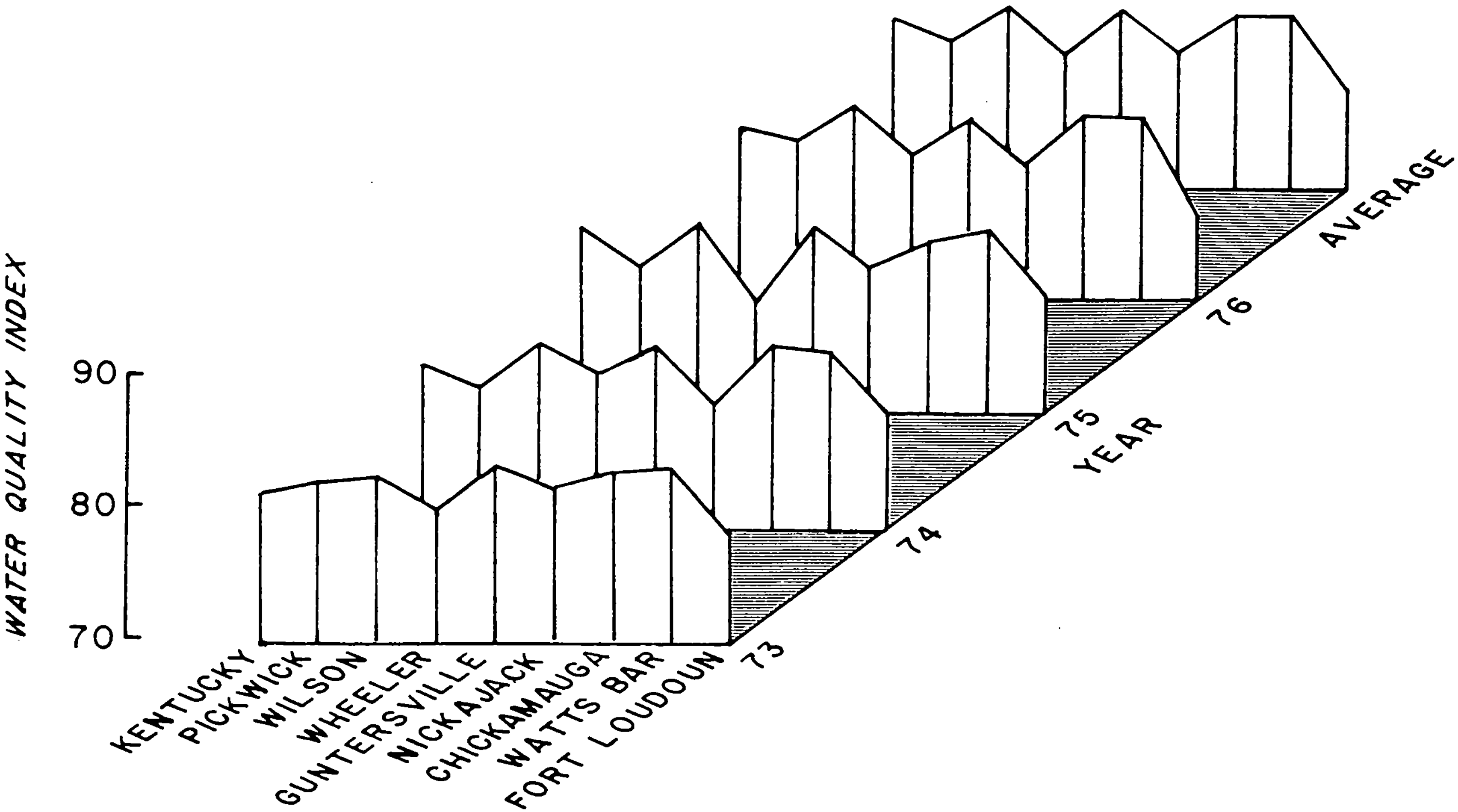


Figure 28. Variation in the National Science Foundation's water quality index as a function of time and Tennessee River reservoir.

record or for an individual year. Figure 29, for example, shows a typical plot of weekly average concentration of dissolved oxygen discharged from Fort Loudoun Reservoir. The user can also request that yearly average values for a particular variable be calculated and plotted. Figure 30 shows the yearly average values for dissolved oxygen discharged from Fort Loudoun Reservoir. The user can request computation and display of the cumulative amount of dissolved oxygen required to raise the average discharge value to a specified level. These results show the change in biological degradation (oxygen demand) in the reservoir. Figure 31 shows such a plot for Fort Loudoun Reservoir. Note that, in 1967, there appears to have been a marked reduction in the amount of dissolved oxygen needed to reaerate the discharge. Finally, information from various reservoirs can be combined to display trend plots, as shown in Figure 32, which illustrates spring temperatures in the major Tennessee River reservoirs over the past 16 years.

Water Source Mapping

A system was designed to assist in the preparation of graphics and reports required for reports on siting nuclear power plants and environmental impact statements. A map is needed to show ground and surface water supplies, both municipal and industrial, within a 20-mile radius of proposed plant sites. A listing of the use characteristics for each source must also be prepared. This information is updated periodically, and a new map is prepared about eight times during the assessment process for a typical nuclear power plant. Manual techniques for recording the information and preparing the displays are time-consuming and tedious.

A system was designed around a data base containing information on water use and source locations associated with proposed sites. Programs were identified to generate specially formatted lists and special graphic displays. Updating routines were provided to keep the data base current. The procedure for generating a typical display involves several steps:

1. All the data or a particular subset of the information on water source can be called from the data base for plotting.

2. A symbol characteristic of each source type with an identifying number is plotted on the terminal screen at a position corresponding to its exact latitude and longitude. The plant site and a representative 20-mile circle are also drawn (Figure 33).

3. Source symbols and identifying numbers will commonly overlap, resulting in a confused and unclear display. Using the terminal's cross-hair cursor, a particular source symbol can be identified to the computer and adjusted to a new location. The process continues until a satisfying arrangement results (Figure 34).

4. The final desired positions of all symbols are then stored. A plot is generated on a flat bed plotter using the stored symbol locations with the size adjusted to a particular scale (e.g., 1:250,000). The results then are transformed photographically into a clear acetate overlay, which can be placed over a standard base map and photographed to arrive at the final figure for the report (Figure 35).

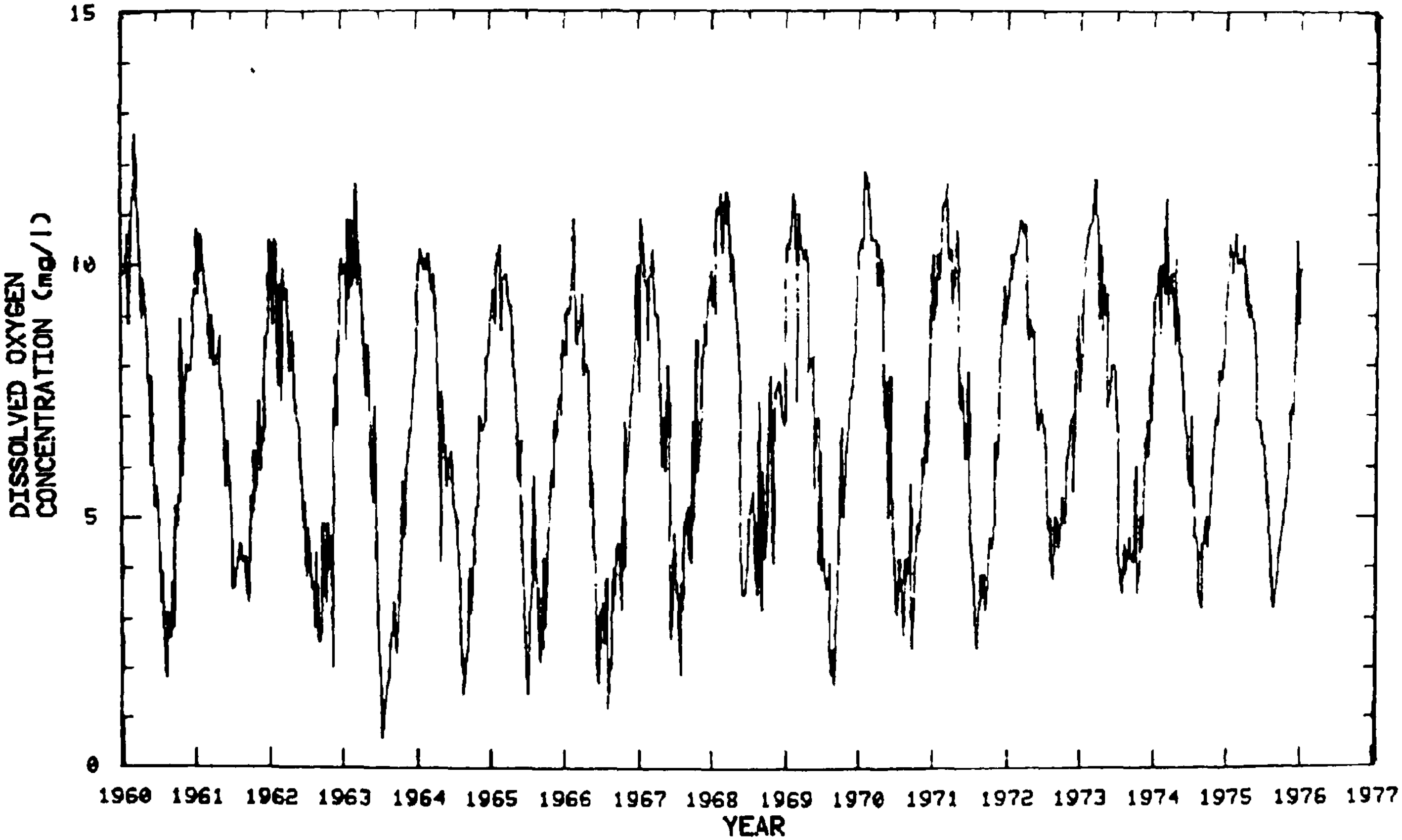


Figure 29. Average weekly concentration of dissolved oxygen in discharge waters from Fort Loudoun Reservoir over the past 16 years.

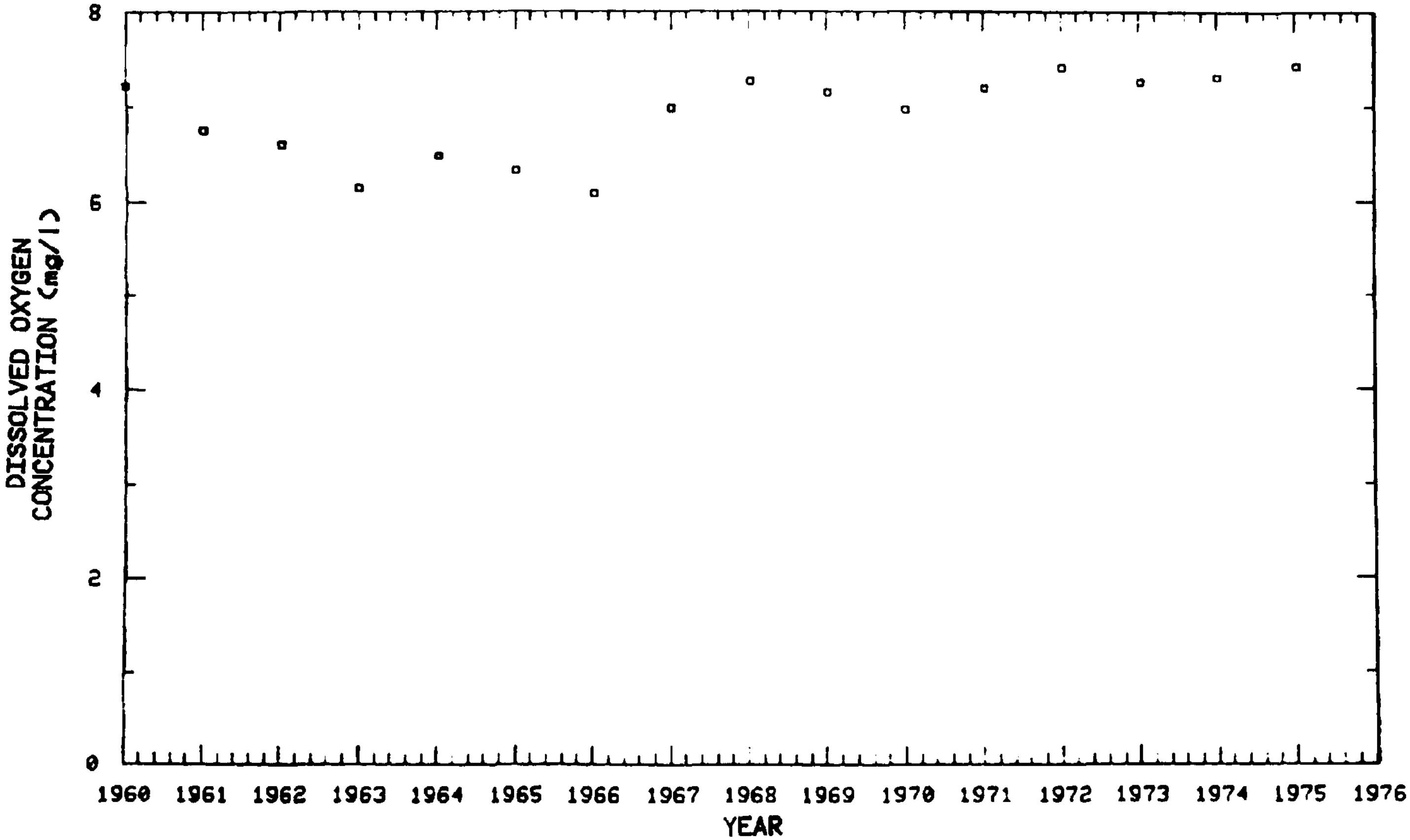


Figure 30. Yearly average concentration of dissolved oxygen in discharge waters from Fort Loudoun Reservoir over the past 16 years.

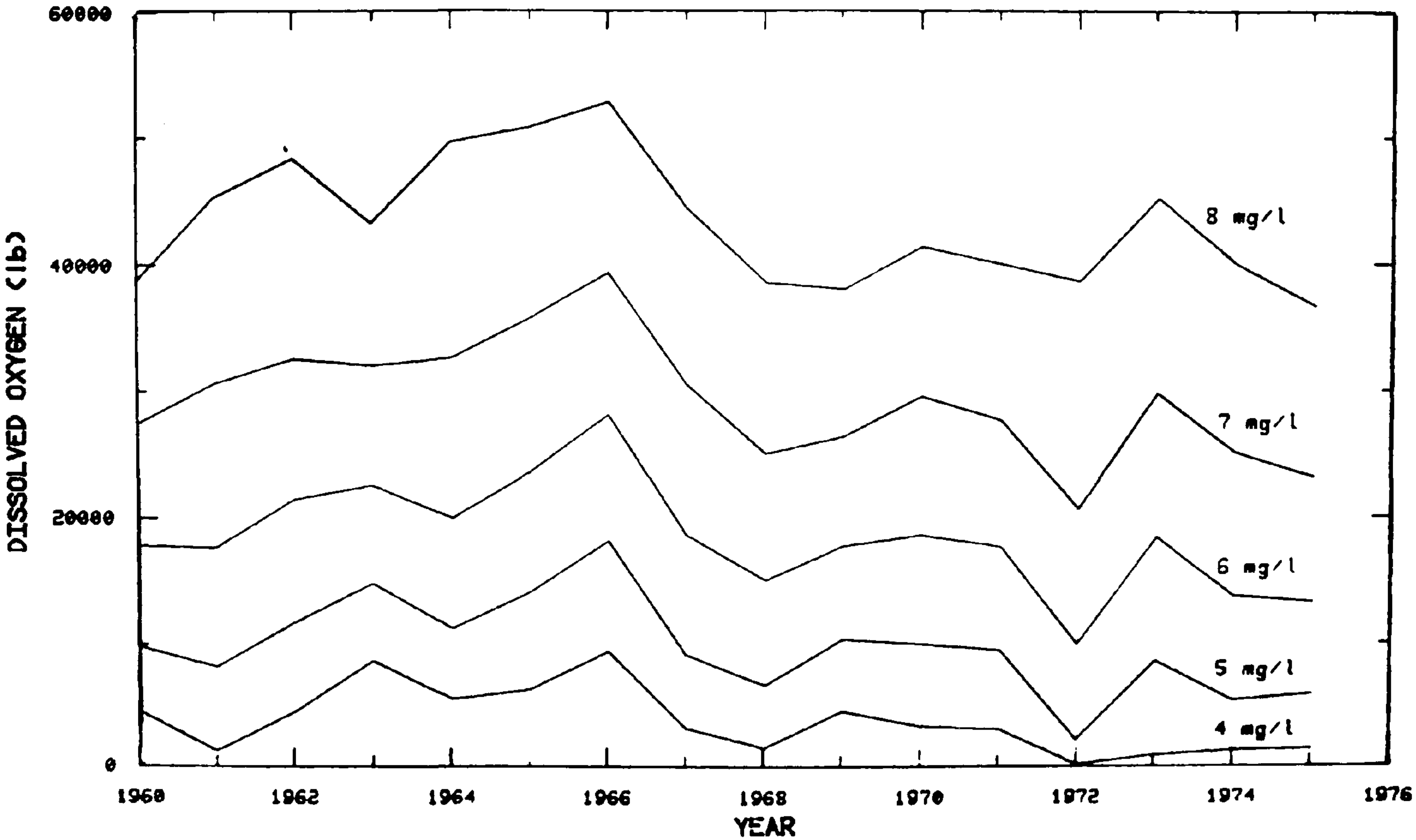


Figure 31. Yearly average amount of oxygen that would have to be added to discharge waters of Fort Loudoun Reservoir for the past 16 years to bring the concentration to the specified levels.

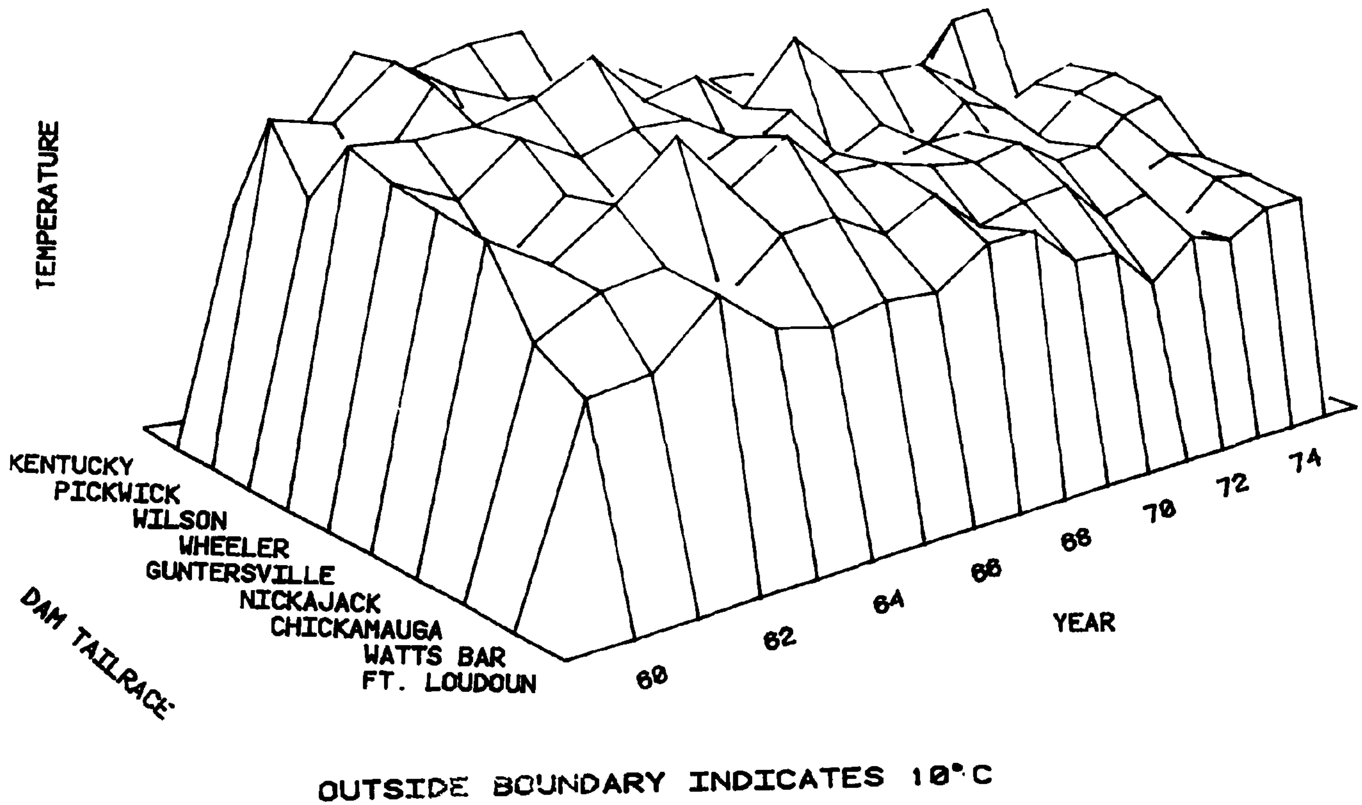


Figure 32. Average temperatures of spring discharge water for reservoirs on the Tennessee River over the past 16 years.

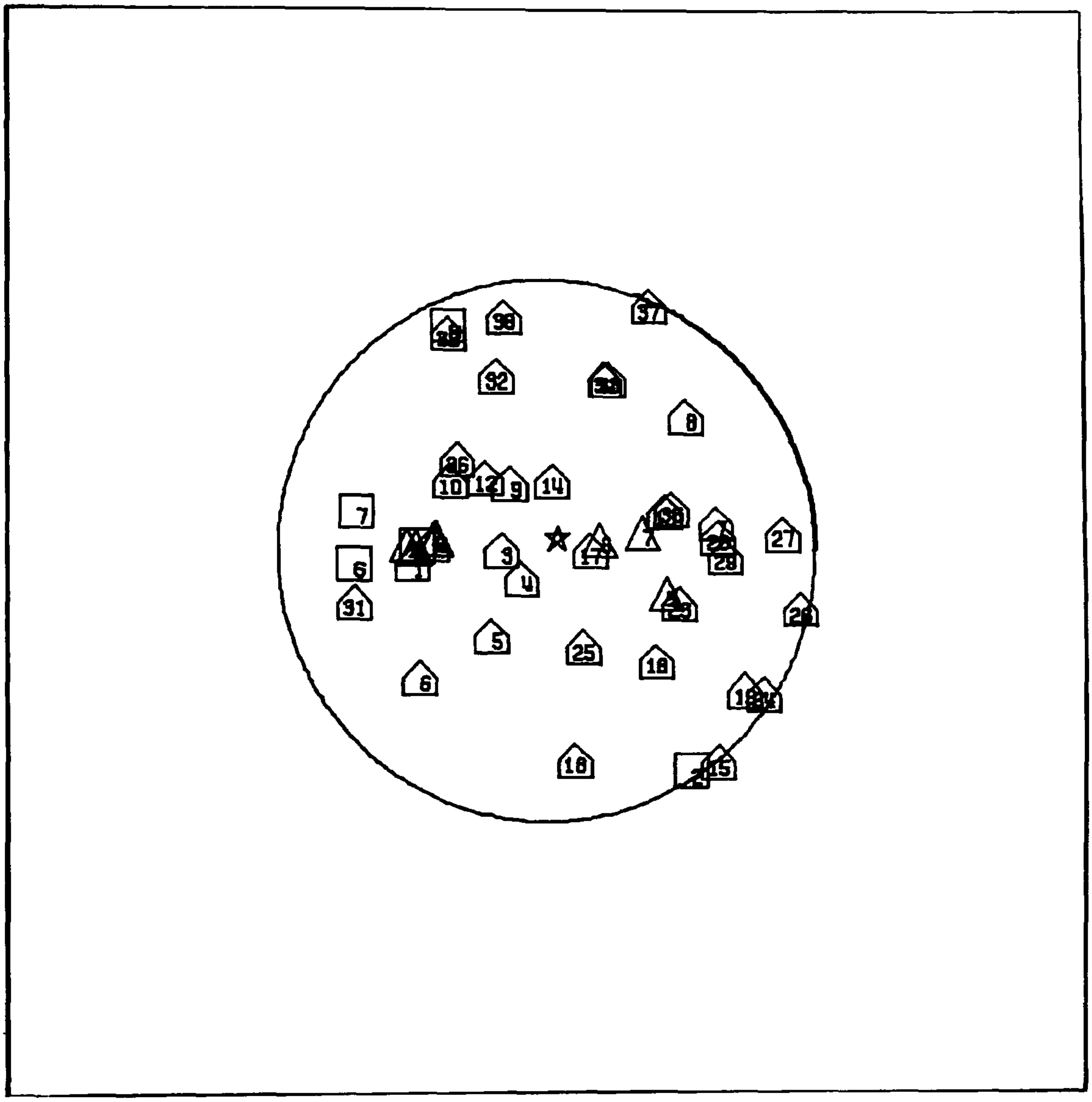


Figure 33. Initial display by cathode ray tube of water source symbols plotted on the basis of latitude and longitude.

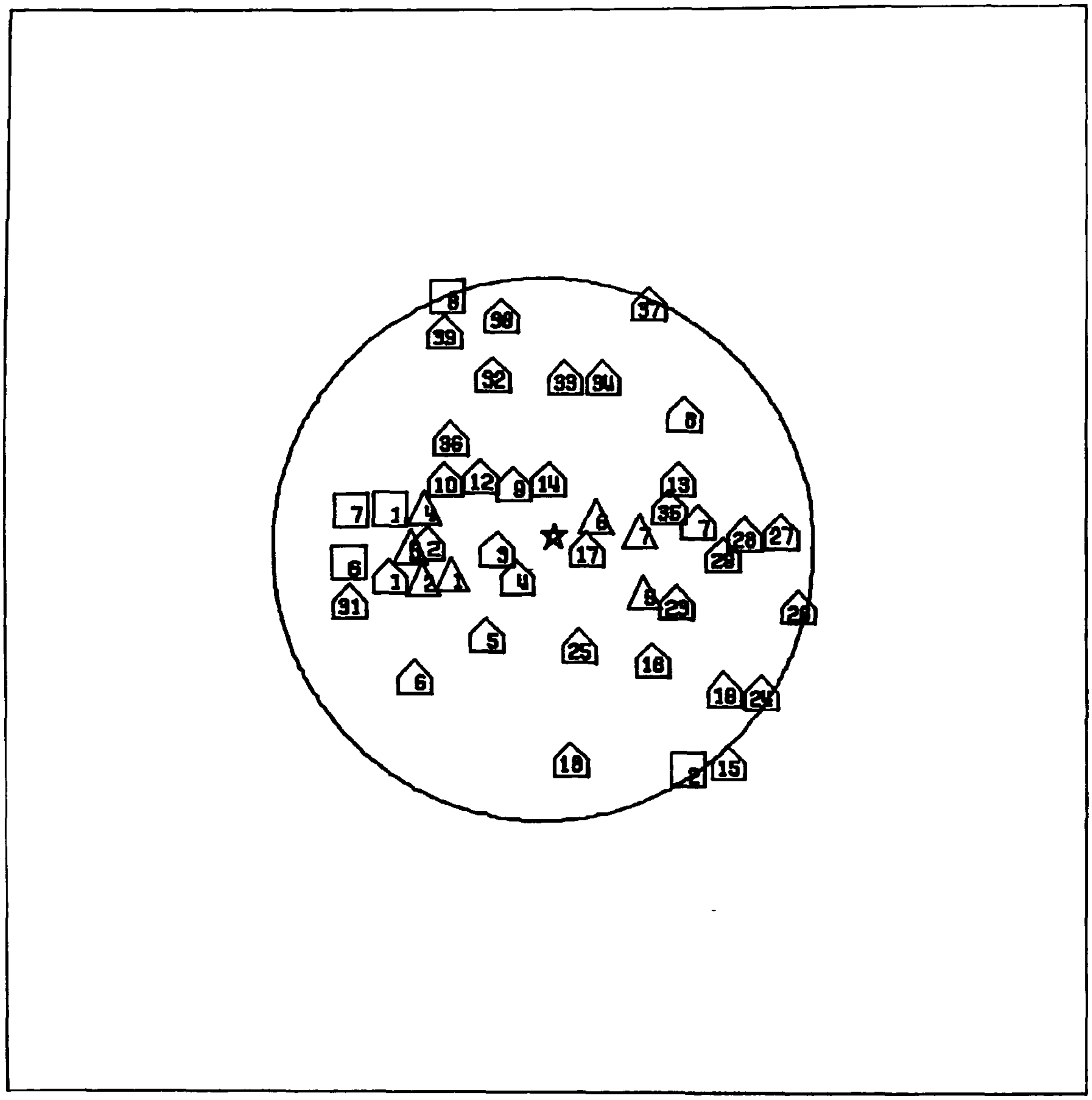


Figure 34. Final display by cathode ray tube of water source symbols after visual adjustment.

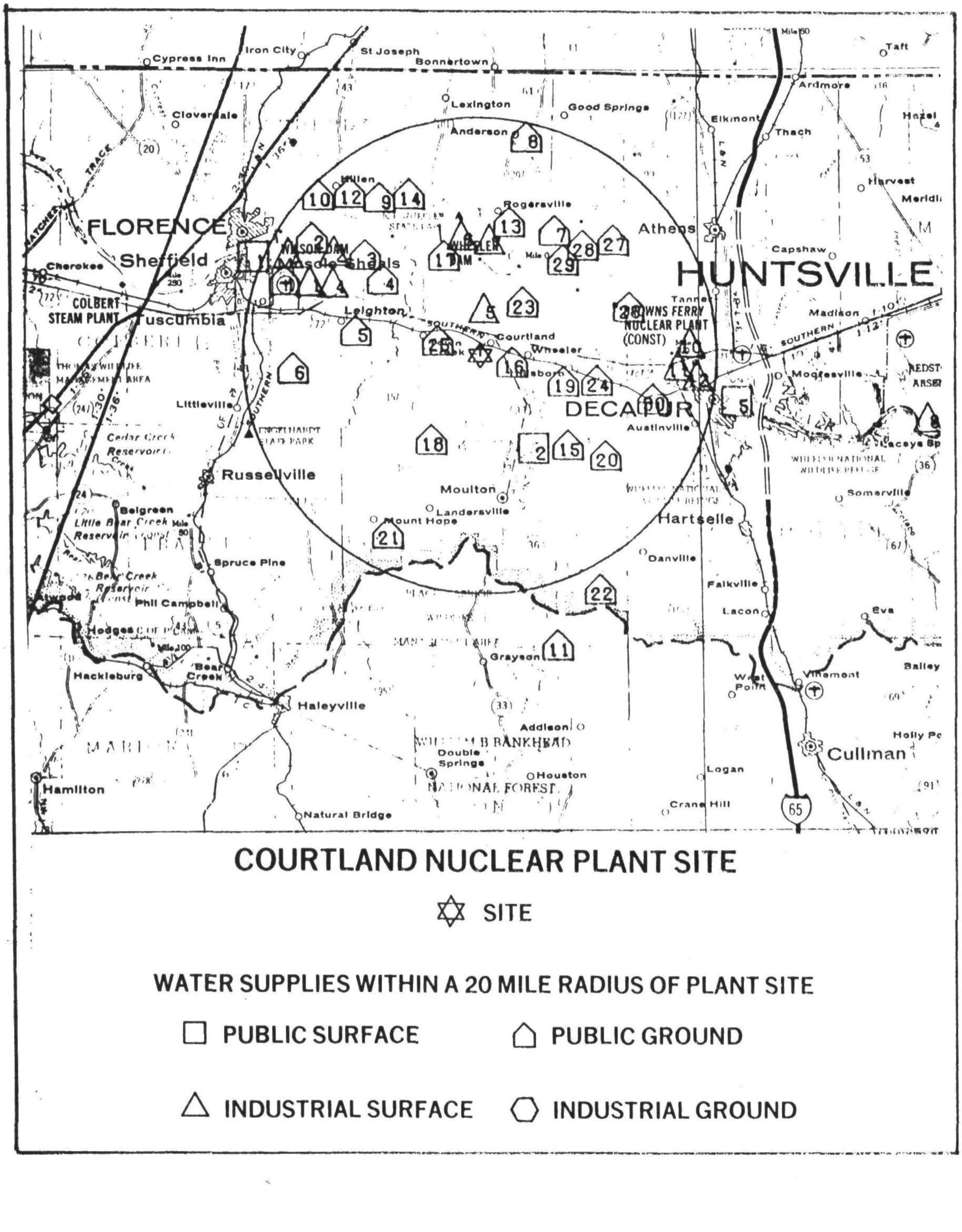


Figure 35. Figure for final report prepared by interactive graphics showing water sources in the vicinity of a proposed nuclear electric generating facility.

Although the advantages of using a computerized graphics display system were demonstrated, the methodology was never implemented on a routine basis because of the limited accessibility and slow response of TVA's overloaded computer system.

Interactive Analysis of Water Quality Models

Numerous mathematical models of water quality are used routinely for environmental analysis. These range in complexity from modifications to the classic Streeter-Phelps equation for a deficit of dissolved oxygen in streams to those models that predict detailed spatial distr ibutions of multiple biological, chemical, and physical variables in lakes, reservoirs, and estuaries. Many of these models can be used interactively in a time-sharing computer environment. Others require a great deal of computation necessitating batch processing. Both input entered into and output generated by these models can be complex and voluminous. For example, one of TVA's water quality models can predict the concentration of 18 variables in a deep reservoir at each meter of depth, four times a day, during the course of a year.[16] Input to this model consists of hydrodynamic, hydrologic, chemical, biological, physical, and meteorological conditions that impact on the reservoir.

Another model commonly used predicts temperature distributions in a reservoir. Input data consist of daily inflows and discharges, solar radiation flux, cloud cover, wind velocity, and temperature of the inflow water.[17] Also, a number of variables are required to define hydraulic mixing, water clarity, and reservoir morphology. This model requires about 30 seconds of CPU time on TVA's computer system to complete a one-year simulation. An interactive scheme of input and analysis was developed (Figure 36). Overall program control and file allocation are embodied in a command language program (CLIST). Each of the various steps of the analysis can be accomplished by answering yes-and-no questions. The user must, however, be familiar with the features of this model since the intent of this demonstration is to provide an analysis tool to extend the technical capabilities of a water quality modeler, rather than provide modeling capability to someone unfamiliar with this particular analysis.

A typical terminal session involves several steps: The engineer logs on the time-sharing system and selects a certain data set suited for the model. This data set might have been generated initially with a preprocessor program designed to interface with various types of data input sources and transform that data into a format required by this particular model. If this simulation is to be compared with a previous result, the file in which this information is stored is identified. Next, the user has the option of interactively changing various input variables in the model. When this is completed, the model can be run for the desired simulation period. All output is directed to a storage file with direct access for analysis and display. Statistics concerning the accuracy of the model in terms of actual field data are calculated for the entire water column. Other statistical comparisons between predictions and field data could also be made. For example, the user may need to know how well the model predicts average temperatures of epilimnion, hypolimnion, surface, or discharge waters. For this demonstration, however, overall simulation accuracy of the predicted temperature profile was selected for illustration.

After the simulation run is successfully completed, the user is presented with a menu of possible analysis options (Figure 36). Profiles of temperature vs. depth are of primary interest. The user may select the display of any profile based on its Julian day number, and profiles may be overlaid on each other. Figure 37 shows a typical display. Results from a previous run may also be displayed. When the user has satisfied himself with this portion of the analysis, he may return to the original menu of display and analysis. The user may then decide to display the predicted temperature profile overlaid with the profile actually measured for that day in the field. Figure 38 shows such a plot. The user may then select for display the statistics for the simulation. He may choose a tabular listing of the days on which field data were collected and the resulting simulation statistics. These may also be displayed in graphical form (Figure 39). The left graph in Figure 39 shows the root mean square (RMS) for the simulation; the magnitude of this value is the average, unsigned deviation of the predicted results as compared with actual field data averaged over the entire water column:

$$\mathrm{RMS} = \sqrt{\frac{\sum_{1}^{N} (\text{Calculated} - \text{Observed})^2}{N}} ,$$

where N = number of observed points. For this simulation run, the plot shows that the predictions are less accurate in the spring and fall than in the summer. The right graph in Figure 39 is a plot of the average mean error.[16] This statistic is the product of the average temperature of the water column and the normalized mean error (NME), which is calculated by:

$$\mathrm{NME} = \frac{\left[\sum_{1}^{N} \frac{(\text{Calculated} - \text{Observed})}{\text{Observed}} \times 102 \right]}{N} .$$

It provides to the engineer an indication of the relative magnitude of the deviations of predictions from observed results. Thus, Figure 39 shows that the model predicts lower values for average temperature in the spring and fall and higher values in the summer. When the analysis is completed, the user returns again to the basic menu of display and analysis.

One final type of analysis could commonly be made. For this, a display could be generated of selected input data such as meteorological or hydrological conditions or secondary model output data such as the average temperature of water discharged from a reservoir. This data may be viewed over the entire simulation period or over a selected time.

When these analyses are completed, the user may return to the interactive input routine, making necessary changes in a variable, or terminate the session. Simulation results may be stored in a data set at this time for later retrieval. The use of this analysis capability has greatly enhanced the ability of water quality modelers to apply this particular model to specific situations. Previously, processing of model output was accomplished manually with, in some cases, days elapsing between simulation runs. A sensitivity analysis to determine the model's response to small perturbations in input variables was exceedingly time-consuming. The work can now be accomplished conveniently in much shorter time.

Future Applications

Computer-generated animation of highly dynamic phenomena will be used more widely, particularly in studies of hydraulic mixing, biological population migration (e.g., fishery studies), and biological succession. Computer graphics will provide the means for interacting with systems of environmental analysis models and broad data bases. For example, to quantitatively assess the impact of strip mining on aquatic ecosystems, models can be used to evaluate the (1) physical and geological characteristics of the mining site, (2) mining techniques used, (3) reclamation techniques employed and results expected, (4) hydrology of the area, and (5) ecosystem impacts. These models will eventually be capable of integrating the effects of multiple mining sites at any point downstream from these operations. After changes in the quality and quantity of water are translated into biological and aesthetic impacts, they can be assigned costs or semiquantitative rankings. Practical application of such an analysis capability demands that a means be provided to facilitate data input, component model interaction, and output display.

RADIOLOGICAL HYGIENE

The analysis of existing and potential impacts from radiological material can be grouped into two categories: (1) engineering studies, which include modeling the environmental transport of nuclides, protective shielding studies, and expected dose calculations; and (2) analysis of environmental monitoring and personnel exposure data. Applications to date have concentrated on the visual presentation of data. Samples of these displays are described below:

1. Dose conversion factor (to convert a measured air radioactivity to dose rate when given a particle size distribution) vs. particle size for uranium-238 inhalation dose to lung (Figure 40).

2. The probability of a given radiation exposure based on field measurements; a linear plot is characteristic of background (Figure 41).

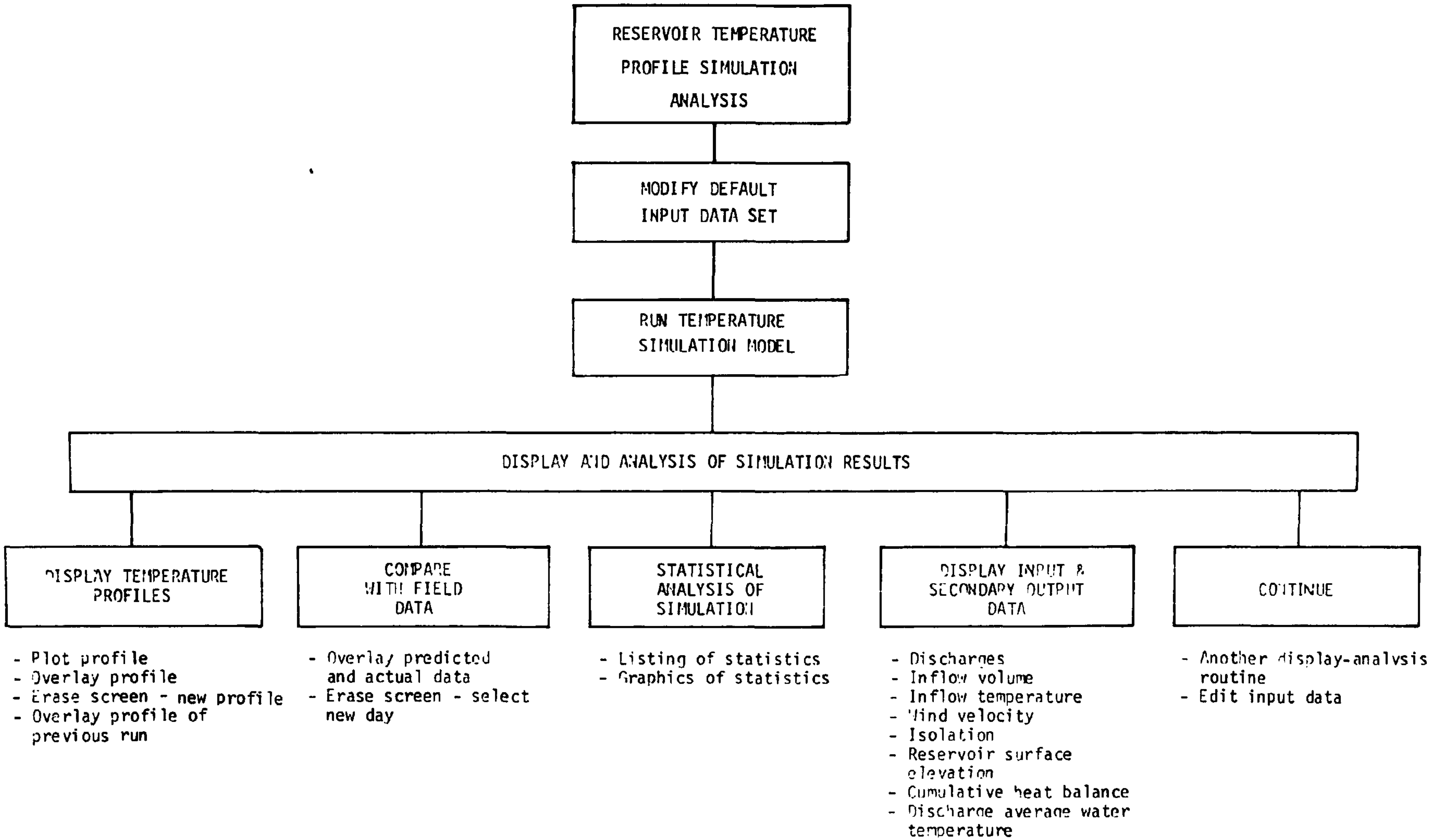


Figure 36. Interactive scheme for the analysis of simulation results through the use of a mathematical model of temperature phenomena in a deep reservoir.

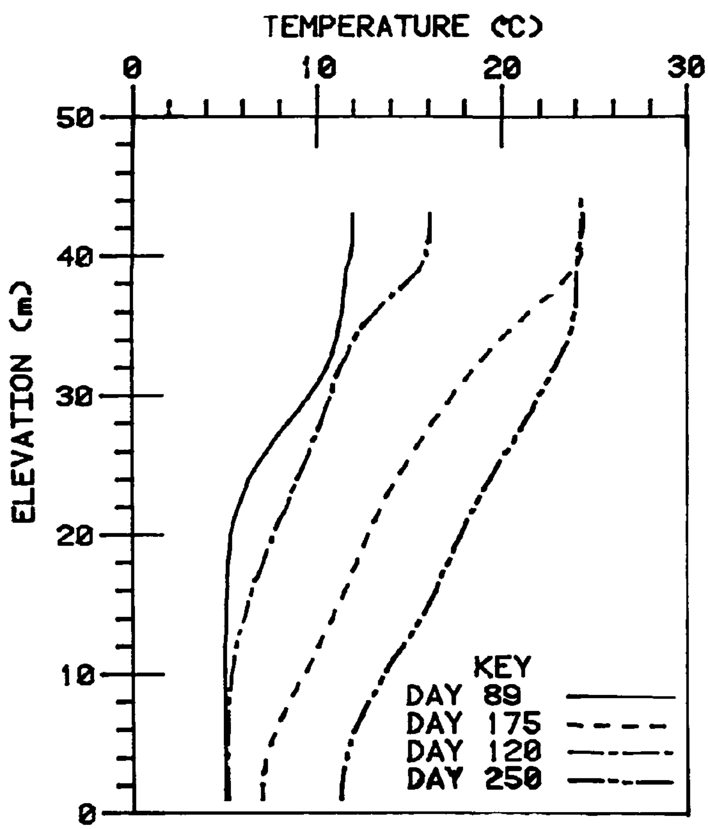


Figure 37. Profiles of predicted temperatures and depth selected interactively by the user and displayed on a cathode ray tube.

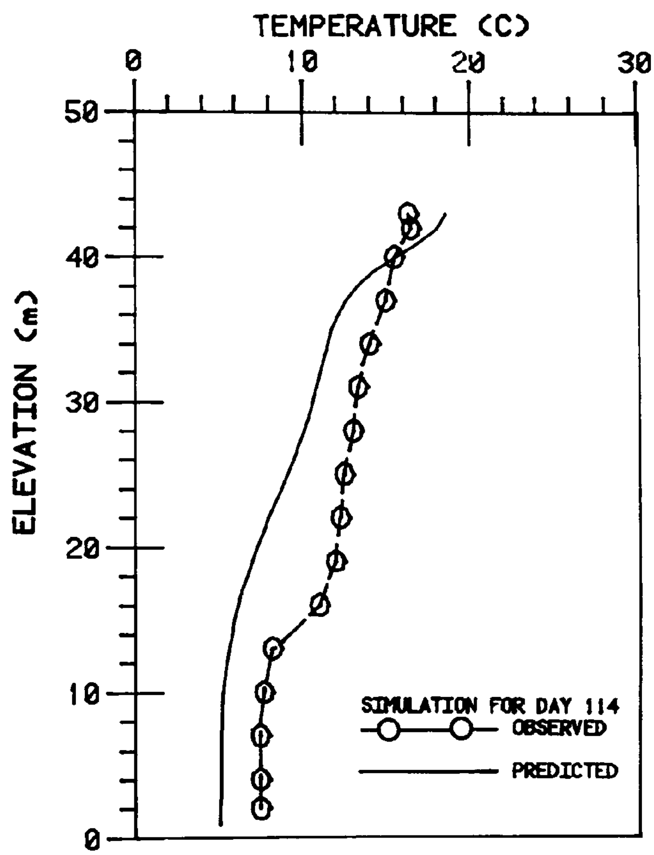


Figure 38. Profile of predicted temperature and depth overlaid with actual temperature profile measured in the field.

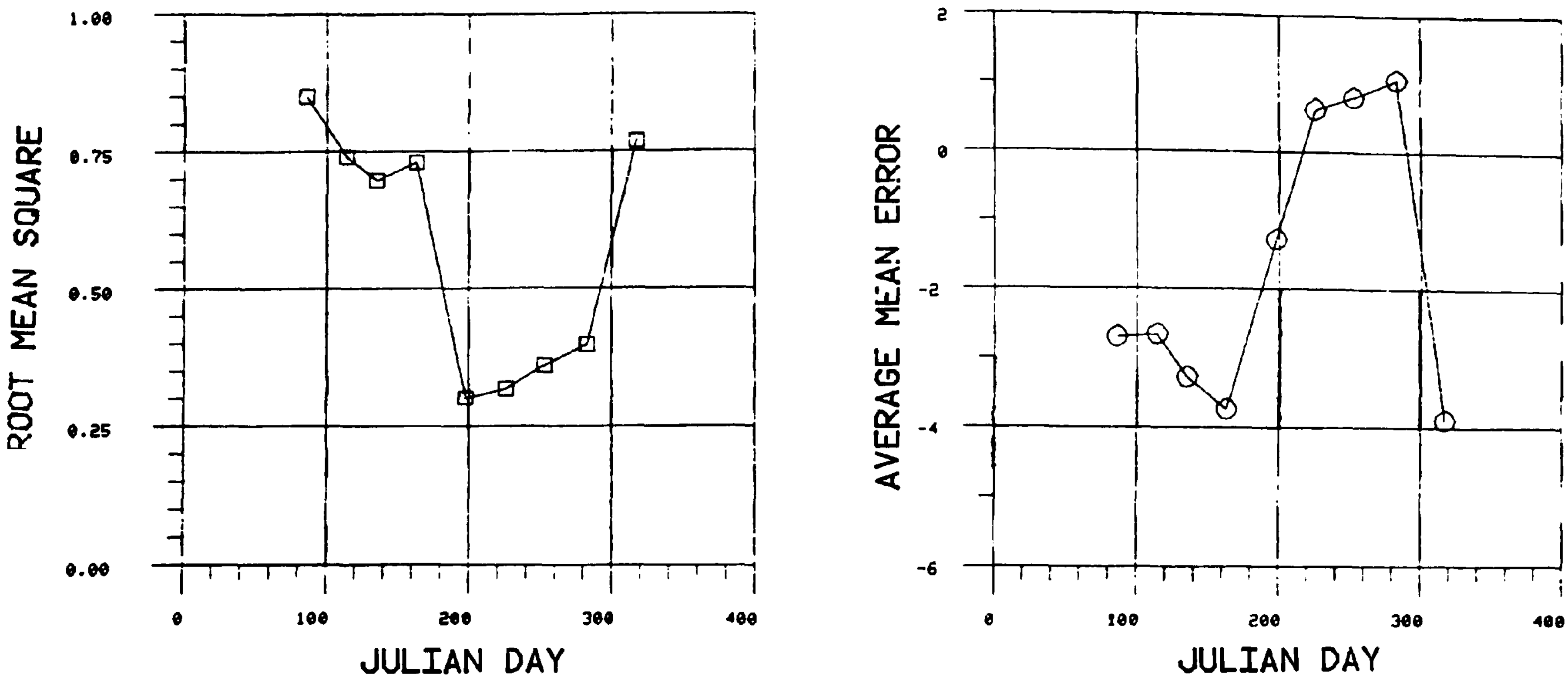


Figure 39. Plot of statistics (root mean square and average mean error) calculated over entire water column for a simulation run.

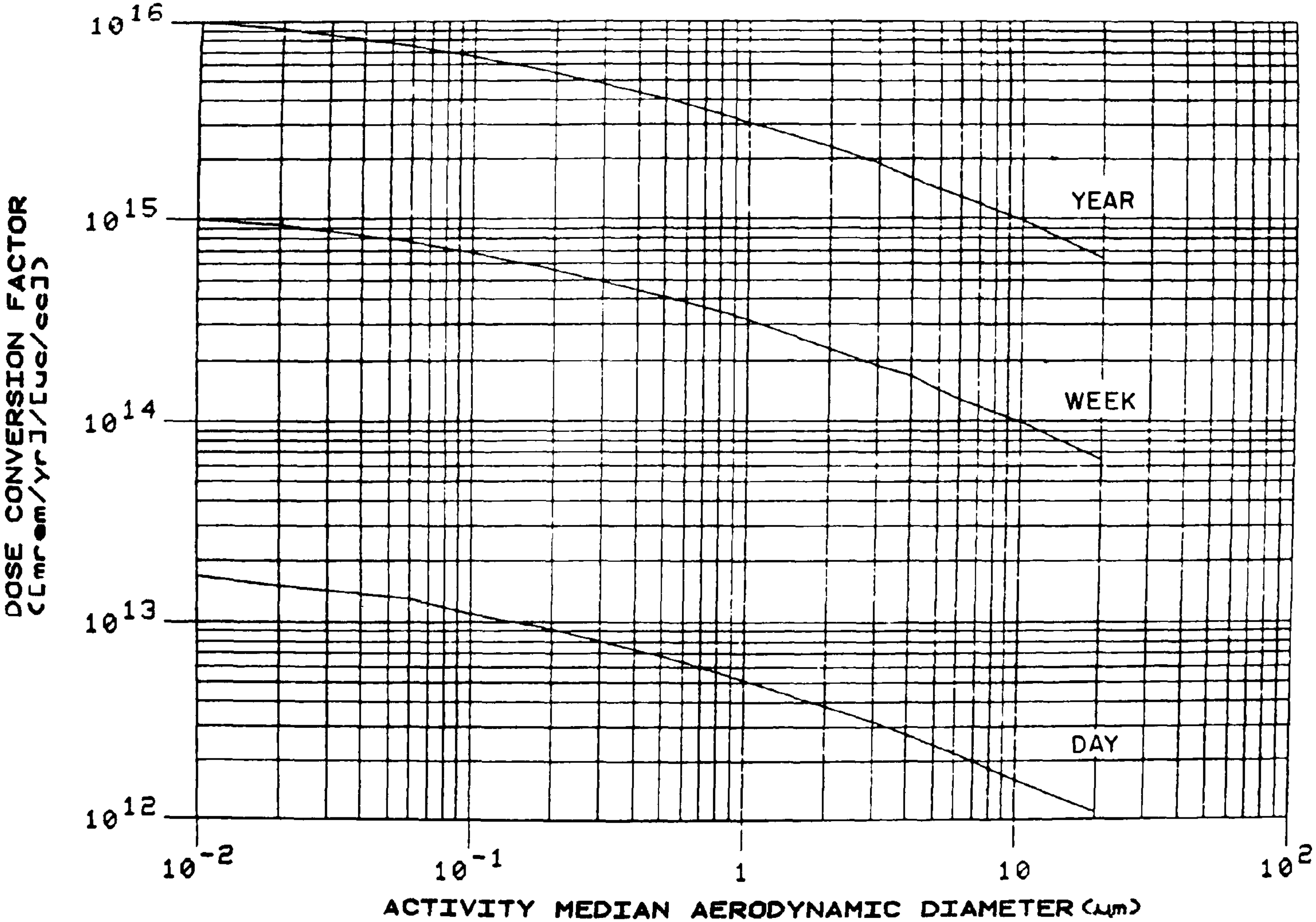


Figure 40. Dose conversion factor vs. uranium-238 particle size.

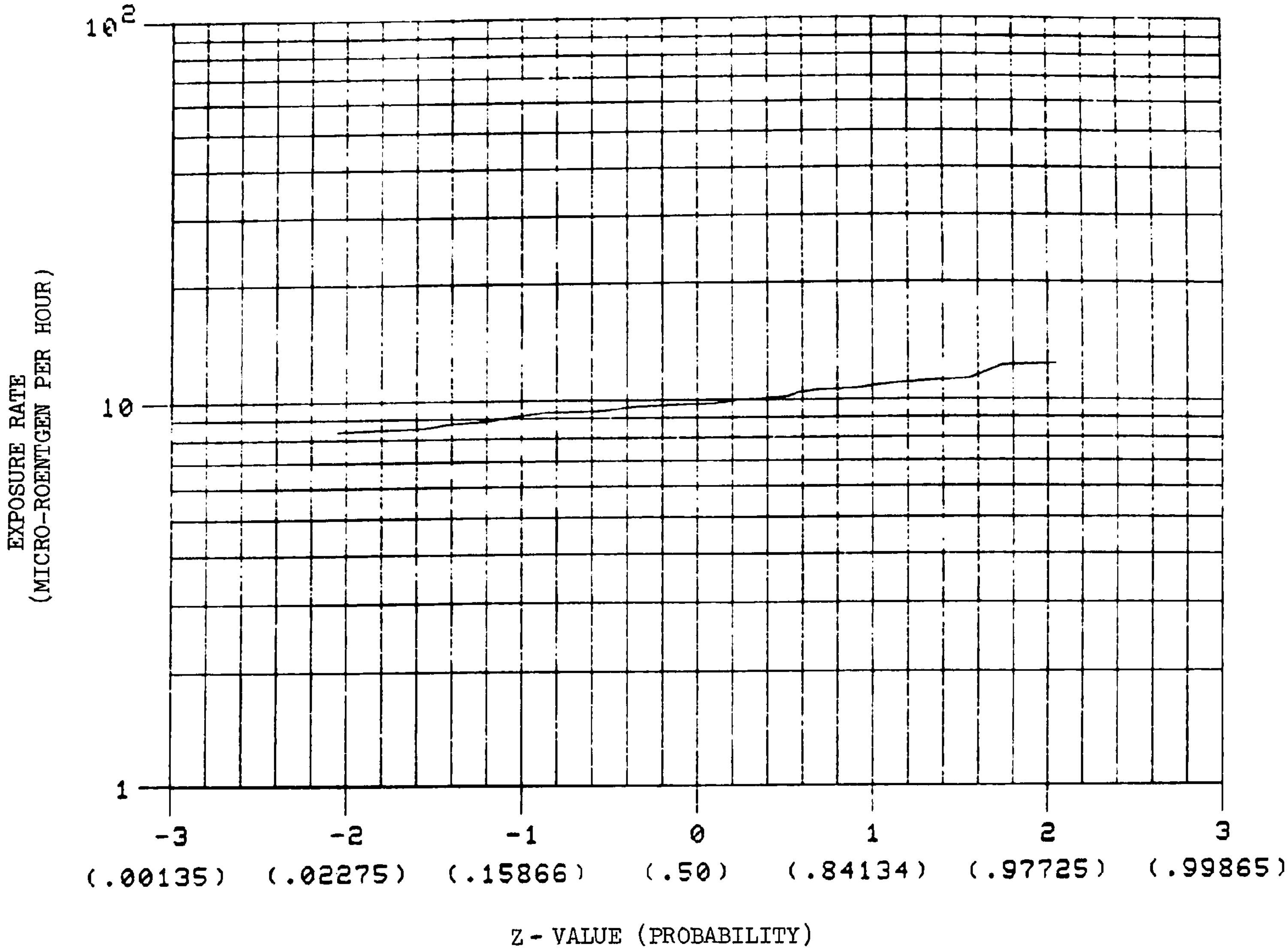


Figure 41. Probability of a given radiation exposure based on field measurements.

3. Curves of time vs. distance for a given exposure to the thyroid gland from an accident situation (Figure 42).

4. Gamma-ray spectrum of cesium-144, as measured by Ge(Li) detector (Figure 43).

Future applications include interfacing interactive graphics with mathematical models of the environmental transport of radionuclides. Computed airborne dispersion patterns can be combined with population-activity information to produce overlays on a CRT to evaluate deposition and dose effects under a variety of conditions. Graphics combined with exploratory statistical procedures can be used to identify trends in environmental monitoring data. Graphics will inevitably play an integral part in the implementation of a nearly real-time analysis system for predicting the transport of accidental releases of radioisotopes to the atmosphere or receiving waters. After the necessary input conditions are specified, automated procedures will compute dispersion patterns. Graphics will be used to interpret and communicate these results rapidly so that suitable monitoring and hazard abatement schemes can be implemented.

INDUSTRIAL HYGIENE--DISPLAY OF NOISE DATA

Measurement and control of noise in the working environment presents opportunities to effectively use computer graphics. Octave band field measurements of noise levels can be displayed as shown in Figure 44. Curves of standard frequency attenuation for various types of personal protective devices can be applied to this curve to show the noise levels expected to reach the ear for different frequency bands.

Plans of TVA's Industrial Hygiene Branch call for developing a capability for modeling noise behavior in the immediate working environment and in the community. The ability to change source locations rapidly, to visually position and alter the types of attenuation barriers, and to investigate potential impacts on land use and population distribution can be accomplished most effectively through interactive computer graphics.

SOCIOECONOMIC IMPACT ANALYSIS

Development of a methodology that uses computer graphics for screening potential sites for power plants according to socioeconomic criteria has been underway for two years. During the first year, a review was conducted (by a consultant) of the state-of-the-art of identifying and measuring socioeconomic impacts of large-scale construction of power plants. TVA's procedures for analyzing socioeconomic impact and mitigation were also reviewed. Those capabilities of a computer graphics analysis system that were needed to assist with these analyses were identified.

Twenty-two counties in East Tennessee were selected for testing a screening methodology. Data were collected on 24 socioeconomic indicators (Table 4) and incorporated in a data base that could be manipulated by interactive routines. Basic data management, analysis, and display routines are listed in Table 5.

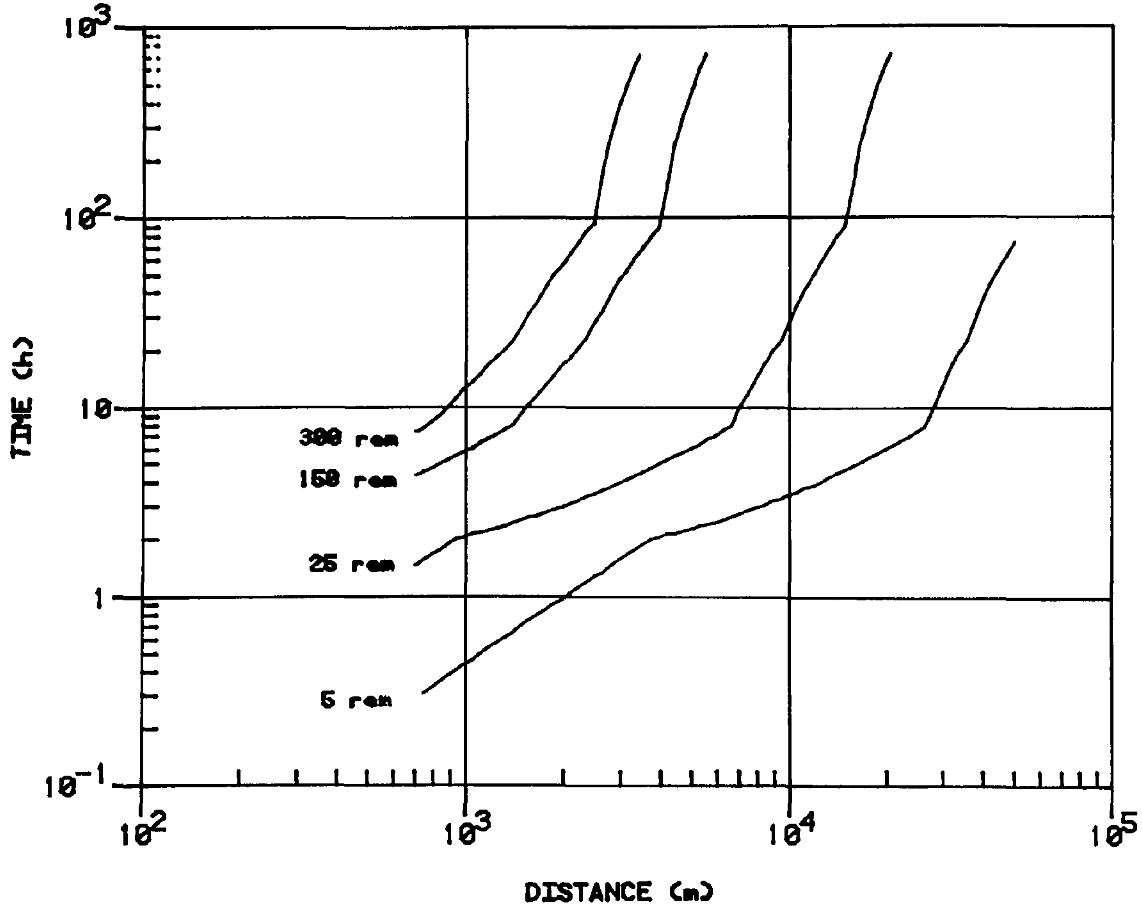


Figure 42. Plot of time vs. distance for a given dose to thyroid gland for an accidental exposure situation.

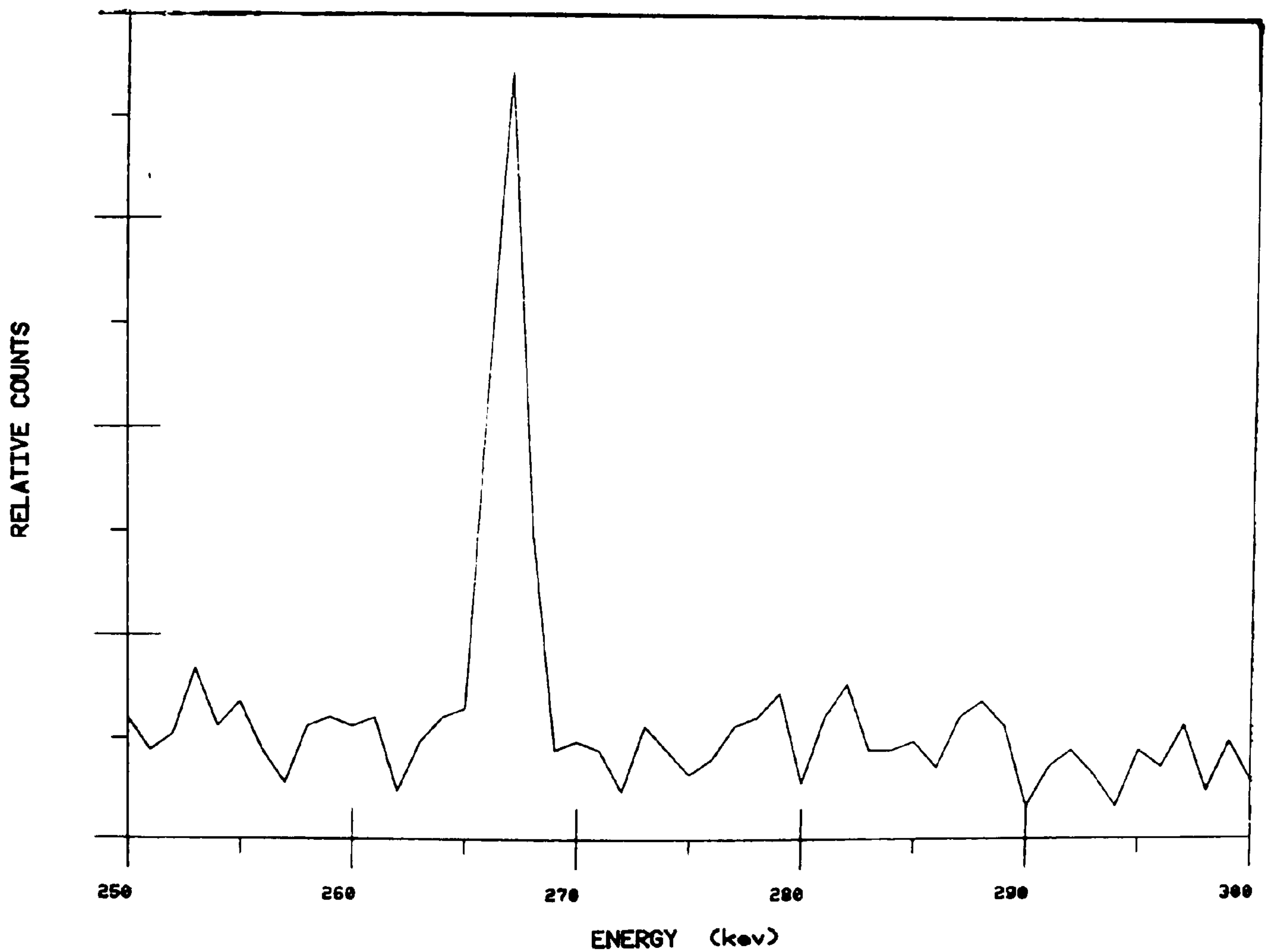


Figure 43. Gamma-ray energy spectrum for cesium-144 as measured by a Ge(Li) detector.

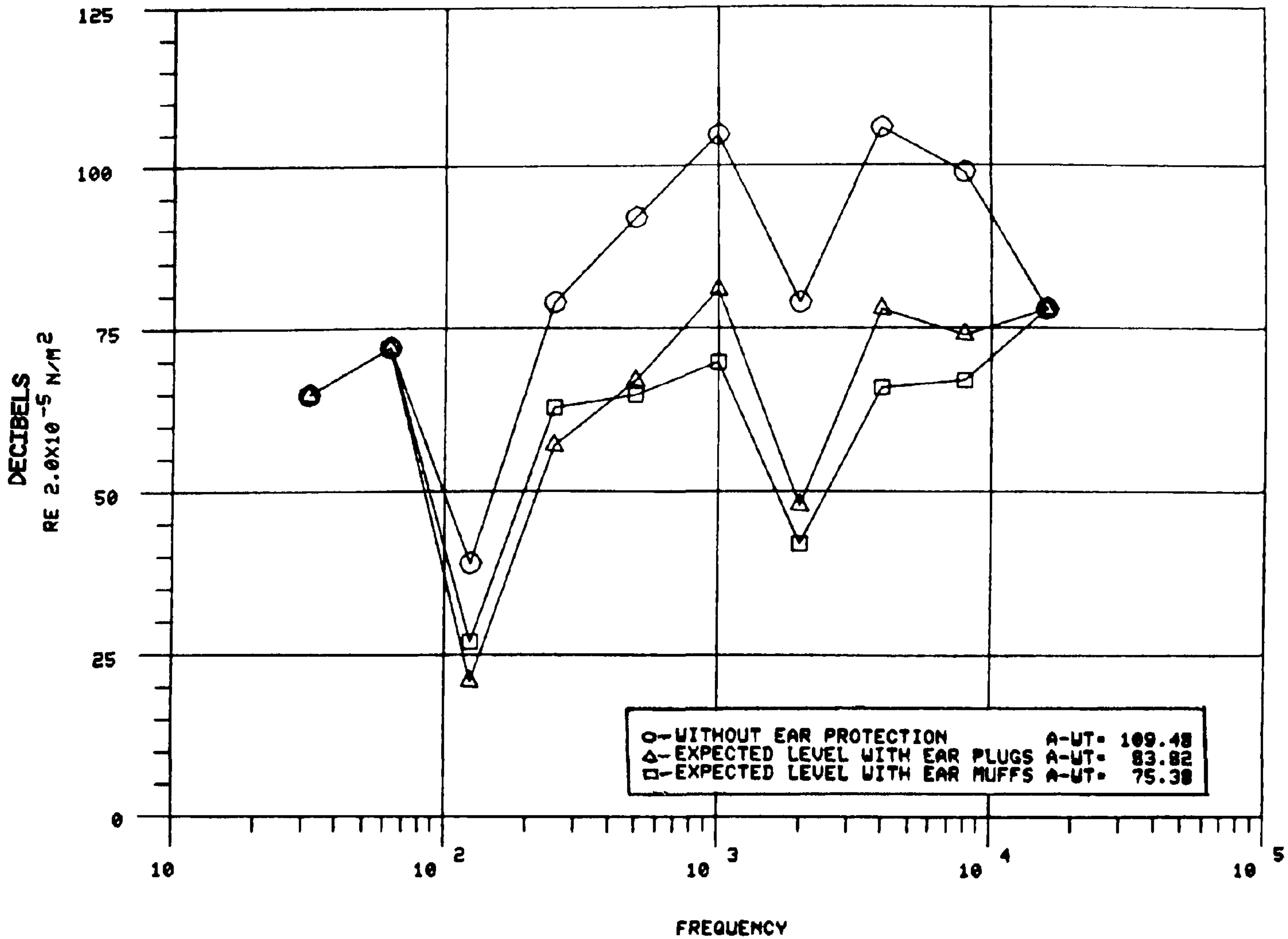


Figure 44. Display of octave band noise measurements and predicted noise levels when personal protective equipment is used.

TABLE 4. COUNTY-LEVEL SITE SCREENING INDICATORS TESTED FOR IMPACT ANALYSIS

1	Recreation: recreation acres per capita
2	Health: population per physician
3	Police: expenditures per capita (weighted average of each county with its cities)
4	Expenditure per pupil
5	Percent students overcrowded
6	Average teacher salary
7	Number of pupils per teacher
8	Percent of county population in jurisdiction having a planning commission
9	Percent of county population in jurisdiction having a comprehensive plan
10	Percent of county population in jurisdiction having a zoning ordinance
11	Percent of county population in jurisdiction having subdivision regulations
12	Percent of county population in jurisdiction having capital budgeting
13	Percent of county population in urban places
14	Housing vacancy rate (1970)
15	Percent of housing built before 1950
16	Percent of change in population (1960-1970)
17	Percent of change in population projected (1970-1990)
18	Unemployment rate
19	Median family income (1970)
20	Percent of population receiving welfare
21	Percent of population in 20- to 44-year age group
22	Percent of population living in same house five years ago
23	Percent of population served by public water
24	Percent of population served by public sewer

TABLE 5. CATALOG OF DATA BASE MANAGEMENT, ANALYSIS, AND GRAPHICS ROUTINES FOR A COUNTY-WIDE SOCIOECONOMIC INFORMATION SYSTEM

Name	Function
	Data base management
CALLO	File allocation routine (to allocate data files to proper logical units)
CFILL	To fill data base with multiple data values
CEDIT	To display and alter individual data values
	Analysis routines
CFIND	To search the data base or a subset of counties for a given data value condition (less than, greater than, equal to)
CRANK	To prepare basic statistics and ranking of counties for a given variable
	Display
CSUM	To prepare a formatted list of data values of an individual county or a group of counties
CXYPLT	To prepare a scatter plot of two county variables (one variable against the other)
CKIV2	To plot up to 12 Kiviat diagrams with a maximum of 20 axes
CDRW	To plot selected county boundaries and one data value at the center of each county

Selected indicators were combined mathematically to form capacity indexes, thus reducing the number of indicators to manageable size and providing a better measure of the potential for each county to absorb or benefit from a particular type of impact. Graphical and statistical methods were used to evaluate the relative merits of each new index formed. Resulting from this work were six indices: (1) public service, (2) planning and public administration, (3) health, (4) education, (5) growth absorption potential, and (6) economic need. Finally, several forms of a composite index composed of these six capacity indices were tested. Procedures were also developed to weight various indicators and capacity indices in these analyses.

Three types of graphic displays were used in this research. Figure 45 shows the results of a program that draws any or all of the county boundaries being considered, identifies the county, and places a value or representative symbol within the boundary. The map can be displayed at various scales, permitting a small selected portion to be enlarged. Figure 46 shows six socioeconomic indicators displayed in the general form of the Kiviat diagram previously described.

Figure 47 shows another useful graphics display. Scatter plot displays were generated for pairs of indicators whose correlation coefficients were unexpected or otherwise of interest. The entire set or a given subset of county data for the selected indicators can be plotted readily, and the axes labeled. Details of this work are presented in Appendic C.

GEOGRAPHIC INFORMATION SYSTEMS AS AIDS TO SITING FACILITIES

Two research tasks were undertaken: (1) to review the state-of-the-art with respect to the use of computer-assisted geographic information systems to support the process of siting major power generating facilities and transmission corridor routes and (2) to provide suggested design criteria for planning a geographic information system for siting power plants. The results are summarized below; details are available in separate reports.[19,20]

To accomplish the first task, a survey of siting methodologies was conducted among public and private utilities in the United States and Canada to determine whether geographic information systems are used and, if so, for what specific siting phases and analysis processes. Also included in this survey were those State governments that maintain geographic data systems that might be applicable to siting power facilities.

The methodologies most frequently used by utilities and their consultants to site power facilities include checklist, overlay, and matrix techniques. In general, utilities have largely restricted their siting efforts to developing comprehensive checklists of siting considerations, whereas consulting firms have concentrated on developing techniques (referred to as methodologies) for evaluating a subset of considerations (such as environmental impacts) at a particular stage of site selection.

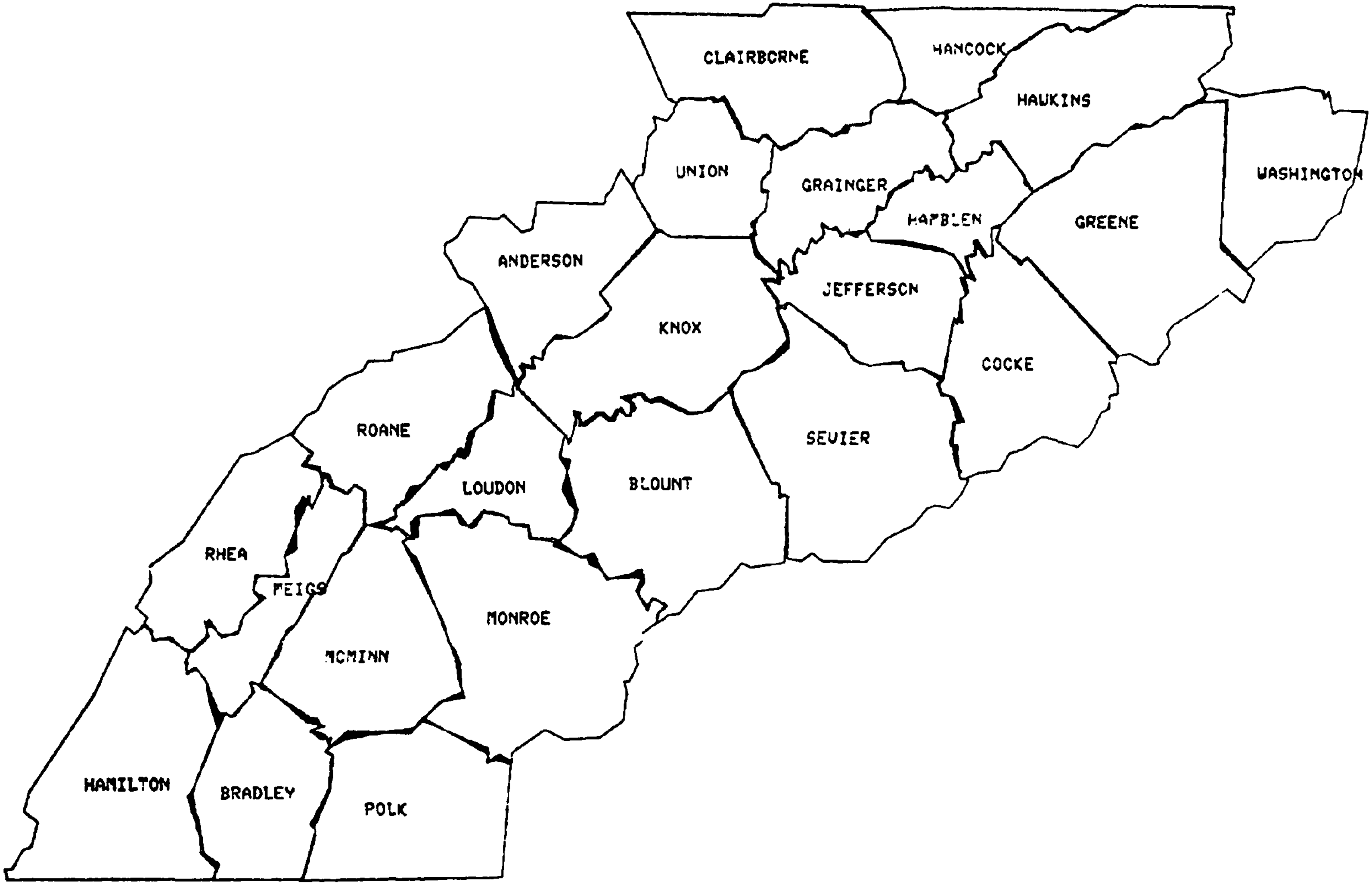


Figure 45. Display of county boundaries in the socioeconomic methodology test area.

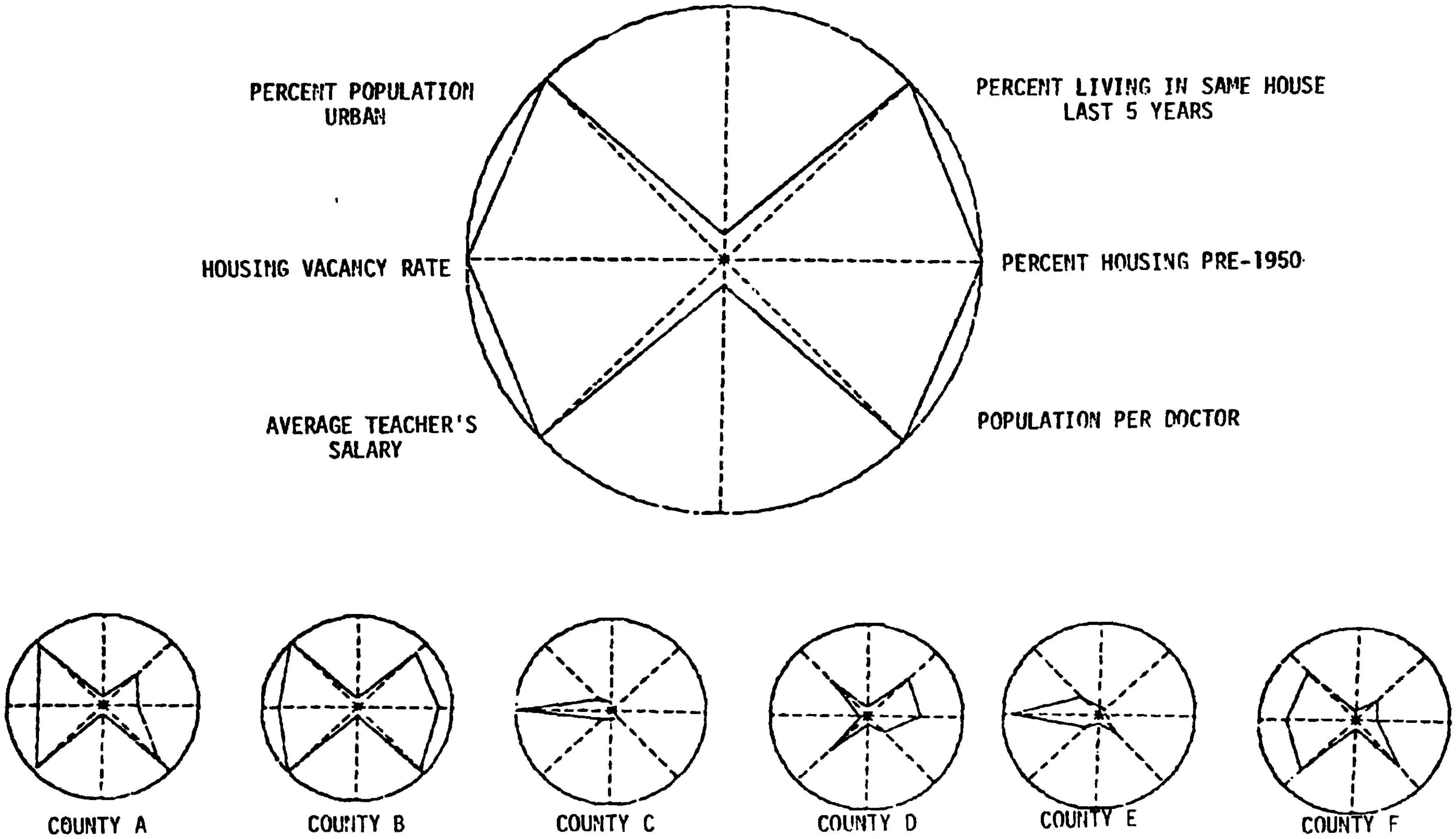


Figure 46. Sample of socioeconomic indicators displayed as Kiviat diagrams.

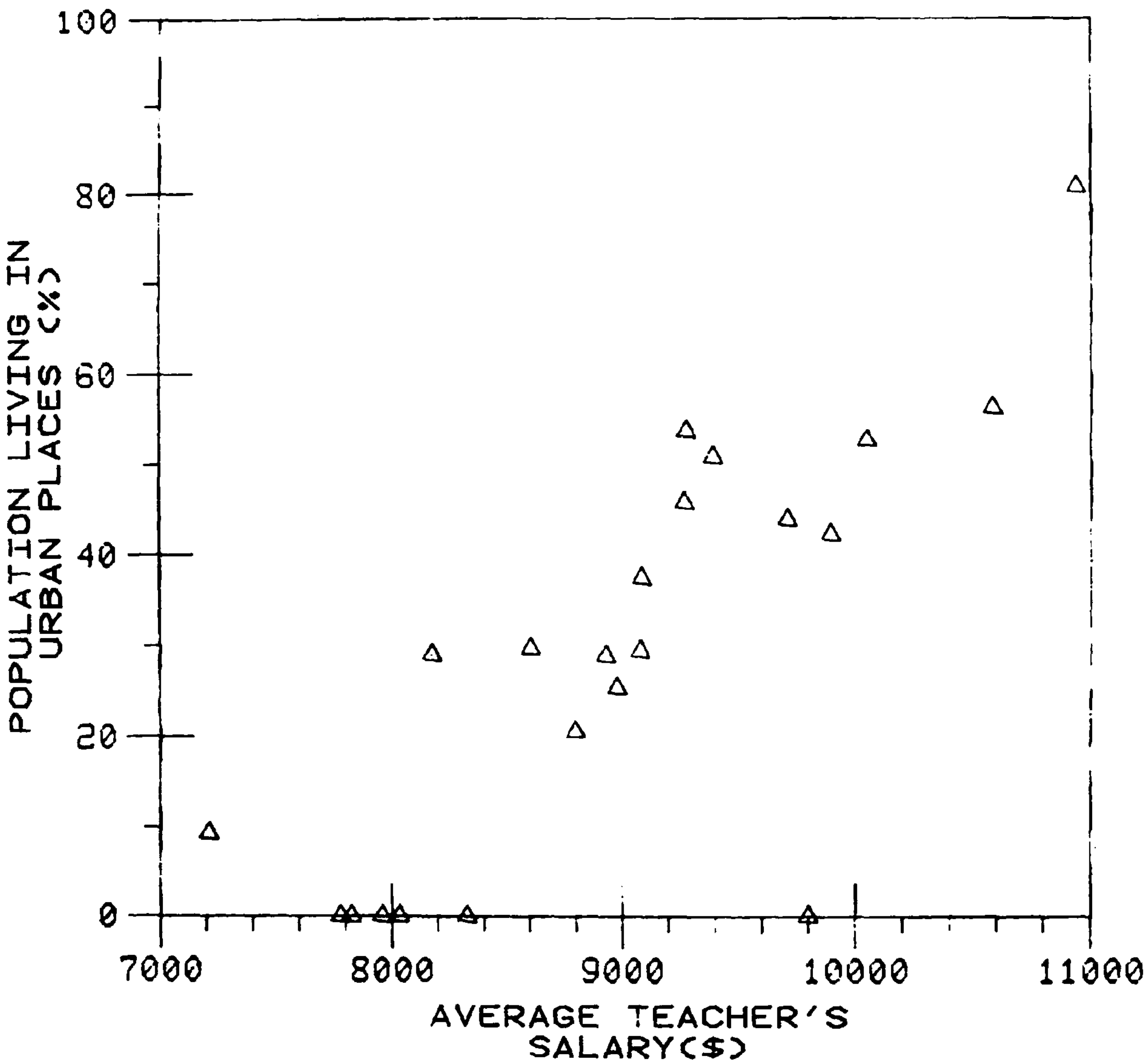


Figure 47. Scatter plot of percent of population living in urban setting vs. average teacher's salary.

The most popular approach at all stages in the siting process is the checklist technique. Overlays are being used increasingly at stages II (multicounty) and III (site-specific) to graphically depict specific sets of variables such as engineering constraints or environmental impacts.

There are four basic methods for routing transmission lines, ranging in sophistication from a direct line (i.e., a line is projected from source to load) to computer-assisted optimization models (i.e., the probable costs and benefits of a wide variety of alternatives are analyzed, and the routes are selected and ranked according to impact). At present, most utilities rely heavily on direct-line routing.

Computer-assisted geographic information systems are not commonly developed or used for siting or for routing transmission corridors. Efforts on the part of utilities and consulting firms to use geographic information systems for routing transmission lines have encountered various difficulties:

1. The level of detail and the degree of resolution of a system's data base usually is inversely related to the amount of area under consideration; detailed, finely resolved, expensive data bases are required for siting transmission lines.

2. The cost ratio between siting and constructing lines becomes unfavorable as data capture expenses for the geographic information system increase the cost of siting.

3. Tradeoffs between resolution and data capture expenses have been made without the benefit of prior experience. In many instances, the resultant analyses have not been useful because coarse resolution eliminated potentially acceptable areas.

One of the most prevalent difficulties associated with assessing sites for power generating facilities is that of analyzing and evaluating large amounts of incommensurate data collected and organized by many diverse sources. Although computer systems have the potential for becoming a useful tool for analyzing these siting variables, they have not yet been developed for or used by utilities. Geographic information systems exist in various forms and degrees of completion. They differ in form of data storage structure, and degree of computer assistance that can be provided to the user, but in many respects they are quite similar. All the systems use computers to store data, and most can retrieve information in map format. Most are structured for some type of natural resource planning and include topographic data, soil type distributions, and land use information. Also, data concerning aquifer recharge areas, unique and endangered species, natural features, historic areas, unique and endangered species, natural features, historic areas, population distribution, and climate are frequently included. Most of the systems use a regular grid format for data analysis. Data are most frequently encoded directly to cellular format, but the trend is toward digitizing information in terms of irregular polygons and using the computer to convert to appropriate cell sizes for analysis. Resolution (cell size) varies widely among systems.

Statewide computer-assisted geographic information systems developed for planning purposes are generally not suitable for direct use by utilities for siting. However, they appear to be useful for providing information pertinent to licensing power plants. Geographic information sharing between utilities using these systems could lower the time and cost of data collection.

After the use of geographic information systems for siting power facilities was surveyed, a study (Task 2) was undertaken to determine general design considerations of a computer-assisted geographic information system that potentially could aid the assessment function within a generalized, comprehensive methodology for siting power plants.

A hierarchical set of subsystems, processes, and modules that compose such an information system was identified. Estimates of resource requirements for system development and implementation were summarized for each subsystem and data base.

A geographic information system can be subdivided into subsystems, and individual subsystem components are properly defined by a thorough investigation of user information needs and objectives. Five generic subsystems can be defined: (1) the system management subsystem, consisting of the system maintenance, scheduling, and operating procedures, the user-system interface, and staffing requirements; (2) the data acquisition subsystem, including procedures for compiling, cataloging, and filing source documents, and techniques for digitizing (converting information to a machine-readable form) data from maps, aerial photographs, or other sources; (3) the data base management subsystem, which maintains and provides procedures that control the access and use of the data base; (4) the data analysis subsystem, including analysis capabilities such as data transformation techniques, derived data processes such as index construction, coincidence and proximity analysis, modeling, statistical analysis, and others; and (5) the data display subsystem, which provides procedures and devices to display output in the form of summary reports, tables, or graphic displays.

One additional aspect of a geographic information system, although not strictly a subsystem, relates to the use of the information. Procedures need to be devised for effectively applying the generated information to solve the problems of concern. This will depend on the user's particular management system for decision making.

A computer-assisted geographic information system is a potentially useful tool to help meet objectives of data handling, analysis, and graphic display in a comprehensive methodology of power plant siting. Possible design objectives of an information system and descriptions of their relationship to power plant siting methodology are listed below.

Objective 1: To store and retrieve spatial engineering, socioeconomic, and environmental data.

The power plant siting process requires the use of large amounts of geographically referenced information. Certain issues related to computer storage and retrieval of information must be resolved: the type of location identifiers attached to the data, the coordinate system to be used, and the hardware and procedures for encoding and storing data.

A flexible system must be able to handle geometric representations of data, including point, line, and area data. Polygons could be used as the primary data sructure for data storage, with the capability of converting to regular grid cells for ease in manipulation.

Location identifiers refer to referenced coordinates. Latitude-longitude can serve as the primary coordinate system, with the capacity to transform into UTM, state plane, or other coordinate systems as required. Data encoding is the conversion of mapped information into computer-readable form. Particular encoding conventions depend on geometric representations of the data and the desired digital structure. Examples include predominant type, percentage, absence-presence, and center point sampling. Both manual and automated techniques for accomplishing this task could be included in the system.

An integral part of managing a large volume of data is the means of data storage. Provisions for both physical and digital storage techniques are required in the system design, including manual files, punch cards, magnetic tape, and discs. Each method has advantages and disadvantages related to specific needs.

Objective 2: To store data and analyses from past siting studies in a form that will allow easy retrieval and updating for use in future investigations in the same region.

Data maintenance is an important consideration in geographic information system design. It includes data archiving, data base additions, and editing.

The ability to archive historic data in a format that will facilitate its use in future siting studies is a major factor in the cost-benefit justification of the system. A system should be able to accommodate increased quantities of data and have the flexibility to add new spatial data types. Editing or error-checking mechanisms are needed to modify the data base. Data inaccuracies may occur as data are input or as a result of an actual change in the condition as described at a particular location.

Objective 3: To consider all locations within a region at a variety of levels in a scaled hierarchy from the multistate level down to specific sites.

Most processes for siting power plants require collection and analysis of data at several levels of resolution in a scaled hierarchy. The criteria for determining potentially suitable sites become more stringent as the scale becomes more site-specific. The system should be designed to accept data collected at any level in the hierarchy and should be able to transform data from one level to another.

Objective 4: To analyze the spatial distribution and interrelationships of environmental, socioeconomic, and engineering conditions.

Objective 5: To review the effects of using a variety of siting scenarios that reflect differential weighting of siting criteria among engineering, socioeconomic, and environmental factors.

Objective 6: To review potential areas for all types of generating facilities, including fossil, nuclear, and hydroelectric plants.

Objective 7: To evaluate alternative development concepts such as nuclear parks.

Objective 8: To consider future changes in siting and power generation technology.

Objectives 4 through 8 address useful data manipulation and analysis capabilities. Possible system capabilities could include (1) rescaling or restructuring of data values, (2) analysis of spatial relationships, (3) logical combinations of data, (4) mathematical manipulation, (5) weighted indexing, (6) statistical operations, (7) windowing, and (8) special-purpose operations.

Objective 9: To communicate to managers, regulatory agencies, and the public the information, analyses, and value judgments related to siting decisions.

Effective communication is an extremely important factor in the use of geographic information. Raw data and the results of analysis can be communicated visually through computer graphics. Information can be presented as maps, graphs, or charts as well as tabular listings. Computer hardware output devices that are most readily used for creating displays include character printers, line and electrostatic plotters, CRT's, and COM (computer on microfilm) devices.

Two types of analyses, which fall under the general title of spatial analysis, lend themselves to interaction with a CRT. Information used in such studies is commonly referenced on a cellular basis. Several well-developed software packages such as SYMAP and IMGRID[21] are available to manipulate these data in a meaningful manner. Two basic types of questions can be asked: (1) "Which cells have given attributes in common?", and (2) "What is the relationship of a particular cell to its neighboring cells or to other map features?"

The attributes referred to in the first question may be the data variables themselves or a combination of the raw data, which in turn indicates a particular attribute. Figure 48 illustrates a composite plot generated by a line printer of septic tank suitability for Knox County, Tennessee. Factors considered in such an analysis might include soil type, percolation rate, and depth to water table. In response to the second question, a cell that is classified as having harvestable trees might be a much better candidate for logging operations if it is surrounded by other cells with harvestable trees, than would the same cell located in a residential area or a park. A similar question might be, "What cells within a given distance from a major road or river meet certain criteria?"

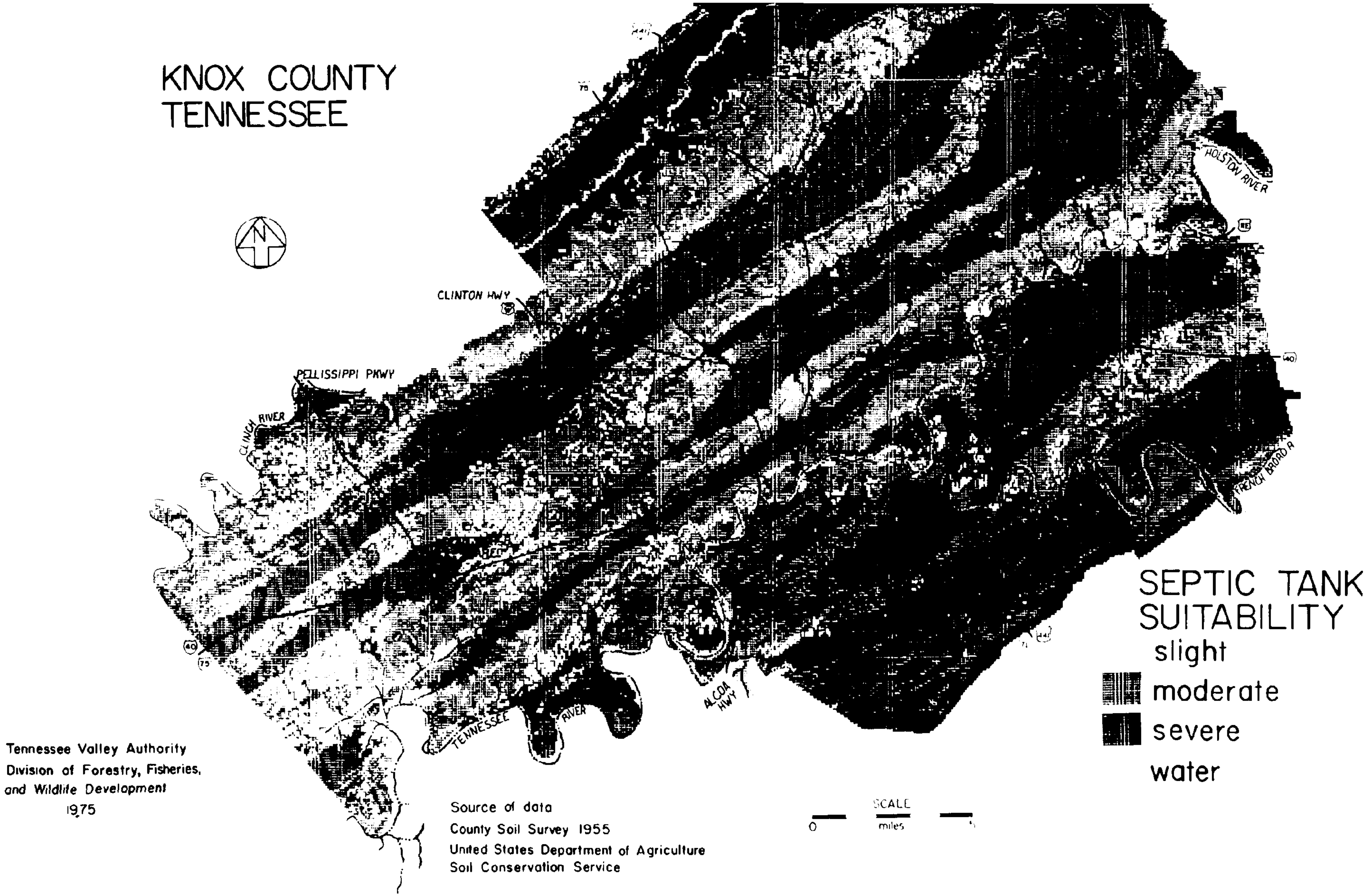


Figure 48. Shaded line-printer composite display of septic tank suitability for Knox County, Tennessee.

To illustrate a typical interactive analysis that might be conducted at a CRT, a test area composed of a 50 x 50 array of 2.5-acre cells is selected. Each cell was classified with respect to eight different types of data (Table 6). At the beginning of the analysis, the user selects any three sets of data. He would then request a display of any one particular factor, such as developed land; Figure 49 shows a display of those cells classified as developed land. Other information related to the area, such as political or property boundaries, roads and topography, can be stored separately on flexible disc and then superimposed on the screen; Figure 50 shows the roads and 50-foot contours overlaid on the display.

Next, the user might request a multifactor analysis. In this example, the user has requested a display of cells classified as being a farm or an estate and having upland conifer trees and a land slope of 3 to 6 percent; Figure 51 shows the CRT display. Cells having the three conditions in common are shown with a star. Cells that meet only part of the requirements are shown with other symbols. The program also keeps count of the number of cells in a particular category. By multiplying the count in each category by the size of each cell, one can tabulate the number of acres for each group. A bar chart of this information is shown in Figure 52.

This technique can be used, for example, to determine the number of cells that remain available for a certain use. Other similar analyses that could be demonstrated relate directly to facilities siting: location of endangered species, proximity to water, avoidance of earthquake-prone areas, or distribution of sensitive crops. The analysis principle, however, remains the same.

The implementation of practical analysis techniques that use computer graphics for regional environmental analysis (including facilities siting) depends to a large extent on the development of a regional geographic information system capable of accommodating a variety of spatially referenced resource data. As a result of the activities of this research project and others within TVA, an interdivisional study team made up of representatives from twelve TVA divisions was established at the direction of the General Manager's Office. Staff from this research project participated heavily in this four-month (March-June 1977) study effort. Objectives were to identify (1) current and future TVA needs for geographic information and (2) opportunities for sharing geographic information and possibly developing the information system.

The first activity of this study involved compiling an inventory for each TVA division, listing (1) program functions that use geographically referenced information, (2) a description of geographic information, (3) data sources from which the information is derived, and (4) relevant, existing, organized systems for handling this information. A sample inventory for the Division of Environmental Planning is shown in Table 7.

A second task completed by the study team involved interviewing TVA division management to identify current and projected needs for information systems and geographic information. A final task was the analysis

TABLE 6. SPATIAL DATA CLASSIFICATIONS USED TO CHARACTERIZE CELLS IN THE DEMONSTRATION AREA

Aspect--land orientation	Slope	Forest type
100% water	100% water	Developed land
Flat (less than 6% slope)	1-3%	Water
North	3-6%	Wetland
Northeast	6-10%	Cropland or pasture
Northwest	10-15%	Lowland coniferous
East	15-25%	Lowland deciduous
West	25-45%	Upland coniferous
Southeast	Greater than 45%	Upland deciduous
Southwest		Upland mixed
Depth to bedrock	Water--predominant type	Residential land use
100%	None	None
1-1.5 ft	Swales	Farms and estates
3-10 ft	First-order streams	Single family--large lot
3-20 ft	Other streams	Single family--medium lot
3-30 ft	Ponds	Single family--small lot
5-20 ft	Reservoirs	Multifamily--low rise
5-30 ft	Lakes	Multifamily--medium rise
5+ ft	Rivers	Multifamily--high rise
100+ ft	Estuary	
	Ocean	
Commercial and industrial land use	Summary land use	Transportation--road type
None	None	None
Shopping centers	Recreation	Unimproved
Downtown	Low-density residence	Paved, light-duty
Strip and roadside	Medium-density residence	Paved, medium-duty
Wholesale storage	High-density residence	Heavy duty
Modern industrial parks	Transportation	Divided with access
Extractive industry	Institutions	Divided with limited access
Individual industry	Industry	Interchange
Old industrial complexes	Commerce	

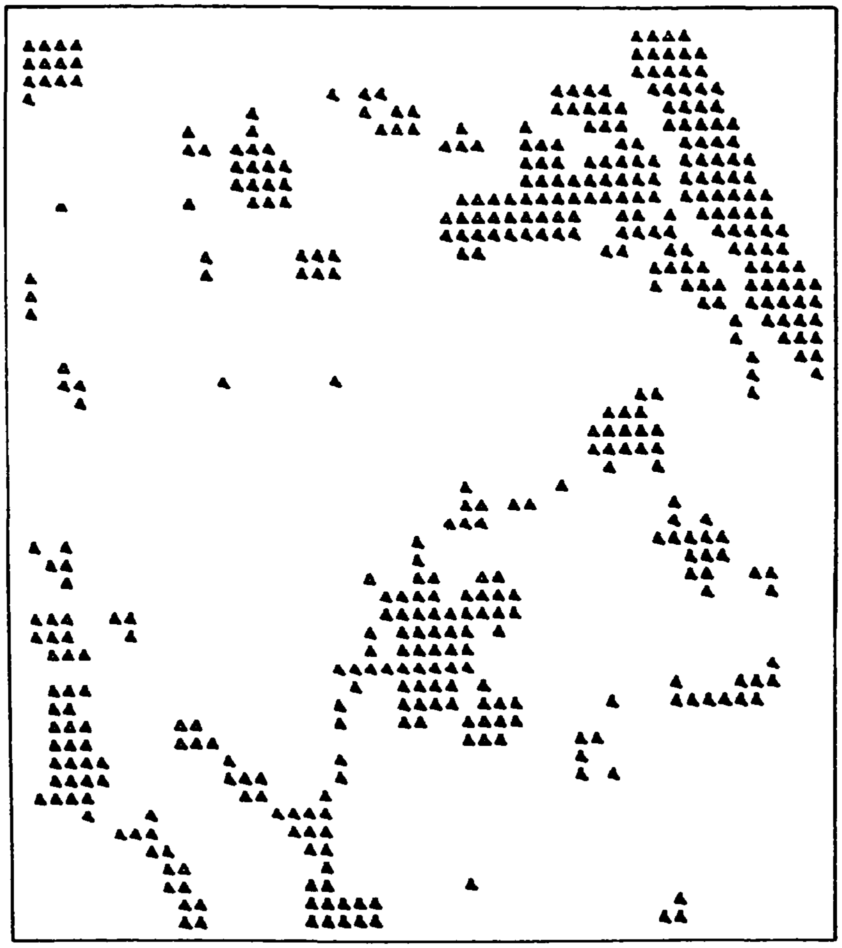


Figure 49. CRT display of cells classified as developed land in the demonstration area.

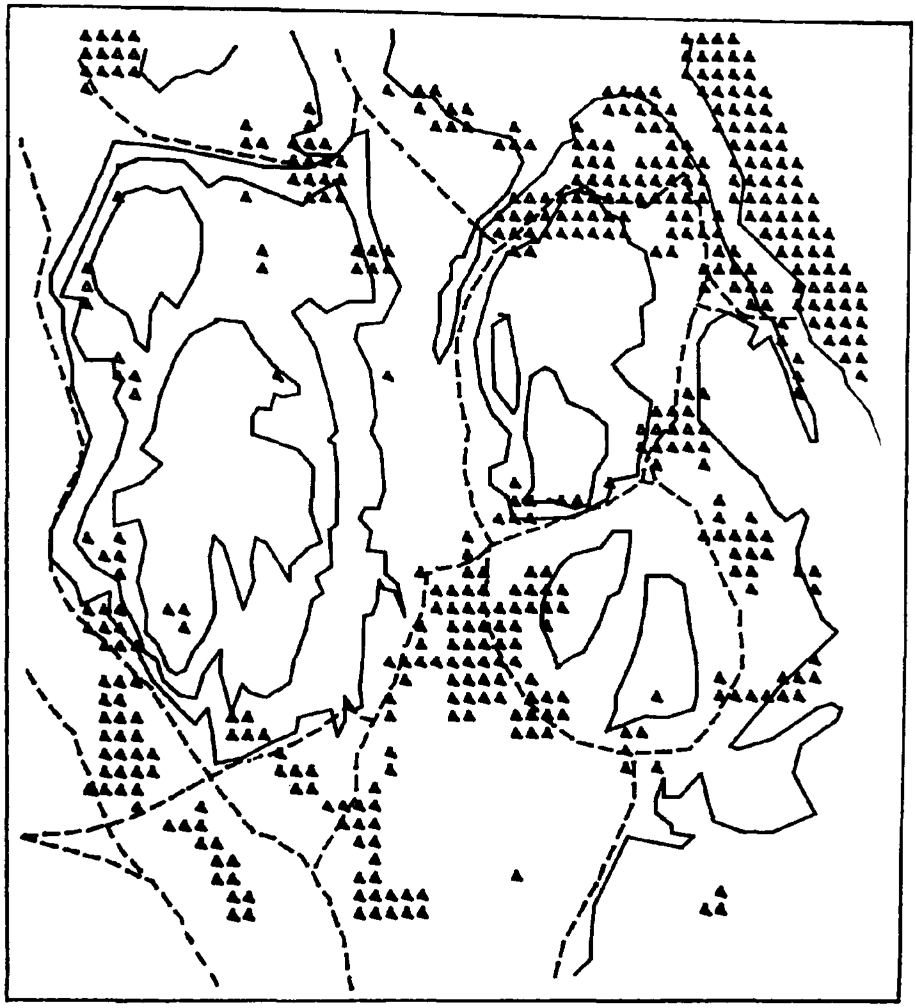


Figure 50. Overlay of major roads and 50-ft. contours on CRT display of developed land.

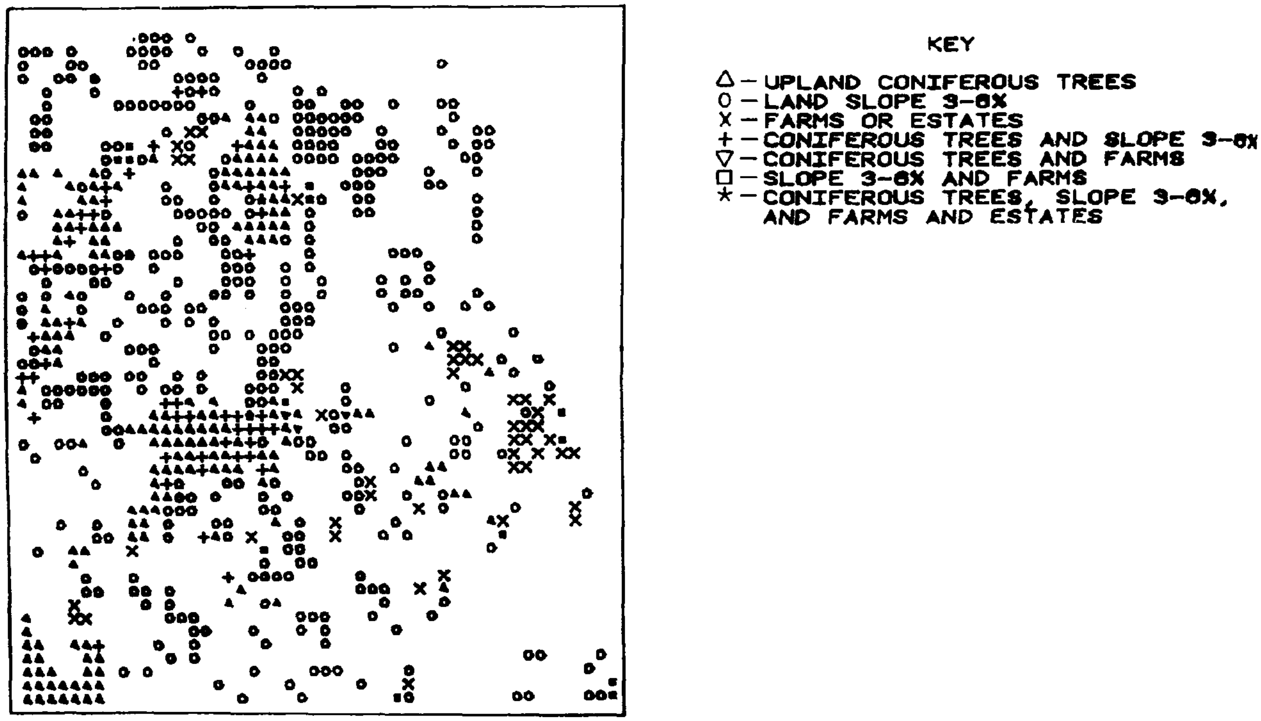


Figure 51. CRT display of cells that possess various combinations of (1) upland coniferous forest, (2) a land slope of 3 to 6%, and (3) farms and estates.

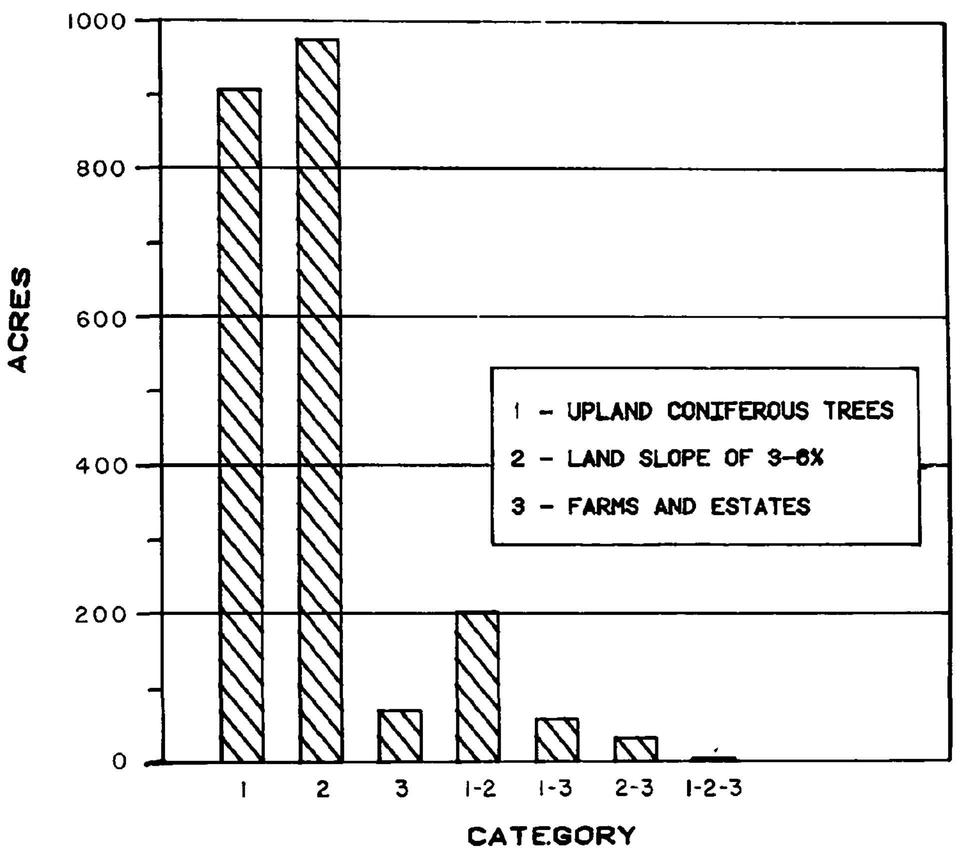


Figure 52. Calculated number of acres in the demonstration area that meet various combinations of the three characteristics selected for analysis.

TABLE 7. INVENTORY OF GEOGRAPHIC INFORMATION SYSTEM USED BY TVA'S DIVISION OF ENVIRONMENTAL PLANNING

Function	TVA client[a]	Information requirements	Data sources	Data sources	Supplied by[b]	Information systems[c]
I. Water Quality and Ecology Branch						
A. Cooperative Planning	State's regional agencies	Existing and proposed land use patterns Water intakes and waste discharge locations Wastewater physical and chemical characteristics Surface water quality (chemical, physical, biological) Land topography TVA facility locations Ecologically sensitive areas Areas with special water quality restrictions Groundwater sources and characteristics Existing or proposed construction projects (government and private) that might impact water quality Reservoir bottom profiles Hydrology Meteorology (wind, insolation, temperature, rainfall) Climatology Reservoir operation data (flow, elevation) Recreation facility locations Power plant operating parameters Water quality and biological criteria and behavior	USWB TVA Met Data TVA reservoir navigation maps Zooplankton data base Water quality monitoring network data base Bottom sediment data base Macrobenthos data base Phytoplankton data base Periphyton data base Daily river bulletin TVA aquatic organism reference collection Historic 26a assessment file State and Federal water quality reports Industrial and municipal construction progress reports Newspaper and trade journals USGS water resources data Water quality legislation Sampling station maps (State, Corps of Engineers, USGS) Topographic maps (1:24,000, 1:250,000) TVA Reservoir Recreation Suitability	USWB TVA Met Data TVA reservoir navigation maps Zooplankton data base Water quality monitoring network data base Bottom sediment data base Macrobenthos data base Phytoplankton data base Periphyton data base Daily river bulletin TVA aquatic organism reference collection Historic 26a assessment file State and Federal water quality reports Industrial and municipal construction progress reports Newspaper and trade journals USGS water resources data Water quality legislation Sampling station maps (State, Corps of Engineers, USGS) Topographic maps (1:24,000, 1:250,000) TVA Reservoir Recreation Suitability Data Forecast sheets WQEB Index File USGS Groundwater Inventory State Geological Office Power Operating Data Base Published literature	EXT ENV PL W MGT ENV PL ENV PL ENV PL ENV PL ENV PL ENV PL W MGT ENV PL ENV PL, P&SVS EXT EXT EXT W MGT EXT — W MGT FF&WD P&SVS NDRS ENV PL W MGT PSO EXT	Map files (E) EPA BIO STORET (E) EPA STORET (E) Aquatic Biology Information System (P) TVA Aquatic Reference System (E) Photo files (E) TVA aerial photographic and remote sensing file (E) Files (E) Technical Library (E) Air Quality Data System (E) Map Index System (O)
1. Regional and basin water resources planning	TAD					
2. Statewide 208 planning	State or regional planning offices, EPA					
3. Environmental assessment of proposed land use actions on multipurpose reservations and/or reservoirs (including TVA Section 26a)	P&SVS					
B. Reservoir and Stream Water Quality Management						
1. Monitoring existing water quality conditions	PRP, OACD, P&SVS, Public					
2. Identification of potential water quality problems	PRP, OACD, P&SVS, Public	Same as above	Same as above	Same as above		Same as above
3. Ecosystem mechanism studies	FF&WD					
4. 316 Nonfisheries biological investigations	PRP, EPA					
5. Development of criteria for setting standards	State, EPA	Same as above	Same as above	Same as above		Same as above
6. Facility siting water quality assessment	PRP	Same as above	Same as above	Same as above		Same as above
7. Nonpoint source pollution assessment	Public, State, EPA OACD, PRP	Same as above	Same as above	Same as above		Same as above
8. Waste assimilation studies	Public, State, EPA	Same as above	Same as above	Same as above		Same as above
9. Pesticide monitoring (proposed)	EPA, State, public	Pesticide/herbicide usage information and all the above	Pesticide/herbicide inventory	Pesticide/herbicide inventory	ENV PL	Same as above

TABLE 7 (continued)

Function	TVA client[a]	Information requirements	Data sources	Data sources	Supplied by[b]	Information systems[c]
C. Water Pollution Spill Control and Prediction of Pollutant Transport and Effects	Public, DPP, OACD, TPE, PRP	Same as I.A. above	Same as above	Same as above		Same as above
D. Water Quality Compliance	DPP, P&SVS, FF&WD, OACD, EPA, State	Same as I.A. above	Same as above	Same as above		Same as above
E. Technology Development--Remote Sensing Techniques for Water Quality Assessment	PRP, W MGT	Water quality conditions (physical, chemical)	Aerial photos	Aerial photos	W MGT	EPA STORET (E)
		Aquatic organism characteristics and distributions	Landsat and aerial scanner data	LANDSAT and aerial scanner data	EXT, ENV PL	Photo file (E)
			Water quality survey data base	Water quality survey data base		Aquatic Biology Information System (P)
			Aquatic organism data base	Aquatic organism data base	ENV PL	Regional ERTS Browse File (E)
						TVA Aquatic Reference System (P)
F. Vector Monitoring and	ENV PL, Public, MED SV	Vector-borne illness occurrences	TVA reservoir maps	TVA reservoir maps	W MGT	Map files (E)
		River flow and elevations	Aerial photos	Aerial photos	W MGT	Photo files (E)
		Land dewatering project locations	National Weather Service data--NOAA	National Weather Service data--NOAA	EXT	Files (E)
		Distribution and characteristics of vector populations	Soil/egg field survey data base	Soil/egg field survey data base	ENV PL	
		Land use patterns	Daily river bulletin	Daily river bulletin	W MGT	
		Climatology	New impoundment survey data	New impoundment survey data	ENV PL	
		Land cover	Sampling station maps	Sampling station maps	ENV PL	
		Distribution of soil/egg sampling stations and egg concentrations	State Agriculture Dept. data	State Agriculture Dept. data	EXT	
		Insecticide application locations	Communicable Disease Center	Communicable Disease Center	EXT	
		Floodplain mosquito habitat areas	Topographic maps	Topographic maps	W MGT	
		Location of field control operations	Project plans	Project plans	ENV PL	
		Mosquito insecticide resistance characteristics and distribution	Published literature	Published literature	EXT	
G. Aquatic Macrophyte Assessment and Control	Public, NDRS, P&SVS P&SVS, FF&WD, Power	Characteristics and distribution of aquatic macrophytes	TVA reservoir maps	TVA reservoir maps	W MGT	Map files (E)
		River flow and elevation	Aerial photos	Aerial photos	W MGT	Photo files (E)
		TVA facility locations	Local herbaria	Local herbaria	EXT	TVA herbaria (E)
		Recreation facility locations	TVA herbarium	TVA herbarium	FF&WD	TVA Heritage Program (E)
		Water quality conditions (nutrients, temperature, turbidity)	Daily river bulletin	Daily river bulletin	W MGT	Files (E)
		Reservoir bottom profiles	Published literature	Published literature	EXT	STORET (E)
		Water Quality Monitoring Network data base	Topographic maps	Topographic maps	W MGT	BIO STORET (E)
			FF&WD Recreation Info	FF&WD Recreation Info	FF&WD	Aquatic Biology Info System (P)
				Water Quality Monitoring Network data base	ENV PL ENV PL	TVA Aquatic Reference System (P)
H. Aquatic Effects of Strip Mining	Public, FF&WD, EPA	Strip mine location and type of mining	Topographic and geologic maps	Topographic and geologic maps	W MGT	Map files (E)
		Hydrology	Aerial photos	Aerial photos	W MGT	Photo files (E)
		Geology	LANDSAT tapes	LANDSAT tapes	EXT	Regional ERTS browse file (E)
		Location and type of reclamation	Water quality data base	Water quality data base	ENV PL	TVA aerial photographic and and remote sensing file (E)
		Existing water quality and ecology	USGS hydrologic data	USGS hydrologic data	W MGT	EPA STORET (E)
		Land use patterns	Water quality survey data base	Water quality survey data base	ENV PL	EPA BIO STORET (E)
		Land cover	State mining permits	State mining permits	EXT	TVA BIO INFO SYS (P)
		Water intakes and waste discharge locations	TVA strip mining contracts	TVA strip mining contracts	PURCH	TVA Aquatic REF SYS (P)
		Meteorology				

TABLE 7 (continued)

Function	TVA client[a]	Information requirements	Data sources	Data sources	Supplied by[b]	Information systems[c]
I. Facilities Siting--Solid Waste Disposal Impact Assessment	PRP, OACD	Location of facility Existing and proposed land use pattern Surface sources and water intakes Groundwater supplies Soil characteristics and distribution Geology Meteorology Topography Site boundaries Archaeological/historic sites Flooding potential	Topographic maps (1:24,000) Geologic maps (1:250,000) USDA soil maps TVA meteorological data base National Weather Service data base--NOAA Regional socioeconomic data base State and local planning and development reports Solid waste regulations	Topographic maps (1:24,000) Geologic maps (1:250,000) USDA soil maps TVA meteorological data base National Weather Service data base--NOAA Regional socioeconomic data base State and local planning and development reports Solid waste regulations	W MGT W MGT EXT ENV PL EXT NDRS NDRS ENV PL	Map files (E) Files (E) Regional Met Data System (O)
J. Planning and Design of Solid Waste Disposal and Collection Systems for Municipalities	TAD, Public	Population distribution Existing and proposed land use Soil characteristics Land cover Flooding potential Geology Surface water sources Transportation networks Groundwater supplies	Same as above	Same as above	Same as above	Same as above
K. Siting Assessment for Resources Recovery Systems	TAD, PRP, Public	Population distribution Existing and proposed land use Flooding potential geology Surface water sources Transportation networks Groundwater supplies Waste distribution	Sames as above	Same as above	Same as above	Same as above
II. Air Quality Branch A. Air Quality Assessment of Potential TVA Facility Sites B. Impact Assessment of New Facilities-Baseline Studies C. Special Studies to Determine Transport, Transformation, Fate and Effects of Atmospheric Emissions D. Air Quality Compliance Monitoring E. Regional Air Quality Management	PRP, OACD PRP, OACD PRP, EPA P PROD, OACD, EPA Public, PRP, NDRS P&SVS	Locations of TVA facilities Location and characteristics of TVA and non-TVA emissions (point, dispersed) Distribution and concentrations of air contaminants and other atmospheric components Physical characteristics of local terrain Existing and proposed patterns of land use Density and distribution of population Regional climatology Local meteorology Location of nondeterioration and nonattainment areas Distribution of major crop species Distribution of endangered terrestrial species Distribution and characteristics of soils Air pollution complaint locations Distribution and extent of vegetation affected by coal-fired power plants	TVA reservoir maps Aerial photos Topographic maps (1:24,000) Industrial survey data Air quality control region designations Tennessee DAPC records State industrial development agencies data files State and local departments of agriculture data files TVA meteorological data base National Weather Service data base--NOAA Regional socioeconomic data base USDA soil conservation service maps Regional agriculture data base Power plant operating manager interviews Air quality legislation Aerial and satellite scanner data	TVA reservoir maps Aerial photos Topographic maps (1:24,000) Industrial survey data Air quality control region designation Tennessee DAPC records State industrial development agencies data files State and local departments of agriculture data files TVA meteorological data base National Weather Service data base--NOAA Regional socioeconomic data base USDA soil conservation service maps Regional agriculture data base Power plant operating manager interviews Air quality legislation Aerial and satellite scanner data	W MGT W MGT W MGT W MGT NDRS EXT NDRS EXT ENV PL EXT NDRS W MGT AGR DV DPP ENV PL ENV PL, EXT	Map files (E) Photo files (E) EPA SAROAD (E) Files (E) Regional ERTS browse file (E) Air Quality Data System (E)

TABLE 7 (continued)

Function	TVA client[a]	Information requirements	Data sources	Data sources	Supplied by[b]	Information systems[c]
III. Radiological Hygiene Branch						
A. Nuclear Plant Radiological Assessment for Licensing Approval	PRP	Water intake locations Local meteorology Population distribution Cow and goat distribution River flow and elevation Recreation areas and use level Milk production Site topography Fisheries harvest Transportation network Environmental radiation levels Sampling station locations	Population distribution data base Regional agriculture data base Daily river bulletin Reservoir recreation suitability data Topographic maps (1:24,000) Fisheries data base Environmental monitoring data base Sampling station maps	Population distribution data base Regional agriculture data base Daily river bulletin Reservoir recreation suitability data Topographic maps (1:24,000) Fisheries data base Environmental monitoring data base Sampling station maps	NDRS AGR DV W MGT FF&WD W MGT FF&WD ENV PL ENV PL	Map files (E) Air Quality Data System (E) Files (E) Ambient Radiation Data System (O) EPA STORET (E) EPA BIO STORET (E) TVA Aquatic Bio. Info Sys. (P) TVA Aquatic Ref. System (E)
B. Nuclear Plant Radiological Assessments for Operational Compliance	P PROD					
IV. Environment Assessment and Compliance Staff[d]						
A. Power Plant, Substation Transmission Line, and Other Major Facility Siting Assessment	PRP TPE OACD	Residual emissions affecting air, water and land, including chemical, radiological, noise, and solid waste Existing land use patterns Proposed land use patterns Land ownership patterns (public and private) Unitized tracts of 1,000 or more acres Political and site boundaries Utilities location Land, air, and water based transportation systems Hazardous material transfer and storage plant locations Active or abandoned mining activities Federal, State, and local offices of civil defense forces Soils and geologic characteristics Archaeological, natural, historic, and cultural areas Projected population, industrial, energy, recreation demands Population distribution Distribution of endangered species	1:250,000 USGS maps 1:24,000 USGS maps TVA reservoir navigation charts D stage reservoir maps Regional Heritage Program Regional, county, local land use plans Aerial photographs and remote sensing USDA Soil Conservation Services Reservoir recreation suitability Population and socioeconomic characteristics and projections data base Facilities siting planning reports Local media and public hearings Federal and State EPA offices/reports Environmental legislation	1:250,000 USGS maps 1:24,000 USGS maps TVA reservoir navigation charts D stage reservoir maps Regional Heritage Program Regional, county, local land use plans Aerial photographs and remote sensing USDA Soil Conservation Services Reservoir recreation suitability Population and socioeconomic characteristics and projections data base Siting planning reports facilities Local media and public hearings Federal and State EPA office reports Environmental legislation	W MGT W MGT W MGT P&SVS FF&WD NDRS W MGT EXT FF&WD NDRS PRP CLIENT EXT EXT EXT	TVA map files (E) Heritage Program (E) TVA aerial photographic and remote sensing files (E) Regional Economic Simulations (E) Siting Information System (P) Valley Outdoor Recreation Plan (E) Socioeconomic Impact Assessment System (P)
B. Land Transfers and 26a Reviews	P&SVS	Residual emissions concerning air, water, and ecological, radiological, noise, and solid waste (especially discharge data) Existing land use patterns Proposed land use patterns Land ownership patterns (public and private) Utilities location Land, air, and water based transportation systems Hazardous material transfer and storage points Active or abandoned mining activities Soils and geologic characteristics Sensitive archaeological, natural, historic and cultural areas Projected population, industrial, energy, recreation demands Site boundaries	1:250,000 USGS maps 1:24,000 USGS maps TVA reservoir navigation charts D stage reservoir maps Regional Heritage Program Regional, county, and local land use plans Aerial photographs and sensing data USDA Soil Conservation Service maps Reservoir recreation suitability data Population and socioeconomic characteristics and projections Local media and public hearings Facilities siting planning reports	1:250,000 USGS maps 1:24,000 USGS maps TVA reservoir navigation D stage reservoir maps Regional Heritage Program Regional, county, and local land use plans Aerial photographs and remote sensing data USDA Soil Conservation Service maps Reservoir recreation suitability data Population and socioeconomic characteristics and projections Local media and public hearings Facilities siting planning reports	W MGT W MGT P&SVS FF&WD NDRS W MGT W MGT FF&WD NDRS EXT PRP	TVA map files (E) Heritage Program (E) sensing file (E) Regional Economic Simulation (E) Siting Information System (P) Valley Outdoor Recreation Plan (E) Socieconomic Impact Assessment System (PO)
C. Outside Agency EIS Reviews Within the Tennessee Valley	State and regional agencies	Same as for B. Land Transfers and 26a Reviews	Same as for B. Land Transfers and 26a Reviews	Same as for B. Land Transfers and 26a Reviews		Same as for B. Land Transfers and 26a Reviews
D. Biothermal Monitoring Program Reports (Browns Ferry Monitoring Report)	EPA	Same as for B. Land Transfers and 26a Reviews	Same as for B. Land Transfers and 26a Reviews	Same as for B. Land Transfers and 26a Reviews		Same as for B. Land Transfers and 26a Reviews
E. Compliance		System operation data	System operation monitoring	System operation monitoring		

TABLE 7 (continued)

Function	TVA client[a]	Information requirements	Data sources	Data sources	Supplied by[b]	Information systems[c]
V. Industrial Hygiene Branch						
A. Surveys of Potential Employee Exposure to Hazardous Agents	DPP, OACD, TPE *Power Const., FF&WD,* ENV PL, P&SVS, NIOSH, OSHA, MED SVS	Location, concentration and distribution of hazardous agents Spatial relationship of work activities		Field survey data base *Manufacturer's product data* Facility engineering reports and plants Technical publications	ENV PL EXT CLIENT EXT	Industrial Hygiene Data System (P) *Map files (E)* Files (E)
B. Community Noise Surveys for Environmental Impact Statements	PRP, OACD, P&SVS, DPP, NDRS	Site location Location of noise sources Amplitude and frequency distribution of generated noise Site boundary location Preconstruction ambient background noise Land use in the vicinity of plant Location of all public and TVA constructed access routes to site Preconstruction traffic volume Meterological information at time of measurements Site topography		Acoustic survey data base Manufacturer's product data Traffic survey data Topographic maps (1:24,000) Facility maps Land use information	ENV PL EXT NDRS W MGT CLIENT NDRS EXT CLIENT	Industrial Hygiene Data System (P) Site Drawings File (E) Map files (E) Files (E) Air Quality Data System (E)

[a]Information supplied to TVA at the request of the indicated client.
[b]Data supplied to ENV PL by the indicated organization; EXT means supplied to TVA from a source external to TVA.
[c]Abbreviation: P--proposed system; E--existing system; O--opportunity system.
[d]Coordinates ENV PL activities that are conducted by the branches using information, data, and systems of the types identified. The staff serves as a corporate function for TVA in coordinating TVA's use of such information to produce the needed output on the areas.

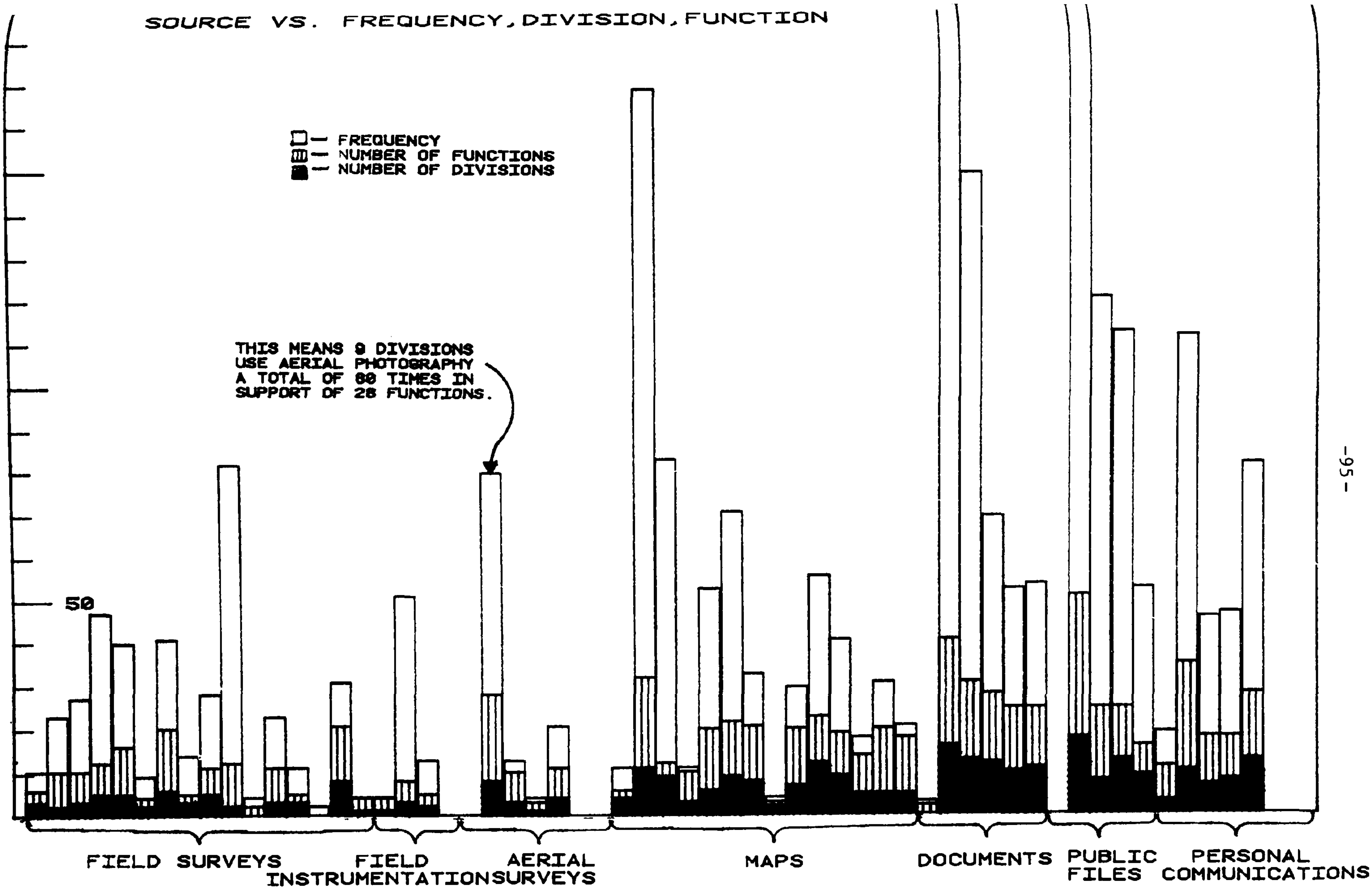


Figure 53. Sample of the computer graphics used in the Interdivisional Study Team Report on the use of geographic information by TVA.

of the inventory and interview data. Inventory data were first condensed into a standardized format and coded into machine-readable form. Statistical analyses showed the TVA functions that use the most geographic information, the divisions that are involved, and the data sources that are most accessed. Computer graphics software developed by this research project was used extensively in these analyses to simplify display of the voluminous results. A sample of these graphics is shown in Figure 53.

On the basis of the results of this study, a report was prepared for TVA management with several recommendations:

1. To define and design data bases for an expanded statistical summary (e.g., demographic and economic data), regional resources (geologic, topographic, environmental, cultural), TVA land features (legal boundaries), and operations impact monitoring. These data bases would support TVA functions that require the largest amounts of geographically referenced data.

2. To implement a series of data directories or catalogs to supplement current informal systems for locating geographic data.

3. To review TVA's files and technical library systems--the agency's most used sources of geographic information--to ensure that they are satisfying current needs.

Systems planning with the PRIDE[22] methodology is now being accomplished to address the first recommendation; this work is to be completed by January 1978. Actual implementation of suitable geographical information data bases (pending approval by TVA's management) will proceed during the remainder of 1978.

SECTION 6

FUTURE DIRECTIONS

During the next three years, many opportunities will exist to determine the feasibility, practicality, and desirability of applying new types of computer graphics hardware and software to environmental analysis.

The emphasis of the work reported here has been on the use of storage tube graphics terminals operating through a time-sharing system with a central computer. A primary problem, yet unsolved, is to ensure that a reliable, responsive computer system is available to the graphics users when required. TVA's computer system is overloaded, particularly with respect to interactive users. The maximum allowable number of time-sharing users is only 35. During normal working hours, the system is used to its fullest capacity. Even if one is successful in accessing the system, there is always the threat of untimely system downtimes or extremely slow response to simple commands. These conditions are not unique to TVA; many users of computer systems in other organizations, both in the governmental and private sectors, report similar problems. This presents difficulties in practical graphics implementation. In addition, problems such as this will grow as the demand for interactive capabilities increase. In many cases, history has shown that these demands can grow almost exponentially.

To cope with this problem, this project's research will concentrate more on the potential use of stand-alone, "intelligent" graphics systems. Numerous commercial systems have recently become available which offer local graphics manipulation and data storage, FORTRAN program processing, a relatively large CPU, and an "intelligent" terminal interface to permit flexible communications with a large central computer. Large mathematical models or data storage can remain on the center computer system. Output data can be transferred to the smaller system for immediate interactive graphics analysis.

Other types of display devices will be used. With a video (raster scan) terminal (black-and-white or color), shading of figures can be used to enhance the graphic effect, thus increasing communications capability. For example, color-shaded contour plots may be more effective in showing drift deposition over a three-dimensional representation of uneven terrain than would an overlay of two conventional line contour plots (one for topography and one for deposition). Use of a stroke-writing (refresh) terminal can produce animated sequences of dynamic behavior. For example, a mass of complex data documenting pollutant dispersion patterns over a period of time, perhaps in three dimensions, can be condensed into a short 10- to 15-second "movie" sequence, which could be shown at a public hearing.

This project has stimulated a great deal of interest in computer graphics in TVA. Computer graphics is being considered as a tool to assist in a variety of business and management applications and in traditional engineering and scientific analysis. TVA is considering the purchase of a variety of software packages that are entirely graphics-oriented. Using a package called DISSPLA,[22] one can readily produce pictures, maps, or two- and three-dimensional graphics with text. Another program, called MOVIE.BYU,[23] allows a user to (1) interactively manipulate a three-dimensional figure in space, (2) accomplish calculations necessary for efficiently removing hidden lines from view, (3) calculate shading patterns for color and black-and-white slides, and (4) create individual frames of dynamic motion that can be combined into a movie sequence. Packages such as these should greatly enhance capability to develop and expand practical applications for graphics.

Finally, the demonstrations that are to be developed will emphasize computer graphics both as a means for <u>interaction</u> with the computer and as a means for <u>communication</u> among people. New ways of summarizing and displaying data will be explored. Emphasis will be placed on graphic communication of information concerning alternative methods of pollution control and relationships to environmental transport and environmental impacts.

SECTION 7

SUMMARY

The need for an adequate supply of electric power is becoming increasingly evident. At the same time, a renewed awareness of the importance of preserving our environment has manifested itself among us all. To adequately meet these two requirements, engineers, scientists, and planners must use the latest and most sophisticated methodologies for planning energy systems and assessing impacts. The techniques used must provide more accurate and timely answers earlier in the planning and design process. Methods that permit a rapid recasting of various analyses must be used. A more integrated (coordinated) approach must be taken to the assessment of alternative methods of pollutant control, environmental impacts, and attendant costs.

Computer graphics provides one means for significantly improving current capabilities of environmental analysis. Through the use of computer graphics, a closer interaction between the power of the computer and the decision-making abilities of the human mind can be achieved. For example, an engineer can concentrate on the meaning of a particular analysis while the computer accomplishes the necessary calculations, manages data, and processes the results into the most meaningful form.

Computer graphics is also an effective means for communicating information. Unique or previously impractical displays can be readily generated. New types of displays can be created and tested for effectiveness. Computer graphics can provide the means for more efficient transfer of information among technical experts, managers, and the public. This, in turn, promotes improved decision making.

Initial project research has emphasized the use of relatively inexpensive, but versatile, storage-tube computer graphics terminals, which depend on a large central computer for computations and manipulation of graphics display. Specific project activities accomplished during the first two years of work include (1) stimulating interest in the use of computer graphics and identifying potential applications, (2) acquiring suitable graphics hardware capability that is accessible to potential users, (3) developing general-purpose software that promotes the use of graphics, (4) identifying and solving difficulties in implementation that potentially limit the use of graphics, and (5) developing demonstrations to illustrate benefits to be derived from using computer graphics for environmental analyses.

Demonstrations addressing various difficulties have been developed to facilitate data display, interactive analysis, and mathematical modeling. Graphics has been successfully applied to analyses of air and water quality, radiological hygiene, industrial hygiene, analysis of socioeconomic impact, and spatial analysis by means of geographically referenced data for siting facilities. Although developed as demonstrations, most techniques have been adopted for routine use. The result has been a savings in time and cost for certain analyses. Also, graphics displays previously considered impractical are being readily accomplished.

Several types of computer graphics hardware other than storage-tube devices show promise in benefiting environmental analysis. For example, devices with capabilities for color and animation might be used effectively to describe complex environmental phenomena. Powerful graphics software is rapidly becoming commercially available which will permit rapid development of complex displays that are highly tailored to a specific need. One yet unresolved problem is that of providing a reliable, responsive graphics capability to users who must depend on a conventional time-sharing system through a large central computer. The use of stand-alone or intelligent graphic systems that can communicate with larger computers may provide a means for solving this remaining difficulty.

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APPENDICES

APPENDIX A

SUMMARY OF POTENTIAL ENVIRONMENTAL ANALYSES TO WHICH COMPUTER GRAPHICS COULD BE APPLIED

Various environmental analyses could potentially be used as the basis for demonstrating the utility of computer graphics. The inventory described in the appendix was conducted by (1) directly contacting potential users, (2) drawing on the experience of this project researcher, and (3) distributing a questionnaire to branch and staff personnel of TVA's Division of Environmental Planning.

I. Air Quality Analysis

A. Modeling of the downwind distribution of air pollutants from a given arrangement of mobile point sources
B. Analysis and display of meteorological data
C. Formulation and cost modeling of air quality monitoring network
D. Analysis and display of air quality data obtained from field measurements to determine data trends and compliance with regulations
E. Display of predictions of modeling concerning transport and transformation of chemical species of air pollutants
F. Display of results of model calculations showing the behavior of emissions from pollution control devices (e.g., stacks, cooling towers, scrubbers)

II. Water Quality Analysis

A. Site screening potential analysis to determine impacts from a specific facility site and a particular project design
B. Display and analysis of water quality trends
C. Predictions of the transport and effects of water pollution spills
D. Display of predictions of natural physical, chemical, and biological phenomena in aquatic systems through the use of mathematical models
E. Analysis and modeling of non-point sources of pollution

III. Radiological Hygiene Analysis

A. Development of radiological dose model
B. Determinations of nuclear plant layout
C. Cost-benefit analysis of systems for controlling radiological waste
D. Real-time accident analysis of contaminant dispersion and transport
E. Radiation shield and analysis
F. Cost-benefit analysis of tritium waste management program
G. Statistical analysis of environmental monitoring data

IV. Safety and Industrial Hygiene

A. Display of accident occurrence data
B. Analysis and display of field measurements of potentially hazardous agents in the working environment
C. Modeling of noise control in working and community environments

V. Generalized Data Reduction, Analysis, and Display

A. Development of an interactive time series analysis package with graphics displays
B. Development of interactive graphics for presenting the results of exploratory statistical analyses
C. Development of a general-purpose contouring routine
D. Development of a three-dimensional perspective plotting routine for environmental data
E. Development of off-line digitizing routines and routines for on-line accessing of the flexible-disc memory units

APPENDIX B

DIFFICULTIES WITH COMPUTER HARDWARE AND SOFTWARE ENCOUNTERED WHEN IMPLEMENTING DEMONSTRATIONS OF COMPUTER GRAPHICS

The following difficulties with hardware and software were addressed by this project between September 1975 and December 1976. The solution of these problems has allowed demonstrations of computer graphics to be developed for a much wider range of applications than was feasible previously.

1. Problem: Complex, high-density information display could not be generated in a reasonable amount of time because of the 300-baud telecommunications rate.

   Solution: Provided necessary justification for upgrading TVA's telecommunications system to 1200 baud and the purchase of the high-speed models.

2. Problem: Effective, interactive engineering analysis was precluded as a result of extremely slow system response.

   Solution: Arrangements were made to obtain time-sharing services from Computer Sciences Corporation (CSC), INFONET, Los Angeles, California. Learning a new time-sharing command language and the use of the unique features of this system was required.

3. Problem: To minimize on-line computer time, a scheme was needed whereby data or programs could be entered and stored off-line and then put on TVA's systems at a TSO session.

   Solution: A documented scheme was developed to enter information manually off-line and store it on the flexible-disc memory. On-line software could then be executed to store the data and program in a user's on-line TSO library.

4. Problem: The capability for digitizing maps and graphs off-line and entering that information into the computer during an interactive session was needed.

   Solution: Procedures for activating the graphics tablet and flexible disc were established. On-line software was written to convert coded bit information stored on the flexible disc to user coordinates. This information could then be stored on the flexible disc or a TSO data set, edited, or translated into moves and draws on the screen.

5. Problem: Many graphics software packages available on TVA's computer system, such as three-dimensional, contour, and spatial analysis packages, are oriented for batch processing.

   Solution: Interactive analysis routines were written to call the basic graphics software packages. Simplified interactive routines were developed by means of the basic algorithms of the original software with TEKTRONIX graphics subroutines.

6. Problem: Several widely used TEKTRONIX graphics output routines handle input information in ASCII decimal equivalent (ADE) form.

   Solution: A general subroutine was written to convert ADE to alphanumeric characters (A/n or A/N) to ADE.

7. Problem: To minimize array sizes in interactive analysis, only that particular set of data values needed for an analysis should be read into a program. To accomplish this effectively, the data must be stored in direct, random-access data sets. The method for generating such data sets on TSO is not readily apparent from the TSO user's manuals.

   Solution: A procedure for establishing this type of data set was established. A command language program was developed to make the necessary allocations and call a system's utility formatting program.

8. Problem: To effectively use time-sharing systems other than TVA's, a method was needed to convert programs residing on TVA's IBM 370/165 and enter them on the other systems.

   Solution: Procedures were established for formatting programs properly on the IBM 370/165 and storing them on the flexible-disc memory unit operating in the paper tape mode. Procedures for transferring this information to and from CSC using their DATA command and system utility programs were then developed.

9. Problem: Numerous "bugs" were discovered in the TEKTRONIX software.

   Solution: These problems were identified and documented. System analysis representatives, advised of the problems, have corrected these errors.

10. Problem: Complex analysis techniques that involve access to several files, calling various programs, and allocating storage require that the person running the analysis know TSO command procedures and enter it properly.

    Solution: Command language programming techniques have been developed to simplify command procedure processing. The user simply answers yes-and-no questions to execute the various programs or system tasks.

11. Problem: Achieving nonstandard graphics displays through the use of Plot-10 software package.

    Solution: Plot-10 software has numerous software "hooks" for incorporating user-written plot routines and accessing internal variables that are useful in creating specialized plots. Routines that explore the use of these features have been developed.

12. Problem: Outside time-sharing services can only be readily accessed through the Federal Telecommunication System (FTS) phones; this ties up FTS phone lines and a TVA switchboard line.

Solution: Under certain conditions, the General Services Administration (GSA) will grant access to "800" numbers that are linked to the outside time-sharing services. The necessary forms were submitted to GSA for approval of eight TVA users.

APPENDIX C

TVA SOCIOECONOMIC IMPACT ASSESSMENT METHODS PROJECT-- DEVELOPMENT OF SITE SCREENING METHODS

INTRODUCTION

The development of a methodology for screening potential sites for power plants according to socioeconomic criteria has been a major aspect of the second year of work in TVA's Socioeconomic Impact Assessment Methods Project. There have been two steps to the development of the method: (1) to compile data for a particular area on the indicators developed during the first year of work and (2) to develop the computer-assisted method for analysis and display.

During the first year of the project, a set of indicators to be used on a county-level basis was developed to provide the data framework for site screening. The second year of work was designed to test this set of indicators, amend them if necessary, and develop a method for analyzing and displaying the overall suitability of different counties for absorbing the impact of a large power generating facility.

DATA COLLECTION

SELECTION OF THE TEST SITE

Twenty-two counties in East Tennessee (Figure C.1) were selected for testing the site screening method for several reasons. The TVA Regional Planning Staff had just completed a site screening exercise by means of existing agency methods. Therefore, repeating this exercise seemed to be a good test of whether a computerized system with fairly extensive data needs would show different results from those of the more intuitive, traditional planning method. Also, the proximity of these counties to Knoxville made data collection easier and less time-consuming. The area is also a good test site because it contains within it a wide variety of counties, ranging from highly urbanized Hamilton County to Hancock County, a small mountain county that has long been one of the poorest counties in the country.

Initially, Knox and Sullivan Counties were not included in the study area. Knox County was excluded because it was felt to be too highly developed along the main river channel to be a reasonable site for additional power facilities. Sullivan County was eliminated because it was felt that water supplies that far upriver would not be sufficient to make a power plant feasible. However, both Knox and Sullivan Counties are now being added to the study area. On reconsideration, it was felt that the reasons for excluding them are only two of many reasons that may eventually exclude any one of these counties from further consideration as power plant sites. One important reason for including them is that any power plant will have impact on the counties adjacent to the one in which it is located, not only the county in which it is located. Therefore, the same types of socioeconomic data are needed for counties that may be close to power plant sites. At this time, data for these two counties have been added, but analysis has yet to be carried out on a 24-county basis.

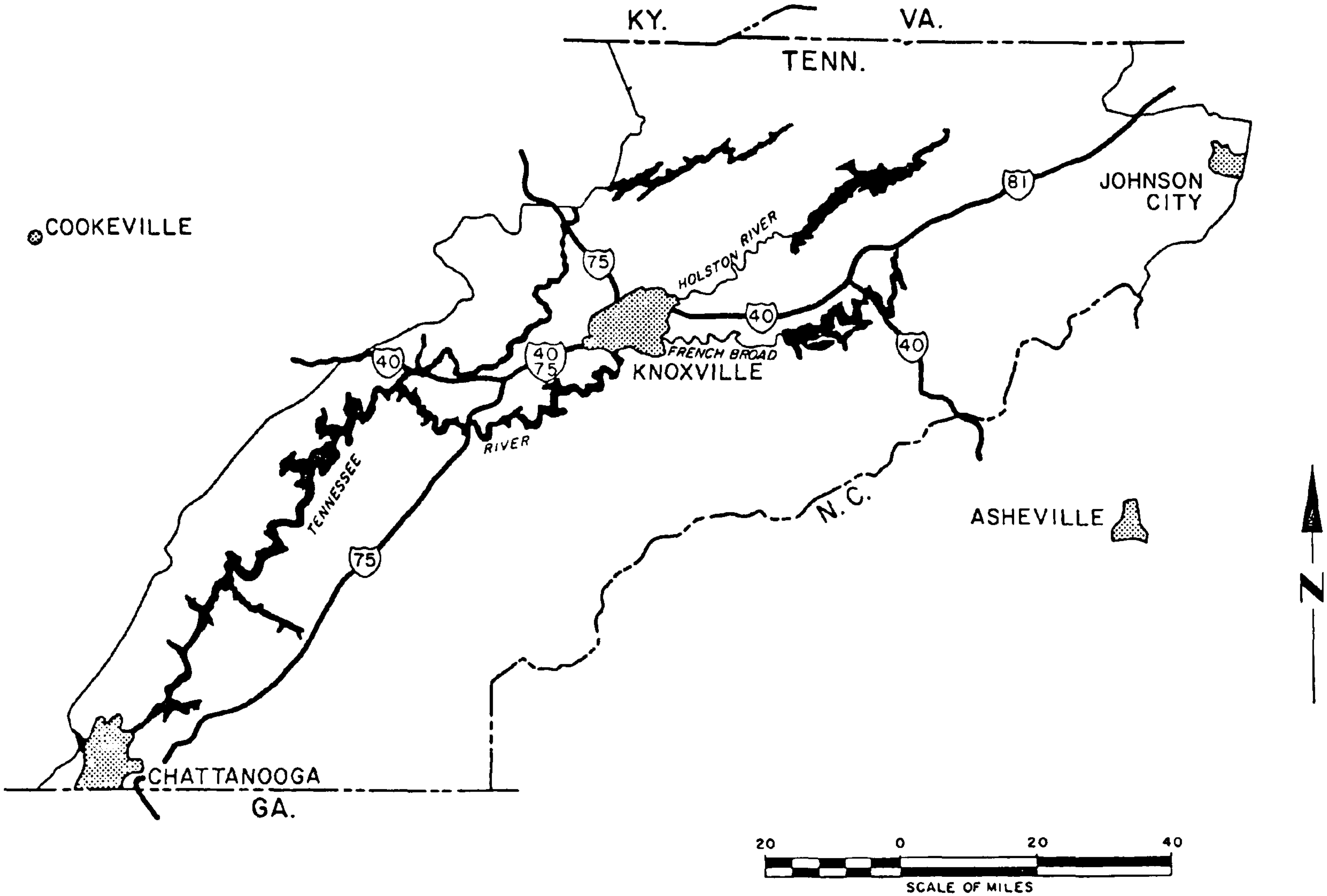


Figure C.1. Regional location map for site screening area in East Tennessee.

COLLECTION OF DATA

Data were collected during July, August, and September of 1976. Many of the data were collected from published sources, although there were several instances for which a trip to Nashville, Chattanooga, or Johnson City was necessary to supply missing information. One difficulty in data collection was the fact that the development districts located in the study area are not always consistent in their method of recording data. Types of the data that were published and up-to-date in one development district were not even collected in another.

Other data that were sought were kept by the various State agencies on a county and municipality level. To get the most up-to-date information, some personal interviews and two trips were necessary. There is a time lag of a year or more in publishing many of the data before they are readily available.

REVISION OF INDICATORS

The indicators were modified, new ones were added, and some were eliminated at several points throughout development of the site screening system. During data collection, several indicators were found to be meaningless or too difficult to obtain; others were changed or further detailed from what was specified in the indicator system outlined after the first year of work. The changes that were made will be described separately for each indicator listed.

Highway, Sewer, and Water Systems

This indicator was eliminated at the end of the data collection period. An attempt was made to visually screen out those areas in which no primary highway was located within 5 miles of a major waterway, thus eliminating counties that had no eligible areas by this criterion. However, no counties could be eliminated by this procedure.

Several other access measures were considered. Working with mapped data when all other indicators were on a gross county level proved difficult, therefore, a county-level access indicator was sought, but none proved satisfactory. One reason for this is that the major transportation routes have tended to develop along rivers, which also define the likely locations for power plants. Therefore, any simple measure was ineffective in screening counties because all looked equally good. The final decision was to rely on the engineering studies by other divisions within TVA to eliminate any inaccessible sites.

Information on all the major and minor highways in the study area was collected from the Tennessee Department of Transportation (DOT), and details on the condition of each of these roads were obtained from knowledgeable staff members of DOT wherever possible. Collection of this data was rather difficult, requiring a trip to regional offices in Chattanooga and personal interviews with highway staff members.

The sewer and water systems could not be located on maps because this information was not readily available. Although boundaries for sewer and water utility districts were available for some parts of the region, they were not available for all counties. Also, utility districts seldom operate sewers throughout their entire service boundaries. Most of these districts--both water and sewer--are small and do not keep good up-to-date maps of their systems. Information from these districts could have been obtained if we had been able to spend the effort to transfer raw data to usable mapped form. The problem would then remain of having mapped sewer and water data that were not necessarily on a county basis, would not be compatible with the other indicators, and could not be readily computerized. To get a measure of the water and sewer service available in various counties, an indicator was substituted which is the percentage of dwelling units served by public water and sewer systems. This is included in the public facilities indicators described below.

Judgmental Ranking or Rating Made of Each of the Public Facilities Systems and Displayed Graphically by County

Several aspects of public facilities were considered--recreation, health, police and fire service, and education. Indicators were developed in each of these public service areas.

Recreation--

The indicator developed for recreation capacity was the recreation acres per capita in a county. This was the total acreage in parks in recreation facilities, including local, county, state, and national park systems. Information was sought on recreation expenditures by public bodies by each county, but data were not readily available. Examination of these figures showed that the figures were distorted because of the presence of large national parks and forests in several counties. While these parks are, in fact, a recreation resource, they are not of the same nature as are local ballfields or other neighborhood or municipal facilities. Therefore, an alternative indicator was developed, which is the local recreation acres per capita. This eliminates State and Federally owned recreation lands from the calculations.

Health--

Several indicators were considered as measures of health care. After discussions with representative staff members of TVA's Health Resources Staff, it was decided that the best single indicator of health care was the availability of physicians. The indicator developed was the number of persons per physician (including osteopaths) in each county. Other indicators were rejected for various reasons. The number of hospital beds per capita was not used because hospital services are primarily a regional phenomenon, and one county need not have a great deal of hospital space if it is close to a county with available hospital beds. Also, there are generally enough hospital beds in this region. The major problem with health care is the lack of primary personnel, such as doctors, in the more isolated rural areas. Our data did show that the smaller, more rural counties have a much greater population per doctor than do the urban counties. Meigs County had no doctors at all.

Police--

The indicator developed for police services was the expenditures per capita for police departments by cities and counties. To convert the collected data to a county level, a weighted average was developed for each county to consider the expenditures of municipal police departments and county sheriffs' departments. Expenditures in 1975 were obtained for every police department and sheriff's department in the study area, and per capita expenditures were calculated for each. The population served by each police force was then used to weight those expenditures. It is assumed that sheriff's departments serve only outside of municipalities. This weighted average was calculated as shown in the following spot table.

Police force	Expenditures per capita (a)	% of total county population (b)	Weighted expenditures (a x b)	Total county weighted average
Bradley Co.	$ 4.10	0.612	$ 2.51	$13.75
Cleveland City	29.53	0.374	11.04	
Charleston City	14.08	0.014	0.20	

Thus, the total county weighted average of $13.75 reflects the fact that about 38% of the county's population lives in cities, where there are considerably higher levels of expenditure than in the county-served areas, where 61% of the people live and where the sheriff's department spends only about $4.00 per capita on police protection.

Fire Protection--

A satisfactory fire protection indicator has not been developed. Data was collected on fire department expenditures per capita, but this indicator has been rejected because of the problem of collecting reliable data. Expenditure figures are available for the cities, and the only problems are occasional incomparability of data (for example, where rescue squads are included within the fire department in one city and separately in another city) and the lack of centralized data sources.

The major problem arises in the rural areas that are served by private or volunteer fire departments. These small fire departments keep very poor records, if any. They also may perform nonfire services, such as rescue or ambulance services. Also, the expenditures are not comparable, even if the correct figures are known. In some instances, firemen are paid only for the fires that they actually fight; in other instances, as in a city fire department, they are on a salary. In still other cases, volunteers are used, and only one or two paid firemen may be employed. These rural fire departments are also difficult to locate, and it is unlikely that reliable information could be obtained from them regularly.

As an alternative indicator, the use of ratings from State insurance fire departments is being investigated. City and rural fire departments are rated differently, and much of the rating depends on such things as water supply and pressure rather than on the proficiency of the fire department, its level of expenditures, or its equipment. However, it is felt that this may be a suitable indicator and the best one available across the State for fire protection. These data are being analyzed.

Sewer and Water Facilities--

As indicated above, a new indicator has been added--the percentage of county dwelling units served by public sewers and water systems. This figure, derived from the 1970 Census, is somewhat limited in its usefulness because it is several years old. However, on the basis of our investigations, this figure is the only readily obtainable measure of sewer and water facilities for the purposes of site screening.

Education--

The education indicators are directed only at the local public school system because the local public schools will feel most of the impact of the added population from power plant construction. For purposes of site screening, higher education, vocational education, and private schools are not considered.

Several education indicators, most of which are readily obtainable from the State Department of Education, were considered. Four indicators were finally included which represent some of the more important dimensions of public education quality: (1) total expenditure per pupil, (2) percentage of students who are in overcrowded classrooms, (3) average teacher salary, and (4) number of pupils per teacher. For each indicator, a weighted average was calculated for each county in a manner similar to that done for police expenditures. However, instead of using the proportion of total population in the various jurisdictions, the total enrollment of each school system within each county was used to weight the statistics to come up with a county average.

Expenditures per pupil, teacher salary, and pupil/teacher ratio are all taken directly from the Annual Statistical Report of the State Department of Education. The percentage of students in overcrowded conditions was calculated from the State Department of Education's Report on Waivers. Any time that a classroom has more than the allowable number of students (25 to 35, depending on the grade), the school system must obtain a waiver from the State. From the data in the Annual Report on Waivers, the percentage of total students who are in classes with more than the allowable number of pupils was calculated.

Existence of a Planning Commission and a Comprehensive Plan; and Existence of Zoning and Subdivision Regulations

The quality of planning and public administration within each county was characterized according to the existence of planning commissions, comprehensive plans, and zoning and subdivision regulations within that county. A list was prepared for each of these planning and administration tools, indicating which cities and counties had planning commissions either in existence or active, which had comprehensive plans, which of these plans were current or not, and which had regulations on zoning and subdivision.

Some manipulation of the data was necessary because the information had to be on a county level. In some counties, municipalities may have zoning, but the areas outside the municipalities do not. Similarly, there may be subdivision regulations in effect in portions of the county and not in others. In some cases, there is a county-wide planning commission; in others, planning commissions exist only within the municipality. Therefore, for each of the four planning and public administration tools, a new statistic was calculated which is the percentage of the population in that county that resides in a jurisdiction covered by a planning commission, a comprehensive plan, a zoning ordinance, or subdivision regulations. For example, in Anderson County, 100% of the population is covered by a planning commission, zoning, and subdivision regulations. However, only 65% of the population lives within an area that has a comprehensive plan.

These calculations allow one to differentiate between counties with county-wide plans and subdivision regulations and those in which only the municipalities or only some of the municipalities have such tools. Also, some counties may have zoning ordinances that do not apply within municipalities, and the municipalities may not have zoning ordinances. Thus, this indicator provides a gross measure of the commitment of that county as a whole to planning and public administration as measured by these four tools. In making these calculations, localities that had a comprehensive plan that was out of date or a planning commission that only existed on paper were not included.

A third indicator, the existence of a budget process including capital budgeting was dropped because analysis of the data indicates that capital budgeting is not a useful indicator. Our information suggests that there is no common definition of the capital budgeting process. The fact that many communities with meager administrative resources report the use of a capital budgeting process casts doubt on the validity of this indicator as a measure of administrative capacity.

Percent of County Population Living in Urban Places

This indicator was obtained directly from the 1970 Census.

Urbanization is a very important criterion in avoiding social impacts; experience has shown that small towns suffer the most significant negative impacts from the construction of power facilities. Therefore, it was attempted to develop a more sensitive indicator of urbanization.

As an alternative indicator, a visual screening was proposed that would eliminate counties in which no area is within 10 miles of a city of 10,000 population or more. This criterion eliminated three counties from consideration: Rhea, Hancock, and Claiborne. However, elimination of counties was not considered realistic at this site screening stage because nothing in our studies or TVA's experience suggested that any single socioeconomic factor is essential. Therefore, another proposal was made to merely downgrade those three counties in the rating system that was to be developed. However, this indicator was finally discarded because it would have been the only one requiring a visual screening and thus could not have been incorporated into a computerized screening system.

The percent of population living in urban areas thus remains the only indicator of urbanization.

Labor Force Availability to be Characterized

TVA's Human Resources Staff regularly compiles information that can be used to show labor force availability. Although a gross measure could be obtained from the 1970 Census, a much more accurate and up-to-date picture is available within TVA. This data has not yet been made available to us, but TVA's Regional Planning Staff is collecting the data.

Vacancy Rate of Housing for Sale and for Rent

This indicator was collected from the 1970 Census, because more up-to-date information is not available.

Percentage of Housing Units that Were Built Before 1950

This indicator was also collected from the 1970 Census.

Population Change from 1960 to 1970 and Projected Population Change

The population change from 1960 to 1970 for each county was obtained from the 1970 Census. The projected population growth for the period 1970 to 1990 was obtained from the U.S. Department of Commerce, Bureau of Economic Analysis. These figures are already collected within TVA's Division of Navigation Development and Regional Studies (ND&RS).

Unemployment Rate

This indicator was obtained for each county from the most current data of the State Department of Employment Security.

Median Family Income

The 1970 Census was used for this indicator.

Percentage of Families and Individuals Receiving Welfare Payments

The most recent data that could be obtained for this indicator is from the 1975 report of the State Department of Human Services.

Proportion of the Population in the 20- to 44-Year Age Group

Information for this indicator was obtained from the 1970 Census.

Percentage of Population Living in Same House Five Years Ago

This indicator was part of the system during the early phases of the study. The percent who have moved in the last five years was intended to be a measure of social stability, particularly out-migration. Further analysis, however, showed that this is not a good indicator of out-migration. Clearly, anyone who had migrated out of the county would not appear in this statistic. Therefore, it shows geographic mobility within counties and in-migration. This was evident from the results showing that some of the most urban counties had a high score on this indicator.

A list of each of the indicators entered into the computerized data sets is shown in Table C.1.

DEVELOPMENT OF DESCRIPTIVE INDICES

PURPOSE

The next step was to develop some indices, or combinations of indicators, that could be used to describe the counties' relative suitability as power plant sites. Each index is intended to describe a functional system of community life, so that together they will provide an accurate representation of the socioeconomic characteristics of the county as a whole. It is important that the indices be small in number, yet comprehend all potential areas of socioeconomic impact. Furthermore, the indices are not necessarily equal in importance. Some functional areas may be more vulnerable to socioeconomic impacts than others, and impacts in some functional areas affect local residents more than they do in others. Therefore, in computing the overall suitability of counties, the indices must be weighted in some way to account for these differences in importance.

The indices relate to the considerations in site screening developed during the first year of work; however, they may not be exactly the same. The purpose of developing indices, in summary, is two-fold: (1) to reduce a large number of indicators to a manageable size and (2) to provide a descriptive model of each county's socioeconomic conditions and potential for absorbing or benefiting from such impacts.

TABLE C.1. SITE SCREENING INDICATORS

Stat. programs number[a]	Graphics programs number[a]	Indicator
1	10	Recreation: recreation acres per capita
2	11	Health: local physicians per thousand persons
3	12	Police: expenditures per capita (weighted average of each county with its cities)
4	14	Expenditures per pupil
5	15	Percent students overcrowded
6	16	Average teacher salary
7	17	Number of pupils per teacher
8	18	Percent of county population in jurisdiction having a planning commission
9	19	Percent of county population in jurisdiction having a comprehensive plan
10	20	Percent of county population in jurisdiction having a zoning ordinance
11	21	Percent of county population in jurisdiction having subdivision regulations
13	23	Percent of county population in urban places
14	25	Housing vacancy rate (1970)
15	26	Percent of housing built before 1950
16	27	Percent of change in population (1960-1970)
17	28	Percent of change in population projected (1970-1990)
18	29	Unemployment rate
19	30	Median family income (1970)
20	31	Percent of population receiving welfare
21	32	Percent of population in 20- to 44-year age group
23	34	Percent of population served by public water
24	35	Percent of population served by public sewer

[a]Separate code numbers were used for the statistical package and the graphics package.

ANALYSIS OF THE INDICATORS

The first step in developing indices was to analyze the indicators. Examination of the distributions of actual statistics collected on each indicator provided a sense of the information and its quality and usefulness. Also, statistical tests were run to identify any redundant indicators that might be eliminated to streamline the data system.

Methods

The methods used for analysis included visual examination of the distributions, Pearson and Spearman rank-order correlations on all pairs of indicators, and scatter diagrams of several pairs of indicators.

Findings

From Visual Examination of Distributions--

Recreation--It was noted that the distribution of recreation acreage was skewed due to the presence of large tracts of State and Federal park lands in some counties. Because this was felt to be an undesirable distortion of the level of recreation resources, the alternative indicator (deleting State and Federal lands) was developed as described previously.

Education--The range of values for all the education indicators was fairly small. This is because, unlike other public facilities and services, the public schools are governed by State minimum standards in many aspects of their operation. The "percent in overcrowded classrooms" indicator showed a much different distribution--including rank order--than did the other three education indicators, which tended to be similar. Counties with very few of their pupils in crowded conditions included both wealthy counties, which had more than adequate facilities, and poor counties, in which, although facilities may not be up to par, continued out-migration has caused declining school enrollments.

Planning and public administration--These indicators were manipulated into county level percentages, and many counties clustered at the maximum potential score (100%). As expected, the urbanized areas tend to use more of the planning and administration tools and therefore have higher scores on these indicators. This is probably a good indication that they will be better able to respond to the demands brought by rapid growth resulting from a power plant.

Because the capital budgeting indicator is of doubtful validity as a measure of administrative capacity, it will be eliminated from the data set.

Indicators of housing, unemployment, welfare, and population age structure all had distributions that tended to cluster within a relatively narrow range of values. The knowledge that these and other distributions had many tied or closely grouped scores contributed greatly to the decision to limit the use of ranks in comparing the counties.

Correlations--

Two types of correlations were run on the indicators: (1) Pearson product-moment (r) using the raw scores and (2) Spearman rank-order (rho) using the rank orders of the counties. The findings of these statistical tests were not as revealing as had been hoped. The principal purpose of these tests was to find indicators that were very highly correlated in order to identify possibilities for elimination or combination of indicators. The only two indicators that were identified as possibly redundant were pupil expenditures and average teacher salaries--the rank-order correlation of these was 0.8 (out of a possible 1.0). However, because this was the only possible redundancy that could be identified both statistically and intuitively, it was decided not to eliminate any indicators.

Two unexpected correlation coefficients are worth noting--education and planning and administration.

Education--The percentage of pupils overcrowded was not highly correlated with the other education indicators. This lack of correlation resulted from this indicator's peculiar distribution. As noted before, the school systems without much crowding tended to be either relatively wealthy and urbanized or poor and rural with a history of out-migration. The other indicators tended to show the urban, wealthy counties with consistently better scores than the poor, rural counties. Thus, the overcrowding indicator seems to be measuring a very different dimension of public education conditions than are the other three indicators--perhaps the immediate physical capacity rather than overall quality or growth adsorption capacity.

Planning and administration--The planning and administration indicators were not all highly correlated with each other or with urbanization, as was expected. The existence of subdivision regulations was not correlated with either capital budgeting ($r = 0.08$) or urbanization ($r = 0.17$), nor was the existence of planning commissions correlated with urbanization ($r = 0.17$). This may say something about the way in which the indicators were developed. For instance, a county may have a high score on urbanization either because it includes a major city or because most of its population lives in small towns that just barely meet the Census "urban place" definition. These small towns may not have subdivision regulations or capital budgeting; and, as noted before, the capital budgeting indicator has serious flaws as a measure of public administration capacity and will be eliminated.

Scatter Diagrams--

These diagrams show graphically the relationship between two indicators. Scatter diagrams were plotted for several pairs of indicators, using the rank orders of counties on each. The diagrams were developed only for those pairs whose correlations were different than expected or in some way noteworthy. Examination helps to identify the reasons for the statistical relationship, particularly where there is no linear statistical relationship between two indicators intuitively felt to be associated. For example, the scatter diagram of "percentage of urban places" with "percentage with planning commissions" shows a definite positive relationship at the lower end of the distribution of planning commission indicator, although the correlation coefficient is only 0.17 (almost no relationship). However, the diagram clearly shows that the reason for the low correlation is the very large number of counties (of all degrees of urbanization) for which 100% of the county is covered by a planning commission.

Thus, the scatter diagrams helped to confirm some intuitive relationships and provide a better understanding of why some unexpected correlation coefficients were obtained. This exercise did not, however, add a great deal to the analysis of the indicators, but served mainly as a check to verify judgmental interpretations of the data.

DEVELOPMENT OF THE COMPUTER-ASSISTED ANALYTIC AND DISPLAY METHOD

PURPOSE

A major purpose of the site screening phase of the socioeconomic impact assessment project was to demonstrate the use of computer graphics in this planning effort. Funds from the Environmental Protection Agency pass-through grant were used to purchase a Tektronix cathode ray tube (CRT) computer terminal, with a floppy-disc data storage component and hard-copy attachment. Thus, the analytic and display method was designed to be compatible with the Tektronix hardware.

COORDINATION WITH RELATED RESEARCH EFFORTS

Related work has been going on at TVA's Division of Forestry, Fisheries, and Wildlife and at Oak Ridge National Laboratory. Since the beginning of this project, efforts have been made to coordinate with these groups to share knowledge as much as possible. Discussions were held with staff at ORNL, who are developing a parallel site screening method, which eventually led to the sharing of an ORNL-employed planning intern with TVA for work on this project.

Meetings were also held with staff at TVA's Division of Forestry, Fisheries, and Wildlife (DFFW). This group has developed the use of a batch-processed program, IMGRID, which will display geographically based information by means of a grid system (based on latitude and longitude) superimposed on the study area. After investigation of the feasibility of using this software and DFFW's expertise, it was determined that IMGRID--a batch, grid system--would not be compatible with the interactive Tektronix equipment, which lends itself to polygon (rather than grid) data storage.

CAPABILITIES OF THE COMPUTER SYSTEM

Statistical Analysis

All the basic statistical analyses that were needed were done on the CRT terminal using simple FORTRAN programs or the SAS packaged program. This packaged program, designed for use by social scientists, was quite adequate for our purposes. It would probably be adequate for any of the basic analyses that planners in such a project are likely to need.

Graphic Display

The graphic display programs were developed by TVA's Division of Environmental Planning and further refined by ND&RS, which provided the principal programmer on the site screening project. Three basic programs were developed: mapping of the counties, Kiviat diagrams, and scatter diagrams.

Mapping--

The mapping program draws the county boundaries within the study area, identifies each county, and enables one to place a value or symbol in the center of each county. One county or a group of counties may be drawn rather than the entire set. The counties may be drawn at different scales, allowing one county or portion of the map to be enlarged. As with all data handled in the CRT system, these maps are drawn and displayed on the CRT with the option of producing a hard copy of each output.

Kiviat Diagrams--

The Kiviat diagram (Figure C.2) is a graphic display method developed for use in this study by TVA's Division of Environmental Planning. The aim of the diagram is to show how a single county ranks or scores on several characteristics (this example is based on ranks). In this example, six indicators are shown, one on each of six axes within a circle. The seventh and eighth axes (at 90° and 180°) are not used; this gives the characteristic "butterfly" shape to a diagram of the county that ranks high on all indicators. If eight indicators were used, all eight axes would be used to form an octagon; similarly, four, five, or six axes could be used with or without null axes and the polygon formed would vary accordingly.

The distance from the center along each axis represents the rank (or score) of the county on that characteristic. In our example, the county with the highest percentage of its population living in urban areas would intersect that axis at the perimeter of the circle. The middle-ranked county would be halfway between the center and that perimeter, and the lowest-ranked county would be closest to the center. Thus, a county that was ranked first on all six indicators in the diagram would show a perfect butterfly shape. The comparative quality of this graphics tool is demonstrated in the several Kiviat diagrams shown in Figure C.3, which clearly illustrates that Anderson and Hamilton Counties rank substantially higher than, for instance, Hancock or Claiborne Counties on most of the indicators.

Scatter Diagrams--

A graphics program was developed to draw scatter diagrams of pairs of indicators. As discussed earlier, these were produced for pairs whose correlation coefficients were unexpected or otherwise of interest. A sample scatter diagram is shown in Figure C.4.

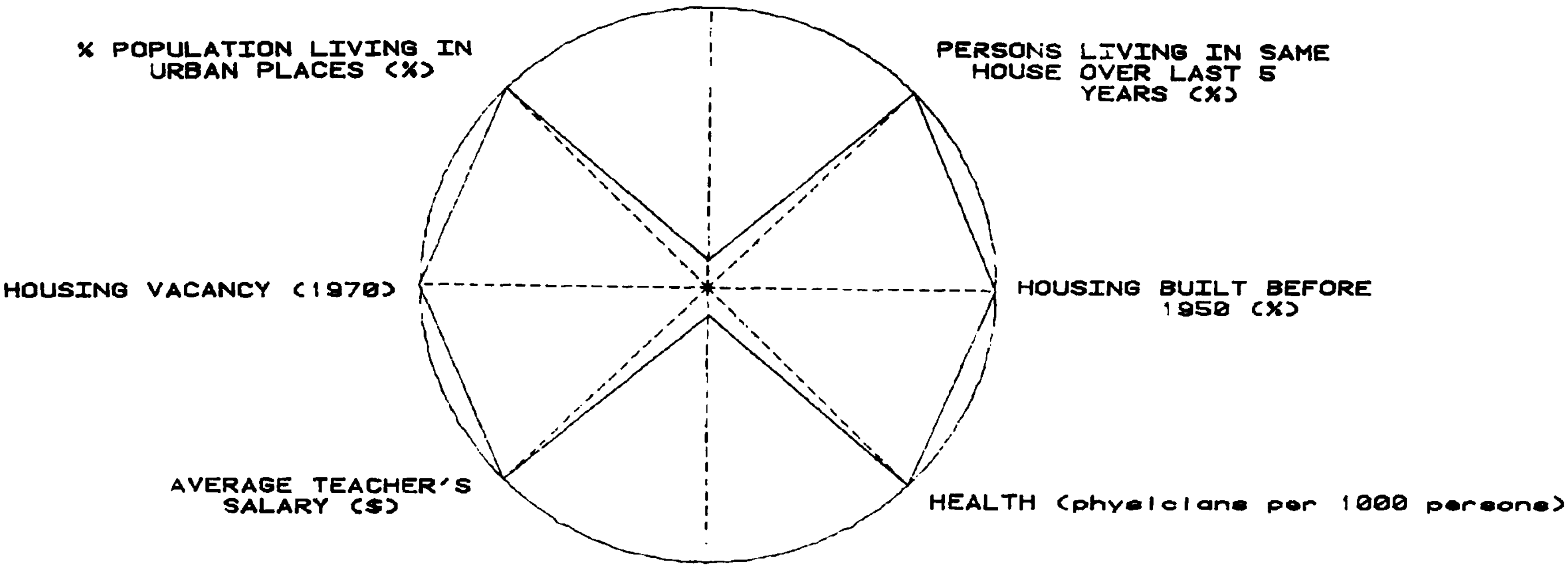


Figure C.2. Sample of socioeconomic indicators displayed as a Kiviat diagram.

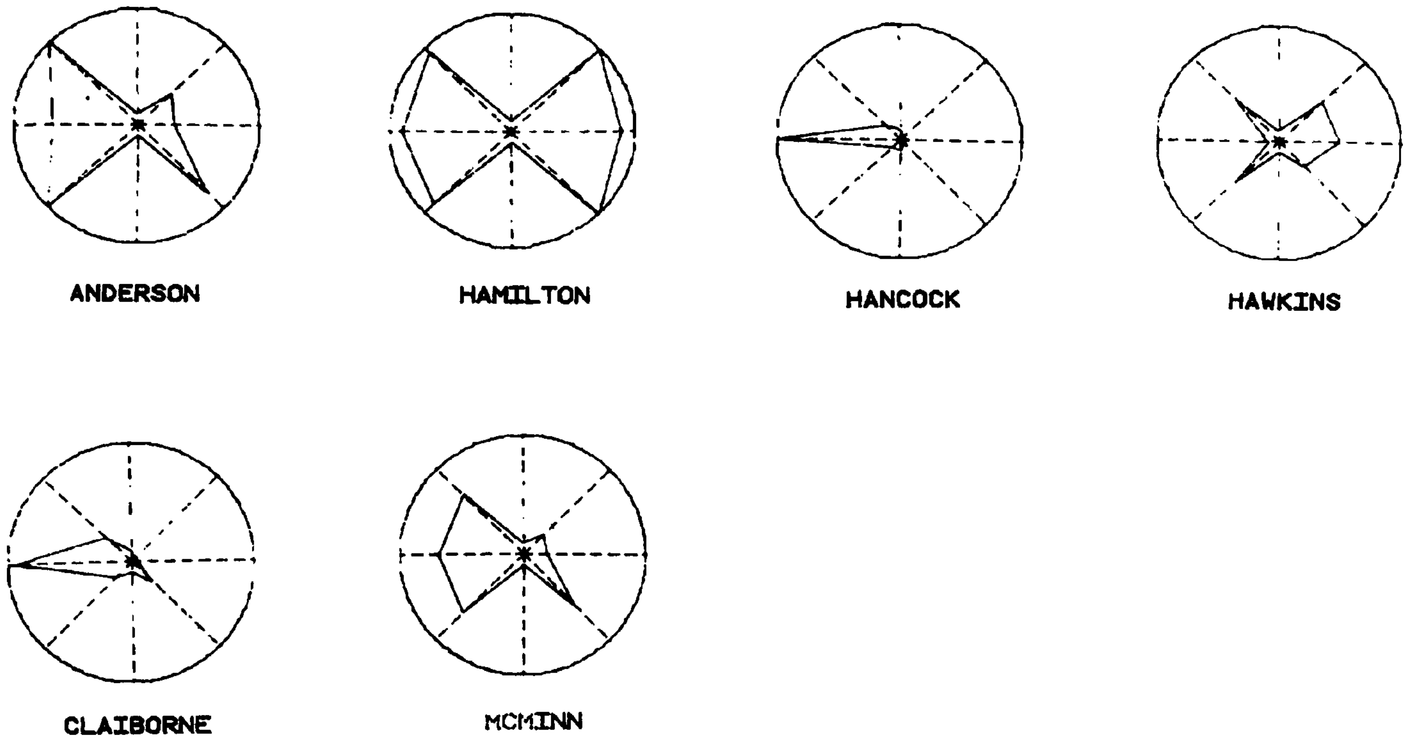


Figure C.3. Butterfly configuration of socioeconomic indicators for various counties.

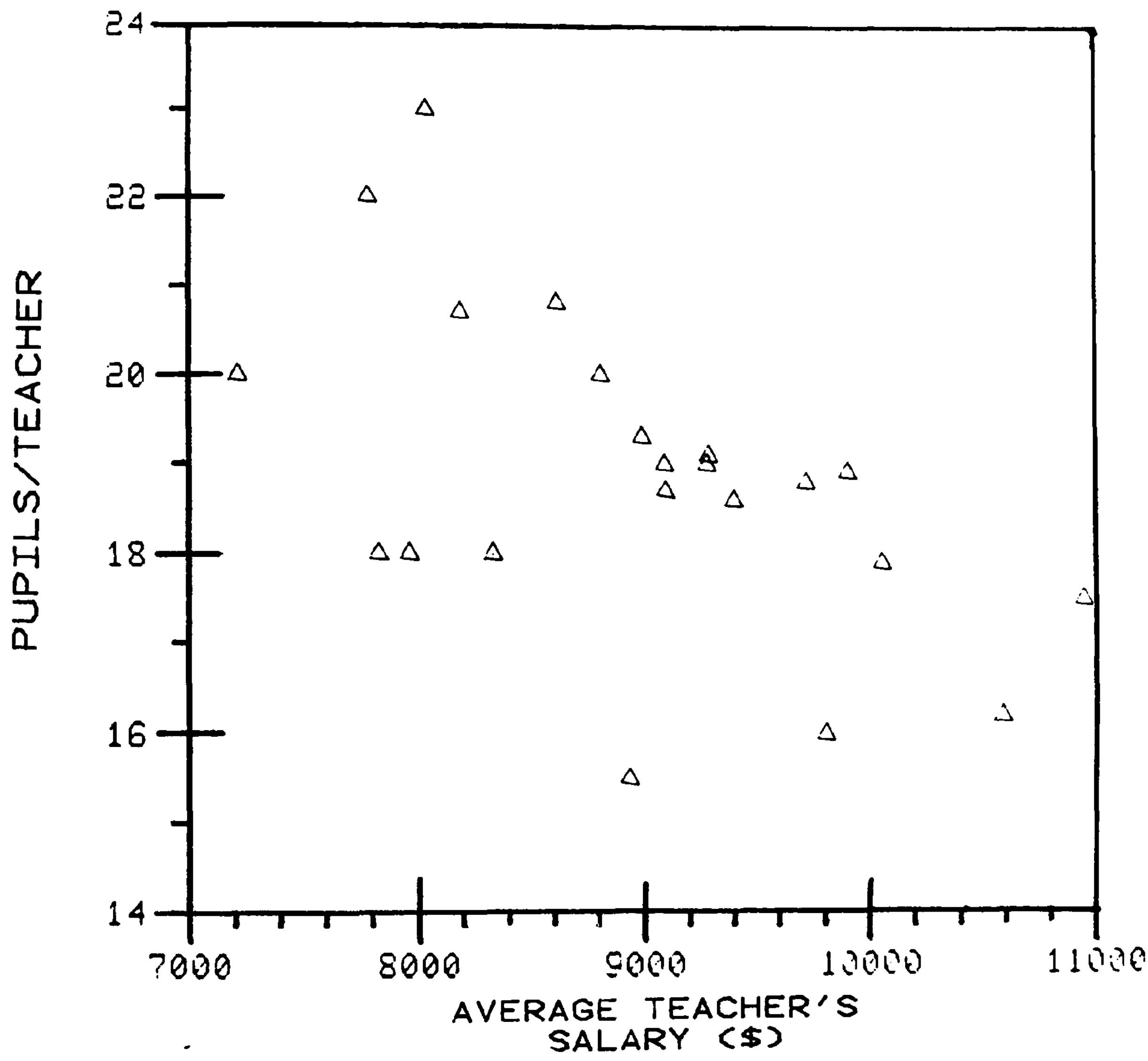


Figure C.4. Sample scatter diagram.

INDICES

Indicators

Several indices that were developed for testing combined indicators so that each index covered a community system:

Community Service Index--

1. Recreation acres (exclusive of Federal and State lands) per capita
2. Police expenditures per capita
3. Percent of population served by public water and sewer systems
4. Fire service indicator (to be added)
5. Physicians per 100 population

Planning Index--

1. Percent of population living in jurisdictions served by planning commission
2. Percent of population living in jurisdictions having a comprehensive plan
3. Percent of population living in jurisdictions having a zoning ordinance
4. Percent of population living in jurisdictions having subdivision regulations

Education Index--

1. Expenditure per pupil
2. Percent of pupils in overcrowded classrooms*
3. Average teacher salary
4. Number of pupils per teacher*

Urbanization and Growth Index--

1. Percent of county population living in urban places
2. Housing vacancy rate
3. Percent of housing built before 1950*
4. Percent change in population (1960-1970)
5. Percent change in population (1970-1990)
6. Labor supply indicator (to be added)

Economic Need Index--

1. Employment rate
2. Median family income*
3. Percent of population receiving welfare
4. Percent of population in 20- to 44-year age group*

---

*Indicators for which a low score rather than a high score is most favorable. Such indicators were subtracted rather than added in computation of the index.

On all indices, the higher a county's score, the better suited it would be for the site of a large power facility. However, the first five indices are directed at measuring its capacity to absorb socioeconomic impacts, whereas the sixth index is designed to measure the county's need for the potential benefits of such a facility. Most counties that have high capacity to absorb impacts do not have great economic need, and vice versa. Therefore, the economic need index was intended to be viewed separately from the five capacity indices.

A composite suitability index was developed to include the scores on all indices. However, inclusion of the need index only dilutes the scores of all counties, and much information is lost. Therefore, it was decided to use a two-step process originally outlined in the site screening procedure used during the first year of work. First, counties received a composite capacity score based on their scores on the four capacity indices. Then, economic need indices of these counties with the highest capacities were used to rank the high-capacity counties according to their degree of economic need.

Weighting

Some functional areas of community life are directly or severely affected by the construction of a power facility, whereas others may not be as seriously affected. Furthermore, adverse effects on different functional areas will have impacts of differing severity on local residents. Finally, the indices are more or less arbitrary in number and scope--the indicators could logically be grouped in ways other than that which we have selected. Health and education, for instance, could be combined or both included under "public services."

Therefore, mere summation of the five capacity indices is not sufficient to obtain a composite index. This would weight all indices equally, and there is little basis for doing so. A weighting scheme is an essential element in the development of the indices.

Weighting of the indicators composing each index is important for the same reasons. Some of the indicators are more significant than others, some cover a broader scope, and the number of indicators in any given area depends more on the availability of good data than on some organic definition of a functional system.

Two independent approaches to weighting were followed: (1) three professional planners from TVA's Division of Navigation Development and Regional Studies, familiar with the study area, were asked to rank the 22 counties according to their ability to absorb socioeconomic impacts; (2) a panel of "experts" made up of eight planners and economists participated in a work session in which weights were agreed on for all indicators and indices. During this session, indicators were ranked by participating individuals, and concensus was reached after several rounds of voting and discussion.

PRODUCING THE INDICES

The indices were produced by means of FORTRAN programs to compute each index described previously. To do so, all scores were first standardized (transformed into "z=scores"). The index formulas, which were the summation of these standard scores, were calculated with and without the weights described above. The weighted and unweighted indexes are as follows:

Unweighted Education Index

EDIDX = V4 - V5 + V6 - V7;

Weighted Education Index

EDIDX = (6 x V4) - (8 x V5) + (5 x V6) - (8 x V7);

where V4 = expenditures per pupil (standardized),

V5 = overcrowding (standardized),

V6 = average teacher salaries (standardized),

V7 = pupils per teacher (standardized).

Unweighted Community Service Index

CSIDX = V1 + V3 + V23 - V24 - V2;

Weighted Community Service Index

CSIDX = (2 x V21) + (6 x V2) + [4 x fire (no number yet)] + (8 x V23) + (8 x V24) + (6 x V2);

where V1 = recreation areas per capita,

V2 = police expenditures per capita,

V23 = percent of population served by public water,

V24 = percent of population served by public sewers,

V2 = physicians per 1000 population.

Unweighted Planning Index

PLNIDX = V8 + V9 + V10 + V11;

Weighted Planning Index

PLNIDX = (6 x V8) + (3 x V9) + (8 x V10) + (5 x V11);

where V8 = percent of population living in jurisdiction served by a planning commission,

V9 = percent of population living in jurisdiction having a comprehensive plan,

V10 = percent of population living in jurisdiction having a zoning ordinance,

V11 = percent of population living in jurisdiction having subdivision regulations.

Unweighted Urbanization and Growth Index

UGIDX = V13 X V14 - V15 + V16 + V17 + labor supply (no number);

Weighted Urbanization and Growth Index

UGIDX = (8 x V13) + (2 x V14) - (3 x V15) + (5 x V16) + (6 x V17) + (2 x labor supply);

where V13 = county population living in urban places,

V14 = housing vacancy rate,

V15 = percent of housing built before 1950,

V16 = percent change in population (1960-1970),

V17 = percent change in population (1970-1990).

Labor supply indicator is to be added.

Unweighted Economic Need Index

ENIDX = V18 - V19 + V20 - V21;

Weighted Economic Need Index

ENIDX = (4 x V18) - (8 x V19) + (2 x V20) - (5 x V21);

where V18 = unemployment,

V19 = median income,

V20 = welfare recipients,

V21 = population 20 to 44 years old.

In addition to computing the individual indices, these two routines also computed a composite suitability index. In contrast to the two-step composite capacity determination described before, these computer indices included the economic need index. They were simply sums of the standardized scores on each individual index. After these calculations were made, it was decided to return to the two-step process, eliminating economic need from the composite index. This second round of composite capacity indices was computed as follows:

CCIDX = sum of weighted standard scores in community service, planning, health, education, and growth absorption indices;

Weighted Composite Capacity Index

CCIDX = (8 x CSIDX) + (3 x PLNIDX) + (5 x EDIDX) + (9 x UGIDX).

RESULTS OF THE TWO APPROACHES TO WEIGHTING

Judgments of Three Professional Planners

The method of paired comparisons was used to obtain estimates of the ability of the 22 counties to absorb socioeconomic impact. All three planners were familiar with the study area. Each was interviewed independently. In the exercise, each county was paired with each other county and presented to the judges, who were asked to indicate which member of the pair had growth capacity or was more socioeconomically suitable as a potential site. The judges were required to designate one of the pair as more suitable. No ties were permitted.

Once the paired comparisons were complete, counties were ranked, and the judges then reviewed results for consistency with their overall judgments for county suitability.

Spearman's Rank Order Correlation Statistics were used to analyze the agreement between the three sets of ratings. All the correlation coefficients were above 0.95 and indicate nearly perfect agreement among the judges. The rankings of one of the judges are presented below:

High	Medium	Low
Hamilton	McMinn	Sevier
Washington	Roane	Claiborne
Anderson	Hawkins	Union
Hamblen	Loudon	Grainger
Bradley	Jefferson	Meigs
Greene	Rhea	Hancock
Blount	Monroe	Polk
	Cocke	

Results from the Computation of the Composite Capacity Index

Computer analysis of the data based on the weighting system described above resulted in the following rankings of the 22 counties in terms of socioeconomic capacity:

High	Medium	Low
Hamilton	Roane	Cocke
Hamblen	Greene	Hawkins
Anderson	Loudon	Claiborne
Bradley	Jefferson	Meigs
Washington	Sevier	Grainger
Blount	Rhea	Union
McMinn	Polk	Hancock
	Monroe	

The economic need index resulted in the following rankings:

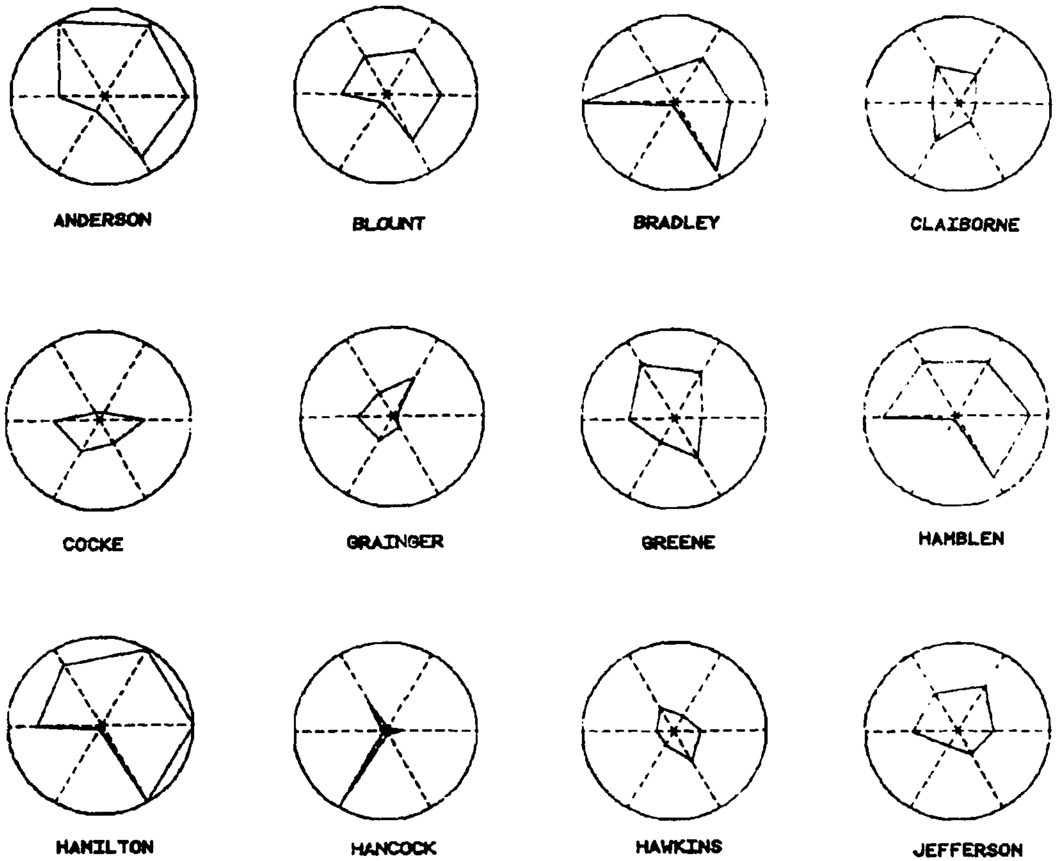
High	Medium	Low
Hancock	Grainger	Hawkins
Claiborne	Roane	Anderson
Cocke	Polk	Blount
Monroe	McMinn	Washington
Meigs	Greene	Hamilton
Rhea	Sevier	Hamblen
Union	Jefferson	Bradley
	Loudon	

It should be noted that none of the counties that are in the high group of economic need was in the high rank in terms of socioeconomic capacity. One county, Rhea, was in the top rank in terms of need and in the middle rank in terms of capacity. Roane and McMinn counties are in the upper half in terms of both need and capacity. In all other instances, the greater the county's capacity, the lower was its need.

THE KIVIAT DIAGRAMS

A Kiviat diagram was produced for each county, showing its standing on all the individual indices in comparison with the other counties. These were done by (1) using index scores computed from their rank orders on weighted indices and (2) using index scores computed from their rank orders on unweighted indices. Diagrams based on weighted data are illustrated in Figures C.5 and C.6.

The raw scores were considered more suitable as a base for the indices because of the numerous problems in using ranks. The Kiviat diagrams of the indices are not programmed in the form of butterflies, as was originally done. The actual form depends on the number of variables (indices) to be displayed and whether null axes (forming the butterfly "body") are used. However, the interpretation is the same: The closer the figure is to a square, in this case, the better the county.



46. Community Services/ Facilities Index

47. Planning/Public Administration Index

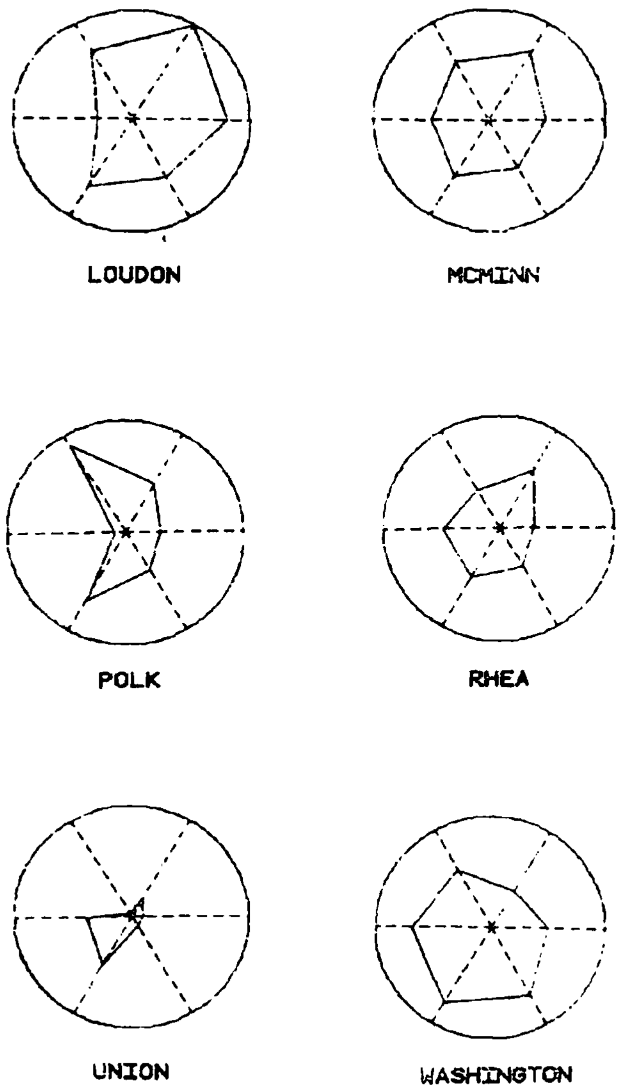
48. Education Index

49. Urbanization/Growth Index

50. Economic Need Index

52. Composite Capacity Index

Figure C.5. Kiviat diagrams based on six weighted indices--raw data.



46. Community Services/ Facilities Index

47. Planning/Public Administration Index

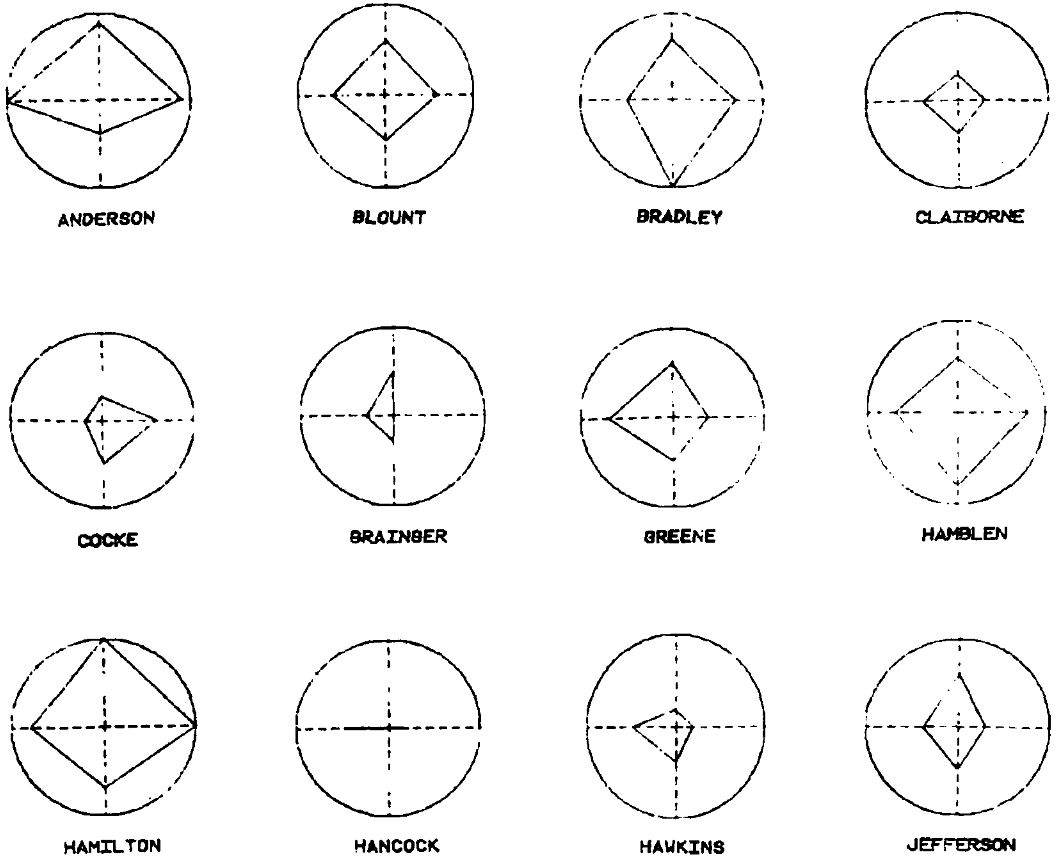
48. Education Index

49. Urbanization/Growth Index

50. Economic Need Index

52. Composite Capacity Index

Figure C.5. (continued)



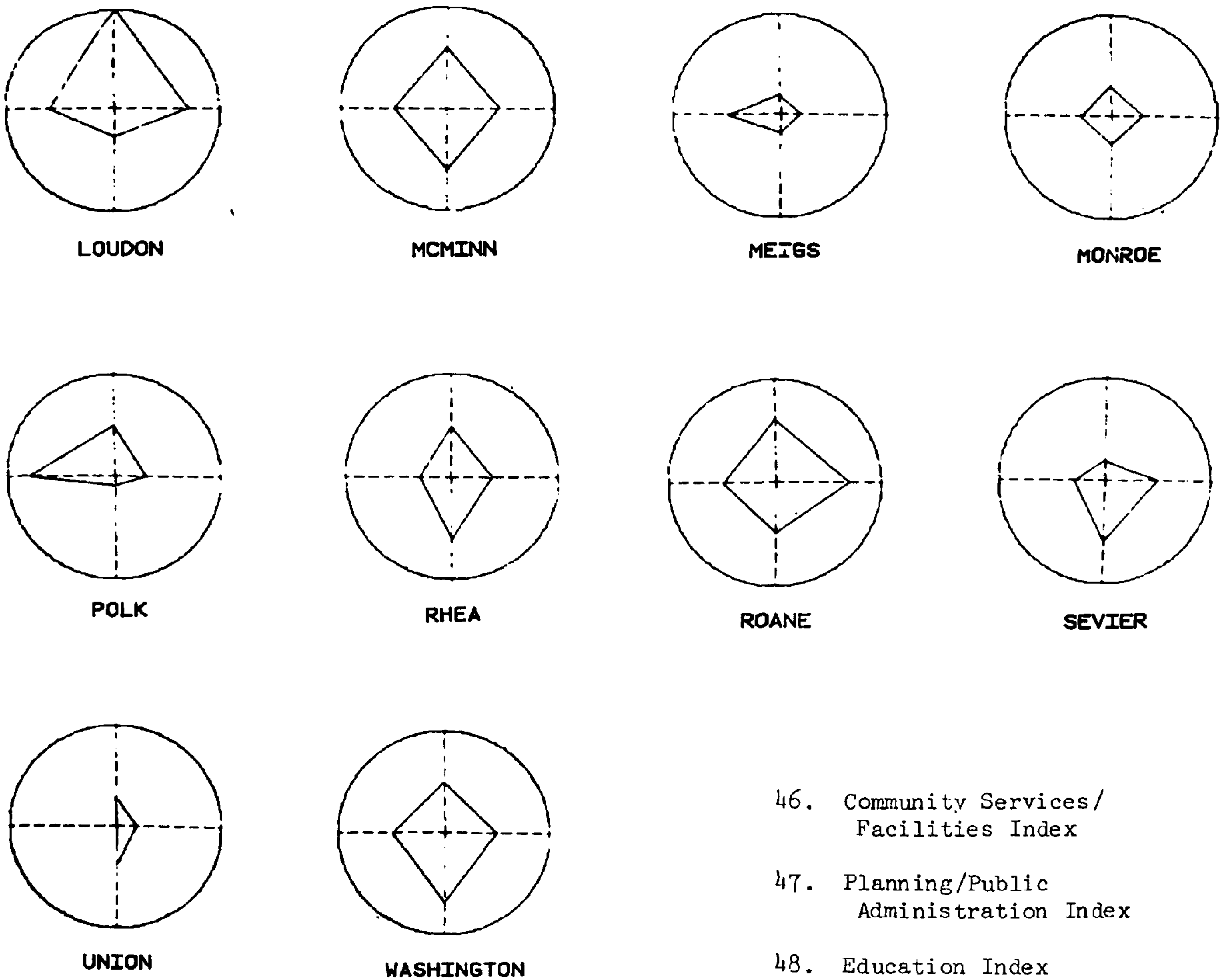
46. Community Services/ Facilities Index

47. Planning/Public Administration Index

48. Education Index

49. Urbanization/Growth Index

Figure C.6. Kiviat diagrams based on four weighted indices--raw data.



46. Community Services/
Facilities Index

47. Planning/Public
Administration Index

48. Education Index

49. Urbanization/Growth
Index

Figure C.6. (continued)

Examination of a preliminary set of Kiviat diagrams helped to establish the need for dealing with economic need factors separately. As can be seen in the diagrams in Figure C.5, capacity indices and the economic need index have a strong inverse relationship. For instance, compare the patterns of Anderson, Blount, and Hamilton (high-capacity counties) with Cocke and Hancock (high-need counties). In no case does a relatively high-capacity county also have a high economic need, although the moderate-capacity counties (such as McMinn, Jefferson, and Roane) have the most balanced hexagonal patterns

A final set of Kiviat diagrams is shown in Figure C.6. These are based on the four composite indexes--education, community services, planning, and urbanization. In these diagrams, the closer the shape is to a square that touches the circumference, the greater the capacity.

RESULTS AND CONCLUSIONS

RESULTS

Refinements

Data are yet to be collected for two indicators and for two counties that were not originally included in the test area. The indicators are fire service (the State insurance fire ratings for each fire department, aggregated by county) and labor force availability in each county for appropriate occupational categories (as collected by TVA's Human Resources Division). Data on all indicators have been collected for Knox and Sullivan Counties, which were added to the test area. The new data were added to the computer data sets, but have yet to be included in the final run of the site screening exercise.

Site Screening Test

The site screening test has five steps.

1. Calculate functional system indices. This was done by using the weighted formulas developed after the weighting session. Each county was given a score for each of the five functional system indices (including economic need). This task involves a very simple statistical computer program.

2. Calculate composite capacity index. The scores of each county on the four capacity indices (excluding the fifth index, economic need) were used to calculate the composite capacity index. The formula was developed by using the weights to be developed by the staff and consultants. Thus, each county will have a computer index score that is a weighted sum of the four indices.

3. Produce Kiviat diagrams. One set of Kiviat diagrams was produced with the four capacity indices. Another set with those four indices plus the composite suitability and economic need indices was also produced. These were used as a supplementary method of making quick comparisons among the area counties.

4. Produce composite capacity maps. This is the one step of the site screening test that had to be done primarily by hand. The intent was to achieve a map showing counties shaded to varying degrees, depending on their relative suitability as project sites. At the present time, there is no efficient, low-cost way to draw such a map using the Tektronix equipment. Therefore, hand drafting techniques are needed for the production of such maps (Figures C.7 and C.8).

   The index scores calculated in steps 1 and 2 were grouped into thirds--the top one-third of the counties, next one-third, and lowest one-third. Each third was assigned a pattern. They may be designated high capacity, average capacity, and low capacity for absorbing socioeconomic impacts. One map was prepared for the overall capacity index, and another was prepared for the economic need index.

   For rapid preparation of these maps, the computer-generated map of the study area was used as the base, with shading added by use of zip-a-tone patterns.

   These maps, particularly the composite capacity map, will probably be the most useful of all site screening outputs for quickly evaluating the relative capacities of candidate counties.

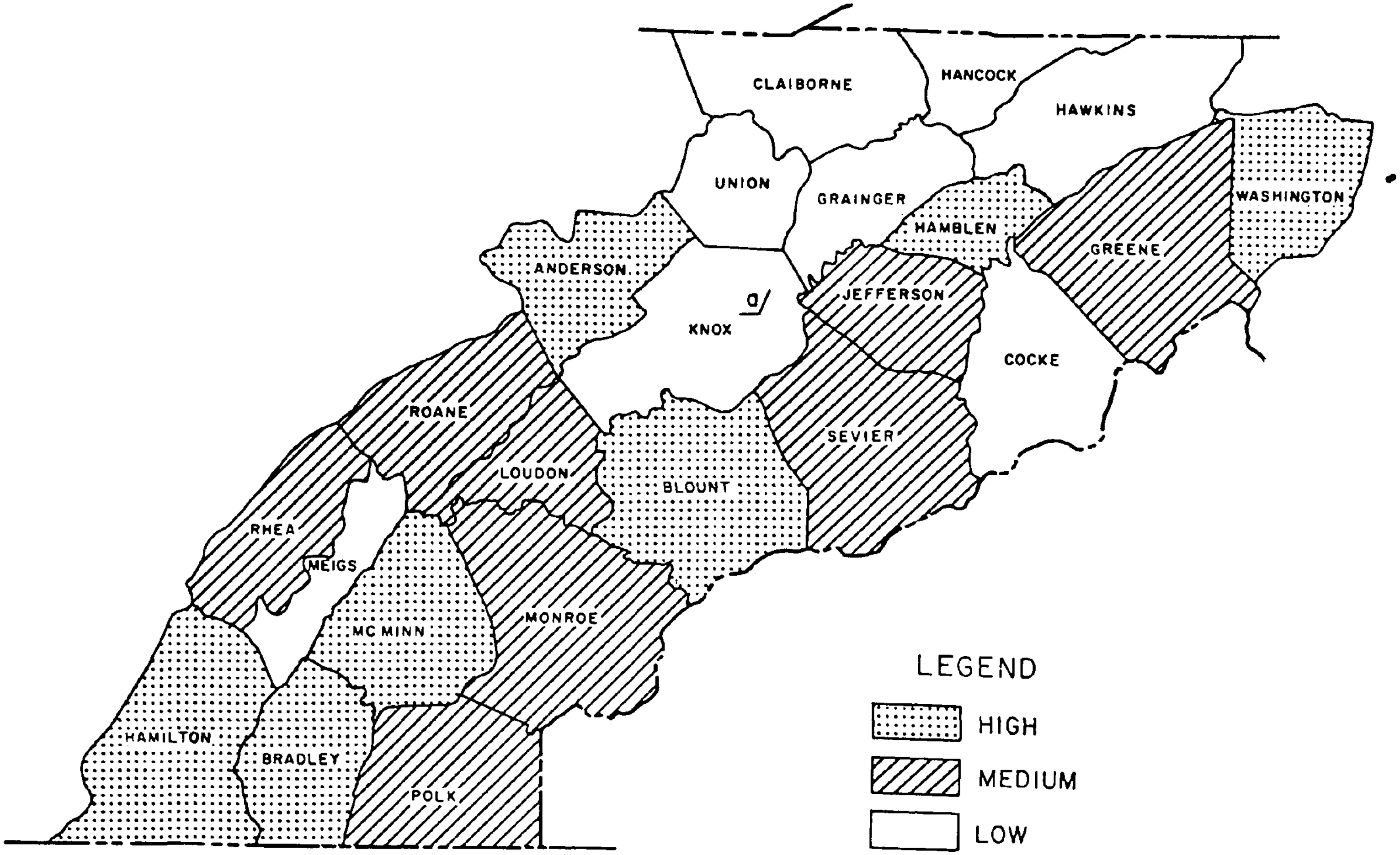
5. Select most needy counties having good capacity. This may be accomplished in two ways, both of which were used. First, the maps prepared in step 4 were used to identify those counties that fall in the top two categories on both the composite capacity and economic need indices. This group of counties can then be designated the higher-priority areas for power plant sites.

   A second method is to select the high-capacity (or high and above average capacity) counties and arrange them according to their scores on the economic need index. This produced a rank ordering of the half-dozen or dozen counties according to need, which could be used to help set socioeconomic siting priorities.

CONCLUSIONS

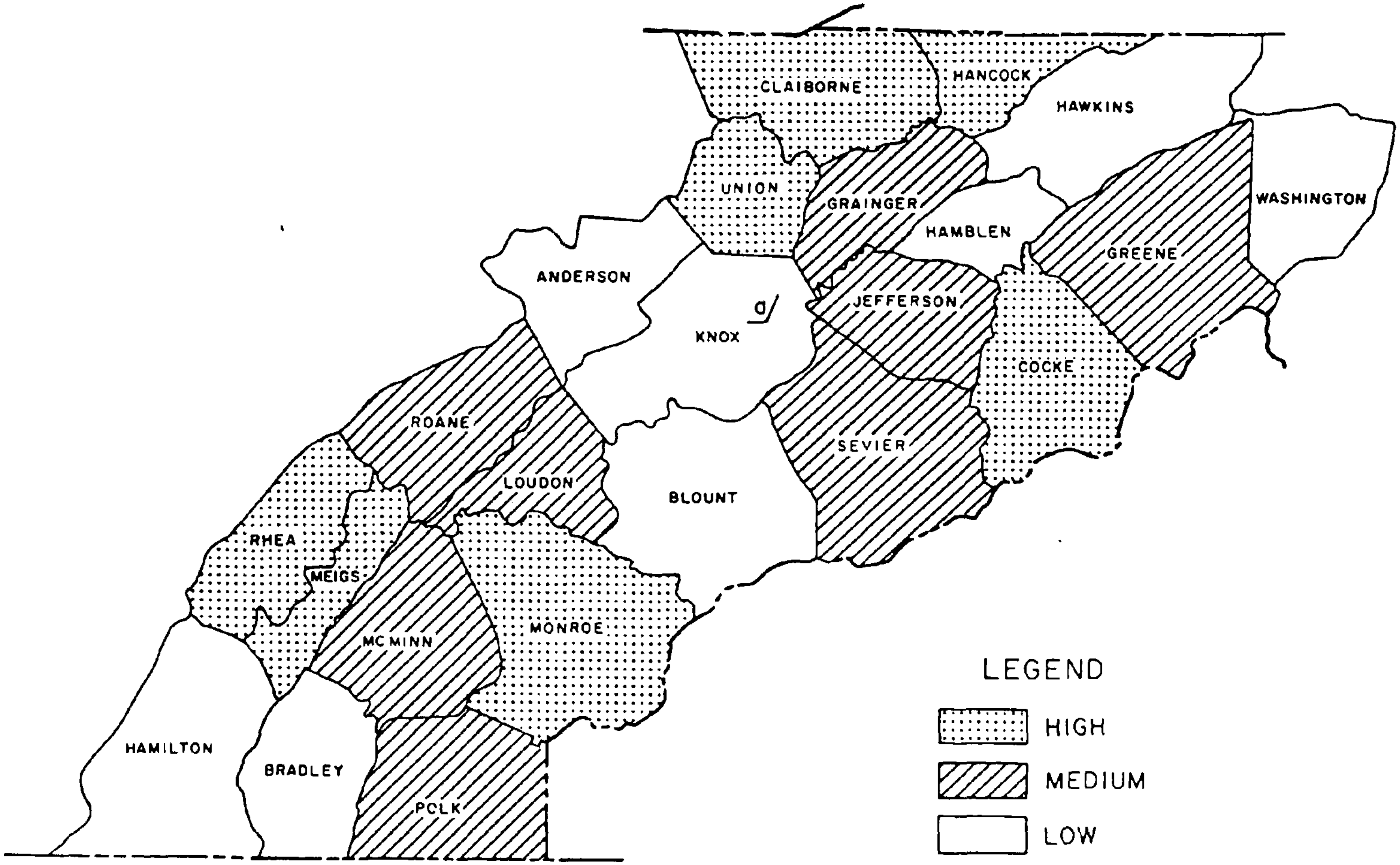
The site screening method developed during the course of this study and described in this report has several advantages over previous, more intuitive methods.

The computer processing of data, particularly in the formation of indices, adds greatly to the amount of information that can reasonably be handled. Thus, planning judgments can be made on the basis of much more complete information. The method does require the collection of many data on a wide variety of subjects, but all are readily available and most are in published form.



a/ EXCLUDED FROM ANALYSIS

Figure C.7. Overall capacity index.



a/ EXCLUDED FROM ANALYSIS

Figure C.8. Economic need index.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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16. ABSTRACT

This report summarizes the first two years of research designed to demonstrate applications of computer graphics to environmental analyses associated with the evaluation of impacts from development of conventional energy systems. The work emphasizes the use of storage-tube computer graphics technology as a means for improving the interaction between the engineer-scientist and the power of the computer. Computer graphics is also shown to be an effective medium for summarizing and communicating information about the environment and pollution control alternatives to technical specialists, managers, and the public. Also, many techniques of analysis previously considered impractical can now be conducted on a routine basis. Applications to several fields of analysis are described in detail, including air quality, water quality, radiological hygiene, industrial hygiene, scoioeconomics, and data facilities siting with the use of geographically referenced data.

17. (Circle One or More) KEY WORDS AND DOCUMENT ANALYSIS

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