COMPUTER-AIDED SUBSURFACE DRAINAGE SYSTEM DESIGN AND DRAFTING

by

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Short title

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ABSTRACT

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Ph.D. Agricultural Engineering

COMPUTER-AIDED SUBSURFACE DRAINAGE SYSTEM DESIGN AND DRAFTING

The use of computers and computer plotters to design and lay out plans of subsurface drainage systems was studied. A systematic approach was developed.

Two existing programs, TOPMAP and CONTUR, were used with some modifications to produce spot elevation topographic and contour maps from survey data.

Four main programs, HYCONS, PROFILE, DSDP and DSLP, were developed for drainage system design and drafting purposes. HYCONS was used to obtain the hydraulic conductivity and drain spacing from single auger hole tests and assigned design parameters. PROFILE was used to draw the profiles of collectors or laterals of the drainage system when needed. DSDP and DSLP were used to design and lay out the plans of those designed systems.

Nomographs for obtaining the equivalent depth of flow below the drains for seven commonly used drainage tubing diameters were presented. Another nomograph was developed interrelating the variables of design drainage rate, equivalent depth, drain depth, hydraulic conductivity and drain spacing between laterals. A new multiple-correlation graph for determining the required size and maximum allowable length of drain tubes was also developed.

RESUME

Ph.D. SIE-TAN CHIENG Génie rural

CONCEPTION ET DESSIN DE SYSTEMES DE DRAINAGE SOUTERRAIN A L'AIDE DE L'ORDINATEUR

L'utilisation des ordinateurs et des appareils à dessin automatiques pour concevoir et tracer les plans de systèmes de drainage souterrain est l'objet de cette étude. Une approche systèmatique a été développée.

Deux programmes déjà existants, TOPMAP et CONTUR, légèrement modifiés ont été utilisés pour produire des cartes avec lignes de contour à partir de relevés topographiques.

Quatre programmes principaux, HYCONS, PROFILE, DSDP et DSLP, ont été développés pour la conception et le dessin de systèmes de drainage. HYCONS utilise les résultats des tests du trou de tarière et d'autres paramètres de conception pour calculer la conductivité hydraulique et l'espacement des drains. PROFILE dessine les profils des collecteurs ou des latéraux du système de drainage au besoin. DSDP et DSLP font la conception et le tracé de plans des systèmes ainsi concus.

Des nomogrammes ont été formulés pour obtenir la profondeur équivalente de débit sous les drains pour les sept diamètres de drains utilisés couramment. Un autre nomogramme a été développé pour relier entre elles les variables de débit de drainage, de profondeur équivalente, d'espacement des drains, de conductivité hydraulique et d'espacement des drains entre les latéraux. Un nouveau graphique à correlation multiple pour déterminer le diamètre et la longueur maximale permise pour les tubes de drainage a également été développé.

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CONTRIBUTIONS TO KNOWLEDGE

This study provides the following contributions to knowledge:

1. The digital computer has been used together with the developed programs to design subsurface drainage systems - Section 3.5.

2. High-speed computer plotters have been used to draw spot elevation topographic and contour maps and the plans for drainage systems from item 1 above - Sections 3.5.2 and 3.5.3.

3. It has been found, using the actual designed samples, that the computer drafting method is faster and cheaper than conventional (manual) drafting methods.

4. Nomographs for obtaining the equivalent depth below the drain centre for seven commonly used drain tube diameters have been developed - Figures 8 to 14.

5. A nomograph was developed to interrelate the variables of design drainage rate, equivalent depth, drain depth, hydraulic conductivity and drain spacing between laterals - Figure 36.

6. A new multiple-correlation nomograph showing the relations between areas drained, drain tube capacities, design drainage coefficients, slopes of the drains, spacings between laterals and the maximum allowable lengths of the drain lines has been presented - Figure 37.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Figure | Page

Figure Page

LIST OF TABLES

LIST OF APPENDICES

LIST OF SYMBOLS

A	area
a	a constant
b	a constant
d	the vertical distance from drain tube center to the impervious soil layer
D	the vertical distance from soil surface to the impervious soil layer
DD	drain depth
d_e	Hooghoudt's equivalent depth of soil, below the drain center, through which flow to drains occurs
DH	depth of auger hole below the ground water level
DWD	desirable water table depth from soil surface
H	total drain depth
h	height of water table at midspacing above subdrain centers
i	number of item
k or K	hydraulic conductivity
k_a or K_a	hydraulic conductivity for soil layer above the subdrain
k_b or K_b	hydraulic conductivity for soil layer below the subdrain
L	length of the drain line
N	number of connections of laterals and collector
n	Manning's roughness coefficient
R	drainage rate (drainage coefficient), volume of outflow per unit area of land drained per unit time
r	radius

s or S	drain spacing between laterals
x or X	horizontal distance from some vertical reference plane
y or Y	vertical distance from some horizontal reference plane
z or Z	elevation above the ground
ΔX	change in X
ΔY	change in Y
ΔZ	change in Z
α, β, θ	angles

LIST OF ABBREVIATIONS

cm	centimeter, centimeters
CRT	Cathode Ray Tube
ft	foot, feet
ha	hectare, hectares
hr	hour, hours
in	inch, inches
I.D.	inside diameter
JCL	Job Control Language
km	kilometer, kilometers
m	meter, meters
mm	millimeter, millimeters
min	minute, minutes
O.D.	outside diameter
OS	Operating System
sec	second, seconds
t	time
yr	year, years
$	dollar, dollars

CHAPTER I

INTRODUCTION

1.1 Statement and the nature of the problem

Subsurface drainage is a recognized and increasingly practised method of removing excess soil water from the agricultural lands. The rates of installations of subsurface drainage systems in the Provinces of Quebec and Ontario have blossomed out in the past few years. In Quebec alone, the installations had reached about 12100 km/year in 1975 (Broughton, 1976).

April (1967) and Jutras (1967) show that about 1214000 hectares, or approximately 60 per cent of the cultivable land in Quebec needs subsurface drainage improvements for its crop productive potential to be realized. Broughton (1976) points out that with installation rates of 13000 km/year and 0.5 km/ha, about 50 years will be required for these installations.

From the point of view of subsurface drainage system cost, it is desirable that the design drainage coefficient (drainage rate) be not larger than necessary to remove excess water adequately soon for the needs of crop growth or field machine operations. In order to obtain adequate drainage systems for the agricultural lands, appropriate theories and approaches to system designing should be carefully chosen.

It is logical that the necessary drainage rate should depend on the climatic regime of the region as well as drainable porosity and available water holding capacity of the particular soils and the water table depth requirements of particular crops or field machine operations. The water balance computer drainage model developed by Chieng et al. (1978) has made good progress in relating subsurface drainage performance to the climatic regime of a region as well as the parameters of a specified soil. This model may be used with the input for a particular region to obtain adequate drainage criteria for the system design.

It is recognized that the number of days available for field operations, i.e., field surveying, drain installations, land smoothing, etc., is limited in this region of the country due to the long cold winter and wet spring and wet autumn conditions. Generally, the work for the soil measurements, topographic survey, system design report preparation and drain installations for a field or farm needs to be spaced over two summers. If the time required for these processes could be reduced, the time between the start of planning and the installation could be reduced. Thus, construction could be done in the same season as the planning, for the smaller more urgent jobs.

It is understood that one of the most tedious time-consuming parts of the processes of a subsurface drainage system design is "drafting," i.e., topographic mapping, contour lines drawing, drain lines layout and special key notes lettering, etc. To reduce this time and tedium, it has been conceived to be possible to apply modern computer plotting techniques to speed up the drafting processes. The computer is a capable helper when adequately instructed. It provides recall, speed, accuracy, and endurance.

The purpose of the present study is: by using the adequate design criteria generated by the water balance computer drainage model suggested by Chieng _et al_. (1978), the hydraulic conductivity measured in the field, to design the subsurface drainage system by using the well known Hooghoudt's equation (Luthin, 1973). The field topographic and contour maps, the designed plans and other necessary information for the system installations will be plotted by the high speed computer plotter.

1.2 Objectives

The objectives of the present study are:

1. To use the computer drainage model suggested by Chieng _et al_. (1978) with some input modifications to obtain adequate subsurface drainage system design criteria for particular fields.
2. To plot the field survey data in different scales and orientations as spot elevation topographic maps by using the high speed computer plotter.

3. To use a contouring program to draw topographic maps with contour lines based on the field spot elevations.
4. To develop programs to instruct the computer to obtain different possibilities of the subsurface drainage designs and produce plans of those designs with a high speed computer plotter.
5. To develop programs for the computer to produce lists of materials needed for each drainage system designed.
6. To produce some sample computer controlled plotter drawings of drainage system designs for particular fields showing desired positions of drainage facilities, lists of materials for cost estimate so that the physically most suitable design, or the least expensive design could be chosen.

1.3 Scope of the work

This study is to make a systematic attempt to design and prepare drawings for subsurface drainage systems using the high speed digital computer and computer plotter. The research is restricted to the cases of agricultural lands whose slopes are less than 8 per cent. This might cover approximately 80% of lands needing subsurface drainage facilities in the world and 2 million hectares in the Province of Quebec.

CHAPTER II

REVIEW OF LITERATURE

2.1 Subsurface drainage

Within the past thirty years, a considerable amount of research on subsurface drainage problems has been done.

The criteria for design of subsurface drainage systems may be specified in terms of the depth of water to be removed within a specified time period, maximum height of the water table, rate of lowering the water table, or some other set of conditions. Hedstorm, Corey and Duke (1971) state that in determining these criteria, the drainage or aeration requirements of the predominant crop should be considered. It is generally considered that a unique analytical formulation of the various processes involved in the subsurface drainage system is very complex, and even if it could be achieved, the improvement over the results obtained by simpler methods may be insignificant. To date, engineering specifications of drainage systems have been based on field observations of existing systems, laboratory tests of soils and drainage materials, drainage equations, and results from models and analogues. There is no universally accepted design procedure, although there is extensive literature on subsurface drainage.

So far, drainage problems have been divided into steady state and non-steady state flow conditions. A steady state condition exists when the boundaries and flow rates of a system do not change with time. Otherwise, a non-steady state prevails (Young, 1970).

One of the earliest analyses of steady state drainage conditions was that by Dupuit in 1863 (Broughton, 1972). On the basis of Dupuit's theory, Forchheimer proposed in 1886 a general equation for the free water surface by applying the equation of continuity to the water in a vertical column in a flow region, bounded above by the phreatic surface and below by an impervious layer.

Later, Hooghoudt (1940) proposed a formula for drain spacing computation for the case of steady flow. Hooghoudt's approach combines the concept of radial flow near the drain tubes and nearly horizontal flow at greater distances from the drains. His theory considers the effect of convergence of streamlines near the drains. Hooghoudt's equation may be expressed as:

$$S^2 = (4\ K_a h^2 + 8\ d_e K_b h)/R \qquad \ldots (1)$$

where S = spacing between drain laterals, m

h = water table height above the drains at mid-spacing, m

R = drainage rate, m/day

d_e = equivalent depth of impermeable layer below drain centre, m (d_e is a function of d and S (Luthin, 1973))

K_a, K_b = hydraulic conductivities of the soil layers above and below the drain, respectively, m/day.

When applying equation (1) to a homogeneous soil, i.e., $K_a = K_b$, the equation may be simplified to:

$$S^2 = 4\ K\ (2\ d_e h + h^2)/R \qquad \ldots (2)$$

Equation (1) applies directly to the drainage cases (a) and (b) shown in Figure 1. Drain spacing can be calculated for case (c) in Figure 1 by using equation (1) if a weighted value of the hydraulic conductivity above the drain is determined for K_a and K_b. Van Beers (1965) suggested that Ernst's equation should be used rather than Hooghoudt's equation to compute drain spacings for case (d) in Figure 1. He had given a nomographic solution of Hooghoudt's equation and more recently, the nomographic solutions have been further generalized by Sakkas (1975).

Subsequent to Hooghoudt's work, various theories and interpretations of the subsurface drainage flow processes have been forwarded by a number of research workers.

Based on Darcy's law, Aronovici and Donnan (1946) developed a formula for the spacing between tile lines using the permeability of the aquifer as a criterion. Donnan (1947) showed with a number of

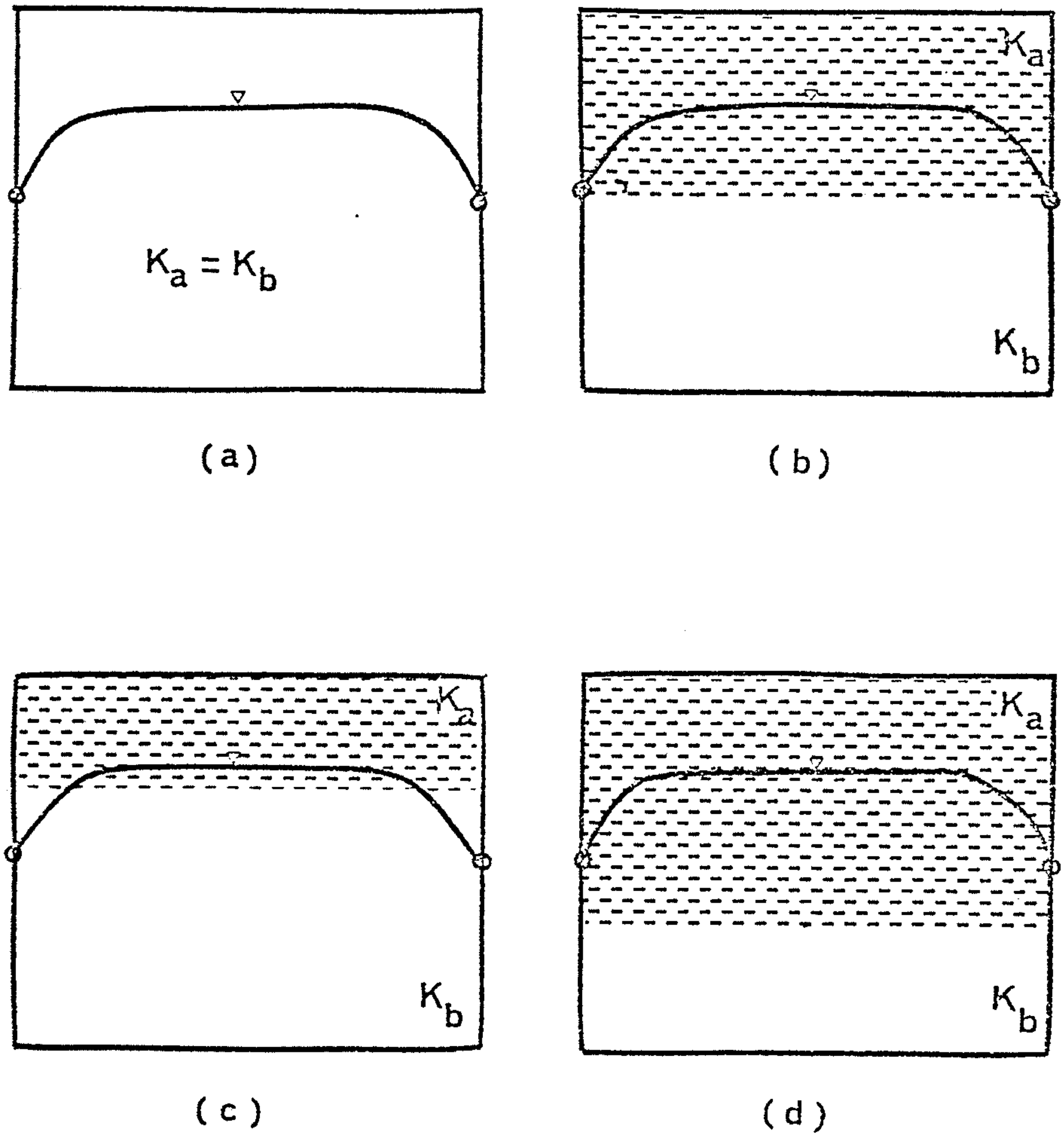


Figure 1. Drainage System in Homogeneous and Layered Soil.

Case (a) Homogeneous soil.
Case (b) Two layered soil with drains at layer interface.
Case (c) Two layered soil with drains in the lower layer.
Case (d) Two layered soil with drains in the upper layer.

laboratory and field experiments that, for a homogeneous soil, the formula is applicable within reasonable limits. Aronovici's spacing formula may be written as:

$$S^2 = 4\ K(b^2 - a^2)/R \qquad \ldots (3)$$

where S = spacing between laterals, m

K = hydraulic conductivity, m/day

R = drainage rate, m/day

a,b = limits of the drawdown curve as delineated by a strata survey of the site, m.

The above equation considers horizontal flow only and design values of the spacing S are calculated when the water table is at or very close to the soil surface. The convergence effect of flow lines near the drains had not been adequately considered. Therefore, Hooghoudt's equation, which takes into consideration the convergence effect by introducing a term d_e (equivalent depth) is considered superior to Aronovici's approach (Bhattacharya, 1977).

Later, Kirkham (1949, 1951) proposed a more rigorous approach by applying potential flow theory. His analysis was done for steady flow under ponded water conditions. His work shows the importance of placing drain laterals directly under the low spots in a field to reduce the distance ponded water must soak through the soil to reach a drain pipe.

During the past quarter century, non-steady state subsurface drainage problems have been studied and have been proposed for design of subsurface drainage systems (Young, 1970). Van Schilfgaarde (1965) reviewed and evaluated several of these analyses. He pointed out that most of the analyses including Boussinesq, Glover, Tapp and Moody, Krayenhoff, Maasland and Brook equations, are based on the simplified Dupuit-Forchheimer assumptions; and a few analyses, including the equations of Bouwer and Van Schilfgaarde, Wiser and Ligon, are based on the time-independent relationship between water table height and drainage rate assumptions. Van Schilfgaarde has also shown that, of the various steady and non-steady state drainage flow equations, Hooghoudt's formula, equation (1), for spacing computation gives the least percentage difference between the actual and calculated spacings.

Luthin (1973) reports that there are as many as 160 different theories associated with subsurface drainage. He states that the Hooghoudt's theory is simpler to use than most others and gives significantly small error to be widely acceptable.

It should be mentioned that Guyon's equation (Lagacé and Sylvestre, 1976) has been used extensively for drainage design work in France and Quebec. However, both the Hooghoudt and Guyon formulae are based on Dupuit-Forchheimer assumptions and they give similar results when applied to the same field conditions.

2.2 Water balance and subsurface drainage design

The water content of a soil volume at any time depends on the balance between water inflow and outflow and the changes of the soil water storage. The basic idea in applying the water balance approach to drainage design is to use some mathematical bookkeeping equations to balance the input and output of a drainage system for some specific time intervals and the process is repeated for a large number of years for which the weather data are available.

In 1965, Van Schilfgaarde (1965) applied the water balance approach to compute the daily water table height above a drain from daily precipitation input. He mentioned that the design criteria for drainage systems would be more meaningful if they take into account the probability distribution of water table height rather than considering only a constant water table level (steady state), or an assigned rate of water table level (non-steady state). He also pointed out that the concept of developing frequency distributions of water table heights by using a water balance model is important and feasible.

Taylor and Watts (1967) have used a water balance model to compute water table frequencies corresponding to various arbitrarily selected spacings and drainage rates. They did not apply any particular spacing equations, but had proposed regression equations between water table depth and time.

Young and Ligon (1972) had modified the water balance approach proposed by Van Schilfgaarde after verifying it with five months of field data. They used the modified model to compute both soil moisture and the daily water table heights above the drain with long-term meteorological data.

Foroud and Broughton (1974) adopted the probability analysis concept to predict the water table position by means of a water balance model with long-term precipitation and evapotranspiration data.

Skaggs (1975) has used the water balance approach to develop a water management model to predict the response of the water table and the soil water regime above it to rainfall and evapotranspiration. He used the model to evaluate conventional drainage systems consisting of both surface and subsurface components, and for drainage systems with water table control and with subirrigation.

Chieng (1975) developed a drainage model for water balance to obtain frequency distributions of water table depths above the drain for different drainage rates, available soil moisture contents, drainable porosities and drain depths. In his model, Hooghoudt's equation was incorporated to compute the drainage rates at different water table depths. The model has been used by Chieng et al. (1978), Asselin (1978), Bhattacharya (1978) and Holsambre and Sinai (1979) with different weather data inputs. All studies mentioned above had carried out field observations (water table depth measurements) in fields with subsurface drainage systems installed in different areas in the St. Lawrence Lowlands and in Israel. The field observations were used to verify the model by comparing the predicted and observed water table depths. Good agreements were found (Chieng et at., 1978).

In this study, Chieng's model will be used to generate drainage criteria for the system design when needed.

2.3 Subsurface drainage system design practice

In order to provide a background perspective for the work presented later, an outline of the current subsurface drainage system design practice seems to be desirable. The outline is based on the literature noted, personal experience of the author and verbal discussions with drainage system designers.

The general practice for design of subsurface drainage systems for those flat lands in the Provinces of Quebec and Ontario, as indicated by Hore (1968), Jutras and Irwin (1970), Broughton (1972), Ministry of Agriculture and Food, Ontario (1976), and Ministry of Agriculture, Quebec (1978) includes the following steps:

1. A topographic survey is carried out in sufficient detail to give field elevations to the nearest 50 mm.
2. A spot elevation map is prepared for the area to be drained, showing spot elevations and topographic symbols.
3. From the spot elevation map, a contour map is prepared. Possible outlet locations and controlling elevations are noted.

4. Auger hole tests are carried out in the field to obtain the saturated hydraulic conductivity and information of soil types and layering conditions. If the water table is low at the time when auger holes are dug, an estimate of the hydraulic conductivity or necessary drain spacing is made from observation of soil structure and experience with drainage performance on similar soils.
5. From the information on the soils, climatic conditions and the knowledge or experience with drainage installations in the region, a design drainage rate (drainage coefficient) is selected and the spacing between laterals is calculated by using the selected drain spacing equation.
6. Subdrain diameters are selected on the basis of having sufficient capacity on the installed grade to discharge a given drainage rate from the area feeding the drain.
7. Finally, a drainage system plan is prepared to show information necessary for the installation and future maintenance.

The sequence of these steps in the process to prepare drainage system design plans is indicated in Figure 2 in a form which shows steps aided by computer programs.

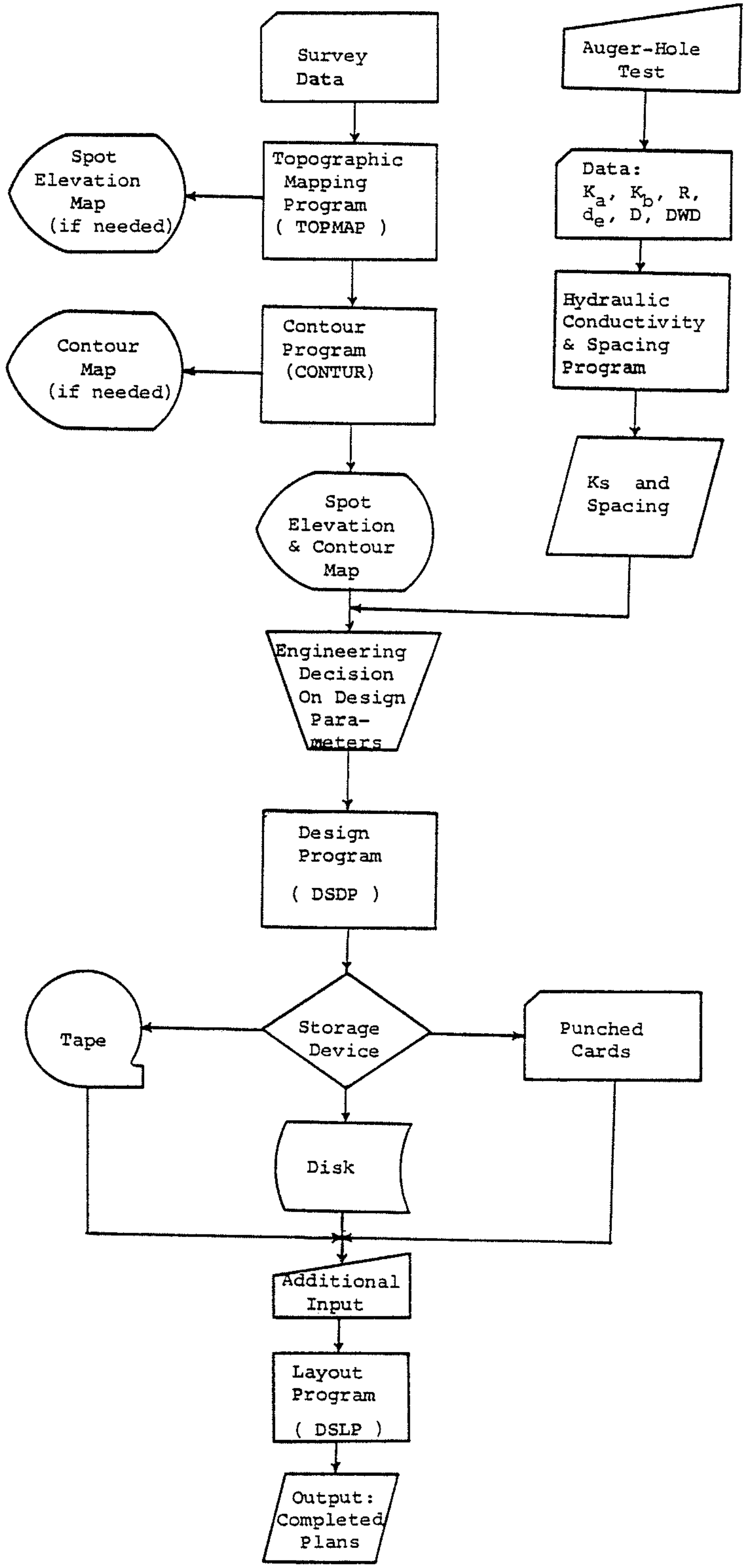


Figure 2. Sequences in Computer-aided Subsurface Drainage System Design and Layout.

2.4 Computer graphics for drafting and drainage system layout

It is a well-known fact that the computer has revolutionized our society in the past two decades. Man's horizon has been widened because of computers. During the past ten years, men and women have used computer systems to teach, contribute to knowledge and improve our environment, solve highly technical problems, and draw complicated engineering, architectural, medical, artistic, structural designs and simulations on picture tubes (Potts, 1975).

Among others, computer graphics is one of the important, far-reaching, sophisticated and glamorous endeavors of the computer field. It has blossomed out from the stage in which it was confined almost exclusively to the large-scale industries of aircraft, automobile and petroleum engineering in the past decade (Parslow _et al._, 1967). Recently, with the advent of microprocessor and hence reduced cost in graphics systems, the computerization of engineering drawing tasks entered the drafting field.

Engineering drawings are a means of visual communication from the design stage on through the production cycle. Concepts are conveyed, reviewed and revised via the drafting medium throughout engineering work. A maximum effort has been made to reduce the cost of human labour and to minimize human errors. The automatic drafting machine has been introduced as an aid in minimizing these costs and errors and to relieve the draftsmen from the many tedious, time-consuming and routine tasks, such as lettering and making new drawings of a revised design which has only a few changes from previous drawings.

Application of computer drafting is growing constantly. At the present time, some of the areas covered are in architecture, business, education, engineering, industry, medicine and science. In science, computer drafting has been used in atomic structure analysis, nuclear explosion, seismograms, weather data mapping, radio telescope studies, satellite flight tracking and submarine hull designs. In industry, applications include critical path method and planning evaluation review techniques, automobile and aircraft designs and gas line distribution. In medicine and psychiatric diagnosis, it has been employed in such studies as the biomedical research on the graph of sound vibrations in the inner ear and the speed of heart beats. In engineering, computer drafting has aided in air traffic recordings, traffic pattern analysis, analogs and contour mapping. In business, studies of inventory and budget control, advertising and market research, profit and loss trends, as well as financial analysis, have been aided. Samples of the items mentioned above can be found in Sedgewick (1974), Potts (1975), Wright (1975), Godfrey (1977), Whitsed (1978), Bleackley (1978), Kellie (1979) and Computer Data (1979).

A literature search for this topic was carried out by using the CAN/OLE (Canadian On Line Enquiry System) and DIALOG Searching System of the United States. It is found that during the past 15 years (1964-March 1979), there were about 5000 studies regarding drainage and/or computer. Among those, only the work presented by Renner and Mueller (1974) was applying the computer and computer drafting techniques in the field of subsurface drainage system design and layout. However, the study was aimed at finding the sensitivity of the system cost to drain spacing computed by using the formula suggested by Dumm, Moody and Tapp (Renner and Mueller, 1974). This program shows horizontal positionsof drain lines between manholes but cannot produce detailed plans for subsurface drainage systems. Features such as slopes, lengths and depths of drains, directions of flow, etc., cannot be produced by their program. Nonetheless, they made a good step toward the application of computer drafting techniques to the field of subsurface drainage.

Recently, Murphy et al. (1979) and Kok and Bégin (1979) have used the computer drafting in preparing topographic spot elevation and contour maps. The former have developed a set of short programs for plotting the spot elevations from stadia survey data and the latter have developed a program for drawing contour lines from spot elevation data. These topographic and contour drawing programs are used in the present study with some modifications to produce spot elevations and contour lines for subsurface drainage system design.

CHAPTER III

METHODOLOGY CONSIDERATIONS

Broadly speaking, the study reported in this dissertation consists of three parts. In the first part, information on the available hardware for computer-aided drafting was gathered and examined. Among these, the accessible devices were closely studied. In the second part, a set of programs for designing and drafting the drainage system were developed. During the processes, some existing programs which may be modified and co-operated in the study were also reviewed. In the third part, the developed programs were used to design and lay out the actual system plans.

3.1 Hardware for computer drafting

It is recognized that there are two distinct divisions in the field of computerized drafting systems. These are passive and interactive drafting. Interactive computer drafting is associated with glamorous graphics as illustrated by commercials on television. This drafting uses a display console in interactive mode. Passive drafting includes plotters, microfilm recorders and other devices which usually do not allow immediate active participation. Generally, a computerized drafting system consists of both passive and interactive devices.

There are many different types of hardware on the market currently, such as equipment manufactured by Tektronix, Hewlett-Packard, Calcomp, Wang Lab, Versatec, Gould, Gerber, etc. Bleackley (1978) indicates that Tektronix, Hewlett-Packard and Calcomp are found to be the most popular devices and dominate the computer graphics and drafting fields at the present time.

In this study, the following devices were used:

1. A Tektronix 4051 terminal.--This graphics CRT (Cathode Ray Tube) terminal is located in the Agricultural Engineering Department at the Macdonald Campus. It was used to compile and debug the drafting programs which it links to the host computer, an Amdahl V7, at the McGill University Computing Centre, via a data phone. The outputs can be routed to Calcomp plotter or produced in small size by the Tektronix 4631 hard copy unit attached to the terminal.

2. A Calcomp 663 plotter.--The McGill Computing Centre operates a Calcomp 663 digital incremental off-line plotter using output produced by a program run on either the Operating System (OS) or McGill University System for Interactive Computing (MUSIC). This particular plotter is a two-axis cylindrical plotter whose plotting surface is the face of the cylinder. Movement of the paper in the

X-direction is obtained by rotating the cylinder, while movement in the Y-direction consists of moving the pen across the face of the cylinder. The pen itself has an up and down position which controls the flow of ink onto the paper. A brief sketch of this plotter's movement is shown in Figure 3.

Communication of pen movements to the plotter is performed by passing arguments to a number of supplied FORTRAN subroutines (Fox, 1978). Plotting instructions are written on an 800 BPI (Bytes per inch) 9-track tape which the computing centre provides. The plotting instructions are sensed from the plot tape and appropriate action is taken by the plotter. The largest individual pen movement in any direction is 0.0635 mm (0.0025 inches). By combining a series of short movements, the plotter is able to draw smooth curves. When the plot program redefines the origin, the plotter senses this and increases its counter by one. The plotter operator can then be instructed to set the counter to stop at any origin redefinition and can change the pen size or ink colour at that point. The plot then continues from the exact position at which it was interrupted. Different sizes of pen, colours of ink and types of paper for the plotter are detailed in the Calcomp Digital Plotter User's Guide (McGill University Computing Centre, 1978).

In general, plotting jobs should be able to be performed by either off-line or on-line plotting systems. However, all the plottings in this study were done by the off-line method since the

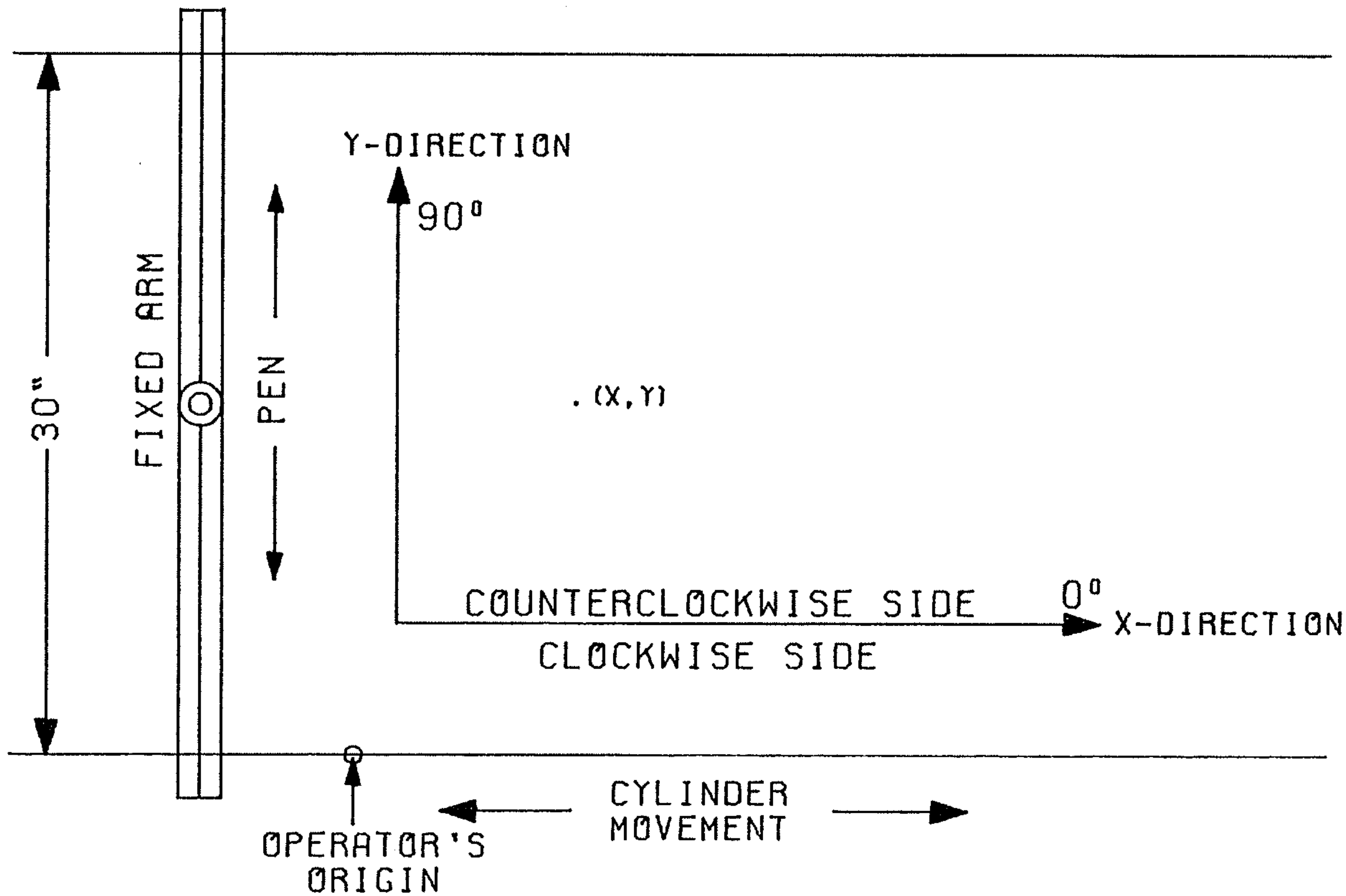


FIGURE 3. PLOTTING CONVENTIONS OF CALCOMP 663 PLOTTER.

McGill Computing Centre has no controller to operate the on-line system. Figure 4 illustrates the steps in off-line and on-line drafting systems.

3.2 Software for computer drafting

Among the computer languages, FORTRAN, COBOL, RPG, PL/1, BASIC and ASSEMBLER, Fortran is the most popular language for science and engineering work (Vaskevitch, 1979). Fortran is widely used as a graphic language. Most of the graphic subroutines or packages like Calcomp, Automat and Tektronix Plot 10 are written in Fortran. In this study, all programs and subprograms are written in Fortran language which can easily call the existing Calcomp subroutines and be called by other programs.

The following few sections discuss the software packages developed and used in the current study.

3.3 Topographic map preparation

An accurate topographic map is essential for good drainage planning. Ground surveys using stadia techniques are currently the most common method of collecting the required topographic information for drainage system design. Aerial photographs can be useful in providing auxilliary information on vegetation, pondings, wetland locations, etc.; but expensive, detailed supplementary ground surveys to establish the elevations of the control points are necessary if topographic maps are to be produced photogrammatrically. Because of

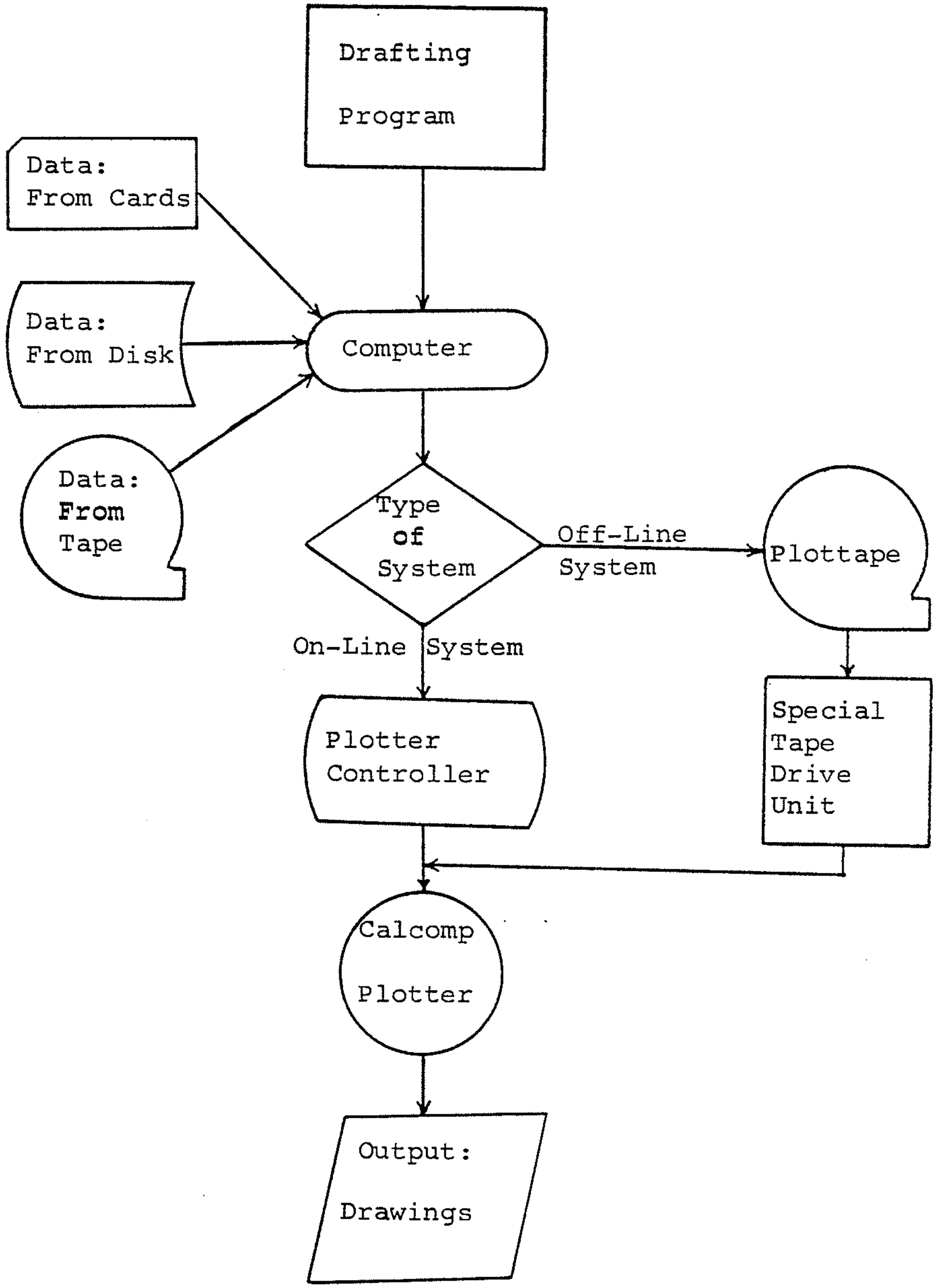


Figure 4. Steps in Off-Line and On-Line Plotting Systems.

the requirements for vertical-axis accuracy in maps for drainage planning, low altitude photography is necessary, requiring several photographs to cover the average farm. Also, air photos should be taken at a time when vegetation and snow cover do not interfere with the observation of ground points. Experience has shown that the stadia survey is a sound choice (Harrington, 1976), although its efficiency can be substantially improved by the introduction of some modern measuring equipment and data processing techniques.

The programs developed by Murphy (1978) for topographic map plotting from stadia surveyed data were used in the study with some modifications. The programs are written in Fortran language and consist of the following components:

1. Input section.--There are four short programs in this section. The main task of this section is to transfer the data from card deck or recording tape to magnetic disk on the system. It also corrects or deletes the bad or unwanted data if necessary. After the processes of this section, the raw data are stored in the system as INPUTFILE.

2. Processing section.--This section consists of ten programs. It calculates the horizontal and vertical distances for the stadia survey. If the survey involves more than one instrument station, the readings from the different stations will be converted into single-station readings by using trigonometry and the observations from the 3-sighting method of moving from station to station. All the numeric,

alphanumeric and alphabetic codings in the INPUTFILE are converted into mapping information and stored as a new file called MAINFILE.

3. Plotting section.--The MAINFILE that was created in the previous section is processed in this section. A new file known as DRAWING-FILE is created at the end of this section. The plotting section has a listing program that displays the contents of the DRAWING-FILE, an update program that is used for editing purposes, and a plotting program that produces the complete spot elevation topographic map.

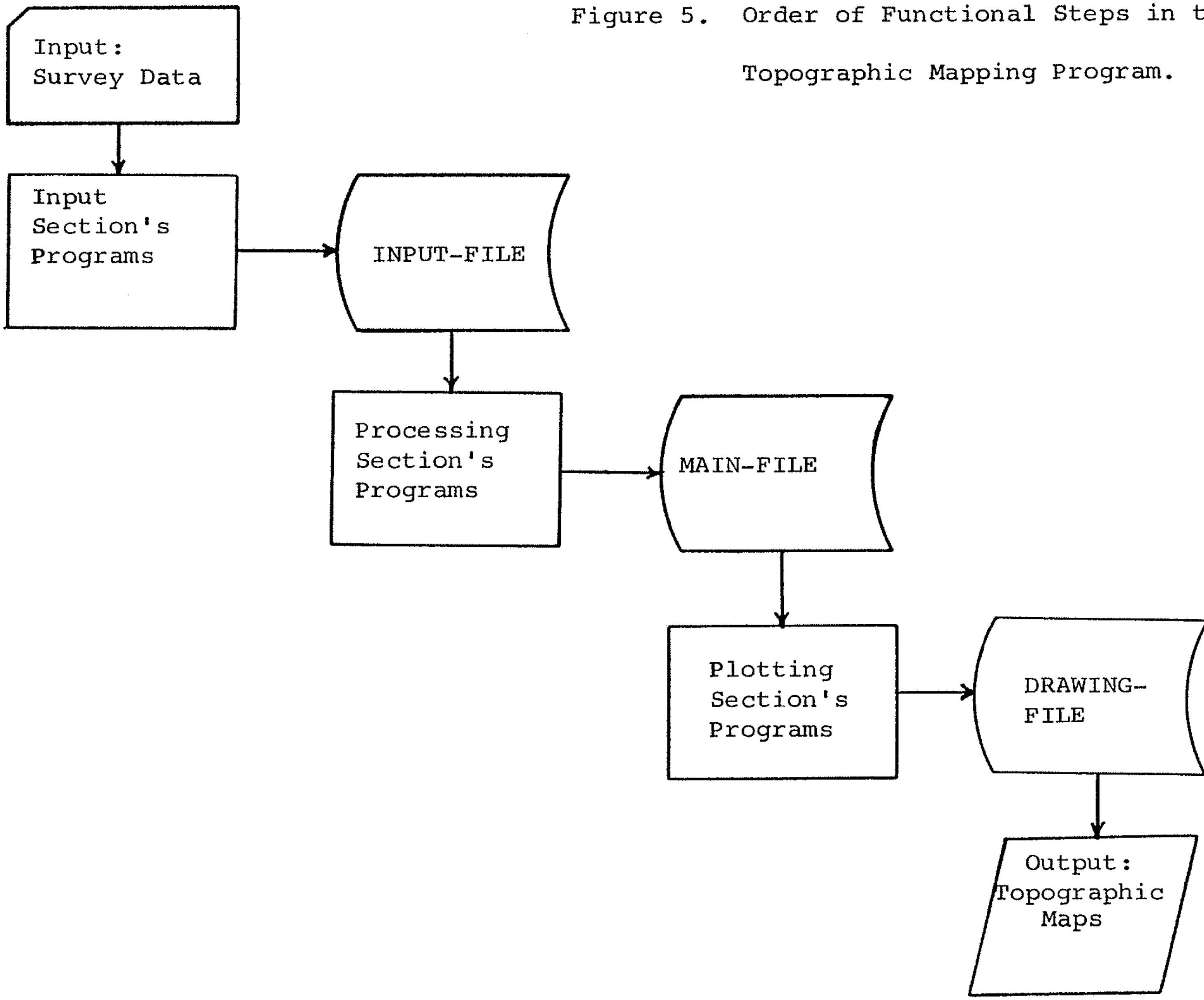
Figure 5 illustrates the step-by-step process of the topographic mapping program. The detailed descriptions are documented by Murphy (1978).

3.4 Contour map drawing

In the conventional way of subsurface drainage plan preparation, the production of a contour plan from a spot elevation map is an essential step.

Kok and Bégin (1979) point out that contour drawing in agricultural industries is usually done by draftspersons. It is a routine activity which is time-consuming, boring and expensive. After reviewing a number of computerized contouring methods and several existing contouring programs, they selected a method which is suitable for farm lands and wrote their own contouring program.

Figure 5. Order of Functional Steps in the Topographic Mapping Program.



The program was tested by comparing the program-generated contour maps to those drawn by the skilled draftspersons using the same field-surveyed data. Good agreements were found (Kok et al, 1979). They also found that it is cheaper to produce contour maps by using computer drafting than manual drawing. The descriptions of the contouring program were detailed by Kok et al (1979). The program was used in the study to produce the contour lines for subsurface drainage system design purposes.

3.5 Development of system design and layout programs

Subsurface drainage systems in general use are the interceptor, natural or partial, herringbone and gridiron types shown in Figure 6.

Among these four types, the gridiron type is the most common system used for flat lands (Schwab et al., 1970; Broughton, 1972). Interceptor and partial drainage systems are used for undulating lands where the subsurface drainage needs are localized. Although the drainage design program was written on the basis of the gridiron type drainage system, it can be used to produce plans for gridiron, herringbone and the combination of these two types of drainage systems.

In the next few sub-sections, the eveluation of parameters used in the system design and the development of the design and layout programs are discussed.

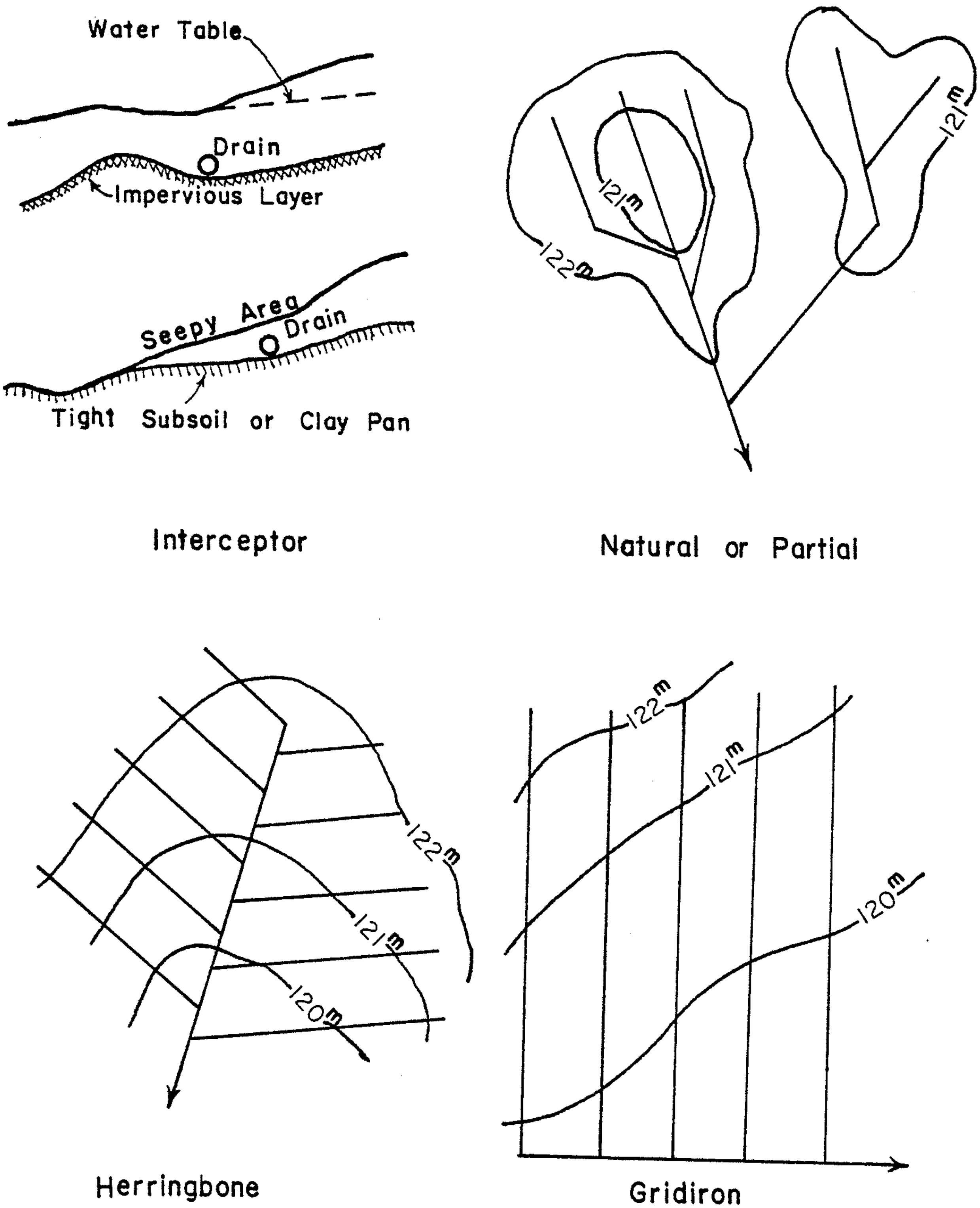


Figure 6. Different Types of Subsurface Drainage Systems.

3.5.1 Evaluation of parameters used in subsurface drainage system design

In planning a subsurface drainage system, designers must take into account many aspects of soil physical characteristics, climate, crops to be grown and topography. The specific combination of these factors for a particular farm gives the design its own final shape. Van Dort (1974) states that drainage areas which look similar at first glance, may turn out to be very different in some of their factors and their drainage systems will be different in the end. Some of the requirements for a particular field may be contradictory, and meeting all of them will be impossible. The final design will therefore be produced by weighing several possibilities, and the result will be a compromise. Risks and disadvantages can never be entirely excluded, but the aim is to ensure that the total negative influence is as small as possible. The design and drafting programs developed in this study take into account many design requirements.

Hooghoudt's equation ($S^2 = (8\ K_b d_e h + 4\ K_a h^2)/R$) is used to obtain the spacing between drain laterals in the design. The symbols of the equation are depicted in Figure 7. Noting from this figure that h = DD - DWD, the equation may be expressed as

$$S^2 = \frac{8\ K_b d_e (DD-DWD)}{R} + \frac{4\ K_a (DD-DWD)^2}{R} \quad \ldots (4)$$

where DD = depth of drain, m

DWD = minimum desirable water table depth from ground surface, m

Other symbols have been defined in equation (1).

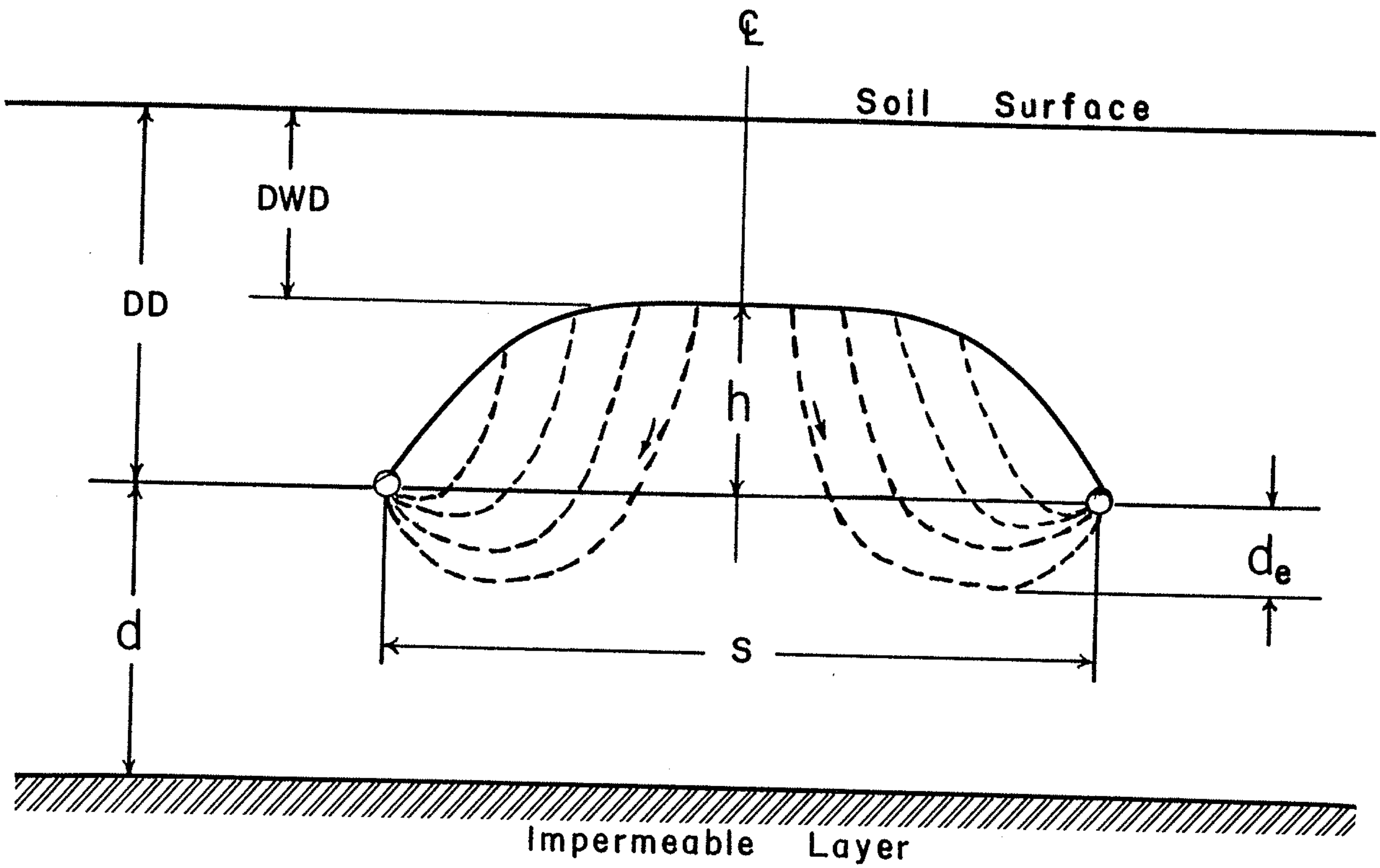


Figure 7. Definition Sketch for Flow to Drains.

In the design program developed in this study, the elements in equation (4) are determined in the following ways:

1. Drainage rate (R).--Selection of drainage rate is based on the climatic regime of the region as well as soil parameters and the water table depth requirement of the particular crop and field machinery operations. The water balance computer drainage model developed by Chieng et al. (1978) can be operated for several drainage rates with different combinations of soil parameters with the climatic data for the region of interest. Table 1 shows some of the results generated by this model using weather data for St. Hyacinthe, Quebec. Results for other sets of soil and drainage parameters could be obtained by running the model with different inputs. From these computer outputs, designers could select an adequate drainage rate to suit a particular field.

2. Drain depth (DD).--Depth of the subsurface drainage systems is generally chosen within the range that can be reached by available drainage machinery. In the Provinces of Quebec and Ontario, drain depths used are generally varied from 0.8 to 1.5 meters. The cost per meter of drains installed is relatively constant for depths less than 1.3 meters, but increases rapidly with depths greater than 1.3 meters.

From inspection of equation (4) it can be seen that wider drain spacings should be able to be used as the drain depth is increased. However, there are several constraints on selection of

TABLE 1. Design drainage rates generated for different soil parameters and drain depths using St. Hyacinthe, Quebec, weather data for the 35 years 1941 to 1975

Drain depth (m)	Drainable porosity (m^3/m^3) Upper zone	Drainable porosity (m^3/m^3) Lower zone	Successive days duration	Region A Condition I (mm/day)	Region A Condition II (mm/day)	Region B Condition I (mm/day)	Region B Condition II (mm/day)
	0.07	0.05	4	10.5	12.0	6.0	9.0
1.0	0.07	0.05	3	12.0	15.5	7.0	10.5
	0.07	0.05	2	14.5	19.0	9.0	12.0
	0.07	0.05	4	10.5	12.0	5.1	6.0
1.4	0.07	0.05	3	12.0	14.0	6.0	7.3
	0.07	0.05	2	13.4	16.4	7.3	9.0
	0.07	0.05	4	9.0	12.0	3.5	5.0
1.8	0.07	0.05	3	10.5	13.8	4.0	6.0
	0.07	0.05	2	12.0	16.0	5.0	7.5

Note: Region A = for those areas whose cultivation season must begin in April.

Region B = for those areas whose cultivation season begins in May (or after April).

Condition I = when the allowable water table is 30 cm or less for not more than the indicated number of successive days duration for a once-in-5-year return period.

Condition II = when the allowable water table is 50 cm or less for not more than the indicated number of successive days duration for a once-in-5-year return period.

drain depth. For irrigated soils where soil salinity problems could occur, the drains should normally be 1.8 meters deep or deeper. For humid regions where salinity is not a problem, drain depth may be restricted by the depth of the outlet watercourse, or by the requirement to maintain a drain slope of at least 1 mm/m, even if the land is flatter than this. In some sandy soils it is desirable to keep the drains between 0.55 and 0.8 meters if possible.

3. Desirable water table depth (DWD).--It can be seen from equation (4) that including the term DWD will lead to a conservative system design in a sense that, for a given R, drain spacing will be reduced if DWD > 0. The value of DWD depends on the type of crop grown and its root zone depth. It appears that 300 to 500 mm is a widely used range for DWD (Bhattacharya, 1978; Chieng, 1975; Luthin, 1973). The value of 400 mm was selected and used in the design program. For soils where DD must be kept smaller than 0.8 m, economics may cause the designers to accept DWD values as low as 200 mm.

4. Equivalent depth (d_e).--d_e is the depth of effective flow below the drain. It is a function of the drain spacing (S), drain tube radius (r) and the depth to impermeable layer below the drain centre (d). Van Schilfgaarde (1963) has suggested the use of equivalent depth to replace the actual depth to the impermeable barrier as a means of accounting for the physical convergence of flow lines near the drains. Van Beers (1965) prepared a nomograph to

obtain de from known values of S and d for a specific drain radius of 100 mm.

In Quebec and Ontario, the most commonly used drain outside diameters are 100 mm, 120 mm, 175 mm, 240 mm, 300 mm, and 360 mm. In the mid-western United States much tubing of 150 mm outside diameter is used. In this study, different graphs for obtaining the values of d_e from d and S are presented for these drain diameters (see Figures 8 to 14, inclusive). The values of d_e for different drain tubes radius were generated by using the Hooghoudt's equivalent depth equations reported by Moody (1966). The equations may be expressed as

$$d_e = [1 + \frac{d}{S}(\frac{8}{\pi} \ln \frac{d}{r} - \alpha)]^{-1} \cdot d \qquad \text{when } 0 < \frac{d}{S} < 0.3 \qquad \ldots (5)$$

where $$\alpha = 3.55 - 1.6 \cdot \frac{d}{S} + 2(\frac{d}{S})^2 \qquad \ldots (6)$$

and $$d_e = [\frac{8}{\pi}(\ln(\frac{S}{r}) - 1.15)]^{-1} \cdot S \qquad \text{when } \frac{d}{S} > 0.3 \qquad \ldots (7)$$

where d_e = equivalent depth, m

S = spacing between lateral drains, m

d = depth of impermeable layer below drain centre, m

r = radius of the drain tube, m

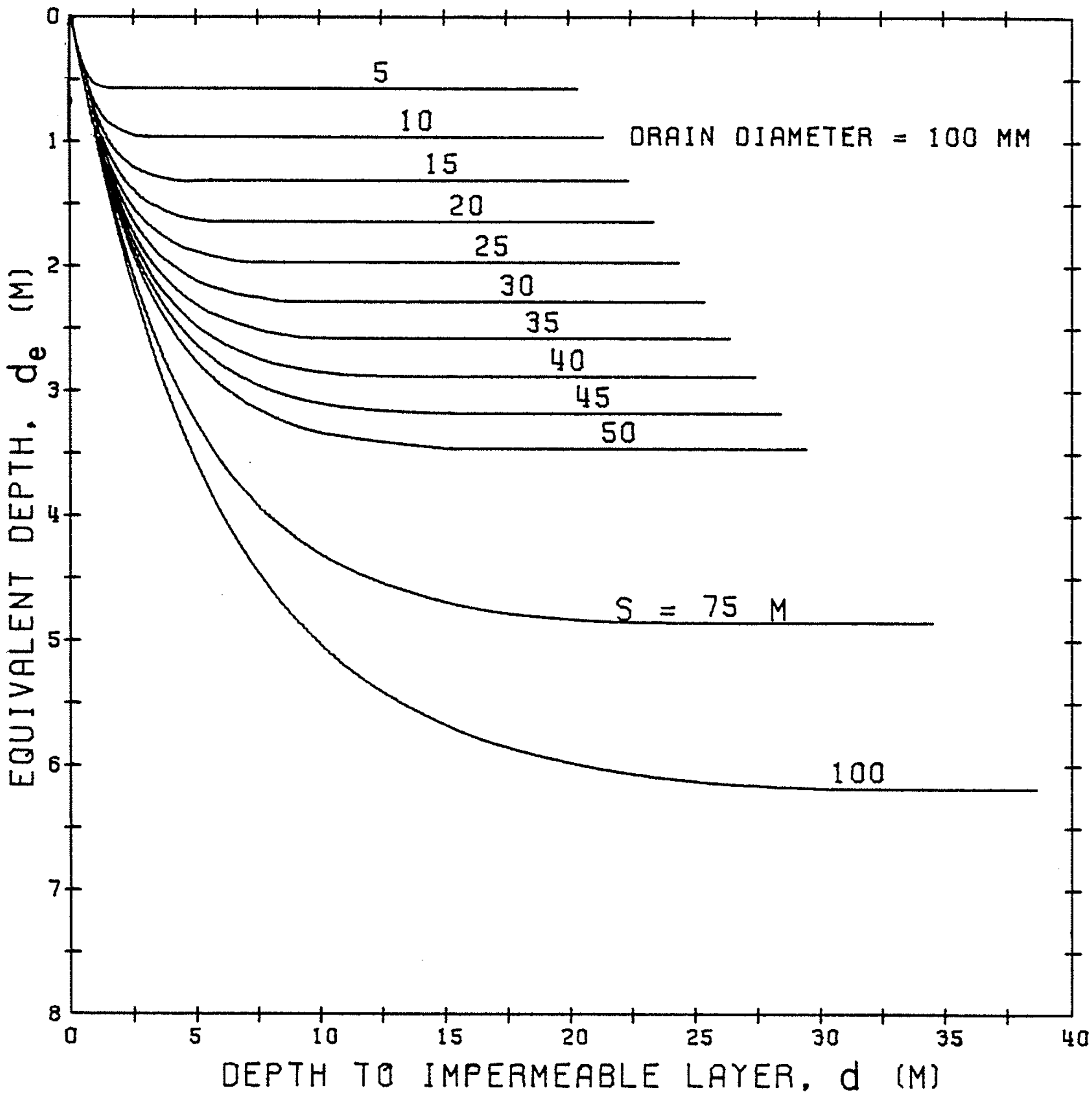


FIGURE 8. RELATIONSHIP BETWEEN d AND d_e WHERE S IS THE SPACING BETWEEN DRAINS.

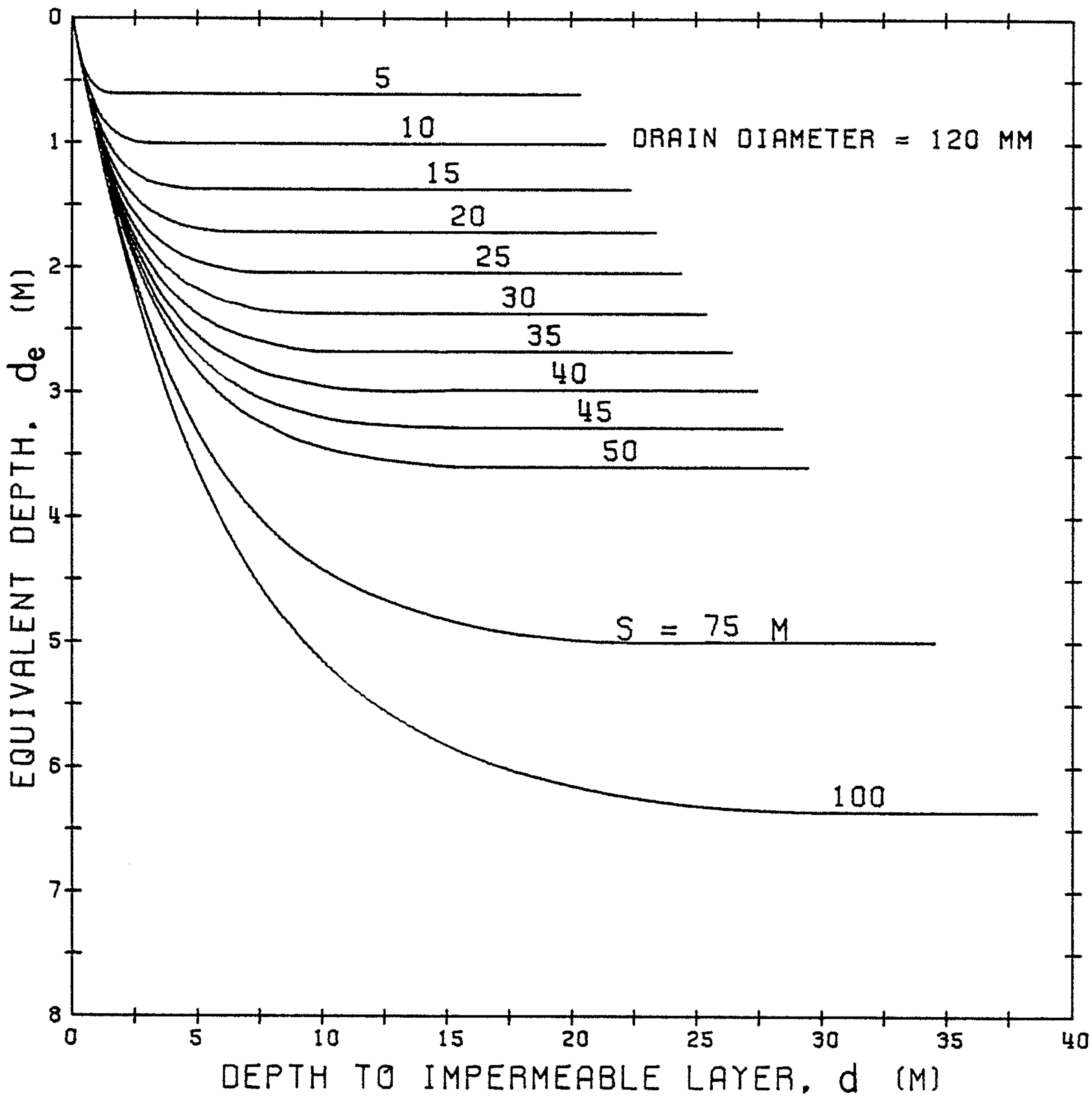


FIGURE 9. RELATIONSHIP BETWEEN d AND d_e WHERE S IS THE SPACING BETWEEN DRAINS.

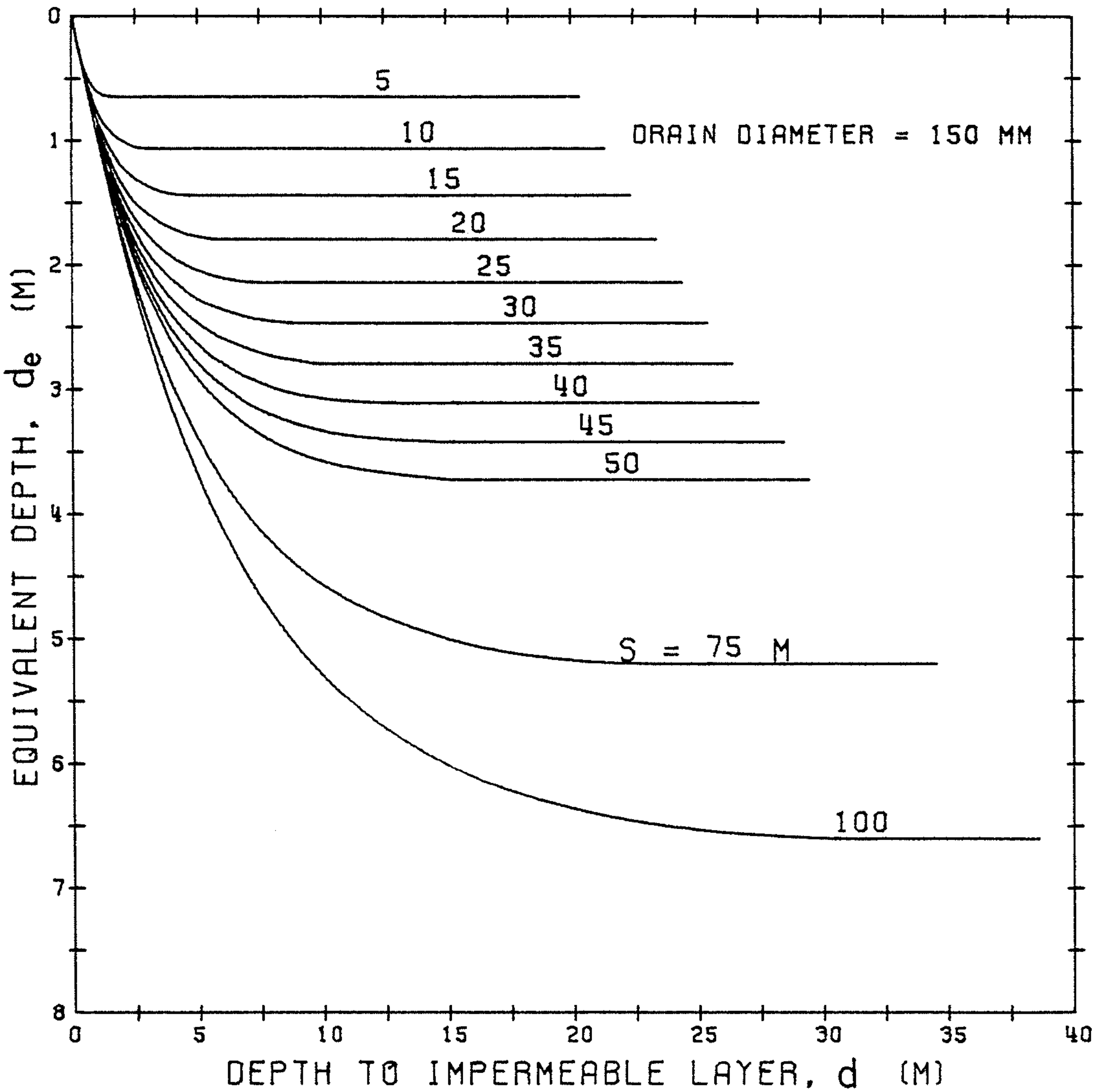


FIGURE 10. RELATIONSHIP BETWEEN d AND d_e WHERE S IS THE SPACING BETWEEN DRAINS.

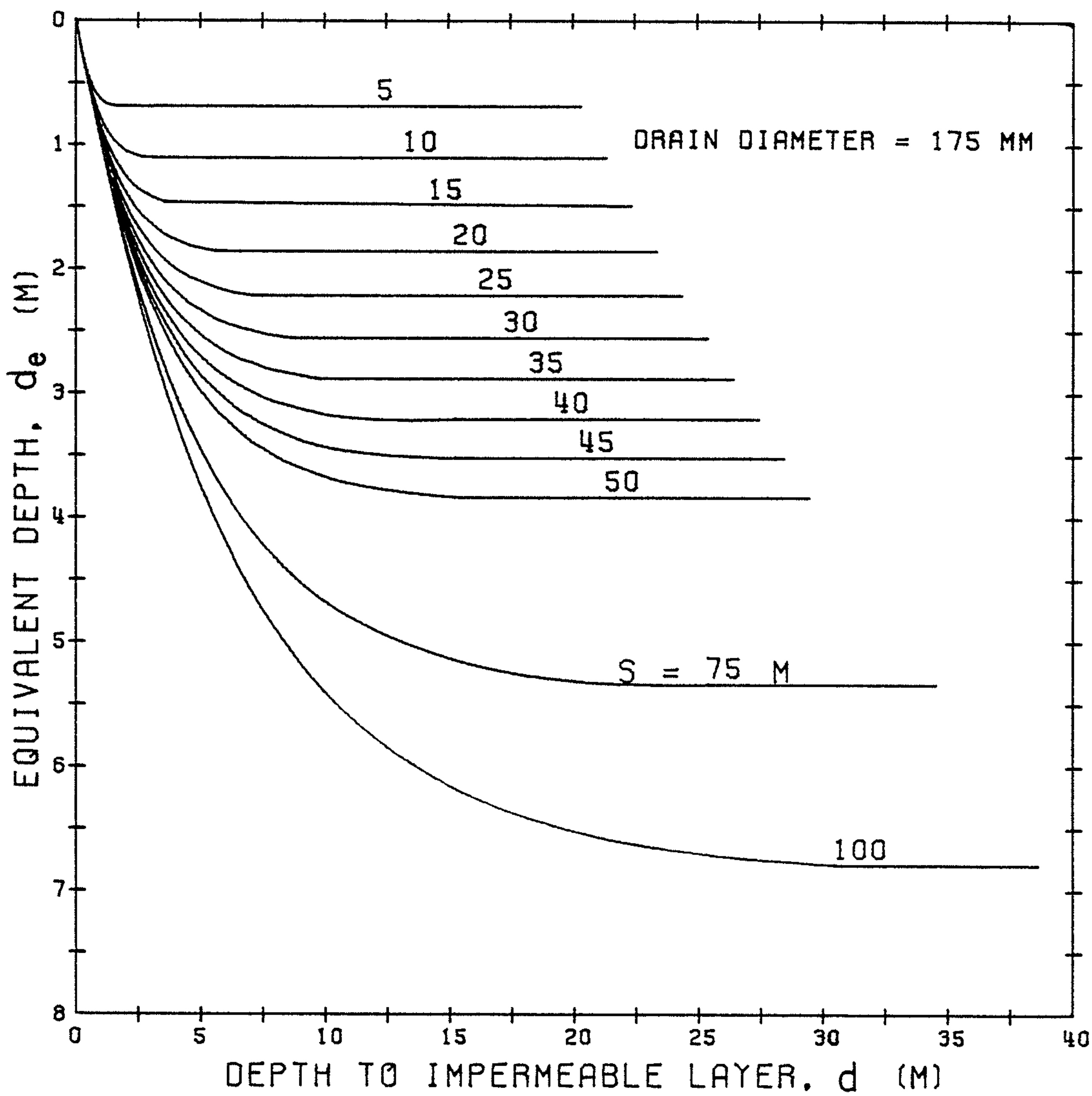


FIGURE 11. RELATIONSHIP BETWEEN d AND d_e WHERE S IS THE SPACING BETWEEN DRAINS.

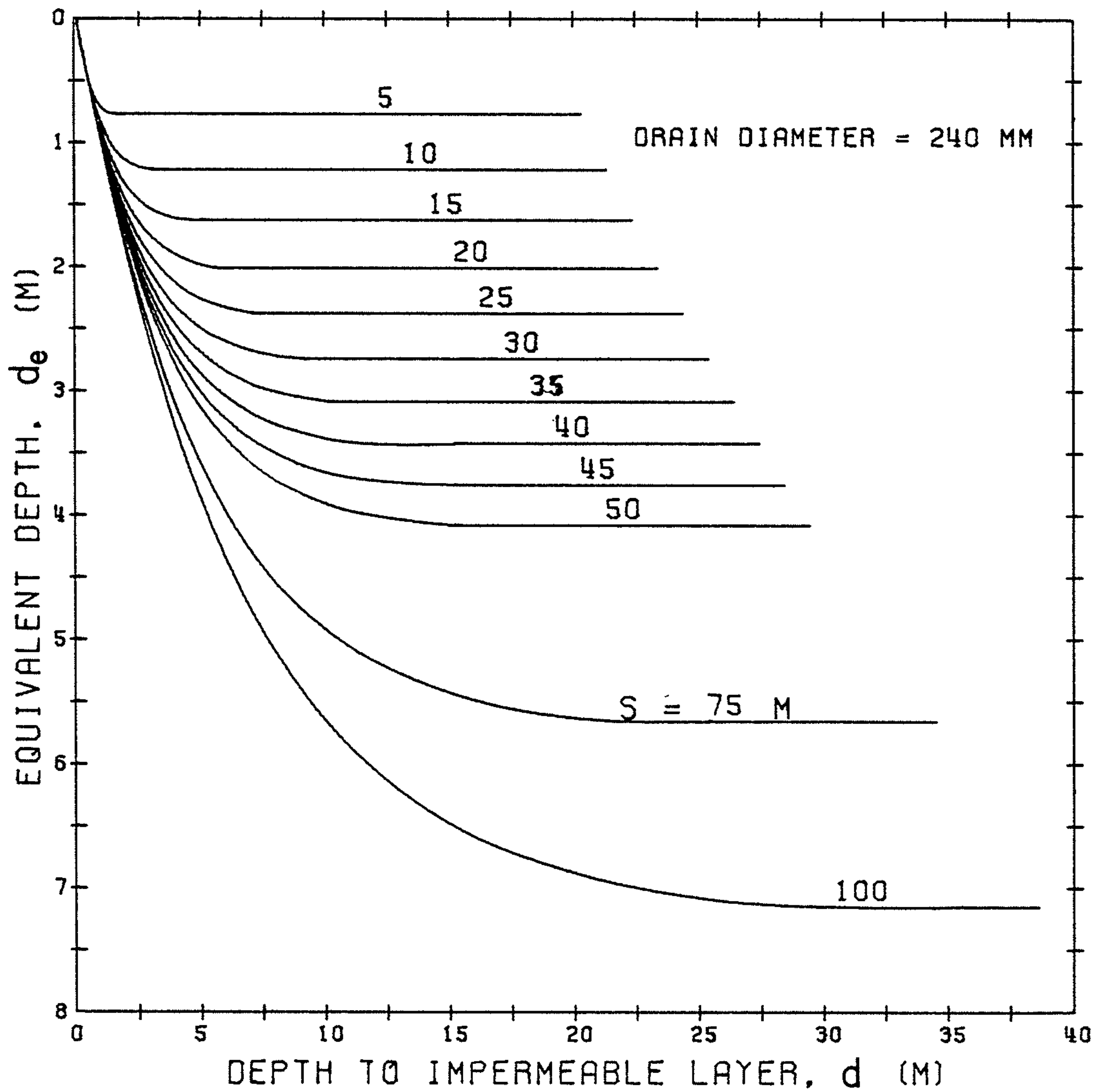


FIGURE 12. RELATIONSHIP BETWEEN d AND d_e WHERE S IS THE SPACING BETWEEN DRAINS.

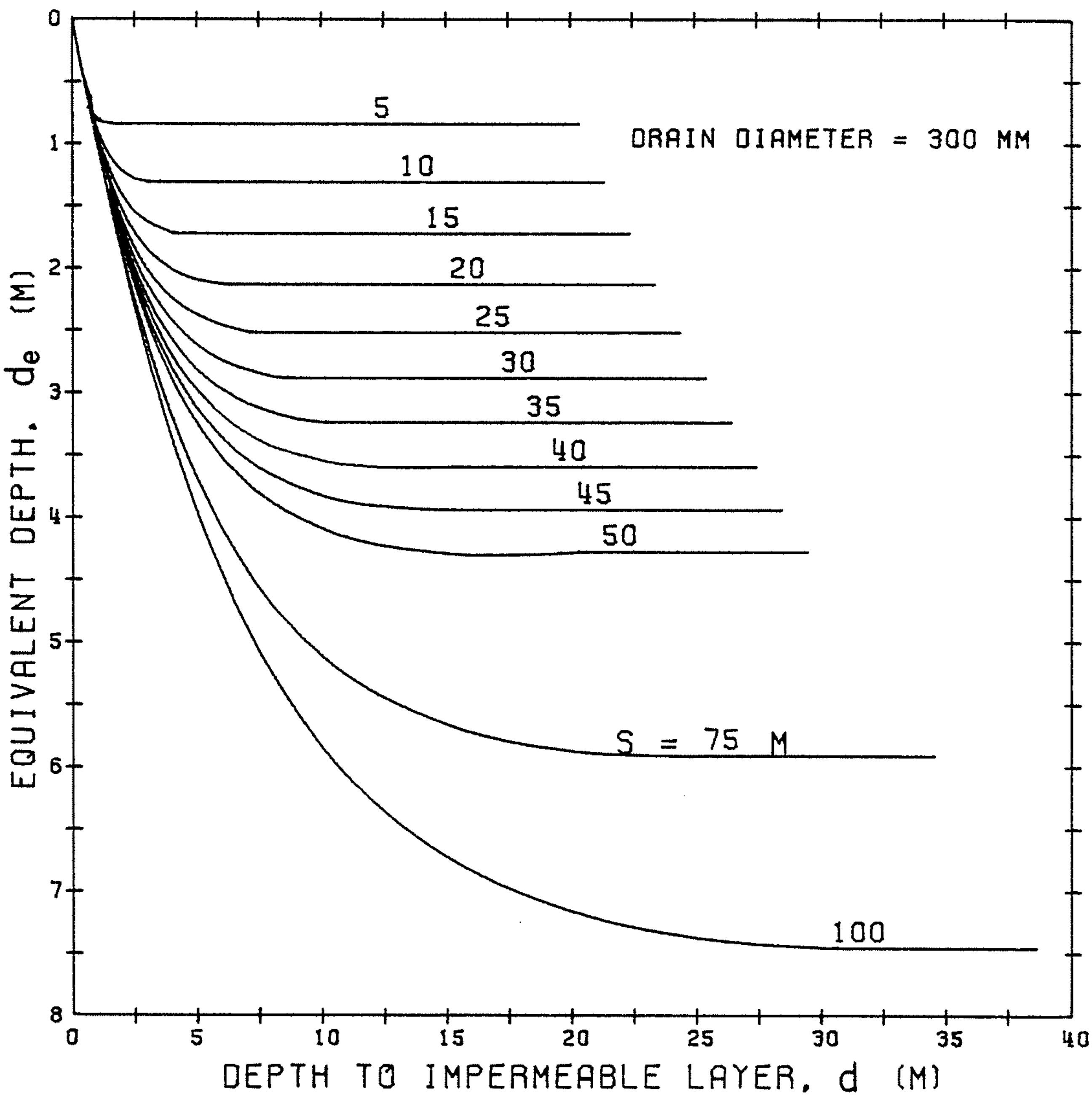


FIGURE 13. RELATIONSHIP BETWEEN d AND d_e WHERE S IS THE SPACING BETWEEN DRAINS.

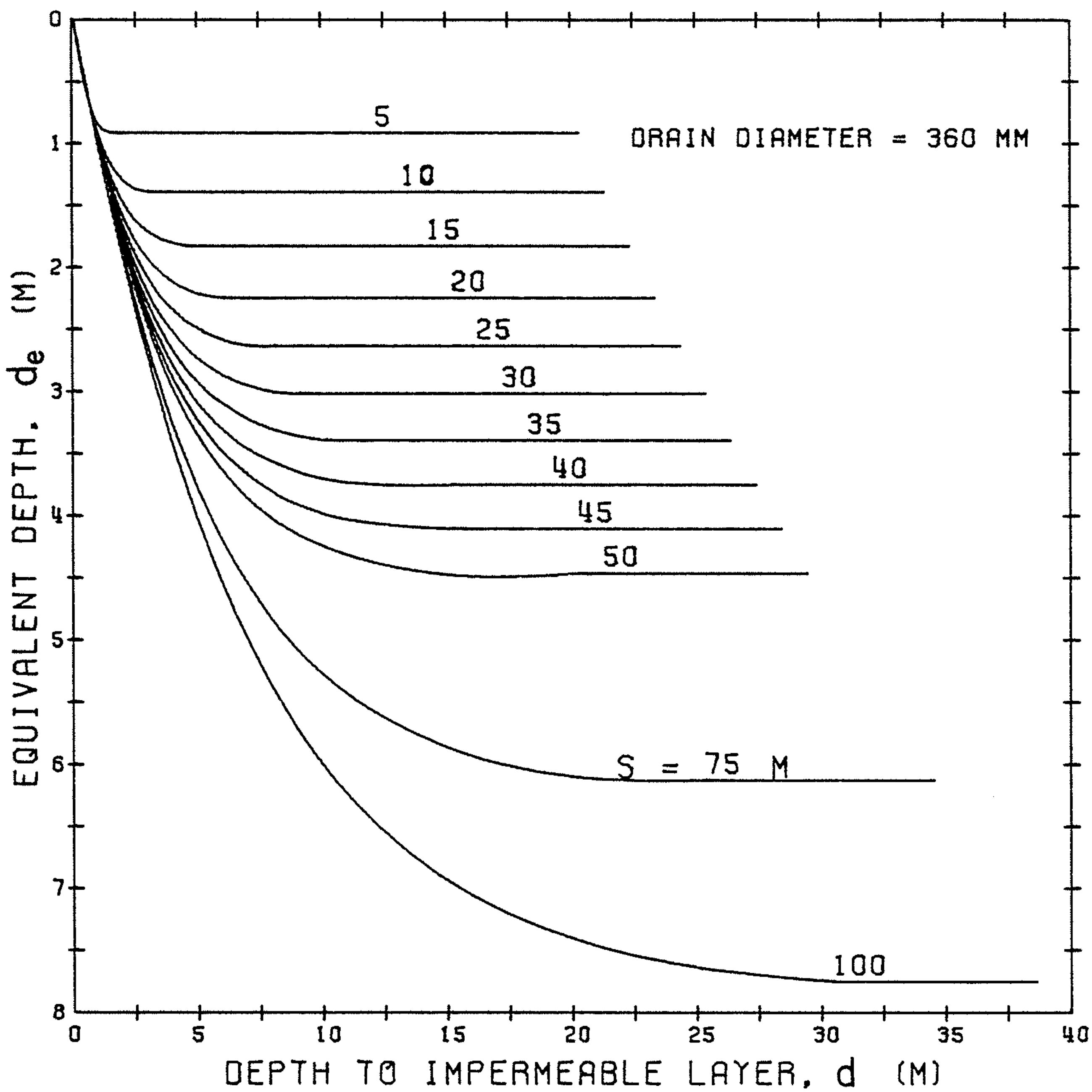


FIGURE 14. RELATIONSHIP BETWEEN d AND d_e WHERE S IS THE SPACING BETWEEN DRAINS.

For many farms in the St. Lawrence Lowlands, it appears that de of 1 m is an acceptable value (Broughton, 1972; Chieng, 1975). For the sake of simplification, d_e of 1 m was used in the design program. However, different values can be assigned to design for drainage areas where soil information indicates other values to be appropriate.

5. Hydraulic conductivity (K_a, K_b).--K_a and K_b are the hydraulic conductivities of the soil above and below the drain, respectively. If $K_a = K_b$, then the soil is said to be homogeneous with respect to hydraulic conductivity. There are at least 10 different methods which could be employed to determine the hydraulic conductivity (Broughton, 1972). Among these, the single auger hole method has been widely used in the field measurements. A detailed description of the procedures of the auger hold method is given by Van Beers (1970).

Auger hole tests should be made when the water table is 200 to 500 mm below the soil surface. In the region of the Ottawa and St. Lawrence lowlands, water table conditions are suitable for auger hole tests primarily in the months of April, May and November. Occasionally, conditions are suitable after rainy days in the months of June, July, August, September and October.

When drainage planning could be done one year and construction in a later year, it is then possible to schedule auger hole test at times when the water table conditions are suitable. Currently, farmers and contractors are more frequently wanting to have drainage plans prepared in summer for construction within a few weeks. In such cases, water table conditions are often not suitable for auger hole tests. Applied research efforts are needed to develop methods other than auger hole tests to obtain reasonable values of hydraulic conductivity for drainage design work. Possible methods which should be investigated for field production use are: the air-entry permeameter test; soil cores for laboratory measurement of hydraulic conductivity; and correlation of qualitative field observations of soil texture and structure with hydraulic conductivity.

In this study, a separate program (HYCONS) was prepared to compute the hydraulic conductivity directly from the data measured in the field by using single auger hole method. The equation for the auger hole method can be written as

$$K = \frac{4000\ r^2}{(DH + 20\ r)(2 - \frac{Y}{DH})\cdot Y}\cdot\frac{\Delta Y}{\Delta t} \qquad \ldots (8)$$

where K = hydraulic conductivity, m/day

DH = depth of hole below the ground water table, m

Y = distance between ground water level and the average level of the water in the hole for the time interval Δt, cm

ΔY = change in ground water level in time interval Δt, cm

Δt = time interval, sec.

r = radius of the hole, cm

Van Beers (1970) indicates that equation (8) represents an empirically derived approximate expression of the results of a number of relaxation constructions. It does not show the exact relationship that should theoretically exist between the different quantities, although value of K will be sufficiently accurate if the following conditions are met:

$$3 \text{ cm} < r < 7 \text{ cm}$$

$$20 \text{ cm} < DH < 200 \text{ cm}$$

$$Y > 0.2\ DH$$

$$d > DH$$

and $$\Delta Y < 1/4\ Y_o$$

where d = depth of the impermeable layer below the bottom of the hole or the layer, which has a permeability of about 1/10 or less of the permeability of the layers above, cm.

The symbols of the equation are depicted in Figure 15.

Based on equation (8), the program HYCONS (Hydraulic Conductivity and Drain Spacing) was written to compute the hydraulic conductivity and the drain spacing from the field measured data. A flow chart, representing the basic operations in the HYCONS, is shown in Figure 16. The program is listed in Appendix A.

The program HYCONS can be used to process the measurements from one up to two fields with as many auger holes as one wishes for each field. However, if the computation is done for two different fields, the design parameters, i.e., design drainage rate, total drain depth,

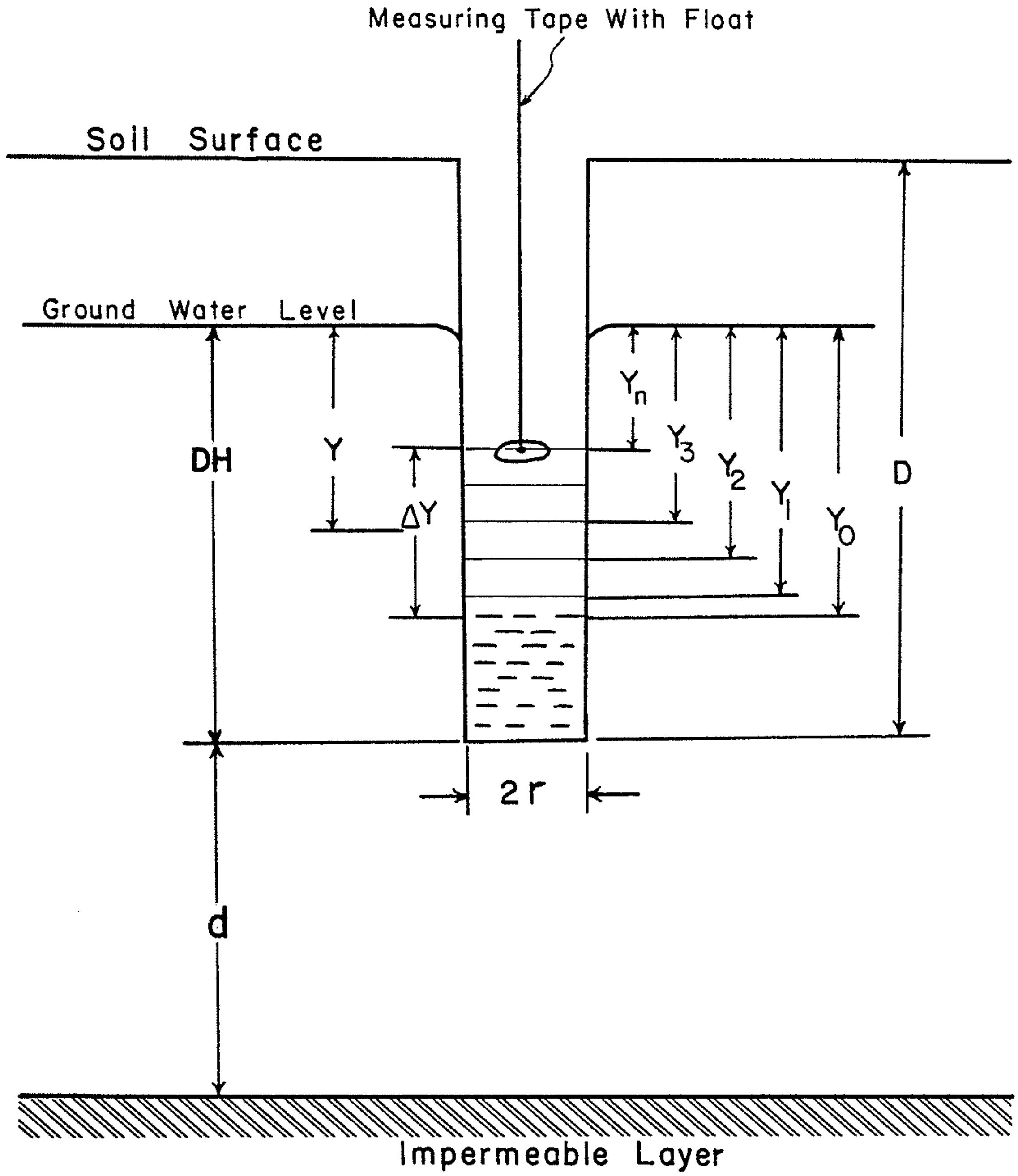


Figure 15. Definition Sketch for Auger Hole Method

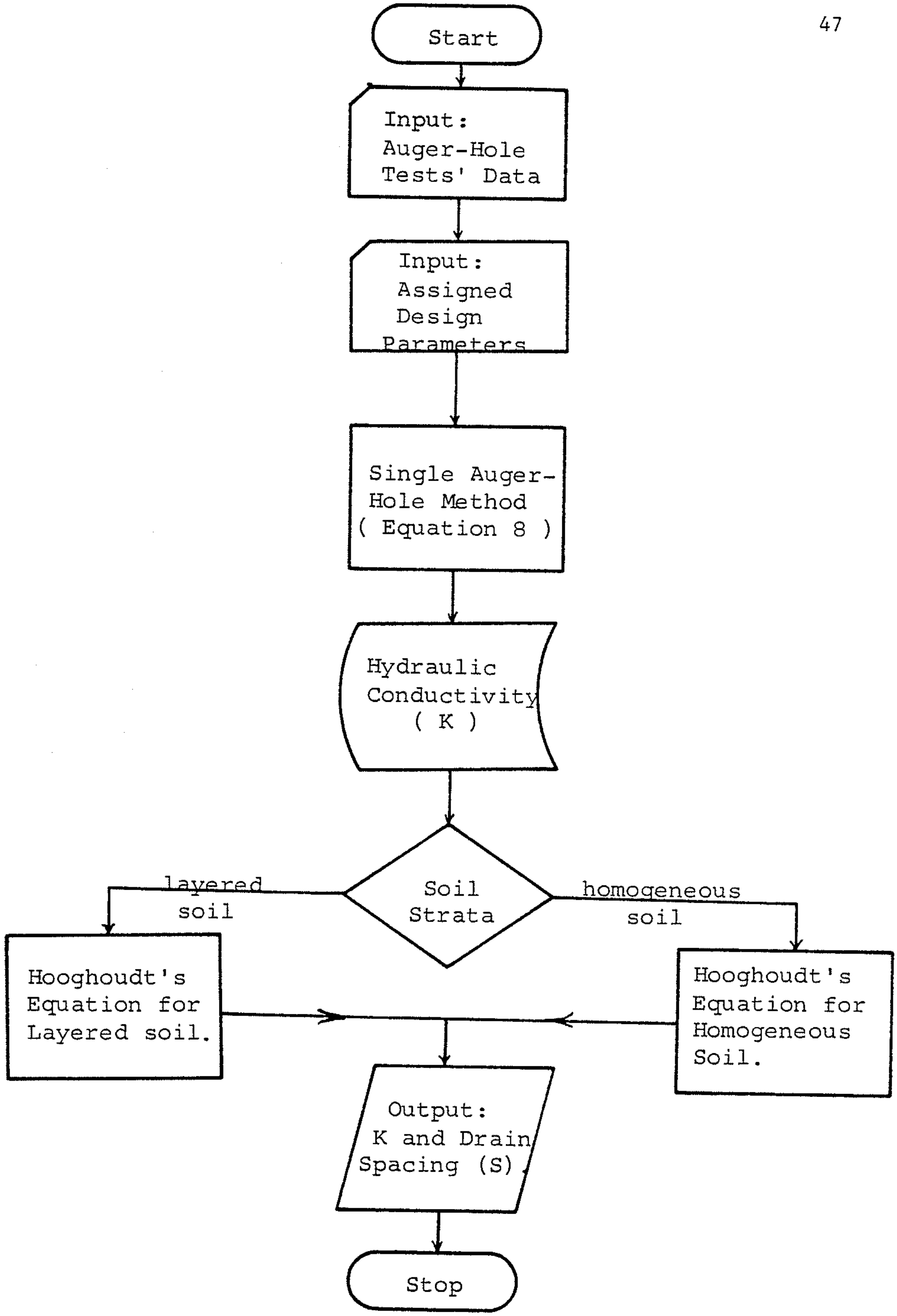


Figure 16. Generalized Flow Chart for Program HYCONS.

and the desirable water table depth from the soil surface, for each field should be declared. Otherwise, design parameters of the first field will be used for the second field.

3.5.2 Development of design program

The Drainage System Design Program (DSDP) contains a main program and several subprograms which perform different functions under different conditions when called by the main program. All programs are written in standard Fortran language and were compiled by Fortran IV G1 compiler. A flow chart of DSDP is shown in Figure 17 and a complete listing of DSDP is given in Appendix B.

Initially, the area or field that needs drainage must be clearly defined. It will be called "design-area" from here on to distinguish it from other areas. The design-area will be the total area under consideration for which a system of parallel drainlines connected by one collector will be designed. A field may have more than one design-area or collector. The program can handle as many as 10 design-areas in a single run. It can be easily modified to handle more than 10 design-areas if necessary.

The design-area can have any number of sides, but they must be straight. The boundaries of the design-area are then defined by corner points.

The locations of the outlets for the system should also be defined. In the primary stage of this study, effort was made to

Figure 17. Generalized Flow Chart for Drainage System Design Program.

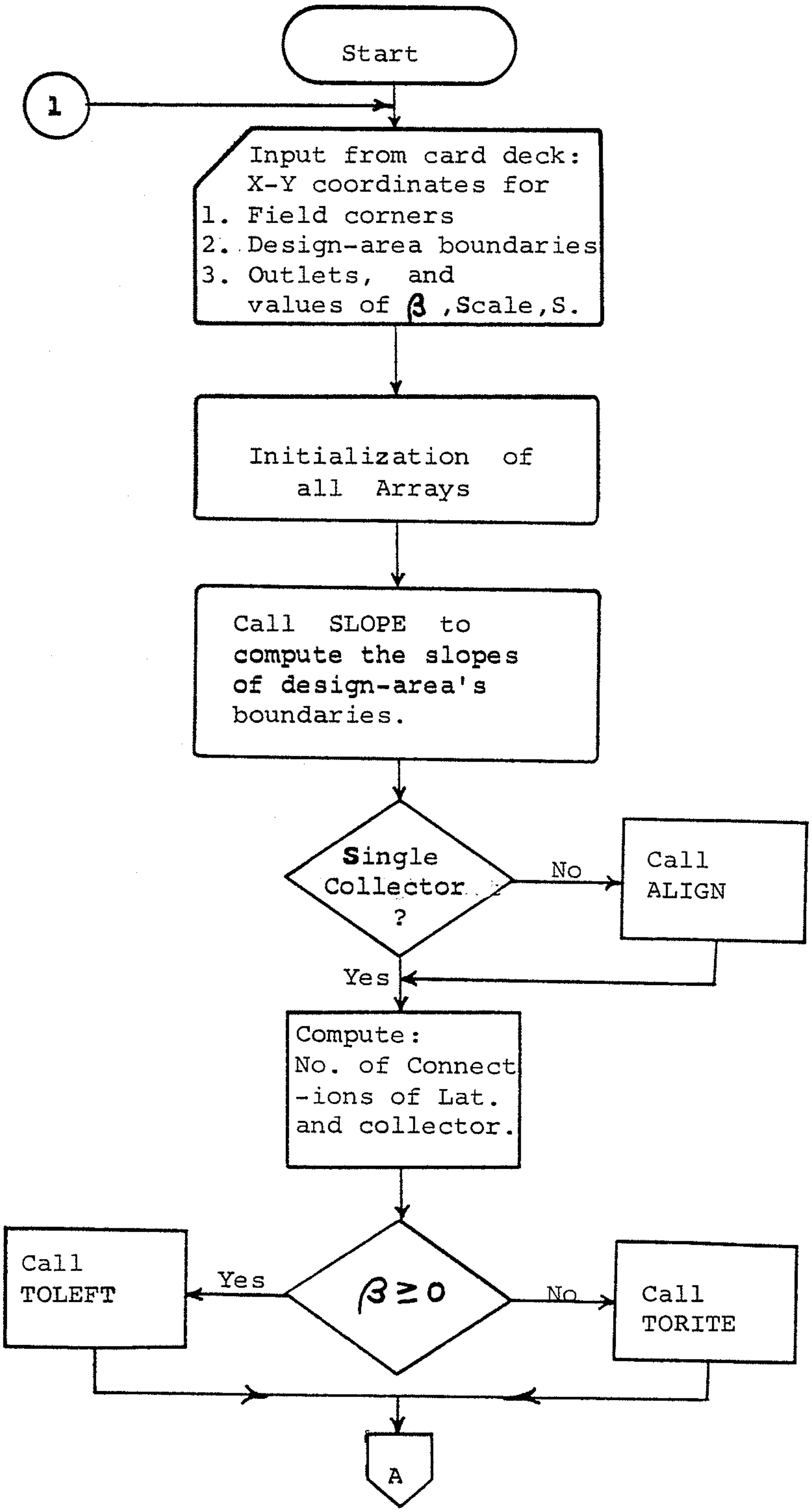
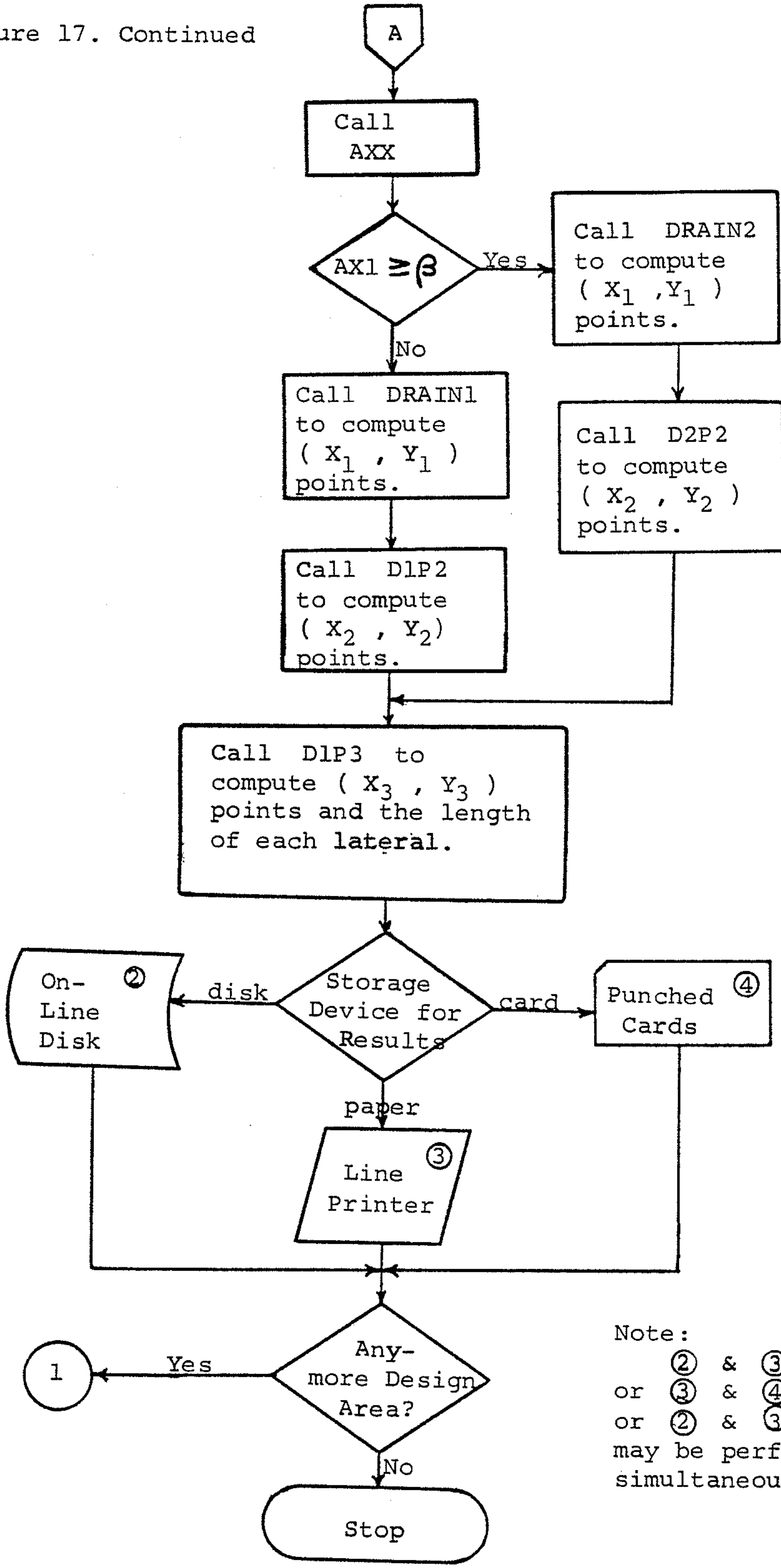


Figure 17. Continued



Note:
② & ③
or ③ & ④
or ② & ③ & ④
may be performed simultaneously.

locate the general slope and the outlet by using a gradient searching program. Due to the large amount of spot elevation points obtained from the field survey, large computer memory and time were needed to store and sort the data in order to get the general slope. It was found that the method was not time efficient and cost effective. On the other hand, after the topographic and contour map has been prepared, the designer may need only a few minutes to select outlet points and possible appropriate paths of collectors. Also, suitable outlet locations are usually selected by the field crew when doing the topographic survey. Therefore, after making several trials of the gradient search by computer, it was decided not to use the searching program but to require the designer to select the locations of outlet and collector during the design processes.

In order to define the relative field boundaries and outlet positions, a grid will be placed over the topographic and contour map. The locations of the field corners can then be expressed by the appropriate coordinates of the grid. The origin of the X-Y coordinate is at the lower left corner of the grid (see Figure 18). It should be mentioned that the placing of the grid over the drainage plan is optional, the designer can specify the option when running the program.

Although the design-area can be in any shape as long as all the field boundaries are straight lines, for the sake of description, a four-sided polygon as shown in Figure 19 is used for illustration purposes.

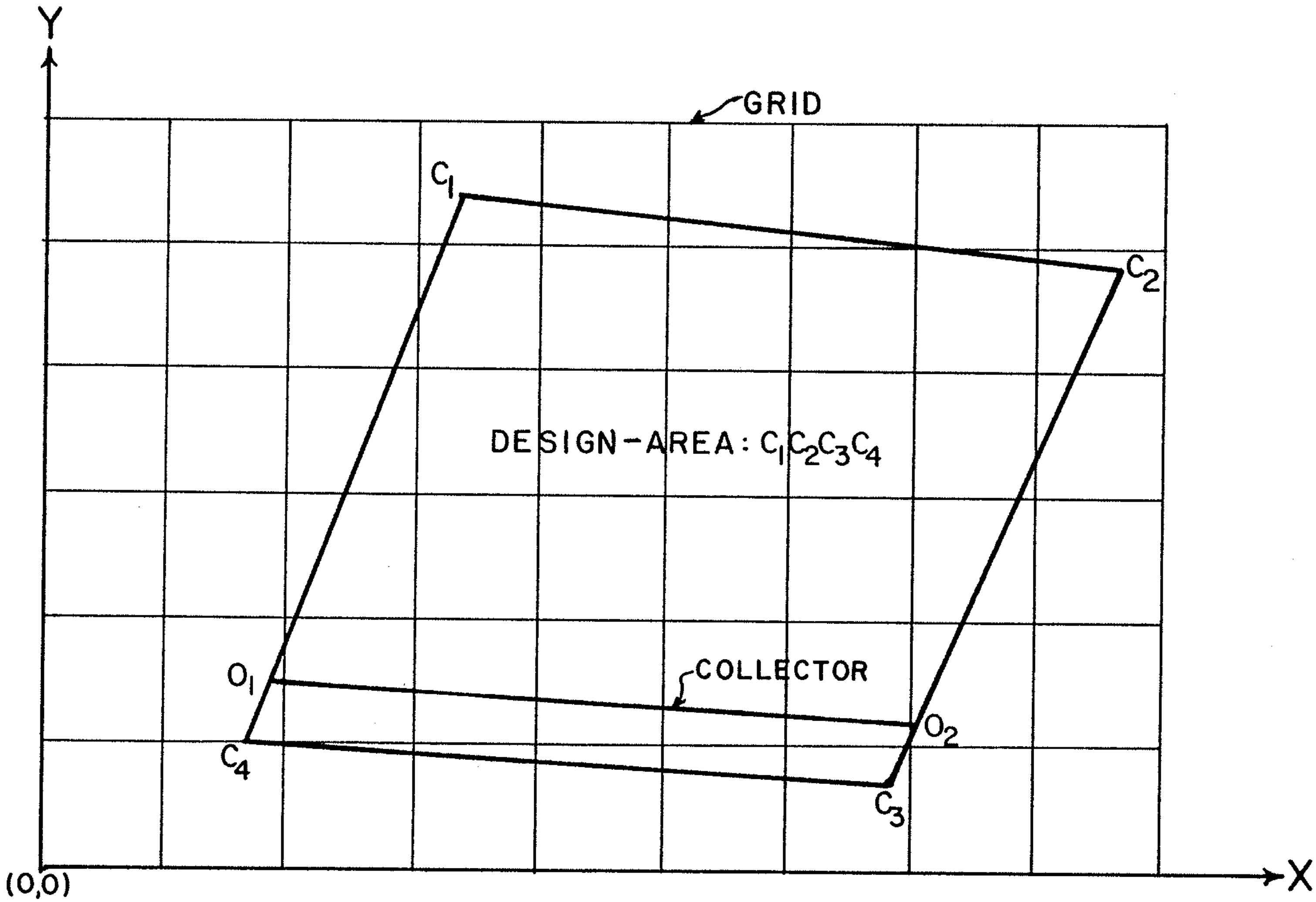


Figure 18. Design-area Boundaries and Corners with the Grid System.

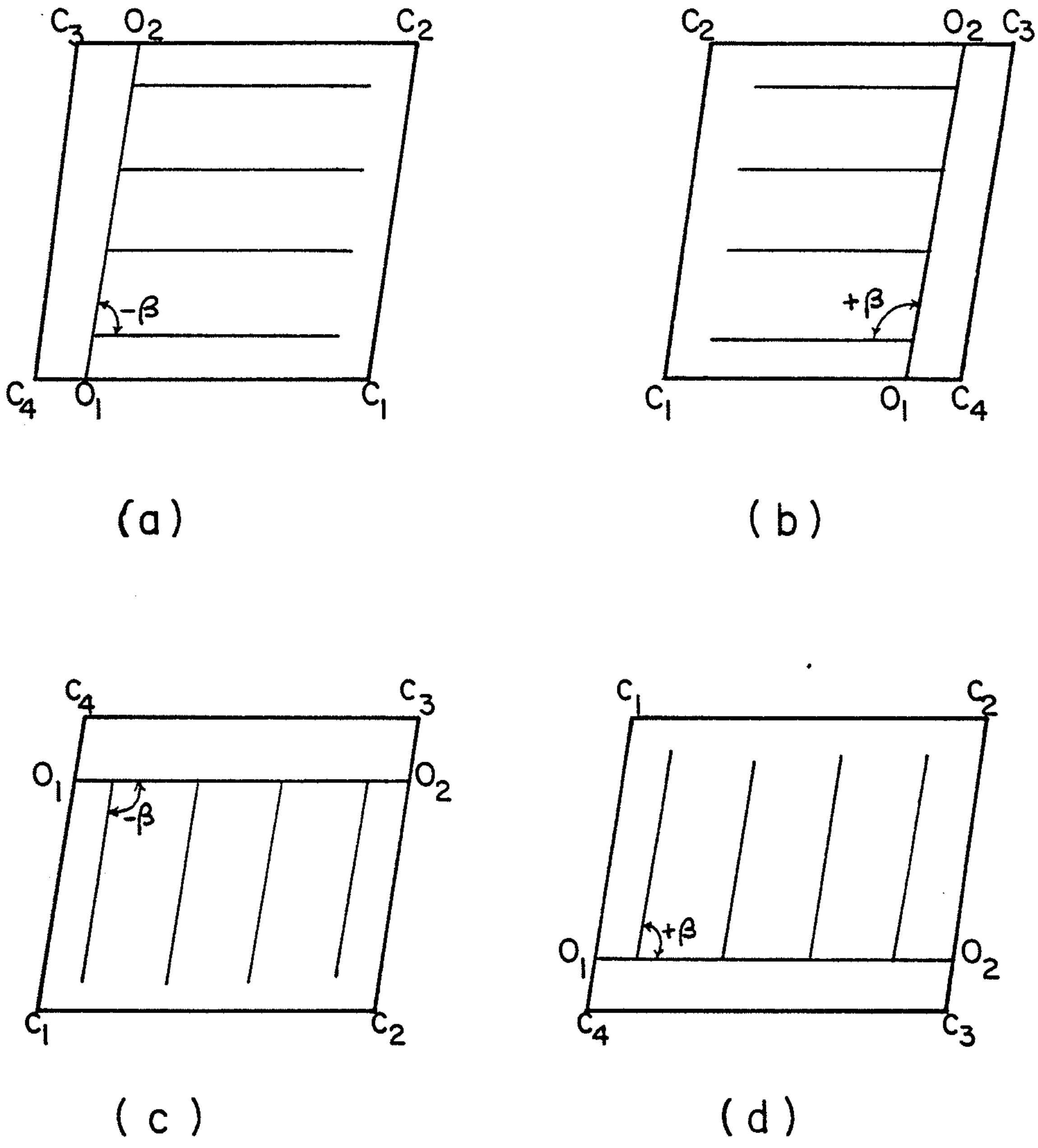


Figure 19. Number Convention of the Corners of Design-area.

Referring to Figure 19, O_1 and O_2 are the start and end points of the collector. Beta (β) is the angle between the lateral and collector. Noting from the same figure that laterals are on the left hand side of the collector when β is greater than zero and on the right when β is smaller than zero. If $\beta = 0$, the program will issue a warning and stop execution since laterals will run on the same path as the collector does.

The program was constructed in such a way that corners of the design-area are numbered clockwise or counter-clockwise depending on the algebraic sign attached to the angle beta. When β has a negative sign, corners are numbered counter-clockwise, otherwise corners will be numbered clockwise. However, corner 1 is adjacent to point O_1 all the time (see Figure 19 (a), (b), (c) and (d)).

It should be noted that O_1 may or may not be the outlet of the drainage system. If the outlet is located beyond the design-area, it can be linked to O_1 by a conduit or open ditch as shown in Figure 20 (a) and (b).

It should also be mentioned that the collector may or may not be a single straight line. It may consist of two or more straight line segments with different directions or slopes as shown in case (c) of Figure 20. The program developed in this study can be used to design a drainage system with a collector consisting of a single straight line or a collector with two straight line segments. However, the program can be easily adjusted to handle the case where a collector consists of more than two straight line segments.

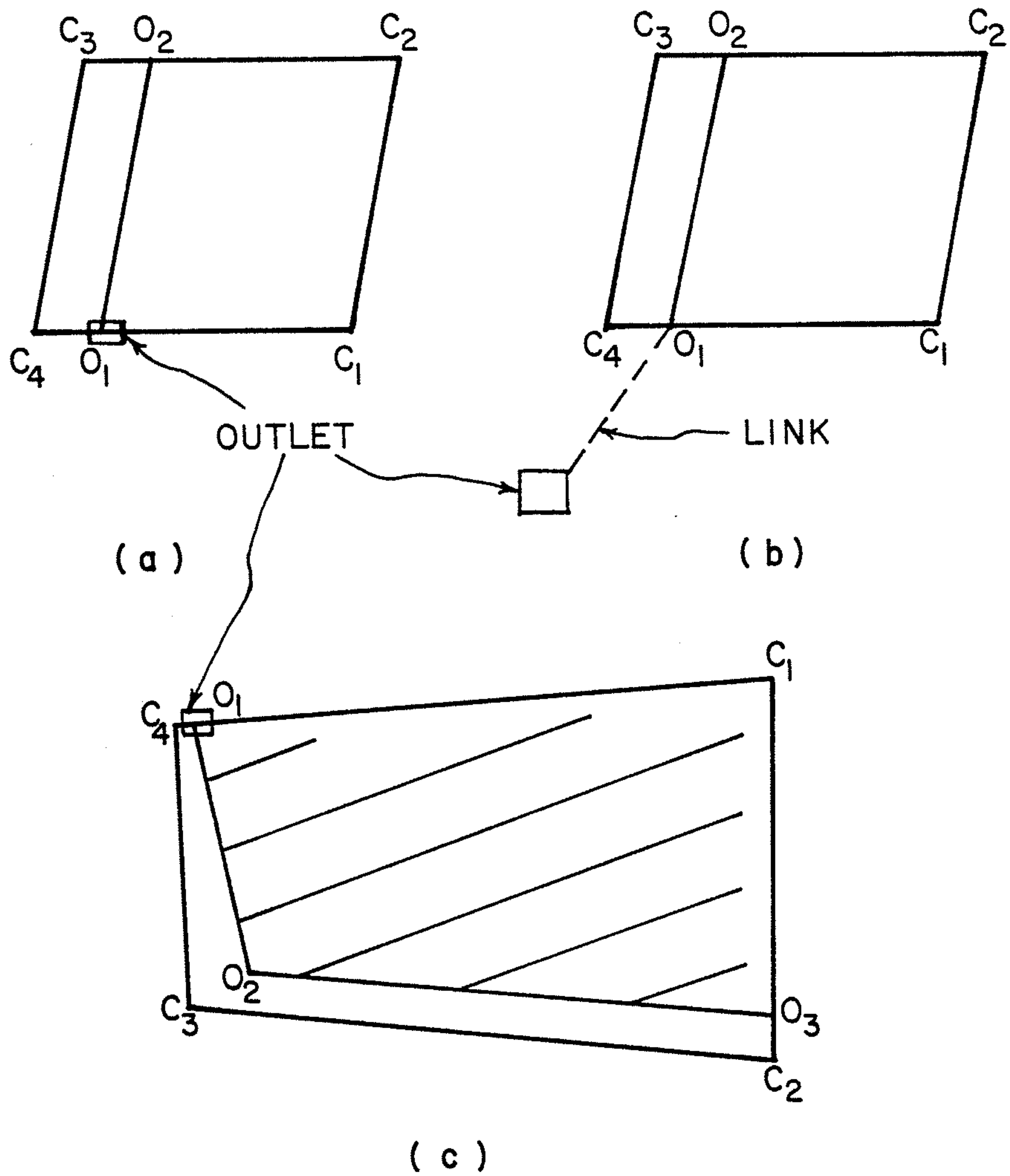


Figure 20. Location of Outlet and the Type of Collector.

After the program has read all the necessary data from card deck or on-line device, it proceeds to design the drainage system in the following ways:

Firstly, the connections of the laterals and collector are determined (i.e. (X_1, Y_1) points in Figure 21). The following equations were developed for determining the (X_1, Y_1) points.

$$(X_1)_i = OX_1 + \Delta X \cdot (2i - 1) \text{ for } 0° < \theta \leqslant 90°,\ i=1,N \quad . . . (9)$$

$$(X_1)_i = OX_1 - \Delta X \cdot (2i - 1) \text{ for } 90° \leqslant \theta \leqslant 180°,\ i=1,N \quad . . . (10)$$

$$(Y_1)_i = OY_1 + \Delta Y \cdot (2i - 1) \text{ for } 0° < \theta < 180°,\ i=1,N \quad . . . (11)$$

where

$$\Delta X = S \cdot \frac{\cos\theta}{\sin\beta} \quad . . . (12)$$

$$\Delta Y = S \cdot \frac{\sin\theta}{\sin\beta} \quad . . . (13)$$

and

S = spacing between laterals, m

β = angle between lateral and collector, degree

θ = angle of the collector from X-axis, degree

i = subscript, i.e., $i = 1,2,3,...N$

(See Figure 21 for notations.)

The total number of laterals required in a design-area is denoted by N which can be determined by the equation:

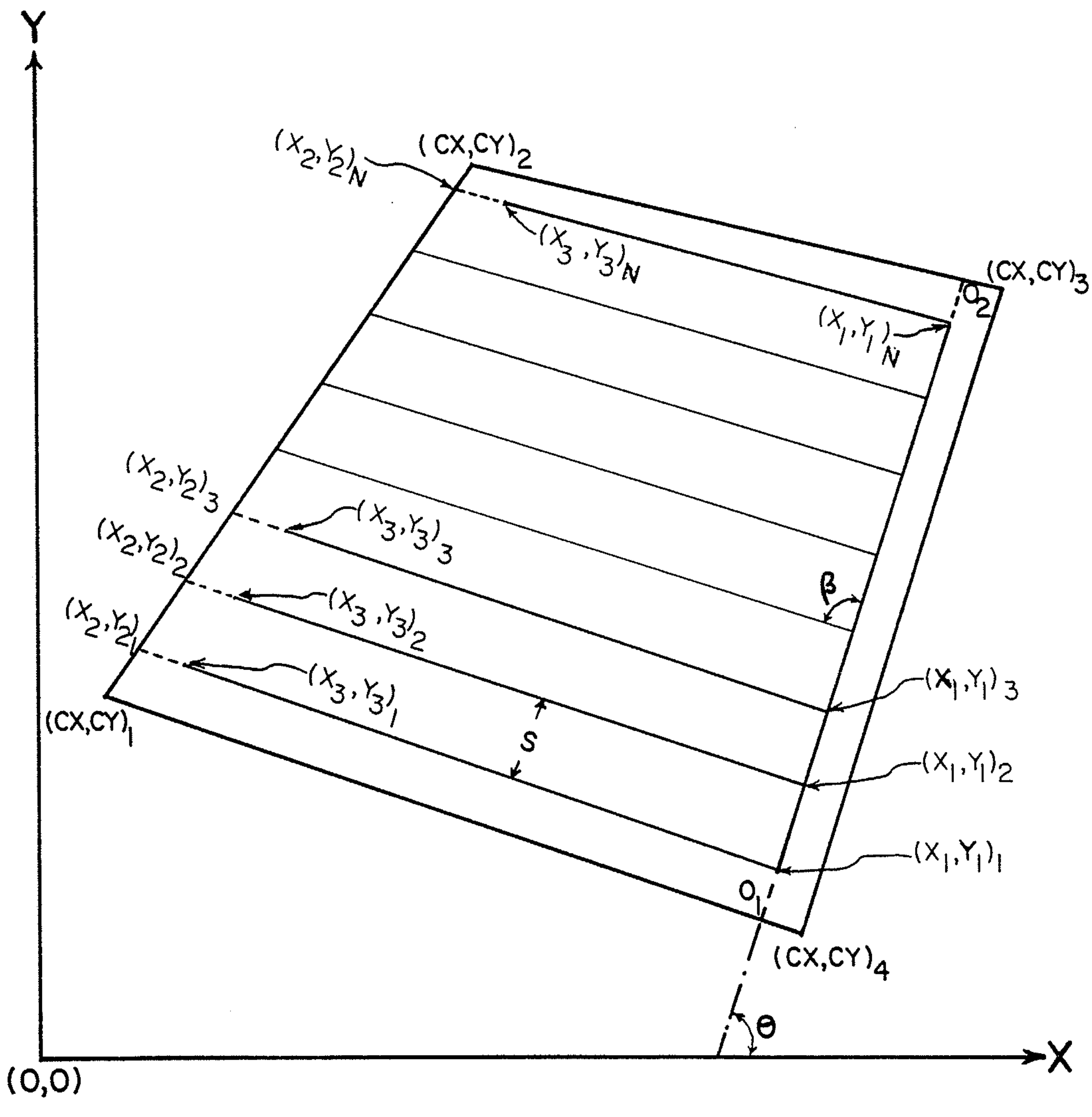


Figure 21. Definition Sketch for Design Program.

$$N = \frac{\sqrt{(OX_2 - OX_1)^2 + (OY_2 - OY_1)^2} \cdot \text{Sin } \beta}{S} \quad . . . (14)$$

where (OX_1, OY_1) and (OX_2, OY_2) are the X-Y coordinates of the points O_1 and O_2 and S and β as defined before.

In the case where N is not an integer number, the next larger integer will be used and the spacing between laterals will be adjusted accordingly. The adjusted spacing is normally a little narrower than the value obtained from the HYCONS program. This will lead to a more conservative design and give slightly better field drainage.

After all the (X_1, Y_1) points have been computed, straight lines will be extended from (X_1, Y_1) to the design-area boundaries with an angle β (lines are imaginary and not actually drawn). All lines will be ended at points (X_2, Y_2) at the boundaries as shown in Figure 21. Points (X_2, Y_2) can be calculated by the following equations:

$$X_2 = \frac{CY_1 - Y_1 - M_1 \cdot CX_1 + M_2 \cdot X_1}{M_2 - M_1} \quad . . . (15)$$

$$Y_2 = Y_2 + M_2 \cdot (X_2 - X_1) \quad . . . (16)$$

where M_1 = slope of the boundary, i.e., $M_1 = \tan(\frac{CY_2 - CY_1}{CX_2 - CX_1})$ in this case.

M_2 = slope of the lateral, i.e., $M_2 = \tan(\theta + \beta)$ in this case.

CX_1, CY_1 = coordinate of the corner C_1.

Note from equations (15) and (16) that (CX_1, CY_1) will be changed to (CX_2,CY_2) if the point (X_2,Y_2) falls on the second boundary and to (CX_3,CY_3) if (X_2,Y_2) is on the third boundary. The slope of M_1 will be changed when (CX_1,CY_1) is changed.

One of the basic design conditions was that all laterals should be started a half-spacing away from the boundaries and ended at collector or outlet. To satisfy this condition, (X_3,Y_3) points (see Figure 21), which are one half-spacing from (X_2,Y_2), are calculated. The following equations were used:

$$X_3 = X_2 + \sqrt{\frac{W^2}{F^2 + 1}} \qquad \ldots (17)$$

$$Y_3 = Y_2 + F \cdot (X_3 - X_2) \qquad \ldots (18)$$

$$\text{for } \theta + \beta \neq 90°, \quad \theta + \beta \neq 180°$$

$$X_3 = X_2 \qquad \ldots (19)$$

$$Y_3 = Y_2 - \frac{S}{2} \qquad \ldots (20)$$

$$\text{for } \theta + \beta = 90°$$

$$X_3 = X_2 - \frac{S}{2} \qquad \ldots (21)$$

$$Y_3 = Y_2 \qquad \ldots (22)$$

$$\text{for } \theta + \beta = 180°$$

where $F = \tan(\theta + \beta)$

$$W = \frac{S}{2 \cdot \mathrm{Sin}\ \alpha} \qquad \ldots (23)$$

and $\alpha = \tan^{-1}\left(\frac{M_2 - M_1}{1 + M_1 \cdot M_2}\right)$

S = drain spacing between laterals

M_1, M_2 = slopes of field boundary and lateral, respectively.

If the boundary is parallel to Y-axis, i.e., $M_1 = \infty$, then equation (24) should be used instead of equation (23).

$$W = \frac{S \cdot l_{12}}{2(X_1 - X_2)} \qquad . . . (24)$$

where

l_{12} = distance between points (X_1, Y_1) and (X_2, Y_2).

Finally, straight lines joining the points (X_1, Y_1) and (X_3, Y_3) are the laterals for the design-area. At this stage, all the input data and computed results will be written on disk or punched on cards as specified for drafting purposes as will be discussed in the next section.

3.5.3 Description of layout program

Similar to DSDP, the Drainage System Layout Program (DSLP) was written in standard Fortran language. However, it was debugged and tested by using the catalogued procedure PLOTTEST created at McGill University Computing Centre.

DSLP is composed of a main program and 25 subprograms. The main program reads the data from disk file or card deck generated by DSDP as discussed in the previous section. Additional data could be supplied on punched cards if necessary. The main program initiates and terminates the plotting operation by calling the subroutines

PLOTON and ENDPLT, respectively. The subroutines PLOTON and ENDPLT must be called once, and only once, at the beginning and at the end of the main program. A generalized flow chart of DSLP is shown in Figure 22 and a complete program listing is given in Appendix C.

DSLP's main program also determines the positions where the grades or pipe sizes of the drain lines need to be changed. It estimates the maximum areas that can be drained by the hydraulic capacity of a given drain pipe size with a specific design drainage coefficient. The equation used to determine the areas drained was derived from Manning's formula (Chow, 1959) and can be expressed as,

$$A_c = \frac{0.311685}{n} \cdot (DIA)^{8/3}(SL)^{1/2} \cdot \frac{86400}{R} \qquad \ldots (25)$$

where

A_c = maximum areas drained, sq.m

n = Manning's roughness coefficient for the drain pipe

DIA = diameter of the drain pipe, m

SL = slope of drain pipe

R = design drainage rate, m/day

86400 = conversion factor from flow rate per day to flow rate per second.

The areas drained by each lateral can be found from the equation

$$A_1 = L \cdot S + \frac{S^2}{2} \qquad \ldots (26)$$

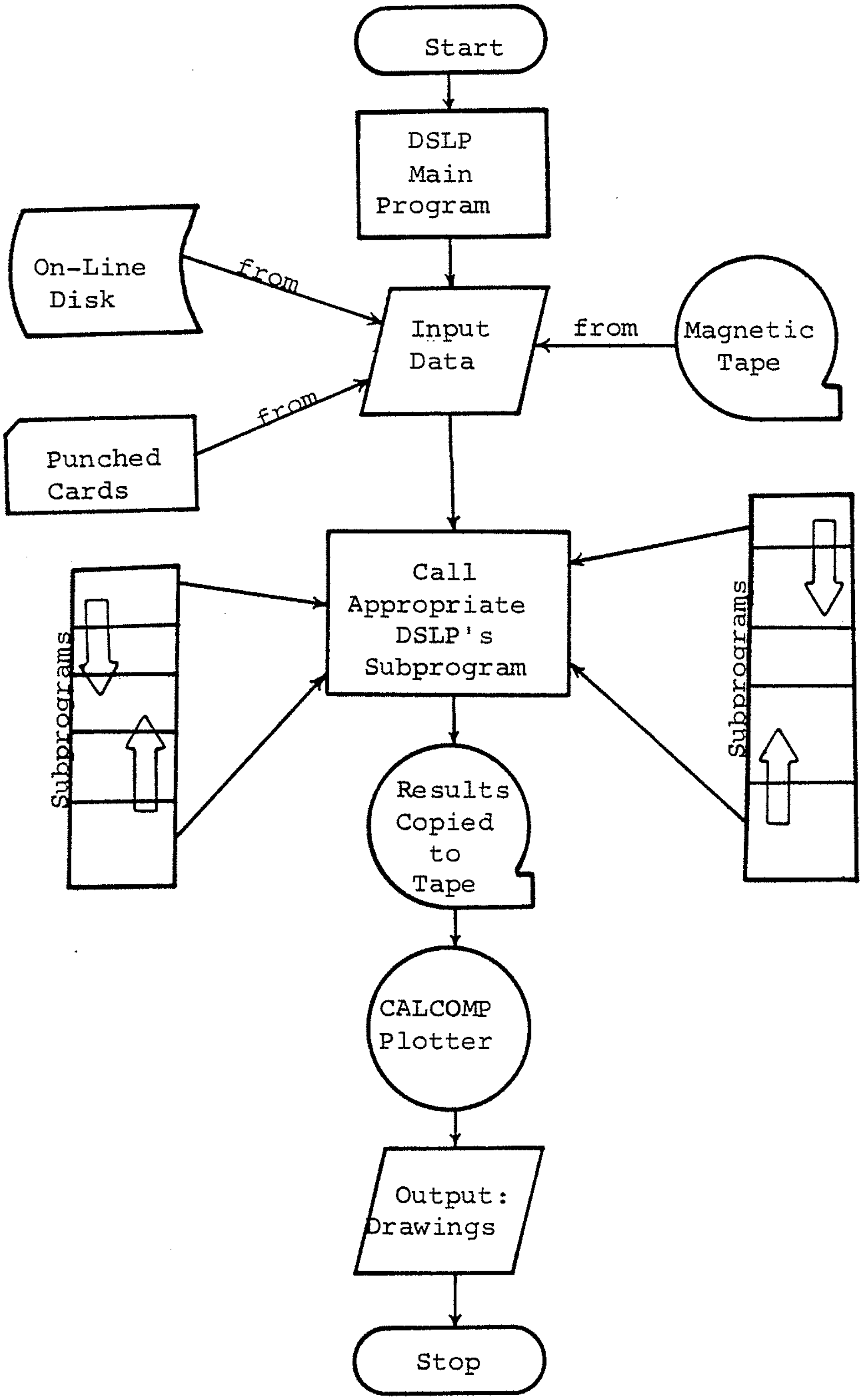


Figure 22. Generalized Flow Chart for Drainage System Layout Program.

where A_1 = maximum areas drained by a given size of drain line, m^2.

L = length of the drain line, m

S = spacing between laterals, m.

If the drain pipe capacity is not to be exceeded, the areas A_1 must not be larger than A_c. In general, the collector size should be gradually enlarged, starting from the upper end of the line because more and more laterals are connected to it along the line (see Figure 23).

The full flow hydraulic capacity of some commonly used plastic drain tubes has been estimated by Wesseling and Homma (1967), Hermsmier and Willardson (1970), Irwin (1971), Broughton and Ami (1975), Ami, Broughton and Shady (1978) and others. The Manning's roughness coefficient of plastic drain tubes of several makes has been measured by Broughton and Negi (1971) and Irwin and Motycka (1979) as given in Table 2.

Subprograms in DSLP were initially prepared for plotting key-symbols for the drainage plans, but most of them were generalized and can be used in DSLP as well as in other Fortran programs. These subprograms call one or several CALCOMP subroutines to perform different functions such as drawing straight lines, tracing smooth curves, plotting special symbols and lettering alphabetic, numeric and alphanumeric characters, etc. Different subprograms have different functions and options. The subprogram AR01 has been used

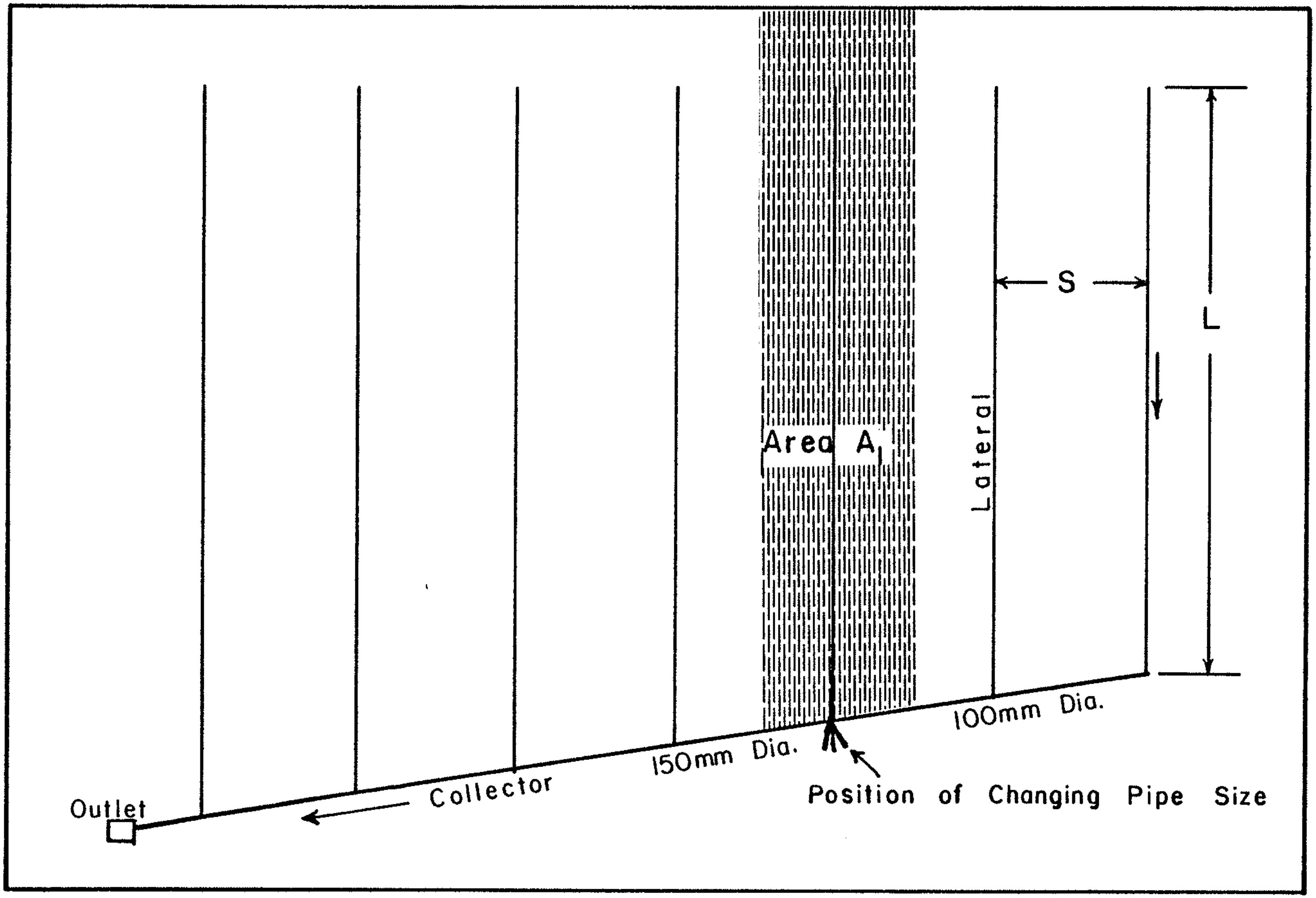


Figure 23. Definition Sketch for a Gridiron Type Subsurface Drainage System.

TABLE 2. Representative Manning's n values for some plastic drain tubes

Plastic drain tube diameter (mm)	Manning's n value
80 †	0.0167
100 *	0.0160
150 †	0.0160
200 *	0.0190
250 *	0.0180
300 *	0.0220

† After Broughton *et al*. (1971).

* After Irwin *et al*. (1979).

to exemplify the flexibility and applicability of the subprograms in DSLP. Input formats and their options are specified in each subprogram as shown in Appendices C and D.

As can be seen in Figure 24, subprogram AR01 draws the North Arrow in different sizes and orientations as required. Case (1) indicates the North Arrow is 2 inches long at 90° from X-axis. Case (2) shows an arrow of 3 inches long at 230° from X-axis, and North Arrow in Case (3) is 4 inches long with an angle of 60° from X-axis.

Figures 25 through 27 are the samples drawn by some of the subprograms. Other symbols produced by DSLP's subprograms can be seen in the completed drainage plans given in Appendices F, H1 and H2.

DSLP requires a setup step that instructs the console operator to mount a plottape. In addition, instructions can be sent directly to the Calcomp plotter operator at this time. The plotter is offline at McGill Computing Centre and the instructions are copied by the console operator onto a card that accompanies the completed plottape.

Plans produced by using DSLP can be drawn in a variety of pen sizes and ink colours. However, it is necessary to execute a particular plotter instruction (origin redefinition) in order to pause the plotter so that the plotter operator may make changes.

It should be mentioned that the subroutine PLOTON defines the plotter's origin twice. Therefore, with DSLP, plotting starts with

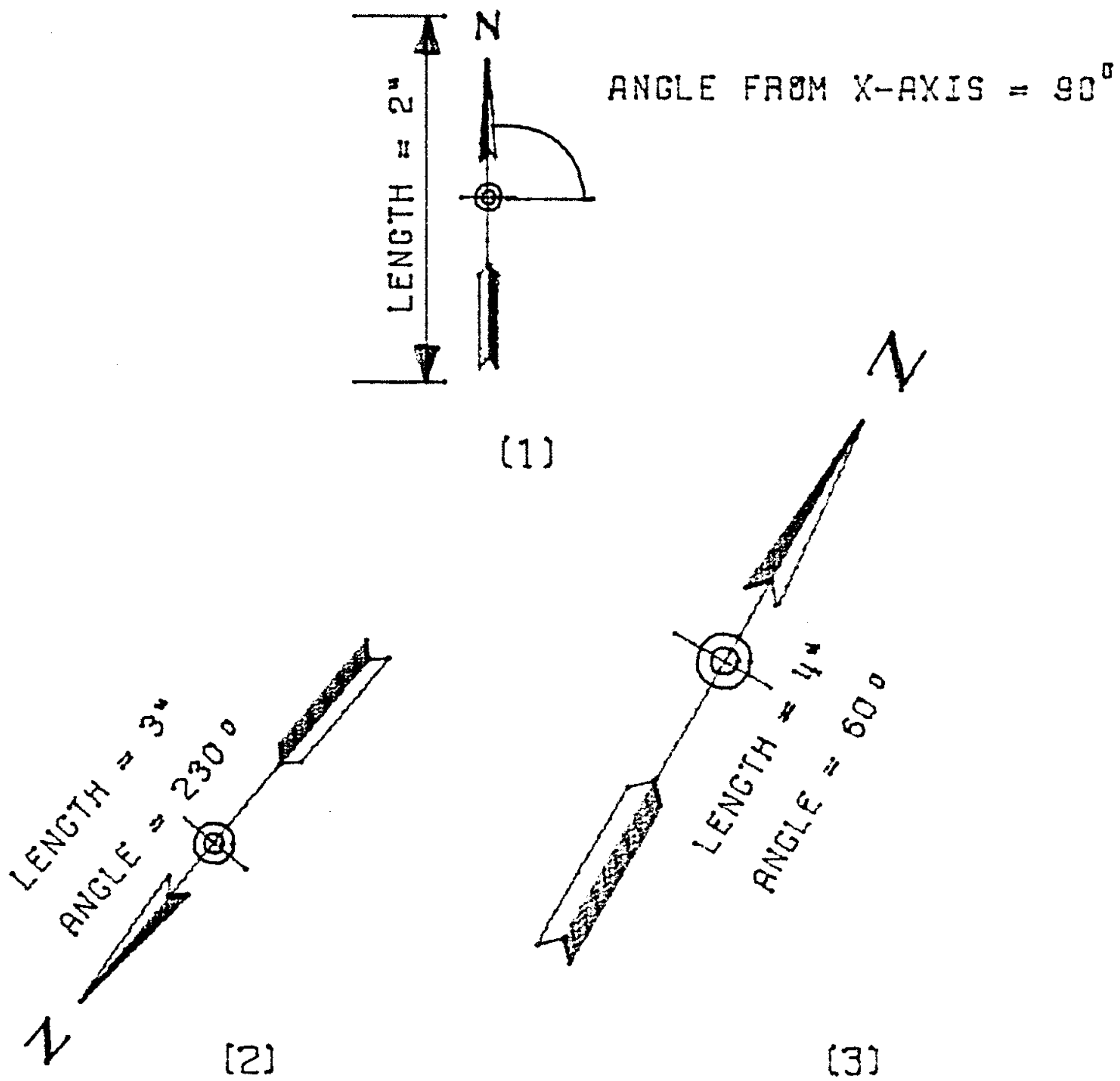


FIGURE 24. NORTH ARROWS IN DIFFERENT SIZES AND ORIENTATIONS DRAWN BY SUBPROGRAM AR01.

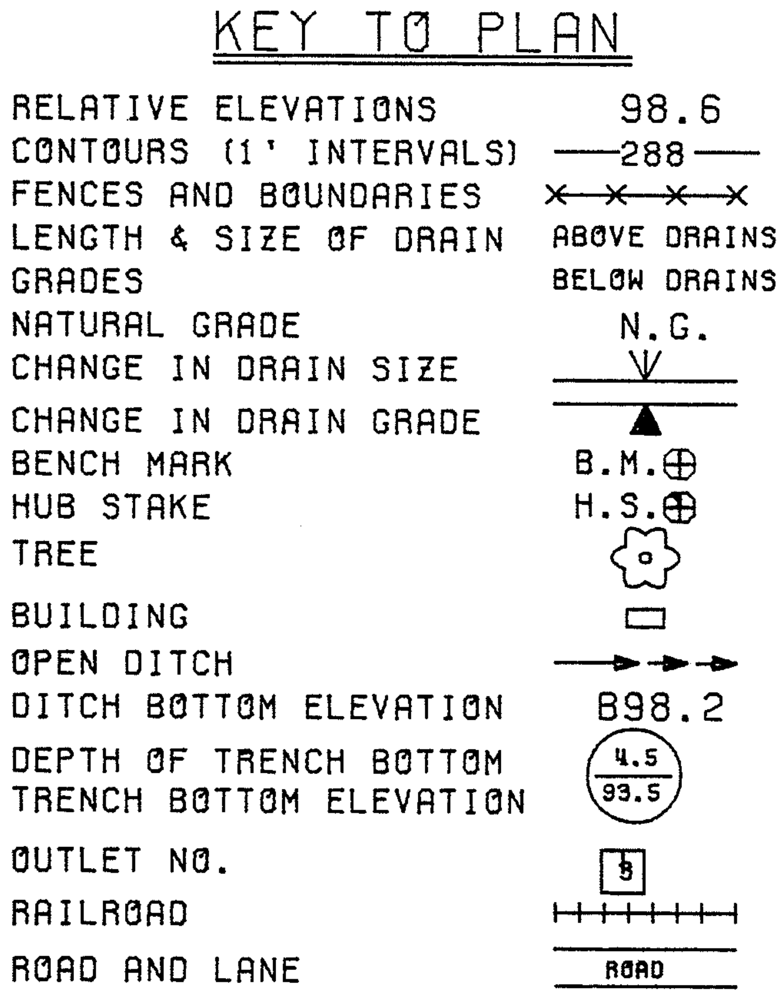


FIGURE 25. KEY TO DRAINAGE PLAN DRAWN BY SUBPROGRAM PKEY10.

<table>
<tr><td></td><td></td><td colspan="4"></td></tr>
<tr><td>REVISION</td><td>DATE</td><td colspan="4">DESCRIPTION</td></tr>
<tr><td colspan="6">AGRICULTURAL ENGINEERING DEPARTMENT
MCGILL UNIVERSITY</td></tr>
<tr><td colspan="6">BOX 950, MACDONALD COLLEGE, QUE. H9X 1C0</td></tr>
<tr><td colspan="6">SAMPLE TITLE
AGR. ENG. DEPT. MACDONALD COLLEGE
MCGILL UNIVERSITY, QUEBEC, CANADA</td></tr>
<tr><td rowspan="4">SCALE

1CM = 100M</td><td></td><td>DATE</td><td>PERSON</td><td rowspan="4" colspan="2">DWG. NO.

AG79-01</td></tr>
<tr><td>DRAWN</td><td></td><td></td></tr>
<tr><td>CHECKED</td><td></td><td></td></tr>
<tr><td>REVISED</td><td></td><td></td></tr>
</table>

FIGURE 26. TITLE BLOCK FOR DRAINAGE PLAN DRAWN BY SUBPROGRAM TBLK17.

COLLECTOR	DRAIN TUBE REQUIRED METERS				
	100 MM	150 MM	200 MM	250 MM	300 MM
A					
B					
C					
D					
E					
F					
G					
H					
J					
K					
TOTAL					
OVERALL TOTAL:				METERS	

FIGURE 27. TABLE OF MATERIALS FOR DRAINAGE PLANS PRODUCED BY SUBPROGRAM COLEN4.

the plotter's origin #003. The first redefinition of the origin sets the counter to #004, and each subsequent origin redefinition increases it by 1. With the following JCL statements, the plottape is mounted and the message concerning the pen sizes is displayed at the console. DSLP itself will then execute.

```
// EXEC SETUP
//SETUP.SYSIN DD *
T8=PLTTP(RI,SL,30" PLAIN PAPER. PENS: 0.3mm AT START #003,)
(CONTINUED. 0.5mm AT #004, AND 0.8 mm AT #005. THANKS)
```

A complete setup JCL can be seen in the program listing in Appendix D.

3.5.4 Profile program

In drainage system design, profiles are often employed to show graphically the relation of the surface to the grade and depth of the drain pipe. Generally, profiles are prepared to supplement plans of drainage systems.

In practice, the vertical scale for a unit of distance is very much greater than the horizontal in order that the vertical distances may be more accurately represented. The scales of 1 m to 50 m for vertical and 1 m to 5000 m for horizontal in the profile drawings are currently used by most of the design engineers in the Ministry of Agriculture of the Province of Quebec. However, designers in different regions may use different scales in drawing profiles for particular purposes.

The profile program developed in this study can be used to draw any magnitudes of vertical and horizontal scales. The vertical and horizontal scales need not be the same. Two profile samples representing two different scales drawn by the program are shown in Figures 28 and 29. The listing of the profile program is given in Appendix E.

Since the plotter operated by McGill University Computing Centre was designed in Imperial units, the conversion from Imperial to Metric units was found to be impractical because of the rounding error performed by computer during the computation and conversion. However, the programs developed in this study can be used with minor modifications, i.e., changing the labels from feet to meters, etc., if the plotters used are designed in metric specifications. Currently, new machines manufactured by Calcomp (Guardado, 1979) and Hewlett-Packard (Casola, 1979) are designed in metric specifications. The programs may be used with those plotters in the foreseeable future.

14.22.59 AE33000 PROFIL1 WED DEC 12, 1979

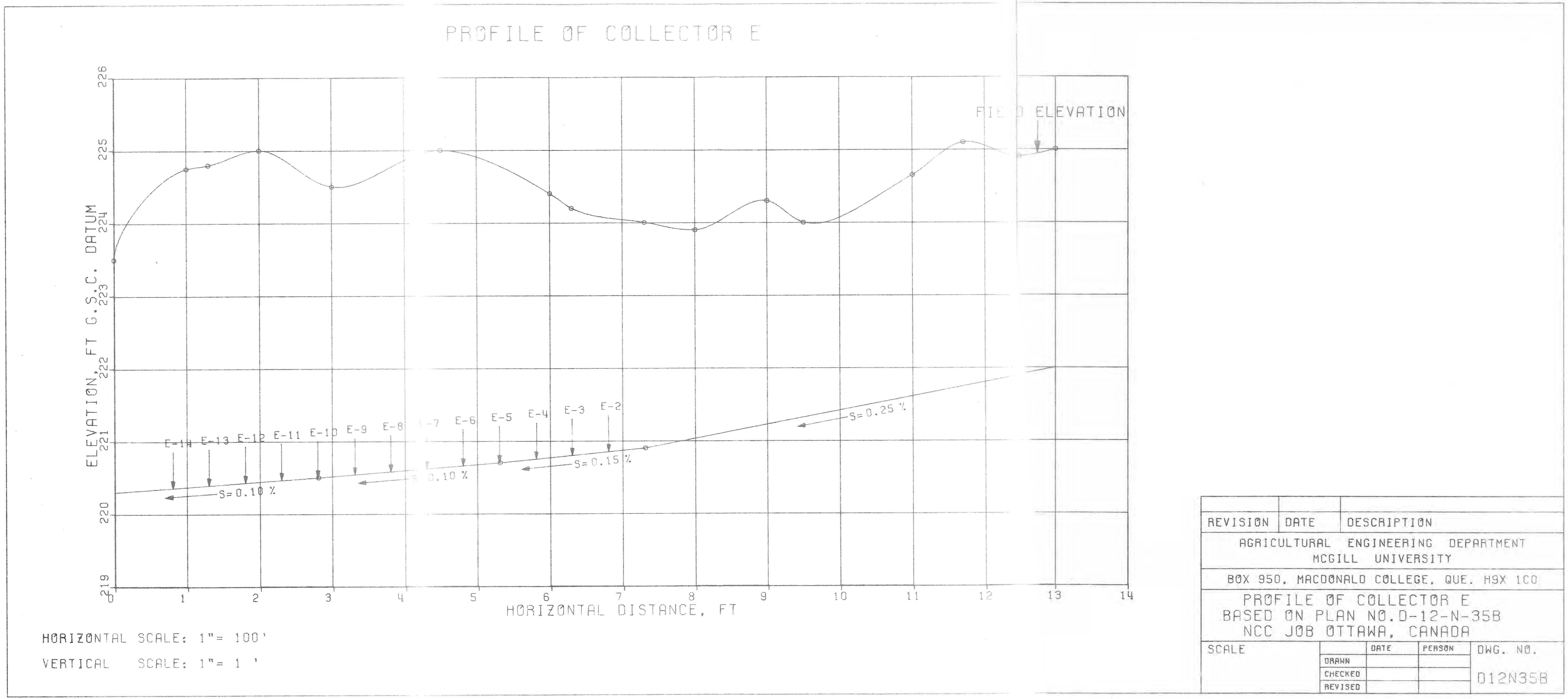


Figure 28. Profile for land surface and collector drain drawn by program PROFILE.

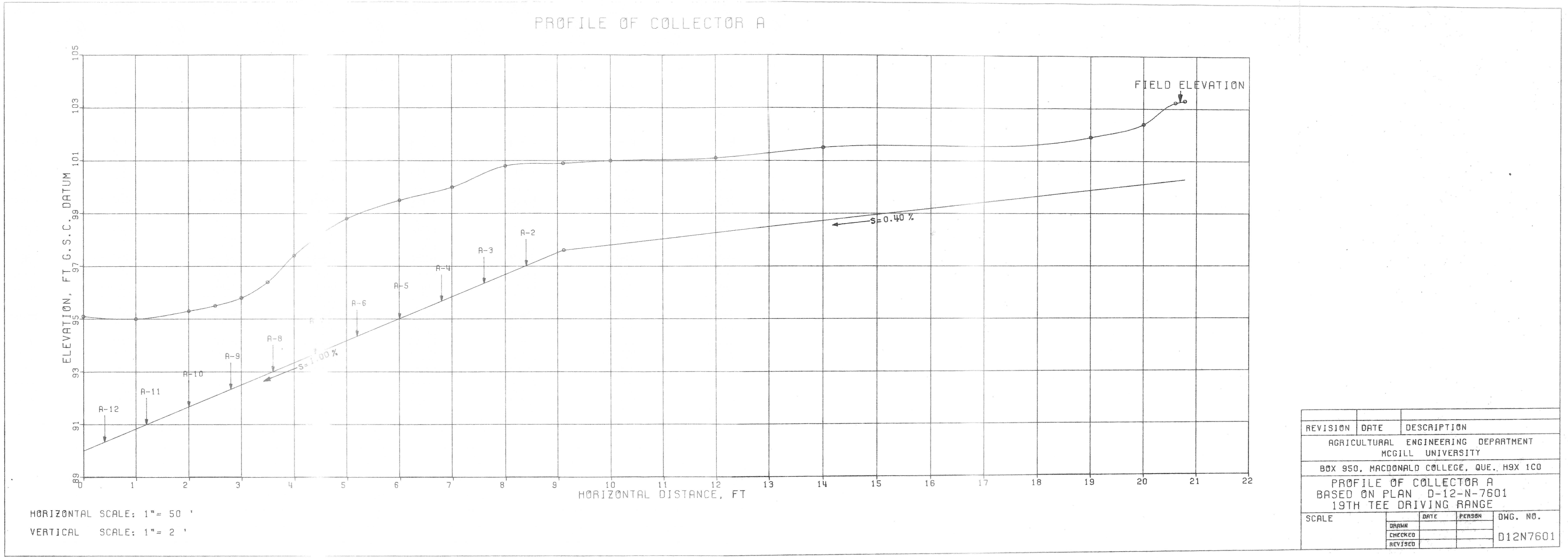


Figure 29. Profile for land surface and collector drain drawn by program PROFILE.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 General

A systematic approach for designing subsurface drainage systems has been developed. Programs have been developed to direct a computer plotter to draw drainage plans. The entire process can be completed in four steps after the spot elevations of the field have been obtained. The block diagrams shown in Figure 30 illustrate the functions in each step.

The spot elevation topographic program (TOPMAP) developed by Murphy (1978) was modified and used to compute the X-Y coordinates for each of the spot elevations (Z) from the field survey data. The spot elevations were plotted at appropriate X-Y positions after the values of X-Y were determined. It was found that TOPMAP can be used to draw topographic spot elevation maps at any desired scale. Figures 31 and 32 are examples of spot elevation maps produced with different scales. Figure 31 was drawn on a paper 11 inches (28 cm)

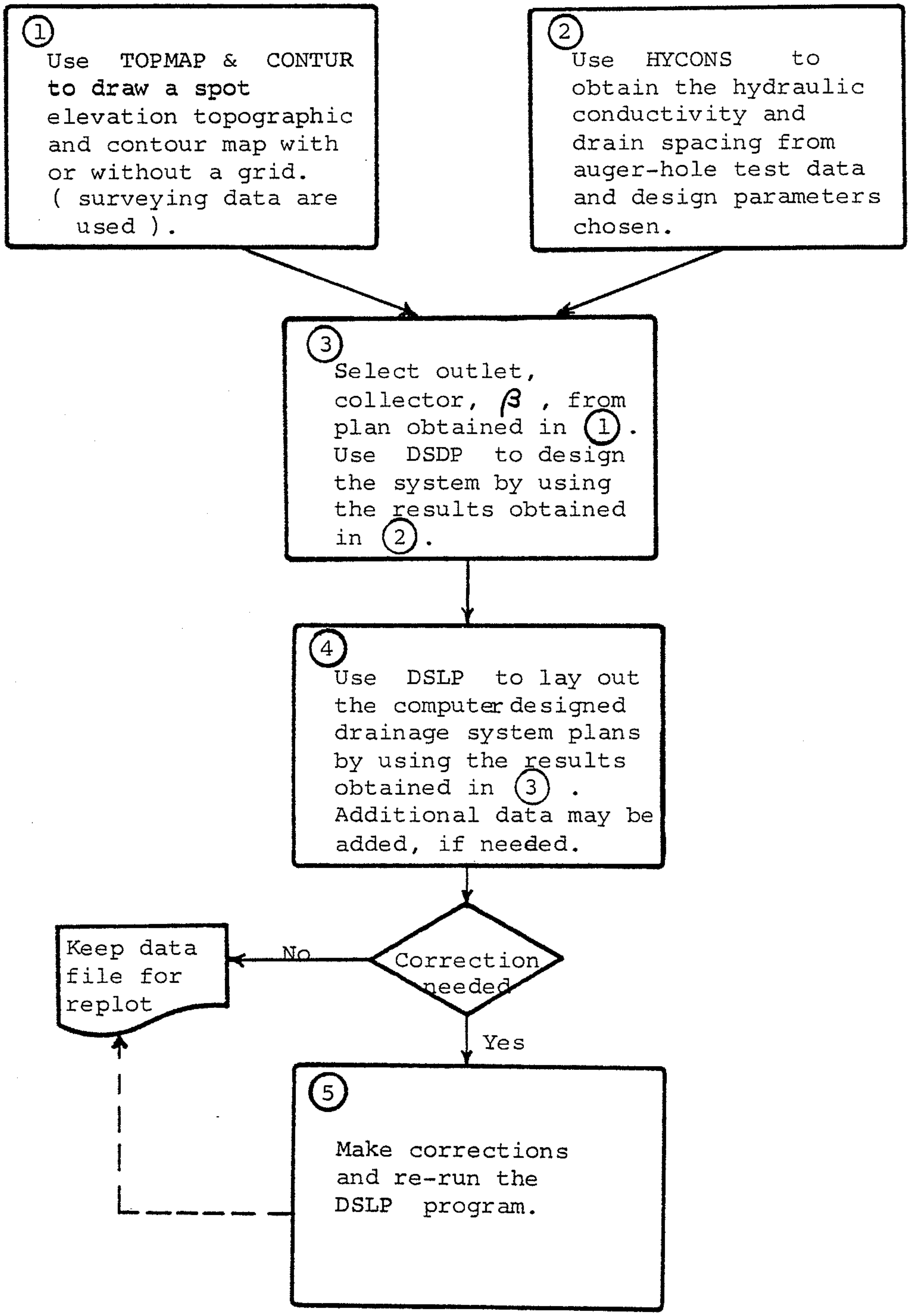


Figure 30. Steps' Functions in Computer-aided Design and Layout System.

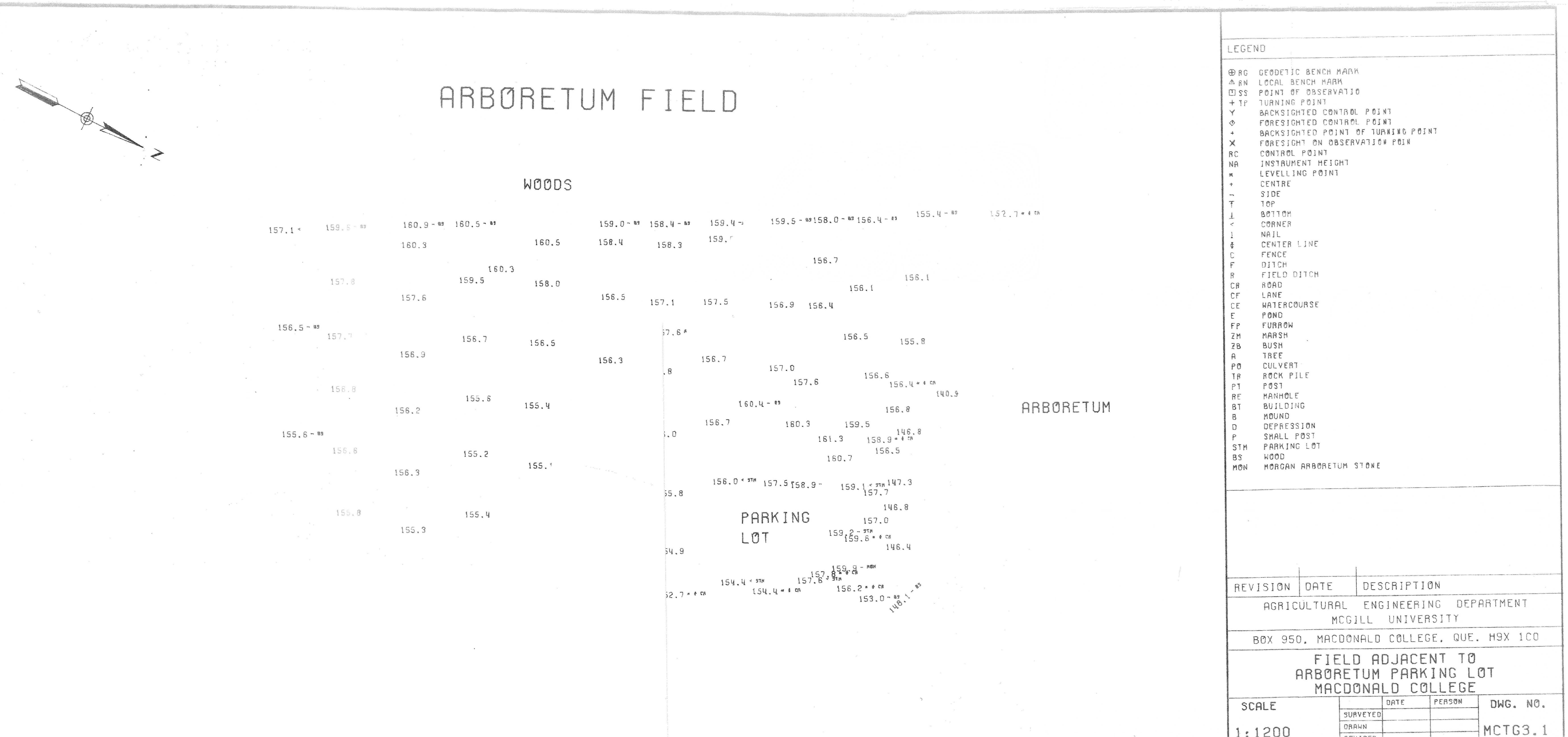


Figure 31. Spot elevation topographic map produced by program TOPMAP (scale: 1:1200).

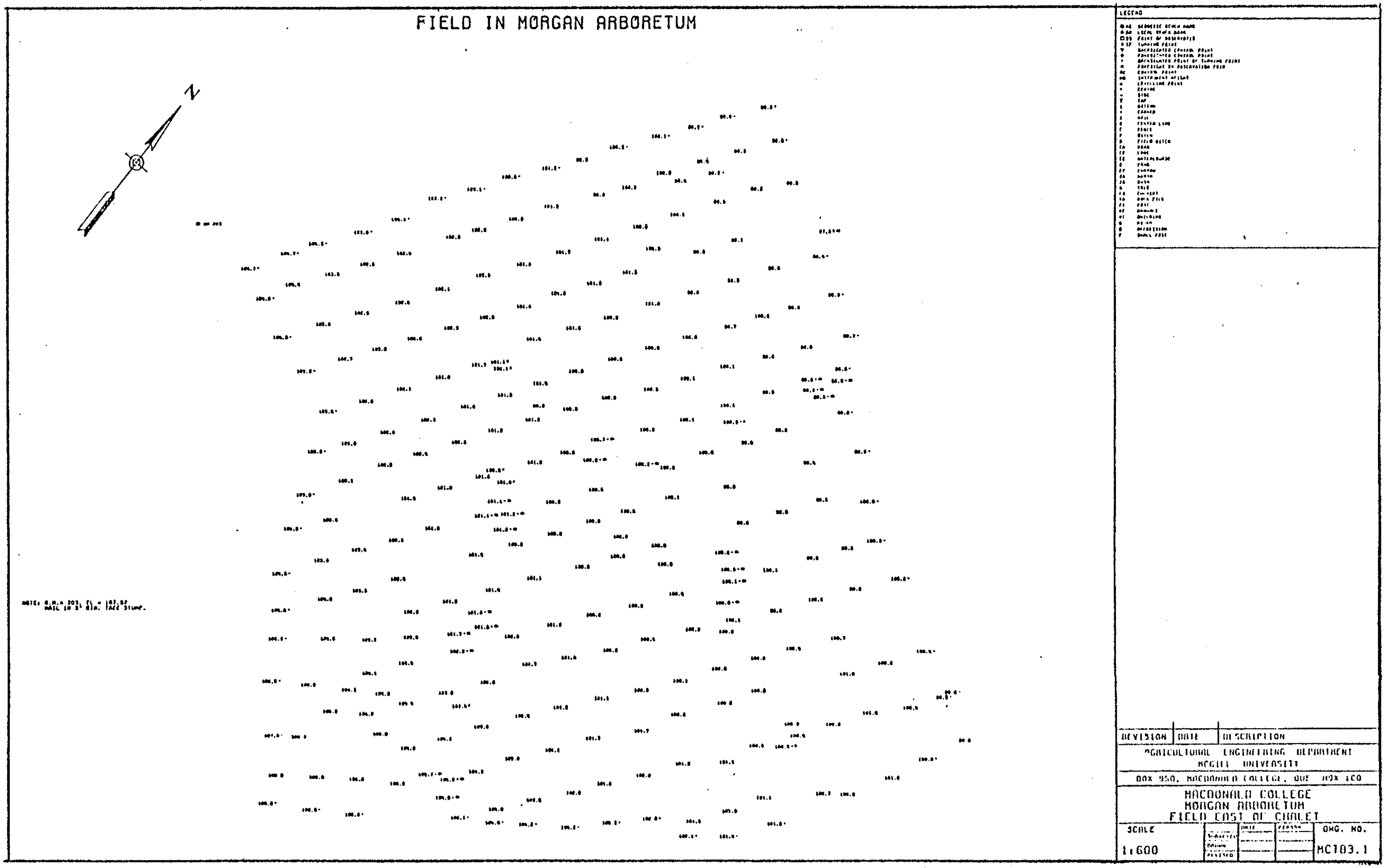


Figure 32. A much reduced size reproduction of a spot elevation topographic map produced by program TOPMAP. On the full size drawing at a scale of 1:600 the spot elevations and notes are all clear.

high with a scale of 1 inch to 100 feet (1:1200). Figure 32 was plotted on 30-inch (76 cm) height paper with a scale of 1 foot to 600 feet (1:600).

It must be mentioned here that most of the drawings reported in this dissertation were drawn in Imperial units because the equipment used such as surveying instruments, recording devices, and Calcomp plotter, use inches and feet. Conversion to metric units is found to be impractical. It was found that rounding errors occur in converting figures, lengths of drain lines and elevations of the ground from Imperial to Metric units. Since there is a scale factor involved in drawing drainage plans, a small deviation in the length or height may end up with troublesome error on the plan.

However, programs developed in this study can be easily adjusted to work with equipment made for metric system, when such equipment becomes available.

It was found that in order to program TOPMAP in an efficient way, a good background of programming knowledge is needed. TOPMAP involves several complicated Job Control Language (JCL) setup procedures. Some of these JCL procedures are found to be difficult to follow for those who are not familiar with JCL. It is felt that TOPMAP could be simplified if it is used for production of a large number of maps.

The contour maps, as shown in Figures 33 and 34, were drawn by using the contouring program (CONTUR) developed by Kok and Bégin

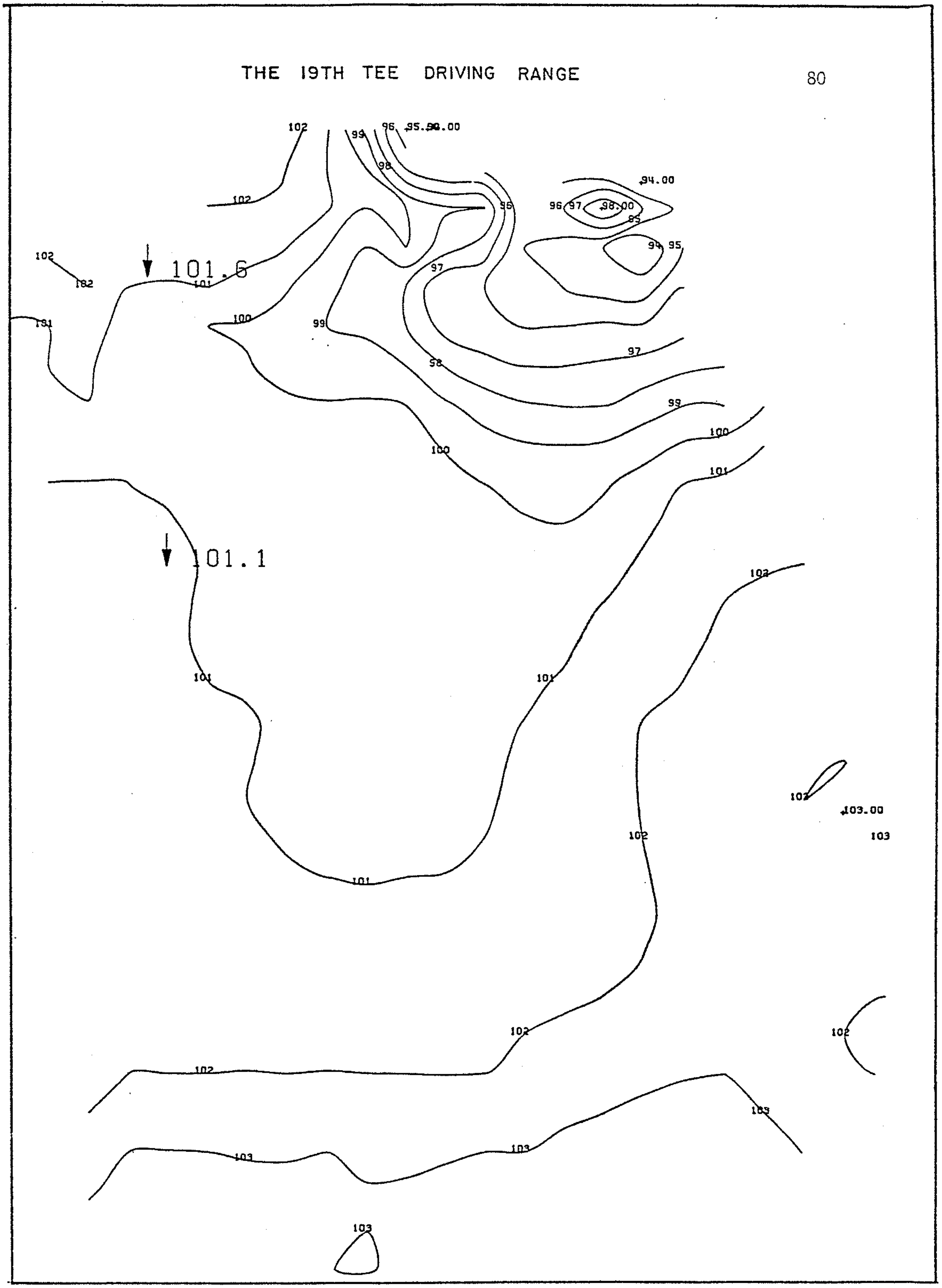


Figure 33. Contour map produced by program CONTUR
(The 19th tee driving range).

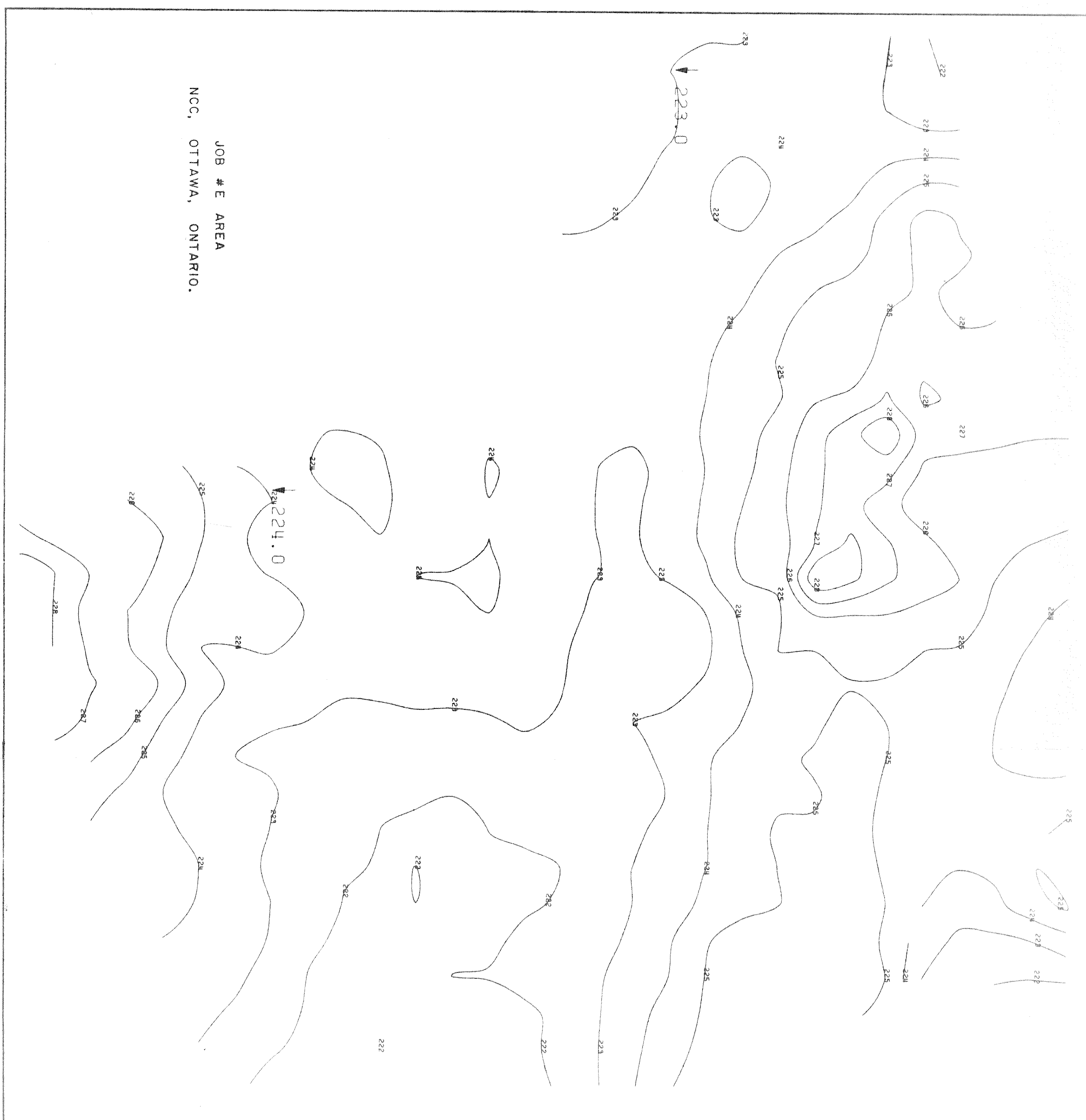


Figure 34. Contour map produced by program CONTUR (Job #E, N.C.C., Ottawa).

(1978). It was found that, unlike TOPMAP's complicated setup procedures, CONTUR only requires a simple single-step setup procedure and it can easily be followed by a person with little programming experience. The main reason may be the fact that TOPMAP handles most of the complicated parts of computations, transformations and conversions for spot elevation calculation from surveyed data. CONTUR simply uses the results, i.e., X, Y, Z values, computed by TOPMAP.

It should be noted that the original CONTUR program drew the contour lines but did not print the spot elevation value on the map. In order to have the contour lines drawn as well as the spot elevations printed, CONTUR was modified. Figure 35 shows a map of spot elevation and contour lines produced by the modified CONTUR program.

Generally, it can be said that CONTUR can produce results similar to those of a draftsman for drainage areas whose slopes are less than 7 per cent. More spot elevation data are needed for areas with a rapid change in slopes, i.e., a valley or a mound, in order to obtain more accurate contour lines.

4.2 Advantage of the computer-aided drafting system

DSDP and DSLP programs provide a faster way to design a drainage system and prepare the designed system plans. It was realized that many advantages can be gained by using a computer-aided

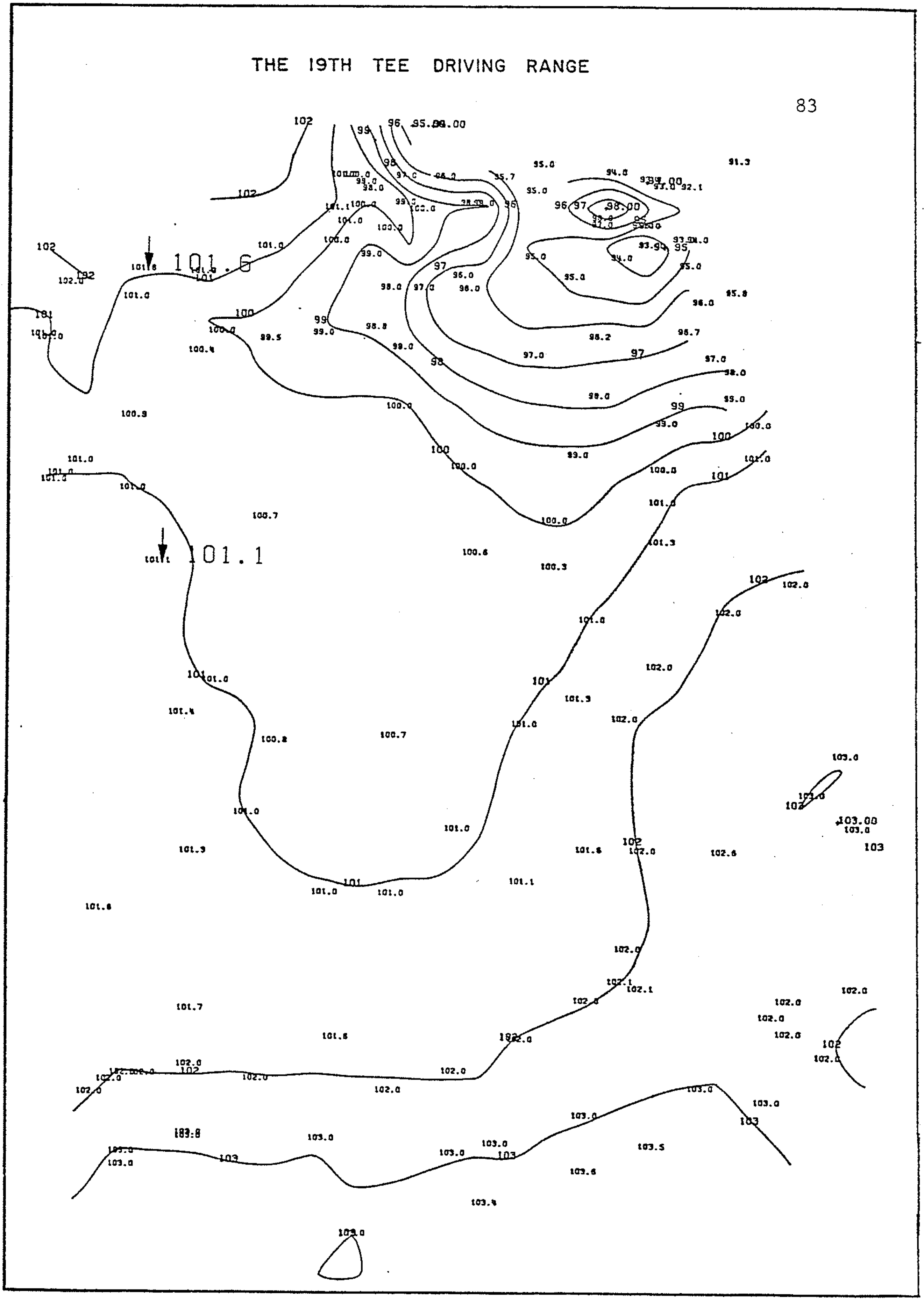


Figure 35. Spot elevation topographic and contour map produced by modified CONTUR program.

drafting system in subsurface drainage system design. The most distinct advantages are:

1. The speed of the drafting was increased. The author experienced that the speed of computer plotting is very much faster than manual drawing. Although some engineering consulting firms claimed that computer drafting systems could cut map-drawing man-hours from 2 1/2 man-years to 1 man-week (Civil Eng. ASCE, 1977; Computer Data, July 1978), it is the author's observation that computer drafting can speed up work by only 5 to 10 times, depending on the size of the jobs. Table 3 compares the time spent by conventional manual drafting methods and computer drafting methods developed in this study for the same drainage area. Appendices G1, G2 and H1, H2 show plans done by a draftsman and computer plotter, respectively. Note in Appendices H1 and H2 that the lists of materials needed in the designed systems were presented by computer.

It can be seen in Table 3 that more time can be saved in steps 1 and 5 if the spot elevation data were recorded on a recording device and an interactive screen terminal were used to edit the data or generated results.

During the development of the DSLP program, it was found that some of the irregular shapes and lines or curves are extremely difficult to express in mathematical forms. Those irregular shapes or lines may be drawn by draftsmen. However, a light pen

TABLE 3. Comparision of time spent for manual and computer-aided drafting methods

Step	Manual drafting	Computer drafting
1	Writing spot elevations at appropriate positions on a master plan: 2 hours	Punching spot elevation data on cards (using IBM 029 key-punch machine with drum control): 2 hours
2.	Interpolation for spot elevations and drawing contour lines: 3 hours	Contour lines drawing and spot elevations lettering: 31 minutes
3.	System design parameters determined by designers	
4.	Design and draw the first draft of designed system on the tracing paper and obtain a blueprint: 8 hours	Design and draw the first draft of designed plan by using DSDP and DSLP : 1.5 hours
5.	Modifications on the first draft: 3 hours	Modifications on the first draft: 3 hours
6	Draw the complete drainage plan on a master sheet: 24 hours	Replot drainage plan: 52 minutes
7	Contingencies: 1 hour	Contingencies: 1 hour*
	Total : 41 hours	Total : 9 hours

*Including system downtime and data handling.

or digitizer can be used together with a CRT screen terminal to trace special lines or draw irregular shapes. The digitizer manufactured by Hewlett-Packard has demonstrated its applicability in handling the task mentioned above. Due to financial constraints, it was impossible for the author to set up such an integrated system in this study. It is suggested that further investigation for an integrated system should be carried out when financially feasible; for example, when the computer-aided drafting of plans becomes a commercial operation.

2. The cost of the drafting can be reduced. By using computer drafting systems, less drafting time is required for each drafting job. This not only results in labour-saving but also reduces space costs per job. By providing good draftspersons and technicians with computer-aided drafting tools, the drafting group of a company can produce plans for more land per year, with less time delay and costs for the clients - in this case for the farmers and the people who buy food.

A comparison between costs for the same job as discussed in Table 3 is listed in Table 4.

3. Errors are reduced. It can be said that when drawings are made and calculations done manually, errors are occasionally made in looking up trigonometric functions, pressing wrong keys on calculators, or on the drafting table in plotting wrong grades or elevations. Since the computer is an error-free machine, the errors can be reduced to a minimum when it is used for computing and

TABLE 4. Cost comparison between manual and computer-aided drafting methods

Item	Manual drafting		Computer-aided drafting	
1	2 hr x $8/hr*=	$ 16.00	2 hr x $8/hr	= $16.00
2	3 hr x $8/hr =	24.00	Execution charges** 16 min plotting x $20/hr***=	= 9.90 5.33
3	- - - - S A M E - - - -			
4	8 hr x $8/hr =	64.00	DSDP execution charges DSLP execution charges 18 min plotting x $20/hr	= 3.71 = 6.06 = 6.00
5	3 hr x $8/hr =	24.00	3 hr x $8/hr	= 24.00
6	24 hr x $8/hr =	192.00	Execution charges 51 min plotting x $20/hr	= 12.64 = 17.00
7	1 hr x $8/hr =	8.00	1 hr x $8/hr	= 8.00
	Total	$328.00	Total	$108.64

* The pay for drafting work varies with skill and may range between $6 and $10 per hour. $8 per hour is the average pay.

** See Table 5 for the execution charges.

*** McGill Computing Centre charges $20 per hour for Calcomp plotting jobs.

TABLE 5. Samples of execution charges*

Chargeable items	TOPMAP and CONTUR program ($)	DSDP ($)	DSLP (first draft) ($)	DSLP (complete plan) ($)
CPU	5.38	0.50	2.47	7.24
I/O	0.42	0.05	0.46	0.89
U/R	1.30	2.36	0.33	1.71
Setup	2.00	-	2.00	2.00
Handling	0.80	0.80	0.80	0.80
Total	9.90	3.71	6.06	12.64

* Based on McGill University Computing Centre commercial charges.

plotting under instructions from bug-free (or debugged) programs. Quinn (reported by Godfrey, 1977) states that computer drafting cuts off errors by 90 per cent.

4.3 Discussion of features of programs and nomographs

It should be mentioned that all subprograms in DSLP developed in this study were generalized. They can be used in DSLP as well as in other standard Fortran programs where the Calcomp software package is accessible.

In addition to DSDP and DSLP, two short programs, i.e., HYCONS and PROFILE, were written. HYCONS was used to compute the hydraulic conductivity (K) and drain spacing (S) between laterals from auger hole measurement data. PROFILE was employed in drawing the profiles of collectors or laterals of the drainage system. Their functions and examples were given in sections 3.5.1 and 3.5.4, respectively.

Since the single auger hole equation and the Hooghoudt equation were utilized in the HYCONS for K and S computations, the equivalent depth (de) should be defined when using HYCONS. In this report, nomographs for obtaining de for some commonly used drain tube outside diameters, i.e., 100 mm, 120 mm, 150 mm, 175 mm, 240 mm, 300 mm, and 360 mm, are presented (see Figures 8 to 14, inclusive).

When K is obtained by other methods rather than auger hole test, one may get the drain spacing from the multiple correlation graph which has been developed and is given in Figure 36.

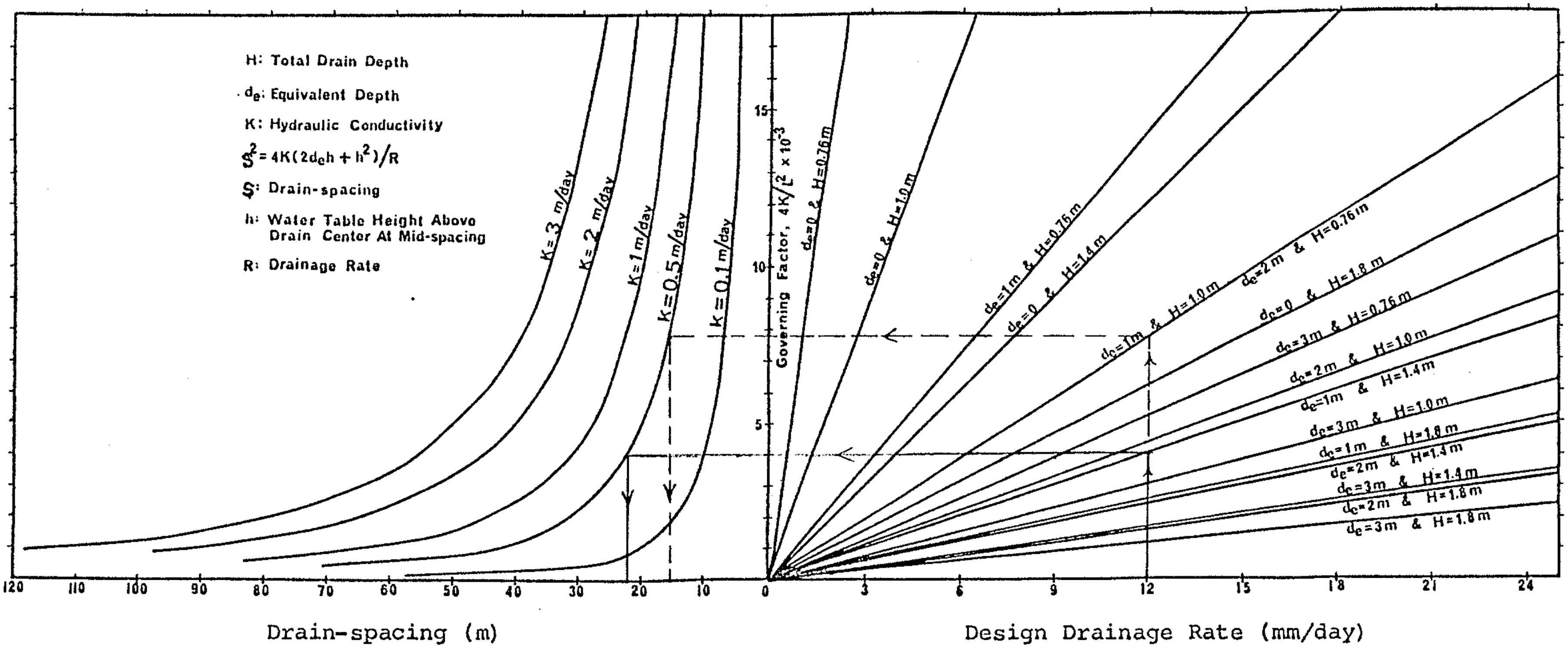


Figure 36. The Graph for Determining the Spacing Between Drain Laterals.

Figure 36 is based on Hooghoudt's equation for a homogeneous soil use, h = H - 0.40 m. The 0.40 m in this case is the desirable water table depth below the soil surface. For example, when design drainage rate (R) = 12 mm/day, K = 0.5 m/day and de = 1 m, Figure 36 gives the drain spacing (S) of 22 m for a drain depth (H) of 1.4 m, a spacing of 15 m when H is 1 m.

Another new multiple correlation graph (Figure 37), which shows the relations between the areas drained (A), maximum allowable length of the lateral (L), drain spacing (S), drainage rate (R), slope of the drain line (SL), drain tube inside diameter (ID), and drain tube hydraulic capacity (Q) was developed. Figure 37 provides an easier and faster way to obtain certain numbers when other parameter numbers are known. For example, if ID, S, R, SL are known, L or A can be obtained from the graph immediately, i.e., ID = 100 mm, SL = 0.1%, S = 30 m and R = 12 mm/day, L and A are found to be 300 m and 0.95 ha respectively.

In general, it can be concluded that all the programs and nomographs developed in this study give benefits of reducing the time and cost of producing drainage plans per unit of land area.

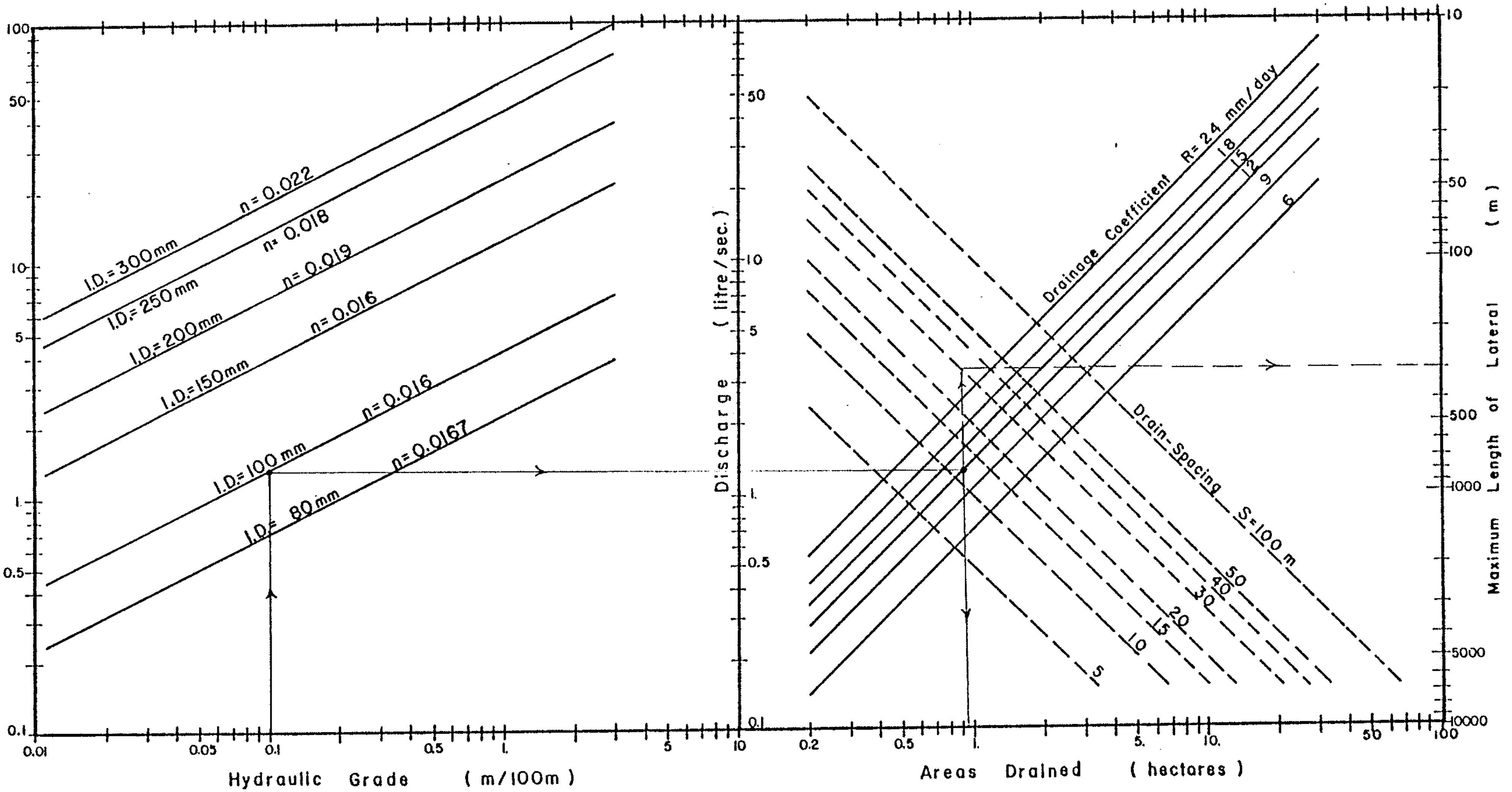


Figure 37. Chart for Determining the Required Size and Maximum Length of Laterals of Corrugated Plastic Drainage Tubing.

CHAPTER V

SUMMARY AND CONCLUSIONS

The design of subsurface drainage systems is a complex of multi-disciplinary activities requiring both time and money. To operate successfully, the designer needs to understand the process of design and its component parts in order to be aware of the full range of activities necessary for the satisfactory execution of the project.

The principal objectives of this study were to develop computer programs for drainage design calculations and for producing drainage maps by computer controlled plotters.

The conclusions of this research work are summarized as follows:

1. Adequate design drainage coefficients for different areas in different regions can be obtained by using the computer drainage model developed by Chieng _et al_. (1978). The model can be used to run with as many years of weather data as are available for a

particular region for different soil parameters. The recommended drainage coefficients presented in Table 1 are based on the 35 years of weather data from the Ste. Hyacinthe, Quebec, area.

2. The topographic mapping program developed by Murphy (1978) was modified to prepare the spot elevation topographic maps from survey data. The program can produce maps with different scales and orientations as required. It was found that the program can prepare good topographic maps with less time and cost compared with manual drafting methods.

3. The contouring program developed by Kok and Bégin (1979) was modified and used to draw contour lines from the spot elevation data obtained in part 2. The program is able to produce contour lines similar to those drawn by draftsmen. However, it was found that more spot elevation data are required to obtain more accurate contours for those areas where the slopes change rapidly.

4. Programs DSDP and DSLP were developed for drainage systems design and produce the plans of those designs with the aid of computers and computer plotters. The additional two programs, HYCONS and PROFILE, were written. HYCONS can be used to obtain hydraulic conductivity and the drain spacing between laterals from auger hole tests and design parameters. PROFILE is used to draw the profiles of a collector or lateral when required. Both DSLP and PROFILE conform to Fortran language and Calcomp software. These programs can produce drawings in any desired scale.

5. A list of materials needed for the drainage system can be provided by one of the subprograms in DSLP. It lists the lengths of laterals and collectors as well as their diameters alongside the drain lines and in tables. The lists of materials needed can be printed on separate paper by a line printer or plotted on the drainage plan.

6. Samples of some designed drainage system plans produced by the developed programs are given. All the necessary symbols and figures such as slopes, flow directions, positions of laterals and collectors, lengths and sizes of the drain lines, locations of fence lines, streams and roads; north arrow and other key notes are provided. It is found that the drafting done by computer plotters is faster and cheaper than by manual drafting methods. However, the use of a light pen or digitizer may increase the speed in drawing irregular shapes or lines which cannot be easily expressed in mathematical forms.

CHAPTER VI

RECOMMENDATIONS FOR FURTHER RESEARCH

The following topics related to the work of this dissertation are considered important for further investigations:

1. The spot elevation mapping programs need to be further modified in order to provide an easier access for users who have little programming experience. It should be modified to suit surveying methods other than the stadia survey method.

2. An integral computer system containing a card reader, line printer, disk and tape drives, CRT screen graphic terminal with a light pen or digitizer is believed to be an ideal drafting system for drainage design works. The performance of this sort of integral graphic system should be investigated, when financially feasible; that is, when production scale mapping is organized.

3. Methods other than stadia survey to obtain spot elevation data should be studied. Electronic surveying instruments may be investigated. Surveying work is considered to be an important but

time-consuming and costly activity in drainage system design processes. New electronic instruments may be able to help to speed up the work and reduce cost.

4. New methods of survey data handling such as recording the survey data directly onto a recording device during the field work should be investigated. This should be able to reduce greatly the time and effort in transferring data from notebooks to punched cards as currently required.

5. Methods for obtaining hydraulic conductivity other than single auger hole method should be investigated in order to obtain the data when the field conditions are not suitable for use of the auger hole method. Methods like the air entry permeameter test or soil cores for laboratory measurement of hydraulic conductivity; and correlation of qualitative field observations of soil texture and structure with hydraulic conductivity should be considered.

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APPENDICES

APPENDIX A

LISTING OF COMPUTER PROGRAM FOR HYDRAULIC CONDUCTIVITY AND DRAIN SPACING CALCULATIONS, HYCONS

```
C      *******************************************************************
C      *******************************************************************
C      *******************************************************************
C      ***                                                             ***
C      ***                                                             ***
C      ***     X                PROGRAM  HYCONS                X       ***
C      ***    X X                     BY                      X X      ***
C      ***   X   X              SIE-TAN  CHIENG              X   X     ***
C      *** X DEC.X                                          X '79 X    ***
C      ***   X   X      AGRICULTURAL ENGINEERING DEPARTMENT   X   X    ***
C      ***    X X                                             X X      ***
C      ***     X       MACDONALD COLLEGE, MCGILL UNIVERSITY     X      ***
C      ***                                                             ***
C      ***                                                             ***
C      *******************************************************************
C      *******************************************************************
C      *******************************************************************
C
C      -------------------------------------------------------------------
C
C      PROGRAM FOR CALCULATING THE HYDRAULIC CONDUCTIVITY FROM THE
C      FIELD MEASUREMENTS ( AUGER HOLE METHOD ).
C      AFTER THE K HAS BEEN CALCULATED, THE DRAIN SPACING OF THAT
C      FIELD WILL BE COMPUTED BY USING THE HOOGHOUDT EQUATION FOR
C      HOMOGENEOUS SOIL OR TWO LAYERED SOIL WHATEVER IS APPLICABLE.
C
C      -------------------------------------------------------------------
C
C      R = DESIGN DRAINAGE RATE.
C      AWT = ALLOWABLE WATER TABLE DEPTH FROM SOIL SURFACE.
C      H = WATER TABLE HEIGHT ABOVE DRAIN CENTER.
C      DD = DRAIN DEPTH.
C      DE = EQUIVALENT DEPTH.
C      WT = WATER TABLE BELOW SOIL SURFACE.
C      D = DEPTH TO HOLE'S BOTTOM FROM WATER TABLE.
C      RAD = RADIUS OF THE AUGER HOLE.
C      DELT = DIFFERENCE IN TIME.
C      DELY = CHANGE IN WATER TABLE.
C      HK = HYDRAULIC CONDUCTIVITY.
C
C      -------------------------------------------------------------------
C
       DIMENSION T(30),Y(30),DELY(30)
       INTEGER HOLE
C      READ IN DESIGN PARAMETERS.
   1   READ(5,2,END=550) R,AWT,DD,DE
   2   FORMAT(F10.4,3F5.1)
       H=DD-AWT
C      READ IN AUGER HOLE DIMENSIONS.
   5   READ(5,10,END=551) WT,D,RAD
  10   FORMAT(2F5.2,F10.5)
       HW=D-WT
  20   READ(5,30,END=553) HOLE,JOB
  30   FORMAT(I2,2X,I1)
```

```
      WRITE(6,560)
 40   DO 50 I=1,30
      Y(I)=0.0
      T(I)=0.0
      DELY(I)=0.0
 50   CONTINUE
      NO=1
C
C     DATA INPUT.
C     T IN COL. 1-5.  Y IN COL. 6-10.   ID IN COL. 15. LAYER IN COL. 20.
C
 60   READ(5,70) T(NO),Y(NO),ID ,LAYER
 70   FORMAT(2F5.1,4X,I1,4X,I1)
      NO=NO+1
      IF(ID.EQ.1) GO TO 80
      GO TO 60
 80   NO=NO-1
      YO=Y(1)-WT
      DY= Y(1)-Y(NO)
      YY=YO-DY/2.0
      CHK=YO/4.0
      IN=0
      SUM=0.0
      DO 100 I=2,NO
      OBS=Y(I-1)-Y(I)
      IF(OBS.GT.CHK) GO TO 110
90    DELY(I)=OBS
      SUM=SUM+DELY(I)
      GO TO 100
110   WRITE(6,120) HOLE,JOB,Y(I-1),Y(I),CHK
120   FORMAT(1X,'THE OBSERVATION LISTED BELOW GIVES A ',/,
     *         1X,'"DELY" GREATER THAN (YO*1/4). IF IT IS ',/,
     *         1X,'THE LAST OBSERVATION, IT WILL NOT BE ',/,
     *         1X,'USED IN THE COMPUTATION FOR K :',//,
     * 5X,'HOLE= ',I2,2X, 'JOB= ',I2,2X, /,
     * 5X,'Y(I)= ',F7.2,3X,'Y(I+1)= ',F7.2,/,5X, 'CHK=YO*1/4=',F8.4,///)
      IF(I.LT.NO) GO TO 90
      IN=IN+1
100   CONTINUE
      DELT=ABS(T(1)-T(NO))
      IF(IN.NE.0) DELT=ABS(T(1)-T(NO-1))
      AVE=SUM/DELT
      A=4000.*RAD**2
      B=(HW+20.*RAD)*(2.0-YY/HW)*YY
      HK=AVE*A/B
      IF(JOB-1) 130,140,150
130   WRITE(6,135) HOLE
135   FORMAT(2X,' JOB # IS 0. ==> CHECK INPUT DATA FOR HOLE NO.',I2,//)
      GO TO 500
140   HK1=HK
      GO TO 230
150   HK2=HK
      SA=(8.0*HK2*DE*H)/R
      SB=(4.0*HK1*H**2)/R
      SPACE=SQRT(SA+SB)
```

```
C     PRINT OUT RAW DATA AND COMPUTED RESULTS.
      WRITE(6.242) HOLE.JOB
      WRITE(6.244)
      WRITE(6.245) (I,T(I),Y(I),DELY(I),I=1,NO)
      WRITE(6.246) DELT.SUM
      WRITE(6.247) YO,DY,YY,D,WT,HW
      WRITE(6.248) R.AWT,DD,DE,H
      WRITE(6.250) HK1,HK2 ,SPACE
242   FORMAT(//,5X,'HOLE NO.',I2,3X,'JOB NO.',I2,//)
244   FORMAT(/,5X,'NO.',5X,'T',9X,'Y',6X,'DELY',/,5X,29('-'),/)
245   FORMAT(5X,I2,3X,F5.1,5X,F5.1,4X,F5.1)
246   FORMAT(/,5X,'DELT=',F5.1,5X,'SUM-DELY=',F5.1,//)
247   FORMAT(//,1X,'RESULTS :',//, 5X,'YO = ',F6.2,/,
     * 5X,'DY = ',F6.2,/,  5X,' Y = ',F6.2,/, 5X,' D = ',F6.2,/,
     * 5X,'WT = ',F6.2,/, 5X,'HW = ',F6.2,//)
248   FORMAT (5X,'DESIGN DRAINAGE RATE = ',F7.4,' M/DAY',/,
     *          5X,'ALLOWABLE WATER TABLE= ',F5.2,'   M',/,
     *          5X,'DRAIN DEPTH          = ',F5.2,'   M',/,
     *          5X,'EQUIVALENT DEPTH     = ',F5.2,'   M',/,
     *          5X,'WATER TABLE HEIGHT   = ',F5.2,'   M',/)
250   FORMAT(///,5X,'THE HYDRAULIC CONDUCTIVITY :',/,
     *          5X,'UPPER LAYER K        = ',F5.2,'   M/DAY',/,
     *          5X,'LOWER LAYER K        = ',F5.2,'   M/DAY',/,
     * /,       5X,'DRAIN SPACING        = ',F5.2,'   M',//,
     * 5X, '*** FIELD WITH TWO LAYERED SOIL ***',///)
      GO TO 1
230   SPACE=SQRT((4.*HK1*(2.*DE*H+H**2))/R)
C     PRINT OUT RAW DATA AND COMPUTED RESULTS.
      WRITE(6.242) HOLE.JOB
      WRITE(6.244)
      WRITE(6.245) (I,T(I),Y(I),DELY(I),I=1,NO)
      WRITE(6.246) DELT.SUM
      WRITE(6.247) YO.DY.YY.D.WT.HW
      WRITE(6.248) R.AWT,DD,DE,H
      IF(LAYER.NE.2) WRITE(6.260) HK1.SPACE
      IF(LAYER.EQ.2) WRITE(6.270) HK1
260   FORMAT(///,5X,'HYDRAULIC CONDUCTIVITY = ',F5.2,' M/DAY',/,
     * /,       5X,'DRAIN SPACING        = ',F5.2,'   M',//,
     * 5X, '*** THE FIELD WITH HOMOGENEOUS SOIL ***',///)
270   FORMAT(///,5X,'HYDRAULIC CONDUCTIVITY = ',F5.2,' M/DAY',/,
     * /,       5X,'TWO LAYERED SOIL --- DRAIN SPACING',/,
     * /, 5X, 'WILL BE CALCULATED IN NEXT STEP.',///)
      IF(LAYER.EQ.2) GO TO 20
      GO TO 1
500   WRITE(6.510) HOLE
510   FORMAT(//,1X,'***ERROR*** JOB # = 0 FOR HOLE #',I2,/)
551   WRITE(6.552)
552   FORMAT(1X, 'MISSING DATA FOR WT,D,RAD -- CHECK STATEMENT 5',/)
      GO TO 550
553   WRITE(6.554)
554   FORMAT(1X, 'MISSING DATA FOR HOLE,JOB -- CHECK STATEMENT 20',/)
550   WRITE(6.560)
560   FORMAT('1')
      STOP
      END
```

APPENDIX B

LISTING OF COMPUTER PROGRAM FOR DRAINAGE SYSTEM DESIGN PROGRAM, DSDP

```
C       *****************************************************************
C       *****************************************************************
C       *****************************************************************
C       ***                                                           ***
C       ***                                                           ***
C       ***      X                  PROGRAM  DSDP               X     ***
C       ***     X X                      BY                    X X    ***
C       ***    X   X               SIE-TAN  CHIENG            X   X   ***
C       *** X DEC.X                                          X '79 X  ***
C       ***    X   X      AGRICULTURAL ENGINEERING DEPARTMENT   X   X   ***
C       ***     X X                                            X X    ***
C       ***      X       MACDONALD COLLEGE,  MCGILL UNIVERSITY   X     ***
C       ***                                                           ***
C       ***                                                           ***
C       *****************************************************************
C       *****************************************************************
C       *****************************************************************
C                                                                       C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                       C
C       ENTIRE PACKAGE CONSISTS OF:                                     C
C               MAIN,SLOPE,ALIGN,TORITE,TOLEFT,AXX,DRAIN1,DRAIN2,       C
C               D1P2,D1P3,D2P2.                                         C
C                                                                       C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C1      NB (I2) ------- # OF FIELD BOUNDARY.
C2      BX,BY (2F10.2) ------- CO-ORDINATES OF FIELD BOUNDARY.
C3      SP,BETA,DSCALE (3F10.2) ------- SPACING,ANGLE BETWEEN LATERAL
C4         AND COLLECTOR, AND THE SCALE OF THE DRAWING PLAN.
C5      NC (I2) ------- # OF BOUNDARY FOR DRAINAGE SUB-AREA.
C6      CX,CY (2F10.2) ------- COORDINATES OF SUB-AREA BOUNDARY.
C7      IOUT,JOINT,JNO (I2,2X,I1,4X,I1) ---- # OF COORDINATES OF COLLECTOR
C8         IF JOINT=1 CONNECTING POINTS EXIST FOR COLLECTOR & OUTLET.
C9      JNO IS THE # OF CONNECTING POINTS.
C10     OX,OY (2F10.2) ------  CO-ORDINATES OF COLLECTOR.
C11     PJX,PJY (2F10.2) ------- CO-ORDINATES OF CONNECTING POINTS.
C
        DIMENSION BX(10),BY(10),CX(10,10),CY(10,10)
     1            ,X1(10,50),Y1(10,50),X2(10,50),Y2(10,50)
     2            ,X3(10,50),Y3(10,50),XLEN(10,50),XLMIN(10)
     3            ,OX(10,10),OY(10,10),OX1(10),OY1(10),OX2(10),OY2(10)
     4            ,PJX(10,5),PJY(10,5),LINE(10),S(10,10),SPAC(10)
     5            ,NONC(10),SECLEN(10),COSEC(10,5),TLSUM(10)
     6            ,BANGLE(10),NOUT(10),JOINT(10)
C       INITIALIZATION OF ARRAYS.
        DO 04 I=1,10
        LINE(I)=0
        SECLEN(I)=0.0
        XLMIN(I)=999.0
        DO 03 J=1,50
        X1(I,J)=0.0
        Y1(I,J)=0.0
        X2(I,J)=0.0
```

```
      Y2(I,J)=0.0
      X3(I,J)=0.0
      Y3(I,J)=0.0
   03 CONTINUE
   04 CONTINUE
      RAD=3.1415926/180.0
      SUMLEN=0.0
      IDA=0
      LTSUM=0
      IGO=0
C     NB = # OF BOUNDARY CORNERS.
C     ICOPY BRANCHING DECISION.   ICOPY=1 COPY RESULTS TO DISK.
C     NO COPY TO DISK FILE WILL BE DONE IF ICOPY NOT =1.
C     IWRT = DISK OR TAPE DEVICE UNIT #.
      READ(5,1000) NB,ICOPY,IWRT
 1000 FORMAT(3I2)
      READ(5,1050) BX(1),BY(1)
      BXL=BX(1)
      BXS=BX(1)
      BYL=BY(1)
      BYS=BY(1)
      DO 1100 I=2,NB
      READ(5,1050) BX(I),BY(I)
 1050 FORMAT(2F10.2)
      IF(BX(I).GE.BXL) BXL=BX(I)
      IF(BX(I).LE.BXS) BXS=BX(I)
      IF(BY(I).GE.BYL) BYL=BY(I)
      IF(BY(I).LE.BYS) BYS=BY(I)
 1100 CONTINUE
 1150 IDA=IDA+1
      READ(5,1155,END=6500 ) SP,BETA,DSCALE
 1155 FORMAT(3F10.2)
      BANGLE(IDA)=BETA
      IF(SP.EQ.0.0.AND.BETA.EQ.0.0) GO TO 6500
      READ(5,1200) NC
 1200 FORMAT(I2)
      SUM=0.0
      NONC(IDA)=NC
      READ(5,1300) (CX(IDA,I),CY(IDA,I),I=1,NC)
 1300 FORMAT(2F10.2)
      CALL SLOPE(IDA,NC,CX,CY,S)
      READ(5,1400) NOUT(IDA),JOINT(IDA)
 1400 FORMAT(I2,1X,I2)
      IOUT=NOUT(IDA)
      READ(5,1500) (OX(IDA,I),OY(IDA,I),I=1,IOUT)
 1500 FORMAT(2F10.2)
      IF(IOUT.NE.2) GO TO 1600
      OX1(IDA)=OX(IDA,1)
      OY1(IDA)=OY(IDA,1)
      OX2(IDA)=OX(IDA,2)
      OY2(IDA)=OY(IDA,2)
      GO TO 1800
 1600 CALL ALIGN (OX,OY,IDA,IOUT,OX1,OY1,OX2,OY2,BETA,RAD,W,W1,W2)
 1800 IF(JOINT(IDA).EQ.0) GO TO 2000
      JNO=JOINT(IDA)
```

```
      READ(5,1900) (PJX(IDA,I),PJY(IDA,I),I=1,JNO)
1900  FORMAT(2F10.2)
2000  CONTINUE
      TL = SQRT((OX2(IDA)-OX1(IDA))**2 + (OY2(IDA)-OY1(IDA))**2)
      IF(IOUT.NE.2) GO TO 2200
      TLSUM(IDA)=TL
      GO TO 2400
2200  TLSUM(IDA)=0.0
      DO 2300 I=2,IOUT
      TL1=SQRT((OX(IDA,I)-OX(IDA,I-1))**2 +
     *           (OY(IDA,I)-OY(IDA,I-1))**2)
      COSEC(IDA,I-1)=TL1
      TLSUM(IDA)=TLSUM(IDA)+TL1
2300  CONTINUE
2400  DELC=SP/(DSCALE*2.0*SIN(BETA*RAD))
      DELC=ABS(DELC)
      NOL=TL/(2.0*DELC)
      IF(NOL*2*DELC.EQ.TL) GO TO 2600
      XN=TL/(2.0*DELC)
      NX=TL/(2.0*DELC)
      DIFF=XN-NX
      IF(DIFF.EQ.0.0) GO TO 2500
      NOL=NX+1
      GO TO 2600
2500  NOL=NX
2600  DELC=TL/(2.0*NOL)
      SPAC(IDA)= ABS(DELC*2.0*SIN(BETA*RAD))
      LINE(IDA)=NOL
C     TO GET THE TOTAL # OF LATERALS .
      LTSUM=LTSUM+NOL
C
      IF(IOUT.EQ.2) GO TO 2800
      TLA= SQRT((OX(IDA,2)-OX(IDA,1))**2 + (OY(IDA,2)-OY(IDA,1))**2)
      NOL1=(TLA-DELC)/(2.0*DELC) + 1
      NOL2=NOL-NOL1
      NOLS=NOL1+1
2800  XCHK=OX2(IDA)-OX1(IDA)
      YCHK=OY2(IDA)-OY1(IDA)
      WRITE(6,2900)
2900  FORMAT('1')
      WRITE(6,2910) (I,BX(I),BY(I),I=1,NB)
2910  FORMAT(1X,I2,3X, '(BX,BY) = ',2F8.2)
      WRITE(6,2920) BXL,BYL,BXS,BYS
2920  FORMAT(/,2X,'BXL=',F8.2,T23, 'BYL=',F8.2,/,
     * 2X,'BXS=',F8.2, T23, 'BYS=',F8.2,/)
      IF(IOUT.EQ.2) GO TO 2950
      WRITE(6,101) OX1(IDA),OY1(IDA),OX2(IDA),OY2(IDA), W,W1,W2,BETA
 101  FORMAT(1X,'(OX1,OY1)=',2F8.2,2X,'(OX2,OY2)=',2F8.2,/,
     * 1X,'W =',F7.2,2X,'W1 =',F7.2,2X,'W2 =',F7.2,2X,'BETA=',F7.2,/)
2950  WRITE(6,3000) IDA,NC,BETA,DELC,SPAC(IDA),SP,TL,NOL
3000  FORMAT(2X,'IDA=',I7, T23, 'NC=',I7,/,
     1 2X, 'BETA=',F7.2, T23, 'DELC=',F7.3,/,
     2 2X, 'SPACING=',F6.2, T23, 'ORIGINAL SPACING=',F7.2,/,
     3 2X, 'TL=',F7.2, T23, 'NOL=', I7,/)
      WRITE(6,3100)
```

```
3100  FORMAT( 2X,' INPUT FIELD BOUNDARIES :')
      DO 3500 I=1,NC
3500  WRITE(6,3600) I,CX(IDA,I),CY(IDA,I),S(IDA,I)
3600  FORMAT(2X,I3, 3X,'(CX,CY) =', 2(F7.2,3X),2X,'SLOPE=',F7.2)
      WRITE(6,3800)
3800  FORMAT(/,2X,'COLLECTOR CO-ORDINATES :',/)
      WRITE(6,4000) (IDA,I,OX(IDA,I),IDA,I,OY(IDA,I),I=1,IOUT)
4000  FORMAT(2X,'OX(', I2,',', I1, ' ) =',F7.2,3X,
     *           'OY(', I2, ',', I1, ' ) =',F7.2,/)
      IF(IOUT.EQ.2) GO TO 4200
      ITS=IOUT-1
      WRITE(6,4100) (I,COSEC(IDA,I),I=1,ITS)
4100  FORMAT(2X,' COSEC',I1, '=',F7.2,/)
4200  WRITE(6,4300) IDA,TLSUM(IDA)
4300  FORMAT(2X,'TLSUM(',I2, ' )=',F8.2,/)
      IF(JOINT(IDA).EQ.0) GO TO 4700
      WRITE(6,4500)
4500  FORMAT('0',' COLLECTOR CONNECTING-POINTS CO-ORDINATES :',/)
      WRITE(6,4600) (IDA,I,PJX(IDA,I),IDA,I,PJY(IDA,I),I=1,JNO)
4600  FORMAT(2X,'PJX(',I2, ',',I1,' )=',F7.2,3X,
     * 'PJY(',I2, ',',I1,' )=',F7.2,/)
      GO TO 5000
4700  WRITE(6,4800) IDA
4800  FORMAT('0',' MAIN: FIELD #',I2, ', JOINT=1 NOT ENCOUNTERED.',/,
     * ' NO CONNECTING POINT FOR COLLECTOR FOR THIS AREA.',/)
5000  IF(BETA.LT.0.0) GO TO 5100
      CALL   TOLEFT      (NC,IDA,BETA,S,CX,CY,X1,Y1,X2,Y2,X3,Y3,DELC,
     * OX1,OY1,OX2,OY2,OX,OY,LINE,XLEN,SPAC,XCHK,YCHK,NOL,ALPHA,
     * SL,DELX,DELY,W1,W2,W,NOLS,IOUT,RAD)
      GO TO 5500
5100  CALL   TORITE      (NC,IDA,BETA,S,CX,CY,X1,Y1,X2,Y2,X3,Y3,DELC,
     * OX1,OY1,OX2,OY2,OX,OY,LINE,XLEN,SPAC,XCHK,YCHK,NOL,ALPHA,
     * SL,DELX,DELY,W1,W2,W,NOLS,IOUT,RAD)
5500  CONTINUE
      IF(IGO.EQ.1) GO TO 1150
      WRITE(6,5600) ALPHA,SL,DELX,DELY
5600  FORMAT(2X,'ALPHA=',F7.2,10X,'SL=', F7.2,/,
     1 2X,'DELX=', F7.2,10X,'DELY=',F7.2,/)
      LINE(IDA)=NOL
      WRITE(6,5700) LINE(IDA),IDA
5700  FORMAT(2X,'THE TOTAL NUMBER OF LATERAL IS',I4,
     1 '   FOR FIELD NO. ',I2,//,
     2 2X,'NO',7X,'X1',7X,'Y1',7X,'X2',7X,'Y2',7X,'X3',7X,'Y3',
     3 6X,'XLEN',/,2X,67('-'),/)
      DO 5900 J=1,NOL
      SUM=SUM+XLEN(IDA,J)
      IF(XLMIN(IDA).GT.XLEN(IDA,J)) XLMIN(IDA)=XLEN(IDA,J)
      WRITE(6,5800)J,X1(IDA,J),Y1(IDA,J),X2(IDA,J),Y2(IDA,J),
     1 X3(IDA,J),Y3(IDA,J),XLEN(IDA,J)
5800  FORMAT(1X,I3,4X,7(F7.2,2X),/)
5900  CONTINUE
      WRITE(6,6000)
6000  FORMAT(2X,67('-'),//)
      SECLEN(IDA)=SUM
      WRITE(6,6100) SECLEN(IDA),XLMIN(IDA)
```

```
6100  FORMAT(2X,'THE TOTAL LENGTH OF ALL THE LATERALS FOR THIS SECTION '
     * , 'IS : ', F8.2,//,2X,
     * 'THE SHORTEST LATERAL IN THIS SECTION IS : ',F9.2,/)
      SUMLEN=SUMLEN+SECLEN(IDA)
6200  CONTINUE
      GO TO 1150
6500  IDA=IDA-1
C     PRINT OUT THE TOTAL LENGTH OF PIPE NEEDED FOR THIE FIELD.        C
      WRITE(6,6600) LTSUM,SUMLEN
6600  FORMAT(2X,67('-'), //, 2X, 'THIS FIELD HAS ',I3,' LATERALS AND',
     * ' THE TOTAL LENGTH IS :',F14.2, //,2X,67('-') )
C
      IF(ICOPY.NE.1) GO TO 9999
C     WHEN ICOPY=1 THAT MEANS ALL DATA SHOULD BE COPIED TO DISK
C     OR TAPE FOR FUTURE PLOTTING PURPOSES.
C     THIS WILL BE DONE IN THIS SECTION
C
C
C     COPYING DATA TO DISK FOR FUTURE PLOTTING PURPOSES.
C     IWRT IS THE UNIT OF THE DEVICE USED .
C
      WRITE(IWRT,8000) NB,IDA
8000  FORMAT(2I2)
      DO 8100 I=1,NB
8100  WRITE(IWRT,8200) BX(I),BY(I)
8200  FORMAT(2F10.2)
      WRITE(IWRT,8300) BXL,BYL,BXS,BYS
8300  FORMAT(4F10.2)
      DO 9000 I=1,IDA
      WRITE(IWRT,8400)SPAC(I),BANGLE(I),NONC(I),LINE(I),NOUT(I),JOINT(I)
8400  FORMAT(2F10.3,4I5)
      IOUT=NOUT(I)
      WRITE(IWRT,8200) (OX(I,J),OY(I,J),J=1,IOUT)
      LN=LINE(I)
      DO 8500 K=1,LN
      J=LN-(K-1)
8500  WRITE(IWRT,8600) X1(I,J),Y1(I,J),X2(I,J),Y2(I,J),X3(I,J),Y3(I,J),
     1  XLEN(I,J)
8600  FORMAT(7F10.2)
      IF(JOINT(I).EQ.0) GO TO 8800
      JNO=JOINT(I)
      WRITE(IWRT,8200) (PJX(I,J),PJY(I,J),J=1,JNO)
8800  WRITE(IWRT,8200) XLMIN(I),SECLEN(I)
9000  CONTINUE
      WRITE(IWRT,9100) SUMLEN
9100  FORMAT(F10.2)
C
C     END OF COPYING DATA TO DISK-FILE.
9999  STOP
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C                   SUB-PROGRAM  ALIGN                                 C
C     THIS SUBROUTINE ALIGNS THE COLLECTOR-SEGMENTS INTO ONE MAIN      C
C     LINE.  AFTER LOCATES THE  (X1,Y1)  POINTS ON THE MAIN LINE,      C
C     PROGRAM WILL PROJECTS THE POINTS BACK TO THE ORIGINAL            C
C     COLLECTOR-SEGMENT.                                               C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE ALIGN (OX,OY,IDA,IOUT,OX1,OY1,OX2,OY2,BETA,
     *  RAD,W,W1,W2)
      DIMENSION OX(10,10),OY(10,10),OX1(10),OY1(10),OX2(10),OY2(10)
      XA=OX(IDA,2)-OX(IDA,1)
      YA=OY(IDA,2)-OY(IDA,1)
      IF(XA.EQ.0.0.AND.YA.EQ.0.0) GO TO 10
      W1=ATAN2(YA,XA)/RAD
      IF(XA.LT.0.0.AND.YA.LT.0.0) W1=ATAN2(ABS(YA),ABS(XA))/RAD
      GO TO 20
   10 W1=90.0
   20 XB=OX(IDA,3)-OX(IDA,2)
      YB=OY(IDA,3)-OY(IDA,2)
      IF(XB.EQ.0.0.AND.YB.EQ.0.0) GO TO 30
      W2=ATAN2(YB,XB)/RAD
      IF(XB.LT.0.0.AND.YB.LT.0.0) W2=ATAN2(ABS(YB),ABS(XB))/RAD
      GO TO 40
   30 W2=90.0
   40 IF(BETA-0.0) 45,50,55
   45 IF(ABS(BETA).EQ.W1) W=0.0
      IF(ABS(BETA).LT.W1) W=W1-ABS(BETA)
      IF(ABS(BETA).GT.W1) W=W1+180.0-ABS(BETA)
      GO TO 100
   50 WRITE(6,47)
   47 FORMAT('0','BETA=0.0.  CHECK #50 IN ALIGN')
      GO TO 100
   55 TESTW=180.0-ABS(BETA)
      IF(TESTW.LT.W1) W=W1-TESTW
      IF(TESTW.EQ.W1) W=0.0
      IF(TESTW.GT.W1) W=W1+ABS(BETA)
  100 IF(W.EQ.90.0) GO TO 105
      AX = (OY(IDA,1)-OY(IDA,3)-OX(IDA,1)*TAN(W1*RAD)+
     * OX(IDA,3)*TAN(W*RAD) )/(TAN(W*RAD)-TAN(W1*RAD) )
      GO TO 110
  105 AX=OX(IDA,3)
  110 AY = OY(IDA,1)+TAN(W1*RAD)*(AX-OX(IDA,1))
      OX1(IDA)=OX(IDA,1)
      OY1(IDA)=OY(IDA,1)
      OX2(IDA)=AX
      OY2(IDA)=AY
      RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                       C
C      SUBROUTINE  SLOPE                                                C
C                                                                       C
C      THE SUB-PROGRAM SLOPE COMPUTES THE SLOPES OF ALL THE BOUDARIES   C
C      OF THE DRAINAGE FIELD.  SIDE #1 IS THE ONE THAT THE OUTLET       C
C      LIES IN IT.                                                      C
C                                                                       C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE SLOPE(IDA,NC,CX,CY,S)
      DIMENSION CX(10,10),CY(10,10),S(10,10)
      DO 10 I=2,NC
      DY=CY(IDA,I)-CY(IDA,I-1)
      DX=CX(IDA,I)-CX(IDA,I-1)
      IF(DX.EQ.0.0) GO TO 20
      S(IDA,I)=DY/DX
      GO TO 10
   20 S(IDA,I)=999.0
   10 CONTINUE
      DY=CY(IDA,1)-CY(IDA,NC)
      DX=CX(IDA,1)-CX(IDA,NC)
      IF(DX.EQ.0.0) GO TO 30
      S(IDA,1)=DY/DX
      GO TO 40
   30 S(IDA,1)=999.0
   40 RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                       C
C      FUNCTION  SUBROUTINE  AXX                                        C
C                                                                       C
C      THE FUNCTION SUB-PROGRAM CALCULATES THE ANGLE OF AX1.            C
C      AX1 IS THE ANGLE FORMS BY THE LINES  (X1,Y1)-(CX1,CY1) AND       C
C      (X1,Y1) - (OX2,OY2).                                             C
C      IF  AX1 < BETA THEN THE FIRST (X2,Y2) POINT WILL BE LIED IN      C
C      FIRST FIELD BOUDARY.   IF AX1 > BETA THE (X2,Y2) POINT WILL      C
C      START IN SECOND FIELD BOUNDARY.                                  C
C                                                                       C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      FUNCTION  AXX(IDA,CX,CY,X1,Y1,OX1,OY1,OX2,OY2)
      DIMENSION CX(10,10),CY(10,10),X1(10,50),Y1(10,50),OX1(10),
```

```
     * OY1(10),OX2(10),OY2(10)
      SA=SQRT((CX(IDA,1)-X1(IDA,1))**2+(CY(IDA,1)-Y1(IDA,1))**2)
      SB=SQRT((X1(IDA,1)-OX2(IDA))**2+ (Y1(IDA,1)-OY2(IDA))**2)
      SC=SQRT((CX(IDA,1)-OX2(IDA))**2+(CY(IDA,1)-OY2(IDA))**2)
      AXX=(SA**2+SB**2-SC**2)/(2.0*SA*SB)
      RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C                       SUBROUTINE  TOLEFT                             C
C                                                                      C
C      IF THE LATERALS ARE ON THE  LEFT HAND SIDE OF THE MAIN COLLECTOR C
C      THIS SUB-PROGRAM ( TOLEFT ) WILL BE CALLED TO DESIGN THEM.      C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE TOLEFT (NC,IDA,BETA,S,CX,CY,X1,Y1,X2,Y2,X3,Y3,DELC,
     * OX1,OY1,OX2,OY2,OX,OY,LINE,XLEN,SPAC,XCHK,YCHK,NOL,ALPHA,
     * SL,DELX,DELY,W1,W2,W,NOLS,IOUT,RAD)
      DIMENSION OX(10,10),OY(10,10)
      DIMENSION CX(10,10),CY(10,10),X1(10,50),Y1(10,50),X2(10,50),
     1 Y2(10,50),X3(10,50),Y3(10,50),S(10,10),OX1(10),OY1(10),
     2 OX2(10),OY2(10),LINE(10),XLEN(10,50),SPAC(10)
      IF((YCHK.EQ.0.0).OR.(ABS(YCHK).LT.0.001)) GO TO 100
      IF((XCHK.EQ.0.0).OR.(ABS(XCHK).LT.0.001)) GO TO 200
      ALPHA=ATAN2(YCHK,XCHK)/RAD
      IF(ALPHA.LT.0.0) ALPHA=180.0-ABS(ALPHA)
      DELX=SPAC(IDA)*COS(ALPHA*RAD)/(2.0*SIN(BETA*RAD))
      DELY=SPAC(IDA)*SIN(ALPHA*RAD)/(2.0*SIN(BETA*RAD))
      DELX=ABS(DELX)
      DELY=ABS(DELY)
      IF(ALPHA.GT.90.0) GO TO 110
      GO TO 118
 110  IF(OX1(IDA).LT.OX2(IDA).AND.OY1(IDA).GT.OY2(IDA)) GO TO 111
      DO 112 I=1,NOL
      X1(IDA,I)=OX1(IDA)-DELX*(2*I-1)
 112  Y1(IDA,I)=OY1(IDA)+DELY*(2*I-1)
      GO TO 115
 111  DO 113 I=1,NOL
      X1(IDA,I)=OX1(IDA)+DELX*(2*I-1)
 113  Y1(IDA,I)=OY1(IDA)-DELY*(2*I-1)
 115  IF(IOUT.EQ.2) GO TO 125
      DO 116 I=NOLS,NOL
      X1(IDA,I)= (Y1(IDA,I)-OY(IDA,2)+TAN(W2*RAD)*OX(IDA,2)-
     * TAN(W*RAD)*X1(IDA,I) )/( TAN(W2*RAD)-TAN(W*RAD))
 116  Y1(IDA,I)=OY(IDA,2)+TAN(W2*RAD)*(X1(IDA,I)-OX(IDA,2))
      GO TO 125
 118  IF(OX1(IDA).LT.OX2(IDA).AND.OY1(IDA).LT.OY2(IDA)) GO TO 119
```

```
      DO 120 I=1,NOL
      X1(IDA,I)=OX1(IDA)-DELX*(2*I-1)
120   Y1(IDA,I)=OY1(IDA)-DELY*(2*I-1)
      GO TO 115
119   DO 121 I=1,NOL
      X1(IDA,I)=OX1(IDA)+DELX*(2*I-1)
121   Y1(IDA,I)=OY1(IDA)+DELY*(2*I-1)
      GO TO 115
125   AX=AXX(IDA,CX,CY,X1,Y1,OX1,OY1,OX2,OY2)
      AX1=ARCOS(AX)*(1.0/RAD)
      WRITE(6,126) AX1
126   FORMAT(/,2X,'AX1=',F7.2,' AFTER STATEMENT #125 IN TOLEFT.',/)
      IF(ALPHA+BETA-180.0) 130,140,150
130   IF((ALPHA+BETA).EQ.90.0) GO TO 135
      SL=TAN((ALPHA+BETA)*RAD)
      GO TO 160
135   SL=999.0
      GO TO 160
140   SL=0.0
      GO TO 160
150   IF((ALPHA+BETA).EQ.270.0) GO TO 135
      SL=TAN((ALPHA+BETA-180.0)*RAD)
160   IF(AX1.GE.BETA) GO TO 170
      CALL  DRAIN1 (IDA,CX,CY,X1,Y1,X2,Y2,X3,Y3,S,OX1,OY1,
     * OX2,OY2,XLEN,SPAC,BETA,ALPHA,NC,SL,AX1,NOL,RAD)
      GO TO 350
170   CALL  DRAIN2 (IDA,CX,CY,X1,Y1,X2,Y2,X3,Y3,S,OX1,OY1,
     * OX2,OY2,XLEN,SPAC,BETA,ALPHA,NC,SL,AX1,NOL,RAD)
      GO TO 350
100   ALPHA=0.0
      DELX=DELC
      DELY=0.0
      IF(OX1(IDA).LT.OX2(IDA).AND.OY1(IDA).EQ.OY2(IDA)) GO TO 212
      DO 210 I=1,NOL
      X1(IDA,I)=OX1(IDA)-DELX*(2*I-1)
210   Y1(IDA,I)=OY1(IDA)
      GO TO 214
212   DO 213 I=1,NOL
      X1(IDA,I)=OX1(IDA)+DELX*(2*I-1)
213   Y1(IDA,I)=OY1(IDA)
214   IF(IOUT.EQ.2) GO TO 218
      DO 216 I=NOLS,NOL
      X1(IDA,I)= (Y1(IDA,I)-OY(IDA,2)+TAN(W2*RAD)*OX(IDA,2)-
     * TAN(W*RAD)*X1(IDA,I) )/( TAN(W2*RAD)-TAN(W*RAD))
216   Y1(IDA,I)=OY(IDA,2)+TAN(W2*RAD)*(X1(IDA,I)-OX(IDA,2))
218   IF(BETA.EQ.90.0) GO TO 220
      IF(BETA.GE.89.95.AND.BETA.LE.90.05) GO TO 220
      GO TO 125
220   AX=AXX(IDA,CX,CY,X1,Y1,OX1,OY1,OX2,OY2)
      AX1=ARCOS(AX)*(1.0/RAD)
      WRITE(6,221) AX1
221   FORMAT(/,2X,'AX1=',F7.2,' AFTER STATEMENT #220 IN TOLEFT.',/)
      IF(AX1-BETA) 230,240,240
230   CALL  DRAIN1 (IDA,CX,CY,X1,Y1,X2,Y2,X3,Y3,S,OX1,OY1,
     * OX2,OY2,XLEN,SPAC,BETA,ALPHA,NC,SL,AX1,NOL,RAD)
```

```
      GO TO 350
 240  CALL  DRAIN2 (IDA,CX,CY,X1,Y1,X2,Y2,X3,Y3,S,OX1,OY1,
     * OX2,OY2,XLEN,SPAC,BETA,ALPHA,NC,SL,AX1,NOL,RAD)
      GO TO 350
 200  ALPHA=90.0
      DELX=0.0
      DELY=DELC
      IF(OX1(IDA).EQ.OX2(IDA).AND.OY1(IDA).GT.OY2(IDA)) GO TO 261
      DO 260 I=1,NOL
      X1(IDA,I)=OX1(IDA)
 260  Y1(IDA,I)=OY1(IDA)+DELY*(2*I-1)
      GO TO 263
 261  DO 262 I=1,NOL
      X1(IDA,I)=OX1(IDA)
 262  Y1(IDA,I)=OY1(IDA)-DELY*(2*I-1)
 263  IF(IOUT.EQ.2) GO TO 268
      DO 266 I=NOLS,NOL
      X1(IDA,I)= (Y1(IDA,I)-OY(IDA,2)+TAN(W2*RAD)*OX(IDA,2)-
     * TAN(W*RAD)*X1(IDA,I) )/( TAN(W2*RAD)-TAN(W*RAD))
 266  Y1(IDA,I)=OY(IDA,2)+TAN(W2*RAD)*(X1(IDA,I)-OX(IDA,2))
 268  IF(BETA.EQ.90.0) GO TO 270
      IF(BETA.GE.89.95.AND.BETA.LE.90.05) GO TO 270
      GO TO 125
 270  AX=AXX(IDA,CX,CY,X1,Y1,OX1,OY1,OX2,OY2)
      AX1=ARCOS(AX)*(1.0/RAD)
      WRITE(6,271) AX1
 271  FORMAT(/,2X,'AX1=',F7.2,' AFTER STATEMENT #270 IN TOLEFT.',/)
      IF(AX1-BETA) 280,290,290
 280  CALL  DRAIN1 (IDA,CX,CY,X1,Y1,X2,Y2,X3,Y3,S,OX1,OY1,
     * OX2,OY2,XLEN,SPAC,BETA,ALPHA,NC,SL,AX1,NOL,RAD)
      GO TO 350
 290  CALL  DRAIN2 (IDA,CX,CY,X1,Y1,X2,Y2,X3,Y3,S,OX1,OY1,
     * OX2,OY2,XLEN,SPAC,BETA,ALPHA,NC,SL,AX1,NOL,RAD)
C
 350  RETURN
      END




CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C                       SUBROUTINE   TORITE                            C
C                                                                      C
C      IF THE LATERALS ARE ON THE RIGHT HAND SIDE OF THE MAIN COLLECTOR C
C      THIS SUB-PROGRAM ( TORITE ) WILL BE CALLED TO DESIGN THEM.       C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE TORITE (NC,IDA,BETA,S,CX,CY,X1,Y1,X2,Y2,X3,Y3,DELC,
     * OX1,OY1,OX2,OY2,OX,OY,LINE,XLEN,SPAC,XCHK,YCHK,NOL,ALPHA,
     * SL,DELX,DELY,W1,W2,W,NOLS,IOUT,RAD)
      DIMENSION OX(10,10),OY(10,10)
```

```
      DIMENSION CX(10,10),CY(10,10),X1(10,50),Y1(10,50),X2(10,50),
     1 Y2(10,50),X3(10,50),Y3(10,50),S(10,10),OX1(10),OY1(10),
     2 OX2(10),OY2(10),LINE(10),XLEN(10,50),SPAC(10)
      BETA=ABS(BETA)
      IF((YCHK.EQ.0.0).OR.(ABS(YCHK).LT.0.001)) GO TO 100
      IF((XCHK.EQ.0.0).OR.(ABS(XCHK).LT.0.001)) GO TO 200
      ALPHA=ATAN2(YCHK,XCHK)/RAD
      IF(ALPHA.LT.0.0) ALPHA=180.0-ABS(ALPHA)
      DELX=SPAC(IDA)*COS(ALPHA*RAD)/(2.0*SIN(BETA*RAD))
      DELY=SPAC(IDA)*SIN(ALPHA*RAD)/(2.0*SIN(BETA*RAD))
      DELX=ABS(DELX)
      DELY=ABS(DELY)
      IF(ALPHA.GT.90.0) GO TO 110
      GO TO 118
  110 IF(OX1(IDA).LT.OX2(IDA).AND.OY1(IDA).GT.OY2(IDA)) GO TO 111
      DO 112 I=1,NOL
      X1(IDA,I)=OX1(IDA)-DELX*(2*I-1)
  112 Y1(IDA,I)=OY1(IDA)+DELY*(2*I-1)
      GO TO 115
  111 DO 113 I=1,NOL
      X1(IDA,I)=OX1(IDA)+DELX*(2*I-1)
  113 Y1(IDA,I)=OY1(IDA)-DELY*(2*I-1)
  115 IF(IOUT.EQ.2) GO TO 125
      DO 116 I=NOLS,NOL
      X1(IDA,I)= (Y1(IDA,I)-OY(IDA,2)+TAN(W2*RAD)*OX(IDA,2)-
     * TAN(W*RAD)*X1(IDA,I) )/( TAN(W2*RAD)-TAN(W*RAD))
  116 Y1(IDA,I)=OY(IDA,2)+TAN(W2*RAD)*(X1(IDA,I)-OX(IDA,2))
      GO TO 125
  118 IF(OX1(IDA).LT.OX2(IDA).AND.OY1(IDA).LT.OY2(IDA)) GO TO 119
      DO 120 I=1,NOL
      X1(IDA,I)=OX1(IDA)-DELX*(2*I-1)
  120 Y1(IDA,I)=OY1(IDA)-DELY*(2*I-1)
      GO TO 115
  119 DO 121 I=1,NOL
      X1(IDA,I)=OX1(IDA)+DELX*(2*I-1)
  121 Y1(IDA,I)=OY1(IDA)+DELY*(2*I-1)
      GO TO 115
  125 AX=AXX(IDA,CX,CY,X1,Y1,OX1,OY1,OX2,OY2)
      AX1=ARCOS(AX)*(1.0/RAD)
      WRITE(6,126) AX1
  126 FORMAT(/,2X,'AX1=',F7.2,' AFTER STATEMENT #125 IN TORITE.',/)
      IF(ALPHA-0.0) 128,130,130
  128 ALPHA=180.0+ALPHA
  130 IF(ALPHA-BETA) 135,140,150
  135 IF((ABS(ALPHA-BETA)).EQ.90.0) GO TO 138
      SL=TAN((ALPHA-BETA)*RAD)
      GO TO 160
  138 SL=999.0
      GO TO 160
  140 SL=0.0
      GO TO 160
  150 IF((ALPHA-BETA).EQ.90.0) GO TO 138
      SL=TAN((ALPHA-BETA)*RAD)
  160 IF(AX1.GE.BETA) GO TO 170
      CALL  DRAIN1 (IDA,CX,CY,X1,Y1,X2,Y2,X3,Y3,S,OX1,OY1,
```

```
     * OX2,OY2,XLEN,SPAC,BETA,ALPHA,NC,SL,AX1,NOL,RAD)
      GO TO 350
170   CALL  DRAIN2 (IDA,CX,CY,X1,Y1,X2,Y2,X3,Y3,S,OX1,OY1,
     * OX2,OY2,XLEN,SPAC,BETA,ALPHA,NC,SL,AX1,NOL,RAD)
      GO TO 350
100   ALPHA=0.0
      DELX=DELC
      DELY=0.0
      IF(OX1(IDA).LT.OX2(IDA).AND.OY1(IDA).EQ.OY2(IDA)) GO TO 212
      DO 210 I=1,NOL
      X1(IDA,I)=OX1(IDA)-DELX*(2*I-1)
210   Y1(IDA,I)=OY1(IDA)
      GO TO 214
212   DO 213 I=1,NOL
      X1(IDA,I)=OX1(IDA)+DELX*(2*I-1)
213   Y1(IDA,I)=OY1(IDA)
214   IF(IOUT.EQ.2) GO TO 218
      DO 216 I=NOLS,NOL
      X1(IDA,I)= (Y1(IDA,I)-OY(IDA,2)+TAN(W2*RAD)*OX(IDA,2)-
     * TAN(W*RAD)*X1(IDA,I) )/( TAN(W2*RAD)-TAN(W*RAD))
216   Y1(IDA,I)=OY(IDA,2)+TAN(W2*RAD)*(X1(IDA,I)-OX(IDA,2))
218   IF(BETA.EQ.90.0) GO TO 220
      IF(BETA.GE.89.95.AND.BETA.LE.90.05) GO TO 220
      GO TO 125
220   AX=AXX(IDA,CX,CY,X1,Y1,OX1,OY1,OX2,OY2)
      AX1=ARCOS(AX)*(1.0/RAD)
      WRITE(6,221) AX1
221   FORMAT(/,2X,'AX1=',F7.2,' AFTER STATEMENT #220 IN TORITE.',/)
      IF(AX1-BETA) 230,240,240
230   CALL  DRAIN1 (IDA,CX,CY,X1,Y1,X2,Y2,X3,Y3,S,OX1,OY1,
     * OX2,OY2,XLEN,SPAC,BETA,ALPHA,NC,SL,AX1,NOL,RAD)
      GO TO 350
240   CALL  DRAIN2 (IDA,CX,CY,X1,Y1,X2,Y2,X3,Y3,S,OX1,OY1,
     * OX2,OY2,XLEN,SPAC,BETA,ALPHA,NC,SL,AX1,NOL,RAD)
      GO TO 350
200   ALPHA=90.0
      DELX=0.0
      DELY=DELC
      IF(OX1(IDA).EQ.OX2(IDA).AND.OY1(IDA).GT.OY2(IDA)) GO TO 261
      DO 260 I=1,NOL
      X1(IDA,I)=OX1(IDA)
260   Y1(IDA,I)=OY1(IDA)+DELY*(2*I-1)
      GO TO 263
261   DO 262 I=1,NOL
      X1(IDA,I)=OX1(IDA)
262   Y1(IDA,I)=OY1(IDA)-DELY*(2*I-1)
263   IF(IOUT.EQ.2) GO TO 268
      DO 266 I=NOLS,NOL
      X1(IDA,I)= (Y1(IDA,I)-OY(IDA,2)+TAN(W2*RAD)*OX(IDA,2)-
     * TAN(W*RAD)*X1(IDA,I) )/( TAN(W2*RAD)-TAN(W*RAD))
266   Y1(IDA,I)=OY(IDA,2)+TAN(W2*RAD)*(X1(IDA,I)-OX(IDA,2))
268   IF(BETA.EQ.90.0) GO TO 270
      IF(BETA.GE.89.95.AND.BETA.LE.90.05) GO TO 270
      GO TO 125
270   AX=AXX(IDA,CX,CY,X1,Y1,OX1,OY1,OX2,OY2)
```

```
      AX1=ARCOS(AX)*(1.0/RAD)
      WRITE(6,271) AX1
  271 FORMAT(/,2X,'AX1=',F7.2,' AFTER STATEMENT #270 IN TORITE.',/)
      IF(AX1-BETA) 280,290,290
  280 CALL  DRAIN1 (IDA,CX,CY,X1,Y1,X2,Y2,X3,Y3,S,OX1,OY1,
     * OX2,OY2,XLEN,SPAC,BETA,ALPHA,NC,SL,AX1,NOL,RAD)
      GO TO 350
  290 CALL  DRAIN2 (IDA,CX,CY,X1,Y1,X2,Y2,X3,Y3,S,OX1,OY1,
     * OX2,OY2,XLEN,SPAC,BETA,ALPHA,NC,SL,AX1,NOL,RAD)
  350 RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C                      SUBROUTINE  DRAIN1                              C
C                                                                      C
C     SUBPROGRAM DRAIN1 IS USED TO DESIGN THE SYSTEM WHEN AX1 < BETA.  C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE DRAIN1 (IDA,CX,CY,X1,Y1,X2,Y2,X3,Y3,S,
     * OX1,OY1,OX2,OY2,XLEN,SPAC,BETA,ALPHA,NC,SL,AX1,NOL,RAD)
      DIMENSION CX(10,10),CY(10,10),X1(10,50),Y1(10,50),X2(10,50),
     1 Y2(10,50),X3(10,50),Y3(10,50),S(10,10),OX1(10),OY1(10),
     2 OX2(10),OY2(10),LINE(10),XLEN(10,50),SPAC(10)
      MS=1
      NL=1
      KO=1
      TS= S(IDA,KO)
      TX=OX1(IDA)
      TY=OY1(IDA)
      TTS= S(IDA,KO+1)
      TTX=CX(IDA,KO)
      TTY=CY(IDA,KO)
  101 BL=SQRT((TTX-TX)**2+(TTY-TY)**2)
      CALL  D1P2 (ALPHA,BETA,AX1,IDA,NL,TS,TX,TY,TTS,TTX,TTY,
     * X1,X2,Y1,Y2,SL,NOXY2)
      SEG1=SQRT((TX-X2(IDA,NL))**2+(TY-Y2(IDA,NL))**2)
      IF(NL.EQ.NOL) GO TO 210
      NL=NL+1
      CALL  D1P2 (ALPHA,BETA,AX1,IDA,NL,TS,TX,TY,TTS,TTX,TTY,
     * X1,X2,Y1,Y2,SL,NOXY2)
      DELB=SQRT((X2(IDA,NL)-X2(IDA,NL-1))**2+
     *  (Y2(IDA,NL)-Y2(IDA,NL-1))**2)
      SEG=SQRT((X2(IDA,NL)-TX )**2+(Y2(IDA,NL)-TY)**2)
  102 IF(BL-SEG) 100,110,120
  100 IF(NL.EQ.2) GO TO 103
      IF(BL-SEGO) 130,140,150
  103 IF(BL-SEG1) 130,140,150
```

```
130   WRITE(6,135)
135   FORMAT(3X,' ERROR --- NO LATERAL IS NEEDED FOR THIS FIELD',
     *', PROGRAM TERMINATED AT STATEMENT #100 IN DRAIN1',/)
      IGO=1
      GO TO 260
140   NL=NL+1
      X2(IDA,NL)=TTX
      Y2(IDA,NL)=TTY
200   XM2=SL
      XM1=TS
      IF(XM2.EQ.999.0) GO TO 201
      IF(XM1.EQ.999.0) GO TO 202
      GO TO 203
201   H=SPAC(IDA)/2.0
      GO TO 205
202   P1P2=SQRT((X1(IDA,NL)-X2(IDA,NL))**2+(Y2(IDA,NL)-Y2(IDA,NL))**2)
      H=SPAC(IDA)*P1P2/(2.0*(X1(IDA,NL)-X2(IDA,NL)))
      GO TO 205
203   BX=ATAN((XM2-XM1)/(1.0+XM1*XM2))
      BX=ABS(BX)
      H=SPAC(IDA)/(2.0*SIN(BX))
205   CALL D1P3 (ALPHA,BETA,AX1,MS,NL,X1,Y1,X2,Y2,H,SL,SPAC,
     *  IDA,X3,Y3,XLEN,NOXY3)
      IF(NOXY3.EQ.0)  STOP
      NL=NL+1
      MS=NL
      IF(NL.GT.NOL) GO TO 260
      KO=KO+1
      TS=TTS
      TX=TTX
      TY=TTY
      IF(KO.EQ.NC) GO TO 145
      TTS= S(IDA,KO+1)
      TTX=CX(IDA,KO)
      TTY=CY(IDA,KO)
      GO TO 101
145   TTS= S(IDA,1)
      TTX=CX(IDA,KO)
      TTY=CY(IDA,KO)
      GO TO 101
150   GO TO 200
110   X2(IDA,NL)=TTX
      Y2(IDA,NL)=TTY
      NL=NL+1
      GO TO 200
120   IF(NL.LT.NOL) GO TO 170
210   XM2=SL
      XM1=TS
      IF(XM2.EQ.999.0) GO TO 211
      IF(XM1.EQ.999.0) GO TO 212
      GO TO 213
211   H=SPAC(IDA)/2.0
      GO TO 215
212   P1P2=SQRT((X1(IDA,NL)-X2(IDA,NL))**2+(Y2(IDA,NL)-Y2(IDA,NL))**2)
      H=SPAC(IDA)*P1P2/(2.0*(X1(IDA,NL)-X2(IDA,NL)))
```

```
      GO TO 215
 213  BX=ATAN((XM2-XM1)/(1.0+XM1*XM2))
      BX=ABS(BX)
      H=SPAC(IDA)/(2.0*SIN(BX))
 215  CALL D1P3 (ALPHA,BETA,AX1,MS,NL,X1,Y1,X2,Y2,H,SL,SPAC,
     *  IDA,X3,Y3,XLEN,NOXY3)
      IF(NOXY3.EQ.0)  STOP
      GO TO 260
 170  IF(BL-SEG-DELB) 230,240,250
 230  GO TO 200
 240  NL=NL+1
      X2(IDA,NL)=TTX
      Y2(IDA,NL)=TTY
      GO TO 200
 250  NL=NL+1
      CALL  D1P2 (ALPHA,BETA,AX1,IDA,NL,TS,TX,TY,TTS,TTX,TTY,
     * X1,X2,Y1,Y2,SL,NOXY2)
      SEGO=SEG
      SEG=SQRT((X2(IDA,NL)-TX)**2+(Y2(IDA,NL)-TY)**2)
      IF(NL.LT.NOL) GO TO 102
      GO TO 210
 260  RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C                     SUBROUTINE  DRAIN2                               C
C                                                                      C
C      SUBPROGRAM DRAIN2 IS USED TO DESIGN THE SYSTEM WHEN AX1 > BETA.  C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE DRAIN2 (IDA,CX,CY,X1,Y1,X2,Y2,X3,Y3,S,
     * OX1,OY1,OX2,OY2,XLEN,SPAC,BETA,ALPHA,NC,SL,AX1,NOL,RAD)
      DIMENSION CX(10,10),CY(10,10),X1(10,50),Y1(10,50),X2(10,50),
     1 Y2(10,50),X3(10,50),Y3(10,50),S(10,10),OX1(10),OY1(10),
     2 OX2(10),OY2(10),LINE(10),XLEN(10,50),SPAC(10)
      NL=1
      MS=1
      KO=1
      TS=S(IDA,KO)
      TX=CX(IDA,KO)
      TY=CY(IDA,KO)
      TTS= S(IDA,KO+1)
      TTX=CX(IDA,KO+1)
      TTY=CY(IDA,KO+1)
 101  BL=SQRT((TTX-TX)**2+(TTY-TY)**2)
      CALL  D2P2 (ALPHA,BETA,AX1,IDA,NL,TS,TX,TY,TTS,TTX,TTY,
     * X1,X2,Y1,Y2,SL,NOXY2,S,KO)
```

```
      SEG1=SQRT((TX-X2(IDA,NL))**2+(TY-Y2(IDA,NL))**2)
      IF(NL.EQ.NOL) GO TO 210
      NL=NL+1
      CALL  D2P2 (ALPHA,BETA,AX1,IDA,NL,TS,TX,TY,TTS,TTX,TTY,
     * X1,X2,Y1,Y2,SL,NOXY2,S,KO)
      DELB=SQRT((X2(IDA,NL)-X2(IDA,NL-1))**2+
     *  (Y2(IDA,NL)-Y2(IDA,NL-1))**2)
      SEG=SQRT((X2(IDA,NL)-TX )**2+(Y2(IDA,NL)-TY)**2)
102   IF(BL-SEG) 100,110,120
100   IF(NL.EQ.2) GO TO 103
      IF(BL-SEGO) 130,140,150
103   IF(BL-SEG1) 130,140,150
130   WRITE(6,135)
135   FORMAT(3X,' ERROR --- NO LATERAL IS NEEDED FOR THIS FIELD',
     *', PROGRAM TERMINATED AT STATEMENT #100 IN DRAIN2',/)
      IGO=1
      GO TO 260
140   NL=NL+1
      X2(IDA,NL)=TTX
      Y2(IDA,NL)=TTY
200   XM2=SL
      XM1=TTS
      IF(XM2.EQ.999.0) GO TO 201
      IF(XM1.EQ.999.0) GO TO 202
      GO TO 203
201   H=SPAC(IDA)/2.0
      GO TO 205
202   P1P2=SQRT((X1(IDA,NL)-X2(IDA,NL))**2+(Y2(IDA,NL)-Y2(IDA,NL))**2)
      H=SPAC(IDA)*P1P2/(2.0*(X1(IDA,NL)-X2(IDA,NL)))
      GO TO 205
203   BX=ATAN((XM2-XM1)/(1.0+XM1*XM2))
      BX=ABS(BX)
      H=SPAC(IDA)/(2.0*SIN(BX))
205   CALL D1P3 (ALPHA,BETA,AX1,MS,NL,X1,Y1,X2,Y2,H,SL,SPAC,
     *  IDA,X3,Y3,XLEN,NOXY3)
      IF(NOXY3.EQ.0)  STOP
      NL=NL+1
      MS=NL
      IF(NL.GT.NOL) GO TO 260
      KO=KO+1
      TS=TTS
      TX=TTX
      TY=TTY
      IF(KO.EQ.NC) GO TO 145
      TTS= S(IDA,KO+1)
      TTX=CX(IDA,KO+1)
      TTY=CY(IDA,KO+1)
      GO TO 101
145   TTS= S(IDA,1)
      TTX=CX(IDA,1)
      TTY=CY(IDA,1)
      GO TO 101
150   GO TO 200
110   X2(IDA,NL)=TTX
      Y2(IDA,NL)=TTY
```

```
      NL=NL+1
      GO TO 200
  120 IF(NL.LT.NOL) GO TO 170
  210 XM2=SL
      XM1=TTS
      IF(XM2.EQ.999.0) GO TO 211
      IF(XM1.EQ.999.0) GO TO 212
      GO TO 213
  211 H=SPAC(IDA)/2.0
      GO TO 215
  212 P1P2=SQRT((X1(IDA,NL)-X2(IDA,NL))**2+(Y2(IDA,NL)-Y2(IDA,NL))**2)
      H=SPAC(IDA)*P1P2/(2.0*(X1(IDA,NL)-X2(IDA,NL)))
      GO TO 215
  213 BX=ATAN((XM2-XM1)/(1.0+XM1*XM2))
      BX=ABS(BX)
      H=SPAC(IDA)/(2.0*SIN(BX))
  215 CALL D1P3 (ALPHA,BETA,AX1,MS,NL,X1,Y1,X2,Y2,H,SL,SPAC,
     *  IDA,X3,Y3,XLEN,NOXY3)
      IF(NOXY3.EQ.0)  STOP
      GO TO 260
  170 IF(BL-SEG-DELB) 230,240,250
  230 GO TO 200
  240 NL=NL+1
      X2(IDA,NL)=TTX
      Y2(IDA,NL)=TTY
      GO TO 200
  250 NL=NL+1
      CALL  D2P2 (ALPHA,BETA,AX1,IDA,NL,TS,TX,TY,TTS,TTX,TTY,
     * X1,X2,Y1,Y2,SL,NOXY2,S,KO)
      SEGO=SEG
      SEG=SQRT((X2(IDA,NL)-TX)**2+(Y2(IDA,NL)-TY)**2)
      IF(NL.LT.NOL) GO TO 102
      GO TO 210
  260 RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                       C
C                    SUBROUTINE  D1P2                                   C
C                                                                       C
C     SUBPROGRAM D1P2 COMPUTES ALL THE (X2,Y2) POINTS FOR DRAIN1.       C
C                                                                       C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE  D1P2 (ALPHA,BETA,AX1,IDA,NL,TS,TX,TY,
     *  TTS,TTX,TTY,X1,X2,Y1,Y2,SL,NOXY2)
      DIMENSION X1(10,50),Y1(10,50),S(10,10),X2(10,50),Y2(10,50),
     * SPAC(10),XLEN(10,50)
      RAD=3.1415926/180.0
```

```
      IF((ALPHA.EQ.0.0).AND.(BETA.EQ.90.0).AND.(AX1.LT.BETA)) GO TO 100
      IF((ALPHA.EQ.90.0).AND.(BETA.EQ.90.0).AND.(AX1.LT.BETA))GO TO 200
      IF((ALPHA.NE.0.0).AND.(BETA.NE.180.).AND.(AX1.LT.BETA)) GO TO 300
      NOXY2=0
      WRITE(6.50)
   50 FORMAT('  ERROR---NO (X2,Y2) POINT --- CHECK D1P2 SUBPROGRAM',//)
      GO TO 500
  100 IF(TS.EQ.999.0) GO TO 110
      X2(IDA,NL)=X1(IDA,NL)
      Y2(IDA,NL)=TY+TS*(X2(IDA,NL)-TX)
      GO TO 500
  110 WRITE(6.120)
  120 FORMAT('  ERROR--- LATERAL IS PARELLEL TO BOUNDARY BUT ',
     1'INTERSECTION OCCURS. CHECK STATEMENT NO. 100 IN D1P2.')
      GO TO 500
  200 IF(TS.EQ.999.0) GO TO 210
      Y2(IDA,NL)=Y1(IDA,NL)
      X2(IDA,NL)=TX+(Y2(IDA,NL)-TY)/TS
      GO TO 500
  210 Y2(IDA,NL)=Y1(IDA,NL)
      X2(IDA,NL)=TTX
      GO TO 500
  300 IF(TS.EQ.999.0.OR.SL.EQ.999.0) GO TO 310
      X2(IDA,NL)=(Y1(IDA,NL)-TTY+TS*TTX-SL*X1(IDA,NL))/(TS-SL)
      Y2(IDA,NL)= TTY+TS*(X2(IDA,NL)-TTX)
      GO TO 500
  310 IF(SL.NE.999.0) GO TO 330
      WRITE(6.320)
  320 FORMAT('  IMPOSSIBLE OUTCOME OCCURS ! SL & TS ARE VERTICAL LINES
     *--- CHECK STATEMENTS 300-310 IN D1P2')
      GO TO 500
  330 IF((ALPHA+BETA).EQ.180.0) GO TO 350
      X2(IDA,NL)=TX
      Y2(IDA,NL)=Y1(IDA,NL)+SL*(X2(IDA,NL)-X1(IDA,NL))
      GO TO 500
  350 X2(IDA,NL)=TX
      Y2(IDA,NL)=Y1(IDA,NL)
  500 RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C                       SUBROUTINE  D2P2                               C
C                                                                      C
C     SUBPROGRAM D2P2 COMPUTES ALL THE (X2,Y2) POINTS FOR DRAIN2.       C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE  D2P2 (ALPHA,BETA,AX1,IDA,NL,TS,TX,TY,
```

```
     *  TTS,TTX,TTY,X1,X2,Y1,Y2,SL,NOXY2,S,KO)
      DIMENSION X1(10,50),Y1(10,50),S(10,10),X2(10,50),Y2(10,50),
     * SPAC(10),XLEN(10,50)
      RAD=3.1415926/180.0
      IF((ALPHA.EQ.0.0).AND.(BETA.EQ.90.0).AND.(AX1.GE.BETA)) GO TO 100
      IF((ALPHA.EQ.90.0).AND.(BETA.EQ.90.0).AND.(AX1.GE.BETA)) GO TO 200
      IF((ALPHA.NE.0.0).AND.(BETA.NE.180.).AND.(AX1.GE.BETA)) GO TO 300
      NOXY2=0
      WRITE(6,50)
 50   FORMAT('  ERROR---NO (X2,Y2) POINT --- CHECK D2P2 SUBPROGRAM',//)
100   IF(TTS.EQ.999.0) GO TO 110
      X2(IDA,NL)=X1(IDA,NL)
      Y2(IDA,NL)=TY+TTS*(X2(IDA,NL)-TX)
      GO TO 500
110   WRITE(6,120)
120   FORMAT('  ERROR--- LATERAL IS PARELLEL TO BOUNDARY BUT ',
     1'INTERSECTION OCCURS. CHECK STATEMENT NO. 100 IN D2P2.')
      GO TO 500
200   IF(TTS.EQ.999.0) GO TO 210
      Y2(IDA,NL)=Y1(IDA,NL)
      X2(IDA,NL)=TX+(Y2(IDA,NL)-TY)/TTS
      GO TO 500
210   Y2(IDA,NL)=Y1(IDA,NL)
      X2(IDA,NL)=TTX
      GO TO 500
300   IF(TTS.EQ.999.0) GO TO 310
      X2(IDA,NL)=(Y1(IDA,NL)-TY+TTS*TX-SL*X1(IDA,NL))/(TTS-SL)
      Y2(IDA,NL)=TY+TTS*(X2(IDA,NL)-TX)
      GO TO 500
310   IF(SL.EQ.999.0) GO TO 350
      IF(SL.EQ.0.0) GO TO 340
      X2(IDA,NL)=TX
      Y2(IDA,NL)=Y1(IDA,NL)+SL*(X2(IDA,NL)-X1(IDA,NL))
      GO TO 500
340   X2(IDA,NL)=TX
      Y2(IDA,NL)=Y1(IDA,NL)
      GO TO 500
350   X2(IDA,NL)=X1(IDA,NL)
      Y2(IDA,NL)=TTY+(X2(IDA,NL)-TTX)* S(IDA,KO+1)
500   RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                       C
C                       SUBROUTINE  D1P3                                C
C                                                                       C
C     SUBPROGRAM D1P3 COMPUTES THE POINTS (X3,Y3) WHICH ARE HALF        C
C     SPACING BACK FROM THE FIELD BOUNDARY.                             C
```

```
C                                                                                    C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE  D1P3 (ALPHA,BETA,AX1,MS,NL,X1,Y1,X2,Y2,H,SL,SPAC,
     * IDA,X3,Y3,XLEN,NOXY3)
      DIMENSION X1(10,50),Y1(10,50),S(10,10),X2(10,50),Y2(10,50),
     * SPAC(10),XLEN(10,50),X3(10,50),Y3(10,50)
      RAD=3.1415926/180.0
      IF((ALPHA.EQ.0.0).AND.(BETA.EQ.90.0)) GO TO 100
      IF((ALPHA.EQ.90.0).AND.(BETA.EQ.90.0)) GO TO 300
      IF((ALPHA.NE.0.0).AND.(BETA.NE.180.)) GO TO 500
      NOXY3=0
      WRITE(6,50)
   50 FORMAT('  ERROR---NO (X2,Y2) POINT --- CHECK D1P3 SUBPROGRAM',//)
      GO TO 800
  100 DO 200 I=MS,NL
      X3(IDA,I) =X1(IDA,I)
      Y3(IDA,I)= Y2(IDA,I)-SPAC(IDA)/2.0
  200 XLEN(IDA,I)= SQRT((Y3(IDA,I)-Y1(IDA,I))**2+
     *                    (X3(IDA,I)-X1(IDA,I))**2)
      GO TO 700
  300 DO 400 I=MS,NL
      X3(IDA,I)= X2(IDA,I)-SPAC(IDA)/2.0
      Y3(IDA,I)= Y1(IDA,I)
  400 XLEN(IDA,I)= SQRT((Y3(IDA,I)-Y1(IDA,I))**2+
     *                    (X3(IDA,I)-X1(IDA,I))**2)
      GO TO 700
  500 IF((ALPHA+BETA).EQ.90..OR.(ALPHA+BETA).EQ.270.) GO TO 100
      IF((ALPHA+BETA).EQ.180.0) GO TO 300
      FACTOR=SQRT(H**2/(1.0+SL**2))
      ASL=ABS(SL)
      IF(X2(IDA,MS)-X1(IDA,MS)) 510,520,530
  510 IF(Y2(IDA,MS)-Y1(IDA,MS)) 610,620,630
  610 DO 640 I=MS,NL
      X3(IDA,I)=X2(IDA,I)+FACTOR
      Y3(IDA,I)=Y2(IDA,I)+ASL*(X3(IDA,I)-X2(IDA,I))
  640 XLEN(IDA,I)= SQRT((Y3(IDA,I)-Y1(IDA,I))**2+
     *                    (X3(IDA,I)-X1(IDA,I))**2)
      GO TO 700
  620 DO 650 I=MS,NL
      X3(IDA,I)=X2(IDA,I)+FACTOR
      Y3(IDA,I)=Y2(IDA,I)
  650 XLEN(IDA,I)= SQRT((Y3(IDA,I)-Y1(IDA,I))**2+
     *                    (X3(IDA,I)-X1(IDA,I))**2)
      GO TO 700
  630 DO 660 I=MS,NL
      X3(IDA,I)=X2(IDA,I)+FACTOR
      Y3(IDA,I)=Y2(IDA,I)-ASL*(X3(IDA,I)-X2(IDA,I))
  660 XLEN(IDA,I)= SQRT((Y3(IDA,I)-Y1(IDA,I))**2+
     *                    (X3(IDA,I)-X1(IDA,I))**2)
      GO TO 700
  520 IF(Y2(IDA,MS)-Y1(IDA,MS)) 710,720,730
  710 DO 740 I=MS,NL
      X3(IDA,I)=X2(IDA,I)
      Y3(IDA,I)=Y2(IDA,I)+ASL*(X3(IDA,I)-X2(IDA,I))
  740 XLEN(IDA,I)= SQRT((Y3(IDA,I)-Y1(IDA,I))**2+
```

```
     *                        (X3(IDA,I)-X1(IDA,I))**2)
      GO TO 700
720   DO 750 I=MS,NL
      X3(IDA,I)=X2(IDA,I)
      Y3(IDA,I)=Y2(IDA,I)
750   XLEN(IDA,I)= SQRT((Y3(IDA,I)-Y1(IDA,I))**2+
     *                        (X3(IDA,I)-X1(IDA,I))**2)
      GO TO 700
730   DO 760 I=MS,NL
      X3(IDA,I)=X2(IDA,I)
      Y3(IDA,I)=Y2(IDA,I)-ASL*(X3(IDA,I)-X2(IDA,I))
760   XLEN(IDA,I)= SQRT((Y3(IDA,I)-Y1(IDA,I))**2+
     *                        (X3(IDA,I)-X1(IDA,I))**2)
      GO TO 700
530   IF(Y2(IDA,MS)-Y1(IDA,MS)) 810,820,830
810   DO 840 I=MS,NL
      X3(IDA,I)=X2(IDA,I)-FACTOR
      Y3(IDA,I)=Y2(IDA,I)-ASL*(X3(IDA,I)-X2(IDA,I))
840   XLEN(IDA,I)= SQRT((Y3(IDA,I)-Y1(IDA,I))**2+
     *                        (X3(IDA,I)-X1(IDA,I))**2)
      GO TO 700
820   DO 850 I=MS,NL
      X3(IDA,I)=X2(IDA,I)-FACTOR
      Y3(IDA,I)=Y2(IDA,I)
850   XLEN(IDA,I)= SQRT((Y3(IDA,I)-Y1(IDA,I))**2+
     *                        (X3(IDA,I)-X1(IDA,I))**2)
      GO TO 700
830   DO 860 I=MS,NL
      X3(IDA,I)=X2(IDA,I)-FACTOR
      Y3(IDA,I)=Y2(IDA,I)+ASL*(X3(IDA,I)-X2(IDA,I))
860   XLEN(IDA,I)= SQRT((Y3(IDA,I)-Y1(IDA,I))**2+
     *                        (X3(IDA,I)-X1(IDA,I))**2)
700   NOXY3=999
800   RETURN
      END
```

APPENDIX C

LISTING OF COMPUTER PROGRAM FOR DRAINAGE SYSTEM LAYOUT PROGRAM, DSLP

```
C       ****************************************************************
C       ****************************************************************
C       ****************************************************************
C       ***                                                          ***
C       ***                                                          ***
C       ***      X                 PROGRAM  DSLP               X     ***
C       ***     X X                    BY                     X X    ***
C       ***    X   X              SIE-TAN  CHIENG            X   X   ***
C       ***   X DEC.X                                       X '79 X  ***
C       ***    X   X      AGRICULTURAL ENGINEERING DEPARTMENT X   X  ***
C       ***     X X                                           X X    ***
C       ***      X      MACDONALD COLLEGE,  MCGILL UNIVERSITY  X     ***
C       ***                                                          ***
C       ***                                                          ***
C       ****************************************************************
C       ****************************************************************
C       ****************************************************************
C
C       PROGRAM "DSLP"  (DRAINAGE SYSTEM LAYOUT PROGRAM) IS WRITTEN
C       FOR DRAWING ALL THE INFORMATION AND SYMBOLS FOR A DRAINAGE
C       PLAN.
C
C       THE ENTIRE PACKAGE CONSISTS OF A MAIN PROGRAM AND
C       TWENTY-FIVE SUBPROGRAMS.
C       SUBPROGRAMS ARE: ARO1, DDXY, MULTI, BUILD2, BOUND3, COLEN4,
C                        DRAW5, FLOWA, FLOWB, ELE6, FENCE7, GRADE8,
C                        MARSH9, PKEY10, POUT11, RAIL12, REF13,
C                        ROAD14, STM15, TAB16, TBLK17, TREE18,
C                        XTOY19, BM20, WRIT21, OUT22.
C
      DIMENSION X1(10,50),Y1(10,50),X3(10,50),Y3(10,50),XLEN(10,50)
     *           ,PJX(10,5),PJY(10,5),XLMIN(10),SECLEN(10)
     *          ,BX(10),BY(10),SPAC(10),BANGLE(10),NOUT(10),NONC(10)
     *          ,LINE(10),JOINT(10),X2(10,50),Y2(10,50),OX(10,5)
     *          ,OY(10,5),S31(10,50)
      INTEGER*2 LAB,LABAL(15)
      DATA  LABAL/' A',' B',' C',' D',' E',' F',' G',' H',' J',
     *            ' K',' L',' M',' N',' O',' P'/
C     MAIN PROGRAM
      CALL PLOTON
      READ(5,7700) IRD,IWRT,IGRID,IFLO,NGRIDX,NGRIDY
 7700 FORMAT(4I2,2I3)
      READ(5,7800) DSCALE,CHH,CHC,DW,DH,WP ,CEM
 7800 FORMAT(7F10.4)
      TW=5.0
      IF(DH.GT.15.0) TW=7.0
      RAD=3.1415926/180.0
      X0 = 0.0
      Y0 = 0.0
      XL1=1.0
      YL1=1.0
      XL2=DW-TW
      YL2=DH-1.0
      XP1=DW+0.1
```

```
      YP1=DW+0.1
      CALL PLTSZE(XP1,YP1)
C
C     READ IN DATA FROM CARDS OR STORAGE DEVICE
C
      READ(IRD,8000) NB,IDA
8000  FORMAT(2I2)
      DO 8100 I=1,NB
8100  READ ( IRD,8200) BX(I),BY(I)
8200  FORMAT(2F10.2)
      READ ( IRD,8300) BXL,BYL,BXS,BYS
8300  FORMAT(4F10.2)
      DO 9000 I=1,IDA
      READ ( IRD,8400)SPAC(I),BANGLE(I),NONC(I),LINE(I),NOUT(I),JOINT(I)
8400  FORMAT(2F10.3,4I5)
      IOUT=NOUT(I)
      READ ( IRD,8200) (OX(I,J),OY(I,J),J=1,IOUT)
      LN=LINE(I)
      DO 8500 J=1,LN
8500  READ ( IRD,8600) X1(I,J),Y1(I,J),X2(I,J),Y2(I,J),X3(I,J),Y3(I,J),
     1  XLEN(I,J)
8600  FORMAT(7F10.2)
      IF(JOINT(I).EQ.0) GO TO 8800
      JNO=JOINT(I)
      READ ( IRD,8200) (PJX(I,J),PJY(I,J),J=1,JNO)
8800  READ ( IRD,8200) XLMIN(I),SECLEN(I)
9000  CONTINUE
      READ ( IRD,9100) SUMLEN
9100  FORMAT(F10.2)
      DO 9500 J=1,IDA
      LN=LINE(J)
      DO 9400 JJ=1,LN
      READ(5,9250) S31(J,JJ)
9250  FORMAT(F10.5)
9400  CONTINUE
9500  CONTINUE
C     PS ---  PENSIZE OR CHARACTER HEIGHT FOR FLOW ARROW PLOTTING
      PS=0.10
C     ------------------------------------------------------------------
C     DECISION AND BRANCHING TO DIFFERENT SUBROUTINES.
C     ------------------------------------------------------------------
 300  READ(5,310,END=900)L1,L2,L3,L4,DATA1,DATA2,DATA3,DATA4,
     *                   DATA5,DATA6,DATA7,DATA8,NO1
 310  FORMAT(2I1,I2,I1,5X,8F7.2,4X,I2)
      IF(L1.EQ.0.AND.L2.EQ.0) GO TO 902
      IF(L3.EQ.0) GO TO 300
      IF(L2.EQ.2) GO TO 400
      GO TO (401,402,403,404,405,406,407,408,409,410,411,412,413,414,
     *       415,416,417,418,419,420,421,422),L3
      GO TO 300
C     CHANGE THE PLOTTER PEN SIZE.
 400  CALL PLOT(0.0,0.0,-3)
      GO TO 300
 401  CALL   ARO1(L3,L4,XL1,YL1,XL2,YL2,DATA1,DATA2,DATA3,DATA4)
      GO TO 300
```

```
402   CALL BUILD2(L3,L4,DATA1,DATA2,DATA3)
      GO TO 300
403   CALL BOUND3(L3,L4,XL2,DW,DH,DATA1,DATA2,DATA3,DATA4)
      GO TO 300
404   CALL COLEN4(L3,L4,DATA1,DATA2,DATA3,10)
      GO TO 300
405   CALL        DRAW5(OX,OY,X1,Y1,X3,Y3,XLEN,NOUT,LINE,IDA,PS,S31,
     * XO,YO,RAD,BX,BY,NB,LABAL,DSCALE,IFLO,CEM)
      GO TO 300
406   CALL ELE6  (L3,L4,DATA1,DATA2,DATA3,DATA4,NO1)
      GO TO 300
407   CALL FENCE7(L3,L4,DATA1,DATA2,DATA3,DATA4,DATA5)
      GO TO 300
408   CALL GRADE8(L3,L4,DATA1,DATA2,DATA3,DATA4,DATA5,NO1)
      GO TO 300
409   CALL MARSH9(L3,L4,DATA1,DATA2,DATA3)
      GO TO 300
410   CALL PKEY10(L3,L4,DW,DH,TW,DATA1)
      GO TO 300
411   CALL POUT11(L3,L4,DATA1,DATA2,DATA3,DATA4,DATA5,DATA6)
      GO TO 300
412   CALL RAIL12(L3,L4,DATA1,DATA2,DATA3,DATA4,DATA5)
      GO TO 300
413   CALL REF13 (L3,L4,DW,DH,TW,DATA1,DATA2,DATA3,NO1)
      GO TO 300
414   CALL ROAD14(L3,L4,DATA1,DATA2,DATA3,DATA4,DATA5)
      GO TO 300
415   CALL STM15 (L3,L4,DATA1,DATA2,DATA3,DATA4,DATA5,DATA6)
      GO TO 300
416   CALL        TAB16(CHH,CHC,DSCALE,DH,XO,YO,LAB,LABAL,IDA,
     * LINE,XLEN,SUMLEN,CEM,DATA1)
      GO TO 300
417   CALL TBLK17(L1,L2,L3,L4,DW,DH,TW,XL2)
      GO TO 300
418   CALL TREE18(L3,L4,DATA1,DATA2,DATA3)
      GO TO 300
419   CALL XTOY19(L3,L4,DATA1,DATA2,DATA3,DATA4)
      GO TO 300
420   CALL BM20  (L3,L4,DATA1,DATA2,DATA3)
      GO TO 300
421   CALL WRIT21(L3,L4,DATA1,DATA2,DATA3)
      GO TO 300
422   CALL OUT22(L3,L4,DATA1,DATA2,DATA3)
      GO TO 300
900   WRITE(6,901)         L1,L2,L3,L4,DATA1,DATA2,DATA3,DATA4,
     *                     DATA5,DATA6,DATA7,DATA8,NO1
901   FORMAT('0',' UNIT 5 ENCOUNTERED. LAST CARD READ WAS :',/,
     *          1X,2I1,I2,I1,5X,8F7.2,4X,I2)
902   IF(IGRID.NE.1) GO TO 905
      IF(NGRIDX.LE.0.OR.NGRIDY.LE.0) GO TO 903
      CALL GRID(1.0,1.0,1.0,1.0,NGRIDX,NGRIDY)
      GO TO 905
903   WRITE(6,904)
904   FORMAT(/, ' GRID # IS LESS OR EQUAL TO 0 FOR X/Y DIRECTION',/)
905   CONTINUE
```

```
      CALL ENDPLT
      STOP
      END




      SUBROUTINE   ARO1(L3,L4,XL1,YL1,XL2,YL2,X1,Y1,D1,A1)
C     ------------------------------------------------------------------
C     ARROW : TO DRAW A NORTH ARROW
C
C     X1,Y1 --- CO-ORDINATES OF THE LOCATION FOR NORTH ARROW.
C     D1 ------ TOTAL LENGTH OF THE ARROW.
C     A1 ------ ANGLE OF THE ARROW WITH RESPECT TO X-AXIS.
C
C     ------------------------------------------------------------------
      DIMENSION A(2,19)
      DATA A/ 0.4375, 0.0250, 0.5000, 0.0250, 0.4500,-0.0250,
     1        0.5000,-0.0250, 0.4375,-0.0250, 0.4875, 0.0250,
     2        0.3750, 0.0   , 0.1000, 0.0250, 0.1250, 0.0   ,
     3        0.1000,-0.0250,-0.4375, 0.0   ,-0.4625, 0.0250,
     4       -0.2125, 0.0250,-0.1875, 0.0   ,-0.2125,-0.0250,
     5       -0.4625,-0.0250, 0.0   , 0.0750, 0.0   ,-0.0750,
     6        0.0   , 0.0/
      IF(X1.LT.XL1.OR.X1.GE.XL2)GO TO 07
      IF(Y1.LT.YL1.OR.Y1.GE.YL2)GO TO 07
      DO 01 J=1,19
      DO 01 I=1,2
      A(I,J) = D1*A(I,J)
   01 CONTINUE
      DO 02 J=1,19
      CALL DDXY(A(1,J),A(2,J),XM,YM,A1)
      A(1,J) = XM
      A(2,J) = YM
   02 CONTINUE
      DO 03 J=1,19
      A(1,J) = A(1,J) + X1
      A(2,J) = A(2,J) + Y1
   03 CONTINUE
      XR1 = 0.0188*D1
      XR2 = 0.0375*D1
      CALL DASH(A(1,1),A(2,1),A(1,2),A(2,2),0.0)
      CALL MULTI(A(1,2),A(2,2),A(1,6),A(2,6),A(1,3),A(2,3),
     1           A(1,5),A(2,5),4)
      CALL DASH(A(1,5),A(2,5),A(1,4),A(2,4),0.0)
      CALL MULTI(A(1,8),A(2,8),A(1,9),A(2,9),A(1,7),A(2,7),
     1           A(1,7),A(2,7),5)
      CALL DASH(A(1,7),A(2,7),A(1,10),A(2,10),0.0)
      CALL DASH(A(1,9),A(2,9),A(1,8),A(2,8),0.0)
      CALL DASH(A(1,9),A(2,9),A(1,14),A(2,14),0.0)
      CALL DASH(A(1,17),A(2,17),A(1,18),A(2,18),0.0)
```

```
      CALL DASH(A(1,10),A(2,10),A(1,9),A(2,9),0.0)
      CALL CIRCLE(A(1,19),A(2,19),XR1)
      CALL CIRCLE(A(1,19),A(2,19),XR2)
      CALL MULTI(A(1,14),A(2,14),A(1,15),A(2,15),A(1,11),A(2,11),
     1          A(1,16),A(2,16),5)
      CALL DASH(A(1,16),A(2,16),A(1,11),A(2,11),0.0)
      CALL DASH(A(1,11),A(2,11),A(1,12),A(2,12),0.0)
      CALL DASH(A(1,12),A(2,12),A(1,13),A(2,13),0.0)
      CALL DASH(A(1,13),A(2,13),A(1,14),A(2,14),0.0)
      CALL DASH(A(1,14),A(2,14),A(1,15),A(2,15),0.0)
      GO TO 15
   07 WRITE(6,12)
      GO TO 15
   12 FORMAT('0','ARROW: NORTH ARROW FALLS OUTSIDE OF MAP BOUNDARY.')
   15 RETURN
      END




      SUBROUTINE DDXY(X,Y,XM,YM,A1)
C     ----------------------------------------------------------------
C     DDXY: THIS SUBROUTINE CALCULATES THE NEW X-Y COORDINATES OF A POIN
C     ROTATED COUNTER-CLOCKWISE ABOUT ITS ORIGIN.
C     ----------------------------------------------------------------
      IF(X.EQ.0.0.AND.Y.EQ.0.0)GO TO 01
      R  = SQRT(X**2 + Y**2)
      A  = ATAN2(Y,X)
      A  = A + A1*3.1415926/180.0
      XM = R*COS(A)
      YM = R*SIN(A)
      GO TO 02
   01 XM = 0.0
      YM = 0.0
   02 CONTINUE
      RETURN
      END




      SUBROUTINE MULTI(X1,Y1,X2,Y2,X3,Y3,X4,Y4,N)
C     ----------------------------------------------------------------
C     SHADED AREA PLOTTING SECTION. THE FIRST LINE IS DRAWN BETWEEN POIN
C     1 AND 3. INCREMENTATION IS FROM 1 TO 2 AND FROM 3 TO 4.
C     ----------------------------------------------------------------
      T1 = X1 - X2
```

```
      T2 = Y1 - Y2
      XA = T1/N
      YA = T2/N
      T1 = X3 - X4
      T2 = Y3 - Y4
      XB = T1/N
      YB = T2/N
      K = N+1
      DO 03 I=1,K
      XS = X1 - (I-1)*XA
      YS = Y1 - (I-1)*YA
      XF = X3 - (I-1)*XB
      YF = Y3 - (I-1)*YB
      CALL DASH(XS,YS,XF,YF,0.0)
   03 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE BUILD2(L3,L4,XO,YO,H)
C     ------------------------------------------------------------------
C     SUBPROGRAM BLOCK IS USED TO DRAW THE SYMBOL OF THE BUILDING
C     XO,YO  ---  THE X-Y POSITION OF THE CENTER OF THE BUILDING
C     H  ---  THE HEIGHT OR WIDTH OF THE BUILDING
C     IF H IS A POSITIVE NUMBER ,HEIGHT WILL BE GREATER THAN WIDTH.
C     IF H IS A NEGATIVE NUMBER ,HEIGHT WILL BE SMALLER THAN WIDTH.
C     ------------------------------------------------------------------
      IF(H.LT.0.0) GO TO 20
      XL=H/4.0
      YL=H/2.0
   10 X1=XO+XL
      Y1=YO+YL
      X2=XO-XL
      Y2=YO+YL
      X3=XO-XL
      Y3=YO-YL
      X4=XO+XL
      Y4=YO-YL
      GO TO 30
   20 H=ABS(H)
      XL=H/2.0
      YL=H/4.0
      GO TO 10
   30 CALL PLOT(X1,Y1,3)
      CALL PLOT(X2,Y2,2)
      CALL PLOT(X3,Y3,2)
      CALL PLOT(X4,Y4,2)
      CALL PLOT(X1,Y1,2)
      RETURN
```

```
      END

      SUBROUTINE BOUND3(L3,L4,X2,DW,DH,XL,YL,XR,YR)
C     ----------------------------------------------------------------
C     BOUND3 : FIELD BOUNDARY PLOTTING.
C     ----------------------------------------------------------------
      IF(XL.EQ.0.0.OR.YL.EQ.0.0.OR.XR.EQ.0.0.OR.YR.EQ.0.0) GO TO 10
      X22=XR-XL
      CALL PLOT(XL,YL+0.01,3)
      CALL PLOT(XL,YR,2)
      CALL PLOT(XR,YR,2)
      CALL PLOT(XR,YL+0.01,2)
      CALL PLOT(XL,YL+0.01,2)
      CALL PLOT(X22,YL+0.01,3)
      CALL PLOT(X22,YR,2)
      GO TO 20
   10 CONTINUE
      CALL PLOT(0.0,0.01,3)
      CALL PLOT(0.0,DH,2)
      CALL PLOT(DW,DH,2)
      CALL PLOT(DW,0.01,2)
      CALL PLOT(0.0,0.01,2)
      CALL PLOT(X2,0.01,3)
      CALL PLOT(X2,DH,2)
   20 CONTINUE
      RETURN
      END

      SUBROUTINE COLEN4(L3,L4,X1,Y1,DLEN,N1)
C     ----------------------------------------------------------------
C     SUBPROGRAM IS DESIGNED TO CONSTRUCT A TABLE FOR LENGTH OF
C     COLLECTOR.
C     X1,Y1 ---- THE LOWER LEFT COORDINATES OF THE TABLE.
C     DLEN  ---- LENGTH OF THE TABLE
C     N1   ----  NO. OF ROW OF THE TABLE
C     ----------------------------------------------------------------
      DIMENSION DIA(5),LAB(10)
      DATA DIA/100.,150.,200.,250.,300./
      DATA LAB/'A ','B ','C ','D ','E ','F ','G ','H ','J ','K '/
      NR=10
      IF(N1.GT.NR) NR=N1
```

```
      DX=DLEN/6.3
      H=DX/10.0
      X2=X1+DLEN
      Y2=Y1+4.0*0.3+NR*0.25
      CALL PLOT(X1,Y1,3)
      CALL PLOT(X2,Y1,2)
      CALL PLOT(X2,Y2,2)
      CALL PLOT(X1,Y2,2)
      CALL PLOT(X1,Y1,2)
      CALL PLOT(X1+1.3*DX,Y2-0.3,3)
      CALL PLOT(X2,Y2-0.3,2)
      CALL PLOT(X1,Y1+0.3,3)
      CALL PLOT(X2,Y1+0.3,2)
      CALL PLOT(X1+1.3*DX,Y1+0.3,3)
      CALL PLOT(X1+1.3*DX,Y2,2)
      CALL SYMBOL(X1,Y2-0.4, H,' COLLECTOR',0.0,10)
      CALL SYMBOL(X1+1.3*DX+10*H,Y2-0.23,H,'DRAIN TUBE REQUIRED',0.0,19)
      CALL SYMBOL(X1+1.3*DX+32*H,Y2-0.23,H*0.85,' FEET ',0.0,6)
      CALL SYMBOL(X1+3*H,Y1+0.39,H,'TOTAL',0.0,5)
      CALL SYMBOL(X1+3*H,Y1+0.09,H,'OVERALL TOTAL:',0.0,14)
C     NORMALLY LIGHT CHACTERTER STRING AND LINES.
C
      X=X1+H+1.5*DX
      CALL NUMBER(X,Y2-0.55,H,DIA(1),0.0,-1)
      CALL SYMBOL(X+H*3.2,Y2-0.55,H*0.85,'MM',0.0,2)
      DO 20 I=2,5
      X=X+DX
      CALL NUMBER(X,Y2-0.55,H,DIA(I),0.0,-1)
      CALL SYMBOL(X+H*3.2,Y2-0.55,H*0.85,'MM',0.0,2)
   20 CONTINUE
      X=X1+H+1.5*DX
      DO 25 J=2,5
      X=X+DX
      CALL PLOT(X-H-0.2*DX,Y2-0.30,3)
      CALL PLOT(X-H-0.2*DX,Y1+0.3,2)
   25 CONTINUE
      Y=Y2-0.6
      CALL PLOT(X1,Y,3)
      CALL PLOT(X2,Y,2)
      DO 30 I=1,NR
      Y=Y-0.25
      CALL SYMBOL(X1+5.0*H,Y+0.05,H,LAB(I),0.0,1)
      CALL PLOT(X1,Y,3)
      CALL PLOT(X2,Y,2)
   30 CONTINUE
      CALL SYMBOL(X1+5.0*DX,Y1+0.05,H*0.9,' FEET ',0.0,6)
   50 RETURN
      END
```

```
      SUBROUTINE DRAW5(OX,OY,X1,Y1,X3,Y3,XLEN,NOUT,LINE,IDA,PS,S31,
     * XO,YO,RAD,BX,BY,NB,LABAL,DSCALE,IFLO,CEM)
C     ------------------------------------------------------------------
C     DRAW IS USED TO LABEL THE LATERALS' LENGTH
C     WHEN THE DIRECTION OF THE FLOW IS NEEDED, FLOWA & FLOWB ARE CALLED
C     ------------------------------------------------------------------
      DIMENSION X1(10,50),Y1(10,50),X3(10,50),Y3(10,50),XLEN(10,50)
     *          ,BX(10),BY(10),SPAC(10),BANGLE(10),NOUT(10),NONC(10)
     *          ,LINE(10),JOINT(10),OX(10,5),OY(10,5),S31(10,50)
      INTEGER*2 LAB,LABAL(15)
      DO 112 I=1,IDA
      IOUT=NOUT(I)
      LN=LINE(I)
      IF(IOUT.EQ.2) GO TO 110
      CALL PLOT(OX(I,1),OY(I,1),3)
      CALL PLOT(OX(I,2),OY(I,2),2)
      CALL PLOT(X1(I,1),Y1(I,1),2)
      GO TO 113
  110 CALL PLOT(OX(I,1),OY(I,1),3)
      CALL PLOT(X1(I,1),Y1(I,1),2)
  113 DO 111 J=1,LN
      CALL PLOT(X1(I,J),Y1(I,J),3)
      CALL PLOT(X3(I,J),Y3(I,J),2)
  111 CONTINUE
  112 CONTINUE
      SLAB=16*PS
      DO 200 LC=1,IDA
      LN=LINE(LC)
      LAB=LABAL(LC)
  115 IF(X3(LC,1)-X1(LC,1)) 120,140,160
  120 IF((Y3(LC,1)-Y1(LC,1)).EQ.0.0) GO TO 125
      ANGLE=ATAN ((Y3(LC,1)-Y1(LC,1))/(X3(LC,1)-X1(LC,1)))/RAD
      GO TO 130
  122 ANGLE=90.0
      GO TO 130
  125 ANGLE=0.0
  130 COSX=PS*COS(ANGLE*RAD)
      SINY=PS*SIN(ANGLE*RAD)
      DO 135 I=1,LN
      A=-I
      XA=X3(LC,I)+2*COSX
      YA=Y3(LC,I)+2*SINY
      CALL SYMBOL(XA,YA,PS,LAB,ANGLE,2)
      XB=X3(LC,I)+4.5*COSX
      YB=Y3(LC,I)+4.5*SINY
      CALL NUMBER(XB,YB,PS, A,ANGLE,-1)
      IF(XLEN(LC,I).LT.SLAB) GO TO 135
      XC=X3(LC,I)+11*COSX
      YC=Y3(LC,I)+11*SINY
      CALL NUMBER(XC,YC,PS,XLEN(LC,I)*DSCALE/CEM,ANGLE,1)
      XD=X3(LC,I)+17.5*COSX
      YD=Y3(LC,I)+17.5*SINY
      CALL SYMBOL(XD,YD,PS,'FT',ANGLE,2)
  135 CONTINUE
```

```
      GO TO 200
140   IF(Y3(LC,1)-Y1(LC,1)) 122,150,165
150   WRITE(6,155)X1(LC,1),Y1(LC,1),X3(LC,1),Y3(LC,1)
155   FORMAT(1X,'***ERROR***  (X1,Y1) = (X3,Y3).  TERMINATION OCCURRED',
     * ' AT #150 IN "DRAW".',/,
     * 2X,'(X1,Y1) = ',2F8.2,3X,'(X3,Y3) = ',2F8.2)
      GO TO 200
160   IF((Y3(LC,1)-Y1(LC,1)).EQ.0.0) GO TO 180
      ANGLE=ATAN ((Y3(LC,1)-Y1(LC,1))/(X3(LC,1)-X1(LC,1)))/RAD
      GO TO 190
165   ANGLE=90.0
      GO TO 190
180   ANGLE=0.0
190   COSX=PS*COS(ANGLE*RAD)
      SINY=PS*SIN(ANGLE*RAD)
      DO 195 I=1,LN
      A=-I
      XA=X1(LC,I)+2.0*COSX
      YA=Y1(LC,I)+2.0*SINY
      CALL SYMBOL(XA,YA,PS,LAB,ANGLE,2)
      XB=X1(LC,I)+4.5*COSX
      YB=Y1(LC,I)+4.5*SINY
      CALL NUMBER(XB,YB,PS, A,ANGLE,-1)
      IF(XLEN(LC,I).LT.SLAB) GO TO 195
      XC=X1(LC,I)+11*COSX
      YC=Y1(LC,I)+11*SINY
      CALL NUMBER(XC,YC,PS,XLEN(LC,I)*DSCALE/CEM,ANGLE,1)
      XD=X1(LC,I)+17.5*COSX
      YD=Y1(LC,I)+17.5*SINY
      CALL SYMBOL(XD,YD,PS,'FT',ANGLE,2)
195   CONTINUE
200   CONTINUE
      IF(IFLO.NE.1) GO TO 310
C     DRAWING ARROW TO SHOW FLOW DIRECTION.
      DO 300 J1=1,IDA
      LN=LINE(J1)
      DO 290 J2=1,LN
      IF(XLEN(J1,J2).LT.(PS+0.80)) GO TO 290
      X11=X1(J1,J2)
      X33=X3(J1,J2)
      Y11=Y1(J1,J2)
      Y33=Y3(J1,J2)
      CALL        FLOWA(X11,Y11,X33,Y33,PS,RAD,RX1,RY1,RX2,RY2,
     * RX3,RY3,RX4,RY4,AN)
      CALL AROHD(RX2,RY2,RX1,RY1,0.10,0.06,16)
      IF(S31(J1,J2).EQ.0.0) GO TO 280
      CALL SYMBOL(RX3,RY3,PS,'S=      %',AN,8)
      CALL NUMBER(RX4,RY4,PS,S31(J1,J2),AN,2)
      GO TO 290
280   CALL SYMBOL(RX3,RY3,PS, 'S= N.G.',AN,7)
290   CONTINUE
300   CONTINUE
      GO TO 330
310   WRITE(6,320)
320   FORMAT(/,' FLOW DIRECTION NOT SHOWN-- IFLO=1 NOT ENCOUNTERED',/)
```

```
 330  RETURN
      END




      SUBROUTINE FLOWA(X11,Y11,X33,Y33,PS,RAD,RX1,RY1,RX2,RY2,
     * RX3,RY3,RX4,RY4,AN)
C     ----------------------------------------------------------------
C     FLOW & FLOWB :  DRAW THE ARROW TO SHOW THE DIRECTION OF THE FLOW
C     X33,Y33 -- X1-Y1 OF THE LATERAL
C     X33,Y33 -- X3-Y3 OF THE LATERAL
C     PS  -- PEN SIZE OR CHARACTER HEIGHT
C     ALL RX-RY S VALUES ARE X-Y COORDINATES OF THE ARROW
C     AN -- ANGLE OF THE ARROW WITH RESPECT TO X-AXIS
C     ----------------------------------------------------------------
      IF(X33-X11) 40,50,60
   40 RR1=PS
      RR2=RR1+0.40
      RR3=RR2+9*PS
      RR4=RR3-2*PS
      GO TO 90
   50 IF(Y33.LT.Y11) GO TO 40
   60 RR1=PS
      RR2=RR1+0.40
      RR3=RR2+PS
      RR4=RR3+2.0*PS
   90 CALL       FLOWB(X11,Y11,X33,Y33,RR1,PS,RAD,X,Y,AN)
      RX1=X
      RY1=Y
      CALL       FLOWB(X11,Y11,X33,Y33,RR2,PS,RAD,X,Y,AN)
      RX2=X
      RY2=Y
      CALL       FLOWB(X11,Y11,X33,Y33,RR3,PS,RAD,X,Y,AN)
      RX3=X
      RY3=Y
      CALL       FLOWB(X11,Y11,X33,Y33,RR4,PS,RAD,X,Y,AN)
      RX4=X
      RY4=Y
      RETURN
      END




      SUBROUTINE FLOWB(X11,Y11,X33,Y33,RR,PS,RAD,X,Y,ANGLE)
      DX=X33-X11
```

```
      DY=Y33-Y11
      DL=SQRT(DX**2+DY**2)
      IF(DX.EQ.0.0) GO TO 200
      IF(DY.EQ.0.0) GO TO 300
      AN=ATAN2(DY,DX)/RAD
      ANGLE=AN
      ANN=AN
      IF(ANN.GT.90.0) ANGLE=ANN-180.0
      IF(ANN.LT.-90.0) ANGLE=ANN+180.0
      AN=ABS(AN)
      IF(AN.GT.90.0) AN=180.0-AN
      DINX=1.2*PS/SIN(AN*RAD)
      DINY=1.2*PS/COS(AN*RAD)
      ARO=0.60*DL-9.0*PS+RR
      FX=ARO*COS(AN*RAD)
      FY=ARO*SIN(AN*RAD)
      IF(ARO.LT.0.0) FX=0.0
      IF(ARO.LT.0.0) FY=0.0
      IF(X33-X11) 100,200,150
100   IF(Y33-Y11) 105,300,125
 105  X4=X11
      Y4=Y11-DINY
      X=X4-FX
      Y=Y4-FY
      GO TO 500
 125  X4=X11-DINX
      Y4=Y11
      X=X4-FX
      Y=Y4+FY
      GO TO 500
150   IF(Y33-Y11) 155,300,165
 155  X4=X11
      Y4=Y11-DINY
      X=X4+FX
      Y=Y4-FY
      GO TO 500
 165  X4=X11+DINX
      Y4=Y11
      X=X4+FX
      Y=Y4+FY
      GO TO 500
 200  ANGLE=90.0
      D=1.2*PS
      ARO=DL/2.0-9.0*PS+RR
      IF(Y33-Y11) 210,220,230
 210  X4=X11+D
      Y4=Y11
      X=X4
      Y=Y4-ARO
      GO TO 500
220   WRITE(6,225) X11,Y11,X33,Y33
225   FORMAT(1X,'(X1,Y1)=(X3,Y3)---',2F7.2,2X,2F7.2,
     * 'CHECK #200 IN FLOW',/)
      GO TO 500
 230  X4=X11+D
```

```
      Y4=Y11
      X=X4
      Y=Y4+ARO
      GO TO 500
 300  ANGLE=0.0
      D=1.2*PS
      ARO=DL/2.0-9.0*PS+RR
      IF(X33-X11) 310,220,330
 310  X4=X11
      Y4=Y11-D
      X=X4-ARO
      Y=Y4
      GO TO 500
 330  X4=X11
      Y4=Y11-D
      X=X4+ARO
      Y=Y4
 500  RETURN
      END
```

```
      SUBROUTINE ELE6 (L3,L4,X,Y,DD,BE,N)
C     ---------------------------------------------------------------------
C     ROUND ---  SUBPROGRAM TO DRAW SYMBOL SHOWING DRAIN DEPTH &
C                DRAIN'S BOTTOM-ELEVATION.
C     X,Y  ---  POSITION OF THE POINT
C     N    ---  QUADRANT OF THE CIRCLE TO BE DRAWN.     1 = 1ST QUAD.
C     2 = 2ND QUAD.  3 = 3RD QUAD.    4 = 4TH QUAD.
C     IF N HAS A VALVE WHICH IS NOT 1,2,3 OR 4 SYMBOL WILL BE PLOTTED
C     AT THE X-Y POINT GIVEN (CENTERED AT X-Y).
C     DD   ---  DRAIN DEPTH
C     BE   ---  DRAIN BOTTOM ELEVATION
C     ---------------------------------------------------------------------
      GO TO (10,20,30,40),N
      XC=X
      YC=Y
      GO TO 50
  10  XC=X+0.251
      YC=Y+0.251
      GO TO 50
  20  XC=X-0.251
      YC=Y+0.251
      GO TO 50
  30  XC=X-0.251
      YC=Y-0.251
      GO TO 50
  40  XC=X+0.251
      YC=Y-0.251
  50  IF(DD.EQ.0.0.AND.BE.EQ.0.0) GO TO 60
```

```
      CALL CIRCLE(XC,YC,0.250)
      CALL DASH(XC-0.2,YC,XC+0.2,YC,0.0)
      CALL NUMBER(XC-0.090,YC+0.06,0.08,DD,0.0,1)
      CALL NUMBER(XC-0.158,YC-0.127,0.08,BE,0.0,1)
      GO TO 70
   60 CALL CIRCLE(XC,YC,0.20)
   70 RETURN
      END




      SUBROUTINE FENCE7(L3,L4,XA,YA,XB,YB,S)
C     ------------------------------------------------------------------
C     FENCE IS WRITTEN FOR DRAWING THE FENCE LINE
C     XA,YA,XB,YB ----  TWO POINTS , STARTING & ENDING POINTS, OF
C                          THE FENCE LINE ARE GIVEN
C     S  --  THE SPACING BETWEEN CROSSES.
C     ------------------------------------------------------------------
      DIMENSION X(100),Y(100)
      AL=SQRT((XA-XB)**2+(YA-YB)**2)
      XN=AL/S
      IF(XN.GT.100.0) XN=99.0
      NO=XN
      IF(NO.GT.100) NO=99
      IF(NO.EQ.XN) GO TO 10
      IF(XN-NO.LE.0.5*S) NO=NO+1
   10 SS=AL/NO
      RAD=3.1415926/180.0
      DX=XA-XB
      DY=YA-YB
      IF(DX.EQ.0.0) GO TO 100
      IF(DY.EQ.0.0) GO TO 200
      AN=ATAN (DY/DX)/RAD
      DDX=ABS(SS*COS(AN*RAD))
      DDY=ABS(SS*SIN(AN*RAD))
      IF(XA.LT.XB.AND.YA.GT.YB) GO TO 20
      IF(XA.GT.XB.AND.YA.LT.YB) GO TO 30
      IF(XA.LT.XB.AND.YA.LT.YB) GO TO 40
      IF(XA.GT.XB.AND.YA.GT.YB) GO TO 50
      GO TO 90
   20 X(1)=XB
      Y(1)=YB
      X(NO+1)=XA
      Y(NO+1)=YA
      GO TO 33
   30 X(1)=XA
      Y(1)=YA
      X(NO+1)=XB
      Y(NO+1)=YB
   33 DO 35 I=2,NO
```

```
      X(I)=X(I-1)-DDX
35    Y(I)=Y(I-1)+DDY
      GO TO 300
40    X(1)=XA
      Y(1)=YA
      X(NO+1)=XB
      Y(NO+1)=YB
      GO TO 55
50    X(1)=XB
      Y(1)=YB
      X(NO+1)=XA
      Y(NO+1)=YA
55    DO 60 I=2,NO
      X(I)=X(I-1)+DDX
60    Y(I)=Y(I-1)+DDY
      GO TO 300
90    WRITE(6,95) XA,YA,XB,YB,S
95    FORMAT('0','NO FENCE LINE ----',5F8.2)
      GO TO 350
100   AN=90.0
      IF(YA.GT.YB) GO TO 110
      X(1)=XA
      Y(1)=YA
      X(NO+1)=XB
      Y(NO+1)=YB
101   DO 105 I=2,NO
      X(I)=XA
105   Y(I)=Y(I-1)+SS
      GO TO 300
110   X(1)=XB
      Y(1)=YB
      X(NO+1)=XA
      Y(NO+1)=YA
      GO TO 101
200   AN=0.0
      IF(XA.GT.XB) GO TO 210
      X(1)=XA
      Y(1)=YA
      X(NO+1)=XB
      Y(NO+1)=YB
201   DO 205 I=2,NO
      X(I)=X(I-1)+SS
205   Y(I)=YA
      GO TO 300
210   X(1)=XB
      Y(1)=YB
      X(NO+1)=XA
      Y(NO+1)=YA
      GO TO 201
300   CALL PLOT(XA,YA,3)
      CALL PLOT(XB,YB,2)
      M=NO+1
      DO 310 I=1,M
310   CALL SYMBOL(X(I),Y(I),0.10, 4,AN,-1)
350   RETURN
```

```
      END

      SUBROUTINE GRADE8(L3,L4,X,Y,ANGLE,AL,DIR,ITEM)
C     ------------------------------------------------------------------
C     SYMBOL TO SHOW THE CHANGE OF GRADE OR PIPE-SIZE OF A LINE.
C     X,Y  --  COORDINATES OF TRIANGLE TIP ON THE LINE
C     ANGLE -- THE SLOPE OF THE LINE (IN DEGREE)
C     AL   --  THE HEIGHT OF THE TRIANGLE SYMBOL
C     DIR -- DIRECTION OF THE TRIANGLE POINTING
C            IF DIR > 0   SYMBOL PLOT ON THE LEFT  HAND SIDE OF THE LINE
C            IF DIR < 0   SYMBOL PLOT ON THE RIGHT HAND SIDE OF THE LINE
C     ITEM --- CONTROL NO.  ITEM=1 V-SHAPE SYMBOL IS PLOTTED FOR
C              CHANGING PIPE-SIZE.  OTHERWISE SOLID TRIANGLE SYMBOL
C               IS PLOTTED FOR GRADE CHANGE.
C     ------------------------------------------------------------------
      RAD=3.1415926/180.0
      AN=ANGLE*RAD
      IF(DIR.GE.0.0) GO TO 200
C     PLOT TRIANGLE SYMBOL ON LEFT HAND SIDE OF THE LINE.
C
      IF(ANGLE.EQ.0.0 ) GO TO 220
      IF(ANGLE.EQ.180.0) GO TO 210
      IF(ANGLE.EQ. 90.0) GO TO 260
      IF(ANGLE.EQ.-90.0) GO TO 250
      CO=1.0/TAN(AN)
      IF(ANGLE.LT.0.0.AND.ANGLE.GT.-180.0) GO TO 150
      XA=X-SQRT(AL**2/(1.0+CO**2))
      YA=Y+CO*(X-XA)
      GO TO 300
  150 XA=X+SQRT(AL**2/(1.0+CO**2))
      YA=Y+CO*(X-XA)
      GO TO 300
  200 IF(ANGLE.EQ.0.0) GO TO 210
      IF(ANGLE.EQ.180.0) GO TO 220
      IF(ANGLE.EQ. 90.0) GO TO 250
      IF(ANGLE.EQ.-90.0) GO TO 260
      CO=1.0/TAN(AN)
      IF(ANGLE.GT.0.0.AND.ANGLE.LT.180.0) GO TO 230
      XA=X-SQRT(AL**2/(1.0+CO**2))
      YA=Y+CO*(X-XA)
      GO TO 300
  230 XA=X+SQRT(AL**2/(1.0+CO**2))
      YA=Y+CO*(X-XA)
      GO TO 300
  210 XA=X
      YA=Y-AL
      GO TO 300
  220 XA=X
```

```
      YA=Y+AL
      GO TO 300
 250  XA=X+AL
      YA=Y
      GO TO 300
 260  XA=X-AL
      YA=Y
 300  CONTINUE
      IF(ITEM.EQ.1) GO TO 310
      CALL AROHD(XA,YA,X,Y,AL,AL,16)
      GO TO 320
 310  CALL AROHD(XA,YA,X,Y,AL,AL,14)
 320  RETURN
      END
```

```
      SUBROUTINE MARSH9(L3,L4,X,Y,H)
C     ------------------------------------------------------------------
C     MARSH : FOR MARSH OR SWAMP SYMBOL.
C     X,Y  ----  X-Y POSITION OF THE TREE.
C     X,Y --- X-Y COORDINATE  OF THE CENTER OF THE MARSH.
C     H  ---  RADIUS OF THE MARSH.
C     ------------------------------------------------------------------
      H=ABS(H)
      ANGLE=0.0
      DO 10 I=1,7
      A=ANGLE*3.1415926/180.0
      DX=H*COS(A)
      DY=H*SIN(A)
      X1=X+DX
      Y1=Y+DY
      CALL PLOT(X,Y,3)
      CALL PLOT(X1,Y1,2)
      ANGLE=ANGLE+30.0
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PKEY10(L3,L4,DW,DH,TW,Y1)
C     ------------------------------------------------------------------
C     SUBROUTINE PKEY10  ----  PLOTS THE LEGEND OF THE PLAN.
C     ------------------------------------------------------------------
```

```
D=0.12*24+0.20*8
IF(D.GT.TW) GO TO 50
X2=DW-TW
Y2=Y1-0.25
CALL SYMBOL(X2+12*0.1,Y2+0.07,0.2,'KEY TO PLAN',0.0,11)
CALL DASH(X2+12*0.1-0.02,Y2+0.04,X2+12*0.1+11*0.2,Y2+0.04,0.0)
CALL DASH(X2+12*0.1-0.02,Y2,X2+12*0.1+11*0.2,Y2,0.0)
X2=X2+0.12
Y2=Y2-0.30
CALL SYMBOL(X2,Y2,0.12,'RELATIVE ELEVATIONS',0.0,19)
CALL SYMBOL(X2+27*0.12,Y2,0.14,'98.6',0.0,4)
Y2=Y2-0.23
CALL SYMBOL(X2,Y2,0.12, 23HCONTOURS (1' INTERVALS), 0.0,23)
CALL SYMBOL(X2+27*0.12,Y2,0.12,'288',0.0,3)
CALL DASH(X2+24*0.12,Y2+0.07,X2+26.8*0.12,Y2+0.07,0.0)
CALL DASH(X2+30.2*0.12,Y2+0.07,X2+33*0.12,Y2+0.07,0.0)
Y2=Y2-0.23
CALL SYMBOL(X2,Y2,0.12,'FENCES AND BOUNDARIES',0.0,21)
XXA=X2+0.12*24
YYA=Y2+0.07
XXB=X2+0.12*32
CALL FENCE7(7,4,XXA,YYA,XXB,YYA,0.3)
Y2=Y2-0.23
CALL SYMBOL(X2,Y2,0.12,'LENGTH & SIZE OF DRAIN',0.0,22)
CALL SYMBOL(X2+24.0*0.12,Y2+0.03,0.10,'ABOVE DRAINS',0.0,12)
Y2=Y2-0.23
CALL SYMBOL(X2,Y2,0.12,'GRADES',0.0,6)
CALL SYMBOL(X2+24.0*0.12,Y2+0.03,0.10,'BELOW DRAINS',0.0,12)
Y2=Y2-0.23
CALL SYMBOL(X2,Y2,0.12,'NATURAL GRADE',0.0,13)
CALL SYMBOL(X2+27*0.12,Y2,0.13,'N.G.',0.0,4)
Y2=Y2-0.23
CALL SYMBOL(X2,Y2,0.12,'CHANGE IN DRAIN SIZE',0.0,20)
CALL DASH(X2+24*0.12,Y2,X2+32*0.12,Y2,0.0)
CALL GRADE8( 8,4,X2+28.0*0.12,Y2,0.0,0.16,-1,1)
Y2=Y2-0.28
CALL SYMBOL(X2,Y2,0.12,'CHANGE IN DRAIN GRADE',0.0,21)
CALL DASH(X2+24*0.12,Y2+0.16,X2+32*0.12,Y2+0.16,0.0)
CALL GRADE8(8,4,X2+28*0.12,Y2+0.16,0.0,0.16,1,0)
Y2=Y2-0.23
CALL SYMBOL(X2,Y2,0.12,'BENCH MARK',0.0,10)
CALL SYMBOL(X2+25*0.12,Y2+0.02,0.12,'B.M.',0.0,4)
CALL SYMBOL(X2+29.5*0.12,Y2+0.07,0.16,1,0.0,-1)
CALL SYMBOL(X2+29.5*0.12,Y2+0.07,0.16,3,0.0,-1)
Y2=Y2-0.23
CALL SYMBOL(X2,Y2,0.12,'HUB STAKE',0.0,9)
CALL SYMBOL(X2+25*0.12,Y2+0.02,0.12,'H.S.',0.0,4)
CALL SYMBOL(X2+29.5*0.12,Y2+0.07,0.16,1,0.0,-1)
CALL SYMBOL(X2+29.5*0.12,Y2+0.07,0.16,3,0.0,-1)
Y2=Y2-0.30
CALL SYMBOL(X2,Y2+0.05,0.12,'TREE',0.0,4)
CALL TREE18(18,4,X2+28*0.12,Y2+0.10,0.18)
Y2=Y2-0.28
CALL SYMBOL(X2,Y2,0.12,'BUILDING',0.0,8)
CALL BUILD2(2,4,X2+28*0.12,Y2+0.06,-0.2)
```

```
      Y2=Y2-0.25
      CALL SYMBOL(X2,Y2,0.12,'OPEN DITCH',0.0,10)
      CALL STM15 (15,4,X2+32*0.12,Y2+0.07,X2+24*0.12,Y2+0.07,0.2,0.06)
      Y2=Y2-0.23
      CALL SYMBOL(X2,Y2,0.12,'DITCH BOTTOM ELEVATION',0.0,22)
      CALL SYMBOL(X2+26*0.12,Y2,0.14,'898.2',0.0,5)
      Y2=Y2-0.28
      CALL SYMBOL(X2,Y2-0.01,0.12,'DEPTH OF TRENCH BOTTOM',0.0,22)
      XXA=X2+27.5*0.12
      CALL ELE6(6,4,XXA,Y2-0.02,4.5,93.5,5)
      Y2=Y2-0.28
      CALL SYMBOL(X2,Y2+0.06,0.12,'TRENCH BOTTOM ELEVATION',0.0,23)
      Y2=Y2-0.26
      CALL SYMBOL(X2,Y2,0.12,'OUTLET NO.',0.0,10)
      CALL SYMBOL(X2+27*0.12-0.01,Y2-0.03,0.09,'3',0.0,1)
      CALL SYMBOL(X2+27*0.12,Y2+0.01,0.40,53,0.0,1)
      CALL SYMBOL(X2+27*0.12,Y2+0.01,0.40,54,0.0,1)
      Y2=Y2-0.28
      CALL SYMBOL(X2,Y2,0.12,'RAILROAD',0.0,8)
      XXA=X2+24*0.12
      XXB=X2+32*0.12
      YY=Y2+0.07
      CALL RAIL12(12,4,XXA,YY,XXB,YY,0.13)
      Y2=Y2-0.30
      CALL SYMBOL(X2,Y2,0.12,'ROAD AND LANE',0.0,13)
      YYA=Y2+0.08
      CALL ROAD14(14,4,XXA,YYA,XXB,YYA,0.2)
   50 RETURN
      END
```

```
      SUBROUTINE POUT11(L3,L4,X1,Y1,X2,Y2,SLOPE,PEN)
C     -----------------------------------------------------------------
C     SUBROUTINE POUT11 ---- DRAWS THE FLOW DIRECTION AND LABELS
C     THE SLOPE OF THE COLLECTOR
C     X1,Y1  ---  COORDINATE OF THE ARROW'S TIP.
C     X2,YI --- COORDINATE OF THE ARROW'S TAIL.
C     SLOPE --- SLOPE OF THE COLLECTOR.
C     PEN --- CHARACTER HEIGHT OR PENSIZE
C     -----------------------------------------------------------------
      IF(L3.NE.11) GO TO 10
      RAD=3.1415926/180.0
      IF(PEN.EQ.0.0) PEN=0.10
      CALL FLOWA (X1,Y1,X2,Y2,PEN,RAD,RX1,RY1,RX2,RY2,RX3,RY3,
     * RX4,RY4,AN)
      CALL ARDHD(RX2,RY2,RX1,RY1,PEN ,0.06,16)
      IF(SLOPE.EQ.0.0) GO TO 5
      CALL SYMBOL(RX3,RY3,PEN,'S=      %',AN,8)
      CALL NUMBER(RX4,RY4,PEN,SLOPE,AN,2)
```

```
      GO TO 10
    5 CALL SYMBOL(RX3,RY3,PEN, 'S= N.G.',AN,7)
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE RAIL12(L3,L4,X1,Y1,X2,Y2,D)
C     ------------------------------------------------------------------
C     RAILWAY SUBPROGRAM IS CALLED WHEN YOU WANT TO DRAW A RAIL ROAD.
C     TWO POINTS COORDINATES ARE NEEDED ===> START & END POINTS
C     SPECIFY THE DISTANT BETWEEN THE TIES ===> D.
C     ------------------------------------------------------------------
      DIMENSION A(200),B(200)
      RAD=3.1415926/180.0
      IF(D.EQ.0.0) D=0.20
      DX=X2-X1
      DY=Y2-Y1
      IF(DX.EQ.0.0.AND.DY.EQ.0.0) GO TO 500
      DO 90 I=1,200
      A(I)=0.0
   90 B(I)=0.0
      ABLEN =SQRT(DX**2+DY**2)
      NO=ABLEN/D
      IF(NO.GE.200) NO=199
      A(1)=X1
      B(1)=Y1
      A(NO+1)=X2
      B(NO+1)=Y2
      IF(DX.EQ.0.0) GO TO 300
      IF(DY.EQ.0.0) GO TO 400
C     WHEN DX AND DY ARE NOT = 0.0 ====> ANGLE=ATAN2(DY,DX).
      AN=ATAN2(DY,DX)
      ANGLE=AN/RAD
      FA=ABS(D*COS(AN))
      FB=ABS(D*SIN(AN))
      IF(X1.GT.X2) GO TO 200
      IF(Y1.GT.Y2) GO TO 150
      DO 110 I=2,NO
      A(I)=A(I-1)+FA
  110 B(I)=B(I-1)+FB
      GO TO 600
  150 DO 160 I=2,NO
      A(I)=A(I-1)+FA
  160 B(I)=B(I-1)-FB
      GO TO 600
  200 IF(Y1.GT.Y2) GO TO 250
      DO 210 I=2,NO
      A(I)=A(I-1)-FA
```

```
 210   B(I)=B(I-1)+FB
       GO TO 600
 250   DO 260 I=2,NO
       A(I)=A(I-1)-FA
 260   B(I)=B(I-1)-FB
       GO TO 600
C      WHEN DX=0.0 ====> ANGLE=90.0
 300   ANGLE=90.0
       IF(Y1.GT.Y2) GO TO 350
       DO 310 I=2,NO
       A(I)=X1
 310   B(I)=B(I-1)+D
       GO TO 600
 350   DO 360 I=2,NO
       A(I)=X1
 360   B(I)=B(I-1)-D
       GO TO 600
C      WHEN DY=0.0 ====> ANGLE=0.0
 400   ANGLE=0.0
       IF(X1.GT.X2) GO TO 450
       DO 410 I=2,NO
       A(I)=A(I-1)+D
 410   B(I)=Y1
       GO TO 600
 450   DO 460 I=2,NO
       A(I)=A(I-1)-D
 460   B(I)=Y1
       GO TO 600
 500   WRITE(6,510) X1,Y1,X2,Y2
 510   FORMAT(1X,' SINGLE POINT DATA ==> NO RAIL LINE CAN BE PLOTTED',
      * 2X,4(F7.2,2X),/)
       GO TO 700
 600   NN=NO+1
       CALL PLOT(X1,Y1,3)
       CALL PLOT(X2,Y2,2)
       DO 610 J=1,NN
 610   CALL SYMBOL(A(J),B(J),D*0.80,13,ANGLE,-1)
 700   RETURN
       END
```

```
       SUBROUTINE REF13 (L3,L4,DW,DH,TW,X1,Y1,H1,NO)
C      ------------------------------------------------------------------
C      REF13 : TO LABEL THE SPECIAL NOTES OR LABELS ON THE PLAN
C      X1,Y1   --  COORDINATE OF THE LOWER LEFT CORNER OF THE START POINT
C                  OF THE LABEL.
C      H1 --  CHARACTER HEIGHT (0.2" IS RECOMMENDED).
C      A1 --  ANGLE OF THE LABELLING WITH RESPECT TO X-AXIS (0.0 DEGREE)
C      LEN --  TOTAL NUMBER OF CHARACTERS OF THE LABEL.
```

```
C       ----------------------------------------------------------------
        DIMENSION A(10)
        RAD=3.1415926/180.0
        A1=0.0
        IF(H1.EQ.0.0) H1=0.15
        IF(NO.EQ.0) NO=40
        D1=H1*NO
        IF(X1.EQ.0.0) X1=DW-TW
        IF(Y1.EQ.0.0) Y1=DH-0.50
    4   READ(5,10,END=20) L1,L2,L3,L4,A
   10   FORMAT(2I1,I2,I1,5X,10A4)
        IF(L3.NE.13) GO TO 6
        IF(L4.NE.4) GO TO 8
        X2=X1+D1*COS(A1*RAD)
        Y2=Y1+D1*SIN(A1*RAD)
        IF(X1.LT.0.0.OR.X1.GE.DW) GO TO 11
        IF(Y1.LT.0.0.OR.Y1.GE.DH) GO TO 11
        IF(X2.LT.0.0.OR.X2.GE.DW) GO TO 11
        IF(Y2.LT.0.0.OR.Y2.GE.DH) GO TO 11
        CALL SYMBOL(X1+0.8*H1,Y1,H1,A,A1,NO)
        Y1=Y1-1.8*H1
        GO TO 4
   11   WRITE(6,12)
   12   FORMAT('0', ' REF13: LABEL EXTENDS BEYOND MAP BOUNDARY.')
        GO TO 4
    6   WRITE(6,7)
    7   FORMAT('0', ' REF13: CONTROL L3=13 NOT ENCOUNTERED.')
        GO TO 20
    8   WRITE(6,9) L1,L2,L3,L4,A
    9   FORMAT('0',' REF13: CONTROL L4=4 NOT ENCOUNTERED.',/,
       * 1X,'LAST CARD READ WAS : ',2I1,I2,I1,5X,10A4)
        GO TO 4
   20   RETURN
        END
```

```
        SUBROUTINE ROAD14(L3,L4,X1,Y1,X2,Y2,W)
C       ----------------------------------------------------------------
C       ROAD --- A SUBPROGRAM TO DRAW ROAD OR LANE SYMBOL
C       (X1,Y1) & (X2,Y2) --- STARTING & ENDING POINTS OF THE ROAD
C                             ( ITS CENTER-LINE. )
C       W --- WIDTH OF THE ROAD
C       ----------------------------------------------------------------
        RAD=3.1415926/180.0
        IF(W.EQ.0.0) W=0.25
        DX=X1-X2
        DY=Y1-Y2
        IF(DX.EQ.0.0) GO TO 20
        IF(DY.EQ.0.0) GO TO 30
```

```
      IF(DY.EQ.0.0) GO TO 30
      GO TO 40
20    AN=90.0
      X3U=X1+0.5*W
      X3L=X1-0.5*W
      CALL PLOT(X3U,Y1,3)
      CALL PLOT(X3U,Y2,2)
      CALL PLOT(X3L,Y2,3)
      CALL PLOT(X3L,Y1,2)
      CALL SYMBOL(X1+0.25*W,(Y1+Y2)/2.-W,0.4*W,'ROAD',AN,4)
      GO TO 100
30    AN=0.0
      Y3U=Y1+0.5*W
      Y3L=Y1-0.5*W
      CALL PLOT(X1,Y3U,3)
      CALL PLOT(X2,Y3U,2)
      CALL PLOT(X2,Y3L,3)
      CALL PLOT(X1,Y3L,2)
      CALL SYMBOL( (X1+X2)/2.-W,Y1-0.25*W,0.4*W,'ROAD',AN,4)
      GO TO 100
40    AN=ATAN (DY/DX)/RAD
      IF(X1.GT.X2) GO TO 50
      GO TO 70
50    IF(Y1.GT.Y2) GO TO 60
      X=(X1+X2)/2.0-W
      DDX=X-X2
      DDY=TAN(AN*RAD)*DDX
      DDY=ABS(DDY)
      Y=Y2-0.25*W-DDY
      GO TO 90
60    X=(X1+X2)/2.0-W
      DDX=X-X2
      DDY=TAN(AN*RAD)*DDX
      DDY=ABS(DDY)
      Y=Y2-0.25*W+DDY
      GO TO 90
70    IF(Y1.GT.Y2) GO TO 80
      X=(X1+X2)/2.0-W
      DDX=X-X1
      DDY=TAN(AN*RAD)*DDX
      DDY=ABS(DDY)
      Y=Y1-0.25*W+DDY
      GO TO 90
80    X=(X1+X2)/2.0-W
      DDX=X-X1
      DDY=TAN(AN*RAD)*DDX
      DDY=ABS(DDY)
      Y=Y1-0.25*W-DDY
90    Y3L=Y1-0.5*W
      Y3U=Y1+0.5*W
      Y4L=Y2-0.5*W
      Y4U=Y2+0.5*W
      CALL PLOT(X1,Y3U,3)
      CALL PLOT(X2,Y4U,2)
      CALL PLOT(X2,Y4L,3)
```

```
      CALL PLOT(X1,Y3L,2)
      CALL SYMBOL(X,Y,0.4*W,'ROAD',AN,4)
  100 RETURN
      END


      SUBROUTINE STM15 (L3,L4,XS,YS,XE,YE,AROL,AROS)
C     ------------------------------------------------------------------
C     SUBPROGRAM  STREAM IS USED TO DRAW A SERIES OF ARROW TO SHOW
C     THE DIRECTION OF A STREAM OR CHANNEL.
C
C     XS,YS -- X-Y COORDINATE OF THE POINT AT DOWNSTREAM END
C     XE,YE -- X-Y COORDINATE OF THE POINT AT UPSTREAM END
C     AROL -- LENGTH OF THE ARROW.
C     AROS -- SPACE BETWEEN THE ARROWS.
C     ------------------------------------------------------------------
      DIMENSION RX1(100),RY1(100),RX2(100),RY2(100)
      IF(AROL.EQ.0.0) AROL=0.30
      IF(AROS.EQ.0.0) AROS=0.150
      DO 10 I=1,100
      RX1(I)=0.0
      RY1(I)=0.0
      RX2(I)=0.0
   10 RY2(I)=0.0
      AL  =SQRT((XS-XE)**2 +(YS-YE)**2)
      NOARO = AL/(AROL+AROS)
      IF(NOARO.GT.100) NOARO=100
      DX=XE-XS
      DY=YE-YS
      RX1(1)=XS
      RY1(1)=YS
      RX2(NOARO)=XE
      RY2(NOARO)=YE
      IF(DX.EQ.0.0.AND.DY.EQ.0.0) GO TO 800
      IF(DX.EQ.0.0) GO TO 100
      IF(DY.EQ.0.0) GO TO 200
      GO TO 300
  100 ANGLE=90.0
      IF(YS.GT.YE) GO TO 150
      DO 110 I=2,NOARO
      RX1(I)=RX1(I-1)
      RY1(I)=RY1(I-1)+(AROL+AROS)
      RX2(I-1)=RX1(I-1)
  110 RY2(I-1)=RY1(I-1)+AROL
      GO TO 700
  150 DO 160 I=2,NOARO
      RX1(I)=RX1(I-1)
      RY1(I)=RY1(I-1)-(AROL+AROS)
      RX2(I-1)=RX1(I-1)
```

```
160   RY2(I-1)=RY1(I-1)-AROL
      GO TO 700
200   ANGLE=0.0
      IF(XS.GT.XE) GO TO 250
      DO 210 I=2,NOARO
      RX1(I)=RX1(I-1)+(AROL+AROS)
      RY1(I)=RY1(I-1)
      RX2(I-1)=RX1(I-1)+AROL
210   RY2(I-1)=RY1(I-1)
      GO TO 700
250   DO 260 I=2,NOARO
      RX1(I)=RX1(I-1)-(AROL+AROS)
      RY1(I)=RY1(I-1)
      RX2(I-1)=RX1(I-1)-AROL
260   RY2(I-1)=RY1(I-1)
      GO TO 700
300   ANGLE=ATAN2(DY,DX)
      FA=ABS( (AROL+AROS)*COS(ANGLE))
      FB=ABS( (AROL+AROS)*SIN(ANGLE))
      FAA=ABS(AROL*COS(ANGLE))
      FBB=ABS(AROL*SIN(ANGLE))
      IF(XE.GT.XS) GO TO 500
      IF(YE.GT.YS) GO TO 400
      DO 350 I=2,NOARO
      RX1(I)=RX1(I-1)-FA
      RY1(I)=RY1(I-1)-FB
      RX2(I-1)=RX1(I-1)-FAA
350   RY2(I-1)=RY1(I-1)-FBB
      GO TO 700
400   DO 450 I=2,NOARO
      RX1(I)=RX1(I-1)-FA
      RY1(I)=RY1(I-1)+FB
      RX2(I-1)=RX1(I-1)-FAA
450   RY2(I-1)=RY1(I-1)+FBB
      GO TO 700
500   IF(YE.GT.YS) GO TO 600
      DO 550 I=2,NOARO
      RX1(I)=RX1(I-1)+FA
      RY1(I)=RY1(I-1)-FB
      RX2(I-1)=RX1(I-1)+FAA
550   RY2(I-1)=RY1(I-1)-FBB
      GO TO 700
600   DO 650 I=2,NOARO
      RX1(I)=RX1(I-1)+FA
      RY1(I)=RY1(I-1)+FB
      RX2(I-1)=RX1(I-1)+FAA
650   RY2(I-1)=RY1(I-1)+FBB
700   DO 750 J=1,NOARO
750   CALL AROHD(RX2(J),RY2(J),RX1(J),RY1(J),0.12,0.08,16)
      GO TO 850
800   WRITE(6,801) XS,YS,XE,YE
801   FORMAT(1X,'SINGLE POINT X,Y --- NO STREAM LINE CAN BE PLOTTED',/)
850   RETURN
      END
```

```
      SUBROUTINE TAB16(CHH,CHC,DSCALE,DH,XO,YO,LAB,LABAL,IDA,
     * LINE,XLEN,SUMLEN,CEM,Y2)
C     ------------------------------------------------------------------
C     TABLE : TABLE OF LENGTHS OF LATERALS OF THE ENTIRE SYSTEM
C     ------------------------------------------------------------------
      DIMENSION XLEN(10,50),LINE(10)
      INTEGER*2 LAB,LABAL(15)
      MAXL=(DH-1.0-5*CHH)/(1.5*CHC)
      X1=XO+0.5
      Y1=YO+0.5
      IF(Y2.EQ.0.0) Y2=Y1+MAXL*1.5*CHC+5*CHH
      J1=0
      DO 90 J=1,IDA
      LN=LINE(J)
   90 J1=J1+LN
      NCOL=1
      IF(J1.GT.MAXL.AND.J1.LT.2*MAXL) NCOL=2
      IF(J1.GT.2*MAXL.AND.J1.LT.3*MAXL) NCOL=3
      CALL PLOT(X1,Y2,3)
      CALL PLOT(X1+NCOL*18*CHH,Y2,2)
      CALL PLOT(X1,Y2-2*CHH,3)
      CALL PLOT(X1+NCOL*18*CHH,Y2-2*CHH,2)
      T1=X1+CHH
      T2=Y2-1.5*CHH
      DO 100 I=1,NCOL
      TA=T1+(I-1)*18*CHH
      CALL SYMBOL(TA,T2,CHH, 'LAT.NO  LENGTH',0.0,14)
      CALL SYMBOL(TA+15*CHH,T2,CHH*0.80,'FT',0.0,2)
  100 CONTINUE
      X3=X1+CHH
      Y3=Y2-2*CHH
      K=0
      SUMLEN=0.0
      DO 140 K1=1,IDA
      LN=LINE(K1)
      LAB=LABAL(K1)
      DO 120 K2=1,LN
      SUMLEN=SUMLEN+XLEN(K1,K2)
      Y3=Y3-1.5*CHC
      K=K+1
      A=-K2
      I=LN-(K2-1)
      CALL SYMBOL(X3,Y3,CHC,LAB,0.0,2)
      X4=X3+3*CHC
      CALL NUMBER(X4,Y3,CHC,A,0.0,-1)
      X5=X3+7*CHH
      TX=XLEN(K1,K2)*DSCALE/CEM
      IF(TX.LT.10.0) X5=X5+3.0*CHH+3.0*CHC
```

```
      IF(TX.GE.10.0.AND.TX.LT.100.0) X5=X5+3.0*CHH+2.0*CHC
      IF(TX.GE.100.0.AND.TX.LT.1000.0) X5=X5+3.0*CHH+CHC
      IF(TX.GE.1000.0) X5=X5+3.0*CHH
      CALL NUMBER(X5,Y3,CHC,TX,0.0,1)
      IF(K.LT.MAXL) GO TO 120
      IF(I.EQ.1.AND.K1.EQ.IDA) GO TO 150
      X3=X3+18*CHH
      Y3=Y2-2*CHH
      K=0
  120 CONTINUE
      Y3=Y3-1.5*CHC
  140 CONTINUE
  150 X6=X1
      CALL PLOT(X6,Y3,3)
      CALL PLOT(X6,Y2,2)
      DO 160 I=1,NCOL
      CALL PLOT(X6+7.5*CHH,Y2,3)
      CALL PLOT(X6+7.5*CHH,Y3,2)
      CALL PLOT(X6+18*CHH,Y3,3)
      CALL PLOT(X6+18*CHH,Y2,2)
      X6=X6+18*CHH
  160 CONTINUE
      CALL PLOT(X1,Y3,3)
      CALL PLOT(X1,Y3-2*CHH,2)
      CALL PLOT(X1+NCOL*18*CHH,Y3-2*CHH,2)
      CALL PLOT(X1+NCOL*18*CHH,Y3,2)
      CALL PLOT(X1,Y3,2)
      CALL SYMBOL(X1,Y3-1.5*CHH,CHH,' TOTAL',0.0,6)
      CALL NUMBER(X1+8.5*CHH,Y3-1.5*CHH,CHH,SUMLEN*DSCALE/CEM,0.0,1)
      CALL SYMBOL(X1+16*CHH,Y3-1.5*CHH,CHH*0.85,'FT',0.0,2)
      RETURN
      END
```

```
      SUBROUTINE TBLK17(L1,L2,L3,L4,DW,DH,TW,X2)
C     ------------------------------------------------------------------
C     TTLBLK : DRAWING TITLE-BLOCK
C     X2 -- THE STARTING POSITION OF THE TITLE-BLOCK
C     DW -- WIDTH OF THE PAPER
C     TW -- WIDTH OF THE TITLE-BLOCK ( MINIMUM 4".  5" FOR 11" PAPER,
C                                      7" FOR 30" PAPER IS THE BEST ).
C     T  --  THE TITLE OF THE JOB ( 3 LINES )
C     SCALE -- THE SCALE USED FOR THE JOB
C     DWG -- THE DRAWING NUMBER OR REFERENCE NUMBER OF THE JOB
C     ------------------------------------------------------------------
      DIMENSION T(9),SCALE(3),DWG(3)
      F = TW/7.0
      IF(L1.EQ.5) GO TO 5
C     NORMALLY HEAVY LINES.
```

```
      CALL DASH(X2+F*2.7,F*3.8,X2+F*2.7,F*3.1,0.0)
      CALL DASH(X2+F*1.5,F*3.1,X2+F*1.5,F*3.8,0.0)
      CALL DASH(X2,F*3.5,DW,F*3.5,0.0)
      CALL DASH(DW,F*3.1,X2,F*3.1,0.0)
      CALL DASH(X2,F*2.4,DW,F*2.4,0.0)
      CALL DASH(DW,F*2.0,X2,F*2.0,0.0)
      CALL DASH(X2,F*1.0,DW,F*1.0,0.0)
      CALL PLOT(X2,0.01,3)
      CALL PLOT(X2,F*3.8,2)
      CALL PLOT(DW,F*3.8,2)
      CALL PLOT(DW,0.01,2)
      CALL PLOT(X2,0.01,2)
C
C     NORMALLY FINE LINES AND CHARACTER STRINGS.
      CALL DASH(X2+F*2.3,F*1.00,X2+F*2.3,0.0    ,0.0)
      CALL DASH(X2+F*3.2,0.0    ,X2+F*3.2,F*1.00,0.0)
      CALL DASH(X2+F*4.2,F*1.00,X2+F*4.2,0.0    ,0.0)
      CALL DASH(X2+F*5.2,0.0    ,X2+F*5.2,F*1.00,0.0)
      CALL DASH(X2+F*5.2,F*0.75,X2+F*2.3,F*0.75,0.0)
      CALL DASH(X2+F*2.3,F*0.50,X2+F*5.2,F*0.50,0.0)
      CALL DASH(X2+F*5.2,F*0.25,X2+F*2.3,F*0.25,0.0)
      CALL SYMBOL(X2+F*3.3,F*0.825,F*0.1,'DATE',0.0,4)
      CALL SYMBOL(X2+F*4.3,F*0.825,F*0.1,'PERSON',  0.0,6)
      CALL SYMBOL(X2+F*2.4,F*0.575,F*0.1,'DRAWN',  0.0,5)
      CALL SYMBOL(X2+F*2.4,F*0.325,F*0.1,'CHECKED',0.0,7)
      CALL SYMBOL(X2+F*2.4,F*0.075,F*0.1,'REVISED',0.0,7)
C     NORMALLY MEDIUM CHARACTER STRINGS.
      CALL SYMBOL(X2+F*0.15,F*3.225,F*0.15,'REVISION',0.0,8)
      CALL SYMBOL(X2+F*1.65,F*3.225,F*0.15,'DATE',0.0,4)
      CALL SYMBOL(X2+F*2.85,F*3.225,F*0.15,'DESCRIPTION',0.0,11)
      CALL SYMBOL(X2+F*0.76,F*2.825,F*0.15,'AGRICULTURAL  ENGINEERING  D
     1EPARTMENT',0.0,37)
      CALL SYMBOL(X2+F*2.18,F*2.525,F*0.15,'MCGILL  UNIVERSITY',0.0,18)
      CALL SYMBOL(X2+F*0.53,F*2.125,F*0.15,'BOX 950, MACDONALD COLLEGE,
     1QUE. H9X 1C0',0.0,40)
C     NORMALLY HEAVY VARIABLE CHARACTER STRINGS.
      CALL SYMBOL(X2+F*0.15,F*0.775,F*0.15,'SCALE'  ,0.0,5)
      CALL SYMBOL(X2+F*5.35,F*0.775,F*0.15, 'DWG. NO.',0.0,8)
      GO TO 30
    5 DO 8 I=1,3
      READ(5,7) L1,L2,L3,L4,T
    7 FORMAT(2I1,I2,I1,5X,8A4,A1)
      CALL SYMBOL(X2+F*0.24,F*(2.0-I*0.3),F*0.20,T    ,0.0,33)
    8 CONTINUE
      READ(5,9) L1,L2,L3,L4,SCALE,DWG
    9 FORMAT(2I1,I2,I1,5X,2A4,A2,2A4,A2)
      CALL SYMBOL(X2+F*0.15,F*0.2,F*0.20,SCALE,0.0,10)
      CALL SYMBOL(X2+F*5.35,F*0.2,F*0.16,DWG,0.0,10)
   30 RETURN
      END
```

```
      SUBROUTINE TREE18(L3,L4,X,Y,H)
C     ------------------------------------------------------------------
C     TREE : TO DRAW THE SYMBOL OF THE TREE OR BUSH.
C     X,Y --- THE POSITION OF THE TREE ( X-Y COORDINATE )
C     H   --- THE HEIGHT OF THE TREE (0.3" IS RECOMMENDED)
C     ------------------------------------------------------------------
      DIMENSION X1(6),Y1(6),X2(6),Y2(6)
      IF(H.EQ.0.0) H=0.20
      AN=0.0
      BN=30.0
      RAD=3.1415926/180.0
      DO 20 I=1,6
      A=AN*RAD
      B=BN*RAD
      X1(I)=X+H*COS(A)
      Y1(I)=Y+H*SIN(A)
      X2(I)=X+0.7*H*COS(B)
      Y2(I)=Y+0.7*H*SIN(B)
      AN=AN+60
      BN=BN+60
   20 CONTINUE
      CALL CIRCLE(X,Y,0.03)
      CALL FIT(X2(6),Y2(6),X1(1),Y1(1),X2(1),Y2(1) )
      DO 30 J=1,5
      CALL FIT(X2(J),Y2(J),X1(J+1),Y1(J+1),X2(J+1),Y2(J+1) )
   30 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE XTOY19(L3,L4,X1,Y1,X2,Y2)
C     ------------------------------------------------------------------
C     XTOY19 --- SUBROUTINE TO JOIN TWO POINTS .
C     (X1,Y1), (X2,Y2) ---- POINTS TO BE JOINED
C     L3 ---  CONTROL NO. L3=19 IN THIS CASE.
C     L4 --- PLOTTING COMMAND L4=4 IF PLOTING REQUIRED.
C     ------------------------------------------------------------------
      IF(L3.NE.19) GO TO 10
      IF(L4.NE.4) GO TO 15
      CALL PLOT(X1,Y1,3)
      CALL PLOT(X2,Y2,2)
      GO TO 20
   10 WRITE(6,11)
   11 FORMAT('0', ' XTOY19 : L3=19 NOT ENCOUNTERED')
      GO TO 20
   15 WRITE(6,16)
```

```
16   FORMAT('0', ' XTOY19 : L4=4 NOT ENCOUNTERED')
20   RETURN
     END
```

```
     SUBROUTINE BM20  (L3,L4,X,Y,ELE)
C    ------------------------------------------------------------------
C    SUBPROGRAM BM20 DRAWS THE SYMBOL FOR A BENCH MARK
C    X,Y ---  THE EXACT LOCATION OF THE BENCH MARK.
C    ------------------------------------------------------------------
     IF(L3.NE.20) GO TO 20
     IF(L4.NE.4) GO TO 20
     CALL SYMBOL(X,Y,0.18,1,0.0,-1)
     CALL SYMBOL(X,Y,0.18,3,0.0,-1)
     CALL NUMBER(X+0.43,Y-0.09,0.18,ELE,0.0,-1)
     GO TO 30
20   WRITE(6,25)
25   FORMAT(1X,'L3=20 OR L4=4 NOT ENCOUNTERED',/)
30   RETURN
     END
```

```
     SUBROUTINE WRIT21(L3,L4,X,Y,H)
C    ------------------------------------------------------------------
C    WRITE IS PREPARED TO LABEL A CHARACTER STRING
C    X,Y --- COORDINATE OF THE LOWER LEFT HAND CORNER OF THE FIRST
C            LETTER OF THE CHARACTER STRING.
C    H   ---- HEIGHT OF THE LETTER.
C    L3  --- CONTROL NO.  L3=21 IN THIS CASE.
C    L4  ---  PLOTTING COMMAND.  L4=4 IF PLOTTING NEEDED.
C    ------------------------------------------------------------------
     DIMENSION A(13)
     IF(L3.NE.21) GO TO 20
     IF(L4.NE.4) GO TO 30
     IF(H.EQ.0.0) H=0.22
     READ(5,10,END=30) L1,L2,L3,L4,A,A1,N
10   FORMAT(2I1,I2,I1,5X,13A4,3X,F5.1,I2)
     IF(N.EQ.0) N=50
     CALL SYMBOL(X,Y,H,A,A1,N)
     GO TO 30
20   WRITE(6,25)
25   FORMAT( ' L3=21 NOT ENCOUNTERED',/)
30   RETURN
```

```
      END
```

```
      SUBROUTINE OUT22 (L3,L4,X,Y,XNO)
C     ------------------------------------------------------------------
C     SUBPROGRAM IS PREPARED FOR PLOTTING THE SYMBOL OF THE OUTLET.
C     X,Y ---  POSITION OF THE OUTLET.
C     XNO -- NUMBER OF THE OUTLET.  EX. 1,2 OR 3
C     ------------------------------------------------------------------
      IF(L3.NE.22) GO TO 10
      CALL RECT(X-0.2,Y-0.1,0.2,0.4,0.0,3)
      CALL NUMBER(X,Y-0.05,0.1,XNO,0.0,-1)
      GO TO 30
   10 WRITE(6,20)
   20 FORMAT(1X,'L3=22 NOT ENCOUNTERED.',/)
   30 RETURN
      END
```

APPENDIX D

JOB CONTROL LANGUAGE STATEMENTS SETUP AND INPUT FORMATS FOR COMPUTER PROGRAMS DSDP AND DSLP

JCL SETUP FOR PROGRAM DSDP

A. FOR A SOURCE PROGRAM.

THE COMPLETE SET OF JCL STATEMENTS FOR RUNNING PROGRAM DSDP USING THE FORTRAN IV (G-LEVEL) :

```
//DSDPCARD JOB (AE33,000,010,0100,0000,22,1),'DRAINAGE',MSGLEVEL=1
//*PASSWORD=XXXXX
//  EXEC  FORTGCLG
//FORT.SYSIN  DD  *

        FORTRAN SOURCE DECK
    ( DSDP PROGRAM IN THIS CASE )

/*
//GO.SYSIN  DD  *

       DATA CARDS

/*
//
```

B. FOR A LOAD MODULE.

THE SAME PROGRAM, DSDP, IF IT IS STORED AS A LOAD MODULE IN THE PARTITIONED DATA SET "AE33.MAP" CAN BE EXECUTED BY SIMILAR JCL SETUP. HERE THE NAME ON THE JOB STATEMENT HAS BEEN CHANGED TO "DSDPLOAD" TO INDICATE THAT A LOAD MODULE, RATHER THAN A SOURCE PROGRAM, IS BEING EXECUTED.

```
//DSDPLOAD JOB (AE33,000,010,0100,0000,22,1),'DRAINAGE',MSGLEVEL=1
//*PASSWORD=XXXXX
//  EXEC  PGM=DSDP
//STEPLIB  DD  DSN=AE33.MAP,DISP=OLD
//FT06F001  DD  SYSOUT=A
//FT05F001  DD  *

       DATA CARDS

/*
//
```

JCL SETUP FOR PROGRAM DSLP

A. FOR A SOURCE PROGRAM.

THE COMPLETE SET OF JCL STATEMENTS FOR RUNNING THE PROGRAM DSLP USING THE FORTRAN IV (G-LEVEL):

```
//DSLPCARD JOB (AE33.000.010.0100.0000.22.1),'DRAINAGE',MSGLEVEL=1
//*PASSWORD=XXXXX
//   EXEC  SETUP
//SETUP.SYSIN   DD   *
T8=PLOTTP(RI.SL.30" PLAIN PAPER. PENS: 0.2MM AT #003 START)
( CONTINUATION.. 0.4MM AT #004, AND 0.8MM AT #005. THANKS)
//   EXEC   FORTGCLG
//FORT.SYSIN   DD   *

         FORTRAN PLOT PROGRAM
   ( DSLP PROGRAM IN THIS CASE )

//GO.PLOTTAPE   DD   UNIT=TAPE8.VOL=SER=PLOTTP.LABEL(1,SL).DISP=NEW
//GO.SYSIN   DD   *

       DATA CARDS

/*
//
```

B. FOR A LOAD MODULE.

IF DSLP IS STORED AS LOAD MODULE IN THE PARTITIONED DATA SET "AE33.MAP" THE FOLLOEING JCL STATEMENTS SHOULD BE USED :

```
//DSLPLOAD JOB (AE33.000.010.0100.0000.22.1),'DRAINAGE',MSGLEVEL=1
//*PASSWORD=XXXXX
T8=PLOTTP(RI.SL.30" PLAIN PAPER. PENS: 0.2MM AT #003 START)
( CONTINUATION.. 0.4MM AT #004, AND 0.8MM AT #005. THANKS)
//SETUP   EXEC   PGM=DSLP
//STEPLIB   DD   DISP=SHR.DSN=AE33.MAP
//FT05F001   DD   *

       DATA CARDS

//FT06F001   DD   SYSOUT=A,
//      DCB=(RECFM=FA.BLKSIZE=133.BUFNO=1)
//PLOTTAPE   DD   UNIT=TAPE8.VOL=SER=PLOTTP.DISP=NEW.DCB=BLKSIZE=8300
/*
//
```

```
 ------------------------------------------------------------------------
|                                                                        |
|                      INPUT FORMATS FOR DSDP                             |
|                                                                        |
 ------------------------------------------------------------------------
```

THE FOLLOWING INPUT FORMATS SPECICATIONS MUST BE USED FOR PREPARING THE DATA CARDS TO RUN DSDP PROGRAM.

```
-----  FIELD BOUNDARY AND OPTION CARD.
-----  FIELD BOUNDARY POINT COORDINATES CARD
-----  DESIGN PARAMETERS CARD.
-----  DESIGN-AREA CORNERS CARD.
-----  COORDINATES OF DESIGN-AREA CORNERS CARD.
-----  NO. OF OUTLET AND SPECIAL JOINT.
-----  COLLECT POINT AND COORDINATES.
-----  SPECIAL JOINT POINT COORDINATES.
```

NOTE:
REPEAT STEPS 3 TO 7 INCLUSIVE IF THERE IS ANY OTHER DESIGN-AREA TO BE DESIGNED IN A SINGLE RUN.

```
I.    FIELD BOUNDARY AND OPTION CARD.

1.     NB: NO. OF BOUNDARY (I2) ----------------------------COL. 1-2.
2.     ICOPY: IF ICOPY=1, ALL RAW DATA AND COMPUTED RESULTS
              WILL BE WRITTEN ONTO DISK OR TAPE AS
              SPECIFIED FOR IWT (I2) -----------------------COL.3-4.
3.     IWT: UNIT NO. OF STORAGE DEVICE (DISK OR TAPE) (I2)--COL.5-6.

II.    BOUNDARY POINT COORDINATES CARD.
       BOUNDARY POINT X.Y COORDINATES ( AS MANY AS NB ) ONE
       POINT PER CARD (2F10.2) ----------------------------- COL.1-20.


III.   DESIGN PARAMETERS CARD.

1.     SP: DRAIN SPACING (F10.2) --------------------------- COL.1-10
2.     BETA: ANGLE BETWEEN LATERAL AND COLLECTOR (F10.2) --- COL.11-20.
3.     DSCALE: SCALE USED IN DESIGN (F10.2) ---------------- COL.21-30.


IV.    DESIGN-AREA CORNER CARD.

       NC: NO. OF CORNER FOR THE DESIGN-AREA (I2) ---------- COL.1-2.
```

V. COORDINATES OF DESIGN-AREA CORNERS.

CX,CY: COORDINATES OF DESIGN-AREA CORNERS (AS MANY AS NC SPECIFIED), ONE POINT PER CARD.(2F10.2) ------ COL.1-20.

VI. NO. OF COLLECTOR POINT AND SPECIAL JOINT.

1. NOUT: NO. OF COLLECTOR POINT (I2) ------------------ COL.1-2.
2. JOINT: NO. OF SPECIAL JOINT POINT (I2) -------------- COL.4-5.

VII. COLLECTOR POINT COORDINATES.

OX,OY : COORDINATES OF COLLECTOR POINTS (AS MANY AS NOUT SPECIFIED), ONE POINT PER CARD (2F10.2) ---- COL.1-20.

VIII. SPECIAL JOINT COORDINATES.

PJX,PJY : COORDINATES OF SPECIAL JOINTS (AS MANY AS JOINT SPECIFIED). ONE POINT PER CARD (2F10.2) ---- COL.1-20.

INPUT FORMATS FOR DSLP

FOLLOWING DATA CARDS MUST BE SUPPLIED FOR THE DSLP PROGRAM TO RUN.

----- OPTIONS SPECIFICATIONS CARD.
----- PLOTTING PARAMETERS CARD.
----- BOUNDARY AND DESIGN-AREA.
----- BOUNDARY POINT COORDINATES.
----- UPPER AND LOWER LIMITS FOR BOUNDARY POINTS.
----- DESIGN PARAMETERS.
----- COLLECTOR POINT COORDINATES.
----- START AND END POINT AND LENGTH OF LATERAL.
----- SPECIAL JOINT POINT COORDINATES.
----- SHORTEST LATERAL AND SUBTOTAL LATERAL-LENGTH.
----- TOTAL LENGTH OF LATERALS FOR ALL DESIGN-AREAS.
----- ADDITIONAL DATA FOR SPECIAL SYMBOLS PLOTTING.

NOTE:
IF THE FIELD HAS MORE THAN ONE DESIGN-AREA, STEPS 6 TO 11 INCLUSIVE WILL BE REPEATED FOR ALL DESIGN-AREAS. GENERALLY, DATA FROM STEPS 3 TO 11 ARE GENERATED AND STORED ON DISK OR TAPE BY PROGRAM " DSDP ". THE PROGRAM DSLP SIMPLY READS THE STORED DATA FROM THE STORAGE DEVICE BY USING THE SAME FORMATS THAT USED BY DSDP DURING THE STORING PROCESSES. DATA IN STEPS 1,2, AND 12 ARE PUNCHED ON CARDS.

I. OPTIONS SPECIFICATIONS CARD.

1. IRD: UNIT NO. FOR READER (I2) ---------------------- COL.1-2.
2. IWRT: UNIT NO. FOR PRINTER OR STORAGE DEVICE(I2) ---- COL.3-4.
3. IGRID: IF IGRID=1, A GRID WILL BE DRAWN ON THE DRAINAGE PLAN (I2) -------------------------------- COL.5-6.
4. IFLO: IF IFLO=1, FLOW DIRECTIONS FOR ALL LATERALS ARE DRAWN (I2) ------------------------------------- COL.7-8.
5. NGRIDX: NO. OF GRID ALONE X-DIRECTION (I3) ---------- COL.9-11.
6. NGRIDY: NO. OF GRID ALONE Y-DIRECTION (I3) ---------- COL.12-14.

II. PLOTTING PARAMETERS CARD.

1. DSCALE: DRAWING SCALE (F10.4) ---------------------- COL.1-10.
2. CHH: HEIGHT OF CHARACTER (HEADING) (F10.4) ---------- COL.11-20.
3. CHC: HEIGHT OF CHARACTER (CONTENT) (F10.4) ---------- COL.21-30.
4. DW: DRAWING WIDTH (F10.4) -------------------------- COL.31-40.
5. DH: DRAWING HEIGHT (F10.4) ------------------------- COL.41-50.
6. WP: WIDTH OF PAPER REQUIRED (F10.4) ---------------- COL.51-60.
7. CEM: CONVERSION FACTOR (FROM IMPERIAL UNIT TO METRIC UNIT) (F10.4) ----------------------------- COL.61-70.

III. BOUNDARY AND DESIGN-AREA.

1. NB: NO. OF BOUNDARY OF THE FIELD (I2) --------------- COL.1-2.
2. IDA: NO. OF THE DESIGN-AREA (I2) -------------------- COL.3-4.

IV. BOUNDARY POINT COORDINATES.

BOUNDARY POINTS X.Y COORDINATES (AS MANY AS NB SPECIFIED). ONE POINT PER CARD (2F10.2) ------------- COL.1-20.

V. UPPER AND LOWER LIMITS FOR BOUNDARY POINTS.

1. BXL: LARGEST BX (F10.2) ------------------------------ COL.1-10.
2. BYL: LARGEST BY (F10.2) ------------------------------ COL.11-20.
3. BXS: SMALLEST BX (F10.2) ----------------------------- COL.21-30.
4. BYS: SMALLEST BY (F10.2) ----------------------------- COL.31-40.

VI. DESIGN PARAMETERS.

1. SPAC: DRAIN SPACING (F10.3) ------------------------- COL.1-10.
2. BANGLE: ANGLE BETWEEN LATERAL AND COLLECTOR (F10.3) - COL.11-20.
3. NONC: NO. OF CORNER OF THE DESIGN-AREA (I5) --------- COL.21-25.
4. LINE: NO. OF LATERALS (I5) -------------------------- COL.26-30.
5. NOUT: NO. OF COLLECTOR POINTS (I5) ------------------ COL.31-35.
6. JOINT: NO. OF SPECIAL JOINTS (I5) ------------------- COL.36-40.

VII. COLLECTOR POINT COORDINATES.

COLLECTOR POINTS X.Y COORDINATES (AS MANY AS NOUT SPECIFIED). ONE CARD PER POINT (2F10.2) ------------- COL.1-20.

VIII. START AND END POINT AND LENGTH OF LATERAL.

1. (X1.Y1). (X2.Y2). (X3.Y3) POINTS X-Y COORDINATES (6F10.2) --- COL.1-60.
2. XLEN: LENGTH OF LATERAL (F10.2) --------------------- COL.61-70.

IX. SPECIAL JOINT POINT COORDINATES.

PJX.PJY POINT X-Y COORDINATES (AS MANY AS JOINT SPECIFIED) (2F10.2) ------------------------- COL.1-20.

X.   SHORTEST LATERAL AND SUBTOTAL LATERAL-LENGTH.

1.   XLMIN: LENGTH OF SHORTEST LATERAL (F10.2) ----------- COL.1-10.
2.   SECLEN: TOTAL LENGTH OF LATERALS FOR ONE DESIGN-
     AREA (F10.2) -- COL.11-20.

XI.   TOTAL LENGTH OF LATERALS FOR ALL DESIGN-AREAS.

SUMLEN:TOTAL LENGTH OF ALL LATERALS FOR ALL
THE DESIGN-AREAS (F10.2) ---------------------------- COL.1-10.

XII.   ADDITIONAL DATA FOR SPECIAL SYMBOLS PLOTTING.

SEE STATEMENT NO. 300 AND 310 IN THE "MAIN"
PROGRAM OF DSLP.

APPENDIX E

LISTING OF COMPUTER PROGRAM PROFILE

```
C     ***********************************************************************
C     ***********************************************************************
C     ***********************************************************************
C     ***                                                                 ***
C     ***                                                                 ***
C     ***     X                  PROGRAM PROFILE                  X       ***
C     ***    X X                       BY                        X X      ***
C     ***   X   X                SIE-TAN  CHIENG                X   X     ***
C     *** X DEC.X                                              X '79 X    ***
C     ***   X   X        AGRICULTURAL ENGINEERING DEPARTMENT    X   X     ***
C     ***    X X                                                 X X      ***
C     ***     X        MACDONALD COLLEGE,  MCGILL UNIVERSITY      X       ***
C     ***                                                                 ***
C     ***                                                                 ***
C     ***********************************************************************
C     ***********************************************************************
C     ***********************************************************************
C
C     -----------------------------------------------------------------------
C
C     PROGRAM "PROFILE" IS WRITTEN FOR DRAWING THE PROFILES OF
C     LATERAL OR COLLECTOR OF THE SUBSURFACE DRAINAGE SYSTEM.
C     IT IS CONSIDERED AS A COMPONENT OF THE SYSTEM DESIGN
C     AND LAYOUT PACKAGE.
C     HS --- HORIZONTAL SCALE
C     VS --- VERTICAL SCALE
C     XO,YO -- COORDINATE OF LOWER LEFT HAND CORNER OF THE PROFILE PLAN.
C     TW --- TITLE BLOCK'S WIDTH
C     DH --- HEIGHT OF THE DRAWING WIDTH (PAPER)
C     TITLE -- TITLE OF THE JOB.
C     S --- ARRAY OF SLOPE
C     X-Y -- ARRAY OF FIELD ELEVATION DATA
C     -----------------------------------------------------------------------
C
      DIMENSION X(100),Y(100),TITLE(6),PX(5,15),PY(5,15),HD(5,100)
     *,DATA1(5),NSTR(10),XLAB(5,100),SEGL(10),AN(10),S(10),XKEY(13)
      CALL PLOTON
      CALL PLOT(0.0,0.5,-3)
      RAD=3.1415926/180.0
C     READ IN FROM CARDS : HORIZONTAL AND VERTICAL SCALES,
C                          ORIGIN OF CO-ORDINATES AND TITLE OF JOB.
      READ(5,5) HS,VS,XO,YO,TW,DH,TITLE,ITTL
    5 FORMAT(2F5.1,4F5.2,6A4,5X,I1)
C
C     READ IN FIELD ELEVATION DATA.
C     AND FIND THE MAX. & MIN. OF THE CO-ORDINATES.
      IC=1
      READ(5,20) X(IC),Y(IC),IEND1
   20 FORMAT(2F10.2,I1)
      XMAX=X(1)
      XMIN=X(1)
      YMAX=Y(1)
      YMIN=Y(1)
   10 IC=IC+1
```

```
      READ(5,20) X(IC),Y(IC),IEND1
      IF(X(IC).GT.XMAX) XMAX=X(IC)
      IF(Y(IC).GT.YMAX) YMAX=Y(IC)
      IF(X(IC).LT.XMIN) XMIN=X(IC)
      IF(Y(IC).LT.YMIN) YMIN=Y(IC)
      IF(IEND1.EQ.1) GO TO 30
      GO TO 10
 30   CONTINUE
C
C     NO. OF SEGMENTS OR TURNING-POINTS TO BE DRAWN.
C     IF NTP=1 --- MAIN LINE HAS A SINGLE SEGMENT ONLY.
C     IF JOINT=1 --- NO LINE JOINS TO THE MAIN LINE.
C
      CALL PLTSZE(XMAX+10.0,DH+1.0)
      READ(5,40) NTP,JOINT
  40  FORMAT(2I1)
C     READ IN : COORDINATES OF SEGMENTS AND THEIR SLOPES.
      DO 60 I=1,NTP
      READ(5,50) PX(I,1),PY(I,1),PX(I,2),PY(I,2),S(I)
  50  FORMAT(4F10.2,F5.2)
      F1=PX(I,2)-PX(I,1)
      F2=PY(I,2)-PY(I,1)
      SEGL(I)=SQRT(F1**2+F2**2)
      F11=F1/HS
      F22=F2/VS
      AN(I)=ATAN2(F22,F11)/RAD
  60  CONTINUE
      IF(PX(NTP,2).GT.XMAX) XMAX=PX(NTP,2)
      IF(PX(1,1).LT.XMIN) XMIN=PX(1,1)
      IF(JOINT.EQ.1) GO TO 120
      DO 100 I=1,NTP
      N1=1
C
C     HD IS THE ARRAY OF HORIZONTAL DISTANCE.
C     XLAB IS THE LABEL FOR THE JOINING SEGMENT.
  70  READ(5,80) HD(I,N1),XLAB(I,N1),IEND2
  80  FORMAT(F10.2,A4,5X,I1)
      IF(IEND2.EQ.1) GO TO 90
      N1=N1+1
      GO TO 70
  90  NSTR(I)=N1
      IF(HD(I,N1).EQ.-999.0) NSTR(I)=0
 100  CONTINUE
 120  IF(PY(1,1).LT.YMIN) YMIN=PY(1,1)
      MINY=YMIN-1.0
      IF(YMIN.LE.1.0) MINY=YMIN
      YMIN=MINY
C     DETERMINE THE NO. OF GRIDS FOR X-Y DIRECTIONS.
C
      NX=(XMAX-XMIN)/HS+1.5
      NY=(YMAX-YMIN)/VS+1.5
      IF(NX.LT.5) NX=5
      IF(NY.LT.4) NY=4
      XL=NX*1.0
      YL=NY*1.0
```

```
      CALL GRID(XO,YO,1.0,1.0,NX,NY)
      CALL AXS(XO, YO, 'HORIZONTAL DISTANCE, FT', -23,XL,0.0,0.0,1.0,
     * -1,0.0,1.0)
      CALL AXS(XO, YO, 'ELEVATION, FT G.S.C. DATUM', 26,YL,90.0,
     * YMIN,VS,-1,0.0,1.0)
C
C     DRAW THE FIELD ELEVATION  ( A SMOOTH CURVE ).
C
      TX=XO+(X(1)-XMIN)/HS
      TY=YO+(Y(1)-YMIN)/VS
      CALL CIRCLE(TX,TY,0.03)
      CALL SMOOT(TX,TY,0)
      DO 130 I=2,IC
      TX=XO+(X(I)-XMIN)/HS
      TY=YO+(Y(I)-YMIN)/VS
      CALL CIRCLE(TX,TY,0.03)
      CALL SMOOT(TX,TY,-2)
  130 CONTINUE
      CALL SMOOT(TX,TY,-24)
C
C     LABELLING THE CURVE.
C
      XRT=X(IC-1)+(X(IC)-X(IC-1))/2.0
      YRT=Y(IC-1)+(Y(IC)-Y(IC-1))/2.0
      XRS=XRT+0.5*COS(60.0*RAD)
      YRS=YRT+0.5*SIN(60.0*RAD)
      XRT=XO+(XRT-XMIN)/HS
      YRT=YO+(YRT-YMIN)/VS
      XRS=XO+(XRS-XMIN)/HS
      YRS=YO+(YRS-YMIN)/VS
      CALL AROHD(XRS,YRS,XRT,YRT,0.15,0.08,16)
      CALL SYMBOL(XRS-0.70,YRS+0.05,0.14,'FIELD ELEVATION',0.0,15)
      DO 140 I=1,NTP
      TX1=XO+(PX(I,1)-XMIN)/HS
      TY1=YO+(PY(I,1)-YMIN)/VS
      TX2=XO+(PX(I,2)-XMIN)/HS
      TY2=YO+(PY(I,2)-YMIN)/VS
      CALL PLOT(TX1,TY1,3)
      CALL PLOT(TX2,TY2,2)
      IF(I.GT.1) CALL CIRCLE(TX1,TY1,0.03)
  140 CONTINUE
C     FLOW DIRECTION & SLOPE ASSOCIATED.
C
      STORE=PX(1,1)
      DO 250 I=1,NTP
      IF((SEGL(I)/HS).LE.0.90) GO TO 250
      DA=(SEGL(I)/HS-0.70-7*0.10)/2.0
      XA=XO+PX(I,1)/HS+DA*COS(AN(I)*RAD)
      YAA=PY(I,1)+DA*SIN(AN(I)*RAD)
      YA=YO+(YAA-YMIN)/VS-0.12
      XB=XA+0.70*COS(AN(I)*RAD)
      YB=YA+0.70*SIN(AN(I)*RAD)
      CALL AROHD(XB,YB,XA,YA,0.10,0.06,16)
      CALL SYMBOL(XB+0.05,YB-0.05,0.10,'S=      %',AN(I),8)
      XC=XB+2.8*0.10*COS(AN(I)*RAD)
```

```
      YC=YB+2.8*0.10*SIN(AN(I)*RAD)-0.05
      CALL NUMBER(XC,YC,0.10,S(I),AN(I),2)
C     DRAW THE JOINTS FOR THE LATERAL OR COLLECTOR
C
      N3=NSTR(I)
      IF(N3.EQ.0) GO TO 250
      SLOPE=(PY(I,2)-PY(I,1))/(PX(I,2)-PX(I,1))
      DO 240 K=1,N3
      DX=PX(I,1)+(HD(I,K)-STORE)
      RX=XO+(DX-XMIN)/HS
      DY=PY(I,1)+(HD(I,K)-STORE)*SLOPE
      RY=YO+(DY-YMIN)/VS
      RXX=RX
      RYY=RY+0.50
      CALL ARDHD(RXX,RYY,RX,RY,0.10,0.06,16)
      CALL SYMBOL(RXX-0.10,RYY+0.08,0.10,XLAB(I,K), 0.0,4)
  240 CONTINUE
      STORE=PX(I,2)
  250 CONTINUE
      XT=XO+(XL-24*0.20)/2.0
      YT=YO+YL+0.5
      CALL SYMBOL(XT,YT,0.20,TITLE,0.0,24)
      CALL SYMBOL(0.5,0.75,0.12, 26HHORIZONTAL SCALE: 1"=     ',0.0,26)
      XXS=22.0*0.12+0.50
      CALL NUMBER(XXS,0.75,0.12,HS,0.0,-1)
      CALL SYMBOL(0.5,0.40,0.12, 25HVERTICAL   SCALE: 1"=    ',0.0,25)
      CALL NUMBER(XXS,0.40,0.12,VS,0.0,-1)
      X2=XL+XO+1.0
      DW=X2+TW
C
      IF(ITTL.EQ.0) GO TO 300
      CALL        TTLBLK(X2,DW,TW)
      CALL PLOT(0.0,0.0,3)
      CALL PLOT(0.0,YT+0.5,2)
      CALL PLOT(DW,YT+0.5,2)
      CALL PLOT(DW,0.0,2)
      CALL PLOT(0.0,0.0,2)
C
      GO TO 350
  300 CALL PLOT(0.0,0.0,3)
      CALL PLOT(0.0,YT+0.5,2)
      CALL PLOT(XL+XO+1.0,YT+0.5,2)
      CALL PLOT(XL+XO+1.0,0.0,2)
      CALL PLOT(0.0,0.0,2)
  350 CALL ENDPLT
      STOP
      END
```

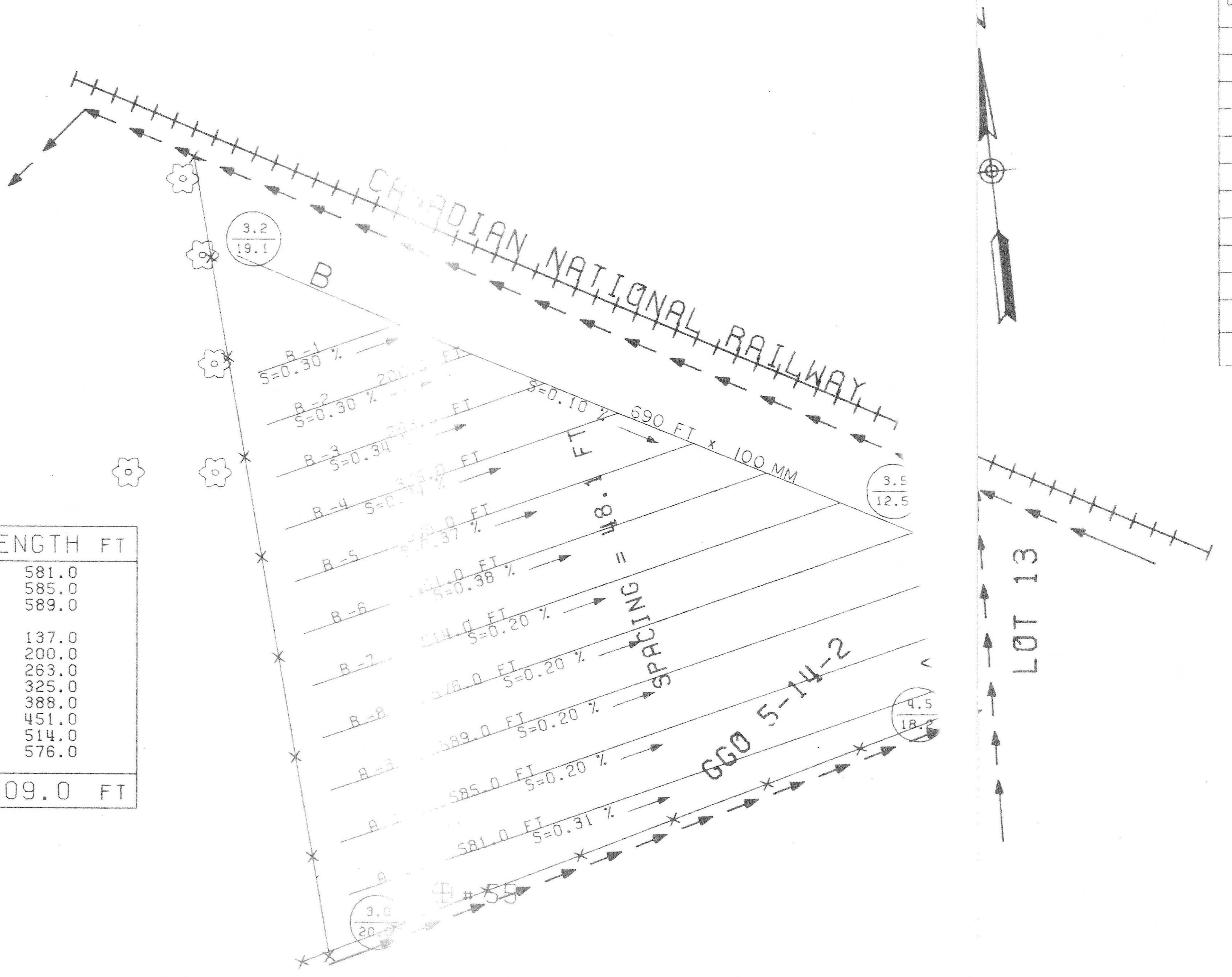
```
      SUBROUTINE TTLBLK(X2,DW,TW)
      DIMENSION T(9),SCALE(3),DWG(2)
      F = TW/7.0
      CALL DASH(X2+F*2.7,F*3.8,X2+F*2.7,F*3.1,0.0)
      CALL DASH(X2+F*1.5,F*3.1,X2+F*1.5,F*3.8,0.0)
      CALL DASH(X2,F*3.5,DW,F*3.5,0.0)
      CALL DASH(DW,F*3.1,X2,F*3.1,0.0)
      CALL DASH(X2,F*2.4,DW,F*2.4,0.0)
      CALL DASH(DW,F*2.0,X2,F*2.0,0.0)
      CALL DASH(X2,F*1.0,DW,F*1.0,0.0)
      CALL PLOT(X2,0.0,3)
      CALL PLOT(X2,F*3.8,2)
      CALL PLOT(DW,F*3.8,2)
      CALL PLOT(DW,0.0,2)
      CALL PLOT(X2,0.0,2)
      CALL DASH(X2+F*2.3,F*1.00,X2+F*2.3,0.0    ,0.0)
      CALL DASH(X2+F*3.2,0.0    ,X2+F*3.2,F*1.00,0.0)
      CALL DASH(X2+F*4.2,F*1.00,X2+F*4.2,0.0    ,0.0)
      CALL DASH(X2+F*5.2,0.0    ,X2+F*5.2,F*1.00,0.0)
      CALL DASH(X2+F*5.2,F*0.75,X2+F*2.3,F*0.75,0.0)
      CALL DASH(X2+F*2.3,F*0.50,X2+F*5.2,F*0.50,0.0)
      CALL DASH(X2+F*5.2,F*0.25,X2+F*2.3,F*0.25,0.0)
      CALL SYMBOL(X2+F*3.3,F*0.825,F*0.1,'DATE',0.0,4)
      CALL SYMBOL(X2+F*4.3,F*0.825,F*0.1,'PERSON',  0.0,6)
      CALL SYMBOL(X2+F*2.4,F*0.575,F*0.1,'DRAWN',  0.0,5)
      CALL SYMBOL(X2+F*2.4,F*0.325,F*0.1,'CHECKED',0.0,7)
      CALL SYMBOL(X2+F*2.4,F*0.075,F*0.1,'REVISED',0.0,7)
      CALL SYMBOL(X2+F*0.15,F*3.225,F*0.15,'REVISION',0.0,8)
      CALL SYMBOL(X2+F*1.65,F*3.225,F*0.15,'DATE',0.0,4)
      CALL SYMBOL(X2+F*2.85,F*3.225,F*0.15,'DESCRIPTION',0.0,11)
      CALL SYMBOL(X2+F*0.76,F*2.825,F*0.15,'AGRICULTURAL  ENGINEERING  D
     1EPARTMENT',0.0,37)
      CALL SYMBOL(X2+F*2.18,F*2.525,F*0.15,'MCGILL  UNIVERSITY',0.0,18)
      CALL SYMBOL(X2+F*0.53,F*2.125,F*0.15,'BOX 950, MACDONALD COLLEGE,
     1QUE. H9X 1C0',0.0,40)
      CALL SYMBOL(X2+F*0.15,F*0.775,F*0.15,'SCALE'  ,0.0,5)
      CALL SYMBOL(X2+F*5.35,F*0.775,F*0.15, 'DWG. NO.',0.0,8)
C
C     READ IN TITLE BLOCK INFORMATION.
C     T: TITLE OF THE DRAWING.
C     SCALE: SCALE USED IN THE DRAWING.
C     DWG: REFERENCE NO. OF DRAWING.
C
      DO 20 J=1,3
      READ(5,10) T
   10 FORMAT(8A4,A1)
      CALL SYMBOL(X2+F*0.24,F*(2.0-J*0.3),F*0.20,T,0.0,33)
   20 CONTINUE
      READ(5,30,END=100) SCALE,DWG
   30 FORMAT(2A4,A2,2X,2A4)
      CALL SYMBOL(X2+F*0.15,F*0.2,F*0.20,SCALE,0.0,10)
      CALL SYMBOL(X2+F*5.35,F*0.2,F*0.20,DWG,0.0,8)
  100 RETURN
      END
```

APPENDIX F

SUBSURFACE DRAINAGE PLAN OF JOB #1 AREA, OTTAWA, ONTARIO, PRODUCED BY COMPUTER PLOTTER

00.32.02 AE33000 PLOT1 FRI DEC 14, 1979

CONCESSION 4 .F., GLOUCESTER TW ETON CO., ONTARIO



LAT.NO	LENGTH FT
A -1	581.0
A -2	585.0
A -3	589.0
B -1	137.0
B -2	200.0
B -3	263.0
B -4	325.0
B -5	388.0
B -6	451.0
B -7	514.0
B -8	576.0
TOTAL	4609.0 FT

COLLECTOR	DRAIN TUBE REQUIRED FEET				
	100 MM	150 MM	MM	250 MM	300 MM
A	1891	65			
B	3544	—			
C					
D					
E					
F					
G					
H					
J					
K					
TOTAL	5435	65			
OVERALL TOTAL:					FEET

NOTES

1. BM #55 ELEV. 25.49' VERTICAL NAIL IN EAST ROOT OF ELM TREE ON SOUTH SIDE CD DITCH, ABOUT 700' SOUTH OF CNR TRACKS, 1800' EAST OF ANDERSON ROAD.
2. DRAINAGE MATERIALS: CORRUGATED POLYETHYLENE DRAINAGE TUBING.
3. ALL LATERALS ARE 100 MM DIA. UNLESS LABELLED OTHERWISE.

KEY TO PLAN

RELATIVE ELEVATIONS	98.6
CONTOURS (1' INTERVALS)	288
FENCES AND BOUNDARIES	
LENGTH & SIZE OF DRAIN	ABOVE DRAINS
GRADES	BELOW DRAINS
NATURAL GRADE	N.G.
CHANGE IN DRAIN SIZE	
CHANGE IN DRAIN GRADE	
BENCH MARK	B.M.
HUB STAKE	H.S.
TREE	
BUILDING	
OPEN DITCH	
DITCH BOTTOM ELEVATION	898.2
DEPTH OF TRENCH BOTTOM / TRENCH BOTTOM ELEVATION	4.5 / 93.5
OUTLET NO.	5
RAILROAD	
ROAD AND LANE	ROAD

APPENDIX F

REVISION	DATE	DESCRIPTION
AGRICULTURAL ENGINEERING DEPARTMENT MCGILL UNIVERSITY		
BOX 950, MACDONALD COLLEGE, QUE. H9X 1C0		
PLAN OF DRAINS JOB #I AREA NCC OTTAWA, ONTARIO		

SCALE		DATE	PERSON	DWG. NO.
1" = 100'	DRAWN			D-12-N-110
	CHECKED			
	REVISED			

APPENDICES G1 AND G2

G1. DRAINAGE PLAN OF JOB #E AREA, OTTAWA, ONTARIO, DRAWN BY DRAFTSMAN

G2. DRAINAGE PLAN OF THE 19th TEE DRIVING RANGE, OTTAWA, ONTARIO, DRAWN BY DRAFTSMAN

NOTES

1. BM #226 ELEV. 223.97' 100' EAST OF INTERSECTION OF 4th LINE ROAD AND KEMP ROAD. 30' SOUTH OF 4th LINE ROAD AND 10' EAST OF SMALL CLUSTER OF PINE TREES.
2. ADD 200' TO RELATIVE ELEVATIONS TO OBTAIN G.S.C. ELEVATIONS.
3. FILTER MATERIALS REQUIRED.
4. FILTER MATERIALS TO BE OF A QUALITY EQUAL OR BETTER THAN DUPONT "TYPAR" OR KNITTED NYLON SOCK.
5. LANE CROSSING OF COLLECTOR "A" SHALL BE MADE WITH A CORRUGATED STEEL PIPE 15' LONG AND 8" IN DIAMETER.
6. DITCH CROSSING OF COLLECTOR "A" SHALL BE MADE WITH A CORRUGATED STEEL PIPE 20' LONG AND 12" IN DIAMETER.
7. ALL DRAINAGE MATERIALS AND INSTALLATION PRACTICES SHALL BE OF A QUALITY EQUAL OR BETTER THAN THOSE OUTLINED IN ONTARIO MINISTRY OF FOOD AND AGRICULTURE PUBLICATION #29.

OUTLET		REQUIRED LENGTH IN FEET				
NO.	SIZE	Collector	4"	6"	8"	10"
1	12"x10'	A	10,150	1,000	-	750
		B	15,720	200	450	-
2	10"x10'	D	12,350	250	1,300	-
3	10"x10'	E	6,560	250	280	-

KEY TO PLAN

RELATIVE ELEVATIONS 98.6
CONTOURS (1 FOOT INTERVALS) 299
FENCES AND BOUNDARIES
LENGTH AND SIZE OF DRAIN — above drains
GRADES — below drains
NATURAL GRADE — N. G.
CHANGE IN DRAIN SIZE
CHANGE IN DRAIN GRADE
BENCH MARK B.M HUB STAKE H.S.
TREE BUILDING UTILITY
OPEN DITCH CREEK
DITCH BOTTOM ELEVATION -B 98.2
5.5 DEPTH OF TRENCH BOTTOM
93.5 TRENCH BOTTOM ELEVATION
OUTLET No. 3 RAILROAD
CULVERT
ROAD & LANE
MANHOLE

APPENDIX G1.

REVISION	DATE	DESCRIPTION

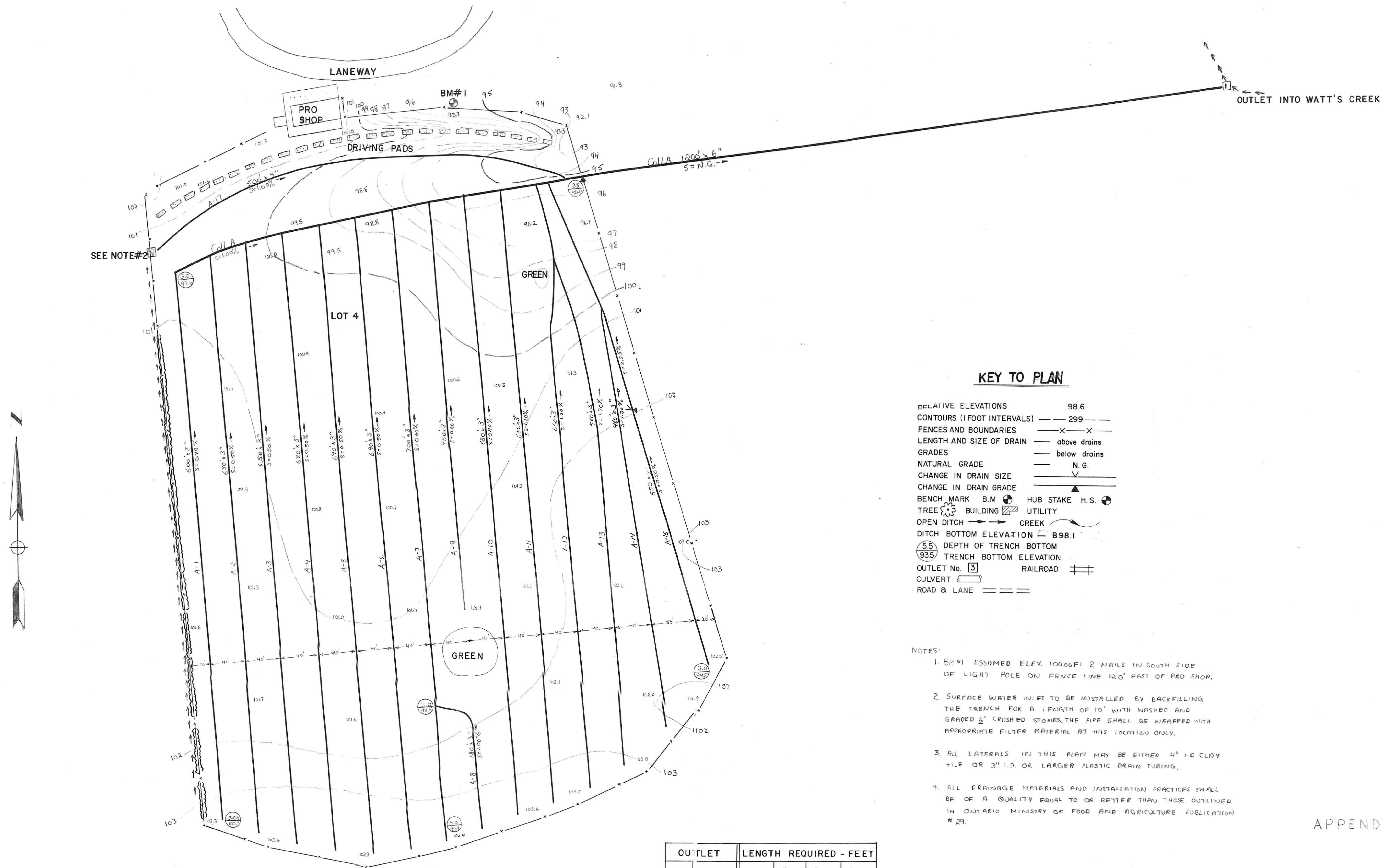
AGRICULTURAL ENGINEERING DEPARTMENT
McGILL UNIVERSITY
BOX 950 MACDONALD COLLEGE, QUE. H9X-1C0

PLAN OF DRAINS
JOB #E AREA

NATIONAL CAPITAL COMMISSION, OTTAWA, ONTARIO

R. S. BROUGHTON

CONCESSION 3 O.F., NEPEAN TWP., CARLETON CO., ONTARIO.



KEY TO PLAN

RELATIVE ELEVATIONS 98.6
CONTOURS (1 FOOT INTERVALS) 299
FENCES AND BOUNDARIES
LENGTH AND SIZE OF DRAIN — above drains
GRADES — below drains
NATURAL GRADE — N.G.
CHANGE IN DRAIN SIZE
CHANGE IN DRAIN GRADE
BENCH MARK B.M. HUB STAKE H.S.
TREE BUILDING UTILITY
OPEN DITCH CREEK
DITCH BOTTOM ELEVATION B98.1
5.5 / 93.5 DEPTH OF TRENCH BOTTOM / TRENCH BOTTOM ELEVATION
OUTLET No. 3 RAILROAD
CULVERT
ROAD & LANE

NOTES:

1. BM #1 ASSUMED ELEV. 100.00 Ft 2 NAILS IN SOUTH SIDE OF LIGHT POLE ON FENCE LINE 120' EAST OF PRO SHOP.
2. SURFACE WATER INLET TO BE INSTALLED BY BACKFILLING THE TRENCH FOR A LENGTH OF 10' WITH WASHED AND GRADED 1/2" CRUSHED STONES. THE PIPE SHALL BE WRAPPED WITH APPROPRIATE FILTER MATERIAL AT THIS LOCATION ONLY.
3. ALL LATERALS IN THIS PLAN MAY BE EITHER 4" I.D CLAY TILE OR 3" I.D. OR LARGER PLASTIC DRAIN TUBING.
4. ALL DRAINAGE MATERIALS AND INSTALLATION PRACTICES SHALL BE OF A QUALITY EQUAL TO OR BETTER THAN THOSE OUTLINED IN ONTARIO MINISTRY OF FOOD AND AGRICULTURE PUBLICATION # 29.

APPENDIX G2

OUTLET		LENGTH REQUIRED - FEET			
NO.	SIZE	COLL.	3" Lat.	4" Lat.	6" Coll.
1	6" x 10'	A	8330	1050	1200

DRAINAGE MATERIAL: 3", 4", 6", CORRUGATED PLASTIC DRAIN TUBING.
DRAINAGE MACHINE: TRENCHLESS PLOW WITH LASER GRADE CONTROL.

REVISION	DATE	DESCRIPTION
# 1	JAN '77	DRAINS AS INSTALLED SUMMER '76

AGRICULTURAL ENGINEERING DEPARTMENT
McGILL UNIVERSITY
BOX 400, MACDONALD COLLEGE, QUE. H0A-1C0

PLAN OF DRAINS
THE 19th TEE DRIVING RANGE
NATIONAL CAPITAL COMMISSION, OTTAWA, ONTARIO.

SCALE				DWG. NO.
1" = 50 Ft.	DRAWN	S. AMI	Feb '77	D-12-N-7601
	CHECKED	A. SHAH	Feb '77	
	REVISED	S. AMI	Feb '77	

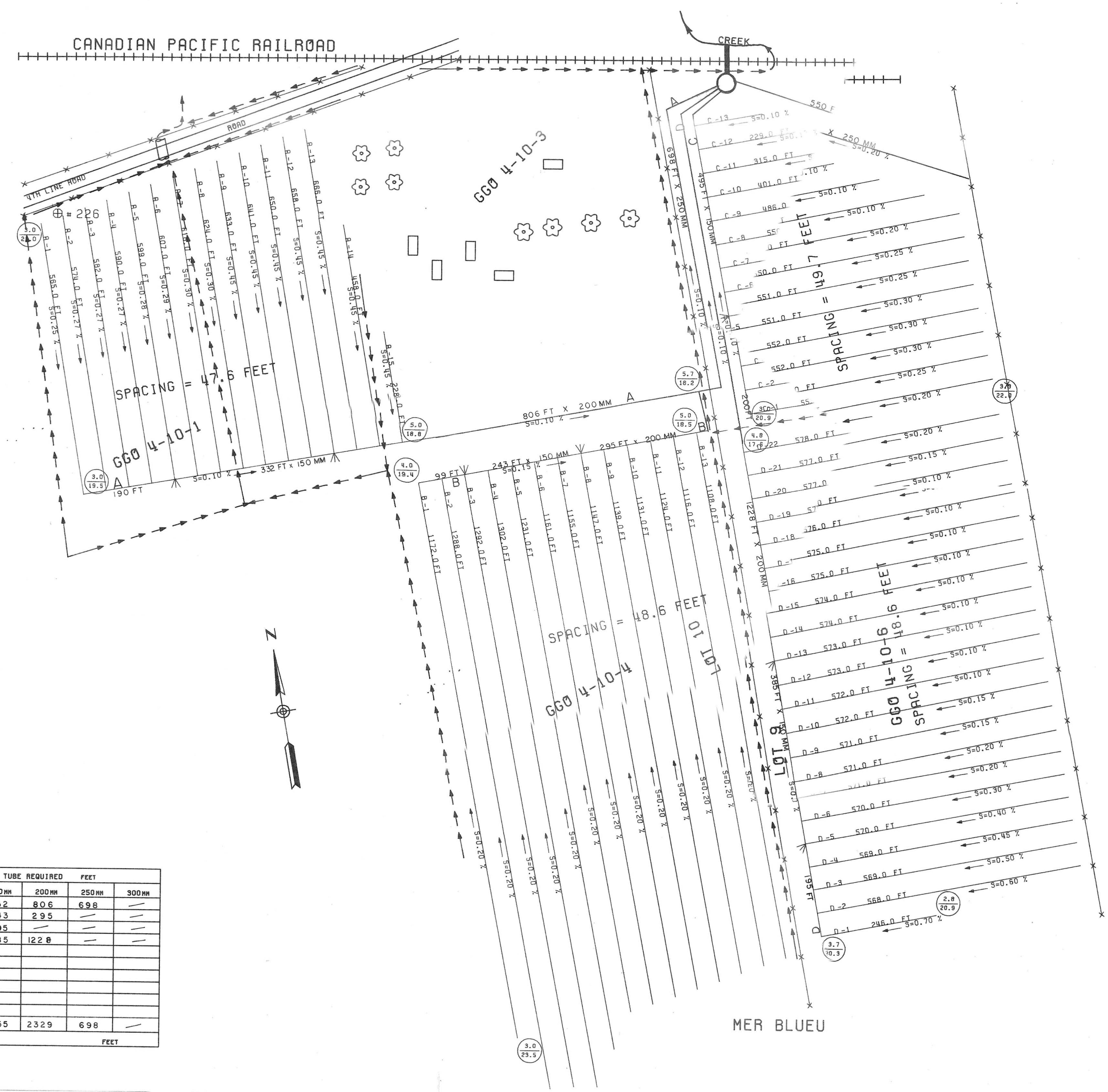
APPENDICES H1 AND H2

H1. DRAINAGE PLAN OF JOB #E AREA, OTTAWA, ONTARIO, DESIGNED AND DRAWN BY COMPUTER

H2. DRAINAGE PLAN OF THE 19th TEE DRIVING RANGE, OTTAWA, ONTARIO, DESIGNED AND DRAWN BY COMPUTER

CONCESSION 4 O.F. CLOUCESTER TWP. CARLETON CO. ONTARIO

LAT.NO	LENGTH FT
A -1	565.0
A -2	574.0
A -3	582.0
A -4	590.0
A -5	599.0
A -6	607.0
A -7	616.0
A -8	624.0
A -9	633.0
A -10	641.0
A -11	650.0
A -12	658.0
A -13	666.0
A -14	458.0
A -15	228.0
B -1	1172.0
B -2	1288.0
B -3	1292.0
B -4	1302.0
B -5	1231.0
B -6	1161.0
B -7	1155.0
B -8	1147.0
B -9	1139.0
B -10	1131.0
B -11	1124.0
B -12	1116.0
B -13	1108.0
C -1	553.0
C -2	553.0
C -3	552.0
C -4	552.0
C -5	551.0
C -6	551.0
C -7	550.0
C -8	550.0
C -9	486.0
C -10	401.0
C -11	315.0
C -12	229.0
C -13	143.0
D -1	246.0
D -2	568.0
D -3	569.0
D -4	569.0
D -5	570.0
D -6	570.0
D -7	571.0
D -8	571.0
D -9	571.0
D -10	572.0
D -11	572.0
D -12	573.0
D -13	573.0
D -14	574.0
D -15	574.0
D -16	575.0
D -17	575.0
D -18	576.0
D -19	576.0
D -20	577.0
D -21	577.0
D -22	578.0
TOTAL	42319.7 FT



NOTES

1. BM #226 ELEVATION 223.97 FEET 100' EAST OF INTERSECTION OF 4TH LINE ROAD AND KEMP ROAD. 30' SOUTH OF 4TH LINE ROAD AND 10' EAST OF SMALL CLUSTER OF PINE TREES.
2. ADD 200' TO RELATIVE ELEVATIONS TO OBTAIN G.S.C. ELEVATIONS.
3. FILTER MATERIALS REQUIRED.
4. FILTER MATERIALS TO BE OF A QUALITY EQUAL OR BETTER THAN DUPONT "TYPAR" OR KNITTED NYLON SOCK.
5. LANE CROSSING OG COLLECTOR "A" SHALL BE MADE WITH A CORRUGATED STEEL PIPE 15 FEET LONG AND 8" IN DIAMETER.
6. DITCH CROSSING OF COLLECTOT "A" SHALL BE MADE WITH A CORRUGATED STEEL PIPE 20 FEET LONG AND 12" IN DIAMETER.
7. ALL DRAINAGE MATERIALS AND INSTALLATION PRACTICES SHALL BE OF A QUALITY EQUAL OR BETTER THAN THOSE OUTLINED IN ONTARIO MINISTRY OF FOOD AND AGRICULTURE PUBLICATION #29.
8. ALL LATERALS ARE 100 MM-DIA UNLESS LABELLED OTHERWISE.

KEY TO PLAN

RELATIVE ELEVATIONS	98.6
CONTOURS (1' INTERVALS)	288
FENCES AND BOUNDARIES	
LENGTH & SIZE OF DRAIN	ABOVE DRAINS
GRADES	BELOW DRAINS
NATURAL GRADE	N.G.
CHANGE IN DRAIN SIZE	
CHANGE IN DRAIN GRADE	
BENCH MARK	B.M.
HUB STAKE	H.S.
TREE	
BUILDING	
OPEN DITCH	
DITCH BOTTOM ELEVATION	B98.2
DEPTH OF TRENCH BOTTOM TRENCH BOTTOM ELEVATION	4.5 / 93.5
OUTLET NO.	5
RAILROAD	
ROAD AND LANE	ROAD

COLLECTOR	DRAIN TUBE REQUIRED FEET				
	100MM	150MM	200MM	250MM	300MM
A	8881	332	806	698	—
B	15461	243	295	—	—
C	6186	495	—	—	—
D	12472	385	1228	—	—
E					
F					
G					
H					
J					
K					
TOTAL	43000	1455	2329	698	—
OVERALL TOTAL:					FEET

APPENDIX H1.

REVISION	DATE	DESCRIPTION

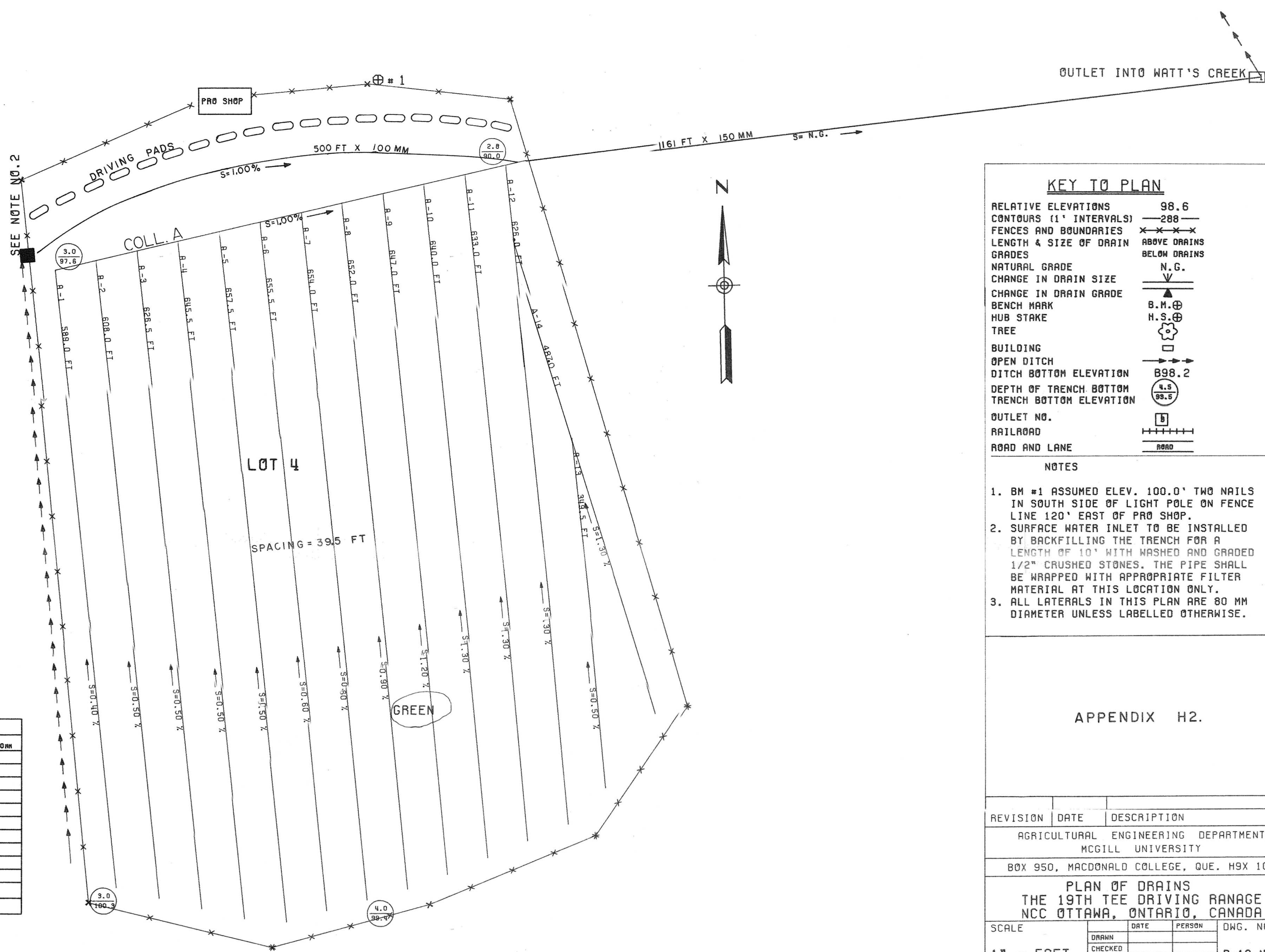
AGRICULTURAL ENGINEERING DEPARTMENT
MCGILL UNIVERSITY

BOX 950, MACDONALD COLLEGE, QUE. H9X 1CO

PLAN OF DRAINS
JOB OF #E AREA
NCC OTTAWA, ONTARIO

SCALE		DATE	PERSON	DWG. NO.
	DRAWN			
1" = 100'	CHECKED			D-12-N-35B
	REVISED			

LAT.NO	LENGTH FT
A -1	589.0
A -2	608.0
A -3	626.5
A -4	645.5
A -5	657.5
A -6	655.5
A -7	654.0
A -8	652.0
A -9	647.0
A -10	640.0
A -11	633.0
A -12	626.0
A -13	349.5
A -14	487.0
TOTAL	8470.5 FT



COLLECTOR	DRAIN TUBE REQUIRED FEET				
	100MM	150MM	200MM	250MM	300MM
A	500	1161			
B					
C					
D					
E					
F					
G					
H					
J					
K					
TOTAL	500	1161			
OVERALL TOTAL:				FEET	

KEY TO PLAN

RELATIVE ELEVATIONS	98.6
CONTOURS (1' INTERVALS)	288
FENCES AND BOUNDARIES	×—×—×
LENGTH & SIZE OF DRAIN	ABOVE DRAINS
GRADES	BELOW DRAINS
NATURAL GRADE	N.G.
CHANGE IN DRAIN SIZE	
CHANGE IN DRAIN GRADE	
BENCH MARK	B.M.⊕
HUB STAKE	H.S.⊕
TREE	
BUILDING	
OPEN DITCH	
DITCH BOTTOM ELEVATION	898.2
DEPTH OF TRENCH BOTTOM / TRENCH BOTTOM ELEVATION	4.5 / 93.5
OUTLET NO.	b
RAILROAD	
ROAD AND LANE	ROAD

NOTES

1. BM #1 ASSUMED ELEV. 100.0' TWO NAILS IN SOUTH SIDE OF LIGHT POLE ON FENCE LINE 120' EAST OF PRO SHOP.
2. SURFACE WATER INLET TO BE INSTALLED BY BACKFILLING THE TRENCH FOR A LENGTH OF 10' WITH WASHED AND GRADED 1/2" CRUSHED STONES. THE PIPE SHALL BE WRAPPED WITH APPROPRIATE FILTER MATERIAL AT THIS LOCATION ONLY.
3. ALL LATERALS IN THIS PLAN ARE 80 MM DIAMETER UNLESS LABELLED OTHERWISE.

APPENDIX H2.

REVISION	DATE	DESCRIPTION

AGRICULTURAL ENGINEERING DEPARTMENT
MCGILL UNIVERSITY

BOX 950, MACDONALD COLLEGE, QUE. H9X 1C0

PLAN OF DRAINS
THE 19TH TEE DRIVING RANAGE
NCC OTTAWA, ONTARIO, CANADA

SCALE		DATE	PERSON	DWG. NO.
	DRAWN			
	CHECKED			
1" = 50FT	REVISED			D-12-N-760