AN EROSION CONTROL PLAN FOR PART OF THE GREEN'S CREEK RAVINE

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INTRODUCTION

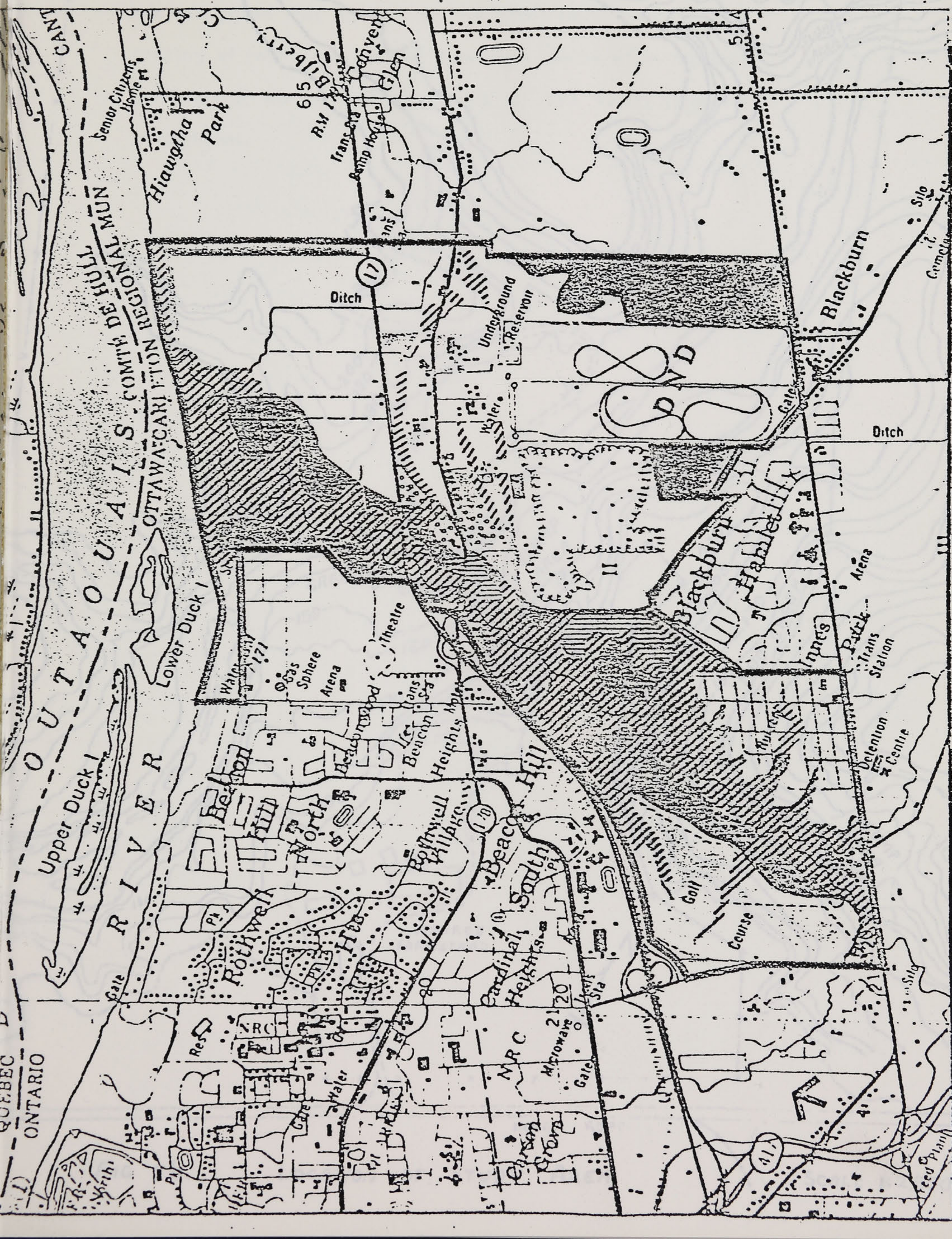
While floods and bank erosion are natural phenomena, damages caused by these forces are usually a consequence of man's unwise development on flood plains and lands adjacent to valley slopes.

In response to the desire to maintain the Green's Creek sector of the National Capital Commission's (N.C.C.) land holdings in a more natural state, a study of the slope stability in the valley right of way was undertaken and remedial works suggested. This particular study covers the valley reach through the Monroe farm leasehold which is located just north of Innes Road along a stream distance of approximately 0.8 km. (Lot 19, Concession 3, O.F. Gloucester Twp.)

The N.C.C. Greenbelt (20,350 hectares) is a band of open lands and forests which bounds the city of Ottawa to the west, south and east. The role of this land is to put aside a natural setting for the Nation's Capital and to maintain an open and essentially rural atmosphere (11). Of this greenbelt, the N.C.C. owns 14,950 hectares of which 33% is farmland, 46% is designated for conservation and the rest for misolaneous uses.

The Green's Creek Valley (see fig 1a and 1b) has been avoided as a site for programmes and activities because of unstable slope conditions. The creek cuts deeply into sensitive marine clays and is known widely to contain fossil bearing clay modules (14). Urban development has encroached upon this watershed and is expected to increase in the future. The N.C.C.

FIG. 1a. LOCATION OF GREEN'S CREEK



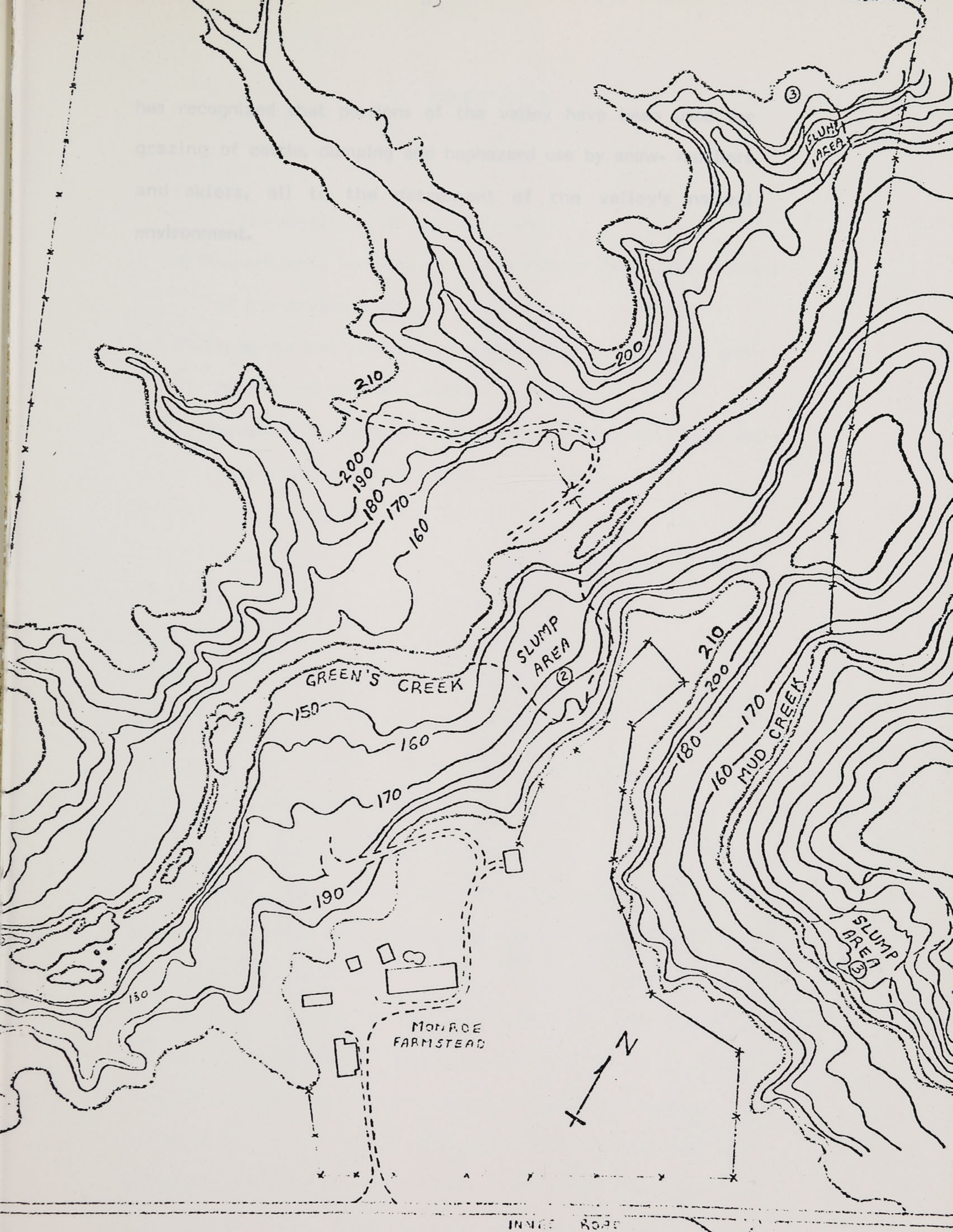


FIG 1b. LOCATION OF STUDY AREA SCALE 1:2,500

has recognized that portions of the valley have been used for grazing of cattle, dumping and haphazard use by snow- mobilers and skiers, all to the detroment of the valley's natural environment.

OBJECTIVES

The objectives of the study are:

1) Present basic understanding of the slope failure mechanisms of the creeks banks.
2) Recognize the location and extent of unstable slopes and recommend remedial works.
3) Recognize the location and extent of soil erosion sites and recommend remedial works.

WATERSHED DESCRIPTION

The watershed (104 sq.km. in area) is located just east of Ottawa in a region of flat to gently undulating marine clay plains, interrupted by ridges of outcrop. The dominating clay plains (up to 60 metres deep) were formed by post glacial deposits of the Champlain Sea epoch of 11,500 years ago. These overlie highly undulating Ordovician bedrock formed 450 million years ago (Gadd 1963). The study area is underlain by the Billings Formation, a black shale with some brown shale. This is exposed and can be observed at the Innes Road crossing of Green's Creek.

Due to the sensitive nature of the marine clays and the fact that the land is still rebounding from the now absent glacial weight, (causing the Green's Creek to continually erode downward) landslides and other types of slope erosion are common along the valley's slopes.

Green's Creek has a slow, meandering flow which is characteristic of the rivers which flow through the gently sloping farmland of the area. Recent urban encroachment, land-use and drainage alterations have caused an increase in the rate and volume of runoff and a greater seasonal fluctuation in streamflow.

The Rideau soils are the main type found in the study area and these have been differentiated into two types of clay deposits. The first is a layer, ranging in depth of a few metres to 60 metres deep, of soft unoxidized blue-grey calcareous and fossiliferous marine clay, capped with a much thinner layer of stiff, oxidized, rust-mottled, non-calcareous and non- fossiliferous reworked clay (Gadd 1963). The reworked clay, of medium to high sensitivity, is highly fissured. The lower layer is extremely sensitive,non-plastic but not as fissured. Both layers occasionally contain large amounts of silt and are then typed as silty clays. Poor drainage conditions prevail especially on the level sections where little surface runoff can take place. The Manotick are the second most predominate soil type in the area. It has developed into an acidic, coarse textured veneer overlying the neutral clays. The deposition of the veneer was by marine, estuarine and fluvial processes creating an extremely fragmented cover of varying depths.

SLOPE STABILITY

The various types of erosion which occur along Green's Creek are: undercutting at stream bends,surface water erosion, gully erosion and slope slumping. Slope failure is the main component contributing to the sediment load of the stream.

Instability of the Green's Creek valley slopes is associated with abundant ground water pore pressure, surface water and steepening of the slopes by toe erosion on the outer sides of river bends (Eden and Mitchell 1973).

Most slope failures in this area occured at wet times. It has been observed that high ground water pressures and subsequent deep-seated creep movements create tension cracks near the top of the slope. These cracks allow surface water to infiltrate directly into the critical zones thereby promoting failure (Eden and Mitchell 1973). Figure two illustrates how deep seated rotational bank failure can occur.

Mitchell (1970) found in drained lab tests that deformation of wetted samples could be arrested by lowering the back pressure to its original value. This behavior suggested that a temporary rise in ground water pressure may cause slope deformation without complete collapse. Extended periods of high water pressures may result in sufficient strain to develop tension cracks near the top of the slope. Complete failure may depend upon the availability of surface water entering via these tension cracks to satisfy the dilatant tendencies of the clay. Mitchell thought that in view of these observations, it may not be an overly conservative

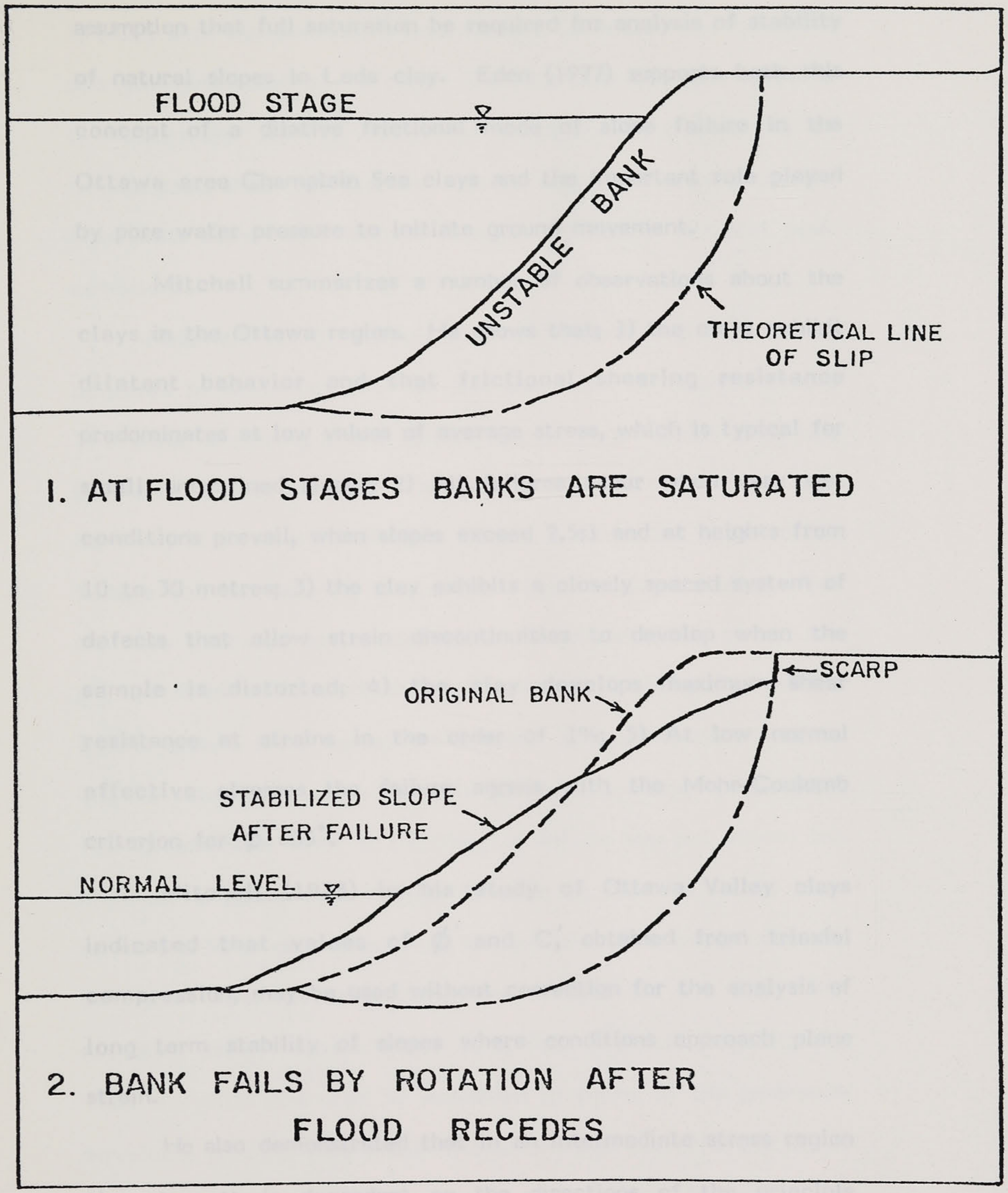


FIG 2. DEEP SEATED ROTATIONAL BANK FAILURE

assumption that full saturation be required for analysis of stability of natural slopes in Leda clay. Eden (1977) supports both this concept of a dilative frictional mode of slope failure in the Ottawa area Champlain Sea clays and the important role played by pore water pressure to initiate ground movement.

Mitchell summarizes a number of observations about the clays in the Ottawa region. He shows that; 1) the clays exhibit dilatant behavior and that frictional shearing resistance predominates at low values of average stress, which is typical for small unconfined slopes; 2) All failures occur when very wet conditions prevail, when slopes exceed 2.5:1 and at heights from 10 to 30 metres; 3) the clay exhibits a closely spaced system of defects that allow strain discontinuities to develop when the sample is distorted; 4) the clay develops maximum shear resistance at strains in the order of 1%; 5) At low normal effective stresses the failure agrees with the Mohr-Coulomb criterion for $\phi' = 35^{\circ}$.

Mitchell (1973) in his study of Ottawa Valley clays indicated that values of ϕ' and C', obtained from triaxial compression, may be used without correction for the analysis of long term stability of slopes where conditions approach plane strain.

He also demonstrated that in an intermediate stress region the strength is dependent on the directions of the principle stresses. This is interpreted as strength anisotropy and should be taken into consideration in effective stress analysis of embankment stability for this region.

Lo (1974) suggests the use of the post-peak envelope , Fig.

3, along with the probable failure surface to deduce the operative strength parameters of the clay. The post-peak strength envelope is determined from a method of extrapolating the results of triaxial test, shear box test and triaxial tests with pre-cut planes. The results show that the field strength approaches the post peak condition.

Mitchell (1970) studied a small slide (1560 M^3) which occurred in November 1967 on the west bank of Green's Creek. The slide, occurring in the shallow crater of an earlier slip, was studied using tube samples. The slope was about nine metres high inclining at an average of 28°. Figure 4 shows the slope before failure and the best fit slip circle. Piezometers installed after the slide indicated an artesian effect of ground water at the toe of the slide. The phreatic level was found to be 2.4 metres below ground level during the summer subsequent to the slide. The Ru value (defined in appendix B) was determined to be 0.45. The groundwater level at the time of failure was not known but Mitchell suggests that surface freezing at the toe would have raised the inner pore-pressure. Analysis was then made with the post-peak envelope using Ru values of 0.4, 0.5 and 0.6. The resulting safety factors where 1.26, 0.95 and 0.81 respectively. Thus the slide may well be explained in terms of the post-peak envelope, yielding data pertaining to the average effective shear and normal stresses on the probable slip surface. The values for Green's Creek were found to be 12.4 kpa and 13.2 kpa respectively. It was also found that the post-peak envelope could be approximated by a straight line defined by $C'=0$ and $\phi'=43$. Hence as a first approximation to the long term strength

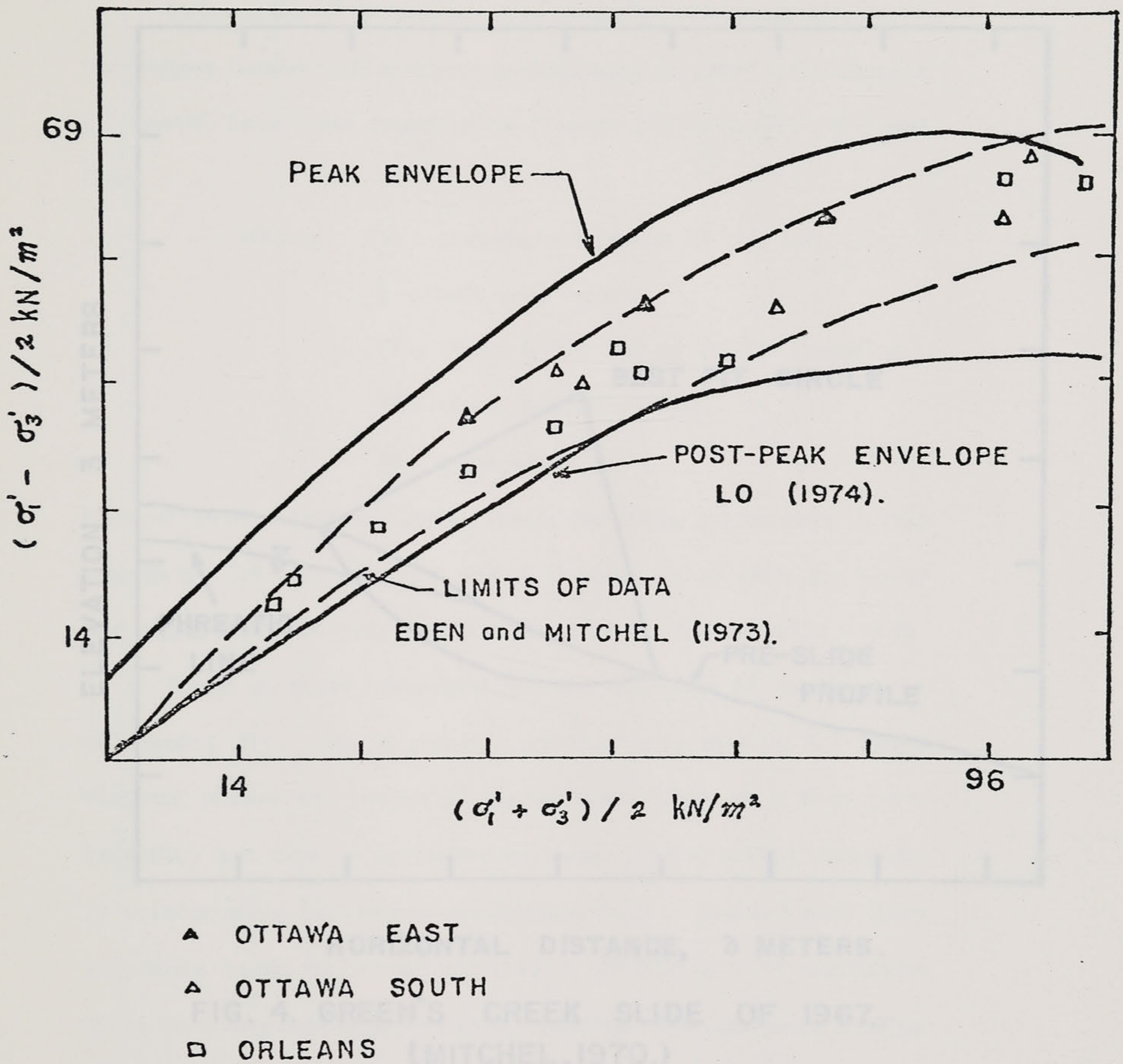


FIG. 3 SUMMARY OF STRENGTH DATA FOR CHAMPLAIN SEA CLAYS

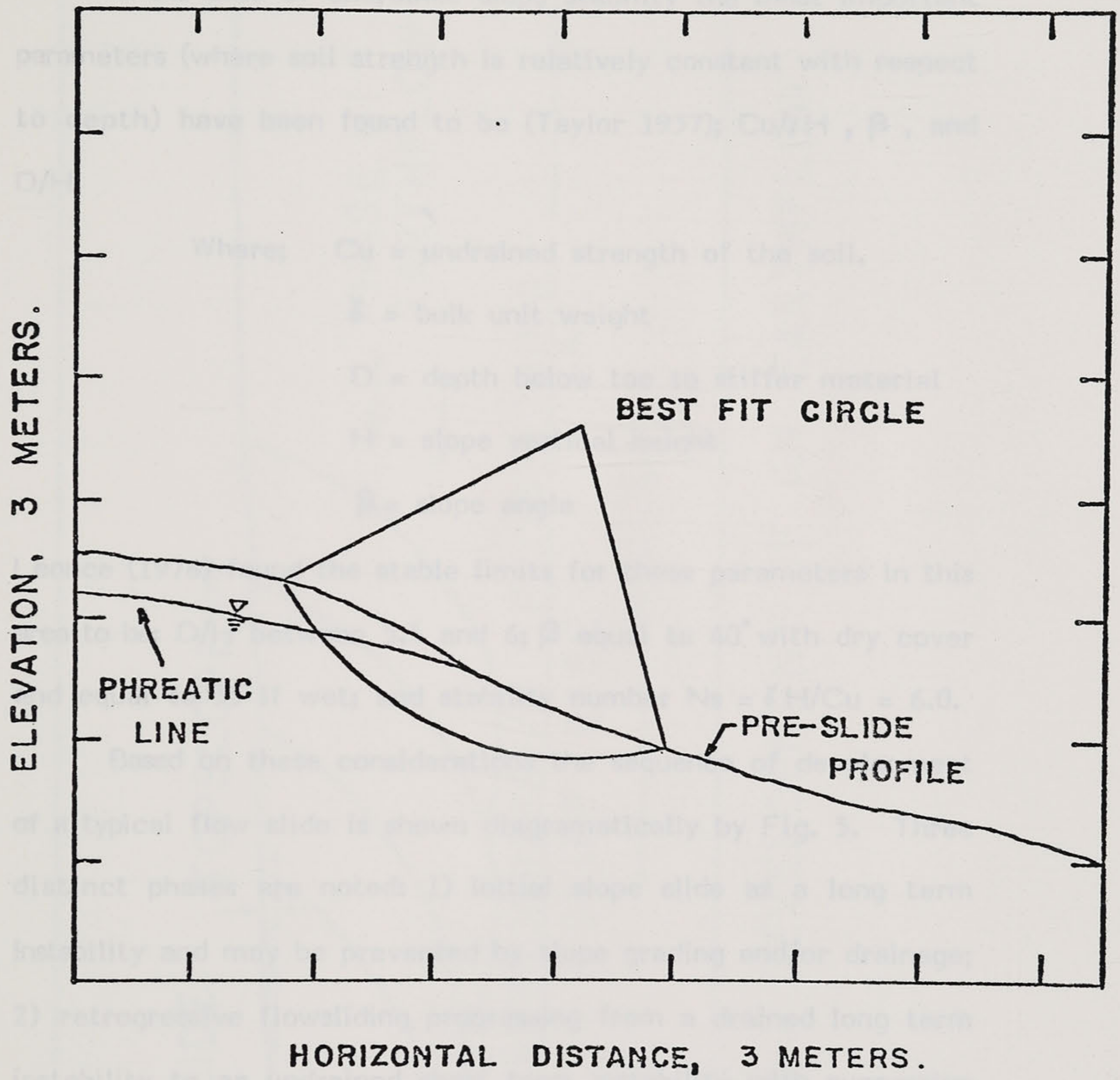


FIG. 4. GREEN'S CREEK SLIDE OF 1967.
(MITCHEL, 1970.)

parameters in natural slopes of this area a linearized envelope can be used without significant error.

In the case of undrained slope stability the most important parameters (where soil strength is relatively constant with respect to depth) have been found to be (Taylor 1937); $Cu/\gamma H$, β , and D/H.

Where; Cu = undrained strength of the soil.

γ = bulk unit weight

D = depth below toe to stiffer material

H = slope vertical height

β = slope angle

Leonce (1976) found the stable limits for these parameters in this area to be: D/H between 5.5 and 6; β equal to 40° with dry cover and equal to 35° if wet; and stability number $Ns = \gamma H/Cu = 6.0$.

Based on these considerations the sequence of development of a typical flow slide is shown diagramatically by Fig. 5. Three distinct phases are noted: 1) initial slope slide as a long term instability and may be prevented by slope grading and/or drainage; 2) retrogressive flowsliding progressing from a drained long term instability to an undrained short term instability with successive slides involving deeper layers (when possible) and producing steeper back slopes; 3) earthflows involving extrusion and flow of soft underlaying materials thus transporting the overlaying materials along.

Observations of the Green's Creek study area establish it as an area mainly involving the first type followed by minor retrogression extending generally in the order of 60 metres and up to a maximum of 120 metres.

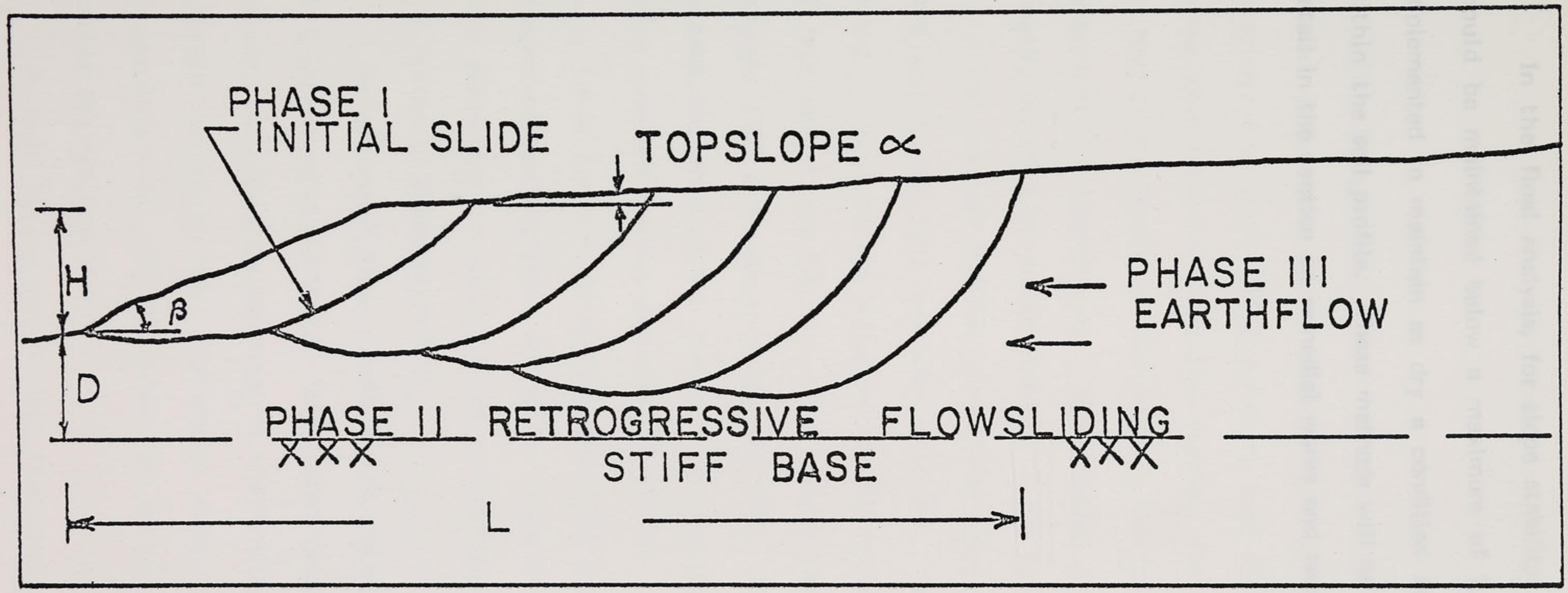


FIG. 5. DEVELOPMENT OF AN EARTHFLOW

In the final analysis, for slope stability, the valley banks should be maintained below a maximum of 2.5:1 and methods implemented to maintain as dry a condition as possible on and within the soil profile. These methods will be dicussed in more detail in the section on remedial works and recommendations.

HYDROLOGY

The Ottawa region has a cool and humid climate with relatively large temperature variations throughout the year. It is characterized by warm (20° C) summers, cold winters (-10° C) with a snow cover season of about five months. The average dates of last frost in the spring and first frost in the fall are May 13 and September 22 respectively. Precipitation averages, 850 mm annually including an annual snowfall of 216 cm.

The greatest monthly precipitation was measured in July 1972 and August 1952 equalling 18.54 cm. During the record period, of 76 years, the maximum rainfall amount occurring in a 24 hour period was 9.4 cm. This intense rainfall occurred in October 1887 and again in September 1942. The meteorological records indicate that the maximum 24 hour rainfall during the spring snowmelt has not exceeded 7.1 cm (4).

Table 1 shows the design rainfall for the 25, 50 and 100 year recurrance intervals. Intensities during the six hour periods were distributed according to the methodology outlined by the U.S. Bureau of reclamation (12).

Surface runoff from a basin equals the total rainfall minus the basin retention and losses. Basin retention includes temporary ponding and temporary interception which delays surface runoff. Rainfall losses include phenomena such as infiltration and evaporation. All tend to reduce the amount of runoff which reaches the drainage channel.

A unit hydrograph method developed by the U.S. Soil

Conservation Service (12) was employed to synthesis the design flow which can be expected to occur in the watershed during a major rainfall event (see appendix A for details). In this computational approach, runoff volumes are assumed directly related to soil type and vegetative cover on the watershed in addition to the time of distribution and quantity of rainfall. For the design storm, the soil and cover data were defined by a hydrologic complex number representing the soil and cover characteristics with respect to there ability to produce runoff. Topographic and soil maps, together with aerial photos were employed in conjunction with field observations to evaluate watershed characteristics. See figure 6.

The quantity of direct storm runoff also depends on the antecedent soil moisture condition of the watershed with the percent of rainfall converted to direct runoff increasing with increased soil moisture content. An average saturated soil condition was used during the study in accordance with the Ontario Ministry of Natural Resources policy for evaluating regional design floods.

There are neither stream flow records nor stage records available for Green's Creek that can be used directly to estimate the frequency of floods which may be experienced along the water way. The hydrographs were produced using the following general procedure as outlined by the U.S. S.C.S.: 1) estimate the precipitation duration and depth for each frequency from rainfall records in the area; 2) average the total rainfall amount in a typical rainfall pattern for the area (5); 3) estimate the surface runoff deducting watershed retention and losses from the total

HYDROGRAPH

100 YEAR RETURN PERIOD

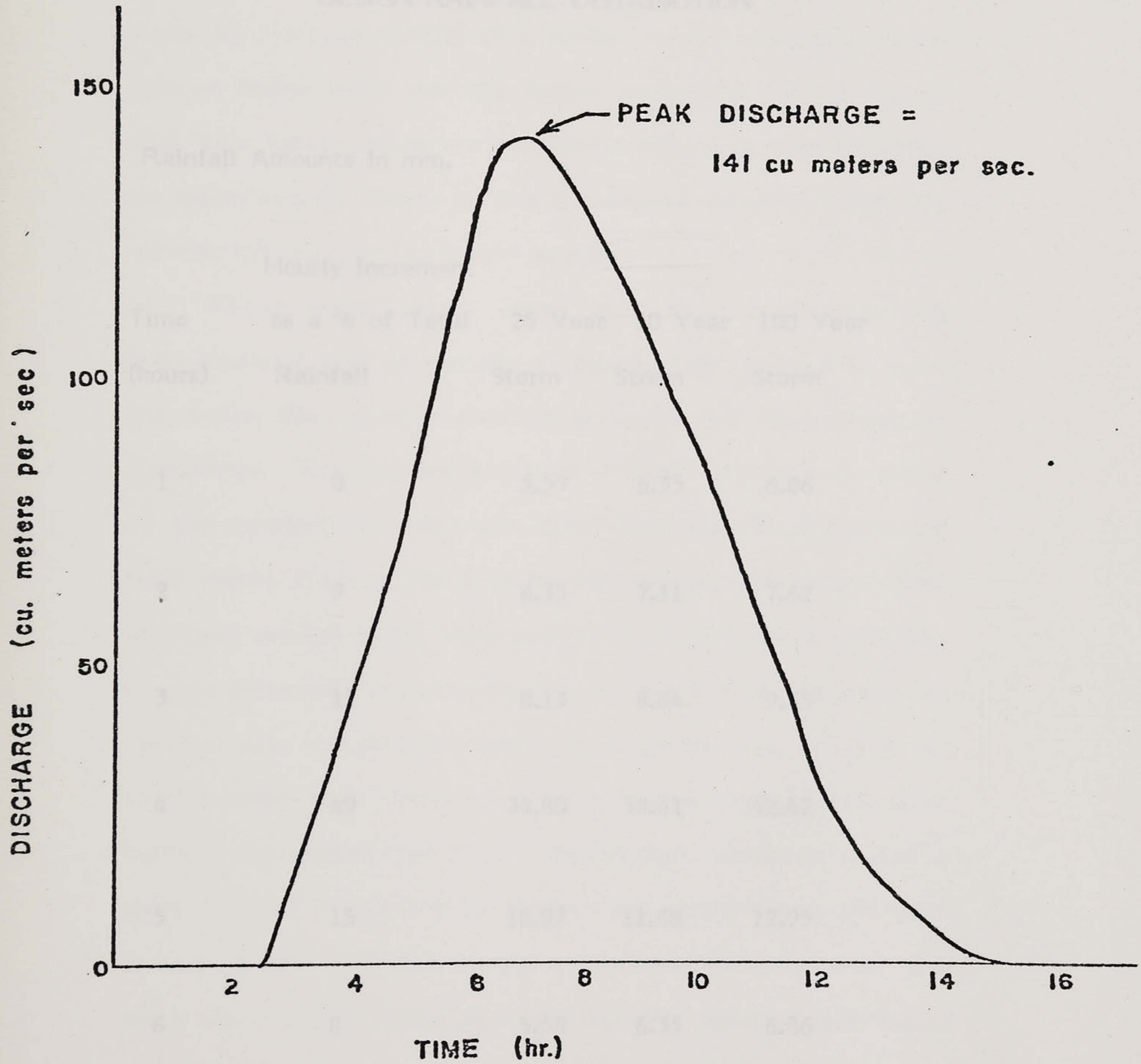


FIG. 6 FLOOD HYDROGRAPH

TABLE 1

DESIGN RAINFALL DISTRIBUTION

Rainfall Amounts In mm.

Time (hours)	Hourly Increment as a % of Total Rainfall	25 Year Storm	50 Year Storm	100 Year Storm
1	8	5.59	6.35	6.86
2	9	6.35	7.11	7.62
3	11	8.13	8.64	9.65
4	49	34.80	38.61	42.42
5	15	10.07	11.68	12.95
6	8	5.56	6.35	6.86
TOTAL	100	71.12	78.74	86.36

precipitation by use of the complex number; 4) Determine the hydrograph shape using watershed characteristics.

The spring breakup in the Green's Creek basin often results in high flows which cuase considerable erosion. This is especially true if a severe spring thaw coincides with a rainfall event. A study by MacLaren (1976) of a similar nearby watershed in the Ottawa region found that the design hydrographs for the natural peak flow rates for the summer floods are larger than those for the spring events. Based on this the authour considered only the summer hydrographs for design purposes.

Flood water levels were found by a combination of; cross-sectional area at the site of construction required to carry the design flow rates; in-situ interpretation; and local inhabitant knowledge. The observed elevation of near vertical cuts caused by the meandering stream are higher than the calculated water level depths for the 100 year rainfall events. Therefore these observed erosion levels were used to determine the size of the erosion protection structures required. By use of the observed vertical cuts it was found (using mannings formula, see app. A) that common peak summer flows are in the order of 270 cubic metres per second. The S.C.S. hydrograph method produced a peak flow of only 141 cubic metres per second for a 100 year return period. This discrepancy emphasizes the impact of the storm water outlets which discharge into the Green's Creek Basin.

REMEDIAL WORKS AND RECOMMENDATIONS

The Green's Creek valley within the Monroe leasehold exhibits a number of excessive erosive processes. Listed in order of magnitude they are; 1) slope toe- erosion by the stream leading to slope failure; 2) overland flow from adjacent fields indiscriminately running down the valley slopes; and 3) denuding of the vegetal cover by cattle overgrazing. Observe photographs one through ten.

All these erosive processes can be controlled to varying degrees and at varying costs. The third listed can be corrected completely. Cattle grazing within the valley must be stopped. The topography and vegetation are too sensitive for this practice to continue. Cattle movement over the stream banks and valley slopes remove the vegetation to the point of exposing the soil to water erosion. It also prevents natural reforestation of the valley and steepens the slopes.

Reforestation should be encouraged in the valley. Heavy tree cover can intercept 10 - 40% of a rainfall event (6). The roots of the trees serve two functions; 1) they hold the soil together as one unit; and 2) they keep the upper soil profile more dry. Both actions tend to increase the soil shear strength. A heavy leaf matter cover on the ground reduces soil erosion by rain droplet impact but reduces infiltration. The net effect of a forest cover is less erosion and more stable slopes. Reforestation can be allowed to occur naturally on the more gentle slopes in the valley but the steeper slopes (those over 2.5:1) should have young trees planted immediately.

Site three (see fig. 7) is a case in point of adjacent overland runoff causing erosion of the valley slopes. To the south and south-east of the Monroe farmstead is a field measuring seven hectares. Runoff from Innes Road and these fields combine and flow through the Monroe cattle corrals (picking up pollutants from the manure) and down the valley slopes at site three. A berm measuring 0.5 metres high by 2.0 metre wide should be constructed along the top edge of the slope and a grassed waterway maintained parallel to this berm (see fig. 11). A small ditch may be required to divert the overland flow around the corral. The cattle should not be allowed access to this waterway and berm area. The grassed waterway can carry the water to a chute constructed in the ravin to the west of the farmstead. This chute could then carry the water in a non-erosive manner down to the stream proper. The chute can be constructed of inverted half culverts imbedded and anchored into the slope with stakes. An alternative would be to use a gabion mattress of 150mm thickness anchored in the same manner. The latter would be more expensive but more aesthetically pleasing in that, with time, vegetal cover would obscure them from view.

Control of overland flow into the valley can be accomplished in the same manner with berms, grassed waterways and chutes at any location where indescriminant runoff over the slopes is causing erosion to occur.

In designing bank protection works, care must be taken that the measures are sufficient to withstand erosive forces while at

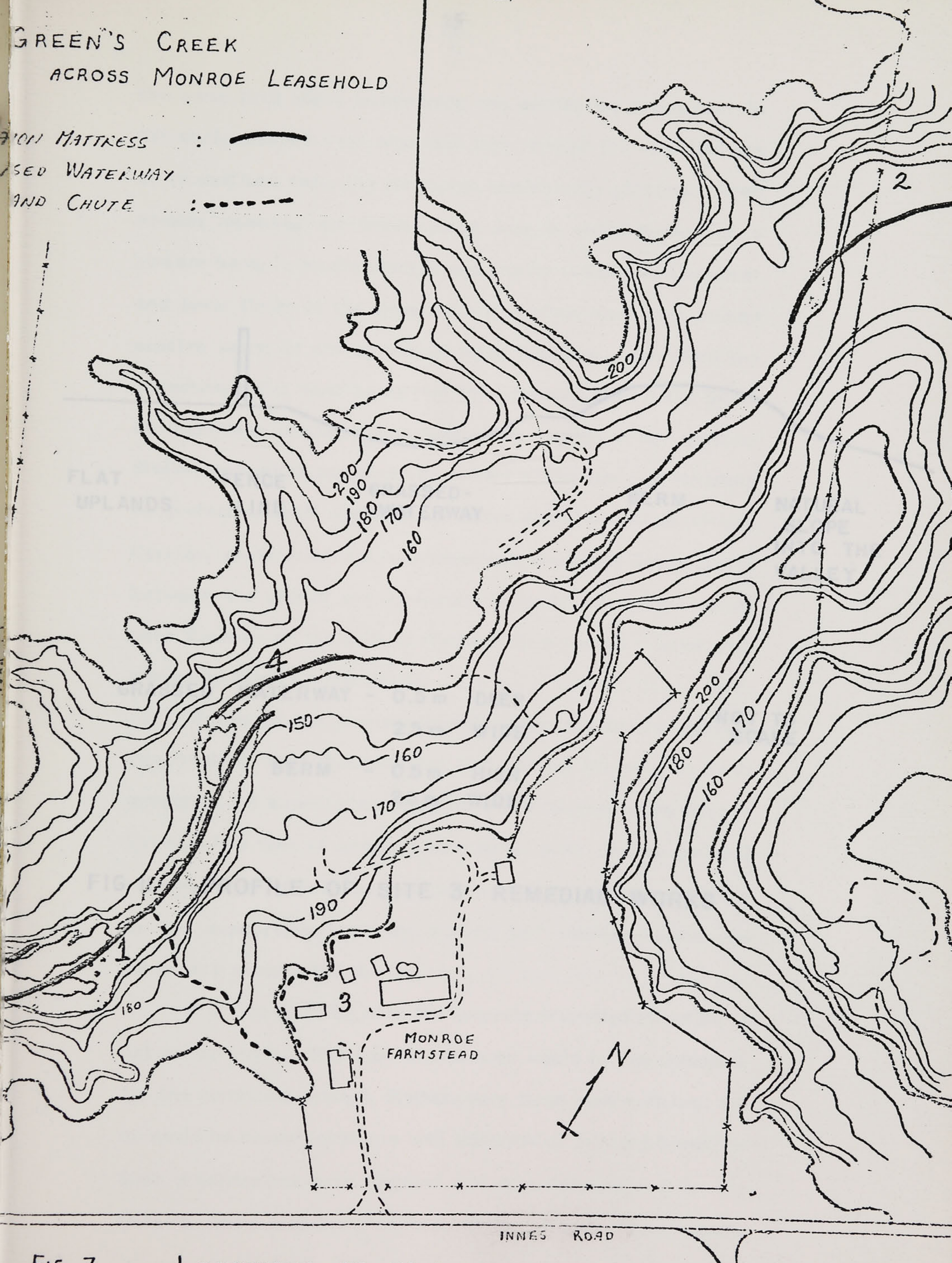
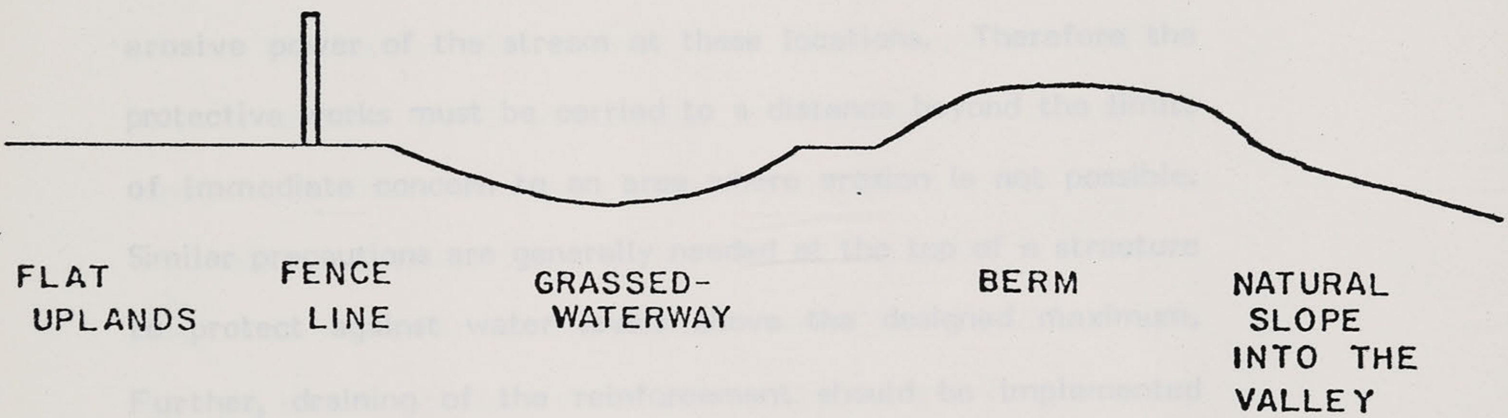


FIG 7 LOCATIONS OF WORK SITES



GRASSED WATERWAY - 0.5 m DEEP
2.5 m WIDE

BERM - 0.5 m HIGH
2.5 m WIDE

NOT TO SCALE

FIG II. PROFILE OF SITE 3 REMEDIAL WORKS the same time resist undermining and outflanking processes. In this study area we must also take into account the objective use of the land and make the structures aesthetically pleasing. When erosion measures are implemented over a short section of a stream bank, hydraulic changes are usually induced at the upper and lower limits of the structure. This often leads to increased erosive power of the stream at these locations. Therefore the protective works must be carried to a distance beyond the limits of immediate concern to an area where erosion is not possible. Similar precautions are generally needed at the top of a structure to protect against water levels above the designed maximum. Further, draining of the reinforcement should be implemented between the stream and its natural banks to allow the internal pore pressure of the soils to fluctuate in a normal manner with respect to stream water levels.

Based on the previous considerations and on the ease of construction, it is recommended that gabions be used for bank protection and stream channelization where required along Green's Creek. This type of armour protection is quite flexible and self adjusting after installation such that it absorbs moderate changes in the supporting bank and stream bed without failure and subsequent exposure of the bank.

If rip-rap is to be used the concrete imbedded structure is not recommended. This type of structure would be too inflexible for the conditions present. Rather, very large stones (0.3 to 1.0 m) could be placed forming a wall thickness of 1.5 to 2.0 metres. Such a barrier has been installed and is performing well on the Ottawa River shoreline just west of the Green's Creek mouth.

This rock was obtained for only trucking costs and would be economically viable under the same conditions. But the confines of the Green's Creek site make it difficult to place the stone without destroying much of the natural setting.

A gabion is defined as a container made of steel wire, woven in a uniform hexagonal triple twist pattern, reinforced on corners and edges with heavier wire (1). A gabion mattress utilizes smaller stone than would be required for rip-rap by containing it within wire mesh baskets, each tied together to form a monolithic structure (see Fig 8). The smaller stone is easier to place and results in thinner walls. A savings of 50-60% of wall thickness can be obtained above the water line and 70-80% below the water line. With a stream velocity of 3.5 metres per second (App. A) it is recommended that the mattress be installed with a thickness of 250 to 300mm. Unless rip-rap is labouriously imbedded in concrete the individual stones are free to move relative to each other. This leads to uneven settling when placed upon a soil of low bearing capacity and possible movement of stones by ice action during the spring breakup. The result is a need for more maintenance in the future than would be required on a properly installed gabion mattress. A gabion mattress requires no special technical skill for installation. They are usually delivered in collapsed form, are easily assembled, placed, filled with stone and the lids closed. If the installation is scheduled for the dry period of the summer, little problem will be encountered with water or wet soils. With time the voids fill with silt which leads to plant growth upon the mattress thereby enhancing the aesthetic value of the structure. Finally, the

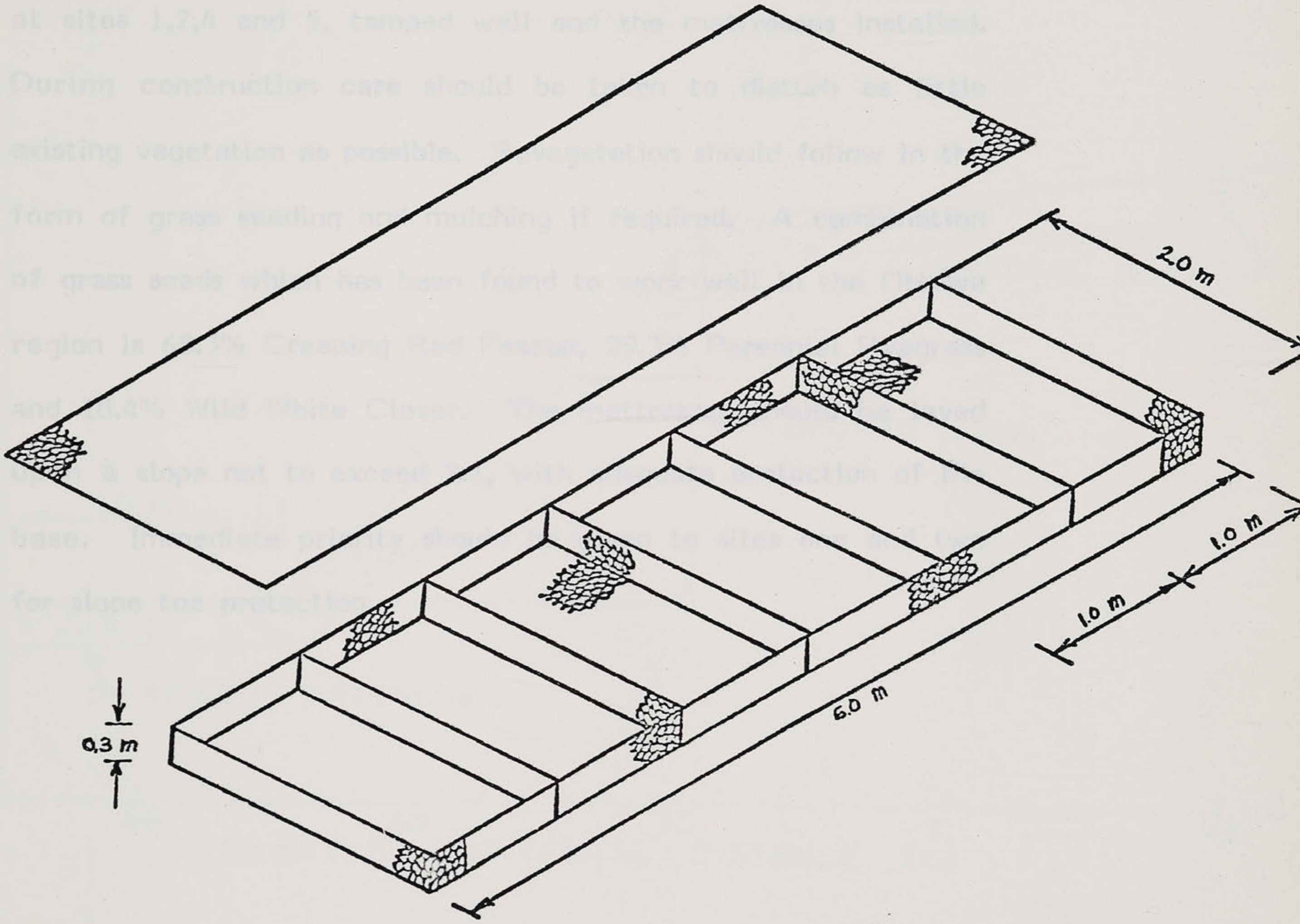


FIG. 8 EXAMPLE OF A GABION MATTRESS

mattress is permeable, therefore self draining and is not effected by frost action.

The slopes should be altered as shown in figures 9 and 10 at sites 1,2,4 and 5, tamped well and the mattresses installed. During construction care should be taken to disturb as little existing vegetation as possible. Revegetation should follow in the form of grass seeding and mulching if required. A combination of grass seeds which has been found to work well in the Ottawa region is 60.3% Creeping Red Fescue, 29.3% Perennial Ryegrass and 10.4% Wild White Clover. The mattresses should be layed upon a slope not to exceed 2:1, with adequate protection of the base. Immediate priority should be given to sites one and two for slope toe protection.

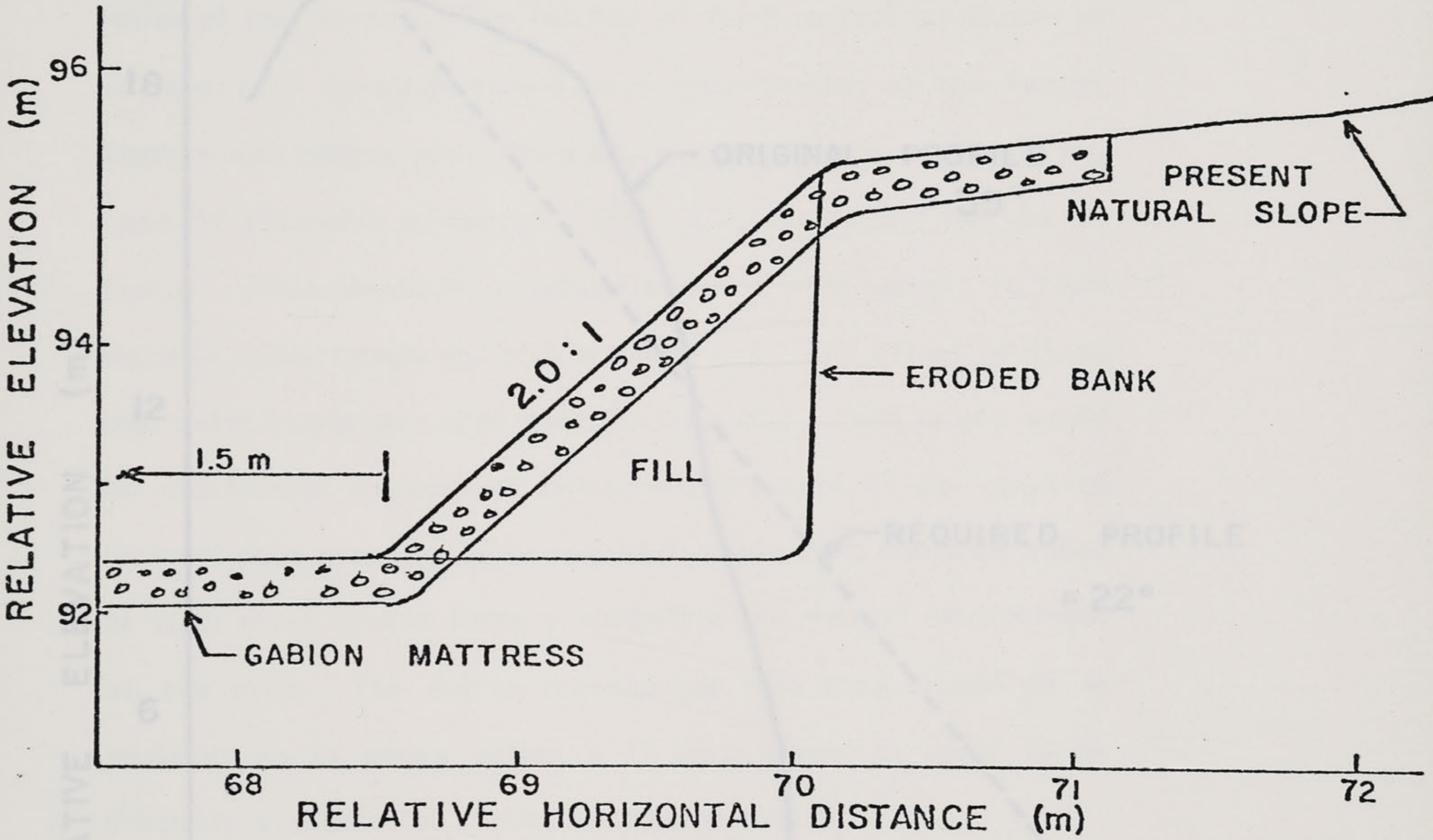


FIG. 9 SITE I REMEDIAL WORKS.

WIDTH OF MATTRESS = 6.0 m
LENGTH OF MATTRESS = 160 m

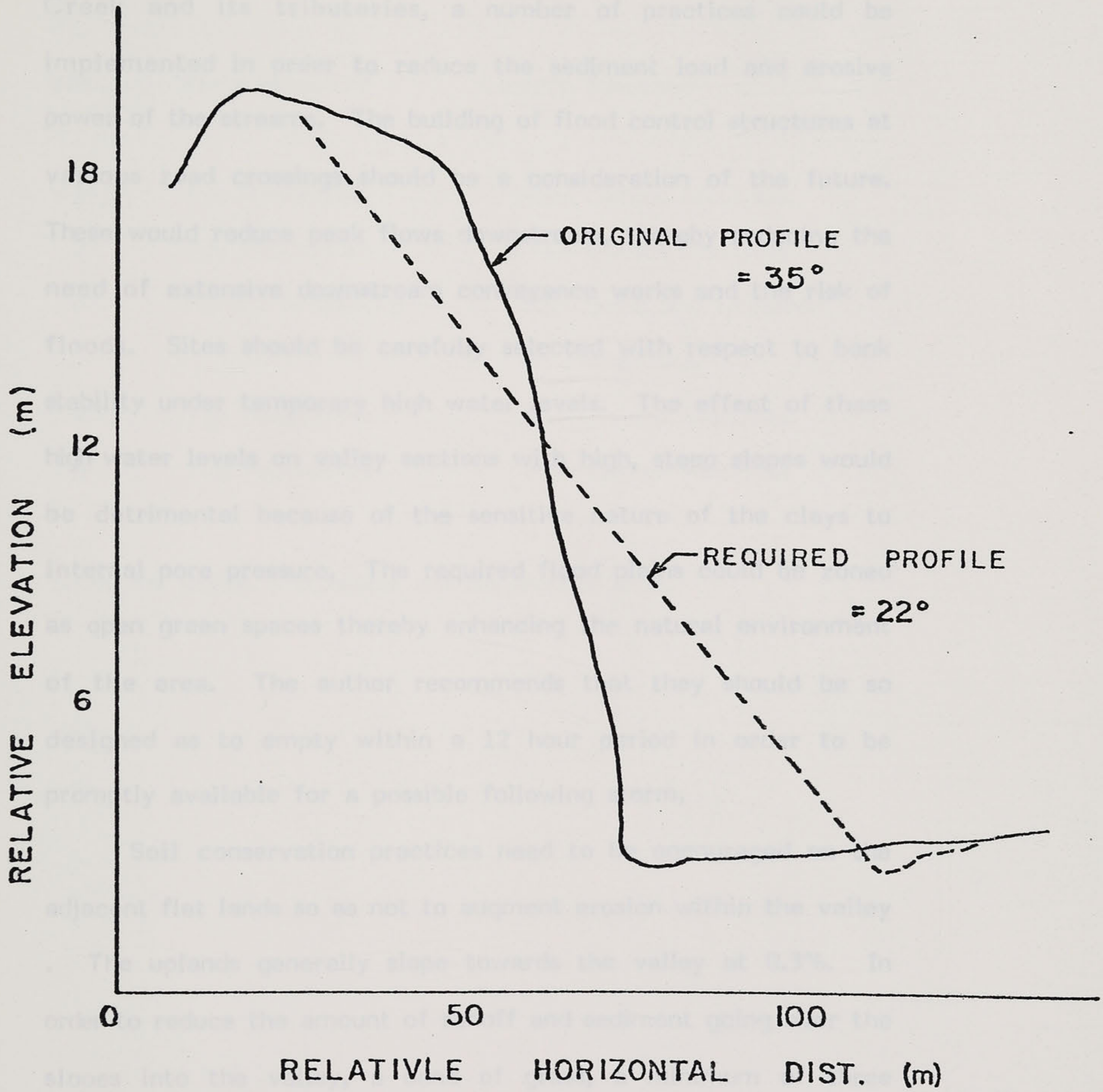


FIG. 10 PROFILE OF SITE 2 REMEDIAL WORKS

NOTE. GABION MATTRESS REQUIRED AT TOE AS SHOWN IN FIG. 9. FOR 130 m.

Within the study area as well as over the length of Green's Creek and its tributaries, a number of practices could be implemented in order to reduce the sediment load and erosive power of the streams. The building of flood control structures at various road crossings should be a consideration of the future. These would reduce peak flows downstream, thereby reducing the need of extensive downstream conveyance works and the risk of floods. Sites should be carefully selected with respect to bank stability under temporary high water levels. The effect of these high water levels on valley sections with high, steep slopes would be detrimental because of the sensitive nature of the clays to internal pore pressure. The required flood plains could be zoned as open green spaces thereby enhancing the natural environment of the area. The author recommends that they should be so designed as to empty within a 12 hour period in order to be promptly available for a possible following storm.

Soil conservation practices need to be encouraged on the adjacent flat lands so as not to augment erosion within the valley . The uplands generally slope towards the valley at 0.3%. In order to reduce the amount of runoff and sediment going over the slopes into the valley, a band of grass, a minimum of three metres wide, should be maintained along the full length of the valley. This band should be fenced off wherever cattle may encroach. Farmers should practice contour cropping and follow an accepted mixture of small grain and row cropping such that a maximum of two-thirds of the adjacent lands are in corn at any one time.

TABLE 2

CONSTRUCTION REQUIRED

Site	Works Required	Lengths Required
1	Toe Protection	160m Gabion Mattress
2	Toe Protection	130m Gabion Mattress
3	Runoff Protection	50m Berm and Grassed waterway
4	Toe Protection	80m Gabion Mattress
5	Toe Protection	80m Gabion Mattress

Note: All gabion Mattresses are six metres wide.

Observations have shown that all slope failures are related to high water content in the soil. Therefore, any practice which will decrease the amount of infiltration into the soil near the valley slopes will add to slope stability. The methods outlined above need to be implemented. Subsurface drainage of adjacent farmlands should be considered seriously.

In light of the observed impact that storm water outlets have upon the peak flow rates of the stream and the expected use of the valley by the public, it is recommended that a quantitative and qualitative study be made of these and other types of outlets discharging into the Green's Creek watershed.

COST ESTIMATE

The National Capital Commission has at their disposal, their own fleet of trucks, machinery and manpower. The N.C.C. knows better than the author the cost of these items. Therefore no estimate of this portion of the job site requirements were made. The cost estimate presented accounts solely for material requirements and earthmoving. It was estimated that bulldozing of steeper slopes and re-grading for implementation of toe protection and berms with grassed waterways will require the moving of approximately 8,000 cubic metres of soil. At a cost of $1.50 per cubic metre this will total $12,000. The volume of rock required to fill the gabion mattresses is 3,060 cubic metres of six to eight inch rock costing approximately $600. Seed for re-establishing the grasses on reshaped slopes was estimated to total $2,500. The gabion mattresses themselves will cost $18,700.

The result is that materials will cost a total of $21,800 and earthmoving will cost $12,000.

CONCLUSIONS

Natural geologic erosion will continue to occur along Green's Creek. By implementing proper soil and water managment techniques one can avoid accelerating this natural process and even slow it down.

Slope stability was found to be dependent upon two main factors. These factors are, slope angle and soil moisture content (internal pore pressure). The first can be controlled by constructing toe protection structures at the base of any slope being eroded by stream action and by altering present steep slopes to more gentle angles by bulldozing and revegetation.

The use of gabion mattresses for toe protection was recommended over rip-rap because of its ease of construction, superior strength, flexibility and durability. Also, the mattress will with time, become overgrown with vegetation thereby better suiting the natural environment desired for the valley.

The effect of the second factor can be kept to a minimum by proper revegetation of the valley and by controlling the flow of uplands surface runoff with the use of berms, grassed waterways and chutes.

Cattle grazing is simply too harmful to the sensitive clays present in the valley for this practice to continue.

The Green's Creek Valley should be maintained as a limited access, natural environment, recreational area. The inherent soil type and the topography of the valley result in the area being too sensitive to allow for heavey public use. Installation of nature interpretation trails with small day use picnic areas should represent the limit of development within this section of the valley. Below site 3 (fig 7) is one area where the slopes are gentle enough and the flood plane wide enough for such a picnic area to be created. Observations should be maintained continually in the future, to determine the extent of damage being caused by this use and corrections in design implemented to correct the situation. Nature trails should pose no problem to the stability of the slopes if they are restricted to the more gentle slopes and where they must cross steeper slopes that they do so through well established forested areas.

The benifits of implementing the remedial works recommended are numerous. First and foremost, it will result in the conservation of farmlands adjacent to the valley, a major national resource. Good farming soils are becoming more scarce with urban expansion and soil erosion. Second, it will result in a reduction of the sediment load carried by the stream. This will create a better environment for aquatic life. Third, it will result in a more stable yet still natural setting which can be enjoyed by the public. This being a primary aim of the N.C.C. for this area.

Photo 1. Green's Creek at low flow exhibiting its meandering behavior which results in toe erosion of the slopes.

Photo 2. Without grazing more vegetal growth affords better protection of the valley slopes.

Photo 3. Evidence of cattle grazing; causing soil erosion and water pollution. Also note the rill and gully erosion of the slope below the farmstead.

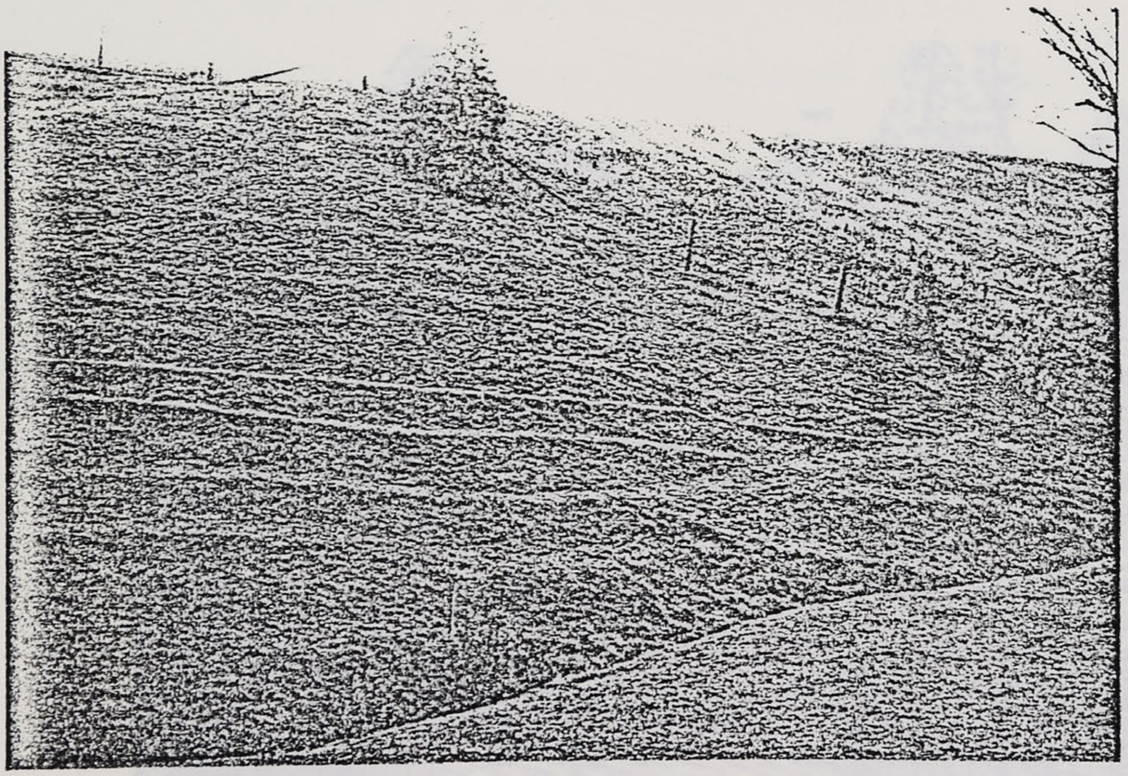


Photo 4. Grazing results in short vegetation and the development of ridges on the slopes(Cattle have access only to the left side of the fence line).

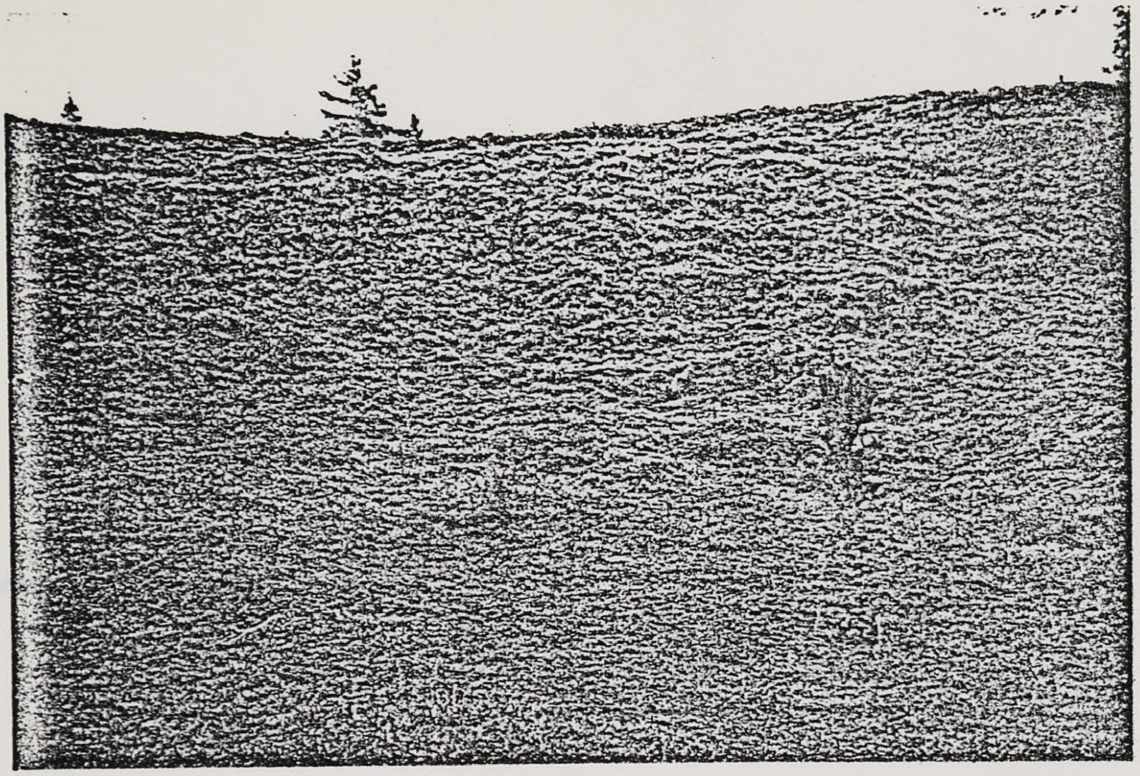


Photo 5. The upper section of a slumped area. Note the characteristic bowl shape, the steepness of the head wall and the cracks at the top of the slope.

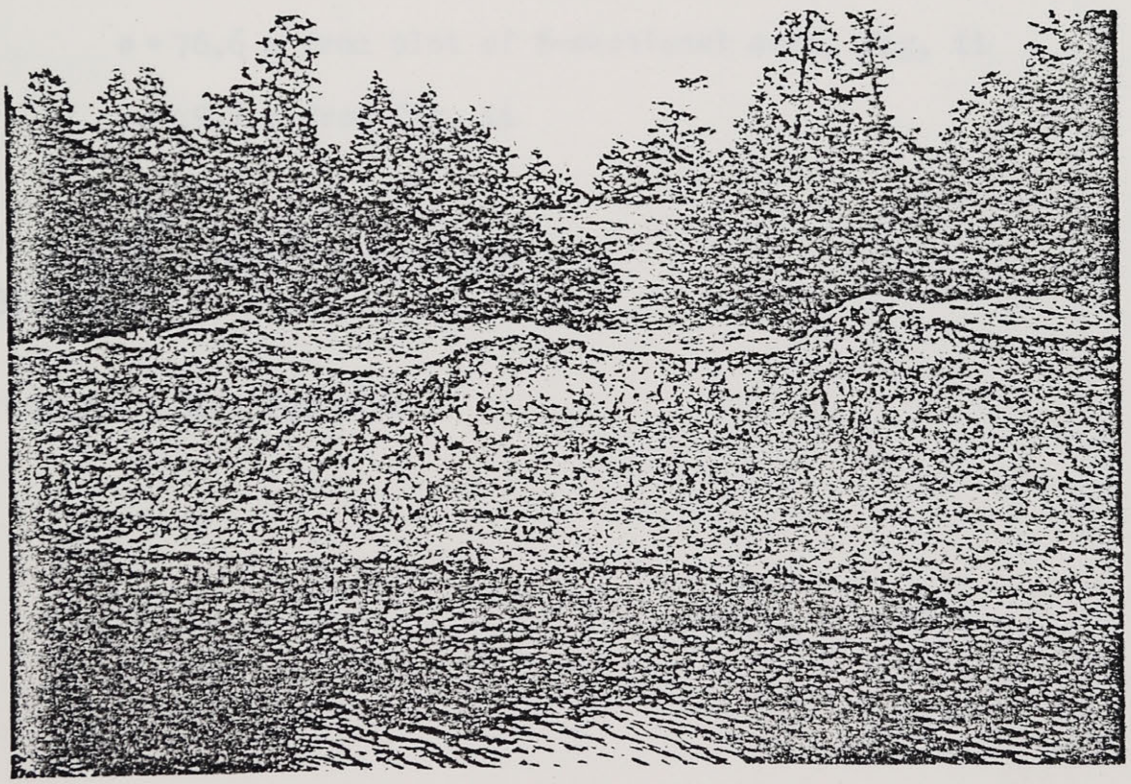


Photo 6. The toe of the same slump. This gives an indication of the sediment load caused by these slumps. Note the criss-cross tilting of the trees caused by the soil movement.

APPENDIX A

CALCULATION OF FLOW RATES

A) By use of Manning's Formula

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

where: V: average velocity of flow, m/s.

n: roughness coefficient, Swab page 631

R: a/p, a: cross-sectional area of channel, m^2

p: wetted perimeter, m

S: hydraulic gradient

at site 1: n = .035

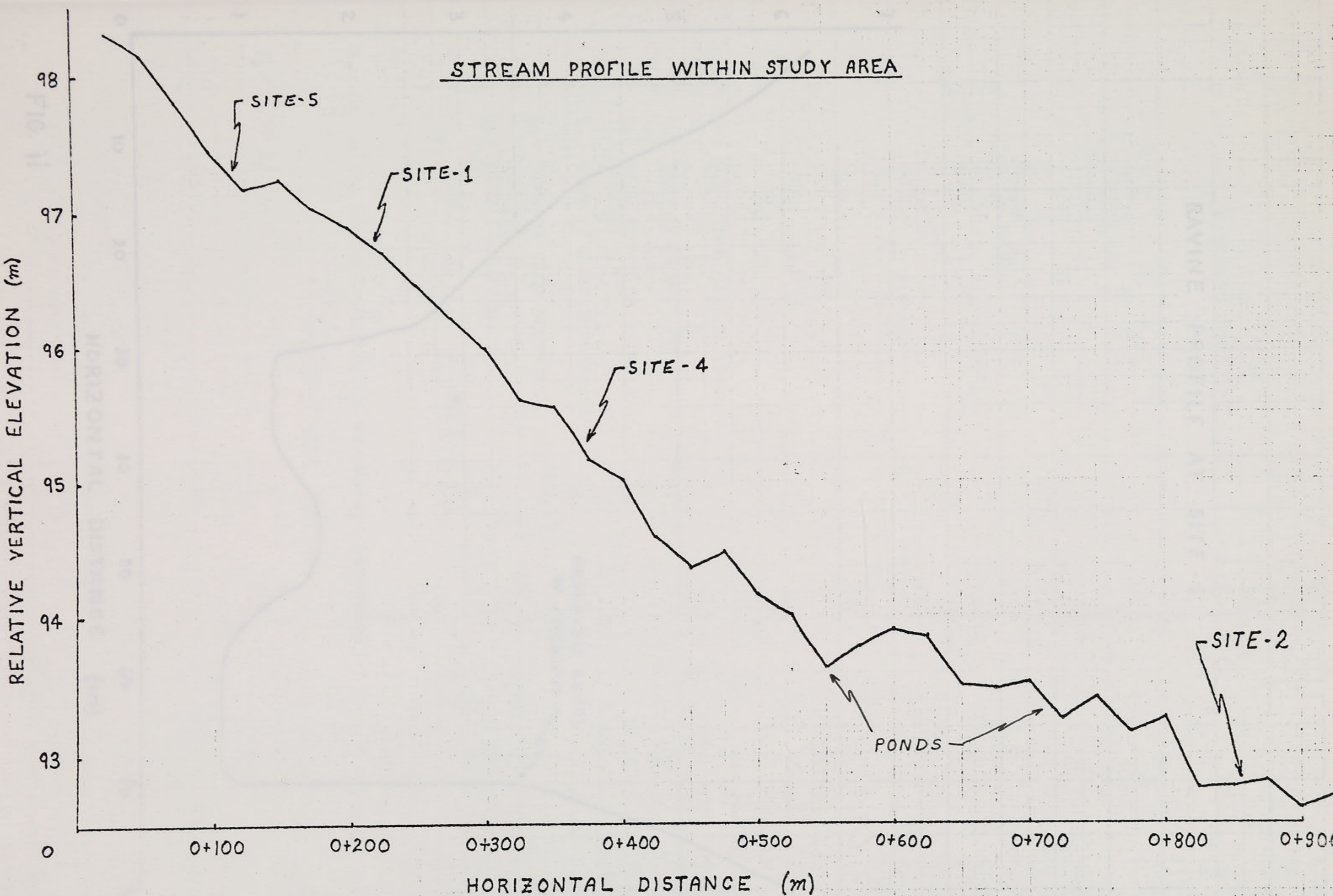
S = .0085 from plot of stream profile, fig. i

a = 76.6 m^2 from plot of X-sectional area, fig, ii

p = 49.7 m from fig, ii

$$V = \frac{1}{.035} \left(\frac{76.6}{49.7}\right)^{2/3} .0085^{1/2} = 3.51 \text{ m/s}$$

$$Q = aV = 76.6 \times 3.51 = 270 \text{ m}^3/\text{s}$$



NOTE ; 0+000 → 0+550 : $S = 0.0085$; 0+550 → 0+925 : $S = 0.0024$; AVE $S = 0.0058$

FIG (i)

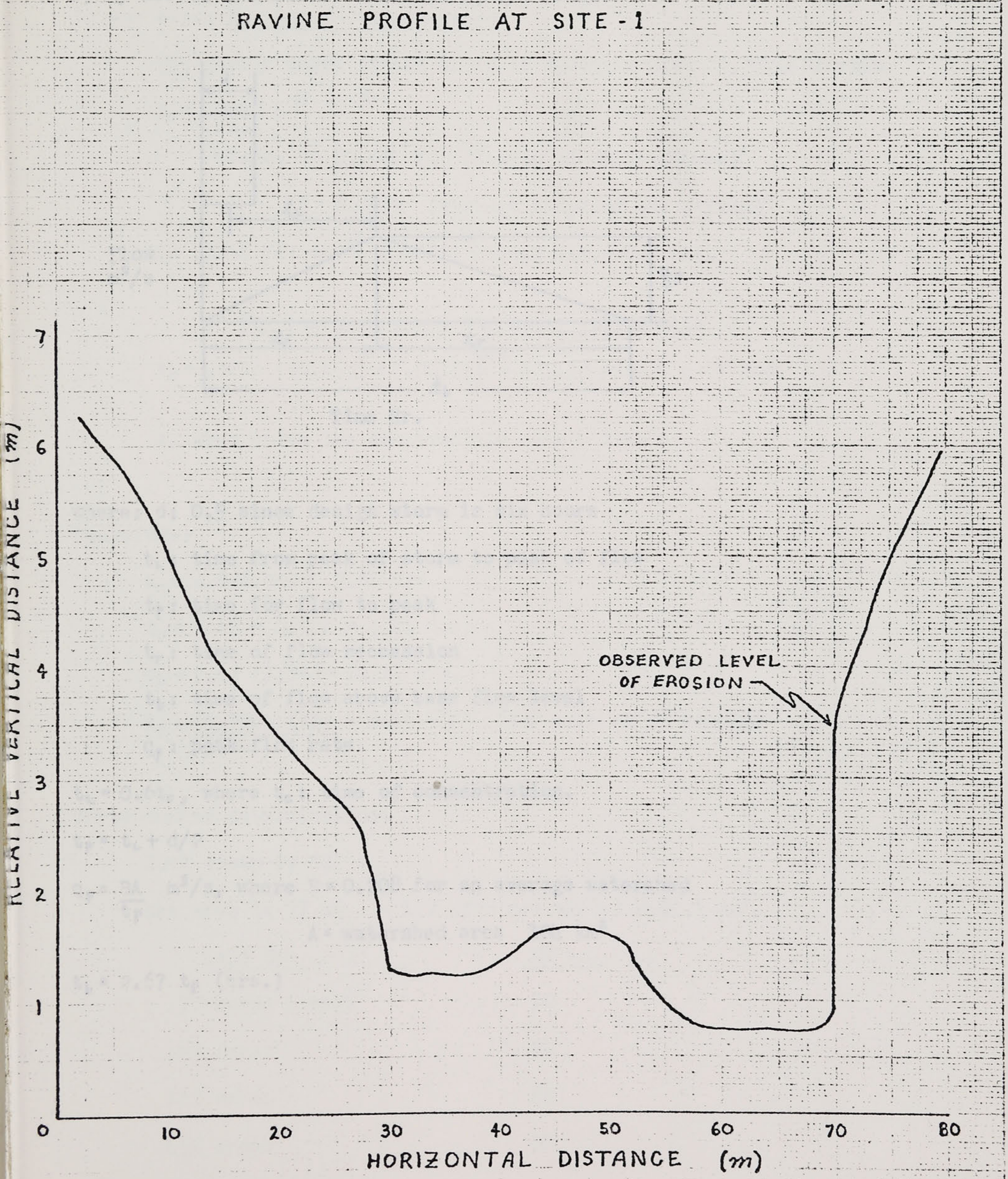
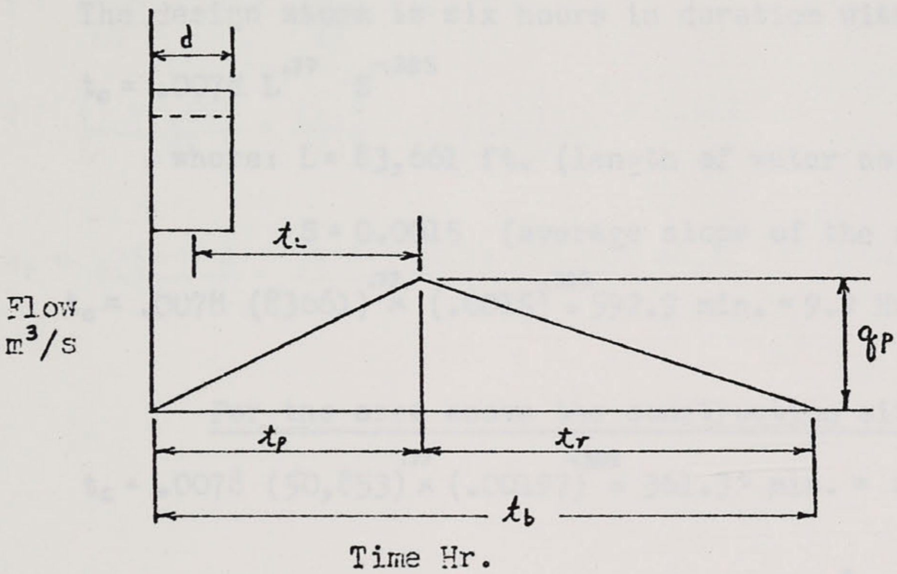

RAVINE PROFILE AT SITE - 1
RELATIVE VERTICAL DISTANCE (m)
HORIZONTAL DISTANCE (m)
OBSERVED LEVEL OF EROSION
0
10
20
30
40
50
60
70
80
1
2
3
4
5
6
7

FIG. ii

B) By use of the S.C.S. Unit Hydrograph Method



where: d: 0.5 since design storm is six hours

t_L : time from peak of storm to peak of flow

t_p : time for flow to peak

t_r : time of flow reccession

t_b : time of flow above base flow level

q_p : peak flow rate

$t_L = 0.6 t_c$, where t_c : time of concentration.

$t_p = t_L + d/2$

$q_p = \frac{BA}{t_p}$ m^3/s, where B = 0.208 for an average watershed

A = watershed area 104 km^2.

$t_b = 2.67\ t_p$ (hrs.)

In our case: <u>For the whole watershed</u>

The design storm is six hours in duration with 56.36mm of rain.

$t_c = .0078\ L^{.77}\ S^{-.385}$

where: L = 83,661 ft. (length of water course)

S = 0.0015 (average slope of the stream)

$t_c = .0078\ (83661)^{.77} \times (.0015)^{-.385} = 592.9$ min. = 9.9 Hrs.

<u>For the area above the construction site</u>

$t_c = .0078\ (50,853)^{.77} \times (.00197)^{-.385} = 361.32$ min. = 6.02 Hrs.

A; area above the construction site = 77km^2.

Therefore:

$t_L = 0.6(6.02) = 3.61$ Hrs.

$t_p = 3.61 + 0.5/2 = 3.86$ Hrs.

$t_b = 2.67\ (3.86) = 10.31$ Hrs.

$q_p = \frac{(0.208)\ (77)}{3.86} = 4.15\ m^3/s$ (for each mm of runoff)

Curve number determination:

Soil group is "C"

Net area is 77 km − 10% (for mer bleue) = 69.3 km^2.

Land Use	CN no.
7% roads & rail	90
10% forest	70
18% urban	85
45% crops	82
20% pasture & grasses	73

The weighted curve number average is 81.

$$S = \frac{1000}{CN} - 10 = \frac{1000}{81} - 10 = 2.346$$

$$Q = \frac{(I - .2S)^2}{I + .8S} = \frac{(2.5 - .2(2.346))^2}{2.5 + .8(2.346)} = 0.942$$

$$q_p = \frac{.756\ Q\ A}{t_p} = \frac{.756\ (.942)\ (25{,}600\ \text{ac.})}{3.862} = 4720.6\ \text{cfs}$$

$$= 134\ m^3/s$$

For 100 year return period;

Time Hrs.	F.cum. %	Cumulative Rainfall mm	Direct Runoff Cum. mm	Direct Runoff Incre. mm	t_p	t_b	q_p	incre. runoff m /s	time start Hr.	time peak Hr.	time end Hr.
0.5	.02	1.73	-	-	3.86	10.31	4.15	-	-	-	-
1.0	.04	3.45	-	-	↓	↓	↓	-	-	-	-
1.5	.08	6.91	-	-	↓	↓	↓	-	-	-	-
2.0	.12	10.36	-	-	↓	↓	↓	-	-	-	-
2.5	.19	16.41	-	-	↓	↓	↓	-	-	-	-
3.0	.70	60.45	20.00	20.00	↓	↓	↓	83.00	2.5	6.36	12.81
3.5	.83	71.68	29.00	9.00	↓	↓	↓	37.35	3.0	6.86	13.31
4.0	.89	76.86	33.00	4.00	↓	↓	↓	16.60	3.5	7.36	13.81
4.5	.93	80.31	36.00	3.00	↓	↓	↓	12.45	4.0	7.86	14.31
5.0	.96	82.90	38.00	2.00	↓	↓	↓	8.30	4.5	8.36	14.81
5.5	.98	84.63	39.50	1.50	↓	↓	↓	6.32	5.0	8.86	15.31
6.0	1.00	86.36	40.00	0.50	↓	↓	↓	2.08	5.5	9.36	15.81

Note: See plot of values in fig. iii

: Similarly, values for return periods of 25 and 50 years were determined and plotted in figs. iv & v.

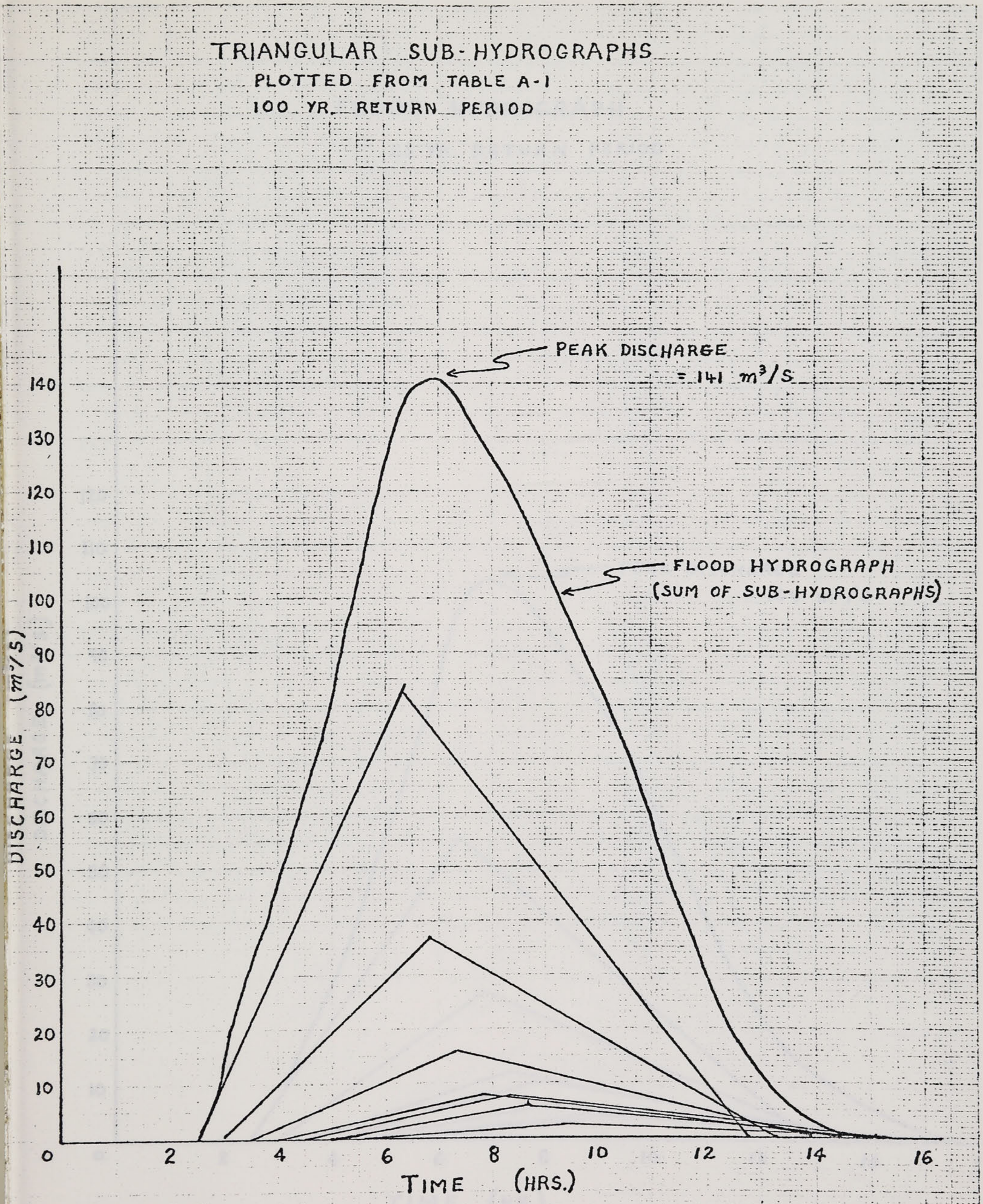

TRIANGULAR SUB-HYDROGRAPHS
PLOTTED FROM TABLE A-1
100 YR. RETURN PERIOD
PEAK DISCHARGE = 141 m³/S
FLOOD HYDROGRAPH (SUM OF SUB-HYDROGRAPHS)
DISCHARGE (m³/S)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
2
4
6
8
10
12
14
16
TIME (HRS.)

FIG. iii

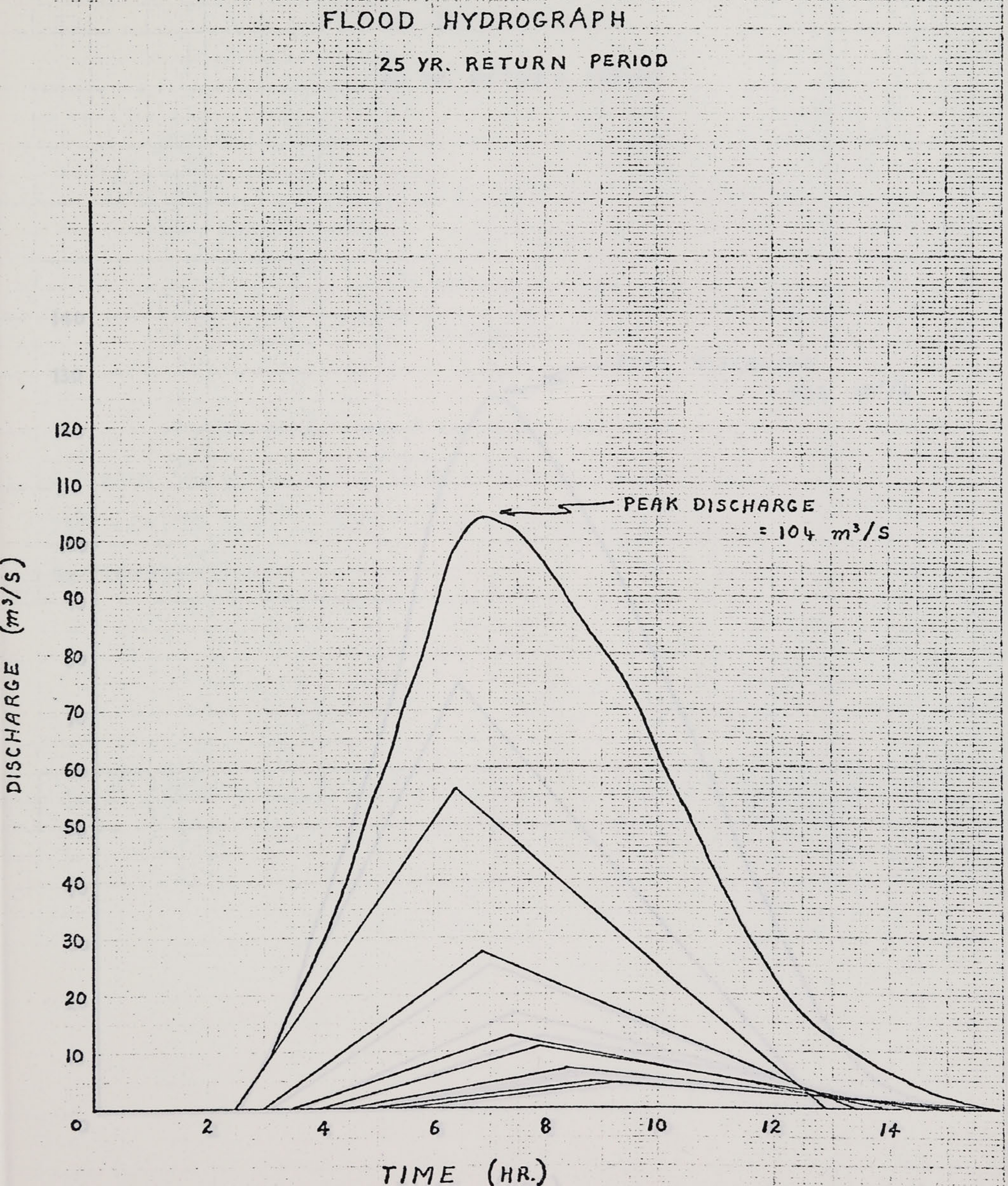

FLOOD HYDROGRAPH
25 YR. RETURN PERIOD
PEAK DISCHARGE = 104 m³/S
DISCHARGE (m³/s)
0
10
20
30
40
50
60
70
80
90
100
110
120
2
4
6
8
10
12
14
TIME (HR.)

FIG. iv

FLOOD HYDROGRAPH

50 YR. RETURN PERIOD

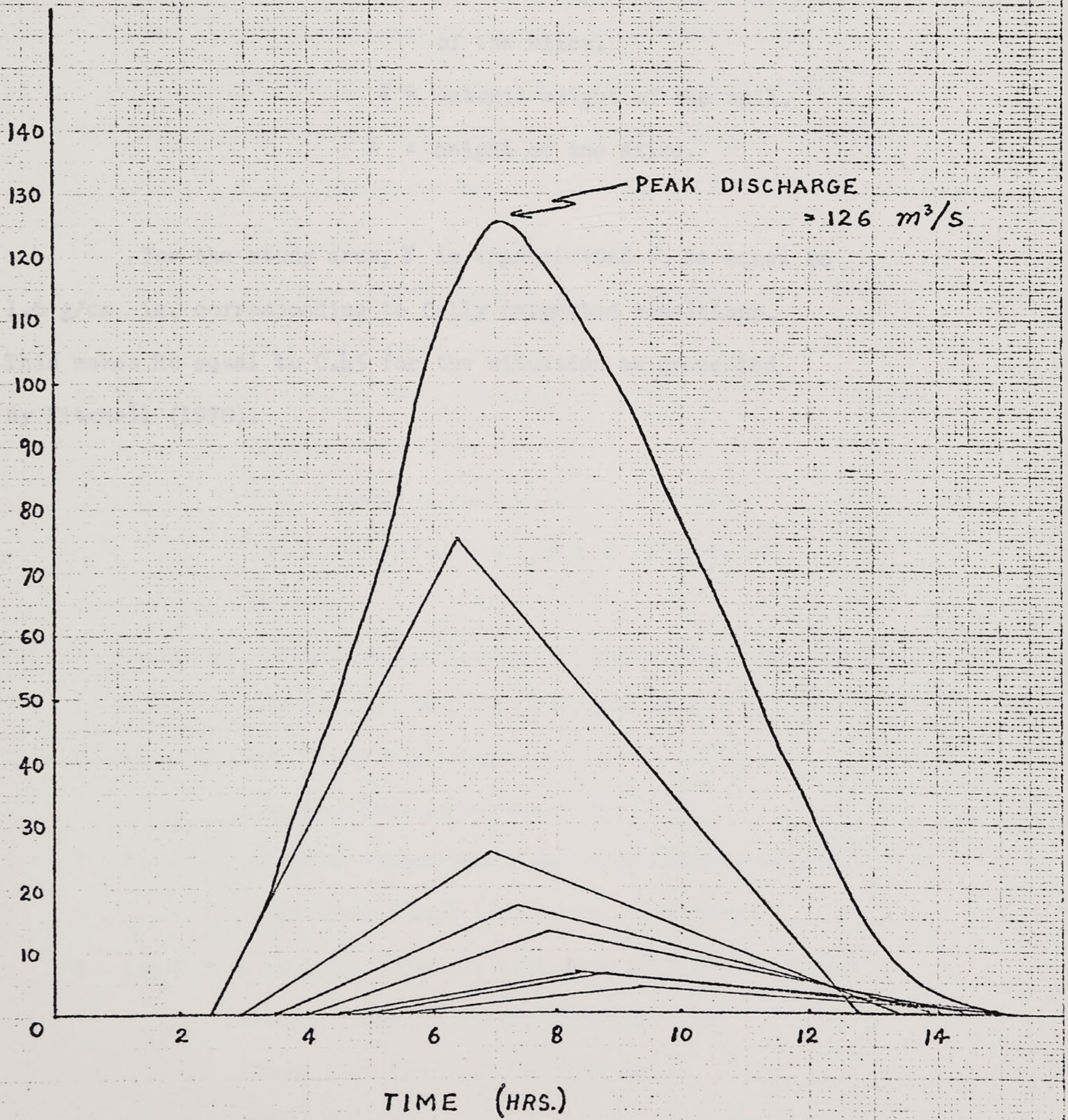


FIG. V

APPENDIX B

DEFINITION OF "Ru"

$Ru = U/\gamma h$ where: U = pore water pressure at the base of the slice.

γ = wetunit weight of the soil.

h = height of the slice.

For the study area, γ is approximated to be equal to 1.6 g/cm ie. corresponding to fully satyrated conditions. This makes Ru equal to 0.45 for the situation as presented by Mitchell (1970).

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