J BUYS
G J VAN TONDER
J F BOTHA

CONVERSION OF THE SOFTWARE PACKAGES TRICON AND BAYES FROM PERSONAL COMPUTERS TO MACHINES USING THE UNIX OPERATING SYSTEM

Report to the
WATER RESEARCH COMMISSION
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UNIVERSITY OF THE ORANGE FREE STATE

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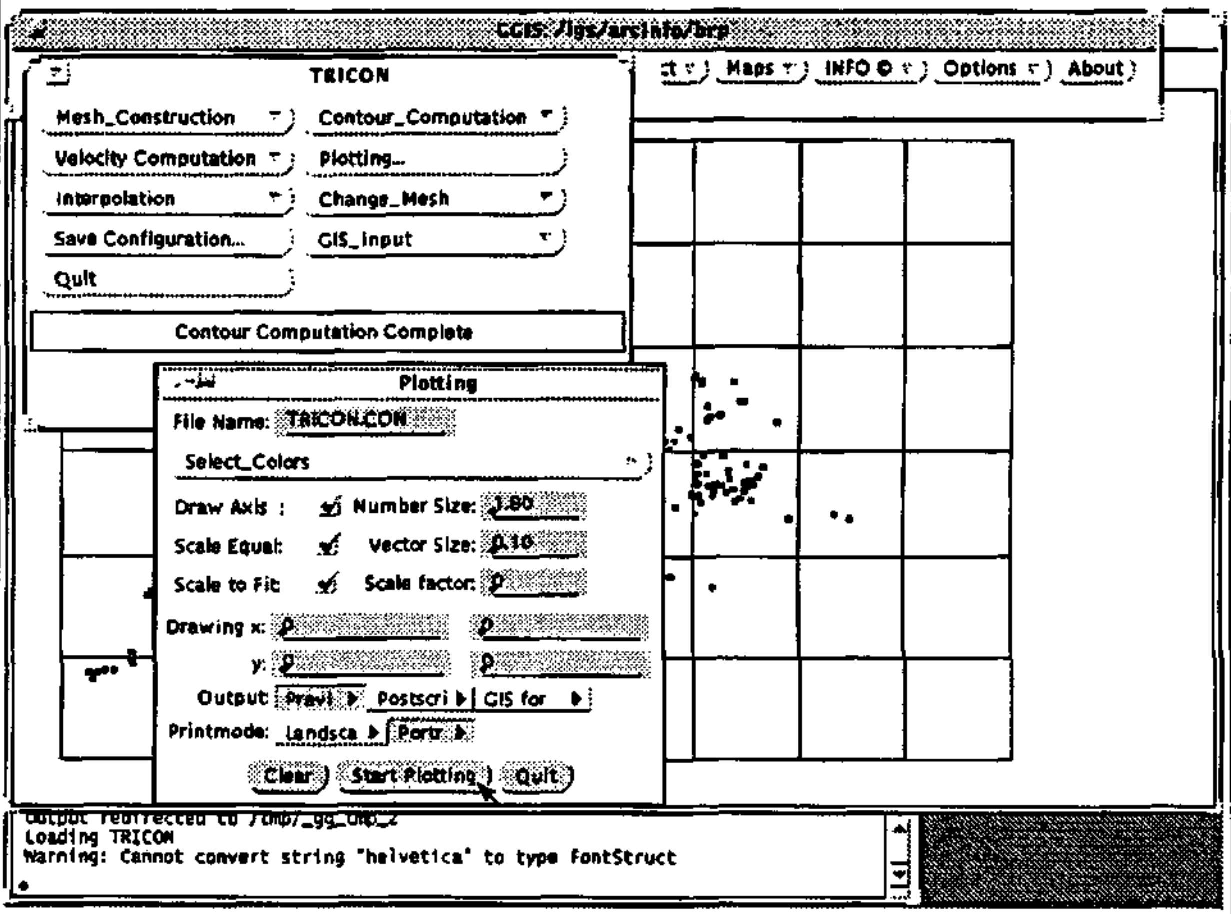

by

J. Buys,
G.J. van Tonder
and
J.F.Botha

Instituut vir Grondwater Studies
Universiteit van die Oranje Vrystaat
Posbus 339 Bloemfontein 9300

Institute for Groundwater Studies
University of the Orange Free State
P.O. Box 339 Bloemfontein 9300

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EXECUTIVE SUMMARY

1 INTRODUCTION

The invisibility of groundwater and the unique nature of aquifers make it extremely difficult to manage and control groundwater resources. One method to overcome these difficulties is to represent waterlevels in observation boreholes graphically by contour maps. This approach has the advantage that it allows one to visualize the trends in the data.

An important aspect in groundwater is the management of the resource. Mathematical models are often used for this purpose. However, to apply these models, values for variables are often needed at points where no measurements were taken, which require reliable estimation techniques.

The packages TRICON and BAYES (or TRIPOL as it is now referred to, because it includes three different interpolation methods) were originally developed for the contouring and interpolation of geohydrological data. However, there is nothing in the programs that would prevent a potential user applying them to other regional variables.

2 PURPOSE OF THE PROJECT

The packages TRICON and BAYES were developed on a personal computer as part of the project: *A Comparative Study of Two- and Three-dimensional Groundwater Models*, between the Water Research Commission and the Institute for Groundwater Studies, that ended in December 1991. The main properties of these packages, which are described in the reports by Buys *et. al.* (1992) and Van Sandwyk *et. al.* (1992), respectively, are briefly as follows:

> To draw accurate and aesthetically acceptable contour maps of a regionalized variable - that is a variable that varies in space.
>
> To estimate values of a regionalized variable, and its associated error, at points where no measurements are available.

Both these packages were developed on IBM-compatible personal computers under the DOS operating system, because of the widespread use of these machines in South Africa. However, towards the end of the project, it became clear that the maximum of 640 Kb memory, available on these machines under the DOS operating system, limits the application of both packages considerably (Buys *et. al.*, 1992). A research proposal '*Conversion of the Software Packages TRICON and BAYES from Personal Computers to Machines using the UNIX operating System*', was therefore put before the Water Research Commission. The purpose of this project, as stated in the terms of reference, is as follows:

> (a) To convert the present research package BAYES to a commercial package, (b) to convert the two packages, TRICON and BAYES, developed for personal computers, that use the DOS operating system to machines that use the UNIX operating system and (c) to incorporate them in the GIS system, presently developed at the Institute for Groundwater Studies, with funds from the Water Research Commission.

The proposal was accepted by the Commission and work on the project began in January 1993. The present report describes the work carried out under this project, which ended in December 1993.

3 STRUCTURE OF THE REPORT

The work on this project was undertaken in different phases, which will be discussed in Sections 2 to 7 of this report. The phases were:

(a) Conversion of program TRICON to the SUN workstation, so that it can run under the UNIX operating system.

(b) Combine the BAYES program with the program KRIGING, developed by Prof. G.J. van Tonder at the Institute for Groundwater Studies, into a package called TRIPOL that includes three different interpolation methods: (i) the classical Distance Weighting Method, (ii) Kriging and (iii) Bayesian Estimates. A facility for the computation of semi-variograms and the fitting of a theoretical semi-variogram to the semi-variogram values, needed by the Kriging and Bayes methods, were also included.

(c) Develop user friendly interfaces for the DOS version of TRIPOL and the UNIX and SUN versions of both TRICON and TRIPOL.

(d) Replace the DOS graphic library, PLOT88, presently used on DOS machines, with a Postscript library.

(e) Incorporation of TRICON into the GIS system, presently developed at the Institute for Groundwater Studies.

(f) The User Manual for TRICON was adapted for the UNIX version and a User Manual for TRIPOL was written from scratch. The User Manuals are included in Appendix A and B of this report.

4 SUMMARY AND CONCLUSIONS

TRICON and TRIPOL have been used extensively by the geohydrology students at the Institute for Groundwater Studies, since the second half of 1993. The UNIX versions of both packages proved to be very valuable for the handling of large data sets, required by numerical models.

The rapid development of IBM compatible personal computers in terms of speed and memory, however, increased the demand for DOS versions of TRICON and TRIPOL that require more memory than the basic 640 Kb available under current DOS versions. This problem may be solved in the near future with the publication of a linker, called BLINKER, by BLINK Inc.

CONVERSION OF THE SOFTWARE PACKAGES TRICON AND BAYES FROM PERSONAL COMPUTERS TO MACHINES USING THE UNIX OPERATING SYSTEM

1 INTRODUCTION

The packages TRICON and BAYES (or TRIPOL, so-called because it includes three different interpolation methods) were originally developed for the contouring and interpolation of geohydrological data. However, there is nothing in the programs that prevents a potential user applying them to other regional variables - that is variables that vary in space.

Regionalized variables are usually associated with very large areas. Therefore, it is practically impossible to measure them at all points of interest - least at points where their values may coincide with prescribed contour values or pre-defined nodes in a simulation problem. The variable is, consequently, mostly known at a small number of points (considerably less than needed to generate smooth contour lines or coinciding with each node of the mesh) scattered throughout the domain.

There are two methods that can be used to circumvent the discretization of arbitrary spaced points: (a) use an irregular triangular finite element mesh for contouring, and (b) interpolate or extrapolate the measured values, if values are needed at points where no measurements were taken. TRICON and TRIPOL do just that.

2 PROGRAM TRICON

TRICON is a graphical package that can be used to contour a regionalized variable with known discontinuities (Buys *et al*, 1992). However, it can also be used for interpolation of the variable to a regular rectangular grid, as well as to draw maps of any specified geographic information about a region and to represent groundwater velocities graphically.

TRICON uses a triangular irregular mesh, constructed between the actual data points, for contouring, interpolation and velocity computation. It constructs a Deluanay triangulation between the actual data points, but it can also be used to triangulate points on a square grid.

Contour lines, constructed by TRICON, are consistent and reflect changing roughness of the terrain. Contouring with TRICON is fast and provides piecewise linear, or smoothed, contours. The smoothing of contour lines can be controlled by the user to avoid intersecting contour lines.

Separation of the triangulating and contouring steps makes it possible to compute various sets of contour lines for the same set of data points, without reconstructing the triangulation. Using piecewise linear contours is a good way of checking for erroneous points, and to see if the expected trends are present. Contours are smoothed, using curve fitting techniques, but extensive smoothing is not done because this may lead to inconsistent contours.

TRICON incorporates discontinuities in the triangulation by *partially* subdividing the region into subregions, with the discontinuities as boundaries, while the terrain around the discontinuity is still viewed as a whole. Contour lines are interrupted where they cross the discontinuity, without increasing the computer time needed to compute the contours.

3 PROGRAM TRIPOL

TRIPOL is an interpolation program that estimates values for random variables from a given set of regionalized variables, that is variables distributed in space (and/or time). Variables encountered in environmental sciences such as geohydrology, geology, weather forecasting etc., are all regionalized variables.

TRIPOL includes the following:

•Computation of a semi-variogram for a given set of regionalized variables (data points);
•Fitting a mathematical function to the semi-variogram;
•Estimating values for any set of random variables from the given set of data points.

TRIPOL implements three interpolation methods, namely:

•Distance Weighting;
•Kriging;
•Bayesian Estimates.

The interpolation procedures do not only yield an estimate of the random variable, but also the error in the estimate.

The Distance Weighting method is a classical method that is based on the assumption that the variable of interest can be represented by a smooth function, and its use is consequently limited.

The Kriging method describes the spatial variability of environmental variables by representing them with random functions. This approach has the advantage that it allows one to describe an environmental variable in statistical terms, through the Theory of Regional Variables. The best known estimation methods, based on this approach, is Ordinary Kriging, or *Kriging* as it is conventionally known and Universal Kriging.

The Bayes method is a versatile procedure for estimation of groundwater levels (Van Sandwyk *et al*, 1992). The method has the advantage that one can use any expert knowledge about a given regionalized variable as a qualified guess. For example, a useful qualified guess for the groundwater level is the topography. Unfortunately, difficulties can be experienced in establishing a suitable qualified guess for some regionalized variables. It is therefore recommended that this method be used only when the user can establish a suitable qualified guess for the base variable, otherwise it may be better to use Kriging.

Because of the nature of Kriging and Bayesian Kriging, a semi-variogram, computed from the regionalized variables or data points, is needed to estimate the manner in which the mean value of the variable varies over the region. The computation of a semi-variogram for a given set of regionalized variables (data points) was therefore also built into the program, as well as a facility to fit a mathematical function to the semi-variogram.

Drawings created by TRIPOL can be drawn on the screen or a Laser Jet printer. Alternatively, a Postscript file or HPGL (Hewlett Packard Graphic Language) file, can be created which can be imported into a word processor.

4 USER INTERFACES FOR DOS, UNIX AND OPEN WINDOWS

The SUN versions of both programs were written on a SUN SPARC station II, that uses the SUN-OS 4.1.1 operating system based on Unix, and the OPEN WINDOWS 3.1 window manager based on the X window system.

The X Window System is an industry-standard software system that allows programmers to develop portable graphical user interfaces. X Windows is available on most Unix systems, like the SUN, IBM, HP and DEC workstations. The most widely used low-level interface to X is the standard C language library known as Xlib. Xlib defines an extensive set of functions that provide complete access and control over the display, windows, and input devices linked to the computer.

Although programmers can use Xlib to build applications, most prefer to use one of the higher level toolkits designed for use with X Windows, for example, the standard X or Xview toolkits.

The standard X toolkit consists of two parts: a layer known as the Xt Intrinsics, and a set of user interface components known as widgets. Applications based on the X toolkit, can use either the widget set OPEN LOOK (also known as OLIT), developed by AT&T and Sun Microsystems, or MOTIF, developed by the Open Software Foundation. They are both written in C and are built on top of Xlib.

The graphical user interfaces (GUI's) of TRIPOL and TRICON use the OLIT toolkit (Young *et al*, 1992), since it is available on all SUN workstations. It implements user interface components like scroll bars, menus and buttons, as well as graphics for drawing maps and graphs in a graphic window. However there is today a trend to shift towards Motif. Sun has already announced that they will move to Motif. An implementation of Motif exists already for the majority of workstations (HP, IBM, DEC, ...). It may therefore be useful to transfer the GUI's of TRIPOL and TRICON to Motif later.

Both programs can, however, already be used on other workstations, since the Unix versions run in any Unix shell, but it is much more aesthetically acceptable using OPEN LOOK.

The DOS version of TRIPOL was originally developed in FORTRAN. I decided to keep it that way and to develop a user interface that uses the Microsoft FORTRAN graphic library. The Unix and SUN versions of TRIPOL were, however, successfully linked with the C and X libraries.

5 GRAPHIC LIBRARY

The PC version of TRICON was originally developed in C and uses the PLOT88 graphics library, from PLOTWORKS Inc., to create drawings. This library has the advantage that it includes a wide variety of drivers for various printers and can also create HPGL (Hewlett Packard Graphic Language) and Postscript files for importing graphs into word processors, like Word for Windows or Mac. The only disadvantage is that royalties must be paid for programs that include the PLOT88 library, when they are sold. An agreement has been reached with PLOTWORKS that only a small amount of $10 have to be paid on each package, if TRICON is distributed at $100 only.

Although the drawings on the Sun version can be previewed in a graphics window, the SUN and Unix versions use a Postscript Library that was assembled from public software, to create hard copies. It frees these versions from any obligations to software developers, and makes it very versatile for use on other workstations. Without this library, it would not be possible to port the programs to other Unix machines, since PLOTT88 is only available on Sun workstations.

6 GGIS

GGIS is an interface between the geographic information system ARC INFO and the HYDROCOM data base, developed for use on SUN workstations, by the Institute for Groundwater Studies.

The SUN version of TRICON was adapted to receive input directly from the GGIS system, through temporary files. TRICON is then automatically initiated from GGIS. All the facilities of TRICON can still be used to create and view drawings, whereafter the drawings can be exported to GGIS, for incorporation in the ARC INFO system.

7 COMMERCIALIZATION

The Institute for Groundwater Studies regularly receives requests for commercial versions of both programs. Since a complete user manual for both programs is now available, the software is available through the Institute for Groundwater Studies at a small administration fee. A review of the PC version of TRICON has been published in an issue of the international journal, *Geographical Systems*.

8 CONCLUSIONS

The packages TRICON and TRIPOL are particularly useful for the contouring and interpolation of any set of values, associated with a two-dimensional regionalized variable. Although the packages may not satisfy the needs of all users, experience has shown that it is very versatile and user friendly. It also allowed scientists at the Institute for Groundwater Studies and other institutions to solve problems that were previously thought to be intractable. This applies in particular to groundwater pollution studies and phenomena where accurate contours and estimations are needed.

9 RECOMMENDATIONS

The Unix and Sun version of TRICON and TRIPOL can now be used for very large data sets, but the demands for DOS versions that can utilize more memory than the basic 640 Kb memory, that can be addressed by current DOS versions, still remains. These demands are also increasing because of the fast development of IBM compatible personal computers in terms of

Appendix A

User Documentation

TRICON

by

J. Buys

Institute for Groundwater Studies
University of the Orange Free State
Bloemfontein

TRICON was developed by the Institute for Groundwater Studies with funds provided by the Water Research Commission. It can be obtained free of charge by any bona fide research organization. In all other instances, contact the IGS for conditions under which this program may be used.

Should you have any suggestions to help us better meet your needs we will welcome them. Please write to us directly at

Institute for Groundwater Studies,
P.O. Box 339
Bloemfontein
9300
South-Africa,

or call (27) - 51 - 4012625 or fax (27) - 51 - 473541.

Thank you for using TRICON. We hope you enjoy using it.

J Buys
Institute for Groundwater Studies,
Bloemfontein.

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Mr. J.P. Verwey for his valuable assistance in testing the program.

Preface

TRICON is a graphical package that is primarily developed for automatic contouring of geological data, making provision for known discontinuities in a region. Secondary, it can also be used for interpolation of a surface to a regular rectangular grid, as well as for graphical representation of fluid velocities. It can also be used as a general plot program, to draw maps of any specified information about a region.

The following is a few good reasons why you should choose TRICON for contouring:

TRICON uses a triangular irregular network, constructed between the actual data points, for contouring, interpolation and velocity computation.

"Irregular spaced data arise from many experimental and surveying sources, each of which has its own typical pattern of scattering. Practically all program packages, with a few notable exceptions, start with irregular distributed points, interpolate them to a regular grid, then compute the contour lines. This type of data processing is so frequent in computer mapping that many studies see interpolation as a component of the production of contour lines.

Once converted, the new grid has all the advantages and disadvantages of a regular grid. To obtain the same accuracy for computation of geomorphometrical parameters, one needs fourteen regular points for every irregular one (Mark, 1975). However, to make sure that no structural line is misrepresented, the ratio has to be closer to 1:287 (Peucker *et al*, 1976).

One therefore has to ask whether the computation of explicit topological relations, maintaining the irregular structure of the points, would not lead to better results. The usual way to compute these relations is by triangulation." (Peucker, 1980)

Other disadvantages of a rectangular grid, mentioned by Peucker (Peucker, 1980), is the saddle point problem, while the subdivision of the rectangles into triangles, to obtain a regular triangular grid, can influence the shape of the curve and introduce undesirable trends.

TRICON constructs a Delaunay triangulation, using an algorithm that is also capable of triangulating points on a square grid.

"A triangulation is regarded as 'good' for the purposes of interpolation if its triangles are nearly equiangular. ... It is the purpose of this note to show that there is only one locally equiangular triangulation of the convex hull of a finite set of distinct data sites, and to identify that triangulation as the Delaunay triangulation" (Sibson, 1978).

The algorithm used to compute the triangulation allows the construction of a consistent Delaunay triangulation for all sets of data, even a square grid. "This is an important feature because a rectangular grid, which is fully degenerated, can now also be triangulated with the modified algorithm" (Buys *et al*, 1990a). This algorithm was implemented in TRICON.

Contour lines constructed by TRICON are consistent and reflects changing roughness of the terrain in a time- and space- efficient way.

"The major disadvantage of the regular grid, rectangular and triangular alike, is its inability to adapt to a changing roughness of terrain. The mesh width has to be adapted to the area of highest relief changes. One can thus say that regular grids tend to be highly redundant with respect to storage needs" (Peucker, 1980).

"Unless the data points all coincide with grid nodes, it is possible for the contours so drawn to be inconsistent with the original data" (Schagen, 1982).

"When contouring a data set with known singularities or large values which occur over small regions, it is recommended that fine spacing of nodal points be used to assure that the singularities appear in the map" (Yates, 1987).

By constructing the triangulation between the actual data points, TRICON produces *consistent contours*, following the laws of logical contouring, representing linearly interpolated values between neighboring data points - this makes the need for fine spacing of nodal points irrelevant. Furthermore, no contours are constructed outside the region covered by data points.

Contouring with TRICON is fast, provides piecewise linear contours as well as smoothed contours, while smoothing of contour lines can be controlled to avoid smoothed contours to cross each other.

"A triangulation method with plane facets in the triangles should be provided as the quickest, cheapest way of taking a quick look at data" (Sabin, 1978).

Separation of the triangulating and contouring steps, makes it possible to compute various sets of contour lines for the same set of data points, without reconstructing the triangulation. Using plane facets, is a good way of checking for erroneous points, and for seeing if the expected trends are present. Contours are smoothed, using curve fitting techniques, but extensive smoothing is not done because this would lead to inconsistent contours.

Known discontinuities are incorporated into the contour map in a time efficient way.

"If the actual surface has singularities, such as discontinuities (cliffs) or discontinuous first derivatives (escarpments) the algorithm (using a regular grid) will smooth these out, and they will appear as regions where the contours are close together, sharply bent or otherwise untypical. If we know in advance where such discontinuities occur, the algorithm could be adapted by ignoring the contribution from the data point (x_i,y_i) to the value at the point(a,b) if the line joining these intersects the discontinuity. Thus the weight would be a function not only of the distance between two points, but the direction and location of the line joining them. As is clear from the SYMAP program, (Robertson, 1967), the computer time in such techniques can be large. A more efficient approach would be to separate the area onto subregions with the discontinuity as boundaries" (McLain, 1974).

TRICON incorporates discontinuities in the triangulation, by *partially* subdividing the region into subregions, with the discontinuities as boundaries, while the terrain around the discontinuity is still viewed as a hole. This technique does not increase the computer time needed to compute the contours. Contours are interupted where they cross the discontinuity (Buys *et al*, 1990b).

J. Buys.

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1. GENERAL DESCRIPTION

1.1. INTRODUCTION

Description

TRICON is an on-line, *menu driven*, program that uses a triangular irregular network to draw contour maps, gives a graphical representation of the flow direction and magnitude of groundwater velocities and estimates values for any given point in the region, defined by a set of data points. Contours, representing the difference between two sets of data values, can also be drawn.

Properties

By using a *triangular irregular network (triangulation)*, drawn between the actual data points, it is possible to eliminate errors caused by interpolation to a square grid. A facility to alter the boundary of the triangular network, makes it possible to delete oblong triangles on the boundary of the network, that can cause distortion of contour lines.

Discontinuities

Except for the geographical position of data points, it is also possible to specify the position of dams, coastlines and discontinuities that are present in the region. This information is added to the triangular irregular network, and their effect can then be reflected by the contour lines and other applications.

Hardware Requirements

PC Version
TRICON runs on a MS-DOS and PC-DOS micro computer and it is therefore limited by the amount of memory addressable - 640K bytes being the maximum. A numeric coprocessor is used to speed up execution time, but a version of TRICON without coprocessor is also available. The TRICON executable needs between 360 and 510Kb memory to run, depending on the number and kind of printer drivers loaded. The amount of data points that it can handle, are limited by the available memory, after loading the TRICON executable. TRICON can handle up to ±600 data points on a PC with 640Kb memory, but the TRIBIG version of TRICON, that needs only 180Kb memory, can handle more than ±1000 data points, depending on the available memory. TRIBIG can, however, not be used to produce graphical output - TRICON must be loaded afterwards for that purpose.
SUN version
The SUN version of TRICON runs on a SUN SPARC station with SunOS 4.1.1 and the OPEN WINDOWS 3.0 window manager. It can handle much larger data sets because the UNIX operating System is not confined to 640Kb memory.
UNIX version
The UNIX version can run on any UNIX machine in a Unix shell.

Supported Devices

PC Version
TRICON supports a wide variety of graphic devices on which the graphic output can be drawn.

The following display devices are supported:

- •IBM Colour Graphics Adapter (CGA) or equivalent
- •IBM Enhanced Graphics Adapter (EGA) or equivalent
- •IBM Video Graphics Array (VGA) or equivalent
- •Herculus Graphics Card

The following dot matrix printers are supported:

- •EPSON FX-80, FX-80+, JX-0, FX-85, FX-185,FX-286
- •EPSON RX-80,RX-100
- •EPSON MX-80,MX-100
- •EPSON FX-100,FX-100+
- •EPSON LQ-1500 8" and 13.6"
- •BM Personal Computer Graphics Printer
- •IBM ProPrinter
- •Okidata ml 92/93/182/192/193
- •Centronics GLP printer

The following plotters are supported:

- •HP ColorPro (7440A/7470A/7475A) Plotter
- •HP 7470A/7475A/7550A Graphic Plotter
- •HP 7580A/7585A/7586A
- •HP DraftPro (7570A) Graphic Plotter
- •HP DraftMaster I/II (7595A/7596A) Plotter
- •Houston Instrument DMP-51/52/56
- •Enter Computer SP-600 Desktop Plotter in HPGL mode
- •Enter Computer SP1000 Plotter
- •Enter Computer SP-600 Drafting Plotter
- •Ioline LP 3700 Large Format Plotter

The following jet printers are supported:

- •HP ThinkJet (2225A) Printer
- •HP QuietJet (2228A) Printer
- •HP QuietJet Plus (2227A) Printer
- •HP 2686A LaserJet Plus Printer

SUN version

The SUN version creates the following graphical ouput.

- •Screen Display
- •Postscript Files
- •Text Files

UNIX version

The Unix version creates only Postscript Files, to be printed on a Postscript printer or viewed by a Postscript viewer.

1.2. BASIC COMMANDS

TRICON consists of the following set of basic commands that operate on-line, and can be given in sequence or independently.:

- •Mesh Construction
- •Contour Computation
- •Velocity Computation
- •Plotting
- •Interpolation
- •Change Mesh

The *Mesh Construction* command is used to construct the triangular irregular network (TIN) that is used by the *Contour Computation*, *Velocity Computation* and *Interpolation* commands for various applications. The *Plotting* command is used to create the graphic representations computed by TRICON.

Mesh Construction

TRICON computes a triangular irregular network between a given set of scattered data points, that is as near as possible equiangular. The property of the triangulation is such that, for any two triangles sharing a common edge and defining a strictly convex quadrilateral, the replacement of the chosen diagonal by the alternative one, will not increase the minimum of the six angles in the two triangles making up the quadrilateral.

Contour Computation

Contour lines are computed by means of linear interpolation on the sides of the triangles. These piecewise linear contour lines are then smoothed by using a weighted least square bicubic spline approximation. When meandering of smoothed contour lines occurs, because of the degree of smoothing used, the smoothing degree can be decreased. Contour lines, representing the difference between two sets of values, can be computed by specifying both values in the input file. A *plot file* is created by this command and can be plotted under the *Plotting* command

Plotting

The *Plotting* command is used to plot the various plot files, constructed by TRICON, on any chosen output device. It is the only command that can produce graphic output. The *plot files*, constructed by other commands, are such that they can be used as input to the Plotting command. It will produce a graphic representation of the triangulation, the contour map or the position and levels of data points and velocity vectors.

Any additional geographic information that is needed on the maps, can be added to the plot files, following the prescribed format. The plotting command can also be used as an independent plot program to plot any user created plot files, as long as they satisfy the prescribed format for TRICON plot files (see Section 4.2).

Velocity Computation

This command constructs a plot file that will give a graphical representation of the flow direction and magnitude of groundwater velocities. The fluid velocities of each triangle are calculated from Darcy's law, for given values of porosity and conductivity. The resulting velocity vector is drawn at the centroid of the triangle. The length of the vector is drawn relative to the maximum magnitude of all the vectors.

Interpolation

The triangular irregular network, constructed by TRICON, can also be used to estimate the z-values for given grid points. For each grid point, the triangle containing it must be found. Two methods are available to estimate the z-values. The first method, linear interpolation, uses a plane surface over each triangle, to approximate the z-values of points lying inside the triangulation. When sampling is sparse, the second method, gradient interpolation, can be used. This method uses both the size and the slope of the surrounding triangles to estimate the value of the point. The second method is also the method used for all grid points lying outside the triangulation. In this case, the nearest triangles are used, although the quality of these points cannot be guaranteed. Otherwise, the estimates compare well with other techniques, like Kriging and Universal Kriging.

Change Mesh

The boundary of the triangulation always forms a polygon that is strictly convex. This may cause the construction of boundary triangles, that are elongated or quite thin, which may have a negative effect on contour lines in that region. Such triangles can be avoided by specifying a boundary around the region, or they can be deleted from the triangulation, using the *Change Mesh* command. This command can also be used to exclude an area inside the region from the triangulation.

1.3. GEOGRAPHIC INFORMATION

Geographical information, like the position of discontinuities, as well as coastlines and other lines that represent a constant z-value along the whole line, can also be specified and taken into account in the various applications. A set of points is selected from these lines, by means of a segmentation algorithm, and added to the triangulation. For each set of points, representing a single value, only one value is given in the input files, which is then associated with all the points in the set.

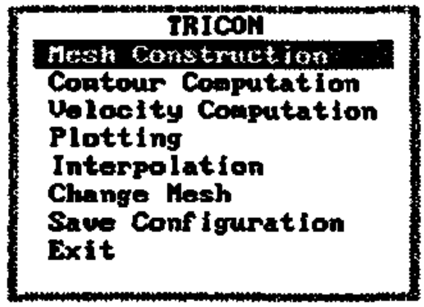
In the case of discontinuities, two values are associated with each point, one for each side of the discontinuity. These values are estimated, using the three nearest data points on each side. The line connecting these points, forms a boundary that partially subdivides the region at this position. Contour lines that pass through this region, will now be interrupted at this line, reflecting the effect of the discontinuity in that region.

1.4. TRICON MENU SYSTEM

TRICON is a menu driven program, which makes it extremely easy to use. All commands are given on-line, while the configuration needed for a specific machine, or file names used for a specific study, can be saved in a configuration file. It is then automatically loaded when TRICON is executed.

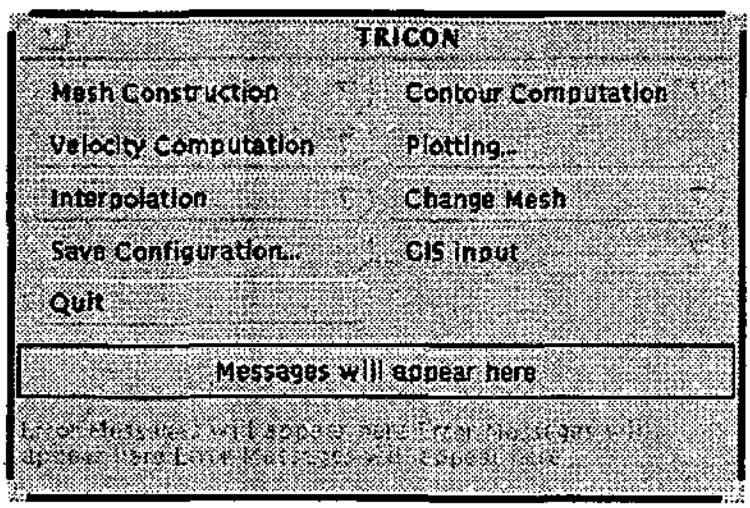
Menus

When TRICON is executed, the following main menu appears on the screen, showing the basic commands that can be executed.



By selecting one of these commands, a sub-menu appears on the screen, carefully leading the user through each step of the program.

The SUN version has one extra command, named *GIS input*, on the main menu for importing data from the geographic information system GGIS, available with ARC/INFO.



Selection

PC version

To execute any of the commands shown in the main menu, move the cursor to the command you want to select. This can be achieved by using either the ↑,↓ keys, or press the first letter of the command, which will automatic move the cursor to that position. Press ↲(Enter). All selections can be made in this manner. A sub-menu will now appear on the screen, showing the input and output files, as well as the available options for this command.

A *Busy window* will pop up, when TRICON is processing a particular command, showing some messages that reflects the actions of the program. An *Error window* will pop up when an error or warning occurs.

SUN version

The mouse buttons are used to set the input focus or to select options and to execute commands. To popup menus, listed in the menu buttons, either the left or right mouse buttons must be used, depending on the type of button. A ∇ indicates a popup menu button - use the right mouse button; ... indicates a popup menushell button - use the left mouse button.

The main menu contains an area were the *busy massages* will appear when processing is complete. No intermediate messages, as shown in the paragraphs, **Reaction of Tricon**, will appear in the *Sun version*. Just underneath this area, the *error massages* will appear in red.

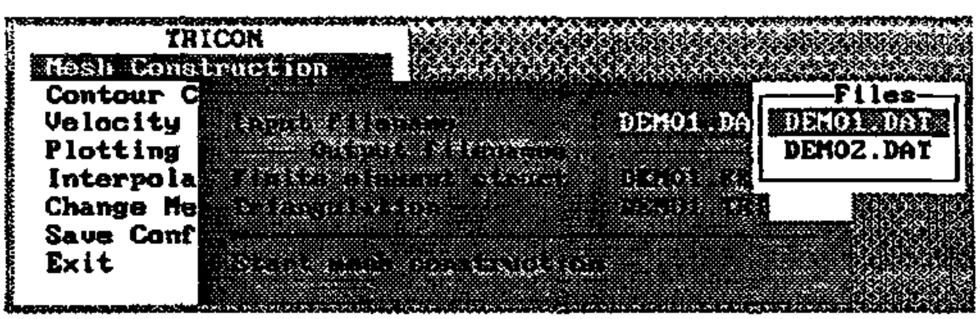
Options

The value of the options can be altered by moving the cursor to it and pressing ↵. Alter the value of the option and press ↵ again, to accept the new value. If the new value is incorrect, a message will appear on the screen. Press the *Esc* key and enter the correct value. The *Esc* key can always be used to cancel a selection, or to return to the previous menu.

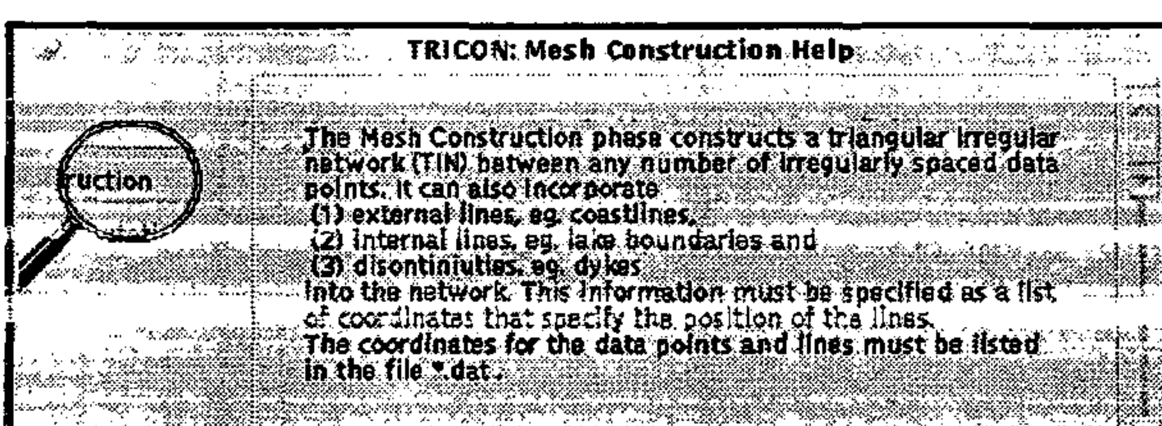
Help

Help is available on several options in the sub-menus, by pressing the *F1* (help) key, after selecting the option and pressing the ↵ key. Press *Esc* again to remove the help window.

PC version
On the PC version help is also available for selecting the correct file names. Move the cursor to the file name and press ↵, followed by *F1*. A list of all the qualifying file names will appear on the screen. Select a file name by moving the cursor to it, and accept it by pressing ↵.



SUN version
On the SUN version help is available on all the buttons on the main menu. Position the mouse pointer on the button and press *F1*. An example of the help menu follows:



1.5. TRICON FILES

File Names

All necessary input files must be created in the prescribed format, before executing TRICON. File names have the form *name.extension*. You may choose any file name, but use the prescribed extension, as indicated in the sub-menus of each command. Files with a fixed extension will be referenced as * *.extension*. If the file name of the *.dat file is changed, the new file name is used as the default file in place of the initial default file name, TFEC or TRICON. All file names are automatically updated to the new file name. Note that the *.dat file is the only file that will change the default and update the other file names.

File Format

All data lines in the input files are free format, unless otherwise indicated, in which case the format will be specified next to the description of the lines. The following notations will be used, where *width* indicates the number of characters to be read from the input line. Leading zeros in real and integer numbers may be substituted by blank characters:

Fwidth	A real number.
Iwidth	An integer number.
Awidth	A character string.
∇	A blank character.

File Construction

Data files consist of various data lines. All data lines in the input files are line orientated (ends at the first carraige-return character), unless otherwise indicated. This means that each data line must be terminated by a carraige-return character, and that the list of data fields may be followed by comments, if required, before the carraige-return character.

Square brackets are used to indicate optional data fields. In some cases, a semicolon is used to separate data fields and comments. It is only necessary when these data fields are actually followed by comments, otherwise it is optional. It will be indicated as [;] in the line description. For example,

| Field1 Field2 [;] | *format*

Data lines that are not line orientated, are string orientated.
These lines may not be followed by comments, because they may be composed of several lines. All data fields must be separated by at least one blank space.

2. MESH CONSTRUCTION

2.1. THE MESH CONSTRUCTION COMMAND

Data Points

In order to construct the triangular irregular network, the geographical coordinates of each data point must be given as a pair (*x*,*y*). The coordinates can be given in a cartesian or surveyor coordinate system. The default coordinate system is cartesian coordinates. If the alternative system is used, it must be specified, as indicated in Section 2.2

Sub-menu

When the Mesh construction command is selected on the main menu, the following sub-menu will appear on the screen.

Mesh Construction

Input file name	:TRICON.DAT
-----Output file names-----	
Finite Element Structure	:TRICON.FEM
Triangulation	:TRICON.TRI
Start Mesh Construction	

It shows the names of all the necessary input and output files. One preconstructed input file is needed and two output files are constructed. Change the names of the files, if necessary, or select the file name by using *F1*, but remember that the extensions are fixed. Initiate the mesh construction by moving the cursor to *Start Mesh Construction* and press ↵.

2.2. INPUT FILE

File Contents

The *.dat file is the only input file needed under this command. It must contain the coordinates of all the data points.

An optional boundary, consisting of a set of coordinates, specified counter-clockwise around the data points, can be given. This can prevent oblong triangles, formed at the boundary of the triangulation. Note that the polygon formed by these boundary points must include all data points, it must be **strictly convex** and the set of boundary coordinates may not include any of the data points. The default boundary used, stretches up to two times the width of the region in both *x* and *y* directions.

If a boundary is specified, it will have the same effect as when triangles are deleted from the triangulation, by using the *Change Mesh* command. However, in most cases, it will be unnecessary and can be omitted.

The coordinates of internal lines - like dams and lakes - external lines - like coastlines - as well as the position of discontinuities - like dykes - can also be specified in this file. Extra points, selected from these lines, will be added to the triangulation. Their coordinates are specified in the output files.

Data Format of *.dat

Line 1	nb np mne [si so] [;]
nb	Number of coordinates in boundary. nb = 0, no default boundary.
np	Number of data points.
mne	mne = 0, no lines are specified. mne > 0, space for *mne* extra points must be allocated in memory. *mne* must be large enough to accommodate all extra points.
[si so]	Coordinate system of input and output coordinates. Optional, if both are cartesian coordinate systems.
si	Coordinate system of coordinates in the input file. si = c, cartesian coordinate system. si = s, surveyors coordinate system.
so	Required coordinate system of coordinates in plot files, produced by applications using the triangulation. so = c, cartesian coordinate system. so = s, surveyors coordinate system.

The coordinate system used in the *.fem and *.tri files, is always cartesian coordinate systems.

Line 2	x y *repeat nb times*
x,y	(*x*,*y*) coordinate of a boundary point.

Line 3	x y *repeat np times*
x,y	(*x*,*y*) coordinate of a data point.

Lines 4,5 and 6 are only required if mne>0.

Line 4	ni ne nf
ni	Number of internal lines.
ne	Number of external lines.
nf	Number of discontinuities.

Lines 5 and 6 must be repeated for each line, that is ni+ne+nf times.

Line 5	nn nc
nn	Number of coordinates in this line (nn≥2).
nc	Minimum number of coordinates that must be chosen by the segmentation algorithm (nn≥2).

Line 6	x y *repeat nn times*
x,y	(x,y) coordinate of a point in specified lines.

2.3. OUTPUT FILES

The output files constructed under this command, are the *.tri and *.fem files.

***.tri** A plot file, giving a graphic representation of the triangulation, when plotted under the

Plotting command. It will also show the corresponding numbers of the data points, as well as the triangle numbers, shown at the centroid of each triangle. The data points can also be referred to as nodes and the triangles as elements.

***.fem** Contains the information about the triangulation, and is called the finite element output.

The format of the plot files is discussed in Section 2.3. For completeness, the format of the *.fem file is included, but is usually not needed by the user, because this file is automatically constructed by TRICON.

Data Format of *.fem

Line 1	`xmin ymin xmax ymax [si so]`
xmin,ymin	coordinates of the extreme *south-west* point.
xmax,ymax	coordinates of the extreme *north-east* point.
[si so]	Coordinate system of input and output. Optional, if both are cartesian coordinate systems.
si = c	Coordinates are always in a cartesian coordinate system.
so	Required coordinate system for coordinates in the plot files, of applications using *.fem as input file. so = c, cartesian coordinate system. so = s, surveyor coordinate system.

Line 2	`np ne nl`
np	Number of points (nodes).
ne	Number of triangles (elements).
nl	Number of specified lines.

Line 3	s_1 s_2 s ... s_i ... s_{nl} *string orientated*
s_i	Number of points selected from line **i**, 1≤i≤nl. These values define the number of extra points that must be assosiated with each line, in chronological order. $s_i < 0$ indicates that line **i** was specified as a discontinuity, and that for the corresponding set of extra points, *z*-values are unknown.

Line 4	`n x y` *repeat np times*
n	Node number.
x,y	(*x*,*y*) coordinate of node *n*.

Line 5	n n_1 n_2 n_3 m_1 m_2 m_3 zz *repeat ne times*
n	Element number.
n_1,n_2,n_3	Three nodal numbers of element *n*.
m_1	Element next to edge n_3n_1.
m_2	Element next to edge n_1n_2.
m_3	Element next to edge n_2n_3.
zz	Zone number, only if discontinuities were specified.

Line 6	n nn c1 c_2 ... c_i ... c_{nn} *repeat np times*

n	Node number.
nn	Number of nodes linked to node *n*.
c_i	Node linked to node *n*.
	$c_i = 0$, Blank node.

2.4. REACTION OF TRICON

PC version
When the mesh construction is initiated, TRICON will respond by showing a *Busy* window on the screen. The user can observe the progress of the program from the messages inside this window. If an error occurs, the *Error window* will appear in the centre of the screen, showing an error messages. Use the *Esc* key to continue.

Progress Report

The messages, indicating the progress of the program, are the following (where *n* is an integer):

- •Reading boundary points.
- •Reading data points.
- •Adding data points.
- •**n**: *x*–coordinate *y*–coordinate.

When lines were specified in the data file:

- •Reading coordinates of specified lines.
- •Line n: m coordinates.
- •Selecting points from line n (please wait).
- •Adding extra points.
- •n: x-coordinate y-coordinate.
- •n points added from line m.

When discontinuities were specified in the data file:

- •Area divided into *n* zones

When the output files are being constructed:

- •Write finite element data to file.
- •Write file to plot triangulation.

Duplicate Points

When the same coordinates are specified twice in the data file, the Busy window will give the messages:

- •**n**: *x*–coordinate -*y*–coordinate duplicate.

The *Error window* will also appear on the screen, with the message:

•Duplicate point, it will be ignored.

Execution is now delayed, until the *Esc* key is pressed. TRICON will now continue adding the rest of the data points, ignoring the duplicate point. The set of data points that was added to the triangulation is listed in the output files. After adding all data points, the *Error window* appears again with the message:

•There were n duplicate points.

Press *Esc*. The execution will now continue normally, with the writing of the two output files to disk.

SUN version
When the mesh construction is complete, the following message will appear in the message area on the main menu:

•Mesh Construction complete.

If the same coordinates are specified twice in the data file, the following error massage will indicate how many duplicate points were found and ignored:

•There were n duplicate points.

Note that the corresponding z-values in the *.LEV file are not deleted and should be checked by the user to ensure that the correct z-value corresponds with each coordinate.

3. CONTOUR COMPUTATION

3.1. THE CONTOUR COMPUTATION COMMAND

The *Contour Computation* command uses the finite element output, defining the triangulation computed for a set of data points, to follow the contour lines through the triangles. Therefore, the *Mesh Construction* command must have been executed previously for this set of data points, to generate the triangulation. Secondly, the levels associated with each of these data points must be given and the contour values for which contour lines are required must be specified.

Method

A piecewise linear representation of the contour lines is computed first. These lines are then smoothed afterwards, using a weighted least square bicubic spline approximation. The lesser smoothing is applied on these lines, the more the contour lines will follow the linear representation, giving the exact position of the contour lines, as defined by this triangulation. Triangulations other than the Delaunay triangulation, will define different positions for contour lines, but these triangulations have different properties. When too much smoothing is applied to contour lines, meandering of smoothed contour lines may occur.

Sub-menu

When the Contour Computation command is selected on the main menu, the following sub-menu will appear on the screen.

Contour Computation

Input Mesh File	:TRICON.FEM
Input Level File	:TRICON.LEV
Output Contour File	:TRICON.CON
Output Plot FIle	:TRICON.PLT
Less smoothing [0-4]	
Sharpness of bends [%]	
Mimimum line length[%]	
Line Quality	
Start Contour Computation	

Select the correct file names, change the options, if necessary, and initiate the contour computation command.

Several options are available to control the degree of smoothing. Select the set of contour lines added and specify the line quality.

Less Smoothing *Default:4*

Any integer from 0 to 4. Decreasing this value when contour lines overlap each other. The amount of knots used by the bicubic spline approximation, is increased, causing the smoothed contour lines to lie closer to the piecewise linear representation. Zero indicates no smoothing - the piecewise linear segments are output to file *.con.

Sharpness of Bends *Default:25*
Any integer between 1 and 99. To lessen the sharpness of bends, this value can be decreased. It will decrease the amount of knots used at the bends, but, in some cases, it may cause the contour lines to overlap. When contour lines cross each other at bends, this value can be increased.

Minimum Line Length *Default:0*
Any integer between 0 and 100. This option makes it possible to exclude, for aesthetic reasons, some very short contour lines from the final contour map. The minimum line length is computed as a percentage of the maximum line length. Contour lines shorter than this minimum are not added to the plot file.

Line Quality *Default:2*
Any integer from 0 to 4. This value can be increased/decreased to increase/decrease the line quality. Changing this value has a direct effect on the size of the *.con file, generated by this command.

3.2. INPUT FILES

File Contents

There are two input files required, the *.fem file, defining the triangulation, and the *.lev file, giving the levels and contour values. The *.fem file is constructed by TRICON under the Mesh Construction command.

One level must be specified for each data point. Only one level per line is required for each internal and external line specified for the region. To compute contour lines, representing the difference between two sets of levels, both levels associated with a point must be given in the *.lev file.

Data Format of File *.lev

Line 1 `nc [par] [;]`

nc Number of contour values.

[par] par = **d** or **D**. Compute contour lines, representing the difference between the given levels.
For velocity computation purposes this parameter can also take other values, as specified in Section 5.2.

Line 2 $c_1\ c_2 \ldots c_i \ldots c_{nc}$ *string orientated*

c_i Contour value of *i*th contour, $1 \leq i \leq nc$.

Line 3 `z [zz]` repeat np[+ni+ne] times

Must be repeated for each data point, and once for each internal and external line, that were specified in the triangulation.

z Level of corresponding data point.

zz Second level of the corresponding data point. Differences are computed as *zz-z*.

Line 4 [Hdng] *repeat 2 times*

Hdng Heading, maximum 80 characters per line, that will be added to the contour map. If no heading is provided, the next default heading is added to the map:
Contour lines computed by program TRICON.
Smoothing parameters: n, m.
n and m are the values used for the options *Less Smoothing* and *Sharpness of bends.*

3.3. OUTPUT FILES

Two output files are constructed, both of them are plot files. The format of the plot files is discussed in Section 4

***.con** Coordinates of the contour lines, together with the contour level, that will be used by *Plotting* to label each contour line.

***.plt** Coordinates and levels of each data point that were used to produce the contour map. *Plotting* uses this file to give a graphical representation of the position of all data points, each of them labelled with the level associated with it.

3.4. REACTION OF TRICON

PC version
When the contour computation command is initiated, TRICON will respond with the following messages in the *Busy window*:

- Reading mesh information.
- Compute contour level: **n**.
- **n** contour segments.
- Smooth segment: **n**

Errors that occur during the computation, will appear in the *Error window.*

4. PLOTTING

4.1. THE PLOTTING COMMAND

The *Plotting* command uses any file that is constructed in the prescribed format, as input file, and draws the corresponding geographical map of the region. The coordinates can be given in cartesian or surveyor coordinates. The default coordinate system is cartesian coordinates. If the alternative system is used, it must be specified, as indicated in the file format.

There are four basic types of data geographical outputs that can be drawn on the map:

- Points.
- Lines.
- Splines.
- Arrows.

Points

The position of a point is marked with a centered symbol, at the exact spot indicated by its (x,y) coordinates, and labelled with a given string.

Centered Symbol
Either Δ/+/x/◊ or no symbol.

String
Maximum 20 characters, drawn either to the right of the symbol, or above or under it. If no centered symbol is required, the string starts at the given position.

Lines

Lines connect a given set of points, specified by (*x*,*y*) coordinates, either with solid or dashed lines. Different colours can be used to draw lines on devices that allow multiple colours, and lines can be labelled.

Label
When a label is specified with the set of points, the line is interrupted at a position that is straight enough to accommodate the string. If the line is too short to contain the given string, no label is added. Leading blanks are deleted from the label. Real numbers, containing only zeros after the decimal point, are plotted as integer numbers.

Splines

A given set of coordinates is connected by a smoothed line, solid or dashed. No label is added to these lines. This facility is only available on the PC version.

Arrows

This type of output is needed to give a graphical representation of the velocity vectors, computed under the *Velocity Computation* command. The information needed to plot the vectors, is the angle, the magnitude in (*x*,*y*) coordinates and the starting point of the vector. An arrow is then plotted at this position. The length of the arrow is relative to the maximum magnitude, specified in the plot file and multiplied by the representation factor, listed in the menu for scaling options. Oblong triangles can give rise to abnormal large velocity magnitudes - too long arrows - although their directions are not influenced.

Sub-menu

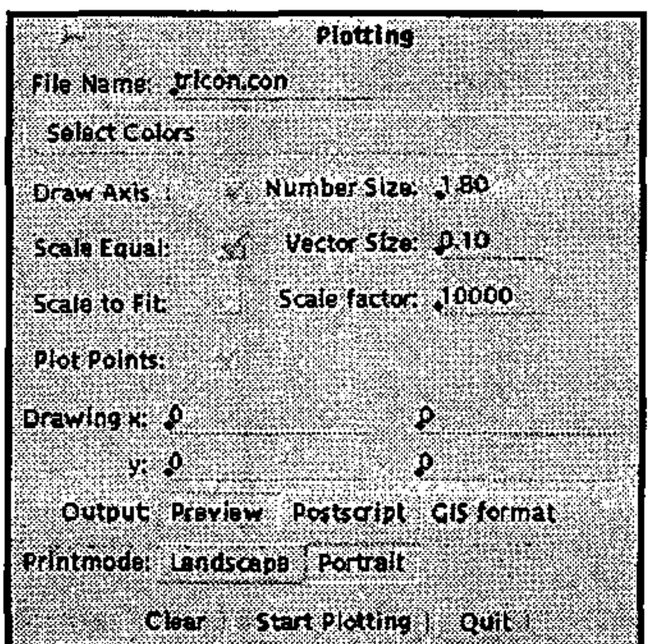
PC Version - The following sub menu will appear when *Plotting* is selected on the main menu.

Plotting

File: TRICON.CON
Select Colours
Scaling Options
Zoom Area
Output Device
Paper Size
Start Plotting

Enter the correct file name, change the options, if necessary, and initiate the plotting command. Note that the extension of this input file is not fixed. Any file name can be chosen, as long as the file contents are in the correct format.

SUN Version - The following Plotting Menu looks slightly different on a SUN workstation, although it provides for the same options. Note that when changes are made to the parameters, you should press ↵(Enter), before changes will take effect.



Several options are available to control the way the map is drawn. They will be discussed in this section.

Select Colours

Select this option to display contour lines in different colours. A table with two columns, for *Level* and *Colour*, will appear. A maximum of 16 colour specifications, for different contour values, can be given. Enter the value of the contour line and select a colour from the colour table. All lines with matching labels will be displayed in the selected colours.

For HP Plotters with a penstall for different coloured pens, the colours can be selected likewise. The penstall must be loaded with corresponding coloured pens.

Scaling Options

The following choices can be made from this menu:

- Size of Numbers
- Draw Axes
- Scale to Fit
- Scale Equally
- Scale Factor
- Arrow Size

Size of Numbers *Default:1.8*

The size is given in millimetres. It specifies the size of all numbers and text on the map.

Draw Axes *Default:Y*

Y Annotate the axis with tic marks at several intervals.

N Annotate the axis only at the extreme x and y-points. The exact minimum and maximum values, as specified in the plot file, are used as extreme boundary points.

Scale to Fit *Default:Y*

Y The drawing scale of the map is calculated to fit it into the specified paper size. On the Sun version only A4 is supported.

N The value, specified in the option *Scale factor*, is used as the scaling factor to draw the map.

Scale Equally *Default:Y*

Y The x– and y–axes are scaled equally.

N The x– and y–axes are scaled independent, to fit both axes into the specified paper size. *Scale to fit* must have value Y.

Scale Factor *Default:0*

This value can only be changed, when *Scale to fit* equals N. An Error message will indicate if this value is too small to fit the map into the specified paper size.

Arrow Size *Default:0.1*

This value indicates the display factor used for the length of the arrows, representing the velocity vectors. Increasing this value, will increase the length of the arrows.

Zoom Area

To display the map between other boundaries than the extreme x– and y–values specified in the plot file, a zoom area can be specified. The initial values shown in this menu, when this option is selected, are read from the plot file. When they are changed, the new values will be used to calculate the boundary of the map. All information specified on the map that falls outside this boundary, will be cut. No decimal points are allowed when specifying the zoom area from this menu. A zoom area can also be specified directly in the plot file, instead of the extreme x– and y–values, allowing decimals points.

Output Device

PC Version —This menu indicates the default specifications for:

- •Screen.
- •Printer.
- •Plotter.
- •HPGL File.

The active device is highlighted. Select any of them to change the default. The various choices are displayed in the accompanying tables.

Output that was directed to a HPGL file is saved in a file with a .HPL extention and can be plotted at a later stage. Use a DOS copy command to plot the contents of the file on any HP plotter or LaserJet printer supporting HPGL. To plot the file to a LaserJet printer, not supporting HPGL, use a program like Laser Plotter, developed by Insight Development Corporation, or similar.

SUN version — This version supports the following:

- •Screen Display
- •Postscript File
- •GIS Output

The active device is highlighted.

Output that was directed to GIS output is saved in two text files with a .gis and .att extention. This files are used to input map information from TRICON to GIS.

UNIX version — Only Postscript files with a .ps extension are created.

Paper Size

Only the PC version allows the selection of a paper size other than the standard A4 size. The sizes of the paper associated with the different specifications, are (width and height in millimetres):

A1	840 x 594
A2	594 x 420
A3	420 x 297
A4	297 x 210
A5	210 x 148.5

If a bigger paper size than the maximum for a printer, is specified, the print-out will be spread over several pages.

4.2. INPUT PLOT FILE

No fixed extension is required for the plot file.

Some of the data lines in this file have fixed format specifications that must be met. If the line format violates this specifications, it will produce an error.

Data Format of plot file

Line 1 | Hdng | *repeat 2 times*

Hdng Heading of the map. A maximum of 2 lines, consisting of 80 characters each, is allowed.

Line 2 | xmin ymin xmax ymax [si so [pmode]] [;] |

xmin,ymin (*x,y*) coordinates of the extreme *south-west* point.

xmax,ymax (*x,y*) coordinates of the extreme *north-east* point.

[si so] Coordinate system of input and output. Optional, if both are cartesian coordinate systems.

si Coordinate system of coordinates in the input file.
si = **c** Cartesian coordinate system.
si = **s** Surveyor coordinate system.

so Required coordinate system for coordinates in the plot files, of applications using *.fem as input file.
so = **c** Cartesian coordinate system.
so = **s** Surveyor coordinate system.

pmode This is only available on the SUN and UNIX versions. It specifies the mode in which the Postscript files are plotted. Either portrait or landscape mode are available.
pmode=**p** Portrait mode
pmode=**l** Landscape mode

Line 3 | np nl ns na |

np Number of points.

ne Number of lines.

nl Number of splines.

na Number of arrows.

Line 4 | how where string x y | *format(I1,I1,A20,F15,F15)*

how how = **0/4/5/6** Mark the point *only* with the following corresponding centered symbol: Δ/+/x/◊.
how = **1/7/8/9** Mark the point with the following corresponding centered symbol, Δ/+/x/◊ and the given string.
how = **2** Mark the point with Δ, and number it with *n* for the *n*'th point.
how = **3** Write only the string at the given position.

where where = **1/2/3** Write the string to the right, above, or under the centered symbol, respectively.

string Character string of 20 characters long.

x,y (*x,y*) coordinate of the position where the centered symbol or string must be placed.

Lines 5 and 6 must be repeated for each line, that is *nl* times.

Line 5 | label type nn | *format(A10,∇,I1,I5)*

label Line label, 10 characters long.

type Type of line connecting the points.

type = 0 Solid line in default colour.
type = 1 Dashed line in default colour.
type = 2 to 9 Solid line, using colours 1 to 8 in the colour table, for a display device, or pen number 2 to 9, for a plotter devices.

nn Number of points in the line.

Line 6 | x y | *repeat nn times*

x,y (*x*,*y*) coordinates of points.

Lines 7 and 8 must be repeated for each spline, that is ns times.

Line 7 | label type nn | *format(A10,V,I1,I5)*

label The label is ignored in this case.

type Line type, to connect the points.
type = 0 Solid line in the default colour.
type = 1 Dashed line in the default colour.

nn Number of points in the spline.

Line 8 | x y | *repeat nn times*

x,y (*x*,*y*) coordinates of points.

Line 9 | vmax | *only needed if na>0*

vmax Maximum velocity, computed as the maximum of
$\sqrt{\text{x-component}^2+\text{y-component}^2}$
for all velocity vectors.

Line 10 | angle xc yc x y | *repeat na times*

angle Angle of velocity vector in radials.

xc,yc *x* and *y* velocity components.

x,y (*x*,*y*) coordinate, starting position of the arrow.

4.3. OUTPUT

The output device that was chosen, must be connected and ready to plot.

4.4. REACTION OF TRICON

PC version
The name of the plot file will appear in the *Busy* window, when plotting is initiated. When the output is displayed on the screen, you must press ↵ to continue.

When the data in the plot file violate the format specification, one of the following messages will appear in the *Error window*, followed by an indication where the error occurred:

- •Data format error in Input File.
- •End of file reached in Input File.

5. VELOCITY COMPUTATION

5.1. THE VELOCITY COMPUTATION COMMAND

The *Velocity Computation* command uses the finite element output, defining the triangulation computed for a set of data points, to compute the fluid velocity for each triangle. Therefore, the *Mesh Construction* command must have been executed previously for this set of data points to generate the triangulation. Secondly, the levels associated with each of these data points, must be given, and values for porosity and conductivity for the region are required.

Method

The program defines a linear interpolation over each triangle; that is a plane surface is fitted through the three z-values, defined at the corners of the triangle. The gradient of this surface then gives an approximation to the actual z-gradient within each triangle. Given values of porosity and conductivity, the fluid velocities can now be computed from Darcy's law.

If the values for porosity and conductivity are entered from the screen, they must apply to the whole region. These values are then applied to all triangles. If different values apply to each data point, they can be specified together with the level associated with each data point.

Note that triangles which are elongated or quite thin, may influence the magnitude of the velocity vectors, although their directions are not influenced.

Sub-menu

When the Velocity Computation command is selected on the main menu, the following sub-menu will appear on the screen:

Velocity Computation

Input Mesh File	:TRICON.FEM
Input Level File	:TRICON.LEV
Output Plot File	:TRICON.PLT
Output List File	:TRICON.LST
Porosity	: 0.10
Conductivity Kxx	: 1.0
Conductivity Kyy	: 1.0
Line Quality	: 0.0
Start Velocity Computation	

Enter the correct file, change the options, if necessary, and initiate the velocity computation command.

Options

Values for porosity and conductivity are specified here.

Porosity *Default:0.1*

Any real number between 0 and 1.

Conductivity
Kxx *Default:1.0*
Kyy *Default:1.0*
Kxy, Kyx *Default:0.0*
Any positive real number. The conductivity values, Kxx, Kyy, Kxy and Kyx correspond to the usual values in the conductivity matrix

$$\begin{pmatrix} Kxx & Kxy \\ Kyx & Kyy \end{pmatrix}$$

5.2. INPUT FILES

There are two input files required, the *.fem file, defining the triangulation, and the *.lev file, specifying the levels of each data point.

The *.fem file is constructed by TRICON under the *Mesh Construction* command.

Data Format of File *.lev

The data format of file *.lev, as specified in Section 3.2, can be left unchanged, if also used to compute contours. The contour values specified are ignored by this command. If no contour values are given, specify a zero for the number of contour values in line 1.

To enter different conductivity and porosity values for each data point, the following line format must be used:

Line 1 `nc [par] [;]`
nc Number of contour values. This value can be zero in this case.
[par] par = k or K Indicates that a conductivity value is specified for each data point. This value will be associated with both *Kxx* and *Kyy*.
par = v or V Indicates that a porosity- and two conductivity values, for *Kxx* and *Kyy*, are specified for each data point.

Line 2 must be added only if nc > 0

Line 2 $c_1\ c_2 \ldots c_i \ldots c_{nc}$ *string orientated*
c_i Contour value of the *i*'th contour, $1 \leq i \leq nc$.

Line 3 must be repeated for each data point and once for each internal and external line, specified in the triangulation.

Line 3 `z [p] [kx] [ky]` *repeat np[+ni+ne] times*
z Level of corresponding data point.
Porosity associated with the corresponding data point. Only if par = v.
[kx] Conductivity value, *Kxx*, for this data point, if par = k or v.
[ky] Conductivity value, *Kyy*, for this data point, if par = v.

Line 4 Heading, see Section 2.2.1.

5.3. OUTPUT FILES

Two output files are constructed, the *.plt and *.lst files.

***.plt** A plot file, containing the information needed by *Plotting*, to draw the velocity vectors at the centroid of each triangle. The default heading, added to this map, can be changed before plotting this file. The heading is:
Plot of velocity vectors computed by TRICON.
Porosity n Conductivity (Kxx, Kyy, Kxy, Kyx).

*.lst A list of information computed under this command. It states the values for porosity and conductivity, used to compute the values. Then, there are five columns, giving the element number, the magnitude, the (*x*,*y*)-components and the angle of the velocity vectors, for each element in the triangulation. The magnitude is computed as $\sqrt{\text{x-component}^2+\text{y-component}^2}$

5.4. REACTION OF TRICON

PC version
When the velocity computation is initiated, TRICON will respond with the following messages in the *Busy window*:

- Reading mesh information.
- Compute velocities: element n.

Errors that occur during the computation will appear in the *Error window*.

6. INTERPOLATION

6.1. THE INTERPOLATION COMMAND

The triangulation, computed for a set of data points, can also be used to estimate z-values for any given point, like nodes on a predefined grid. The *Mesh Construction* command must be executed previously for this set of data points to generate the triangulation. Secondly, the levels associated with each of these data points, and the coordinates of the grid points must be given.

Method

For each grid point, the program searches the triangle containing this point. The z-values of the data points defining this triangle, as well as the slope of the surrounding triangles, are then used to compute the estimates. The user can choose between two methods of interpolation, either linear or gradient interpolation.

With linear interpolation, the value is simply estimated from the plane surface passing through the three defining points of the triangle. With gradient interpolation, an inverse distance weighted method is applied to the gradient planes, formed from the vector sums of cross products of the set of triangles surrounding each point. Gradients obtained in this manner reflect the aggregate effect of both the slope and the size of all the triangles, surrounding any data point. Both methods give good quality estimates.

For grid points lying outside the triangulation, gradient interpolation is used, based on the slope of the nearest triangle and the surrounding ones. However, the quality of these values cannot be guaranteed.

Sub-menu

When the Interpolation command is selected on the main menu, the following sub-menu will appear on the screen:

Interpolation

Input Mesh File	:TRICON.FEM
Input Level File	:TRICON.LEV
Output Grid File	:TRICON.GRD
Output List File	:TRICON.PLT
Linear / Gradient [L/G]	:L
Start Interpolation	

Enter the correct file names, change the options, if necessary, and initiate the interpolation command.

Options

The interpolation method must be chosen here.

Linear/Gradient Interpolation *Default: L*

L Linear interpolation.
G Inverse Distance Gradient interpolation.

6.2. INPUT FILES

File Contents

Three input files are required, the *.fem file, defining the triangulation, the *.lev file, specifying the levels of each data point, and the *.grd file, containing the coordinates of the grid points.

The *.fem file is constructed by TRICON under the *Mesh Construction* command.

The data format of the *.lev file is specified in Section 3.2 Specify a zero for the number of contour values, or leave it unchanged, if it is also used to compute contour lines. If contour values are specified, they are ignored. For each data point, one level must be given. For each internal and external line specified for the region, only one level per line is required.

The *.grd file must list the coordinates of all the grid points for which values must be estimated.

Data Format of file *.grd

Line 1	ng
ng	Number of grid points.
Line 2	x y *repeat ng times*
x,y	(*x,y*) coordinates of grid point.

6.3. OUTPUT FILES

Only one output file is constructed, the *.lst file.

*.lst A list of the (*x,y*)-coordinates of the grid points and estimates computed by TRICON.

6.4. REACTION OF TRICON

PC version
When the interpolation is initiated, TRICON will respond with the following messages in the *Busy window*:

- •Reading mesh information.
- •Compute the gradient for each data point.
- •Linear/Gradient interpolation: element n.

Errors that occur during the computation will appear in the *Error window*.

7. CHANGE MESH

7.1. THE CHANGE MESH COMMAND

The triangulation, computed by TRICON, can be slightly changed to obtain a different set of boundary elements, by deleting some of the boundary elements. Inner elements can also be deleted to obtain a triangulation that excludes a certain area within the region.

The triangulation must first be created by the *Mesh Construction* command and the numbers of the triangles that have to be deleted, must be known. To get these element numbers, plot the *.tri file to get a graphic representation of the triangulation, and determine the triangle numbers of the redundant elements.

Method

Elements are deleted, by changing the information in the *.fem file, containing the finite element output created by the mesh construction command. The element map - list of elements next to the three edges of an element - of the surrounding elements is changed, by making all references to the deleted element zero, indicating a boundary element. Element numbers, of elements following the deleted element, are updated, as are all references to these elements. The set of data points always stays the same.

Note that all elements and data points are numbered, starting at 1. A graphic representation of the altered triangulation can be made, because the *.tri file is also altered.

Sub-menu

When the Change Mesh command is selected on the main menu, the following sub-menu will appear on the screen:

Change Mesh
Input Mesh File: TRICON.FEM
Select Elements
Start Changing Mesh

Enter the correct file name, enter the element numbers and initiate the change mesh command.

Options

Select Elements
Enter all element (triangle) numbers that must be deleted. To indicate a range of elements, enter only the first element number multiplied by -1, followed by the last element number in the range. For example, to delete all elements from 12 to 18, enter -12 and 18. There is no restriction on the number of elements that may be deleted, but the maximum number of elements that may be listed here are 64.

A complete range of boundary points or a window surrounding all the data points can also be specified. TRICON will then select all elements outside this boundary and use them as the list of selected elements. To accomplish this, leave the list of selected elements empty and add the list of boundary points or window coordinates at the end of file *.fem. The boundary points or window coordinates must be listed in order, counterclockwise around the region. When *Change Mesh* are initiated with an empty list of selected elements, TRICON will automatically try to read the list from the *.fem file. There is no restriction on the number of points in this list.

7.2. INPUT FILE

The *.fem file, constructed by TRICON under the *Mesh Construction* command, is the only input file. To specify a complete list of boundary points, add the following two lines:

Line 7 [-]nb

nb Number of boundary points or window coordinates. A *minus sign* must be used to indicate that window coordinates are specified.

Line 8 $b_1\ b_2 \ldots b_i \ldots b_{nb}$ *string orientated*

b_i *i*'th boundary point/window coordinate, $1 \le i \le nb$, out of the complete list of boundary points/window coordinates, listed counterclockwise around the region.

7.3. OUTPUT FILE

The *.fem file, containing the finite element output of the initial triangulation, is used to store the finite element output of the new triangulation. The *.tri file is updated to show the new triangulation. No other output files are created.

7.4. REACTION OF TRICON

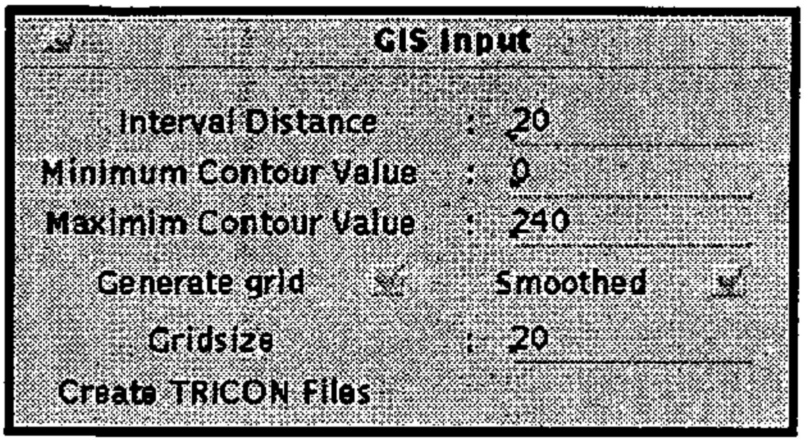
When *Change Mesh* is initiated, TRICON will respond with the following messages in the *Busy window*:

- Reading mesh information.
- Selecting elements to be deleted.
- Changing mesh.
- Writing mesh information to file.

Errors that occur during the computation will appear in the *Error window*.

8. GIS INPUT

The GIS input command is only available on the the SUN version of TRICON. This command must be executed if information were exported from GGIS. It creates the *.dat and *.lev files from the (x,y,z) information, provided by GGIS, on each data point.



Options

Interval Distance, Minimum Contour value, Maximum Contou r value
These values are used to determine the which contours must be drawn on the map. It is written on the top of the *.lev file.

Generate grid
When this option is selected, a grid is generated over the data points, and z-values are estimated from the values given by GGIS. Although this is the default option, the user should be aware that the surface is now smoothed and may therefore not be an exact representation of the data given, although it may be aesthetically more acceptable. Should a exact contour map be required, this option should be unmarked.

Smoothed
This option only have an affect a grid must be generated. If Smoothed is marked, the estimation of grid values is done by using Gradient interpolation, otherwise Linear interpolation is used. A description of the interpolation methods that are used is given in Section 6.1: **The Interpolation Command.**

Grid size *20*
This value indicates the size of the grid that will be generated. The default size is 20x20, which means 20 intervals in the x and y directions.

9. SAVE CONFIGURATION

All file names and options that were altered, while running TRICON, can be saved in the configuration file, by using this command. Use this command if your screen or printer set-up differs from the default configuration, or if you repeatedly use the same set of options. TRICON will then be initiated with the options stored in the configuration file, TRICON.cnf, when loaded.

10. RESTRICTIONS

Memory

The amount of random access memory available on your computer is the only factor restricting the size of data sets that can be handled by TRICON. The executable file, TRICON.exe (PC version) or TRICON (SUN/UNIX version), does only reserve memory for program instructions. All memory needed for storing data is allocated at run time. If there is not enough memory available for a certain data set, after loading TRICON, the following error message occurs on the screen:

•Insufficient memory for ...
This message gives an indication of the data set that could not be loaded.

There are several steps that can be taken to side-step the problem on a PC, if memory becomes insufficient during the execution of TRICON.

•Exit and reload: If several commands have been executed prior to the last command giving the memory error, exit and reload TRICON and execute the last command again. This may make more memory available for executing the last command.

•Change contouring options: More memory is needed by contour lines when the line quality is increased or less smoothing is specified. By using more smoothing or decreasing the line quality, the memory requirements are decreased.

•Load TRIBIG: The executable file, TRIBIG.exe (only with the PC version), is smaller than TRICON.exe, leaving more memory for data allocation. TRIBIG can be used for executing all the TRICON commands, except the *Plotting* command. To plot files, exit TRIBIG and load TRICON again.

Path Names

No path names can be specified for TRICON input and output files. The current directory must always contain these files. Therefore, when loading TRICON from another directory than the TRICON directory, just specifying the full path name:

e.g. \path\TRICON

11. IF THINGS GO WRONG

11.1. INTRODUCTION

Error messages will appear in an *Error window* when incorrect data values in input files cause errors during the execution of TRICON. Program execution is then delayed until *Esc* is pressed. This will initiate one of two possible actions: If the error that occurred is fatal, program execution will return to the main menu. Errors that are not fatal can be regarded as warnings, and the program execution will continue normally.

If data format errors could not be trapped upon reading the input files, they may cause unexpected errors. In this case, a message will appear in the top line of the screen. The program will *Exit* directly upon pressing *Esc*, without clearing the screen. When this happens, check your input files thoroughly and make sure that the correct file names were specified. In some rare cases, it may be necessary to *re-boot* your machine (*Ctrl+Alt+Del*). If you are still unsuccessful in running TRICON with the specified files, save the files and report the error.

11.2. ERROR MESSAGES

Abnormal Exit from smoothing routine;
Change smoothing parameter.
Unexpected values in the linear contour segment caused an error during smoothing. Check your input files, or change the smoothing parameter.

Arithmetic Problem caused by lack of accuracy;
Output files may be incorrect.
The specified discontinuity caused an arithmetic error, due to lack of accuracy caused by computer limitations, while adding the crossing points to the triangulation. Try to redefine the discontinuity.

Cannot delete more then 256 elements.
A maximum of 256 elements can be deleted by *Change Mesh*.

Can't open HPGL File.
A DOS error occurred during opening of the HPGL file.

Can't open temporary File: *file name*.
A DOS error occurred during opening of the temporary file. Try again or exit and reload the program.

Data Format Error in Input File.
The program failed to read the required data values from the input file. Check your input file format.

Disk full.
There is no more disc space left for writing the output files *.fem or *.con.

Discontinuity segments not properly allocated to zones, caused by too few data points

around the discontinuity.
Problems may arise when searching element zones.
Too few data points can prevent the program from properly incorporating discontinuities. Execution will continue normally upon pressing Esc.

Duplicate point; it will be ignored.
A *warning* to make the user aware of a duplicate point in the input file. Execution will continue normally upon pressing **Esc**.

End of File reached in Input File.
TRICON failed to read the needed data values from the input file because the end of the file was reached.

Warning: Too few data points around discontinuity.
Contour line may be inconsistant.
There are to few data points in the vicinity of the discontinuity, causing conflicts in the zone numbers associated with elements. The program will continue normally, but some contours may cross the discontinuity. If possible, add some data points to the set, or try to simplify the form of the discontinuity.

Insufficient memory ...
Insufficient memory available for dynamic memory allocation. Try to *Exit* and reload the program or load TRIBIG to execute the command.

Minimum exceeds maximum *x* or *y* value.
The minimum *x/y* value, specified in the plot file, exceeds the maximum x/y value.

mne too small; Increase maximum number of extra points.
The total number of extra points chosen from all the specified lines exceeds *mne*, specified in the first line of the *.dat file.

There were n duplicate points.
A *warning* to inform the user about the total number of duplicate points. Data points cannot be added twice to the triangulation. Therefore, if duplicate points are present in the data set, the final number of data points added to the triangulation will be less than *np*, specified in *.dat.

Boundary must be strictly convex and listed counter clockwise around the data points.
The polygon formed by the boundary coordinates must include all data points, it must be strictly convex and the set of boundary coordinates may not include any of the data points.

Problem finding element zone, caused by too few data points around the discontinuity. Output will be incorrect.
Too few data points prevented the program from properly incorporating discontinuities.
Execution will continue normally upon pressing *Esc*.

Scaling factor too small; Increase paper size.
The map, displayed in the specified scale, does not fit onto the chosen paper size. Increase the paper size or the scaling factor. If the paper size exceeds the maximum for the printer or

plotter, it will cover more than one page.

Stack too small to find elements.

Boundary elements are followed and stacked until an element containing internal points is reached, or no more adjacent elements lying outside the boundary can be found. The maximum stack size is 64. The change of a stack growing beyond this limit is very unlikely.

Too many knots; Use less smoothing.

The number of knots are more than the maximum allowed for, with respect to the number of points in the line to be smoothed. Increase the smoothing parameter.

Zone division failed - Try to swap the order of discontinuities added

Points added from discontinuities must be connected through triangles. This chain were broken when adding the next discontinuity. Swapping the discontinuities may eliminate the problem.

12. EXAMPLES

Each example in this Section includes a brief description, input file listings, additional input and the output drawings.

All drawings were created using a PC-AT micro computer with 640K bytes memory and a numeric 8087 coprocessor, running DOS 5.0, with output to a LaserJet printer.

The data files and output plot files are provided on the *Tricon Examples* disk.

12.1. EXAMPLE 1

A water level contour map, for a region where the presence of two known discontinuities - dykes - influence the water levels across the dykes, are drawn. The water levels at 80 data points, as well as the position of the dykes, are given in the input files DEMO1.DAT and DEMO1.LEV.

DEMO1.MAP is the final plot file used to produce the map in Figure 1. It is a combination of the output files DEMO1.PLT and DEMO1.CON, computed by TRICON. The specifications for labelling points were slightly changed to prevent labels plotted on top of each other, and the specified position of the discontinuities were also added. The altering of these files can be done by using any suitable *text editor*.

The triangulation computed by TRICON, using file DEMO1.DAT, was changed, using the *Change Mesh command* to delete elements 25, 26 and 27. Those elements were oblong boundary triangles having a negative effect on the contours in that region, as can be seen by plotting the output file DEMO1.TRI and DEMO1.CON.

Figure 2 was produced by plotting file DEMO1.MAP, specifying a *zoom area* between 50000 and 55000 for the latitude and between -24000 and -18000 for the longitude. The input coordinates are specified in cartesian coordinates and the output was specified to be in surveyor coordinates.

Input: Figure 1 and 2

Input listing of file DEMO1.DAT:

```
0 80 100
        46788.2100    -16459.6300
        48612.8600    -17355.7600
        48688.5800    -17771.7100
```

(Only 3 data point coordinates are listed here. See the TRICON example disk for a complete list of all 80 coordinates).

```
0 0 2
5       2
        51806.3780    -22608.8120
        52193.9375    -23239.7813
        53089.8872    -24676.3125
        53863.6636    -25995.1250
        54555.5767    -27344.3438
22      2
```

49400.9810	-24962.2813
50050.5288	-23933.7813
50477.6694	-23212.9688
50880.9458	-22584.3125
51037.6694	-22364.4688
51146.7666	-22230.0625
51236.9624	-22125.0000
51325.7515	-22064.8438
51399.5718	-22004.2188
51427.0786	-21987.1250
51525.2402	-21723.4688
51918.1040	-21427.1250
52164.5464	-21213.0938
52354.1079	-20997.2813
52565.6650	-20653.3125
52343.0700	-20218.4688
53140.9238	-19700.4063
53636.4683	-18804.9375
54207.6157	-17791.9688
54536.2275	-17250.8750
54987.3184	-16530.8125
55364.0181	-15985.2188

Input listing of file DEMO1.LEV:
15
1430 1435 1440 1445 1450 1455 1460 1465 1470 1475 1480 1485 1490 1495 1500
1499.3500
1477.5500
1479.6600
(Only 3 levels from the set of 80 levels are listed here. See the TRICON example disk for a complete list of all 80 levels).
Water level contours for a region influenced by
the specified discontinuities.

Output: Example 1

Output listing of file DEMO1.MAP - Only lines 1 to 10 and lines 85 to 152 are listed to demonstrate the composition of this file. Plot files are automatically constructed by TRICON:
Watel-level contours for a region influenced by
the specified discontinuities.
46788.210000 -27344.343800 59110.950000 -12637.470000 c s
80 38 0 0

11 1499	46788.2100	-16459.6300
11 1477	48612.8600	-17355.7600
11 1479	48688.5800	-17771.7100
11 1464	55163.2000	-15558.5500
11 1501	55262.8200	-13086.7200
11 1497	57666.3300	-12637.4700

Lines 85 to 152, specifying some of the lines to be plotted:

5	5
51806.3780	-22608.8120
52193.9375	-23239.7813
53089.8872	-24676.3125
53863.6636	-25995.1250
54555.5767	-27344.3438

5	22
49400.9810	-24962.2813

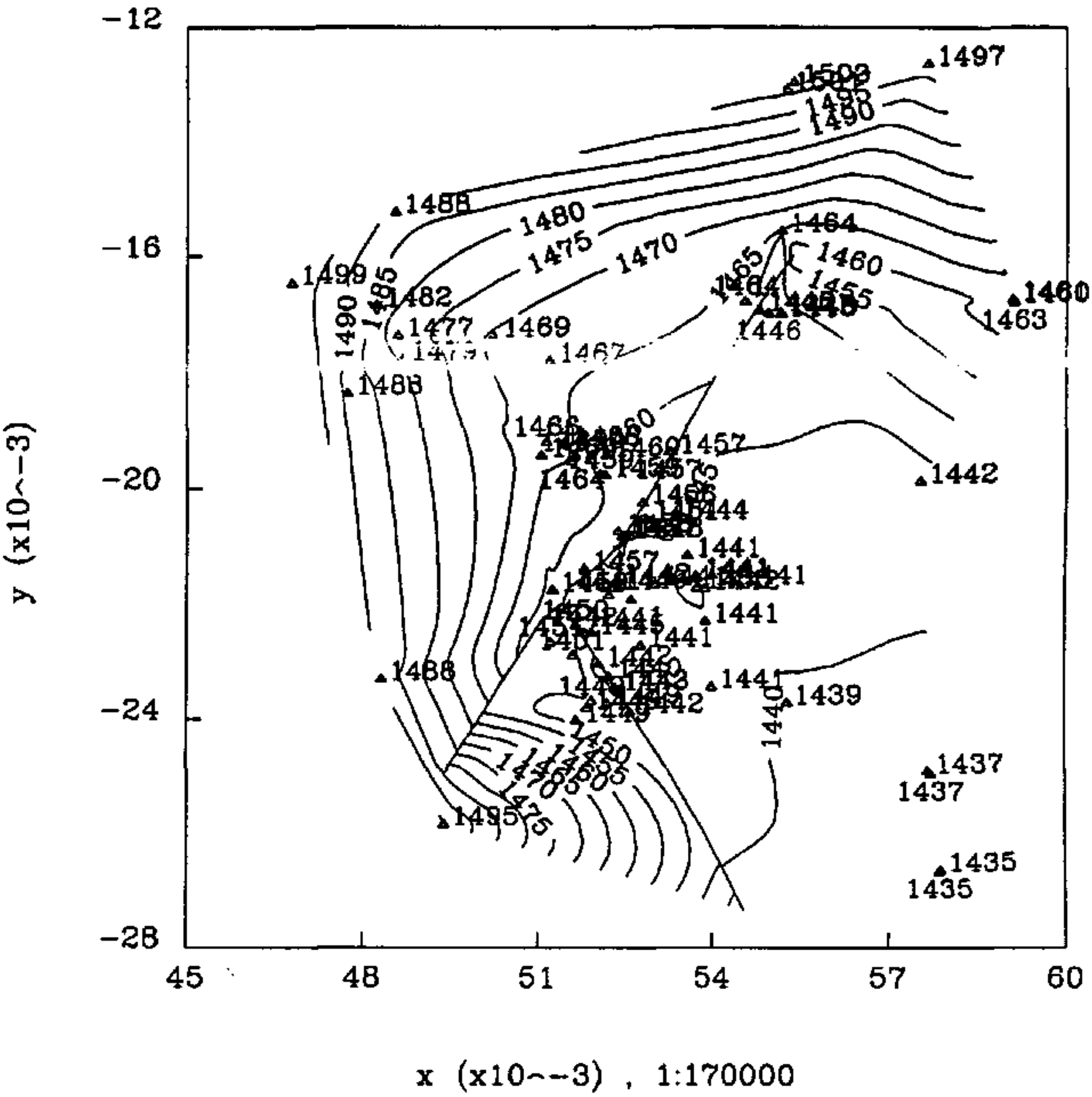


Figure 1: Water level contours for a region influenced by the specified discontinuities.

50050.5288	-23933.7813
50477.6694	-23212.9688
50880.9458	-22584.3125
51037.6694	-22364.4688
51146.7666	-22230.0625
51236.9624	-22125.0000
51325.7515	-22064.8438
51399.5718	-22004.2188
51427.0786	-21987.1250
51525.2402	-21723.4688
51918.1040	-21427.1250
52164.5464	-21213.0938
52354.1079	-20997.2813
52565.6650	-20653.3125

	52843.0000	-20218.4688
	53140.9238	-19700.4063
	53636.4683	-18804.9375
	54207.6157	-17791.9688
	54536.2275	-17250.8750
	54987.3184	-16530.8125
	55364.0181	-15985.2188
1440.00	0	37
	57650.1303	-22469.1613
	57638.1494	-22470.3223
	57626.1872	-22471.5850
	57614.2434	-22472.9482
	57602.3177	-22474.4108
	57097.4778	-22616.5227

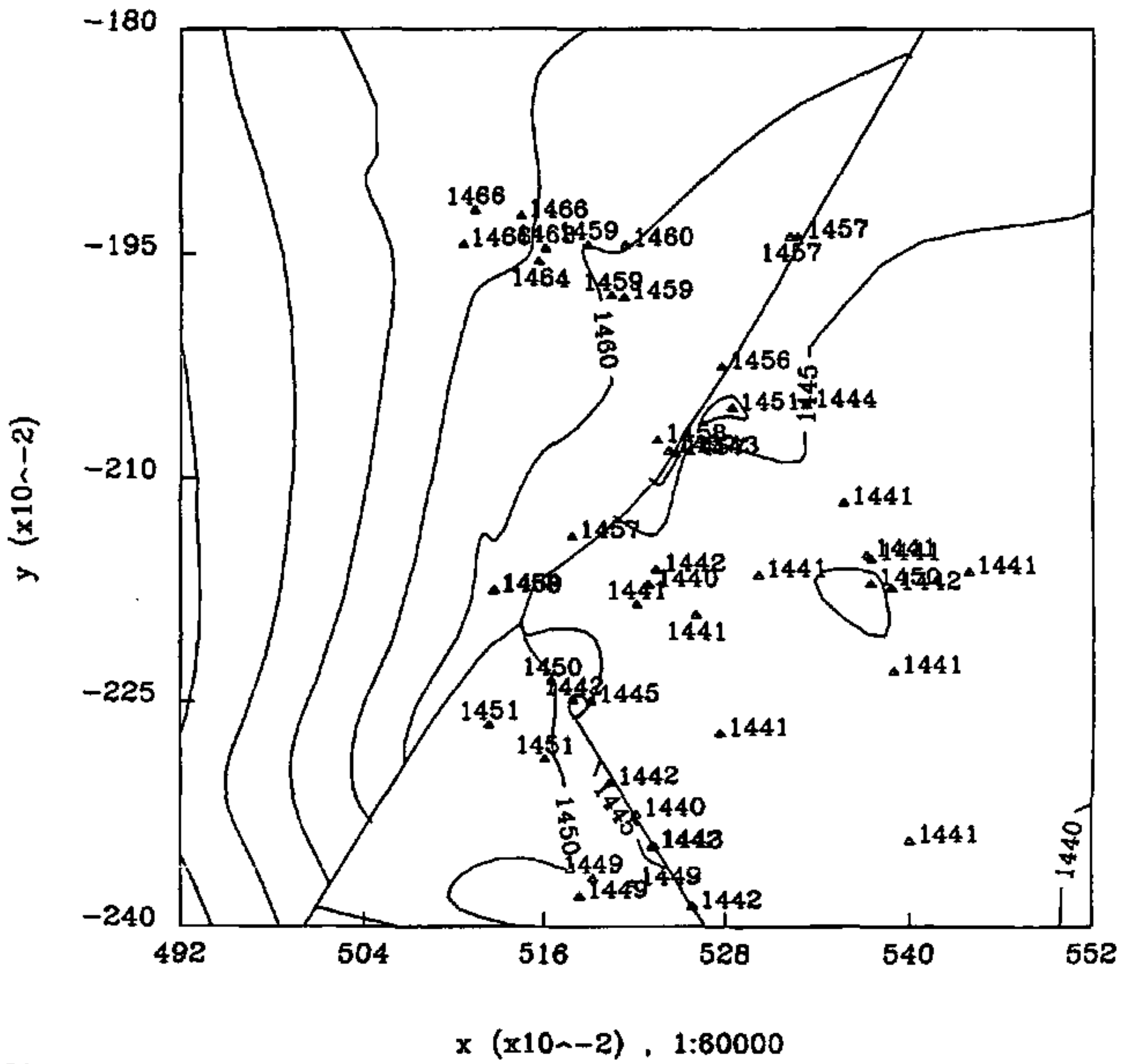


Figure 2: A part of the contour map in Figure 1, using the Zoom facility provided by TRICON.

12.2. EXAMPLE 2

A contour map for the recharge in the water levels for the area around an infiltration pan was computed here. The values of the recharge at each data point are also plotted on the same map. The water levels on two different dates at 30 data points, as well as the water levels of the pan and the digitized outline of the pan, were given in the input files DEMO2.DAT and DEMO2.LEV. Also specified in this input file, although not necessary, is a boundary consisting of four coordinates, listed counter-clockwise around the region.

DEMO2.MAP is the final plot file used to produce the map in Figure 3. It is a combination of the output files DEMO2.PLT and DEMO2.CON, computed by TRICON. The outline of the lake was also added.

Figure 4 was computed by TRICON, specifying the second set of levels as water levels to compute the water level contours and the velocity components, using a display factor of 0.03 for plotting the arrows. Default coordinate systems were used to draw the maps. The output is in DEMO2.VEL on your TRICON example disk.

Input: Example 2

Input listing of file DEMO2.DAT:

```
4      30      100
-52000.0       -23800.0
-50600.0       -23800.0
-50600.0       -21000.0
-52000.0       -21000.0
        -51575.612    -22594.437
        -51652.226    -22710.082
        -51377.788    -22707.091
        -51409.044    -22743.598
        -51824.634    -22827.897
        -51960.325    -22502.269
        -51504.933    -22112.718
        -51400.199    -21561.068
        -51795.520    -22371.980
        -51344.970    -22083.330
        -51087.130    -21670.250
        -50886.700    -21845.990
        -50836.460    -21950.870
        -50808.930    -21908.100
        -50871.330    -22446.280
        -50837.980    -22484.910
        -50810.590    -22558.030
        -51036.010    -22853.330
        -50953.830    -22996.820
        -51255.391    -23314.448
        -51432.430    -22573.960
        -51435.350    -22593.950
        -51519.060    -22457.540
        -51405.470    -22846.080
        -51732.564    -22549.511
        -51900.900    -22633.830
        -51059.260    -21726.520
        -50643.830    -22098.770
        -51351.720    -22577.610
```

```
        -51556.490      -22447.050
1 0 0
        195    2
        -50865.6300     -22126.8800
        -50858.6700     -22099.8100
        -50844.7300     -22062.7500
```

(Only 3 lines of this set of 195 digitized coordinates of the outline of the pan are listed here. See the TRICON example disk for the complete list).

Input listing of file DEMO2.LEV:

```
5 d ;   Water levels on 23-03-87 and 13-08-87.
0.0 0.5 1.0 1.5 2.0
        52.94   54.16
        51.57   52.03
        54.96   55.26
        53.98   54.79
        48.98   49.15
        49.26   49.51
        53.74   54.87
        53.33   53.16
        51.32   51.82
        55.08   57.02
        55.46   55.84
        57.71   58.27
        58.04   58.62
        58.11   58.21
        56.96   57.96
        56.84   57.50
        56.62   57.14
        55.42   55.90
        55.21   55.44
        53.69   53.37
        54.26   56.67
        54.15   56.20
        53.72   55.92
        53.72   54.18
        51.27   52.14
        49.18   49.52
        55.87   57.33
        58.26   58.27
        54.90   56.95
        52.81   54.10
        57.15   59.01
Recharge contours for a region around an infiltration pan.
Porosity 0,18; Conductivity (8,6;8,6;0,0;0,0).
```

To compute the water level contours and velocity components for the first set of levels, replace the first two lines of DEMO2.LEV with:

```
9  :   Water levels on 23-03-87.
50 51 52 53 54 55 56 57 58
```

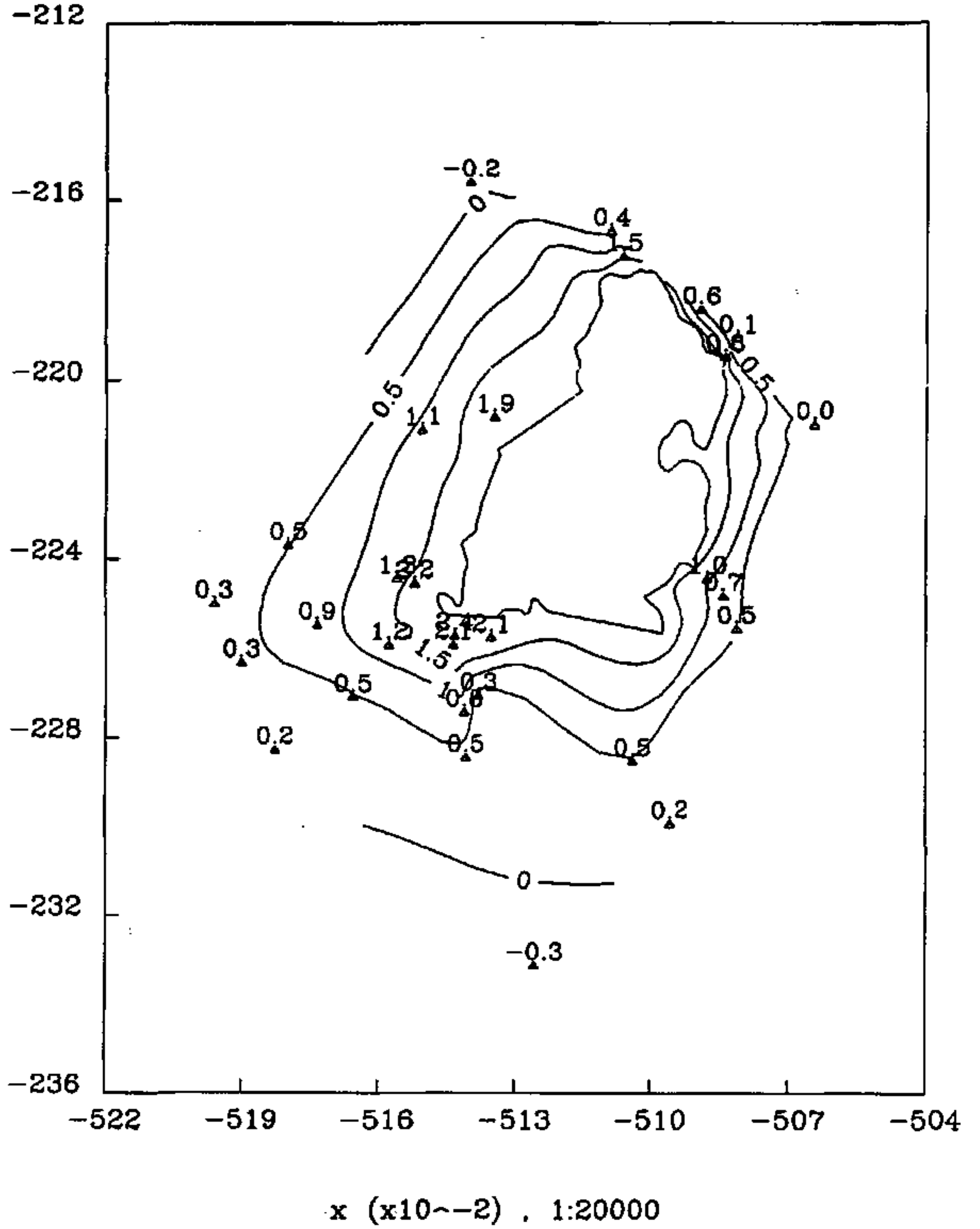


Figure 3: Recharge contours around the specified pan, for two given sets of water levels

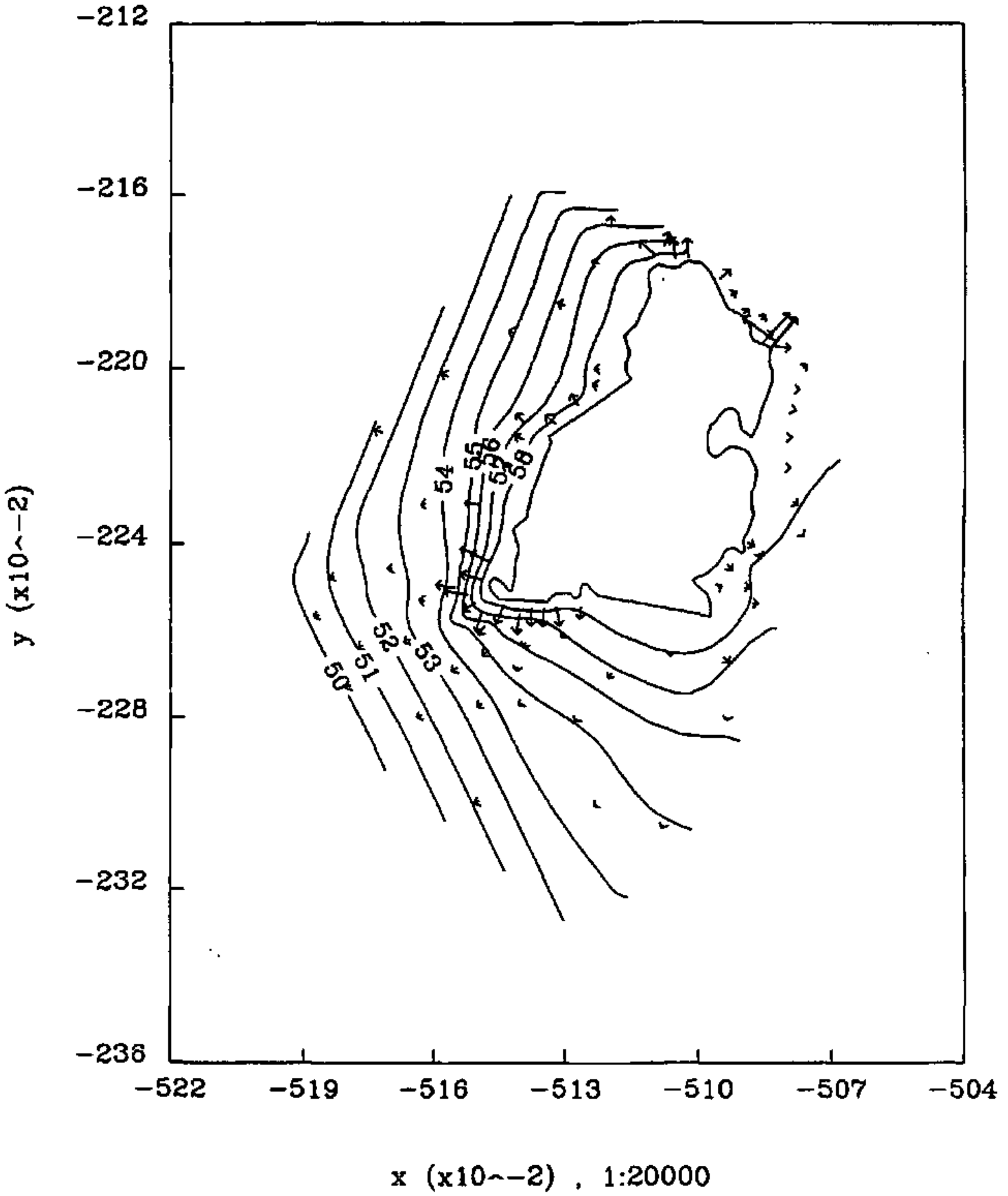


Figure 4: Water level contours and velocity vectors around the pan (Porosity 0,18; Conductivity 8,6;8,6;0;0)

13. COMPUTER CONFIGURATION

PC version

- IBM PC/XT, PC/AT, PS/2 compatible.
- MS-DOS/PC-DOS Operating System.
- 512Kb Memory
- CGA, EGA, VGA and Herculus Graphics display devices and compatible.
- Diskette Drive
- Serial/Parallel port for Graphic output.
- Hard Disk required
- Numeric Coprocessor recommended

SUN version

- SUN Sparc staion
- SUN OS 4.1.1
- OPEN WINDOWS 3.0

UNIX version

- Any machine that runs under the UNIX operating system

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Appendix B

User Documentation

TRIPOL

by

J. Buys
and
G.J. van Tonder

Institute for Groundwater Studies
University of the Orange Free State
Bloemfontein

TRIPOL was developed by the Institute for Groundwater Studies with funds provided by the Water Research Commission. It can be obtained free of charge by any bona fide research organization. In all other instances, contact the IGS for conditions under which this program may be used.

Should you have any suggestions to help us better meet your needs, we will welcome them. Please write to us directly at

Institute for Groundwater Studies,
P.O. Box 339
Bloemfontein
9300
South-Africa,

or call (27) - 51 - 4012840 or fax (27) - 51 - 473541.

Thank you for using TRIPOL. We hope you enjoy it.

J Buys and G J van Tonder
Institute for Groundwater Studies,
Bloemfontein.

Acknowledgements

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The Water Research Commission, for the financial support given.

The Institute for Groundwater Studies, in particular:
The Director, Prof. F.D.I. Hodgson, for his encouragement during the development;
Prof. J.F. Botha for the opportunity to develop the program;
Mr. S. Staats for his valuable assistance in writing the user documentation.

Preface

TRIPOL is an interpolation program that estimates values for random variables from a given set of regionalized variables, that is variables distributed in space (and/or time). Variables encountered in environmental sciences such as geohydrology, geology, weather forecasts etc., are all regionalized variables.

TRIPOL includes the following:
•Computation of a semi-variogram for a given set of regionalized variables (data points);
•Fit a mathematical function to the Semi-variogram;
•Estimate values for any set of random variables from the given set of data points.

TRIPOL implements three interpolation methods, namely:

•Distance Weighting;
•Kriging;
•Bayesian Estimates.

The interpolation procedures do not only yield an estimate of the random variable, but also the error in the estimate.

The Distance Weighting method is a classical method that is based on the assumption that the variable of interest can be represented by a smooth function, and its use is therefore limited.

The Kriging method describes the spatial variability of environmental variables by representing them with random functions. This approach has the advantage that it allows one to describe an environmental variable in statistical terms, through the Theory of Regional Variables. The best known estimation method, based on this approach, is Ordinary Kriging, or *Kriging* as it is conventionally known, and Universal Kriging.

The Bayes method is a versatile estimation procedure for estimation of groundwater levels. The method has the advantage that one can use any expert knowledge about a given regionalized variable as a qualified guess. For example, the qualified guess for groundwater is the topography. Furthermore, the guess near a production field, for example, could be reduced relative to the water levels further afield. However, difficulties can be experienced to derive a suitable qualified guess for some regionalized variable. It is therefore recommended that this method is used, whenever the user can establish a suitable qualified guess, otherwise it may be better to use Kriging.

Because of the nature of Kriging and Bayesian Kriging, a semi-variogram, computed from the regionalized variables or data points, is needed to estimate the manner in which the mean values of the phenomena behave over the region, often referred to as the *drift* or *trend* of the regionalized variable. The computation of a semi-variograms for a given set of regionalized variables (data points), was therefore also built into the program, as well as a facility to fit a mathematical function to the semi-variogram,

Drawings created by TRIPOL can be sent to the screen, a Laser Jet printer, a Postscript file or a Hewlett-Packart Graphics Language (HPGL) file to be printed or imported by any program that can handle files in HPGL.

G.J. van Tonder and J. Buys.

Table of Contents

1. MATHEMATICAL BACKGROUND

1.1. INTRODUCTION

Environmental phenomena (e.g. rainfall and the occurrence of groundwater) cover such vast areas, that it is not always possible to measure their associated variables at all relevant points in space and time. *Interpolation* is a method to obtain values for these variables at points where no measurements were taken.

TRIPOL is an interpolation program that estimates values for random variables from a given set of regionalized variables, i.e. variables distributed in space (and/or time). Variables encountered in environmental sciences such as geohydrology, geology, weather forecasts etc., are all regionalized variables.

TRIPOL includes the following:

- Computation of a semi-variogram for a given set of regionalized variables (data points);
- Fitting of a mathematical function to the semi-variogram;
- Estimation of values for any set of random variables from the given set of data points.

TRIPOL implements three interpolation methods, namely:

- Distance Weighting;
- Kriging;
- Bayesian Estimates.

The interpolation procedures, Kriging and Bayes, do not only yield an estimate of the random variable, but also the error in the estimate.

1.2. NOTATIONS

Regionalized variables are variables distributed in space (and/or time). Mathematically, one can state that a regionalized variable is simply a function that describes the value of a characteristic quantity z at point $\mathbf{x} = (x,y)$ in space. We denote this quantity z as $z(\mathbf{x})$.

A *random variable* is, by definition, a variable that can attain different numerical values, subject to a certain probability distribution. The random function associated with a random variable, $z(\mathbf{x})$, is conventionally denoted by $Z(\mathbf{x})$.

The basic estimation problem addressed by TRIPOL can now be defined as obtaining some estimate for the function $Z(\mathbf{x})$ at a site $\mathbf{x}_0$, where no observations on $Z(\mathbf{x})$ are available.

The *estimator* for a function $Z(\mathbf{x})$ at a site $\mathbf{x}_0$ will be denoted as $Z^*(\mathbf{x}_0)$.

The *observations* available for a given set of *n* regionalized variables or data points are denoted as $Z(\mathbf{x}_i)$, $i=1,\ldots,n$.

1.3. SEMI-VARIOGRAM COMPUTATION

Because of the nature of Kriging and Bayesian Kriging, a semi-variogram, computed from the regionalized variables or data points, is needed to estimate the manner in which the mean values of the phenomena behave over the region, often referred to as the *drift* or *trend* of the regionalized variable. A mathematical function is then fitted to the semi-variogram values, to obtain certain parameters that are needed for interpolation by Kriging and Bayesian Kriging.

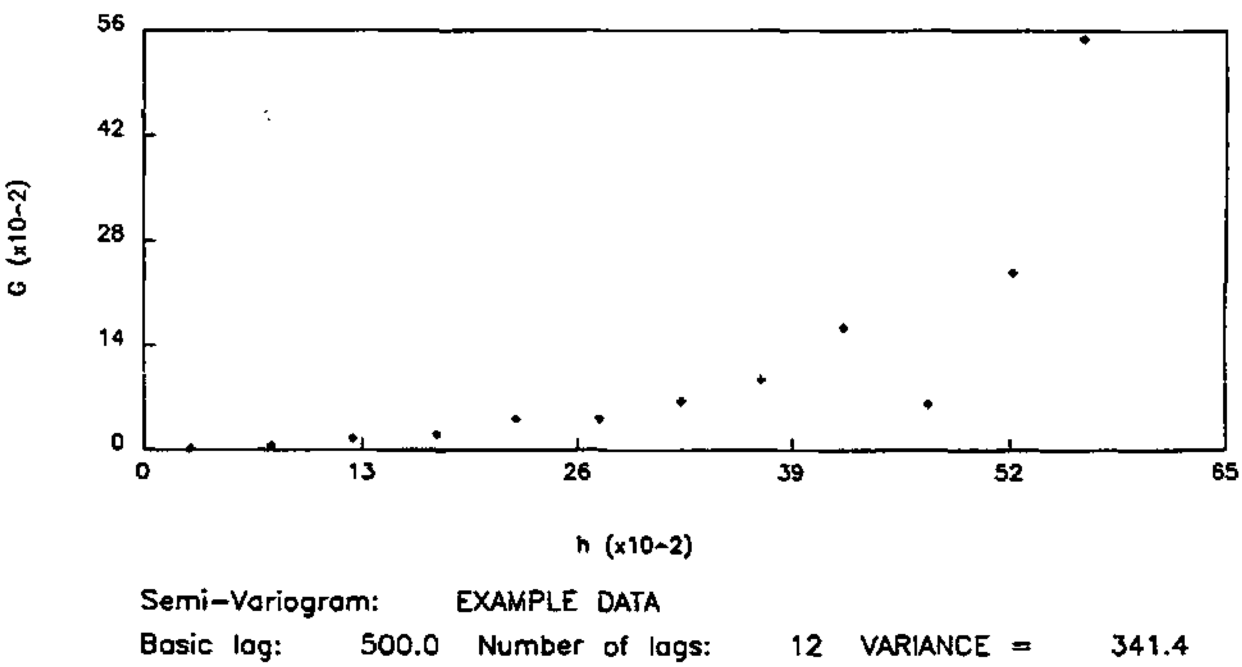
A semi-variogram describes the connection between two points at distance h from each other. It can be estimated by the function $\gamma(h)$ in the following equation:

$$\gamma(h) = \frac{1}{2n(h)} \sum^{n(h)} \left[z(\mathbf{x}_i) - z(\mathbf{x}_j) \right]^2 \text{ for all } i,j \leq n$$

such that $d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} = h$, where d_{ij} is the distance between two points $\mathbf{x}_i$ and $\mathbf{x}_j$, $\gamma(h)$ is the semi-variogram value of lag h, n the number of observations and $n(h)$ is the number of pairs $(\mathbf{x}_i, \mathbf{x}_j)$, such that $d_{ij} = h$.

In practice, the approximation for the semi-variogram $\gamma(h)$ is computed for fixed values of h, given by some *basic lag distance*, a, say, thus for $\gamma(a)$, $\gamma(2a)$, $\gamma(3a)$, and so forth, where $\gamma(a)$ is computed for <u>all</u> pairs $(\mathbf{x}_i, \mathbf{x}_j)$ such that $a-1 < d_{ij} \leq a$. Futher, h is approximated by the mean distance between all pairs $(\mathbf{x}_i, \mathbf{x}_j)$ used in the computation of $\gamma(a)$. Thus $\gamma(d) \equiv \gamma(a)$ for

$d = \frac{1}{n(h)} \sum^{n(h)} d_{ij}$ (see Figure 1.1 with a=500).



1.3.1. Figure 1.1. Graph of an example semi-variogram.

Experience indicates that $\gamma(h)$ generally tends to increase with h, until it reaches a maximum value, called the *sill* at some lag a. This distance is customarily referred to as the *range* of $\gamma(h)$ The semi-variogram is then approximated with either one of the six model equations, given in the next section.

1.4. FITTING

Interpolation by Kriging and Bayesian Kriging requires a theoretical semi-variogram and functional terms of an assumed trend in a given neighbourhood of the input data. The neighbourhood is determined by the *number of nearest points* that are used for interpolation. The most commonly used theoretical semi-variograms are shown in Figures 1.2 to 1.7. The quantity, C_0, which corresponds to $\gamma(0)$, is usually referred to as the *nugget effect*.

Type 1, Polynomial semi-variogram given by:

$$\gamma(h)=0 \qquad h=0$$
$$\gamma(h)=Ch^a+C_0 \qquad h>0,\quad 0<a<2$$

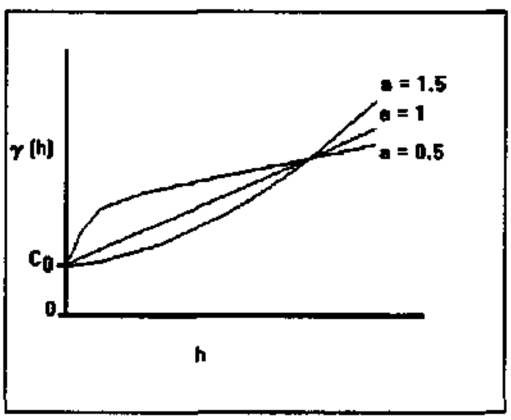


Figure 1.2. Graph of polynomial semi-variogram.

Type 2, Spherical semi-variogram given by:

$$\gamma(h)=0 \qquad h=0$$
$$\gamma(h)=C\left[1.5\left(\frac{h}{a}\right)-0.5\left(\frac{h}{a}\right)^3\right]+C_0 \qquad 0<h<a$$
$$\gamma(h)=C+C_0 \qquad h>a$$

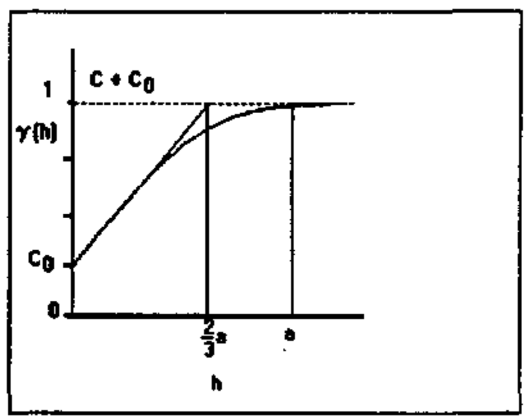


Figure 1.3. Graph of spherical semi-variogram.

1.5. THE DISTANCE WEIGHTED METHOD

Classical interpolation methods are all based on the assumption that the variable of interest can be represented by a smooth function. In the estimation of a random variable, these methods assume that the estimator, $Z^*(x_0)$, is a linear combination of the observations, $Z(x_i)$. In other words, to assume that it can be expressed in the form

$$Z^*(\mathbf{x}_o)=\sum_{i=1}^{n} w_i z(\mathbf{x}_i)$$

where w_i (i=1,...,n) is a weight function dependent on the distance d between the observation point $x_i=(x_i,y_i)$ and the estimation point $x_0=(x_0,y_0)$, d is given by

$$d_i=\sqrt{(x_i-x_0)^2+(y_i-y_0)^2}$$

Type 3, Exponential semi-variogram given by:

$$\gamma(h) = 0 \qquad h = 0$$

$$\gamma(h) = C\left[1 - e^{-\left(\frac{h}{a}\right)}\right] + C_0 \qquad h > 0$$

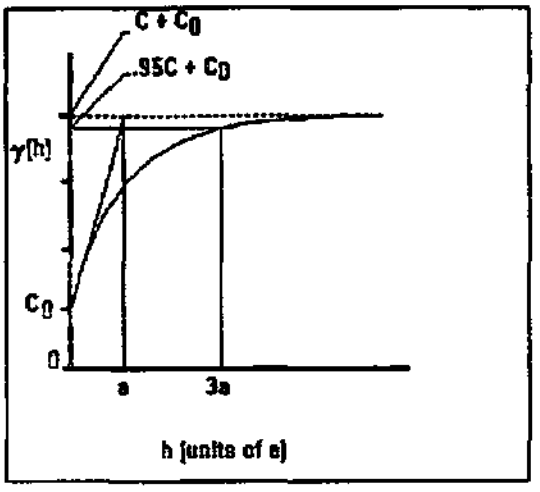


Figure 1.4. Graph of exponential semi-variogram.

Type 4, Gaussian semi-variogram given by:

$$\gamma(h) = 0 \qquad h = 0$$

$$\gamma(h) = C\left[1 - e^{-\left(\frac{h}{a}\right)^2}\right] + C_0 \qquad h > 0$$

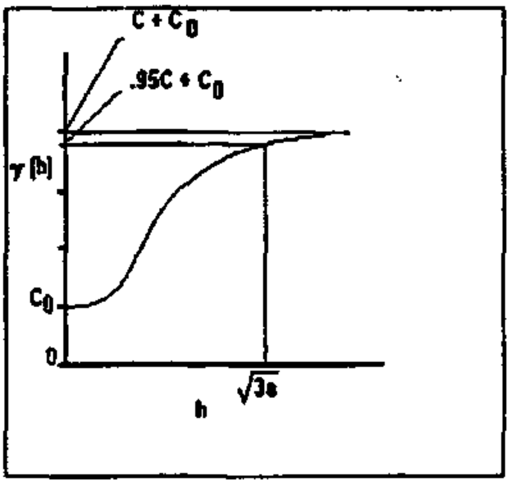


Figure 1.5. Graph of Gaussian semi-variogram.

Type 5, De Wijsian semi-variogram given by:

$$\gamma(h) = 0 \qquad h = 0$$

$$\gamma(h) = a\ln(h) + C_0 \qquad h > 0$$

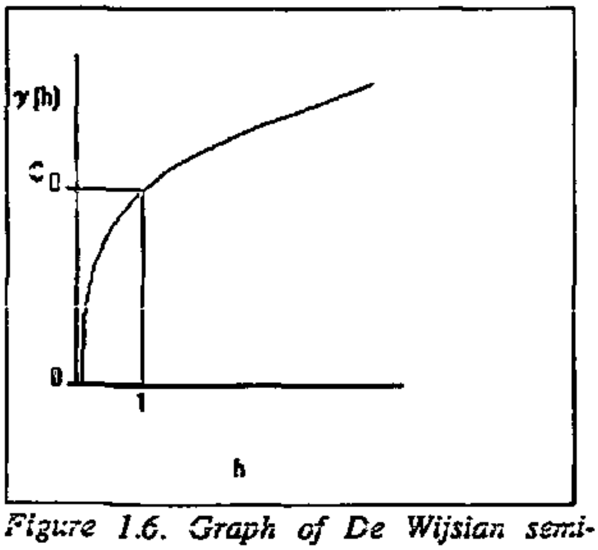


Figure 1.6. Graph of De Wijsian semi-variogram.

Type 6, Bayesian (kRho of De Waal) semi-variogram given by:

$$\gamma(h) = \sigma^2 \qquad h = 0$$

$$\gamma(h) = \sigma^2\left[1 + k\left(1 - \rho^h\right)\right] \qquad h > 0$$

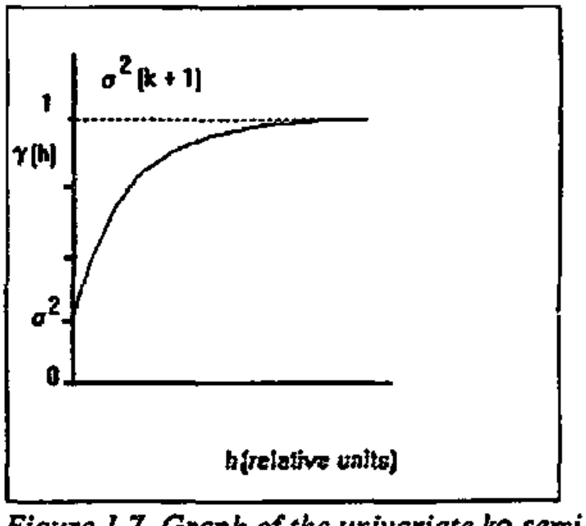


Figure 1.7. Graph of the univariate kρ semi-variogram.

Many different weight functions can be used. The following weight functions were built into TRIPOL for completeness:

Type 1: $w_i = \frac{1}{d_i}$

Type 2: $w_i = \left(1 - \frac{d_i}{1.1 d_{max}}\right)^2 \Big/ \left(\frac{d_i}{1.1 d_{max}}\right)^2$

Type 3: $w_i = e^{-\alpha d_i}$

Type 4: $w_i = \frac{1}{d_i^2}$

Type 5: $w_i = e^{(-\alpha d_i^2)/(d_i^2+\varepsilon)}$

Type 6: $w_i = e^{\left(\frac{-1}{d_i^2}\right) \Big/ (d_i^2+\varepsilon)}$

Type 7: Trend surface analysis where the estimation $Z^*(x_0)=g_j(x_0,y_0)$ is chosen from the set of polynomials $P_k(x_0,y_0)=x^{\mu}y^{\nu}$ for $\mu+\nu=k$.

1.6. KRIGING

The most appropriate way to describe the spatial variability of environmental variables, is to present them with random functions. This approach has the advantage that it allows one to describe an environmental variable in statistical terms, through the Theory of Regional Variables. The best known estimation method, based on this approach, is Ordinary Kriging or *Kriging*, as it is conventionally known.

Interpolation done with Kriging, where the mean value of $Z(x)$ is unknown, is given by:

$$Z^*(\mathbf{x}_o) = \sum_{i=1}^{n} w_i Z_i$$

where the weight function w_i is calculated by solving the system of linear equations

$$\sum_{j=1} w_j \gamma_{ij} = \gamma_{io}, \text{ with } \sum_{i=1} w_i = 1 \text{ where } \gamma_{ij} = \gamma(d_{ij})$$

The semi-variogram function, $\gamma(h)$, as a function of h, must be known for all values of h. This condition requires the approximations of the semi-variogram with any of the models in the previous section.

Since Kriging is a linear procedure, difficulties are experienced if the variable to be estimated contains a non-linear trend, or drift as it is called in geostatistical literature. To solve this, *Universal Kriging* was developed, but it is numerically unstable and often singular. In TRIPOL, Universal Kriging is restricted to polynomials of first and second order.

1.7. BAYESIAN ESTIMATES

There are many situations in the environmental sciences where *a given variable correlates with another one*. For example, groundwater levels often follow the surface topography of the aquifer. If the latter variable can be sampled more frequently than the first one, then one can use this information to improve estimates of the first variable. Bayesian Kriging is an interpolation method that uses this principle. In this approach, the classical statistical analysis of Ordinary Kriging is replaced by a Bayesian statistical analysis. The beauty of the Bayesian approach is that it allows one to express prior knowledge of the variable with a *qualified guess* that can be included in the estimation.

Bayesian interpolation is done with the estimator

$$Z^*(\mathbf{x}_o) = \sum_{i=1}^{n} \alpha_i \left[Z(\mathbf{x}_i) - \mu(\mathbf{x}_i) \right] + \mu_0(\mathbf{x}_0)$$

where $\mu(\mathbf{x}_i)$ is the qualified guess for site $\mathbf{x}_i$. The coefficients α_i , $i=1,\dots,n$ can again be determined from a system of linear equations and is a function of the parameters σ(Sigma) , k and ρ(Rho). These values can be estimated by the approximation of the semi-variogram with the theoretical kρ semi-variogram in Figure 1.7.

2. PROGRAM REFERENCE

2.1. SELECTING AND EDITING

The program TRIPOL was implemented on both a PC DOS microcomputer and a SUN workstation. Although the menus look different on the PC Version and the SUN Version, their contents are basically the same. Whenever there are specific differences on the two implementations, it will be denoted as such. There is also a UNIX version of TRIPOL available that can run on any machine with a UNIX Operating System. This version operates from a Unix shell. Although it does not have the same look and feel as the PC and Sun Versions, it can do exactly the same.

PC Version
To select a field, move the highlight with the arrow keys to the appropriate field. To edit a field, select a field and press enter. You can now enter the new value followed by the enter key. Use the left and right arrow keys to move within a field while editing.

SUN Version
The mouse buttons are used to set the input focus or to select options and to execute commands. To pop up menus, listed in the menu buttons, either the left or right mouse buttons must be used, depending on the type of button. A ∇ indicates a pop-up menu button - use the right mouse button; ... indicates a pop-up menushell button - use the left mouse button.

2.2. PARAMETERS, TERMS AND OPTIONS

Compute Difference Between Values *Default: N*

N The Z-value given in the input file is used as z(x).

Y Only used for Bayesian Estimates. The observation value (z) and guess (z*) for each data point must be given in the data file. The value for z(x).is then calculated as z-z*.

Logarithmic Transform *Default: N*

N The X and Y-values are used as are for computations.

Y The X and Y-values are logarithmic transformed before any computations are done.

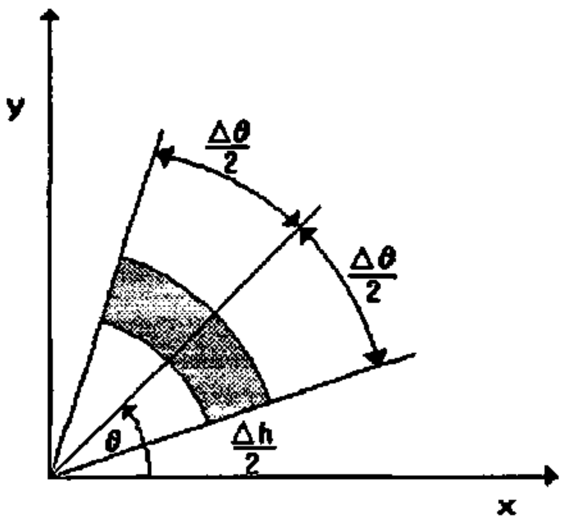
Basic Lag
The *basic lag* distance is the interval for calculations of the semi-variogram.

Number of Lags
This is the number of intervals (basic lags) that must be computed or used for calculations and fitting of the semi-variogram.

Direction *Default: 0*
This number specifies the direction (angle) for the semi-variogram calculation (see θ in Figure 1.8).

Direction of Tolerance *Default: 360*
This specifies the degrees or spectrum forming a circle segment to use for calculations (see $\Delta\theta$ in Figure 1.8).

Type of Semi-Variogram
The semi-variogram type corresponds with the types 1 to 6 in Section 1.4.



2.2.1. Figure 1.8. Classification pattern for calculation of the semi-variogram

Slope, Power and C_0
The *slope* and *power* correspond to the parameters in semi-variogram type 1, defined as $\gamma(h) = C_0 + \quad Sn^P$, where S is used as the slope and P as the power.

Range (A)
Some lag A such that γ(A) reaches a maximum value.

Sill, C, C_0
See Figure 1.3, where Sill = C + C_0, C = the variance and C_0 = the nugget effect.

Sigma (σ), k, Rho (ρ)
Sigma (σ), k and Rho (ρ) correspond to the parameters in semi-variogram type 6 (see Figure 1.7).

Compute Best Fit *Default: Y*

Y Specify that a *best* fit must be computed from the *initial* values specified. The best fit will be find by varying the parameters between the shown *minimum* and *maximum* values

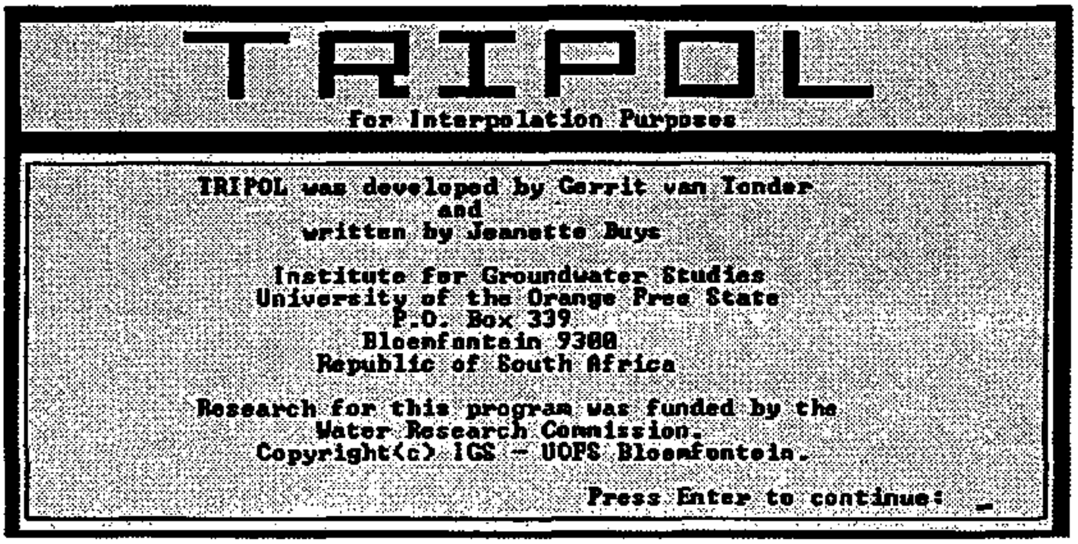
N Specify that the given values must be used as the parameters for the theoretical semi-variogram.

Number of nearest points
The number of nearest points to use for estimating the value of a point. This is the so-called viewing window.

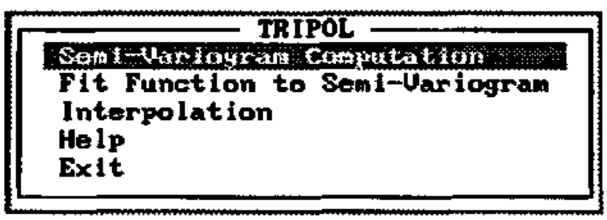
2.3. PROGRAM FLOW

Start the program by typing TRIPOL followed by the enter key. You are presented with the following introductory screen:

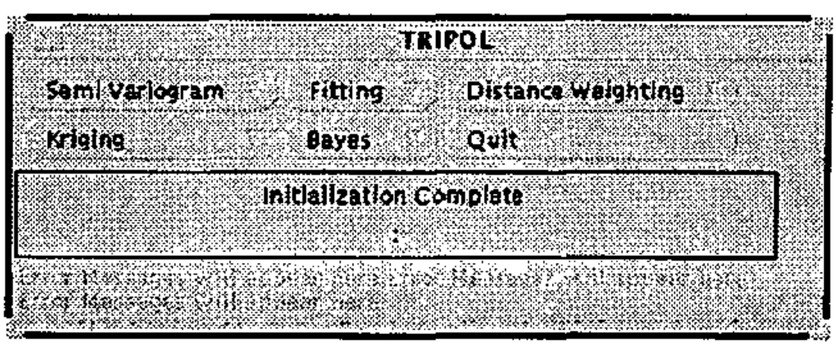
PC Version



Continue by pressing the enter key to bring you to the following Main Menu of TRIPOL.



SUN Version



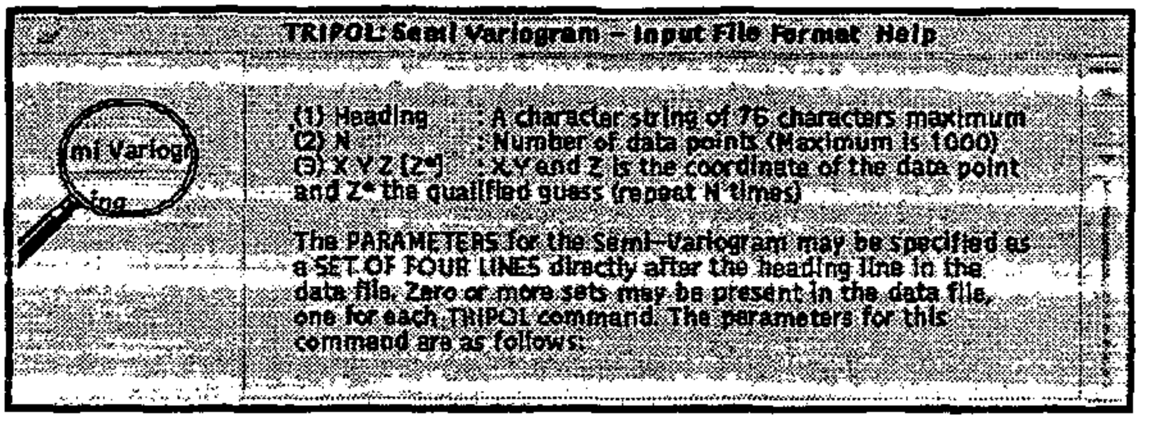
An explanation of each of the entries of the main menu follows in the following chapters.

2.4. HELP

PC Version
Selecting the Help Command on the Main Menu will bring up a Help Menu. Select any of the Subjects and press the enter key, which will show a Help Menu on the specific subject.

SUN Version

Whenever the F1 key is pressed, with the mouse pointer pointing to a button, a Help Menu will pop up, giving information on the parameters connected to the button, for example:



3. SEMI-VARIOGRAM COMPUTATION

3.1. INPUT FILE

The only input file is a file that must have the extension .DFL.

Data format of file *.DFL

1: | Hdng | Heading of the map, consisting of a maximum of 76 characters.

2: | N | N specifies the number of data points given.

3: | X_i Y_i Z_i [Z^*_i] | for $i = 1$ *to* N

(X_i, Y_i, Z_i)	Coordinate of the actual data point i.
Z^*_i	Qualified guess at point *i*. Only necessary if differences between Z_i and Z^*_i must be computed for Bayesian estimates.

The semi-variogram parameters that must be used during computation may also be specified in this file, but it is not necessary. If specified, it must be entered as a set of four lines directly after line 1, the heading line, as follows:

1: | S/s | S indicates that semi-variogram parameters follow.

2: | NLAG | NLAG specifies the maximum number of lags that must be computed.

3: | DLAG | DLAG specifies the basic lag distance.

4: | | Blank line.

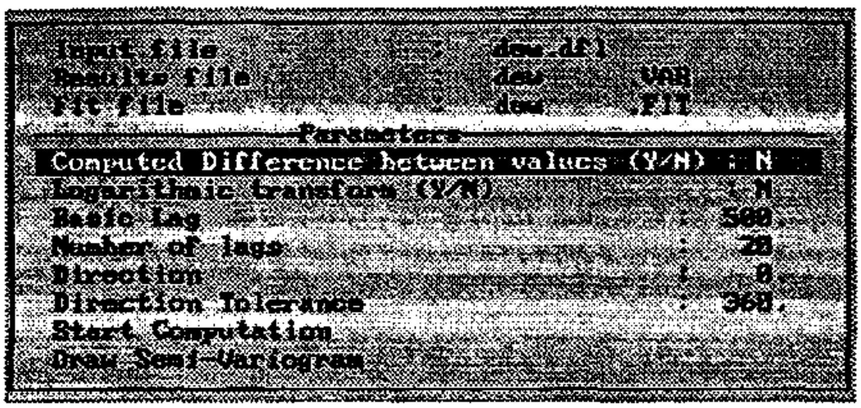
The interpolation parameters that must be used during interpolation may be specified in the *.DFL file, but it is not necessary. If specified, it must also be entered as a set of four lines directly after line 1, the heading line. Each set starts with an identifying character, which can be either in small or capital letters.

For example:
Heading
Semi-Variogram Parameters
Distance Weighing Parameters
Kriging Parameters
Bayes Parameters
lines 2-5: Information about observations and point interpolations.

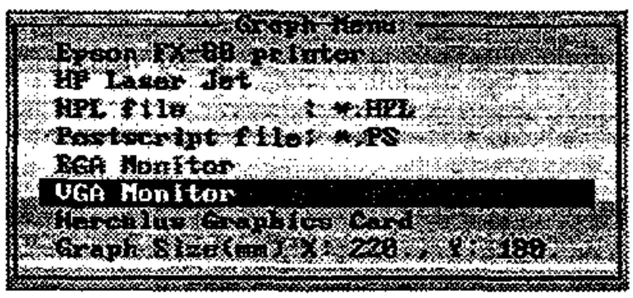
3.2. OPTIONS

PC Version
Select *Semi-Variogram Computation* from the Main Menu to give you a small menu consisting of two options. First edit the *Input File name* field to type the correct input filename. Next, select *Continue Computation* to edit the various computation options as

shown in the following *Semi-Variogram Menu.* The default values are shown as retrieved from the input file.

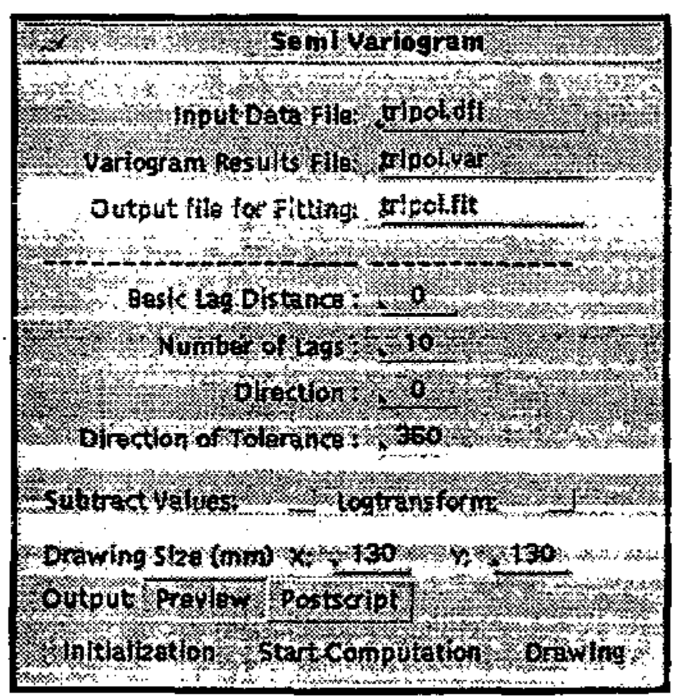


The upper half of the menu displays the file names for input and output for this option. You can edit the values in the lower part. Select *Start Computation* to compute the semi-variogram. Select *Draw Semi-Variogram* to choose an output device from the Graph Menu. You can also alter the graph size on this menu.



SUN Version

The Semi-Variogram menu contans three buttons, *Initialization*, *Start Computation* and



Drawing. The initialization command reads the appropriate parameters from the input file, if present, and initiate the parameters shown on the menu. The drawing command generates either a graphic window or a postscript file with a .ps extension, depending on the state of the *Output* button.

3.3. OUTPUT

The output files have the extension .VAR and .FIT. The format for the .FIT file is described in the next paragraph. The drawings that are created can be printed to any of the devices or files shown in the Graph Menu. A HPL file is in Hewlett-Packard Graphic Language (HPGL) format and can be printed or imported by any program that can handle HPGL files.

4. FIT FUNCTION TO SEMI-VARIOGRAM

4.1. INPUT FILE

This file has the extension .FIT and is created when the semi-variogram computation is done and must be used as input for this step. It has the following format:

Data format of file *.FIT

1: | Hdng | Heading of the map, consisting of a maximum of 76 characters.

2: | N | N specifies the number of lags (maximum 50).

3: | D_i G_i | for *i = 1 to N*

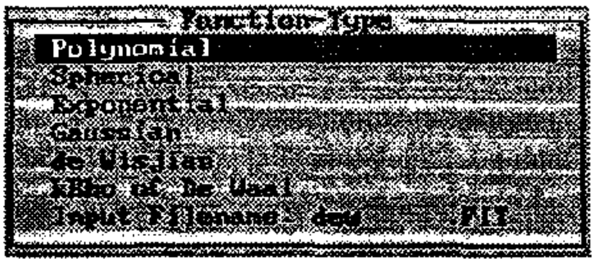
D_i Average distance / lag / direction at point i.

G_i Semi-Variogram value at point i.

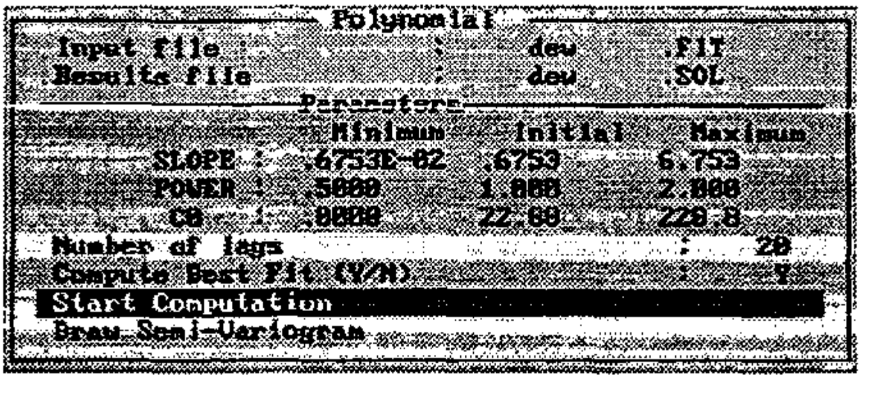
4.2. OPTIONS

PC Version

Six different methods for fitting a function are displayed on the following Function-Type Menu.



Selecting any one of these options brings you to one of the following Fitting Menus: Polynomial, Spherical, Exponential, Gaussian, De Wijsian and kRho. The upper half is for information purposes only and displays various file names for input and output. You can edit the values in the lower part to suit your needs.

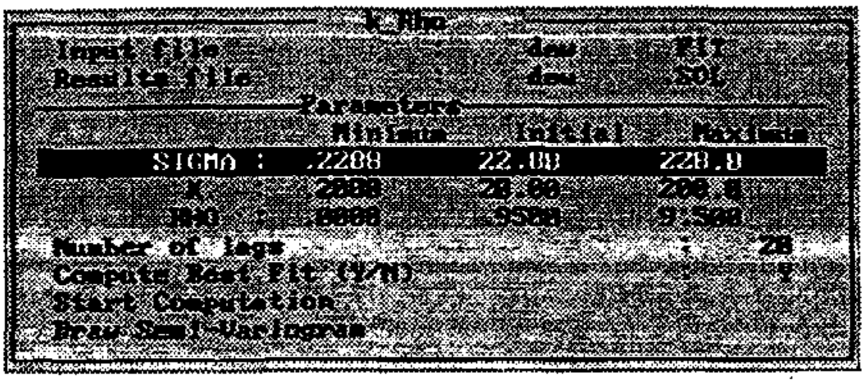


```
                         Spherical
 Input file                 :      dew      .FIT
 Results file               :      dew      .SOL
                         Parameters
                    Minimum      Initial     Maximum
        SILL   :   63.06        6329.       .6329E+05
        RANGE  :   95.85        9585.       .9585E+05
          C0   :   .0000        22.88       228.8
 Number of lags                                 :    28
 Compute Best Fit (Y/N)                         :     Y
 Start Computation
 Draw Semi-Variogram
```

```
                         Exponential
 Input file                 :      dew      .FIT
 Results file               :      dew      .SOL
                         Parameters
                    Minimum      Initial     Maximum
        SILL   :   63.06        6329.       .6329E+05
        RANGE  :   95.85        9585.       .9585E+05
          C0   :   .0000        22.88       228.8
 Number of lags                                 :    28
 Compute Best Fit (Y/N)                         :     Y
 Start Computation
 Draw Semi-Variogram
```

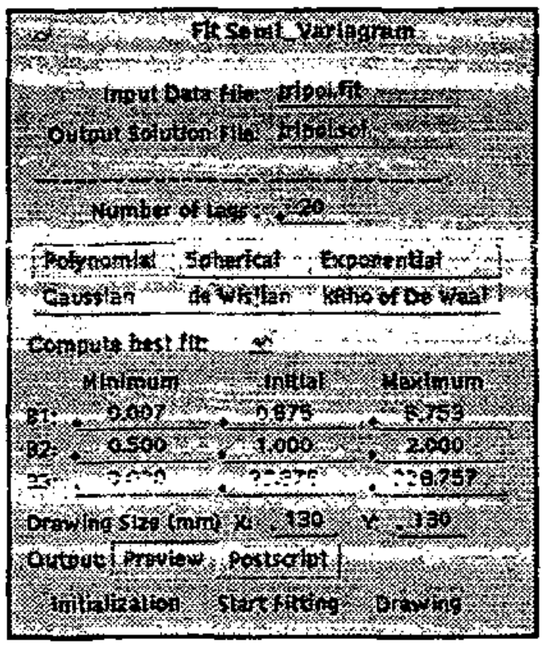
```
                         Gaussian
 Input file                 :      dew      .FIT
 Results file               :      dew      .SOL
                         Parameters
                    Minimum      Initial     Maximum
        SILL   :   63.06        6329.       .6329E+05
        RANGE  :   95.85        9585.       .9585E+05
          C0   :   .0000        22.88       228.8
 Number of lags                                 :    28
 Compute Best Fit (Y/N)                         :     Y
 Start Computation
 Draw Semi-Variogram
```

```
                         De Wijsian
 Input file                 :      dew      .FIT
 Results file               :      dew      .SOL
                         Parameters
                    Minimum      Initial     Maximum
        SILL   :   63.06        6329.       .6329E+05
        RANGE  :   95.85        9585.       .9585E+05
          C0   :   .0000        22.88       228.8
 Number of lags                                 :    28
 Compute Best Fit (Y/N)                         :     Y
 Start Computation
 Draw Semi-Variogram
```



SUN Version

Six different methods for fitting a function are displayed on the Fit Semi-Variogram Menu. The fitting parameters are labelled B1, B2 and B3. Use the F1 help key to obtain information on the meaning of the parameters for every Semi-Variogram Type selected.



For the Polynomial / Spherical / Exponential / Gaussian / De Wijsian and kRho semi-variograms, their meaning are as follows:

	Polynomial	Spherical, Exponential, Gaussian, De Wijsian	kRho
B1	Slope	Sill	Sigma
B2	Power	Range	K
B3	C_0	C_0	Rho

4.3. OUTPUT

The output file has the extension .SOL and contains the solution. The equation parameters B(1), B(2) and B(3) have the same meaning as in the table for the SUN version.

5. INTERPOLATION

5.1. INPUT FILE

The same input file that was used for *Semi Variogram Computation* can be used for any of the three types of interpolation. This file must have the extension .DFL. and has the following format:

Data format of file *.DFL

1: | Hdng | Heading of the map, consisting of a maximum of 76 characters.

2: | N | N specifies the number of data points given.

3: | X_i Y_i Z_i [Z^*_i] | for *i = 1 to N*

- (X_i,Y_i,Z_i) Coordinate of the actual data point i.
- Z^*_i Qualified guess at point *i*. Only necessary if differences between Z_i and Z^*_i must be computed for Bayesian estimates.

4: | NW | NW specifies the number of point interpolation values to be computed.

5: | XW_i YW_i [ZG_i] | for *i = 1 to NW*

- (XW_i,YW_i) x- and y-coordinate of interpolation point i.
- ZG_i Qualified guess at point *i*. Only necessary for Bayesian estimates.

The interpolation parameters that must be used during interpolation may be specified in the *.DFL file, but it is not necessary. If specified, it must be entered as a set of four lines directly after line 1, the heading line. Each set starts with an identifying character, which can be either in small or capital letters.

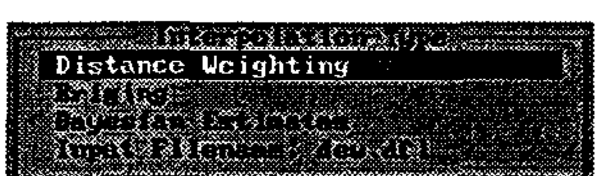
For example:

Heading
Semi-Variogram Parameters
Distance Weighing Parameters
Kriging Parameters
Bayes Parameters
lines 2-5: Information about observations and point interpolations.

5.2. OPTIONS

PC Version

Three different methods for interpolation are shown on the Interpolation Type Menu.



Selecting any one of these options brings you to the appropriate Interpolation Menu. The upper half is for information purposes only and displays various file names for input and output. You can edit the values in the lower part to suit your needs.

PC Version
Each Interpolation Menu contains two commands namely *Start Error Analysis* and *Start Interpolation*. The first command initializes the computation of the estimated error for each observation point and the root mean square error. The second command computes the estimated value for each given interpolation point in the .DFL file.

SUN Version
Each Interpolation Menu contains three buttons namely *Initialization*, *Error Analysis* and *Start Interpolation*. The first button initializes the parameters with the values given in the .DFL file, if any. The second button computes the estimated error for each observation point and the root mean square error. The third button computes the estimated value for each given interpolation point in the .DFL file.

5.3. OUTPUT

The following three files are created during interpolation:

1. File *.DAT. This file contains the x- and y-coordinates of the interpolation points and the estimates values for each point. The file is ready to be used in program TRICON for computing the triangular mesh.
2. File *.LEV contains the estimated values for each point interpolation. The file is ready to be used in TRICON for contouring.
3. File *.LST contains the Error Analysis.

6. DISTANCE WEIGHTING INTERPOLATION

6.1. INPUT FILE

The distance weighting parameters that must be used during interpolation may be specified in the *.DFL file, but it is not necessary. If specified, it must be entered as a set of four lines directly after line 1, the heading line, as follows:

1: | D/d | D indicates that distance weighting parameters follow.

2: | NUM | NUM specifies the number of nearest points to be used for interpolation.

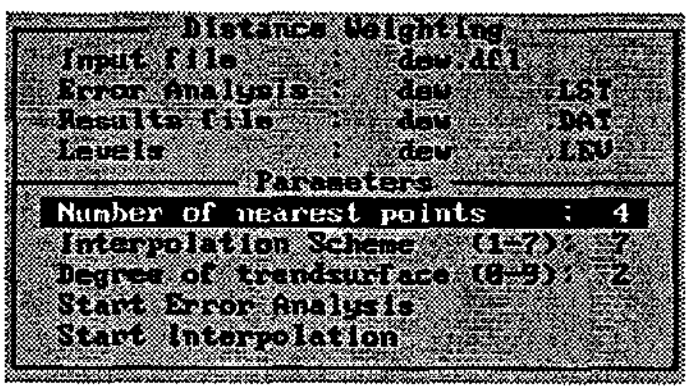
3: | WFUNC | 1/2/.../6 specifying the type of weight function to be used (Section 1.5).

4: | DEGREE | Degree of polynomial to be used for a trend surface analysis (WFUNC=6).

6.2. OPTIONS

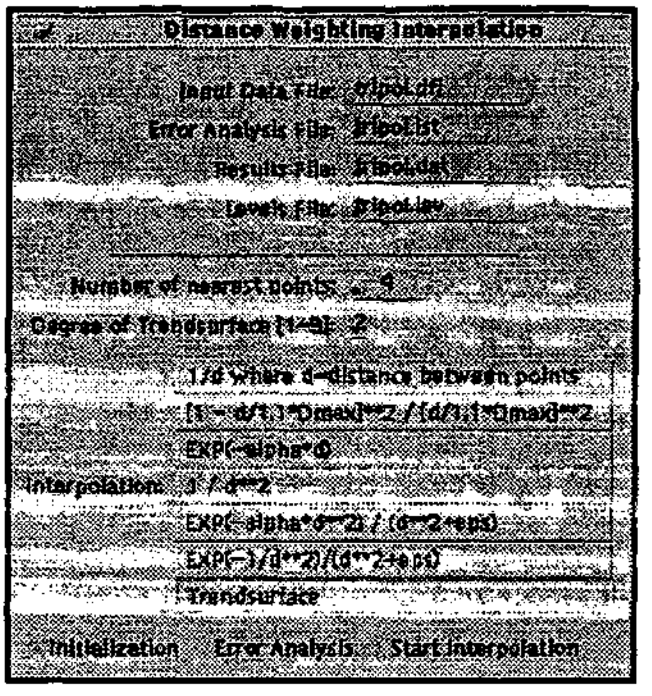
The following Distance Weighting Menu will appear:

PC Version



The interpolation scemes that are build into the program is defined in Section 1.5 (page 5).

SUN Version



6.3. OUTPUT

Three files are created during interpolation. Refer to the section on interpolation.

7. KRIGING

7.1. INPUT FILE

The Kriging parameters that must be used during interpolation may be specified in the *.DFL file, but it is not necessary. If specified, it must be entered as a set of four lines directly after line 1, the heading line, as follows:

1: | K/k | K indicates that Kriging parameters follow.

2: | NUM TYPE LOG ORDER |

NUM	Number of nearest points to be used for interpolation.
TYPE	Theoretical semi-variogram type, 1 to 6, to use as an approximation of the semi-variogram (see Section 1.4). 1. Linear. 2. Spherical. 3. Exponential. 4. Gauss. 5. De Wijsian. 6. Special kRho-variogram of De Waal.
LOG	Logarithmic transform values (0 for no, 1 for yes).
ORDER	0 for Ordinary Kriging and 1 or 2 for Universal Kriging of the first or second order.

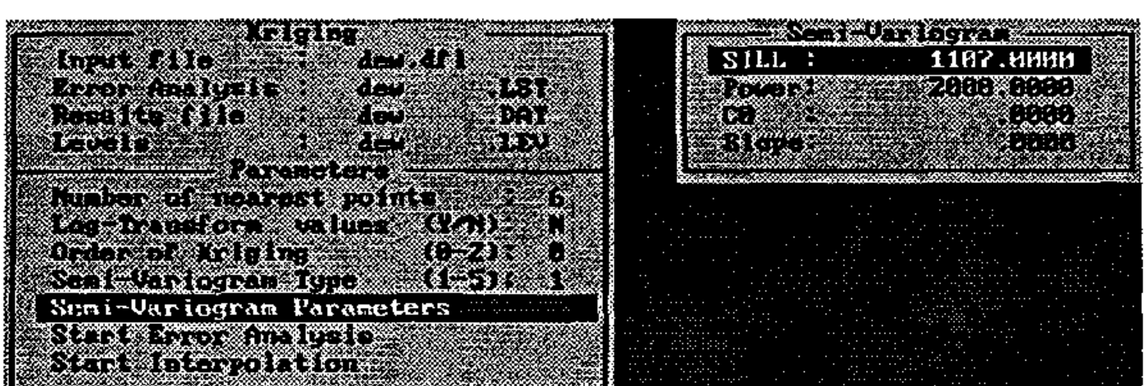
3: | SEMI-VARIOGRAM VALUES |

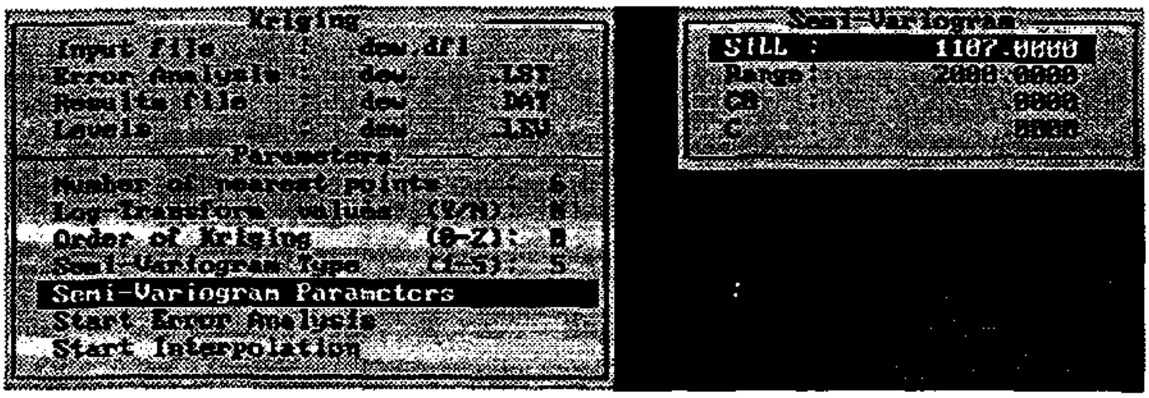
SILL,C,C0,A	for semi-variogram type 1 or 5.
SILL,C0,A	for semi-variogram type 2, 3 or 4.

4: | | Blank Line.

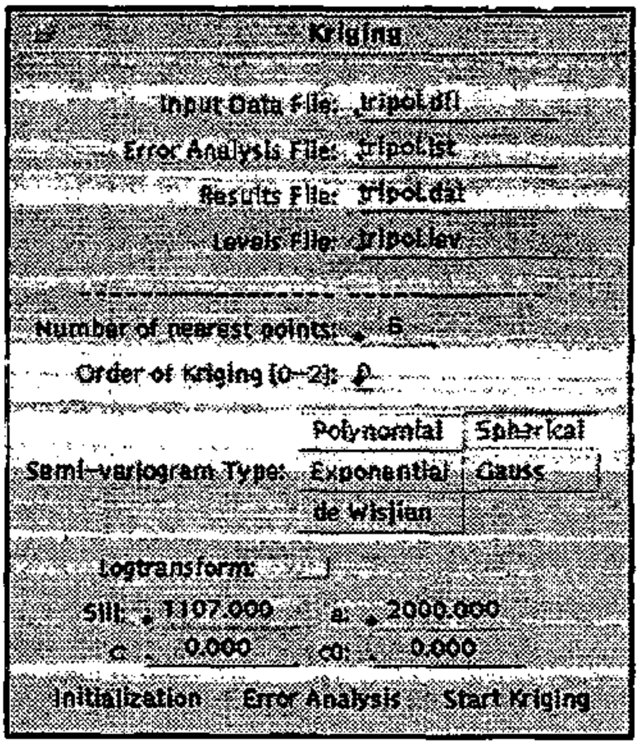
7.2. OPTIONS

PC Version
The Kriging Menu contains the command *Semi Variogram Parameters* which allows for changing or entering the appropriate parameters. The different Semi Variogram Menus for the different Semi Variogram Types are as follows:





SUN Version



7.3. OUTPUT

Three files are created during interpolation. Refer to the section on interpolation.

8. BAYESIAN ESTIMATES

8.1. INPUT FILE

The Bayesian parameters that must be used during interpolation may be specified in the *.DFL file, but it is not necessary. If specified, it must be entered as a set of four lines directly after line 1, the heading line, as follows:

1: | B/b | B indicates that Bayesian parameters follow.

2: | NUM TYPE LOG SCALE |

NUM	Number of nearest points to be used for interpolation.
TYPE	Theoretical semi-variogram type, 1 to 6, to use as an approximation of the semi-variogram (see Section 1.4). 1. Linear. 2. Spherical. 3. Exponential. 4. Gauss. 5. De Wijsian. 6. Special kRho-variogram of De Waal.
LOG	Logarithmic transform values (0 for no, 1 for yes).
SCALE	Scaling information. 0 = No scaling (values taken as guesses). 1 = Guesses are scaled with the mean of NUM points. 2 = Guesses are scaled with the mean of all N values. 3 = Guesses are scaled linear between the maximum and minimum height of topography (water levels are usually deeper at high topo elevation).

3: | SEMI-VARIOGRAM VALUES |

SILL,C,C0,A for semi-variogram type 1 or 5.
SILL,C0,A for semi-variogram type 2, 3 or 4.
SIG,K,RHO,DLAG for semi-variogram type 6. DLAG is the basic lag distance.

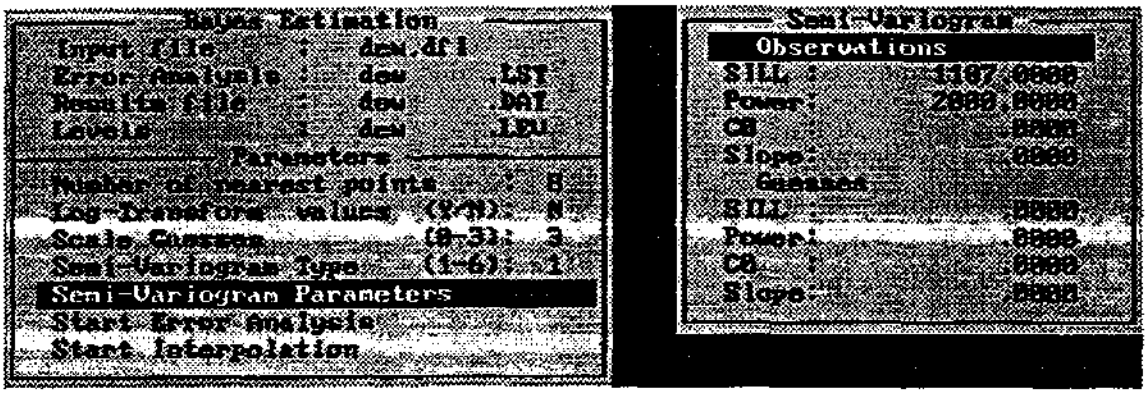
4: | SEMI-VARIOGRAM VALUES | *for Guesses Semi-Variogram..*

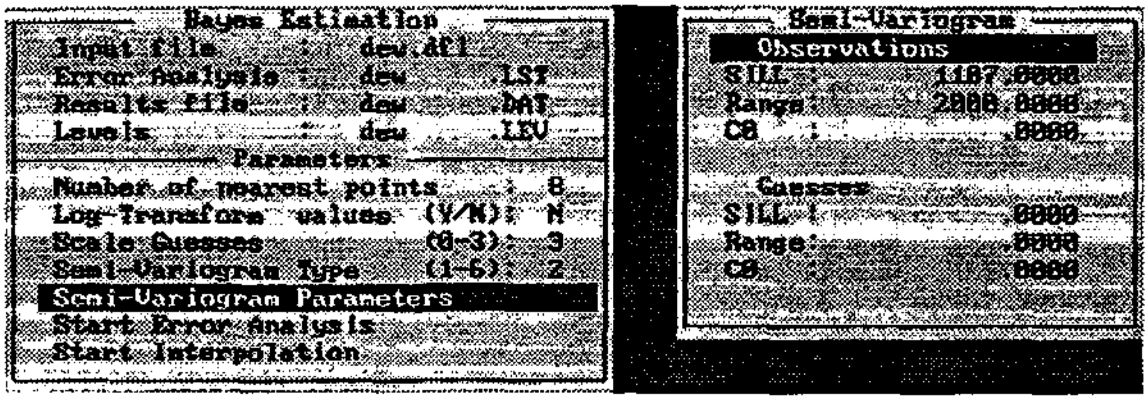
SILL,C,C0,A for semi-variogram type 1 or 5.
SILL,C0,A for semi-variogram type 2, 3 or 4.
Blank line if TYPE = 6.

8.2. OPTIONS

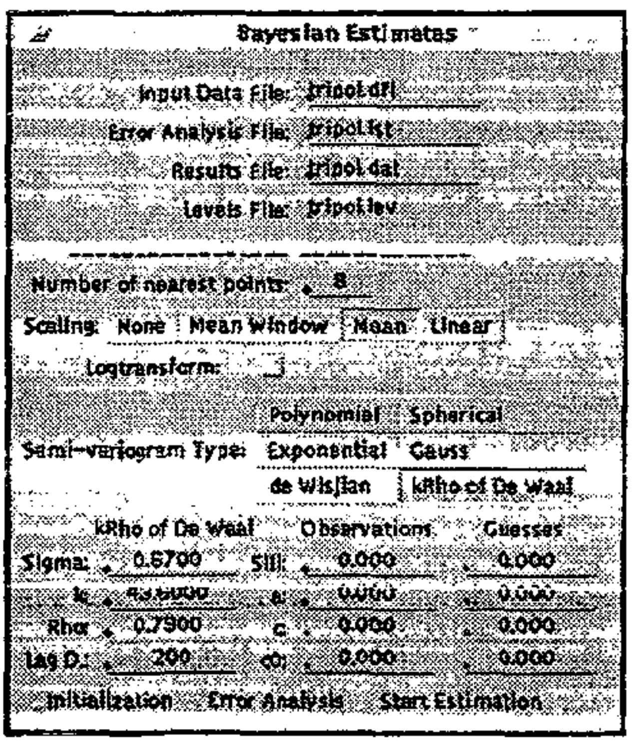
PC Version

The Bayesian Menu contains the command *Semi Variogram Parameters* which allows for changing or entering the appropriate parameters. The different Semi Variogram Menus for the different Semi Variogram Types are as follows:





SUN Version



8.3. OUTPUT

The same output files as in the distance weighted methods are created.

9. EXAMPLE

The program flow and capabilities can best be illustrated by means of an example. We begin with step by step instructions with an example file (with the extension .DFL), followed by the various output files.

9.1. EXAMPLE DATA FILE: tripol.dfl

Input listing of file tripol.dfl

(Note: The sets of parameters, consisting of 4 line each, starting with s, b, d and k, is optional.)

```
Dewetsdorp data
s
20
500
0
b
8 6 0 3
67 43.6 .79  200
0
d
4
7
2
k
6 2 0 0
1107 0 2000
0
72
-29353.00    -270367.00         1466.7         1486.0
-29330.00    -270354.00         1467.0         1486.0
    .             .                .              .
542
      -31154.079        -269336.220    1500
      -31153.932        -269348.875    1500
      -31143.754        -269366.663    1500
          .                  .           .
```

Step 1:
With a prepared data file as in the previous paragraph, start the program by typing TRIPOL followed with the enter key to display the introductory screen. Press the enter key to display the Main Menu.

Step 2:
Select the first option (*Semi-Variogram Computation*) to display the Computation Menu and edit the *Input Filename* entry by typing the correct input file name in this field. Select *Continue Computation* to display the Semi-Variogram Menu..

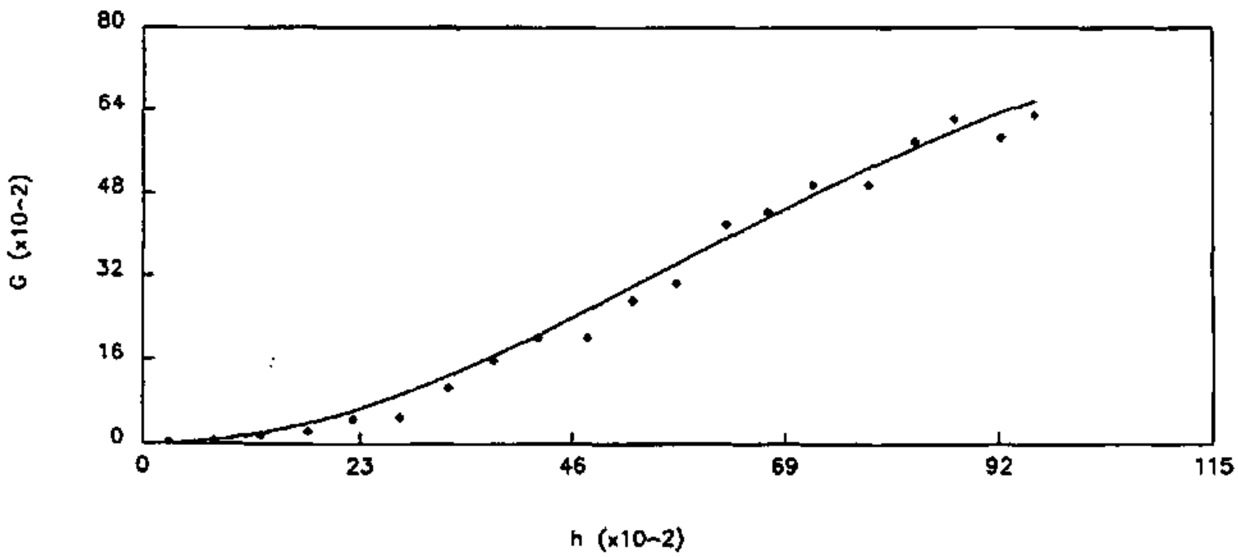
Step 3:
After setting the values in the Semi-Variogram Menu, select *Start Computation* to compute the semi-variogram. With the PC version a *Message Box* will be displayed below the menu to

display the results. Press any key to clear the message box in order to return to the menu. The SUN version contains the message box on the main menu.

Step 4:
To draw the semi-variogram, select *Draw Semi-Variogram* to display the Graph Menu. Select the appropriate output device to display the semi-variogram. After viewing, press any key to return to the Semi-Variogram Menu.

Step 5:
You have now generated the *.FIT file needed for fitting a function to the semi-variogram. Press the escape key to go from the Semi-Variogram Menu to the Main Menu. Select *Fit Function to Semi-Variogram* to display the Function-Type Menu and select the appropriate method to use to fit the function.

Step 6:
After setting the options in one of the Fitting Menus, select *Start Computation*, clear the message box and select *Draw Semi-Variogram* from the Graph Menu, select the output device to view the semi-variogram and the fit (Figure 1.9).



Semi–Variogram: Dewetsdorp data.
Gaussian : SILL = 8826.0 RANGE= 8182.0 CO = .00000

Figure 1.9.

Step 7:
The last stage of the program is to do the interpolation. Select interpolation from the Main Menu. Choose between the different interpolation schemes on the Interpolation Type Menu. After setting the various options on the Distance Weighting, Kriging and Bayesian Estimates Menus, select *Start Error Analysis* to compute the error in the estimate and select *Start Interpolation* to do the point interpolations for all interpolation points given in the data file.

9.2. EXAMPLE OUTPUT FILES

Output listing of file tripol.var

Semi-Variogram: Dewetsdorp data
AVERAGE = 1511.24167
VARIANCE = .11077E+04
NUMBER OF DATA POINTS = 72

DIRECTION TOLERANCE = 360.0 degrees
STEP SIZE = 500.0 meters
DIRECTION = 0. degrees

LAG	#points	DISTANCE	1/2 VARIO
1	127	281.52	22.8757
2	212	764.59	67.1359
3	260	1250.03	162.1264
4	363	1750.46	237.2865
5	321	2230.43	464.5948
6	243	2730.78	500.7854
7	234	3252.36	1056.9241
8	158	3735.55	1579.9574
9	134	4223.17	2020.9207
10	124	4764.82	2010.7043
11	89	4760.47	2723.9197
12	107	5737.81	3056.6428
13	67	6265.79	4190.3031
14	37	6719.37	4433.7247
15	38	7215.38	4966.7630
16	15	7809.38	4951.2287
17	14	8305.41	5789.2032
18	8	8728.99	6225.0163
19	4	9224.73	5866.1300
20	1	9584.77	6305.6450

Output listing of file tripol.fit

(This file is used as input for the *Fitting* Command)

Semi-Variogram: Dewetsdorp data
20

281.5230	22.8757
764.5856	67.1359
1250.0290	162.1264
1750.4561	237.2865
2230.4253	464.5948
2730.7775	500.7854
3252.3619	1056.9241
3735.5452	1579.9574
4223.1653	2020.9207
4764.8156	2010.7043
5260.4681	2723.9197
5737.8148	3056.6428
6265.7852	4190.3031
6719.3708	4433.7247
7215.3806	4966.7630
7809.3830	4951.2287
8305.4111	5789.2032

8728.9899	6225.0163
9224.7290	5866.1300
9584.7700	6305.6450

Output listing of file tripol.sol

```
Semi-Variogram: Dewetsdorp data
ICON= 2   CHI2= 5640142.8      ITERATION NO. = 101
Lin: SLOPE=112.59   POWER=1.1491   C0 =.00000
        SOLUTIONS OF THE EQUATIONS
        B( 1)=  112.59293
        B( 2)=  1.1491051
        B( 3)=  .00000000
   281.523      22.876     112.593     -.897172E+02
   764.586      67.136     354.913     -.287777E+03
  1250.029     162.126     624.380     -.462254E+03
  1750.456     237.287     919.356     -.682070E+03
  2230.425     464.595    1214.539     -.749945E+03
  2730.778     500.785    1532.556     -.103177E+04
  3252.362    1056.924    1873.475     -.816551E+03
  3735.545    1579.957    2196.709     -.616751E+03
  4223.165    2020.921    2529.307     -.508386E+03
  4764.816    2010.704    2905.520     -.894815E+03
  5260.468    2723.920    3255.445     -.531526E+03
  5737.815    3056.643    3597.138     -.540495E+03
  6265.785    4190.303    3980.029      .210274E+03
  6719.371    4433.725    4312.858      .120867E+03
  7215.381    4966.763    4680.666      .286097E+03
  7809.383    4951.229    5126.111     -.174883E+03
  8305.411    5789.203    5501.995      .287209E+03
  8728.990    6225.016    5825.646      .399370E+03
  9224.729    5866.130    6207.414     -.341284E+03
  9584.770    6305.645    6486.615     -.180970E+03
```

Output listing of file tripol.lst

Distance Weighting: Dewetsdorp data.

Trend Surface Coefficients (1 = constant term)

6.089E+04
-1.863E-01
4.672E-01
2.078E-06
-1.110E-06
9.364E-07

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F-Test
Regression	73491.86	5	14698.37	154.8423
Deviation	6265.04	66	94.92	
Total Variation	79756.89	71		

Goodness of Fit = .9214

Correlation Coefficient = .9599

Degree = 2

Output listing of file tripol.lst

Kriging: Dewetsdorp data

X	Y	Z	Z*	Z-Z*
-29353.00	-270367.00	1466.70	1467.34	.64
-29330.00	-270354.00	1467.00	1466.34	-.66
-29937.00	-269726.00	1479.00	1552.06	73.06
-31031.00	-270378.00	1484.70	1478.08	-6.62
-31738.00	-269668.00	1496.00	1498.14	2.14
-31549.00	-269454.00	1495.00	1490.82	-4.18
.	.	.	.	.
-32631.00	-270907.00	1515.90	1512.17	-3.73

Average Error = 4.125E+00
Standard Error = 2.234E-01
Root Mean Square Error = 2.469E+01
Greatest Error = 1.343E+02
Mean Absolute Error = 1.108E+01

Output listing of file tripol.lst

Bayes Estimation : Dewetsdorp data.

X	Y	Z	GUESS	Z*	Z-Z*	STD
-29353.0	-270367.0	1466.70	1481.45	1468.13	1.43	1.88
-29330.0	-270354.0	1467.00	1481.45	1467.86	.86	1.89
-29937.0	-269726.0	1479.00	1478.86	1473.52	-5.48	4.74
.	.	.	.	.	.	.

Average Error = 2.38736E-01
Standard Error = 1.25158E+00
Root Mean Square Error = 4.85917E+00
Greatest Error = 1.82887E+01
Mean Absolute Error = 3.29059E+00

Output listing of file tripol.dat

```
0 542 0
-31154.07900   -269336.22000   1484.39273     1
-31153.93200   -269348.87500   1484.42341     2
     .               .              .         .
     .               .              .         .
-33941.88400   -275390.97100   1578.70722   542
```

Output listing of file tripol.lev

```
  5
1466  1502  1538  1574  1610
  1484.39273
  1484.42341
      .
      .
  1578.70722
```

10. COMPUTER CONFIGURATION

PC version

•IBM PC/XT, PC/AT, PS/2 compatible.

•MS-DOS/PC-DOS Operating System.

•640Kb Memory.

•CGA, EGA, VGA and Herculus Graphics display devices and compatible.

•Diskette Drive.

•Serial/Parallel port for Graphic output.

•Hard Disk required.

•Numeric Coprocessor recommended.

SUN version

•SUN Sparc station

•SUN OS 4.1.1

•OPEN WINDOWS 3.0

UNIX version

•Any machine that runs under the UNIX operating system

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11. REFERENCES

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