CONTOURING AND EARTHWORK
ESTIMATION FOR BORDERED
STRIP IRRIGATION

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SYNOPSIS

Computer programmes were developed for processing data from grid, direct, and random stadia field contouring systems. The three systems were evaluated for their use in providing contour plans for bordered strip irrigation design.

A computer method of calculating the earthwork volumes associated with bordered strip irrigation was developed which uses terrain data from the above surveying methods or any other convenient source. This method was compared with land grading to form plane or warped paddock surfaces onto which levees may be formed, thus creating bordered strips.

With the aid of the bordered strip earthwork calculating programme, the effect of changes of bordered strip paddock layout and slope restraints was investigated. An attempt to correlate estimated earthworks with earthmoving machine times was made.

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GENERAL INTRODUCTION

In spite of rising costs, bordered strip irrigation land preparation on major Government schemes and individual farmers' properties is continuing. The cost of the earthworks alone range upward from about $140 per hectare. This irrigation development, therefore, amounts to a considerable capital investment which is a significant percentage of the land value.

In most cases, contractors are unwilling to give firm quotations for earthworks because it is impossible for them to accurately estimate the amount of work which has to be done. They prefer to work on an hourly rate basis for machines. Under this system the contractor cannot lose but it affords no assurance to the farmer or person who hires the contractor that the work is done as efficiently as possible and does not allow for competitive tendering. Unless the farmer records all hours of work by all machines he has no check on the contractor's price at all.

Some of the factors which influence the design of border layouts can be quantified in terms of cost. The most costly factor, the earthworks, has been impossible to estimate with any degree of accuracy. Alternative layouts, therefore, cannot be quantitatively assessed. It is an aim of this study to quantify the earthworks so that more soundly based judgements can be made with respect to earthworks.

A number of different methods of calculating earthwork quantities for land levelling have been developed elsewhere (see Part II) but these methods do not relate well to the current field practice in New Zealand. The number of repetitive calculations required to estimate earthwork quantities based on alternative designs over many thousands of hectares means that the problem is beyond manual solution and in the realm of computer methods. A major practical difficulty, however, is to supply the computer with adequate terrain data on which to perform the calculations.

The approach taken in this study was to develop a computer contouring routine which would process field survey data and produce contour plans, which also serves to provide computer-compatible data for earthwork calculations. Contour plans are currently used for the design of border layouts on all major Government schemes and are recommended for individual schemes also. They are therefore, a good source of data for earthwork calculations.

This report is divided into two main parts:

Part I "COMPUTER CONTOURING" in which the development of suitable computerised contouring methods is discussed.

Part II "EARTHWORKS" in which the development of suitable methods for calculating earthwork quantities for bordered strip irrigation are discussed.

Two computers were available for this work. The main University of Canterbury computer, a Burroughs B6718 with a terminal at Lincoln College, and an older IBM 1130 with only 16K memory. Lately a PDP 11/40 has been installed to replace the IBM 1130. Most of the initial programme development work was done on the IBM 1130, however, because of ease of access to this computer. The 1130 was available 24 hours a day for users to run their own programmes. This enabled the fast turn around of computer jobs which is necessary for rapid programme development.

PART I

COMPUTER CONTOURING

1.0 CONTOUR REPRESENTATION BY COMPUTERS

Contours can be represented by computer on a line printer as well as on a line plotter. With a line printer they can be shown as a series of characters spaced closely together to form a line or they can be shown as the line marking a change in printed characters on the printed computer output (see Figure 1.1). The line plotter may draw the contours directly and label the contour lines.

Contours may also be represented on a graphic display screen. This is particularly appropriate for interactive work such as correcting errors, but it does demand that the hardware is easily accessible which is not the case at Lincoln College. The choice is therefore between a plotter and a printer. The main advantages of using a line printer compared with a plotter are as follows:

(a) There is ready access to the line printer on almost any computer. A line plotter was not available on the IBM 1130.

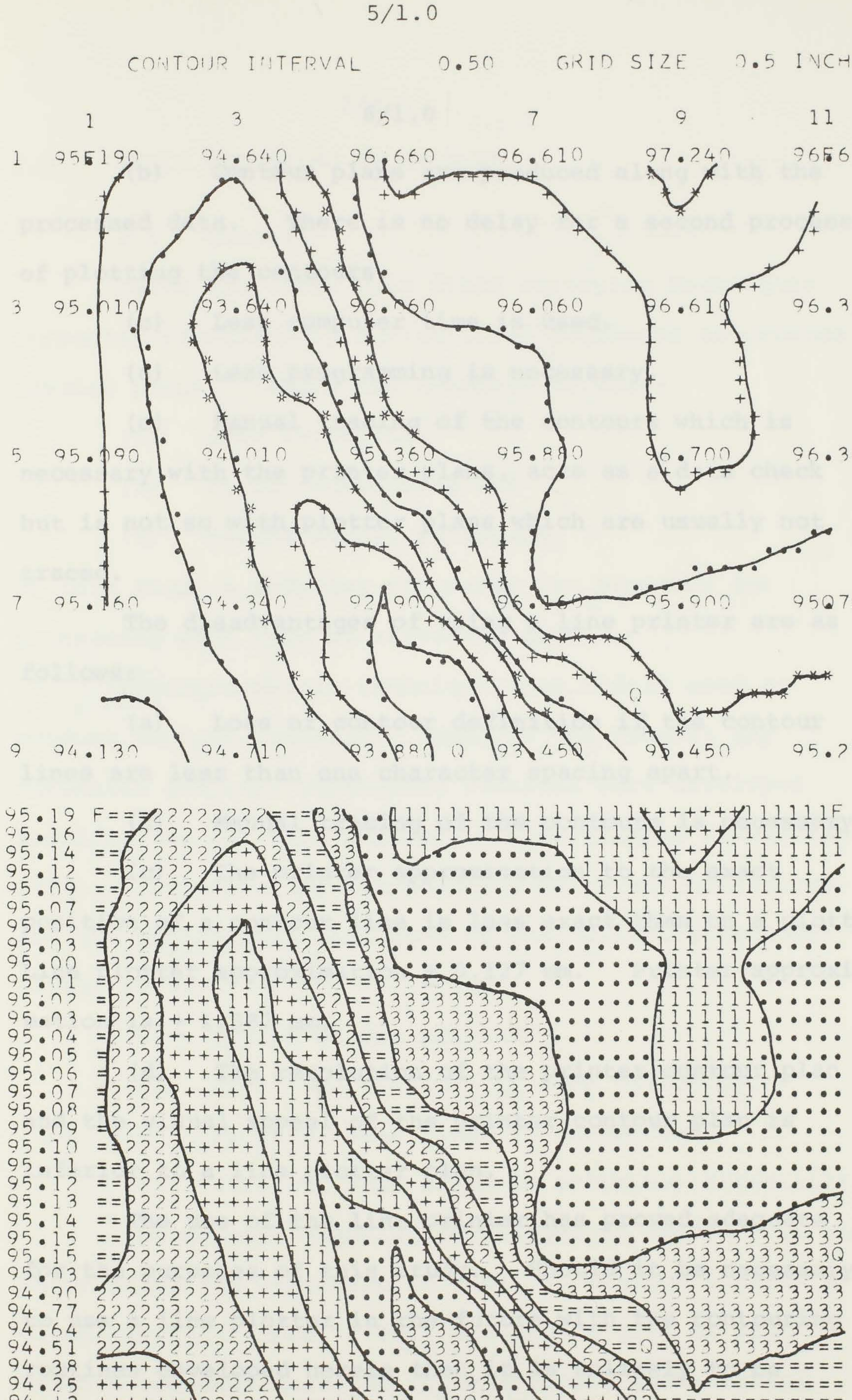


Figure 1.1 Two methods of displaying contours on a line printer

(b) Contour plans are produced along with the processed data. There is no delay for a second process of plotting the contours.

(c) Less computer time is used.

(d) Less programming is necessary.

(e) Manual tracing of the contours which is necessary with the printer plans, acts as a data check but is not so with plotter plans which are usually not traced.

The disadvantages of using a line printer are as follows:

(a) Loss of contour definition if the contour lines are less than one character spacing apart.

(b) Manual tracing of the contours is necessary.

(c) The printer approximation to the exact position of a contour line is less exact than on a plotter. Line plotter approximation $\pm$ 0.127 mm. Printer approximation is $\pm$ 1.587 mm.

(d) The resolution of the printer contour plan and the visual appeal of the printer contour plan is inferior to a line plotter plan.

The use of the line printer has proved adequate for the purposes of this study. Should it be necessary to use a line plotter in the future with the contouring routines developed herein then it is unlikely to be difficult.

2.0 FIELD SURVEYING TECHNIQUES

2.1 General

There are three main field surveying techniques currently practised by agricultural engineers to produce contour plans. These are commonly termed:-

(1) grid surveying,

(2) direct contouring and

(3) random stadia surveying.

In this study a computer programme was prepared for processing each type of surveying data.

Photogrammetric techniques are widely used to produce terrain contours. Many of the present day automatic computer contouring routines were developed specifically for this purpose. (For example Stewardson 1972). Briefly, the stereoscopic pairs may be scanned and the photographs digitised by the following methods:- (Yoeli 1975).

(a) Random sample points,

(b) Digitised contours by line following,

(c) Parallel scan lines of photograph,

(d) Straight scan lines in arbitrary directions.

The easiest scanning techniques to automate is (c) which scans the stereoscopic model at regular intervals along parallel lines. This produces a grid of spot heights commonly referred to as a square grid Digital

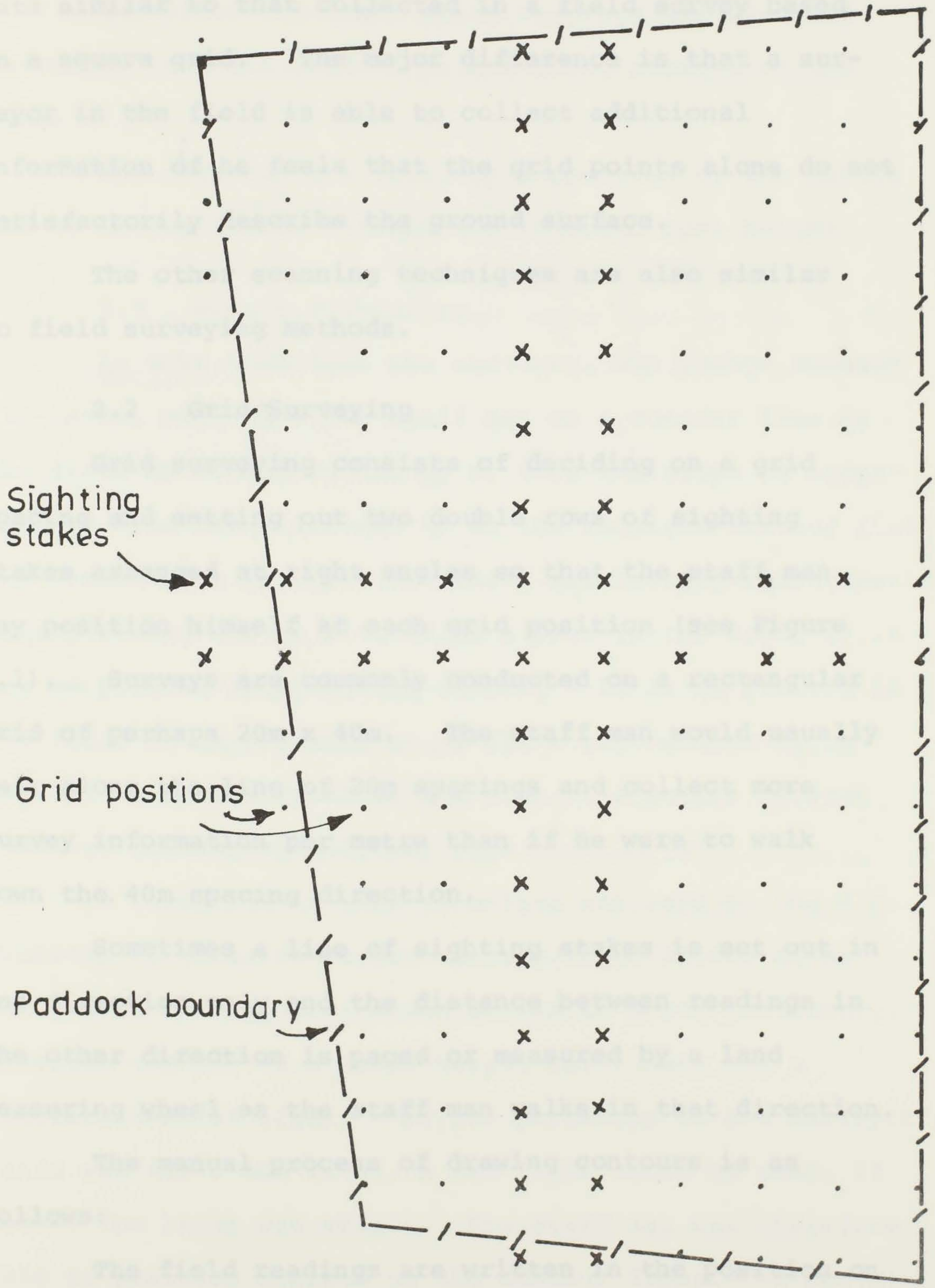


Figure 2.1 Layout of sighting stakes

Terrain Model (DTM). Such scanning techniques produce data similar to that collected in a field survey based on a square grid. The major difference is that a surveyor in the field is able to collect additional information if he feels that the grid points alone do not satisfactorily describe the ground surface.

The other scanning techniques are also similar to field surveying methods.

2.2 Grid Surveying

Grid surveying consists of deciding on a grid spacing and setting out two double rows of sighting stakes arranged at right angles so that the staff man may position himself at each grid position (see Figure 2.1). Surveys are commonly conducted on a rectangular grid of perhaps 20m x 40m. The staff man would usually walk along the line of 20m spacings and collect more survey information per metre than if he were to walk down the 40m spacing direction.

Sometimes a line of sighting stakes is set out in one direction only and the distance between readings in the other direction is paced or measured by a land measuring wheel as the staff man walks in that direction.

The manual process of drawing contours is as follows:

The field readings are written in the position on the plan representing the position in the field.

Sometimes the field staff readings are used and sometimes they are reduced before being plotted on the plan.

The contours are found by inspection of the levels and by interpolation between the recorded spot heights.

2.3 Direct Contouring

In this technique the surveyor, who sights through the level, positions the staff man on a contour line in the field by directing him up or down the slope as necessary. When the staff man is on the required contour line the position is recorded by stadia and bearing measurements. This position may be plotted on a plan in the field or it may be plotted later in the office. If it is plotted in the field it is possible to re-check the reading if it appears to be incorrect on the plan. A series of such readings defines the contour line.

A variation in this technique was used by the N.Z. Ministry of Works to contour survey about 12,000 ha on the Morven-Glenavy Irrigation Scheme in South Canterbury. A beacon was set at a known height which sent out a rotating beam of light. If the periscope on the surveyor's staff was above the level, a red light could be seen, if below, the light was white. The staff man was therefore able to position himself on the contour lines. A shovel full of lime was used to mark each position of the contour on the ground. These patches of lime were very clearly shown on the aerial photographs and the contours were formed by joining up the appropriate patches.

2.4 Random Stadia Surveying

The staff man is free to take readings at any point in the area to be surveyed using this system. The usual method is to take readings on the boundaries of the survey area and at key points within the survey boundary. These key points are usually at changes of grade in the land or local extrema such as valley bottoms, ridge tops etc. The readings are seldom plotted in the field but rather in the office. The reduced levels or the original field staff readings may be plotted on the plan. Contours are found by inspection of the spot heights and interpolation between the readings. Clarke (1957) stated that "this system is the most popular, particularly on large surveys". He also describes a method of sections where a series of levels are taken along defined lines which are not necessarily parallel but spaced and angled to suit the topography. Yoeli (1975) also considers that terrestial surveys are usually carried out in the random point fashion.

The field practice in New Zealand varies between surveyors and organisations. A practical field test (see Appendix 4) was carried out using the three main methods of surveying. Each method was attempted twice to show the variation between surveying teams using the same general method.

Random stadia surveying was shown to be by far the most rapid method in the field and was considerably more flexible to cope with actual field situations.

3.0 COMPUTER PROCESSING OF FIELD SURVEYS

3.1 General

All of the field surveying methods mentioned above are suitable for computer data processing but the limitations and/or advantages of computerisation are not fully realised until computer methods are actually applied. The practical field comparison described in Appendix 4 was carried out following the development of the grid and the direct contouring computer methods and served to inspire the development of the random stadia system. Random stadia systems have been used in the past in Australia for agricultural engineering surveys (Heiler pers. comm), but their use was abandoned because the programmes were unable to interpret the random data sufficiently well to produce satisfactory contours.

A description of the computer methods developed for survey data processing follow.

3.2 Grid Surveying Programme

3.2.1 Background

Boughton (1969) developed a computer grid contouring routine for terrain surveys. It was decided to begin with this basic programme and modify it to suit the current requirements. A close examination revealed that the programme had considerable limitations.

(a) The programme as it stood was limited to reduced levels on a square grid. The data could not be used directly from the field survey, it had to be manually reduced.

(b) The grid levels were plotted on a one-inch square grid on the printout. This is due to the character spacing of 1/10 inch along a line and 1/8 inch between lines of characters. The square grid on the printout is therefore formed by using 10 character spaces along the line of printout and 8 lines down the printout page. This restricted grid size limited the scale of the plan to a scale of one grid spacing equal to one inch. For the common grid spacing of 20m the scale that resulted was 787.4 to one.

(c) The contouring system used a line of characters to delineate the contour line (see Figure 1.1). The interpolation of the spot heights to position the characters which form the contour line was carried out across the page only. When the contour lines also ran along the lines of computer output then very few characters were shown on the output to mark the line.

(d) Every fourth contour line was marked with asterisks. All the other contours were marked with full-stop characters. It was difficult to differentiate between the contours marked with the full stops when the contours were close together.

(e) Because the grid system imposed rigid limits on the position where spot heights could be read, sharp discontinuities such as valleys and ridges which did not coincide with a row of readings were interpreted as a series of humps or hollows centred on the occasional recorded spot heights in valleys or ridges (see Figures 3.1 and 3.2).

(f) The programme as it stood was very inefficient of computer time. Each single character used to mark the contour lines was printed separately. This meant that the printout was very slow especially on the relatively slow line printer attached to the IBM 1130 computer.

15/3.2.1.

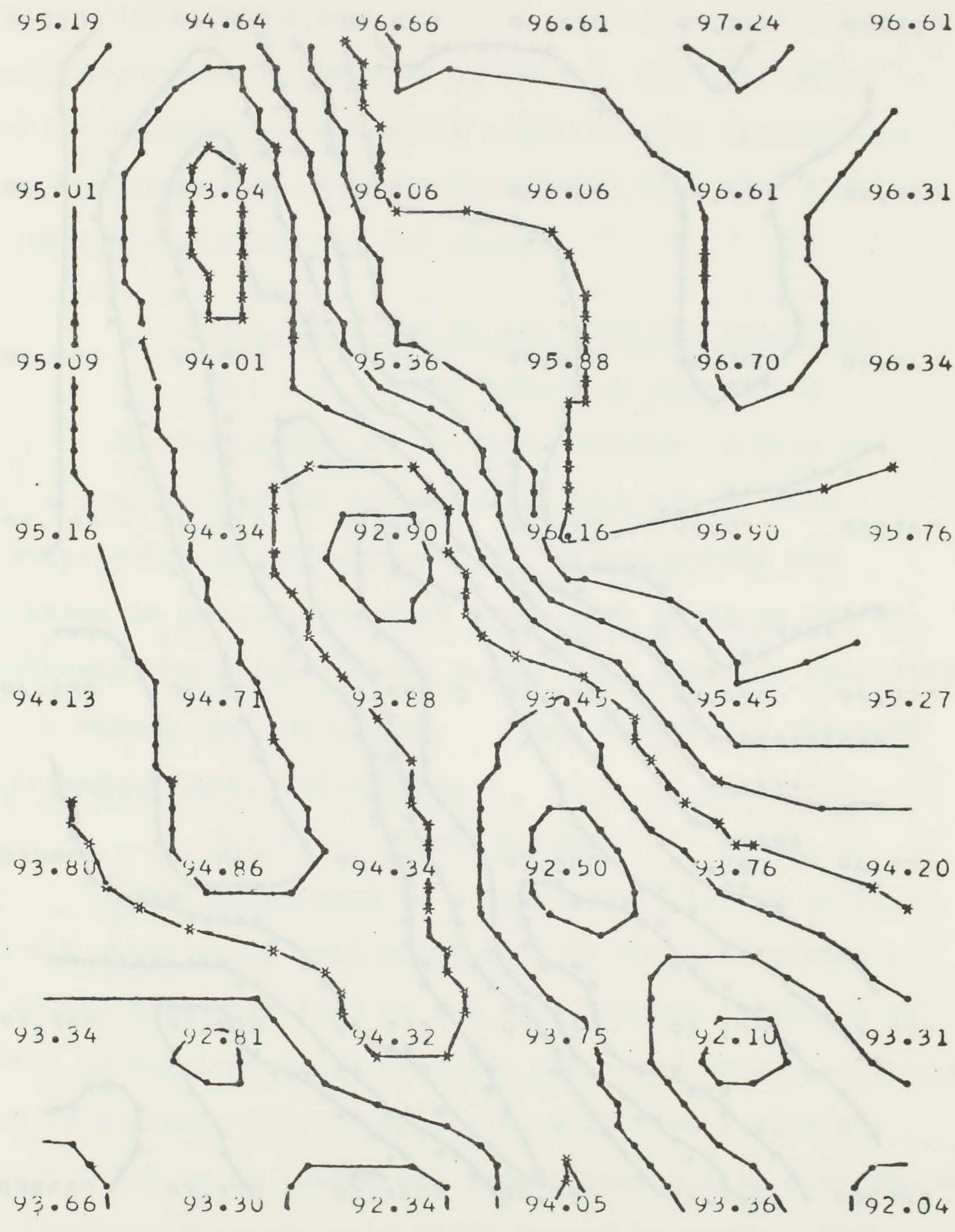


Figure 3.1 Contour plan showing a valley as a series of hollows. (Boughton 1969)

16/3.2.1

CONTOUR INTERVAL 0.50 GRID SIZE 0.5 INCH

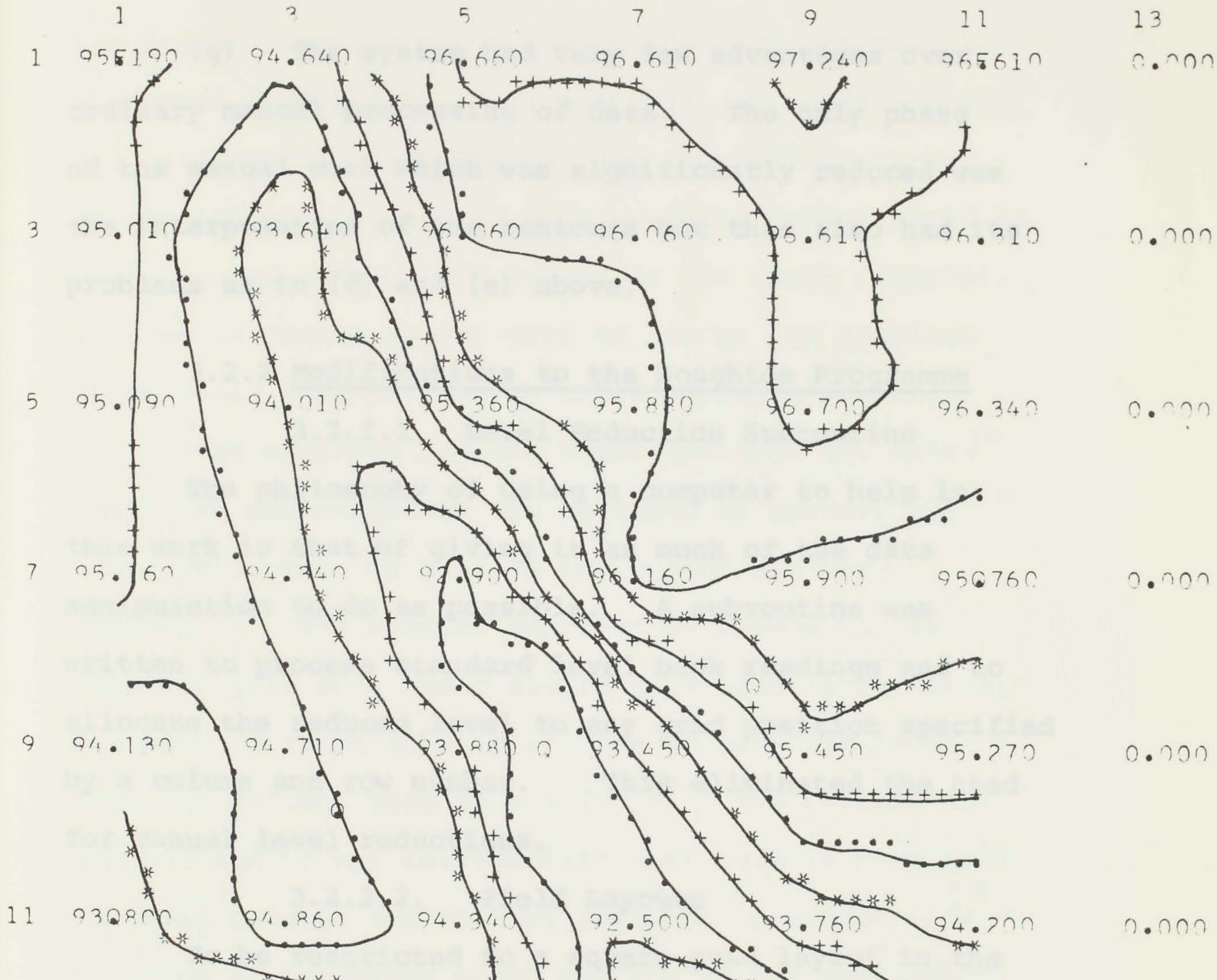


Figure 3.2 Contour plan showing the valley in Figure 3.1 without the hollows. Additional data was inserted to give this effect.

(g) The system had very few advantages over ordinary manual processing of data. The only phase of the manual work which was significantly reduced was the interpolation of the contours but this also had its problems as in (d) and (e) above.

3.2.2 Modifications to the Boughton Programme

3.2.2.1 Level Reduction Subroutine

The philosophy of using a computer to help in this work is that of giving it as much of the data manipulation to do as possible. A subroutine was written to process standard level book readings and to allocate the reduced level to any grid position specified by a column and row number. This eliminated the need for manual level reductions.

3.2.2.2. Field Layouts

To be restricted to a square grid layout in the field where every grid point must be levelled places a considerable work load on the field survey in excess of what is required for manually processed data. Although it is suitable for a computer to work with a square grid there is no reason why a rectangular grid composed of multiples of square grid units cannot be used. The effect of this is to allow the survey to be carried out on a rectangular grid of (say) 20m column spacing and

40m row spacing which is common practice for manually processed survey data. If the data are collected on the rectangular grid, they must then be used to interpolate the missing square grid readings (which would be every second column spot height in the above example). This would form a square-grid of 20m by 20m spacings which could then be used by the contouring routine.

The standard booking sheet designed for this surveying method allows the surveyor to specify the basic grid size, as well as the column and row interval. The routine employed to reduce the rectangular grid to a basic square grid used linear interpolation to first fill in all the unspecified readings down the columns read in the field. The columns are scanned and if any intermediate spot heights have been recorded between the regular readings, a linear interpolation is performed along the row to the next column. The regularly recorded rows are then linearly interpolated for the full length of each row. Intermediate columns are interpolated followed by intermediate rows and by successively reducing the row and column interval all points on the basic grid are evaluated (see Figure 3.3).

This seemingly complex but very rapid system is used to ensure that the surveyor could adequately describe

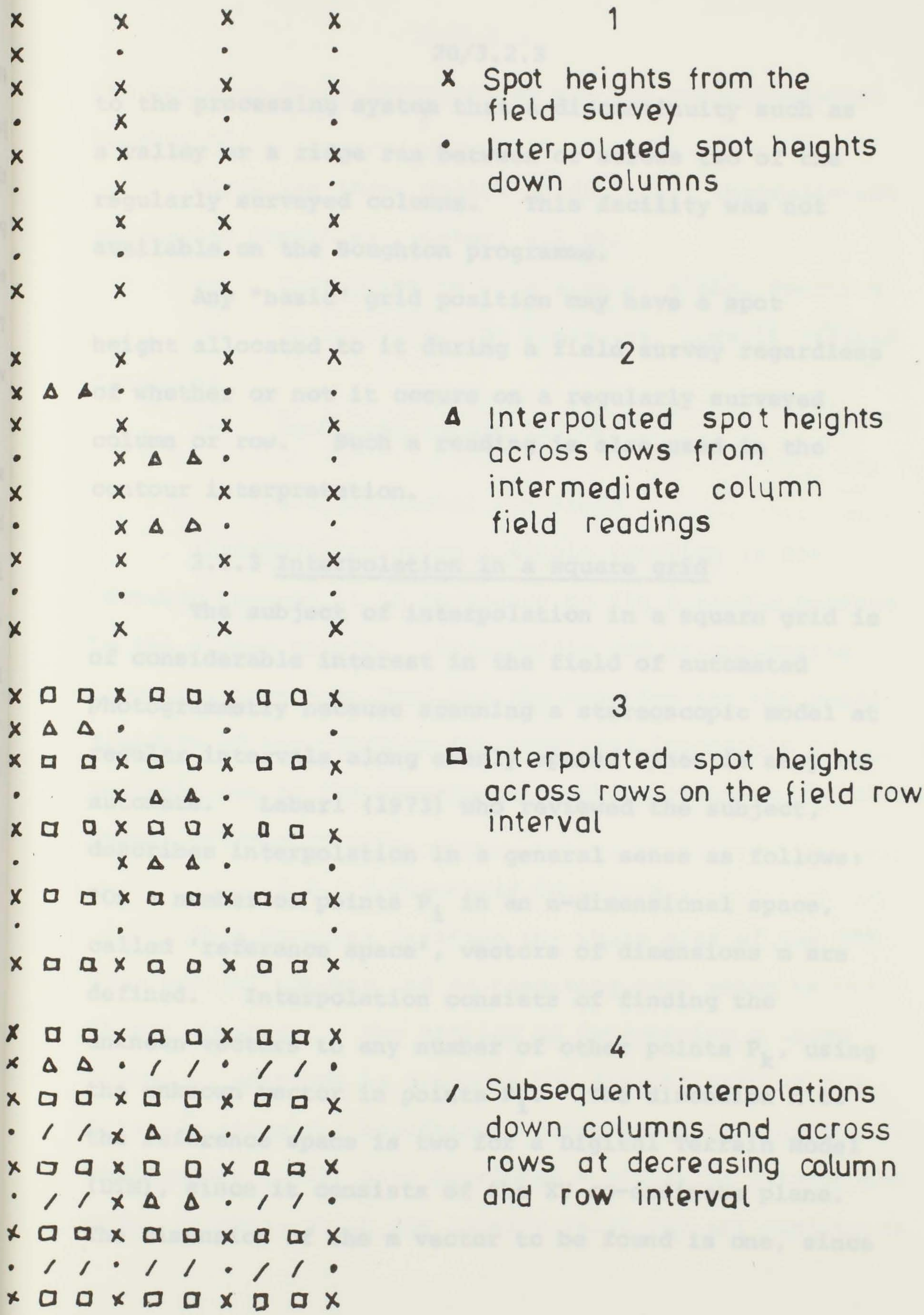


Figure 3.3 Grid survey interpolation sequence

to the processing system that a discontinuity such as a valley or a ridge ran between or across two of the regularly surveyed columns. This facility was not available on the Boughton programme.

Any "basic" grid position may have a spot height allocated to it during a field survey regardless of whether or not it occurs on a regularly surveyed column or row. Such a reading is also used in the contour interpretation.

3.2.3 Interpolation in a square grid

The subject of interpolation in a square grid is of considerable interest in the field of automated Photogrammetry because scanning a stereoscopic model at regular intervals along evenly spaced lines is easy to automate. Leberl (1973) who reviewed the subject, describes interpolation in a general sense as follows: "On a number of points P_i in an n-dimensional space, called 'reference space', vectors of dimensions m are defined. Interpolation consists of finding the unknown vectors to any number of other points P_k, using the unknown vector in points P_i. The dimension n of the reference space is two for a Digital Terrain Model (DTM), since it consists of the XY co-ordinate plane. The dimension of the m vector to be found is one, since the entities to be interpolated are the one-dimensional heights Z".

There are three basically different interpolation approaches possible: (Leberl (1975)).

(a) Interpolation by a single, global function

(b) Interpolation by piecewise, locally defined functions

(c) Pointwise interpolation.

3.2.3.1 Global functions

Interpolation using a single function is not favoured because it is necessary to fit a single surface to the n data points. Polynomials and trigonometric functions have been used but the solution for the coefficients of the function are sometimes impossible or unstable due to the unevenness of the terrain or the large number of data points.

3.2.3.2 Piecewise functions

This involves dividing the whole area of the DTM into smaller patches and representing each patch by one chosen function. The problem of determining a large number of unknowns is overcome but discontinuities are possible along the boundaries of the patches. Jancaitis and Judkins (1973) have developed a system of fitting low order patches, which are locally valid and are continuous with neighbouring patches, by weighting a series of preliminary surfaces. Considerable computer storage is however required for this technique. (Pfaltz (1973)).

3.2.3.3 Pointwise Interpolation

Most of the existing operational DTMs are based on pointwise interpolation. (Leberl (1973)). Boughton's programme used a bilinear pointwise interpolation method. For the production of contour plans using a line printer, pointwise interpolation is appropriate since continuous lines are represented by a series of points.

In general the choice of interpolation method, however, is based on the characteristics of the data and the end use to which the contour plan will be subjected, along with the speed and accuracy of the method. Terrain data from tacheometric surveys such as a grid survey produces data of which every reading is relevant and must be represented on the contour plan. Sudden departures from an even surface must be accepted and contoured accordingly rather than smoothed. Smoothing is a more appropriate operation on geologic data sets where trends in the surface are required rather than the exact value of the point measurement being represented. The aesthetic qualities of the line printer plans produced for this study are of no importance because the plans are merely used as base plans for tracing. The most important characteristic of field survey data is that it can be selectively collected. This fact was used in the selection of the various interpolation techniques employed in this study.

As linear interpolation is used to interpolate contour line positions for manually produced plans and these plans are acceptable for their end use of irrigation planning, there seemed little point in adopting a more complex and time consuming method than bilinear interpolation of the space between any four square grid points as used by Boughton and modified herein.

3.2.4 Printer Plan Scales and Display of Contours

One of the problems of sampling a variable surface at regular intervals is that the sampling points may not coincide with key changes of grade in the surface and hence produce a non-representative contour plan. By reducing the basic grid spacing in the field to, say, 5m these changes in grade can be recorded more accurately. In the field, the survey can be conducted in the usual 20m by 40m pattern but the key points can be recorded on the finer basic grid and used in the interpolation process to more accurately describe the ground surface.

Although they have now been superseded by other methods the following modifications were made to the Boughton contour display. With the grid size displayed on the line printer as one inch by one inch, a spacing of 5m between grid points yields a scale of 196.8 to one which is unacceptably large. The unit square grid on a normal line printer is a half inch by a half inch corresponding to 5 characters along a line and 4 lines of characters. The programme was modified to give a basic grid size of ½ inch which meant that for a 20m field spacing the plan scale resulted as 1574.8 to one. If the grid size in the field is increased to 25.4 metres then a scale of 2000.0 to one results, which is a very acceptable and normal scale for the contour plans which are currently used in agricultural work. If the basic grid size in the field was 12.7 metres and regular readings were taken at every second grid point along a column and every second grid point along a row, - also allowing any of the intermediate points to be sampled as necessary, - then a reasonably acceptable compromise between plan scale (of 1000 : 1) and ability to record sufficient field information is reached.

While changing the plan grid spacing from one inch to ½ inch the programme efficiency was increased by writing a line of characters at a time and changing the characters that marked the contour lines to dots, crosses, and asterisks. This facilitated differentiation between adjacent contour lines. The Boughton programme interpolated along the line of output to find the point where a contour line was crossed and marked it off with a character. The interpolation procedure to find the contour positions was modified to interpolate down the page of output if the fall was greater in this direction within any four basic grid points. This resulted in a better definition of the contour lines where they ran across the page of output.

The Boughton system makes the basic assumption that a surveyed grid point must necessarily coincide with a character position on a line printer output. It is, in fact, unduly restrictive on the line printer display to make this assumption. The original choice of a one inch by one inch line printer grid-spacing was probably decided in order to display the recorded spot heights along with the contour plan. Although the display of the spot heights is essential for manual interpolation of the contours they are merely of interest when the contours are found by computer.

If the shaded type of contour display is used, it is not necessary to have a grid point coinciding with any printer positions. The technique associated with the shaded type of contours is to evaluate the spot height at each character position and have an appropriate character corresponding to that height printed in that position. This type of display largely removes the restriction on the scale of the contour plan. It is probably unreasonable, however, to have a grid spacing in the field which is smaller than the character spacing on the line printer contour plan. (At a plan scale of 2000.0 to 1 a character spacing of 1/8 inch corresponds to 5.08 metres). For the contour plans produced for agricultural work this minimum basic grid size is sufficiently small. A subroutine was written to produce shaded contours from the grid survey data.

From the point of view of computer processing there is a penalty involved in reducing the grid size, because the smaller it is the larger is the number of grid points and hence the larger are the computer memory requirements of the programme to cope with any given area of land.

3.2.5 <u>Land features</u>

While the procedures outlined above produce satisfactory contours of the ground surface, additional features of the surveyed area such as fencelines or shelter belts etc. must be recorded separately and plotted onto the contour plan manually. Where the grid positions are displayed on the output, it is easy to record such land features in the field and plot them on the plan manually. The shaded type of plan disguises the grid positions making this process more difficult. It is not difficult to have any alphabetic or numeric character printed in any character position on the line printer output and so the programme was modified to allow the surveyor to specify any character to be plotted at any position on the contour plan. Such a character is specified as being 'x' metres in the direction of the columns and 'y' metres in the direction of the rows from any grid position in the field.

3.2.6 Summary of modifications

(a) Manual reduction of levels was eliminated by writing a survey level reduction subroutine.

(b) Considerably more freedom was given to the surveyor to lay out the grid in the field on any normal spacing.

(c) Data showing the position of land features not related to the contours can be marked on the contour plan as the contours are drawn.

Appendix 1 describes in detail the use of this programme.

3.2.7 Computer laboratory standard programme

The standard grid contouring routine available on the B6718 was run using ordinary survey data but the resulting contours were unsatisfactory for the purpose at hand and that programme was abandoned.

3.2.8 Further development

The system as it stands is very flexible but it involves, perhaps, more effort at both the field and processing stages than is really necessary. The present programme is written in such a way that each spot height must have its column and row number specified. Each spot height reading requires one computer card to be punched.

The system could probably be streamlined by drawing up a field booking sheet in the form of a grid with spaces along the top to specify column numbers and spaces down the left hand side to specify row numbers. Spot height recordings could be recorded directly in the appropriate column or row. This would mean that several readings could be recorded on one computer card and column and row numbers would require specification less often. At each change of instrument position a new booking sheet could be used with the new instrument height specified at the top of the sheet. This booking procedure would be easy for the surveyor to relate to the field and probably tend to minimise field errors associated with allocating readings to incorrect grid positions.

Topographic data in grid form is used in a number of land-levelling design procedures and cuts and fills to achieve certain design grades are specified for each of the grid nodes in the field. Grid surveying is therefore, an appropriate method to consider where this form of earthwork design and land preparation is practised. (See Section 10).

3.3 Direct Contouring Programme

Unlike the grid surveying method, which achieves horizontal control by setting out a grid in the field, direct contouring horizontal measurements are taken using stadia and bearings to fix the position of readings. A survey reduction programme was written to cope with the direct-contouring surveying system.

The general principle adopted for the programme was to print a suitable character on the computer output associated with every field reading. Adjacent contours are automatically represented with different characters. Like the grid contouring procedure any alphabetic or numeric character is able to be specified to mark the position of any land feature not related to the contours (e.g. fencelines or ditches). The accuracy with which the recorded positions of the readings are plotted depends on the scale of the plan. Any plan scale may be specified for this programme. The points are plotted on the nearest character position to the exact spot determined mathematically by the programme. At a scale of 2000.0 to 1 the accuracy is ± 1.27mm across the computer page and ± 1.58mm down the page. This corresponds to a distance of ± 2.54m and ± 3.17m respectively on the ground.

Appendix 2 describes in detail the use of this programme.

3.4 Random Stadia Surveying Programme

3.4.1 General

Although random stadia surveying is the most rapid technique in the field (see Appendix 4) the data are by far the most difficult to interpret by computer. The problem of contouring randomly spaced data occurs in many disciplines, for example, in geology (in relation to the elevation of subsurface strata), in meteorology (in relation to isobaric contours), and in groundwater hydrology (in relation to contouring piezometric water pressure levels or water table levels), to name a few. In view of the wide application of such a computer technique it is not surprising to find considerable study has been made of the subject. In the particular field of terrain contours much of the reported work is in relation to photogrammetric interpretation of contours.

Wooding (1975) has attempted using computer techniques to produce contour plans from stadia survey data. He found that the contours produced by his programme were unsatisfactory for his purposes. The field technique used by Wooding was to record the survey readings verbally onto a cassette tape recorder. The readings were subsequently punched onto computer cards, processed by a survey reduction programme and plotted by a drum plotter. The contours were interpreted manually from the computer plotted points.

Yoeli (1975) states that professionally executed terrestial engineering surveys are usually carried out in a random point fashion with some logic to the point distribution. The surveyors choose salient points such as extrema, those at which the terrain slope changes, or along valleys or ridges. He therefore classifies such surveys as semi-ordered. No reported work has been found which makes use of this semi-order to aid the computer processing system to interpret the contours more accurately. The method called the random stadia system developed in this study and reported herein makes use of this semi-order.

An examination of the manual method indicated that the sequence in which data was collected in a field survey is a key factor in the human interpretation of the contour information contained in an otherwise random set of spot heights. The sequence gives clues as to whether an error has been made in booking by displacing a spot height so that it does not conform to the surveying pattern remembered by the surveyor. The other important feature of human interpretation is the ability to identify ridges and valleys, as distinct from mounds and hollows, from the random spot heights. This is done manually by using the surveying sequence to some degree but primarily from a general knowledge of the landform or from memory.

On the assumption that the human method is a good technique an attempt was made to display the sequence in which the data were collected. The obvious way to do this is to join up the spot heights in sequence. This was done by joining the characters which represented the recorded position of the spot heights by a straight line of other characters (see Figure 3.4). The 'other characters' are printed in the character positions available between the recorded spot heights on the computer output.

The manual technique in the field is to record spot heights along roughly straight lines, which need not be parallel, at any changes of grade in the topography as shown in figure (3.5).

3.4.2 Line Printer Display of Profiles

A character convention was adopted to show the relative height of recordings on the printed computer output. In ascending order of height the character convention runs 1, +, 2, -, 3, ., repeated as required. These six characters were chosen because they are visually markedly different, and the numbers 1,2,3, show whether the contours are ascending or descending.

Which of these six characters represents a particular elevation is decided by first finding the contour number (elevation divided by contour interval) rounded down to the nearest integer and dividing this number by six (i.e. the number of characters). The remainder will be 0, 1, 2, 3, 4, or 5. In the convention adopted 1 stands for 0, + for 1, 2 for 2, - for 3, 3 for 4, and . stands for 5.

For example, if the spot height is 98.4 and the contour interval is 5m, the contour number is 98.4/5 = 19. The remainder, after dividing 19 by six is one and the character to represent this spot height is therefore +. Had the remainder been three then a - would be

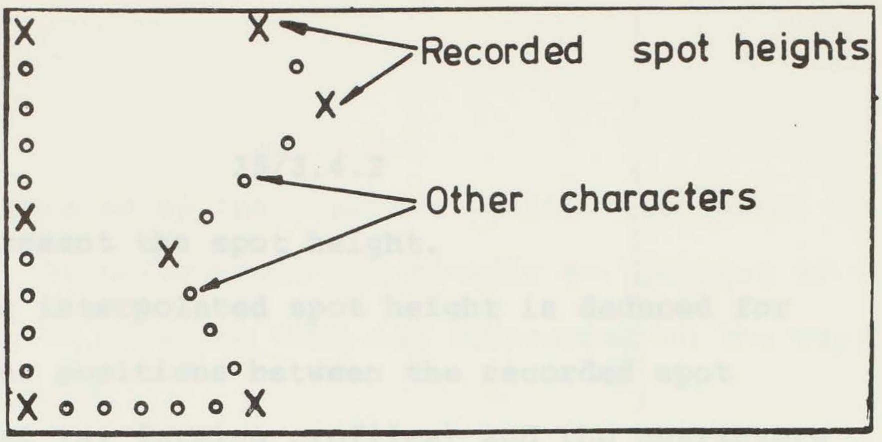


Figure 3.4 Recorded spot heights joined in sequence by a line of other characters

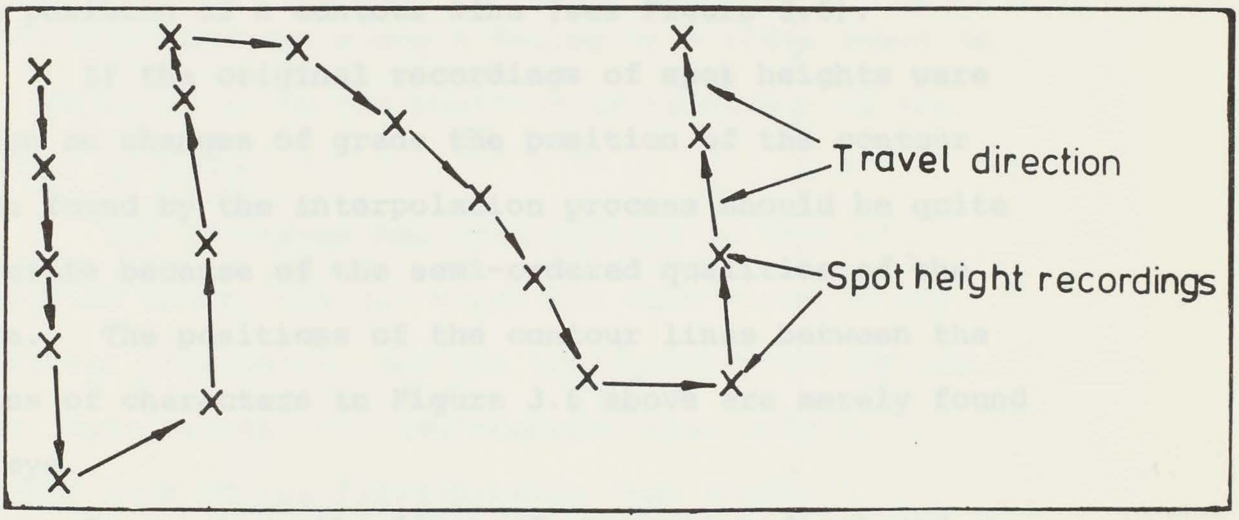


Figure 3.5 Typical pattern of data collection in the field

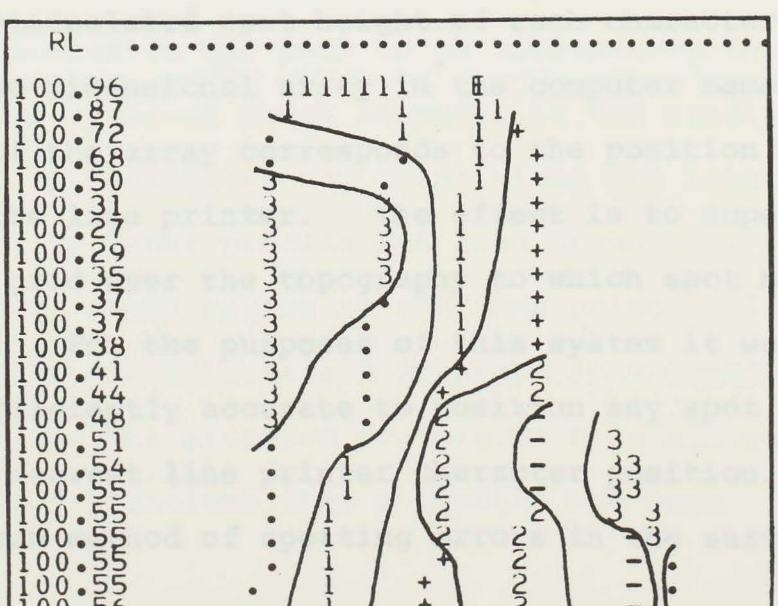


Figure 3.6 The position of contour lines indicated by a change in the printed characters

used to represent the spot height.

If an interpolated spot height is deduced for the character positions between the recorded spot heights (that is, forming profiles) and the characters printed according to the above convention, then each change of character along the surveyed lines indicates the position of a contour line (see Figure 3.6).

If the original recordings of spot heights were taken on changes of grade the position of the contour line found by the interpolation process should be quite accurate because of the semi-ordered qualities of the data. The positions of the contour lines between the lines of characters in Figure 3.6 above are merely found by eye.

In essence, the lines of characters displayed on the line printer form profiles of the topography, and the recorded or interpolated spot height of each character is stored in a two-dimensional array in the computer memory. Each element of the array corresponds to the position of a character on the line printer. The effect is to superimpose a fine grid over the topography to which spot heights are allocated. For the purposes of this system it was considered sufficiently accurate to position any spot height in the nearest line printer character position.

The human method of spotting errors in the survey data is simulated by the computer as it draws these profiles. Mistakes stand out clearly to the user if the pattern of profiles does not correspond to the way it was recorded.

The second human ability mentioned earlier of being able to interpret valleys and ridges correctly is also simulated using this method of profiles. If a profile is drawn along a valley or a ridge there is no confusion as to the position or existence of the valley or ridge.

The programme has been written so that if profiles cross, the one which was made first in any area has precedence, and the subsequent profiles are not drawn between the two recorded spot heights on either side of the first profile (see Figure 3.7).

The method employed to ensure that the profiles do not cross is to first check that no spot heights have been allocated to the path to be followed by the profile line. A second check is made, if the profile line is drawn diagonally at any point along its length, to ensure that no other profile has been drawn in a diagonal path at right angles at the same point. If four adjacent grid positions are arranged in a square configuration and the proposed profile path is across any two diagonal positions then a profile has been

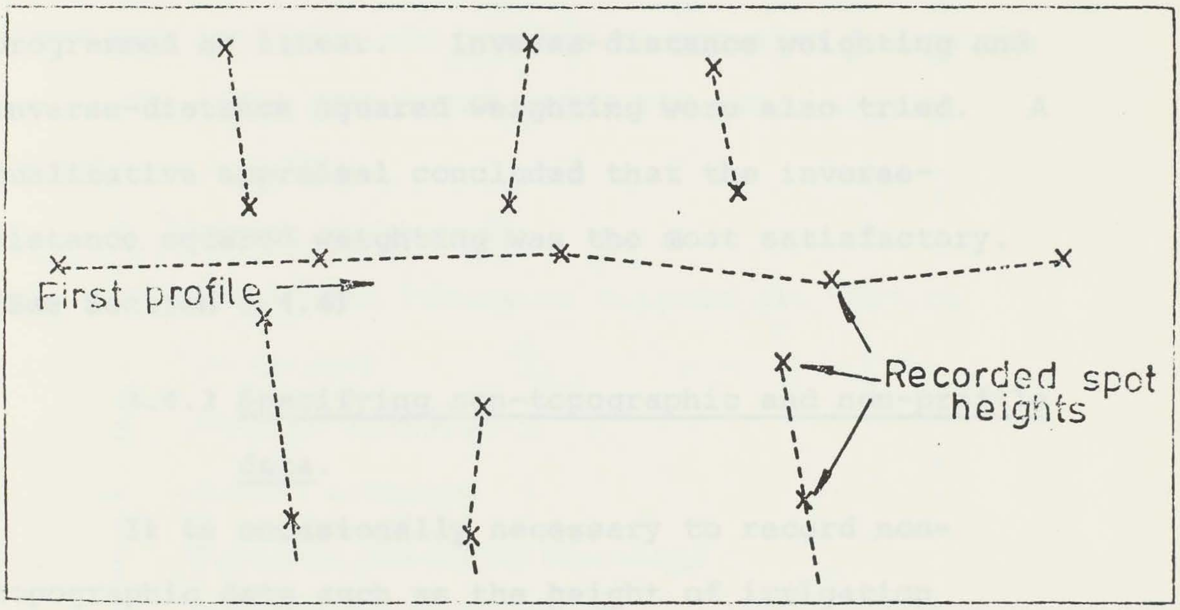


Figure 3.7 Profiles which cross one another

crossed if the other two print positions are full. If none or only one of the remaining positions has been allocated a spot height then no profile has been crossed. Once these two criteria have been satisfied spot heights are allocated to form the profile.

Interpolation of the raw data along the profile lines between recorded spot heights was originally programmed as linear. Inverse-distance weighting and inverse-distance squared weighting were also tried. A qualitative appraisal concluded that the inverse-distance squared weighting was the most satisfactory. (See Section 3.4.4)

3.4.3 Specifying non-topographic and non-profile data.

It is occasionally necessary to record non-topographic data such as the height of irrigation structures during a field survey. With this system it is possible to specify whether the data are topographic or not. Similarly, in some situations it is not appropriate to draw a profile between consecutive spot heights. In this case it is possible to specify that the profile is to be discontinued. (See Appendix 3 for further details).

3.4.4 Interpolation between profiles.

To produce a shaded contour plan it is necessary to use the remainder of the character positions available on the line printer to deduce the position of the contour lines running between the profile lines. The problem is to interpolate intermediate spot heights from randomly spaced data as distinct from gridded data mentioned earlier. In principle the interpolation techniques available are similar to the grid techniques.

Among the techniques available are: (Crain (1970))

- Finite difference
- Global and Patchwise Polynomials (Spline functions)
- Fourier analysis
- Moving averages
- Distance weighted functions
- Combined techniques

A distance weighted function was chosen for the interpolation algorithm. It was chosen for its simplicity and versatility and its appropriateness to defining spot heights in a pointwise fashion required for line printer output. Schmidt and Zafft (1975) have reported that the SYMAP program is the most widely known and distributed programme and it also used the distance weighted algorithm. It is also primarily

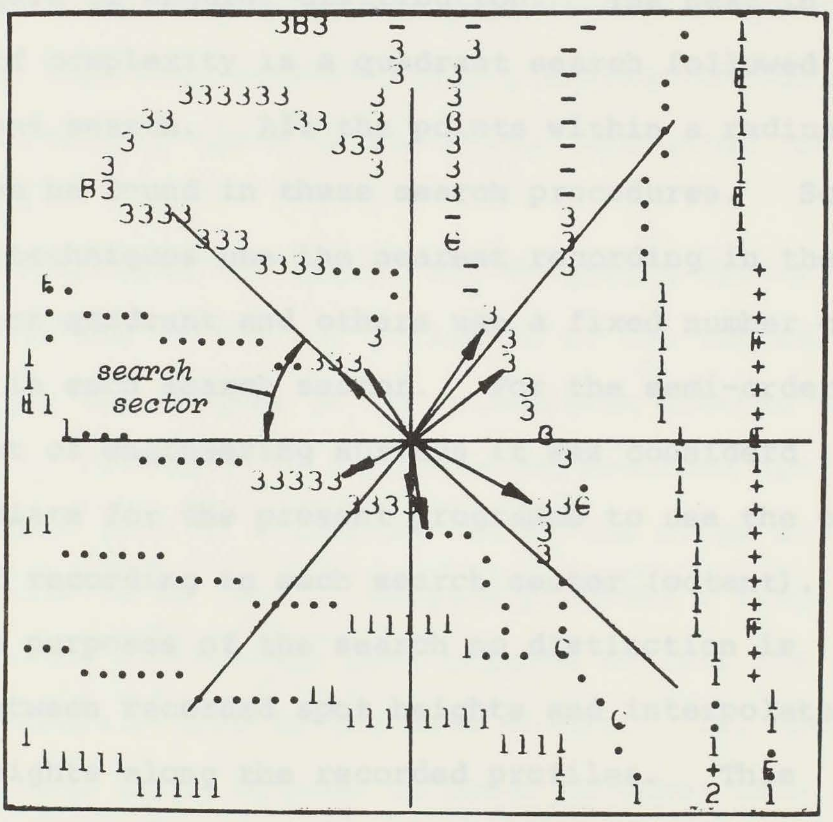


Figure 3.8 Limitation on the computer search

used to output on a line printer.

In discussing the SURFACE II system Sampson (1975) stated that the simplest method of search to find data points for the distance weighted function was to find the nearest or neighbouring points without regard to angular distribution. The next in order of complexity is a quadrant search followed by an octant search. All the points within a radius may also be found in these search procedures. Some search techniques use the nearest recording in the octant or quadrant and others use a fixed number of points in each search sector. For the semi-ordered data set of engineering surveys it was considerd appropriate for the present programme to use the one nearest recording in each search sector (octant). For the purposes of the search no distinction is made between recorded spot heights and interpolated spot heights along the recorded profiles. This means that the search ends wherever a profile is found and no information is used from beyond the first profile (see Figure 3.8).

Shepard (1968) proposed a system of weighting the surrounding data to interpolate unknown spot height estimates. He first proposed that they should be weighted according to the inverse of the distance from the recorded spot height to the position of unknown spot height. Although he was able to show that this weighting produced a surface which was once differentiable and fitted the data points satisfactorily, the recorded spot heights tended to show as localised high or low points. Weighting by the inverse square of the distance produced much more aesthetically pleasing contours. This was confirmed by tests on surveying data using the present programme.

In general the higher the weighting factor, the greater is the circle of influence of the recorded spot height and the steeper is the transition between the circles of influence of neighbouring recorded spot heights.

This type of weighting causes the slope at the data points to be zero. Shepard proposed a slope factor based on the surrounding spot heights so that the slope is not necessarily zero at the data points. It, therefore, also allowed local extrema to occur at other than the data points. This additional sophistication was not considered necessary in the case of the semi-ordered survey data set where local extrema are deliberately recorded and need not be implied from the data.

The interpolation function used in the present programme is as follows:-

$$H = \sum_{n=1}^{n=N} 1/d_n^p \times H_n \Big/ \sum_{n=1}^{n=N} 1/d_n^p \qquad - (1)$$

Where H = the interpolated spot height

N = the number of surrounding spot heights

d_n = the distance from the unspecified position to the surrounding nth spot height

p = the power (in this case p = 2)

H_n = the nth spot height

Other weighting functions have been used such as in meteorology (Cressman 1959).

$$W = \frac{R^2 - d^2}{R^2 + d^2}, \quad d \leq R$$

Where W = weighting function value

R = the radius of neighbourhood centred at the estimated point

d = distance of sample to estimated point

also $W = 12(d + 1)$)
) Newman (1967)
also $W = 24\ (d^2 + 1)$)

In some cases it is desirable for the surface to be discontinuous. For applications such as mapping census data,Shepard (1968) developed a system where logical boundaries such as rivers or roads separate the surface, which limits the interpolation of spot heights from data to one side of the barrier or lightly weights the data from the other side of the barrier. The effect is achieved by increasing the distance from the unknown spot to the data point by a 'detour' distance. The longer the detour distance, the lower is the weighting.

The insertion of such barriers requires a pointwise interpolation algorithm and no successful attempts have been reported using other routines (Leberl (1975)). The use of such barriers in contouring programmes can result in an increase in process time of up to 70%. (Rhind 1971). The Experimental Cartography Unit (Anon 1971) have stated that the use of these barriers result in a twenty-fold increase in computer time.

The use of barriers in contouring terrain data can save recording a large number of spot heights which would otherwise be necessary to describe the surface to the processing system. It is useful to be able to describe lines which mark discontinuities such as sharp ridges, valleys, or terrace banks. These areas are described as 'terrain break lines'.

In the present programme the profile lines effectively form break lines and can be manipulated by the surveyor to best advantage at the time of surveying. The insertion of these break lines or barriers in this context actually reduces the search time because the data are found more readily and closer to the position of the unspecified spot height. The method of insertion of the break lines, which is merely to allocate spot heights to a line of grid points, would allow the fitting of analytical surfaces if required. This may be a solution to the problem mentioned above by Leberl.

3.4.5 Comparison of contours with and without break lines.

In order to evaluate the significance of using break lines the following comparison was made of contours derived from data with and without the use of break lines. With the present programme the use of break lines is optional and may be specified for all or some of the data in any survey. Figures 3.9 to 3.12 show contours produced by computer with and without the use of break lines. All the data are taken from actual field surveys. Figure 3.9 is from the Waiau Irrigation Scheme area and the plans are drawn with a contour interval of 0.5m, 142 level readings and an original scale of 2000:1. Figures 3.10, 3.11 and 3.12 used the same data from the Greenstreet Irrigation Scheme and are drawn with a contour interval of 0.25m, 267 level readings and an original scale of 1250:1.

From Figure 3.9 it should be immediately apparent that the use of break lines on even topography produces no significant change in the contour plan. A comparison of Figures 3.10 and 3.11, however, would indicate that a very significant difference occurs on more broken topography. (See also Figure 3.13). As mentioned above the four sharp valleys which are shown on Figure 3.11 reduce to a series of hollows on Figure 3.10. The four valleys were considered significant for the purposes of the survey and were fixed in position by a line of levels made in sequence along their length at the beginning of the survey.

Without a knowledge of the actual topography it would be difficult to manually modify Figure 3.10 to more correctly resemble the actual ground surface. Apart from the contour lines extending outward from the edge of the surveyed area, Figure 3.12, produced by a standard New Zealand Ministry of Works programme (Graphic 2 Users Manual Anon 1974) is very similar to Figure 3.10.

The data which produces contour plans with many small humps and hollows such as Figure 3.10, is sometimes referred to as "noisy". From the above comparison it would seem that, in the case of topographic survey data the noise results when insufficient data are supplied to satisfy the needs of the contouring procedure. It would also appear that if profiles are used to form break lines less data are required to produce satisfactory contours particularly of broken topography.

Unordered data sets such as stratigraphic data, besides not being easily joined by profile lines are also subject to considerable error of measurement. The unreliability of the data does not allow any particular importance to be placed on isolated irregularities. Such irregularities tend to cloud any other important features of the surface and so various techniques have been developed for smoothing the data to highlight surface trends. (Harbaugh 1968). Terrain survey data, however, can be considered accurate for the purposes of contouring. Smoothing is therefore inappropriate. A comparison of Figure 3.10 (without smoothing) and Figure 3.12 shows that some smoothing has occurred because some of the isolated hollows are not as deep in Figure 3.12.

The comparison of the two different contouring systems is to some degree unfair because the data were collected specifically for one of the programmes, but it does emphasise that if the programme is matched to the data, a more realistic result will follow.

3.4.6 <u>Computer Search Procedures</u>

The search for recorded spot heights from which to interpolate intermediate spot heights can be a time consum-

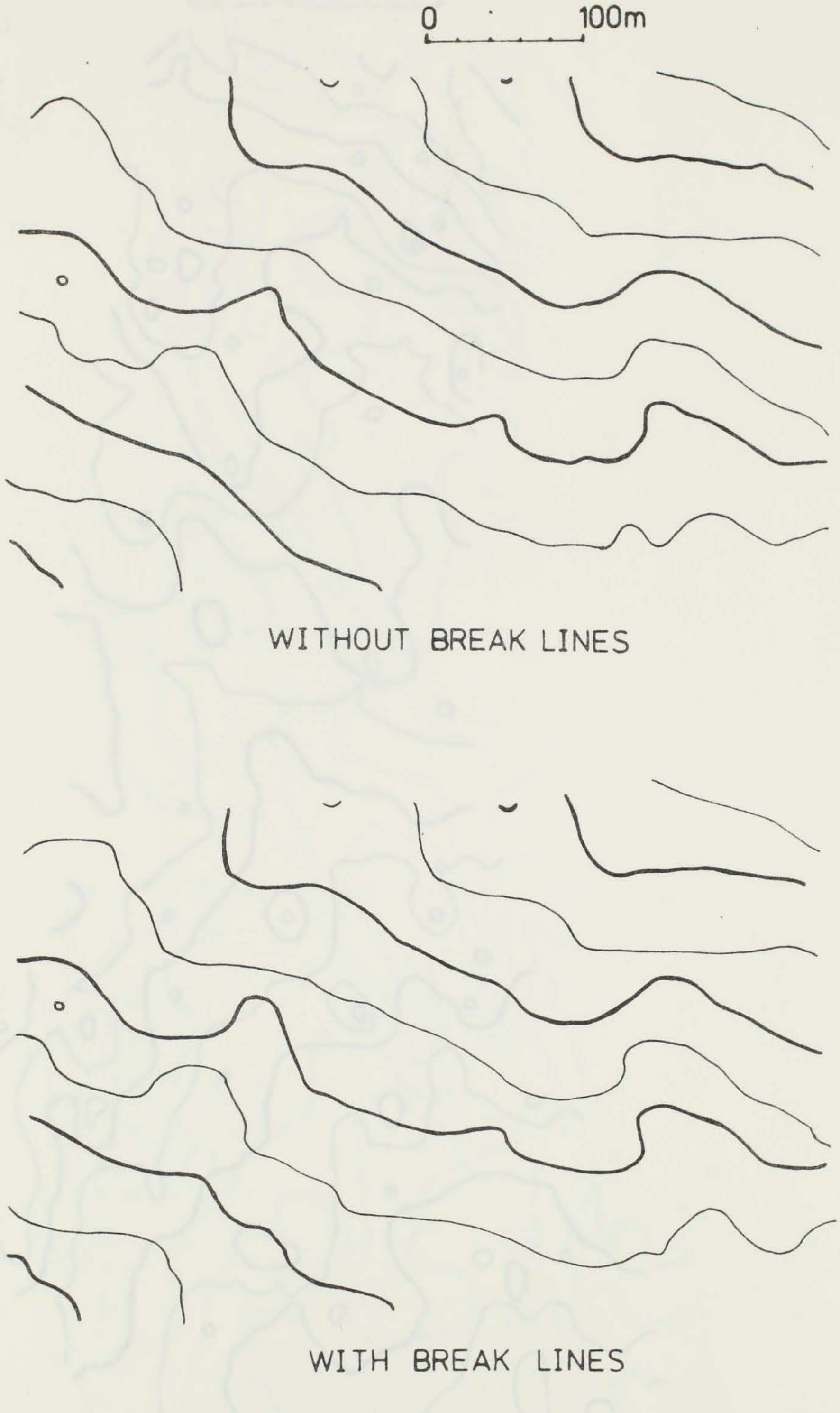


Figure 3.9 Contours produced by computer on even topography with and without the use of break lines

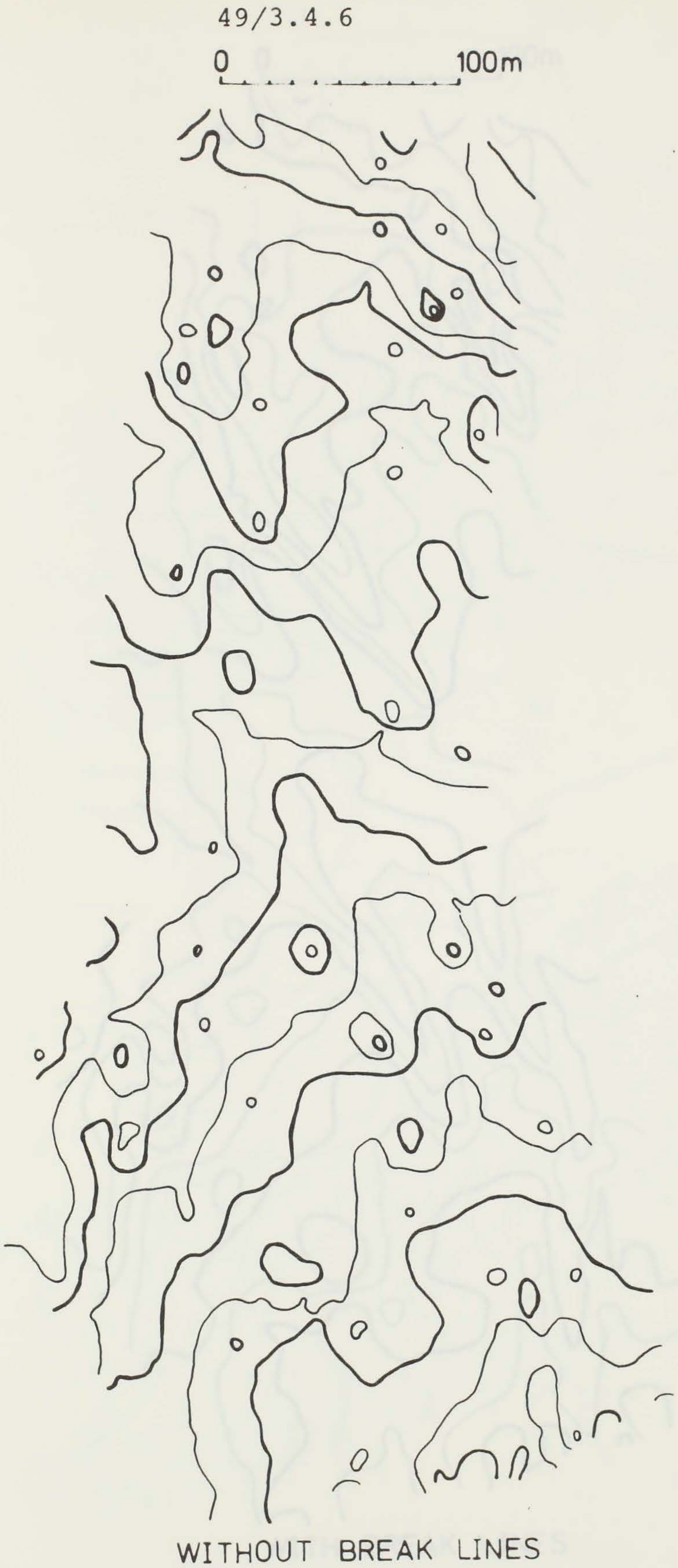


Figure 3.10 Contours produced by computer on broken topography without the use of break lines

Figure 3.11 Contours produced by computer using the same data as Figure 3.10 but with the use of break lines

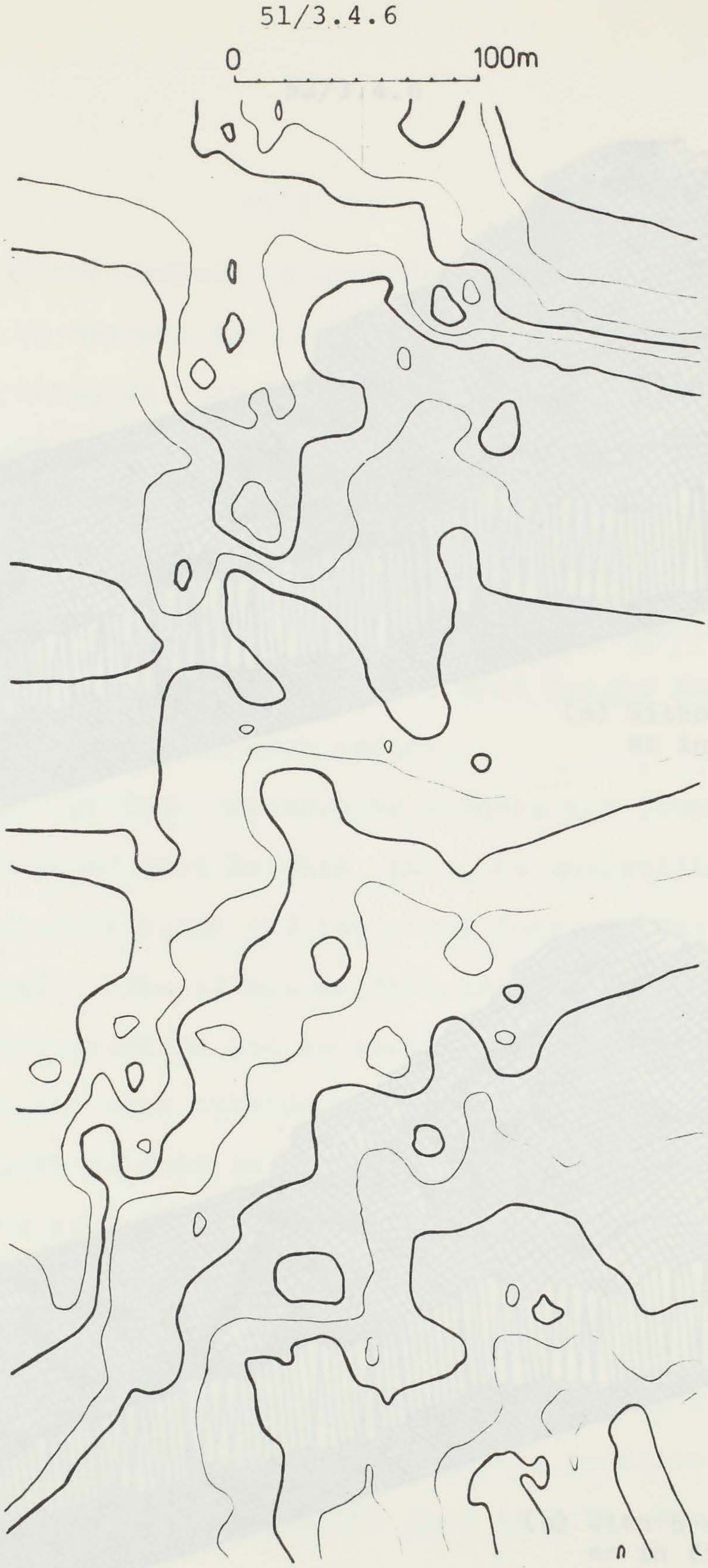
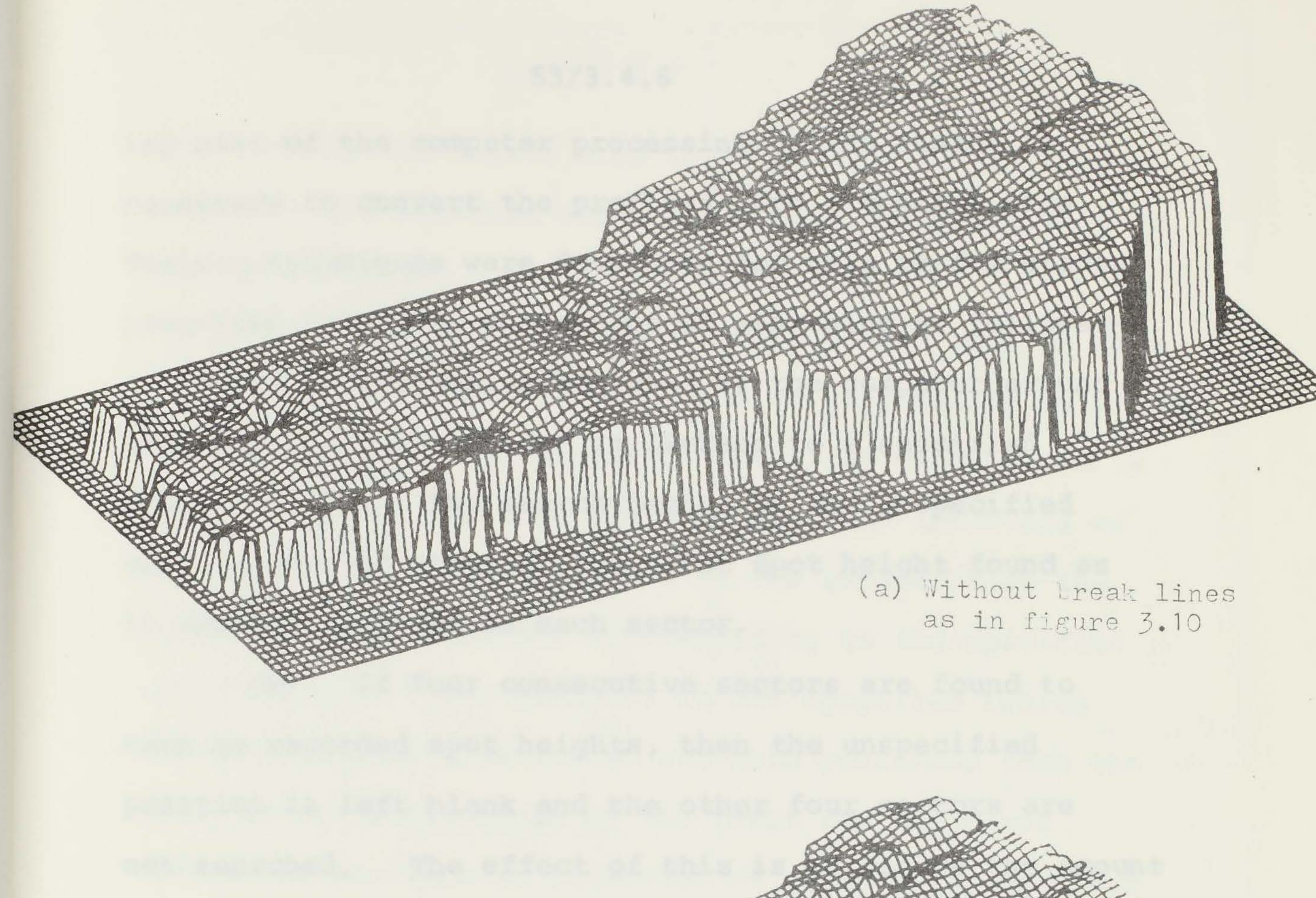


Figure 3.12 Contours produced by a standard Ministry of Works and Development programme using the same data as Figures 3.10 and 3.11



(a) Without break lines as in figure 3.10

(b) With break lines as in figure 3.11

Figure 3.13 Three dimensional projections of surfaces shown in Figures 3.10 and 3.11

ing part of the computer processing. The search is necessary to convert the profiles into a contour plan. Various techniques were developed for this random stadia programme to reduce the amount of searching as follows:-

(a) The radius searched by the computer around any unspecified position* is limited to a specified search radius. The search begins at the unspecified spot height and stops at the first spot height found as it searches outward in each sector.

(b) If four consecutive sectors are found to have no recorded spot heights, then the unspecified position is left blank and the other four sectors are not searched. The effect of this is to reduce the amount of searching required and to indicate the survey boundary by leaving the area outside the boundary blank. The other benefit of this is to avoid unjustifiable interpolation of spot heights based on data completely to one side of the unspecified position.

(c) The processing time can be reduced by not evaluating all the character positions. It is possible to specify that only every nth character position (n = 1 to 9) along and down the page is to be evaluated.

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*(Line printer character position which does not have a spot height allocated to it in any previous operation.)

This reduces the search time in proportion to the number of characters searched but also reduces the definition of the contour plan.

(d) By making several search passes over an area at progressively smaller intervals it is possible to reduce the search time considerably. The first search pass is conducted along and down the page with the intervals of grid positions being one power of two greater than the number of grid positions corresponding to the specified search radius. For example, if the specified search radius indicated a search of six grid positions then the first search would begin at the first row and first column and continue at intervals of eight grid positions (2^3) along the columns and rows with a search radius also of eight grid positions. The values thus determined are then added to the array of spot heights and interpolated profiles and are available for subsequent searches. The second search pass begins at the fourth column and fourth row and continues at intervals of eight grid positions. The search radius however is reduced to four grid positions. On every second subsequent search pass it is possible to halve both the search interval and search radius. The saving in search time is considerable and obvious if one counts the number of times that each grid position is searched. For a search radius of eight grid positions,

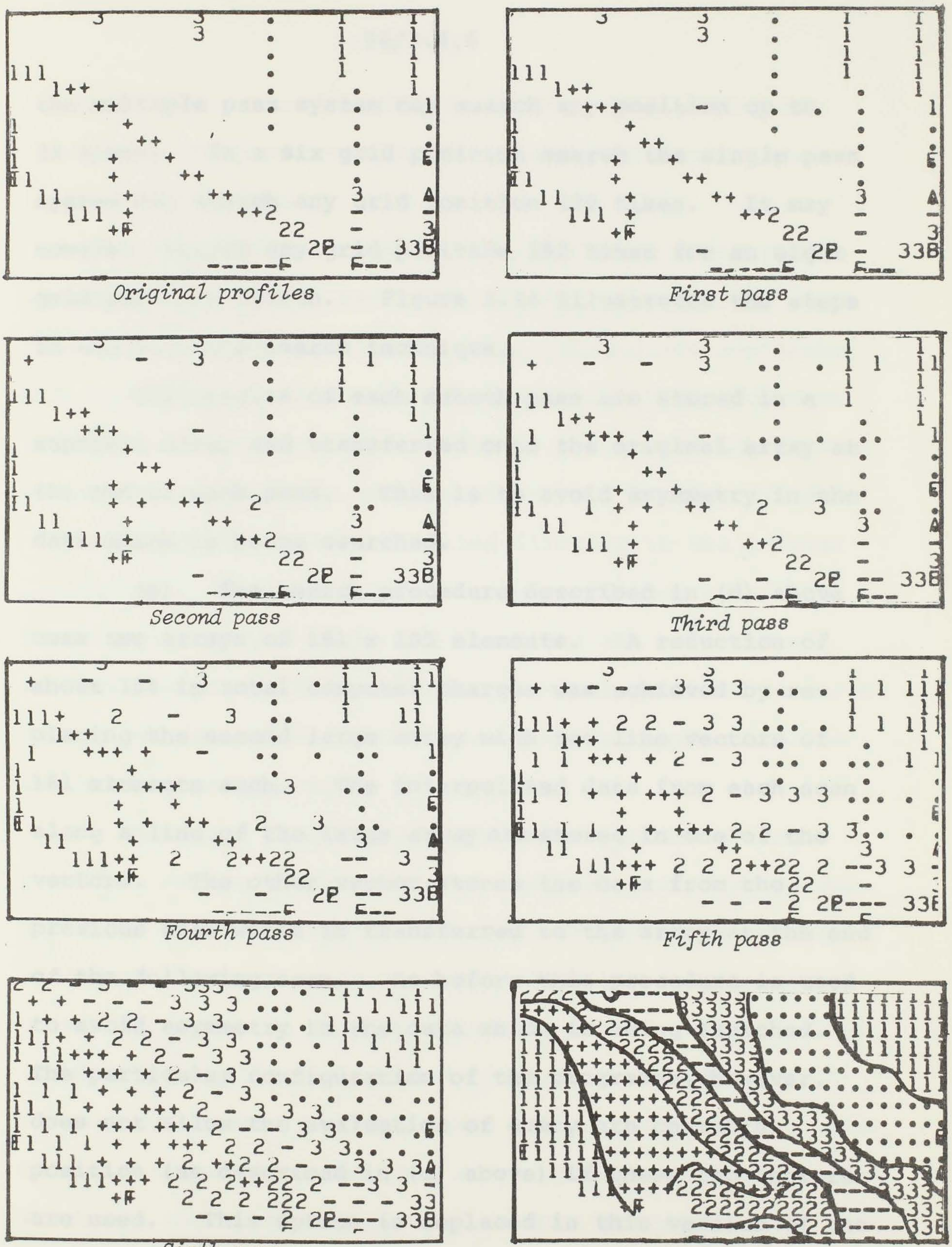


Figure 3.14 Steps in the multiple pass search technique

the multiple pass system may search any position up to 32 times. In a six grid position search the single pass system may search any grid position 120 times. It may however search any grid position 192 times for an eight grid position search. Figure 3.14 illustrates the steps in the multiple search technique.

The results of each search pass are stored in a separate array and transferred onto the original array at the end of each pass. This is to avoid asymmetry in the data which is being searched.

(e) The search procedure described in (d) above uses two arrays of 161 x 105 elements. A reduction of about 10% in total computer charges was achieved by replacing the second large array with two line vectors of 161 elements each. The interpolated data from each scan along a line of the large array are stored in one of the vectors. The other vector stores the data from the previous scan which is transferred to the array at the end of the following scan. As before this procedure is used to avoid asymmetry in the data which is being searched. The particular configuration of the programme, however, does not allow the evaluation of every nth character position (as described in (c) above) if these two vectors are used. This option is replaced in this version of the programme by being able to specify the maximum number of interpolation scans (see Figure 3.14). The effect is similar to the evaluation of every nth position except that n must be a power of 2.

In the SYMAP programme (Shepard 1968) every third character along every second line is evaluated using the distance weighted algorithm. The intermediate positions are evaluated by bilinear interpolation. This method of reducing the process time, although untried in the present programme, is unlikely to be satisfactory because all data points and profiles are allocated directly to the printer positions. The remaining character positions after the first interpolation would not be all of the same shape. Where the distance between data points or profiles is large on the plan the method could have a useful application in the present programme.

There are fundamental differences in the search procedure of the SYMAP programme and the present programme. The SYMAP procedure is to order the original data points in ascending order of x and y, and to find the neighbouring points by searching through this list (Rhind 1971). This is clearly an efficient method of finding the data. The present programme, however, takes into account the sequence of the original data and uses it to generate additional data which are the spot heights used to form the profiles. Because of the fixed grid size determined by the line printer spacing, this system can generate many times the number of original spot heights, depending on the scale. Typically, at a scale of 2000 : 1 and the usual spot height density of the original field data, the number of spot heights is increased by between five and ten times. Surveys have been processed by this system with about 1500 original data points. If the multiplication factor were as high as 10 then 15000 spot heights would have to be sorted. Furthermore, the process of checking for interference of profiles mentioned above would be made considerably more time consuming.

The second major difference is the re-use of the derived data from the search scans for further distance weighted interpolation. Each scan produces further data.

3.4.7 The Use of Sub-areas

To reduce the amount of memory required to store the array of character positions, the survey data are processed as a number of overlapped sub-areas. The degree of overlap has been set at twenty character positions so that it is larger than the distance between spot heights recorded in the field when the usual plan scales are used. The sub-areas are set at 65 lines ($2^6 + 1$) down the page and 121 character positions across the page (corresponding to the width of computer page available for the contour plan.) The multiple pass search process actually uses 129 character positions (i.e. $2^5 + 1$). The overlaps are necessary to ensure continuity between sub-areas.

3.4.8 Line Printer Display of Land Features.

With a manually processed survey it is easy to draw in features other than the contours, such as fence lines, drainage lines and trees. With the random stadia programme it is possible to allocate any alphabetic or numeric character to any position of the survey staff to mark any land features onto the plan automatically.

3.4.9 Experience with the Random Stadia Programme.

The main use of the programme so far has been to contour in excess of 3000 ha of surface irrigation and drainage areas with a contour interval of 0.1m, 0.25m or 0.5m. Scales of either 2000 : 1 or 2500 : 1 and profile separations of about 30m have normally been used. It is well suited to this application. A number of surveyors have used the system and considerable programme development has resulted.

Two thousand spot height recordings of stadia field data can be processed by the programme as it stands but there is no reason why an arbitrarily large number of spot height readings cannot be processed (depending on the size of the computer memory) and an arbitrarily large size of plan may also be produced. Experience has shown, however, that

Figure 3.15 Field surveying on the Greenstreet Irrigation Scheme using the random Stadia system. (A three wheeled motor cycle is being used to improve mobility. The area is also shown in Figures 3.10. to 3.13.)

because of data errors it is preferable to keep the number of readings in any survey well below the 2000 mentioned above. Large areas should be divided into smaller areas in the field and these processed separately.

Further development of the program could be undertaken to link it to a line plotter and in the field to an automatic data recording system to save having to punch data cards from the field data. Because these facilities are not available at present this development is not planned in the meantime.

Appendix 3 describes in detail the use of this programme.

PART TWO

EARTHWORKS

4.0 DESCRIPTION OF A BORDERED STRIP IRRIGATION SYSTEM

The term "bordered strip" has been chosen to describe the type of irrigation otherwise known as "borderdyke" irrigation. The term bordered strip more accurately describes the system and avoids a confusion in terms when describing the borders of the bordered strip. Figure 4.1 shows a schematic diagram of a typical bordered strip layout.

4.1 Bordered Strips

Bordered strip irrigation is a method of surface application of water where the distribution of the water is controlled by the form of the ground surface. Typical New Zealand bordered strips of land for irrigation are about 200m to 400m long with average slopes ranging from 0.1% to 5% and about 12m wide with zero cross slope (tolerance $\pm$ 0.01m desirable). To minimise earth movement, the longitudinal slope may be allowed to vary with the general trends of the undisturbed ground except that adverse slopes are not permitted and are graded out accordingly. Where practicable the bordered strips are run straight and parallel, but to

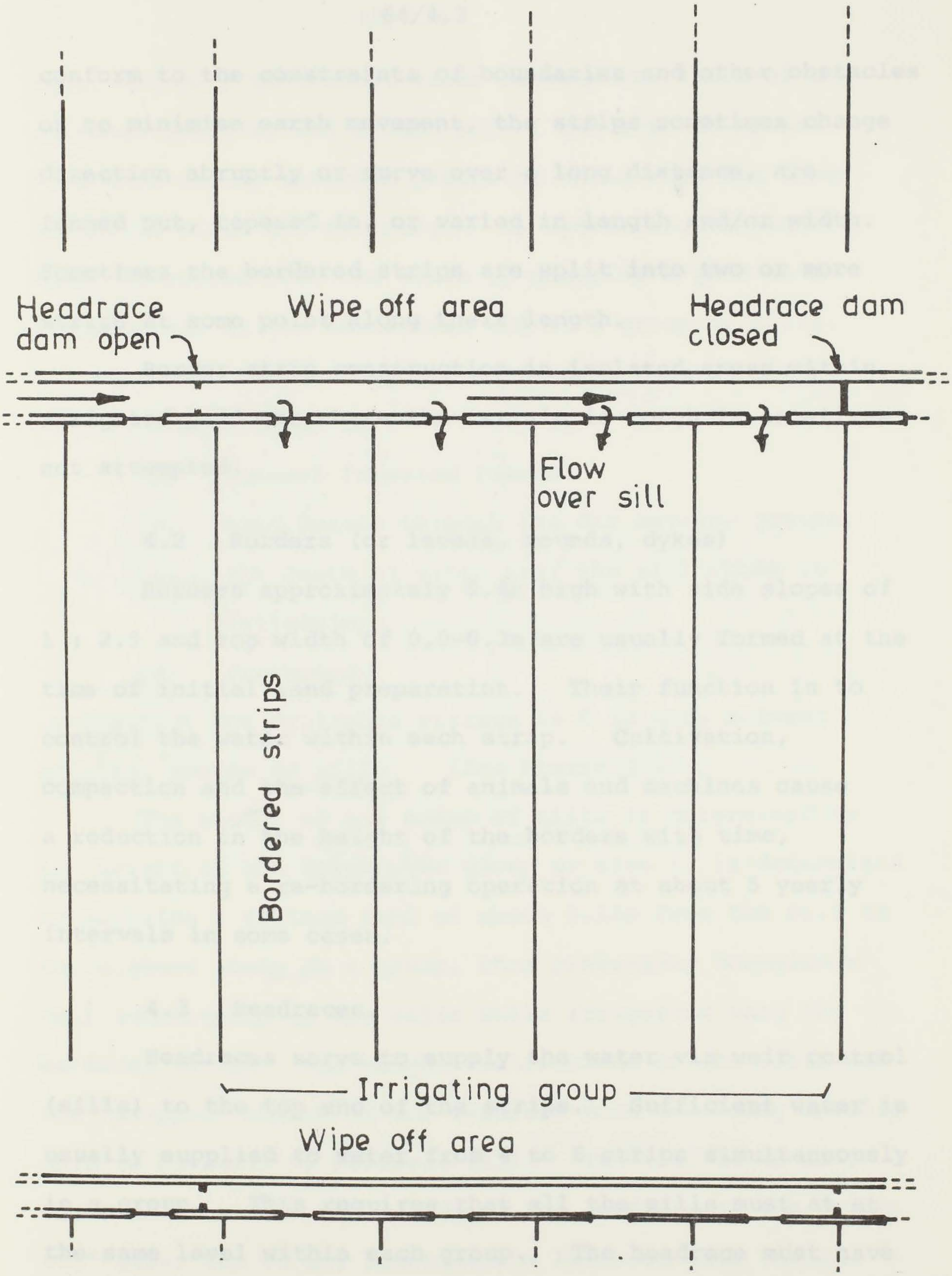


Figure 4.1 Schematic diagram of a typical bordered strip irrigation layout.

conform to the constraints of boundaries and other obstacles or to minimise earth movement, the strips sometimes change direction abruptly or curve over a long distance, are fanned out, tapered in, or varied in length and/or width. Sometimes the bordered strips are split into two or more strips at some point along their length.

Border strip construction in isolated areas within irrigated paddocks where the terrain is rough is sometimes not attempted.

4.2 Borders (or levees, mounds, dykes)

Borders approximately 0.4m high with side slopes of 1 : 2.5 and top width of 0.0-0.3m are usually formed at the time of initial land preparation. Their function is to control the water within each strip. Cultivation, compaction and the effect of animals and machines cause a reduction in the height of the borders with time, necessitating a re-bordering operation at about 5 yearly intervals in some cases.

4.3 Headraces

Headraces serve to supply the water via weir control (sills) to the top end of the strips. Sufficient water is usually supplied to water from 4 to 8 strips simultaneously in a group. This requires that all the sills must at at the same level within each group. The headrace must have fall, not only to conduct water beneath the sills of any upstream group to the groups below, but also to allow clearance on any upstream groups of sills when the lower groups of sills are watering. In operation, the water level is raised over the sills by dropping a gate in a headrace dam at the downstream end of a group of sills. The clearance between any two adjacent groups of sills therefore must allow for:

(a) channel friction losses.

(b) head losses through the dam between groups.

(c) the depth of water over the sill which is irrigating.

(d) freeboard.

In practice the desirable minimum is 0.1m drop between adjacent groups of sills. (See Figure 4.2)

The height of any group of sills is determined by the height of the downstream group or else it is determined by allowing a minimum fall of about 0.15m from the sill to the highest strip in a group, thus preventing downstream weir submergence of the sills while irrigating onto the bordered strip. The height restrictions on the sills and the "stepped" nature of the headrace mean that they usually have to be built of borrowed fill. The fill is usually borrowed from the uphill side of the headrace in the "wipe-off" area, but it may sometimes be borrowed from various

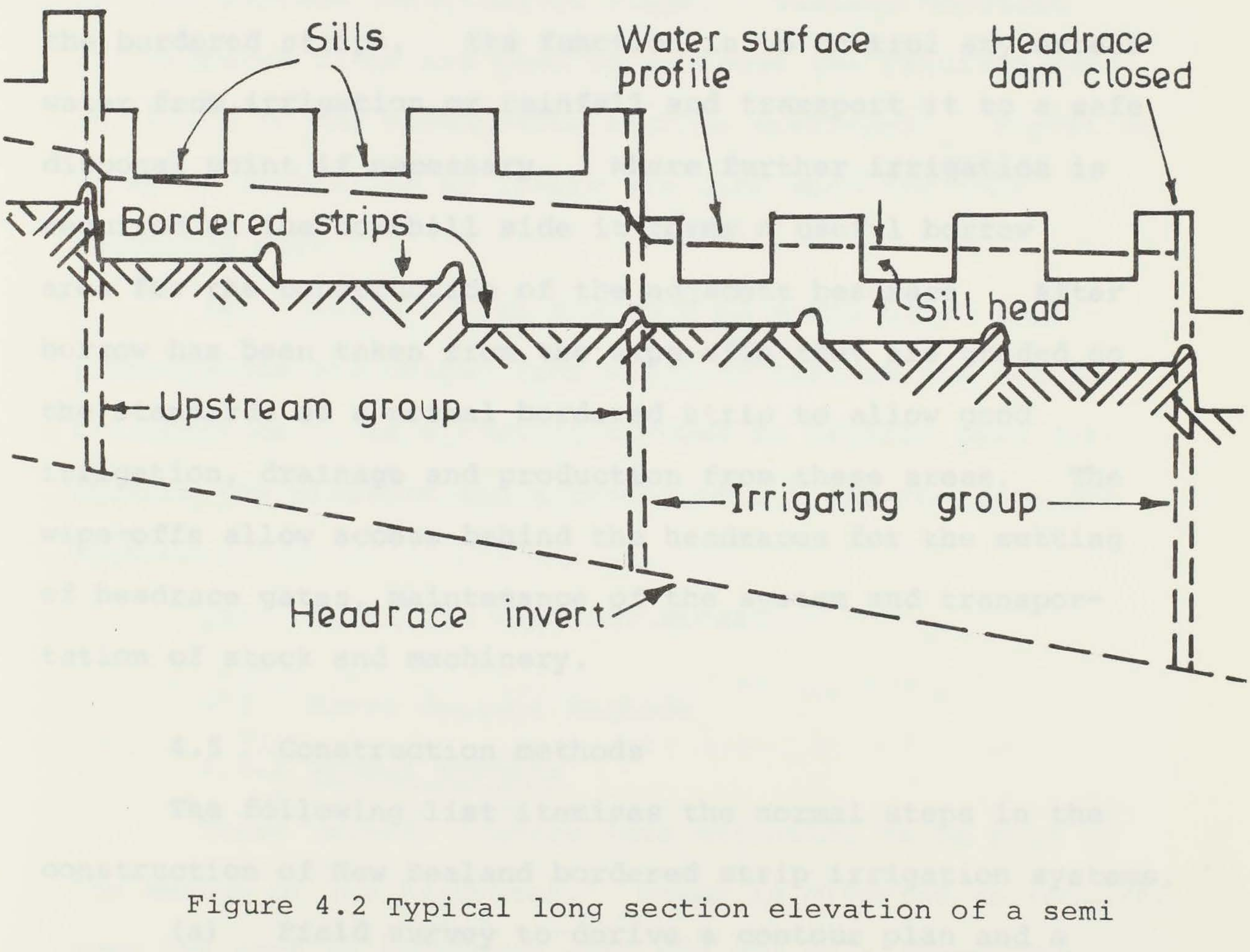


Figure 4.2 Typical long section elevation of a semi automatic irrigation headrace.

otherwise awkward mounds of earth or from the uphill bordered areas. Borrowing earth from a high downhill bordered strip may supply fill and also serve to reduce the required height of the headrace.

4.4 Wipe-offs

The wipe-off is the area at the downstream end of the bordered strips. Its function is to control any excess water from irrigation or rainfall and transport it to a safe disposal point if necessary. Where further irrigation is required on the downhill side it forms a useful borrow area for the construction of the adjacent headrace. After borrow has been taken from the wipe-offs they are graded to the standards of a normal bordered strip to allow good irrigation, drainage and production from these areas. The wipe-offs allow access behind the headraces for the setting of headrace gates, maintenance of the system and transportation of stock and machinery.

4.5 Construction methods

The following list itemises the normal steps in the construction of New Zealand bordered strip irrigation systems.

(a) Field survey to derive a contour plan and a bordered strip layout plan (see section 5).

(b) Smooth very large mounds and depressions if necessary.

(c) Form the borders of the bordered strips according to the layout plan usually with a grader,

(d) Cross level and longitudinal level within the strips. A grader or elevating scraper may be used. Field staff use an Abney level to determine the depths of cut and fill to satisfy the cross levelling tolerance and the minimum longitudinal slope. Various coloured and numbered flags are used to indicate the required cuts and fills to the earthmoving machine operators. Elevating scrapers controlled by lasers are also used for this levelling work.

(e) Build a flat platform of earth of an appropriate width and height from which to cut out the vee for the headrace. An elevating scraper is usually used for forming the platform and a grader to cut out the race vee section.

(f) Level the wipe-off areas.

4.6 Water Control Methods

4.6.1 Manual Systems

These usually require less attention to be paid to the design of the headraces. Water is diverted as required over the bank of headraces with the aid of a canvas dam set in the race at some appropriate position. The diverted water may fall over a sill or be directed by digging out sods from the side of the headrace. In some cases the sills are fitted with drop boards which may be removed as required to let water flow into the bordered strips. Subsequent canvas dams are conveniently erected downstream in the dry so that when the present dam is dismantled, water will be diverted to other downstream strips commanded by the headrace.

Other manual methods not used widely in New Zealand are:- syphon tubes to draw the water from the headraces and portable gated pipe used to eliminate the need for headraces. Gated pipe also allows the farmer to vary the length of his strips to suit the prevailing conditions in the border strips.

4.6.2 Semi-Automatic and Automatic Methods

Many methods are semi-automatic in that water is switched from one group of borders to the next without manual intervention, however, the diversion gates must be manually reset. Following the automatic release and closure of a headrace gate the water rises in the headrace until it flows over the group of sills (weirs) immediately upstream. The groups of sills are stepped so that water does not spill over the sills of any groups further upstream. Following the irrigation of the present group, the next gate to be automatically released is immediately upstream (unlike the manual method) and the process is repeated.

There are three main types of gate release mechanism used in New Zealand.

(a) Alarm clock system.

Alarm clocks may be present to release the gates after a given time interval. This method is partially fail safe and results in only one group getting twice the volume of water in the event of a gate not being released before a gate further up the headrace is automatically released. The clocks may be set one cycle ahead of up to 12 hours or 24 hours depending on the clock. This means that only 12 to 24 hours may be preset in advance. (The release mechanisms may in fact allow only about 11 and 23 hours respectively).

(b) Pneumatic System.

An inverted cup is placed in a sump near the downstream end of a strip. As water enters the sump it forces air up into the cup and along a small diameter tube to a diaphragm release mechanism attached to the gate.

The position of the sump therefore controls the time of watering. Watering times in existing installations may be varied by controlling the rate that the water enters the strip which contains the sump and so obtain good watering on the other strips in the group while sacrificing either water (by over-irrigation) or compete coverage (by under-watering) on the controlling strip. The mechanism results in continuous watering of one group of bordered strips if a release mechanism fails, however the gates may be preset at any time before irrigation.

(c) Electronic Systems.

These are similar in principle to the pneumatic system. Instead of a sump, an electrical circuit is created by water on the sensor placed in the bordered strip. One such system activates a heating coil which burns through a cord holding up the gate.

Like the pneumatic system, the mechanism is not fail safe and the gates may be preset at any time before irrigation.

Robinson (1970) described an electrically released spring loaded gate used in Victoria, Australia and Haise (1967) and (1969) has described experiments with fully automatic systems using radio control and pneumatic or hydraulic systems to release and reset diversion gates in America.

5.0 THE DESIGN OF BORDERED STRIP LAYOUTS

5.1 Hydrologic and Hydraulic Considerations

From a theoretical point of view the bordered strips should be designed to allow the application of a design depth of water as evenly as possible over the whole border strip at a frequency depending on evapotranspiration. A widely quoted method for the mathematical analysis of bordered strip irrigation is the "unit stream method" Schwab

(1966), Criddle (1956). The otherwise good theoretical base of the method relies heavily on the "basic infiltration rate" and assumes this to be a constant and characteristic of the soil. Zimmerman (1966) considers that mathematical formulae may be correct under certain restricted conditions but that the non-homogeneity of nature restricts the use of such formulae to demonstrating to a student the hydraulic principles involved. Israelson (1962) considers surface irrigation systems to be complex and not readily subject to quantitative analysis.

The basic problem is to achieve balance between the flow of water available at the top end of the strip and the physical properties of the strip to achieve the theoretical objectives mentioned above.

The major variables to be considered are:- (Hazen 1962)

(a) Size of stream
(b) Rate of advance
(c) Length of run time required
(d) Depth of flow
(e) Intake rate
(f) Slope of land surface
(g) Surface roughness
(h) Erosion hazard

(i) Shape of flow channel

(j) Depth of water to be applied

The ideal design would send a wave of water down the border strip which has approximately the same contact time with any area in the border and hence should infiltrate approximately the same depth of water. This forms the basis for a practical field testing method (in areas where no local experience is available) of plotting advance and recession curves and calculating the contact time of the water at any distance down the border strip (Criddle (1956)).

Further discussion of the hydrology and hydraulics is beyond the scope of this study which is primarily concerned with the earthworks following decisions as to the best size and shape for hydrologic purposes.

5.2 Farm Management Factors

Farm management can do much to influence the design and performance of a bordered strip irrigation system. Where the system is for pasture production only, considerable freedom is given to the designer to lay out the strips to minimise earthworks and accommodate existing fences and other obstables by varying the shape and size of strips. If cropping is important then straight parallel strips of a width to suit the farm machinery may be a governing criterion.

Considerations of labour input particularly with manually controlled systems favours longer strips because fewer headrace gates need be set per day leaving a longer interval of time in which the irrigation operates unattended.

Overall capital costs of irrigation development usually favour longer strips because of the fewer headrace structures and the fewer headraces to fence out.

Long strips and high infiltration rates decrease the application efficiency of the irrigation water and so where water is limited or expensive, shorter strips are favoured.

Grazing management and the stage of growth of non-grazed crops greatly affect the performance of the system by changing the vegetative retardance. Bare soil or cultivated soil may cause an erosion hazard on steeper strips.

5.3 EARTHWORKS

This is by far the most expensive single capital item in the bordered strip system (see Appendix 6). The cost can vary upwards from about $140 per hectare (1976 price). The design objectives are usually to minimise earthwork quantities consistent with the hydrologic and farm management considerations. The basic principle is to run the bordered strips down the greatest fall. This tends to minimise cross and longitudinal levelling because the contours run at right angles to the strip.

On complex topography the greatest fall is sometimes difficult to identify visually or else it is intersected in many places by ridges or valleys which require considerable earth movement to form a suitable strip in that particular direction.

The wider the strip on any given cross-slope the more cross-levelling earthwork is required. Doubling the width causes twice the volume of earth to be shifted twice as far and leaves a higher step from one strip to the next.

A further consideration is the removal of topsoil by deep cuts which reduces the fertility and hence production.

The slope is usually allowed to vary longitudinally down the strips following the natural topography and graded out if the fall becomes adverse. This both reduces the earthworks and the volume of topsoil shifted compared with levelling on an even longitudinal slope.

Machinery controlled by lasers is beginning to be used in New Zealand. These are capable of levelling a border on a precise plane with no cross fall. They will probably become very popular with contractors in the near future because they reduce the need for ground personnel setting out cuts and fills on the bordered strips. It is not clear if this is resulting in a lower cost for the land preparation but there is undoubtly some price being paid by removal of fertility because of the deeper cuts being made to form the plane surface.

The present solution to this complex problem is very much an art and it is an aim of this study to quantify these earthwork factors so that more soundly based judgements can be made on alternative designs from the point of view of earthworks.

6.0 THE FITTING OF PLANE AND WARPED SURFACES TO THE TERRAIN

No reported work has been found on the calculation of earthwork quantities specifically for the evaluation of alternative bordered strip irrigation layouts of the type common in New Zealand. The USDA Soil Comservation Service (SCS) Handbook (Anon 1959) describes the volume of earthwork for contour bench strips in general terms depending on the slope of the land and a method of setting out the contour benches. Various techniques described below have been developed for calculating suitable land slopes and earthwork quantities in relation to land levelling not only for irrigation but also for drainage. Land is commonly graded for furrow irrigation and to ensure uniformity of water application an even furrow slope and cross-furrow slope may be specified. Such a specification requires a flat plane to be fitted to the natural ground surface. Many of the reported techniques are based on shaping the terrain into a flat plane with minimum earth movement and modifications thereof. The equation describing the plane land surface is of the form:

$$Z\ (xy) = aX + bY + c$$

where Z (xy) is the elevation of the point at co-ordinates (X,Y)

a is the slope in the X direction

b is the slope in the Y direction

c is the reference height at the origin.

Spot heights on a square grid pattern are required for most of the techniques which fit a plane to the surface.

A brief discussion of the various techniques is relevant as they are used for comparison with the bordered strip technique developed herein.

(a) Least Squares Fitting

Givan (1940) drew the attention of designers to the technique of least squares fitting of a plane to a rectangular shaped field which was further developed by Chugg (1947) to suit an irregularly shaped field.

The slope of the best plane of fit on a rectangular area with a square grid of spot heights is expressed by the following equations:

$$a = \Sigma \frac{(DxHy) - (A)(H)}{B}$$

$$b = \Sigma \frac{(DyHx) - (A)(H)}{B}$$

where Dx = distance in stations from the y axis

Dy = distance in stations from the x axis

H = sum of elevations of all the grid points.

Hx = sum of elevations in the x direction along a grid line.

Hy = sum of elevations in the y direction along a grid line.

a = slope of the plane in the x direction.

b = slope of the plane in the y direction.

A&B = constants depending on the number of stations in the x and y directions.

The cut to fill ratio is met by lowering the best plane of fit.

Harris (1966) used a variation of the least squares technique and took account of the cut to fill ratio by making the sum of positive deviations from the best plane of fit equal to the cut to fill ratio times the sum of the negative deviations.

(b) Fixed Volume Centre Method

Raju (1960) developed the fixed volume centre method based on the two premises:

(i) To ensure a balance between cut and fill, the total volume of earth before and after grading shall be the same.

(ii) To ensure least cutting and moving of earth, the centre of volume shall remain at the same spot before and after grading.

The slopes in the x and y directions for a rectangular area are determined from the following equations :

$$b = \frac{12}{X^3 Y} M\bar{y}$$

$$a = \frac{12}{XY^3} M\bar{x}$$

where a and b = slopes in x and y directions respectively

X and Y = number of stations in X and Y directions respectively.

$M\bar{x}$ and $M\bar{y}$ = moments about the x and y axes respectively.

A solution for non-rectangular fields made up of a number of rectangular blocks is also presented by Raju.

(c) Average Profile Method

A practical design method discussed by Phillips (1958) is to calculate the average profiles in the x and y directions and find a suitable x and y direction design slope based on slope limitations, earthwork balance and experience.

(d) Plan Inspection Method

In this method, described in the USDA Irrigation Handbook, section 15 (Anon 1959), the designer proposes design elevations for the previously surveyed stations while simultaneously considering down-field slope, cross slope, earthwork balance and haul distance. The method requires considerable judgement and experience.

(e) Contour Adjustment Method

This method, also described in the USDA Irrigation Handbook, consists of a trial and error adjustment of the contour lines on a map. It is specially suited to those conditions where the original surveying stakes cannot be maintained in the field. It demands considerable judgement of the designer to recognise the relative importance of all the factors involved and to select a solution which satisfies the design criteria and requires least earthwork.

(f) Warped Surface Method

Harris et al (1966) described this computer method which repetitively scans the surveyed cross-field stations, and down-field stations, adjusting two station segments at a time until the station levels over the whole field meet the design cross-field and down-field slope limits. The plan inspection and contour adjustment methods also produce warped surfaces if required but need experienced designers.

(g) Symmetrical Residuals Method

This method was developed by Shih et al. (1971). The method is suitable for manual or computer use. It is essentially a mathematical average profile method.

This method was used by Shih (1975) in a computer programme which first fits a plane to a given area then adjusts the plane to form four different warped surfaces.

The programme was used in this study and it is described more fully below. (Section 10).

7.0 THE CALCULATION OF EARTHWORK QUANTITIES

7.1 Cut to Fill Ratios

Field experience has shown that it is necessary to have a ratio of cut to fill greater than one to achieve the desired final ground surface. The reasons put forward by the USDA Soil Conservation Service (Anon 1959) are:-

(a) The bulk of materials moved in land levelling are top soils with a high organic matter content and relatively low original density.

(b) The cut areas are subjected to considerable compaction by earth moving equipment hence the yield from the area of cut is less than calculated.

(c) Level ground surfaces between grade stakes appear to dip in the middle. To the extent that operators of grading equipment allow this optical illusion to influence their judgement, crowning between stakes will occur.

7.2 Calculation Methods

A number of methods of computing earthwork volumes are available. The following five methods are mentioned in the USDA SCS Handbook (1959):

(a) Prisimoidal Formula

$$V = L/6\ (A_1 + 4\ Am + A_2)$$

where V = Volume

L = Perpendicular distance between planes

A_1 = Area of one end plane

A_2 = Area of other end plane

Am = Area of the middle section parallel to the end planes.

(b) The four point method

$$Vc = \frac{L^2}{4} \frac{(Hc^2)}{(Hc + Hf)}$$

$$Vf = \frac{L^2}{4} \frac{(Hf^2)}{(Hc + Hf)}$$

where Vc = Volume of cut

Vf = Volume of fill

L = Grid spacing

Hc = Sum of cuts on four corners of a square grid.

Hf = Sum of fills on four corners of a square grid.

(c) End area method

$$V = \frac{L}{2} (A_1 + A_2)$$

Where V = Volume of cut (or fill)

L = Distance between end areas.

A_1 = Area of cut (or fill)

A_2 = Area of cut (or fill)

(d) Horizontal plane method

$$V = \frac{H}{2}(A_1 + A_2)$$

Where V = Volume of cut (or fill)

A_1 = Area of cut (or fill) horizontal plane

A_2 = Area of cut (or fill) horizontal plane

H = Vertical distance between the two horizontal planes.

(e) Summation Method

$$Vc = L^2 \Sigma Hc$$

$$Vf = L^2 \Sigma Hf$$

Where Vc = Volume of cut

Vf = Volume of fill

L = Square grid spacing

Hc = Depth of cut

Hf = Depth of fill

Another method described by Shih (1970) considered the six possible combinations of cut and fill of 4 spot height readings arranged in a square and developed a series of equations to calculate the volumes of cut and fill in each case. It is described as the "end grid area method". This method yields a calculated volume of earthwork which corresponds to:-

End grid area method = 0.6 x four point method + 0.4 x summation method.

7.3 Earth Transportation

Harris et al (1966) described a method of calculating the minimum distance of haul for a paddock with known cut and fill requirements at grid points. The method used linear programming to minimise the haul distance.

7.4 Accuracy of Volume Determination

Botman et al (1975) discussed the theoretical accuracy of volume determination for topographic surfaces on the assumption that the surface could be described as by a covariance function of the type:

$$\text{Cov}\ (i,j) = \sigma^2\ e^{-2d(i,j)/c}$$

where σ^2 denotes the variance of the function

$d(i,j)$ is the distance between the two points i and j

c is the distance over which there is a detectable correlation between data points.

Because in any one paddock, c is likely to vary over a wide range the application of this method is unlikely to be successful in the present context.

8.0 THE APPLICATION OF STANDARD EARTHWORK CALCULATING METHODS TO BORDERED STRIPS.

The foregoing discussion of typical New Zealand bordered strip irrigation and standard design and calculation methods serves to point out a number of areas in which the New Zealand techniques differ from overseas methods. A major influence is the use of surface irrigation for cropping overseas, whereas it is used extensively for pastoral farming in New Zealand.

In particular, the differences are summarised below:-

(a) With the exception of the contour adjustment method, all of the surface fitting methods rely on a staking of the paddock in a grid fashion and a grid of spot heights being available to fit the surface. In the New Zealand system cuts and fills for each bordered strip are calculated from levels measured in the field during construction (see Section 4.5(d)).

(b) Earthwork calculation methods rely on a grid of spot heights being available with the exception of the horizontal plane method, the end area method, and the contour adjustment method.

(c) Experience with the contouring techniques (Part I) indicated that the normal overseas grid size of about 30m (100 ft) is not always sufficient to adequately describe the ground surface on the geologically recent river planes on which much surface irrigation is practised in New Zealand.

(d) To apply the surface fitting technique to bordered strip irrigation restrains the paddock cross-slope to be not more than the tolerable bordered strip cross-slope. This would require excessive earthworks in some cases.

(e) The direction of the downslope lines of field readings presupposes that this is the best direction for the strips to follow. This may not always be the case.

(f) None of the above surface fitting techniques is suited to fitting a series of long narrow surfaces with very small cross-slope and variable longitudinal-slope. Width variation and changes in direction of the bordered strips are also beyond the scope of the above methods.

(g) The more rapid methods of design of surfaces rely on experienced personnel. No quantitative differences between designs are available from these methods.

It was concluded that the overseas design and calculation methods are not appropriate for the New Zealand conditions and that a more flexible system must be developed. A modified version of the earthwork programme, written by Shih et al (1975), is used below for comparison with New Zealand methods (Section 10.0).

9.0 THE DEVELOPMENT OF A BORDERED STRIP EARTHWORK CALCULATING PROGRAMME.

9.1 Existing Programmes

Enquires were made as to the suitability of the N.Z. Ministry of Works and Development's ROADS programme (Graphic 2 Users Manual, Anon 1974) because the formation of a number of strips down a paddock is similar to building a number of roads. The two main problems with using this programme are that the ROADS programme requires detailed specifications of grades and that the programme is not easily accessible being not available on the University computer. As no other useful earthwork programmes were available, it was decided to develop a programme especially for the purpose.

9.2 Earthwork Programme Characteristics

Although an earthwork calculating programme is potentially useful for cost estimation and as a teaching aid, it is expected to be most useful in the evaluation of alternative bordered strip layouts. The programme is therefore, designed to minimise the number of parameters which must be specified in order to detail the alternative layouts of the borders.

A useful feature would be that the programme could be run in an interactive mode for the evaluation of alternatives. The programme, as it stands, batch processes alternative designs but it could easily be converted to work in an interactive mode on a graphic display screen using a light pen to rapidly delineate the irrigation layout.

Earthwork programmes usually provide design levels to guide the machine operators. It was considered superfluous to provide such information in the case of the typical New Zealand system of construction because setting out the levels would be more trouble than their worth. Such information is easily available from the programme but it is voluminous and would be unwieldy in the field. Instead the programme aims to modify the surface (represented by a Digital Terrain Model (D.T.M.)) within each bordered strip to obtain the desired surface with near minimum earth movement. The emphasis is placed on the volume of earth moved and the haul distance rather than the levels achieved. The underlying assumption in this programme is that, given a strip of land defined by its boundaries, the present field construction practices (Section 4.5) will result in a near minimum volume of earthwork which is similar to the volume derived by calculation based on the data used to draw the contour plan or any other suitable data which may be available.

9.3 Terrain Data Preparation

In order to make use of data from any of the computer survey data processing systems mentioned in Part I, as well as other manually processed data, a general purpose programme to convert randomly spaced or regularly spaced data to a square grid D.T.M. of any specified grid size was written. This programme uses the inverse distance squared weighting methods described above in Section 3.4.4. The conversion of all data to a D.T.M. has the advantages of minimising data storage requirements and also provides a co-ordinate system on which it is easy to specify any position either on or between grid points. To make it easy to see the position of the D.T.M. data points in relation to the original survey data points a printout is made showing the grid points on a half inch square grid (corresponding to every 5th character position along a line of printout and every 4th line) along with the other data. The desired grid spacing on the terrain dictates the scale of this printout. The D.T.M. is stored on a disk file, along with the grid spacing and a title. Any programme which references whe D.T.M. uses the stored title and grid spacing to avoid any confusion of data.

9.4 Bordered Strip Layout Data

In order to calculate earthwork quantities for land preparation, each individual strip must be calculated separately. To supply the computer with details of the boundaries of each individual strip would be exceedingly tedious. The programme has been written to use the x,y, D.T.M. co-ordinates of any 4 points (which need not be grid nodes) on the surface and automatically divide the area bounded by the points into strips. The four points are specified in order around the periphery of the area. The first two relate to the headrace end and the second two relate to the wipe off end. The number of strips in the area may be specified, otherwise the area is automatically divided up into strips of approximately

12m width.

This system of specifying the strips allows them to fan out or to taper in or to take the form of any quadralateral. Curved strips cannot be accommodated unless they may be approximated to two or more straight sections. Vertical continuity where the straight sections join may be achieved by specifying the level at the intersection.

On undulating ground where the top end of the strip may have to be lowered to give fall from the headrace or where the lower end of a strip may have to be raised to allow drainage onto the wipe off area, the maximum top end height and the minimum lower end height may be specified. These limits may be defined by specifying spot heights for the four corners of the block of strips. (The headrace end of the wipe off end height limits may be specified independently). The height specifications define lines above which none of the top ends of the strips in a block may remain and below which none of the lower ends of the strips in a block may remain.

9.5 Earthwork Calculation Procedure for Bordered Strips.

For each individual strip a series of cross sections is defined by interpolation from the D.T.M. They run at right angles to the centre line of each bordered strip. The spacing of the cross sections and the number of interpolated spot heights used to define the cross sections may be varied. The earthwork required at any given cut to fill ratio to level the cross section to any given tolerance is calculated by the end area method described in section 7. It was found that because a small depth over a large area results in a large volume of earthworks a tolerance which would be acceptable in practice was necessary for the cross-levelling so that unrealistically high values of earthwork were not produced by the programme. A cross-levelling tolerance of $\pm$0.01m is usually specified. Areas in cut are reduced to +0.01m and areas in fill are raised to -0.01m with respect to the exact design level.

Once cross-levelling is completed the long section of the strip is examined to see if the grade is less than any specified minimum value and if the strip is above the maximum specified headrace end height or below the minimum specified wipe-off end height. Longitudinal-levelling is carried out to satisfy the above checks by shifting volumes of soil in the areas where cut is required to the closest position where fill is allowed, while satisfying any given cut to fill ratio. The summation method is used to calculate longitudinal-levelling earthwork volumes. (see Section 7.2). In practice, cross-levelling and longitudinal-levelling operations may not be separate items because soil may be shifted from one side of a strip and carried a distance along the strip before being deposited on the other side of the strip. The overall effect is similar however, and it is informative to differentiate between the two.

9.6 Soil Surplus or Deficit

Should there be surplus soil in the strip such that raising of the headrace end or removing soil from the strip is necessary, this is stated on the computer output. The excess volume of soil is also calculated. This facility can also be used to calculate the volume of mounds of soil which may require shifting before the levelling of the strip commences.

Similarly, the volume of soil necessary to fill in any hollow can be calculated.

9.7 Excessive Cuts

Should the cut from the natural ground exceed any specified value, then the volume of soil in all such areas is calculated down to this specified depth. The idea is to give some indication of the topsoil volume which may have to be stockpiled while additional cuts are made into the subsoil followed by topsoil respreading. Because the specified depth is constant it also serves as an indication of the area of subsoil exposed by the earthmoving operations with a consequent loss in fertility if the practice of topsoil respreading is not followed.

9.8 Borders or Levees

The volume of the borders, especially on even ground, can be a very significant fraction of the total earthworks. Since this volume is taken from over the whole area, but does not amount to a significant depth (approx. 0.01m) over the whole area, it is calculated out separately as the cross section of the borders multiplied by their length and not considered as a part of cross-levelling or longitudinal-levelling. The mounds are in fact formed by one sweep of the grader blade down each side of the mound. This leaves the strips slightly crowned and so flattening of the bordered strips is necessary if no other earth movement is required.

9.9 Wipe-Off Areas

The wipe-offs are essentially bordered strips and may be dealt with as such. The complicating factor, however, is that usually the wipe-offs serve as borrow areas for the head-races. It is not always clear from which area in the wipe-off that the soil will be borrowed. If the volume of fill required to construct any adjacent headrace is greater than the sum of the cuts and fills required to form the wipe-off then it may be reasonable to assume that no further gross earth movements will be necessary in the wipe-off area once the headrace has been formed.

9.10 Haul Distances

For each individual bordered strip, the distance between the centre of volume of cut and the centre of volume of fill is calculated. This gives a reasonable indication of the average haul distance of earth during longitudinal-levelling within a bordered strip as long as there is only one main area of cut and one of fill.

9.11 Headraces

By specifying the headrace cross section, length of groups, minimum drops, minimum height of lowest group and maximum height of the upstream group, a second programme can be used on the D.T.M. stored on the computer disk to calculate earthwork quantities associated with headraces. The headrace must be broken down into straight sections and the upstream and downstream x, y co-ordinates specified.

The computer is able to calculate the volume of soil in cut or fill required to build up a headrace platform with any given cut to fill ratio.

Because of constraints on the up and downstream sill levels, it is sometimes necessary to have the sills closer to the natural ground than some specified value. Should this be the case, the places where the condition exists are noted in the computer output. Appropriate action can then be taken to specify maximum values for the headrace end of of bordered strips in these places.

The volume of soil cut from the platform to form any specified race cross section is also calculated.

9.12 Supply Races

A supply race is a special case of headrace and is dealt with by calculating the volume of soil in cut and/or fill to form a sloping platform from the upstream to the downstream line that the race follows. The excess or deficit of cut compared with fill indicates whether additional soil will be required or whether soil will need to be hauled away.

9.13 Steps in using the Earthwork Programmes

(a) Calculate the volume of cut/fill required for the headrace in the paddock at the wipe-off end of the bordered strip.

(b) Consider the wipe off area in relation to (a) above and outfalls for drainage.

(c) Calculate the volume of soil in the headraces and note any areas where it is necessary to reduce the height of the headrace end of the borders.

(d) Using the upstream and downstream height constraints (if necessary) divide the paddocks up into suitable areas and calculate the bordered strip earthwork quantities.

(e) Calculate supply race volumes.

(f) Re-calculate as necessary to balance earthworks in the various phases of the work.

10.0 THE N.C.S.U. PROGRAMME

10.1 Description

A computer programme written at the North Carolina State University was obtained for comparison with the methods of earthwork calculation described in Section 9.0. A listing of the programme together with a general description is given by Shih et al (1975). A brief description of the programme is given here.

The program uses the symmetrical residuals method (Section 6 (g)) to fit a plane to any irregularly shaped field with level readings or reduced levels at grid points 100 feet apart. The actual paddock boundary may be described as departures from the recorded spot height positions near the boundaries. The plane of best fit is adjusted according to the maximum and minimum cross-field and down-field slopes specified by the user. The series of warped surfaces below are also calculated by the programme.

(a) Variable slope with down and cross-field drainage.

(b) Uniform slope in individual down-field lines of data and variable slope in the cross-field direction with down and cross-field drainage.

(c) Uniform slope in the individual down-field lines of data with down-field drainage and a minimum and maximum cross-field slope and no cross-field drainage.

(d) Variable down and cross-field slopes with no cross-field drainage.

The various surfaces above are formed using relaxation methods beginning with the original data and the plane surface found by the above method. The original spot heights are in turn compared with the calculated plane surface spot heights and if the plane surface is in fill, the design warped surface is made lower than the plane surface and tested to see if it is consistent with the slope limitations of the particular design. Similarly if the plane surface is in cut the design warped surface is adjusted upward and tested for conformity to the slope limitations.

10.2 Modifications to the NCSU Programme

10.2.1 <u>Grid Size</u>

The first major limitation of the programme under New Zealand conditions is that the fixed square grid size of 100 feet assumed in the programme does not fit the usual size of surveyed grid and is therefore not consistent with existing data. Experience with data collection for the production of contour plans indicates that under many circumstances a smaller distance between grid points is necessary to describe the ground surface.

The programme was modified to use a specified variable grid spacing.

10.2.2 Units of Measurement

The program was modified to work in S.I. units from f.p.s. units.

10.2.3 Contour Display

As an aid to the appreciation of the original surface and the modifications to the surface by the programme, a contouring subroutine was incorporated which displays the original contours of the ground and the contours of the various design surfaces as well as contours of cut and fill to achieve the design surfaces. The surfaces may also be shown as three dimensional projections in the latest versions of this programme (Figure 12.1)

10.2.4 Data Rotation

The original programme assumed that the desired direction of the downfield-slope is determined by the direction of the lines of field readings in the downfield-direction. It does not allow the designer to test other directions for the downfield-slope.

A subroutine was written to define a new set of data points based on the original data with downfield-lines at any direction to the original downfield-lines.

11.0 COMPARISON OF THE EARTHWORKS USING THE N.C.S.U. AND THE BORDERED STRIP PROGRAMME.

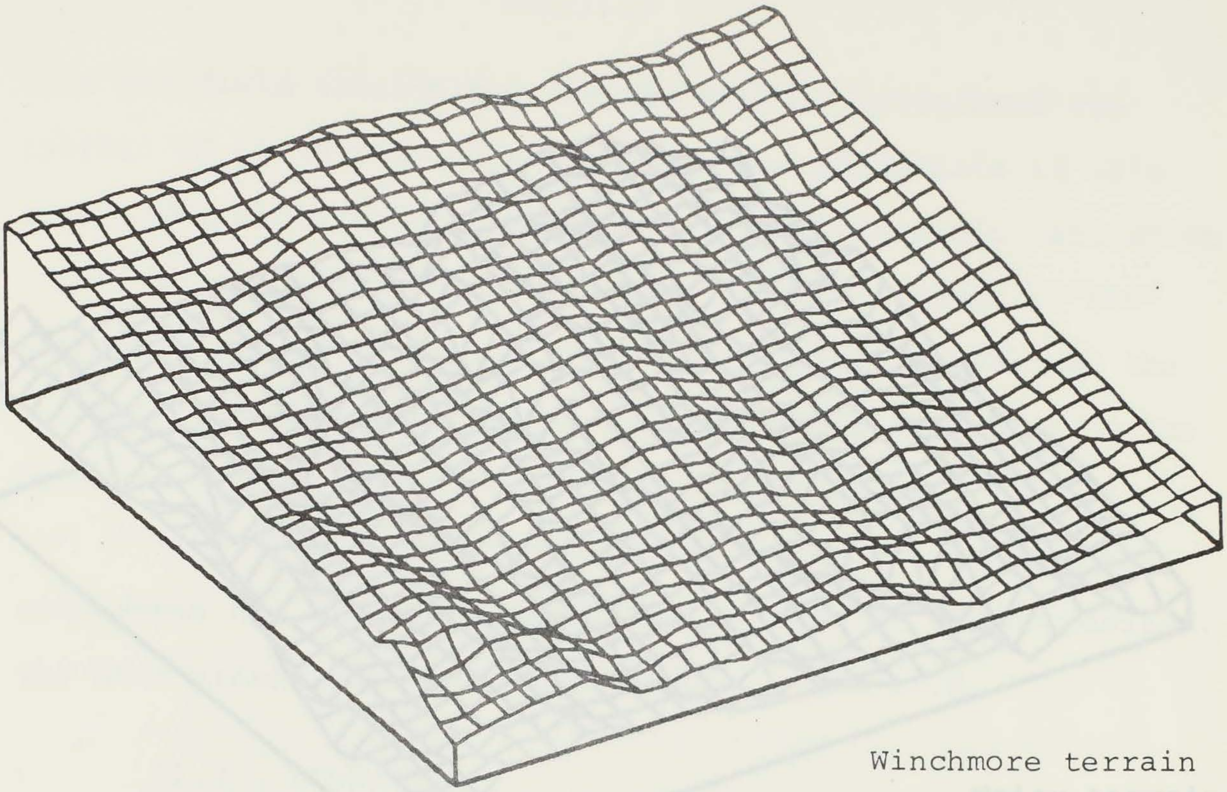
11.1 Terrain Data

Four areas of 9 ha on different terrain types, but all suitable for bordered strip irrigation, were selected for this exercise. These areas had previously been surveyed on a 10m x 10m grid by Winchmore Irrigation Research Station staff. The grid system ensures that the data are not affected by the surveying technique of the surveyer, but it does not ensure that all salient points are recorded. The more even terrain is probably more accurately represented by the grid of spot heights than the rough terrain. The data are very dense compared with most surveys of this type so this tends to lessen the importance of terrain type on the data.

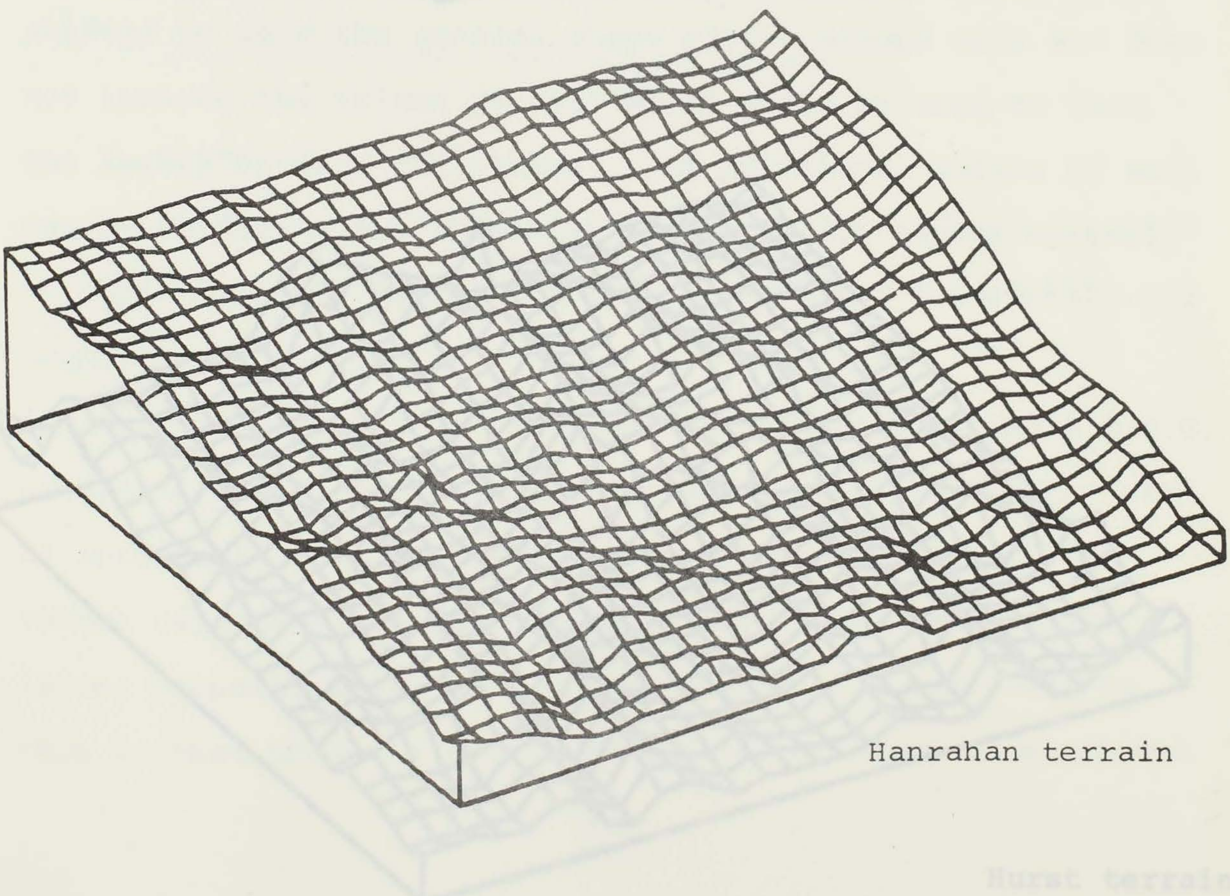
11.2 Method of Comparison

The two programmes are not strictly comparable because they each calculate earthwork quantities appropriate to their particular type of land preparation. It is of interest, however, to compare the volumes of soil shifted using the different methods. Cost comparisons could be made if costing rates for the various soil shifting operations were available.

A range of variables is written into each programme. The variable values were selected as 'normal' values except



Winchmore terrain



Hanrahan terrain

Figure 11.1 Three dimensional projections of Winchmore and Hanrahan terrain.

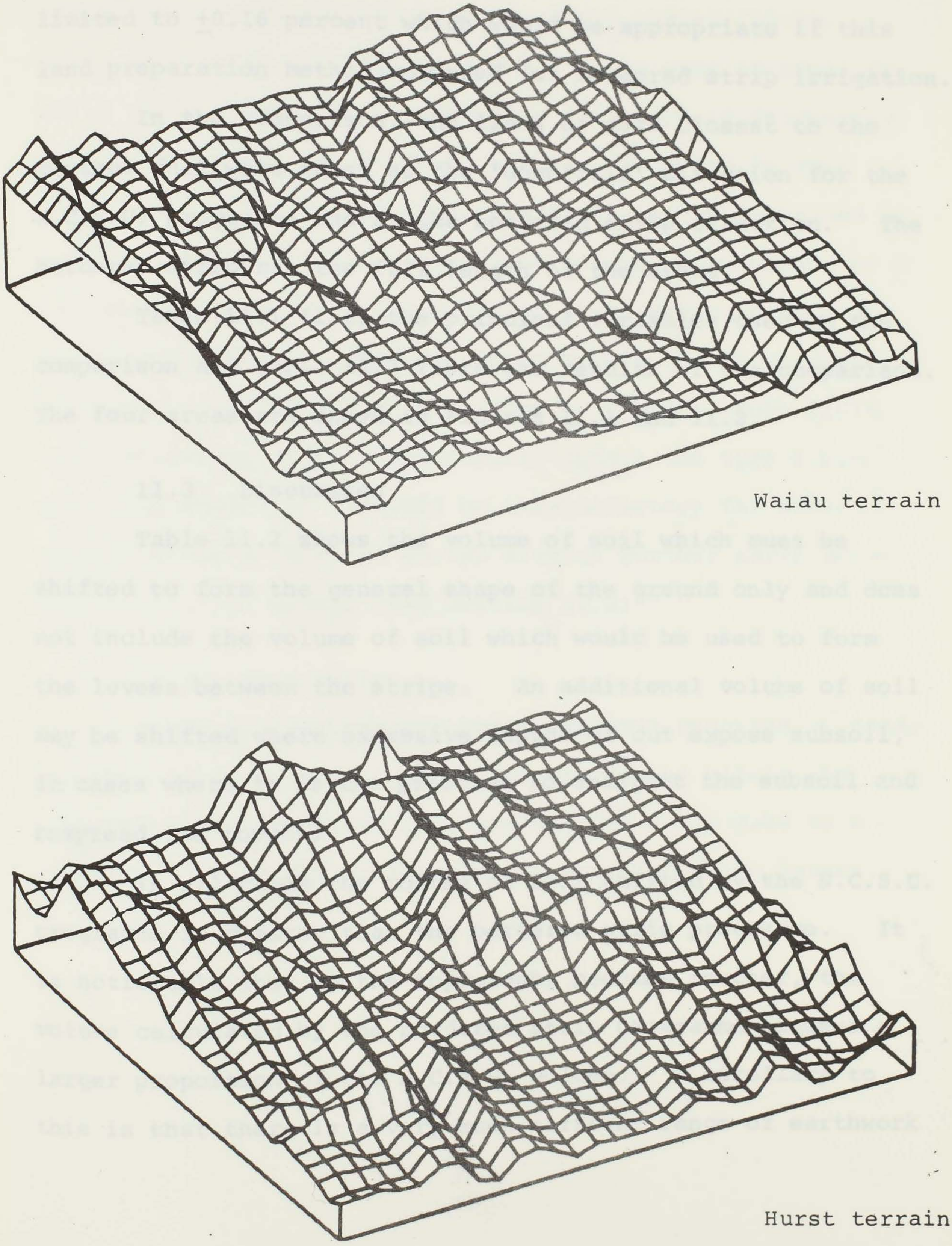


Figure 11.2 Three dimensional projections of Waiau and Hurst terrain.

that the field cross-slope for the N.C.S.U. programme was limited to ± 0.16 percent which would be appropriate if this land preparation method were used for bordered strip irrigation.

In the comparison, the lines of data closest to the maximum fall were taken as the 'downfield' direction for the N.C.S.U. programme and as the bordered strip direction. The bordered strip ran the full length of the areas.

Table 11.1 lists the principal variables used in the comparison and table 11.2 lists the results of the comparison. The four areas are shown in Figures 11.1 and 11.2.

11.3 Discussion

Table 11.2 shows the volume of soil which must be shifted to form the general shape of the ground only and does not include the volume of soil which would be used to form the levees between the strips. An additional volume of soil may be shifted where excessive depths of cut expose subsoil, in cases where it is the practice to undercut the subsoil and respread the topsoil.

In all cases the volume of soil shifted by the N.C.S.U. programme is greater than the bordered strip programme. It is noticeable that as the topography becomes rougher, the volume calculated by the bordered strip programme becomes a larger proportion of the N.C.S.U. volume. A corollary to this is that there is a very much narrower range of earthwork quantities for the range of terrain types using the N.C.S.U. system (2:1) than for the bordered strip system (10:1).

The range of quantities for any one area is small for the N.C.S.U. system but it did show the trend in decreasing earthworks of : plane surface, b,a,c,d, as noted by Shih (1971 (a)). The narrow range of values can be explained by the fact that any field cross slope can be accommodated by a step between strips in the bordered strip programme but any steep slope must be levelled out to within the cross slope tolerance in the N.C.S.U. programme. A wider cross field slope tolerance would significantly reduce the type d surface earthworks but it would be unsatisfactory for subsequently forming bordered strips without further earth movement within the strips (see section 12.2).

11.4 Conclusion

There is considerably less earthwork required to grade the land to a suitable surface for irrigation within the bordered strips compared with grading the whole area to a suitable surface before forming the bordered strip levees.

N.C.S.U.

Downfield Direction		
Maximum Slope	10.0	percent
Minimum Slope	0.1	"
Crossfield Direction		
Maximum Slope	0.16	"
Minimum Slope	-0.16	"
Cut to Fill Ratio	1.25	
Cut to Fill Tolerance	0.1	

BORDERED STRIP

Strip Width	12	m
Cross Levelling Tolerance	0.01	m
Minimum Longitudinal Fall	0.1	percent
Cut to fill ratio	1.25	

Table 11.1 : Principal Variable Values Used in Earthworks Comparison

NAME	WINCHMORE	HANRAHAN	WAIAU	HURST
Terrain	Very Even	Even	Rough	Very Rough
Maximum Average Slope	0.6%	0.7%	0.25%	0.4%
	N.C.S.U. PROGRAMME			
Plane Surface	480	519	492	1056
a*	478	519	489	1050
b*	478	519	490	1052
c*	470	503	446	1008
d*	451	498	428	992
	BORDERED STRIP PROGRAMME			
CL*	37.6	55.8	61.4	129.0
LL*	32.0	20.5	168.5	557.0
TOTAL	69.9	76.3	229.9	686.0
RATIO*	15.4%	15.3%	53.7%	69%

* Legend - see over

Table 11.2 : Earthwork Quantities in Cubic Metres per Hectare for Four Different Terrain Types.

* Legend for Table 11.2 - on previous page.

a   Variable slope with down and cross-field drainage.

b   Uniform slope in individual down-field lines of data and variable slope in the cross-field direction with down and cross-field drainage.

c   Uniform slope in individual down-field lines of data with down-field drainage and a minimum and maximum cross-field slope and no cross-field drainage.

d   Variable down and cross-field slopes with no cross-field drainage.

CL   Cross-levelling within bordered strips.

LL   Longitudinal-levelling within bordered strips.

RATIO   The volume CL + LL expressed as a percentage of the type "d" surface earthworks volume.

12.0 MINIMISING EARTHWORKS USING THE EARTHWORK PROGRAMMES

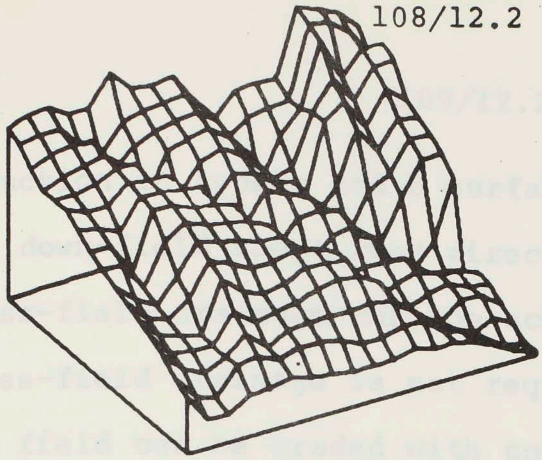
12.1 Terrain Data

For this exercise an 11.5 hectare paddock was chosen which is a part of the North Rakaia Irrigation Scheme. A 20m x 20m grid of spot heights was deduced from a contour plan which had been drawn by the plane table method. There was good agreement between the original contour plan and the computer plan produced from the derived data and so the spot heights were accepted as representative of the area. For the sake of the exercise alone, it is not essential that the surface is represented exactly, but for the sake of authenticity it is better to be realistic.

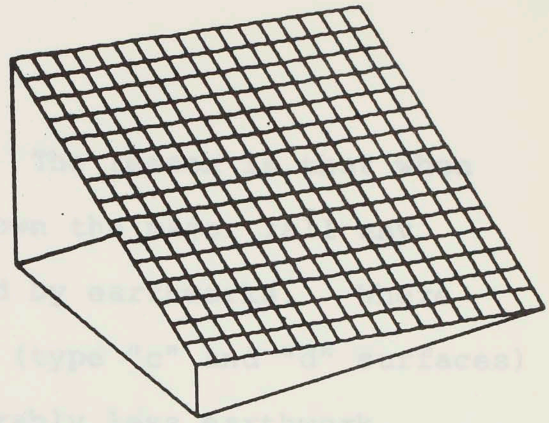
The surface has two major valleys and the general slope running at about 45 degrees from the downfield-lines of data. (See Figure 12.1).

12.2 The N.C.S.U. Programme

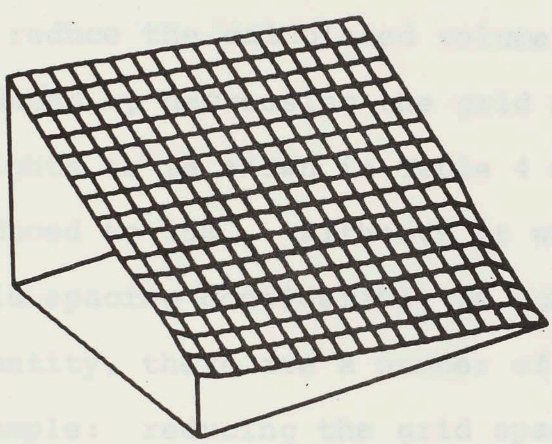
A contribution to the N.C.S.U. programme as a result of this study is the addition of a data rotation subroutine which should allow the designer to select the best direction in which to run the downfield slope. It can be seen on Table 12.2 that with a 45 degree rotation, so that the downfield-slope runs down the major valleys, there is an increase in the earthwork quantities of surface types a and b, and a



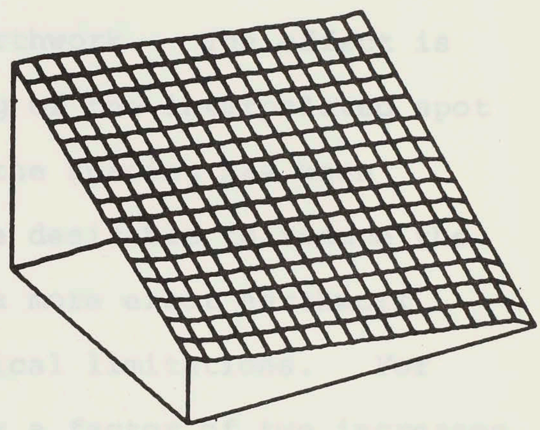
Original terrain



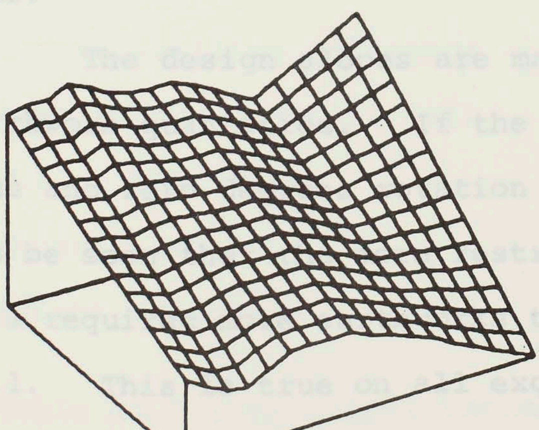
Flat plane of best fit



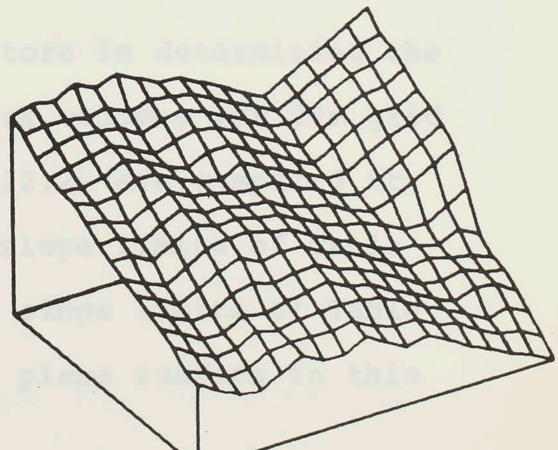
Type a surface



Type b surface



Type c surface



Type d surface

Figure 12.1 Surface modifications to North Rakaia terrain using the N.C.S.U. programme.

reduction in type c and d surfaces. The reason is that when the down-field slope runs directly down the major fall any cross-field drainage must be achieved by earthworks. Where cross-field drainage is not required (type "c" and "d" surfaces) the field can be graded with considerably less earthwork.

To achieve the data rotation, the programme interpolates a new set of spot heights running in the desired direction which results in a smoothing effect on the surface and tends to reduce the calculated volume of earthwork. The effect is reduced by decreasing the grid spacing of the interpolated spot heights as is shown in Table 4 where the spacing has been reduced to 15m. Although it would be desirable to reduce the grid spacing considerably to achieve a more exact earthwork quantity, there are a number of practical limitations. For example: reducing the grid spacing by a factor of two increases the number of field stations, the number of elements in the data arrays and the computer processing time by a factor of four.

The design slopes are major factors in determining the earthwork quantities. If the earthwork volumes for 20m grid size and zero degrees rotation (Table 12.2) are compared it can be seen that the more restrictive slope limits of Table 11.1 required more earthworks than the slope limits of Table 12.1. This is true on all except the plane surface in this example.

N.C.S.U. PROGRAMME

Downfield direction		
Maximum Slope	0.5	percent
Minimum Slope	0.1	"
Crossfield direction		
Maximum Slope	1.0	"
Minimum Slope	0.0	"
Cut to Fill Ratio	1.25	
Cut to Fill Tolerance	0.1	

BORDERED STRIP PROGRAMME

Strip Width	12 (approx)	M
Cross-Levelling Tolerance	0.01	M
Minimum Longitudinal Fall	0.2	percent
Cut to Fill Ratio	1.25	
Topsoil depth	0.1	M
Height of Levees	0.4	M

Table 12.1 : Principal Variable Values Used in Earthworks Minimising.

SLOPE LIMITS	Table 12.1	Table 12.1	Table 12.1	Table 11.1
GRID SIZE	20 m	20 m	15 m	20 m
ROTATION	0^{o}	45^{o}	45^{o}	0^{o}
FLAT PLANE	916	868	927	916
a*	682	861	921	914
b*	789	868	926	915
c*	668	380	418	883
d*	513	275	313	836

* Legend - Refer to Legend of Table 11.2

Table 12.2 : Earthwork Quantities in Cubic Metres per Hectare Using Variations of the N.C.S.U. Programme.

12.3 The Bordered Strip Programme

The following discussion refers to data shown on Table 12.3.

The layout numbers in Table 12.3 refer to the layouts shown in Figures 12.2 and 12.3. Figure 12.1 shows a three dimensional projection of the surface before earthworks.

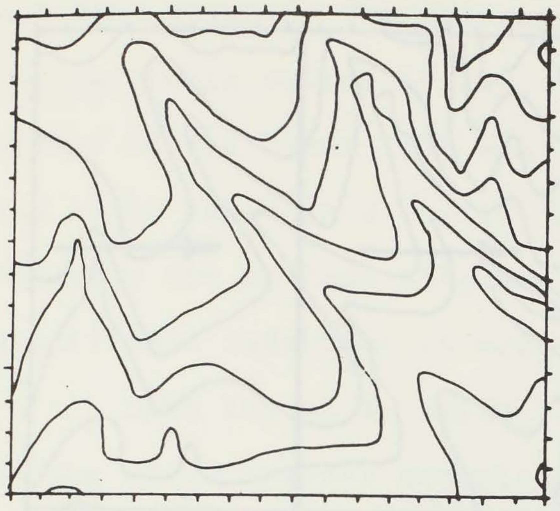
12.3.1 Cross-levelling

The volume of cross-levelling in all layouts is very similar with the layout of borders across the page (No.s 2 and 4) being slightly lower than the other predominantly down the page layouts.

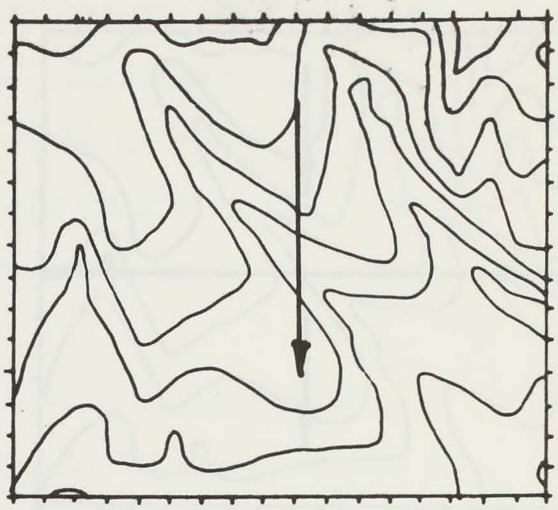
12.3.2 Longitudinal-Levelling

The most significant changes in earthwork volumes are shown in the changes in longitudinal-levelling. The experienced designer would be unlikely to choose layouts 2 or 4 unless there was some other pressing reason more important than the cost of earthworks because of the mound in the top right-hand corner of the contour plan. These two layouts were tested for the sake of completeness.

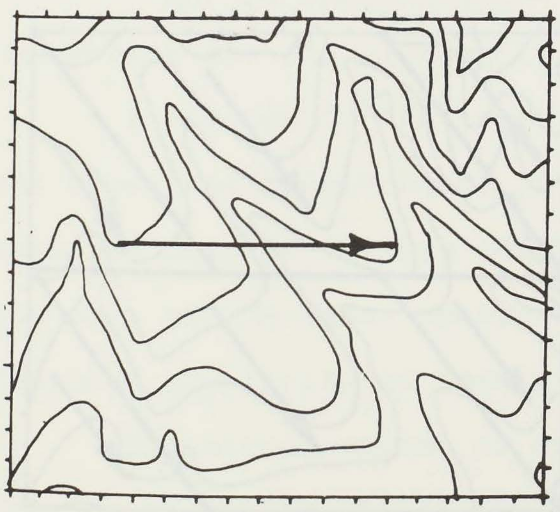
In comparing layouts 1 and 5, it is shown that reducing the strip length alone reduces the earthworks. This is because a shorter strip, if it ends in a valley, does not require the longitudinal-levelling of a strip which requires the valley to be filled in.



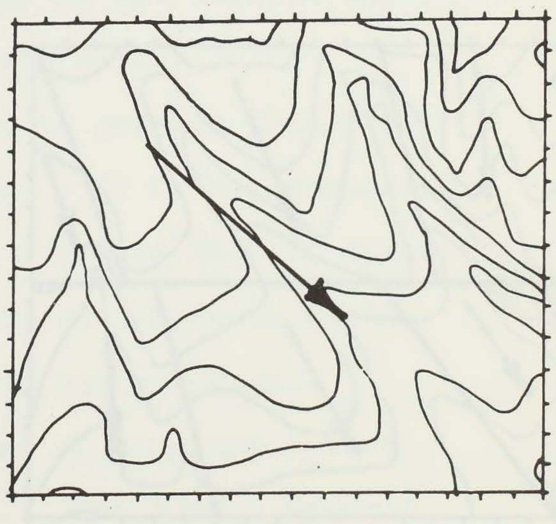
Original contours
Contour interval 0.25 m
Scale 5000:1 (approx)



Layout 1



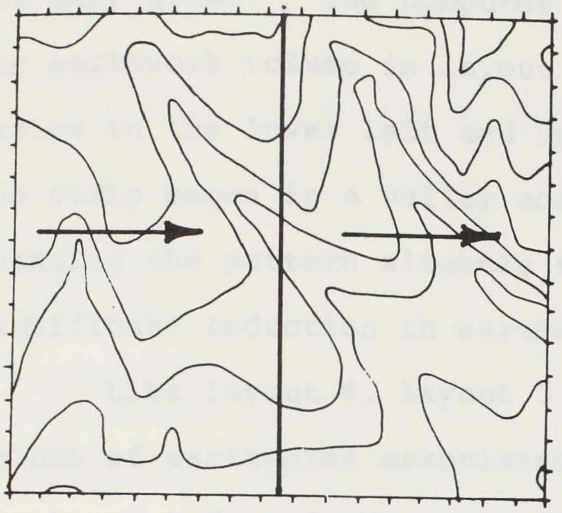
Layout 2



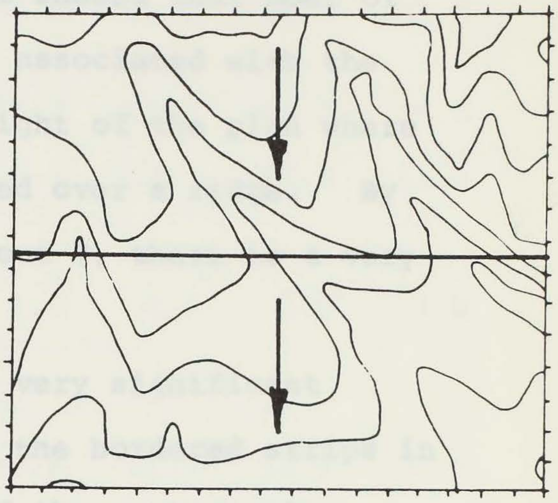
Layout 3

The arrows indicate the bordered strip direction

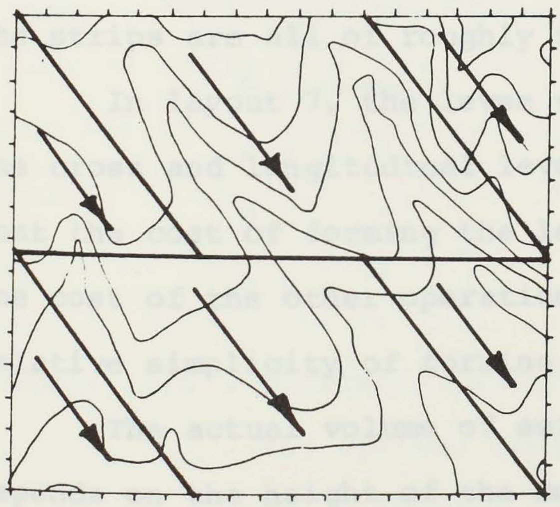
Figure 12.2 Bordered strip layout numbers 1 to 3 on North Rakaia terrain.



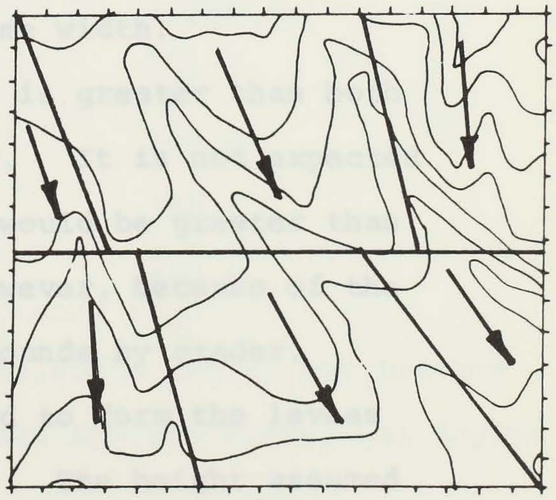
Layout 4



Layout 5



Layout 6



Layout 7

The arrows indicate the bordered strip direction

Figure 12.3 Bordered strip layout numbers 4 to 7 on North Rakaia terrain.

The reduction in earthworks from layouts 5 to 6 is not very great. The computer output showed that most of the earthwork volume in layout 6 was associated with the strips in the lower left and upper right of the plan where the strip began in a valley and passed over a ridge. By changing the pattern slightly to layout 7, there is a very significant reduction in earthworks.

Like layout 6, layout 3 has a very significant volume of earthworks associated with the bordered strips in the lower left and the upper right of the contour plan.

12.3.3 Levees or Border Mounds

As would be expected, the volume of soil associated with the levees is very similar for all layouts because the total length of the strips is similar in all layouts when the strips are all of roughly the same width.

In layout 7, the levee volume is greater than both the cross and longitudinal levelling. It is not expected that the cost of forming the levees would be greater than the cost of the other operations, however, because of the relative simplicity of forming the mounds by grader.

The actual volume of soil used to form the levees depends on the height of the mounds. The height assumed for this exercise is 0.4m of compacted earth, which is a generous allowance compared with normal field practice.

Layout No.	1	2	3	4	5	6	7
Cross - Levelling	69.2	50.4	71.4	50.4	69.4	66.8	72.3
Longitudinal-Levelling	299.6	815.9	295.7	716.2	203.9	160.2	96.8
Levees	112.6	118.2	113.9	118.2	112.7	123.2	111.4
Stockpiled Cross - Levelling	4.4	1.8	6.6	1.8	4.4	4.9	7.8
Stockpiled Longitudi-nal - Levelling	140.0	272.6	114.6	268.8	81.0	55.9	30.7

Table 12.3 : Earthwork Quantities in Cubic Metres per Hectare for Various Paddock Layouts Using the Bordered Strip Programme (See Figures 12.2 and 12.3).

Longitudinal Slope	Earth Quantity Longitudinal Levelling
0.1 percent	236.4
0.2 "	299.6
0.3 "	368.4
0.4 "	486.2

Table 12.4 : Earthwork Quantities in Cubic Metres per Hectare for Various Longitudinal Minimum Slopes for Layout No. 1 (Figure 12.2.).

The volume of 111 cubic metres per hectare can be considered as a depth of only 0.011m over the area.

12.3.4 Stockpiled Topsoil During Cross-Levelling

In all layouts this volume was small. It is noticeable that in layouts 6 and 7 where an effort was made to run the strips along the valleys, that there is a slight increase in stockpiling the topsoil during cross-levelling. This is due to the cross-levelling along the steep valley sides.

12.3.5 Stockpiled Topsoil During Longitudinal-Levelling

In Section 9.7, it is indicated that the volume of stockpiling can be interpreted as the area over which the soil would be removed to greater than the specified topsoil depth. (0.1m in this case). In layout 1, about 14% of the area would have the topsoil removed. Layout 2 would have 27% of its topsoil removed, whereas layout 7 would have about 3.1% removed. Herein lies an as yet unquantified factor in layout design which is the cost of removing topsoil in terms loss of fertility and hence production from these areas. Naturally, the layout which requires the least earthworks also has the least effect on the topsoil.

12.3.6 Minimum Longitudinal Slope

Superimposed on the effects of changes in layout is the effect the minimum longitudinal slope has on the total earthworks. The bordered strip programme shifts soil within a bordered strip so that there is fall from the headrace to the wipe-off and allows the slope to vary as long as there is no adverse fall, or fall less than a specified minimum value.

Table 12.4 shows the effect of changes in minimum slope on the longitudinal-levelling volume. As would be expected, the volume increases with increase in the minimum slope. At the slope of 0.4%, 13 of the 27 longitudinal bordered strips did not have sufficient fall in their undisturbed state so fall had to be created by raising the headrace end of the bordered strip. This is done automatically by the programme.

12.4 Summary

The N.C.S.U. programme allows the designer to minimise earthworks by shaping the ground to form plane or warped surfaces with varying degrees of freedom in the cross and down-field slopes. Not demonstrated here, because the paddock chosen was small, is that the earthworks may in some cases be reduced by using the N.C.S.U. programme on sub-areas within the field.

The bordered strip programme allows the designer to alter the layout of the bordered strips to best suit the terrain in order to minimise earthworks. This allows the designer flexibility, not available in the N.C.S.U. programme, to cope with isolated irregularities in the field which would otherwise require large volumes of earthwork. It also allows the designer to more fully use his design skill although a high level of skill is not required to use it in simple cases.

13.0 COMPARISON OF ESTIMATED EARTHWORK QUANTITIES AND EARTHMOVING MACHINE TIMES

13.1 Introduction

The opportunity was taken to record the earthwork machine times during land preparation work for bordered strip irrigation on "Lyndhurst Farm" belonging to Lincoln College. The terrain is even with a maximum general fall of about 0.5%. The area had previously been surveyed using the computer grid survey method described above (Section 3.2). Figure 13.1 shows the contour plan of the area with the bordered strip layout.

13.2 Method

The aim was to record the times taken in the field of the earthmoving machinery as they performed the operations of cross and longitudinal levelling within each individual strip.

On the particular paddock examined the terrain is very even, so a small quantity of earthworks was required compared with the examples in Sections 11 and 12.

The machine operators were free to grade the bordered strips in the manner which best suited them. Unfortunately, there was no control over the number of machines operating in the area or the changes in operators. Two graders were used:- a Caterpillar 14G (134 KW) and a Caterpillar 14E (112 KW). Their differences in rate of work were assumed to be in proportion to their power and their times were corrected accordingly.

Another uncontrolled factor was the weather which caused an interruption to the work on a number of occasions.

During the earthwork operations, the soil, which is a silt loam, remained moist and very little dust was generated by the machines. The soil was cultivated and sod-free before the earthwork machines began and the earthwork times were recorded after the levees had been formed.

In the strips studied, there was very little longitudinal-levelling required. It was difficult to identify the longitudinal-levelling during the field operations so the cross and longitudinal-levelling times were lumped together.

Table 13.1 shows the principal variable values used in the calculation of the earthwork volumes.

Strip width	12.5	M
Cross-levelling tolerance	0.01	M
Minimum longitudinal fall	0.3	percent
Cut to fill ratio	1.25	

Table 13.1 : Principal Variable Values Used in the Bordered Strip Programme to Estimate Earthwork Volumes for Machine Time Comparison

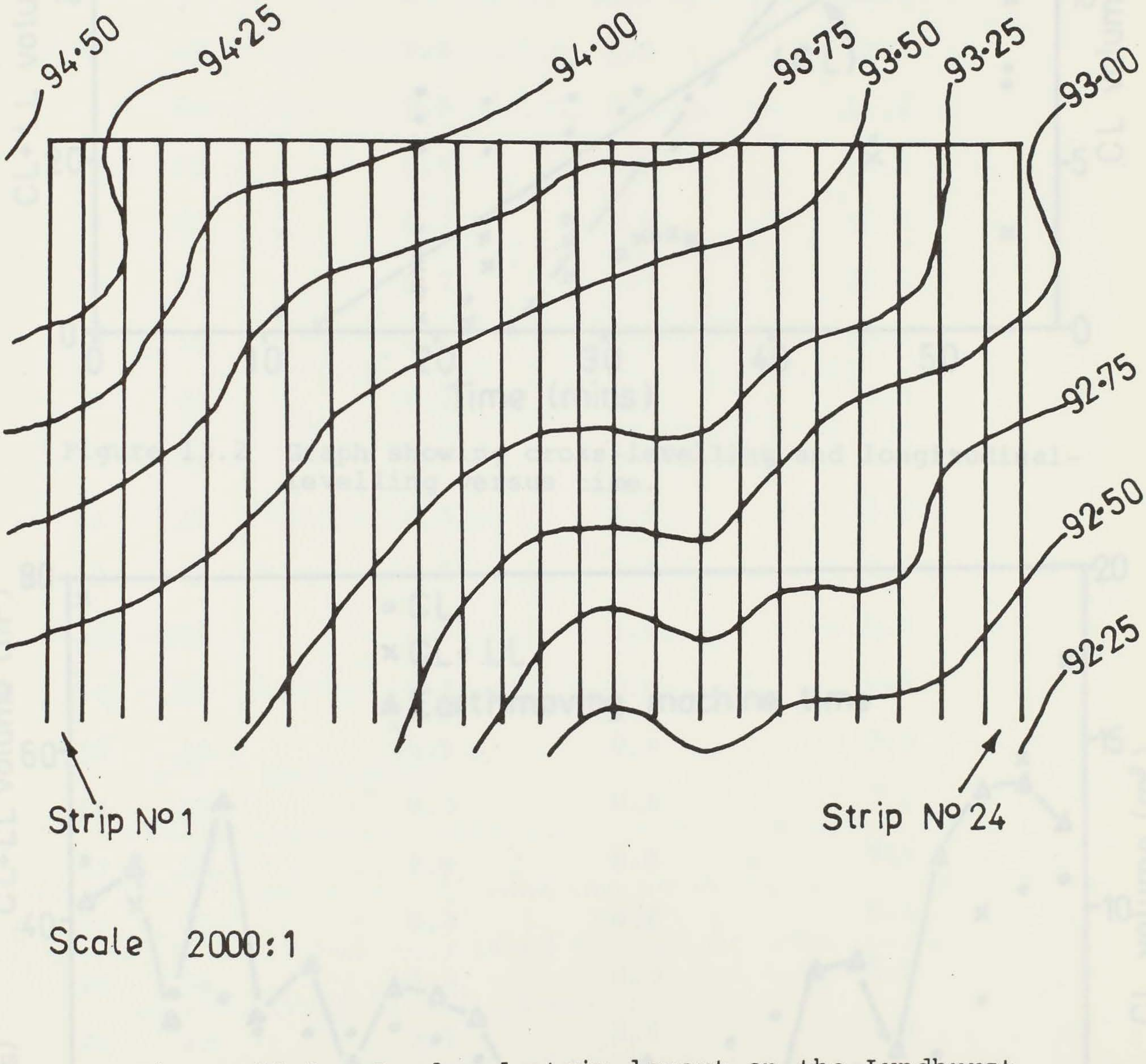


Figure 13.1 Bordered strip layout on the Lyndhurst Farm Paddock.

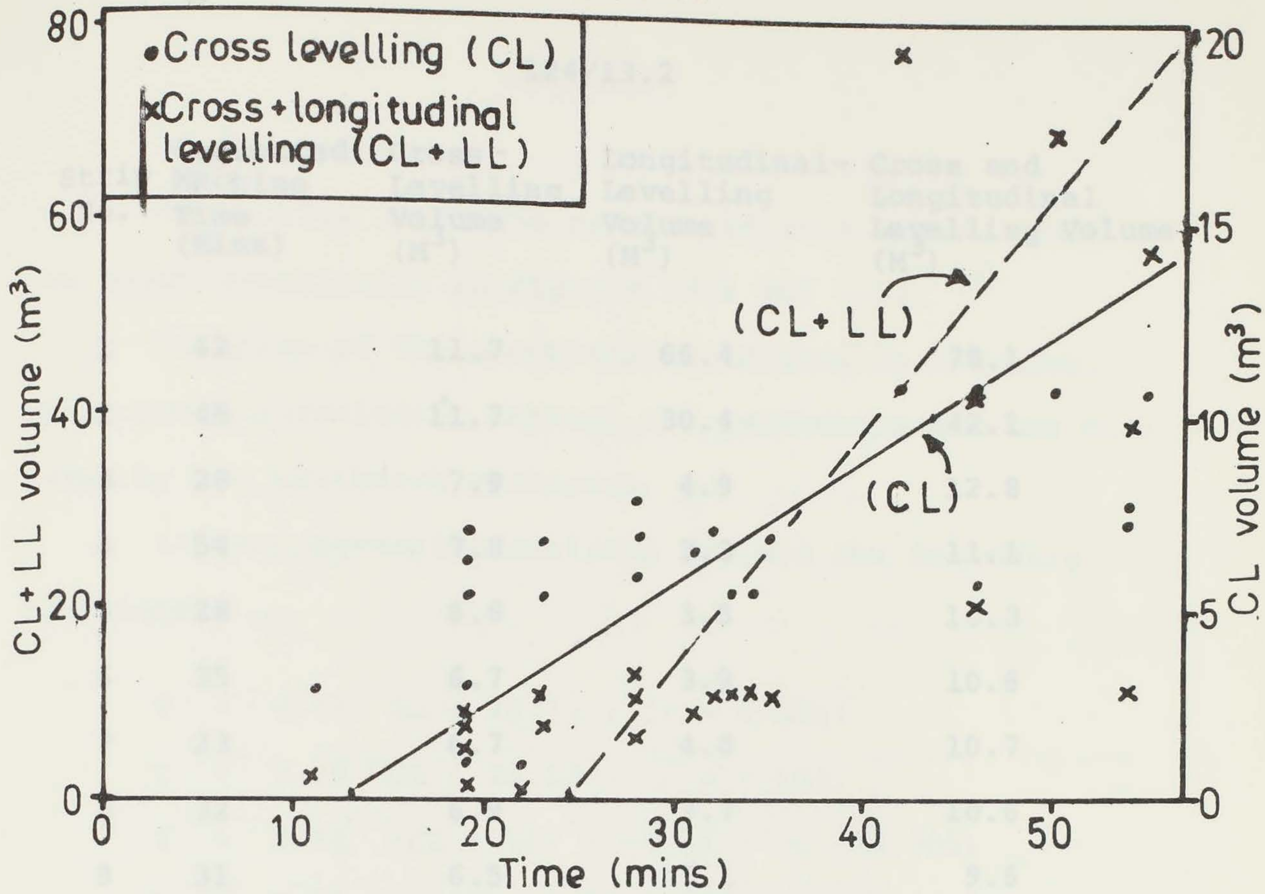


Figure 13.2 Graph showing cross-levelling and longitudinal-levelling versus time.

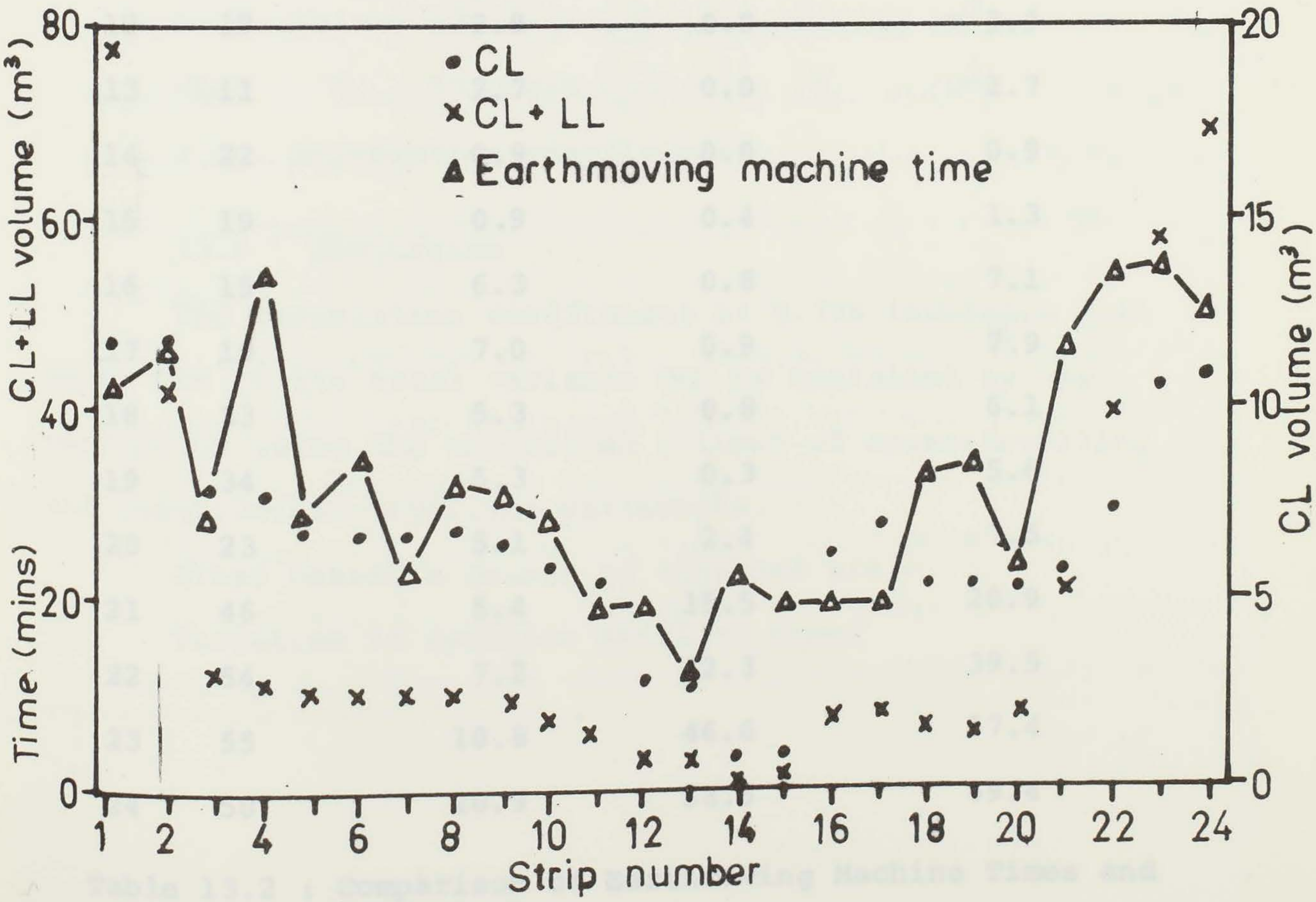


Figure 13.3 Graph showing earthworks and machinery times for individual bordered strips.

Strip No.	Corrected Machine Time (Mins)	Cross-Levelling Volume (M^3)	Longitudinal-Levelling Volume (M^3)	Cross and Longitudinal Levelling Volume (M^3)
1	42	11.7	66.4	78.1
2	46	11.7	30.4	42.1
3	28	7.9	4.9	12.8
4	54	7.8	3.3	11.1
5	28	6.8	3.5	10.3
6	35	6.7	3.9	10.6
7	23	6.7	4.0	10.7
8	32	6.9	3.7	10.6
9	31	6.5	3.1	9.6
10	28	5.7	1.1	6.8
11	19	5.4	0.4	5.8
12	19	2.9	0.0	2.9
13	11	2.7	0.0	2.7
14	22	0.9	0.0	0.9
15	19	0.9	0.4	1.3
16	19	6.3	0.8	7.1
17	19	7.0	0.9	7.9
18	33	5.3	0.8	6.1
19	34	5.3	0.3	5.6
20	23	5.1	2.4	7.5
21	46	5.4	15.5	20.9
22	54	7.2	32.3	39.5
23	55	10.8	46.6	57.4
24	50	10.9	58.5	69.4

Table 13.2 : Comparison of Earthmoving Machine Times and Estimated Earthwork Volumes for Bordered Strips.

13.3 Results

Table 13.2 lists the results of this test. They are shown graphically in Figures 13.2 and 13.3.

In spite of the uncontrolled factors in the test, there was a correlation between the earthworks and the time taken by the earthwork machinery.

Linear regression analysis yielded the following equations -

$$T = 0.45 \; LL + 26.73 \; ; \; (r = 0.686)$$

$$T = 3.09 \; CL + 12.18 \; ; \; (r = 0.688)$$

$$T = 0.41 \; (CL + LL) + 24.44 \; ; \; (r = 0.706)$$

$$T = 0.25 \; LL + 1.78 \; CL + 17.57 \; ; \; (r = 0.734)$$

where T = Time in minutes

LL = Volume of longitudinal-levelling (M^3)

CL = " " cross " (M^3)

r = Correlation coefficient.

13.4 Discussion

The correlation coefficient of 0.734 indicates that about 53% of the total variance can be explained by the regression using the calculated volumes of cross-levelling and longitudinal-levelling earthworks.

Other possible causes of variance are:-

(a) Variation in operator skill or speed

(b) Variation in soil moisture throughout the test.

(c) Incorrect assumption concerning the relative rates of work for the two machines.

(d) Inaccuracy in volume estimates caused by inaccuracies in the terrain model or by approximations in the calculation technique or the assumed cut to fill ratio.

(e) Earthwork associated with cross levelling the strips to remove the crown left in the centre of the strip following the forming of the levees. (Section 9.8).

(f) Minor levelling of surface irregularities too small to be measured by the normal surveying methods.

The fact that all the constant terms in the above equations are positive, would strongly indicate that there is additional earthwork possibly associated with (e) or (f) above. There is perhaps also a tendency on the part of the operators to move soil in such a way that the final surface is well within the slope limitations and not exactly to the relevant minimum and maximum values used in the earthwork estimates.

It is unfortunate that a greater degree of control could not have been exercised so that only one grader and one experienced operator was being used on the whole job. The difficulty is that such a restriction would have interferred with the progress of the job and perhaps altered the overall cost. The fact that the job was being done with the object of forming bordered strips for practical agriculture and not solely as an experiment, meant that further control of the experiment was impossible.

13.5 Conclusion

(a) The volume of earthworks is correlated to the time taken for earthmoving and hence the cost of the overall work.
(b) Until further experimental correlations are performed between estimated earthworks and machinery times, the earthworks programme is unable to be used for cost estimation.
(c) Since earthwork volumes and machine times are correlated, the earthworks programme could reasonably be used to compare the relative cost of alternative bordered strip layouts.

14.0 SUMMARY AND CONCLUSIONS

14.1 Field Surveying Methods

Of the three field surveying methods, grid surveying, direct contouring and random stadia surveying, it is considered that the random stadia method is the most appropriate for bordered strip irrigation surveys. It is the most rapid method in the field and it allows the surveyor flexibility to carry out the survey and collect a suitable number of spot height readings according to the terrain being surveyed. Users guides for the three surveying computer programmes are given in the appendices.

14.2 Survey Data Processing

Although the random stadia method is a very suitable field technique, the data are by far the most difficult to interpret correctly by computer, in order to produce contour plans for use as a design aid in bordered strip irrigation work.

Along with computer programmes to process the two other types of field survey information, a programme was developed which is specially suited to process field survey information from random stadia surveys. It considers all the readings in sequence and forms profiles of the data points in sequence and thereby the computer is able to interpret the actual surface more correctly than by using spot heights alone. The surveyor is able to manipulate this profiling technique to reduce the number of spot height recordings while still giving the processing system sufficient information.

14.3 Earthworks

A programme was written to calculate the earthwork quantities involved in land preparation for bordered strip irrigation using terrain data supplied from the computer surveying systems or from any other convenient source. A programme developed at the North Carolina State University which calculates the earthwork to form various plane and warped surfaces was used to compare the volumes of earthwork using the two techniques.

The use of the N.C.S.U. programme to grade an area to form a plane or warped surface in preparation for bordered strip irrigation involves considerably more earthwork than the usual New Zealand method. The major problem is the constraint that the cross-fall must be not in excess of the cross-fall which is tolerable within any individual bordered strip. The N.C.S.U. programme is more suited to furrow irrigation and drainage applications where the cross-fall limitations are not so restrictive.

The comparison of the earthwork programmes and the methods of minimising earthworks highlighted the fact that if warped surfaces or uneven bordered strip layouts are tolerable from a farm management point of view then they can usually be fitted to the terrain with significantly less earthworks than a plane surface or a regular bordered strip layout. This is by no means a new experience in practice, but the use of these computer techniques allows the designer to appreciate in a quantitative way the effect of different field layouts in terms of the total earthworks and the quantity of topsoil removal. Earthwork comparisons can be made on a single area by computer whereas to compare the earthworks for different layouts in the usual way with machinery requires two different paddocks which may be similar but are unlikely to have the same terrain.

14.4 Estimated Versus Actual Earthworks

14.4.1 Bordered Strip Programme

The bordered strip estimating procedure described above (Section 9.0) attempts to calculate the minimum volume of earthworks required to meet the specified slope limitations. Particularly in relation to longitudinal and cross-levelling the actual volume of earth moved is likely to be in excess of that estimated because of slight errors on the part of the machine drivers which have to be corrected on subsequent passes of the machinery. The less skillful the operator, the more soil he is likely to shift or re-shift. Individual operators may grade the surface in a different way to the computer-generated surface and there is likely to be a considerable variation in skill between operators.

The extent to which the surveyed spot heights and the interpolation procedures correctly represents the micro-topography must affect the accuracy of the estimated volumes. A premise implied by this calculation technique is that if the volume estimated is not exactly the volume shifted, then it is an index value. When the index is used in an appropriate equation it should represent the approximate cost of achieving the desired surface.

If the programme is to be used as a cost estimating tool, therefore, it requires that all areas be surveyed so that they represent the real ground surface with the same level of accuracy. How to measure the level of accuracy and its sensitivity to volume and cost estimation is beyond the scope of this study.

If the bordered strip programme is to be used as a design aid, then the absolute value of the volume of earthworks is of less importance than the relative earthwork volumes of various layouts and so the programme is likely to find more acceptance in this work.

14.4.2 The N.C.S.U. Programme

The degree to which the surveyed grid accurately represents the ground surface also affects the accuracy of the N.C.S.U. programme. The main difference is that the ground crew and the machine operator use their skill to interpret and grade the surface for bordered strips, whereas, all earthwork for the N.C.S.U. system is performed to meet the surveyed spot heights pegged in the field so the final surface is more likely to closely follow the design surface.

14.5 Conclusions

(a) The ability of a digital computer to represent the terrain can be significantly increased if the data may be interpreted as random profiles, instead of random spot heights. This is the basis of a practical computer contouring routine developed in this study.

(b) The normal tacheometric surveys can conveniently be conducted to present the data in the form of profiles for computer interpretation.

(c) Stadia surveys of random spot heights (or profiles) require less surveying time than grid or direct contouring methods.

(d) The volume of earthworks to grade large areas of land for bordered strip irrigation to a plane or warped surface is greater than the volume of earthworks associated with the usual New Zealand method of forming the strips.

(e) A significant decrease in the volume of earthworks is possible if the bordered strip layout is fitted to the terrain.

(f) A correlation exists between the estimated volume of earthworks to level within a bordered strip and the earth-moving machine time and hence earthwork costs.

(g) Until further investigations into the costs associated with all the various phases of soil moving in bordered strip land preparation, the present bordered strip earthwork calculating programme cannot be used for accurate cost estimation of the complete job of land preparation.

(h) The present earthwork calculating programme as developed in this study may be used for quantitative comparisons of earthwork volumes associated with alternative bordered strip irrigation layouts. This makes possible a comparison of relative costs of alternative bordered strip layouts assuming that the earthwork volume is the major cost component.

14.6 Recommendations

Further work is required to meet an ultimate aim of the earthwork calculating programme for bordered strip irrigation which is for reliable cost estimation of the earthworks.

(a) The relationship between estimated earthwork volume and earthmoving machine time for all phases of land preparation requires to be defined.

(b) The accuracy of volume estimation in relation to survey intensity and terrain type needs to be more fully understood in order to establish a practical level of reliability of volume or cost estimation.

(c) The economic significance of topsoil removal as defined by the earthworks programme needs to be appreciated so that it can be costed as a part of the earthworks when comparing alternative layouts.

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APPENDIX A1.0 GRID SURVEY USERS GUIDE

A1.1 General Details

This system overcomes one of the main drawbacks of earlier grid contouring systems. If there is a high or low area between any two grid points it is possible to record this irregularity and have it plotted on the contour plan automatically. Allowance is made for these irregularities in choosing a "basic" grid size to be used on the survey, according to the topography.

The survey is conducted by surveying, on a regular basis, grid points which are multiples of the "basic" grid size. (e.g. every 2nd or 3rd row and/or column). Where an irregularity occurs any one of the otherwise unsurveyed grid points may be used to define it. If there is a significant hill or valley between any two grid positions on the regularly surveyed lines then at least one of the intermediate "basic" grid positions between the regularly surveyed grid positions on the surveyed row or column must be levelled to define the discontinuity. In addition, any other grid positions which are not on the regularly surveyed lines may be used to define departures from the regular terrain. The position of fencelines and other features may be recorded as a column number plus "x" metres and a row number plus "y" metres and hence are not constrained to occur at grid points.

There is a wide choice of alphabetic or numeric characters which can be plotted in these positions on the contour plan.

A1.2 Field Layouts

It is common practice to survey along straight lines, taking spot heights at short intervals. Greater intervals are left between the lines. Such lines (defined for computer purposes as COLUMNS) should tend to run along the contours for the best definition of the contour lines on the plan.

A suitable baseline, such as a fenceline, must be selected. Depending on the topography and the final use of the contour plan, a basic grid size and interval between the columns and rows, must be selected. Depending on whether the baseline runs with the general fall or along the contours, it will be a row or a column.

A typical layout is in Figure A1.1.

For the purposes of plotting the contour plan, the processing system orientates the columns so that they run from top to bottom and the rows run from left to right. Column one, row one, (i.e. 1,1) is always in the top left hand corner of the contour plan. In Figure 1 the column interval is 3 and the row interval is 2 (i.e. the grid is a 3x2 grid e.g. 45m x 30m).

A typical survey may be recorded as in Figure A1.2.

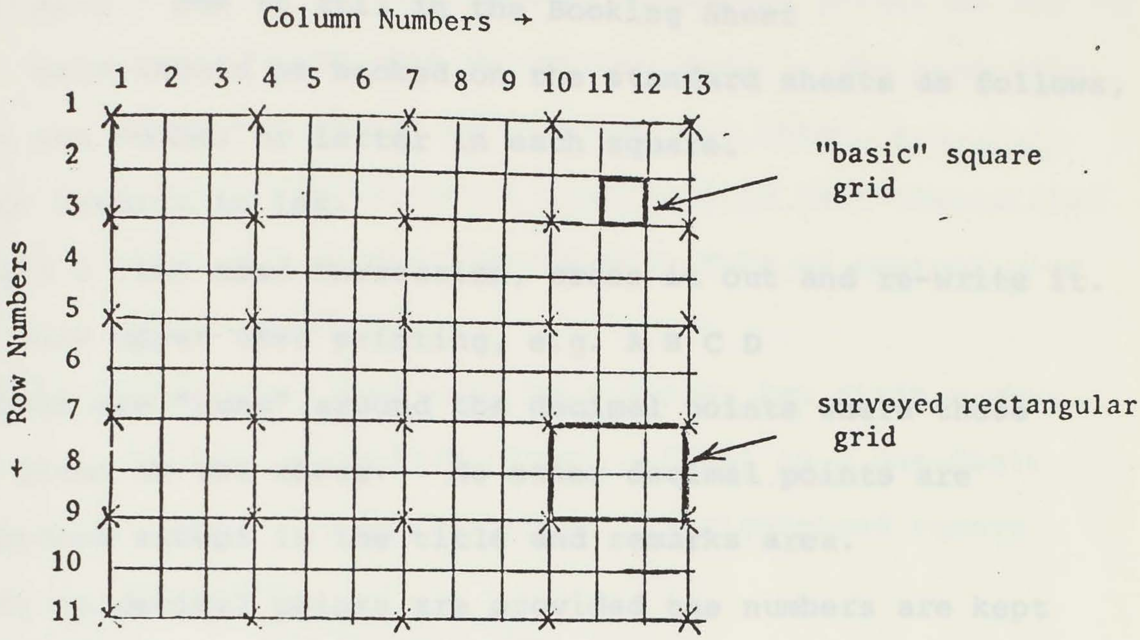

Figure Al.1 Rectangular field layout

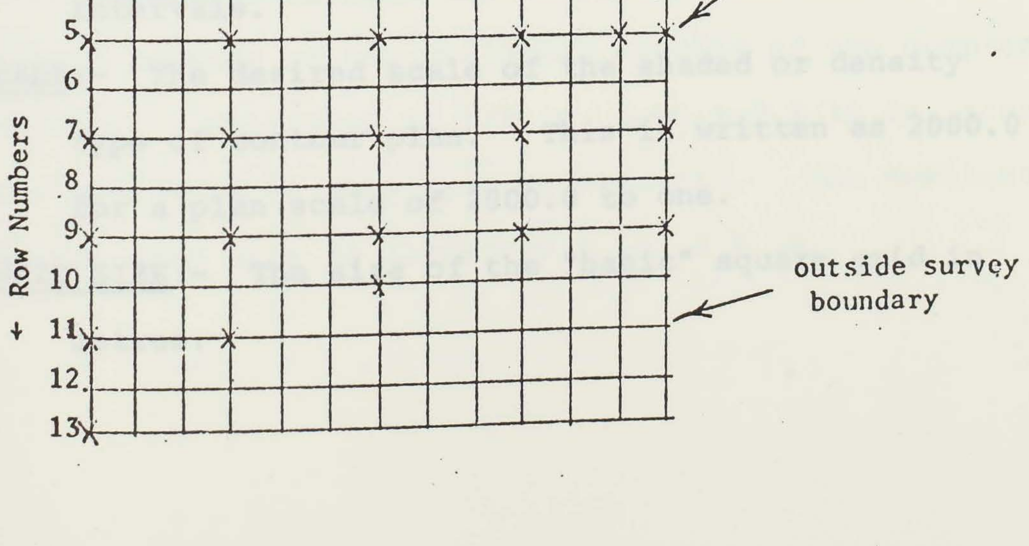

Figure Al.2 Typical grid survey

A1.3 How to fill in the Booking Sheet

Data should be booked on the standard sheets as follows,

- Only one number or letter in each square.
- Write clearly in ink.
- Should a line need correction, cross it out and re-write it.
- Use only upper case printing, e.g. A B C D
- Numbers are "hung" around the decimal points where these are given on the sheet. No other decimal points are permitted except in the title and remarks area.
- Where no decimal points are provided the numbers are kept as far to the right as possible within the allocated space.

The booking sheet parts are defined as follows:-

TITLE:- Any suitable identification including the name of the surveyor.

RL. BM:- The reduced level of the bench mark.

CONTOUR INTERVAL:- Numbers are "hung" around the decimal point provided on the sheet to form the desired contour interval; e.g. 5.0 would produce 5 m contours; 0.20 would produce 0.20 m contour intervals.

PLAN SCALE:- The desired scale of the shaded or density type of contour plan. This is written as 2000.0 for a plan scale of 2000.0 to one.

FIELD GRID SIZE:- The size of the "basic" square grid in metres.

PLAN GRID SIZE:- The distance between grid points on the single-line type of contour plan. The plan grid size may be any multiple of 0.5 inch* (e.g. 0.5, 1.0, 1.5, 3.5, etc.) If this is left unspecified then the single-line-of-dots type of contour plan is not printed.

COLUMN INTERVAL:- This must be a one or two digit number without a decimal point. If it is a one digit number it must be put in the right-hand square provided.

ROW INTERVAL:- As for column interval.

BS - refers to back sight (Numbers "hung" around decimal point provided)

IS - refers to intermediate sight "

FS - " " fore sight "

C - " " column number

R - " " row number

Take care not to confuse the C and R numbers. The comments on the column interval (above) also apply to the

* With this type of plan the scale is fixed within these limits because of the character spacing of the computer's printer. Multiples of 1/8 in. down and 1/10 in. across are available to make up a square grid. The smallest square grid size is therefore ½ in. x ½ in.

C and R numbers

F The space to insert the character positioning a land feature. This character is used on the contour plan to show the position of the land feature.

SEQ refers to the sequence number which begins at 1 and ensures that the data does not get out of order. The sequence numbers are not essential and may be omitted.

REMARKS refers to the spaces provided for any comment on the level sighting.

Al.4 Notes on Data Booking

(a) Standard booking must be used.

(b) For the purposes of this programme the lines on which most of the grid heights are collected are called COLUMNS and these should be regularly spaced. (Or have a regular COLUMN INTERVAL). If all grid positions are levelled the COLUMN INTERVAL is 1. For a 2 x 1 or an 8 x 3 grid the COLUMN INTERVAL is 2 or 8 respectively. (The ROW INTERVAL is 1 or 3 respectively).

(c) Data collected in lines at right angles to the COLUMNS, for the purposes of this programme, are said to be in ROWS. ROWS must number from row one.

(d) COLUMNS must also number from column 1. If the COLUMN INTERVAL is 2 then the second column is 3, and the third is 5 etc. Similarly if the ROW INTERVAL is 2 the second row number is 3 and the third is 5 etc.

(e) If the COLUMN INTERVAL is 1 then no intermediate grid points between the columns are available for levelling. If the COLUMN INTERVAL is 3 then two intermediate points are available for levelling. (Similarly if the ROW INTERVAL is 1 or 3).

(f) It is not necessary to take readings on every regular point in a COLUMN but the first and last should be taken.

(g) The COLUMN and ROW numbers must begin at the point, column one, row one, (i.e., 1.1). The spot heights can be read in any order so long as they are identified by the column and row numbers. The computer printout places column 1, row 1 in the top left hand corner of the plan. From this point column numbers run from left to right and row numbers run from top to bottom. The field layout should be planned accordingly.

(h) Each complete survey must begin with filling out the spaces provided at the head of the booking sheet and with a reading on a real or assumed bench mark. This is required once only for each survey.

(i) Each survey may incorporate up to 100 change points and must end with the BS and IS columns blank and a reading in the FS column. The programme assumes that this is a close onto the bench mark and the survey close is calculated accordingly.

(j) A reading on a change point or the bench mark may also double as a grid point by inserting the proper column and row numbers in the appropriate spaces in the booking sheet.

(k) Zeros or blanks in the C and R columns are permitted. Such entries are not assigned to grid positions but are still reduced by the programme and will appear in the computer printout. This facility is used to take levels which are not on grid points.

(l) In general, to fully describe land features they should be booked using two lines of the booking sheet. One line to describe where the land feature character is to be placed on the plan and the other line to record the level of the level of the land feature. In some cases it may not be necessary to position the land feature on the contour plan and in other cases it may not be necessary to take a level on the land feature.

An example is shown in Figure A1.3.

If the land feature coincides with any grid point then only one line of the booking sheet is necessary to fully describe it as shown in Figure A1.4.

(m) In the F space do not use the characters 1, +, 2, ., 3, =, or *, these may be undistinguishable from the rest of the contour plan.

(n) Comments in the remarks column appear in the computer printout along with the level book readings and reduced levels.

BS	IS	FS	C	+	R	+	F	SEQ	REMARKS
.	0.0	.	4	10	8	1	A	22	LAND FEATURE
.	1.32	.						23	HEIGHT OF 22
.	.	.							
.	.	.							
.	.	.							

Figure A1.3 Booking land features using two lines

BS	IS	FS	C	+	R	+	F	SEQ	REMARKS
.	.	.							
.	2.A	.	10		8		A	19	BOUNDARY
.	.	.							
.	.	.							
.	.	.							

Figure A1.4 Booking land features using one line

(o) The type of contour plan produced will depend on whether or not the PLAN SCALE, FIELD GRID SIZE and PLAN GRID SIZE are specified. If both the PLAN SCALE and PLAN GRID SIZE are specified then the contour plan is the shaded type of contour plan. If the PLAN GRID SCALE is specified then the contours are drawn with lines of characters. Both plans are produced if all the variables are specified.

(p) Clearly identify in the field all the change points, using small pegs or by some other means. <u>Check the survey close before leaving the field.</u> This may avoid having the processing aborted by the computer.

A1.5 Grid Survey Example

The following example illustrates the steps in processing grid survey information:

(a) The survey is recorded on the booking sheet in the field.

(b) The booking sheet information is transferred to punched cards and processed by computer.

(c) The level book readings and the reduced levels are printed.

(d) A printout is made of the recorded spot heights.

(e) Guided by the recorded column and row intervals and the recorded spot heights, the programme estimates the missing grid spot heights.

(f) A contour plan is drawn.

GRID SURVEY BOOKING SHEET (SHEET No 1 OF 2)

TITLE BOUGHTON PROBLEM

BM. RL 95.19 | CONTOUR INTERVAL 0.5 | COLUMN INT 2 | ROW INT 2

PLAN SCALE 1000.0 | FIELD GRID SIZE (M) 12.7 | PLANGRIDSIZE 0.5

BS	IS	F.S	C	+	R	+	F	SEQ	REMARKS
4.81	.	.	1		1		F	1	
.	4.99	.	1		3			2	
.	4.91	.	1		5			3	
.	4.84	.	1		7			4	
.	5.87	.	1		9			5	
.	6.20	.	1		11		Q	6	
.	6.66	.	1		13			7	
.	6.34	.	1		15		F	8	
.	5.36	.	3		1			9	
.	6.36	.	3		3			10	
.	5.99	.	3		5			11	
.	5.66	.	3		7			12	
.	5.29	.	3		9			13	
.	5.14	.	3		11			14	
.	7.19	.	3		13			15	
.	6.70	.	3		15			16	
.	3.34	.	5		1			17	
.	3.94	.	5		3			18	
.	4.64	.	5		5			19	
.	7.10	.	5		7			20	
.	6.12	.	5		9			21	
.	5.66	.	5		11			22	
.	5.68	.	5		13			23	
.	7.66	.	5		15			24	
.	3.39	.	7		1			25	
.	3.94	.	7		3			26	
.	4.12	.	7		5			27	
.	3.84	.	7		7			28	
.	6.55	.	7		9			29	
.	7.50	.	7		11			30	
.	6.25	.	7		13			31	
.	5.95	.	7		15			32	
.	2.76	.	9		1			33	
.	3.39	.	9		3			34	
.	3.30	.	9		5			35	
.	4.10	.	9		7			36	
.	4.55	.	9		9			37	
.	6.24	.	9		11			38	

Figure A1.5 Grid survey booking sheet

L E V E L   B O O K   R E A D I N G S

BOUGHTON PROBLEM

CONTOUR INTERVAL = 0.500 GRID SIZE = 0.5 INCH

COLUMN INTERVAL = 2 ROW INTERVAL = 2

PLAN SCALE = 1000.00 . FIELD BASIC GRID SPACING 12.7

BS	IS	FS	C	+	R	+	RL	F	REMARKS	SEQ
4.810	0.000	0.000	1	0	1	0	95.190	F		1
	4.990		1		3		95.010			2
	4.910		1		5		95.090			3
	4.840		1		7		95.160			4
	5.870		1		9		94.130			5
	6.200		1		11		93.800	Q		6
	6.660		1		13		93.340			7
	6.340		1		15		93.660	F		8
	5.360		3		1		94.640			9
	6.360		3		3		93.640			10
	5.990		3		5		94.010			11
	5.660		3		7		94.340			12
	5.290		3		9		94.710			13
	5.140		3		11		94.860			14
	7.190		3		13		92.810			15
	6.700		3		15		93.300			16
	3.340		5		1		96.660			17
	3.940		5		3		96.060			18
	4.640		5		5		95.360			19
	7.100		5		7		92.900			20
	6.120		5		9		93.880			21
	5.660		5		11		94.340			22
	5.680		5		13		94.320			23
	7.660		5		15		92.340			24
	3.390		7		1		96.610			25
	3.940		7		3		96.060			26
	4.120		7		5		95.880			27
	3.840		7		7		96.160			28
	6.550		7		9		93.450			29
	7.500		7		11		92.500			30
	6.250		7		13		93.750			31
	5.950		7		15		94.050			32
	2.760		9		1		97.240			33
	3.390		9		3		96.610			34
	3.300		9		5		96.700			35
	4.100		9		7		95.900			36
	4.550		9		9		95.450			37
	6.240		9		11		93.760			38
	7.900		9		13		92.100			39
	6.640		9		15		93.360			40
	3.390		11		1		96.610	F		41
	3.690		11		3		96.310			42
	3.660		11		5		96.340			43
	4.240		11		7		95.760	Q		44
	4.730		11		9		95.270			45
	5.800		11		11		94.200			46
	6.690		11		13		93.310			47
	7.960		11		15		92.040	F		48
	6.300		4		5		93.700			49
	7.400		6		9		92.600	Q		50
	7.800		8		12		92.200			51
	7.900		10		14		92.100			52
	6.300		2		14		93.700			53
	5.800		6		14		94.200			54
	7.400		6		10		92.600			55
	7.600		7		12		92.400			56
	7.850		8		13		92.150			57
	7.200		5		8		92.800			58
	7.300		6		8		92.700			59
	6.600		4		6		93.400			60
	6.200		5		6		93.800			61
	0.000		8	5	8	3	0.000	Q		62
	0.000		3	8	9	10	0.000	Q		63
	7.490		4		14		92.510			64
0.000	0.000	4.810	0		0		95.190			65

SURVEY MISSCLOSE -0.000

NUMBER OF COLUMNS = 12

NUMBER OF ROWS= 16

NUMBER OF SPOT HEIGHTS 63

Figure A1.6 Printout of level readings and reduced levels

RECORDED SPOT HEIGHTS

BOUGHTON PROBLEM

	1	2	3	4	5	6	7	8	9	10	11
1	95.190	0.000	94.640	0.000	96.660	0.000	96.610	0.000	97.240	0.000	96.610
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	95.010	0.000	93.640	0.000	96.060	0.000	96.060	0.000	96.610	0.000	96.310
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	95.090	0.000	94.010	93.700	95.360	0.000	95.880	0.000	96.700	0.000	96.340
6	0.000	0.000	0.000	93.400	93.800	0.000	0.000	0.000	0.000	0.000	0.000
7	95.160	0.000	94.340	0.000	92.900	0.000	96.160	0.000	95.900	0.000	95.760
8	0.000	0.000	0.000	0.000	92.800	92.700	0.000	0.000	0.000	0.000	0.000
9	94.130	0.000	94.710	0.000	93.880	92.600	93.450	0.000	95.450	0.000	95.270
10	0.000	0.000	0.000	0.000	0.000	92.600	0.000	0.000	0.000	0.000	0.000
11	93.800	0.000	94.860	0.000	94.340	0.000	92.500	0.000	93.760	0.000	94.200
12	0.000	0.000	0.000	0.000	0.000	0.000	92.400	92.200	0.000	0.000	0.000
13	93.340	0.000	92.810	0.000	94.320	0.000	93.750	92.150	92.100	0.000	93.310
14	0.000	93.700	0.000	92.510	0.000	94.200	0.000	0.000	0.000	92.100	0.000
15	93.660	0.000	93.300	0.000	92.340	0.000	94.050	0.000	93.360	0.000	92.040
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

INTERPOLATED SPOT HEIGHTS

BOUGHTON PROBLEM

	1	2	3	4	5	6	7	8	9	10	11
1	95.190	94.915	94.640	95.650	96.660	96.635	96.610	96.925	97.240	96.925	96.610
2	95.100	94.620	94.140	95.250	96.360	96.347	96.335	96.630	96.925	96.692	96.460
3	95.010	94.325	93.640	94.850	96.060	96.060	96.060	96.335	96.610	96.460	96.310
4	95.050	94.437	93.825	94.275	95.710	95.840	95.970	96.312	96.655	96.490	96.325
5	95.090	94.550	94.010	93.700	95.360	95.620	95.880	96.290	96.700	96.520	96.340
6	95.125	94.650	94.175	93.400	93.800	94.910	96.020	96.160	96.300	96.175	96.050
7	95.160	94.750	94.340	93.620	92.900	94.530	96.160	96.030	95.900	95.830	95.760
8	94.645	94.585	94.525	93.957	92.800	92.700	94.505	95.240	95.675	95.595	95.515
9	94.130	94.420	94.710	94.295	93.880	92.600	93.450	94.450	95.450	95.360	95.270
10	93.965	94.375	94.785	94.447	94.110	92.600	92.975	93.790	94.605	94.670	94.735
11	93.800	94.330	94.860	94.600	94.340	93.420	92.500	93.130	93.760	93.980	94.200
12	93.570	93.702	93.835	94.087	94.330	93.727	92.400	92.200	92.930	93.342	93.755
13	93.340	93.075	92.810	93.565	94.320	94.035	93.750	92.150	92.100	92.705	93.310
14	93.500	93.700	93.055	92.510	93.330	94.200	93.900	93.315	92.730	92.100	92.675
15	93.660	93.480	93.300	92.820	92.340	93.195	94.050	93.705	93.360	92.700	92.040
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure A1.7 Recorded and interpolated spot heights

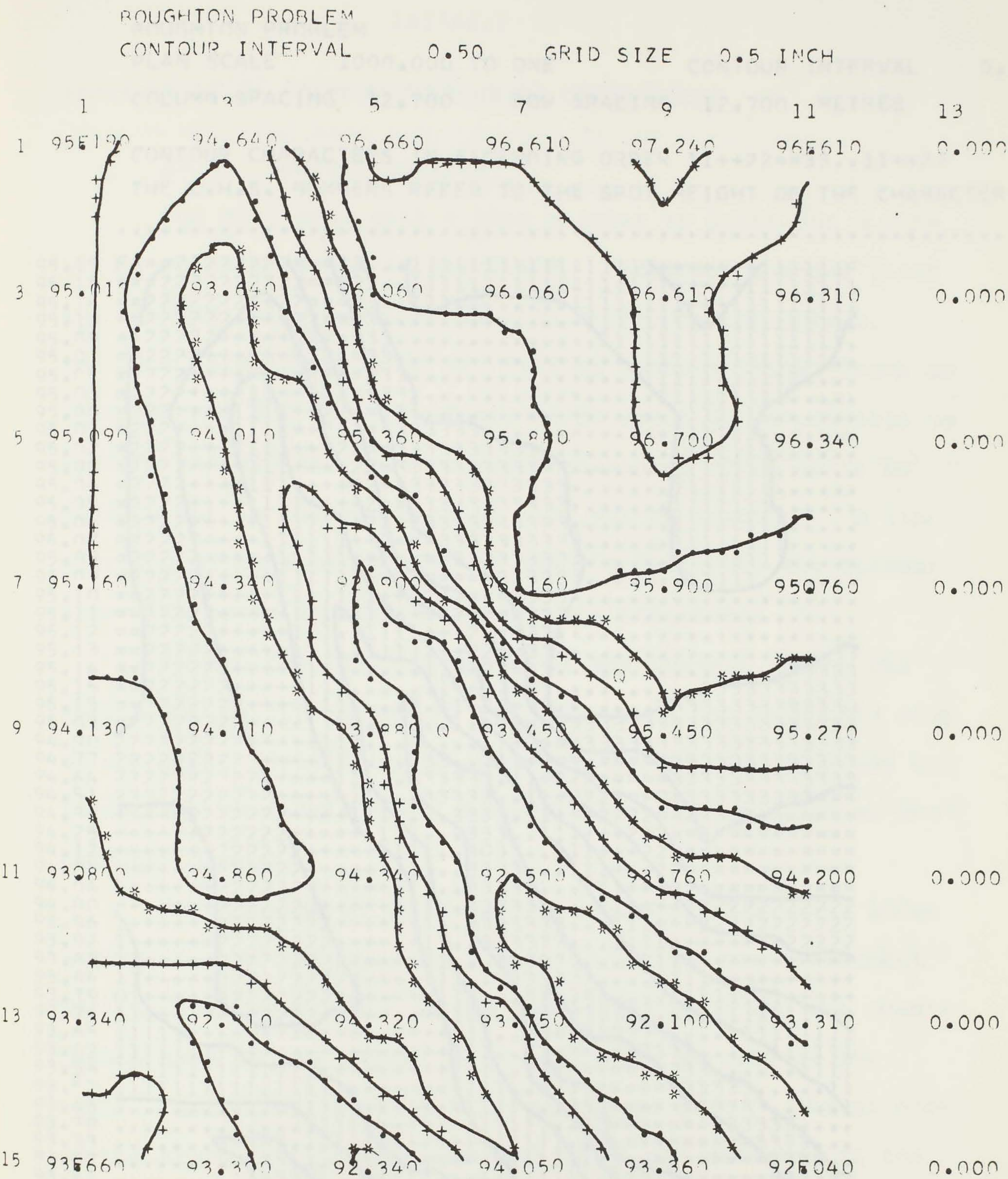

Figure A1.8 Line of dots contour plan

ROUGHTON PROBLEM

PLAN SCALE 1000.000 TO ONE CONTOUR INTERVAL 0.5

COLUMN SPACING 12.700 ROW SPACING 12.700 METRES

CONTOUR CHARACTERS IN ASCENDING ORDER 11++22==33..11++22

THE L.H.S. NUMBERS REFER TO THE SPOT HEIGHT OF THE CHARACTER

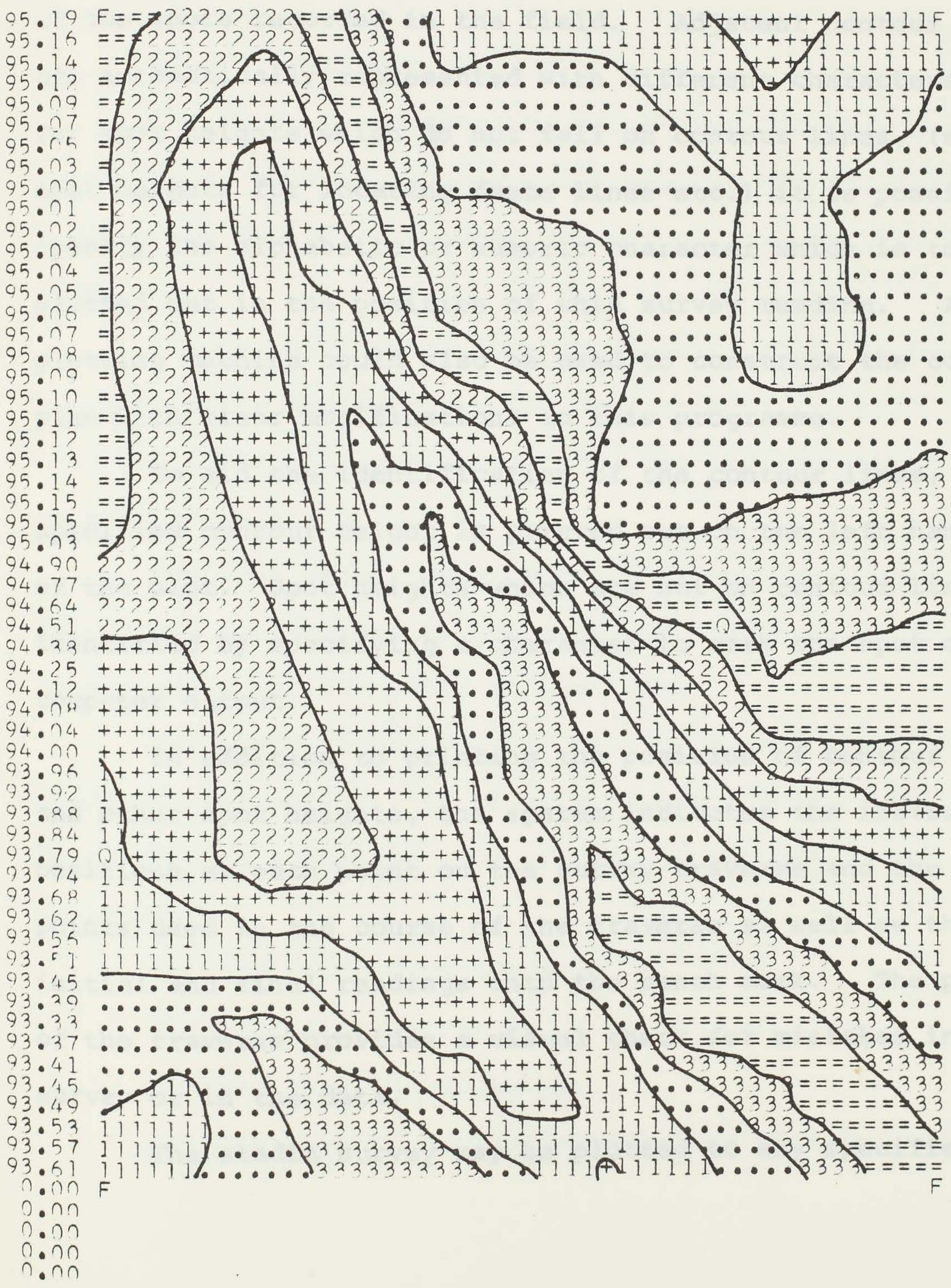

Figure A1.9 Shaded contour plan

APPENDIX A2.0 DIRECT CONTOURING USERS GUIDE

A2.1 General Details

The programme uses a line printer to print out a plot of the spots recorded in the field. Adjacent contour lines are automatically represented with different characters. For spot heights which do not fall on contour lines, (such as spot heights for locating fence lines etc.) it is possible to specify the alphabetic or numeric character which is to be plotted out in the position of this survey reading. A line plotting machine could also be used to construct the contour plan with minor modifications to this programme.

To aid the identification of the contour lines, the specified contour height is printed out on the left hand side of the plot. Spot heights which are not on contour lines are identified by specifying a character to mark the spot on the computer output.

In addition to printing the position of contour lines and other spot heights, the system indicates the instrument positions at each point on the survey traverse and the change points used in the course of the traverse as well as the initial and final readings onto the bench mark. The printout of the traverse provides a visual check for mistakes in the survey or in the data.

The stadia survey may be plotted to any specified scale.

To make the programme more versatile a grid contouring routine has also been incorporated in the programme. Any spot heights specified with column and row numbers are dealt with as grid spot heights.

A2.2 Programme Details

The X, Y co-ordinates of the survey are defined at the initial instrument position. The bearing of zero defines the X direction and the clockwise bearing of 270^{o} defines the Y direction.

Stadia information from the booking sheet is processed by calculating the latitude and departure of the spot from the original instrument position. The initial instrument position is defined as X = O, Y = O.

Any spot height reading which is specified with both column and row numbers is processed as a grid point as well as in any other way the point is specified.

Any staff reading may be used as a grid point and a stadia survey point. If it is a stadia survey point, it may be a point on a contour line as well as any <u>one</u> of the following:-

- initial reading on the BM
- final reading on the BM
- reading on a change point
- the position of a land feature such as a fenceline.

The characters used by the programme in the stadia plot and need not be specified by the user are:-

- "A" and "B" are used to indicate the initial and final readings on the bench mark.
- "C" is used for change points.
- Dots, crosses and asterisks are used to mark contour lines. Adjacent contours are marked automatically with different symbols.
- "I" is used to indicate the survey instrument position. Where two characters occur in the same place on the plan they are placed on top of the other (i.e. over-printed). Overprinted characters are still quite readable.

Any character may be specified for any individual spot height position or position of any land feature which is not already specified as above.

A maximum of 3000 Stadia readings may be made in each survey in addition to or along with 25,600 grid point readings. It is suggested that each survey be kept well below these limits to keep the bulk of data within manageable proportions and to avoid re-processing of the data because of a few data errors.

A2.3 Change Point Procedure

The change point procedure adopted for the programme consists of reading the axial hair, stadia hairs and bearings on two separate change points before and immediately after each change of instrument position. Readings on the two change points <u>may</u> be made at any time before the change of instrument position but after the change of position the first two readings <u>must</u> be onto the two change points.

To aid accuracy the change points should include a reasonably wide angle at the instrument both before and after the change of instrument position. Both stadia hairs should be read at change points to provide a check on the reading.

At each change of instrument position the individual change points are identified by the numbers "1" and "2" placed in the "CP" column in the booking sheet. They need not be read in order but must be identified with the same number before and after the instrument change.

It is not essential to orientate the horizontal circle of the survey instrument in any special direction. It may be useful in some cases, however, to orientate the horizontal circle to define the "X" direction in some significant direction (perhaps aligned with the survey boundary or due north) at the initial instrument position before the commencement of the survey.

A2.4 Data Checks

Several checks are made on the data by the system to point out obvious errors.

- bearings are checked to see that they do not exceed 360.0 degrees.
- the specified contour height ("CONTOUR") is checked against the actual reduced level of the spot height. The spot height must equal the contour height within a tolerance which can be varied.
- where two stadia hairs are read (which should be the case for all change points) a check is made, to ensure that the axial hair is midway between the stadia hairs.
- a check is made to ensure that the second two readings onto the change points are consecutive.
- the difference in level between the two change points before and after the change of instrument position is checked. The change in difference of level must be within a tolerance which can be varied.
- the horizontal and vertical closes are checked to ensure they do not exceed a tolerance which can be varied.
- the sequence numbers are checked to ensure that the data cards are not out of order.
- the column and row numbers are checked to ensure that they do not exceed 160.

Should any of the checks reveal an error then an error message is printed.

A2.5 Data Booking

The booking sheet should be filled in as below:-

- all printing in block letters.
- only one number or letter per square.
- numbers are hung around the decimal points where provided.
- no other decimal points are permitted except in the TITLE and REMARKS areas.
- where no decimal points are provided, the numbers are kept as far to the right as possible within the allocated space.

The booking sheet names are defined as follows:-

TITLE: Any suitable idenfitication

S.SCALE:- The desired scale of the stadia plot. This is specified on the basis of one plan unit of length equals SCALE units of length on the ground. (e.g. 2000.0 is a plan scale of 2000 to one).

S.CONT. INT:- The specified interval of the contour lines.

GRID SIZE:- The distance between adjacent basic grid points on the grid contour plan. This must be multiples of 0.5 inch to fit in with the line printer character spacing. No spaces referring to the grid system need be filled in if no grid survey data has been collected.

COL. INT:- The regular interval between columns in which most of the field data is collected in a grid survey.

ROW. INT:- As for COL. INT.

GRID. CONT. INT:- The desired contour interval for the grid contour plan.

BENCH MARK:- The reduced level of the bench mark.

AH:- The reading of the survey staff corresponding to the axial hair of the surveying instrument. If no entry is made in this column it is assumed to be the same as the last entry on the column.

SH:- The top or bottom stadia hair reading. Either or both of the stadia hairs may be read. At change points both should be read to provide a check on the accuracy of the reading. Every stadia spot must have a non-zero stadia hair reading.

BEARING:- The bearing in degrees is written to the left of the decimal point and minutes to the right of the decimal point.

CP:- This signifies that the reading relates to a change point (see above). There is no limit to the number of times the instrument can change position.

CONTOUR:- This column is used to specify the contour to which the stadia survey spot relates. If no entry is made in this column, it is assumed to be the same as the last entry in the column. Where an "F" character is specified the CONTOUR must also be specified unless it is not on a contour.

F:- The alphabetic or numeric character to be plotted in this position on the plan is specified in this column. If the spot is also on a contour, the CONTOUR column <u>must</u> be filled in for this spot. Do not use the characters A, B, C, I, ., +, or *. They may be indistinguishable from the rest of the contour plan.

COL:- Grid column number (if applicable).

ROW:- Grid row number (if applicable).

SEQ:- The sequence number of the reading. These numbers must begin at one and be consecutive. They are inserted to facilitate quick reference to readings and to ensure that the data remains in order after it is punched onto cards. The use of sequence numbers is optional. They may be omitted.

STADIA SURVEY BOOKING SHEET   Sheet No 1 of 5

TITLE J BOLDERSTON   S.SCALE 2000.0   S.CONT.INT 0.5

GRID SIZE .   COL INT   ROW INT   GRID CONT. INT. .   BENCH MARK 100.0

AH	SH	SH	BEARING	CF	CONTOUR	F	COL	ROW	SEQ	REMARKS
3.175	2.58	3.77	258.40		100.0				1	BENCH MARK
2.65	2.17	.	280.30		100.5				2	
.	2.27	.	304.05		.				3	
.	2.18	.	317.48		.				4	
.	2.15	.	333.48		.				5	
.	2.07	.	350.02		.				6	
.	2.02	.	357.34		.				7	
.	1.97	.	7.25		.				8	
.	1.89	.	359.29		.				9	
.	1.865	.	352.30		100.5	F			10	FENCE LINE
2.175	1.25	.	259.12		101.0				11	
.	1.45	.	19.11		.				12	
.	1.64	.	11.04		.				13	
.	1.76	.	346.02		.				14	
.	1.81	.	333.56		.				15	
.	1.91	.	330.16		.				16	
.	1.96	.	287.45		.				17	
.	1.90	.	287.25		.				18	
.	1.95	.	259.24		.				19	
.	1.99	.	218.38		.				20	
.	1.89	.	198.30		.				21	
.	1.75	.	193.0		.				22	
.	1.63	.	201.45		101.0	D			23	RACE
2.675	2.19	.	230.15		100.5				24	
.	2.33	.	232.50		.				25	

Figure A2.1 Direct contouring stadia survey booking sheet

STADIA SURVEY EXAMPLE

STADIA SCALE ** 2000.00 STADIA CONTOUR INTERVAL ** 0.50

GRID SIZE ** 0.5 COLUMN INTERVAL ** 0 ROW INTERVAL ** 0

GRID CONTOUR INTERVAL ** 0.00 BENCH MARK RL ** 100.000

AH	SH	SH	HA	C	CONTR	F	COL	ROW	SEQ	REMARKS	RL	DIST	X	Y	
3.175	2.580	3.770	258.40	0	100.00		0	0	1	BENCH MARK	100.000	119.0	-23.3	116.7	A
2.650	2.170	0.000	280.30	0	100.50		0	0	2		100.525	96.0	17.5	94.4	*
0.000	2.270	0.000	304.05	0	0.00		0	0	3		100.525	76.0	42.6	62.9	*
0.000	2.180	0.000	317.48	0	0.00		0	0	4		100.525	94.0	69.6	63.1	*
0.000	2.150	0.000	333.48	0	0.00		0	0	5		100.525	100.0	89.7	44.2	*
0.000	2.070	0.000	350.02	0	0.00		0	0	6		100.525	116.0	114.2	20.1	*
0.000	2.020	0.000	357.34	0	0.00		0	0	7		100.525	126.0	125.9	5.3	*
0.000	1.970	0.000	7.25	0	0.00		0	0	8		100.525	136.0	134.9	-17.5	*
0.000	1.890	0.000	359.29	0	0.00		0	0	9		100.525	152.0	152.0	1.4	*
0.000	1.865	0.000	352.30	0	100.50	F	0	0	10	FENCELINE	100.525	157.0	155.7	20.5	F
2.175	1.250	0.000	359.12	0	101.00		0	0	11		101.000	185.0	185.0	2.6	+
0.000	1.450	0.000	19.11	0	0.00		0	0	12		101.000	145.0	136.9	-47.5	+
0.000	1.640	0.000	11.04	0	0.00		0	0	13		101.000	107.0	105.0	-20.4	+
0.000	1.760	0.000	346.02	0	0.00		0	0	14		101.000	83.0	80.5	20.0	+
0.000	1.810	0.000	333.56	0	0.00		0	0	15		101.000	73.0	65.6	32.1	+
0.000	1.910	0.000	330.16	0	0.00		0	0	16		101.000	53.0	46.0	26.3	+
0.000	1.960	0.000	287.45	0	0.00		0	0	17		101.000	43.0	13.1	41.0	+
0.000	1.900	0.000	287.25	0	0.00		0	0	18		101.000	55.0	16.5	52.5	+
0.000	1.950	0.000	259.24	0	0.00		0	0	19		101.000	45.0	-8.2	44.2	+
0.000	1.990	0.000	218.38	0	0.00		0	0	20		101.000	37.0	-28.8	23.1	+
0.000	1.890	0.000	198.30	0	0.00		0	0	21		101.000	57.0	-54.0	18.1	+
0.000	1.750	0.000	193.00	0	0.00		0	0	22		101.000	85.0	-82.7	19.1	+
0.000	1.630	0.000	201.45	0	101.00	D	0	0	23	RACE	101.000	109.0	-101.1	40.4	D
2.675	2.190	0.000	230.15	0	100.50		0	0	24		100.500	97.0	-61.9	74.6	*
0.000	2.350	0.000	232.50	0	0.00		0	0	25		100.500	69.0	-41.6	55.0	*
0.000	2.340	0.000	249.18	0	0.00		0	0	26		100.500	67.0	-23.6	62.7	*
0.000	2.220	0.000	260.11	0	0.00		0	0	27		100.500	91.0	-15.4	89.7	*
0.000	2.900	0.000	270.30	0	0.00		0	0	28		100.500	45.0	0.4	45.0	*
3.175	2.600	0.000	253.50	0	100.00	D	0	0	29	RACE	100.000	115.0	-31.9	110.5	D
0.000	2.600	0.000	259.50	0	100.00	F	0	0	30	FENCE	100.000	115.0	-20.2	113.2	F
2.950	2.200	0.000	348.54	0	0.00	L	0	0	31	LOW SPOT	100.225	150.0	147.2	28.9	L
1.675	1.160	0.000	22.25	0	101.50		0	0	32		101.500	103.0	95.2	-39.2	•
0.000	1.280	0.000	18.32	0	0.00		0	0	33		101.500	79.0	74.9	-25.0	•
0.000	1.350	0.000	8.50	0	0.00		0	0	34		101.500	65.0	64.2	-9.9	•
0.000	1.480	0.000	23.11	0	0.00		0	0	35		101.500	39.0	35.9	-15.3	•
0.000	1.630	0.000	305.12	0	0.00		0	0	36		101.500	9.0	5.2	7.4	•
0.000	1.610	0.000	168.11	0	0.00		0	0	37		101.500	13.0	-12.6	-2.6	•
0.000	1.420	0.000	141.08	0	0.00		0	0	38		101.500	51.0	-39.6	-31.9	•
0.000	1.330	0.000	172.25	0	0.00		0	0	39		101.500	69.0	-68.3	-9.0	•
0.000	1.120	0.000	165.05	0	0.00		0	0	40		101.500	111.0	-107.2	-28.5	•
0.000	1.030	0.000	177.11	0	0.00		0	0	41		101.500	129.0	-128.7	-6.2	•
0.000	1.040	0.000	184.45	0	101.50	D	0	0	42	RACE	101.500	127.0	-126.5	10.5	D
1.175	1.990	0.000	100.10	0	102.00		0	0	43		102.000	163.0	-28.7	-160.3	*
1.230	1.130	0.000	75.50	0	0.00	S	0	0	44	ROCK HEAP	101.945	20.0	4.9	-19.3	S
1.175	0.975	0.000	68.40	0	0.00		0	0	45		102.000	40.0	14.6	-37.2	*
0.990	0.800	0.000	86.50	0	0.00	K	0	0	46	HIGH KNOB	102.185	38.0	2.1	-37.8	K
2.010	1.810	0.000	271.50	0	0.00	S	0	0	47	ROCK HEAP	101.165	40.0	1.3	40.0	S
2.260	1.310	0.000	357.50	0	0.00	T	0	0	48	STRAINER	100.915	190.0	189.9	7.2	T
1.200	0.390	0.000	171.15	1	0.00		0	0	49		101.975	162.0	-160.0	-24.5	C
3.115	2.515	3.715	254.06	2	0.00		0	0	50		100.060	120.0	-32.8	115.4	C

Figure A2.2 Direct contouring stadia survey printout

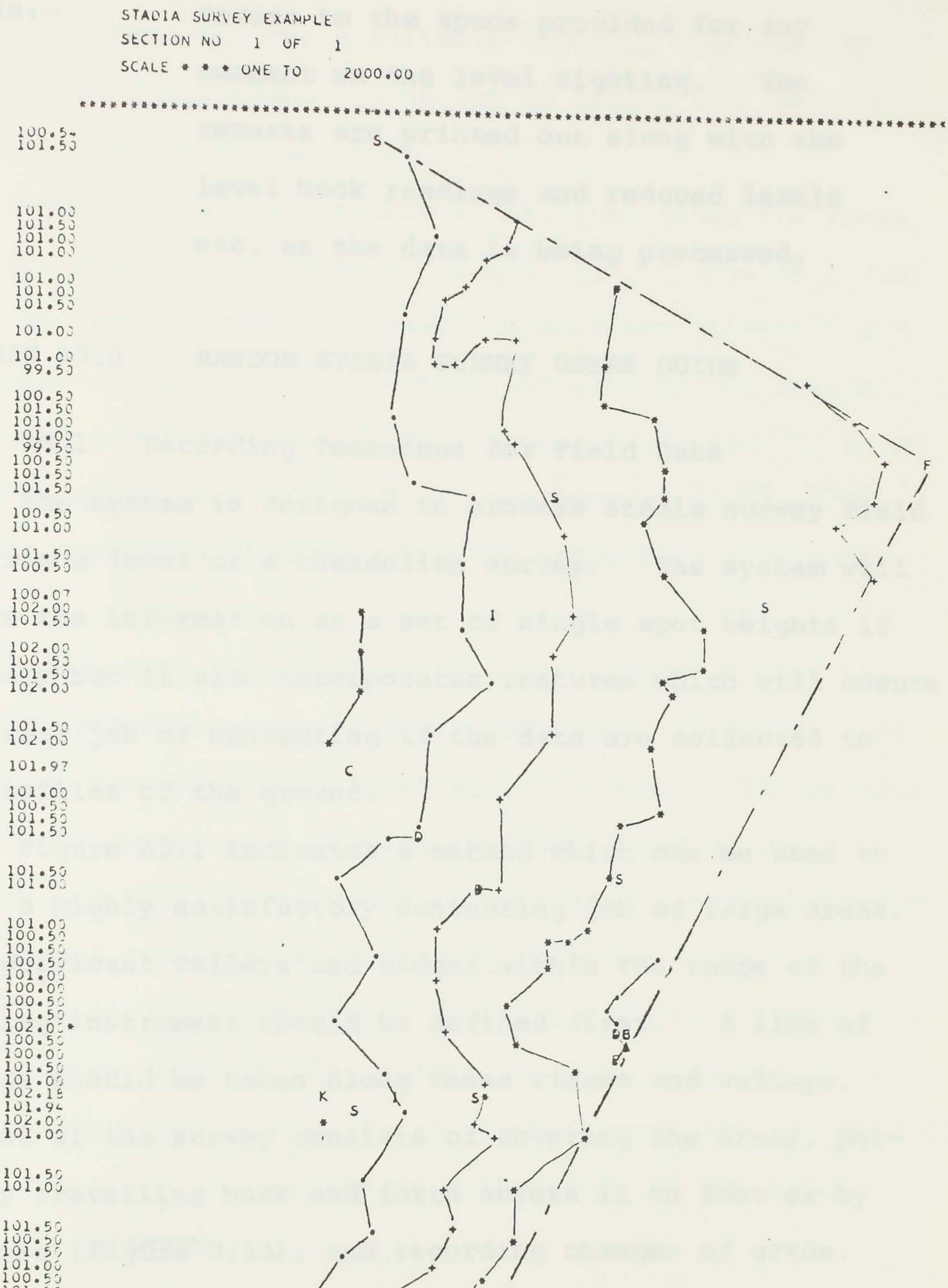

Figure A2.3 Direct contouring stadia survey contour plan

REMARKS:- Refers to the space provided for any comment on the level sighting. The remarks are printed out along with the level book readings and reduced levels etc. as the data is being processed.

APPENDIX A3.0 RANDOM STADIA SURVEY USERS GUIDE

A3.1 Recording Technique for Field Data

The system is designed to process stadia survey field data from a level or a theodolite survey. The system will process the information as a set of single spot heights if necessary but it also incorporates features which will ensure a superior job of contouring if the data are collected to form profiles of the ground.

Figure A3.1 indicates a method which can be used to ensure a highly satisfactory contouring job of large areas. Any significant valleys and ridges within the range of the surveying instrument should be defined first. A line of readings should be taken along these ridges and valleys. The rest of the survey consists of covering the areas, perhaps by travelling back and forth across it on foot or by motorbike (Figure 3.15), and recording changes of grade. This can be done as follows - referring to Figure A3.1. Before leaving point A a pole is placed in the fence at D.

A to D is stepped out for a suitable distance depending on the nature of the survey. A series of levels are taken at changes of grade along the line A - B.

When the staffman reaches B, he paces along the fence toward Y a distance of twice A - D and puts in a second pole at F. He then returns to C which is half way between B and F and takes a line of levels across the area on all changes of grade along the line C - D. On reaching D the pole is moved a distance of twice A - D to E and the process is repeated. It is not essential that the staffman travels in a straight line.

Information collected in this way is very suited to automatic processing because it is reasonable to assume that the surface between the surveyed spots is even. The profile between each consecutive reading is first fixed by the programme and then the computer interpolates a surface between these defined profiles and builds up a contour plan.

If a line of consecutive readings crosses another line of consecutive readings the profile is drawn from the first set of readings and no profile is drawn between the two readings of the second set of readings on either side of the first profile (see Figure 3.7).

In order to produce a contour plan the system defines a grid of spot heights based on and including the spot heights

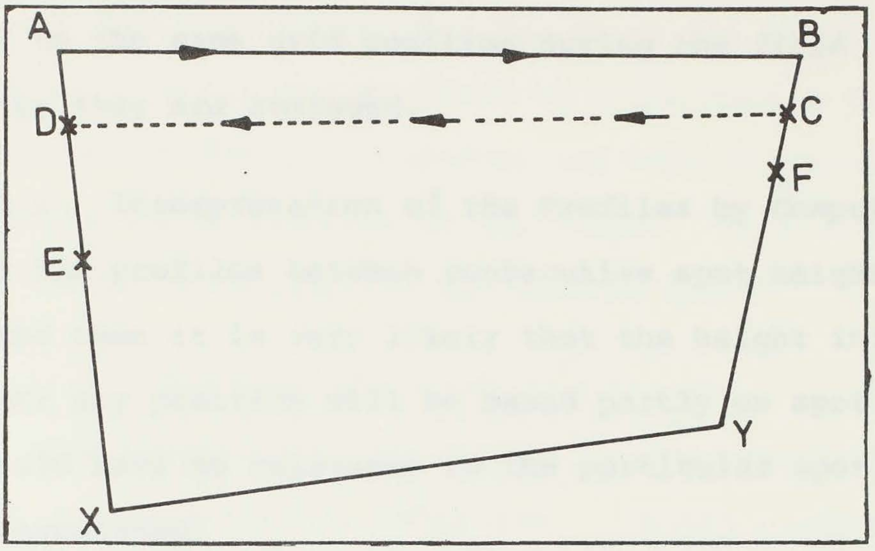

Figure A3.1 A method of contouring large relatively flat areas

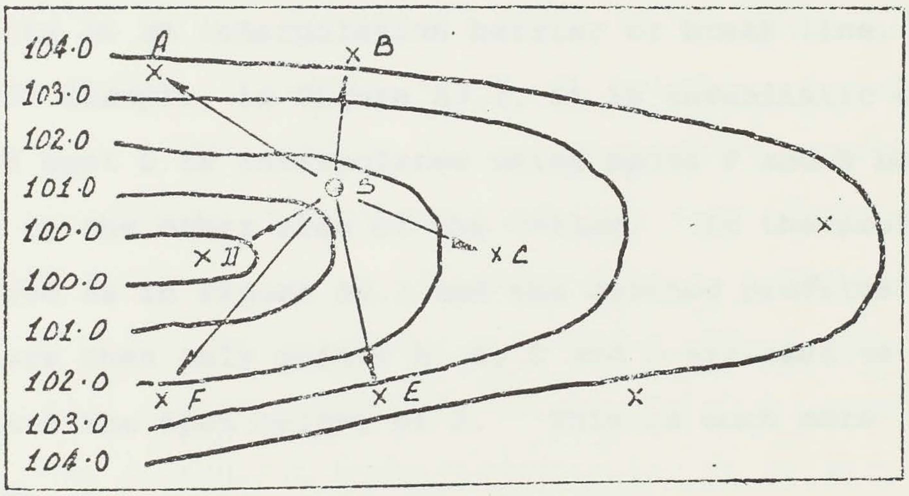

Figure A3.2 Unrealistic interpolation of a spot height

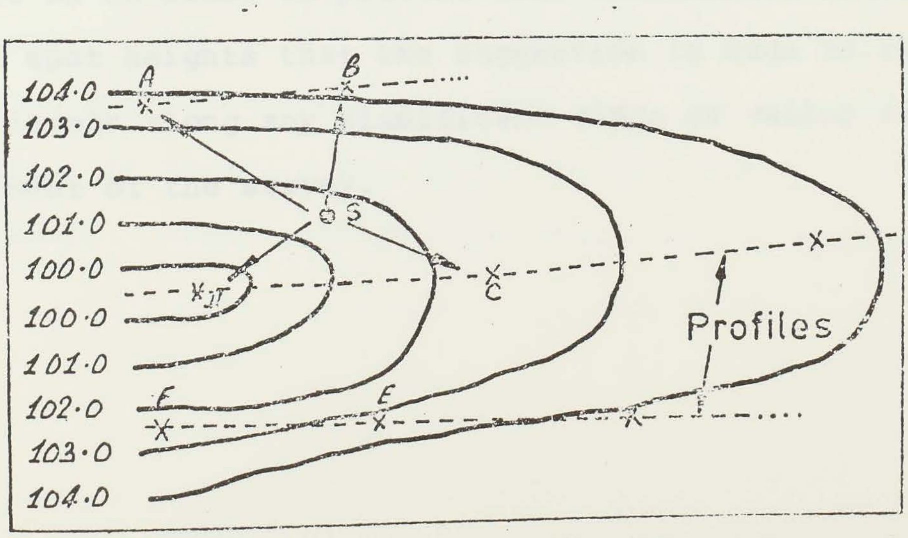

Figure A3.3 Realistic interpolation of a spot height read in the field. If two or more spot heights are allocated to the same grid position during the field survey then they are averaged.

A3.2 Interpretation of the Profiles by Computer

If the profiles between consecutive spot heights are not defined then it is very likely that the height interpolated for any position will be based partly on spot heights which should have no relevance to the particular spot height being interpolated.

Once a profile has been defined it cannot be affected by subsequent profiles and also the profile drawn by the system acts as an interpolation barrier or break line.

For example, in Figure A3.2, it is unrealistic that the height of spot S is interpolated using spots F and E because they are on the other side of the valley. If the profiles are defined as in Figure A3.3 and the defined profiles act as barriers then only points A, B, C and D are used to interpolate the spot height of S. This is much more realistic.

It is in order to prevent this unrealistic interpolation of spot heights that the suggestion is made to run a line of levels along any significant ridge or valley at the commencement of the survey.

A3.3 Displaying Land Features

To cope with other readings which are usually required in the field to fix the position of fencelines, etc., it is possible to specify any character and have it printed on the plan at any staff position in the field. This character is placed in the "F" column in the booking sheet.

A3.4 Stopping the Profiling Process

Each consecutive spot height is assumed to be on a profile unless specified otherwise. During a survey it is often necessary for the staffman to travel to another part of the area to be surveyed and not want to take a series of spot heights at all changes of grade on the way. If this is so a "$" symbol is placed in the "$" column in the booking sheet, at the last reading of the consecutive series. Failure to specify a break in profiling will result in an incorrect profile. If a "$" is used for a number of consecutive spot heights then a series of single spot heights will result which will not be joined by profiles.

When a level is required which is not to form a spot height to be used in the contouring procedure (that is, non-topographic) then an "N" is recorded in the "$" column alongside the non-topographic reading. The "N" also has the effect of breaking the series in the same way as the "$" symbol. After reducing the level the processing system does not use the reduced level any further but may use the position to insert an "F" character if one is specified.

Where it is desired to make a short deviation from the sequence of contour spot heights rather than a break in profiling, a "D" is inserted in the "$" column of the booking sheet alongside the reading. The effect of the "D" is to allow a non-topographic entry to be read without breaking the sequence of contour spot heights. Provided that no "N" or "$" characters are used in the intervening period the consecutive sequencing of data for drawing profiles will continue at the next blank "$" column. An "F" character would normally also be used when there is a "D" in the "$" column.

This information is summarised in Table A3.1.

Booking Sheet "$" Character	Meaning
$	Break in sequence of contour data
N	Break in sequence of contour data for a non-contour reading
D	A deviation from the contour data for non-contour data. The readings before and after the "D" are considered to be in sequence

Table A3.1 Summary of meaning of $ characters

A3.5 Programme Details

The X, Y co-ordinates of the survey are defined with the initial instrument position as the origin. The bearing of zero defines the X direction down the computer page and the clockwise bearing of 270^{o} defines the Y direction across the computer page. For theodolite surveys vertical angles of 270^{o} and 90^{o} are assumed to be horizontal.

Stadia information from the booking sheet is processed by calculating the latitude and departure of the spot from the original instrument position.

Every spot height read in the field is used in the contour plan unless specified otherwise by an "N" or "D" in the "$" column of the booking sheet.

It is assumed that the first and last readings in the survey are readings onto a bench mark and that the survey has been conducted as a traverse. The horizontal and vertical closes are calculated accordingly.

The characters printed automatically by the programme in the stadia plot and which need not be specified by the user are:-

(a) "A" and "B" indicate the initial and final readings of the survey.

(b) "C" for change points.

(c) 1, +, 2, -, 3, ., characters are used to mark contour lines. Adjacent contours are marked automatically with different symbols. Contours ascend in the order that the characters indicate.

(d) "I" is used to indicate the survey instrument position.

Any character specified in the "F" column of the booking sheet will be printed on the plan unless it refers to the initial, final or a change point reading.

Where two characters occur in the same place on the plan they are placed one on top of the other (that is, overprinted). Overprinted characters are still quite readable.

A Maximum of 2000 stadia readings may be made in each survey. It is possible to increase this number if necessary. It is suggested, however, that each survey be kept well below this limit (say 100 to 500 readings) so that a few data errors will not require a large survey to be re-run. The area to be surveyed should be divided into smaller areas if more readings are required.

A significant reduction in computer processing time can be achieved by orientating the horizontal circle so that a bearing of zero is aligned at the initial instrument position of each complete survey with the longest straight boundary of the area to be surveyed. This usually has the effect of reducing the area which has to be searched by computer to interpolate spot heights while constructing the contour plan.

A3.6 Change Point Procedure

The change point procedure adopted for the programme consists of reading the axial hair, stadia hairs, bearings and vertical angles on two separate change points before and immediately after each change of instrument position. Readings on the two change points may be made at any time before the change of instrument position, but after the change of position the first two readings must be onto the two change points.

To aid accuracy the change points should include a reasonably wide angle at the instrument both before and after the change of instrument position. Both stadia hairs should be read at change points to help in cross-checking the readings. At each change of instrument position the individual change points are identified by the numbers "1" and "2" placed in the "CP" column of the booking sheet. Only these digits, "1" and "2", are recognised by the computer in the "CP" column. They need not be read in order but must be identified with the same number before and after the instrument change.

A3.7 Guidelines for the Intensity of Survey Spots

There is no contouring system which will produce a satisfactory result if the necessary information is not recorded accurately in the field.

The first guideline is to vary the intensity of spot heights according to the nature of the ground and the accuracy required in the survey. The proposed contour interval could be used as a guide to indicate to the surveyor whether a surface irregularity is significant or not.

The second guideline is to match the way in which the data is collected to the way in which it is to be processed. With the system described here the important spots to record are where changes in grade occur along the line which is being surveyed. There is an upper limit to the distance between the consecutive spots along a line if there are no changes in grade. This limitation is dictated by the distance the system overlaps sub-areas while contouring (see Table A3.2).

While processing the data to make up the contour plan (see Section 3.4.4) the computer must conduct a search to find relevant spot heights from which others may be interpolated. The greater the area searched the longer the search takes to complete and the less efficient in computer time is the contouring procedure. It is therefore, necessary to specify the search radius on the booking sheet. If the search radius is not specified the computer will search to a radius of 25 mm on the plan. Usually the search radius is specified as the distance between the profiles run in the field. Where the distance between the lines of consecutive spots (or profiles) is greater than the specified search radius the system may not contour all the area between the profiles.

There is a lower limit to the distance between spot heights and this is dictated by the distance between the characters of a line printer. Points taken closer together will be averaged in height and appear at the same location on the plan.

These limitations place no important restraints on the use of the system for contouring agricultural land.

Table A3.2 General guidelines of maximum and minimum distances separating spot heights.

PLAN SCALES	1000:1	2000:1	5000:1
Maximum distance between consecutive readings	50 m	100 m	250 m
Maximum suggested distance between profiles (radius)	50 m	100 m	250 m
Minimum distance between readings	2.5 m	5 m	12 m

A3.8 Data Processing Sequences

The data is processed in the following steps:

(a) The recorded field data is punched onto cards and verified.

(b) The reduced levels of all the spot heights are calculated and reduced levels and positions of all relevant points are printed and stored for later use.

(c) A plot is produced of all the positions of spot heights and other readings in the field (Stage 1).

(d) A plot is produced of all the spot heights in the field joined together by profile lines (Stage 2). It is quite possible to interpret the positions of the contour lines from this plot and where the data is scanty this may be necessary. This plot and the former plot are useful for rapidly spotting errors in the survey. Processing is very rapid up to this stage.

(e) The height of all the grid positions between the profiles are interpolated and a contour plan results (Stage 3).

The stage to which the data is to be processed is specified on the booking sheet. If stage numbers 1, 2 or 3 are specified the data is processed up to and including that stage. Stage 3 should not be specified unless the data is perfectly correct. If any stage number greater than stage 3 is specified then stage 1 and stage 3 only are produced along with the reduced levels.

A3.9 Data Checks

Several checks are made on the data by the system to point out logical surveying errors and warn of other possible errors.

(a) Bearings and vertical angle readings are checked to see that they do not exceed 360 degrees and the minutes are checked to see that they do not exceed 60.

(b) If a bearing is zero or negative, a warning message results.

(c) Where two stadia hairs are read (which should be the case for all change points) a check is made to ensure that the axial hair is midway between the stadia hairs. If both hairs are read then the distance is always calculated using their difference without regard to the axial hair.

(d) If both stadia hairs are zero or negative or the axial hair is zero or negative a warning message results.

(e) A check is made to ensure that the second two readings onto the change points are consecutive.

(f) The difference in level and horizontal distance between the two change points before and after the change of instrument position is checked. The change in difference of level and horizontal distance must be within a certain tolerance which can be varied.

(g) The Change Point (CP) column is checked to see that the digits "1" and "2" are the only characters in the column.

(h) The horizontal and vertical closes are checked to ensure they do not exceed a tolerance which can be varied as required.

(i) The sequence numbers may be checked to ensure that the data cards are not out of order. This check is initiated only if the first survey card contains any sequence number greater than zero.

(j) The profile length between spot heights is checked. This is a very useful check which often points to bearing or stadia errors in the data.

(k) All non-contour readings are checked to ensure that they have an "F" character associated with the reading.

(l) If a "D" is used in the "$" column a check is made to ensure that the contour data has been previously recorded.

Should any of the checks reveal an error then an error or warning message is printed.

A3.10 Data Booking

The booking sheet should be neatly and clearly filled in as follows:-

(a) Use a blue ballpoint pen.

(b) All printing in block letters.

(c) Only one number or letter per square.

(d) Numbers are hung around the decimal points where these are provided.

(e) No other decimal points are permitted except in the TITLE and REMARKS areas.

(f) Where no decimal points are provided the numbers are kept as far to the right as possible within the allocated space.

(g) As a rule it is better to cross out and re-write a line of data than to amend it.

The booking sheet names are defined as follows:

TITLE: Any suitable identification.

RADIUS: The search radius. This is usually equal to the profile spacing in metres on the ground.

STAGE: This is either 1, 2 or 3 (see Section A3.8).

SCALE: The desired scale of the stadia plot. This is specified on the basis of one plan unit of length equals SCALE units of length on the ground (e.g. 2000.0 is a plan scale 2000.0 to one).

CONTOUR INTERVAL: The specified interval of the contour lines.

BENCH MARK: The reduced level of the bench mark. The survey must begin with a staff reading onto this bench mark. The survey close is calculated assuming the last reading is also onto this bench mark.

S: This space is normally left blank but it can be used to specify the number of search passes required (see Section 3.4.6).

AH: The reading of the survey staff corresponding to the axial hair of the surveying instrument.

SH: The top or bottom stadia hair reading. Either or both of the stadia hairs may be read. At change points both should be read to provide a check on the accuracy of the reading.

BEARING: The bearing in degrees, minutes and seconds is written in the spaces provided.

VERTICAL ANGLE: The vertical angle in degrees, minutes and seconds, is written in the spaces provided.

CP: This signifies that the reading relates to a change point (see Section A3.6). There is no limit to the number of times the instrument can change position.

F: The alphabetic or numeric character to be plotted in this position on the plan is specified in this column. Do not use the characters, A, B, C, I, ., +, 1, 2, or 3. They may be indistinguishable from the rest of the contour plan.

$: Insert a "$" in the space if the sequence of contour spot heights is to be terminated at this reading. Insert an "N" to indicate a non-contour spot height and also to terminate a sequence of contour spot heights. Insert "D" where a temporary deviation from consecutive contour data is required (see Section A3.4).

SEQ: The sequence number of the reading. These numbers must be consecutive. They are inserted to facilitate quick reference to readings and to ensure that the data remains in order after it is punched onto cards. The use of sequence numbers is optional. They may be omitted. If they are used, the first staff reading must have a sequence number greater than zero.

REMARKS: Refers to the space provided for any comments on the level sighting. The remarks are printed out along with the level book readings and reduced levels, etc., as the data is being processed.

USE BLUE BALL-POINT PEN

STADIA SURVEY BOOKING SHEET

Sheet № 1 of 3

TITLE WAI RUTH BROS STNG A5 — RADIUS 30.0 — STAGE 3

SCALE 2000.0 — CONTOUR INTERVAL .50 — BENCH MARK 216.08 — S

AH	SH	SH	BEARING DEG	BEARING MIN	BEARING SEC	VERTICAL DEG	VERTICAL MIN	VERTICAL SEC	R/V	F	$	SEQ	REMARKS
1.51	0.98	.	324								$		A5
2.75	2.18	.	346							F			
3.10	2.63	.	0	30									
3.17	2.76	.	22	30									
3.53	3.13	.	49										
3.89	3.41	.	64	30							$		
3.16	2.52	.	133							F			
3.21	2.68	.	144										
3.19	2.77	.	156										
2.92	2.62	.	176	30									
2.12	1.74	.	220	30							$		
1.93	1.17	.	196	30						F			
1.50	0.86	.	201							F			
1.44	1.90	.	213							F			
1.57	1.29	.	259										
1.60	1.32	.	272							F			
0.71	1.06	.	306										
1.29	1.80	.	322							F			
2.20	1.63	.	327										
1.86	1.23	.	330	30						F			
2.55	1.96	.	342							F			
1.39	1.79	.	334										
0.95	0.74	.	313										
1.16	1.30	.	274										
2.09	1.93	.	229	30									

Figure A3.4 Random stadia survey booking sheet

TITLE WAI RUTH BROS STN6 A5

STADIA SCALE ** 2000.00 STADIA CONTOUR INTERVAL ** 0.50

SEARCH RADIUS 30.000 METRES PROCESSING STAGE 3

BENCH MARK RL * * 216.080 SEARCH INTERVAL 0

AH	SH	SH	BEARING DEG	M	S	VERTICAL DEG	M	S	C	F	$	SEQ	REMARKS	RL	DIST	X	Y		PFILE
1.510	0.980	0.000	324	0	0	0	0	0			$	0	A5	216.080	106.000	85.756	62.306	.A	0.000
2.750	2.180	0.000	346	0	0	0	0	0		F		0		214.840	114.000	110.614	27.580	2F	0.000
3.100	2.630	0.000	0	30	0	0	0	0				0		214.490	94.000	93.997	-0.820	+	32.904
3.170	2.760	0.000	22	30	0	0	0	0				0		214.420	82.000	75.759	-31.379	+	35.588
3.530	3.130	0.000	49	0	0	0	0	0				0		214.060	80.000	52.485	-60.376	+	37.181
3.890	3.410	0.000	64	30	0	0	0	0			$	0		213.700	96.000	41.330	-86.648	1	28.542
3.160	2.520	0.000	133	0	0	0	0	0		F		0		214.430	128.000	-87.295	-93.613	+F	0.000
3.210	2.680	0.000	144	0	0	0	0	0				0		214.380	106.000	-85.755	-62.305	+	31.346
3.190	2.770	0.000	156	0	0	0	0	0				0		214.400	84.000	-76.737	-34.166	+	29.549
2.920	2.620	0.000	176	30	0	0	0	0				0		214.670	60.000	-59.888	-3.663	2	34.847
2.120	1.740	0.000	220	30	0	0	0	0			$	0		215.470	76.000	-57.791	49.358	-	53.062
1.930	1.170	0.000	196	30	0	0	0	0		F		0		215.660	152.000	-145.740	43.171	3F	0.000
1.500	0.860	0.000	201	0	0	0	0	0		F		0		216.090	128.000	-119.498	45.871	.F	26.381
1.440	1.900	0.000	213	0	0	0	0	0		F		0		216.150	92.000	-77.157	50.107	.F	42.552
1.570	1.290	0.000	259	0	0	0	0	0				0		216.020	56.000	-10.685	54.972	.	66.650
1.600	1.320	0.000	272	0	0	0	0	0		F		0		215.990	56.000	1.955	55.966	3F	12.679
0.710	1.060	0.000	306	0	0	0	0	0				0		216.880	70.000	41.145	56.632	1	39.196
1.290	0.800	0.000	322	0	0	0	0	0		F		0		216.300	98.000	77.225	60.335	.F	36.270
2.200	1.630	0.000	327	0	0	0	0	0				0		215.390	114.000	95.609	62.089	-	18.467
1.860	1.230	0.000	330	30	0	0	0	0		F		0		215.730	126.000	109.665	62.046	3F	14.056
2.550	1.960	0.000	342	0	0	0	0	0		F		0		215.040	118.000	112.225	36.464	-F	25.709
1.390	1.790	0.000	334	0	0	0	0	0		.		0		216.200	80.000	71.904	35.070	.	40.345
0.950	0.740	0.000	313	0	0	0	0	0				0		216.640	42.000	28.644	30.717	1	43.478
1.160	1.300	0.000	274	0	0	0	0	0				0		216.430	28.000	1.954	27.932	.	26.836
2.090	1.930	0.000	229	30	0	0	0	0				0		215.500	32.000	-20.782	24.333	3	23.019
1.570	1.120	0.000	191	0	0	0	0	0				0		216.020	90.000	-88.346	17.173	.	67.942
2.010	1.440	0.000	188	0	0	0	0	0				0		215.580	114.000	-112.890	15.866	3	24.579
2.310	1.600	0.000	165	30	0	0	0	0		F		0		215.280	142.000	-141.346	13.610	-F	28.545
2.140	1.430	0.000	176	0	0	0	0	0		F		0		215.450	142.000	-141.654	-9.905	-F	23.518
2.110	1.510	0.000	177	0	0	0	0	0				0		215.480	120.000	-119.835	-6.280	-	22.118
1.920	1.460	0.000	177	0	0	0	0	0				0		215.670	92.000	-91.874	-4.815	3	28.000
1.790	1.690	0.000	183	0	0	0	0	0				0		215.800	20.000	-19.972	1.047	3	72.140
1.430	1.350	0.000	347	0	0	0	0	0				0		216.160	16.000	15.590	3.600	.	35.654
1.410	1.100	0.000	354	0	0	0	0	0				0		216.180	62.000	61.661	6.481	.	46.160
2.340	1.780	0.000	355	0	0	0	0	0		F		0		215.250	112.000	111.574	9.762	-F	50.021
2.220	1.650	0.000	7	0	0	0	0	0				0		215.370	114.000	113.151	-13.892	-	23.707
1.670	1.470	0.000	32	30	0	0	0	0				0		215.920	40.000	33.736	-21.492	3	79.777
2.190	2.060	0.000	101	0	0	0	0	0				0		215.400	26.000	-4.961	-25.522	-	38.906
2.470	2.190	0.000	150	30	0	0	0	0				0		215.120	56.000	-48.739	-27.575	-	43.827
2.260	1.700	0.000	163	0	0	0	0	0				0		215.330	112.000	-107.106	-32.745	-	58.595
2.280	1.570	0.000	165	0	0	0	0	0		F		0		215.310	142.000	-137.161	-36.752	-F	30.321
2.520	1.770	0.000	153	30	0	0	0	0				0		215.070	150.000	-134.240	-66.929	-	30.318
2.830	2.180	0.000	149	0	0	0	0	0				0		214.760	130.000	-111.431	-66.955	2	22.808
2.690	2.280	0.000	131	30	0	0	0	0				0		214.900	82.000	-54.334	-61.414	2	57.365
2.190	1.900	0.000	95	30	0	0	0	0				0		215.400	58.000	-5.559	-57.733	-	48.915
2.080	1.770	0.000	65	0	0	0	0	0				0		215.510	62.000	26.203	-56.191	3	31.799
3.320	2.860	0.000	33	30	0	0	0	0				0		214.270	92.000	76.718	-50.778	+	50.804

Figure A3.5 Random stadia survey recorded and reduced level printout

```
TITLE WAI ROTH BROS STN6 A5
SECTION NO    1  OF    1
SCALE * * * ONE TO     2000.00

CONTOUR CHARACTERS IN ASCENDIN

-99.902   Y DIMENSION

RL    ***********************************
215.66                                      B
215.31                   F      F     F
214.97E          -
215.48                          -           E
214.76           2                    3
215.12 -                   -
214.43 F         +              3    .
214.40                  +                    E
214.90           2              2            -
215.08 F                  -
214.86 E
215.80                           3     3
216.02                                        .
215.40              -      -
216.43                           I     .      B
215.64 3
216.16                            .
215.51              3
215.92                        3         1
216.88                                        1
213.70   1
214.06            +
213.88   1                        .
216.20                                   .
214.27               +    +                   E
213.55   E                                    E
216.08                                        -
214.49                           +
214.04                F
214.84                                 E      B
215.37                      -     F     F
RL    ***********************************
```

Figure A3.6   Printout plan of random stadia recorded spot height positions (Stage 1)

```
TITLE WA1 RUTH BROS STN6 A5

SCALE    2000.00  TO ONE

SEARCH RADIUS    30.000 METRE

CONTOUR CHARACTERS IN ASCENDI

-99.902  Y DIMENSION

  RL  ..................................
215.66                             B
215.27           --F    F----F     3
214.978      ----   -    -    -     3
214.982      -      -    -    -     .
215.05 -     2       -    -   3     E
215.11 -     2       -    -   3     .
215.12 -             -    3   3     .
215.61                    3   3     .
215.66                    3   3      .
214.43  H+++++++          3   .      .
214.39          ++                   .
214.40            ++                 E
214.42              ++
214.56                22
214.90        2         2222222------
215.08 F      2       -
215.06 -      2       -
214.96  2     -       -
214.88  2      -      -
214.86  E      -      -
214.91  2      -      -    3    3
215.10  -      -      -    3    3     .
215.40  -      -      -    3    .     .
215.59  3      -      -    1.   .     B
215.64  3      -      3     .   .     .
215.48         -       3    .   .     .
215.50         3       3    .    1    .
215.51         3       3    .    1    1
215.92                 3    .    1    1
216.17                      .    1    1
213.70    111               .    1    1
213.96      1++             .     .   1
214.08          ++          .     .    1
213.88    1       +         .     .    .
213.81    1        ++             .    .
213.62    1      +   +            .    E
213.55    E1     +    ++          .
213.61      11    +    ++         3    B
213.82        111 +       ++2     -    -
214.03           +F          22   -    3
214.82                         2P -  33B
215.37                  -----F    F--

  RL  ..................................
```

Figure A3.7   Printout plan of random stadia profile lines (Stage 2)

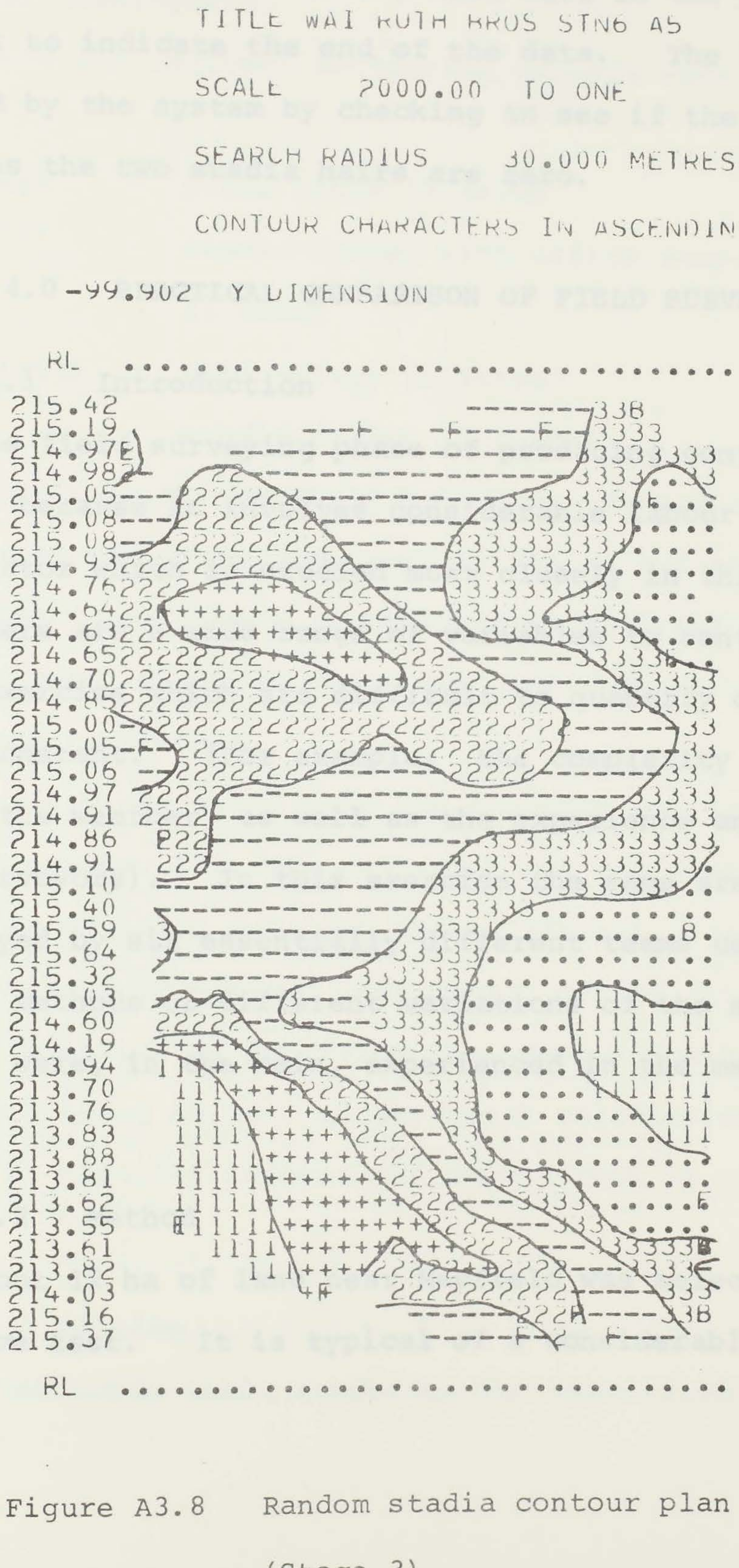

Figure A3.8 Random stadia contour plan

(Stage 3)

A3.11 Computer Job Control

In addition to the normal job control cards, a blank card should be placed after the last card in the punched data deck to indicate the end of the data. The last card is sensed by the system by checking to see if the axial hair as well as the two stadia hairs are zero.

APPENDIX 4.0 PRACTICAL COMPARISON OF FIELD SURVEYING TECHNIQUES

A4.1 Introduction

The field surveying phase of producing contours is important because it involves considerable labour input. This is the factor which is studied most closely in this exercise.

There are a wide range of variables to contend with in such an exercise which are difficult to quantify or difficult to keep constant. (For example; the complexity of the terrain, the weather, as well as the experience and motivation of the surveyors). In this exercise the same area of ground was surveyed by six essentially different teams using different methods or different variations of the same method. The teams were, in the main, experienced in the method they used.

A4.2 Method

About 12 ha of land near Mayfield was selected for this comparative test. It is typical of a considerable area of land which will be involved in surface irrigation development in the future and at the time required surveying for this type of development.

Direct and indirect contouring methods were used as follows:

Direct - plane table (1 team)

- stadia survey with office computations (1 team)

Indirect - grid survey (2 teams)

- stadia survey (2 teams)

The details of the field technique adopted for each type of system was up to each team to decide and so was the number of men in each team. Each survey was performed with a different team, although there was some change of members from one team to another.

Each team was aware that the exercise was being timed. The time to process the data collected was not measured because of the number of teams involved from different organisations and the inability to oversee this aspect of the job. Considering the objective of providing the computer with topographic data for contouring as well as earthwork calculations, the time taken to manually process the survey data is not very relevant.

A4.3 Results

The following table summaries the results of the field exercise.

No.	Survey type	No. of men	Set out time man-hours	Total Survey time man-hours	No. of spot heights	Contour Interval	No. of spot heights per man-hour
1	PLANE TABLE	3	N.A.	9	61	0.5 m	7
2	DIRECT STADIA	2	N.A.	4	120	0.5 m	30
3	GRID. A	2	4	8	183	N.A.	23
4	GRID. B	3	2	4	150	N.A.	38
5	STADIA A	2	N.A.	2	130	N.A.	65
6	STADIA B	3	N.A.	9	160	N.A.	18

Table A4.1 Results of Field Surveying Comparisons

A4.4 Discussion

No field contouring method showed a marked superiority in the ability to produce contours of this area that were sufficiently accurate for the purposes of drainage or irrigation design work. This assessment is subjective as no techniques are available for a quantitative assessment.

The end use of contour plans must be considered when ranking them in order of their acceptability. Aesthetic appeal for example, is not an important quality especially if it was obtained at the expense of accuracy in contour plans for border irrigation design work. Hsu (1974) described a mathematical method of measuring visual differences in multiple map comparisons. The indices used to describe each map for comparative purposes bear no direct relationship to the present requirements. Furthermore, the method presented by Hsu quantifies visual perception and no claims are made that it supersedes visual perception except where a large number of maps are involved.

The general requirements of the present contour plans are:

(a) The theoretical accuracy required is such that a higher standard of accuracy would not cause the design of the border layout to be modified.

(b) To display the contours so that important terrain features are readily identifiable on the ground and conversly.

Such quantitative requirements are not readily amendable to mathematical comparison and none was attempted. All the field methods used in this exercise have no basic theoretical inadequacies and so it could be concluded that provided sufficient accurate topographic data are collected all of the methods can produce satisfactory plans. The important issue, therefore, is the effort required to produce the plans.

The large difference in times taken for the same general method indicates that the details of the method and the efficiency of the teams are also important in determining the time taken. This is probably true of the office work also.

Allowing for the difference in team efficiency the particular area of land surveyed showed some systems up in a better light than others and was, therefore, not an accurate test of differences in method.

A4.4.1 Plane table

On the day the plane table exercise was performed there was a strong wind which makes communication difficult and generally makes work conditions more difficult. Hidden in the field time is the fact that there is no need for office work at the end of the exercise. This could be considered a strong advantage of this method. Doubtful readings can be easily checked in the field before the end of the survey.

The direct contouring method is not as precise a method of finding a contour as could be at first imagined. The contour is usually found within a certain tolerance since placing the staff exactly on the contour height would involve too much time. Minor undulations in the ground can shift the contour line several metres in either direction especially on very flat areas. The contour is probably better described as a band rather than a fine line with no tolerance.

This method produces only the contours which are surveyed. Interpolating between these contours adds nothing to the quality or accuracy of the plan. The field time is high.

The three men on the survey were acting as observer, booker and staffman. All were familiar with this surveying technique.

A4.4.2 Direct Stadia (office computations)

This survey was performed in the field with a team which had worked together in the past. The rate of collecting data indicates reasonable efficiency at gathering the field information. As above, only the contours surveyed are obtained from this system. Twice the time is involved to halve the contour interval. In this particular survey one short contour line was missed.

The field data was booked according to the computerised direct contouring procedure described in Appendix A2.0 above.

A4.4.3 Grid A

The grid size used in this survey was 10 metres by 10 metres. The regular survey and set-out was on a 20 m by 40 m grid but, in order to more accurately record the ground surface at particular points, the 10 m points within larger grid were sometimes surveyed. The 20 m spacings ran approximately along the contours and along the greatest dimension of the area. Considerable care was taken to set out the grid accurately. Because of the shape and size of the area, considerably more pegs had to be set out per hectare than would be normal for the survey of a larger area.

One of the two team members was inexperienced in this method of survey and so the efficiency could probably have been improved with more experience and familiarity with the work.

More spot heights were taken with this survey than with any other of the surveys. But this is not a fault of the method. It is more of a reflection on the care which was being taken to survey the area.

The contour interval selected for the plan is not as restricted as it is in the direct contouring method. Depending on the nature of the topography and the intensity of survey there also is a contour interval beyond which the accuracy and quality of the plan is not improved by a further reduction in contour interval.

Non-grid spot heights are more difficult to position in the field during a grid survey than during a stadia survey because the former involves communication between the staffman and observer. This is something which is not always easy, especially if the weather conditions are poor. The staffman must also be able to clearly identify his position in the field. A good understanding between staffman and observer is necessary to ensure that even the regular spot heights recorded are allocated to the correct grid positions.

Where an important change of grade occurs which is not at a grid point, it is common practice to record it in the position of the nearest grid. While in many cases, especially where the grid size is small, this may not have an important effect on the overall look of the contour plan it is the source of some inaccuracy in the plan.

Narrow ridges and valleys are sometimes completely missed by this system or appear as mounds or hollows because they fall between the grid positions or are only occasionally recorded at a grid position. An experienced surveyor can usually recognise these peculiarities on the plan and redraw the contour lines in a more realistic manner.

Where a grid survey is accurately set out and the spot heights are recorded on the grid positions the accuracy of the positioning of the data on the plan is probably more reliable than the stadia methods and involves less time in positioning the spot on the plan. It is probably reasonable to assume that the office time is less for a grid than a stadia survey.

The field data was booked according to the computerised grid surveying technique described in Appendix A1.0 above.

A4.4.4 <u>Grid B</u>

This grid survey took about half of the time of the other grid survey in both the setting out and recording phases. The grid size was 20 m by 40 m but the 40 m spacings ran along the contours and the longest dimension of the area. Fewer pegs were used in the set-out and fewer survey points were taken than in Grid A.

The team consisted of three men. One observer and two staffmen. The team members were used to working together and rate of collecting data was quite fast.

A4.4.5 Stadia A

This was by far the most rapid survey. It was performed by systematically travelling up and down the area recording changes of grade in the land. The staffman travelled by motorbike and the observer booked the readings. The distinct advantage of this system over a grid system is the ability to vary the intensity of spot heights according to the nature of the ground.

There are very few spot height recordings which are redundant or add little to the plan because of the similar height to others recorded around them.

Where changes of grade are recorded rather than spots at regular intervals, it could be argued that the quality of the data is high and lends itself to interpolation of a reasonably fine contour interval.

The stadia system is inherently more flexible than a grid system in positioning spots on a plan and involves less communication between observer and staffman this being an important factor under normal field conditions.

With the stadia system, there is no time involved in setting up a grid.

A4.4.6 Stadia B

This stadia survey was surprisingly slow. A reasonably high number of spot heights were recorded but the two main factors which caused the team of three to have difficulty was the use of an unfamiliar survey technique in windy weather conditions where communication is difficult.

The data was being collected for a general purpose Ministry of Works computer contouring system which imposed restraints and conditions over the surveyors which they were not used to. In particular, the spot heights had to be collected on a roughly square pattern and the change point procedure was unfamiliar.

A4.5 Conclusions

Although this exercise lacks the controlled conditions which might be expected in an exercise of this nature, it does benefit from the fact that the surveyors were free to survey normally without any unnecessary restrictions imposed for the sake of the comparison. Fortunately, the time margin between the stadia A system and the other methods is so large as to show it to be clearly faster than the other techniques. Not only is it faster, but it is considerably more flexible than the grid surveying technique and is potentially more accurate

Figure A4.1 Plane table contour plan

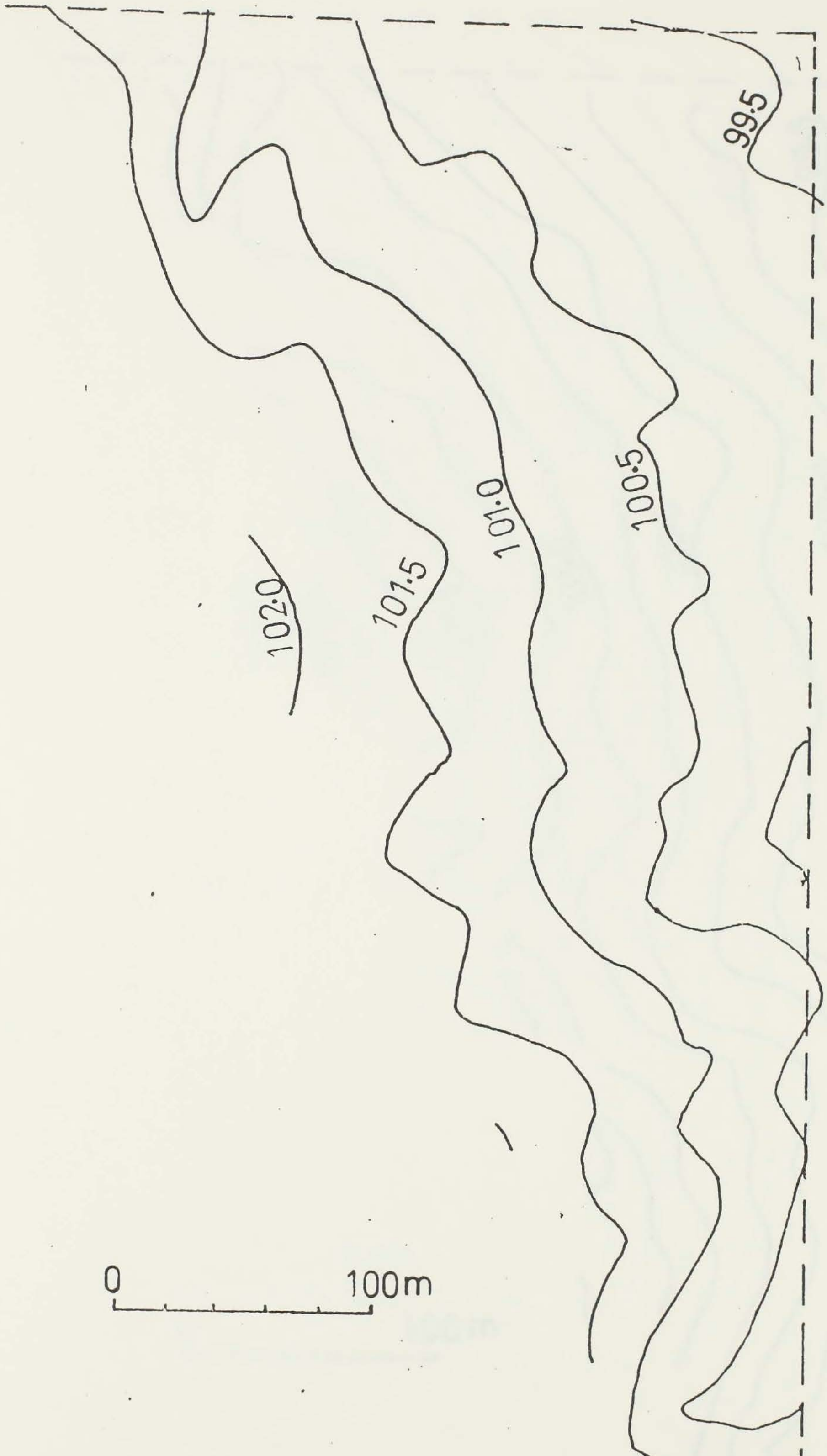

Figure A4.2 Direct stadia contour plan

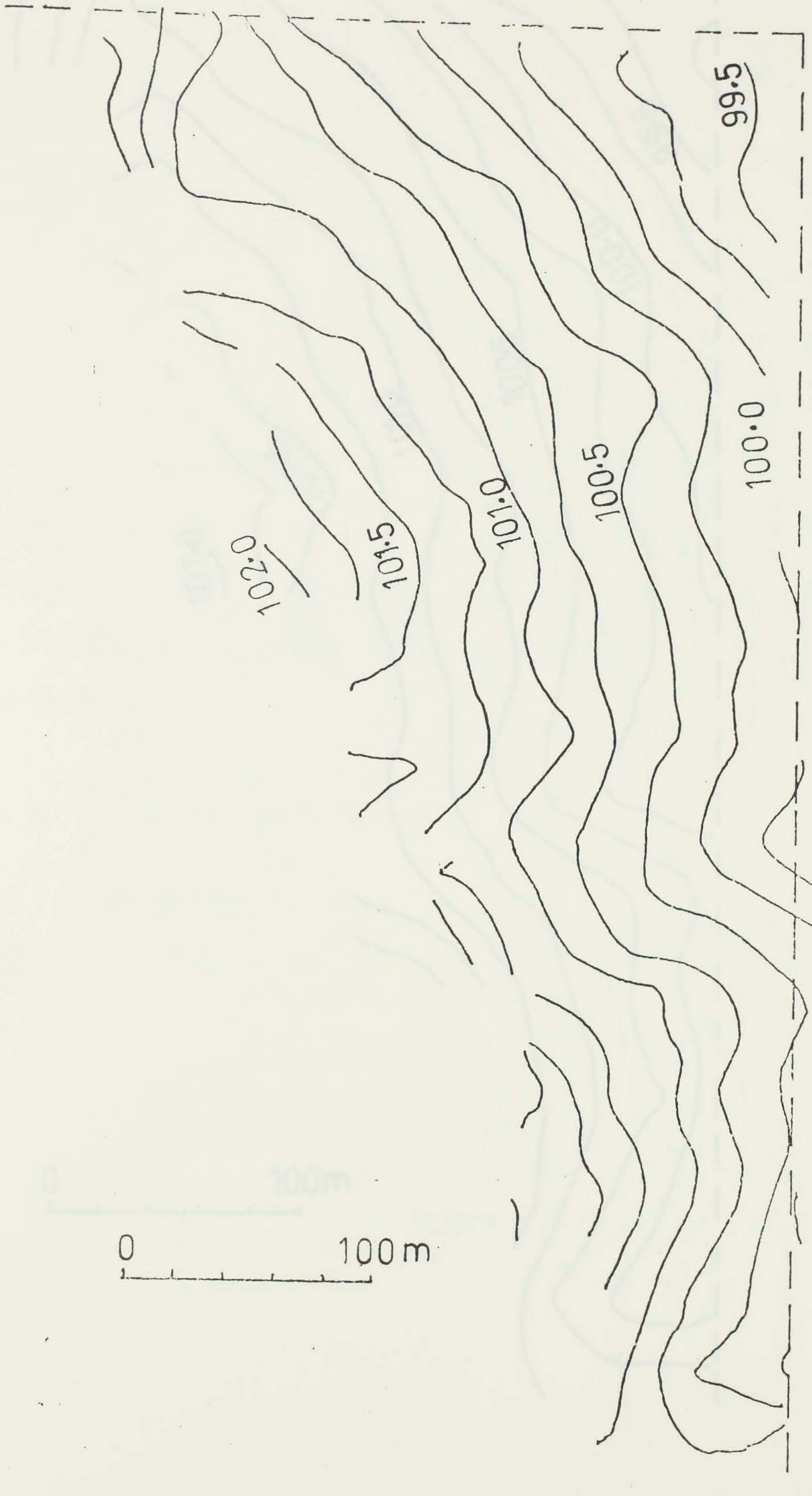

Figure A4.3 Grid A contour plan

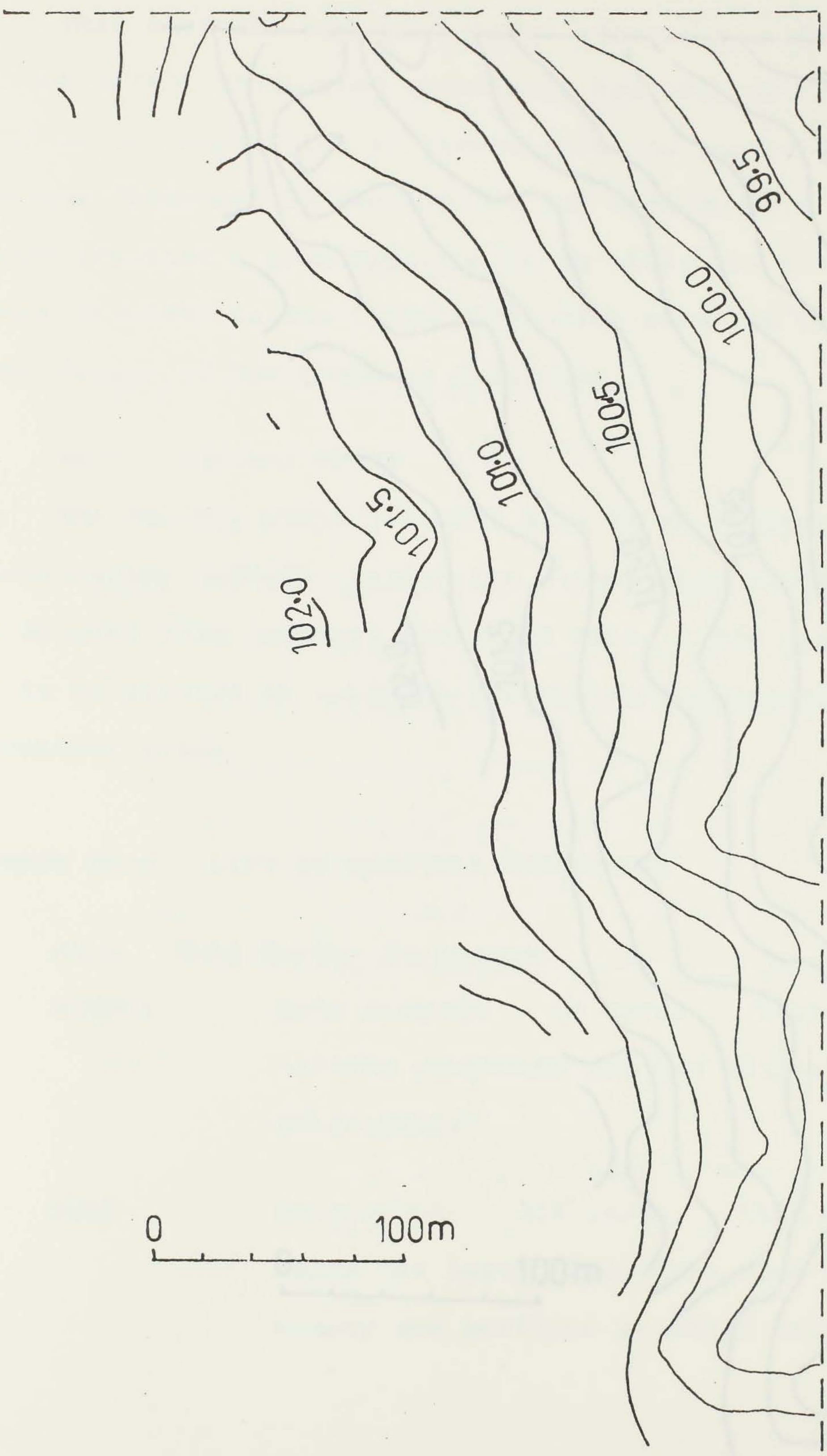

Figure A4.4 Grid B contour plan

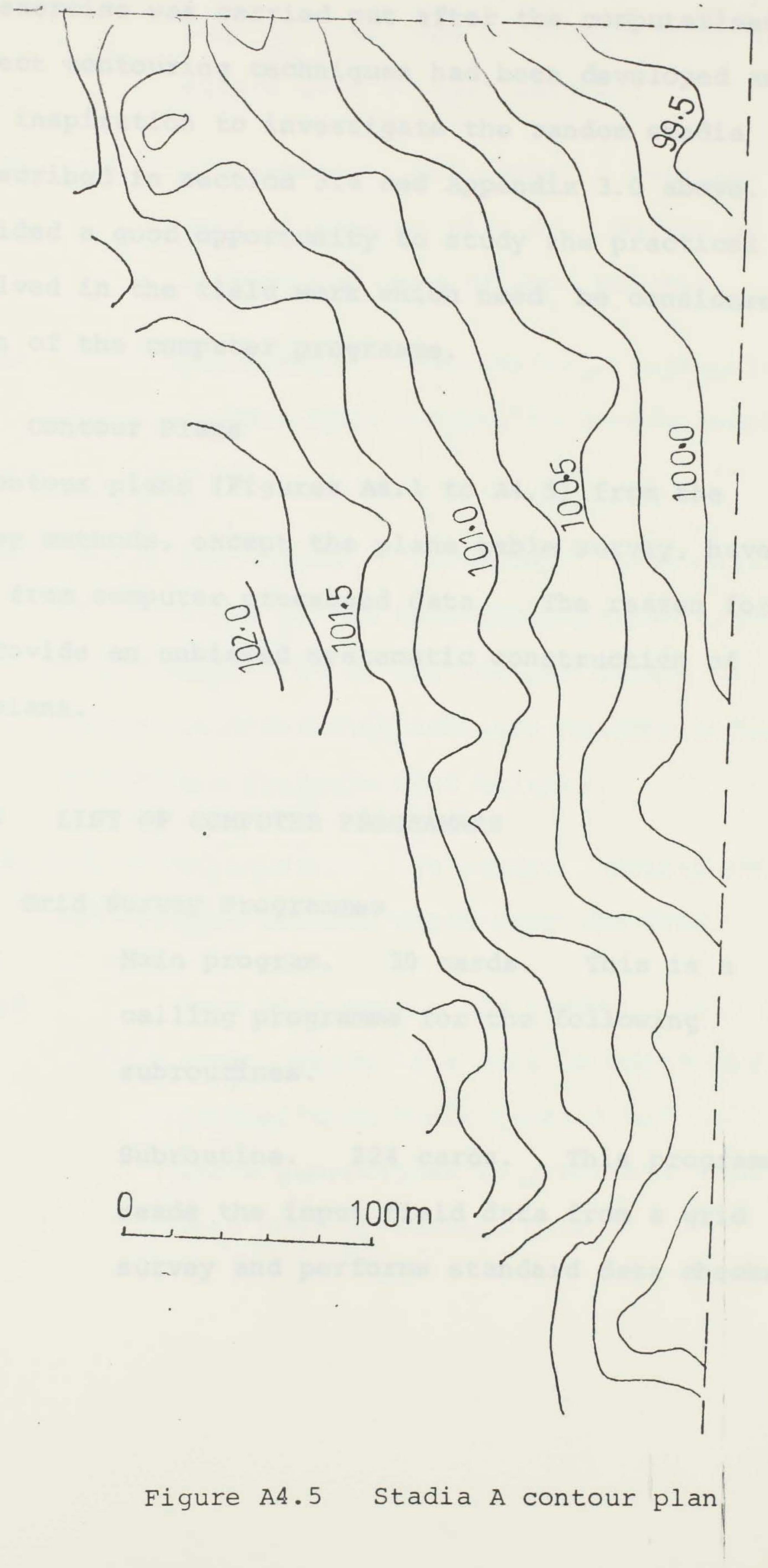

Figure A4.5 Stadia A contour plan

because key points can be selected.

This exercise was carried out after the computerised grid and direct contouring techniques had been developed and served as an inspiration to investigate the random stadia technique described in section 3.4 and Appendix 3.0 above. It also provided a good opportunity to study the practical details involved in the field work which need be considered in the design of the computer programme.

A4.6 Contour Plans

The contour plans (Figures A4.1 to A4.5) from the various survey methods, except the plane table survey, have been derived from computer processed data. The reason for this is to provide an unbiased systematic construction of the contour plans.

APPENDIX A5.0 LIST OF COMPUTER PROGRAMMES

A5.1 Grid Survey Programmes

SURVEY	Main program. 30 cards. This is a calling programme for the following subroutines.
BOOK	Subroutine. 224 cards. This programme reads the input field data from a grid survey and performs standard data checks.

DOTS	Subroutine. 234 cards. Performs the line of dots type of contour plan of a square grid of spot heights.
APLOT	Subroutine. 101 cards. Performs shaded type of contour plan of a square or rectangular grid of spot heights.
INTRP	Subroutine. 170 cards. Interpolates missing spot heights to form a complete grid.
MULTI	Subroutine. 42 cards. This enables the scale of the DOTS contour plan to be magnified by any integer factor by interpolating new spot heights between the original spot heights.
PRINT	Subroutine. 24 cards. Prints out the spot heights which form the grid.
SQDOT	Main programme. 40 cards. This programme reads in a grid of spot heights (rather than field levels) and used the above subroutines to produce a line of dots type of contour plan.

PLOTE — Main programme. 125 cards. Reads data in the form of an irregular grid of different x and y spacings if necessary and produces a shaded type of contour plan.

A5.2 Direct Contouring Programmes

DCON — Main program. 240 cards. Reads in data for direct contouring work and plots out points. Uses core storage only.

DDCON — Main program. 300 cards. Performs the operations of DCON but uses disk storage for data and includes a grid survey system along with the direct contouring system. It calls the following subroutines.

DNTRP — Subroutine. 86 cards. Performs the same functions as INTRP but with data stored on disk.

DDOTS — Subroutine. 200 cards. Similar to DOTS but using data stored on disk.

DPLOT — Subroutine. 72 cards. Similar to APLOT but using data stored on disk.

DULTI Subroutine. 54 cards. Similar to MULTI but using data stored on disk.

DRINT Subroutine. 25 cards. Similar to PRINT but using data stored on disk.

A5.3 Random Data Surveying Programmes

A5.3.1 I.B.M. 1130 Programmes (May also be used on the Burroughs B6700).

CONTR Main programme. 290 cards. Reads in data for random spot heights and performs data checks. Stores x, y, z co-ordinates, land feature characters and "$" characters in sequence in a disk file.

SPLOT Subroutine. 110 cards. Produces a scale plan marking the position of all the spot heights.

SEQI Main Programme. 270 cards. Uses the file of data created by CONTR and joins the recorded spot heights by profile lines and prints out a scale plan of the profiles.

SPIDR Subroutine. 177 cards. Uses the profiles of data created by SEQI to interpolate new spot heights for the remaining printer character positions and produces a scale contour plan.

A5.3.2 Burroughs B6700 Programme

CONTOUR Main Program plus subroutines 1262 cards. This programme was specially developed from the random survey programmes above for the larger B6700 and cannot be run on the I.B.M. 1130. The programme has been developed beyond the stage of the I.B.M. programmes. It is presently being used for commercial contouring work.

A5.4 Earthwork Related Programmes

A5.4.1 I.B.M. 1130 Programmes (May also be used on the Burroughs B6700).

ARRAY Main program. 52 cards. From a deck of grid spot height data cards, this program creates a digital terrain model which is then stored on a disk file.

GSDC Main program. 253 cards. This programme was developed from BOOK especially to create a file of x, y, z data from contour survey data and store it in sequence as a disk file.

EMAIN	Main program. 44 cards. This program calls the two subroutines ESEQI and ESPID and writes out the spot heights used in the digital terrain model.
ESEQI	Subroutine. 320 cards. This was developed from SEQI to create profiles for the subroutine ESPID below using a data file created by CONTR or GSDC.
ESPID	Subroutine. 295 cards. Using the profiles from ESEQI this programme creates a square grid digital terrain model of any grid spacing.
CHECK	Main Program. 136 cards. This programme reads data cards which define the large areas to be formed into bordered strips and then defines the boundaries of each individual bordered strip. Data on level constraints and tolerances are read by this programme.
EARTH	Subroutine. 646 cards. Using the level

constraints and the boundaries of the bordered strips from CHECK, this subroutine calculates all forms of earthwork relating to each individual bordered strip. It uses the digital terrain model created by ESPID or ARRAY.

ERACE — Main programme. 212 cards. Using the digital terrain model, created by ESPID or ARRAY and various race specifications, this programme calculates the earthwork quantities relating to head races and supply races.

A5.4.2 Burroughs B6700 Programme

USAEARTH — Main program plus subroutines 2402 cards This programme calculates the earthworks associated with grading complete fields with various slope constrains. It was originally developed at North Carolina State University, but it has been modified for use in New Zealand as a part of this study. A description of the original programme is contained in Shih (1973).

PLOTT — Subroutine. 91 cards. Additional USAEARTH subroutine to produce a shaded type of contour plan showing modifications to the topography.

ROTATE Subroutine. 104 cards. Additional USAEARTH subroutine to define a new set of spot heights at any angle of rotation compared with the original data.

A5.5 Three Dimensional Projection Programmes

The line plotting facility is available on the Burroughs B6700 so the following programmes were developed for this machine.

GRIDREADIM Main programme. 35 cards. This programme creates a disk file which stores the data array used subsequently in the plotting programmes. Reduced levels are read directly from cards and stored on disk.

CONTOUR3D Main programme. 1286 cards. This programme also creates a disk file of terrain data but it is derived from field readings of a random stadia survey. It is a minor modification of CONTOUR above with an additional feature that allows the user to specify an angle through which the contour plan is to be rotated on the page.

VIEW3D Main programme. 150 cards. The standard Computer Laboratory plotting programmes are bound to this programme. It uses the data file created by GRIDREADIM or CONTOUR3D and performs the necessary data manipulation and plot registration to convert the standard 3D plot (lines in one direction) to a cross-hatched plot.

APPENDIX A6.0 BORDERED STRIP IRRIGATION DEVELOPMENT COSTS

The following costs relate to the total irrigation land preparation and associated costs of Lincoln College Lyndhurst Farm in 1976. The bordered strips are typically 180 m long and are straight and parallel. The topography is even with a maximum general fall of 0.5% (See Figure 13.1)

Cost/ha	$
Total earthworks cost including headraces	140.00
Headrace dams (1.1/ha)	42.90
Headrace sills (3.4/ha)	24.40
Alarm clocks (24 hour)	10.00
Headrace gates	6.20
Culverts	11.70
Syphons	1.80
	237.00