THE DESIGN AND EVALUATION OF SOIL CONSERVATION SYSTEMS IN ST. LUCIA

by

PETER NORVILLE

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Department of Agricultural Engineering
Macdonald College of McGill University
Montreal, Quebec
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ABSTRACT

M.Sc. | Agricultural Engineering

PETER NORVILLE

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Three soil conservation systems: contour drainage, strip cropping, and terracing, were designed and established within separate plots on hillside farmlands in St. Lucia. A control plot with no form of soil conservation was also established. Topographic and soils surveys of these plots were conducted. Rainfall, runoff and soil loss were measured over one wet season. Crop yields and construction and maintenance costs were also determined.

For rainfall amounts between 14.2 and 211.2 mm, runoff depths varied from 0.6 to 203.6 mm in the control plot, 2.1 to 199.2 mm in the contour drained plot, 3.2 to 155.1 mm in the strip cropped plot and 1.3 to 94.7 mm in the terraced plot. The largest amounts of runoff were most often recorded in the strip cropped plot, while on most occasions, the terraced plot produced the least runoff.

Soil loss rates varied from 0.01 to 1.77 kg/ha in the control plot, 0.07 to 16.88 kg/ha in the contour drained plot, 0.2 to 28.86 kg/ha in the strip cropped plot and 0.01 to 6.62 kg/ha in the terraced plot.

Construction costs per hectare were EC$5565 for the contour drainage system, EC$5425 for the strip cropped system and EC$6350 for the terraced system.

Further monitoring of the conservation systems is required for prediction of their long-term effectiveness in runoff and soil erosion control.

RESUME

M.Sc. Génie Rural

PETER NORVILLE

DESIGN ET EVALUATION DE SYSTEMES DE CONSERVATION DES SOLS SUR L'ILE DE SAINTE-LUCIE

Trois systèmes de conservation des sols en montagne: le drainage de contours, la culture en bandes, et la culture en terraces, ont été construis sur des sites de terre arables, à flanc de montagne, sur l'île de Sainte-Lucie. De plus, un site sans système de conservation a été utilisé pour fin de contrôle. Chaque site fut arpenté et son sol analysé. L'évaluation de la performance de chaque système a été basée sur des données recueillies au cours d'une saison des pluies. Ces données consistaient en la quantité des précipitations, la quantité des écoulements de surface et la quantité des pertes en sol. Les rendements des cultures, et les coûts de construction et d'entretient, ont aussi été établis.

Les données recueillies ont indiqué que les précipitations quotidiennes de l'ordre de 14.2 à 211.2 mm causaient des écoulements de 0.6 à 203.6 mm sur le site de contrôle, comparativement à 2.1 à 199.2 mm sur le site de drainage des contours, à 3.2 à 155.1 mm sur le site de culture en bandes, et à 1.3 à 94.7 mm sur le site de culture en terraces. Dans la plupart des cas, les écoulements les plus important ont été mesurés sur le site de culture en bandes et les plus faibles ont été mesurés sur le site de culture en terraces.

Les taux de pertes en sols ont été de 0.01 à 1.77 kg/ha pour le site de contrôle, de 0.07 à 16.88 kg/ha pour le site de drainage des contours, de 0.2 à 28.66 kg/ha pour le site de culture en bandes, et de 0.01 à 6.62 kg/ha pur le site de

cultures en terraces.

Les coùts de construction ont été de EC$5565 par hectare pour le site de drainage des contours, de EC$5425 par hectare pour le site de culture en bandes, et de EC$6350 par hectare pour le site de culture en terraces.

Il est recommandé de poursuivre cette étude pour évaluer l'efficacité à long terme des systèmes de conservation des sols étudiés.

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NOMENCLATURE

A	area
ASAE	American Society of Agricultural Engineers
b	bed width
C	runoff coeffecient
°C	degrees celcius
CARDI	Caribbean Agricultural Research and Development Institute
cm	centimeters
cm/hr	centimeters per hour
d	depth
EC$	Eastern Caribbean dollars (1 US$ = 2.7 EC$)
FAO	Food and Agriculture Organisation of the United Nations
g/cm^3	grams per cubic centimeter
ha	hectares
hrs	hours
i	rainfall intensity
kg/ha	kilograms per hectare
km	kilometers
km/ha	kilometers per hectare
l	length
l/s	liters per second
m	meters
m/s	meters per second
meq/100g	milliequivalents per 100 gram
m^3/s	cubic meters per second
min	minutes

mm	millimeters
mmhos/cm	millimhos per centimetre
mm/hr	millimeters per hour
n	Manning's roughness coefficient
P	wetted perimeter
ppm	parts per million
q	discharge
Q	drain capacity
r	correlation coeffecient
R	hydraulic radius
s	channel grade
S	land slope
sin	sine
T_c	time of concentration
T_p	time to peak
tan	tangent
t/ha	tonnes per hectare
t/ha/yr	tonnes per hectare per year
TS	terrace spacing
USDA	United States Department of Agriculture
VI	vertical interval
WINBAN	Windward Islands Banana Growers Association
X	geographical location constant
Y	soil erodibility and ground cover constant
Z	side slope of drain
°	degrees of slope
%	percentage

CHAPTER 1

INTRODUCTION

1.1 Background

Soil erosion is a widespread problem in St. Lucia and a threat to long term agricultural production. Slopes greater than 30° are often cultivated with no soil conservation measures in areas where rainfall intensities may exceed 200 mm/hr. Such conditions result in extensive sheet, rill and gully erosion.

Several agricultural practices contribute to the problems of erosion. The most significant, is the intensive cultivation of vegetables and root crops on hillsides, without the application of soil conservation measures. This practice causes widespread sheet erosion. With sheet erosion, topsoil rich in organic matter, which provides the desirable physical and chemical conditions for plant growth is lost. This leads to reduced soil productivity and may eventually result in the abandonment of some fields. This situation is most evident in the Delcer area in the South-east of the island. Intensive root or tuber crop cultivation has resulted in thin soils and, in some instances exposed subsoils which can no longer sustain crop production.

Small farmers represent a significant proportion of the farming community. They predominantly occupy farms of less than 2 ha located on slopes of 5° to 30°. These farms are generally scattered and are dominated by mixed, short-term, cropping systems. Due to land tenure problems, many small farmers do not own the lands which they cultivate. Slash and burn agriculture, which causes extensive sheet erosion, is therefore quite common (Madramootoo et al., 1989).

Gully erosion is also common and occurs over a wide range of slopes and rainfall conditions. The construction of unprotected drains and the alignment of crop rows up and down the slope result in extensive gullying. Also, in areas where no provision has been made for drainage, gullies often start in footpaths which concentrate runoff in steep narrow channels where the erosive power of runoff is high (Stark et al., 1966).

The increasing encroachment of food crop cultivation on natural forest lands has, in recent years, resulted in the excessive cultivation of steeper lands in the high rainfall areas. This has led to increased soil erosion throughout the island.

Soil erosion not only affects the productivity of farmlands but also creates the problems of sedimentation of river beds, flooding of low-lying areas, reduction of streamflows, water shortages in the dry season, destruction of wildlife and siltation of reservoirs.

Regrettably, few conservation practices are undertaken by farmers. They have neither the resources, nor the technical skills. Moreover, there is no incentive for landless farmers to carry out soil conservation (Madramootoo et al., 1989).

The planning of soil conservation programmes and the implementation of conservation practices are hampered by a shortage of local data. There were no previous data on runoff and erosion rates. There were also no recent cost estimates of construction and maintenance of soil conservation measures. To obtain the data required for planning and implementing a conservation programme, studies were needed on the effects of soil conservation measures on soil loss, runoff and crop yields.

A research programme was therefore implemented to generate the required data. This thesis presents the methodology applied in the research programme and the initial results obtained.

1.2 Objectives

The objectives of the study were to:

1. Design and construct three appropriate soil conservation systems for small hillside farms in St.Lucia.
2. Measure rainfall, runoff, soil loss and crop yields on these fields, as well as on a field with no soil conservation measures.
3. Determine the construction and maintenance costs of these systems.
4. Evaluate the relative effectiveness of the soil conservation systems in reducing soil loss, controlling runoff, and maintaining crop productivity within reasonable cost limits.
5. Use the data obtained from above to make recommendations on the approaches to be taken in the establishment of soil conservation systems on small hillside farms in St. Lucia.

1.3 Scope

This study provides data from fields of 0.32 to 0.80 ha. Many small farms in the Caribbean fall within this range. Therefore, the results of this study can be immediately applied to other hillside farms in St.Lucia and the other Caribbean islands.

Spatial climatic variability and some differences in soils and farming practices should be considered when applying the results outside of the study area.

The data on runoff and soil loss covers the period immediately subsequent to construction of the conservation systems and crop establishment. Site conditions were therefore dominated by relatively high levels of soil instability and sparse ground cover. The data must therefore be viewed in the context of these conditions. It is expected that subsequent data will provide information on the long-term effectiveness of the conservation systems.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Background information on St. Lucia

2.1.1 Location, size and population.

St. Lucia is a Caribbean island of 616 km^2 in the Windward islands chain. It is located at latitude 14° north, longitude 61° west (Figure 2.1). The island is roughly oval in shape with maximum dimensions of 42 km long and 22 km wide. The population of the island was estimated at 142,000 in 1987 (Ministry of Finance, 1988).

2.1.2 Landscape and physiography

The island has generally steep relief resulting from high rainfall on volcanic rocks which have erupted and eroded during several episodes of volcanic activity. A central mountainous ridge runs south-south-west to north-north-east almost through the entire length of the island, rising at Mount Gimie to an elevation of 950 m above sea level. Numerous spurs and deep gullies radiate down to the coast from this central ridge (Stark et al., 1966).

Most of the island falls within the slope range of 10° to 30°. Approximately 10 percent of the island falls within the slope range of 0° to 5°. The distribution of slope gradients is given in Table 2.1.

Extensive river systems are found throughout the island. Most of the rivers originate from the high rainfall regions in the upper parts of catchments where water seeps from the weathered zone. The central and northern rivers are more

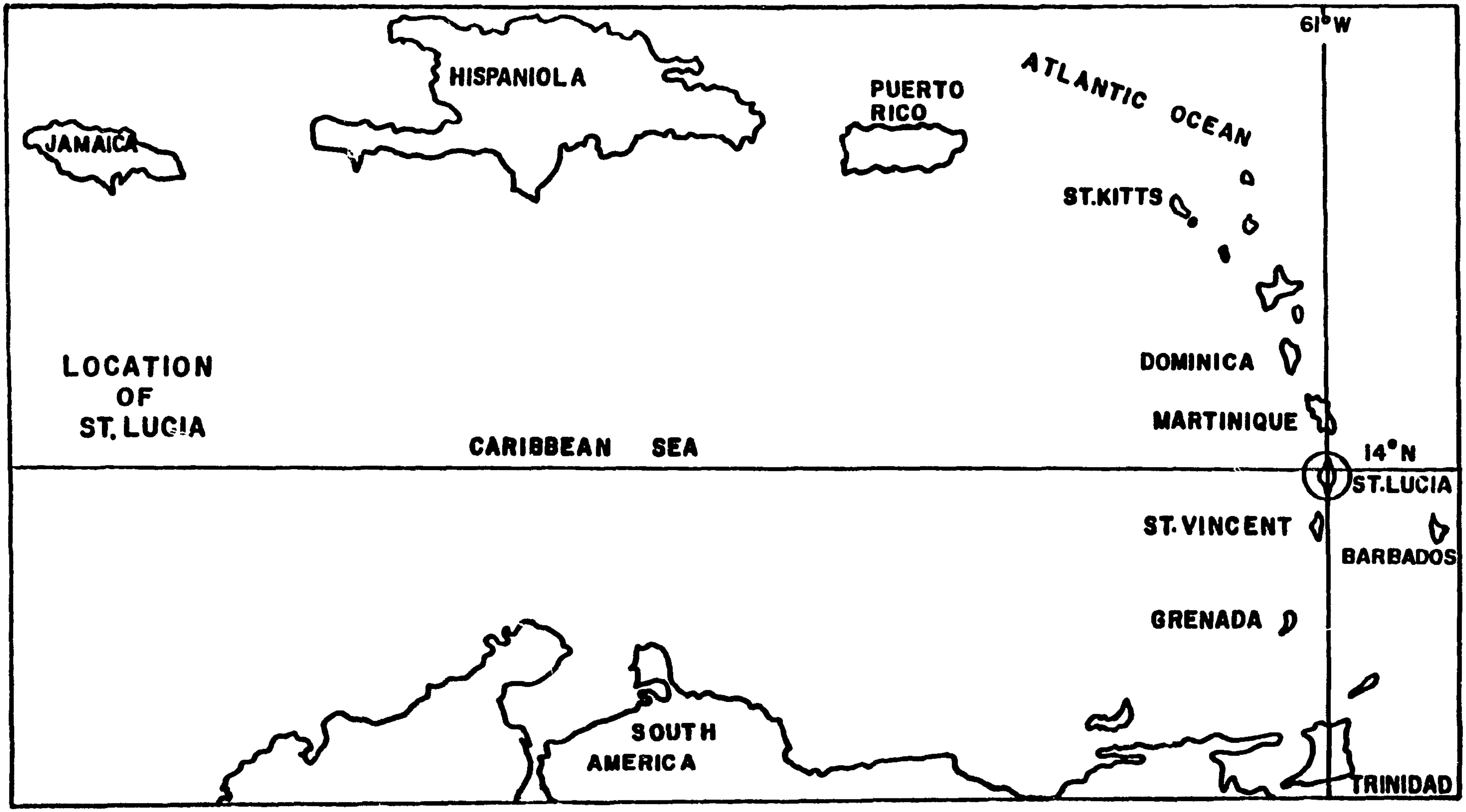


Figure 2.1 Location map of St. Lucia

mature and have attained more graded channel beds than those in the south-west. The Roseau river, which runs for 19 km, is the longest river on the island (Migeot and Hadwen, 1986).

Table 2.1. Distribution of slope gradients in St. Lucia
(After Polius and Pretel, 1981)

Slope (degrees)	Percentage of total area
0 - 2	7.2
2 - 5	2.7
5 - 10	9.8
10 - 20	24.7
20 - 30	30.3
> 30	12.7
Miscellaneous surface types covering several slope categories, eg. bare rock, beach sand and urban areas	12.6
Total	100.0

2.1.3 Climate

St. Lucia has a tropical climate which is modified by oceanic influences. Annual rainfall increases with elevation and varies from 1300 mm in the lowland coastal areas to over 3800 mm in the mountainous interior (Figure 2.2). This variation suggests a marked orographic influence on precipitation. About one-third of the yearly rainfall occurs in the dry season which generally lasts from mid-December to mid-May (Migeot and Hadwen, 1986). The difference between wet and dry season lessens in the high rainfall areas where about 40% of the annual rainfall occurs during the dry season. Rainfall intensities are generally high. For example, intensities of 210 mm/hr for a duration of 5 minutes are expected to occur once in every 5 years at Troumassee in the south-eastern part of the island (Farnum, 1979).

The island is in the hurricane belt and is occasionally affected by hurricanes with high winds and torrential rains between August and October.

Temperatures are generally high and vary slightly over the year. The mean temperature is higher from May to October and is mostly above 27 °C. It reduces to 25 °C in January which is usually the coolest month. At Vigie in the north of the island, the mean monthly maximum temperature varies from 28.9 °C to 31.1 °C with a mean of 30.3 °C and the mean minimum temperature varies from 22.2 °C to 24.4 °C (Migeot and Hadwen, 1986).

Relative humidities are also high. The mean annual value over most of the island is 70%. The maximum relative humidities are usually recorded during the rainy season. The mean monthly relative humidity at Roseau reaches a maximum of 79% in October and November and a minimum of 70% in April. The maximum deviation from the yearly mean is approximately 6%.

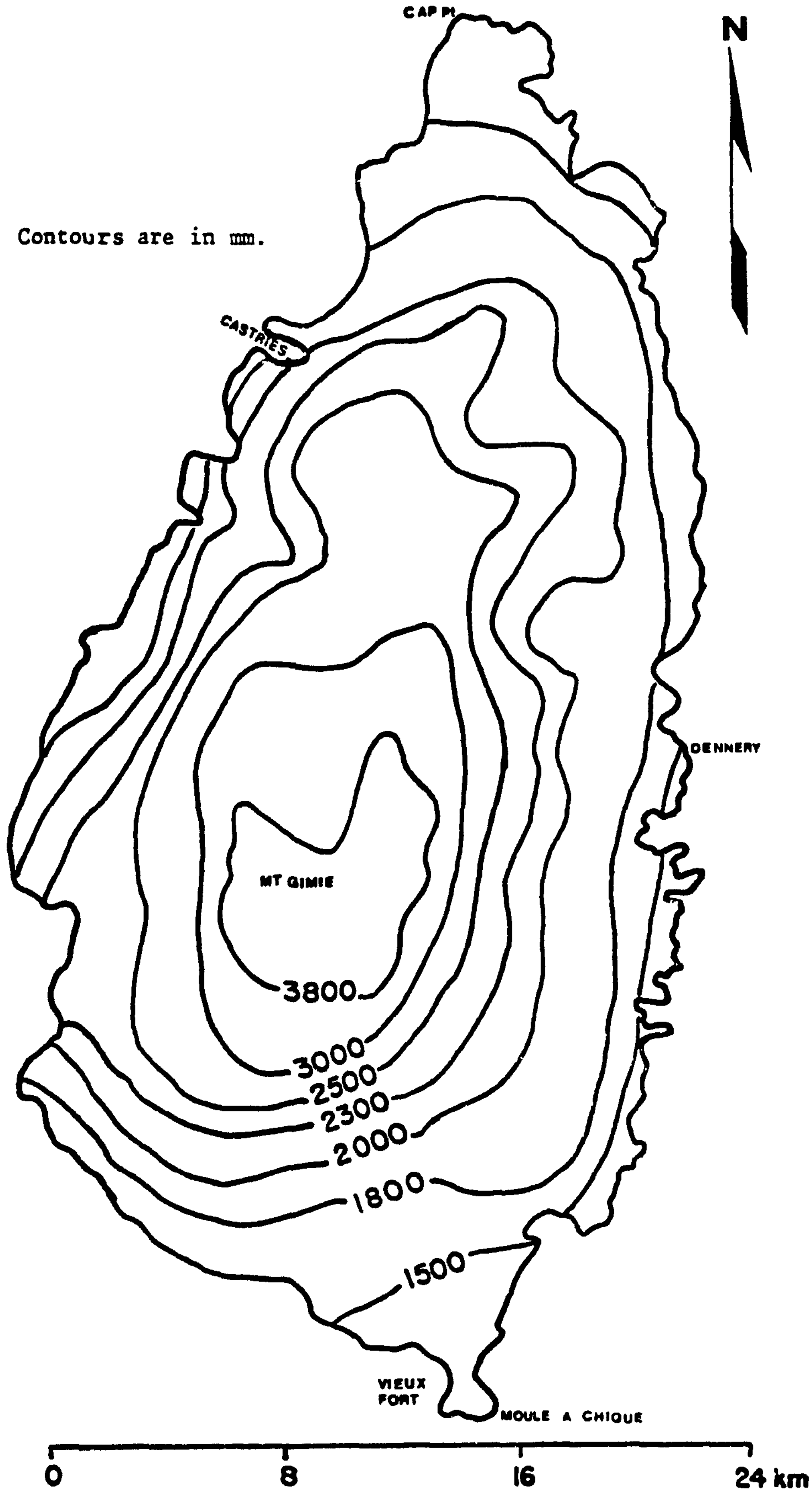


Figure 2.2 Rainfall map of St. Lucia
(total annual rainfall)

2.1.4 Soils

The most comprehensive evaluation of the soils of St. Lucia is provided by Stark et al. (1966). They described the soils of St. Lucia as being formed from a narrow variety of volcanic rocks which vary in age, porosity, and degree of compaction. The main parent materials consist of andecites basalts and dacites. Soils derived from andecites are the most extensively occurring and cover almost half of the island. These soils are characterised by low to medium acidity and problems of drainage and erosion. They are largely found in relatively steep areas with annual rainfalls greater than 1250 mm. With the exception of the alluvial deposits, all other soils bear similar characteristics to the andecites. Alluvial deposits are well drained and fertile, and commonly occur on slopes of less than 5°. Stark et al. (1966) identified a total of 49 soils on the island.

Because of the rainfall distribution patterns over the island, parent materials are subject to different amounts of weathering which generally result in thick soils in the high rainfall areas at higher elevations and thin soils in the lower rainfall areas. In the high rainfall areas, latosols have developed. The clay minerals of these soils are generally kaolinitic, but allophane and illite also occur. In the drier areas, lattice clays of the montmorilonitic type are found.

2.1.5 Vegetation

The natural vegetation of St. Lucia occurs in almost undisturbed concentric zones which largely follow changes in rainfall and altitude (Stark et al., 1966).

Rain forests are found on the higher elevations in the central part of the island. Surrounding the rain forests is an irregular band of secondary forest which merges into the cultivated zone. A discontinuous band of dry scrub woodland occurs around the coastlands. The soils of this zone are frequently shallow, rocky and severely eroded.

The extreme north and south are the driest areas. In these areas, dry scrublands merge into thorn and poor grazing savannah. (Stark et al., 1966).

Small areas of mangrove are found on the western coast and in the south of the island.

2.1.6 Agriculture

Agriculture is the most important productive sector of St. Lucia's economy. In 1987, agriculture contributed to 14% of the Gross Domestic Product and the value of agricultural exports accounted for approximately 60% of total exports (Ministry of Agriculture, 1988).

Agricultural production is concentrated on small farm holdings. Farms of less than 4 ha account for 94% of the total number of farm holdings yet they occupy 35% of total farmland (Ministry of Agriculture, 1987). The distribution of farm sizes is given in Table 2.2. In the banana industry, 90% of the producers are small farmers who account for almost 40% of the production. In the coconut industry, 95% of the producers have holdings of less than 4 ha and occupy 16% of the total coconut lands. The majority of small farming activity takes place on hillside lands while most large farms have extensive areas of flat land.

The banana industry dominates the agriculture sector, and approximately 7000 farmers are involved in banana production. The total area under banana cultivation has been increasing steadily in recent years. Exports, which are directed almost exclusively to the United Kingdom market, have risen from 29,371 tonnes in 1980 to 133,695 tonnes in 1988. In 1987 banana exports amounted to 120 million

Eastern Caribbean dollars. This constitutes 96% of the value of agricultural exports and 58% of total exports (Ministry of Finance, 1988).

The second most important crop is coconut which is processed locally into coconut meal and oil. Coconut production has been increasing slowly in recent years. Production in 1987 reached 4767 tonnes compared to 4001 tonnes in 1985. Cocoa follows bananas and coconuts in importance as an export crop (Ministry of Agriculture, 1988).

Efforts are being made to diversify the agriculture sector and markets are being sought for non-traditional export crops. The export of fresh produce such as mangoes (Mangifera indica), ginger (Zingiber officinale), avocadoes (Persea americana) and pumpkins (Cucurbita moschata) is being promoted.

Root crops such as yams (Dioscorea spp. L.) and dasheen (Colocassia esculentum.) are important staples in the St. Lucian diet and are produced almost exclusively by small farmers. Vegetables and tropical fruits for the local markets are also produced by small farmers.

Livestock production lags behind crop production and accounts for less than 2% of the Gross Domestic Product. St. Lucia is heavily dependant on imports to supply the demand for livestock products.

Land tenure is often cited as the most significant constraint to agricultural development (Walker, 1987). There is excessive fragmentation of land which results in a large number of small farms. This situation leads to inefficient use of labour and capital and the reluctance of farmers to make long-term capital investments. The St.Lucia government is pursuing a land re-distribution policy which involves the conversion of the few large estates on the island into small farm holdings. Walker (1987) cited other constraints to agricultural development as being, the lack of agricultural credit, the lack of input supplies such as fertilizers and herbicides, the lack of available labour and the poor productivity of hired agricultural workers.

Also, because of the topographic conditions, it is difficult to perform farm operations such as cultivation, weed control, fertilizer application and harvesting. Topographic conditions also limit the mechanization of farm operations.

Table 2.2 Distribution of farm sizes in St. Lucia (After, Ministry of Agriculture, 1987)

Farm Size (ha)	Total land area (ha)	Percentage of Total Area	Number of Holdings	Percentage of Holdings
< 2.0	5000	21.3	9620	83.2
2.1-4.0	3159	13.5	1191	10.3
4.1-10.0	3143	13.4	560	4.8
10.1-20.0	1303	5	98	0.9
20.1-40.0	947	4.0	35	0.3
40.1-81.0	904	3.8	17	0.2
81.1-202.0	1976	8.4	17	0.2
> 202.0	7057	30.0	13	0.1
Totals	23489	100.0	11551	100.0

2.2 Crop productivity effects of soil erosion

Soil erosion usually results in a reduction in crop productivity. Yields may be reduced by erosion because of reductions in water holding capacity, infiltration rates, nutrient availability and organic matter (Calacicicco et al., 1989).

Langdale and Schrader (1982) reviewed the results of several studies on the yield reduction effects of erosion on medium textured soils in the U.S.. Yield reductions ranged between 8 and 30% for corn, 20 and 40% for soybeans, 12 and 20% for cotton, 11 and 24% for small grains and 5 and 17% for forages. Studies of the same crops on shallow, medium-to-coarse textured soils showed greater reductions in yield when all the topsoil was removed.

Several studies have shown that yields on eroded soil were restored to their original levels by addition of fertilizers which compensated for the loss of nutrients. Addition of fertilizers cannot however restore soil productivity in all cases. Crosson and Stout (1983) stated that for some shallow soils with unfavourable subsoils, yields cannot be restored by fertilization.

Although rarely measured in tropical environments, declines in crop yield appear to be greater in magnitude than in temperate environments. Stocking (1986) compared yield reductions on Alfisols in Ohio and Nigeria. The first 10 cm soil loss reduced the U.S. maize yield by 25% to 2.0 t/ha, while in Africa the yield fell by 92% to less than 0.5 t/ha. These results, reflect the potentially huge productivity losses as a result of soil erosion in the tropics.

2.3 Soil conservation methods

The aim of soil conservation is to obtain the maximum sustained level of production from a given area of land whilst maintaining soil loss below a threshold level which, theoretically permits the rate of soil erosion to keep pace with the rate of soil formation (Morgan, 1986).

The principles of soil erosion control are based on an understanding of the mechanics of soil erosion. Hudson (1981), Beasley et al. (1984) and Smith and Wischmeier (1962) have described details of the soil detachment, transportation and deposition phenomena which constitute the soil erosion process.

Studies of the mechanics of soil erosion conclude that the strategies for soil conservation must be based on covering the soil to protect it from raindrop impact; increasing the infiltration capacity of the soil to reduce runoff; improving the aggregate stability of the soil; and increasing surface roughness to reduce the velocity of runoff (Morgan, 1986).

The various soil conservation techniques commonly used, can be described under the headings of agronomic measures, soil management and mechanical methods. The planning, design and construction procedures applied to these techniques have been extensively reviewed by Hudson (1981), Schwab et al. (1981), Beasley et al. (1984) and Morgan (1986). Those techniques which bear relevance to St. Lucian conditions shall be described in the succeeding sections.

2.3.1 Agronomic measures

Agronomic measures are based on the role of plant cover in reducing erosion. They are often given preference over other measures because they are less expensive and usually fit easier into existing farm systems than other methods. The most significant agronomic measures are described in this section.

2.3.1.1 Contouring

Contouring (or contour farming) is the practice of performing field operations such as ploughing, planting, cultivating and harvesting approximately on the contour (Schwab et al., 1981). It reduces the surface runoff by impounding water in small depressions and decreases the development of rills in which erosive runoff velocities develop.

Under conditions of high rainfall and soil erodibility, contouring will increase gully erosion because the breakage of rows releases water indiscriminately over the slopes. Breakovers may cause extensive damage as the volume of water increases with each succeeding row (Schwab et al., 1981).

The practice of contouring is most successful on permeable soils and in areas of low intensity rainfall (Beasley et al., 1984). Furthermore, contour farming is best performed on fields that slope uniformly in one or two directions. It is usually impractical on fields having irregular topography (Foster, 1973).

2.3.1.2 Mulching

Mulching is the covering of the soil surface with crop residues. From the conservation viewpoint, a mulch simulates the effect of plant cover (Morgan, 1986).

Crop residue on the soil surface decreases raindrop impact, slows down the flow of water, and increases the infiltration rate. Mulching also encourages soil fauna activity which promotes soil structure and increases permeability (Gumbs, 1987).

Many crop residues such as banana leaves and maize residue serve as mulches. Grass can also be suitable as a mulch (Gumbs, 1987).

In the semi-humid tropics, the side effects of a mulch in the form of reduced soil temperatures and increased soil moisture are beneficial, and may increase the yields of coffee, banana and cocoa (Morgan, 1986). Mulches are so effective against soil erosion that a layer of 4 or 5 cm can reduce soil loss by 95 to 100% (Gumbs, 1987).

Lal (1976a) found that soil loss rates decreased exponentially with increasing mulch rates on Alfisols in Western Nigeria, and that a mulch rate of 2-4 t/ha effectively controlled erosion.

Mulches however have the disadvantage in some cases of being costly to grow, transport and apply and they also sometimes encourage pests and diseases which affect crops (Gumbs, 1987).

2.3.1.3 Crop rotation

Continuous cropping of many annual crops encourages erosion. Under continuous cropping, soil structure breaks down and runoff increases. Rotation of annual crops with grasses or legumes improves crumb structure and reduces erosion and may even increase soil fertility. The grasses may be used for mulching the subsequent crop while the legumes could serve as cash crops. A rotation of crops every three years is recommended and should be included in the cropping or farming system (Gumbs, 1987). Rotation is most often applied to annual crops. It cannot be reularly applied to ratoon crops, such as bananas.

2.3.1.4 Strip cropping

In strip cropping, cultivated and close growing crops are planted in alternate strips across the slope (Beasley et al., 1984). The runoff from the cultivated strip is retarded by the close growing crop, resulting in greater absorption of runoff and deposition of sediment. For this reason strip cropping is more effective in reducing soil loss, than contouring.

Strip cropping is however most effective in reducing soil erosion on land where terraces are not practical because of uneven slopes and in areas of moderate rainfall and permeable soil.

Recommendations on strip widths are usually based on land slope. The United States Department of Agriculture (USDA) recommendations are given in Table 2.3.

Table 2.3 Maximum strip widths for contour strip-cropping (After USDA, 1978)

Land Slope (Percent)	Strip Width (meters)
1 - 2	40
3 - 5	30
6 - 8	30
9 - 12	25
13 - 16	25
17 - 20	18
21 - 25	15

2.3.1.5 Multiple cropping

The aim of multiple cropping is to increase the production from a given land area. This may have the added effect of protecting the soil from erosion. This may involve either sequential cropping, the growing of two or more crops a year in sequence, or intercropping, the growing of two or more crops on the same piece of land at the same time (Morgan, 1986).

Multiple cropping has been traditionally practised in the Caribbean, particularly on the kitchen garden scale (Morgan, 1986).

In the Caribbean, many types of intercropping exist. The combination of bananas and coconuts are commonly found in St. Lucia. The intercropping of bananas with legumes is also being promoted and agronomic aspects of intercropping have been researched in St. Lucia (Walker, 1987).

El-Swaify et al. (1988) studied the effects of intercropping cassava with legumes in Hawaii and found that intercropping had beneficial effects on runoff and soil loss control.

2.3.1.6 Grass strips

On gentle slopes, strips of grass or other close growing vegetation may be left between bands of cropped land. Surface runoff moving down the slope is intercepted by the strips, the velocity is reduced and silt is deposited in the grass strips (Hudson, 1981). These strips do not however handle surface runoff in the same way as drains or terraces, and so they should be used in combination with an appropriate drainage system.

2.3.1.7 Agroforestry

Agroforestry embodies the concept of growing trees on areas which may be unsuitable for traditional methods of intensive cultivation.

Tree canopies reduce the energy of raindrop impact on the soil surface, while the litter from leaf fall and the tree roots limit or prevent sheet erosion by slowing down surface runoff. Trees are recommended for steep slopes especially when other methods of erosion control are not effective, impractical or too costly. The trees must however be sufficiently close together to be effective (Gumbs, 1987).

One of the most important tree species used in agroforestry is leucaena leucocephala. This is a quick growing tree which provides fodder and timber (Morgan, 1986). Fruit trees such as mangoes (Mangifera indica) and avocadoes (Persea americana) can also be used in agroforestry systems.

2.3.2 Mechanical methods of soil conservation

Mechanical methods of soil conservation depend on the manipulation of surface topography to control the flow of water (Morgan, 1986). These methods are often only effective in controlling the transport phase of the erosion process but do little to prevent soil detachment. Therefore, agronomic methods of soil conservation need to be applied with mechanical methods, in order to achieve effective erosion control.

2.3.2.1 Storm water diversion drains

Storm water diversion drains are large drainage ditches at the top of cultivated fields which serve to protect the fields from the runoff from upland areas. Storm water diversion drains are the first line of defence from runoff which causes erosion and it is vital to the entire soil conservation system since all structures will be designed on the assumption that they will effectively control all runoff from above the cultivated area (Hudson, 1981). The design of storm water diversion drains is based on standard drainage design procedures as outlined by Hudson (1981).

In some cases, terraces are used to perform the same functions as storm water diversion drains. The design of these terraces follows the standard terrace design procedures as outlined in section 2.3.2.3.

2.3.2.2 Cutoff drains

Cutoff drains are used at intervals within the cultivated field to limit the overland flow. These drains, by regularly intercepting overland flow, prevent the surface runoff from achieving high velocities which may result in the formation of rills and gullies. They are usually smaller than storm water diversion drains, and are usually placed at intervals between 10 and 30 m. Their exact spacing depends on the degree of slope, the soil type and the crops to be grown.

In St. Lucia and other Caribbean islands cutoff drains are commonly referred to as contour drains because they are aligned approximately on the contour. They are often given a grade, of less than one percent to facilitate discharge at non-erosive velocities. When constructed in this way, they are be referred to as graded contour drains.

Cutoff drains usually measure 50 to 60 cm wide and 30 to 40 cm deep. In stable clayey soils, almost vertical side walls can be used but in more unstable sandy soils, the side walls should be flatter (Gumbs, 1987).

2.3.2.3 Terraces

Terraces are earth embankments constructed across the slope to intercept and convey runoff to a stable outlet at a non-erosive velocity (Morgan, 1986). Like cutoff drains, they decrease the length of the hillside slope, thereby reducing sheet and rill erosion and preventing the formation of gullies. In low rainfall areas, they may also be used to retain runoff. Terracing requires greater investment than other soil conservation measures. It should therefore be considered only where other cropping and soil management practices, singly or in combination, will not provide adequate erosion control (Schwab et al., 1981).

Classification of Terraces: Terraces are classified into three main types: diversion, retention and bench terraces (Morgan, 1986).

Diversion terraces perform the same functions as storm water diversion drains described in section 2.3.2.1.

Retention terraces are used to store water on the hillside. For this purpose they are usually constructed with no grade.

Bench terraces consist of a series of alternating shelves and risers and are employed where steep slopes of up to 30° need to be cultivated. The riser is vulnerable to erosion and is protected by a vegetative cover and is sometimes lined with stones or concrete. The basic bench terrace system can be modified according to the nature of the crops grown (Morgan, 1986).

Scheng (1986) listed four types of bench terraces: level or ridge paddy type, outward sloping type, conservation bench type and reverse sloped type. He suggested that for upland crops or tree crops in tropical or sub-tropical regions where rainfall intensity is high, the reverse sloped or conservation bench terraces are most appropriate.

Bench Terrace Design: Guidelines for the design, layout, construction and maintenance of terraces have been produced by the ASAE (1986) primarily for use in the United States. Scheng (1986) on the basis of his experiences in Taiwan and Jamaica, has prepared similar guidelines which could be applied to tropical areas.

The physical factors which influence the design of bench terraces are the steepness of the land and the depth of soil. Terrace design is also affected by management decisions involving terrace width and the height and slope of the riser (Hudson, 1981).

Slope: Theoretically, terraces can be built on any slope with deep soil. In practice however, on very steep slopes the riser becomes too high and consequently becomes difficult to maintain, and the terrace becomes too narrow (Hudson, 1981). Scheng (1986) gave limits of 20° for machine built terraces, 25° for hand-made terraces and 30° for intermittent, 2 m wide terraces.

Width: Terrace width (Fig. 2.3) is determined by costs, the crop to be cultivated and the construction methods. For terraces constructed by hand, bench widths of 2 to 5 m are suitable. For machine built terraces a width of 3 or 4 m is desirable. The maximum width which is economically practical is determined by the combination of land slope and soil depth (Scheng, 1986).

Terrace spacing: Terrace spacing is expressed as the vertical distance between the channels of successive terraces. This is commonly known as the vertical interval (VI). Many formulae have been developed for terrace spacing. Some are based on theoretical considerations while others have been empirically derived (Morgan, 1986). Schwab (1981) gives the following empirical formula for terrace spacing.

$$VI = 0.3(XS + Y) \qquad \text{....(2.1)}$$

where VI = vertical interval (m)

X = a constant based on geographical location

S = average land slope (%)

Y = a constant based on soil erodibility and cover conditions during critical erosion periods.

The value of X is 0.4 for Caribbean conditions.

The value of Y varies between 1 and 4. A value of 1 is applied for low water intake rates and little ground cover, and a value of 4 is used for average or above average intake rates and good ground cover. Interpolation is used for other conditions

Terrace Length: Terrace lengths are influenced by the size and shape of the field, outlet p lities, rate of runoff and channel capacity (Schwab et al., 1981). Longer terraces reduce construction costs and increase operational efficiency but excessively long terraces may cause accelerated erosion. Scheng (1986) recommended a maximum length of 100 m in one direction, for tropical and sub-tropical countries.

Terrace grades: In areas of light rainfall and permeable soils, the terrace grade may be lower than 0.5% whereas in areas of intense rainfall and heavy soils, 1.0% is preferable. A reverse grade of 5% is also required for the bench in order to contain the runoff at the base of the riser (Scheng, 1986).

Riser height and depth of cut: The higher the riser, the greater the risk involved in the maintenance of the terrace. A maximum height of 2 m after settling is preferred. Scheng (1986) recommended a riser slope of 1:1 for machine built terraces and 0.75:1 for those made by hand, provided they are well compacted and protected by grass cover.

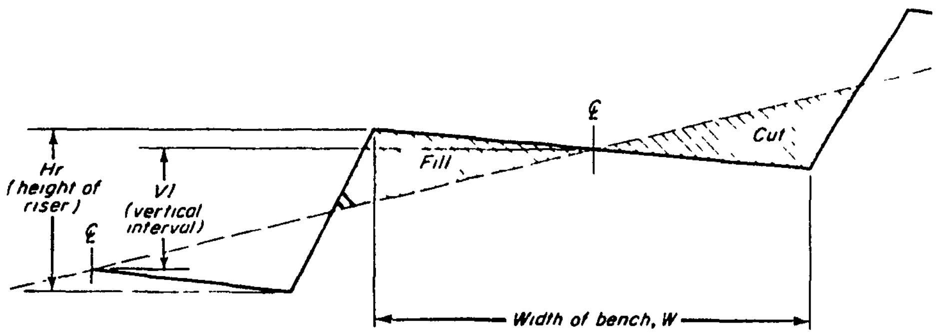


Figure 2.3 Cross-section of bench terraces
(After Hudson, 1981)

2.3.2.4 Artificial waterways

Artificial waterways convey water downslope from cutoff drains and terraces when no suitable natural watercourse exists in the field being drained.

These waterways are usually wide and shallow, with parabolic cross sections. The downslope grade of the waterway should not exceed 25%. On steeper slopes, checkdams, weirs or stepped waterways should be used.

Conditions in St. Lucia most often require stepped waterways. These consist of a series of level steps which serve to reduce the energy of the water moving downslope, thereby preventing the high velocities which cause gully erosion.

2.3.2.5 Gully stabilization structures

Temporary or permanent structures may be used for the stabilization of gullies. These are usually in the form of small dams which are built across the gully to trap sediment, thereby reducing channel depth and slope. They are usually 0.4 to 2.0 m in height. Morgan (1986) provided design criteria for these dams.

Temporary structures are used to provide protection until vegetation for the stabilization of the gully can be established. They are usually made of wire netting, brushwood and logs. Permanent structures such as brick and concrete weirs and gabion structures are usually used to stabilize larger gullies.

2.3.3 Soil management methods for soil conservation

The aims of good soil management are to maintain soil structure and fertility. Fertile soils result in high crop yields and good crop cover, which in turn lead to the conditions which minimize the erosive effects of raindrops and runoff. Also, these soils have a high infiltration capacity and a stable granular structure which does not break down even under cultivation. Therefore soil fertility can be seen as vital to soil conservation (Morgan, 1986).

The soil related factors which most influence soil erosion are organic matter content and tillage practices.

2.3.3.1 Application of organic matter

The application of organic matter to the soil improves the cohesiveness of the soil, increases the water retention capacity and promotes a stable aggregate structure. Organic materials such as manure or straw may be added.

Soils with less than 2% organic matter are generally highly erodible. Increasing the resistance of an erodible soil by building up organic matter is a lengthy process, because organic matter must be raised by 1 or 2 percent before any effect on stability is observed. To achieve this effect, large amounts of organic material are usually required (Morgan, 1986).

2.3.3.2 Tillage practices

Tillage is the manipulation of the soil to improve soil conditions suitable to the growth of crops, the control of weeds and the maintenance of infiltration capacity and aeration (Schwab et al, 1981).

The effect of tillage on erosion depends on the manner in which such factors as aggregation, surface sealing and infiltration, are affected. Where intensive or excessive tillage has destroyed soil structure, increases in the erosion hazard result. Tillage can also contribute to erosion because of the mechanical movement of the soil during the tillage process. (Schwab et al., 1981).

The conventional system of tillage involving ploughing, secondary cultivation with disc harrowing and planting has been found suitable for a wide range of soils. Conventional tillage however causes problems on fine sandy soils, on heavy sticky soils and on structureless soils. Conventional tillage also tends to produce a number of failure planes, pulverize the soil near the surface and create a compacted layer at plough depth which reduces infiltration and increases runoff. The soil is then readily eroded. Thus, whilst tillage can improve the coarse structure of heavy soils, it can destroy the structure of non-cohesive soils (Morgan, 1986).

To overcome the negative effects of conventional tillage, several alternative tillage practices have been developed primarily in the U.S. These methods are commonly referred to as conservation tillage.

Conservation tillage systems rely on surface residues to reduce surface runoff and soil losses. Conservation tillage practices vary from no-till where planting occurs in the undisturbed residue of the previous crop, to modified tillage practices such as chiselling and disking which leave 20 to 80% ground cover under crop residue (Ellis et al., 1985).

Conservation tillage has been gaining wide acceptance in the United states in recent years, and the positive effects have been supported by the results of extensive research. Ellis et al. (1985), measured sediment losses of 771 kg/ha in surface runoff and 220 kg/ha in subsurface tile flows from a field treated with conventional tillage using a mouldboard plough compared to 233 kg/ha in surface runoff and 140 kg/ha in subsurface tile flows from a field with conservation tillage using a chisel plough which left the soil surface covered with corn residue.

2.4 Soil conservation research

2.4.1 Development of soil conservation research

Evidence exists of soil conservation works which date back several centuries (Hudson, 1985). Soil erosion studies however probably began in the late nineteenth century with the work of European researchers who made exhaustive investigations of the physical properties of soils which affect runoff and erosion (Meyer and Moldenhauer, 1985).

The most notable events in the history of the prediction and control of soil erosion are: the installation of erosion plot experiments by Miller in 1917; the establishment of the original erosion experiment stations by Bennett in the 1930's; the initiation of basic research on erosion processes in the 1950's; the development and use of rainfall simulators in the 1960's; the formulation of the USLE by

Wischmeier and Smith in 1960; the development of modern terrace systems by Jacobson in the late 1960's; the establishment of widespread conservation tillage experiments in the 1960's; and the development, in recent years, of mathematical models to simulate soil erosion (Meyer and Moldenhauer, 1985).

2.4.2 Soil conservation research methods

Most soil conservation research has been based on empirical studies where runoff plots and small watersheds were used to study the influence of one or more factors on erosion (Moldenhauer and Foster, 1981).

Runoff plots are of fixed dimensions and are bounded with sheet metal, wood or any stable material which does not leak and is not liable to rust. They are also of known slope steepness, slope length and soil type. They are usually subjected to natural or simulated rainfall. Runoff and sediment are channelled into collection tanks at the plot base. When small runoff volumes are expected, all of the runoff may be collected. For large volumes however, known fractions of the total runoff are collected by means of a Geib divisor or a Coshocton wheel. Total sediment loss is usually determined by drying and weighing the total runoff or a known fraction of runoff. When details of runoff rates are required, the runoff from the plots is passed through a flume where the discharge is automatically recorded (Morgan, 1986). Details of experimental procedures with runoff plots have been described by Hudson (1957) .

Runoff plots may vary in size depending on the objective of the investigations for which they are used. When investigations need to be carried out on conservation systems which require large areas, runoff plots may not be practical. In that case small watersheds may be the practical alternative. In most cases, small watersheds cannot be subject to simulated rainfall because of size limitations. Investigations of sediment production must be carried out on hillslopes and in large drainage channels, streams or rivers within the watershed. Discharge is measured automatically using weirs and water level recorders. Suspended sediment concentrations are usually determined from water samples taken at set times or by specially designed sediment samplers (Morgan, 1986).

Traditionally, runoff plots have been studied using natural rainfall. However, in recent years greater use has been made of field experiments combined with rainfall simulation. This approach has virtually replaced the natural runoff plots as the major research tool in the United States (Moldenhauer and Foster, 1981). This has the advantages of combining the field conditions for soils, slope and plant cover with the benefits of using a repeatable storm.

Reliance on natural rainfall means that field experiments are long term because the rains with the intensities of most interest have return periods of once or twice a year and even when they recur, they are not true replicates because the surface vegetation, surface roughness and soil moisture conditions are likely to be different (Morgan, 1986).

2.4.3 Soil conservation research outside the U.S.

While most soil conservation research has been conducted in the United States, the results of this research, particularly with respect to the Universal Soil Loss Equation (USLE), have been applied and tested in tropical countries with mixed results. Lal (1976b), using data from studies in Africa, found that the EI_{30} index used to determine the rainfall-runoff erosivity factor (R) in the USLE, underestimated the kinetic energy of tropical rainstorms. Gumbs et al. (1985) found few cases of significant correlation between the R factor and soil loss in Trinidad. Lindsay and Gumbs (1982) found that the nomograph used for determining the

USLE soil erodibility factor (K), gave reasonable estimates of measured K values in Trinidad. Lal (1976b) found that the nomograph underestimated the K values for Tanzanian soils.

It is widely accepted however that conditions in tropical countries are so fundamentally different from the U.S. that extreme care must be exercised in applying results from the U.S. to the tropics.

In recent years, the number of soil loss studies in the tropics has been increasing. Lal (1976, 1977, 1988), Hudson (1981) and Morgan (1986) have reviewed and conducted extensive soil erosion and conservation research in the tropics.

Several researchers have developed USLE factors to suit their local conditions and new models are being developed. Cooley and Williams (1981) and Singh et al. (1985) have derived USLE factors for Hawaii and India respectively and Roose (1977) has reviewed the applicability of the USLE in West Africa. Elwell (1978, 1981) has introduced the Soil Loss Estimation Model for Southern Africa (SLEMSA) which is based on research conducted in the Zimbabwean Highveld.

2.4.4 Soil conservation research in the Caribbean

Some of the earliest reports on soil conservation research in the Caribbean came from Puerto Rico. Thomann (1943) reported on several investigations into soil conservation on the island.

Alleyne and Percy (1966) studied two small watersheds over a three year period in Trinidad. One watershed of 0.63 ha was covered in pangola grass (Digitaria decumbers) and the other, of 0.58 ha was planted in pineapples (Ananas comosus) after one-half of the area was bench terraced. The slopes on the watersheds varied from 35 to 38%. Differences in runoff volumes from the watersheds were found to be insignificant and in both cases, less than 10% of the rainfall was lost as runoff over the 3 year period. For most rainfall events, more runoff was recorded from the plots cropped in pineapples than from the other plot. Peak flows were less consistent than runoff volumes. For two years, peak flows were higher in the watershed under grass while for one year the situation was reversed. Despite the similarity in runoff volumes, the soil loss from pineapples was about 10 times that from grass.

Scheng and Michaelson (1973) conducted an extensive study of runoff and soil loss under yellow yams in Jamaica. They assessed three conservation systems: hillside ditches with contour mounds, hillside ditches with individual hills and bench terraces, along with a system with no conservation measures. Their study showed that soil erosion was significantly reduced by applying soil conservation measures, though differences between soil conservation measures were not significant. The soil loss from plots with no soil conservation measures averaged 133.4 t/ha/yr compared to rates of 17.3 t/ha/yr to 39.5 t/ha/yr for the conservation systems. The bench terrace system gave the lowest rates of soil loss. Their investigations of runoff showed that the conservation systems did not appear to have a measurable effect on runoff amounts. The average runoff for all systems varied between 30 and 33% of rainfall. From their observations and analysis, they concluded that the most important factor determining runoff was the amount of rainfall at an intensity greater than 25.4 mm/hr. While the average annual runoff was about one-third of rainfall, they observed that runoff for individual storms reached up to 95% of runoff.

Ahmad and Brekner (1974) measured soil losses from different slopes on three Tobago soils. Their results showed that the classical relationship of increasing erosion with increasing slope did not apply to the conditions in Tobago and that the effects of slope on rainfall amounts and the effect of exposure to wind seemed to have a considerable effect on soil loss.

Cracknell (1981) conducted several demonstrations of soil conservation systems in the Windward Islands, including St. Lucia. His investigations concentrated on determination of the time and expense involved in establishment of terrace systems and on projections of the cost effectiveness of these systems. In a cost benefit analysis of the conservation bench system, he projected that the initial investment would be returned after 7 years with a cost-benefit ratio of 1.78 over 10 years.

Cracknell (1981) cited reports of Lewis and Walsh who found that continuous bench terraces were unsuitable for use in the high rainfall areas of Dominica because of stability and maintenance problems. He concluded that continuous bench terraces were of little practical significance in the Windward Islands unless high value crops were grown. He also suggested that conservation bench terraces were better suited to the established practice of intercropping tree crops with bananas. Mohammed and Gumbs (1982) investigated the effect of plant spacing on runoff, soil loss and yield for a maize crop in Trinidad. They recorded soil losses of 56.6 t/ha from bare soil over a three month period in the rainy season compared to 32.0 t/ha for wide spaced planting and 20.5 t/ha for close spaced planting. Also, the closer plant spacing produced crop yields of 5.1 t/ha, compared to 4.2 t/ha for the wider spacing.

Gumbs and Lindsay (1982) measured runoff from three slopes in Trinidad with and without tillage. They found that for lower rainfall levels, soil loss on the bare soils increased significantly with slope, but soil loss in the cropped plots did not increase significantly. For higher rainfall levels, however, significant increases in soil loss were recorded with increases in slope for bare and cropped plots. They found also that, for low rainfall levels, tillage did not significantly affect soil loss or runoff.

Lindsay and Gumbs (1982) assessed the suitability of several soil erodibility indices for soils in Trinidad and found that the USDA nomograph correctly predicted erodibility while the Australian Index was not adequate for some soils, and the raindrop technique was unsuitable.

Cumberbatch (1969) discussed soil erosion problems in the Scotland district of Barbados, and recommended methods of reclamation using mulches.

2.5 Conclusions

Climatic and physiographic conditions in St. Lucia create the potential for excessive soil erosion over most of the island. The problems associated with soil erosion are increasing, as more steep lands are being intensively cultivated. There is therefore need for widespread adoption of appropriate soil conservation measures.

Soil erosion and conservation research in the Caribbean has not been sufficient to generate the data required for planning and designing soil conservation systems for the region. Appropriate soil conservation measures for the Caribbean could be developed by testing and modifying practices which have been developed elsewhere.

CHAPTER 3

DESIGN, CONSTRUCTION AND EVALUATION METHODS

3.1 The study site

3.1.1 Location

The field used for the study is located at approximately 61° 00′ west and 13° 57′ in the rural area of Roseau which is approximately 7 km south of the capital, Castries (Figure 3.1).

The field is situated on approximately 2.75 ha of hillside lands belonging to St. Lucia Model Farms Limited. This organisation is the implementing agency for an extensive land development and re-distribution programme covering 650 ha within the Roseau river basin. The Windward Islands Banana Growers Association (WINBAN) Research and Development Centre is located approximately 2.5 km west of the study area.

Roseau is the largest river basin in St. Lucia. It covers 4854 ha. Approximately 583 ha of this area have slopes of 5° to 20°, which can be cultivated with proper erosion control measures. Nearly 530 ha of flat, high quality irrigable land are concentrated in the delta of the Roseau river (Polius and Pretel, 1981). Over 75% of the working population in the Roseau community are employed in the banana industry and the catchment is responsible for a significant proportion of St. Lucia's banana production. Roseau therefore is an ideal location for a soil conservation research site in St. Lucia.

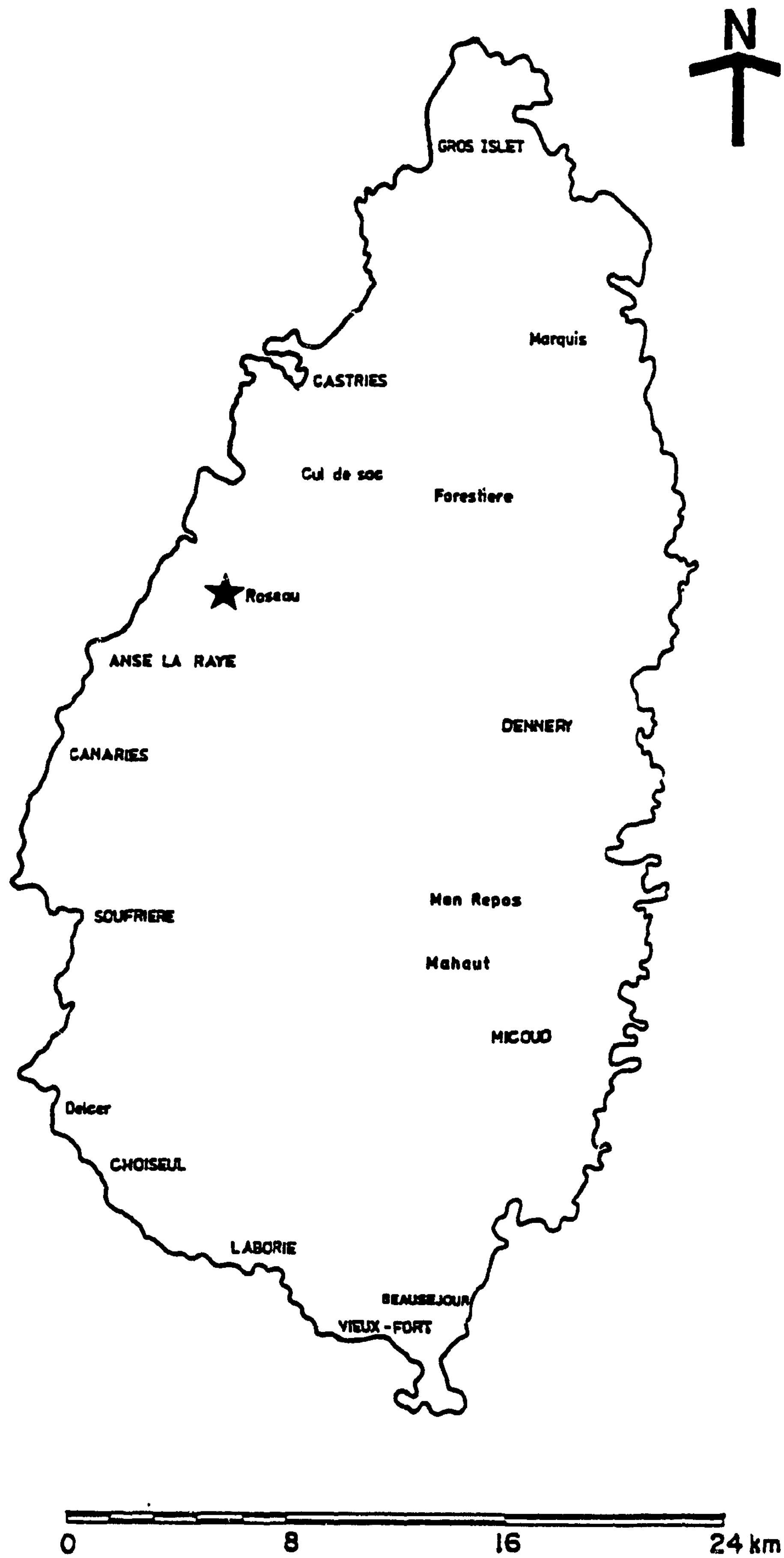


Figure 3.1. Location map of the study site

3.1.2 Climate

Long-term representative climatic data were obtained from the agro-meteorological station at the WINBAN Research and Development Centre. A summary of the data is given in Table 3.1.

The total annual rainfall exceeds potential evaporation by 624 mm. There is a marked wet season between July and January when total rainfall exceeds evaporation by 814 mm. Drainage is required during this period.

High temperatures and relative humidities are experienced throughout the year. Relative humidity averages 74% and the maximum deviation from the mean is only approximately 7%. The maximum deviation from the average temperature of 26.2°C, is approximately 5%.

3.1.3 Relief

The research site forms part of the hillside which flanks the Roseau river valley. It is located on spurs which run in a south-west direction and drain into the river flood plain. It is broken up into two major segments by a ridge which runs in a north-easterly to south-westerly direction. Each of these segments is in turn broken up by several minor ridges and depressions. A slope analysis from the initial topographic survey of the site indicated that the slopes ranged from 10° to 24°.

Table 3.1 Mean monthly meteorological data for Roseau, St. Lucia

Month	Rainfall (mm)	Pan Evaporation (mm)	Temperature (°C)	Sunshine hrs. per day	Relative Humidity (%)	Wind Speed (m/s)
Jan	147.0	105.4	24.8	7.9	76	1.08
Feb	90.9	116.2	24.9	8.3	72	1.18
Mar	83.7	148.8	25.3	8.2	71	1.24
Apr	88.1	159.0	26.0	8.3	69	1.31
May	132.1	161.2	26.9	8.3	72	1.34
Jun	178.2	147.0	27.4	7.4	73	1.45
Jul	240.9	142.6	27.2	7.8	75	1.27
Aug	258.3	136.4	27.0	7.6	76	1.06
Sep	264.5	129.0	26.8	7.1	76	0.87
Oct	272.1	124.0	26.7	7.3	78	0.82
Nov	271.0	99.0	26.2	7.1	78	0.81
Dec	168.5	102.3	25.4	7.5	75	1.02
Total	2195.3	1570.9	--	--	--	--
Mean	182.9	130.9	26.2	7.7	74	1.12
Period	1966/85	1978/88	1968/88	1968/88	1978/88	1978/88

3.1.4 Soils

A soil survey of the site was conducted in January 1988. Six soil types were identified within the study area. These are:

1) Warwick clay
2) Jean Baptiste silty clay loam
3) Mabouya silty clay
4) Bocage stony clay
5) Canelles clay
6) Soucis silty clay loam.

A soils map (Figure A1) showing the distribution of soils over the site, was prepared from the survey. The general characteristics of these soils are described in Appendix B.

Several physical and chemical properties of the soils were measured. Particle size analysis was done by the hydrometer method, bulk densities were determined by the core method and hydraulic conductivities were determined by the constant head method. Electrical conductivity, pH, organic matter content and the concentrations of extractable bases, manganese and phosphorous were also determined.

All of the soils contain relatively high proportions of clay and exhibit low permeability. This suggests that a high proportion of rainfall is likely to run off the soil surface. Given these characteristics and the nature of the topography on the site, the hazards of water erosion are likely to be significant.

The distribution of the soils over the site and results of laboratory analyses are presented and discussed in Chapter 4.

3.1.5 Vegetation and Land Use

The site had been cultivated with sugarcane for several years prior to 1966 when the change of the main cash crop in St. Lucia was made from sugar to bananas. From that time to the commencement of the study in 1987, no organized cultivation had taken place on the site. The vegetation found at the commencement of the study is characteristic of that found in areas where shifting cultivation and subsistence type farming are practised. The original forest cover on the hillsides had been removed and the area was dominated by guava (Psidium guajava) shrub, and a mixture of grasses, the most common of which were bamboo grass (Paspalum fasciculatum), hay grass (Sporobolus indicus) and razor grass (Paspalum virgatum). Several larger plant species were also scattered over the area. These included, bamboo (Bambusa spp.), mango (Mangifera indica), coconut (Cocos nucifera) and breadfruit (Artocarpus communis), (Polius, 1989).

Small food crop gardens were found in patches over the site. These gardens were largely made up of tannia (Xanthosoma sagittifolia), dasheen (Colocasia antiquorum), banana (Musa sapientum) yams (Dioscorea spp) and cassava (Manihot esculenta). There was also widespread and indiscriminate grazing of cattle and the production of charcoal in pits (Polius, 1989).

3.2 Experimental plan

Three soil conservation systems: contour drainage, strip cropping and terracing were established. These were evaluated in terms of soil loss, runoff, crop yields and costs of establishment and maintenance.

Contour drainage was selected because it is a low technology method, familiar to most local farmers. Terracing is most often recommended for steep slopes of up to 30°, and is advisable in many parts of St. Lucia. Strip cropping is an agronomic method of soil conservation not previously applied in St. Lucia. However, given the familiarity with mixed crop farming it is likely to gain acceptance. Also, with the efforts being made to diversify agriculture, strip cropping may provide an opportunity for the introduction of alternative crops on banana lands while at the same time conserving soil and ensuring long term soil productivity.

The effects of soil conservation systems on runoff, soil loss and crop yields could best be evaluated on a field scale. The systems were therefore established on field size plots. Field scale evaluations simulate the small farming situation, thereby allowing the immediate applicability of results to small farms.

Cost limitations and the unavailability of similar lands however prevented the replication of these plots. Therefore, one plot was established for each treatment while a control plot with no soil conservation treatment was also established.

Due to the scale of the study, it was impossible to obtain uniform plot sizes. The topographic features of the site were therefore utilized to separate and delineate the plots.

The site was bounded to the north by an area of secondary forest, to the west by a ravine which flowed into the Roseau river, to the south by a secondary road and to the east by a major ridge.

A topographic survey was conducted in November 1987 from which a contour map of the site (Figure A2) was produced. This map was used for planning the layout of the conservation systems.

The plots were all restricted to the hillside areas. The ridges and depressions which traversed the site, created several micro-catchments which varied in size and slope. The plots were each located in a micro-catchment. The positioning of the plots was largely based on the sizes and slopes of the micro-catchments.

The control plot was positioned in the smallest micro-catchment, which also had the least steep slopes. Positioning of this plot in a large, steep area was expected to result in serious damage to the site as a result of soil erosion. The terraced plot was located in a steep area which was sufficiently large to provide the slope length which would allow several terraces to be constructed. The strip cropped plot was also located in a large area since it required that several crop strips be established. The contour drained plot was located in an area of relatively moderate size and slope.

3.3 Design criteria for the conservation systems

Standard soil conservation design procedures were found to be unsuitable for the site. Most of the Universal Soil Loss Equation (USLE) parameters, particularly those with respect to crops, soils and conservation practices, have not been developed for the conditions in St. Lucia. Approximations of USLE parameters led to impractical design recommendations.

Design criteria were therefore based on previous experiences with conservation systems in St. Lucia. Drainage design procedures using the Rational and Manning's formulas were applied where appropriate.

3.3.1 Contour drainage system

Drainage design procedures were used to design the contour drainage system.

The time of concentration was estimated by the Kirpich formula:

$$T_c = 0.0195\, L^{0.77}\, S^{-0.385} \qquad \text{... (3.1)}$$

$$= 0.0195(130)^{0.77}\,(0.3)^{-0.385}$$

$$= 1.32 \text{ min}$$

where T_c = time of concentration (min)

L = Maximum length of flow (m)

S = average watershed gradient (m per m)

The return period for the design storm was taken as once-in-10 years.

Intensity-duration frequency data are not available for Roseau. Using data for Union, an area of comparable rainfall, The once-in-10 year, 2 minute rainfall was estimated to be 300 mm/hr.

The runoff coefficient for the plot was estimated as 0.68.

The design discharge was calculated by the Rational Formula:

$$q = 0.0028 \ C \ i \ A \qquad \text{... (3.2)}$$

$$= 0.0028(0.68)(300)(0.56)$$

$$= 0.32 \ m^3/s$$

where q = design discharge (m^3/s)

C = runoff coefficient

i = rainfall intensity (mm/hr)

A = catchment area (ha)

The drains selected were of trapezoidal cross section with 30 cm bottom width, 45 cm depth and side slopes of 0.33:1

The cross sectional area of the drains was given by:

$$A = bd + Zd^2 \qquad \text{...(3.3)}$$

$$= 0.30(0.45) + 0.33(0.45)^2$$

$$= 0.20 \ m^2$$

where A = cross sectional area (m^2)

b = bottom width (m)

d = depth (m)

Z = side slope (m/m)

The wetted perimeter P (m), was given by:

$$P = b + 2d\sqrt{(Z^2 + 1)} \qquad ...(3.4)$$

$$= 0.3 + 2(0.45)\sqrt{(0.33^2 + 1)}$$

$$= 1.25 \text{ m}$$

The hydraulic radius R (m), was given by:

$$R = A/P \qquad ...(3.5)$$

$$= 0.2/1.25$$

$$= 0.16$$

Using the Manning formula, the drain capacity was calculated as:

$$Q = 1/n \; A \; R^{2/3} \; S^{1/2} \qquad ...(3.6)$$

$$= (1/0.04)\ (0.2)\ (0.16)^{2/3}\ (0.01)^{1/2}$$

$$= 0.15 \text{ m}^3/\text{s}$$

where Q = drain capacity

n = Mannings roughness coeffecient

s = channel grade

The number of drains required was :

0.32/0.15 = 2.1, or 3 (equation 3.2/equation 3.6)

The provision of 3 drains would result in long slope lengths which were likely to lead to high soil loss rates.

Therefore, to achieve erosion control, more drains were necessary. The spacing usually used in St. Lucia for contour drains of the size specified above, was therefore applied.

The drains were spaced between 8 and 11 m apart. The larger spacing was used in the flatter areas at the base of the plot and the smaller spacings were employed in the steeper areas near the top. This spacing criteria resulted in 9 drains to the west of the stepped drain, and 6 drains on the ridge east of the stepped drain (Figure 3.3).

3.3.2 Strip cropping system

The principal design criteria for strip cropping systems is the strip width, which was selected from USDA recommendations based on slope (Table 2.3).

Using the USDA recommendations, a strip width of 15 m was selected. Strips of bananas, 15 m wide were therefore alternated with strips of a close growing vegetable, legume or root crop of the same width.

Drains are not traditionally constructed in strip cropped areas. However, given the slope gradients and slope lengths in the plot, even with close growing crops, rill and gully erosion would likely occur if runoff was not intercepted.

The drains selected were larger than those of the contour drained plot. They had 40 cm bottom width, 60 cm depth and 0.25:1 side slopes.

Using the design procedure applied in section 3.3.1, the time of concentration was calculated as 1.32 min (equation 3.1), and the design discharge was calculated as 0.46 m^3/s (equation 3.2).

The cross-sectional area of the drain was calculated as 0.33 m^2 (equation 3.3), the wetted perimeter was 1.68 m (equation 3.4) and the hydraulic radius was 0.2 m (equation 3.5). A drain capacity of 0.28 m^3/s was next calculated (equation 3.6).

Therefore, the number of drains required in the strip cropped plot was:

$$0.46/0.28 = 1.64, \text{ or } 2$$

The drains were placed after every strip of the close growing crop. This rendered three contour drains at a spacing of approximately 30 m along the slope (Figure 3.5). Construction of a drain after each crop-strip would have effectively created a contour drainage system, and the effects of the close growing crop on runoff and soil loss would have been nullified by the additional drains.

3.3.3 Terrace system

A conservation bench terrace system was selected. This system of non-continuous terraces suits the topography, and is less costly to install than the continuous bench system.

The terrace width was taken as the width of the tractor blade, 2.5 m.

The vertical interval was calculated using equation 2.1:

$$VI = 0.3\{(0.4)(35) + 2\} = 4.8 \text{ m}$$

From this vertical interval, the terrace spacing along the slope was estimated by

$$TS = VI / (\sin(\tan^{-1} 0.01S)) \quad \ldots (3.7)$$

$$= 14.5 \text{ m.}$$

Based on this spacing, 4 terraces were constructed (Figure 3.6).

A 1% grade was set for the terrace and a minimum reverse grade of 5% was set for the terrace bench.

3.4 Construction methods

3.4.1 Diversion drains

In order to protect the plots from extraneous runoff from the steep forested areas above the site, storm water diversion drains were constructed above the plots using a Caterpillar D4 tractor. These drains also act as the upper plot boundaries.

Three diversion drains totalling 360.2 m in length, were constructed over the site. These had an average bench width of 2.5 m, a 5% reverse grade on the bench and a channel grade of 1%.

3.4.2 Land Clearing

Following construction of the diversion drains, the entire site was cleared of shrub and trees by a Caterpillar D5 tractor, taking care to minimize topsoil disturbance and movement. Some of the steeper areas which could not be reached by the tractor were cleared by hand.

Where possible, the upper 30 cm of soil was chiseled using the tractor tines. This was necessary because surface sealing and compaction of the soil were observed in several areas. This was largely due to the grazing of cattle on the site for several years.

3.4.3 Control plot

While no soil conservation or runoff control methods were applied to the control plot, it was necessary to construct a large drain at the base of the plot for the purpose of collecting runoff. This drain was excavated by a Caterpillar tracked excavator. It measured 41.6 m long, 1.6 m deep, and 1.0 m wide at the base, with side slopes of 2:1.

The plan of the control plot is shown in Figures 3.2. Figure A3 shows the profile along the line A-A′ in Figure 3.2.

3.4.4 Stepped drains

The main drainage channels to existing watercourses were constructed immediately after land clearing. These channels took the form of stepped drains.

Stepped drains are constructed such that the channel bottom consists of a series of consecutive level steps (Figure 3.3). This arrangement is based on the principle that the kinetic energy generated by water falling down the vertical face of the step would be dissipated during movement over the horizontal, level section of the step. The velocity and the erosive forces of the water moving downslope are thereby, reduced.

Design criteria have not been established for stepped drains. Dimensions were based on limited previous experiences with these drains in St. Lucia. The average top widths are 1.0 m, horizontal step lengths are approximately 2.0 m, and the riser heights are approximately 40 cm. These values were adjusted slightly to suit changes in slope along the drain alignment. The drain configuration was however governed by the criterion that the depth should be no less than 30 cm at any point.

The diversion drain above the control plot and the contour drained plot was connected to a stepped drain outside of the study area. The stepped drain in the contour drained plot was constructed along the alignment of a natural waterway which passed through the plot.

A stepped drain was also constructed at the western edge of the strip-cropped plot. This served as a boundary of the strip cropped plot and also collected runoff from the adjacent ridge. The diversion drain above the strip cropped and terraced plots were connected to a stepped drain which ran downhill between the two plots. The stepped drain which served these plots, were located on either side of this central drain.

Stepped drains were constructed by hand. A straight bottom channel was first excavated, the steps were then cut within the channels and the sides were sloped. The vertical faces of the risers were reinforced with horizontal bamboo pegs which served to hold back soil tending to fall forward from the face of the riser, and to protect the riser from the action of the falling water. The bamboo pegs were held in place by vertical pegs made from a readily available local hardwood (gliricidia sepium). An apron of small rocks, approximately 40 cm long, was placed at the base of each riser to shield the soil from the impact of falling water (Figure 3.3).

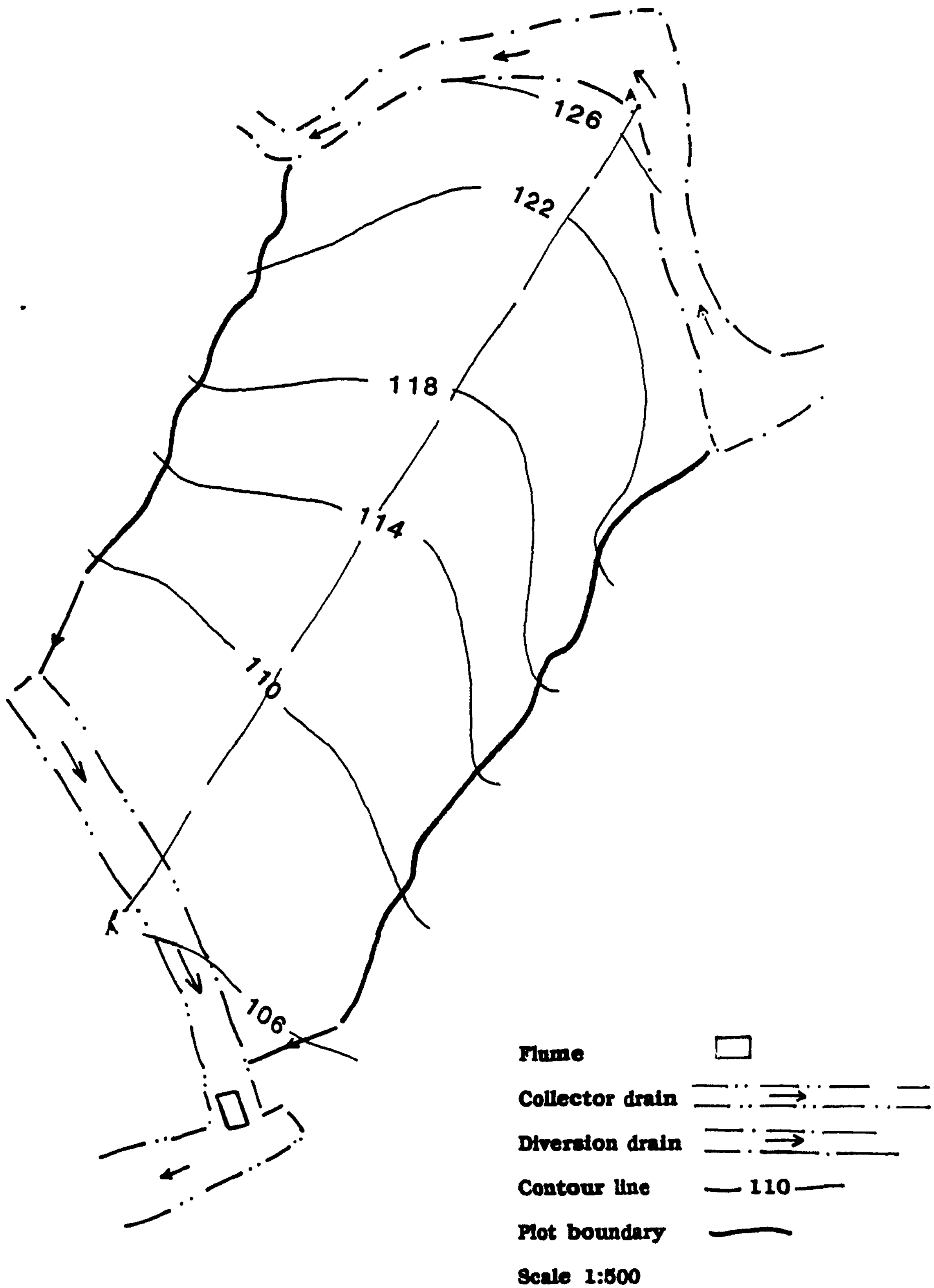


Figure 3.2. Plan of the control plot

The stepped drains within the plots totalled 238.3 m in length, and those outside of the plots totalled 243.1 m. Figure A4, shows the profile of the stepped drain in the terraced plot. This profile is typical of the stepped drains constructed on the site.

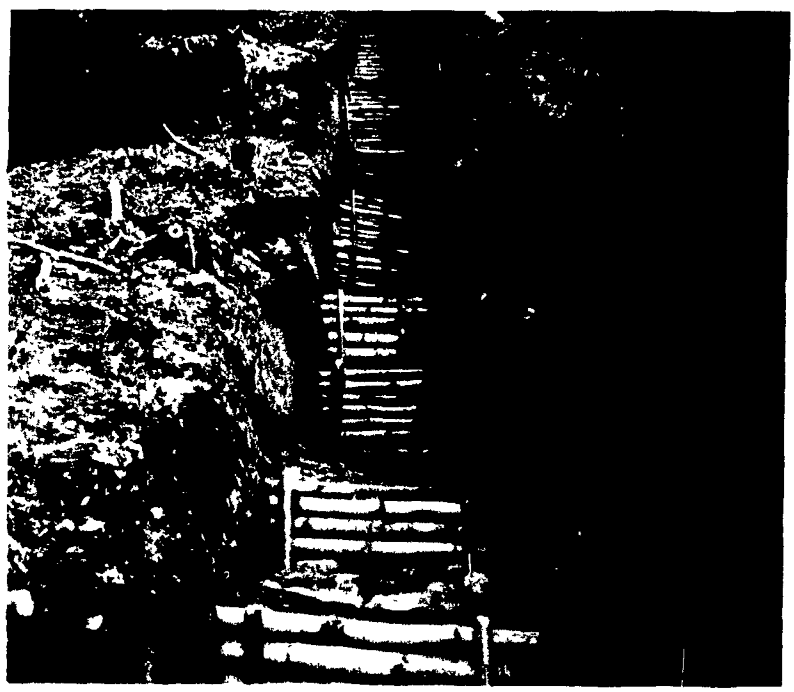


Figure 3.3. Front view of a newly constructed stepped drain

3.4.5 Contour drained plot

An Engineer's level was used to align the contour drains. The alignment was staked with wooden pegs and the drains were constructed by hand to the set dimensions. Fifteen contour drains with a total length of 433.5 m were constructed in the contour drained plot (Figure 3.4). Nine of these were constructed to the west of the stepped drain while the balance were constructed on the ridge east of the stepped drain. Figure A5, shows the profile of the contour drained plot along the line B-B′ in Figure 3.4. A typical profile of a contour drain is shown in Figure 3.5.

3.4.6 Strip cropped plot

Contour drains in the strip cropped plot were constructed in the same manner as those of the contour-drained plot. Three contour drains totalling 255.9 m in length, were constructed in the strip cropped plot. In order to distinguish between the drains in the contour drained plot and those in the strip cropped plot, the drains in the latter shall henceforth be referred to as field drains.

The strip cropped plot was first planted in alternate strips of bananas and cucumbers (Figure 3.6). The cucumbers were planted on a series of contour ridges which were built by hand. These ridges, which were essentially continuous mounds of soil aligned roughly on the contour, were built 30 cm high at a spacing of 90 cm.

The plan of the strip cropped plot is shown in Figure 3.7. Figure A6 shows the profile of the strip cropped plot along the line C-C′ in Figure 3.7.

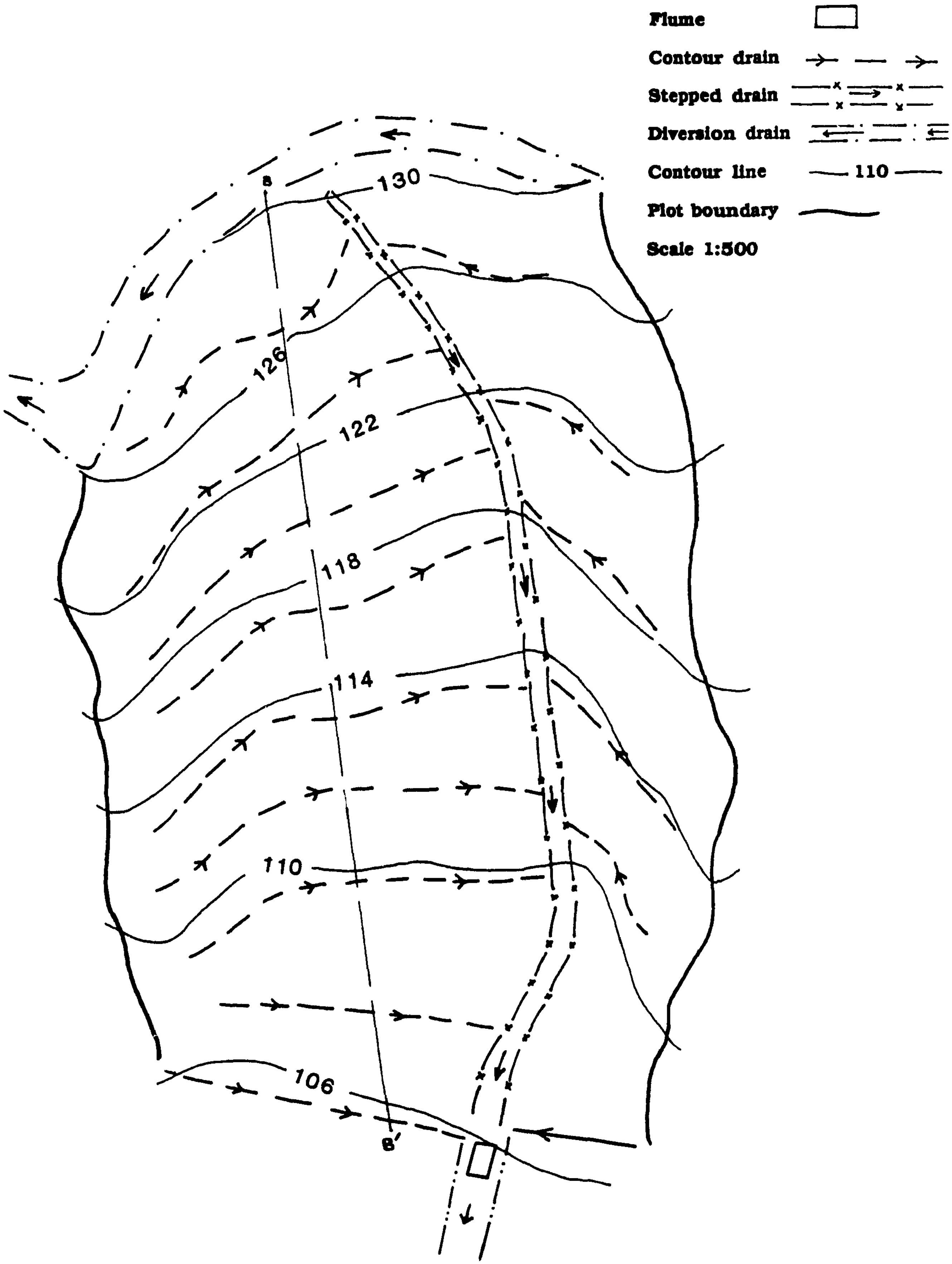


Figure 3.4. Plan of the contour drained plot

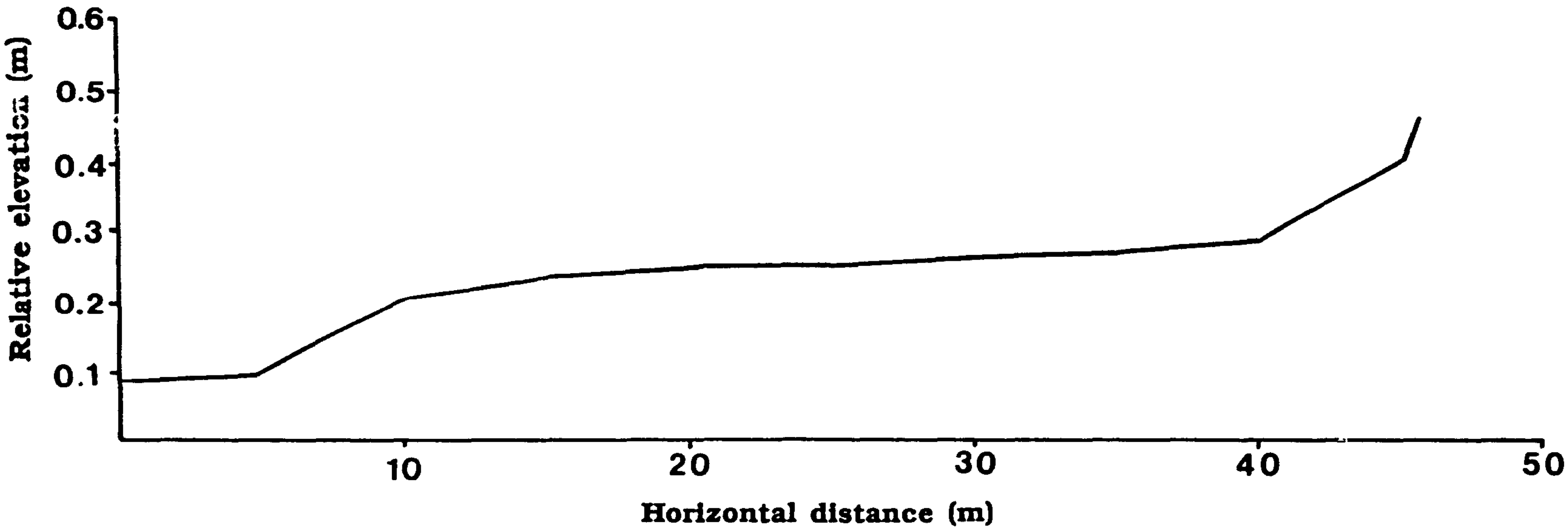


Figure 3.5. Profile of a contour drain

Figure 3.6. A view of the strip cropped plot

3.4.7 Terraced plot

The terraces were laid out according to the design criteria using an engineer's level. Several passes of a Caterpillar D4 tractor were required to obtain the required configuration (Figure 3.8). The excavated soil was pushed sideways to form the outer edge of the terrace bench. The tractor blade was tilted in order to obtain a reverse grade on the terrace bench.

Large boulders were encountered throughout the plot and in several cases these were dislodged by the tractor. A large rock outcrop was however encountered along the alignment of the second terrace from the top. The extent of the rock outcrop prevented any reasonable adjustments to the alignment. The terrace was therefore excavated up to the point where the rock outcrop was encountered resulting in a 40 m reduction in length.

Following construction by the tractor, the grades of the channels at the back of the terraces were checked with an engineer's level. Inconsistencies in the channel grade were noted and then adjusted. The terraces were then connected to the stepped drain.

Experiences with terraces have shown that in newly constructed terraces, risers tend to slump after heavy rainfall, particularly in areas where clay soils predominate. In order to avert this situation, the top of the risers were planted with a row of a deep rooted native grass (Vetiver zizandois). This proved very effective in soil stabilization. The outer edges of the terrace benches were also planted with a row of grass.

Four terraces with a total length of 481.0 m were constructed in the terraced plot (Figure 3.9). The profiles of the terraced plot along the line D-D′ in Figure 3.9, is shown in Figure A7. A typical terrace profile is shown in Figure 3.10.

3.4.8 Plot sizes, drainage densities and slopes

A topographic survey of the site was conducted after construction of the systems. This was used to produce a contour map (Figure A8) of the constructed site on which the plot boundaries were outlined. The areas, drainage densities and the average slopes of each plot given in Table 3.2 were determined from this map.

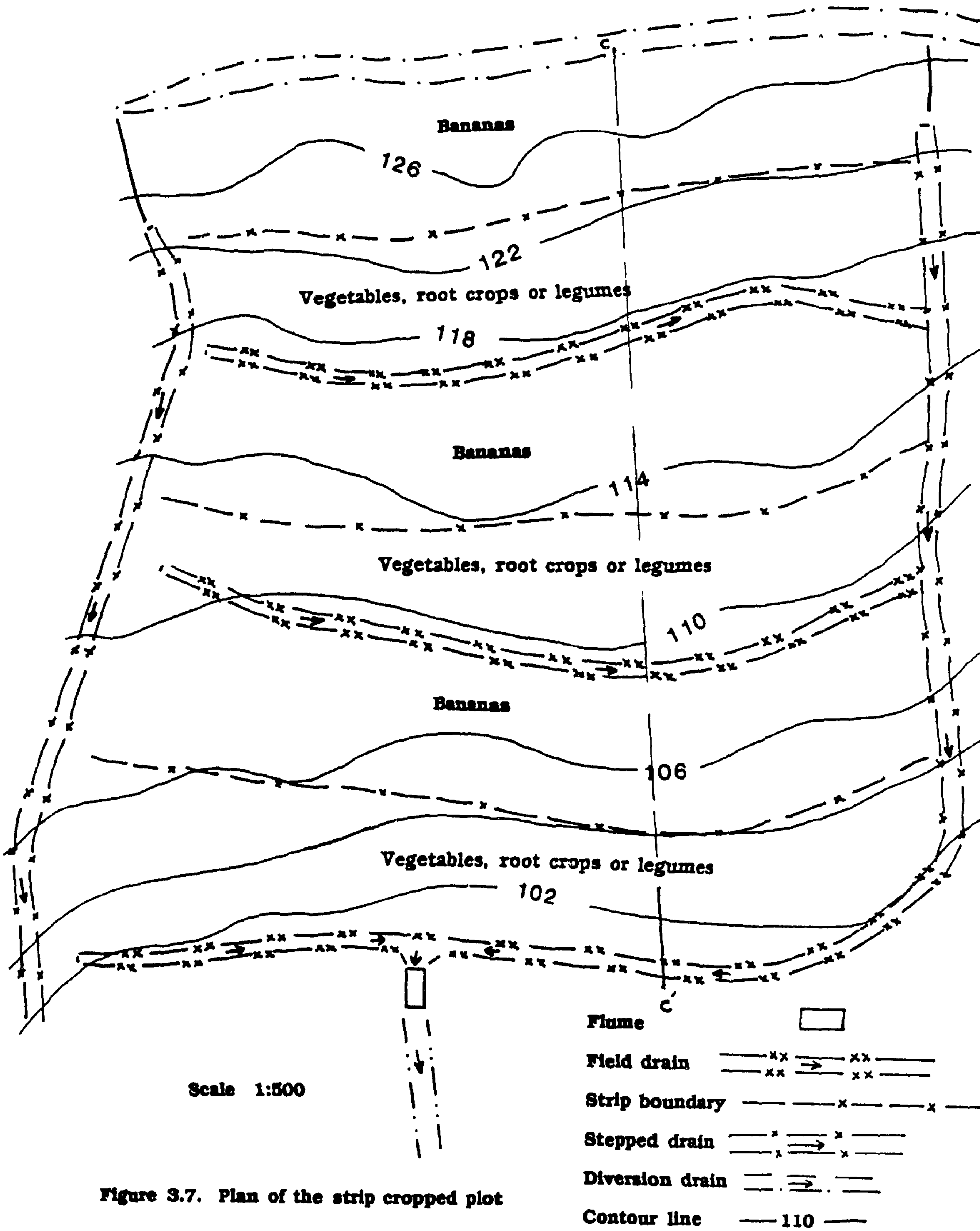
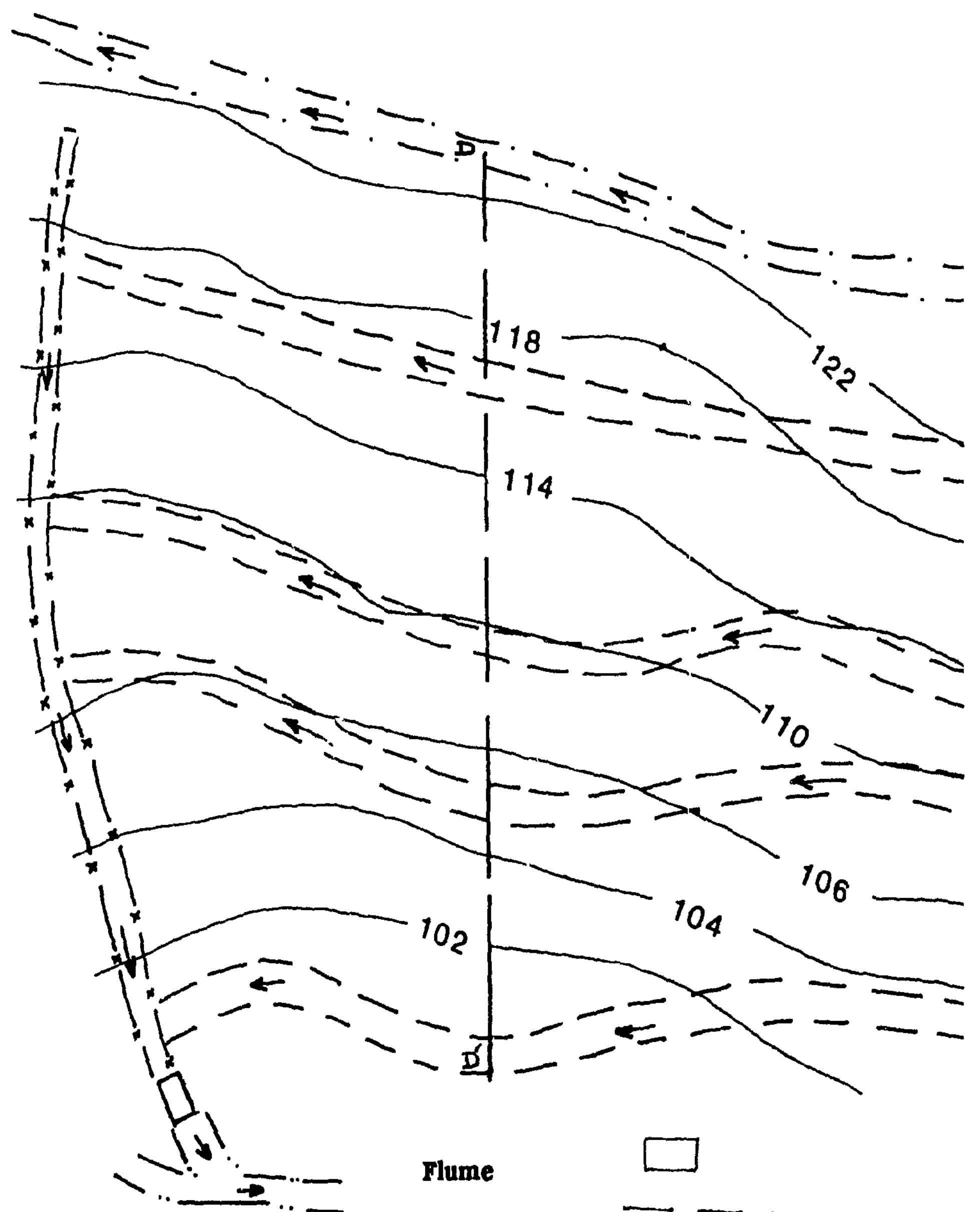


Figure 3.7. Plan of the strip cropped plot

Figure 3.8. Construction of a terrace

Table 3.2 Plot areas, drainage densities and slopes

Plot	Area (ha)	Drainage Density (km/ha)	Average Slope (degrees)
Control	0.32	0.21	16
Contour drained	0.56	0.95	17
Strip cropped	0.80	0.41	21
Terraced	0.78	0.71	20
Total	2.46		



Flume

Terrace

Diversion drain

Contour line —110—

Plot boundary

Scale 1:500

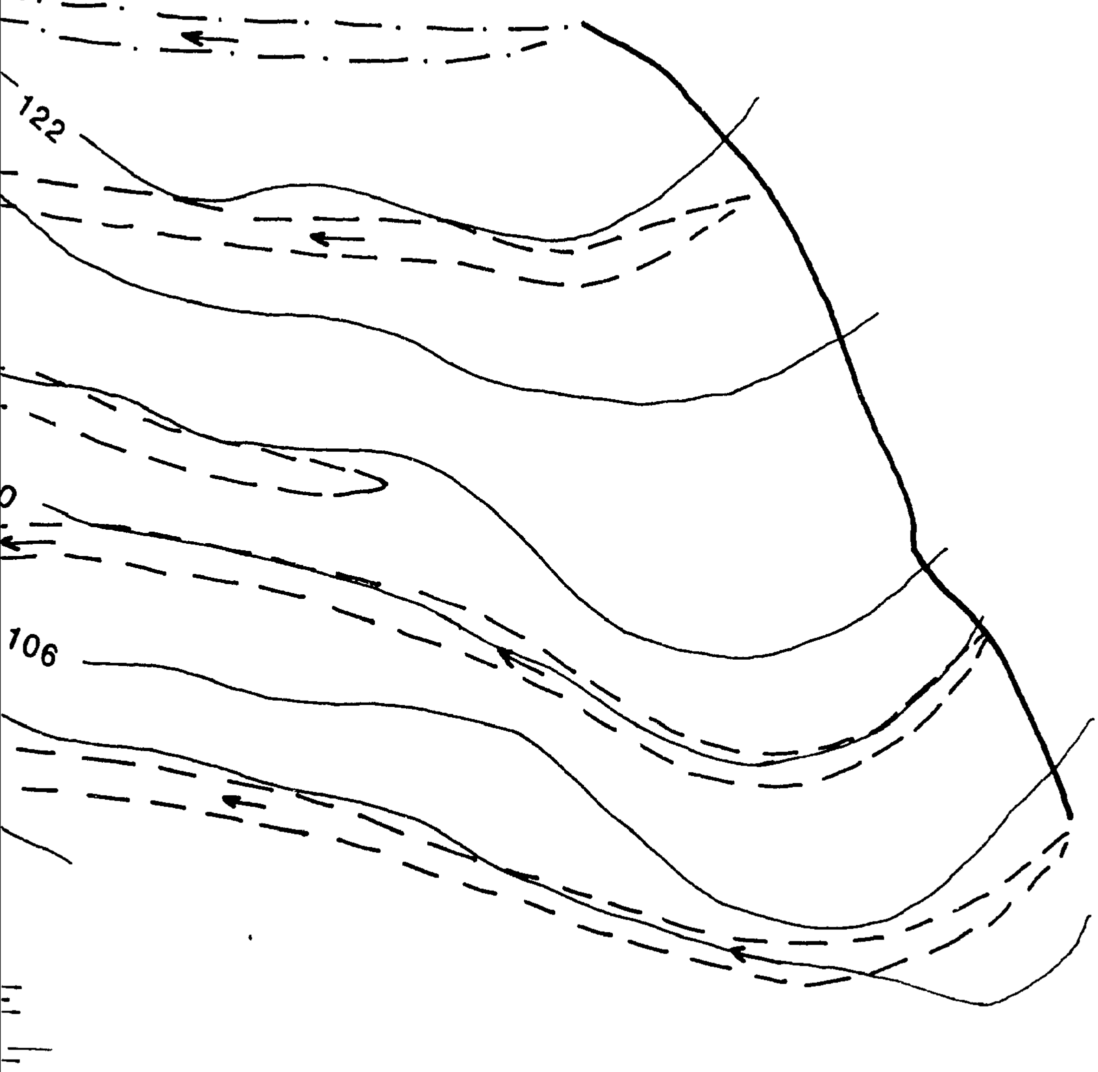


Figure 3.9. Plan of the terraced plot

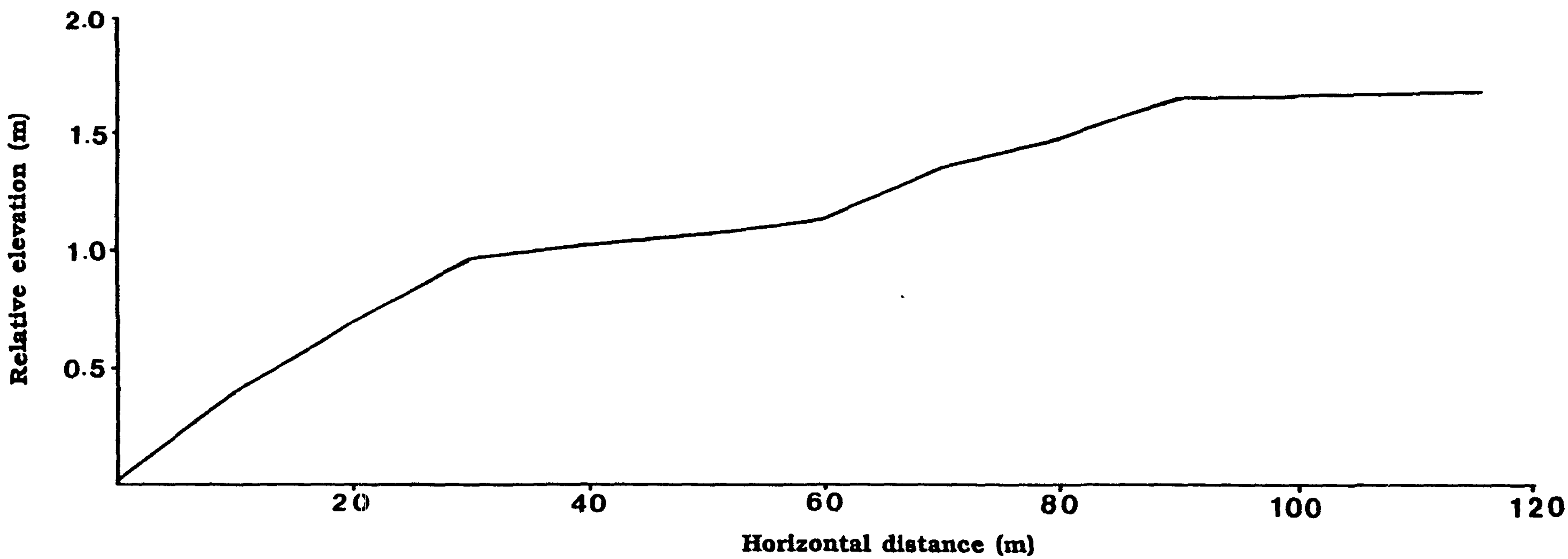


Figure 3.10. Profile of a terrace

3.5 Instrumentation and measurements

3.5.1 Rainfall

A tipping bucket recording raingauge was installed on the main ridge between the contour drained plot and the strip cropped plot. The rainfall data from this gauge is considered representative of the entire study area. A standard non-recording raingauge was installed adjacent to the tipping bucket raingauge to verify the accumulated rainfalls.

Daily rainfall amounts were determined from the non-recording raingauge and the charts of the tipping bucket raingauge were also changed daily.

3.5.2 Runoff

Four H-flumes for the measurement of runoff from each plot, were fabricated together with rectangular metal approach channels. Each flume contained a water level recorder for continuous measurement of runoff (Figure 3.11).

The flumes were calibrated in the Roseau river near the site. For the calibration, the flow through the flumes was controlled by progressively damming the river using sandbags. For each unit rise on the water level recorder chart, the depth of flow in the flume was measured and the flow rate was determined, using a calibrated container and a stopwatch. From these measurements, rating equations and curves were determined for each flume.

A flume was installed at the outlet of the main drain of each plot. Short wing walls made from concrete blocks were used to ensure that all flows from the plot entered the flume. Concrete aprons 1.5 m long, with anti-seep collars were placed immediately before the metal approach channels to prevent seepage and undermining of the flumes. The flume installed in the strip-cropped plot which is the largest, was 0.6 m deep while 0.46 m deep flumes were installed in the other plots.

For each rainstorm, water stage in the flume was recorded on the charts of the water level recorders. These charts were changed daily at approximately 09 00 hours, immediately after the rainfall was recorded. The flow depths were converted to discharges using the rating equations.

Figure 3.11. Arrangement of flume, water level recorder and sediment collection tank

3.5.3 Soil loss

Rectangular metal tanks were fabricated for collection of sediment in the runoff. These tanks were placed immediately below the flumes to proportionately sample all runoff leaving the plots. The tank base had dimensions of 1.83 m by 1.22 m and the side walls were 1.02 m high. The front and back walls were respectively, 0.61 and 0.71 m high, which ensured that all overflows went over the front wall.

Whenever the runoff volume exceeded the tank capacity of 1.37 m^3, the excess runoff flowed over the shorter end. The tanks were positioned with the longer side in the direction of flow so as to ensure proper mixing of runoff at times of overflow.

Samples of runoff were collected from each tank at the time of changing the water level charts. This was done by thoroughly stirring the contents of the tank, followed by the filling of a 500 ml sampling bottle with the stirred mixture.

The sampling bottles were taken to the Ministry of Agriculture laboratory for analysis of sediment concentration. The analysis was conducted as follows:

1) The sample was allowed to stand undisturbed for at least 24 hours to allow complete settlement of the sediment.

2) The clear liquid above the sediment was carefully decanted.

3) The wet sediment was completely transferred to a previously weighed soil moisture can.

4) The cans were then placed in an oven set at 105 °C where they were left for at least 24 hours, or until the sample was thoroughly dry.

5) The cans were then re-weighed and the weight of the sediment was calculated.

3.6 Crop management and crop yield measurements

Following the construction of the conservation systems, bananas of the Valery variety were planted in all plots except in those parts of the strip cropped plot which carried an alternate crop. Banana was chosen because it is the most widely grown crop in St. Lucia.

The banana crop was planted in late May and early June of 1988. Planting was done along the contours in an equilateral triangular array, at a spacing of 2.6 m (Figure 3.8). This planting arrangement reduced the risk of rill and gully erosion.

Crop management activities such as weed control, fertilization and nematode control, were applied in accordance with WINBAN recommendations.

Harvesting of the banana crop began in January 1989, eight months after planting, and was conducted every other week on days designated by the St. Lucia Banana Growers Association. The harvested fruit were packed in boxes in the field and were then taken to a shed where the fruit from each plot were separately weighed.

Harvesting of the cucumber crop in the strip cropped plot commenced in mid-September of 1988, 7 weeks after planting. Marketable and non-marketable yields from sub-plots of 100 m^2 were separated and weighed in the field. A multiplying factor based on the relative sizes of the sub-plot and the strips was then used to determine the yield from each strip.

The cucumbers in the strip cropped plot were replaced by sweet potatoes. The ridges were re-shaped to the original dimensions prior to planting of the sweet potato crop. Harvesting of the sweet potato crop commenced in late March of 1989, 19 weeks after planting. The procedure used for determining sweet potato yields was the same as described above for cucumbers.

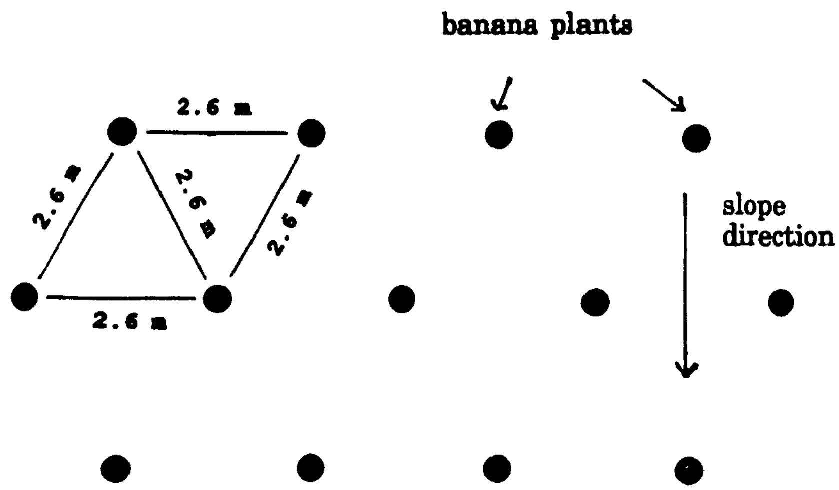


Figure 3.12. Planting arrangement for bananas

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Distribution and properties of soils

4.1.1 Distribution of soils

Six soil types were identified within the general area covered by the soils survey. Five of these ocurred within the areas occupied by the plots. General descriptions of these soil types are given in Appendix B. The areas of each soil type within the plots are given in Table 4.1. Jean Baptiste silty clay loam covers the largest area, 0.85 ha, which is over one-third of the total area of the plots. It however occurs in only three plots. Mabouya silty clay covers 0.69 ha but occurs in all plots.

Warwick clay occurs only in the two most westerly plots, the control and contour drained plots while Bocage stony clay is confined to the two most easterly plots. Soucis silty clay loam occurs in the flat area outside of the plots.

4.1.2 Soil physical properties

The particle size distribution, bulk densities and saturated hydraulic conductivities of the soils on the site were determined by standard laboratory procedures. These soil properties are important in determining the susceptibility of the soil to erosion, and they also influence the extent to which rainfall will run off the soil surface.

All results of soils analyses given in the suceeding sections are averages from 2 samples.

Table 4.1. Distribution of soils at the study site

Soil	Area covered by each soil (ha): Control plot	Contour drained plot	Strip cropped plot	Terraced plot	Total area	Percentage of total area
Warwick clay	0.07	0.08	----	----	0.15	6.1
Jean Baptiste silty clay loam	----	0.34	0.43	0.08	0.85	34.5
Mabouya silty clay	0.05	0.14	0.32	0.18	0.69	28.1
Bocage stony clay	----	----	0.05	0.15	0.20	8.1
Canelles clay	0.20	----	----	0.37	0.57	23.2
Total	0.32	0.56	0.80	0.78	2.46	100.0

4.1.2.1 Particle size distribution

Results of the particle size analysis are given in Table 4.2. The particle size distribution data indicate that all the soils contain relatively high proportions of clay. There is no evidence of consistent changes in particle size distribution down the profile. This suggests that the soils are mixed. The particle size distribution data are consistent with descriptions of the soils given by Stark et al. (1966).

4.1.2.2 Bulk density

Bulk densities of the soils are given in Table 4.3. The bulk densities are all in the range 1.0 to 1.3 g/cm^3, and variations down the soil profile are not significant. These values are similar in order of magnitude to those reported by other researchers. Warkentin (1974) reported values of 0.7 to 1.4 g/cm^3 for clay soils from several other Caribbean islands. Madramootoo (1981) reported values of 1.07 to 1.24 g/cm^3 on a montmorillonitic clay in St. Lucia and Ahmad and Brekner (1974) reported values of 1.29 to 1.53 g/cm^3 for several soils in Trinidad.

Considering the clay contents of the soils, the bulk density values indicate low levels of compaction and good soil structure.

4.1.2.3 Hydraulic conductivity

The hydraulic conductivities of the soils are given in Table 4.4. These values are relatively low. Ahmad and Brekner (1974) measured values ranging from 3.0 to 25.2 cm/hr on a clay, clay loam and sandy clay loam in Tobago.

There were no significant variations in hydraulic conductivity over the top 120 cm of soil and the differences between the soils are minor.

Based on the FAO classification given by Landon (1984), all soils on the site are classified as exhibiting very slow conductivity. This suggests that a relatively high proportion of rainfall is likely to run off the soil surface.

4.1.3 Soil chemical properties

Soil pH, electrical conductivities, organic matter contents and concentrations of some important mineral elements were determined by standard laboratory procedures. The results of these are given in Table 4.5.

4.1.3.1 pH

The pH data show all soils to be acidic. There is however no need for liming because the levels of extractable bases indicate a sufficiently high level of base saturation.

4.1.3.2 Electrical conductivity

The electrical conductivity values were low for all soils. The magnitude of these values place all soils in the USDA electrical conductivity class 0. This designates the soils as being salt free which implies that salinity effects on most crops are likely to be negligible (Landon, 1984).

In most cases the highest electrical conductivities were measured in the surface layers. This is indicative of past fertilizer use. The generally low levels however indicate that fertilizer application would have to be maintained in order to obtain good crop performance and high crop yields.

4.1.3.3 Organic matter

The levels of organic matter were generally low for all soils. This reflects extensive oxidation of organic matter which is commonly found in tropical soils. Lal (1976) reported organic matter contents of 0.18% at 1 m depth to 1.54 % at the surface of an Alfisol in Western Nigeria. Lindsay and Gumbs (1982) however reported slightly higher values, of 1.7 to 4.0% for 10 soils in Trinidad.

Even with the relatively low levels of organic matter, the soils on the site displayed good structure. This is primarily due to the presence of large amounts of iron which play a vital part in soil aggregation.

4.1.3.4 Extractable bases

The levels of extractable bases appear sufficient for crop production, with the exception of potassium which seems low in all soils. This suggests the need for application of potassium fertilizer.

Table 4.2. Particle size distribution of the soils at the study site.

Soil	Depth from soil surface (cm)	Particle Size Distribution (%)		
		Sand	Silt	Clay
Warwick clay	0 - 13	26	36	38
	13 - 25	28	35	37
	25 - 40	32	21	47
	40 - 60	42	15	43
Jean Baptiste silty clay loam	0 - 12	25	25	50
	12 - 40	22	30	52
	40 - 55	18	32	50
	55 - 70	15	32	53
Mabouya silty clay	0 - 25	21	54	25
	25 - 120	20	42	38
Bocage stony clay	0 - 15	45	20	35
	15 - 35	51	19	30
	35 - 90	19	40	41
	> 90	36	20	44
Canelles clay	0 - 25	36	26	38
	25 - 45	38	34	28
	45 - 75	29	29	42
	75 - 145	19	42	29
	> 145	33	30	40
Soucis silty clay loam	0 - 25	35	32	33
	25 - 50	36	32	32
	> 50	16	28	55

Table 4.3. Bulk densities of the soils at the study site

Soil	Depth from soil surface (cm)	Bulk density (g/cm^3)
Warwick clay	0	1.2
	40	1.0
	80	1.0
	120	1.1
Jean Baptiste silty clay loam	0	1.2
	40	1.2
	80	1.2
	120	1.2
Mabouya silty clay	0	1.3
	40	1.3
	80	1.2
	120	1.2
Bocage stony clay	0	1.2
	50	1.2
	80	1.3
	120	1.1
Canelles clay	0	1.2
	40	1.2
	60	1.1
	120	1.0
Soucis silty clay	0	1.1
	40	1.2
	80	1.0
	120	1.1

Table 4.4. Hydraulic conductivities of the soils at the study site.

Soil	Depth from soil surface (cm)	Hydraulic Conductivity (cm/hr)
Warwick clay	0	0.26
	40	0.20
	80	0.19
	120	0.20
Jean Baptiste silty clay loam	0	0.20
	40	0.18
	80	0.30
	120	0.17
Mabouya silty clay	0	0.20
	40	0.17
	80	0.24
	120	0.30
Bocage stony clay	0	0.21
	50	0.20
	80	0.20
	120	0.34
Canelles clay	0	0.23
	40	0.18
	80	0.37
	120	0.37
Soucis silty clay loam	0	0.50
	40	0.23
	80	0.40
	120	0.30

Table 4.5 Chemical properties of soils at the study site

Soil	Depth (cm)	Electrical Conductivity (mmhos/cm)	pH	Organic Matter (%)	Extractable bases Ca	Mg	K	Mn	P
					– meq/100g –			– ppm –	
Warwick clay	0 - 13	0.25	5.2	2.1	24.7	12.8	0.19	89.6	2.3
	13 - 25	0.03	5.6	1.2	27.6	10.8	0.23	45.5	0.3
	25 - 40	0.01	5.4	0.7	27.0	8.3	0.10	25.3	29.8
	40 - 60	0.05	5.7	0.4	33.6	7.6	0.19	15.2	15.3
Jean Baptiste silty clay loam	0 - 12	0.10	5.4	1.6	24.0	12.0	0.25	26.4	14.0
	12 - 40	0.07	5.2	1.0	18.4	8.0	0.14	10.4	1.3
	40 - 55	0.04	5.2	0.5	14.3	5.0	0.13	12.8	0.3
	55 - 70	0.03	5.1	0.5	10.0	3.7	0.10	11.0	0.3
Mabouya silty clay	0 - 25	0.23	5.3	1.2	19.9	8.8	0.26	113.0	2.6
	25 - 120	0.03	5.6	0.7	24.7	10.8	0.16	5.1	4.3
Bocage stony clay	0 - 15	0.08	5.2	1.2	19.9	13.1	0.23	98.5	1.3
	15 - 35	0.05	5.2	0.9	19.3	13.7	0.10	65.9	1.3
	35 - 90	0.04	5.4	0.5	23.6	16.6	0.19	30.3	0.3
	> 90	0.04	5.8	0.3	23.1	20.7	0.23	10.1	0.3
Canelles clay	0 - 25	0.11	5.4	1.6	17.5	8.3	0.19	77.0	5.3
	25 - 45	0.04	5.5	0.7	21.2	10.2	0.23	15.2	0.3
	45 - 75	0.03	5.5	0.9	21.8	11.8	0.10	5.1	0.6
	75 - 145	0.10	5.6	0.5	19.3	12.4	0.23	30.3	0.8
	> 145	0.06	5.3	0.7	19.9	15.6	0.10	20.2	1.3
Soucis silty clay loam	0 - 25	0.07	4.4	1.7	12.6	5.2	0.29	137.0	2.2
	25 - 50	0.02	5.3	0.7	19.3	5.5	0.39	56.8	0.6
	> 50	0.10	5.6	0.5	21.3	13.1	0.32	69.4	1.6

4.1.4. Soil management

The foregoing discussion on soil properties shows that there are no major differences between the soils on the site. The uniformly low hydraulic conductivity values suggest that high proportions of rainfall are likely to run off the soil surface. The particle size distribution and organic matter contents suggest the soils are all moderately resistant to erosion. However, given the steep slopes on the site, extensive gully and rill erosion are likely. The high clay contents also suggest that under high rainfall conditions, soil slumping is likely to occur. Erosion control and drainage are therefore essential if the site is to be cultivated.

The results of the chemical analysis indicate that the soils are deficient in potassium and phosphorous, and that fertilization will be essential for economic crop production.

It is clear therefore, that a high level of soil management is required for soil productivity to be maintained.

4.2 Rainfall

Rainfall amounts and intensities were measured daily. The daily rainfall for the period June 15th to December 31st, 1988 are given in Table 4.6.

The monthly rainfalls for July to December show that the rainy season of 1988 was wetter than average. With the exception of December, the monthly rainfall amounts for the second half of the year were higher than the long term averages. During the period under study, St. Lucia was not affected by hurricanes which are common during that period. A few tropical storms were however experienced, the most significant of which was tropical storm Gilbert which resulted in 211.2 mm of rainfall on the site on September, 9th. This tropical storm later developed into the strongest hurricane of 1988 which caused much damage on other Caribbean islands.

Between June 15th and December 31st, rainfall was recorded on 187 days. An examination of the runoff charts and rainfall data showed that in most instances, runoff was not produced when rainfall was less than 14 mm. In some cases when rainfall exceeded 14 mm, the runoff produced was not measurable. A minimum daily rainfall of 14 mm and measurable flows were therefore used as the criteria for selecting the storms which were later analyzed for rainfall, runoff and soil loss. Twenty seven storms met these criteria and were analyzed.

After November 23rd, 1988, daily rainfall did not exceed 14 mm and no appreciable runoff was recorded. Rainfall intensities were determined from the rainfall recorder charts. For the storms analyzed, the maximum 20 minute rainfall intensities (Table 4.9) varied between 9.6 mm/hr and 69.3 mm/hr with an average of 26.3 mm/hr. These values illustrate the intense nature of the storms.

4.3 Runoff

Twenty-minute discharge values were derived from water level recorder charts and flume calibration data, and used to plot storm hydrographs. Rainfall intensities were also plotted (Appendix C). These hydrographs were all based on a 24-hour period commencing at 09 00hours. In a few cases, the hydrographs were continued beyond 09 00hours on the following day because significant flows were being recorded at that time. In order to highlight the major changes in flow rate, most of the hydrographs cover only the time during which significant changes in flows occurred.

Table 4.6. Daily Rainfall at the study site (mm)
June 15th to December 31st, 1988

Date	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
1	---	9.2	1.1	0.6	19.8	5.6	0.0
2	---	1.0	6.2	2.7	15.8	1.6	0.8
3	---	7.4	0.3	0.2	7.0	8.2	1.6
4	---	0.8	14.4	34.0	36.2	23.6	2.0
5	---	0.0	13.3	11.2	37.4	11.0	0.4
6	---	3.8	0.6	36.3	119.4	5.8	1.4
7	---	1.6	26.5	6.2	4.6	0.2	0.0
8	---	1.4	16.2	13.4	1.2	15.5	11.1
9	---	21.8	11.6	211.2	18.0	0.2	10.6
10	---	13.2	2.6	14.7	12.0	2.0	---
11	---	6.0	0.2	2.0	25.4	1.0	4.2*
12	---	17.4	0.3	24.8	6.2	6.6	0.0
13	---	1.9	12.2	13.0	24.2	14.8	0.0
14	---	5.2	54.4	6.0	22.0	14.4	0.2
15	1.6	2.4	27.4	4.8	23.8	29.9	0.2
16	10.0	4.0	8.4	7.8	10.8	94.6	4.9
17	1.4	3.8	6.2	9.2	1.4	5.3	1.0
18	65.3	3.9	0.2	3.0	10.2	0.1	2.0
19	6.2	1.1	2.1	6.6	12.5	46.0	12.5
20	6.2	11.1	21.1	8.7	5.2	16.3	12.8
21	0.4	0.4	23.2	14.0	4.4	7.5	5.8
22	0.0	---	0.8	1.2	23.6	0.2	3.0
23	7.4	24.0*	0.0	0.4	0.2	30.8	---
24	5.8	0.3	15.6	0.1	0.8	2.0	5.0*
25	4.9	48.6	0.2	0.0	1.0	3.2	2.0
26	2.1	10.2	7.0	0.0	3.4	0.0	0.0
27	0.5	9.6	1.2	2.3	13.0	0.0	0.0
28	25.0	0.3	9.2	2.6	2.2	8.3	7.3
29	14.2	5.9	0.1	1.2	0.8	0.8	1.4
30	5.1	4.7	0.9	12.8	0.7	0.0	2.2
31		34.6	3.9		0.0		0.3
Total	156.1+	255 6	287.4	451.0	463.2	355.5	92.7
Long term average	178.2	240.8	258.3	264.5	272.1	271.0	168.5

* Cumulative rainfall measured for 2 days.

+ This total only covers the period from June 15th to 30th.

4.3.1 Runoff depths and runoff-rainfall ratios

The total volume of runoff for each event was determined from the water level recorder charts and the flume calibration data. These volumes were used to obtain runoff depths and the runoff-rainfall ratios given in Table 4.7.

The runoff depths varied considerably over the data collection period. For the storms analyzed, the runoff depths varied from 0.6 to 203.6 mm in the control plot, 2.1 to 199.2 mm in the contour drained plot, 3.2 to 155.1 mm in the strip cropped plot and 1.3 to 94.7 mm in the terraced plot. The maximum values reflect the large amounts of runoff which were to be accommodated by the drainage systems within the plots and indicate the potential for high erosion rates if runoff were not controlled.

For the storms analyzed, the runoff to rainfall ratios ranged from 0.03 to 0.96 in the control plot, 0.10 to 1.53 in the contour drained plot, 0.15 to 1.99 in the strip cropped plot and 0.05 to 0.79 in the terraced plot. The highest ratios were most often measured in the strip cropped plot. The contour drained plot however also consistently produced large amounts of runoff. The terraced plot most often produced the least amount of runoff. These trends are well illustrated by Figures 4.1 and 4.2.

There appeared to be a change in the trends in runoff after October 1988. From the beginning of November 1988, the maximum runoff-rainfall ratios were recorded in the contour drained plot with increased frequency. It is not clear from the data whether this trend is transient or not. The relatively high drainage density of the contour drained plot, 0.95 km/ha, however suggests that it may produce the most runoff in the long term. The changes which occurred at the end of October 1988 reflect the instability in the plots due to their recent construction.

The average runoff-rainfall ratios given in Table 4.7 show that the proportion of rainfall which went as surface runoff was generally high. These rates however represent most of the major rainfall events of the 1988 wet season.

Table 4.7. Rainfall (mm), runoff depths (mm) and runoff-rainfall ratios

Date	Rainfall (mm)	Runoff depths (mm) and rainfall-runoff ratios+			
		Control plot	Contour drained plot	Strip cropped plot	Terraced plot
88-06-28	25.0	0.9 (0.03)	5.3 (0.21)	*	6.7 (0.27)
88-06-29	14.2	3.3 (0.23)	2.5 (0.18)	6.1 (0.43)	3.6 (0.26)
88-07-09	21.8	3.4 (0.16)	2.1 (0.10)	3.2 (0.15)	1.3 (0.06)
88-07-12	17.4	3.1 (0.18)	4.6 (0.26)	8.5 (0.49)	2.1 (0.12)
88-07-23	24.0	5.1 (0.21)	5.0 (0.21)	6.0 (0.25)	2.6 (0.11)
88-07-25	48.6	11.8 (0.24)	23.1 (0.47)	18.4 (0.38)	2.5 (0.05)
88-07-31	34.6	13.3 (0.38)	13.3 (0.38)	34.1 (0.99)	11.9 (0.34)
88-08-14	54.4	18.0 (0.33)	28.6 (0.53)	34.0 (0.62)	16.2 (0.30)
88-08-15	27.4	7.0 (0.26)	6.3 (0.23)	11.9 (0.43)	6.4 (0.23)
88-08-24	15.6	0.7 (0.04)	2.2 (0.14)	5.9 (0.38)	*
88-09-04	34.0	4.7 (0.14)	9.6 (0.28)	10.3 (0.30)	5.2 (0.15)
88-09-06	36.3	10.7 (0.30)	21.0 (0.58)	20.3 (0.56)	13.4 (0.37)
88-09-09	211.2	203.6 (0.96)	199.2 (0.94)	155.1 (0.73)	*
88-09-12	24.8	15.0 (0.60)	20.6 (0.83)	21.4 (0.86)	6.4 (0.26)
88-10-02	15.8	0.9 (0.06)	4.7 (0.30)	3.2 (0.20)	2.3 (0.14)
88-10-04	36.2	5.1 (0.14)	12.9 (0.36)	15.8 (0.44)	7.2 (0.20)
88-10-06	119.4	99.8 (0.84)	108.5 (0.91)	80.0 (0.67)	94.7 (0.79)
88-10-09	18.0	*	7.4 (0.41)	12.9 (0.72)	1.5 (0.08)
88-10-11	25.4	7.0 (0.28)	*	50.6 (1.99)	6.9 (0.27)
88-10-13	24.2	2.6 (0.11)	7.6 (0.32)	13.1 (0.54)	3.2 (0.13)
88-10-22	23.6	20.1 (0.85)	36.2 (1.53)	38.3 (1.62)	18.3 (0.78)
88-11-13	14.8	2.4 (0.16)	4.7 (0.31)	5.4 (0.37)	1.4 (0.09)
88-11-14	14.4	0.6 (0.04)	5.9 (0.41)	5.6 (0.39)	2.2 (0.16)
88-11-15	29.9	14.3 (0.48)	24.9 (0.83)	20.6 (0.69)	6.5 (0.22)
88-11-19	46.0	28.1 (0.61)	32.5 (0.71)	31.3 (0.68)	12.5 (0.27)
88-11-20	16.3	11.5 (0.71)	22.3 (1.37)	20.0 (1.23)	9.4 (0.58)
88-11-23	30.8	14.3 (0.46)	25.7 (0.83)	17.2 (0.56)	9.0 (0.29)
Totals:	1004.1	507.3	636.7	649.1	253.6

* data unavailable due to equipment malfunction
+ numbers in parentheses are the runoff-rainfall ratios

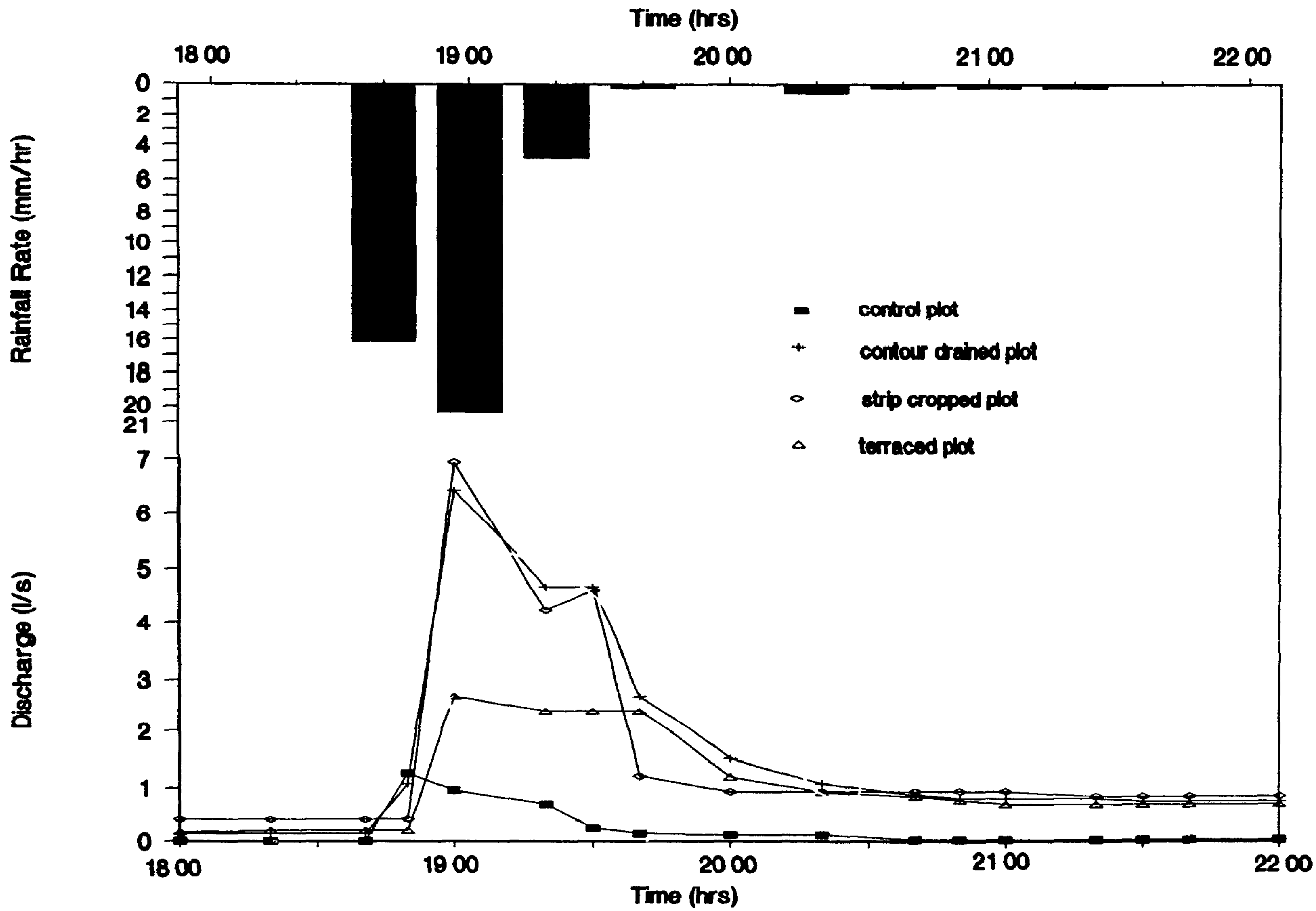


Figure 4.1. Event hydrographs for 88-10-02

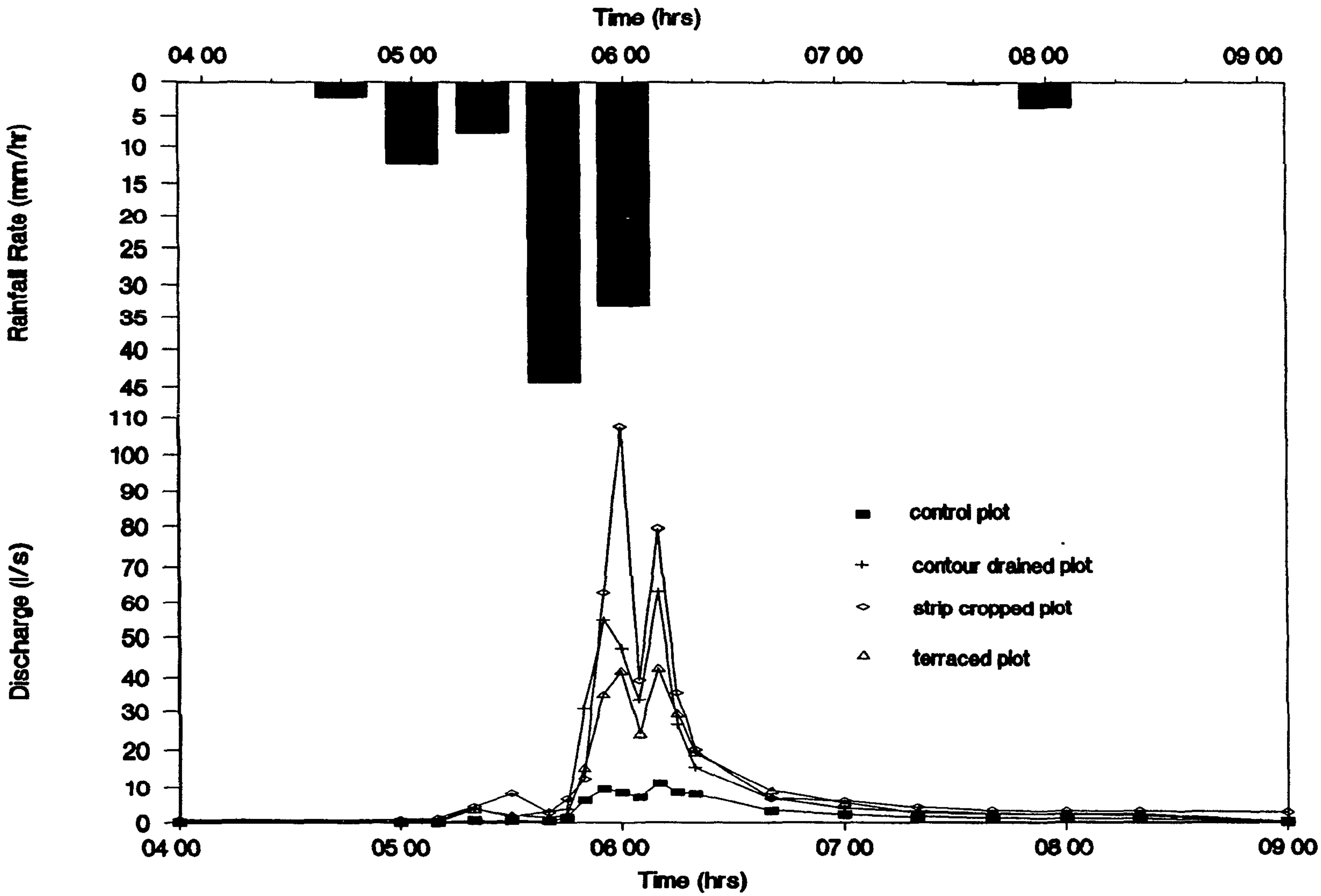


Figure 4.2. Event Hydrographs for 88-09-06

High ratios have been measured elsewhere in the tropics. In Trinidad, Gumbs et al. (1985) measured ratios of 0.8 to 0.9 from bare soil and 0.6 to 0.8 from a plot cropped in maize, from rainfalls of 30 to 60 cm on a 47% slope. In Jamaica, Scheng and Michaelsen (1973) found that the effects of different soil conservation treatments on runoff were very small. On slopes of 17% cropped in yams, they found that about one-third of the annual rainfall contributed to surface runoff.

Published data from the U.S. show that on small catchments, less than one square kilometre, storms commonly yielded more than 25% of the rainfall as storm runoff (Dunne, 1978).

The data showed that the higher runoff-rainfall ratios are closely related to antecedent rainfall. In a sequence of 2 storms closely following one another, the higher initial moisture content at the start of the second storm reduces the infiltration rate and this results in increased runoff. For example, on 88-11-19 when 46.0 mm of rainfall were recorded, the runoff-rainfall ratios were 0.61 for the control plot, 0.71 for the contour-drained plot, 0.68 for the strip-cropped plot, and 0.27 for the terraced plot, compared to 0.71, 1.37, 1.23 and 0.58 respectively, on the following day, when only 16.3 mm of rainfall was recorded. This illustrates the effect of antecedent rainfall on soil moisture and infiltration which in turn affect runoff amounts. Similar results were observed by Scheng and Michaelsen (1973), who measured a runoff-rainfall ratio of 0.95 on a day following a significant rainfall event.

As indicated in Table 4.7, there were some instances when runoff exceeded rainfall. As the diversion drains were designed to intercept surface flows from the adjacent upland areas, it is believed that most of the excess flcws were therefore due to subsurface flows from these upland areas.

The effect of subsurface flows on runoff from hillslopes is often significant. The dynamics of these subsurface flows are described by Whipkey and Kirkby (1978).

Rainfall which infiltrates at the start of a rainstorm percolates downwards and increases soil moisture. When percolated water reaches a less permeable layer, a shallow saturated water zone is formed at the interface of the two layers. This may give rise to significant throughflows.

With extended periods of rainfall, the saturated layer may build up to the surface to produce overland seepage or return flow. The presence of the saturated layer at the surface also prevents the entry of further rainfall which therefore runs off directly as saturated overland flow.

The physical properties and depth of soil are probably the most important controls on subsurface flow production at a site. If the texture is fine, lateral or shallow subsurface flow sometimes occurs quickly. The textures of the soils on the study site and the steepness of the site suggest that this type of rapid shallow flow may have occurred.

Evidence of subsurface flow was most apparent in the contour drained plot where seepage at the head of the stepped drain contributed to flows in the drain. This drain was constructed along the alignment of a natural watercourse which passed through the plot. Seepage resulted from the exposure of a throughflow region due to excavation of the drain. This prolonged the runoff from the plot for several hours and sometimes for more than a day after runoff in the other plots had ceased. The levels of flow due to seepage were, however, relatively low and were not likely to significantly affect peak flows.

The opportunities for shallow subsurface flows to emerge at the surface and contribute to surface runoff were increased in the contour drained, strip cropped and terraced plots where the regions of shallow subsurface flow had been exposed at the terrace risers and the sides of the drains. After emergence at the exposed surfaces, these flows were conveyed by the drainage structures and measured as surface runoff. This may account for the relatively large runoff depths measured in the contour-drained plot, which has the highest drainage density (Table 3.2).

The relatively low amounts of runoff from the terraced plot does not, however, reflect the high drainage densities in that plot. The terrace benches may have affected runoff by providing increased opportunity for infiltration because of their relatively flat surfaces. The relatively short length of the terraced plot may also have resulted in reduced amounts of shallow subsurface flows within the plot. In that case the contributions of subsurface flows to runoff would be lessened, even with the large area taken up by the terrace risers.

Runoff from the control plot did not appear to be significantly influenced by subsurface flows. The control plot is less steep than the others, which suggests that the opportunity for infiltration of overland flow would be greater. This would have resulted in less surface runoff in that plot. Furthermore, there was little opportunity for lateral seepage in the control plot since it carries one main drain. for the collection of runoff. This drain is located adjacent to a large natural watercourse which has a lower bed elevation than the drain. This watercourse may have created a drawdown of subsurface flows which would otherwise have emerged in the collector drain. This may partly account for the low flows in the control plot when compared to the other plots.

The presence of ridges in the strip cropped plot was an additional factor influencing runoff from that plot. The depressions between ridges, in some cases acted as minor drains which contributed to the disposal of runoff. In some instances however, these depressions did not allow for much flow across the contours. They sometimes retarded the downslope movement of runoff and caused depression storage which later infiltrated into the soil and contributed to saturated conditions at the soil surface at the base of the plot.

Regression analyses of the daily rainfall and runoff depths showed generally good correlation between the two parameters (Table 4.8). The regression equations could therefore be expected to provide reasonably accurate estimates of runoff depth for rainfall amounts within the range of those used for this analysis (14.2 to 211.2 mm. Increasing the data base may further increase the correlation coefficients and may also increase the accuracy and range of applicability of the equations.

Table 4.8 Correlation coefficients (r) and regression equations of the relationships between daily rainfall (X), (mm) and runoff depth (Y), (mm)

Plot	r	Regression equations
Control plot	0.979	Y = 1.005X-18.581
Contour drained plot	0.975	Y = 0.981X-12.444
Strip cropped plot	0.942	Y = 0.723X-2.254
Terraced plot	0.903	Y = 0.771X-13.849

In summary, the runoff characteristics of each plot were determined by the soil and topographic conditions, and the configurations of the plots. It is clear, however, that subsurface flows can sometimes significantly affect runoff amounts. Runoff may on occasion exceed the direct rainfall on the cultivated area. This has significance not only for the design of conservation systems within the cultivated area, but also for the design of hydraulic structures further downstream.

4.3.2. Peak Runoff rates

Peak runoff rates were determined from the storm hydrographs. These rates are given in Table 4.9. For some events, multiple peaks were recorded. In a few instances, malfunctioning of the water level recorders prevented recording of flows.

During the event of 88-09-09, the flows from the contour drained plot exceeded the flume capacity. The peak flow given for the contour drained plot on 88-09-09, is therefore an estimate.

For most events, the peak runoff rates were highest in the strip cropped plot. In some instances the highest rates were measured in the contour drained plot. The lowest peak runoff rates were most often recorded in the control plot. These trends are illustrated by the hydrographs in Figures 4.1 and 4.2.

The trends observed in runoff after October 1988 as described in section 4.3.1, also apply to peak flows. From that time the maximum peak flows occurred in the contour drained plot with increased frequency. The conclusions drawn for runoff with respect to the trends after October 1988, apply equally to peak flows.

Peak rates of runoff vary with rainfall intensity, infiltration capacity, land gradient and plot area. Since infiltration data of the soils are not available, the effect of infiltration capacity cannot be accurately assessed.

The data however suggest that peak runoff rates are influenced by plot steepness and size, which are greatest in the strip cropped plot and least in the control plot. The generally high rates from the contour drained plot which has the highest drainage density, indicate that drainage density also influences peak runoff rates.

Regression analyses of the maximum 20-minute rainfall intensities and peak flows showed that in general, the correlation between these factors was not high (Table 4.10). Similar results were obtained from regression analyses of total daily rainfall and peak flow. These results may be due to the complexity of the relationship between these factors. The effects of soil moisture on peak flows are significant and vary considerably with time. The rapid changes in the crop cover during the data collection period would also have added to the complexity of the rainfall-peak flow relationships. The low correlation may have also been due to the small data base. Expansion of the data base and collection of soil moisture and infiltration data may lead to acceptable predictive methods for estimating peak flows.

Table 4.9. Maximum rainfall intensities and peak runoff rates

Date	Maximum 20 min- Rainfall Intensity (mm/hr)	Peak runoff rate (l/s)			
		Control plot	Contour drained plot	Strip cropped plot	Terraced plot
88-06-28	19.2	0.7	1.4	*	4.1
88-06-28	19.2	1.0	1.7	*	4.0
88-06-29	18.0	1.9	1.7	4.0	3.7
88-06-29	18.0	0.3	0.5	2.4	0.8
88-07-09	17.4	3.5	2.7	4.9	4.1
88-07-09	17.4	2.1	1.3	2.4	1.3
88-07-12	12.0	3.9	1.7	6.5	2.7
88-07-12	12.0	2.4	2.7	6.7	2.9
88-07-23	24.6	4.2	1.0	1.1	0.4
88-07-23	24.6	6.7	6.4	4.2	3.0
88-07-25	27.0	2.4	4.3	6.5	0.4
88-07-25	27.0	8.4	31.2	29.8	6.2
88-07-31	21.6	7.4	9.1	12.3	9.4
88-07-31	21.6	9.1	15.1	20.1	12.9
88-08-14	32.1	9.9	33.9	48.7	17.0
88-08-14	32.1	10.8	27.5	48.7	10.3
88-08-15	36.6	11.0	23.6	62.7	25.1
88-08-24	22.2	1.4	4.9	14.8	*
88-08-24	22.2	0.8	2.4	6.5	*
88-09-04	45.3	1.9	13.5	11.6	10.3
88-09-06	44.4	9.4	54.5	107.1	41.8
88-09-06	44.4	11.0	63.1	79.4	42.5
88-09-09	69.3	66.2	86.3	98.1	*
88-09-09	69.3	79.3	193.6+	200.1	*
88-09-12	25.5	7.4	35.3	71.6	9.1
88-09-12	25.5	5.0	4.3	37.8	3.5
88-10-02	20.4	1.3	6.4	7.0	2.7
88-10-04	20.7	2.4	6.0	13.3	3.7
88-10-04	20.7	6.7	23.5	55.9	16.2
88-10-06	58.2	49.8	143.8	147.5	110.6
88-10-06	58.2	29.0	64.1	62.7	30.4
88-10-06	58.2	14.7	26.4	40.8	30.4
88-10-09	21.3	*	21.5	36.6	5.7
88-10-11	20.7	4.8	*	48.1	8.8
88-10-13	9.6	0.8	5.1	21.0	2.0
88-10-13	9.6	0.7	6.7	19.2	1.6
88-10-22	44.4	15.6	68.2	103.1	36.2
88-11-13	14.4	2.1	6.4	3.3	1.2
88-11-14	9.6	1.9	13.1	4.4	2.1
88-11-15	21.6	9.1	47.5	28.2	12.2
88-11-15	21.6	4.0	10.7	4.2	1.5
88-11-19	20.7	6.0	22.5	11.3	4.4
88-11-19	20.7	16.0	59.1	39.0	15.5
88-11-19	20.7	6.9	21.0	16.7	6.7
88-11-19	20.7	11.0	32.6	37.2	20.0
88-11-20	14.4	8.4	30.0	26.7	11.9
88-11-20	14.4	4.4	21.0	10.0	4.1
88-11-23	24.9	7.9	34.6	26.7	11.9
88-11-23	24.9	2.4	9.4	5.3	2.7
88-11-23	24.9	6.5	26.4	19.2	7.4

* data unavailable due to equipment malfunction.
+ estimate of peak flow for contour drained plot.

Table 4.10 Correlation coefficients (r) and regression equations for the relationships between rainfall parameters (X) and peak flow (Y), (l/s)

Parameter (X)	r	Regression equation
Maximum 20-minute rainfall intensity (mm/hr):		
Control plot	0.802	Y = 0.919X-13.733
Contour drained plot	0.731	Y = 1.876X-19.122
Strip cropped plot	0.859	Y = 2.817X-31.551
Terraced plot	0.792	Y = 1.454X-21.063
Daily rainfall (mm):		
Control plot	0.970	Y = 0.400X-4.448
Contour drained plot	0.696	Y = 0.558X+8.722
Strip cropped plot	0.827	Y = 0.974X+6.801
Terraced plot	0.860	Y = 0.907X-13.027

4.3.3 Times to peak (T_p)

The runoff response to rainfall was rapid in all plots. In most events, flows were recorded within five minutes of the commencement of rainfall, irrespective of the soil moisture levels. Similarly, the times to peak flow were relatively short in all plots, seldom exceeding 20 minutes (Table 4.11). This rapid response is reflected in the steep rising of the hydrographs. Similarly, flows fell sharply after the rain had ceased. The rapid response to rainfall is illustrated by the hydrographs in Figure 4.3.

There appeared to be no trend in the differences of time to peak between plots. In most cases, peak flows in all plots occurred within a period of 20 minutes after the peak rainfall intensities.

The rapid response to rainfall reflects the steep slopes and small catchment areas.

It appears that the differences in slope, plot shape, plot size and conservation treatment were not sufficient to create marked differences in times to peak.

Table 4.10 Times to peak (T_p), (min)

Date	Control plot	Contour drained plot	Strip cropped plot	Terraced plot
88-06-28	15	15	*	20
88-06-29	15	20	10	15
88-06-29	15	20	10	15
88-06-29	5	5	5	5
88-07-09	5	5	10	5
88-07-09	5	5	5	5
88-07-12	10	10	20	10
88-07-12	10	10	10	10
88-07-23	5	5	5	10
88-07-23	10	10	10	10
88-07-25	10	10	10	10
88-07-25	20	20	20	10
88-07-31	5	10	10	10
88-07-31	20	5	10	05
88-08-14	5	5	5	5
88-08-14	15	5	10	10
88-08-15	10	5	5	10
88-08-24	5	5	5	*
88-08-24	5	5	10	*
88-09-04	5	5	5	5
88-09-06	15	25	20	20
88-09-06	10	10	5	5
88-09-09	20	20	10	*
88-09-09	20	20	20	*
88-09-12	5	15	15	15
88-09-12	20	5	10	5
88-10-02	10	20	5	5
88-10-04	5	5	5	5
88-10-04	10	10	15	10
88-10-06	20	15	10	10
88-10-06	10	10	10	10
88-10-06	20	10	10	10
88-10-09	*	10	10	5
88-10-11	10	*	10	10
88-10-13	10	10	15	5
88-10-13	10	10	10	5
88-10-22	25	25	20	25
88-11-13	5	10	5	5
88-11-14	5	5	5	5
88-11-15	10	10	15	10
88-11-15	15	15	10	5
88-11-19	5	10	5	5
88-11-19	10	10	10	5
88-11-19	10	5	5	10
88-11-19	10	10	10	5
88-11-20	5	10	10	20
88-11-20	10	5	10	20
88-19-23	10	10	15	5
88-11-23	10	5	15	15
88-11-23	10	10	10	10

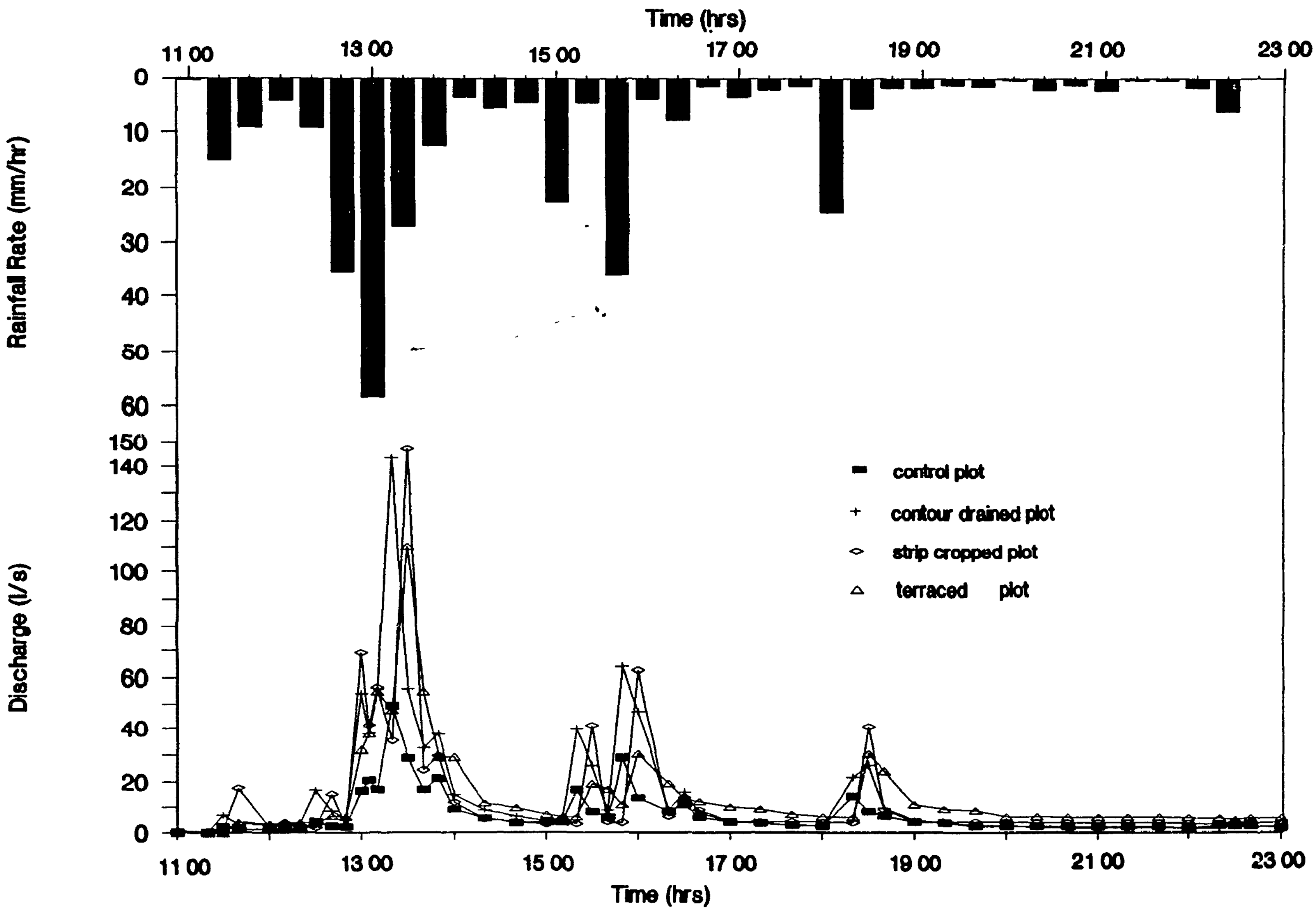


Figure 4.3. Event Hydrographs for 88-10-06

4.4 Soil Loss

The soil loss rates for each storm were determined by applying the sediment concentrations in the runoff samples to the total runoff volumes. These rates are presented in Table 4.12.

Table 4.12. Soil Loss Rates for individual storms (kg/ha)

Date	Total Rainfall (mm)	Control plot	Contour drained plot	Strip cropped plot	Terraced plot
88-08-14	54.4	1.77	16.88	6.59	4.57
88-08-15	27.4	0.21	0.18	0.57	0.56
88-08-24	15.6	0.01	0.07	0.58	*
88-09-04	34.0	0.07	0.57	0.70	0.79
88-09-06	36.3	0.19	3.49	2.88	0.83
88-09-12	24.8	0.51	0.99	17.45	0.68
88-10-02	15.8	0.02	0.41	0.16	0.01
88-10-04	36.2	0.08	1.34	2.43	0.33
88-10-09	18.0	*	1.14	1.08	0.02
88-10-11	25.4	0.10	*	28.86	0.15
88-10-22	23.6	0.32	2.53	4.82	0.77
88-11-13	14.8	0.04	0.21	0.20	0.05
88-11-14	14.4	0.01	0.27	0.20	0.08
88-11-15	29.9	0.26	1.29	15.77	6.62
88-11-19	46.0	1.29	3.05	2.69	0.42
88-11-20	16.3	0.39	2.54	1.04	0.09
88-11-23	30.8	0.40	0.67	0.65	0.24
Total soil loss		5.67	35.65	86.68	16.22
Total Rainfall	463.7				

* data unavailable due to equipment malfunction

In most cases, the highest soil loss rates were recorded in the contour drained plot or the strip cropped plot, and the lowest rates were recorded in the control plot. This matches the general trends observed from the analysis of runoff. Conventional theory predicts significantly higher soil loss rates in the control plot. Because of the low runoff amounts from that plot, soil loss rates were found to be low.

The soil losses for individual storms ranged from 0.01 to 1.77 kg/ha for the control plot, 0.07 to 16.88 kg/ha for the contour-drained plot, 0.2 to 28.66 for the strip-cropped plot and from 0.01 to 6.62 for the terraced plot.

These soil loss rates appear generally low considering that the plots were newly constructed and that the levels of ground cover was sparse for a significant part of the recording period.

With the exception of the Warwick clay which was prone to slumping, all soils appeared to be fairly resistant to erosion. It was clear from field observations that on most occasions, soil loss was due more to soil slumping at the terrace risers and at the sides of some drains, than to sheet erosion.

Even with the slumping of the terrace risers particularly in August and September of 1988, the soil loss rates recorded in the terraced plot were not high.

The low soil loss rates may also be associated with the contribution of subsurface flows to runoff. In the contour-drained, strip-cropped and terraced plots, subsurface flows most often emerge in the drains or terraces. Consequently, they have no impact on sheet or rill erosion which occurs within the field. Their only contribution to soil lose would be due to sedimentation within the drainage channels. The overall soil loss from the plots may therefore depend significantly on the extent to which subsurface flows contribute to runoff. High runoff rates need not necessarily lead to high soil loss rates when subsurface flows are significant.

Another significant factor which may have contributed to the low levels of soil loss is the ground cover provided by weeds and crop residue. Indigenous grasses thrive in the rainy season and their control becomes a significant aspect of plot maintenance. Regular chemical and hand weeding ensured that weeds were always under control but the constant rainfall contributed to their rapid resurgence. These grasses do not only influence erosion by providing ground cover, but their deeply penetrating roots systems also bind the soil together and increase resistance to dislodgement of soil particles by overland flow. Pruning and other crop management practices which provide crop residue, also increase the extent of ground cover. The amount of crop residue left on the soil surface is likely to increase as the crop develops.

A significant feature of the soil loss data is the large proportion of the soil loss recorded in one event. The events varied from plot to plot. In each plot, more than 30% of the total soil loss was recorded in one event. Other studies (Scheng and Michaelsen, 1973, Gumbs and Lindsay, 1982, and Gumbs et. al., 1985) have recorded similar results. This emphasizes the erosive nature of large tropical storms.

Regression analyses were made between soil loss and several rainfall and runoff parameters but the degrees of correlation were low in all cases (Table 4.13). The highest correlation coefficients were obtained in the control plot. This may be a reflection of the complexity of soil loss phenomena in the other plots. The correlations for the relationship between soil loss and the maximum 20-minute rainfall intensity were very low. This may be an indication of the lesser significance of this factor, when compared to runoff rates or amounts. Collection of more rainfall, runoff and soil loss data from the plots may lead to clarification of the initial trends observed. Scheng and Michaelsen (1973) however found low correlation between runoff and soil loss from two years of data in Jamaica.

Table 4.13 Correlation coefficients (r) and regression equations for the relationships between rainfall and runoff parameters (X), and soil loss (Y)

Parameter (X)	Plot	r	Regression equation
Daily rainfall (mm)	Control	0.767	Y = 0.032X-0.547
	Contour drained	0.693	Y = 0.236X-4.237
	Strip cropped	0.118	Y = 0.082X+2.858
	Terraced	0.458	Y = 0.074X-1.050
Runoff depth (mm)	Control	0.757	Y = 0.047X-0.117
	Contour drained	0.471	Y = 0.172X-0.620
	Strip cropped	0.690	Y = 0.426X-3.038
	Terraced	0.280	Y = 0.101X+0.224
Maximum 20-min rainfall intensity (mm/hr)	Control	0.099	Y = 0.004X+0.242
	Contour drained	0.215	Y = 0.078X+0.188
	Strip cropped	0.049	Y =-0.036X+6.032
	Terraced	0.128	Y = 0.021X+0.465
Peak runoff rate (l/s)	Control	0.600	Y = 0.061X-0.093
	Contour drained	0.272	Y = 0.054X+0.586
	Strip cropped	0.256	Y = 0.065X+2.435
	Terraced	0.103	Y = 0.016X+0.776

The soil loss data obtained thus far, does not provide a basis for making firm conclusions on the relative effectiveness of the soil conservation systems. Further investigation of the rainfall, runoff and soil loss phenomena on the site, and additional data collection, are required to arrive at conclusions about the long term effects of the conservation systems on soil loss.

4.5 Crop yields

4.5.1 Banana yields

Harvesting of the banana crop began in January 1989, eight months after planting. Banana production data for the first six months of harvesting are given in Table 4.15. The highest yields were recorded in the contour-drained plot while the terraced plot registered the lowest yield. Because crop husbandry activities were the same on all plots, agronomic practices did not affect banana yields from plot to plot. Also, the minor differences in fertility of the soils, and the high level of fertilization minimized the possibility of global nutrient deficiencies.

The high level of topsoil disturbance and exposure of the subsoil in the construction of the terraced plot may have resulted in reduced soil fertility levels which would result in relatively low yields in that plot. These yields are likely to increase after the soil in that plot has stabilized, and after the full effect of fertilization is realised. Scheng and Michaelsen (1973) found that yields of yams were less on bench terraces than from check plots with no conservation until three years after construction of the terraces. Thereafter, yields increased. This was attributed to exposure of the subsoil during terracing and the gradual increase of productivity afterwards. The results in this study probably reflect a similar situation.

The available yield data are not sufficient to make conclusions about the long-term effects of the conservation systems on crop yields. It appears however that the initial yields were relatively high in all plots. The yields are likely to increase further with time. The trends in the differences between plots may change with time as the plots settle and as trends in soil loss change.

Table 4.15. Banana Production (kg) for January to June, 1989

Harvest date	Plot			
	Control	Contour drained	Strip cropped	Terraced
89-01-12	92	109	71	36
89-01-25	161	229	201	264
89-02-01	99	259	137	332
89-02-16	430	1072	581	735
89-03-03	403	1293	787	1127
89-03-16	587	1056	558	707
89-03-30	213	542	413	602
89-04-12	274	676	405	474
89-04-26	261	691	411	518
89-05-11	199	548	317	406
89-05-24	186	419	325	346
89-06-07	61	61	252	157
89-06-21	227	225	195	122
Total (kg)	3193	7180	4653	5826
Yield (kg/ha)	10104	12799	11377	8411*

* The yield for the terraced plot reflects the area under cultivation and not the total plot area.

4.5.2 Yields in the strip cropped plot

In the strip cropped plot, the strips of bananas were alternated at first with cucumbers and then with sweet potatoes. The yields of these crops are given in Table 4.16. The cucumber crop was planted in early August 1989 and harvesting began 7 weeks later. Because of difficulties in marketing the crop, a large amount of cucumbers were not harvested. This partly accounts for the relatively low marketable yields attained. The heavy rains of 88-09-09 resulted in the collapse of several ridges, particularly in the middle strip, where several plants were damaged or washed away. This led to the lower yields obtained from that strip.

The sweet potato crop was planted in Mid-November and harvesting began 19 weeks later. Two varieties were grown. The variety, A26/7, was grown in the top and bottom strips whilst the Mandela variety was grown in the middle strip. The foliage of the Mandela variety was noticeably less vigorous than that of the A26/7. The better performance of the latter was reflected in the difference in yields. This is supported by agronomic research by the Caribbean Agricultural Research and Development Institute, CARDI (1988) in St. Lucia. They showed that under the same conditions, the A26/7 variety gives significantly higher yields than the Mandela. The yields of the bottom strip are much lower than those of the top strip. This was the result of extensive rotting of the tubers in the lower strip due to high soil moisture levels. Although the crop was harvested in the dry season, subsurface throughflows caused moist conditions in the bottom strip. Crops which are sensitive to high soil moisture levels should therefore not be grown in the lower strips at the base of the hillside.

Table 4.16. Market yields of cucumbers and sweet potatoes in the strip-cropped plot (kg/ha)

Crop	Time of Harvest	Top strip	Middle strip	Bottom strip	Average plot yield
Cucumbers	Sept. 1988	6295	3596	7823	6102
Sweet potatoes	Mar. 1989	5619	899	2748	3024

4.6 Construction and maintenance costs

4.6.1 Construction costs.

One of the major constraints to the widespread implementation of soil conservation systems is the costs of establishment and maintenance. In St. Lucia, small scale subsistence farming is the norm and the limited financial returns from farming are insufficient to allow most farmers to invest in soil conservation. Furthermore, there is limited credit available for long term investments in agriculture.

The limited data available at this stage are insufficient to perform a comprehensive economic analysis of soil conservation systems. However, the available data provide information on the capital and maintenance costs of the systems.

The costs of constructing one hectare plots under different conservation measures are presented in Tables 4.17 to 4.19. The cost of carrying out a similar exercise without the provision of conservation measures within the field, is given in Table 4.20. The costs given relate strictly to work associated with land preparation, land forming and establishment of conservation structures. Costs associated with crop establishment are not taken into account. The costs of machinery hire were based on the prevailing rates for the use of Government owned machinery on agricultural projects. The cost of transportation of machinery to the site were not considered since they vary considerably, depending on the location of the construction site. It should also be noted that the costs presented in Tables 4.17 to 4.19 pertain to specific field layouts. Costs will vary depending on other field , drain, or terrace layouts.

The type of machinery used may also affect the costs of a system. For this study, a Caterpillar D5 tractor was used for land clearing, a Caterpillar D4 tractor was used for excavation of the terraces and diversion drains and a Caterpillar tracked excavator was used for excavation of the collector drain. Because of restricted availability of machinery in many parts of St. Lucia and in most other Caribbean islands, the choice of machinery for construction would often be dictated by the available machinery. The wrong choice of construction machinery may result in constant maintenance work on the conservation systems.

Improper timing of construction may also lead to excessive costs. The timing of the construction of conservation systems is often dictated by the time when the required machinery is available. This may be at a time when construction is not advisable because of wet and slippery ground conditions. This may increase time and expense required to complete the task. Construction of conservation systems in poor soil conditions may also result in improperly constructed systems which are expensive to maintain.

The costs of constructing a contour drained system and a strip cropped system were approximately the same. The construction cost of a terrace system was however greater than that of the other systems. This was largely due to the increased use of machinery in terrace construction. Not only were more tractor hours utilised to construct terraces but also more time was taken up in manoeuvring around the site because of the difficulties posed by the steeper slopes of the terraced areas.

The level of investment required for establishing any of these systems cannot be provided by the average small farmer in St. Lucia. If farmers are encouraged to implement soil conservation measures, some level of subsidy would be required to make the proposition attractive. The necessity for subsidies is further justified by considering the off-farm benefits of erosion control. Benefits such as reduced sedimentation of rivers, harbours and beachfronts affect the society as a whole and as such, the costs should not be borne solely by farmers.

Table 4.17. Construction costs of a 1 ha contour drained plot

Activity	Unit cost (EC$)	Total Cost (EC$)
Land clearing and ploughing:		
12 tractor hours	120/hr	1440
Construction of diversion drain:		
5 tractor hours	120/hr	600
6 man-days	25/man-day	150
Construction of contour drains:		
85 man-days	25/man-day	2125
Construction of stepped drain		
50 man-days	25/man-day	1250
Total		5565

Table 4.18. Construction costs of a 1 ha strip cropped plot

Activity	Unit cost (EC$)	Total Cost (EC$)
Land clearing and ploughing:		
15 tractor hours	120/hr	1800
Construction of diversion drain		
5 tractor hours	120/hr	600
6 man-days	25/man-day	150
Construction of contour drains:		
53 man-days	25/man-day	1325
Construction of stepped drain:		
52 man-days	25/man-day	1300
Construction of ridges:		
10 man-days	25/man-day	250
Total		5425

Table 4.19. Construction costs of a 1 ha terraced plot

Activity	Unit cost (EC$)	Total Cost (EC$)
Land clearing and ploughing:		
17 tractor hours	120/hr	2040
Construction of diversion drain:		
5 tractor hours	120/hr	600
6 man-days	25/man-day	150
Construction of terraces:		
13 tractor hours	120/hour	1560
25 man-days	25/man-day	625
Construction of stepped drains:		
55 man-days	25/man-day	1375
Total		6350

Table 4.20. Construction costs a 1 ha plot with no soil conservation measures

Activity	Unit cost (EC$)	Total Cost (EC$)
Land clearing and ploughing:		
12 tractor hours	120/hr	1440
Construction of diversion drain:		
5 tractor hours	120/hr	600
6 man-days	25/man-day	150
Construction of collector drain:		
5 excavator hours	160/hr	800
Total		2990

4.6.2 Maintenance costs

The annual maintenance activities and estimates of associated costs for 1 ha plots under contour drainage, strip cropping and terracing are given in Table 4.21. The maintenance activities mainly involve the removal of silt deposited in drains and terraces and the replacement of bamboo pegs in stepped drains. In the case of the strip cropped plot the reformation of ridges may also be necessary.

In all cases, the maintenance activities are labour intensive. The strip-cropped and terraced plots require the same labour input while the contour drained system requires less labour. The maintenance costs are based on the prevailing rate of EC$ 25 per man-day.

Maintenance work is recommended during the dry season, before the expected commencement of the wet season. Additional maintenance work may be necessary immediately after damage caused by heavy rains in the wet season. Such damage would most often involve the slumping of the terrace risers and drain sides. Where no drainage or improper drainage exists, gully erosion is likely to occur. Slumping of terrace risers and drain walls are more common during the first rainy season after construction, because of the instability caused by the soil disturbance during construction. Up to three times as much maintenance work may be necessary at that time.

Table 4.21. Annual maintenance activities and costs for 1 ha plots under different conservation treatments.

Treatment	Maintenance Activities	Labour Input (man-days/year)	Cost (EC$)
Contour drainage	Drain cleaning	15	375
Strip cropping	Drain cleaning Reforming ridges	20	500
Terracing	Terrace cleaning Drain cleaning	20	500

4.7 Maintenance activities

The completion of construction coincided with the onset of the 1988 wet season. The impact of heavy rains on the still unstable systems resulted in the need for constant maintenance of the conservation systems.

Maintenance was most often required in the terraced plot where there was extensive slumping of the terrace risers. This resulted in the obstruction of flow at the base of the risers and ponding of water on the terrace benches. It was therefore necessary during the first few months after construction, to clear and regrade the terraces after intense storms.

The other conservation systems required less maintenance. However, bamboo pegs in the stepped drains which were displaced by heavy flows, were regularly replaced. Some slumping of the sides of the stepped drain occurred in the contour-drained plot. This was corrected by re-shaping the sides of the drain.

Most contour drains remained stable. Some slumping of the drain sides occurred in the steeper parts of the strip-cropped plot. Slumping also occurred in contour drains on the ridge which formed the eastern boundary of the contour drained plot. This area was covered by Warwick clay, which appeared to be prone to slumping. The area covered by this soil therefore required constant maintenance.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Summary

Three soil conservation systems: contour drainage, strip cropping and terracing, were designed and established within separate plots on a hillside in St. Lucia. A control plot with no conservation was also established. Bananas were planted in all plots. In the strip cropped plot however, bananas strips were alternated firstly with strips of cucumbers, and then later with strips of sweet potatoes.

A soil survey was conducted to identify the soils on the site and to determine their distribution. Several physical and chemical soil properties were also measured.

A topographic survey was conducted before construction of the systems. This survey was used to plan the site layout and to design the conservation systems. A second topographic survey was conducted after construction of the systems to determine plot sizes and to produce detailed layouts of each plot.

Rainfall amounts and intensities over the area were measured during the 1988 wet season. Runoff and soil loss rates from each plot were also measured. Hydrographs were plotted for 27 events.

Crop yields, and the construction and maintenance costs of each system were also determined.

5.2 Conclusions

1. Five soil types existed within the areas occupied by the plots. These soils all contained appreciable amounts of clay. They exhibited low hydraulic conductivity and contained low levels of organic matter. Potassium and phosphorous deficiencies were also identified. Given the soil properties, the rainfall conditions and the slopes on the site, a high level of soil management was required.

2. Rainfall amounts and intensities were generally high. In most instances, measurable amounts of runoff were not produced when the daily rainfall was less than 14 mm.

3. In most instances, the maximum runoff was produced in the strip cropped plot. The contour drained plot however consistently produced large amounts of runoff. The least runoff was most often produced in the terraced plot. These trends were due to the relatively large size of the strip cropped plot, the high drainage density of the contour drained plot, and the large area taken up by the relatively flat terrace benches. For some events, runoff depth exceeded rainfall. This was due in part to contributions of subsurface seepage originating from upland areas.

4. In most instances, peak runoff rates were highest in the strip cropped plot and lowest in the control plot. There was a general trend towards higher peak flows as time progressed during the rainy season, probably because of general increases in soil moisture levels.

5. The runoff response to rainfall was rapid for all conservation systems. Runoff was recorded at the outlet of each plot within 5 minutes of the commencement of rainfall. In most instances, the times to peak of the hydrographs were less than 20 minutes. This rapid response was largely due to the steepness of the plots and their small catchment areas. The differences in slope, plot shape, plot size and conservation treatment did not appear to be sufficient to create marked differences in the times to peak.

6. The highest soil loss rates were measured in the strip cropped plot and the lowest rates were measured in the control plot. In all plots, over 30% of the total soil loss was recorded in single events. This illustrates the erosive nature of large tropical rainstorms. The soil loss data collected were not sufficient to provide firm conclusions about the long-term effects of the conservation systems on soil loss. Further collection of soil loss data is therefore required.

7. Banana yields from the first six months of production were relatively high. The contour drained plot produced the highest yields while the lowest yields were recorded in the terraced plot. The low yields from the terraced plot were due to the higher levels of topsoil disturbance and subsoil exposure in that plot.

8. The construction costs of the contour-drainage and strip cropping systems were approximately the same. These systems were less costly to establish than terrace systems. The construction costs of the conservation systems are too high for the average small farmer to bear. Some level of subsidy is therefore required if farmers are to be encouraged to construct soil conservation systems.

CHAPTER 6

RECOMMENDATIONS FOR FURTHER WORK

Field observations and data analysis indicated the need for several investigations which would complement the objectives of this study. The following recommendations for further work merit consideration:

1. The results of the runoff and soil loss measurements obtained from this study were are not conclusive. Additional data should be collected in order to fully assess the long term effectiveness of the conservation measures in the control of runoff and soil loss.

2. The runoff and soil loss effects of the common farming practices such as slash and burn cultivation, have not been determined. A study of these practices is required for comparison with the recommended conservation practices.

3. Infiltration rates are a controlling factor in determining runoff. The infiltration rates of the soils on the site should therefore be determined. Knowledge of these rates would contribute to the interpretation of data and would improve understanding of the runoff phenomena on the hillsides.

4. The accuracy of soil loss measurement should be improved by increasing the volumes of runoff samples or replicating the samples taken from each plot.

5. The analysis of runoff samples could be expanded to include determination of nutrient and pesticide losses in runoff. This may lead to improvements in fertilizer and pesticide application on hillsides.

6. Soil moisture should be monitored to provide further understanding of the runoff and soil loss phenomena on hillsides. Soil moisture data would also lead to recommendations on moisture conservation during the dry season.

7. The conservation measures investigated in this study are based on physical methods of erosion control. Investigations should be carried out into the agronomic practices which should be applied to complement these physical methods.

8. The data collected from the site could be expanded to provide for testing of existing soil loss prediction models. Suitable models could therefore be used in conservation planning.

9. Subsurface flows sometimes contribute significantly to runoff from hillsides. Investigations should be carried out into subsurface flow phenomena and the extent of the subsurface flow contribution to runoff.

10. The long term profitability of conservation measures are of fundamental concern to farmers and would be of interest to agencies which may get involved in providing loans, grants or subsidies for conservation. A detailed economic analysis of the conservation measures, should therefore be conducted.

11. The processes which govern runoff and erosion on steep lands have not been as extensively studied as those on flat and gently sloping lands. Investigations into these processes on steep slopes should therefore be conducted.

12. Stepped drains could be applied in many areas throughout the Caribbean. Little technical information is however available on these structures. The hydraulics of stepped drains should be investigated and design criteria should be developed.

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APPENDICES

APPENDIX A

Appendix A is made up of large drawings.
These are located in the pouch at the back of the thesis.

APPENDIX B

Descriptions of the soils at the study site (Adapted from Polius, 1989)

1. Bocage stony clay

Horizon Depth	Description
0 - 15 cm	Very dark greyish brown clay loam; medium granular structure; friable; slightly sticky when wet; numerous small stones (less than 1 cm in diameter).
15 - 35 cm	Dark greyish brown clay loam; fine granular structure; friable; slightly stick when wet; numerous stones, generally larger than those in the above layer.
35 - 90 cm	Dark brown silty clay; well developed medium subangular blocky structure; sticky when wet; stony.
> 90 cm	Dark brown clay; medium subangular blocky structure; firm when moist; sticky to plastic when wet; numerous dark coloured concretions.

Bocage stony clay is classified as a Mollisol. It is derived from colluvium formed from andesitic agglomorate. It is moderately acidic at the surface and its acidity decreases slightly with depth. Available phosphorous levels are low. Medium sized basaltic boulders are found on the surface.

2. Cannelles clay

Horizon Depth	Description
0 - 25 cm	Dark brown clay loam; abundant quartz crystals; numerous manganiferous concretions; moderately fine granular structure; friable; slightly plastic.
25 - 45 cm	Yellowish brown clay loam to clay; many quartz crystals and manganiferous concretions; strong medium subangular blocky structure; firm when moist; slightly sticky when wet.
45 - 75 cm	Dark brown clay; massive structure; extremely firm when moist; sticky when wet.
75 -145 cm	Yellowish brown and light grey clay; weak fine subangular blocky structure; plastic.
> 145 cm	Yellowish brown and light grey clay; weak fine subangular blocky structure; firm when moist; very plastic.

Canelles clay is classified as an Inceptisol. It is derived from dacitic ash. It is moderately acid throughout the profile. It is well supplied with cations especially in the surface layers. The levels of available phosphorous are low. It is fairly resistant to erosion.

3. Jean Baptiste silty clay loam

Horizon Depth	Description
0 - 12 cm	Dark brown silt loam; medium crumb structure; friable; non-sticky when wet.
12 - 40 cm	Dark brown silty loam; subangular blocky structure; friable; slightly sticky when wet.
40 - 55 cm	Brownish yellow silty clay loam; fine subangular blocky structure; friable; slightly sticky when wet.
55 - 70 cm	Light yellowish brown silty clay loam; very friable and saprolytic in appearance.

Jean Baptiste silty clay loam is classified as an Inceptisol. It is derived from weathered yellow andesitic ash. It is acidic throughout the profile. The levels of exchangeable cations are relatively low and tend to decrease down the profile. The levels of phosphorus are also low and decrese sharply with depth. It is a very erodible soil.

4. Mabouya silty clay

Horizon Depth	Description
0 - 25 cm	Dark yellowish brown silty clay loam; subangular blocky structure; friable; plastic; numerous manganiferous concretions.
25 - 120 cm	Dark brown silty clay; coarse strong subangular blocky structure; very firm when moist; sticky when wet; numerous manganiferous concretions.

Mabouya silty clay is classified as an Inceptisol. It is derived from weathered andesitic ash. It is moderately acidic at the surface and the levels of acididty decrease slightly with depth. It is well supplied with cations and the levels of available phosphorus are moderate. It displays slow permeability and is fairly erodible.

5. Soucis silty clay loam

Horizon Depth	Description
0 - 25 cm	Dark brown clay loam; medium subangular blocky structure; firm when wet; plastic.
25 - 50 cm	Dark yellowish brown clay loam; medium strong granular structure; friable; slightly sticky when wet.
> 50 cm	Light grey clay with brown mottling; massive; very firm when moist; very plastic.

Soucis silty clay loam is classified as an Inceptisol. It has developed on alluvial material in the flood plain of the Roseau river. Past use of nitrogenous fertilizers are reflected in strong acidity at the soil surface. It is well supplied with exchangeable cations. Available phosphorous levels are high at the surface, reflecting past use of phosphorous fertilizers.

6. Warwick clay

Horizon depth	Description
0 - 13 cm	Dark greyish brown clay loam; fine medium subangular blocky structure; slightly sticky when wet.
13 - 25 cm	Yellowish brown clay loam; fine subangular blocky structure; slightly sticky when wet.
25 - 40 cm	Light yellowish brown loam; friable; slightly sticky when wet.
40 - 60 cm	Yellowish red loam; very friable; slightly sticky when wet.

Warwick clay is classified as an Inceptisol. It is derived from soft andesitic ash (roche pourrie). It displays uniformly strong acidity throughout the profile. The levels of exchangeable cations are not high. The levels of available phosphorous are low, particularly at the surface. It displays good water retention characteristics and is fairly resistant to erosion.

APPENDIX C

Event Hydrographs

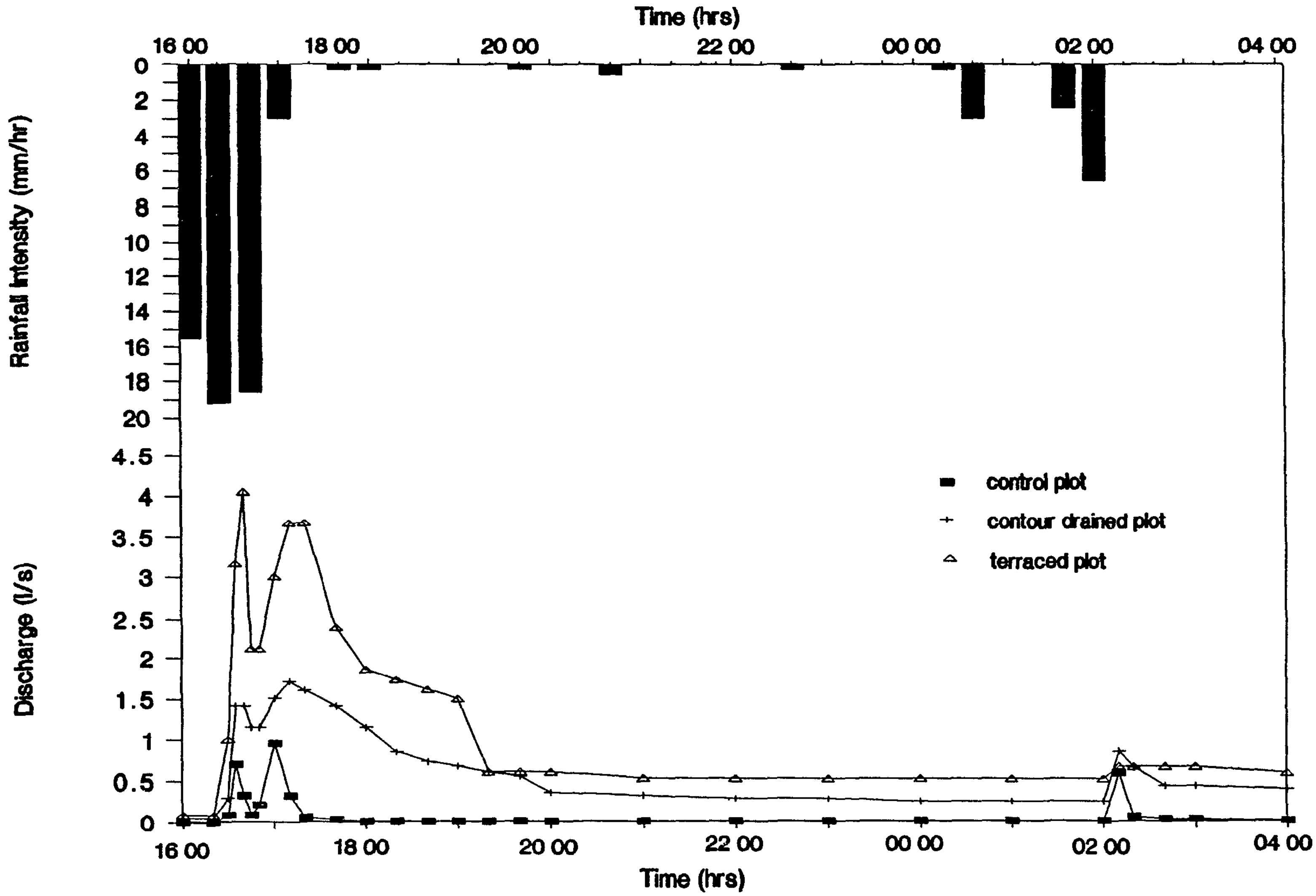


Figure C1. Event Hydrographs for 88-06-28

Note: Data unavailable for strip cropped plot due to equipment malfunction

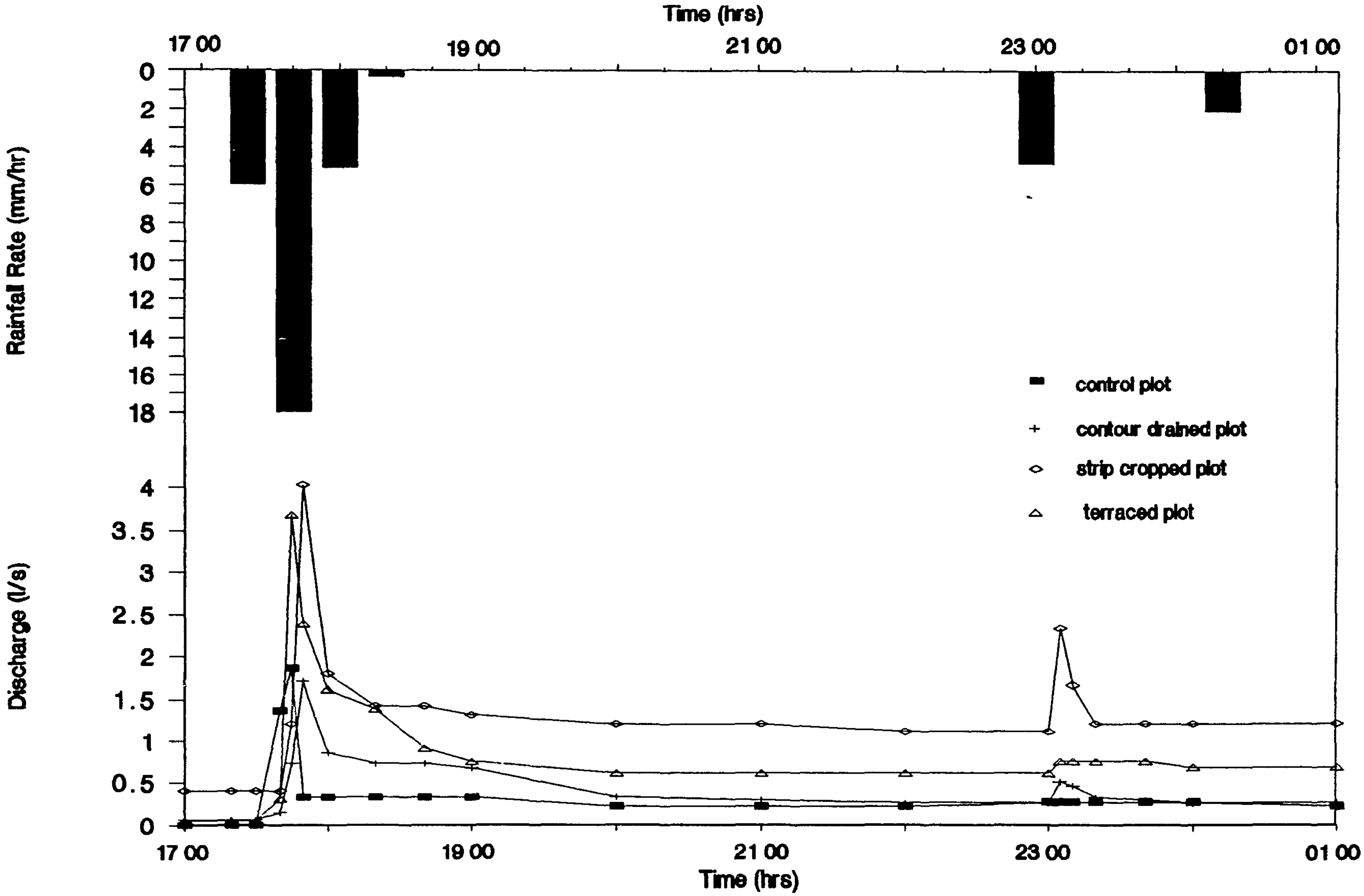


Figure C2. Event Hydrographs for 88-06-29

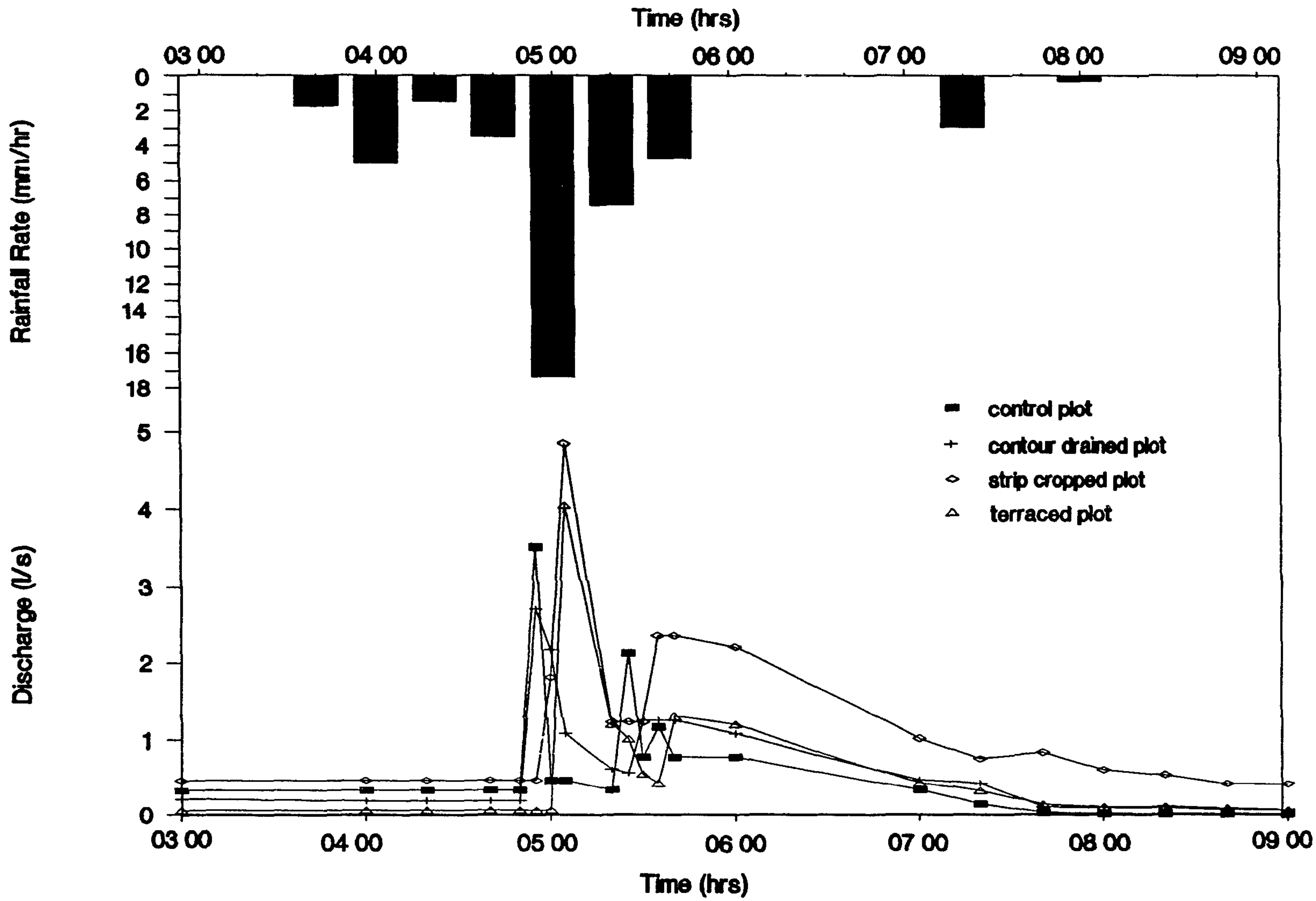


Figure C3. Event Hydrographs for 88-07-09

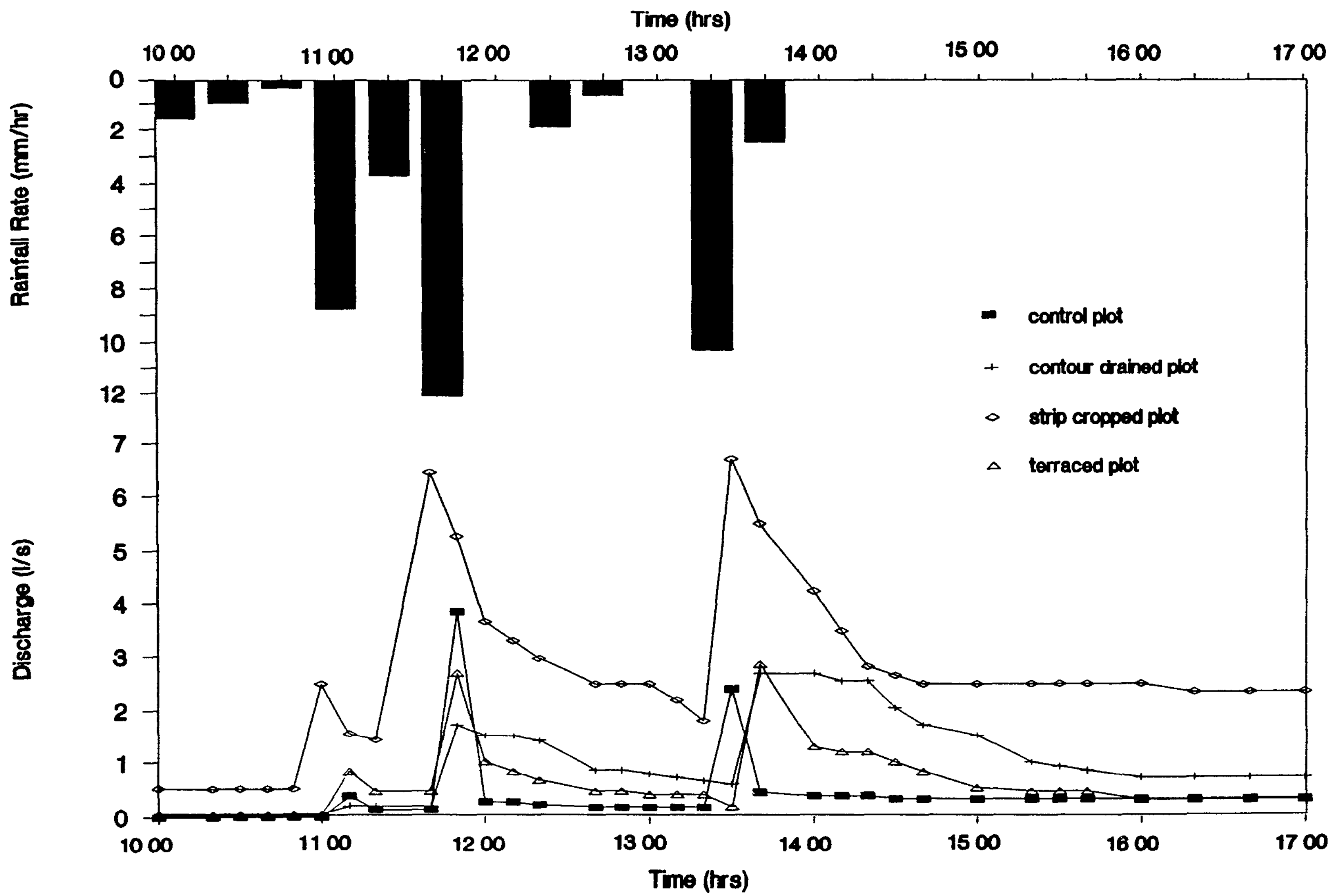


Figure C4. Event Hydrographs for 88-07-12

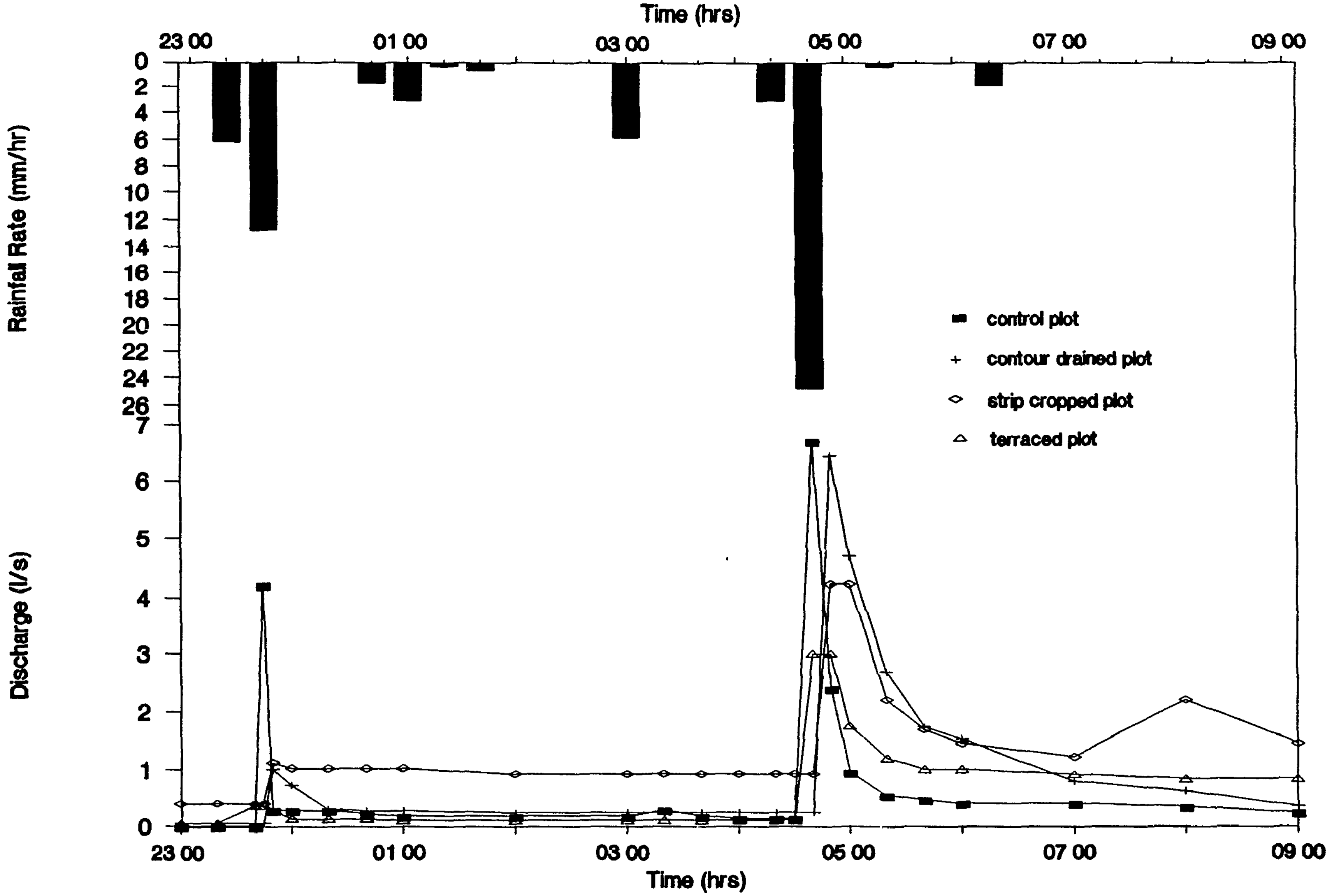


Figure C5. Event Hydrographs for 88-07-23

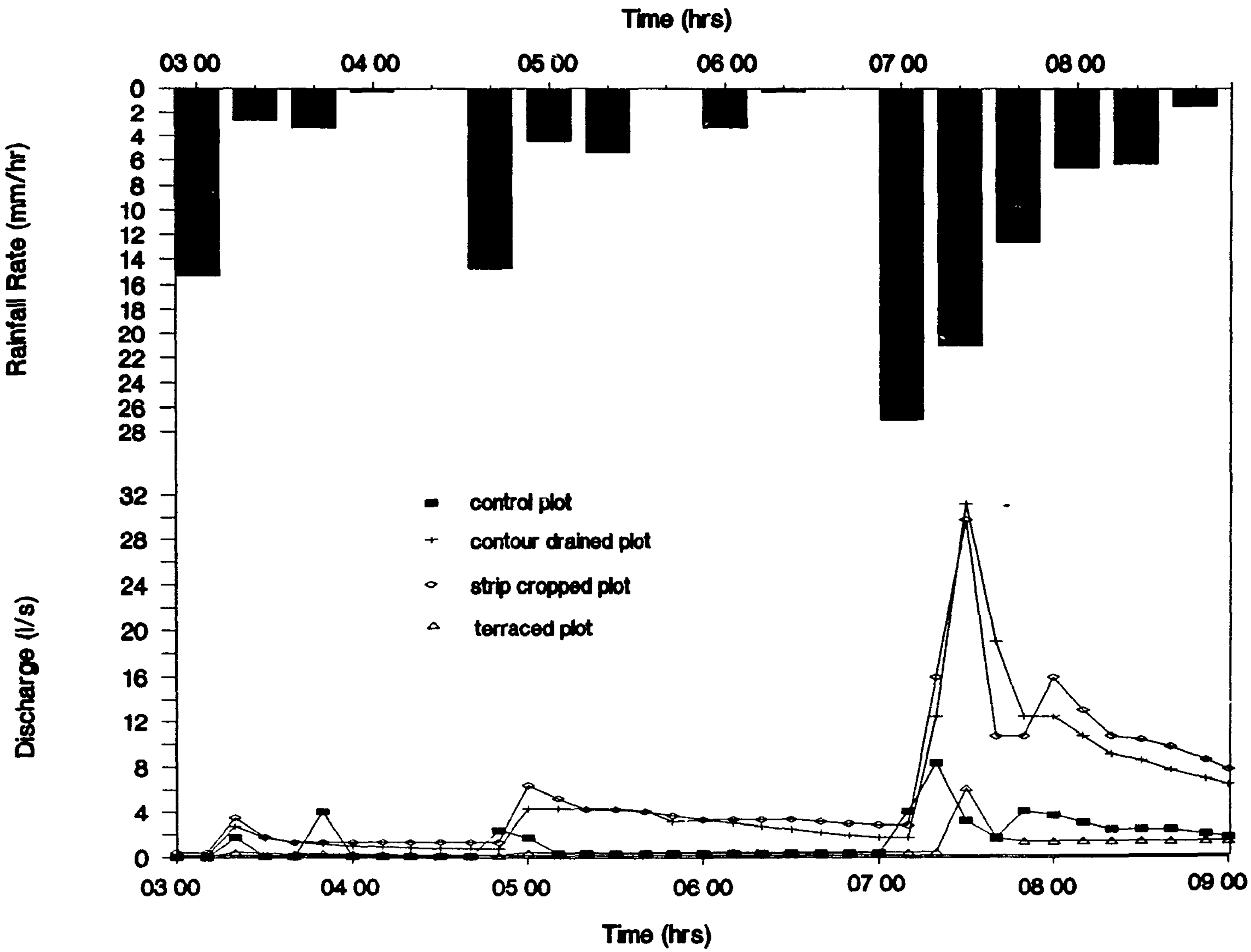


Figure C6. Event Hydrographs for 88-07-25

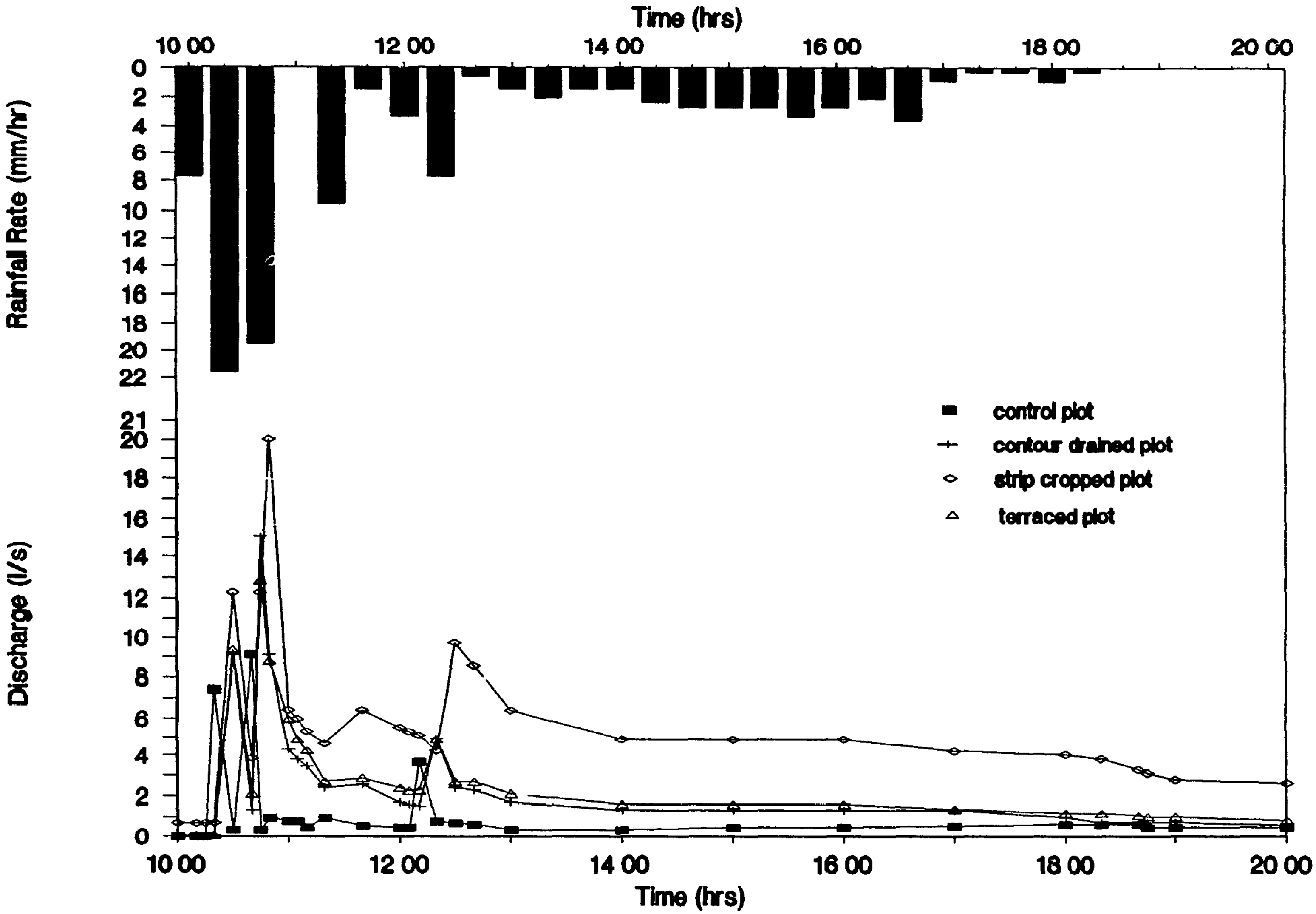


Figure C7. Event Hydrographs for 88-07-31

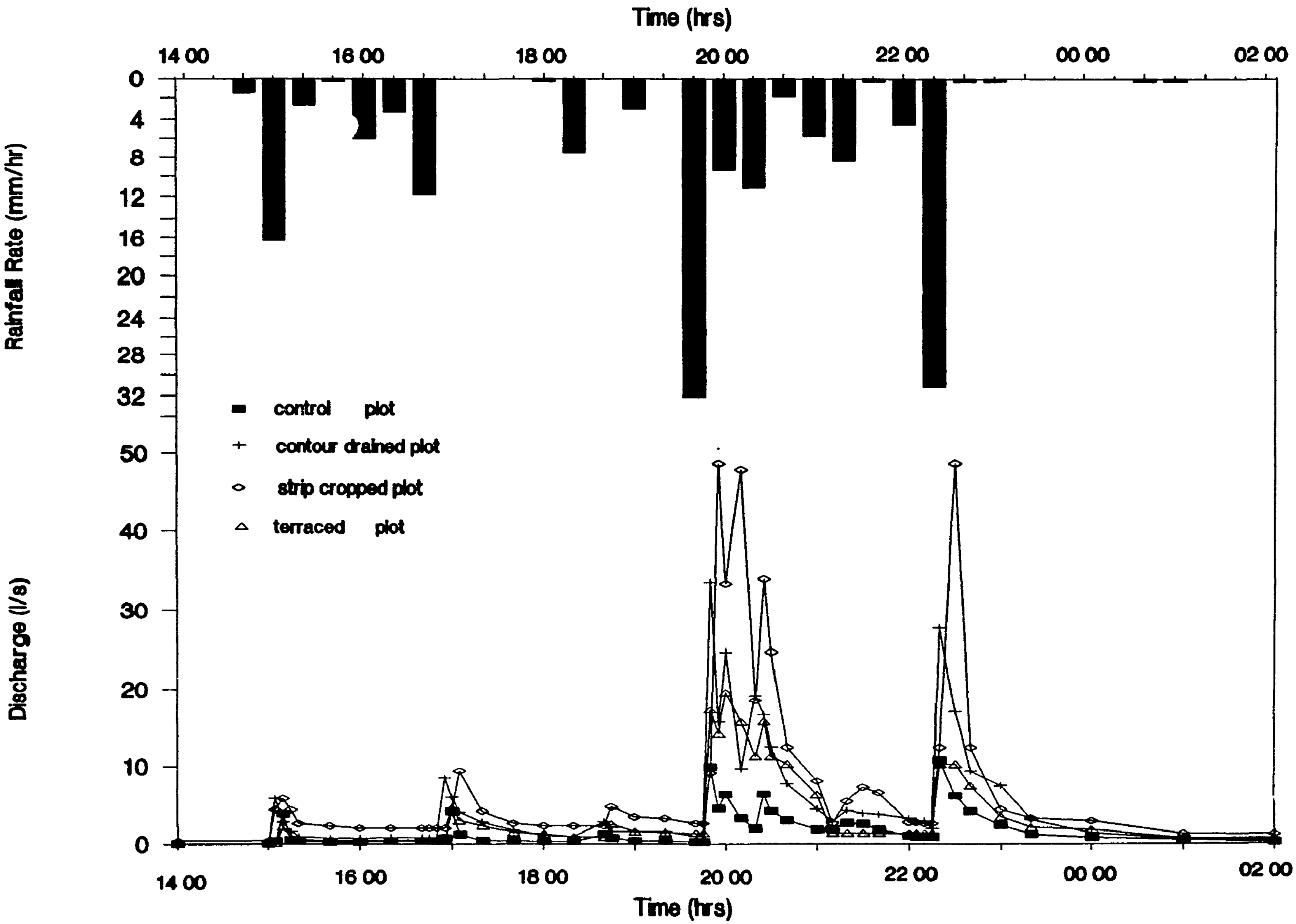


Figure C8. Event Hydrographs for 88-08-14

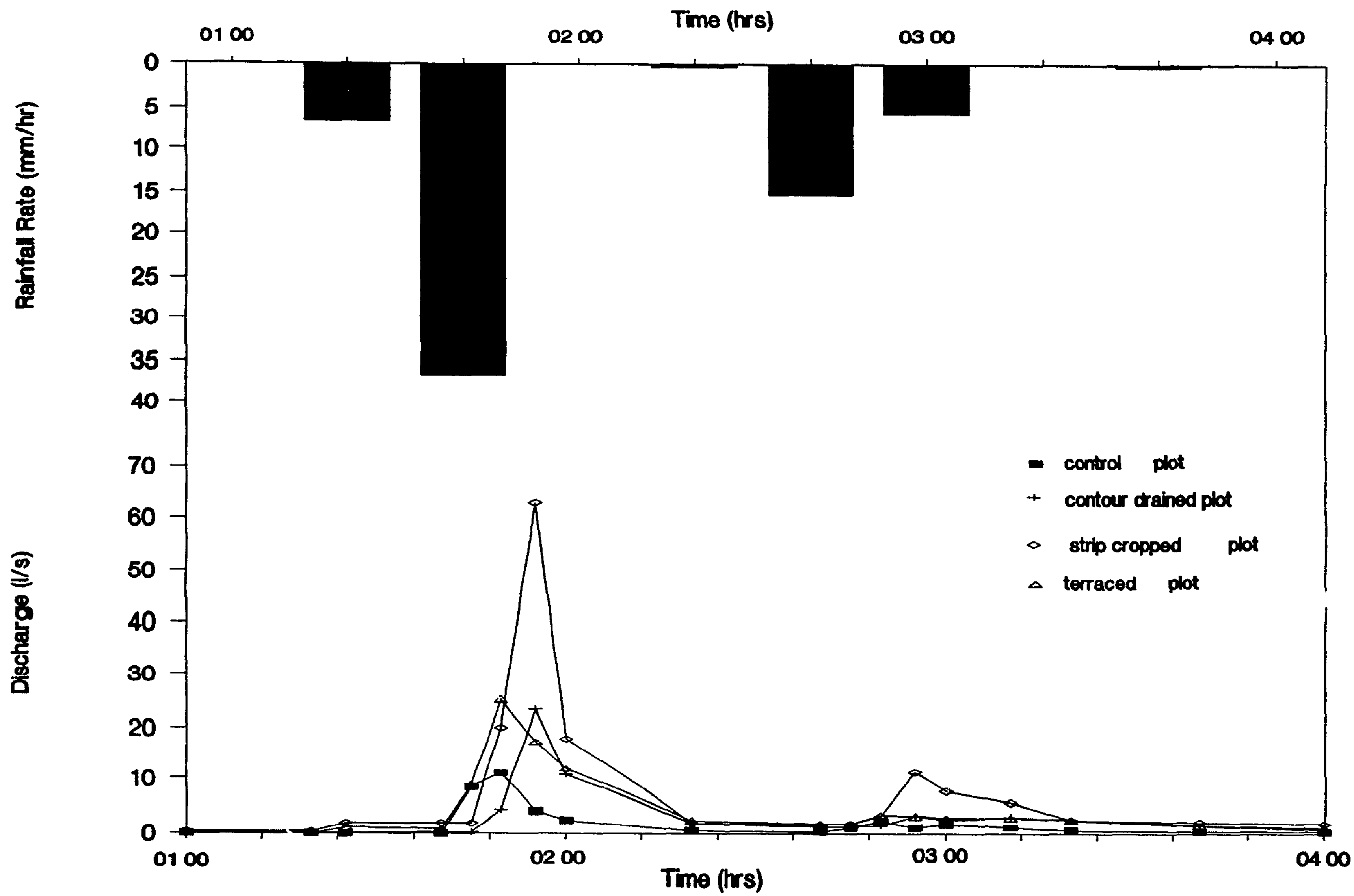


Figure C9. Event Hydrographs for 88-08-15

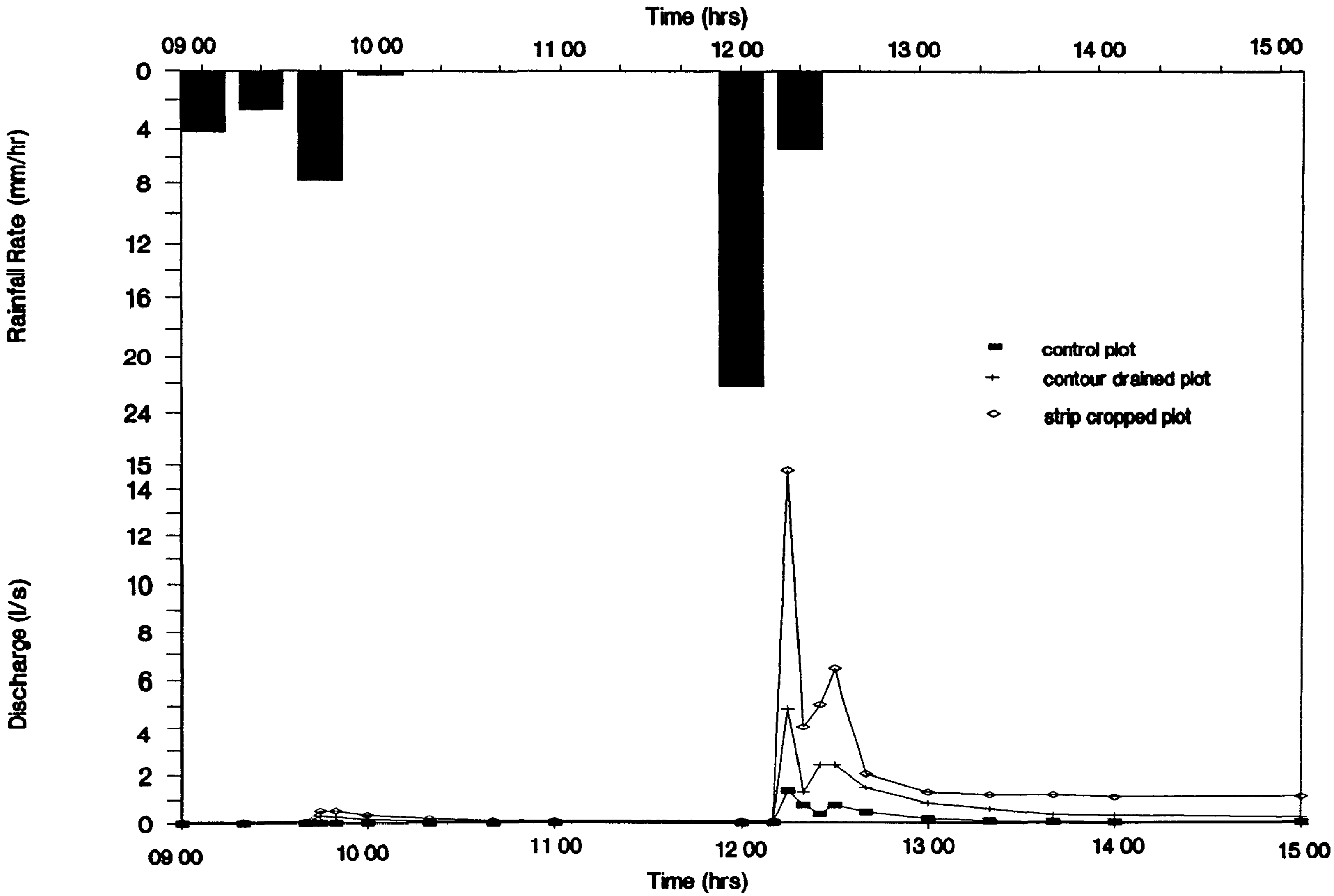


Figure C10. Event Hydrographs for 88-08-24

Note: Data unavailable for terraced plot due to equipment malfunction

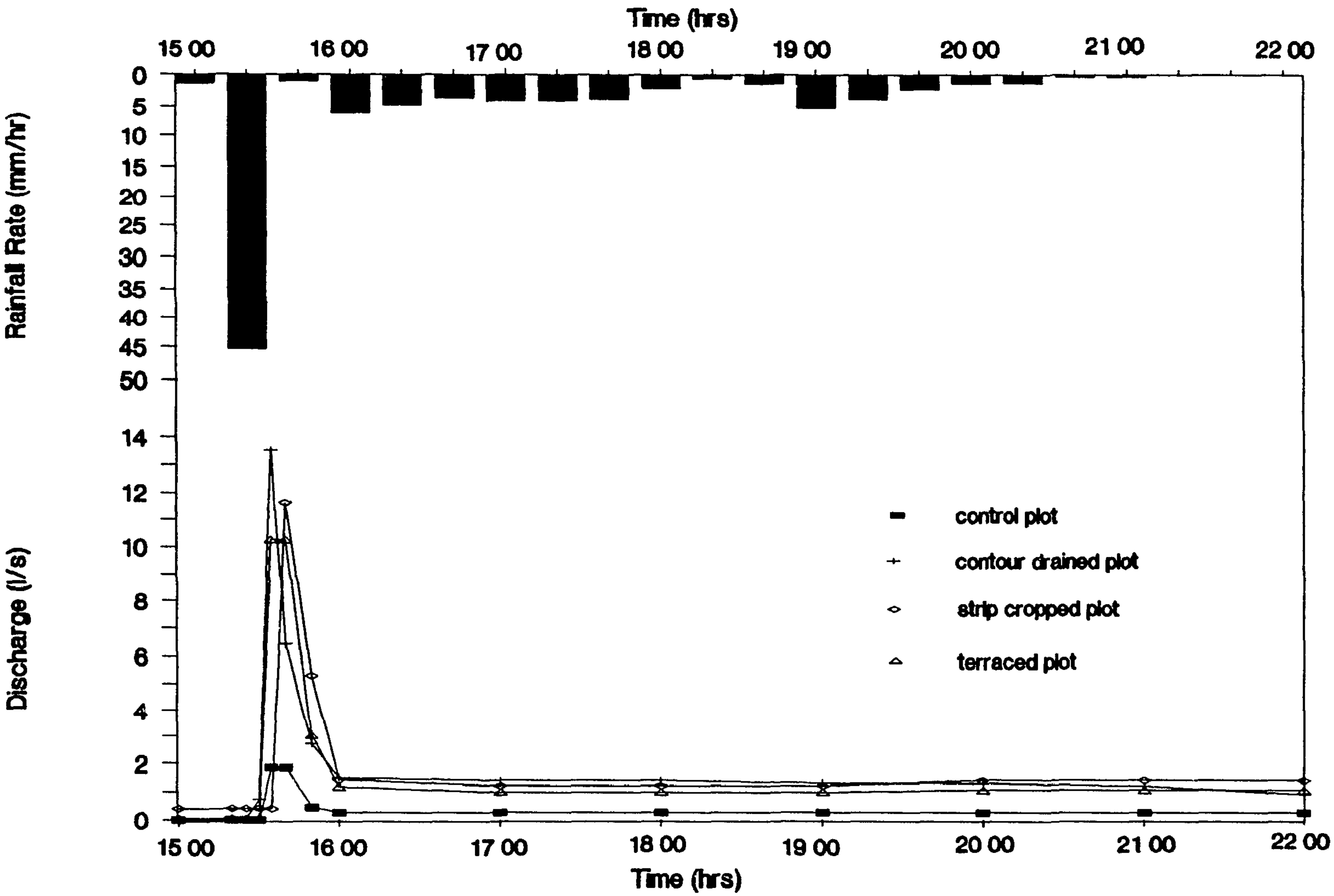
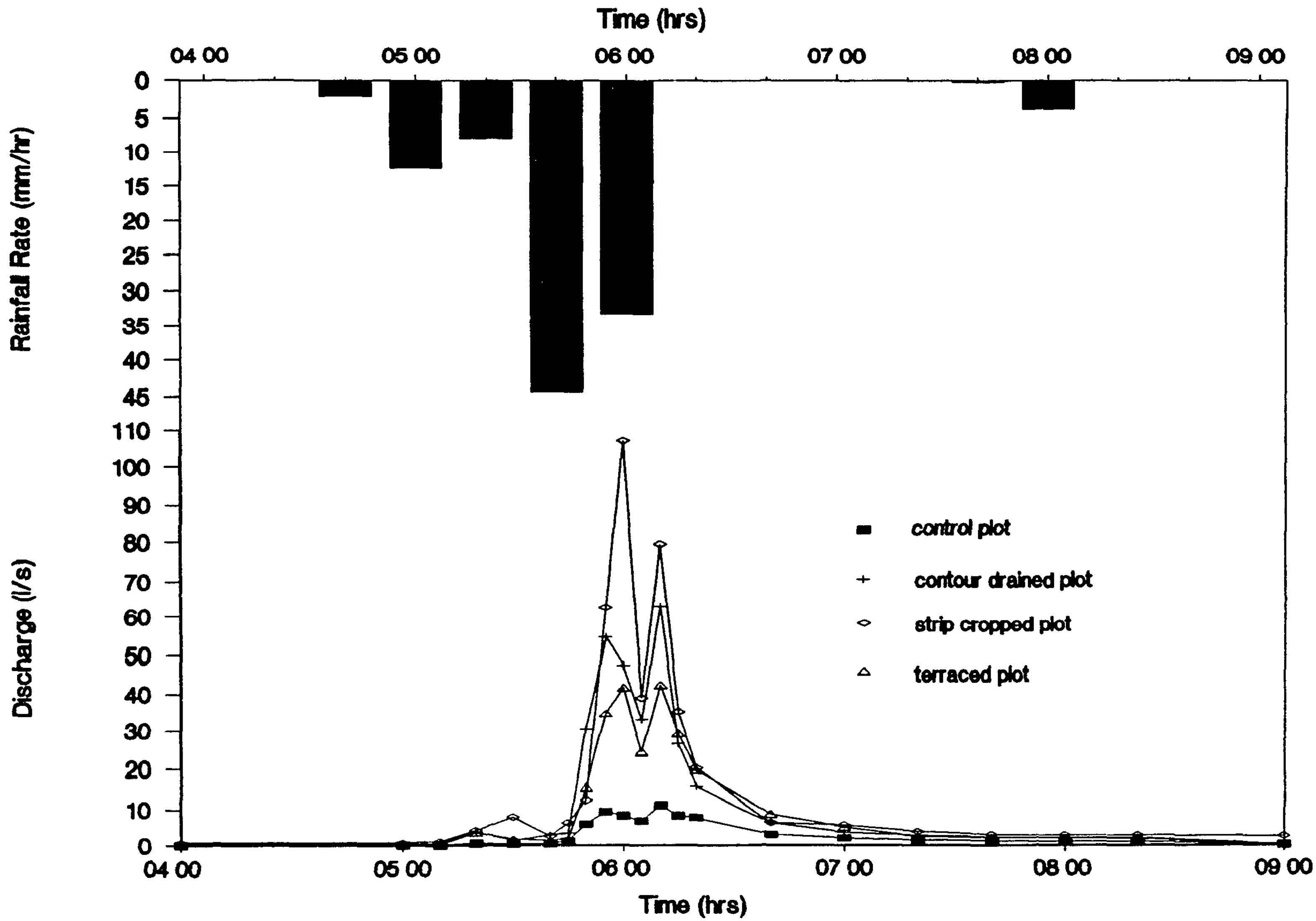


Figure C11. Event Hydrographs for 88-09-04



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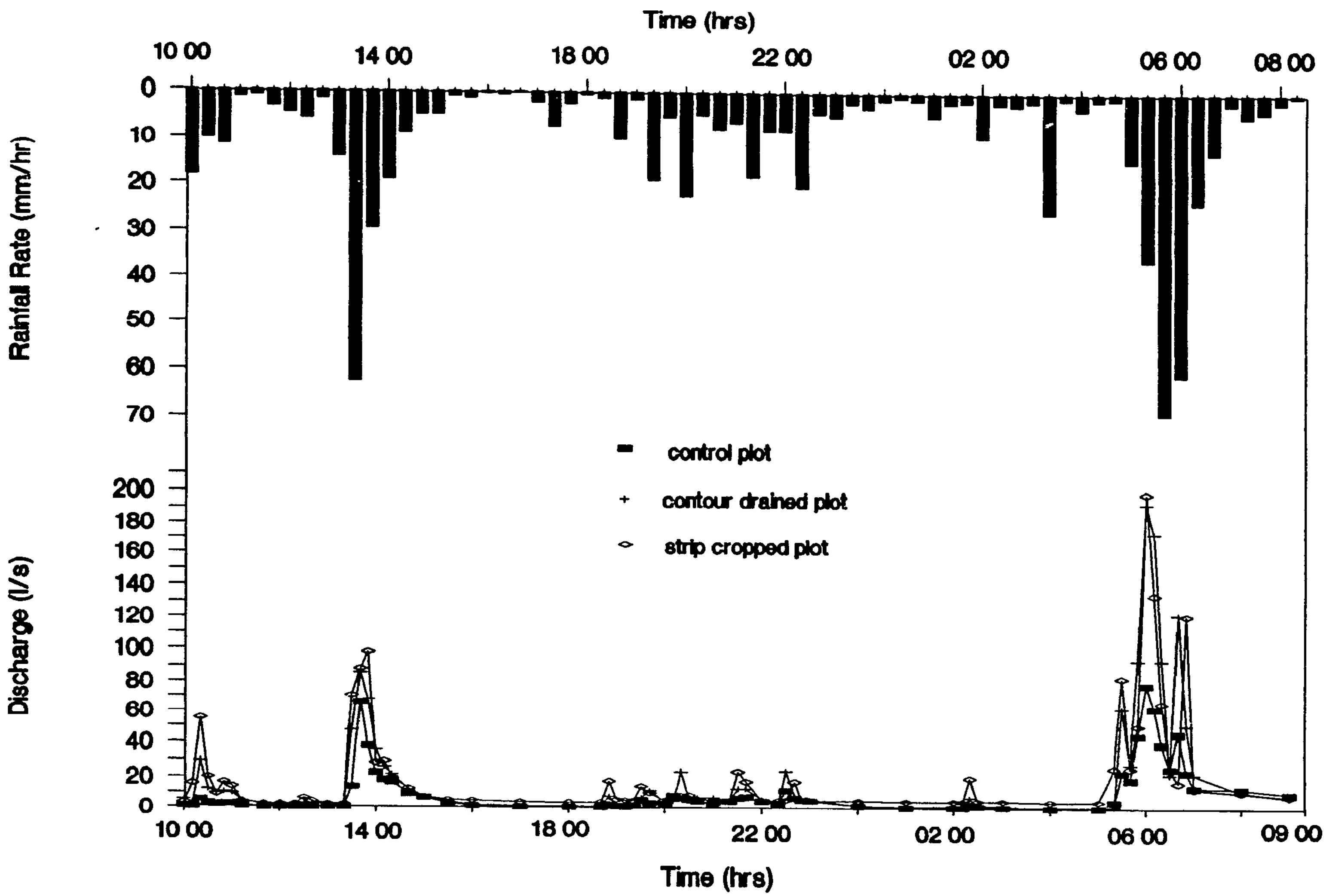
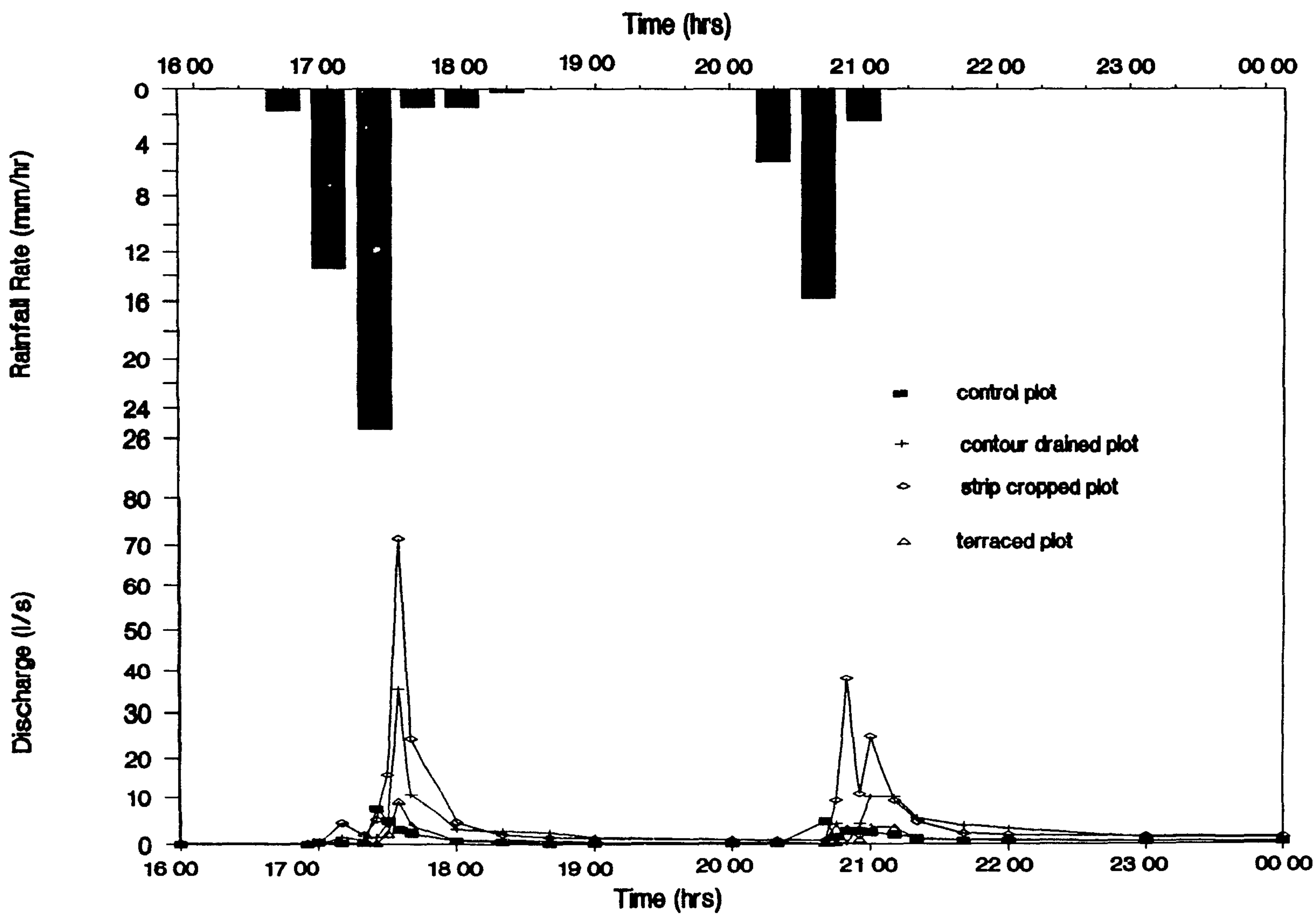


Figure C13. Event Hydrographs for 88-09-09

Note: Data unavailable for terraced plot due to equipment malfunction



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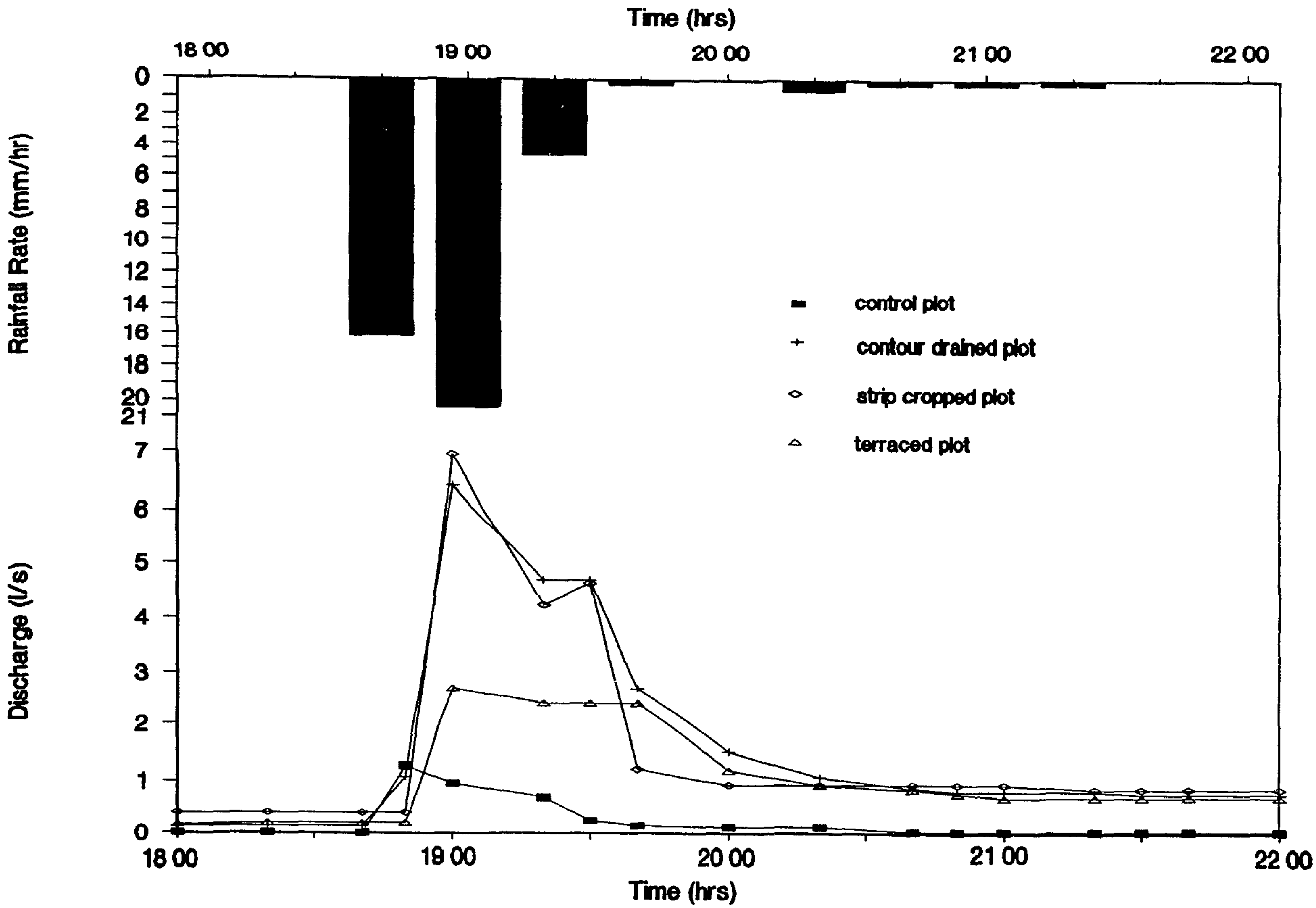
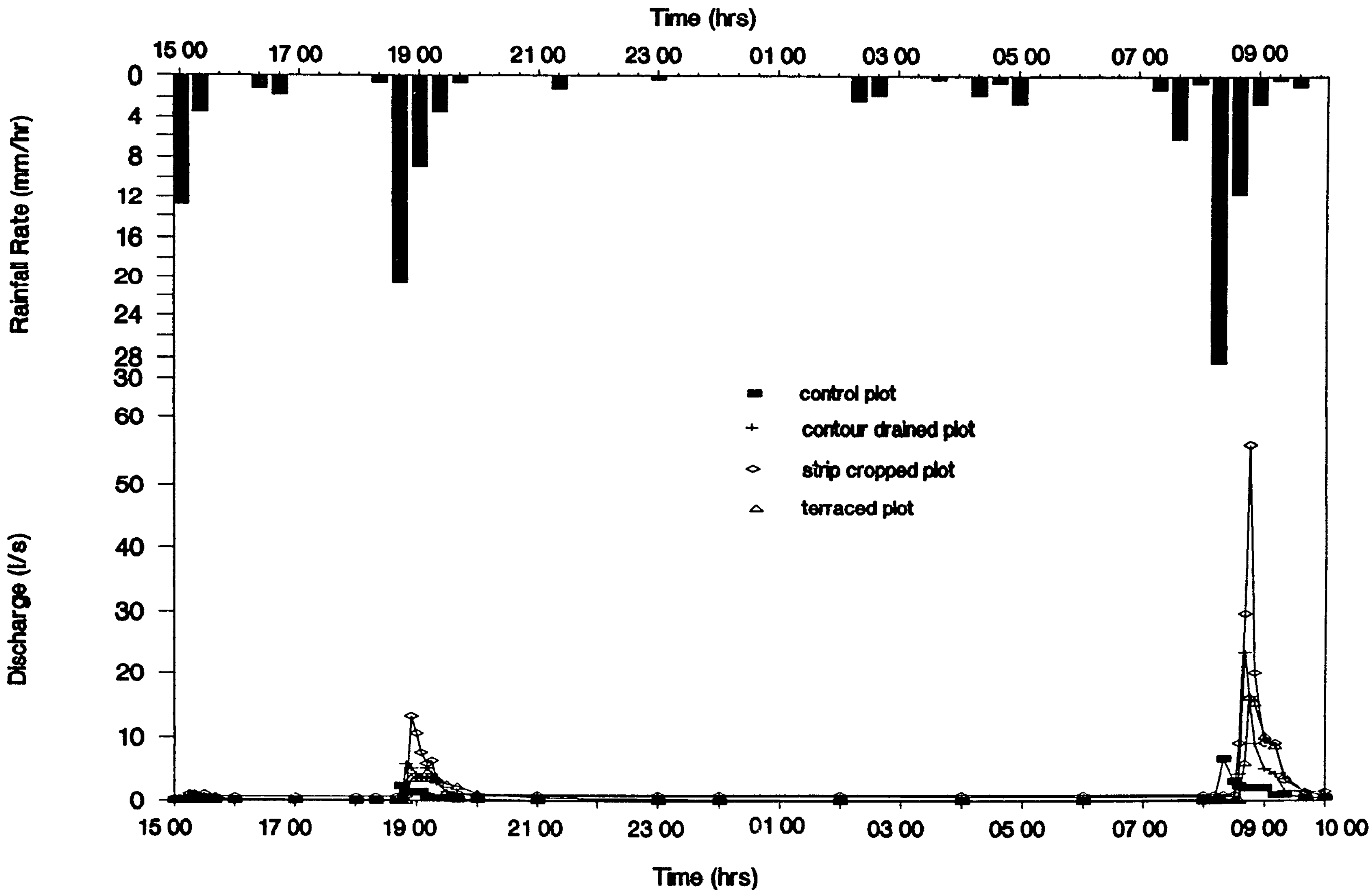


Figure C15. Event hydrographs for 88-10-02



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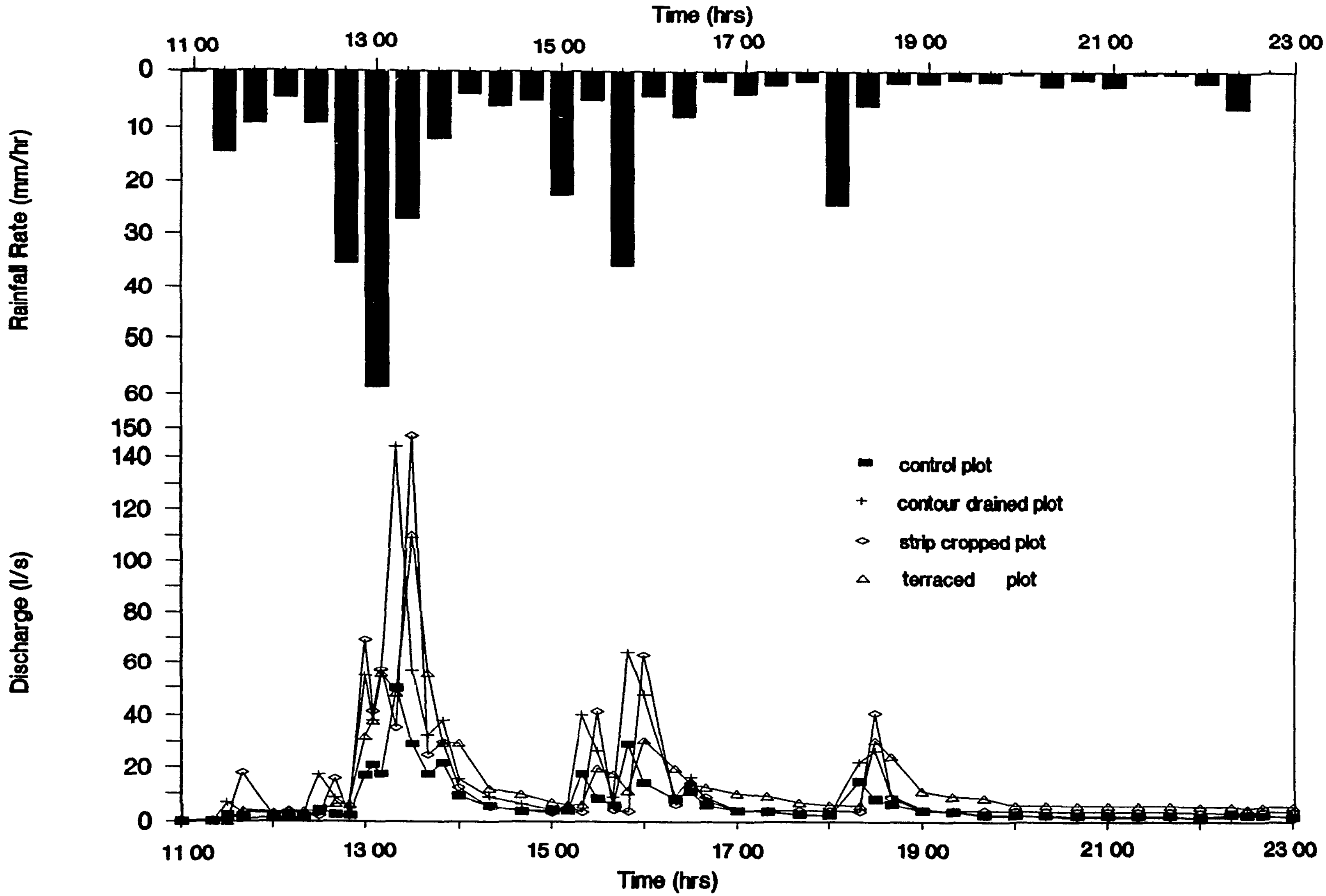

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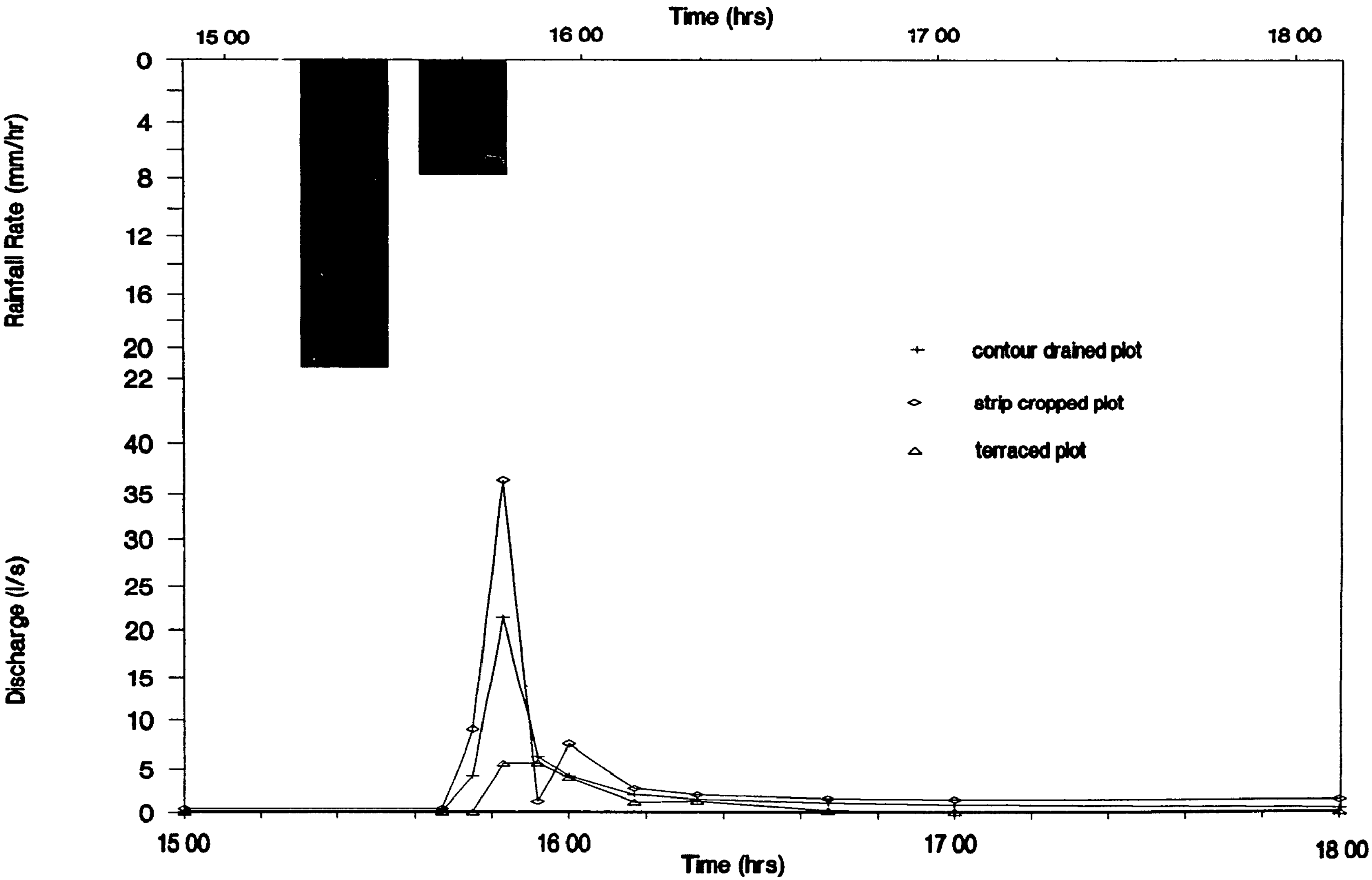


Figure C18. Event Hydrographs for 86-10-09

Note: Data unavailable for control plot due to equipment malfunction.

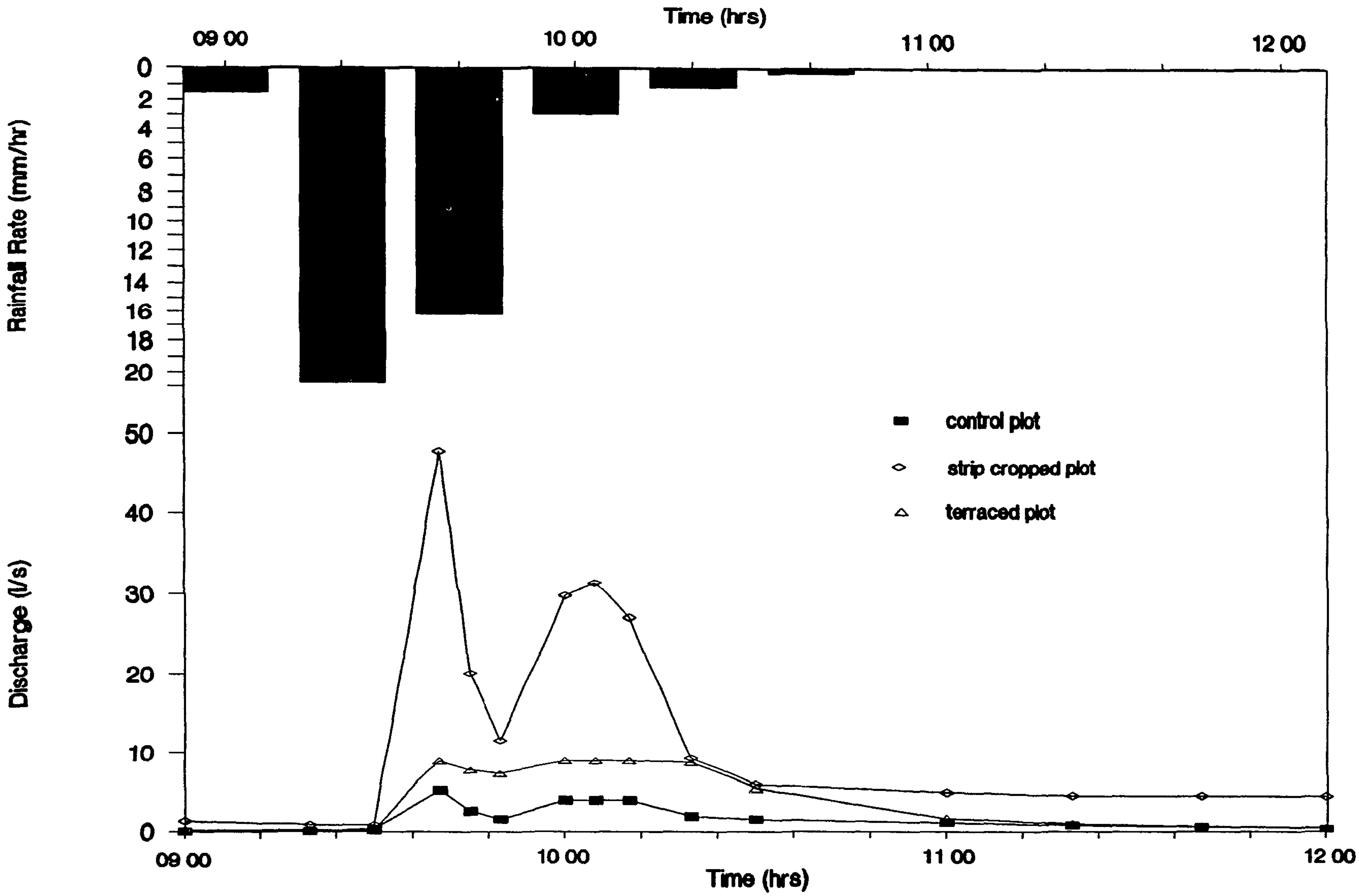
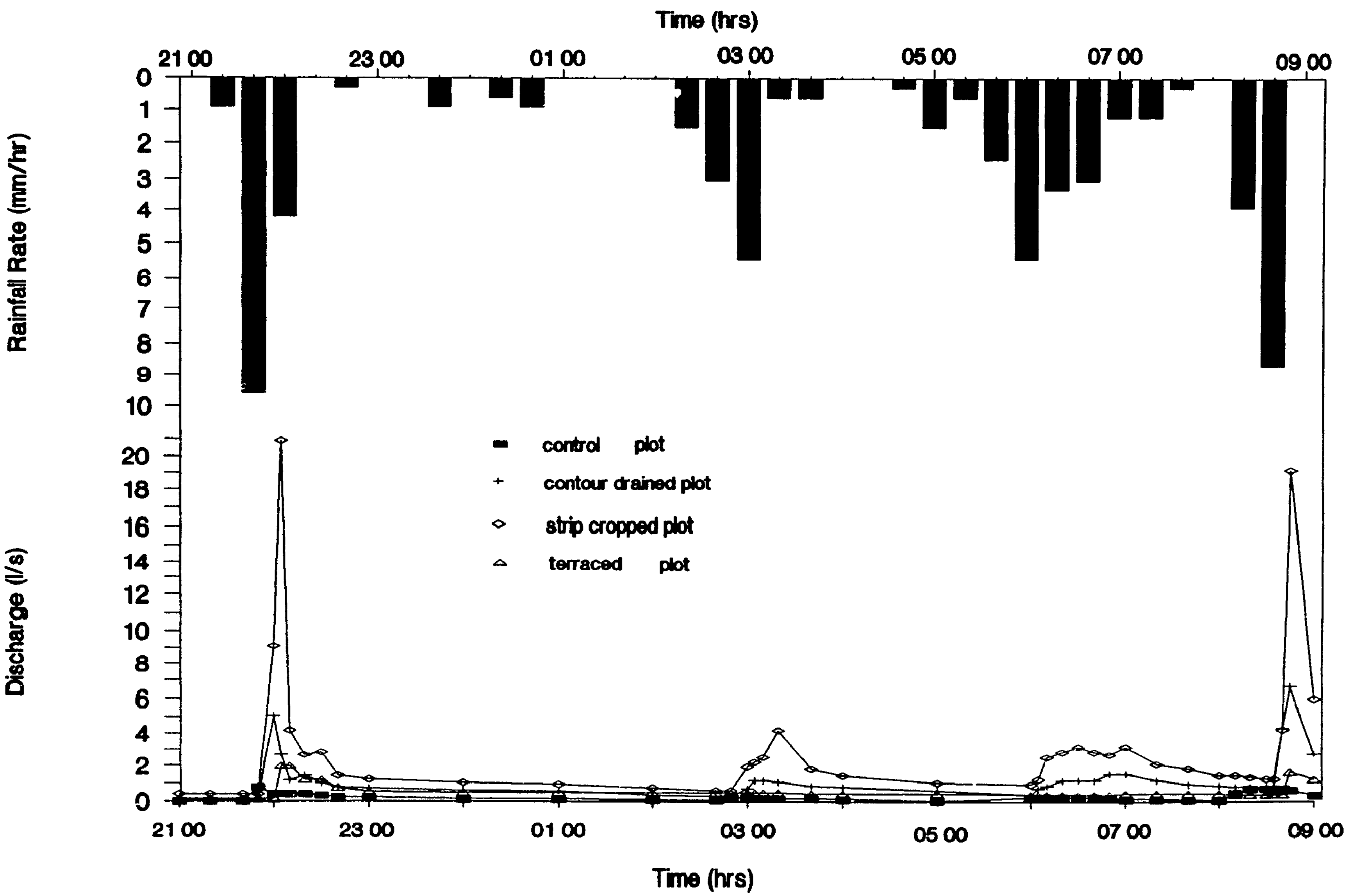


Figure C19. Event Hydrographs for 88-10-11

Note: Data unavailable for contour drained plot due to equipment malfunction



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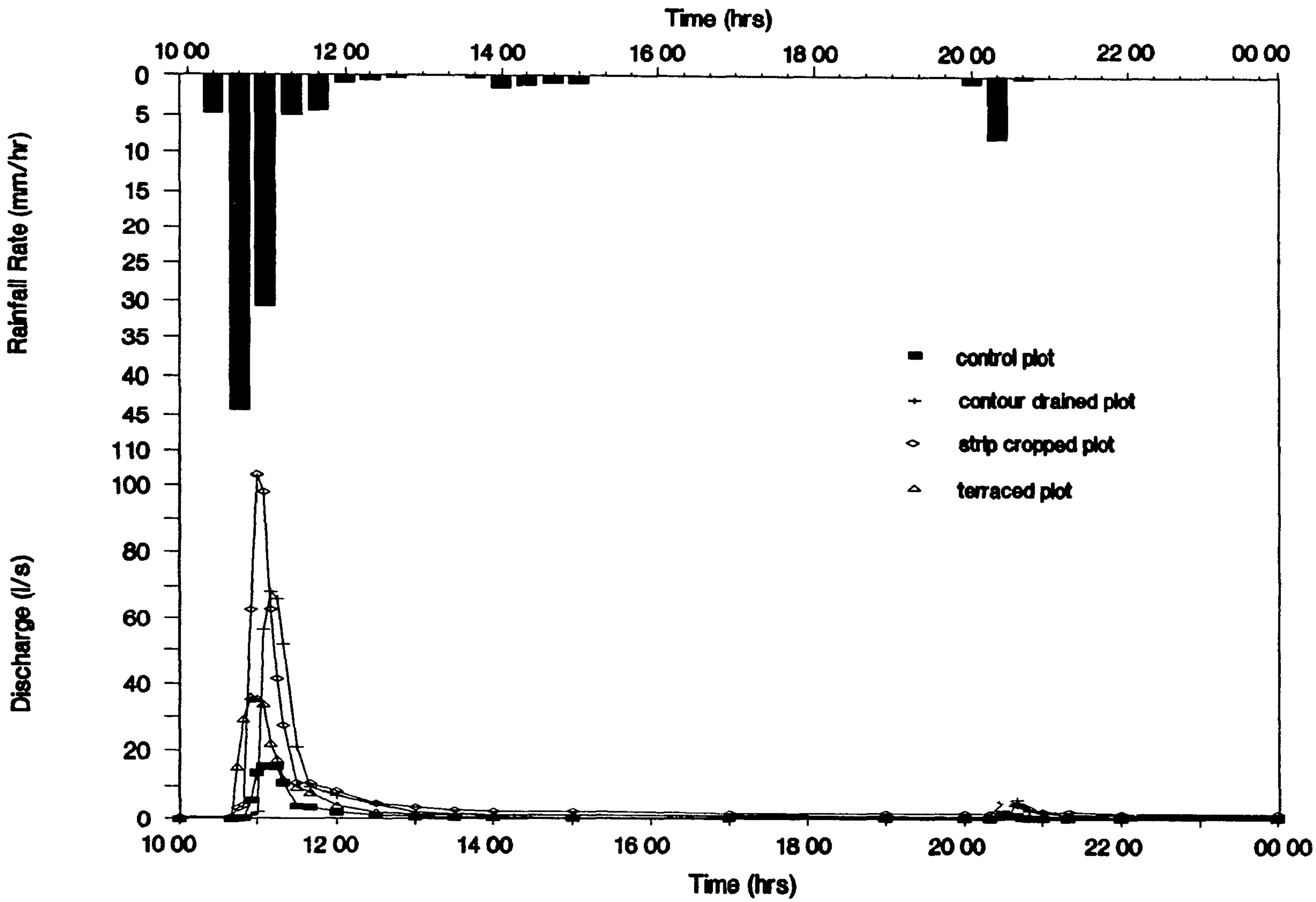

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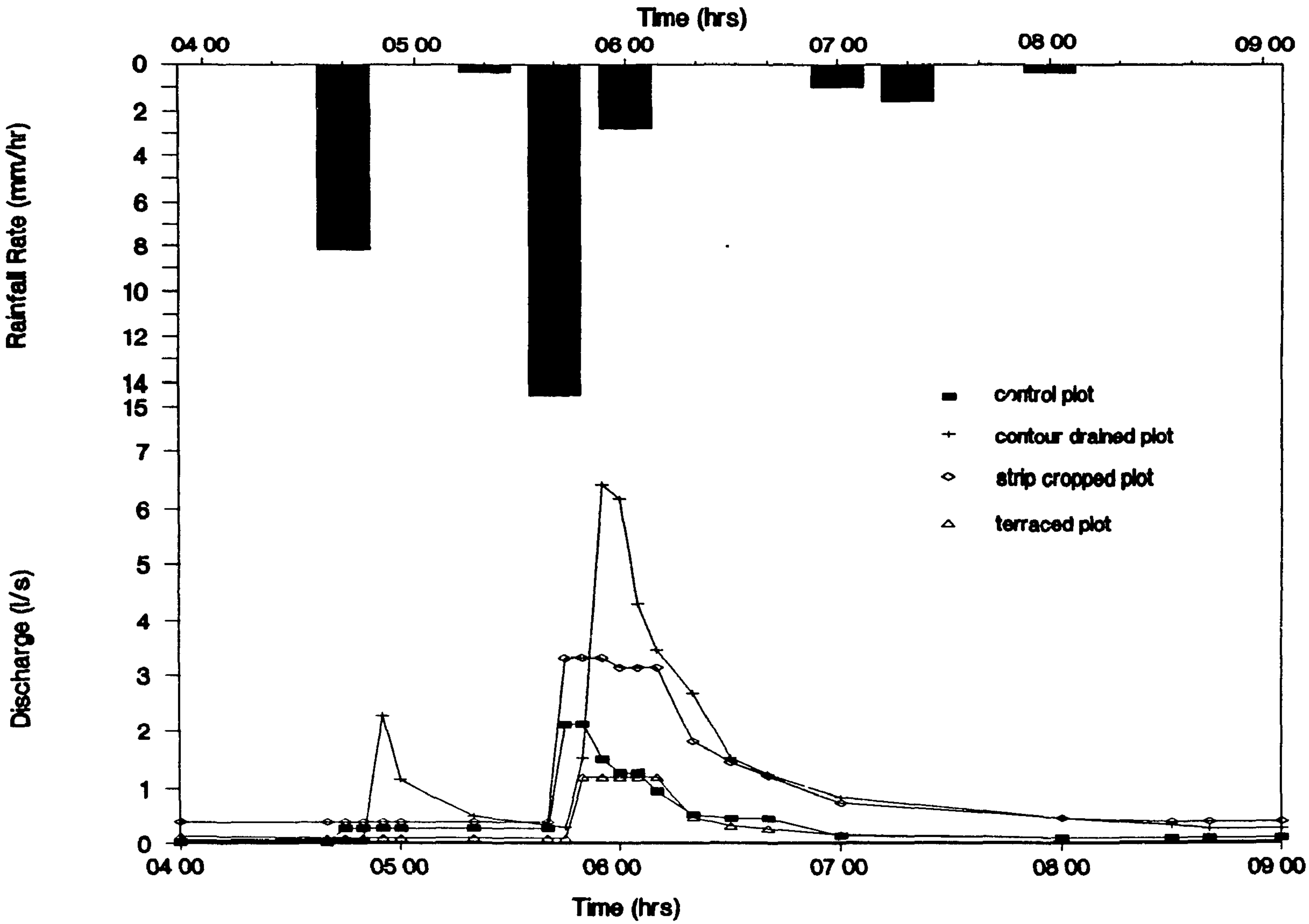

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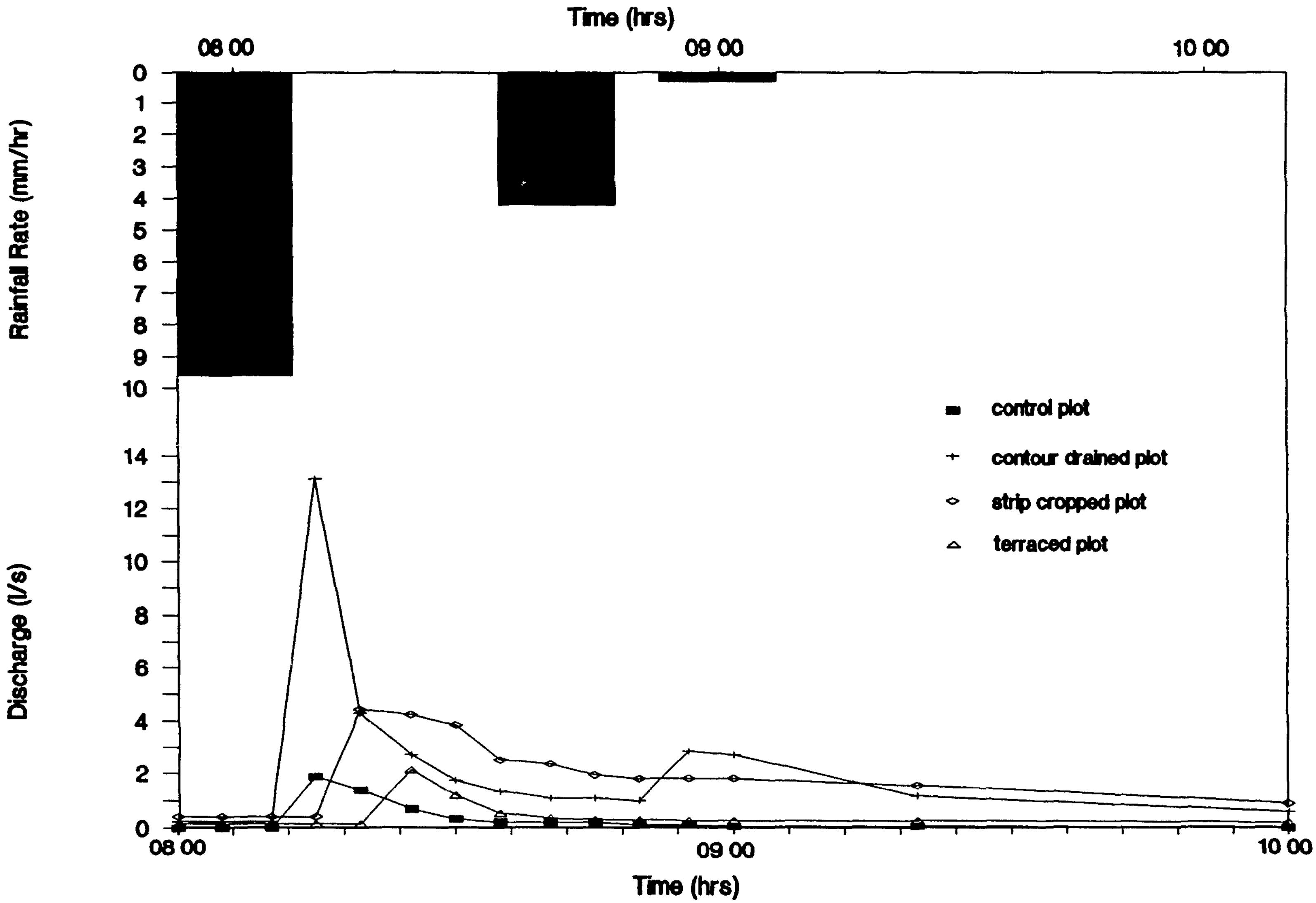

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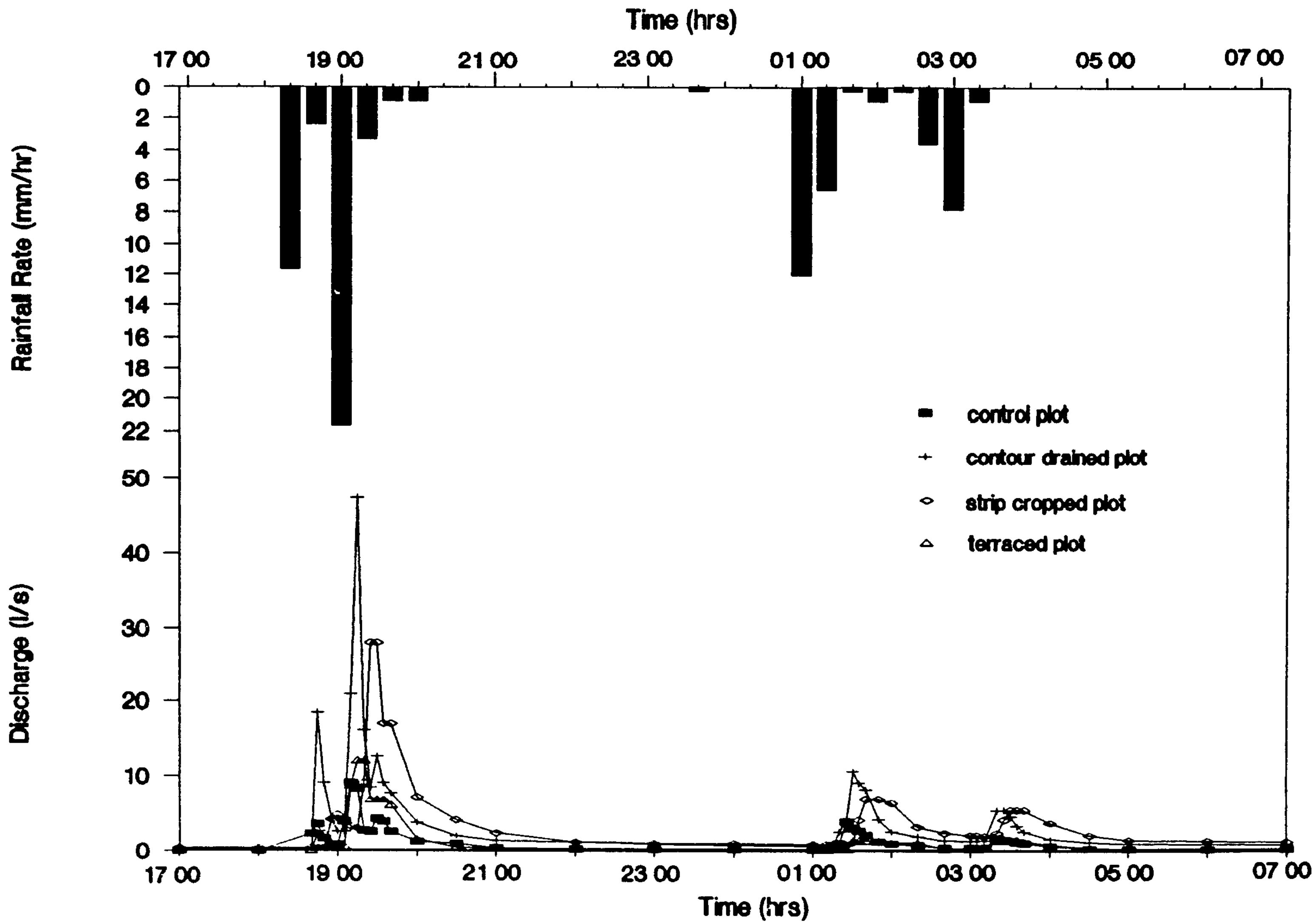

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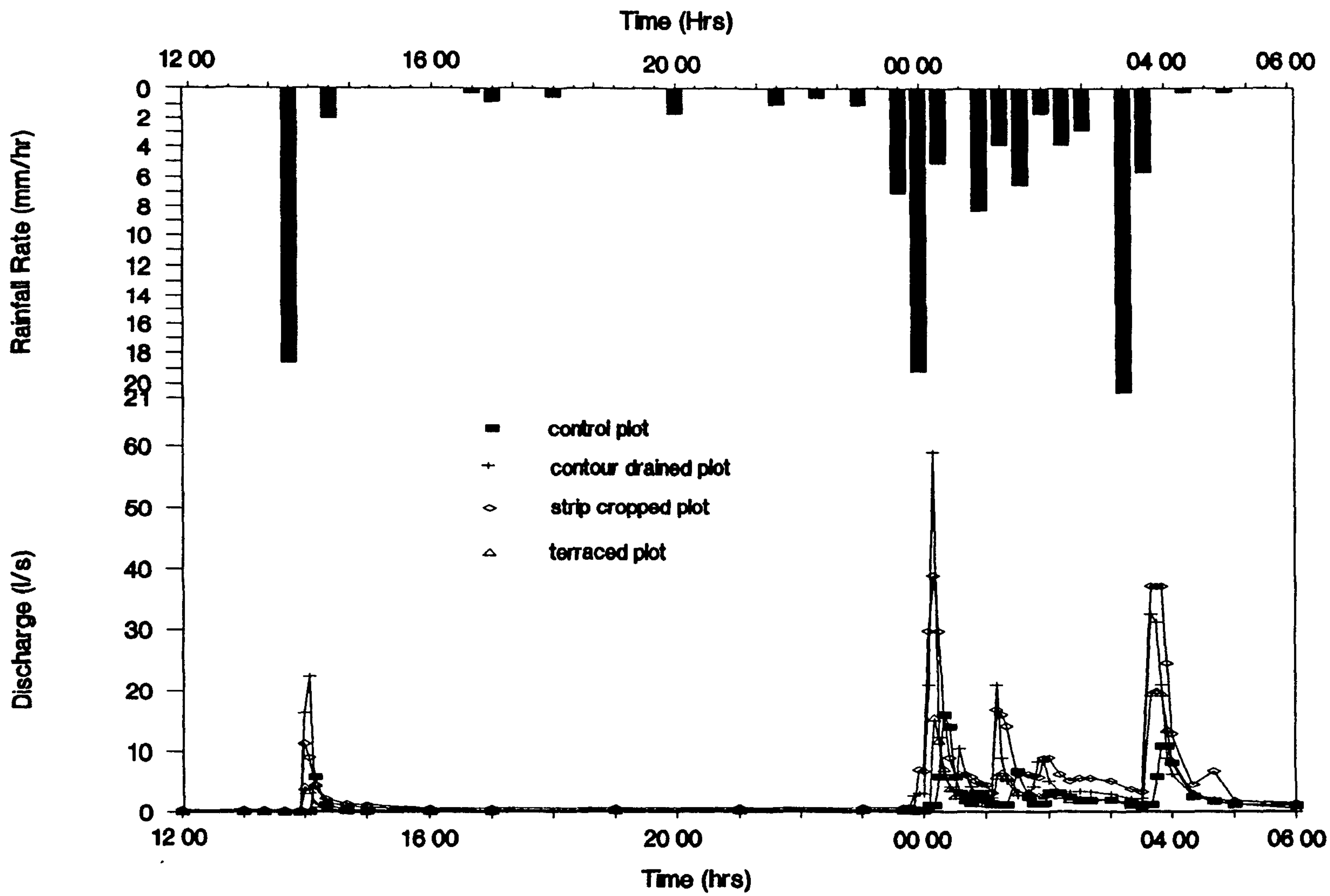

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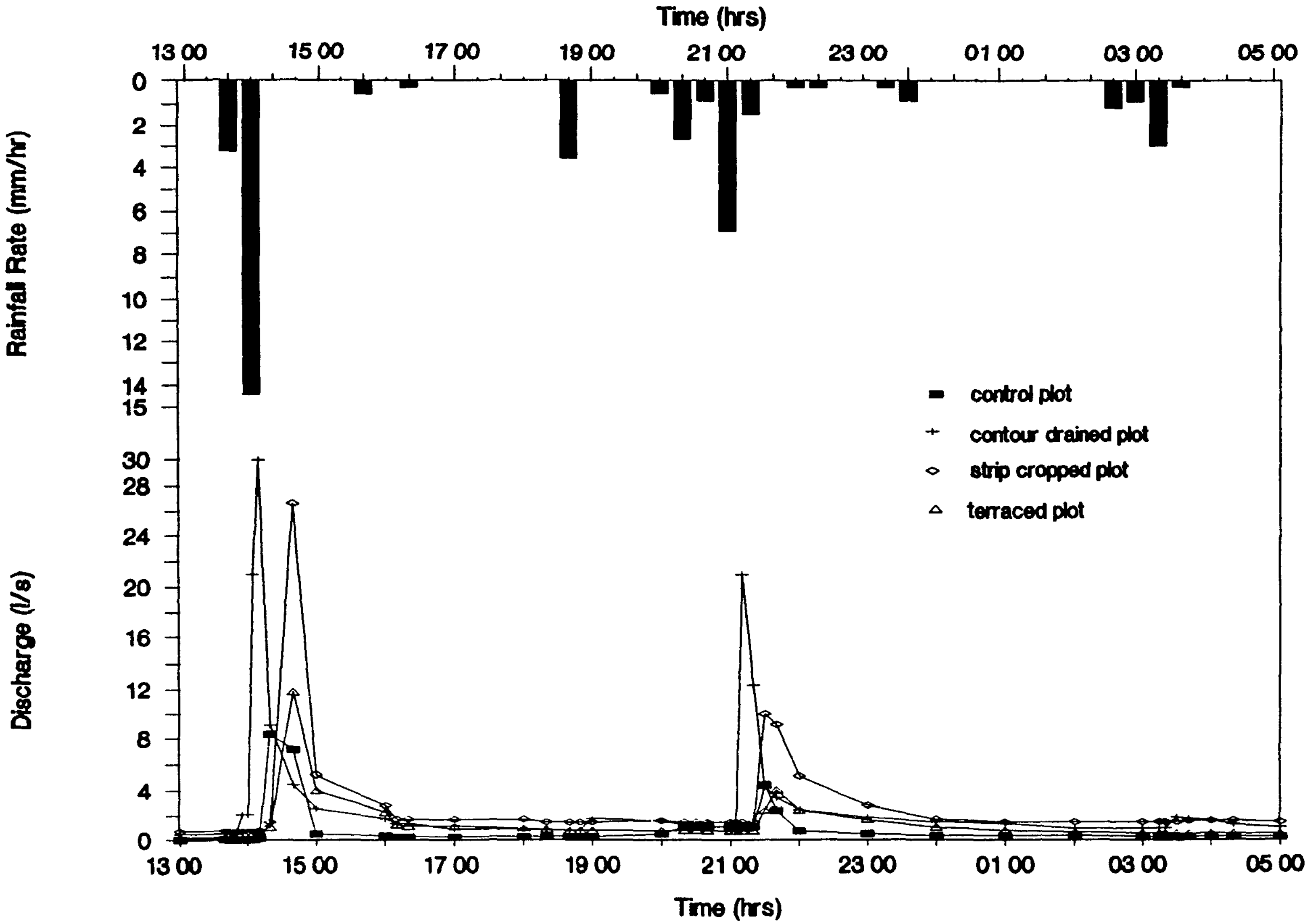

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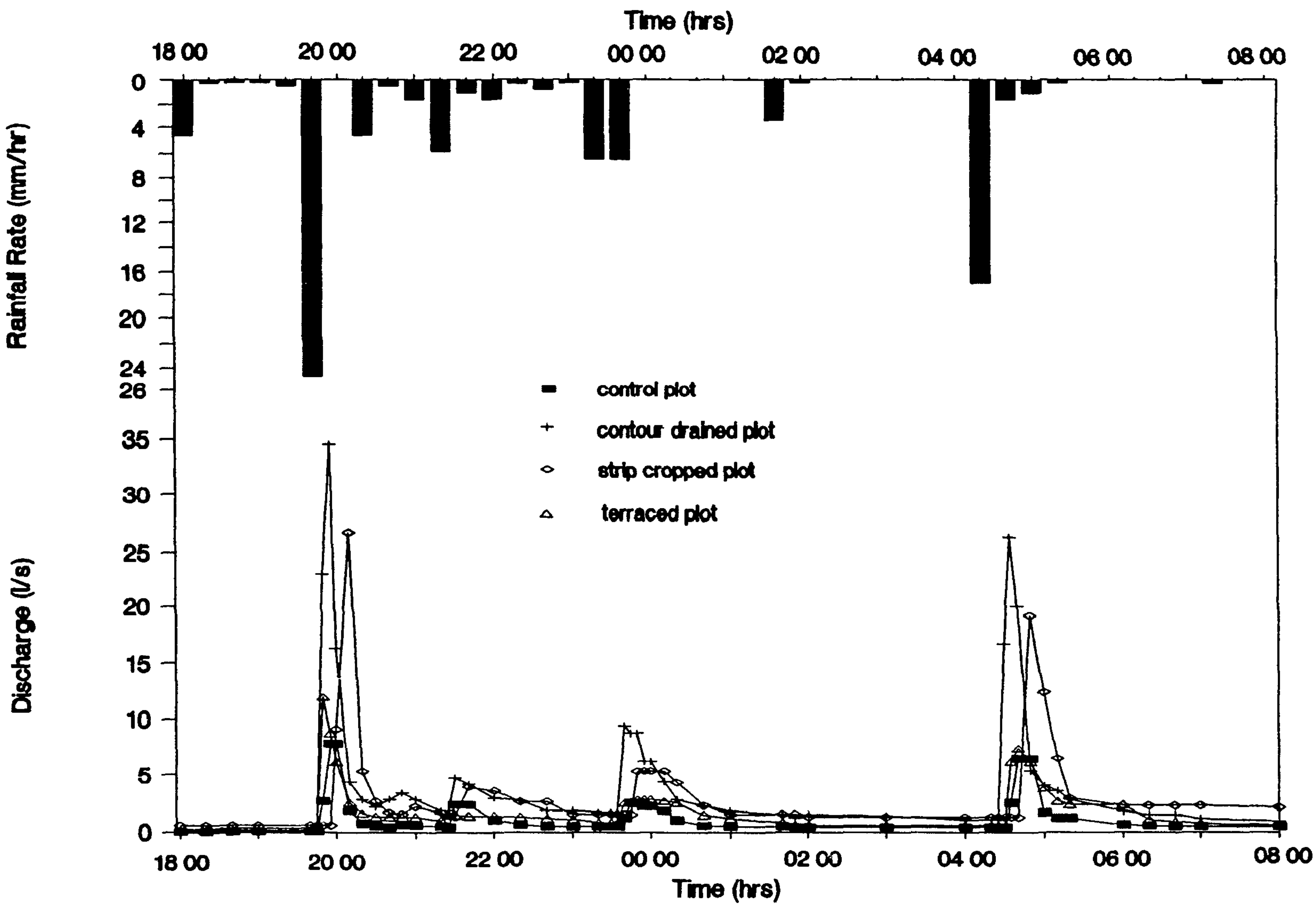
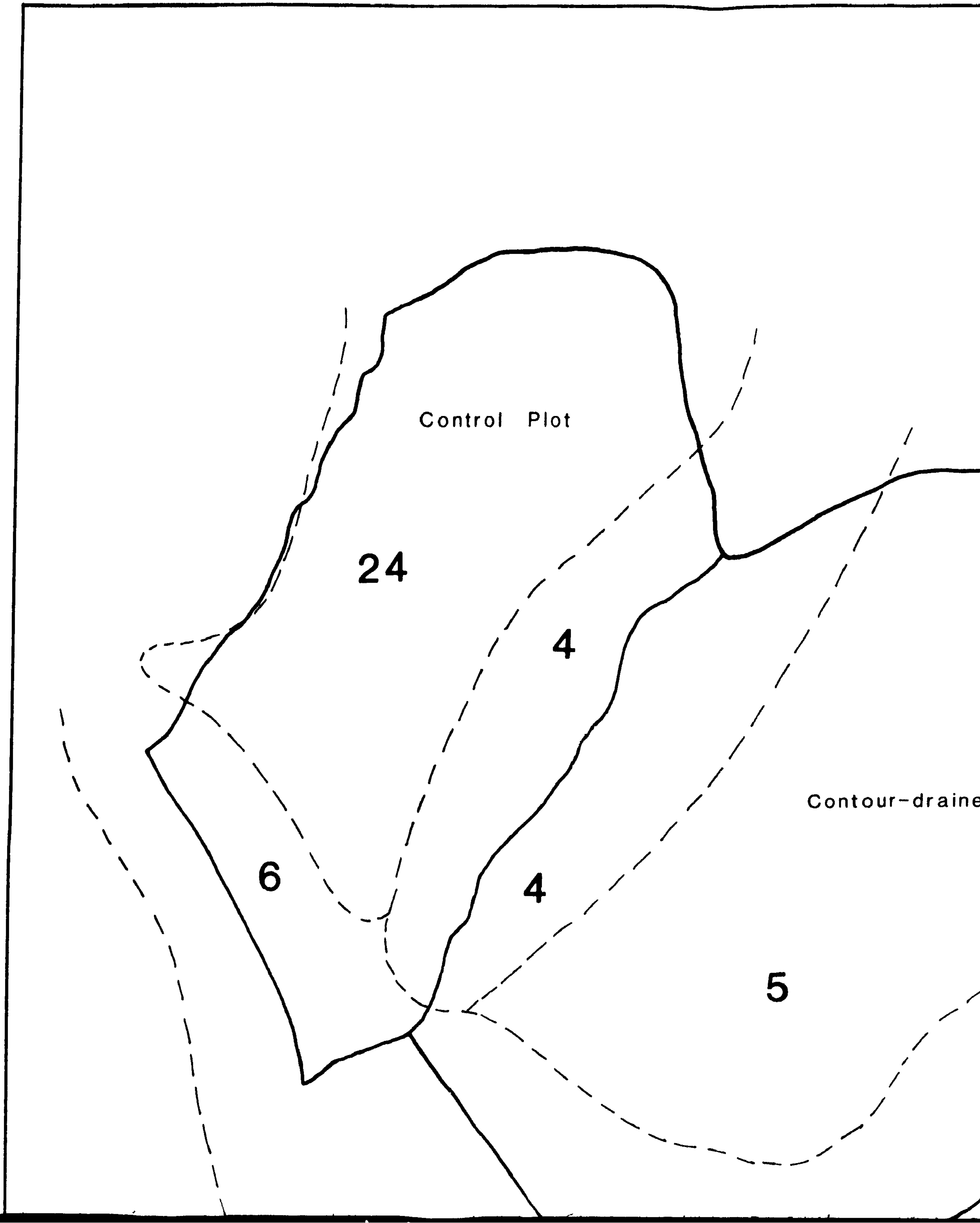


Figure C27. Event Hydrographs for 88-11-23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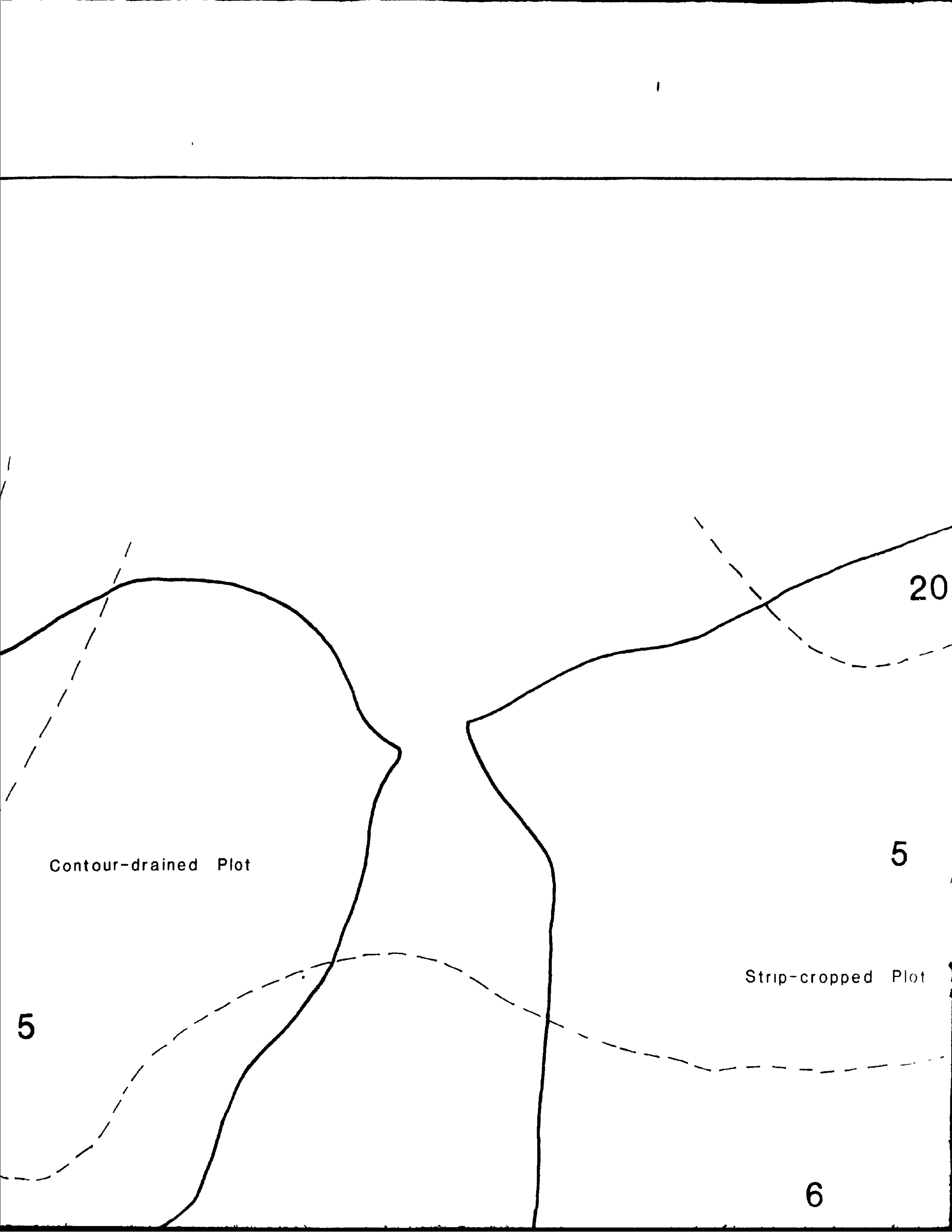

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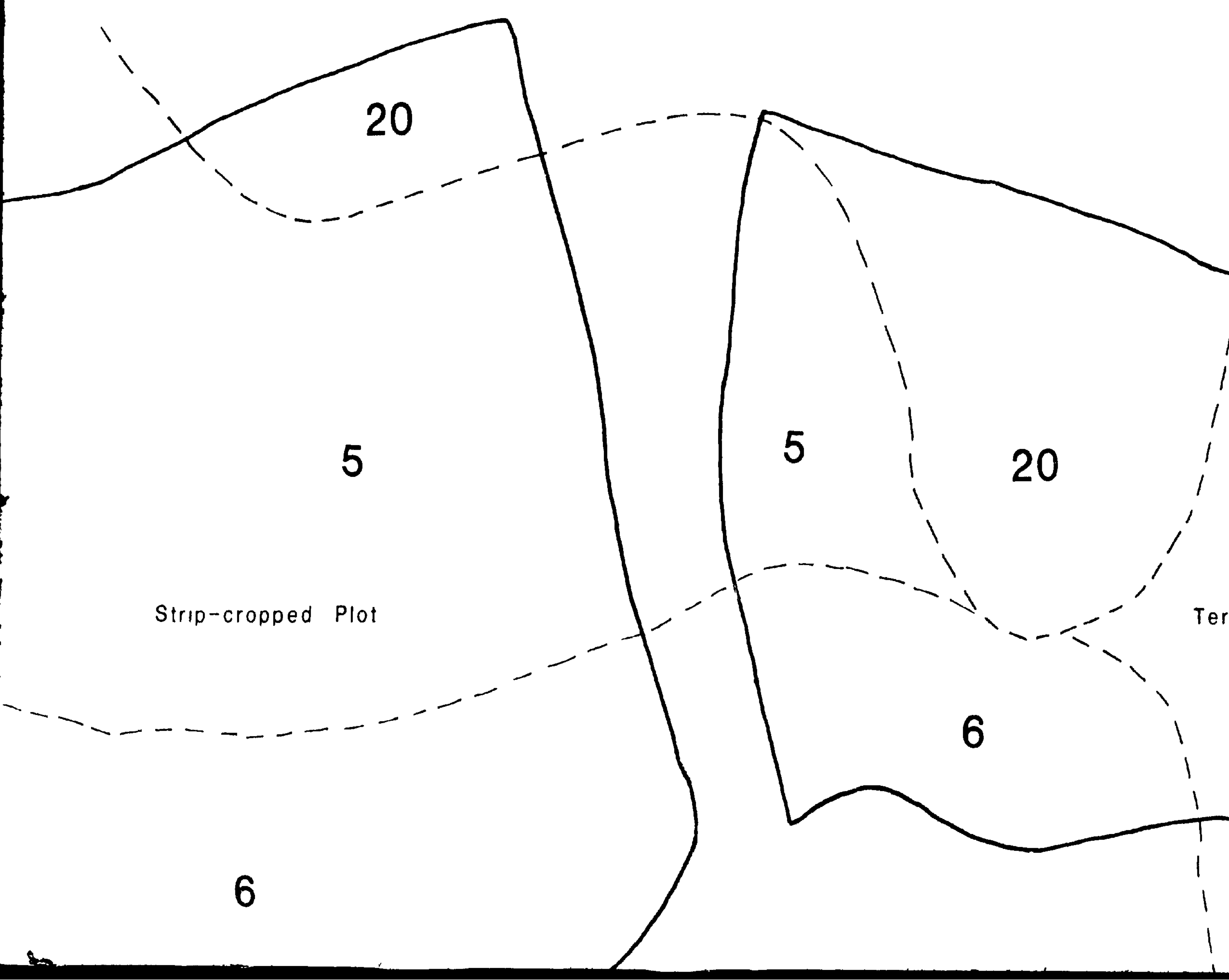

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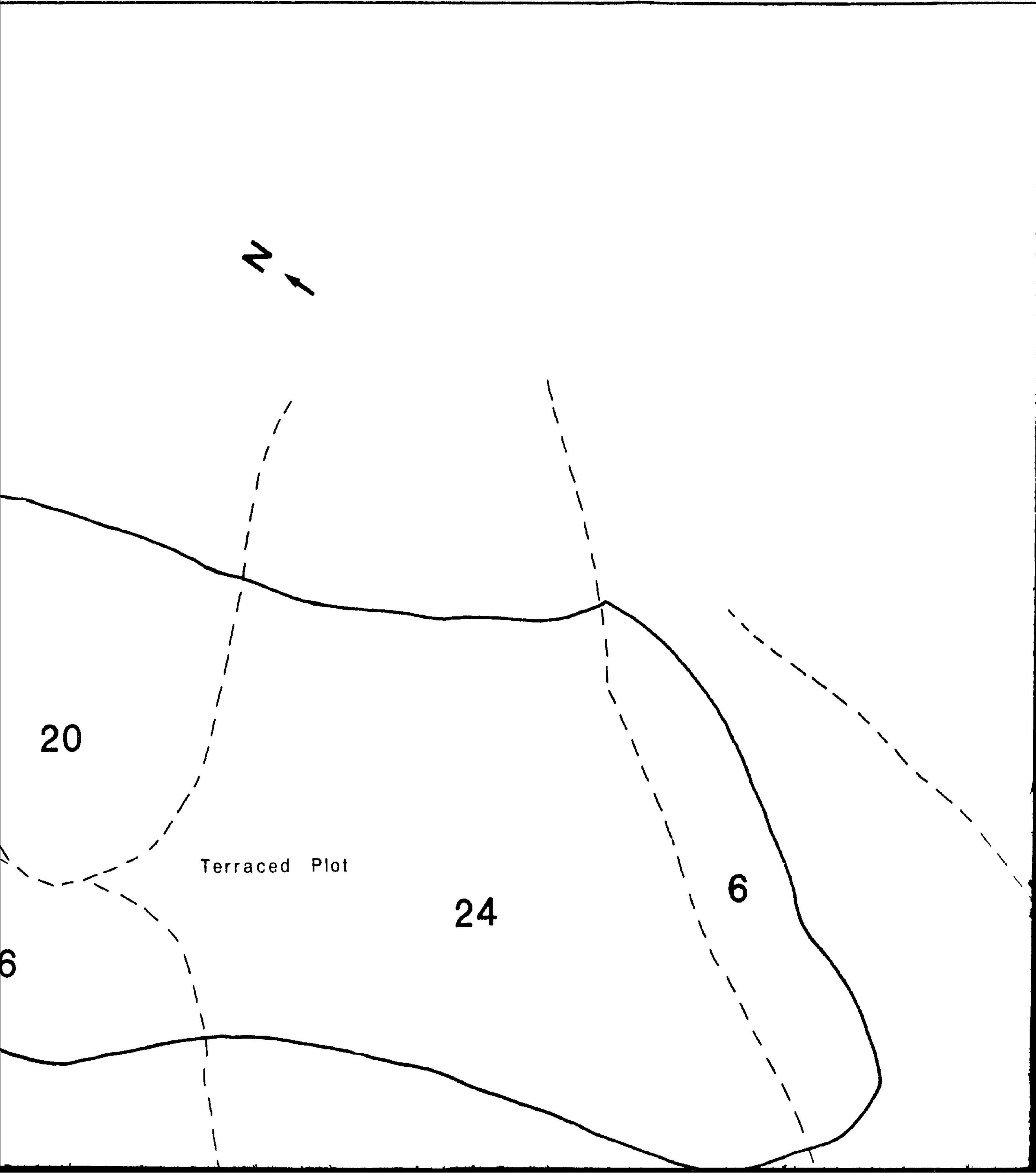
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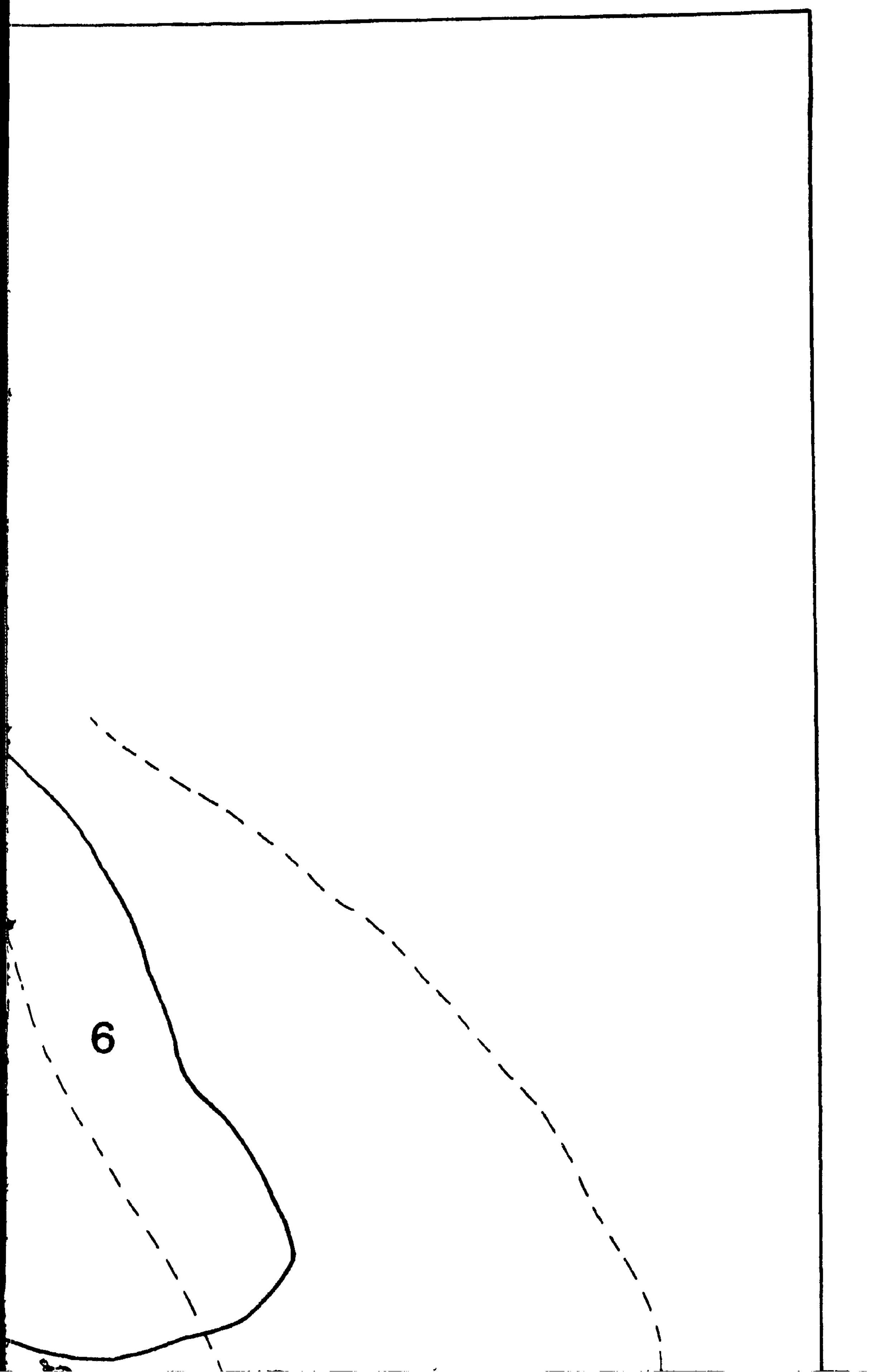
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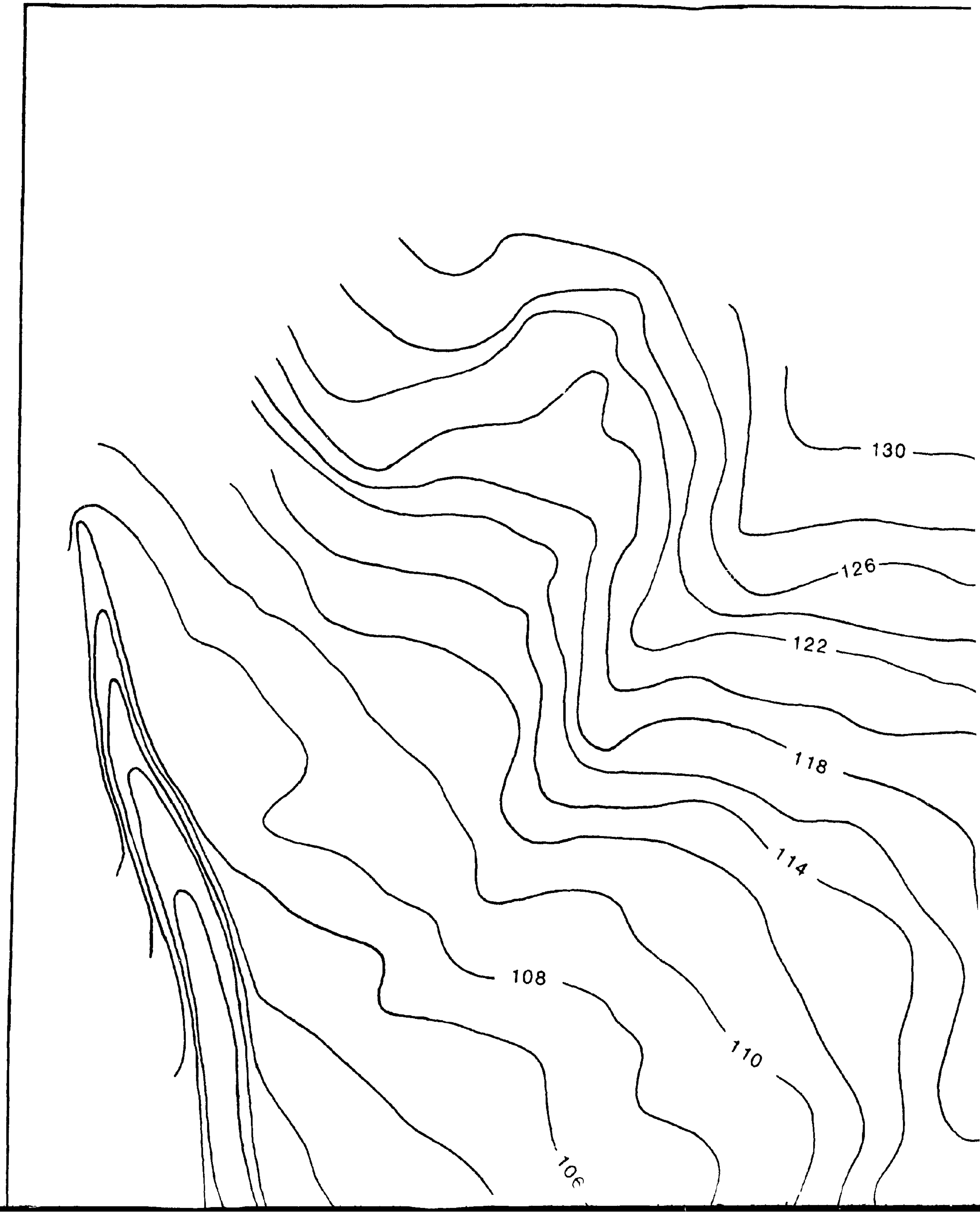

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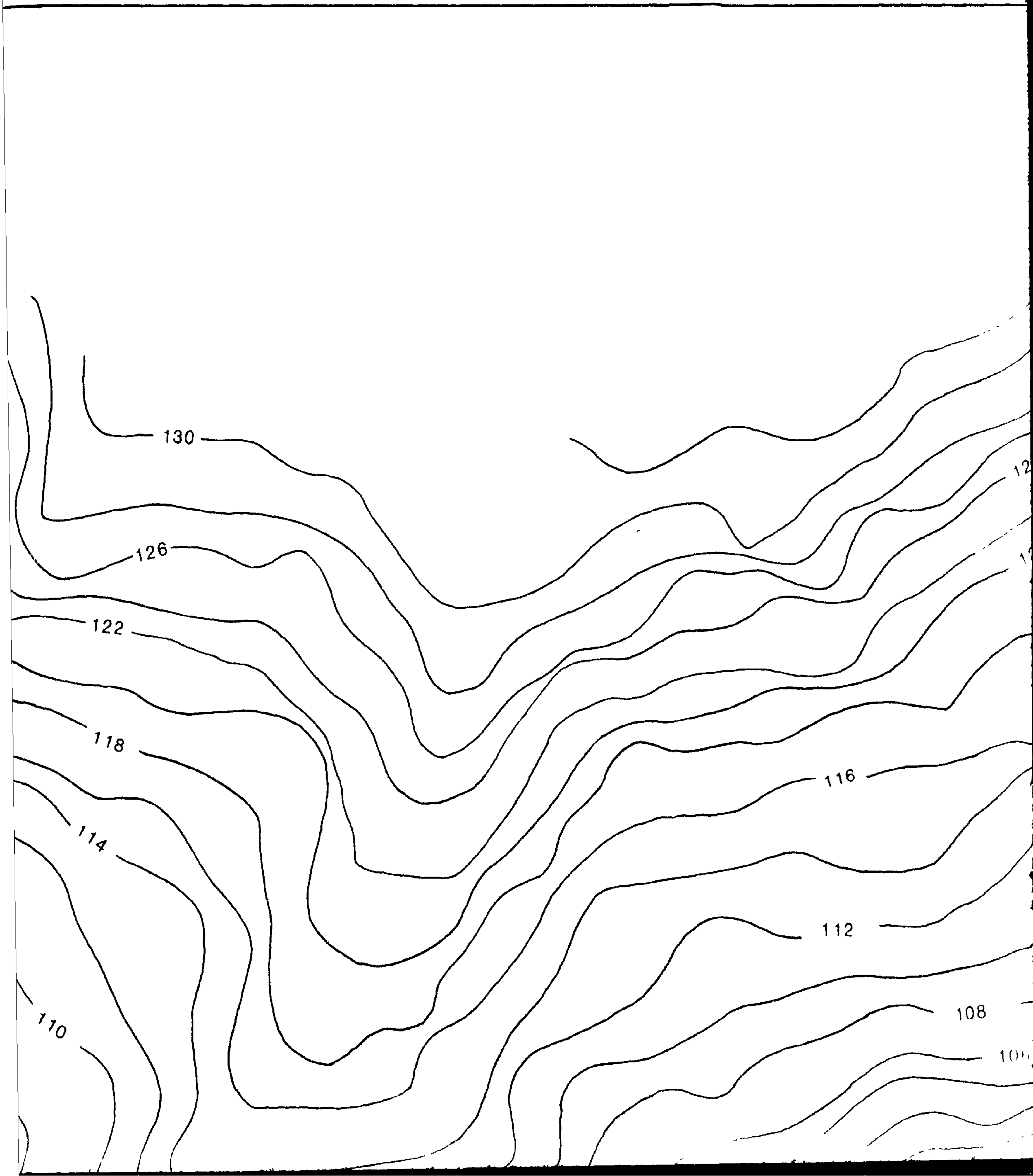
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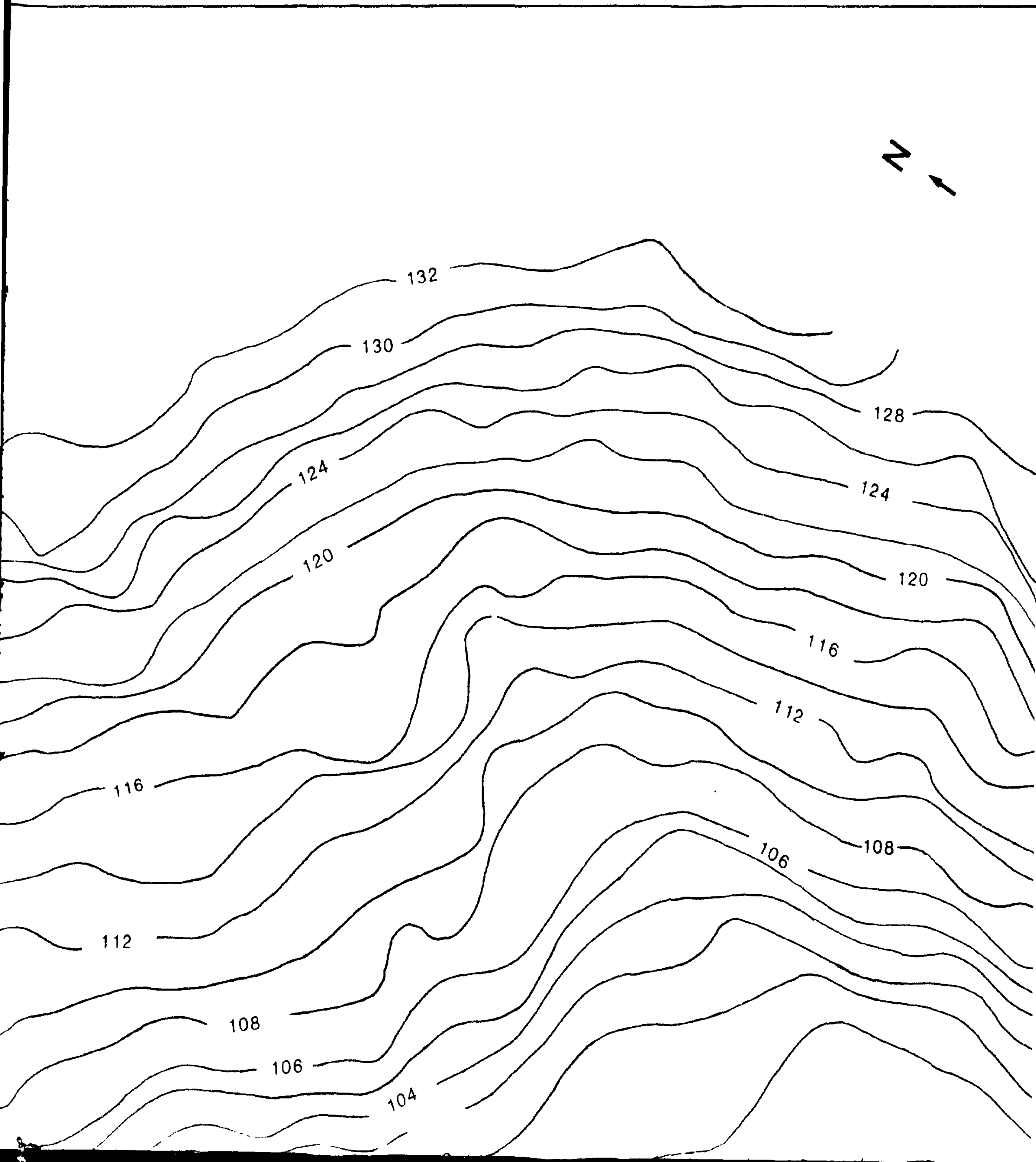

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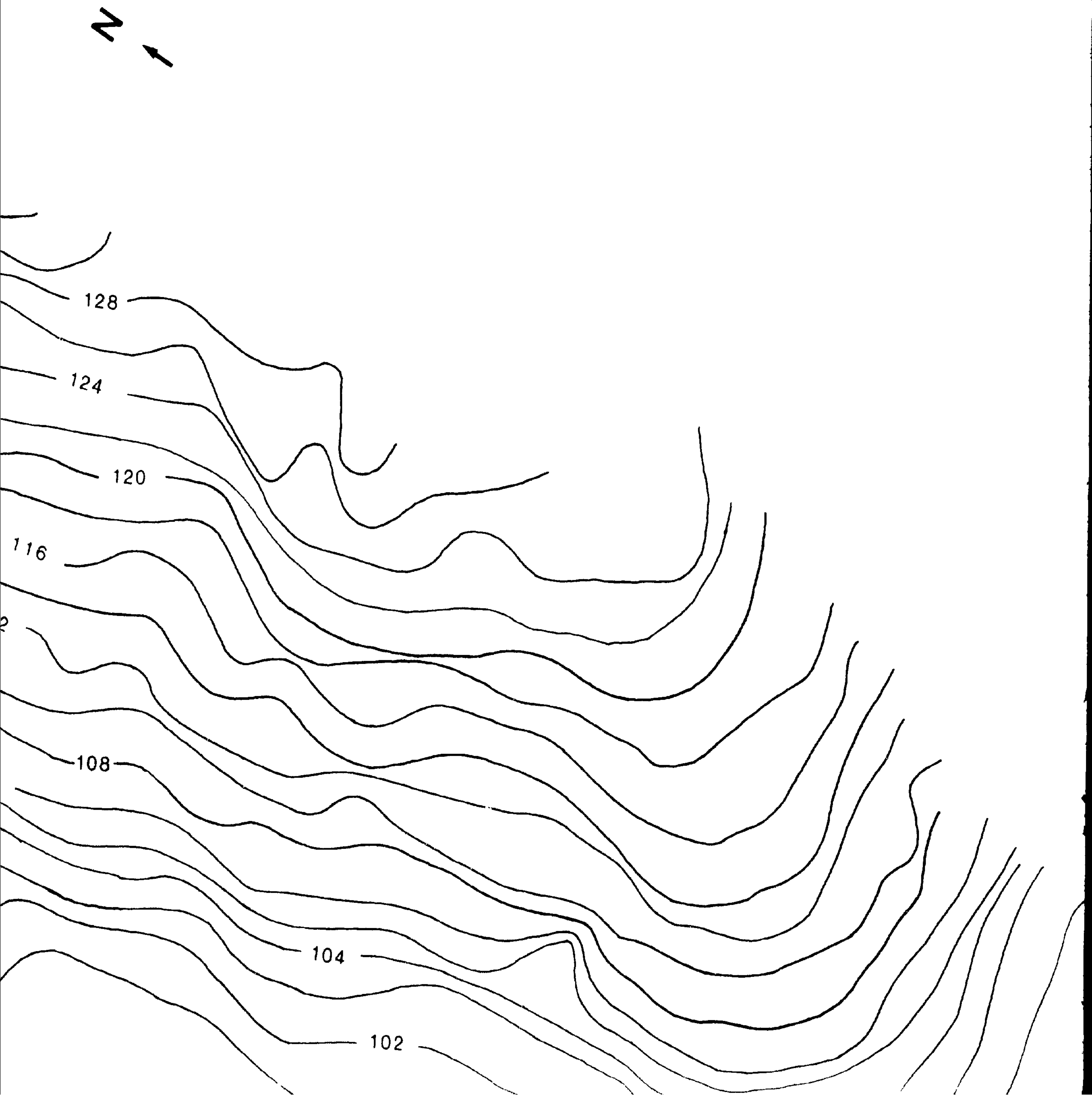
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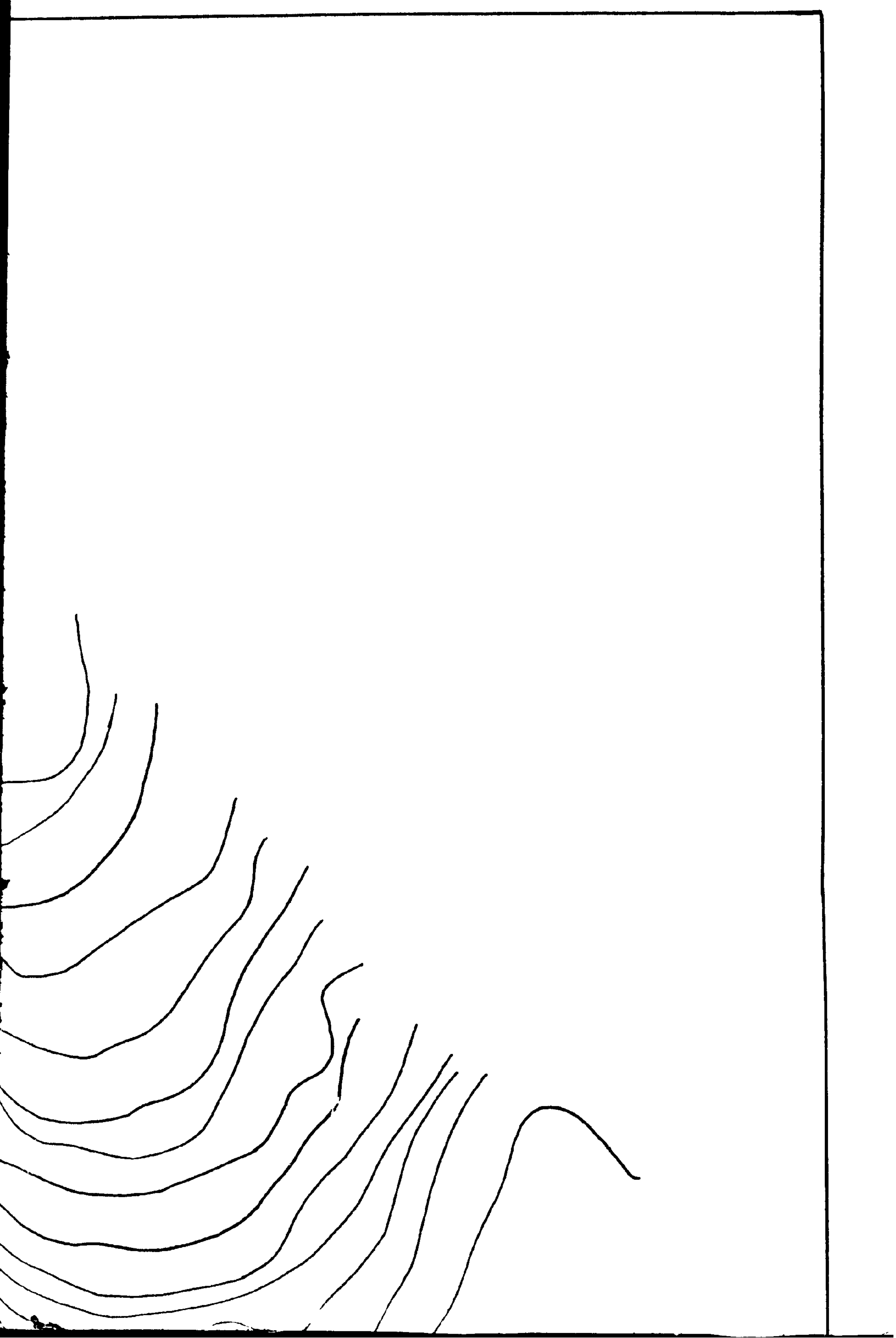

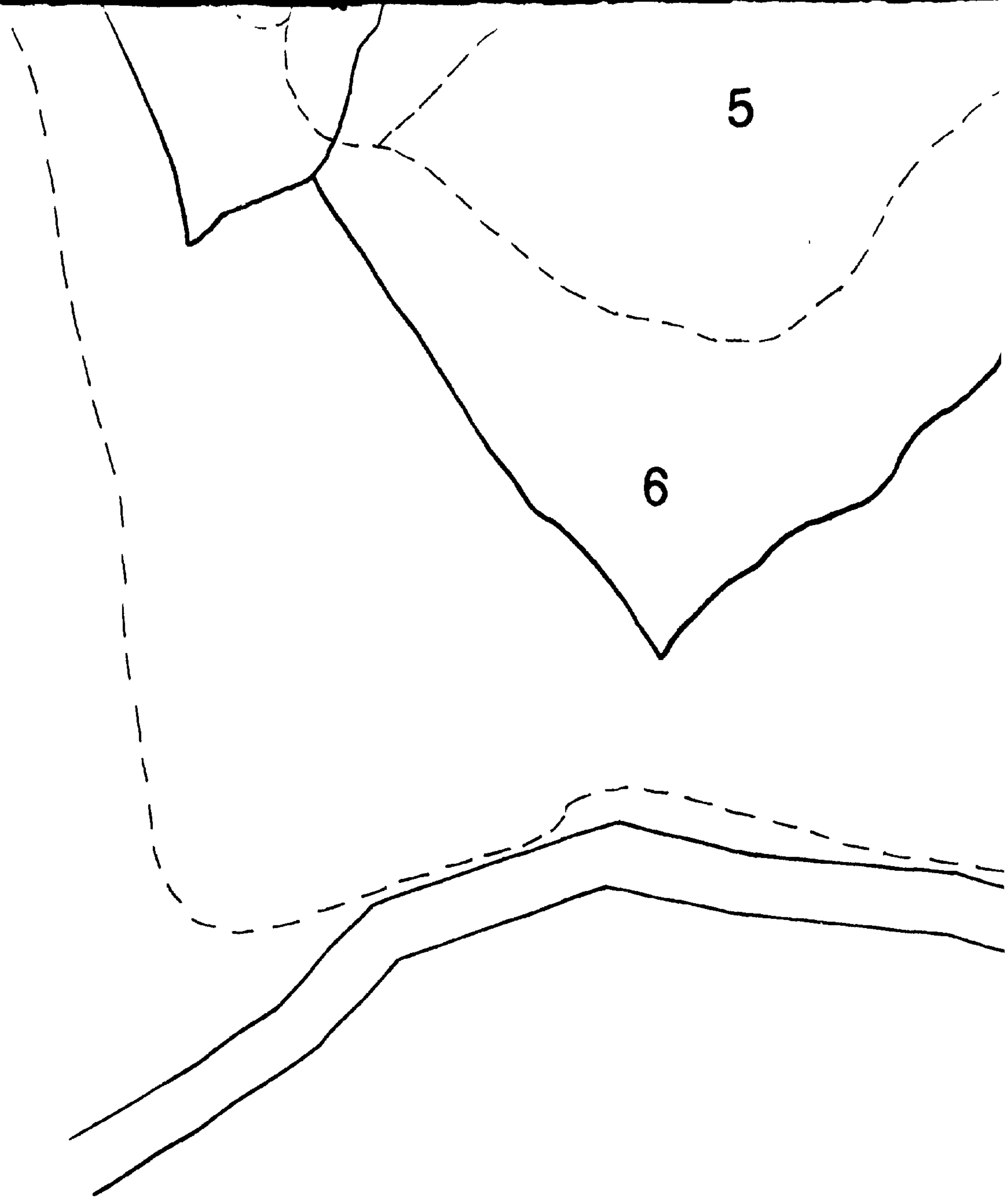
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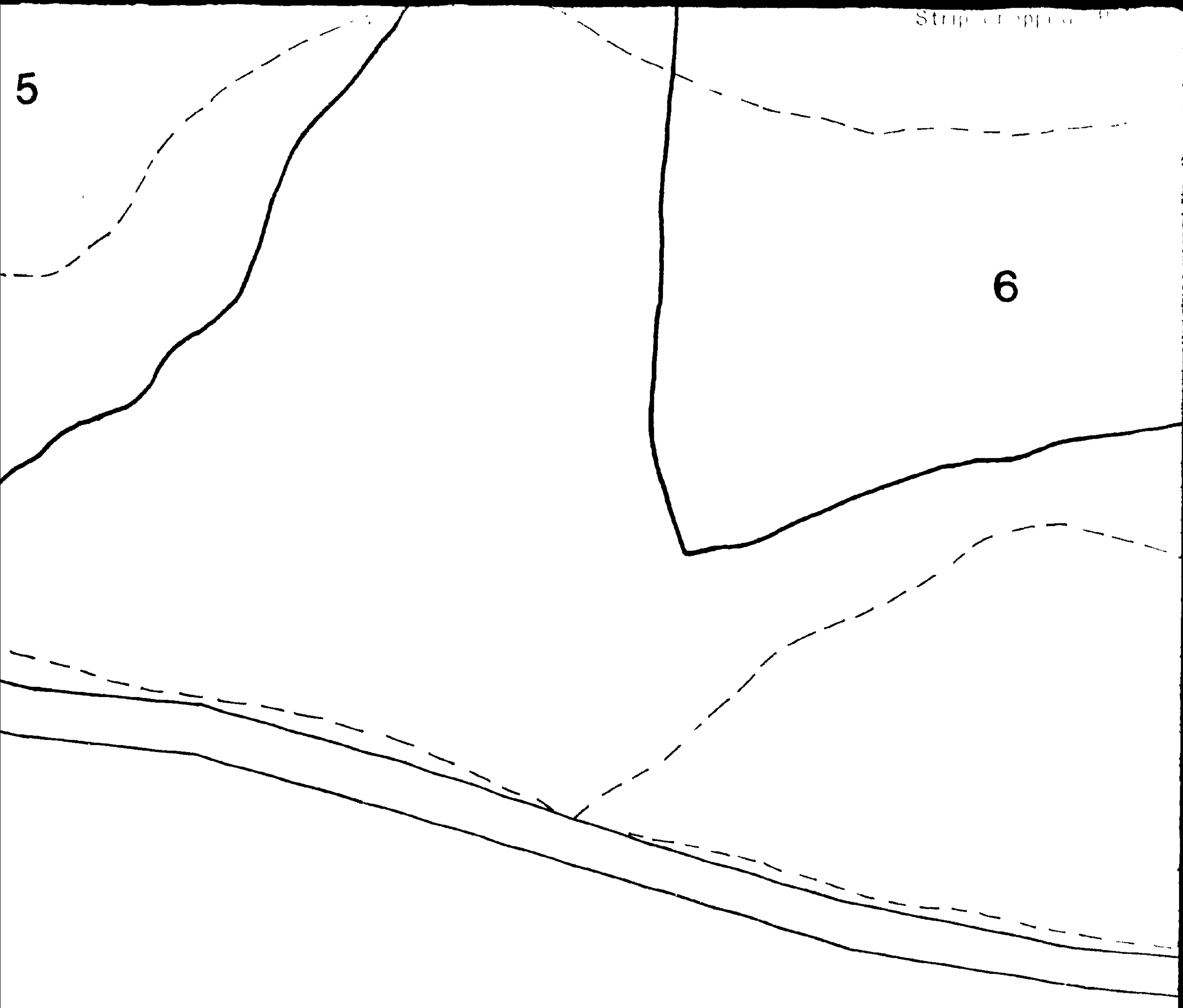

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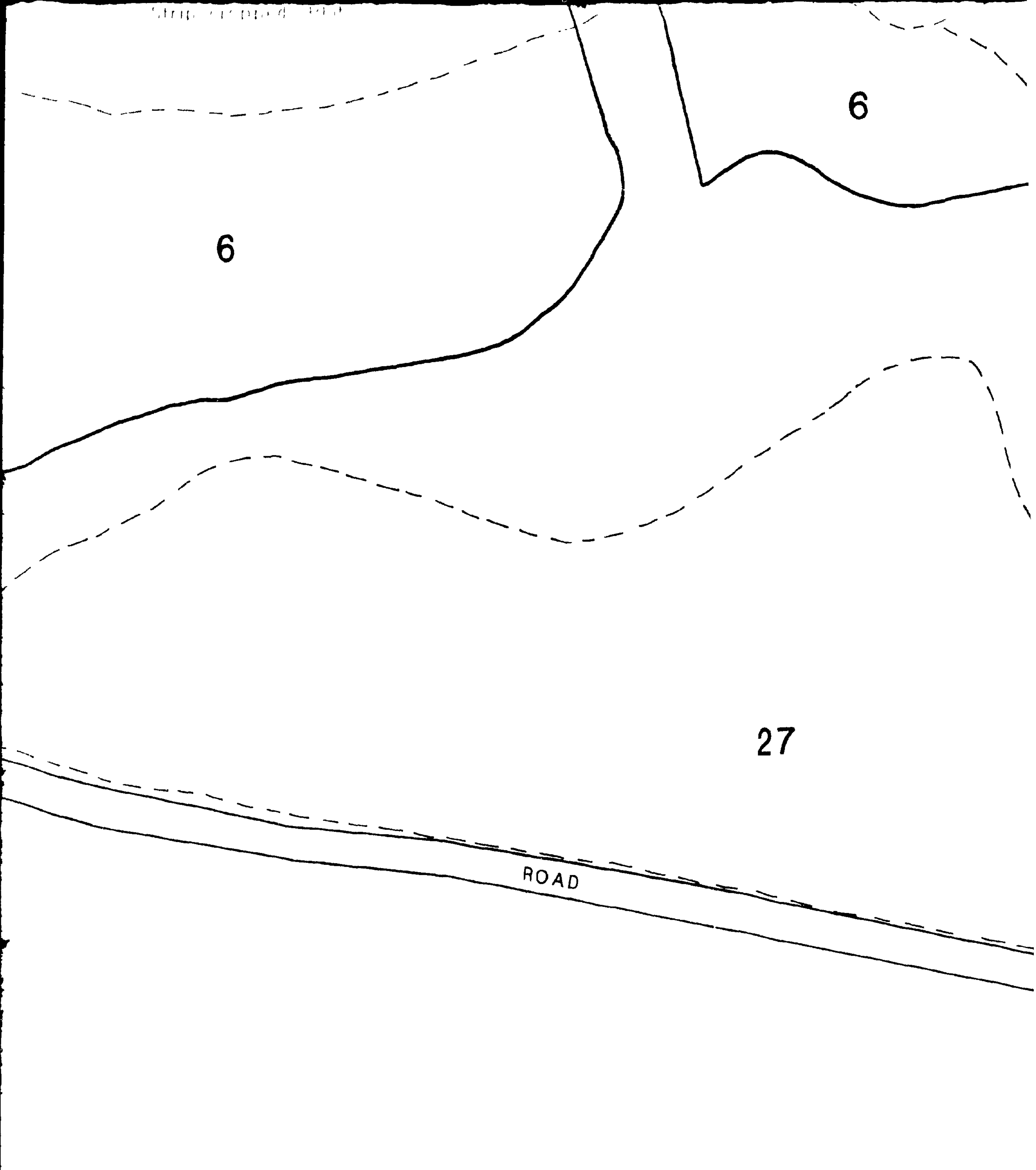

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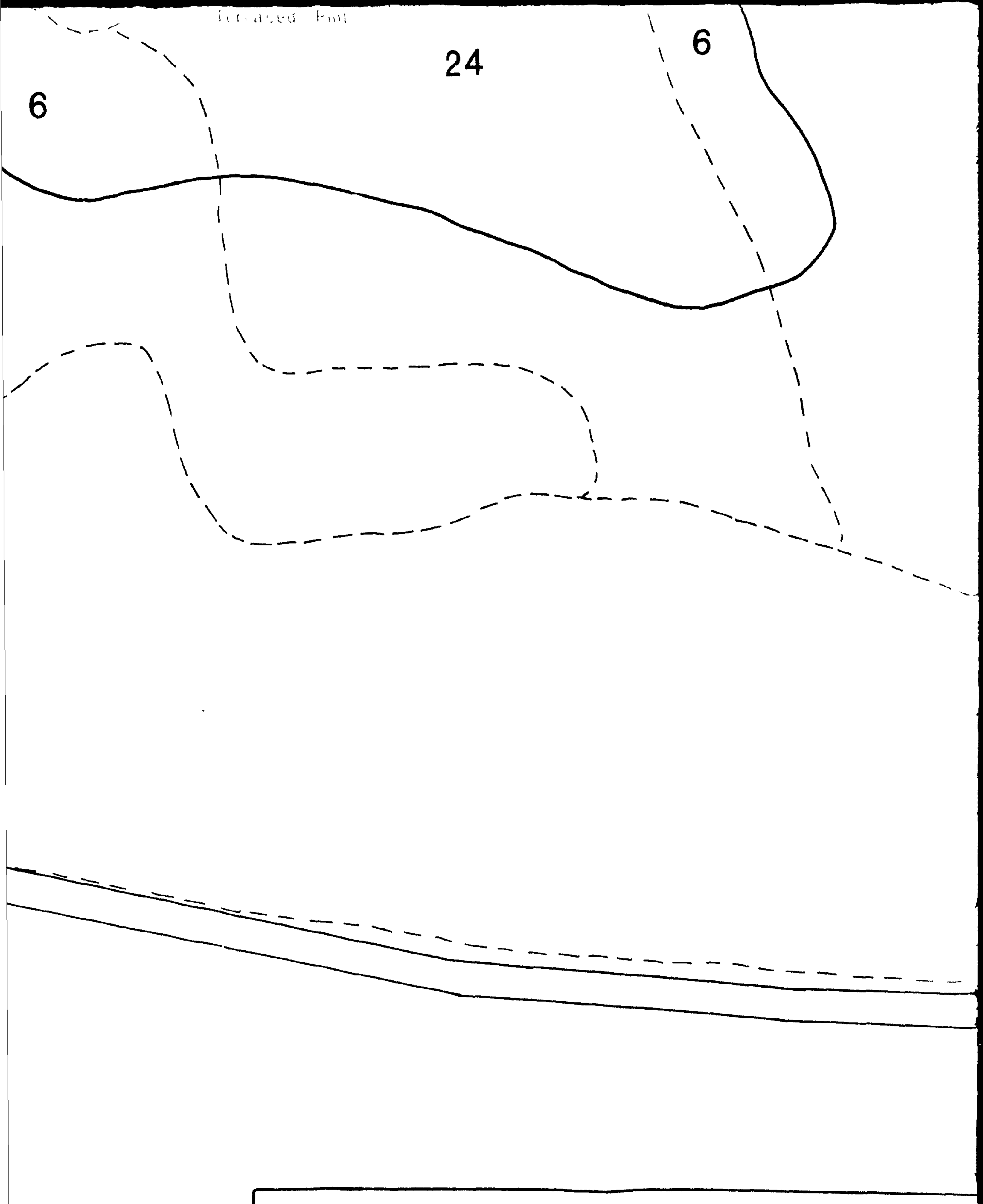

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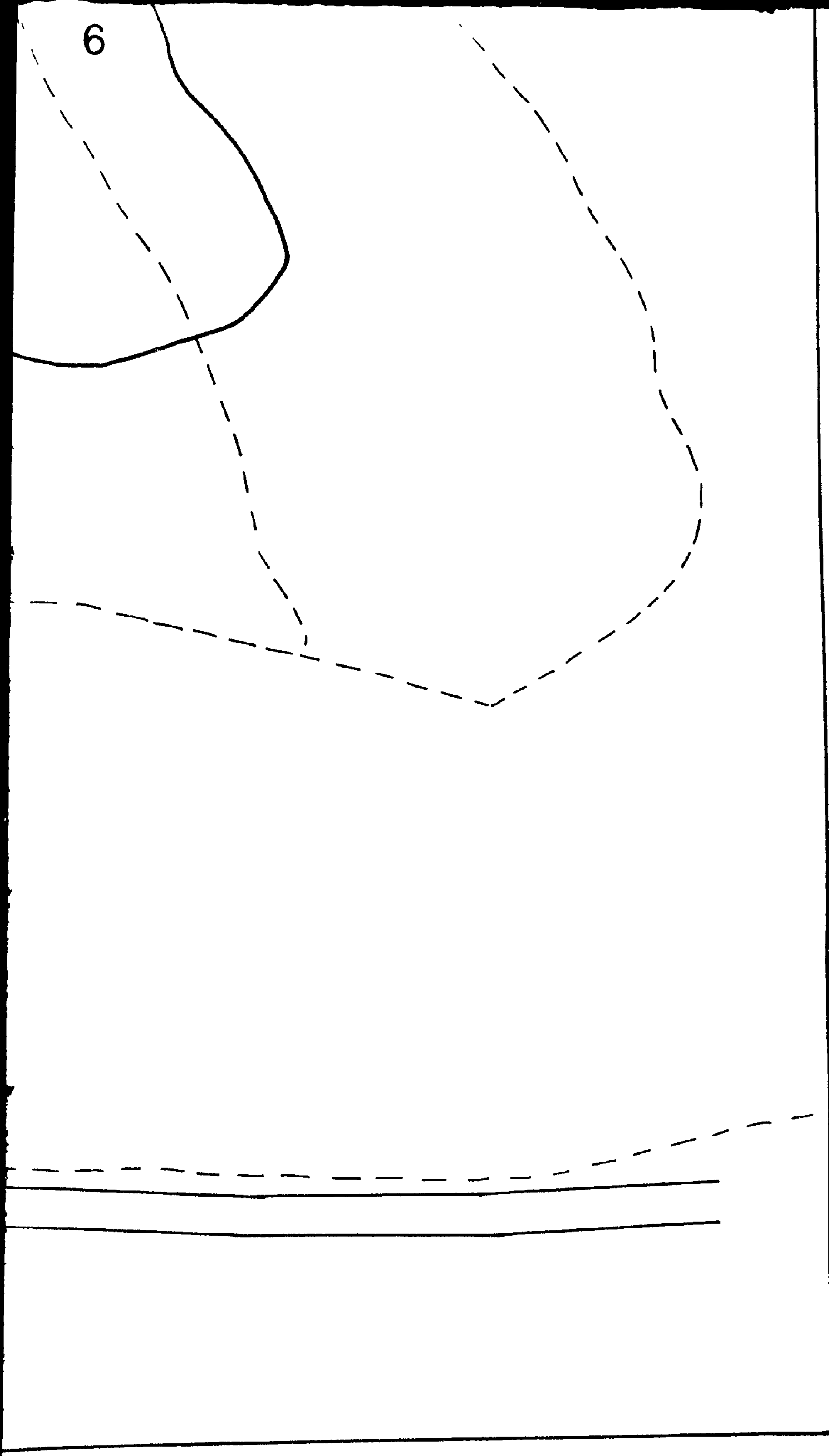

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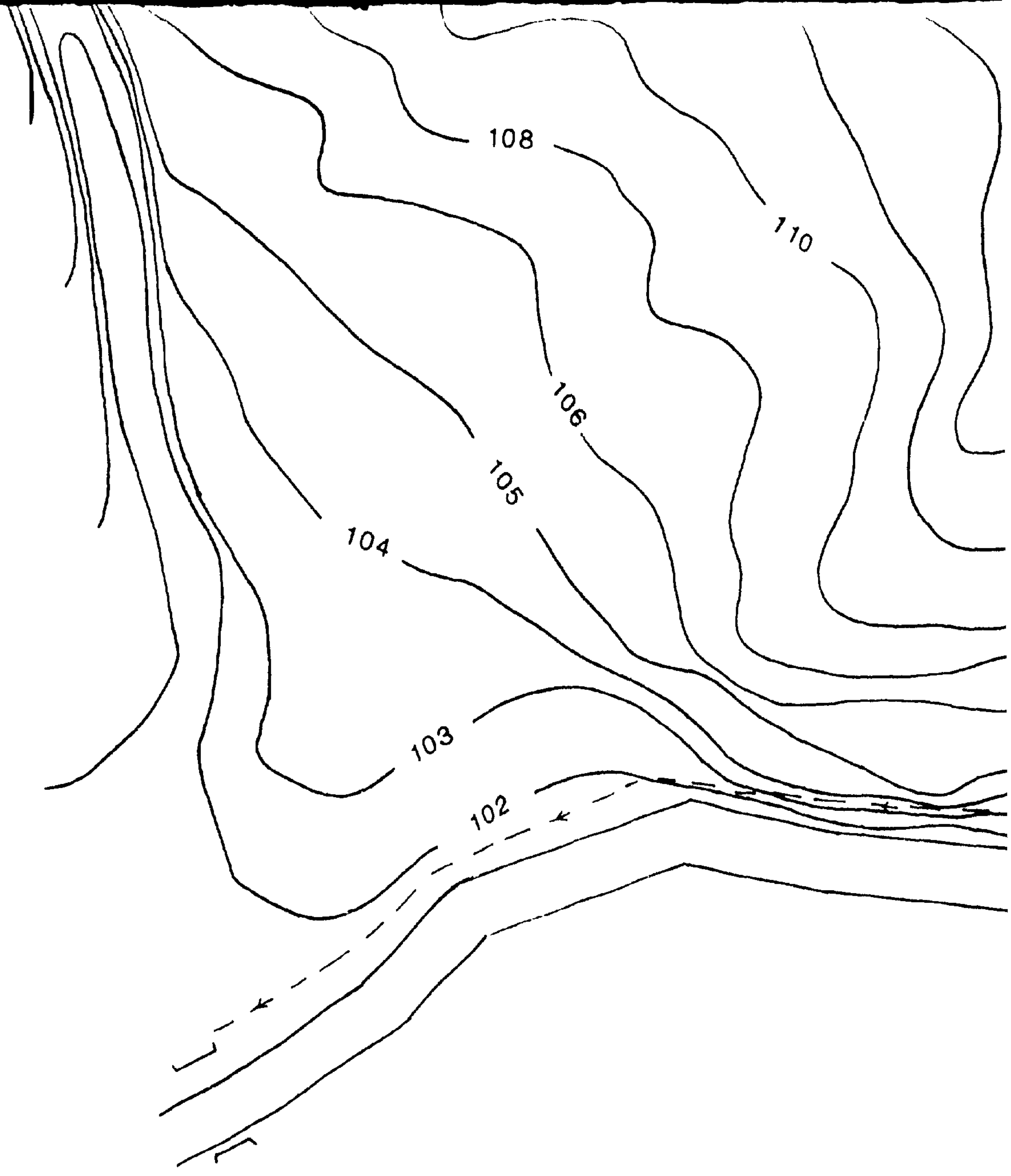

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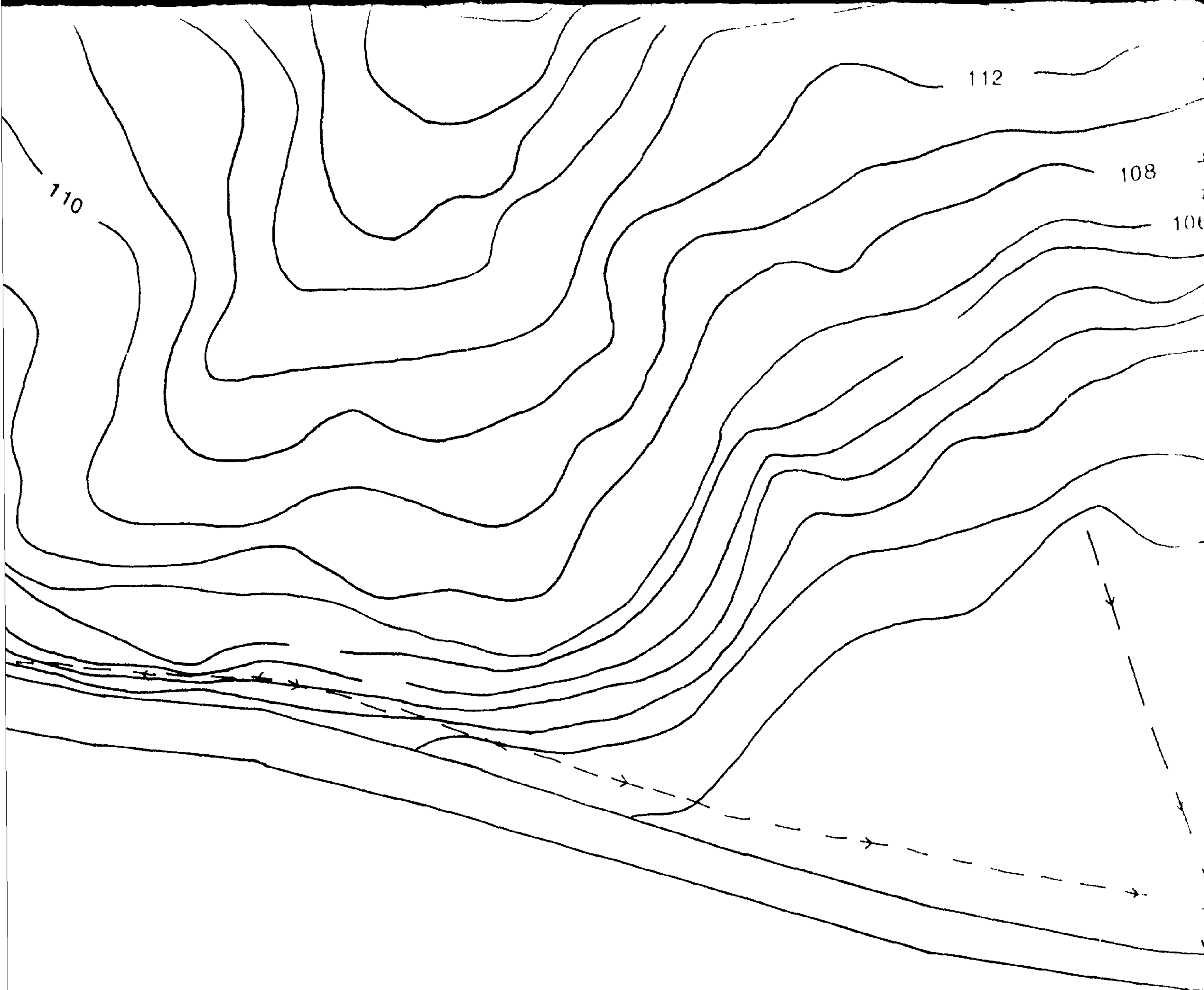
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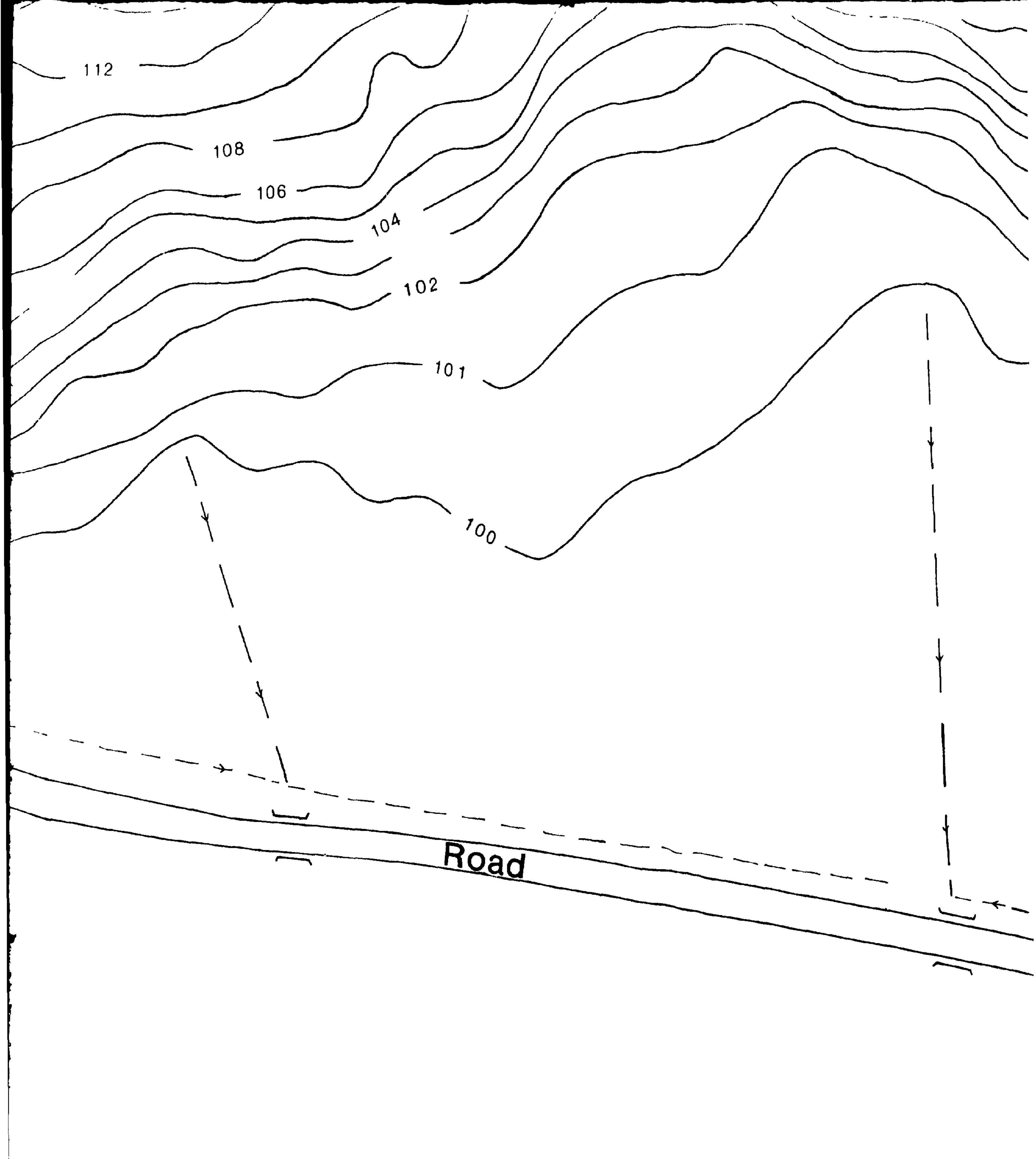
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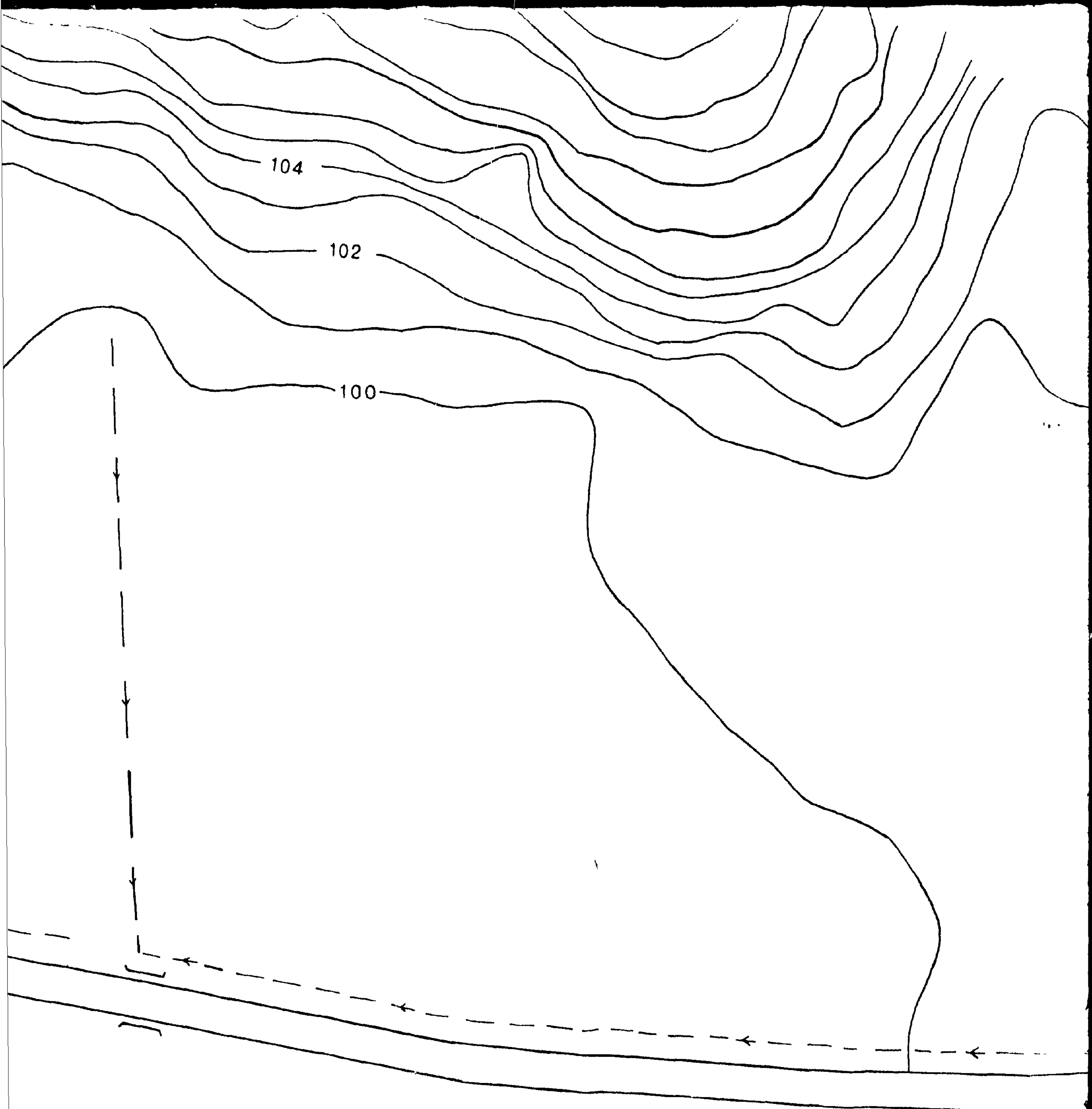

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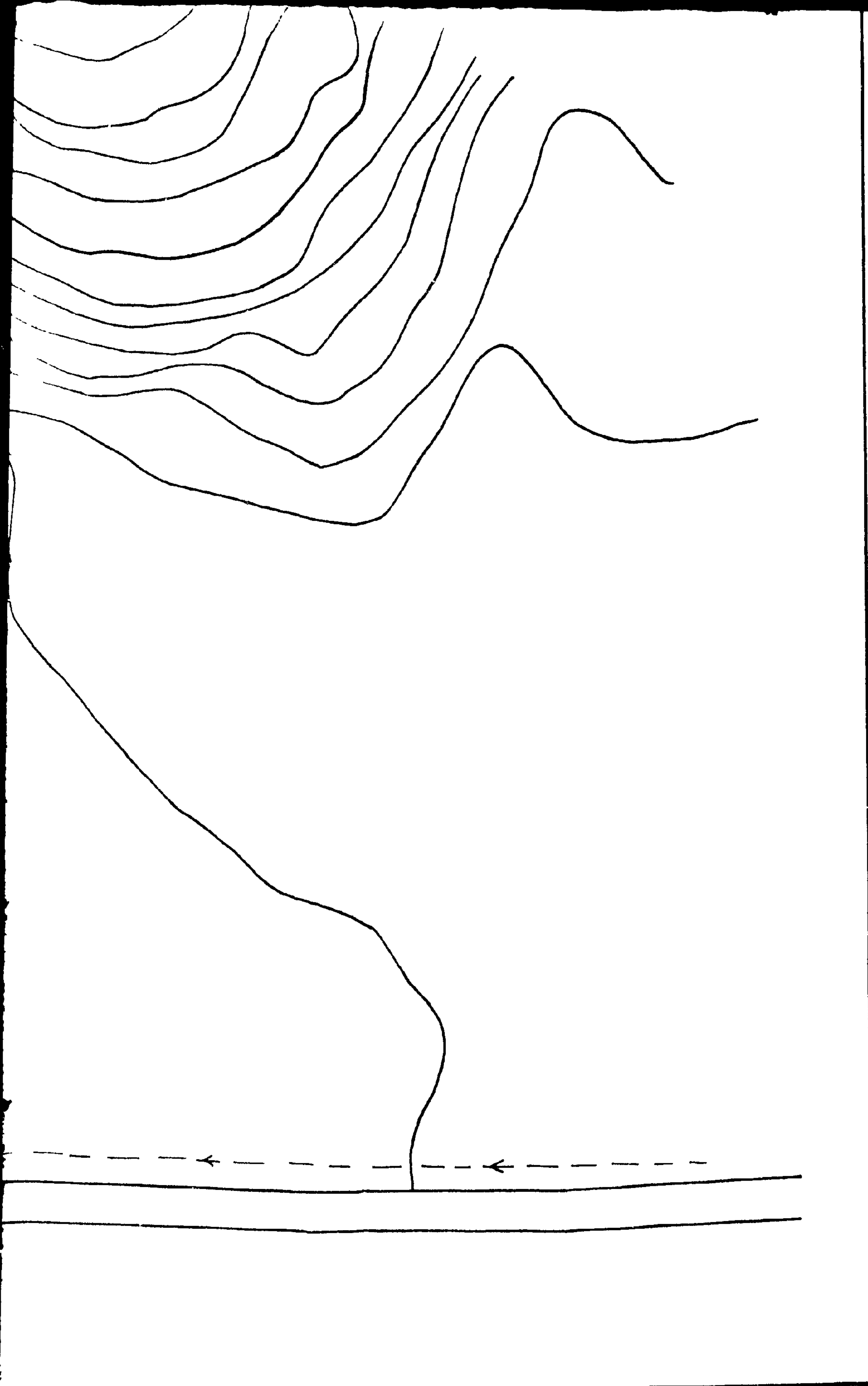

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Scale:

0 10 20 30 40

20 30 40 50m

Soils Index :

MAP UNIT	NAME
4	WARWICK CLAY
5	JEAN BAPTISTE SILTY CLAY LOAM
6	MABOUYA SILTY CLAY
20	BOCAGE STONY CLAY
24	CANELLES CLAY
27	SOUCIS SILTY CLAY LOAM

Index :

NAME

RWICK CLAY

N BAPTISTE SILTY CLAY LOAM

BOUYA SILTY CLAY

CAGE STONY CLAY

NELLES CLAY

JCIS SILTY CLAY LOAM

Legend:

Soil Boundary

Plot Boundary

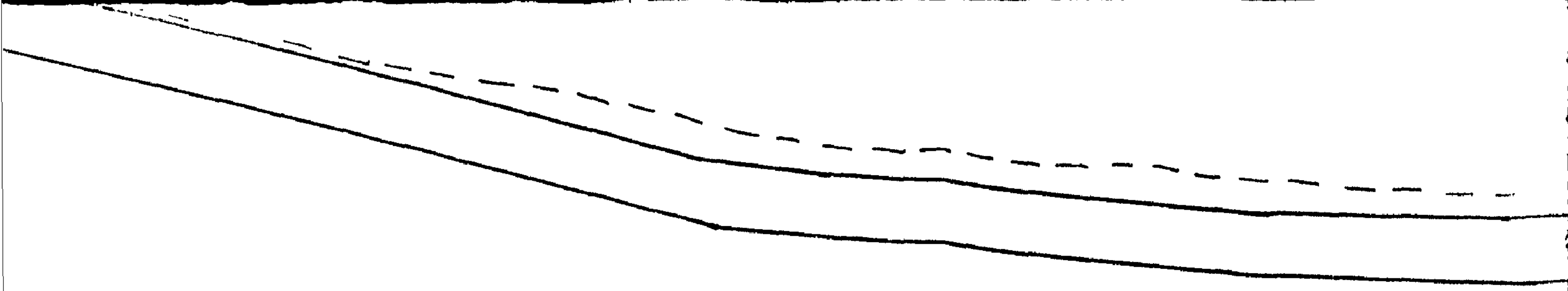


Figure A1.

SOILS MAP

OF THE

SOIL CONSERVATION RESEARCH PRO

ROSEAU, ST. LUCIA

SCALE 1:500

Drawn by Peter Norville C

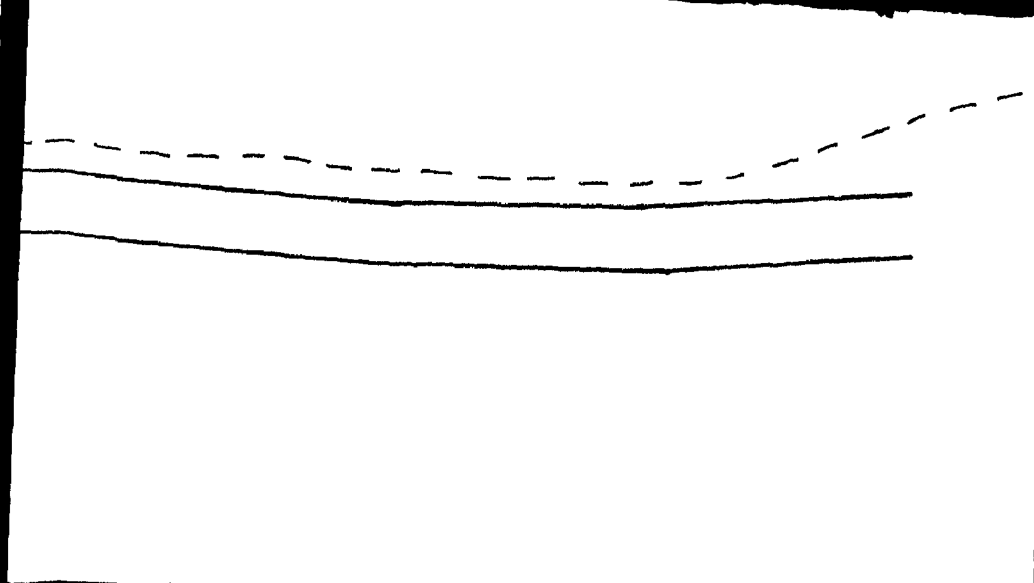


Figure A1.

SOILS MAP

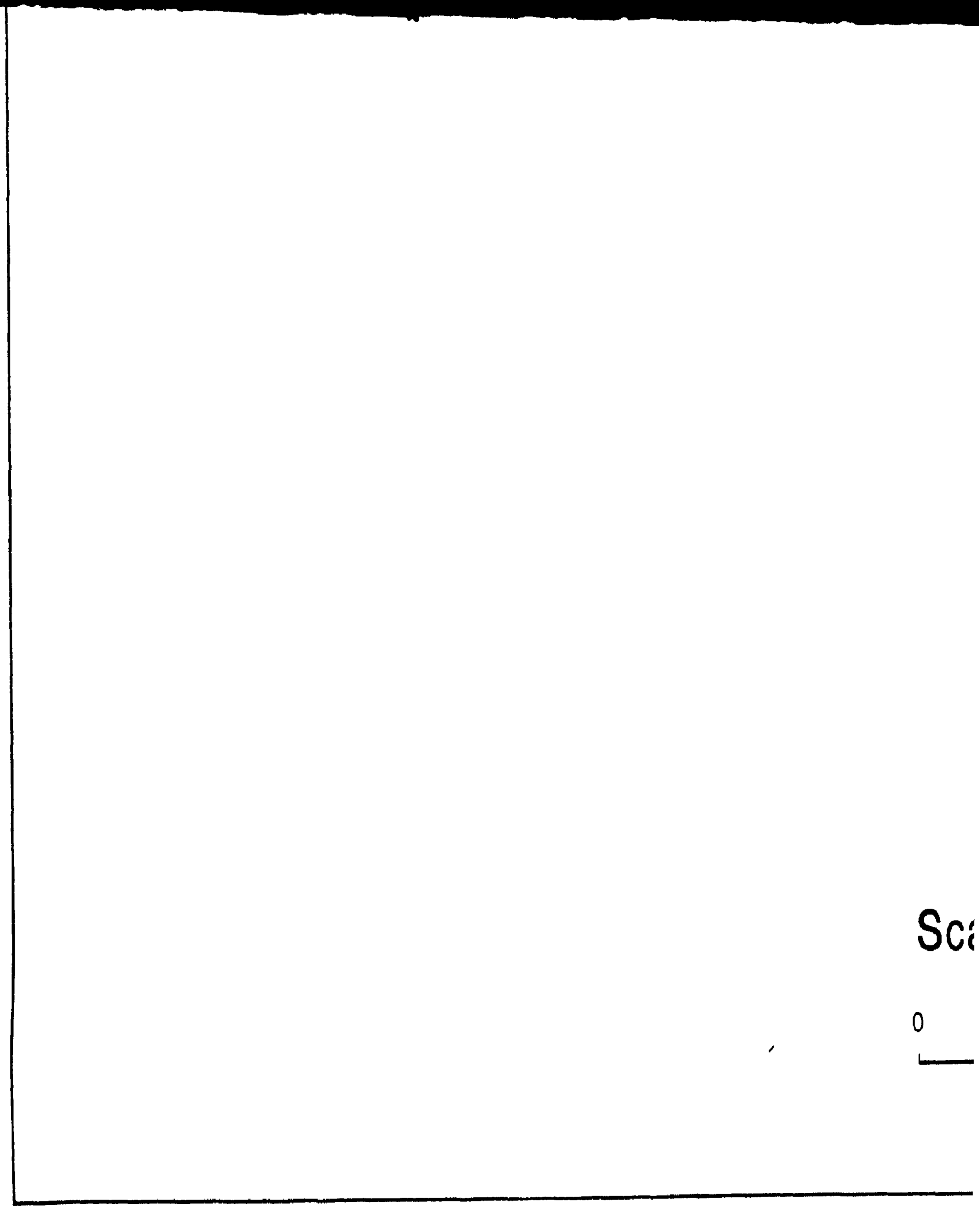
OF THE

ATION RESEARCH PROJECT SITE

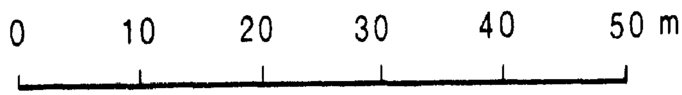
ROSEAU, ST. LUCIA

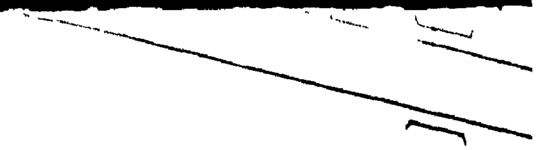
SCALE 1:500

Peter Norville October 1989


Sca
0

Scale:





Legend:

Drain ......

Contour line 112

Culvert ..

Road

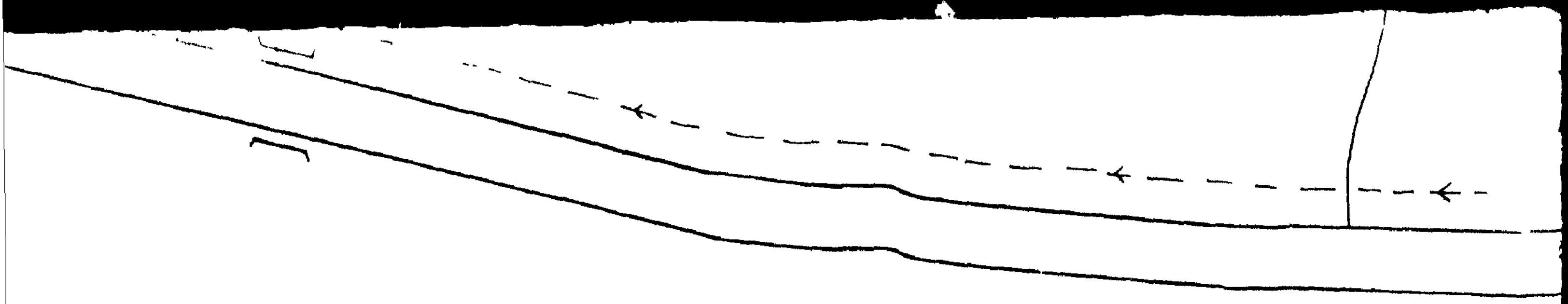


Figure A2.

CONTOUR MAP

OF THE

SOIL CONSERVATION RESEARCH PROJ

ROSEAU, ST. LUCIA

(Before construction of the conservation systems)

SCALE 1:500

Drawn by Peter Norville Oct

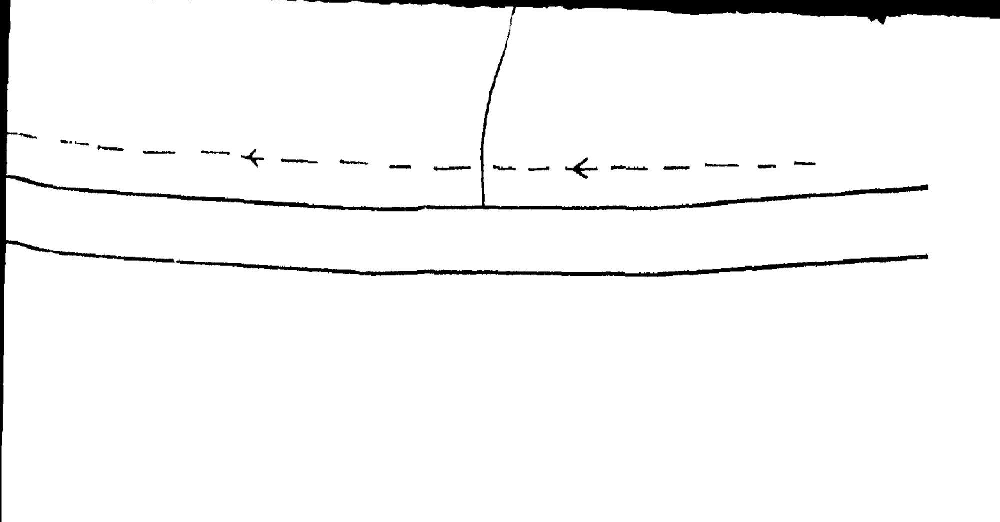


Figure A2.

CONTOUR MAP

OF THE

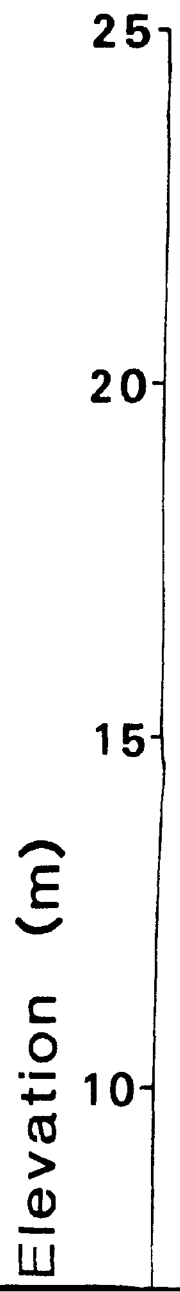
/ATION RESEARCH PROJECT SITE

ROSEAU, ST. LUCIA

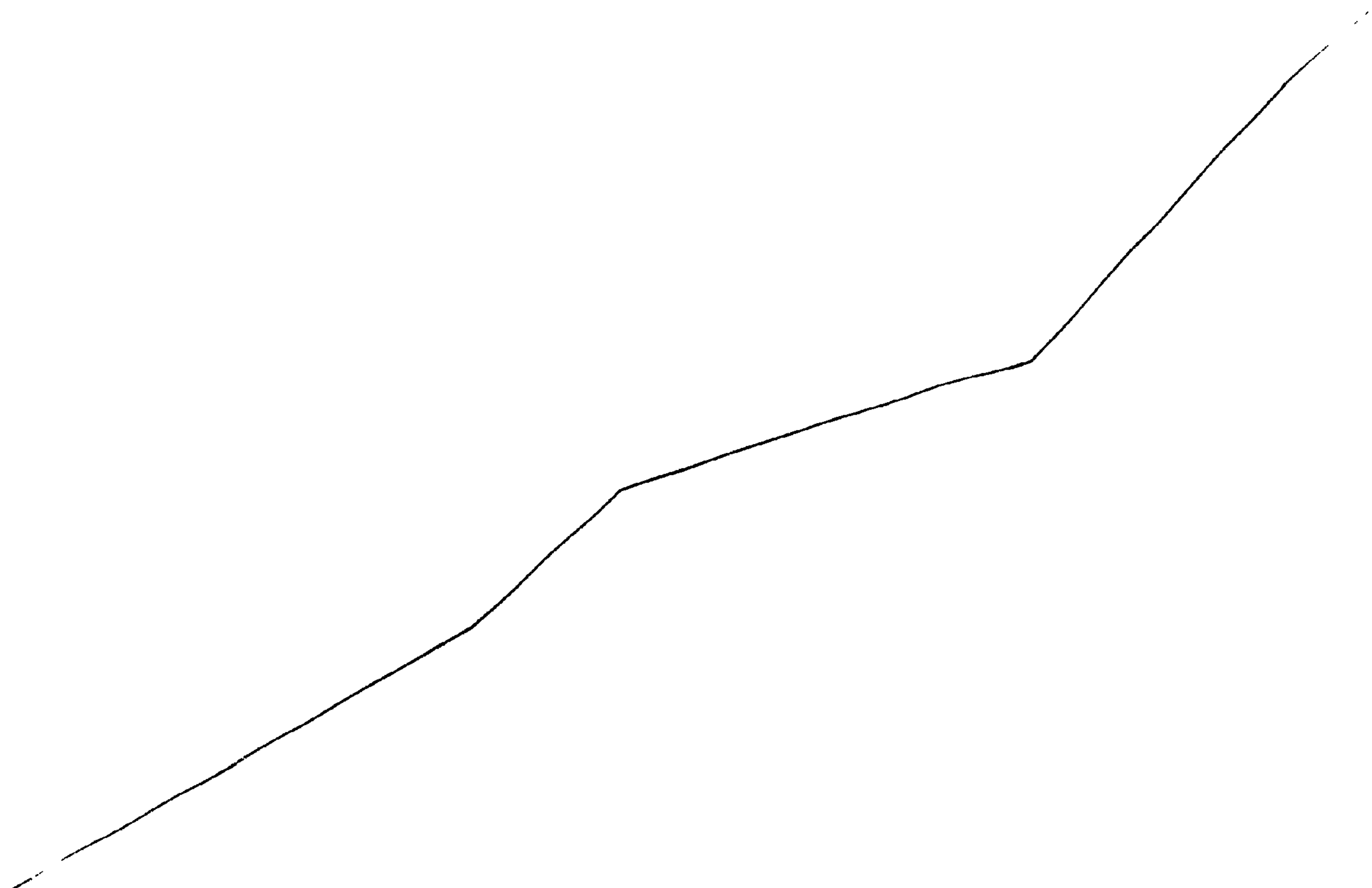
construction of the conservation systems)

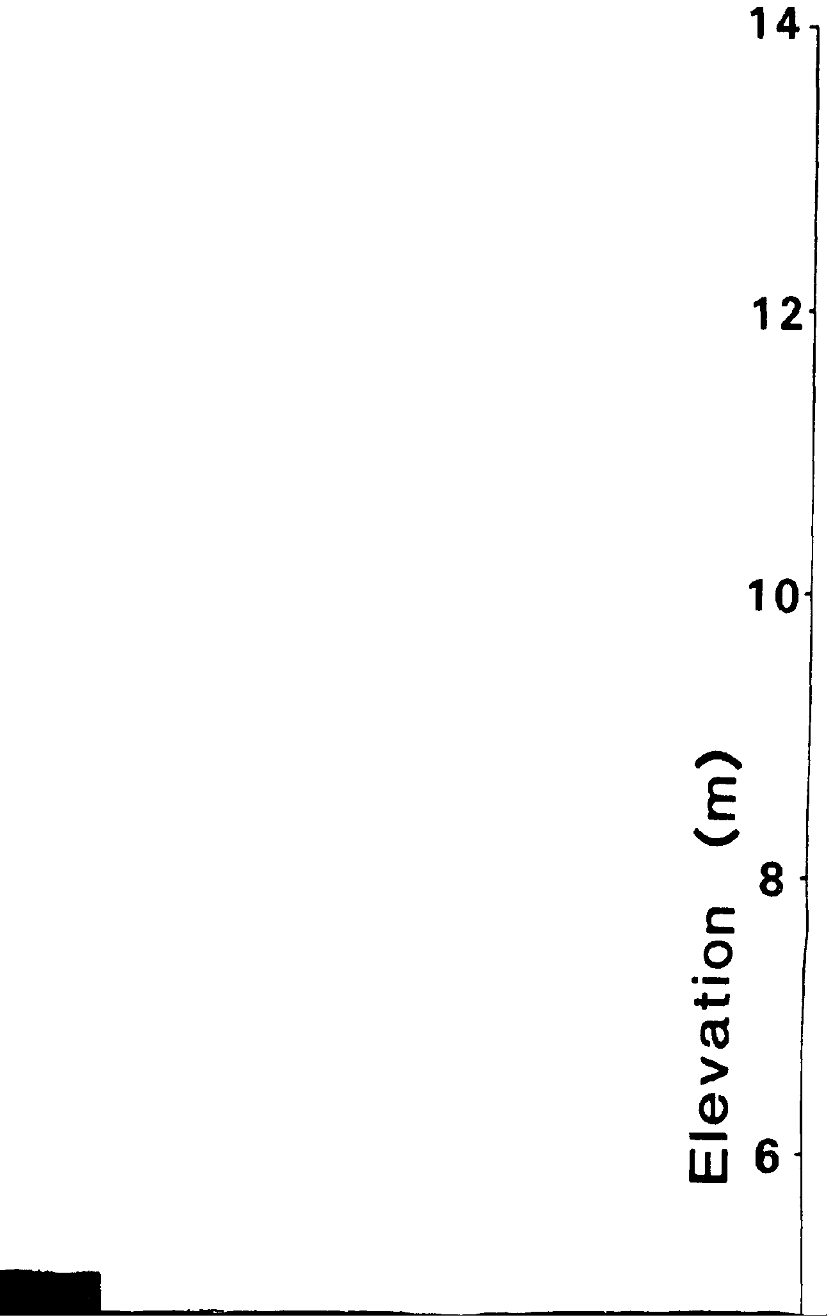
SCALE 1:500

eter Norville October 1989

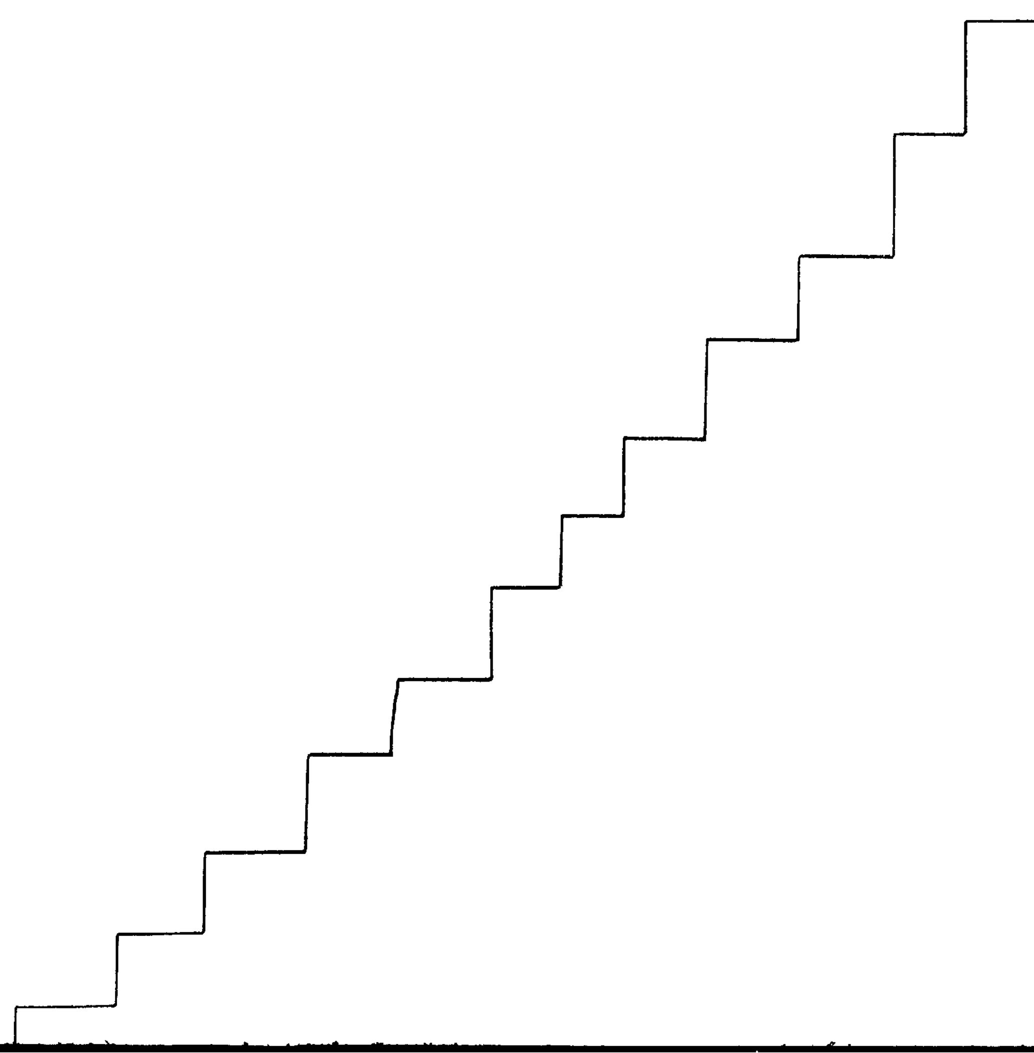


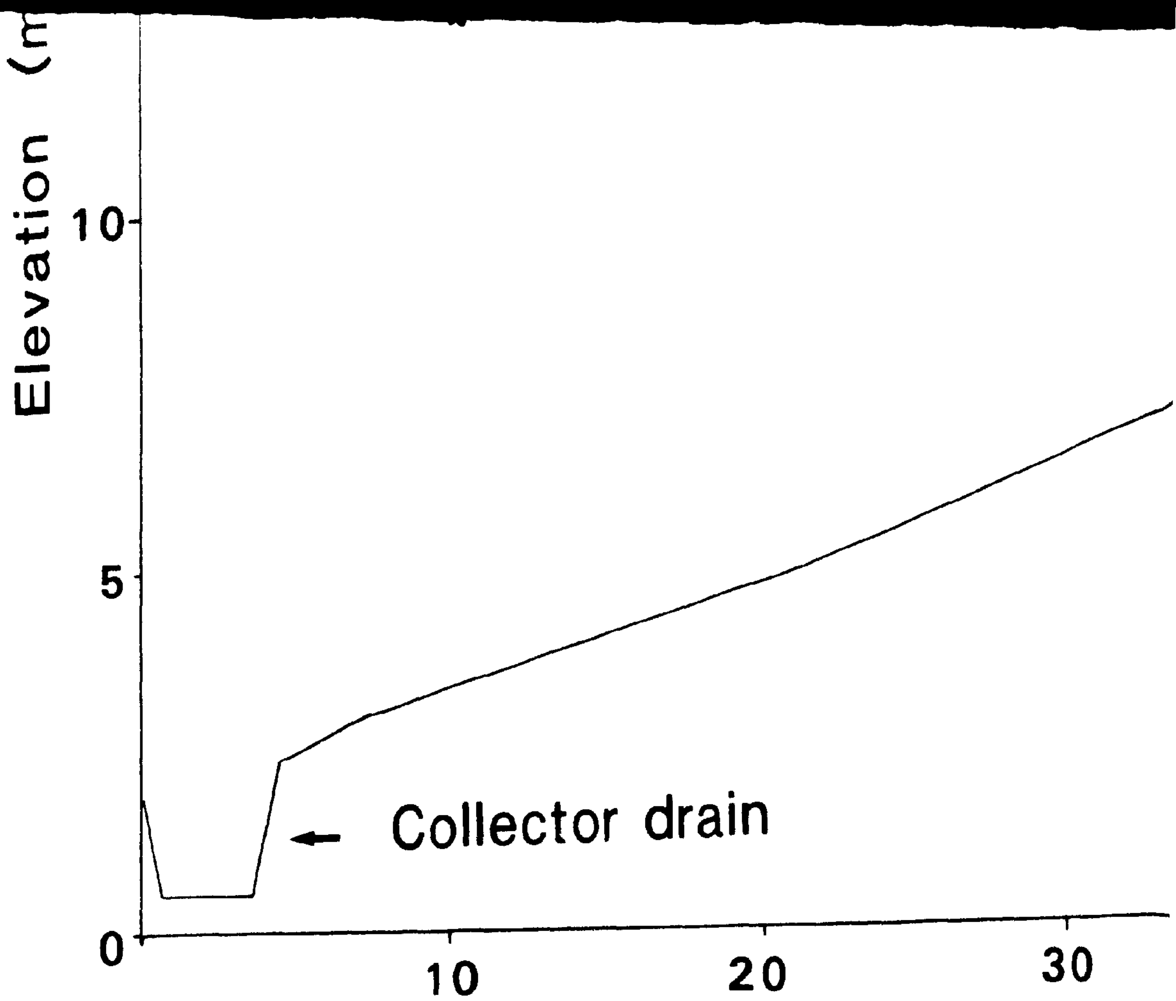
25
20
15
10
Elevation (m)





Elevation (m)
14
12
10
8
6





Elevation (m
10
5
0
Collector drain
10
20
30

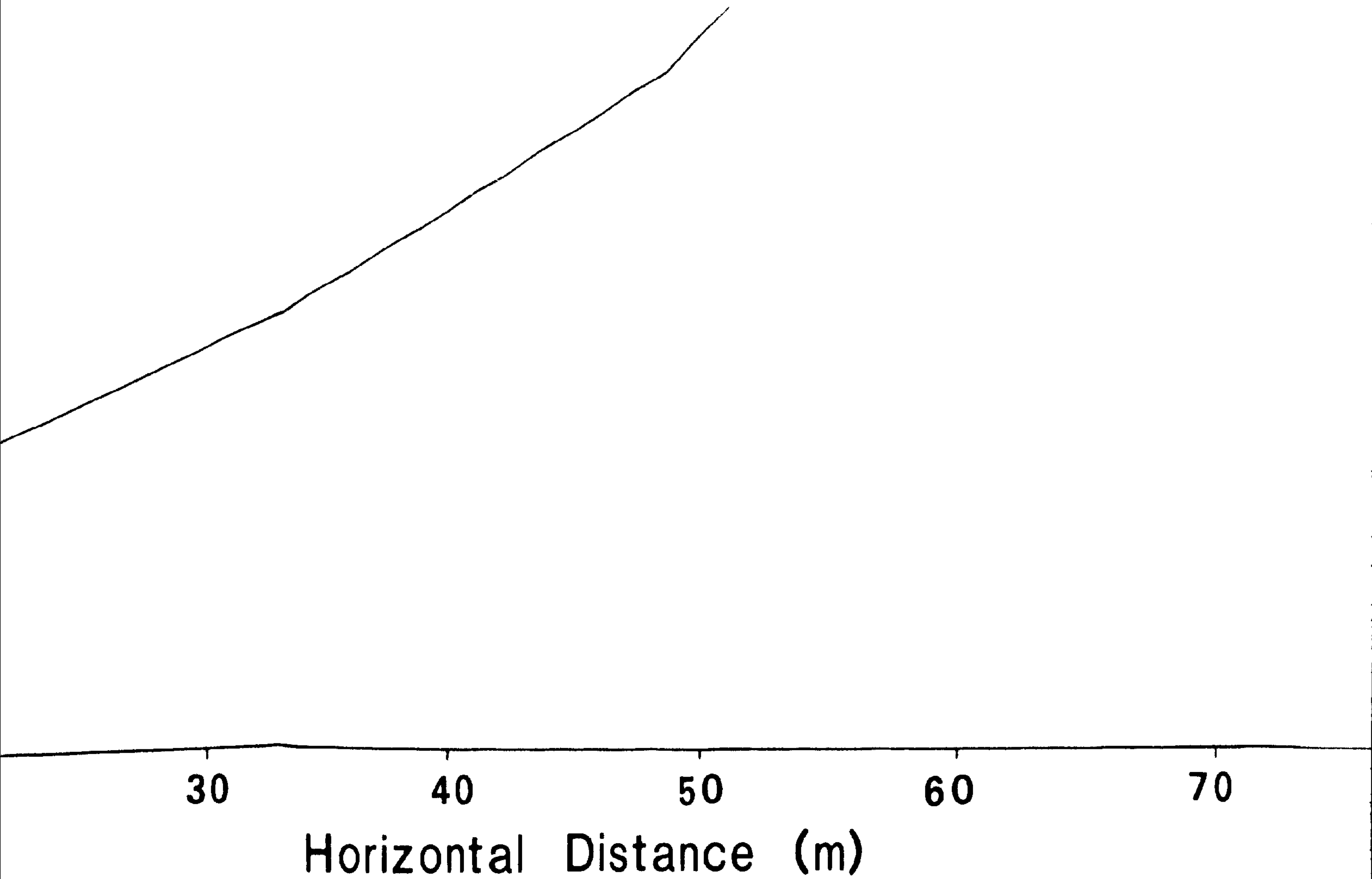
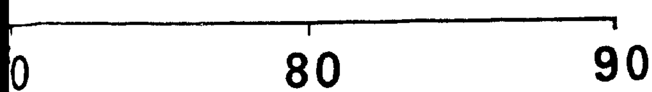
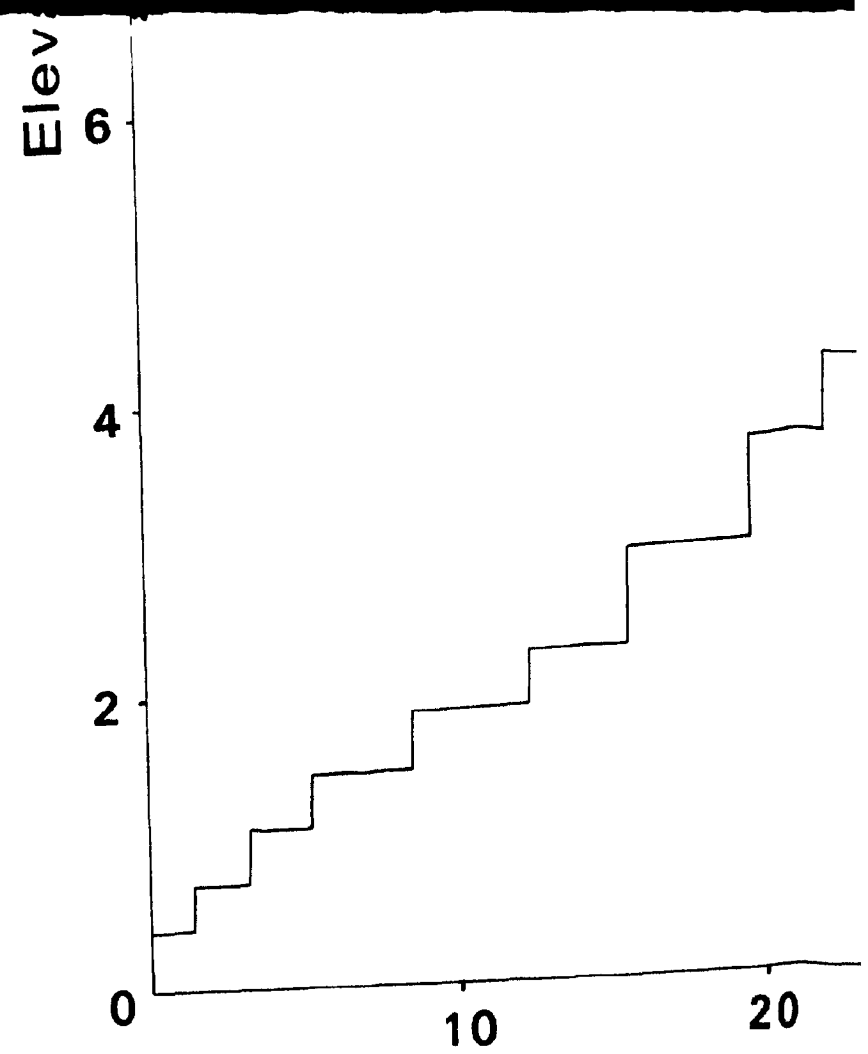


Figure A3. Profile of the Control Plot
(Along line A-A′ in Figure 3.2)


0
80
90


Elev
6
4
2
0
10
20

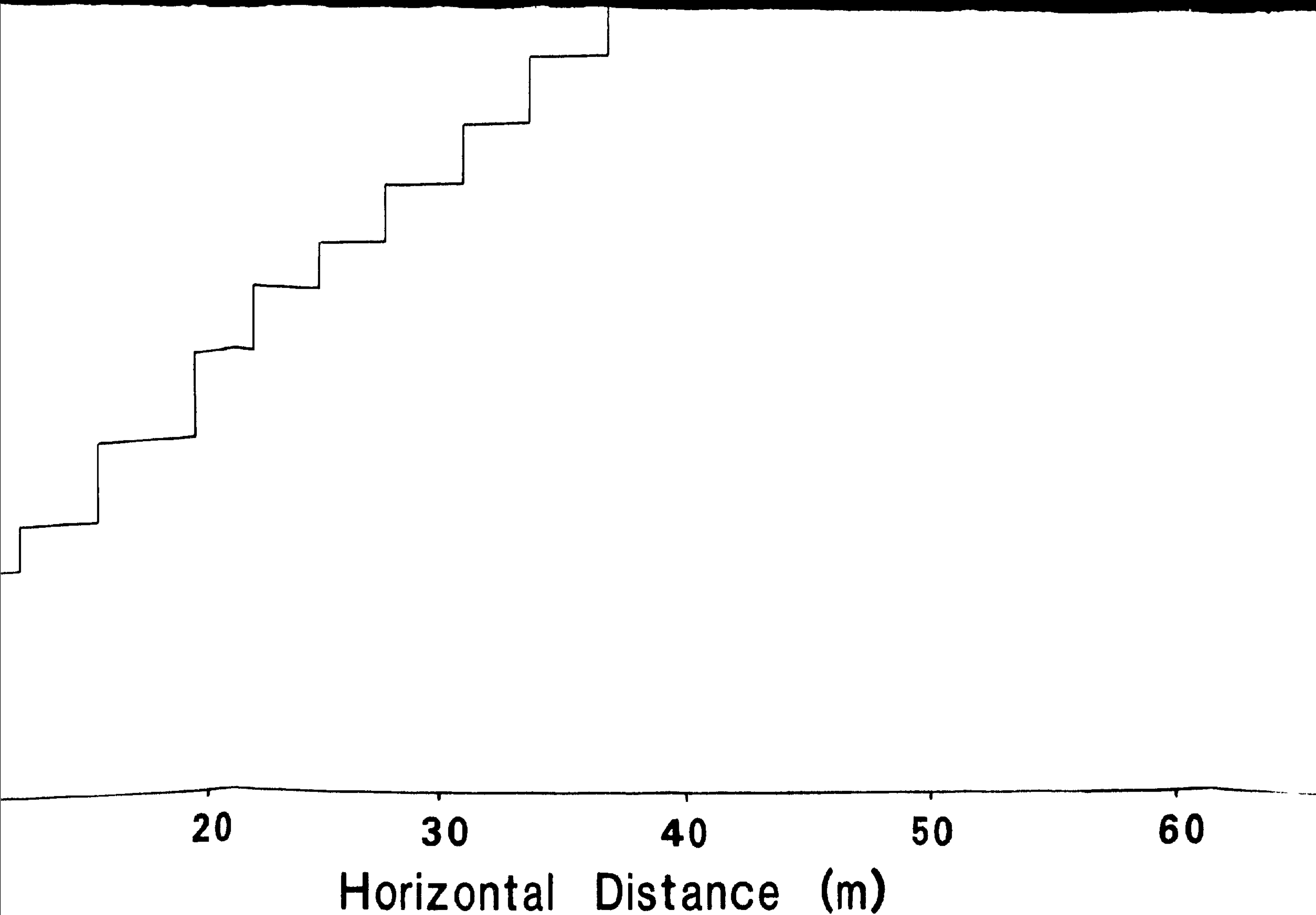
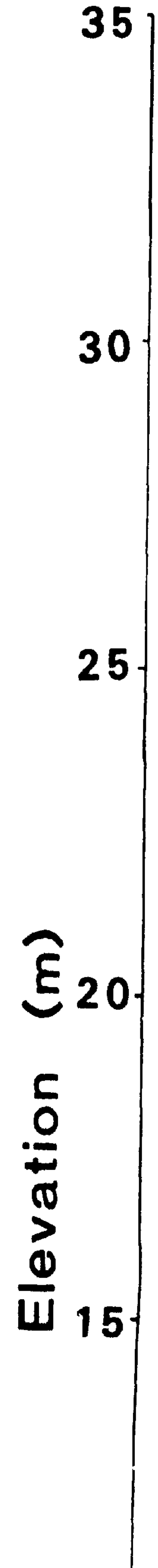
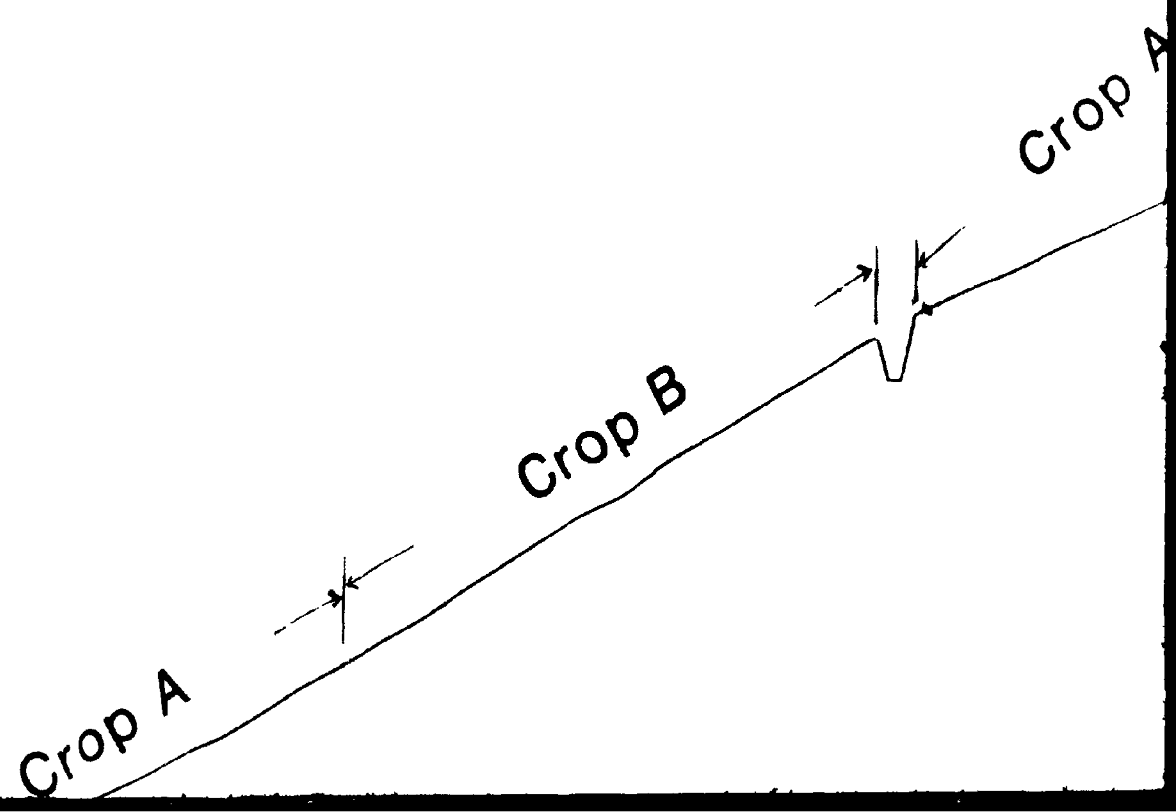


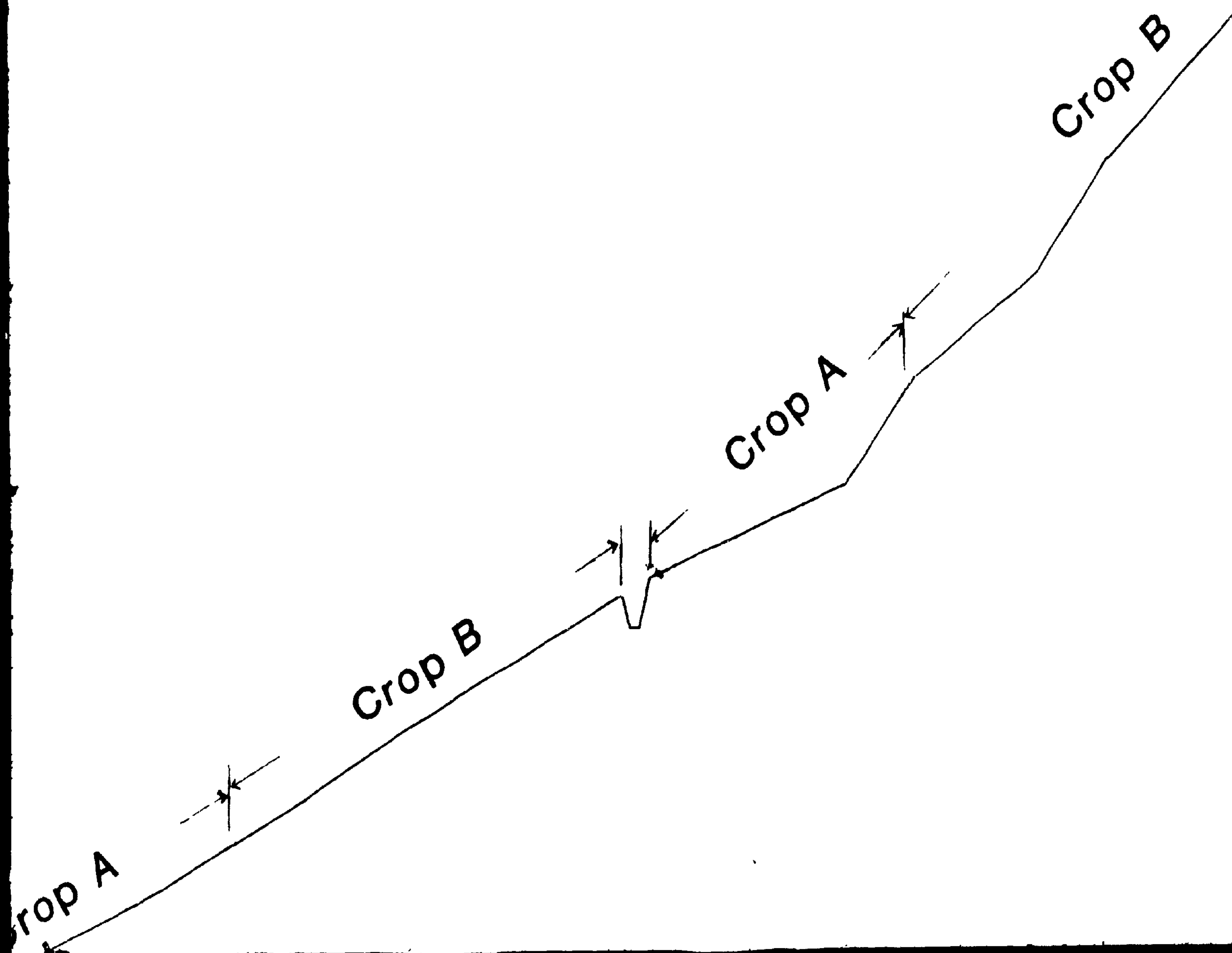
Figure A4. Profile of stepped drain in terraced plot

ed plot


35
30
25
20
15
Elevation (m)

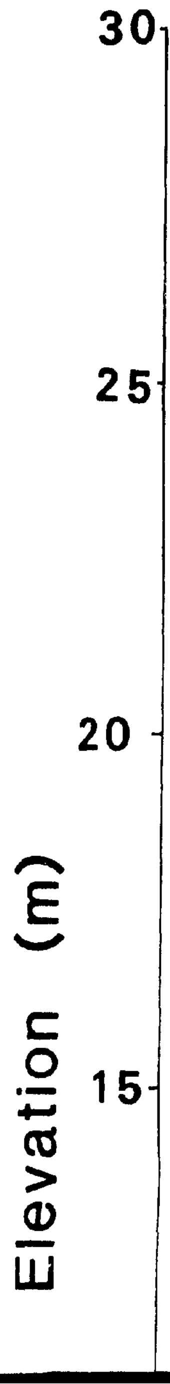


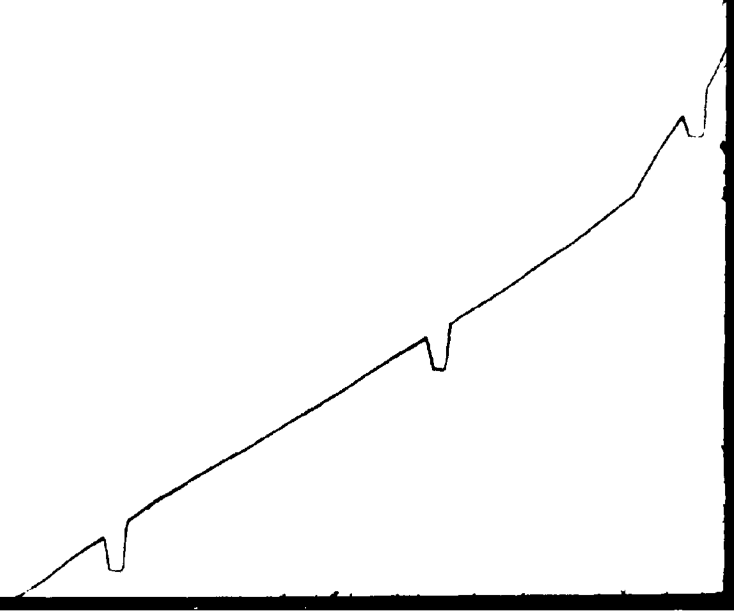
Crop A
Crop B
Crop A

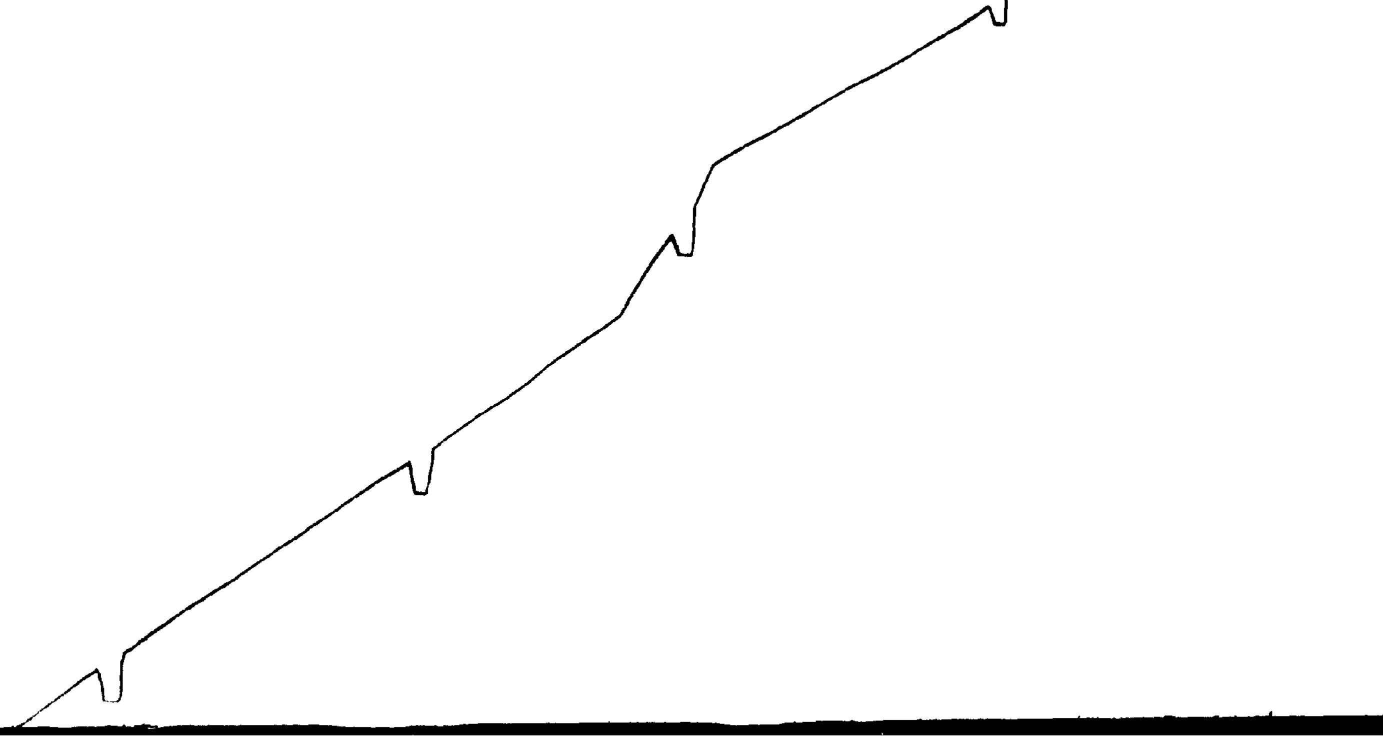


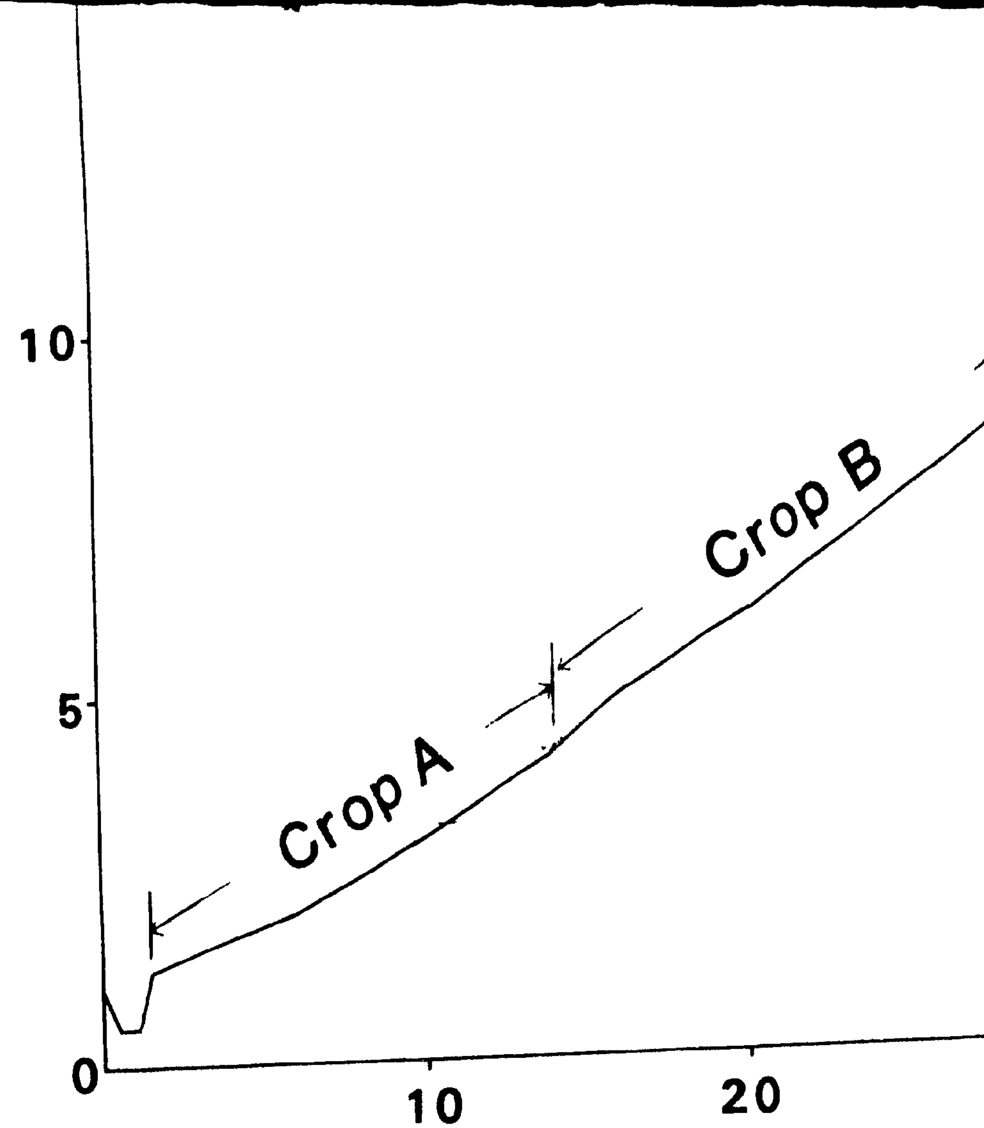
Crop A
Crop B
Crop A
Crop B

Crop B


30
25
20
15
Elevation (m)






10
5
0
10
20
Crop A
Crop B

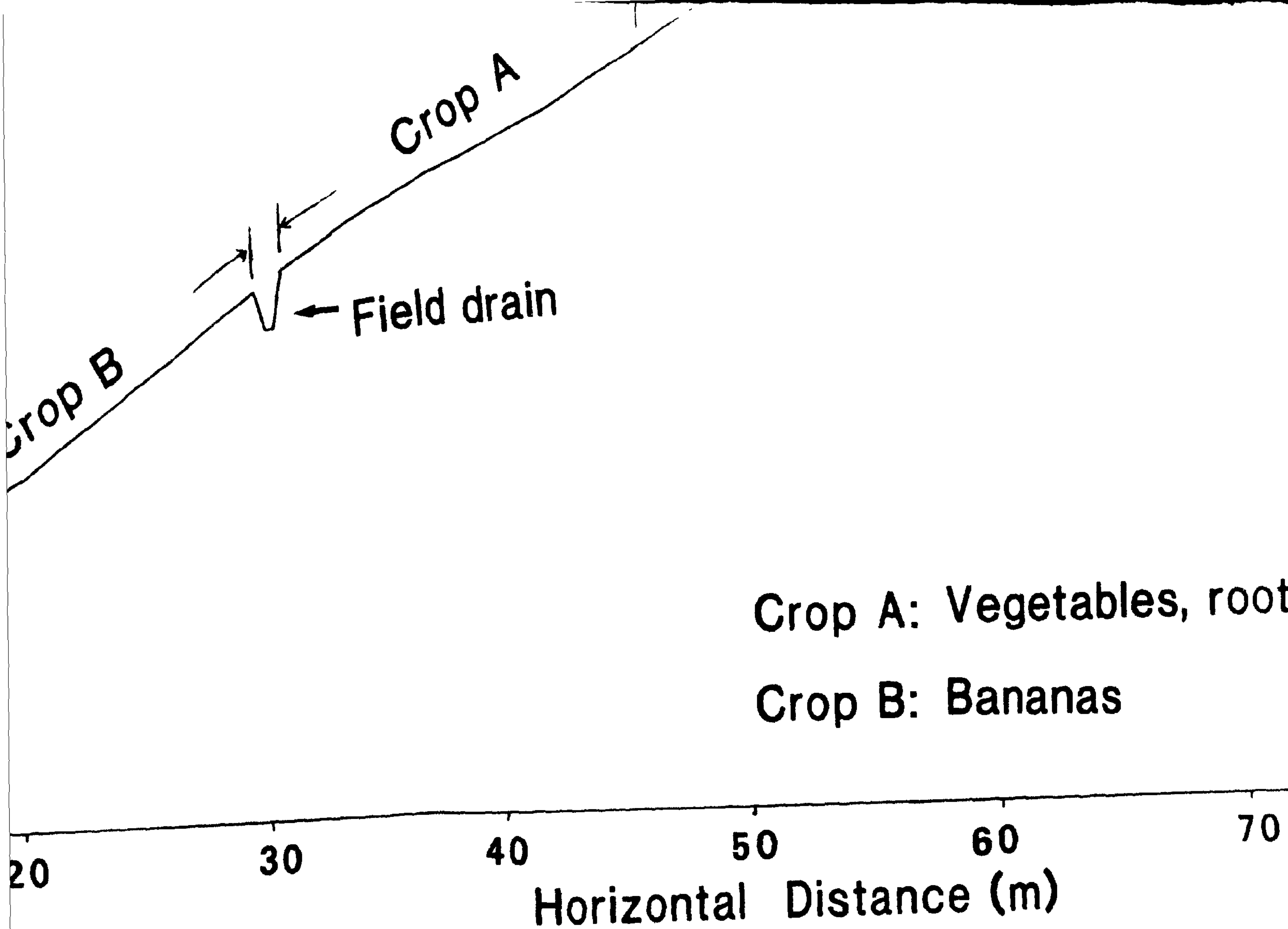


Figure A6. Profile of the Strip Croppe
(Along line C–C′ in Figure 3.7)

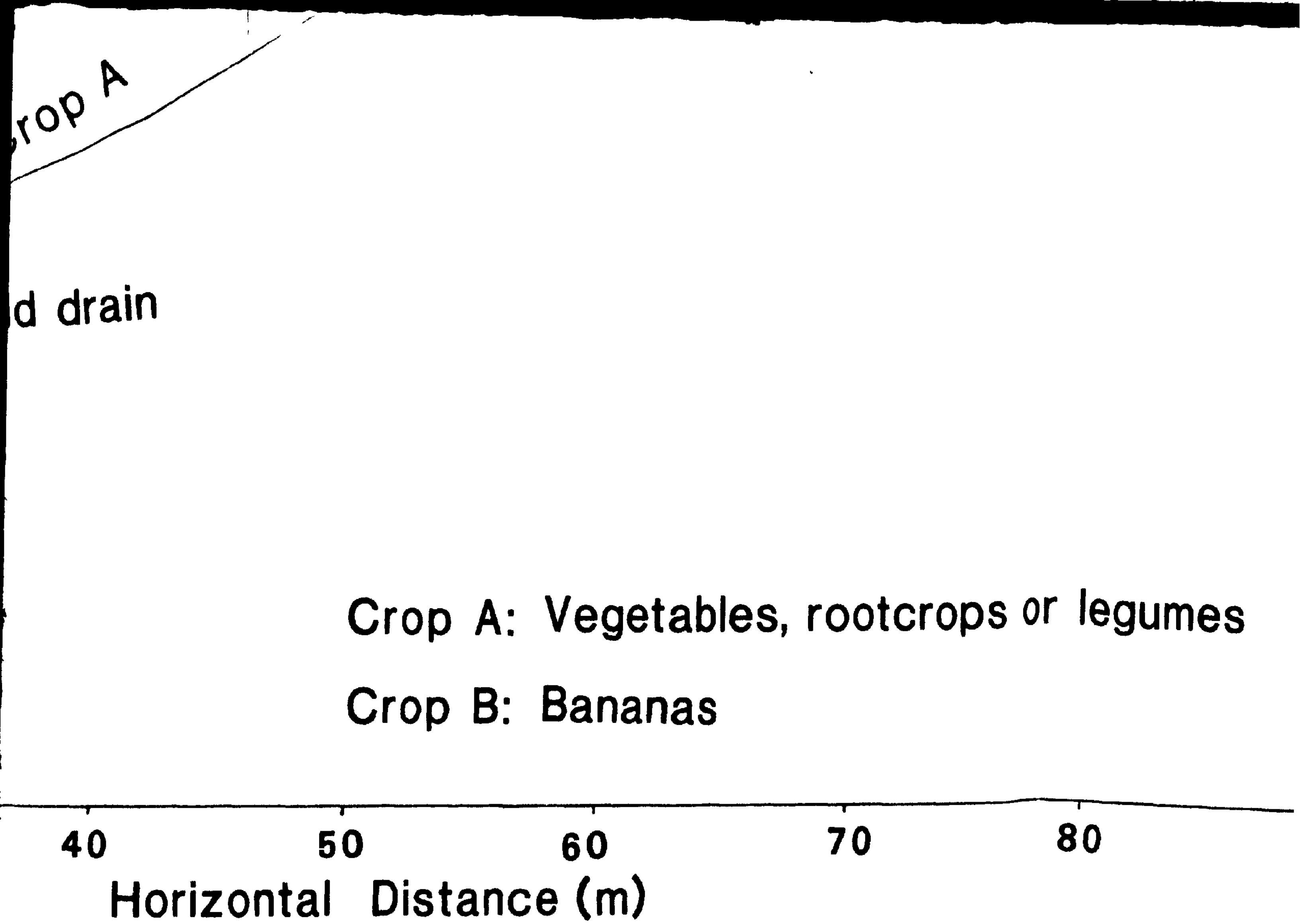
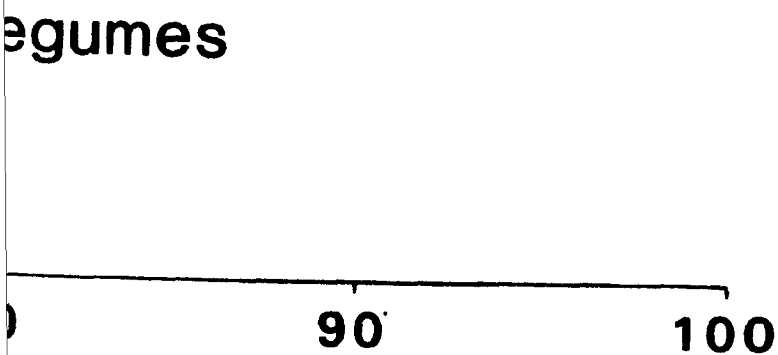
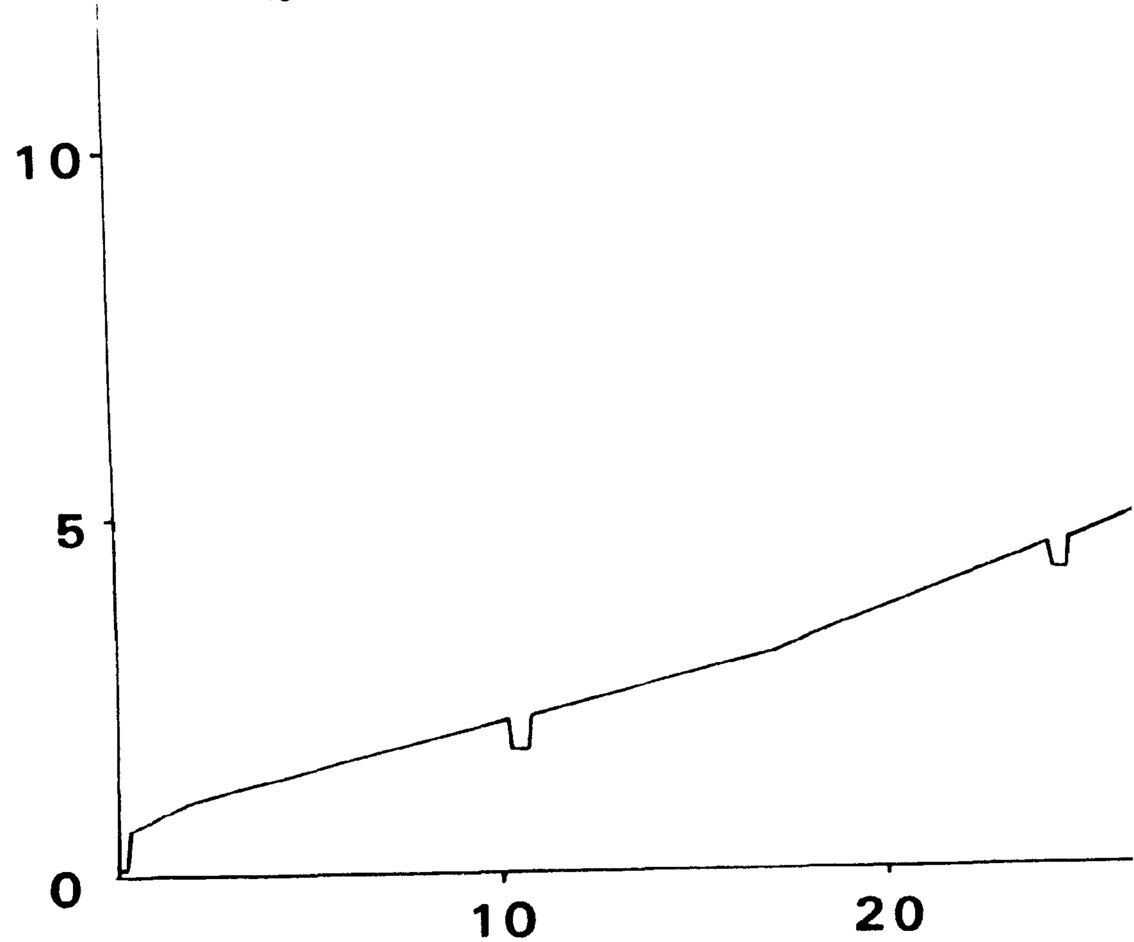


Figure A6. Profile of the Strip Cropped Plot
(Along line C–C′ in Figure 3.7)


egumes
90
100


10
5
0
10
20

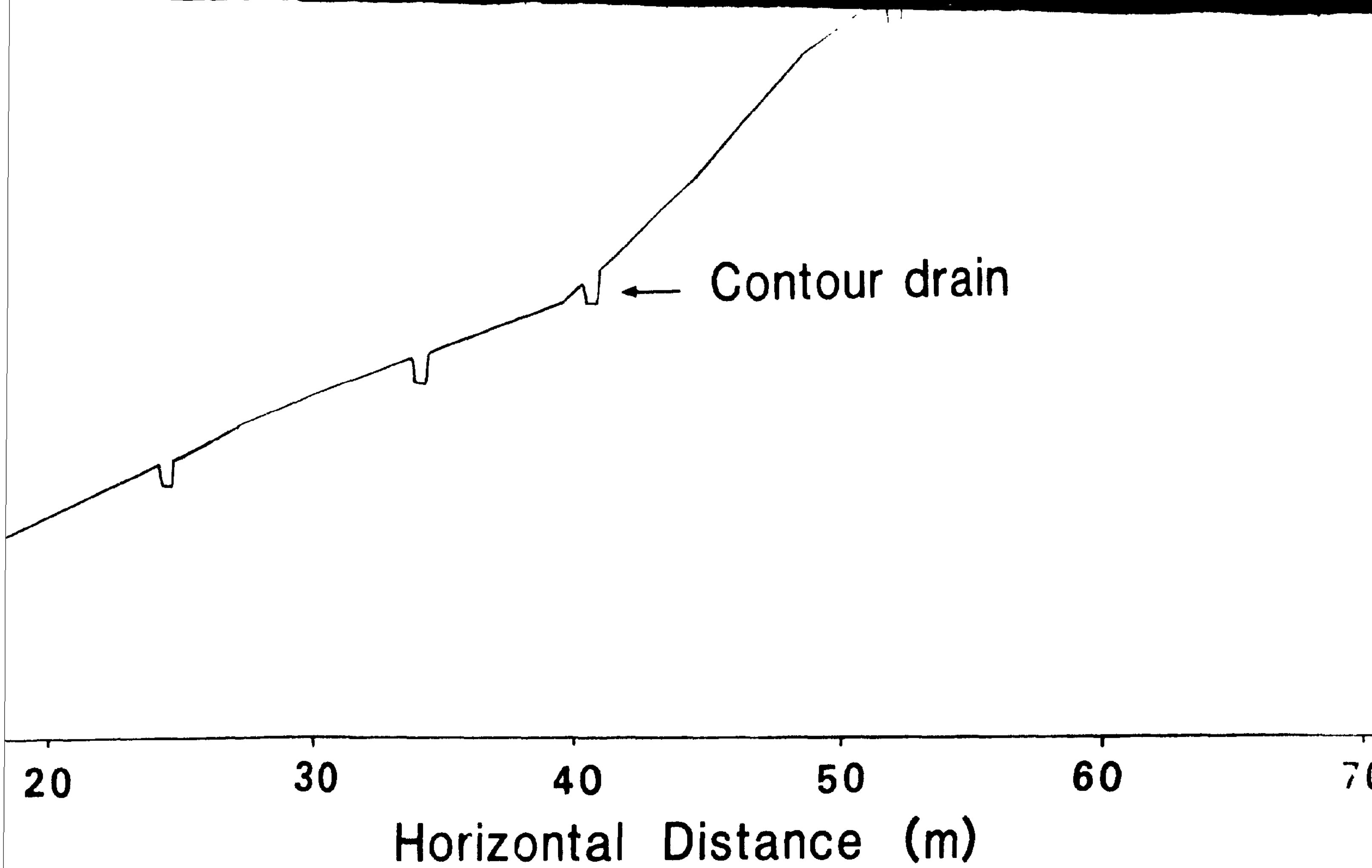
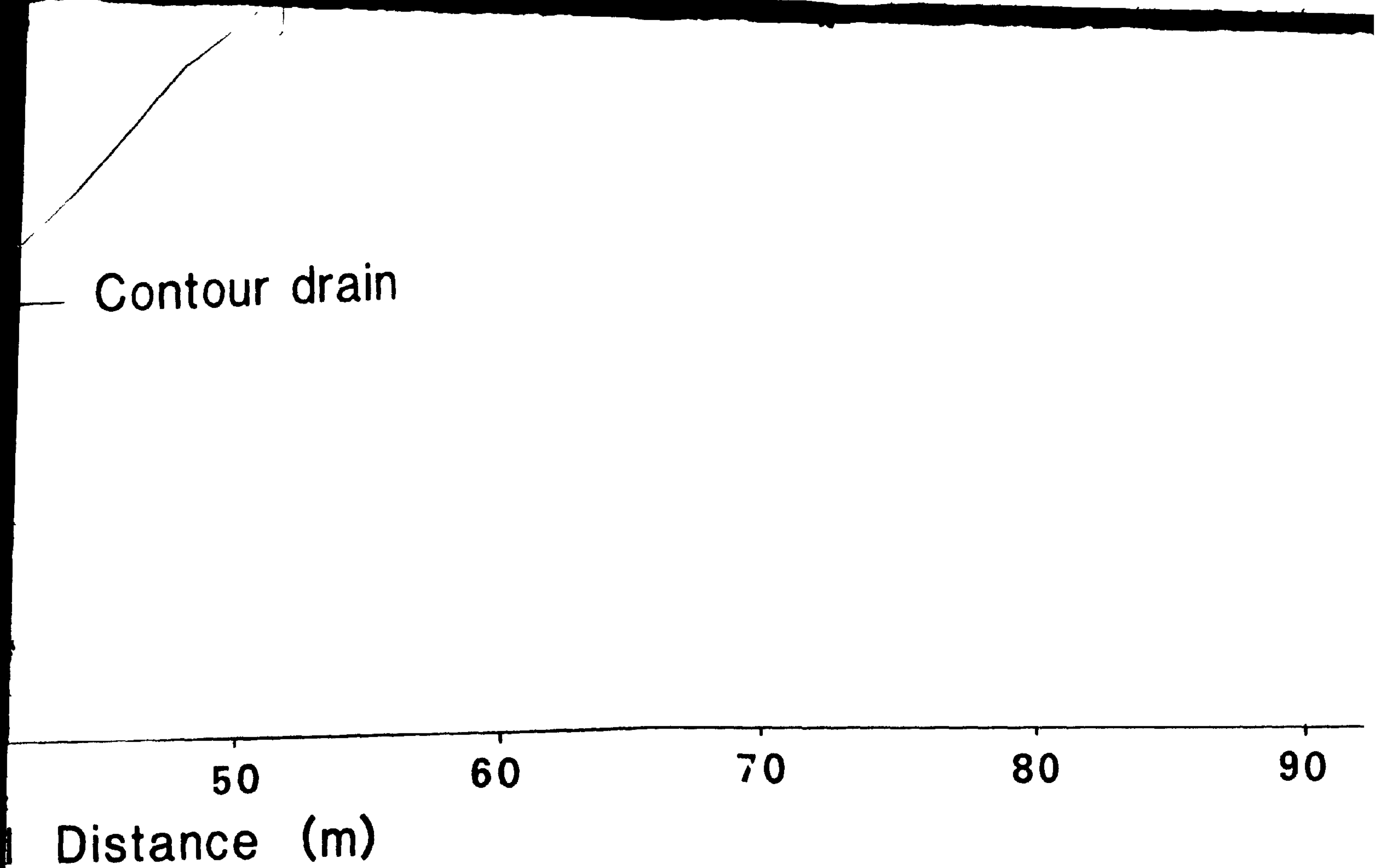
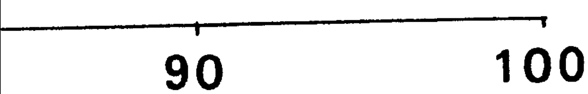
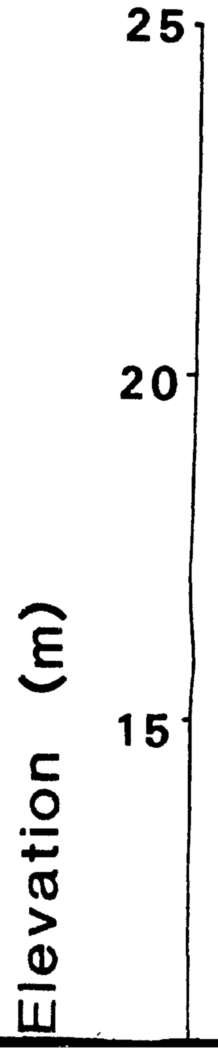


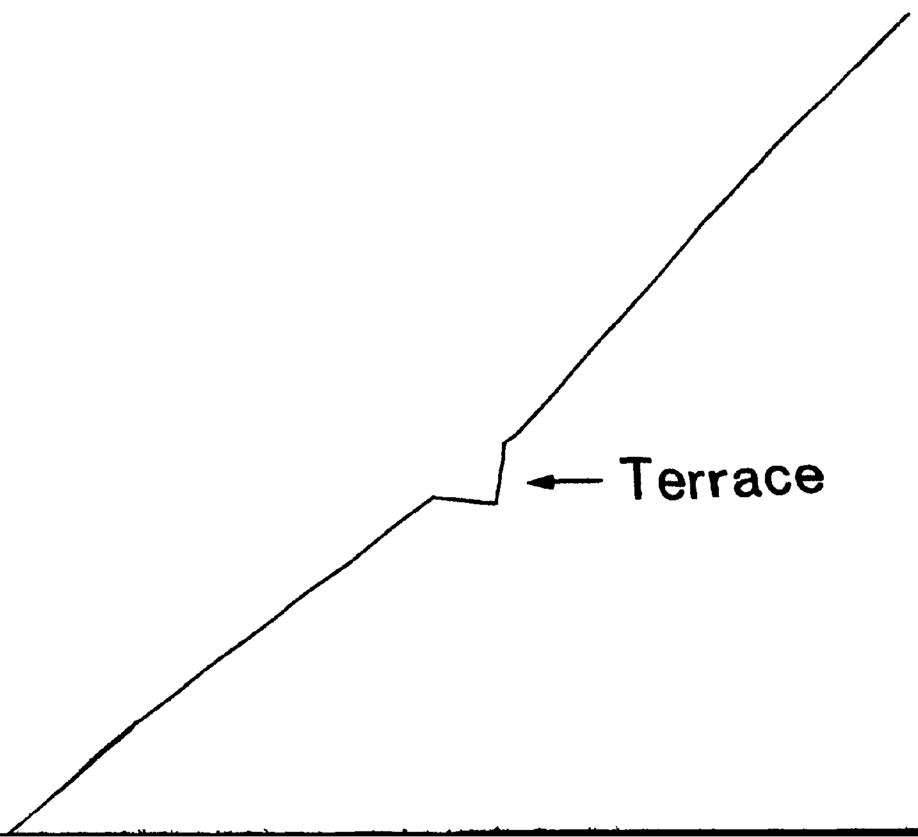
Figure A5. Profile of the Contour Drained Plot
(Along line B–B′ in Figure 3.4)



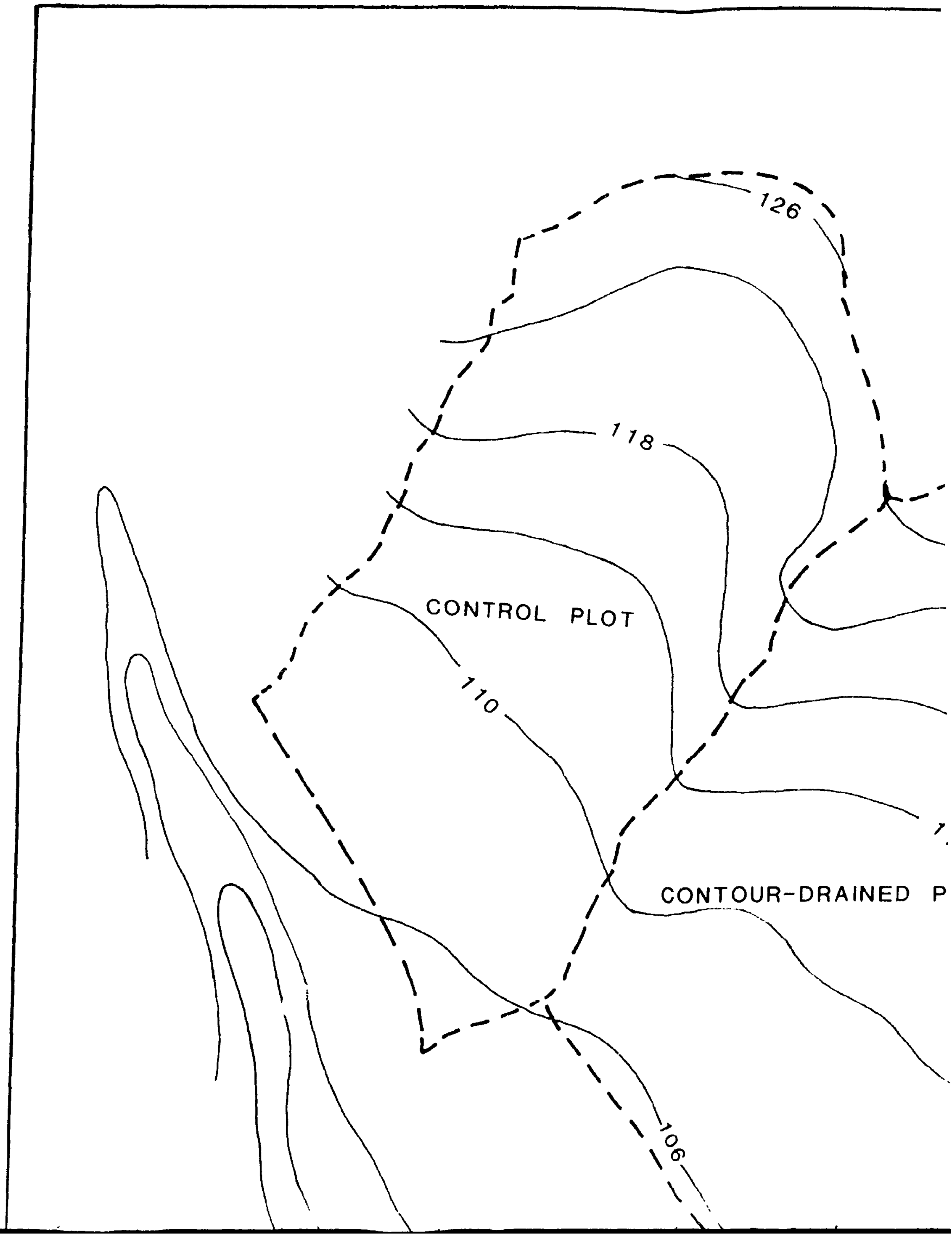
ofile of the Contour Drained Plot
line B–B′ in Figure 3.4)

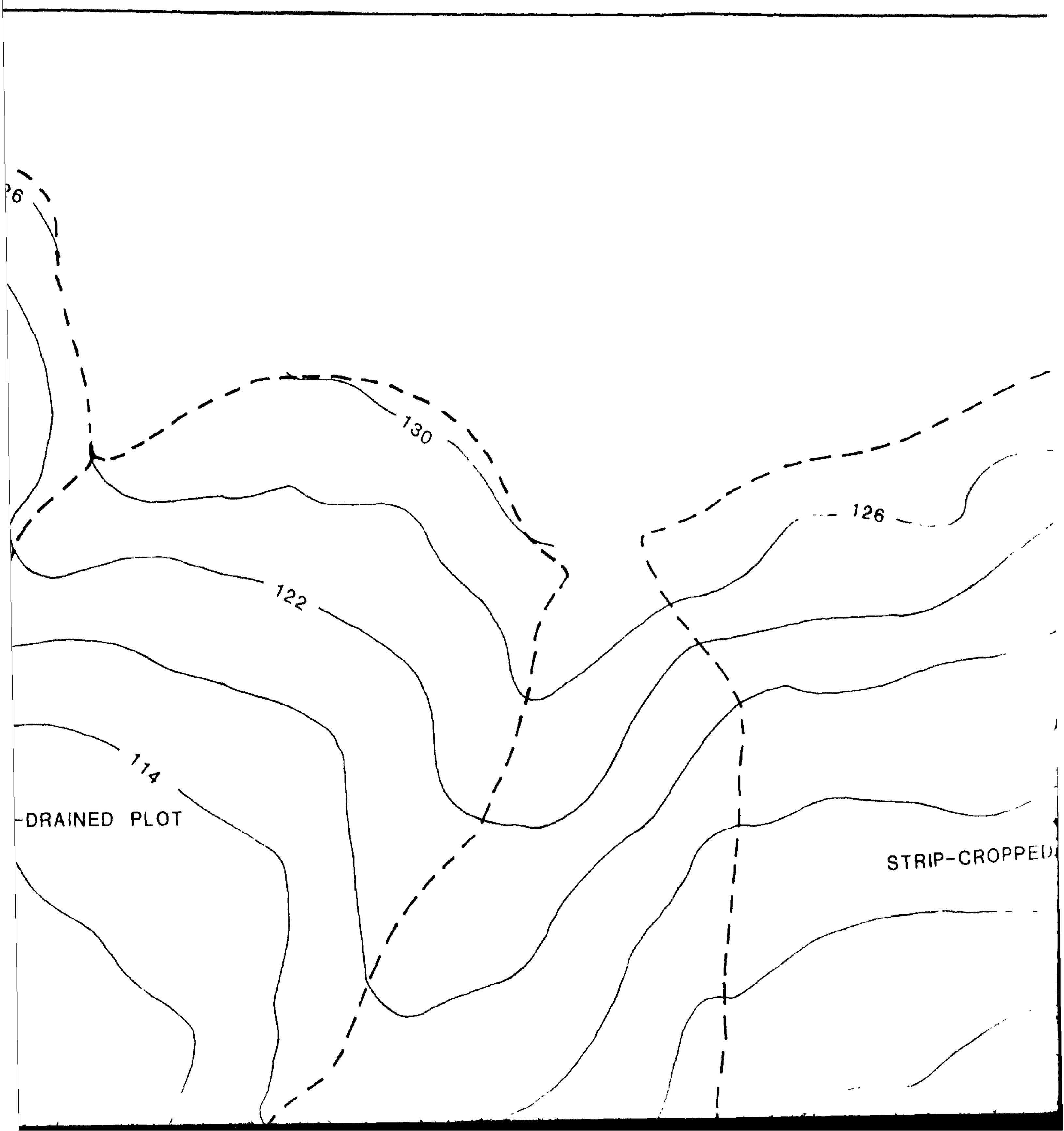

90
100


25
20
15
Elevation (m)

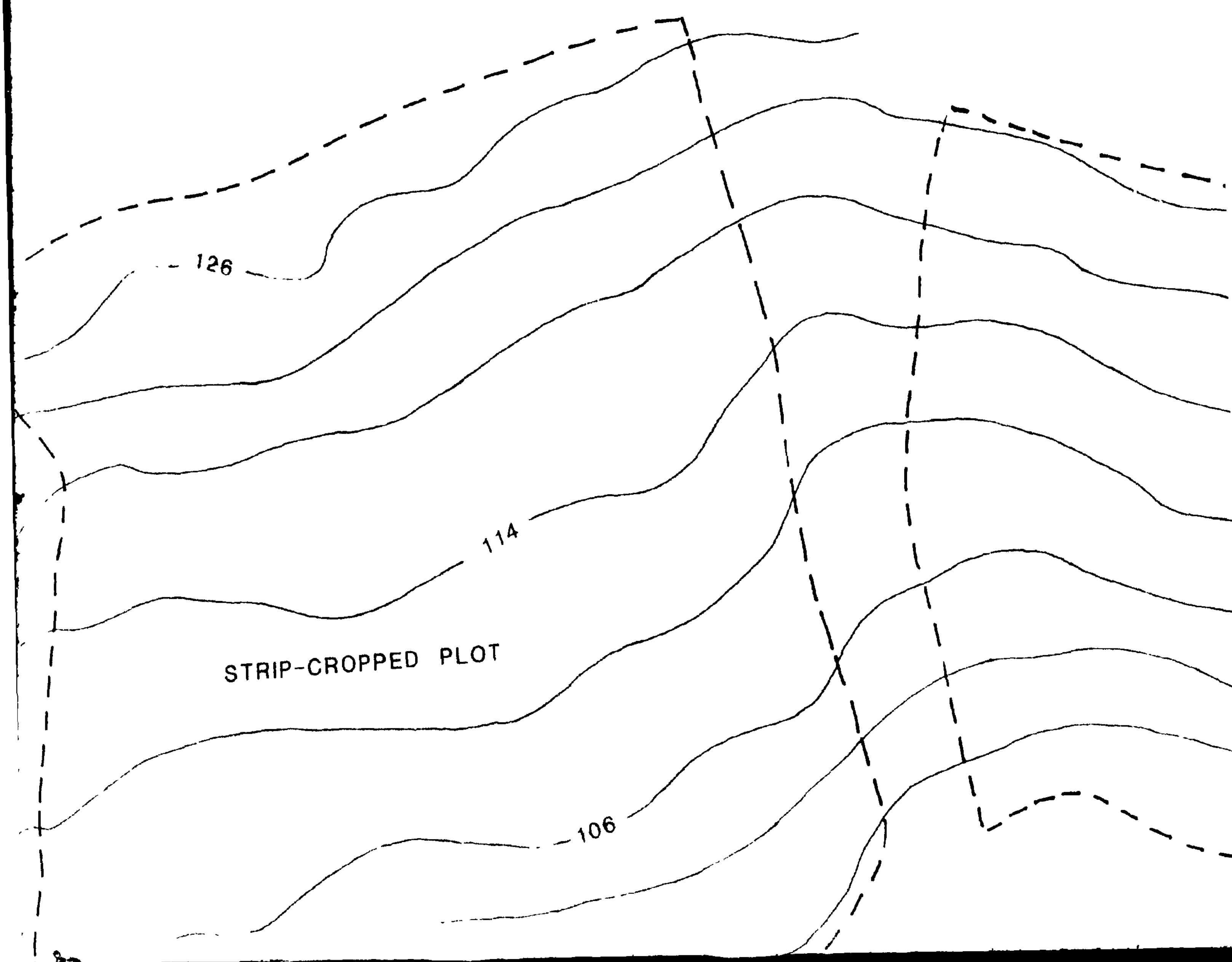

Terrace

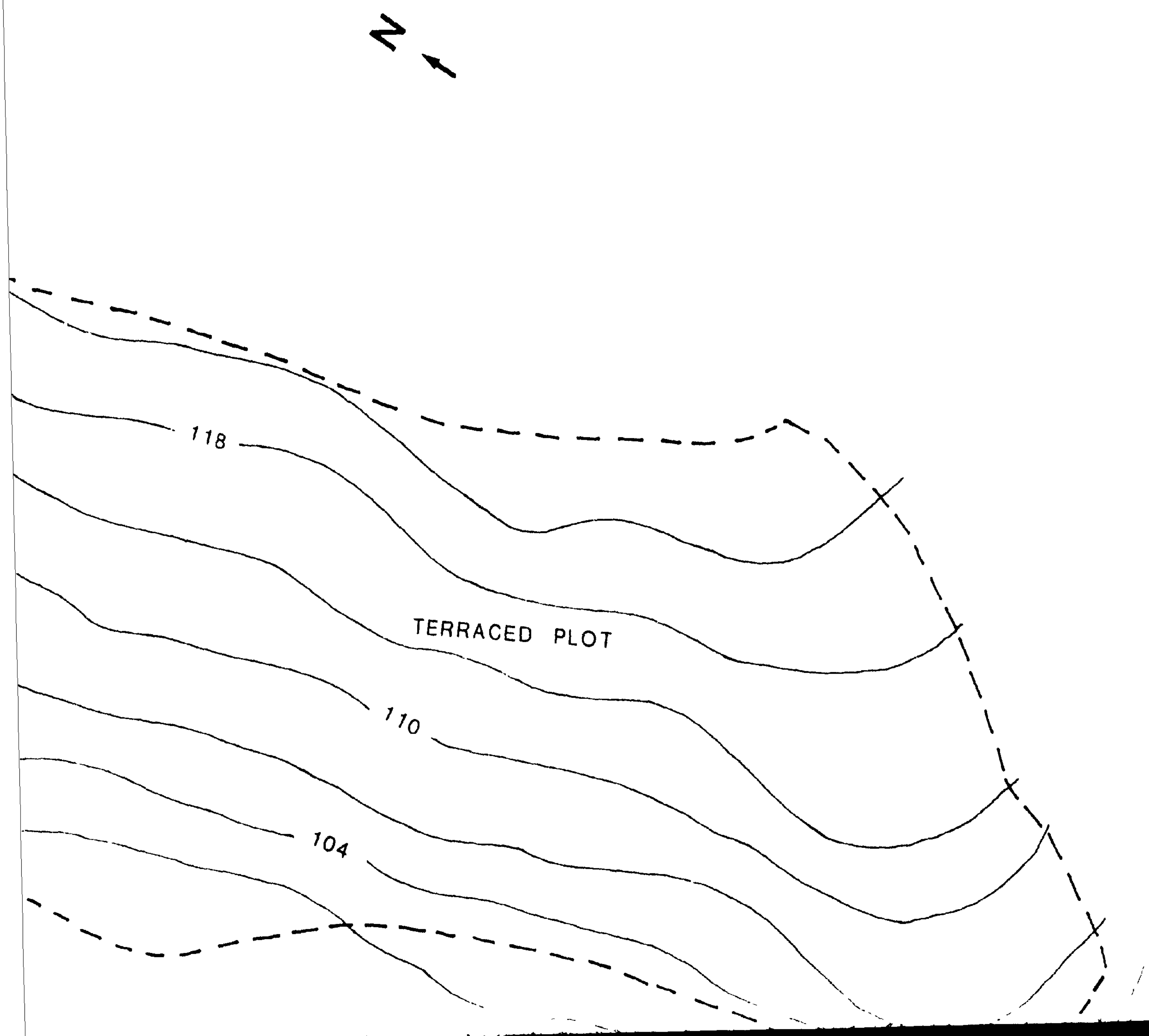
Terrace

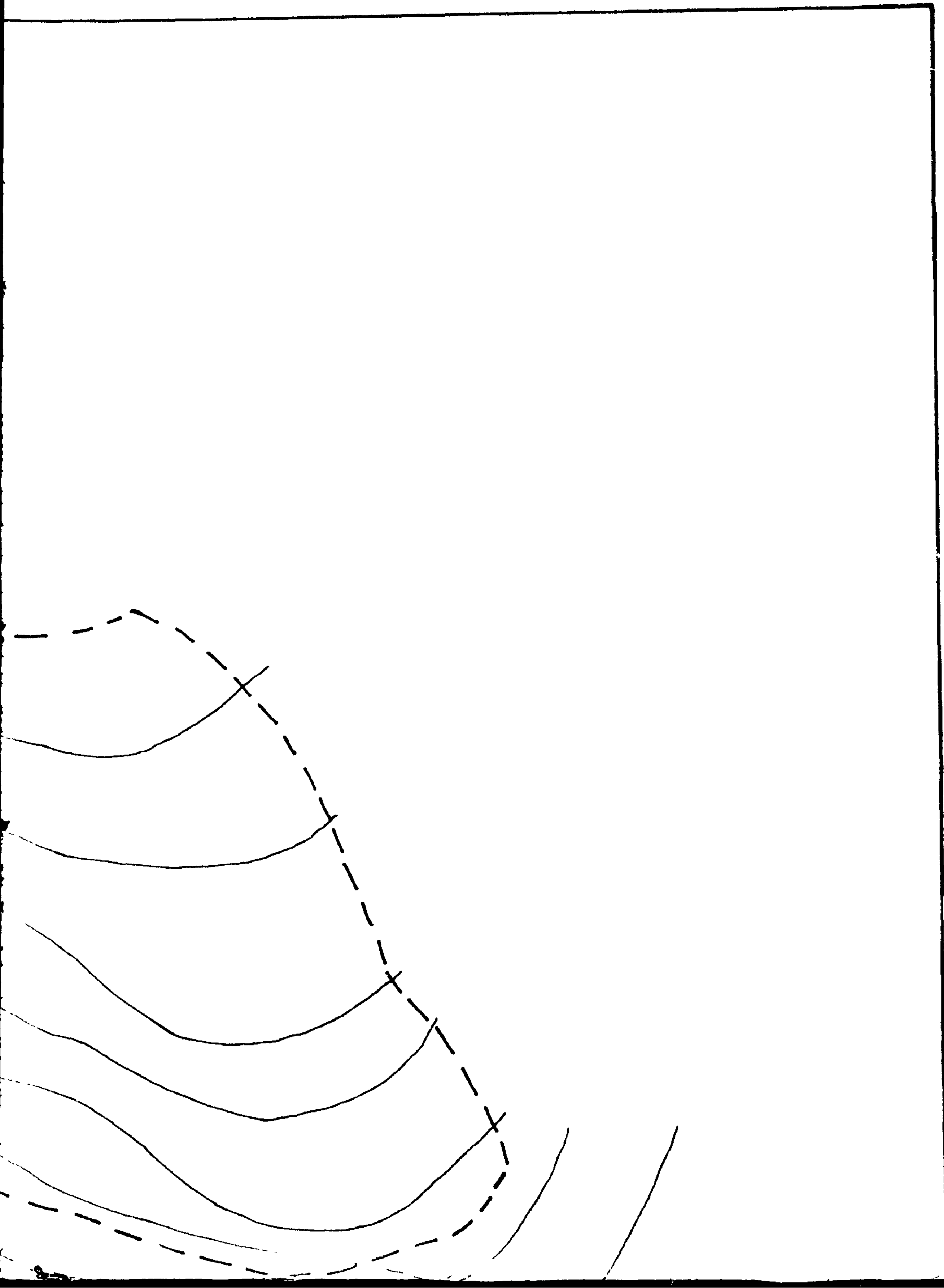

126
118
CONTROL PLOT
110
CONTOUR-DRAINED P
106



130
122
114
126
-DRAINED PLOT
STRIP-CROPPED


126
114
STRIP-CROPPED PLOT
106


N
118
TERRACED PLOT
110
104



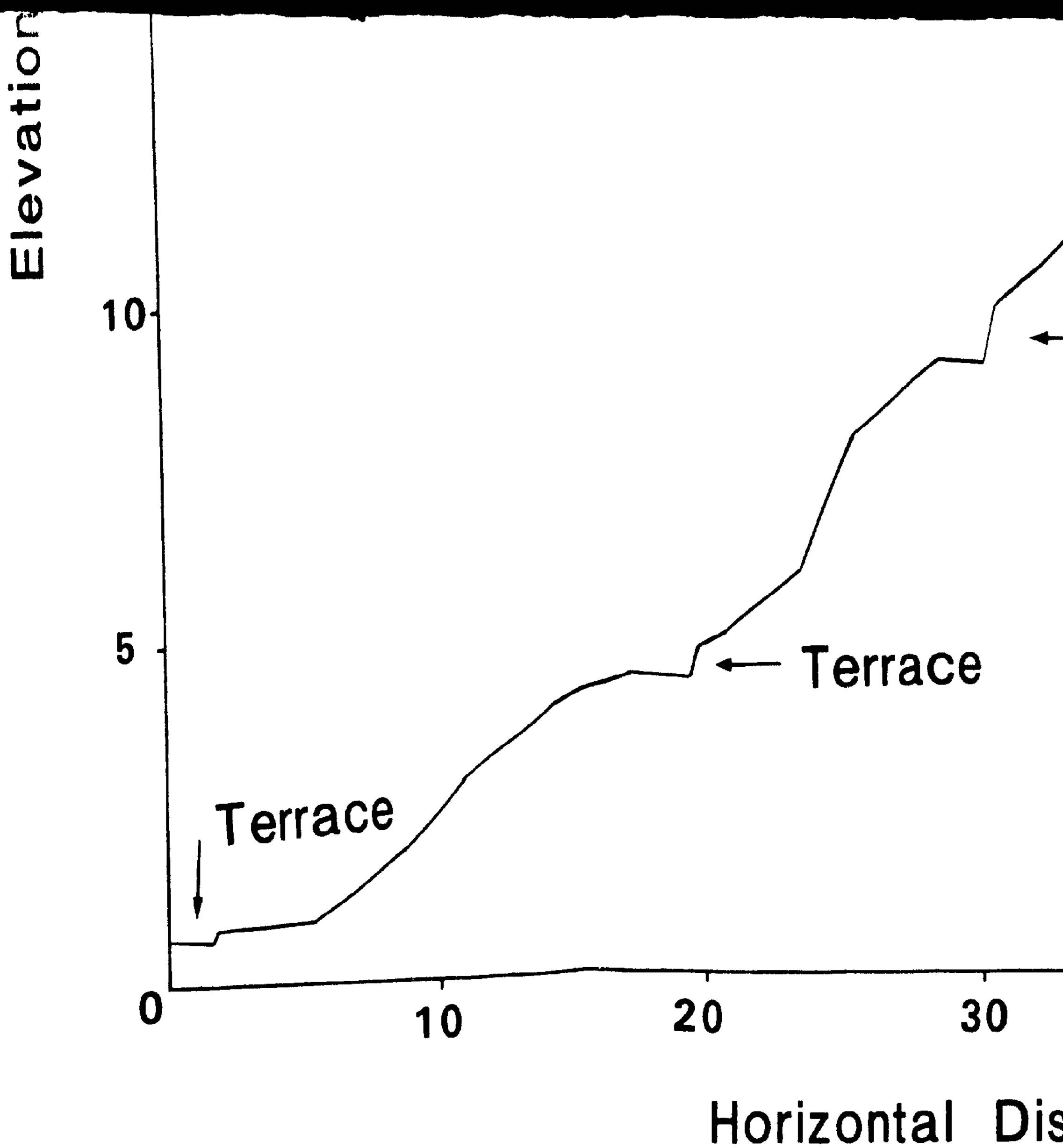
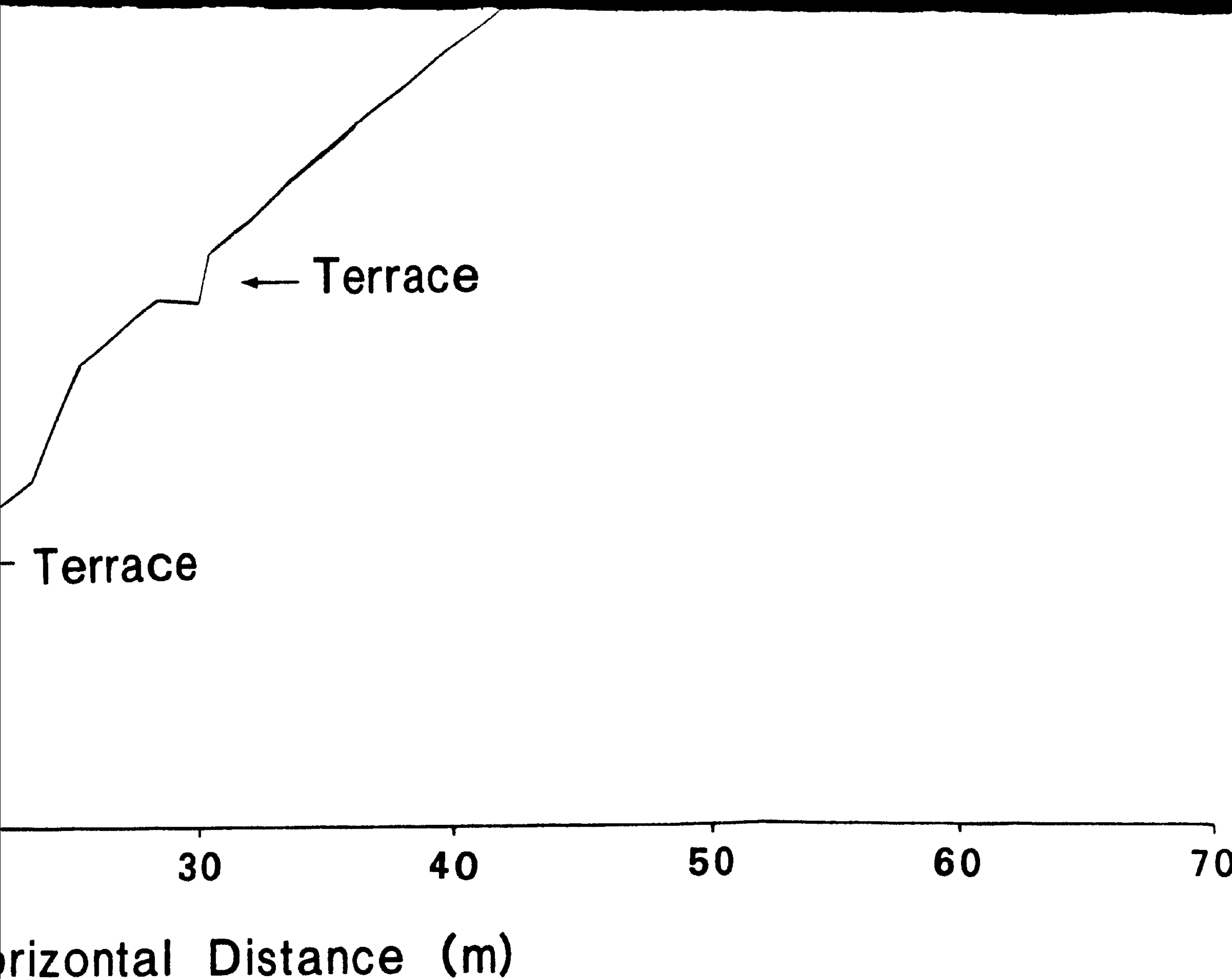
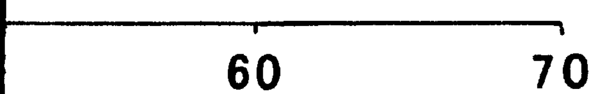
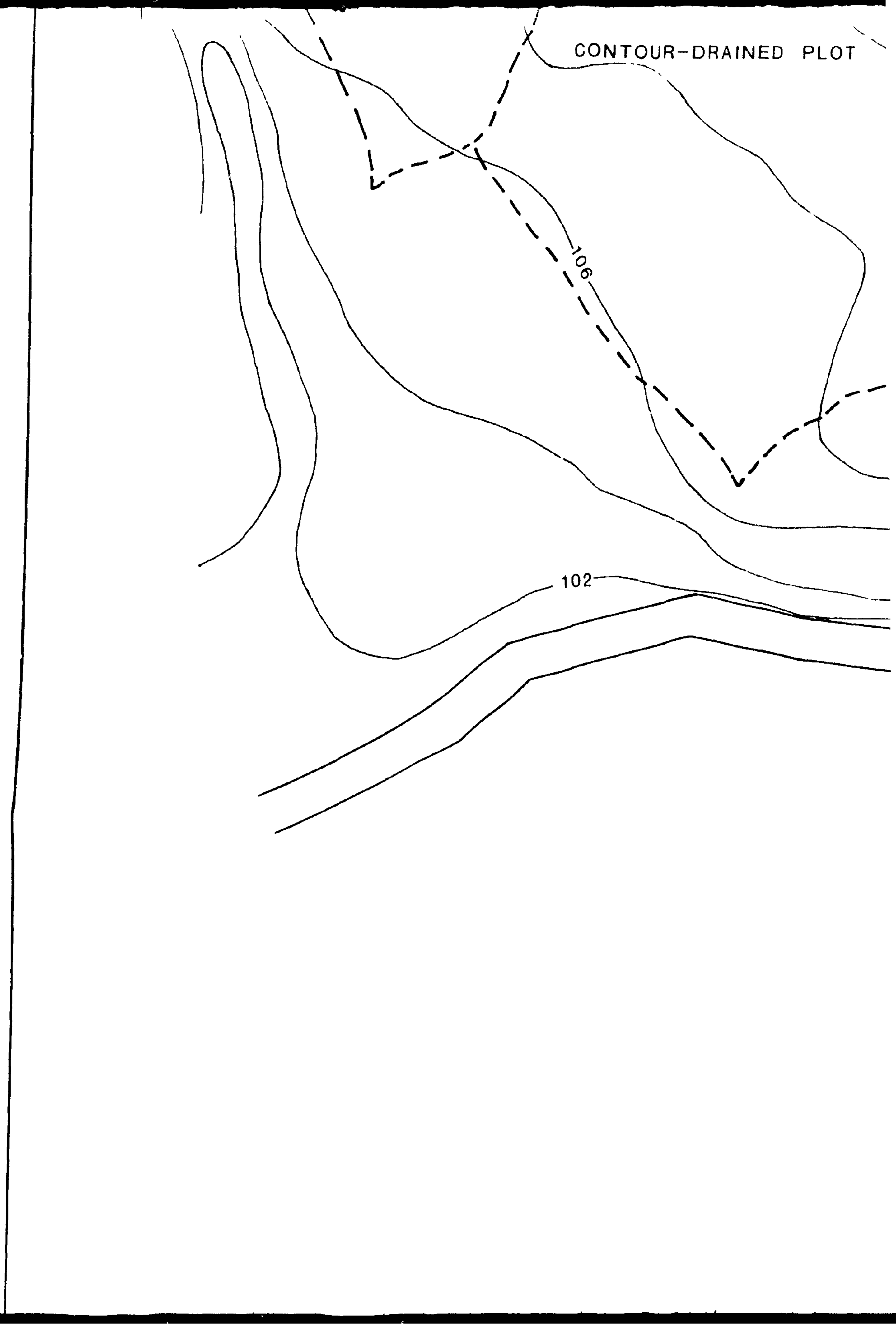


Figure A7. Profile c
(Along line D-

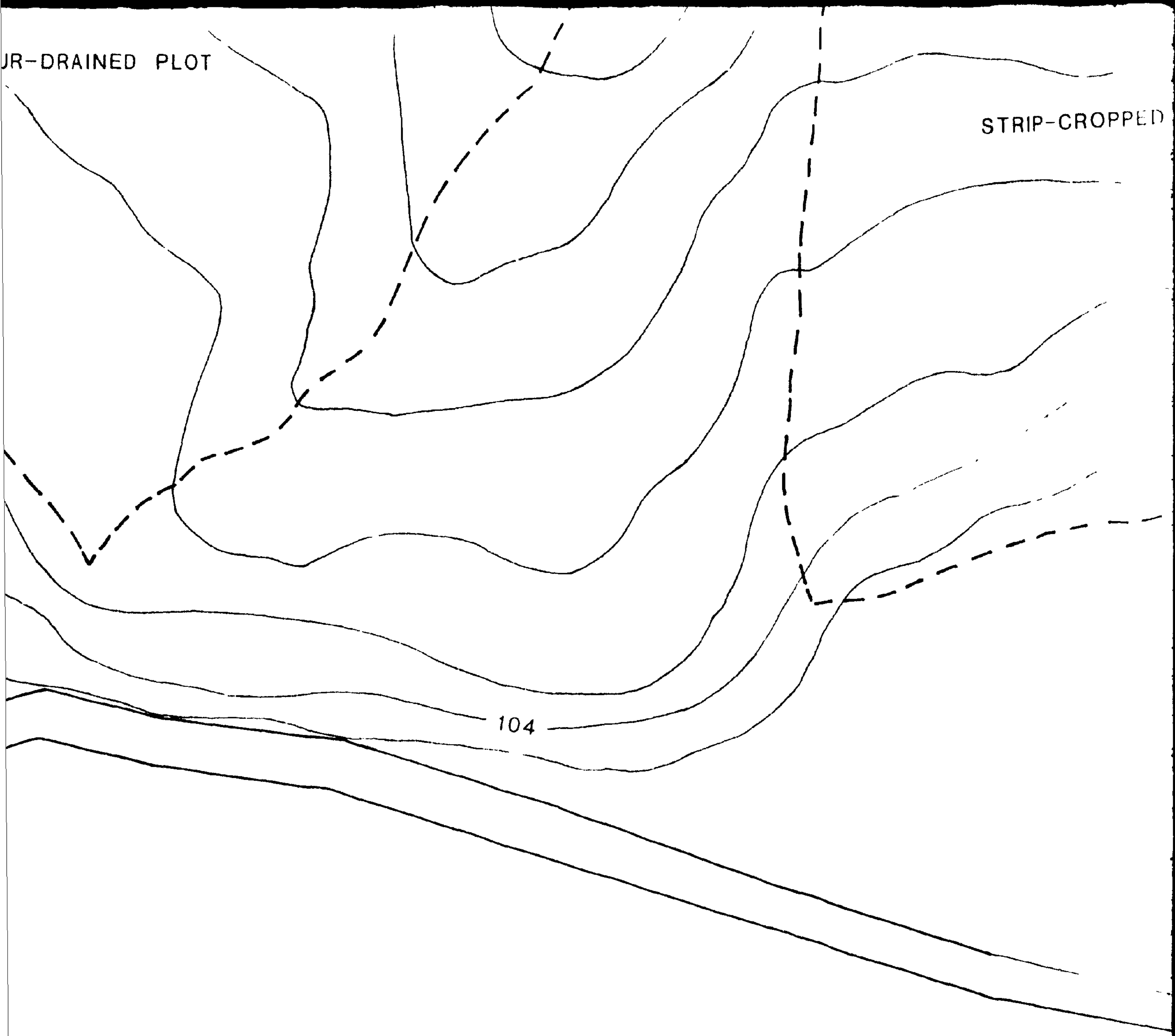


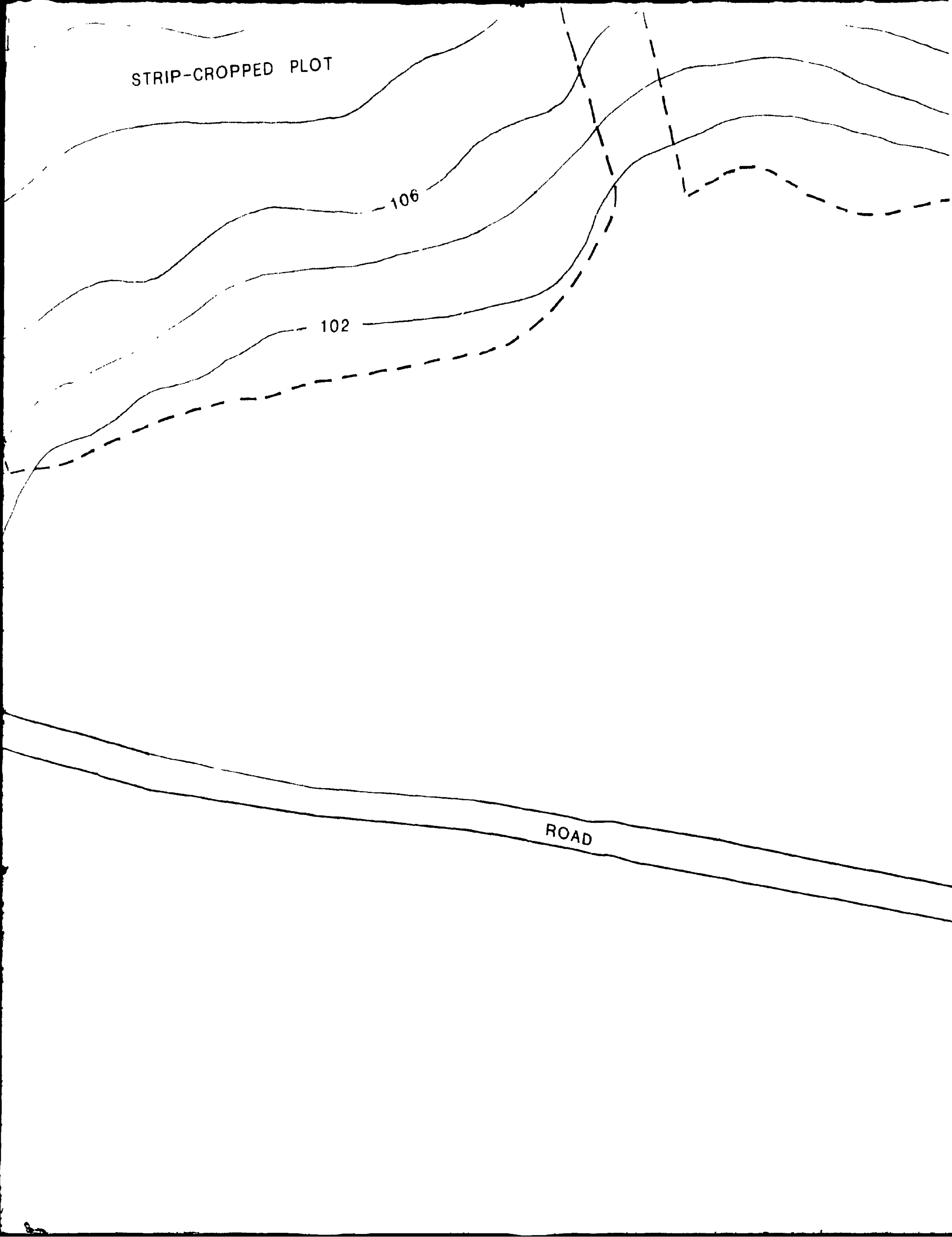
A7.Profile of the Terraced PLot
Along line D-D′ in Figure 3.9)


60
70



CONTOUR-DRAINED PLOT
106
102


JR-DRAINED PLOT
STRIP-CROPPED
104


STRIP-CROPPED PLOT
106
102
ROAD

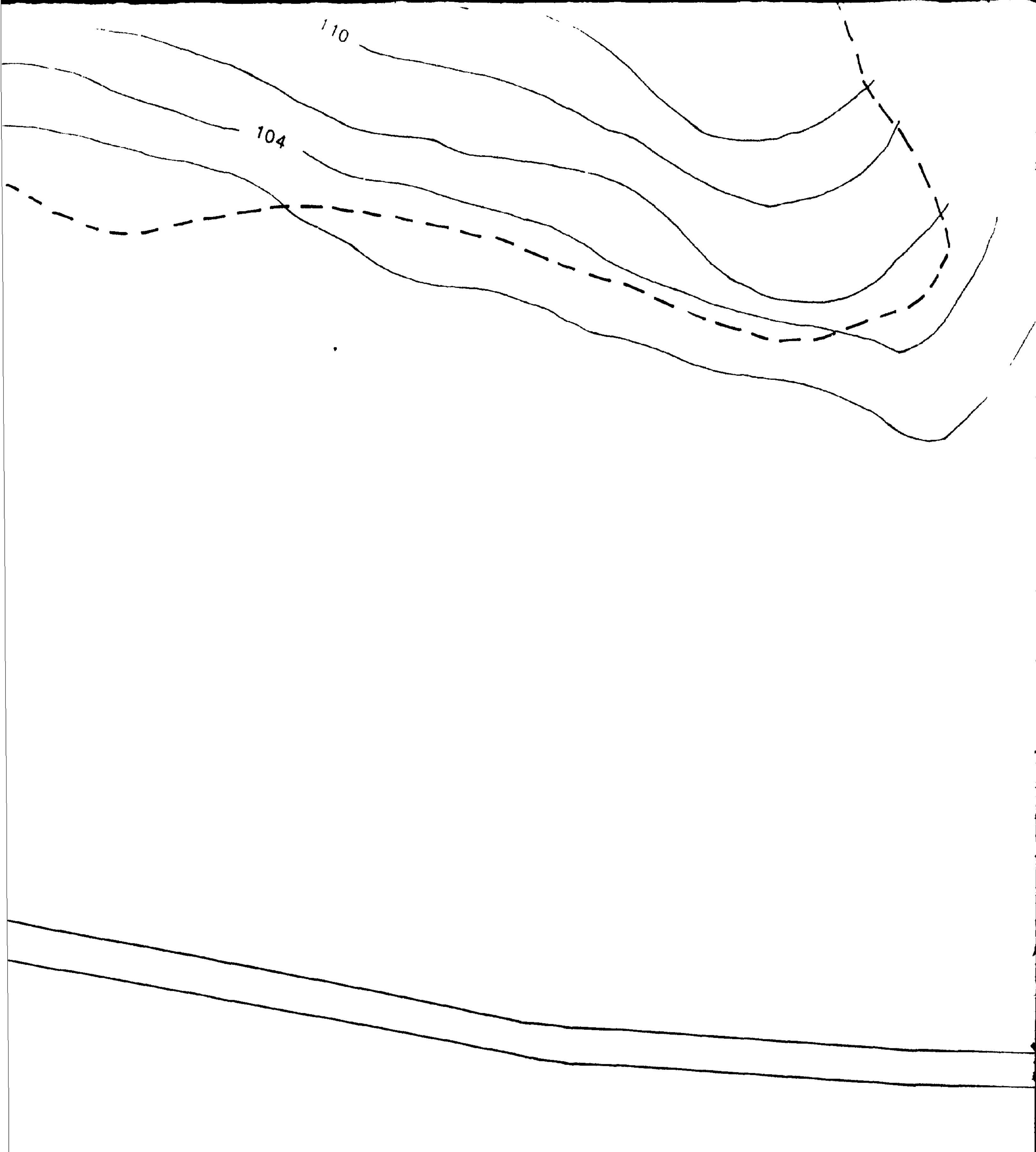


Figure A8.

CONTOUR MAP OF THE

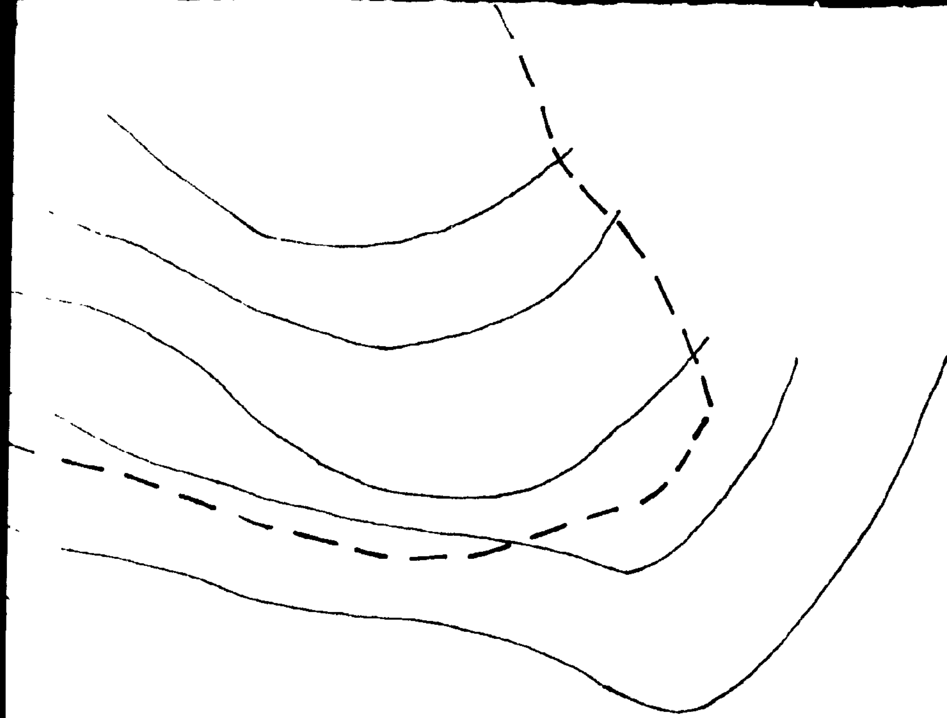
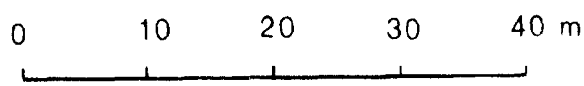


Figure A8.
CONTOUR MAP OF THE

Scale:



Legend:

Road

Contour line — 104 —

Plot boundary

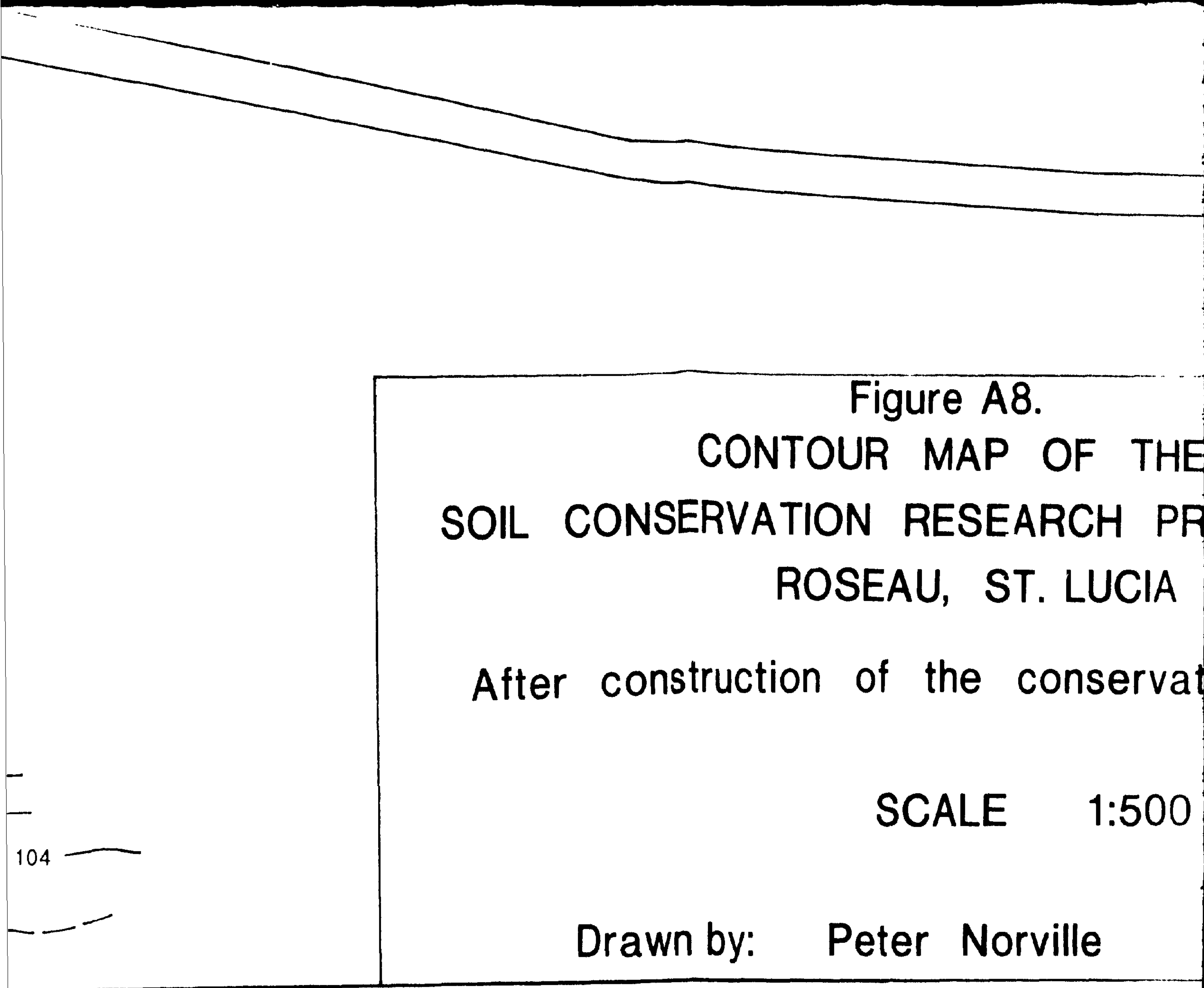


Figure A8.

CONTOUR MAP OF THE

SOIL CONSERVATION RESEARCH PR

ROSEAU, ST. LUCIA

After construction of the conservat

SCALE 1:500

Drawn by: Peter Norville

Figure A8.

CONTOUR MAP OF THE

ERVATION RESEARCH PROJECT SITE

ROSEAU, ST. LUCIA

struction of the conservation systems

SCALE 1:500

wn by: Peter Norville October 1989