NEW ZEALAND AGRICULTURAL
ENGINEERING INSTITUTE

THREE DIMENSIONAL COMPUTER DRAWINGS FOR AGRICULTURAL ENGINEERING

PROJECT REPORT P/17

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1. INTRODUCTION

The sort of three dimensional computer drawings described here are often used as eye catching gimmicks on the front covers of books and journals. It is not often, though, that the way in which these drawings are made is described. In this report the computer drawing technique is outlined in broad terms for the general reader while the details needed to run such a program are provided in an Appendix.

Any phenomenon which can be represented as a surface can be presented graphically using this computer generated method. The results can often be more easily grasped by both engineers and laymen than description by means of contour plans, mathematical formulae, coefficients of variation, or other mathematical or statistical methods.

These three dimensional drawings have a variety of agricultural engineering applications. They have been used as an aid in planning the most suitable earthmoving operations when preparing land for horticulture as the various earthwork patterns can be seen at a glance. The visual representations, together with the costs, assist in decision making (see Figure 1). They have also been used to display the variations in the quantity of water applied to the soil by irrigation sprinklers, and the effect of wind on sprinkler performance (see Figures 2 and 3).

In the future it may be possible to use these projections when planning complex irregular border-dyke irrigation layouts. At present these constitute a difficult problem. If a designer takes the trouble to present a complex layout in detail it is difficult for the machinery operators to interpret the plan in the field. A visual representation may help in meeting both the design and the cost objectives.

The examples show the flexibility of the method and the extent to which these three dimensional drawings can be useful to agricultural engineers. Workers in other fields may also find applications for this method of presentation. The cost of producing any one of the computer drawings illustrated here is no more than about $1.00 at commercial computer charge-out rates.

2. THREE DIMENSIONAL DRAWINGS

2.1 EQUIPMENT REQUIRED

The three dimensional drawings reproduced here were drawn on a plotting machine controlled by a computer. The lines are made by a single pen which is free to

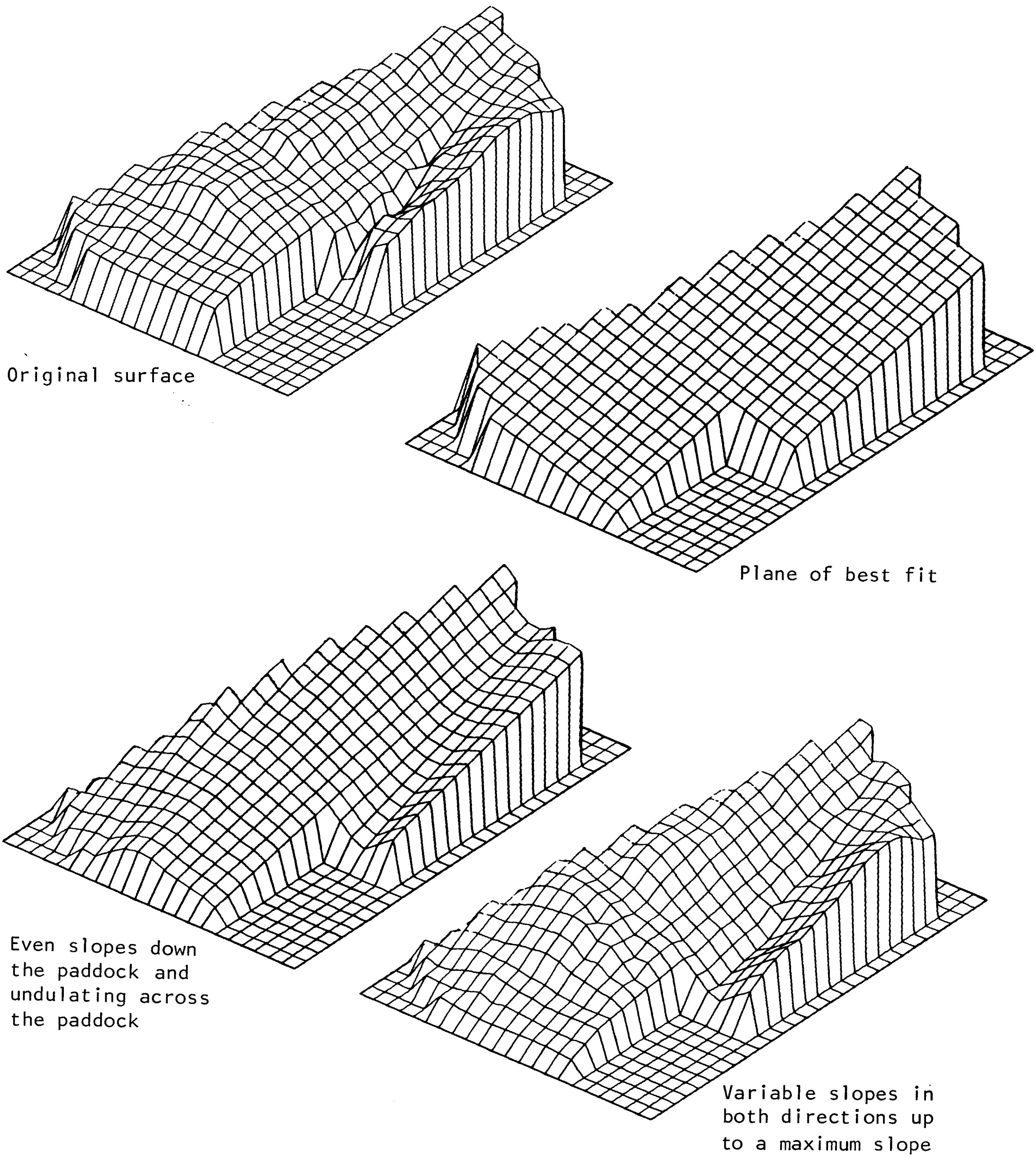
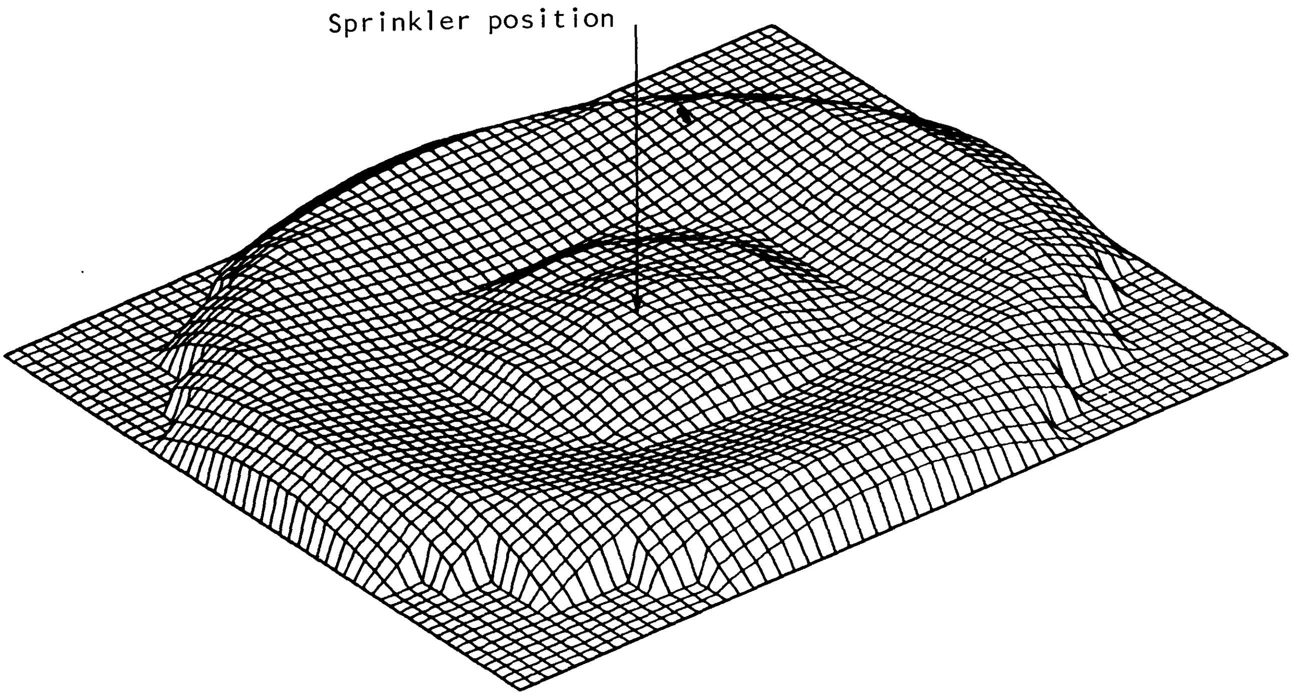
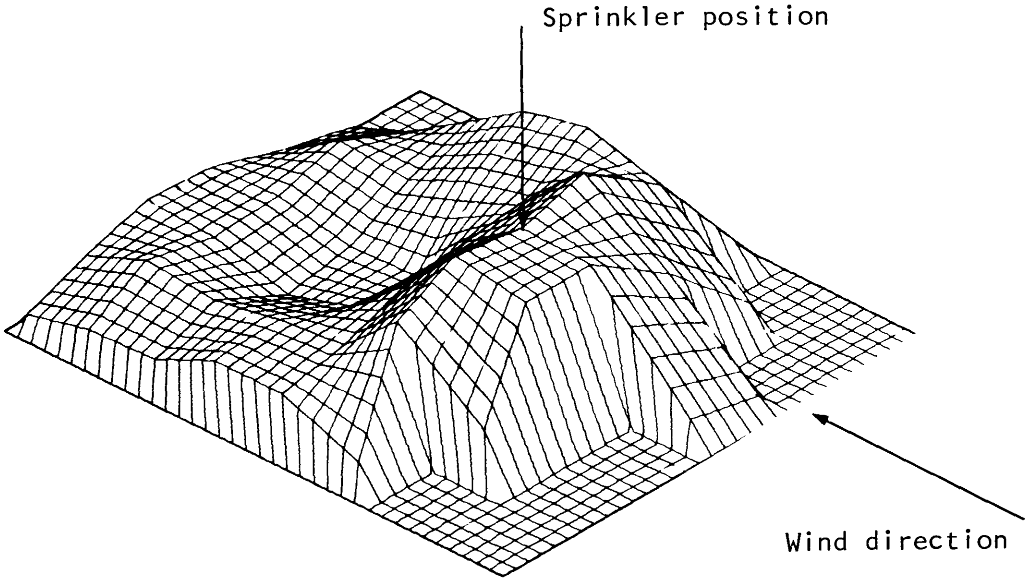


Figure 1. Projections showing the possible modifications to a four hectare block to make it suitable for horticulture.



(a) Still air



(b) Windy

Figure 2. The depth of water spread by an irrigation sprinkler under still air and windy conditions

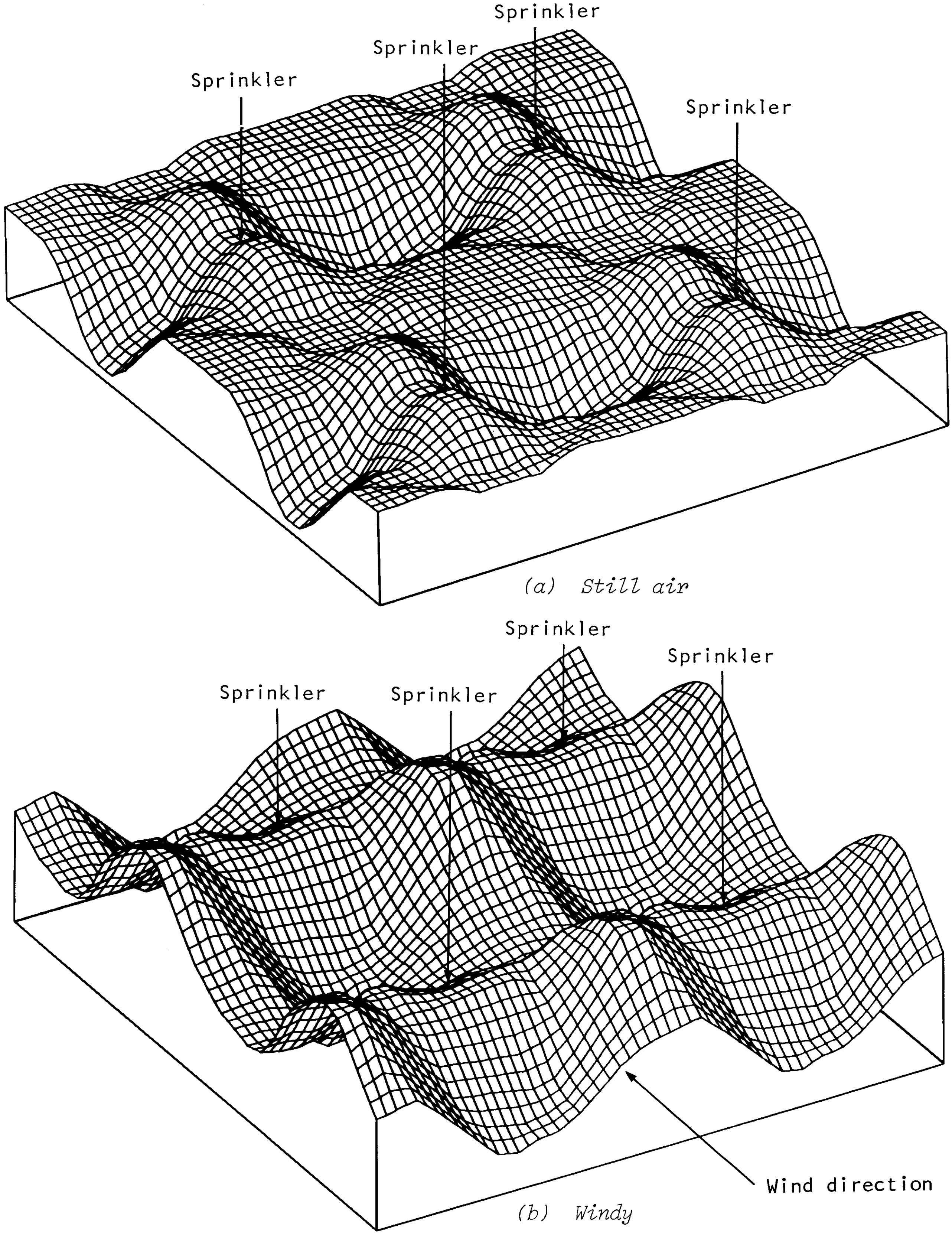


Figure 3. The overlapping patterns from Figure 2 for still air and windy conditions

travel anywhere on the page and can be lowered and raised thus starting and stopping lines where required.

2.2 DATA

To produce these projections a regular grid of spot heights is required to indicate the elevation of the surface above a base level. A spot height must be provided for each line intersection to be shown on the projection. Some of the spot heights may of course be zero.

Regular grids are not always available. However, a computer program may be used to generate this information from a suitable formula or from scatter spot heights (for example, from a stadia survey). Irregular data cannot be plotted directly.

2.3 PLOTTING METHOD

Plotting consists of drawing a series of profiles along each direction of a regular grid of spot heights (that is, along the rows and then down the columns). This forms a 'fishnet' type of surface as shown in Figure 4. Before the lines are actually plotted the

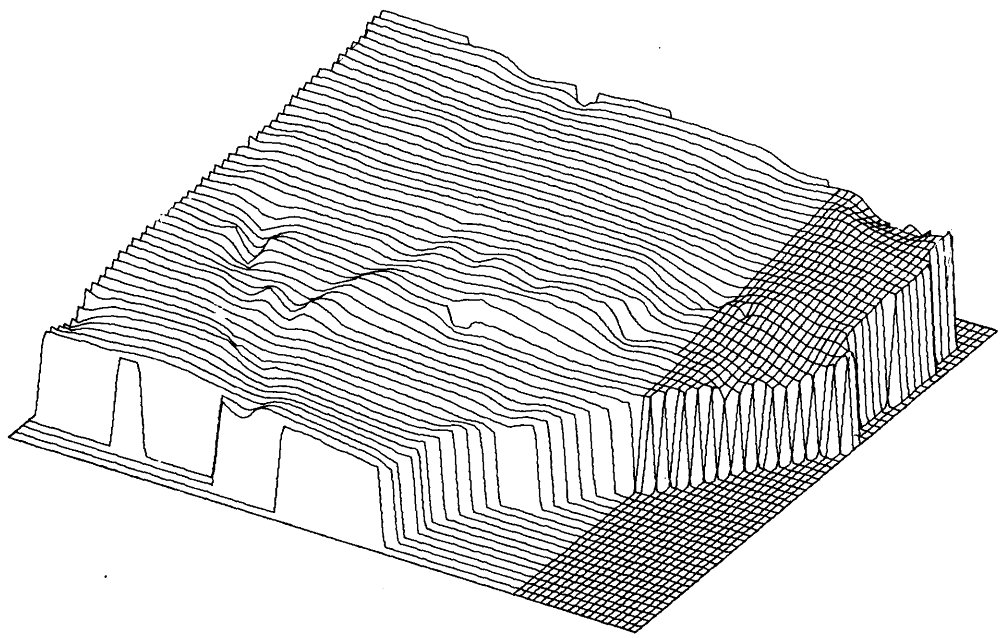


Figure 4. Plotting from the rows of spot heights has been completed while plotting from the columns is not complete. As can be seen each row or column of spot heights constitutes a profile

profiles are mathematically adjusted to allow for any scale distortion required and for the point of view chosen.

2.4 SCALE DISTORTION

The vertical scale need not be the same as the horizontal scale. The relief on the surface can therefore be exaggerated to any desired degree to illustrate pertinent features of the surface (see Figure 5). This

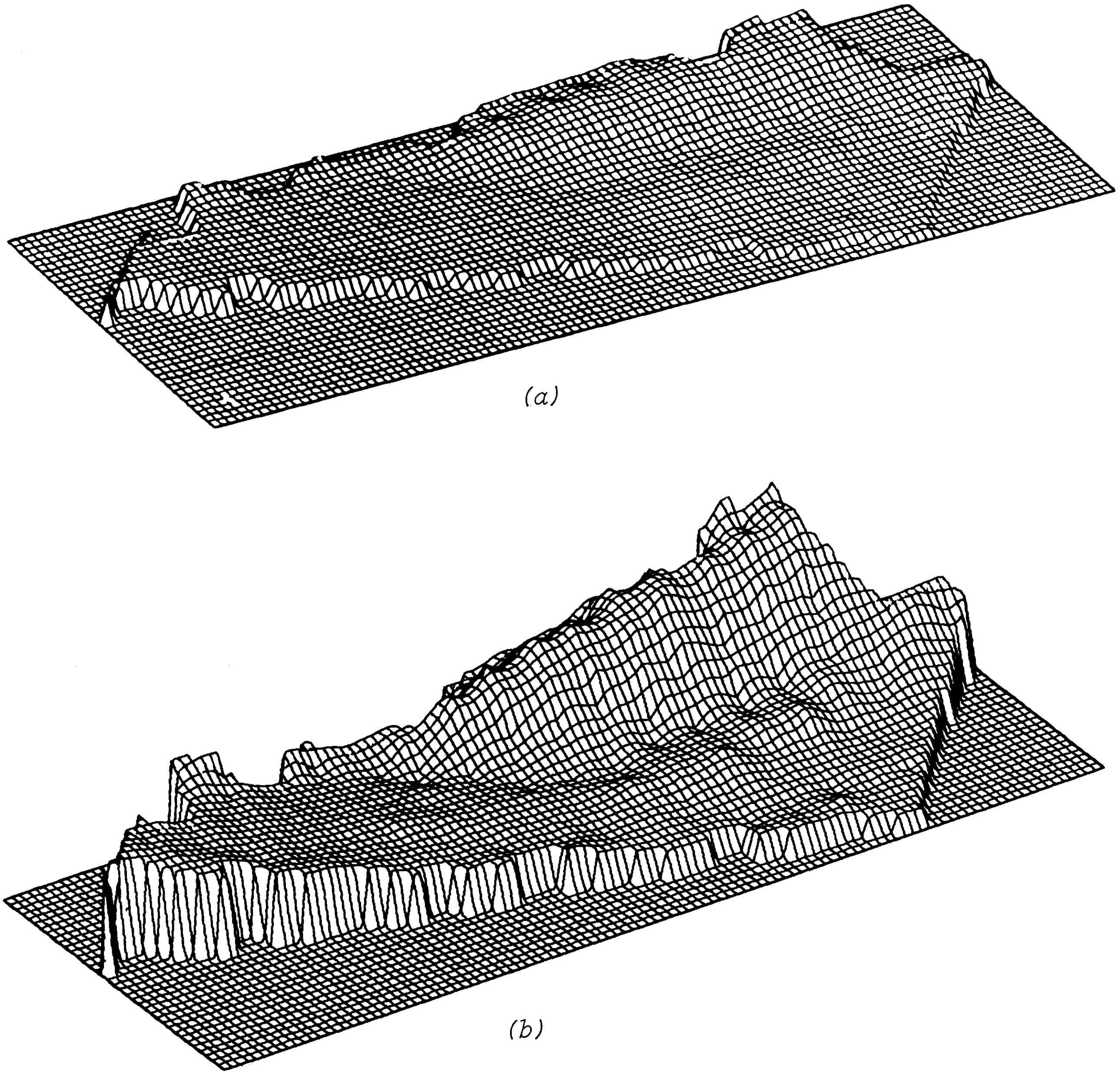


Figure 5. This is a representation of a 20 ha block of land. As illustrated at (b) it has three times the vertical scale of the representation at (a).

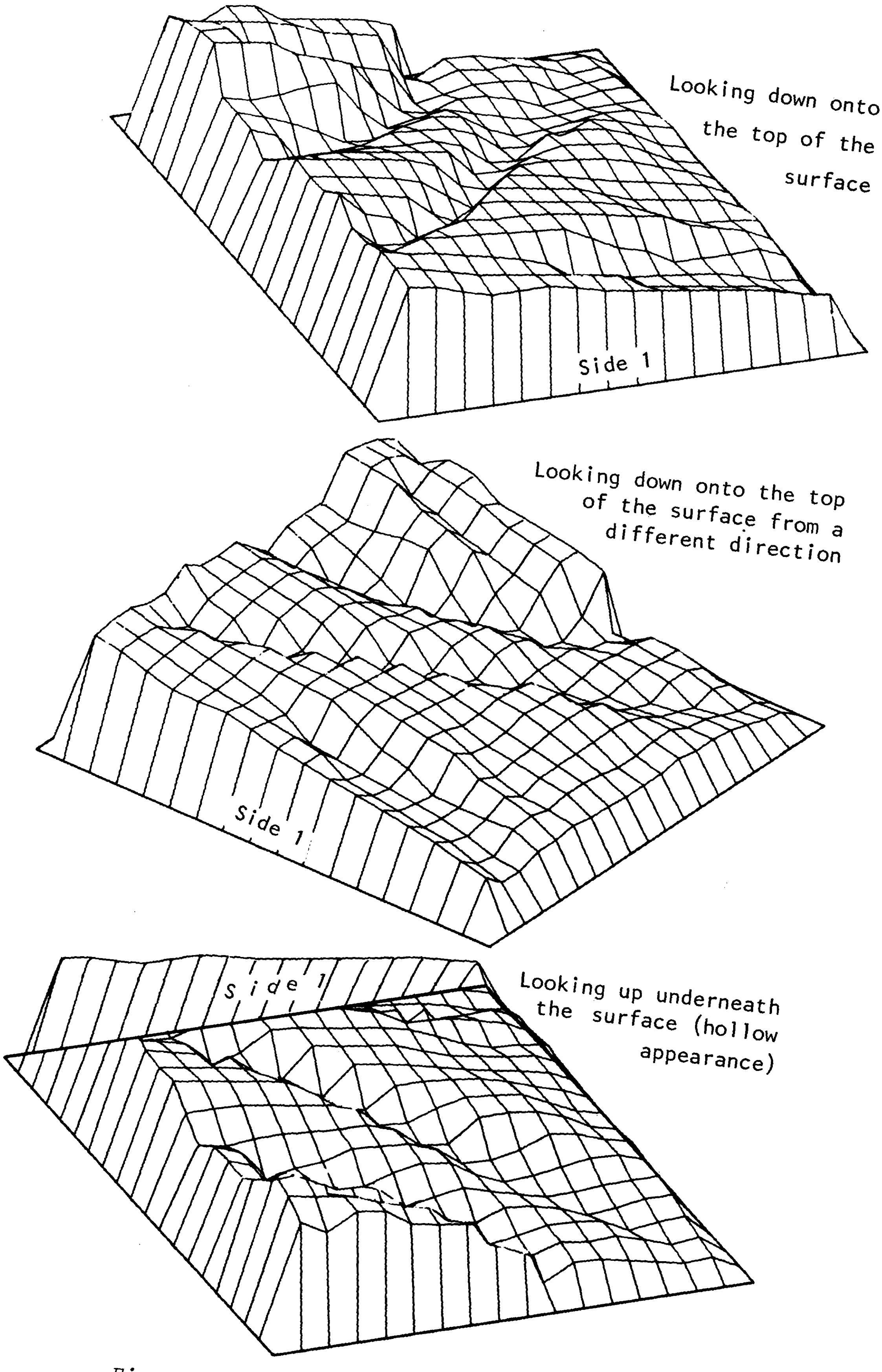


Figure 6. Viewing-angle changes

is a distinct advantage compared with a photograph (particularly of topography) where minor relief is usually indistinct. This minor relief may be very important for surface irrigation or drainage.

2.5 VIEWING ANGLE

The view of the surface is determined by the angles through which the surface is rotated. These angles may refer to a horizontal or a vertical axis or both. Changes in the viewing angle are illustrated in Figure 6 where the surface is seen from two different points of view, both looking down on it, and from a third point of view looking up from underneath the surface.

2.6 REMOVING HIDDEN LINES FROM PROJECTIONS

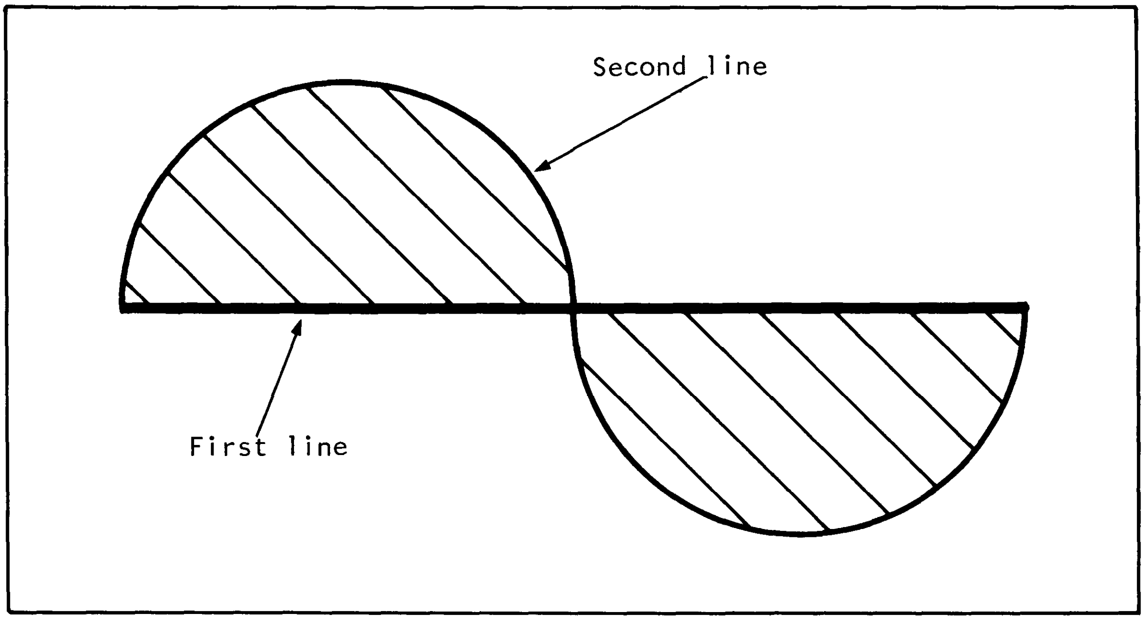
From certain points of view some of the surface represented by the projections would be obscured from the observer by features in the foreground. If these hidden lines are plotted they may confuse the viewer and so automatic methods of removing them have been developed. A masking technique is used in which the machine plots the lines in the foreground first, working from there back to the lines furthest from view. The computer remembers the positions of the first two lines (representing profiles of two rows of data) and when plotting the third line the space enclosed by the first and second lines forms a <u>mask</u> in the computer memory and no further lines are plotted in this area (see Figure 7). The procedure is repeated for each successive row with each new line adding to the area of the mask. The lines plotted at right angles to the first series (that is, from the columns of data) begin a new mask and continue as before.

The procedure is not perfect unless the lines are plotted in one direction only (see Figures 7 and 8) because in some cases the rows should obscure the columns and <u>vice versa</u>. The incorrect lines are easily removed from the final copy by hand.

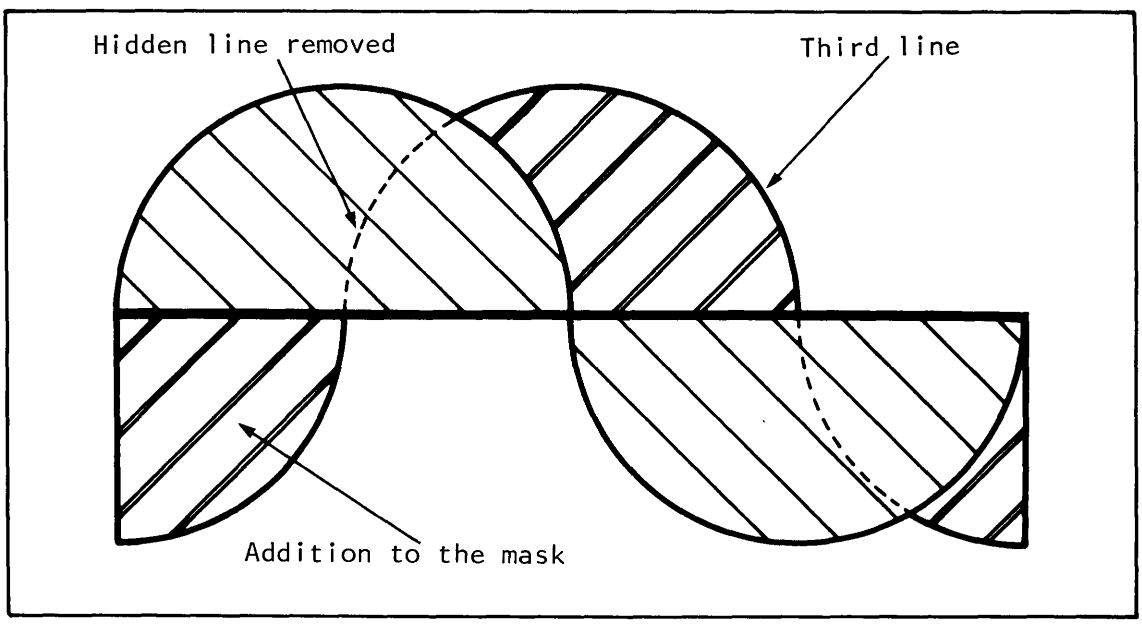
It may sometimes be desirable to plot the otherwise hidden lines; for instance, to generate a steroscopic pair of three dimensional projections. These can be viewed through a stereoscope to see 'inside' the surface.

2.7 MATHEMATICAL TRANSFORMATIONS

The plotting procedure consists of directing the plotter to draw a series of short straight lines between each spot height on the regular grid. To achieve the three dimensional transformation the location of the end points of each individual short straight line (segment between spot heights) must be positioned to give the desired view of the surface. The result is a rotation and a change in length of each line segment.



(a) the mask is shown as the shaded area



(b) increase in masking space with an additional line

Figure 7. Masking technique for the projections

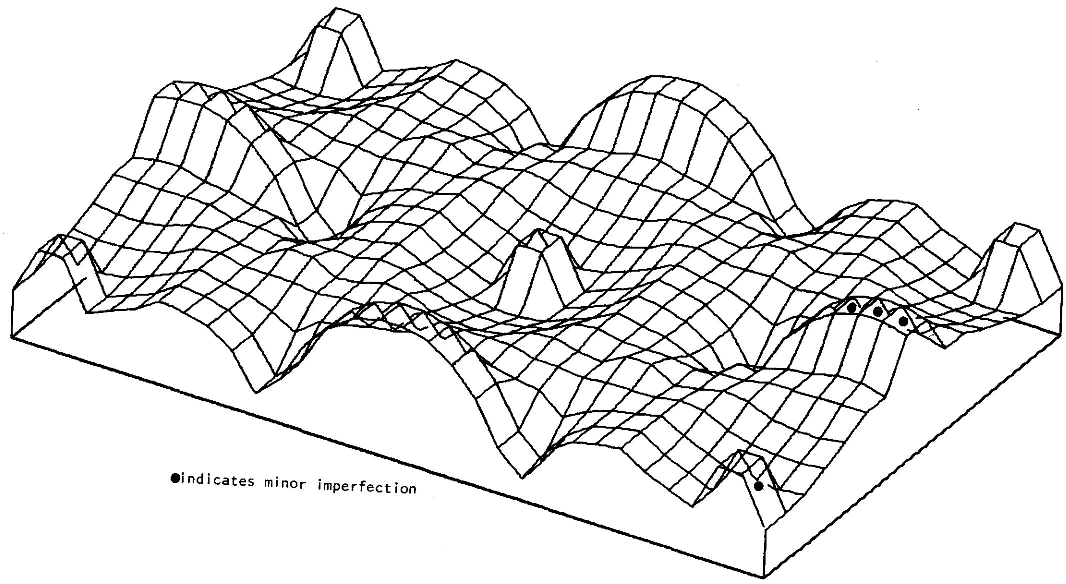


Figure 8. Showing the distribution of water from frost protection sprinklers. The sprinklers coincide with the five small peaks on the surface. Some typical minor imperfections in the masking technique are indicated.

The choice of axes, and the original position of the surface in relation to the axes, are arbitrary. Usually the base is drawn parallel to a horizontal plane.

A typical transformation of a spot height which can be considered to have co-ordinates x,y,z, as shown in Figure 9, is as follows:

The viewing plane is the X-Y, plane and so the point (x, y, z,) would be positioned at point (x,y) on the X, Y, plane when the viewing direction is along the Z axis.

If the point is first rotated about the X axis by an angle θ then the projected position on the X-Y, plane as viewed by the observer will change to:

$$x' = x \qquad \ldots (1)$$

$$y' = y\cos\theta + z\sin\theta. \qquad \ldots (2)$$

The reference axes are then X,Y',Z'.

If a further rotation is performed about the Y' axis through an angle of φ, the projected position on the X-Y plane will then be transformed to:

$$x'' = x\cos\phi - z\sin\phi \qquad \ldots (3)$$

$$y'' = y\cos\theta + x\sin\theta\sin\phi + z\sin\theta\cos\phi. \qquad \ldots (4)$$

These equations provide the basic transformations for rotation about two axes and they are used in the plotting programs illustrated.

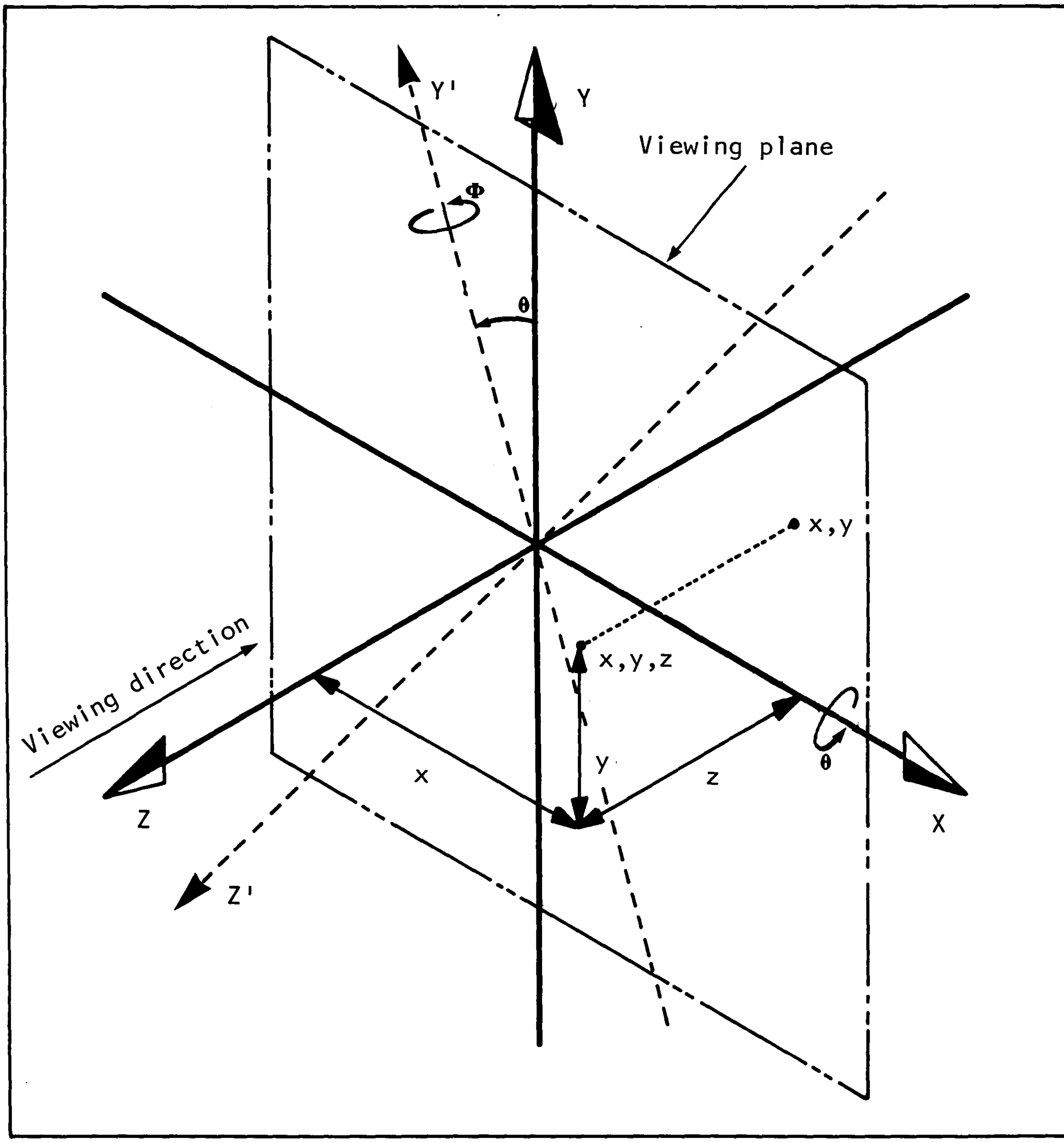
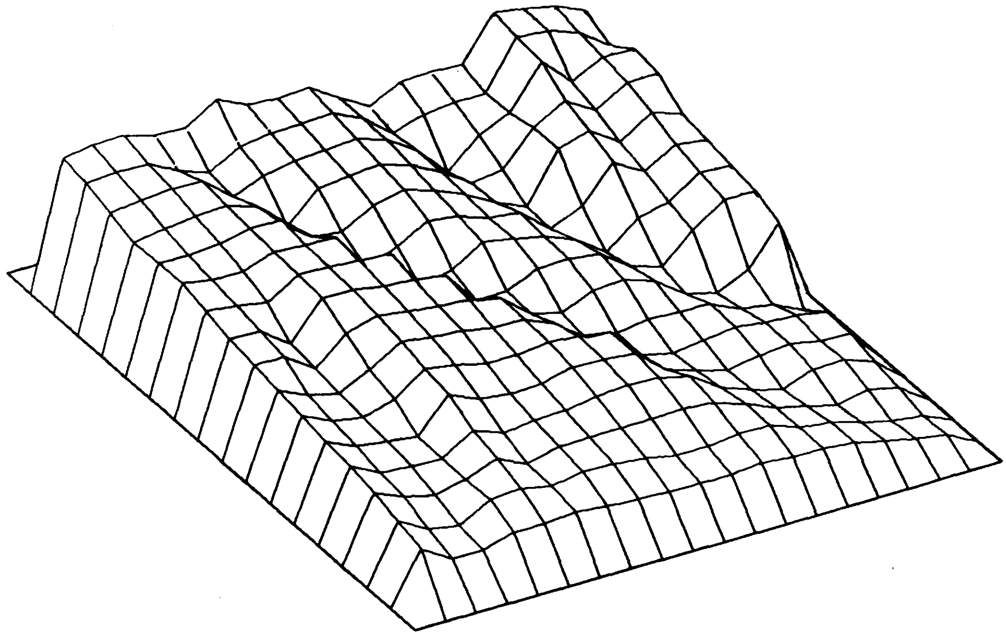


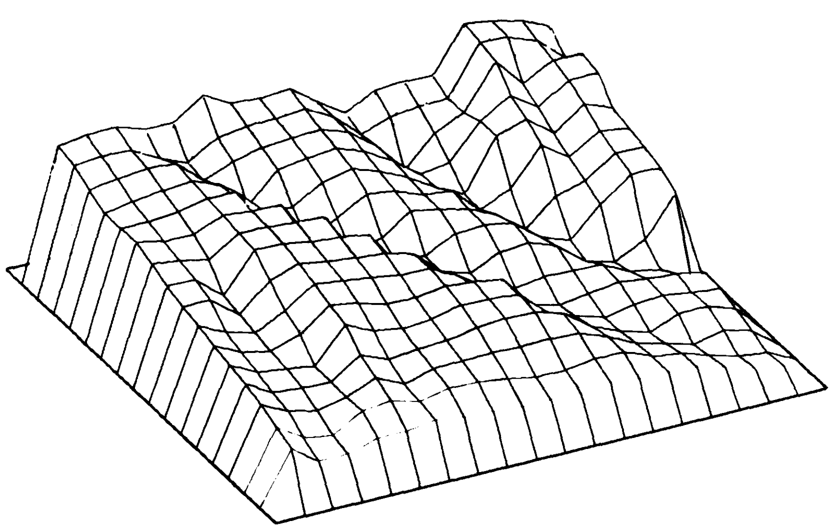
Figure 9. A typical transformation of a spot height considered to have co-ordinates x,y,z

2.8 PROJECTION TYPES

When a three dimensional solid is transformed using the equations 1 to 4 above, the lengths of the segments between adjacent grid points are shorter than their true length. Furthermore the Z axis may be shortened to a different degree compared with the X axis. There is, therefore, some difficulty in taking measurements directly from the projections. By increasing the distance between the grid points so that the projected lengths of the grid spacing are the same as the original, an 'isometric' view is obtained and measurements may be easily made parallel to the axes, (see Figure 10).



Isometric drawing



Non-isometric projection

Figure 10. A non-isometric and an isometric view of the same surface. In the isometric drawing the distance between grid points is increased to equal the true length, rather than the projected length shown by the non-isometric projection.

The following equations are used to increase the grid spacing to produce isometric projections.

$$G\ X' = GX/(\sin^2\theta\sin^2\phi + \cos^2\phi)^{\frac{1}{2}} \qquad \ldots (5)$$

$$G\ Y' = GY/(|\cos\theta|) \qquad \ldots (6)$$

$$G\ Z' = GZ/(\sin^2\theta\cos^2\phi + \sin^2\phi)^{\frac{1}{2}} \qquad \ldots (7)$$

where

GX is the original grid spacing, X direction

GX' is the increased grid spacing, X direction

GY is the original height

GY' is the increased height

GZ is the original grid spacing, Z direction

GZ' is the increased grid spacing, Z direction

This type of computer system can also be used to generate perspective images but because of the purely descriptive nature of these the additional sophistication required was not considered to be warranted in this context.

3. CONTOURS IN THREE DIMENSIONS

3.1 GENERAL

The fish-net type of three dimensional projection gives a good visual impression of a surface. For planning engineering works directly on the surface, however, the additional information given by contours is needed and is provided by this program. Like the profiles which form the fish-net surface the contour lines are composed of a series of short straight line segments and may be transformed on to the viewing surface in the same way (see Figure 11).

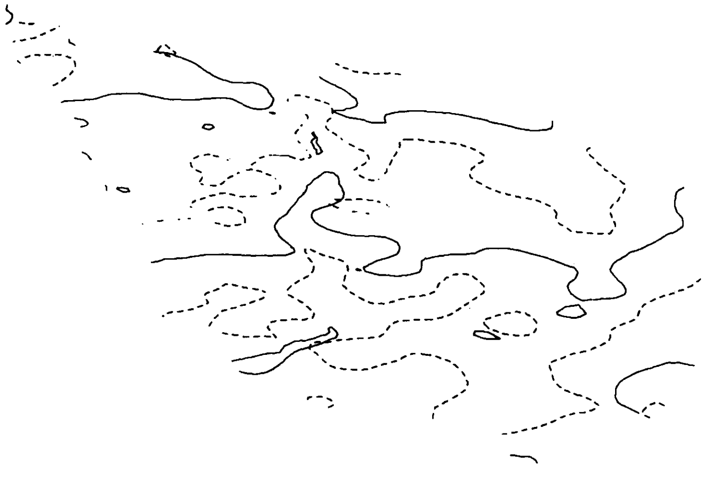
3.2 HIDDEN LINE REMOVAL FOR CONTOURS

The masking technique used with profiles for the fish-net surface is not used on transformed contours because the mask would be very difficult to manipulate in the computer memory.

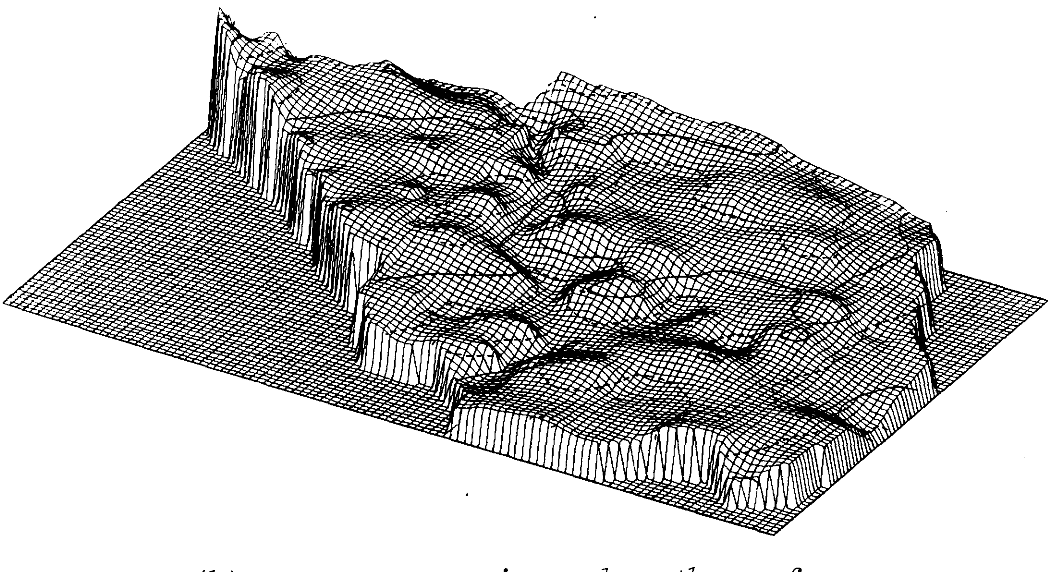
Instead, the procedure consists of drawing an imaginary line from the end of each line segment towards the observer. The position such a line would have in relation to the surface is checked at intervals along the line to see whether it is above or below the surface. If, at any stage, the line changes from above to below the surface or from below to above the surface then the point in question is not in view and the line segments on either side of the point are not plotted.

The imaginary line may originate from below or above the surface depending on whether the surface is being viewed from below or above.

Where a very fine grid spacing is used this procedure may require excessive computer time; in which case, hidden contours may be removed manually.



(a) Contours



(b) Contours superimposed on the surface

Figure 11. Contours of a surface shown independently at (a) and, at (b), superimposed on the surface.

4. CONCLUSION

It has been shown that three dimensional computer drawings can be used for more than purely descriptive purposes and that contours can be added automatically to these drawings.

As this program is one of a number designed for different purposes the interested user is referred to his local computer installation for information on the particular programs available.

APPENDIX

C3D COMPUTER PROGRAM DESCRIPTION AND USE

The programs PLT3D and CON2R of the University of Canterbury have been adapted, modified and extended to produce C3D. (Burroughs B6700 series computer).

The FORTRAN IV program 'C3D' uses a disk data file generated by an independent program. If more than one plot file is generated by the originating program then each file name can be changed to DTMDATA immediately prior to running C3D. The file attributes are as follows:

```
(TITLE      =   'DTMDATA', MAXRECSIZE  =  1,
 BLOCKSIZE  =   120, AREASIZE  =  6000,
 FLEXIBLE   =   TRUE, KIND  =  DISK)
```

The file is composed as follows:

RECORDS 1 to 11	TITLE in A4 format
RECORD 21	Number or rows. I format
RECORD 22	Number of columns. I format
RECORD 23	Plotted row spacing (inches). F Format
RECORD 24	Plotted column spacing (inches). F format
RECORD 25	Contour interval. F format

RECORDS 101 onwards are used to store spot heights according to the formula below:

RECORD No. = 100 + (NNR -1) * NTC + NNC

where

NNR = Row number (greater than 0)

NNC = Column number (greater than 0)

NTC = Total number of columns, but not necessarily as large as the array size dimensions below.

The main data array which uses the disk file data stores data according to the following convention:

ARRAY (No. of Columns, No. of Rows)

The maximum array size dimensioned in the program is 121 x 121.

The program C3D is written with default values for all other variables and may be run using the above disk file data only. The default values may be changed by reading two additional data cards at execution time.

The minimum non-zero number in the array is found by C3D, and the height of the array is reduced to leave only the surface variation height (YHGHT). Alternatively the height of the projection may be truncated by specifying a minimum value (SMIN) to suit the particular application. If a vertical scale (YSCLED) is specified then this over rides the YHGHT specification.

The first card format is as follows:

FORMAT (4I2, 11A4 2F8.3)

VARIABLE	DESCRIPTION	DEFAULT VALUE
1 NC	The number of columns extending out each side of the projection at the base level	1
2 NR	As above for rows	1
3 NCROSS	0 - for cross hatched plot 1 - for row direction plot only 2 - for separate plots of row and column directions 3 - for column direction only	0
4 NTITLE	If a change of title is required NTITLE is specified greater than zero	0
5 TITLE	NTITLE is greater than zero the 'new title' written in this space will be used instead of the title stored on disk (11A4	from disk file data
6 SMIN	The minimum height to be plotted above the base plane. For SMIN = 0 use SMIN = 0.0001 or some other insignificantly small number	lowest non-zero data point
7 YSCLED	The vertical scale in units per inch	refer to YHGHT

The second card format is as follows:

FORMAT (11F7.2, 3I1)

VARIABLE		DESCRIPTION	DEFAULT VALUE
1	PHY	The angle of rotation about the Y axis (degrees). Specify greater than 360 for PHY = 0.0.	-30.0
2	THETX	The angle of rotation about the X axis (degrees). Specify greater than 360. for THETX = 0.0 Set THETX = -90.0 for an ordinary contour plan.	-30.0
3	YHGHT	The spot heights are scaled to give this variation in the surface height (inches).	2.0
4	XINC	The distance between column grid points (inches).	from disk file data
5	ZINC	The distance between row grid points (inches).	from disk file data
6	XREF	The X position on the page of the point ARRAY (1,1) (inches).	automatic
7	YREF	The Y position on the page of the Point ARRAY (1,1) (inches).	automatic
8	XLTH	The length of plot page (inches).	automatic
9	FRAME	0 for no frame around plot base. 1 for frame around plot base.	1
10	CONTR	Contour interval (metres).	from disk file data
11	CLAB	Contour labeld written if CLAB is greater than zero.	0.0
12	MC3D	0 for contours plus a separate projection. 1 for contours only. 2 for contours and projection superimposed. 3 for projections only.	0
13	MASKCN	0 for hidden contour line removal. 1 leaves hidden contour lines present.	0
14	ISOM	0 for projection grid spacings. 1 for isometric grid spacings.	0

NOTE

Some of the dimensions described above are specified to be in inches. This because the plotter used works in increments of 0.01 in. If input data is converted from metric to imperial units within the program a significant rounding off of errors may result in some cases. Therefore, the input must be in imperial units.

OTHER N.Z.A.E.I. PROJECT REPORTS

P/1 The Effect of Fire on Standard 8 S.W.G. and High Tensile 12 S.W.G. Plain Fencing Wire: G.M. Garden (August 1967).

P/2 The Hydraulic Performance of Trough Valves: T.D. Heiler (July 1968) (2nd Edition May 1971) (out of print).

P/3 Procedures for testing trench laid plastic drain pipes up to 4" diameter: T.D. Heiler (July 1968) (out of print).

P/4 A Provisional Test Procedure for Crawler Tractor Safety Frames: E.M. Watson and G.M. Garden (July 1971).

P/5 Procedure for testing Broadcast-type Distributors used for the application of granular insecticide: J.E. Hager and K.R. Humphries (August 1969) (out of print).

P/6 Procedures for testing Boardcast-type Fertiliser Distributors: K.R. Humphries (February 1971).

P/7 Tractor Safety Frame Noise Levels: G.M. Garden with Medical Assessment by J.F. Copplestone (March 1971).

P/8 The Spinning Disc Distributor Part 1: G.R. Davies (February 1972) (out of print).

P/9 The Spinning Disc Distributor Part 2: G.R. Davies (February 1973) (out of print).

P/10 Flow Characteristics of Plastic Drainage Pipe available in New Zealand: M.S. Humphris and G.J. Harrington (June 1973).

P/11 The Flow Characteristics of some Pressure Reducing Valves: G.J. Harrington (October 1975).

P/12 Liquid Manure Pumps: Procedure for Clean Water Hydraulic Testing: A.J. Dakers (July 1976).

P/13 Contouring by Computer from Stadia Field Data: G.J. Harrington (May 1976).

P/14 Report on the Bruff TG1 Trenchless Drainlayer: V.J. Bidwell (October 1976).

P/15 Wind erosiveness summaries for New Zealand sites: D.J. Painter (June 1977).

P/16 Field drainage guide: V.J. Bidwell (May 1978)

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