SUSITNA HYDROELECTRIC PROJECT

RESERVOIR SLOPE STABILITY

TASK 2 - SURVEY AND SITE FACILITIES

SUBTASK 2.15 - SLOPE STABILITY AND EROSION STUDIES CLOSEOUT REPORT

FINAL DRAFT

MARCH 1982

HARZA-EBASCO
Susitna Joint Venture
Document Number

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ALASKA POWER AUTHORITY

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF TABLES

1 - INTRODUCTION

The immediate effect of the filling of the Watana and Devil Canyon Reservoirs on the impoundment slopes will be twofold, the modification of the ground water regime and hence the modification of the balance of driving and resisting forces in the slope and the initiation of thawing in permafrost slopes. The performance of these slopes after impounding will be governed by the effect of flooding on the external factors which have contributed to instability in the past and the rate of permafrost thaw.

Little or no research has been done on large northern reservoirs in the subarctic climatic zone that is subject to permafrost conditions (Newbury, 1978). Impounding of the Susitna River Valley and its tributaries will influence the slope stability of both the Devil Canyon and Watana Reservoirs. Currently on the slopes above the river, evidence of shallow landslides and the presence of discontinuous permafrost imply that instability will also occur during the impounding of these reservoirs. Slopes in thawing permafrost and in frozen soils will add to the complexity and sensitivity of the slopes in stability analysis and therefore in predicting the conditions of the slopes after impounding.

Shoreline erosions will occur as a result of two geologic processes; (1) beaching and (2) mass movements. The types of mass movement encountered in a permafrost terrain which are pertinent to this study are described below (Varnes, 1958, modified by McRoberts and Morgenstern, 1974).

- flows - a broad type of movement that exhibits the characteristics of a viscous fluid in its downslope motion.
    - solifluction - movements restricted to an active layer and generally require fine grained soils.
    - skin flows - detachment of a thin veneer of vegetation and mineral soil and subsequent movement over a planar inclined surface.
    - bimodal flows - movement with a distinctive biangular profile composed of a steep headscarp and a low angle tongue.
    - multiple regressive flow - forms a series of arcuate, concave downslope ridges as it retains some portion of the prefailure relief.
- slides - landslides exhibiting a more coherent displacement, a greater appearance of rigid-body motion.
    - block slides - movement of a large block that has moved out and down with varying degrees of backtilting; coherent displacement.
    - multiple regressive slides - series of a arcuate blocks concave towards the toe, that step backward higher and higher toward the headscarp.
    - rotational slides - landslides which occur in thawed soils.

2 - SUMMARY AND CONCLUSIONS

Some amount of slope instability will be generated in the Watana and Devil Canyon Reservoirs due to reservoir filling. These areas will primarily be in locations where the water level will be at an intermediate level relative to the valley depth.

Slope failure will be more common in the Watana Reservoir due to the existence of permafrost soil throughout the reservoir. The Devil Canyon Reservoir is generally in more stable rock and the relatively thin overburden is unfrozen, in the reach of the river upstream from the dam.

Although skin flows, minor slides and beaching will be common in parts of the reservoirs it will present only a visual concern and poses no threat to the project. Many areas in which sliding does occur will stabilize into beaches with a steep backslope.

Tree root systems left from reservoir clearing will tend to hold shallow surface slides and in cases where permafrost exists, may have a stabilizing influence since this mat will hold the soil in place until excess pore pressures have dissipated.

3 - METHODOLOGY

The potential for instability of the slopes adjacent to both reservoirs after impoundment was evaluated principally by the use of color aerial photographs at a scale of 1:24,000, color infrared photographs at a scale of 1:120,000 and a brief field reconnaissance. Current slope instability as evidenced by flows and slides, their aspect and slope angle, and the distribution of permafrost was delineated. This information in addition to the soil and rock conditions throughout the reservoirs (R&M Subtask 5.02) and the upper and lower reservoir limits were used in identifying the potential types and zones of instability or beaching as a direct affect of the impounding of the reservoirs. For the Watana Reservoir, the limits used were 2185 feet for the normal pool level and 2015 feet for the minimum reservoir level assuming the normal pool level could be dropped as low as 2115 feet. For the Devil Canyon Reservoir, the limit used was 1450 feet for the normal pool level. Only one level was evaluated because the seasonal drawdown in this reservoir will be minimal.

4 - SLOPE STABILITY

Aside from the formation of beaches due to erosion, slope instability along the reservoir slopes can be generated for two principal reasons: a change in the ground water regime and the thawing of permafrost. Beach erosion can give rise to general instability through the sloughing or failure of an oversteeped backslope, enlarging the beach area. This is discussed further in Section 5.

When a reservoir is filled the ground water table reestablishes itself to a new level around the reservoir rim. This change and the submergence of slopes may cause the slope to be less stable than they were previously. Since most slopes on incised valleys lie very close to equilibrium, forces which lessen the stability of a slope generally could result in instability and failure. Certain conditions could also exist upon filling which would enhance the stability of a slope. An example of this condition is the decrease in the gradient across a jointed rock slope.

Drawdown of the reservoir over a short period of time invariably results in instability of susceptible slopes. All of these conditions will be addressed in greater detail in this section.

4.1 - Changes-in-Ground Water Regime

When the reservoir rises to its maximum level the ground water table in the adjacent slope also rises as shown in Figure 4.1. The result is that a slope which, although previously stable and above the ground water table, can now be unstable since it is affected by the pore pressures and seepage forces existing because of higher ground water table. The slope shown in Figure 4.1 whether it is soil or rock is less stable than it was prior to the existence of the reservoir. This is not to say that this slope will necessarily fail since failure is dependent on the strength parameters on the soil or the strength along weakness planes in the rock. The potential for failure of such a slope could extend below the water level depending on the slope configuration and the magnitude of the driving force associated with the unsubmerged portion of the slope above the water table.

The case of the newly submerged slope just below the reservoir level was examined as an infinite slope in three conditions in which it will exist. These are shown in Figures 4.2 through 4.4. The first case is the original slope, above the water table. The second is the submerged case and the third is the condition just above the reservoir level.

The third case could also exist following stabilization of the ground water regime above the reservoir or following a drawdown.

Figures 4.2 and 4.3 indicate that the unsubmerged dry slope and the submerged slope have identical factors of safety. Hence, there is no instability caused purely by submergence of a slope. However Figure 4.4 indicates that for the case of seepage parallel to the slope the factor of safety could be reduced by approximately 50 percent. Therefore, instability can be induced by raising the ground water table similar to Figure 4.1 or by drawdown of the reservoir.

Figure 4.5 indicates that a material which has some cohesion is more stable in the submerged condition and although the case with steady seepage parallel to the slope is less stable than the drained slope due to the introduction of the seepage forces, the degree of instability is not as great as in a cohesionless material.

Figure 4.6 shows that a rock slope which is in equilibrium above the present river would be more stable due to submergence. However, presently drained slopes at higher elevations which are in equilibrium could become less stable due to the reestablishment of a new ground water regime above the reservoir level. There exists only one condition, not addressed in these examples, in which submergence alone causes instability. In this case large block failure could occur when a flatter submerged slope buttresses a steeper slope above the reservoir level. The steeper block is dependent on the lower, flatter lying block for stability. Submergence reduces the sliding resistance of the lower block and although it also reduces the driving force associated with the lower block, it does not reduce the driving force associated with the upper block.

4.2 - Permafrost Thaw

The thawing of permafrost follows the example shown in Figure 4.7, taken from W.G. Brown and, G.H. Johnston (1978).

The instability of thawing permafrost slopes is addressed by McRoberts and Morgenstern (1974). They indicate that a characteristic feature of both solifluction slopes, skin flows, and the lobes of bimodal flows is instability on low angle slopes.

The infinite slope analysis previously discussed is appropriate for long shallow slopes.

Figure 4.7 shows a section in a thawing slope.

Given that:

$$d = \alpha \sqrt{t}$$

where

d = depth of thaw
α = a constant
t = time

The depth of thaw is therefore proportional to the square root of time as shown in the previous formulation. In terms of the thaw consolidation ratio, R.

$$R = \alpha/2 \sqrt{C_v}$$

where Cv = the coefficient of consolidation.

The pressure, u has been found to be:

$$u = \gamma_b \, d/(1 + 1/2R^2)$$

where γd is the effective stress after complete dissipation of the excess pore pressures.

Referring to Figure 4.8 on plane AA'

$$u = \gamma w \ D\cos\theta + \gamma_b \ D\cos\theta \left(\frac{1}{1 + \frac{1}{2R^2}} \right)$$

The factor of safety Fs is therefore:

$$Fs = \frac{\gamma \ b}{\gamma +} \left(1 - \frac{1}{1 + \frac{1}{2R^2}} \right) \frac{\tan \phi}{\tan \theta}$$

If no thaw occurs and therefore no excess pore pressure exists this reduces to:

$$Fs = \frac{\gamma b}{\gamma} \ \frac{\tan \phi}{\tan \theta}$$

which is the same condition as shown in the previous section. The stability of a thawing slope is ultimately dependent primarily on the geotechnical parameters c: ϕ and Cv since the thermal conditions can be determined independently. The excess pore pressures generated during thaw give rise to shallow slides on relatively flat slopes.

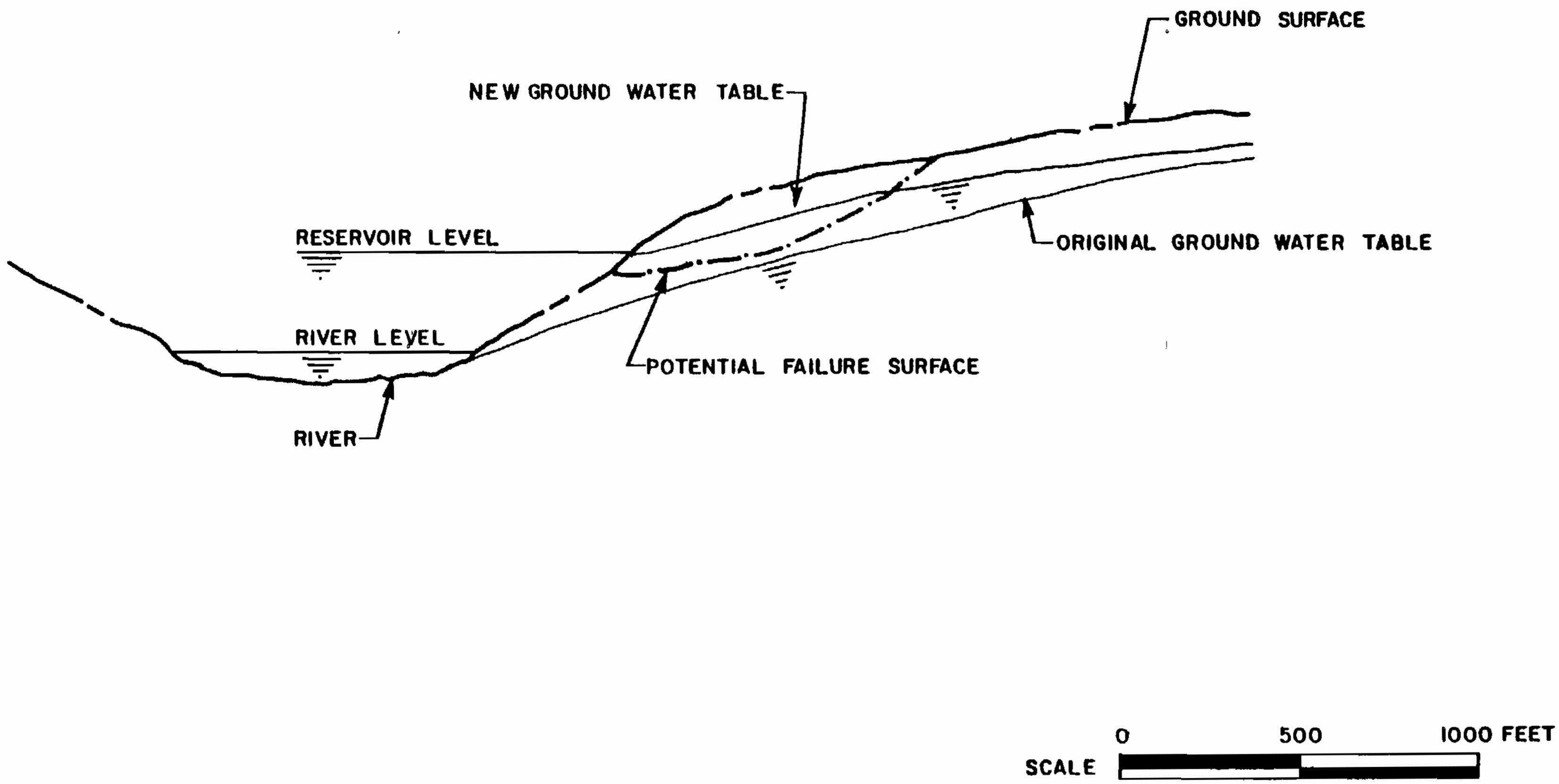
4.3 - Stability During Earthquakes

There are certain conditions which can exist after reservoir filling which will cause slides to occur during earthquakes. This section will address only those situations in which slopes are more susceptible to sliding than in their present condition.

Submerged slopes in fine grained sands or with layers of fine grained sands may be susceptible to liquifaction during earthquakes. This is one example of a case where small slides could occur below the reservoir level. In addition, areas above the reservoir rim in which the ground water table has reestablished itself could have a greater potential for sliding during earthquakes with or without liquifaction.

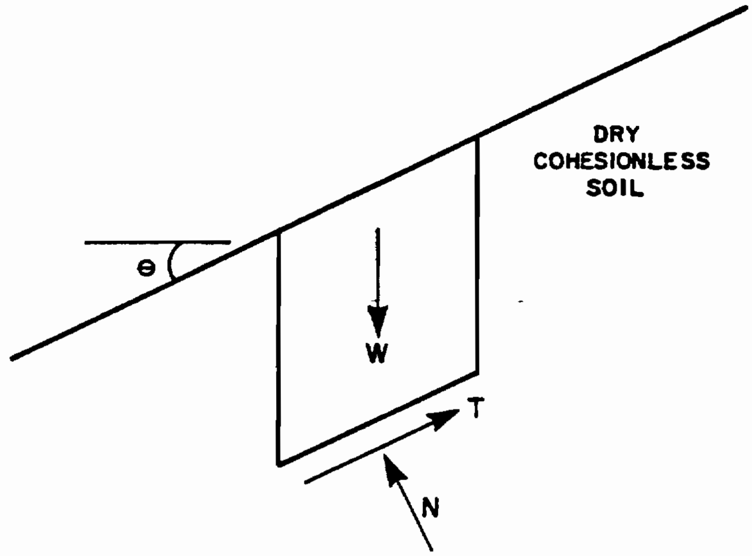
Thawing permafrost generates excess pore pressures. In cases where this situation exists in liquifaction susceptible soils, the potential exists for small slides on flat lying slopes.

The existence of fine grained sands, coarse silts and other liquifaction susceptible materials are not extensive in the reservoir areas. Therefore, it is considered that the extent of liquifaction failures during earthquakes will be small and primarily limited to areas of permafrost thaw. Some slides could occur above the reservoir level in previously unfrozen soils due to the earthquakes shaking.



TYPICAL SLOPE FAILURE

FIGURE 4.1



$$F.S. = \frac{\tan \phi}{\tan \theta}$$

FOR SHEAR STRENGTH FULLY MOBILIZED

$T = N \tan \phi$

$F.S. = 1.0$

DEFINITION OF TERMS:

θ = ANGLE OF THE SLOPE

W = WEIGHT OF THE SOIL MASS

N = NORMAL FORCE ACTING ON THE SLIDING PLANE

T = SHEAR FORCE ACTING ALONG THE SLIDING PLANE

ϕ = ANGLE OF INTERNAL FRICTION OF THE SOIL

F.S. = FACTOR OF SAFETY

SLOPE CONDITIONS IN A
DRY COHESIONLESS SOIL

FIGURE 4.2

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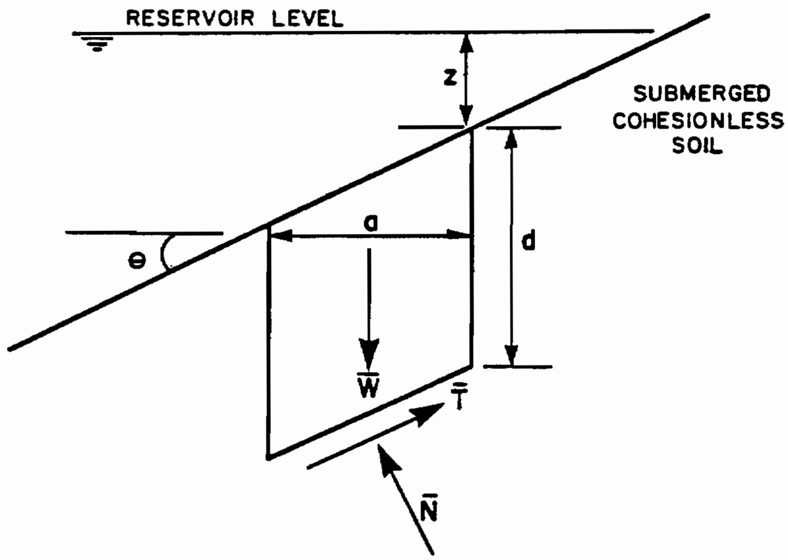


$$\bar{N} = a d \gamma_b \cos\theta$$

$$\bar{T} = a d \gamma_b \sin\theta$$

$$\bar{\sigma} = \gamma_b d \cos^2\theta$$

$$\tau = \gamma_b d \cos\theta \sin\theta$$

IF FULL RESISTANCE IS MOBILIZED

$$\tau = \bar{\sigma} \tan\bar{\phi}$$

THEN $\quad F.S. = \dfrac{\tan\bar{\phi}}{\tan\theta} = 1.0$

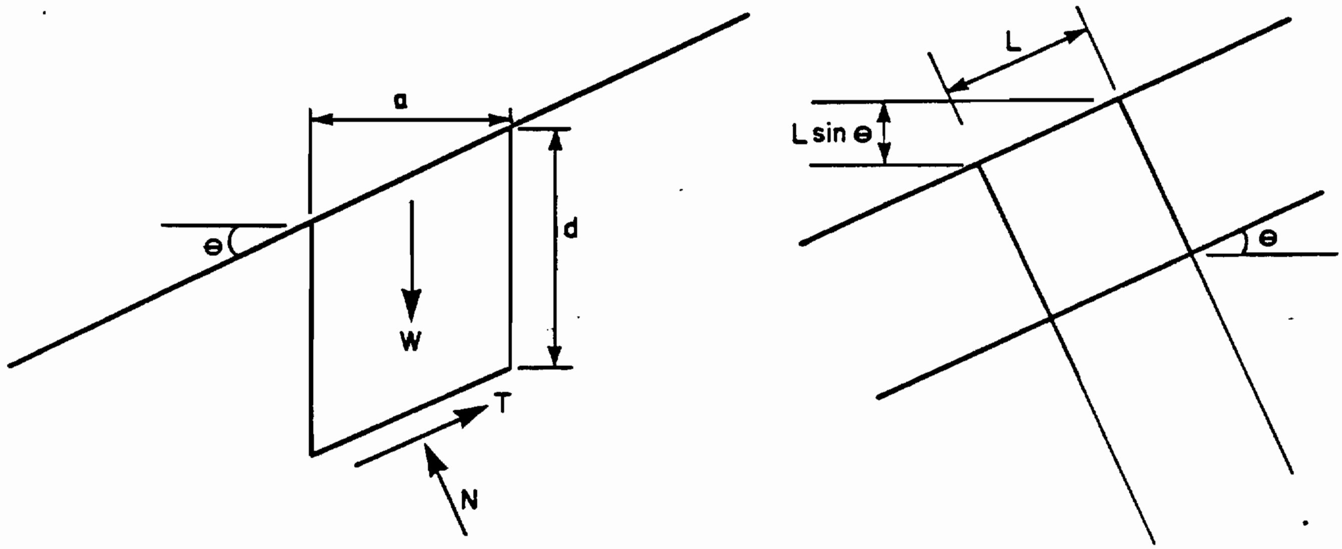
DEFINITION OF TERMS:

θ = ANGLE OF THE SLOPE
$\bar{W}$ = WEIGHT OF SOIL MASS
γ_b = BOUYANT UNIT WEIGHT OF THE SUBMERGED SOIL
$\bar{\phi}$ = ANGLE OF INTERNAL FRICTION OF THE SOIL
F.S.= FACTOR OF SAFETY

SUBMERGED SLOPE CONDITIONS
IN A COHESIONLESS SOIL

FIGURE 4.3

ACRES



$$i = \frac{L\sin\theta}{L} = \sin\theta$$

$$\bar{N} = \gamma_b\, a\, d \cos\theta$$

$$T = \gamma_b\, a\, d \sin\theta + \gamma_w\, a\, d \sin\theta$$
$$= \gamma_t\, a\, d \sin\theta$$

$$F.S. = \frac{\bar{N}\tan\bar{\phi}}{T} = \frac{\gamma_b\, a\, d \cos\theta \tan\bar{\phi}}{\gamma_t\, a\, d \sin\theta} = \frac{\gamma_b \tan\bar{\phi}}{\gamma_t \tan\theta}$$

DEFINITION OF TERMS:

i = HYDRAULIC GRADIENT ACROSS THE SOIL ELEMENT

θ = ANGLE OF SLOPE

γ_b = BOUYANT UNIT WEIGHT OF THE SOIL

γ_w = UNIT WEIGHT OF WATER

γ_t = TOTAL UNIT WEIGHT OF SOIL

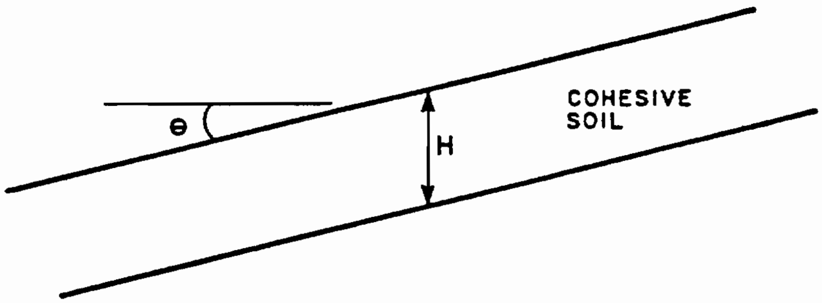
$\bar{\phi}$ = ANGLE OF INTERNAL FRICTION OF THE SOIL

F.S. = FACTOR OF SAFETY

SLOPE CONDITIONS, SEEPAGE PARALLEL TO SLOPE IN COHESIONLESS SOIL

FIGURE 4.4

ACRES



DRY SLOPE

$$F.S. = \frac{\bar{c} + \bar{\sigma}\tan\bar{\phi}}{\tau} = \frac{\bar{c} + \gamma_t H\cos^2\theta\tan\bar{\phi}}{\gamma_t H \sin\theta\cos\theta}$$

SUBMERGED SLOPE

$$F.S. = \frac{\bar{c} + \bar{\sigma}\tan\bar{\phi}}{\tau} = \frac{\bar{c} + \gamma_b H\cos^2\theta\tan\bar{\phi}}{\gamma_b H \sin\theta\cos\theta}$$

SEEPAGE PARALLEL TO SLOPE

$$F.S. = \frac{\bar{c} + \bar{\sigma}\tan\bar{\phi}}{\tau} = \frac{\bar{c} + \gamma_b H\cos^2\tan\bar{\phi}}{\gamma_t H \sin\theta\cos\theta}$$

THE ABOVE EQUATIONS INDICATE THAT:

1.) THE SUBMERGED CASE IS MORE STABLE THAN THE DRY CASE.

2.) SEEPAGE PARALLEL TO THE SLOPE CASE IS LESS STABLE THAN THE DRY CASE.

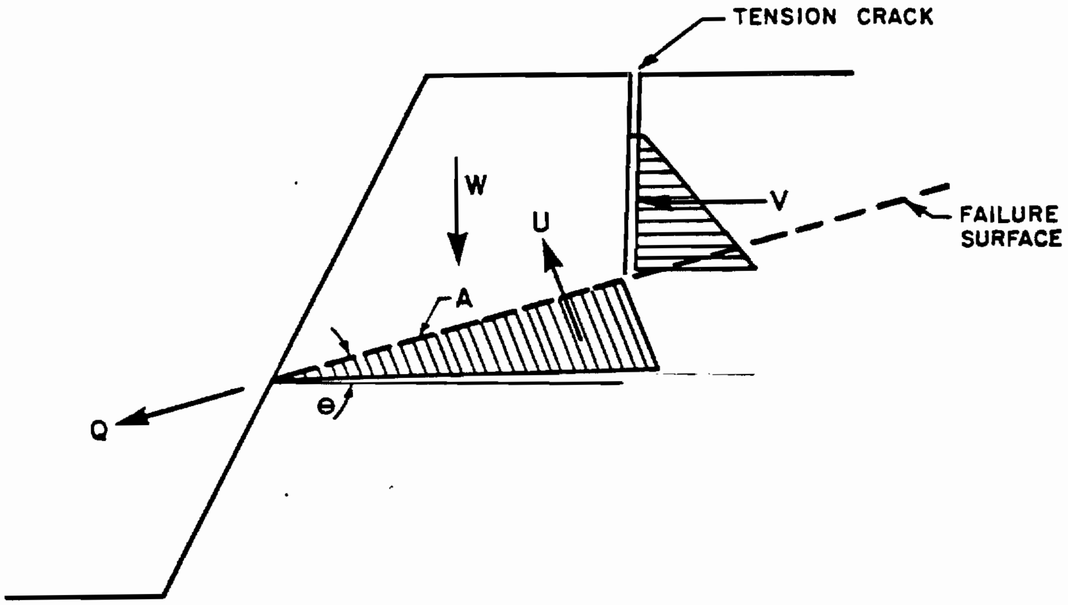
DEFINITION OF TERMS

F.S. = FACTOR OF SAFETY
$\bar{c}$ = COHESION OF THE SOIL
$\bar{\phi}$ = ANGLE OF INTERNAL FRICTION OF SOIL
θ = ANGLE OF THE SLOPE
γ_t = TOTAL UNIT WEIGHT OF SOIL
γ_b = BOUYANT UNIT WEIGHT OF SOIL

SLOPE CONDITIONS IN A COHESIVE SOIL

FIGURE 4.5

ACRES



SEEPAGE PRESSURE CASE

$$F.S. = \frac{\bar{c}A + (W\cos\theta - U - V\sin\theta)\tan\bar{\phi}}{W\sin\theta + V\cos\theta}$$

SUBMERGED CASE

$$F.S. = \frac{\bar{c}A + (\overline{W}\cos\theta)\tan\bar{\phi}}{\overline{W}\sin\theta}$$

THE ABOVE EQUATIONS INDICATE THE SUBMERGED CASE IS MORE STABLE.

DEFINITION OF TERMS:

$\bar{c}$ = COHESION OF THE ROCK MASS
W = WEIGHT OF THE ROCK WEDGE
U = UPLIFT PRESSURE ON THE ROCK WEDGE
V = DRIVING FORCE OF THE WATER BEHIND THE ROCK WEDGE
θ = ANGLE OF THE FAILURE PLANE
$\bar{\phi}$ = ANGLE OF INTERNAL FRICTION OF THE ROCK
$\overline{W}$ = WEIGHT OF SUBMERGED ROCK WEDGE
A = FAILURE PLANE AREA

SLOPE CONDITIONS IN ROCK

FIGURE 4.6

THAW EQUATION:

$$L = \gamma_d \frac{w_i}{100} L_f = (57)\left(\frac{25}{100}\right)(144) = 2052 \text{ BTU/FT.}^3$$

$$c_u = \gamma_d\left(0.17 + \frac{w}{100}\right) = 57\left(0.17 + \frac{40}{100}\right) = 32.5 \text{ BTU/FT.}^3\,{}^\circ\text{F}$$

$$D = \left[\frac{2\,k_u(T_w - T_f)\,t}{(1-a)\,L\left[1 + \left(\frac{\frac{c_u}{2} + \gamma_w a}{L}\right)(T_w - T_f)\right]}\right]^{1/2}$$

$$D = \left[\frac{2\,(0.8)(39-32)\,t}{(1-0.1)(2052)\left[1 + \left(\frac{\frac{32.5}{2} + 62.4\,(0.1)}{2052}\right)(39-32)\right]}\right]^{1/2}$$

$$D = 0.075\sqrt{t}$$

DEFINITION OF TERMS:

D = THAW DEPTH

k_u = THERMAL CONDUCTIVITY OF THAWED SOIL, USE 0.8 BTU/HR., °F, FT.

T_w = WATER TEMPERATURE AT GROUND SURFACE, USE 39° F

T_f = TEMPERATURE AT WHICH WATER WILL FREEZE, USE 32° F

t = TIME

γ_w = UNIT WEIGHT OF WATER, USE 62.4 LB./FT.^{3}

a = PERCENT ICE BY VOLUME, USE 0.10

L = QUANTITY OF HEAT REQUIRED TO MELT ICE IN 1 CUBIC FOOT OF SOIL, = $\gamma_d \frac{w_i}{100} L_f$

γ_d = DRY UNIT WEIGHT OF SOIL, USE 57 LBS./FT.^{3}

w_i = PERCENT ICE CONTENT, USE 25

L_f = LATENT HEAT, USE 144 BTU/LB.

c_u = VOLUMETRIC HEAT CAPACITY = $\gamma_d\left(0.17 + \frac{w}{100}\right)$

w = PERCENT WATER CONTENT, USE 40

MODEL FOR THAWING OF PERMAFROST

FIGURE 4.7

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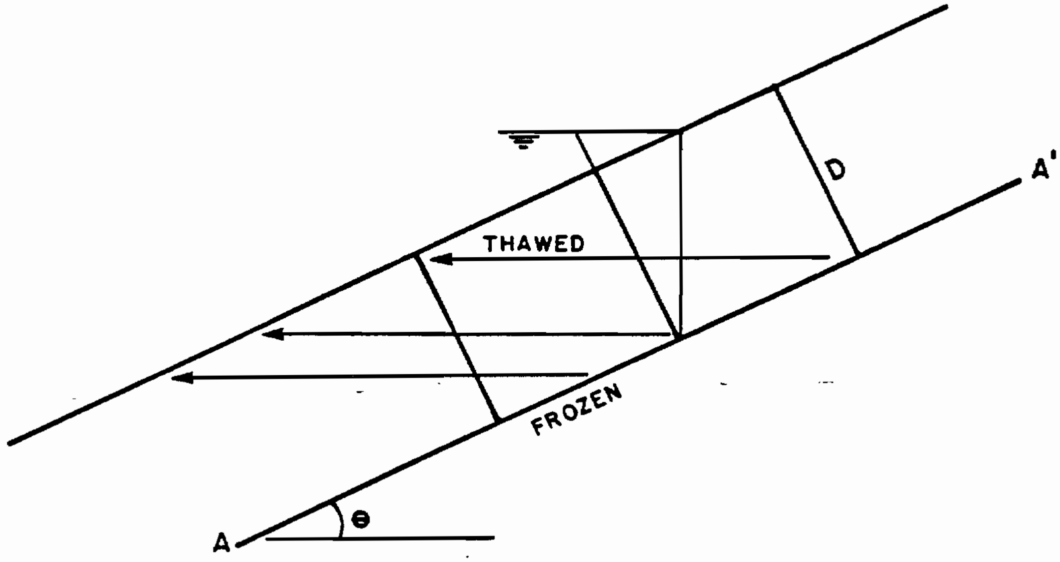


ON PLANE AA'

PORE PRESSURE $u = \gamma_w D \cos\theta + \gamma_b D \cos\theta \left(\frac{1}{1 + \frac{1}{2R^2}} \right)$

EFFECTIVE STRESS $= \gamma_t D\cos\theta - \gamma_w D\cos\theta - \gamma_b D\cos\theta \left(\frac{1}{1 + \frac{1}{2R^2}} \right)$

$$F.S. = \frac{\gamma_b}{\gamma_t} \left(1 - \frac{1}{1 + \frac{1}{2R^2}} \right) \frac{\tan\bar{\phi}}{\tan\theta}$$

WHERE $R = \frac{\alpha}{2\sqrt{C_v}}$

DEFINITION OF TERMS:

F.S.= FACTOR OF SAFETY
γ_w = UNIT WEIGHT OF WATER
γ_b = BOUYANT UNIT WEIGHT OF SOIL
γ_t = TOTAL UNIT WEIGHT OF SOIL
θ = ANGLE OF THE SLOPE
$\bar{\phi}$ = ANGLE OF INTERNAL FRICTION OF THE SOIL
R = THAW-CONSOLIDATION RATIO
α = THAW-CONSOLIDATION CONSTANT
C_v = COEFFICIENT OF CONSOLIDATION

CONDITIONS IN A THAWING SLOPE

FIGURE 4.8

ACRES

5 - RESERVOIR GEOLOGY

5.1 - Watana

Preliminary reconnaissance mapping of the Watana Reservoir was performed during this study. Principal rock types and general types of surficial material were identified.

The topography of the Watana Reservoir and adjacent slopes is characterized by narrow V-shaped stream-cut valley superimposed on a broad U-shaped glacial valley. Surficial deposits mask much of the bedrock in the areas, especially in the lower and uppermost reaches of the reservoir. A surficial geology map of the reservoir, prepared by the COE, distinguishes till, lacustrine and alluvial deposits, as well as general rock types (U.S. COE, 1979).

(a) Surficial Deposits

Generally, the lower section of the Watana Reservoir and adjacent slopes are predominately covered by a veneer of glacial till and lacustrine deposits. Two main types of till have been identified in the areas; ablation and basal tills. The basal till is predominately overconsolidated, has a fine grained matrix (more silt and clay) and has a low permeability. Tne ablation till has less fines and a somewhat higher permeability. Lacustrine deposits consist primarily of poorly graded fine sands and silts with lesser amounts of gravel and clay that exhibit a crude stratification.

On the south side of the Susitna River, the Fog Lake area is characteristic of a fluted ground moraine surface. Upstream in the Watana Creek area, glaciolacustrine material forms a broad, flat plain which mantles the underlying glacial till and the semiconsolidated Tertiary sediments. Significant alluvial deposits exist in the river valley and consist of reworked outwash and alluvium. Glaciation of the area was accompanied by the filling in of the Susitna River valley. Subsequent modification by alluvial processes during deglaciation resulted in the formation of floodlain terraces. Ice disintegration features such as kames and eskers have been observed adjacent to the river valley.

Permafrost exists in the area, as evidences by ground ice, nonsorted polygons, stone nets and slumping of the glacial till overlaying permafrost. Numerous slumps have been identified in the Watana Reservoir area, especially in sediments comprised of basal till.

This subject will be addressed in more detail in the subsequent section.

(b) Bedrock Geology

The Watana damsite is underlain by a diorite pluton. Approximately three miles upstream of the Watana damsite, a non-conformable contact between argillite and the dioritic pluton crosses the Susitna River.

An approximate location of this contact has also been delineated on Fog Creek, 4 miles to the south of the dam site. Just downstream of the confluence of Watana Creek and the Susitna River, the bedrock consists of semiconsolidated, Tertiary, sedimentary rocks (Smith 1974) and volcanics of Triassic age. These Triassic volcanics consist of metavolcaniclastic rocks and marble (Csejtey, et. al. 1978). From just upstream of Watana Creek to Jay Creek, the rock unit consists of a metavolcanogenic sequence dominantly composed of metmorphosed flows and tuffs of basaltic to andesitic composition. From Jay Creek to just downstream of the Oshetna River, the reservoir is underlain by a metamorphic terrain of amphibolite and minor amounts of greenschist and foliated diorite. To the east of the Oshetna River, glacial deposits predominate.

The main structural feature of the Watana Reservoir is a thrust fault, which trends northeast-southwest and is known as the Talkeetna Thrust (Csejtey, et. al. 1980). This thrust fault crosses the Susitna River approximately 8 miles upstream of the Watana damsite. The dip of this fault is uncertain as Csejtey and others (1980) have interpreted it to have a southeast dip, while Turner and Smith (1974) suggest a northwest dip. To date, no evidence has been found for recent displacement along this fault. At the southwest end of the fault, unfaulted Tertiary volcanics overlie the fault (Csejtey, et. al. 1980). Evidence of possible faulting has been observed in the sedimentary and volcanic rock of Jurassic age, north of Watana Creek (Csejtey, et. al. 1980; Turner & Smith, 1974). Investigations of the Tertiary sediments in Watana Creek by members of the University of Alaska Geology Department did not however, uncover any direct evidence of faulting.

(c) Slope Stability and Erosion

The geology of the slopes underlying and adjacent to the reservoir consist primarily of unconsolidated material. Current or previous slope instability on the slopes above the Susitna River, as defined by aerial photographic interpretation and some field reconnaissance indicate that the types of mass movement consist primarily of solifluction, skin flows, bimodal flows, and small rotational slides. These types of movement occur predominately in basal till or in areas where the basal till is overlain by lacustrine deposits (Table 5.1). In addition, solifluction which originated in the basal till has proceeded downslope over some of the floodplain terraces. Aspect, and therefore incoming solar radiation, is not a key factor as all slopes are susceptible to mass movement. In Figures 5.3 through 5.18, the distribution of permafrost has been delineated primarily on the flatter slopes and does not include its delineation outside the 2300 foot contours. These areas are potentially underlain by permafrost. Inclined slopes may be underlain by permafrost, but based on photogrammetric characteristics, the active layer is much thicker, permafrost soils are thawing and/or permafrost doesn't exist. As a generalization, the distribution of permafrost is nearly continuous in the basal till and is scattered/continuously in the lacustrine deposits.

Three major factors will contribute significantly to slope instability in the Watana Reservoir. These are the changes in the ground water regime, the large seasonal fluctuation of the reservoir level (est. at 60 feet) and the thawing of permafrost. The Devil Canyon Reservoir will be primarily affected by the first and to a lesser extent by the second factor. These factors were analyzed for their effects on typical conditons in the reservoir and from this, four basic models of shoreline conditions were developed (Figures 5.1 and 5.2). The two processes affecting the shoreline of the reservoirs are beaching and slope stability. These models were applied to selected reaches of the reservoir shoreline and evaluated for conditions at or near normal pool level (Figures 5.3 through 5.18). It should be noted that the slope stability of the Watana Reservoir was evaluated for the worse case, as two reservoir levels were considered for their potential effect on their slopes. In cases where sliding will occur it will not be uncommon for some flows or possibly beaching to occur over the same reach. Slope instability during and after reservoir impounding will be addressed below.

The filling of the reservoir to the normal pool level is estimated to take approximately three years. Due to the rate of impounding, the potential for slope instability occuring during the flooding of the reservoir will be minimal and confined to shallow surface flows and possibly some sliding. These slopes will be more susceptible to slope instability after impounding when thawing of the permafrost soils will occur and the ground water regime has reestablished itself in the unfrozen soils.

Near the damsite, assuming that the current contours will remain unchanged, the north abutment will have the potential for beaching except for possibly some small flows and slides adjacent to Deadman Creek. On the south abutment, thawing of the frozen basal tills will result in numerous skin and bimodal flows and there will be a potential for small rotational sliding to occur primarily opposite Deadman Creek.

On the south abutment between the Watana damsite and Vee Canyon the shoreline of the reservoir is susceptible to a high potential for flows and shallow rotational slides (Figures 5.19 and 5.20). In contrast to the north abutment, the shoreline is almost exclusively in contact with frozen basal tills, overburden is relatively thick and steeper slopes are present. Thermal erosion, resulting in the erosion and thawing of the ice-rich fine grained soils will be the key factor influencing their stability. In the Watana Creek drainage area there is a thick sequence of lacustrine material overlying the basal till (Figure 5.21). Unlike the till, it appears that the lacustrine material is largely unfrozen. All four models are perceived to have the potential for occurring here, depending on where the seasonal drawdown zone is in contact with the aforementioned stratigraphy. Overall, the north abutment in contrast with the south abutment, doesn't have the constant steep slopes and the slopes are slightly better drained, which may be indicative of less continuous permafrost and/or slightly coarse material at the surface with a deeper active layer. In general, the potential for beaching is higher because the seasonal drawdown zone will be in contact with a thin veneer of colluvium over bedrock and in a number of areas, low slopes (Figure 5.22). In the Oshetna-Goose Creeks area there is a thick sequence of lacustrine material. Permafrost appears to be nearly continuous in this area based on the presence of unsorted polygonal soils and potential thermokarst activity around some of the many small ponds (thaw lakes/kettles). The reservoir will be primarily confined within the floodplain and therefore little modification of the slopes is expected. Where the slopes are steep, there could be some thermal-niche erosion resulting in small rotational slides.

The potential for a large slide occurring and generating a wave with the likelihood of overtopping the dam is ultimately remote. For this condition to occur, a very high, steep slope with a potentially unstable block of large volume would need to exist adjacent to the reservoir. In approximately the first 16 miles upstream of the dam, the shoreline will be in contact with the low slopes of the broad U-shaped valley, above the present river valley. The only areas where these conditions are met is in the zone approximately between 16 and 30 miles upstream of the dam. In this area, no potentially large landslides were observed photogrammetrically. Beyond 30 miles upstream, the reservoir begins to meander and narrows, therefore any wave induced by a large landslide would in all likelihood have a tendency to dissipate prior to reaching the dam.

In general the following conclusions can be drawn about the slope conditions of the Watana Reservoir after impounding:

- the principal factors influencing slope instability are the large seasonal drawdown of the reservoir and the thawing of permafrost soils. Other factors are the change in the ground water regime, the steepness of the slopes, coarseness of the material, thermal toe erosion, and the fetch available to generate wave action;

- the potential for beaching will occur primarily on the north abutment of the reservoir;

- a large portion of the reservoir slopes are susceptible to shallow slides, mainly skin and bimodal flows, and shallow rotational slides;

- the potential for a large block slide which might generate a wave that could overtop the dam is remote; and

- the period in which restabilization of the slopes adjacent to the reservoir will occur is largely unknown.

Generally speaking, reservoir slopes which are totally submerged, or in which the filling is above the break in slope will exhibit less stability problems than those in which the reservoir is at an intermediate or low level. Flow slides induced by permafrost thaw in fine grained soil can, however, occur on very flat lying slopes.

5.2 - Devil Canyon

(a) Surficial and Bedrock Geology

The topography in and around the Devil Canyon Reservoir is bedrock controlled. Overburden is thin to absent, except in the upper reaches of the proposed reservoir where alluvial deposits cover the valley floor.

A large intrusive plutonic body underlies most of the reservoir and adjacent slopes. It is perdominantly a biotite granodiorite with local areas of quartz diorite and diorite. It is light gray to pink, medium grained and composed of quartz, feldspar, biotite and hornblende. The most common mafic mineral is biotite. When weathered, the rock has a light yellow-gray or pinkish yellow-gray color, except where it is highly oxidized and iron stained. The granodiorite is generally massive, competent, and hard with the exception of the rock exposed on the upland north of the Susitna River where the biotite granodiorite has been badly decomposed as a result of physical weathering.

The other principal rock types in the reservoir area are argillite and graywacke, which are exposed at the Devil Canyon damsite. In summary, the argillite has been intruded by the massive granodiorite and as a result, large isolated roof pendants of the argillite and graywacke are found locally throughout the reservoir and surrounding areas. The argillite/graywacke varies to a phyllite of low metamorphic grade, with possible isolated schist outcrops.

The rock has been isoclinally folded into steeply dipping structures which generally strike northeast-southwest. The contact between the argillite and the biotite granodiorite crosses the Susitna River just upstream of the Devil Canyon damsite. It is nonconformable and characterized by an almost aphanitic texture with an apparent wide chilled zone. The trend of the contact is roughly northeast-southwest as it crosses the river. Several large outcrop areas of the argillite which are completely surrounded by the biotite granodiorite are located in the Devil Creek area.

Preliminary joint measurements made in the reservoir area indicate structural trends similar to those encountered at the damsite. Joint spacing at these stations ranged up to 3 feet.

(b) Slope Stability and Erosion

The Devil Canyon Reservoir will be entirely confined within the walls of the present river valley. This reservoir will be characterized by a narrow deep water body which will be subject to only minimal seasonal drawdown. Much of the topography of this reservoir is bedrock controlled. In the vicinity of Devil Creek downstream to the damsite, the slopes of the reservoir and its shoreline consists primarily of bedrock and bedrock with a thin veneer of colluvium or till. Upstream of Devil Creek, the slopes of the reservoir are comprised of increasing amounts of unconsolidated materials, especially on the south abutment between river mile 166 and 178. These materials are composed of basal till and coarse grained floodplain and alluvial fan deposits.

Current or previous slope instability on the slopes above the Susitna River as defined by photogrammetry and limited field reconnaissance, indicate that the types of mass movement present are skin and bimodal flows, a potential block slide in rock and one large rotational slide. The basal tills are the primary materials susceptible to mass movement. As in the Watana Reservoir, aspect is not a key factor in delineating which slopes are more susceptible to mass movement. As a generalization, permafrost is largely absent downstream of approximately river mile 166, except for the higher elevations above the river where solifluction activity is widely scattered. Over this reach, on the south abutment and south of the dam site there is a possibility of sporadic permafrost existing within the delineated areas but it is generally thought to be unlikely. Upstream of this area, the basal till is nearly continuously frozen as evidenced by field information along the access road corridors and in Borrow Area "H".

Downstream of the Devil Creek area, instability is largely reserved to small rock falls. Beaching will be the primary process activity upon the shoreline in this area (Figures 5.23 through 5.33). Although this area is mapped as a basal till, it is coarser grained than that which is found in the Watana Reservoir and therefore is more susceptible to beaching.

In areas where the shoreline is in contact with steep bedrock cliffs, the fluctuation of the reservoir will contribute to rock falls. Fluctuation of the reservoir and therefore the ground water table, accompanied by seasonal freezing and thawing will encourage frost riving as an erosive agent to accelerate degradation of the slope and beaching. These rock falls will in no way have the capacity to produce a large wave which might eventually affect the dam. In Devil Creek, a potential small block slide may exist but it now appears stable and will have no effect on the reservoir. Beyond Devil Creek, beaching will also be the common erosive agent up to river mile 175. Beyond river mile 167 the reservoir will be primarily confined to the river floodplain. Present slope stability above reservoir normal pool level will continue to occur, with primary beaching occurring at the shoreline. At river mile 175 there is a possibility that an old large landslide on the south abutment, which has been stable for quite some time, may become unstable after reservoir impounding. This landslide has a large arcuate back scarp which has become completely vegetated since its last movement. This landslide which has a volume of approximately 3.4 million cubic yards, has the potential for sliding due to either thermal erosion or changes in the ground water regime (Figure 5.34). This large rotational slide is composed of basal till which is for the most part frozen. A large bimodal flow exists within this block and is headed by a large body of ground ice. Each year, ablation of the ice results in flowage of saturated material downslope. The distance from the dam, the meandering of the river valley and the shallow depth of the reservoir indicate that the potential of a wave induced by a possible slide, affecting the dam is remote. Preliminary assessment of a mass slide in this area suggests that blockage of the river flow that would affect the upstream river level would be only a temporary condition until the river was able to erode through the flow.

It is likely that the intial sliding in this area was activated by erosion. Although this will not be a factor after filling the reservoir, the submergence of the lower slope could endanger this old slide mass.

In general the following conclusions can be drawn about the slope conditions of the Devil Canyon Reservoir after impounding:

- minimal drawdown of the reservoir is conducive to stable slope conditions

- the lack of unconsolidated materials along the lower slopes of the reservoir and the existence of stable bedrock conditions are indicative of stable slope conditions after reservoir impounding

- an old large landslide in the upper reservoir has the potential for instability, this could conceivably create problems by blocking reservoir flow to Devil Canyon for a short period of time.

- the probability of a wave overtopping the dam is remote.

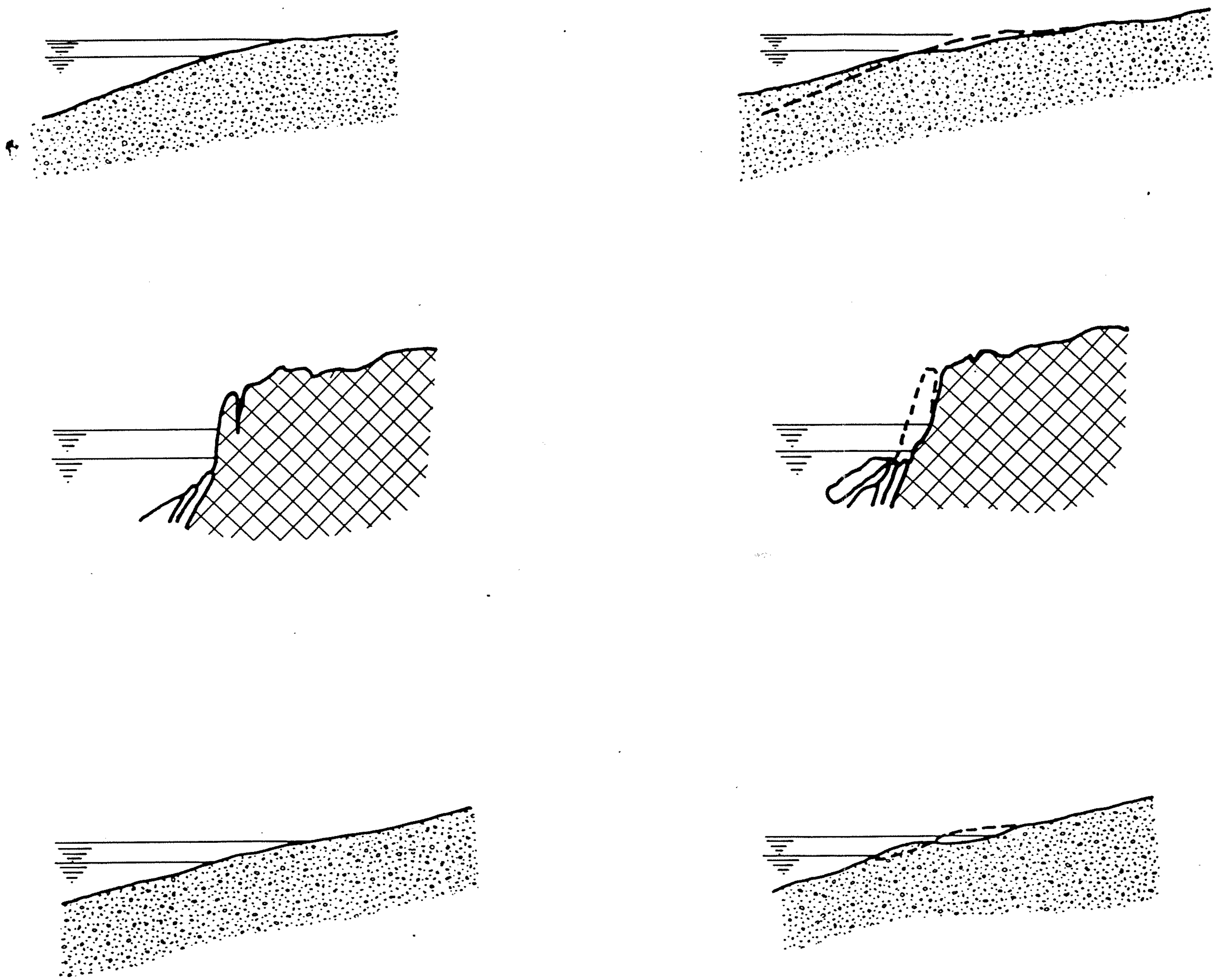
TABLE 5.1: CHARACTERISTICS OF SLOPE MATERIALS

UNIT	TERRAIN UNIT SYMBOL	MATERIAL	PERMAFROST CONDITIONS[1]	CURRENT SLOPE STABILITY	SLOPE CONDITIONS AFTER RESERVOIR FILLING[2]	
					LOW	STEEP
Bedrock	Bxu	Consolidated bedrock.	unfrozen	stable	Beaching (I)[3], [4]	
Colluvium, over bedrock & bedrock exposures	C + Bxu / Bxu	Angular blocks of rock with some sand and silt overlying bedrock.	unfrozen	stable	Beaching (I)	
Floodplain	Fp	Rounded cobbles, gravel and sand, sorted and layered with or without silt cover.	unfrozen	stable	Beaching	
Floodplain Terraces	Fpt	Rounded cobbles, gravel and sand with some silt covered by thin silt layers. Sorted, layered.	unfrozen	stable	Beaching (I)	
Granular Alluvial Fan	Ffg	Rounded cobbles, gravel, with sand and some silt. Some sorting and layering of materials.	unfrozen	stable	Beaching (I)	
Kame Deposits	GFK	Rounded and striated cobbles, and sand. Crudely sorted and layered.	unfrozen	stable	Beaching (I)	
Lacustrine	L	Fine sand to sandy silt with occasional pebbles. Sorted and layered.	unfrozen frozen	stable stable	Beaching (I) Flows (II)	Sliding (III) Sliding (IV)
Basal Till	Gtb-f	Gravelly silty sand and gravelly, sandy silt cobbles and boulders poorly rounded and striated. No layering, poorly graded.	frozen	unstable	Flows (II)	Sliding (IV)
Ablation Till	Gta	Rounded and striated cobbles, gravel and sand, no layering, well graded. Boulder cobble, lag covers surface.	unfrozen frozen	stable stable	Beaching (I) Flows (II)	Sliding (IV) Sliding (IV)
Ablation Till over Unweathered Bedrock	Gta / Bxu	Rounded and striated cobbles, gravel and sand, no layering well graded over bedrock.	unfrozen	stable	Beaching (I)	
Basal Till over Unweathered Bedrock	Gtb-f / Bxu	Gravel, silty sand and sandy silt with no layering or sorting over bedrock.	frozen	stable	Flows (II)	
Lacustrine over Basal Till	L / Gtb-f	Poorly graded silty sand and sandy silt overlying basal till.	L sporadic Gtb frozen	unstable	Flows (III)	Slumping (IV)

FOOTNOTES:

1 As perceived to be in most cases.
2 Beaching vs mass movement over certain reaches of reservoir; where sliding occurs, can expect some potential beaching and flows.
3 Potential of frost riving on rock slopes resulting in rockfall.
4 Numerical values apply to slope models, see Figures 5.1 and 5.2.

INITIALLY | AFTER SEVERAL YEARS | ASSUMPTIONS:



BEACHING (I) — FLAT SLOPES. COARSE GRAINED DEPOSITS OR UNFROZEN TILL AND LACUSTRINE DEPOSITS.

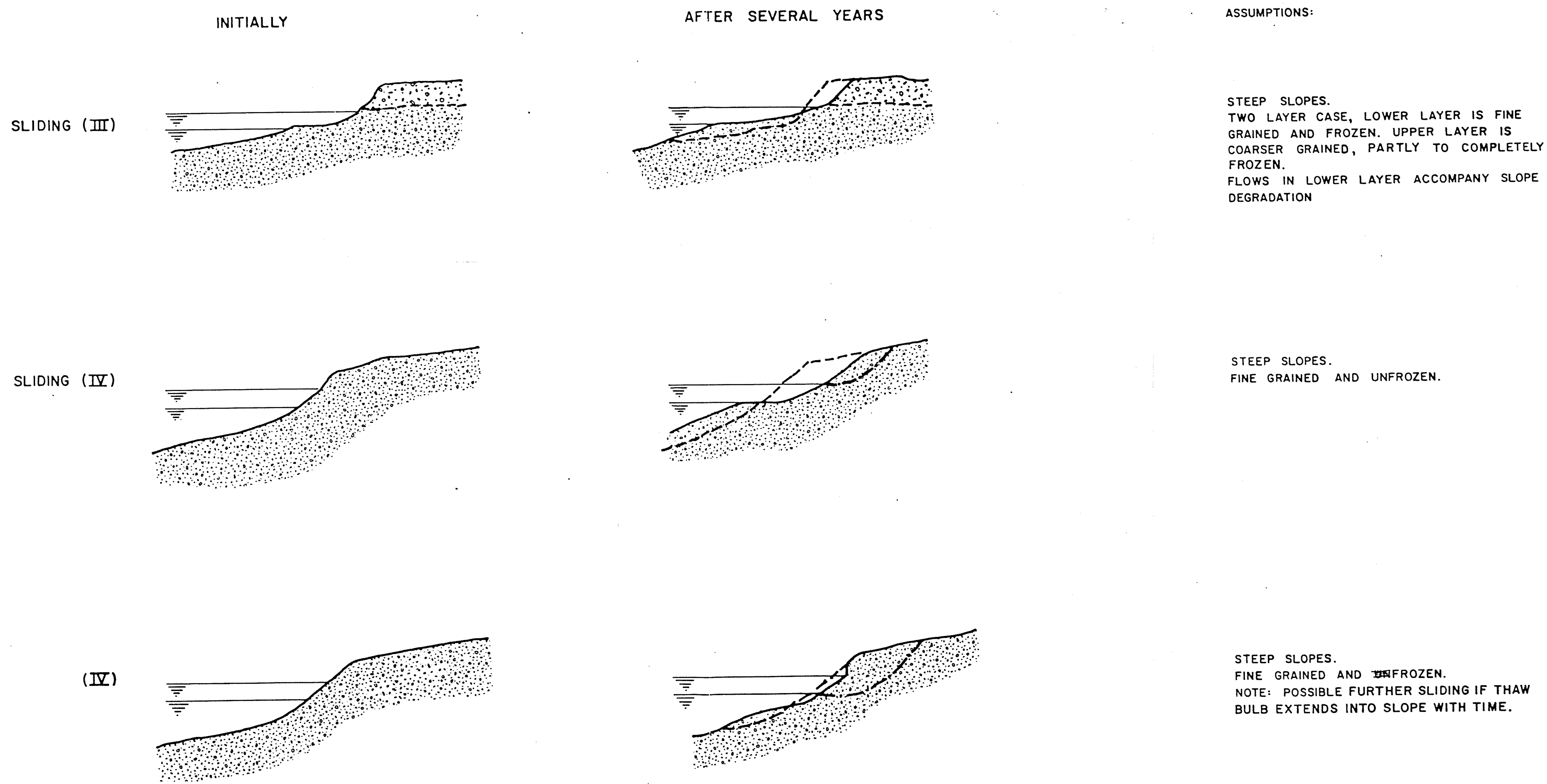
BEACHING (I) MINOR — STEEP BEDROCK SLOPES. FLUCTUATION OF RESERVOIR AND GROUNDWATER TABLE CAUSES FROST WEDGING TO OCCUR CAUSING ROCKFALL.

FLOWS (II) — FLAT SLOPES. GENERALLY FINE GRAINED DEPOSITS, FROZEN.

SLOPE MODELS FOR THE WATANA AND DEVIL CANYON RESERVOIRS

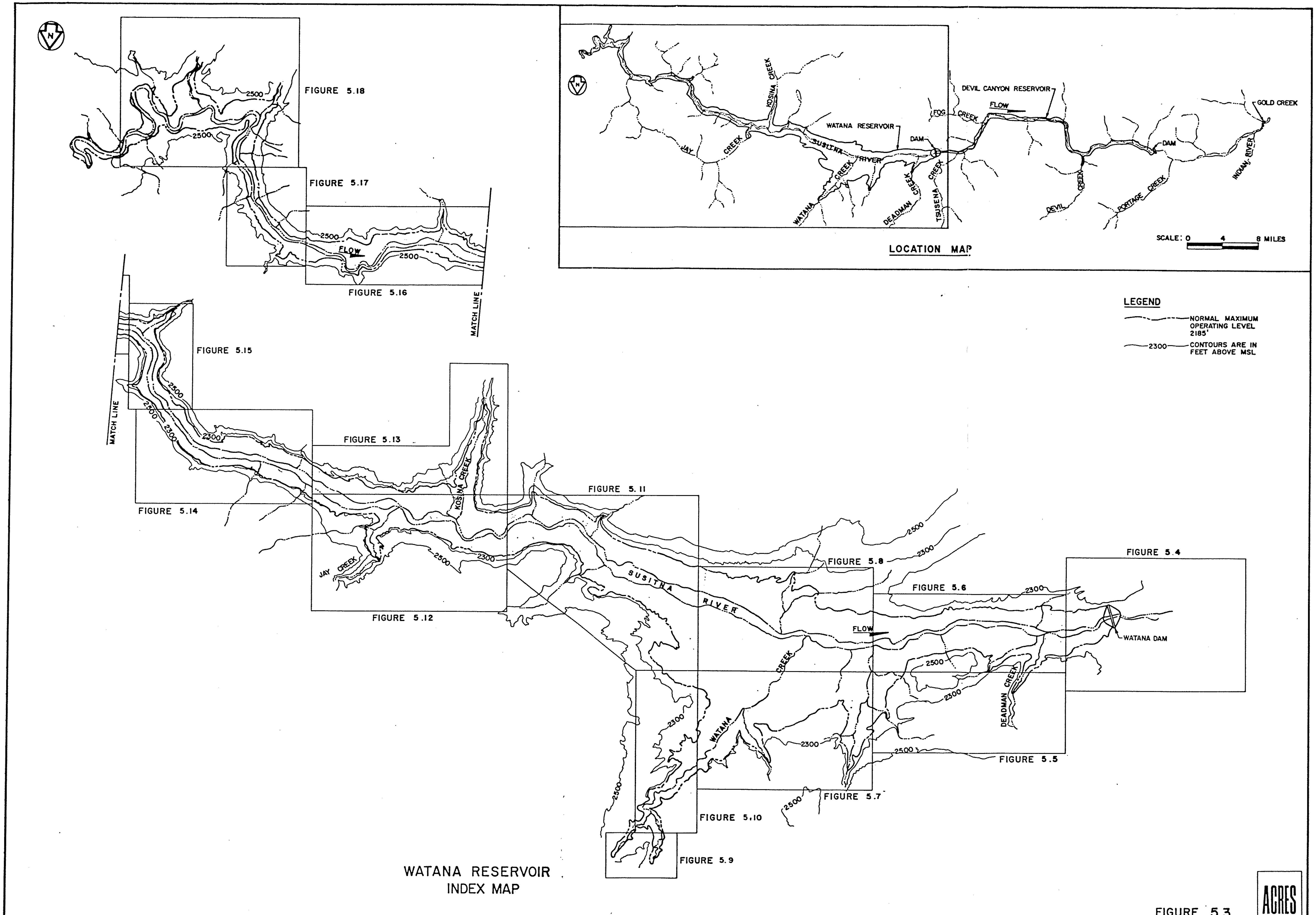
ACRES

FIGURE 5.1



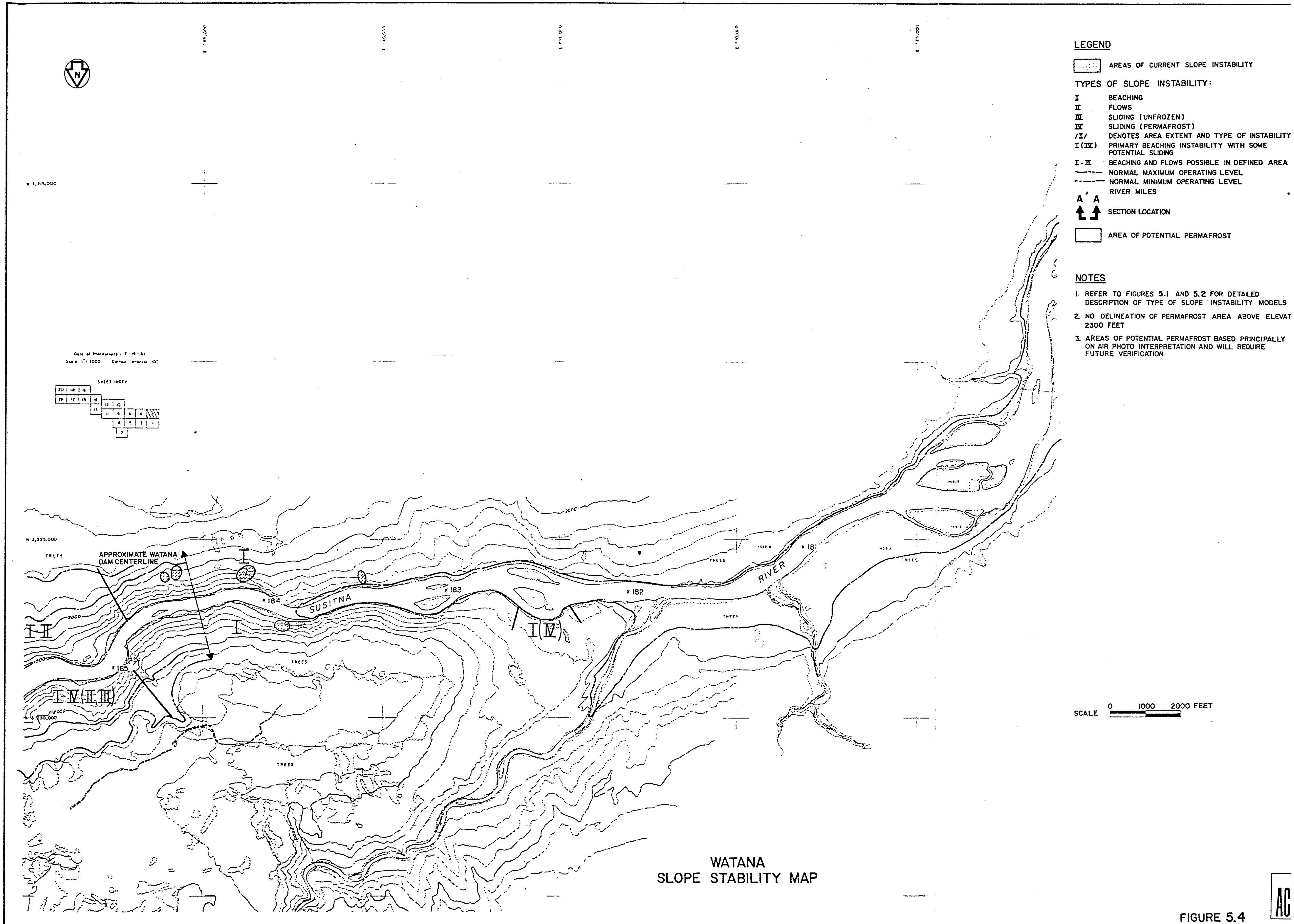
SLOPE MODELS FOR THE WATANA AND DEVIL CANYON RESERVOIRS

FIGURE 5.2



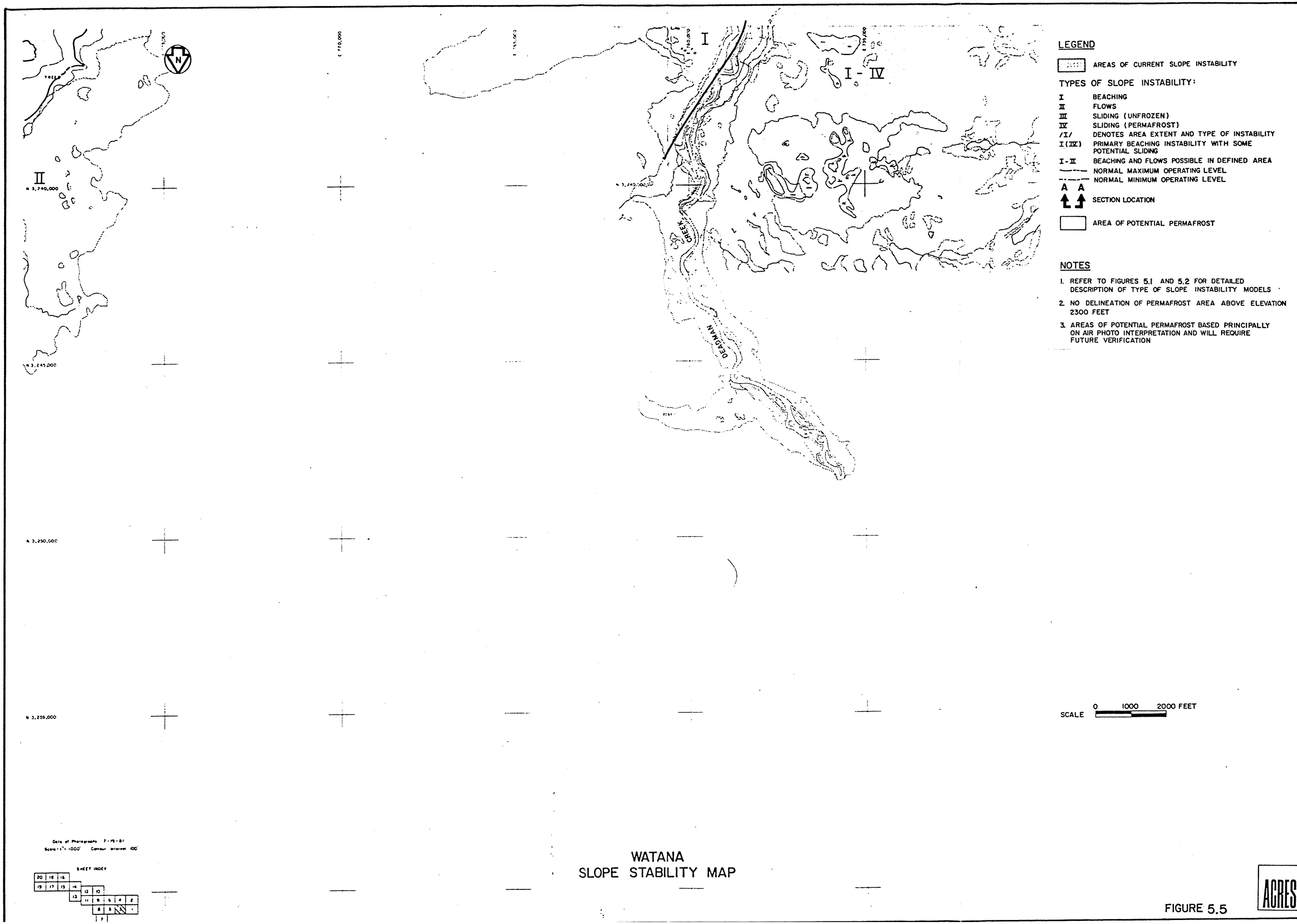
WATANA RESERVOIR
INDEX MAP

FIGURE 5.3



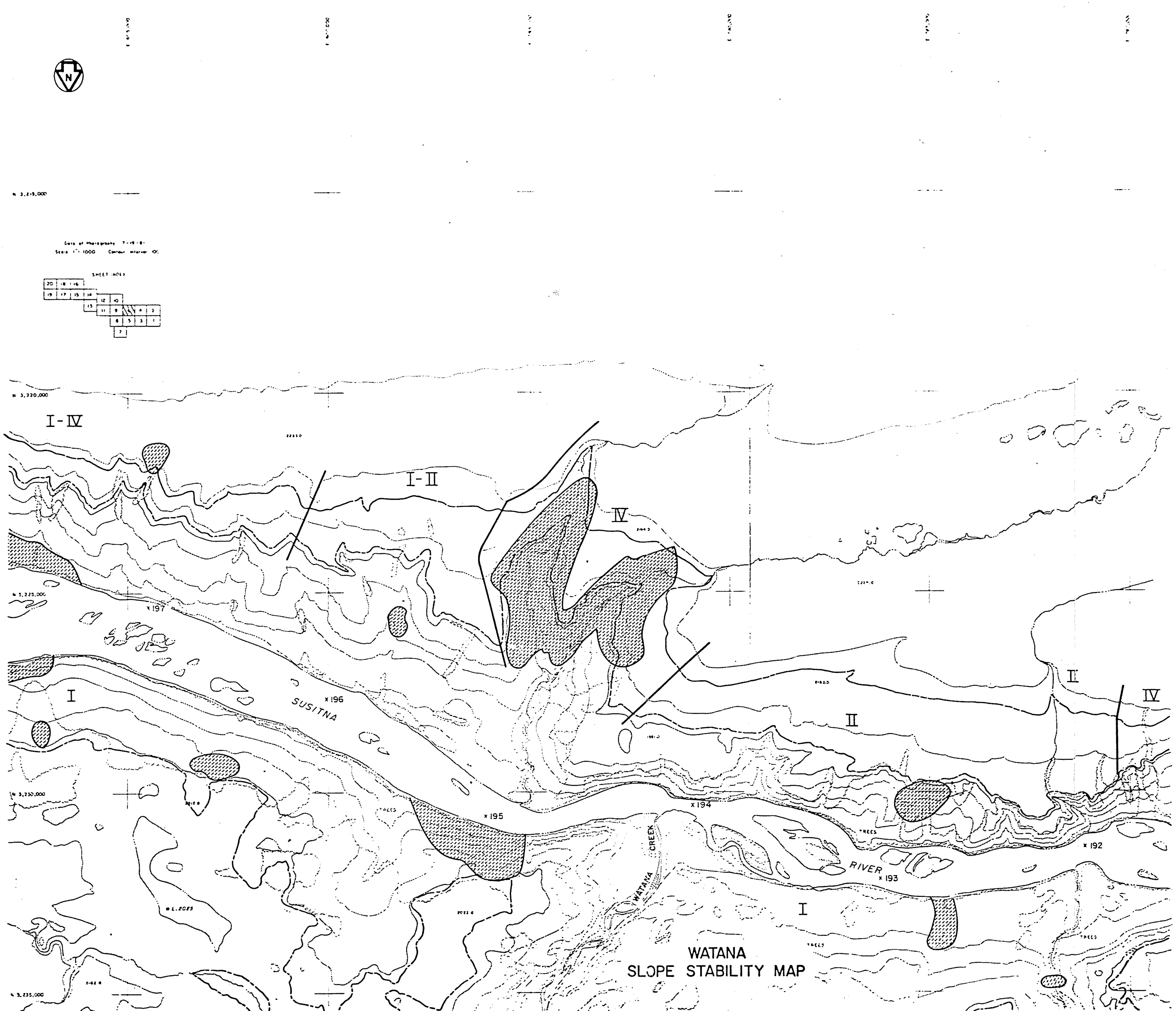
WATANA
SLOPE STABILITY MAP

FIGURE 5.4



WATANA
SLOPE STABILITY MAP

FIGURE 5.5



WATANA
SLOPE STABILITY MAP

LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

I	BEACHING
II	FLOWS
III	SLIDING (UNFROZEN)
IV	SLIDING (PERMAFROST)
/I/	DENOTES AREA EXTENT AND TYPE OF INSTABILITY
I(IV)	PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
I-II	BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
	NORMAL MAXIMUM OPERATING LEVEL
	NORMAL MINIMUM OPERATING LEVEL
x	RIVER MILES
A A	SECTION LOCATION
	AREA OF POTENTIAL PERMAFROST

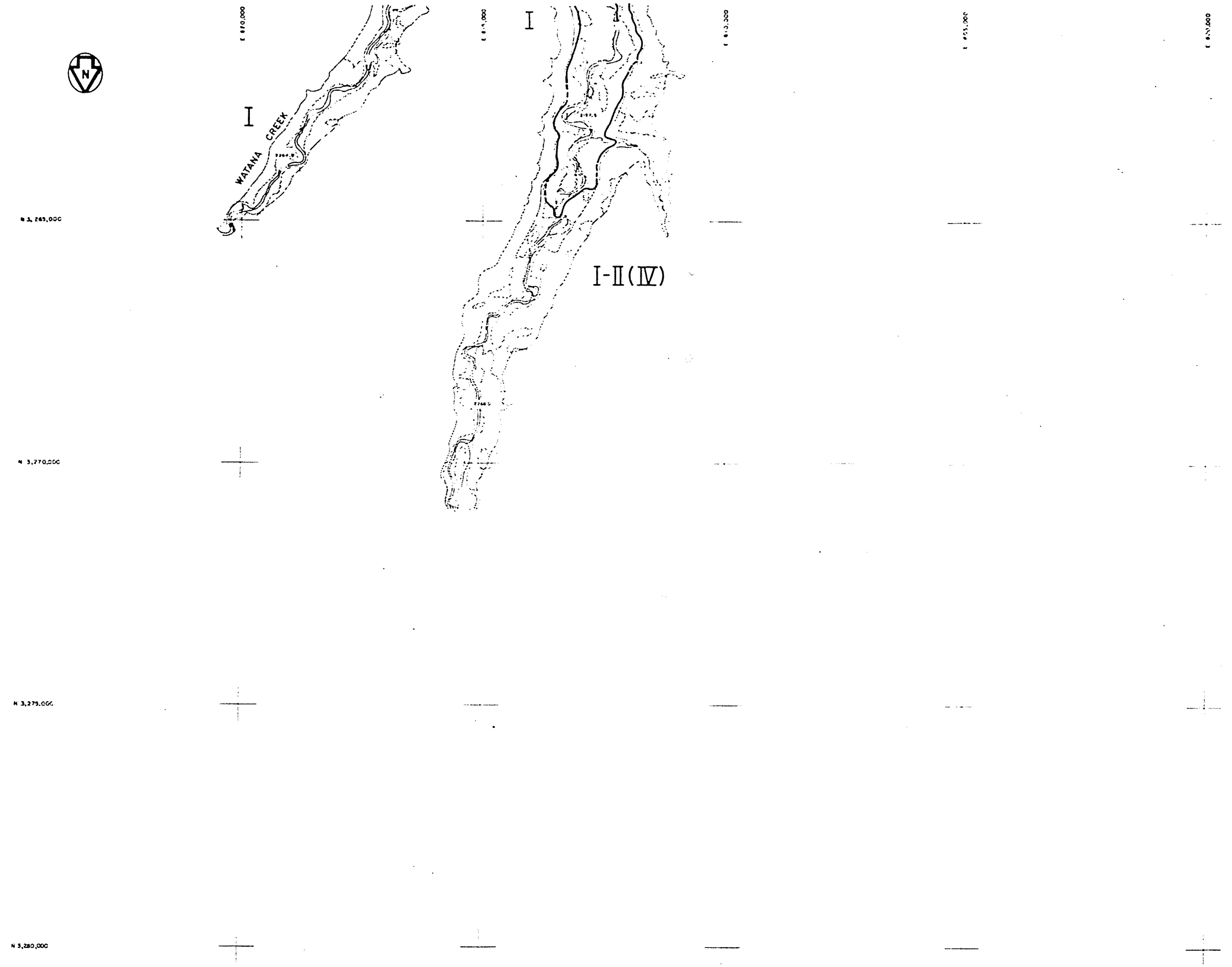
NOTES

1. REFER TO FIGURES 5.1 AND 5.2 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

ACRES

FIGURE 5.8



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

I	BEACHING
II	FLOWS
III	SLIDING (UNFROZEN)
IV	SLIDING (PERMAFROST)
/I/	DENOTES AREA EXTENT AND TYPE OF INSTABILITY
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	NORMAL MINIMUM OPERATING LEVEL
	RIVER MILES
A A	SECTION LOCATION

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SCALE 0 1000 2000 FEET

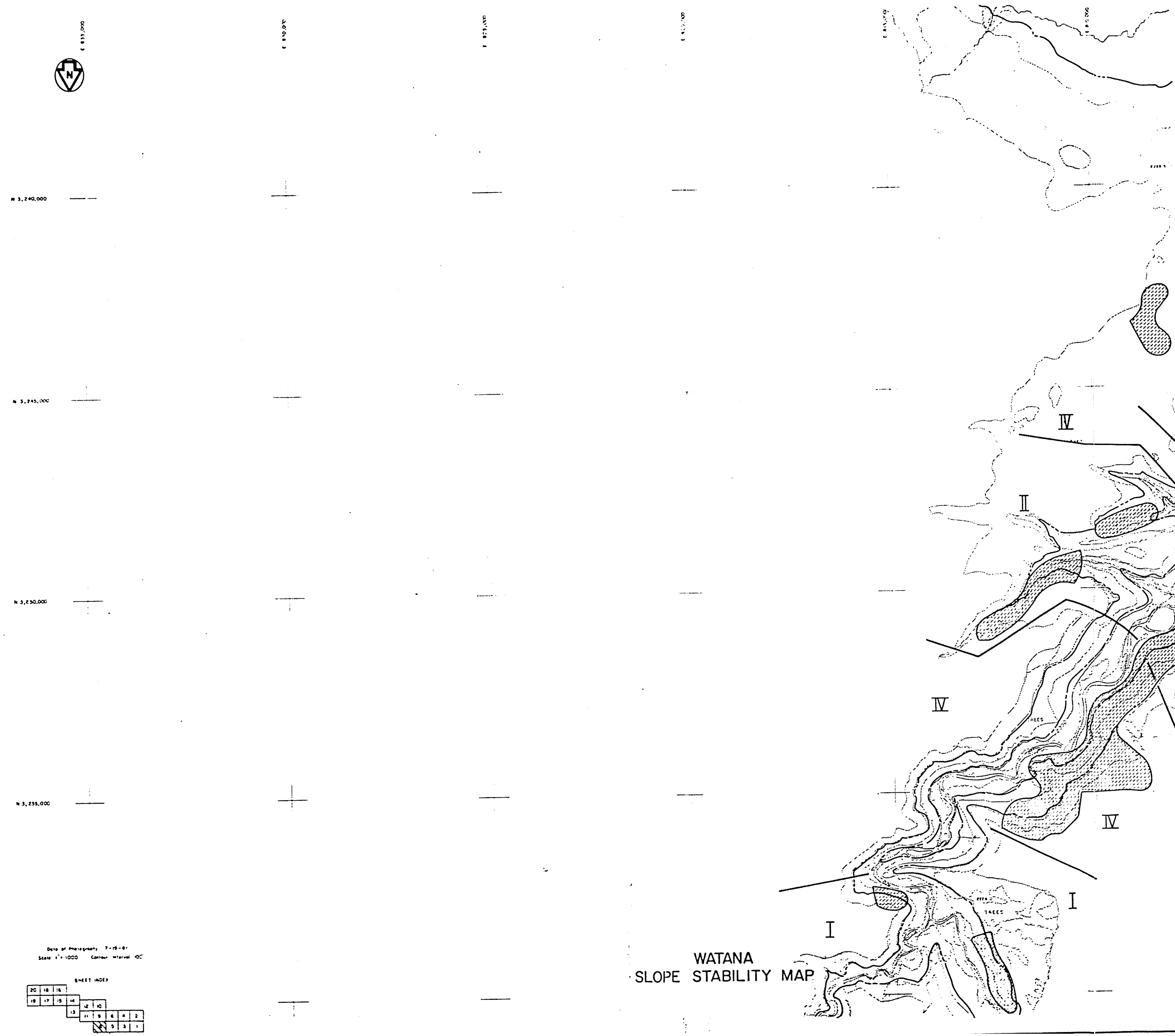
Date of Photography 7-19-81
Scale 1"=1000 Contour Interval 100'

SHEET INDEX

WATANA
SLOPE STABILITY MAP

ACRES

FIGURE 5.9



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

I	BEACHING
II	FLOWS
III	SLIDING (UNFROZEN)
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	NORMAL MINIMUM OPERATING LEVEL
	RIVER MILES
A A	SECTION LOCATION
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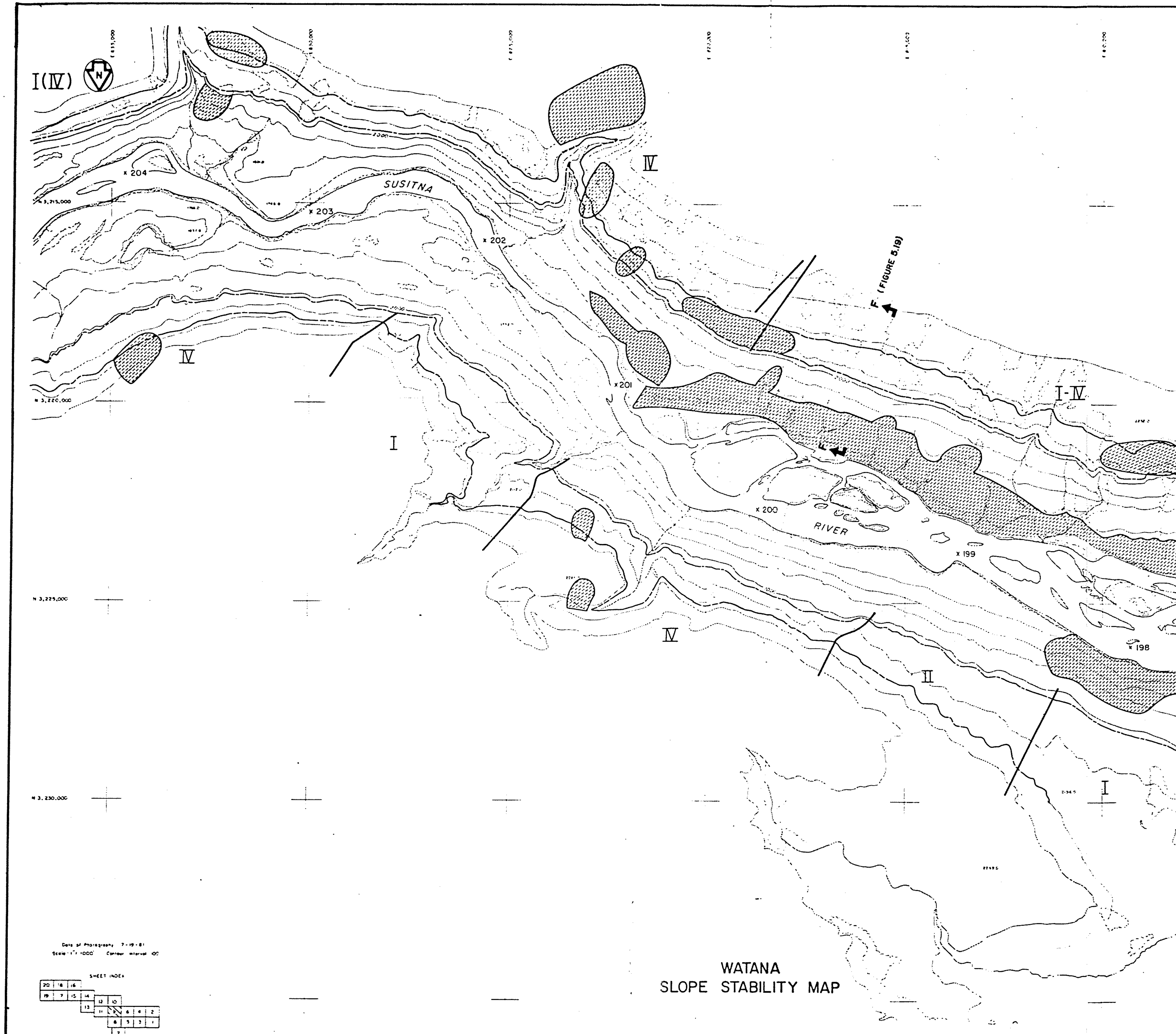
SCALE 0 1000 2000 FEET

WATANA
SLOPE STABILITY MAP

ACRES

FIGURE 5.10



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

I	BEACHING
II	FLOWS
III	SLIDING (UNFROZEN)
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/I/	DENOTES AREA EXTENT AND TYPE OF INSTABILITY
I(IV)	PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
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	NORMAL MAXIMUM OPERATING LEVEL
	NORMAL MINIMUM OPERATING LEVEL
x	RIVER MILES
A A	SECTION LOCATION
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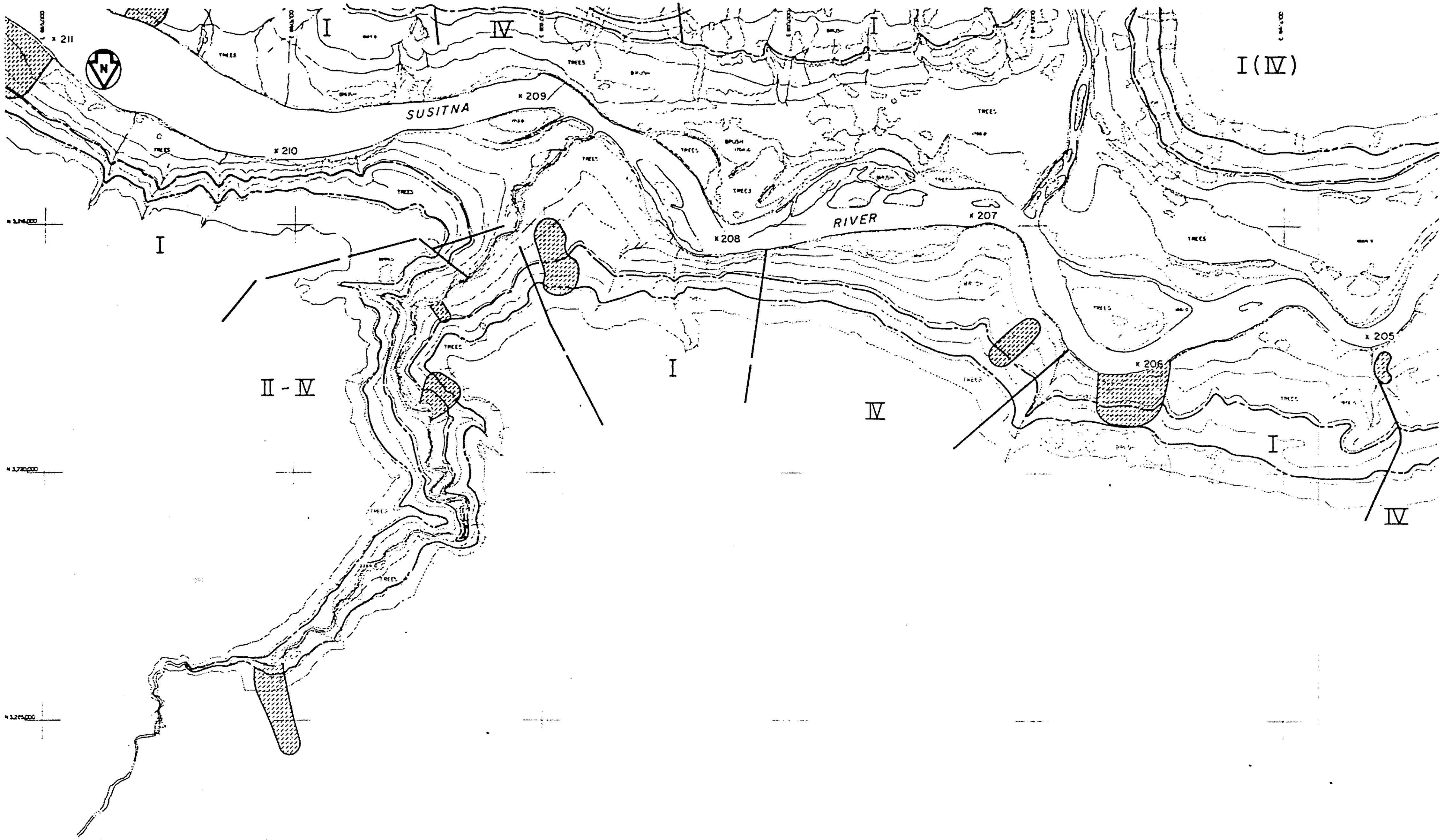
SCALE 0 1000 2000 FEET

WATANA
SLOPE STABILITY MAP

ACRES

FIGURE 5.11



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

I	BEACHING
II	FLOWS
III	SLIDING (UNFROZEN)
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x	RIVER MILES
A A	SECTION LOCATION
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Date of Photography 7-15-81
Scale 1"=1000 , Contour Interval 100'

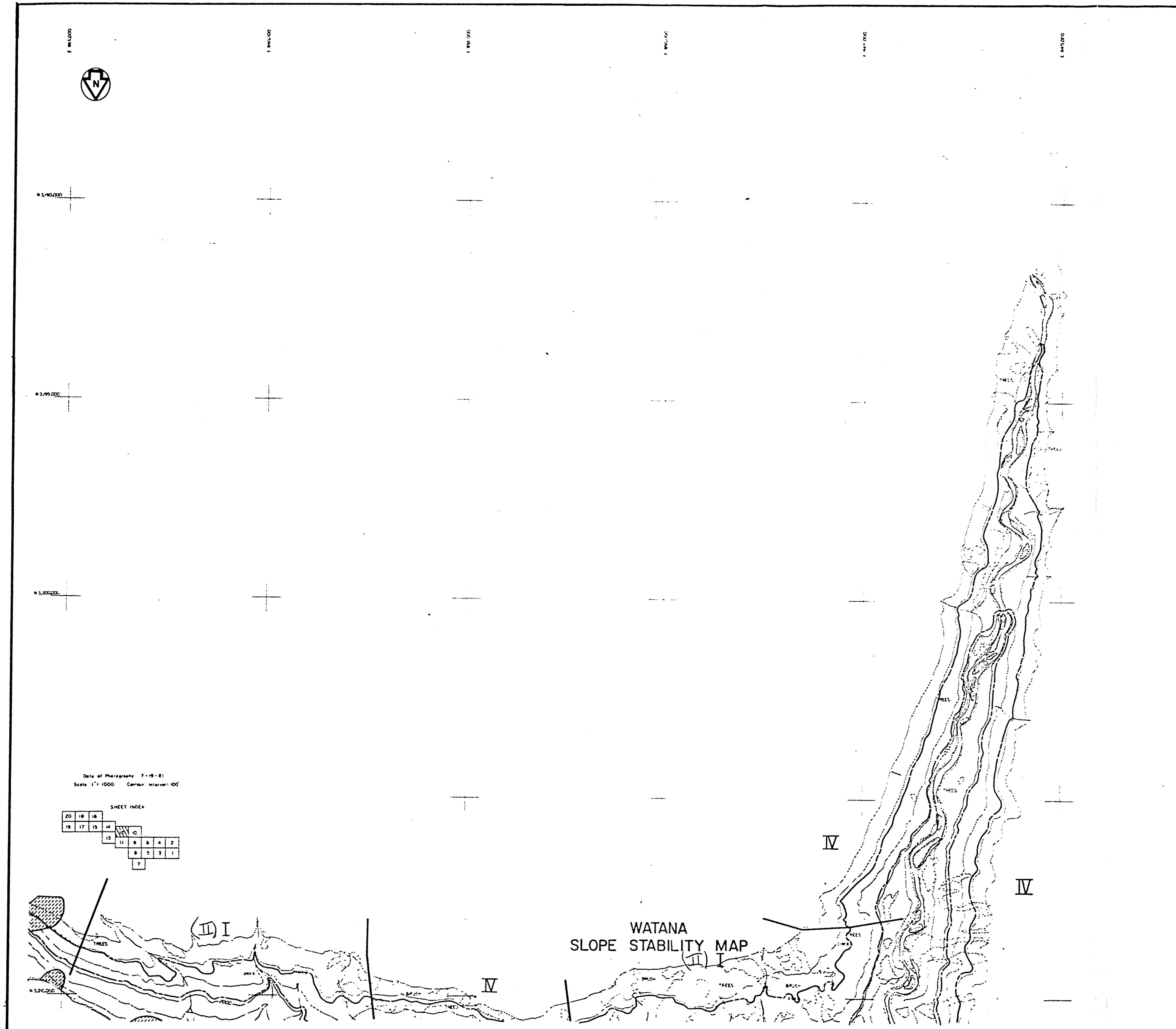
SHEET INDEX

20	18	16				
19	17	15	14	12	10	
			13	11	9	6	4	2
					8	5	3	1
					7			

WATANA
SLOPE STABILITY MAP

FIGURE 5.12

ACRES



WATANA
SLOPE STABILITY MAP

LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I BEACHING
- II FLOWS
- III SLIDING (UNFROZEN)
- IV SLIDING (PERMAFROST)
- /I/ DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I (IV) PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I-II BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- NORMAL MINIMUM OPERATING LEVEL
- RIVER MILES
- A A SECTION LOCATION
- AREA OF POTENTIAL PERMAFROST

NOTES

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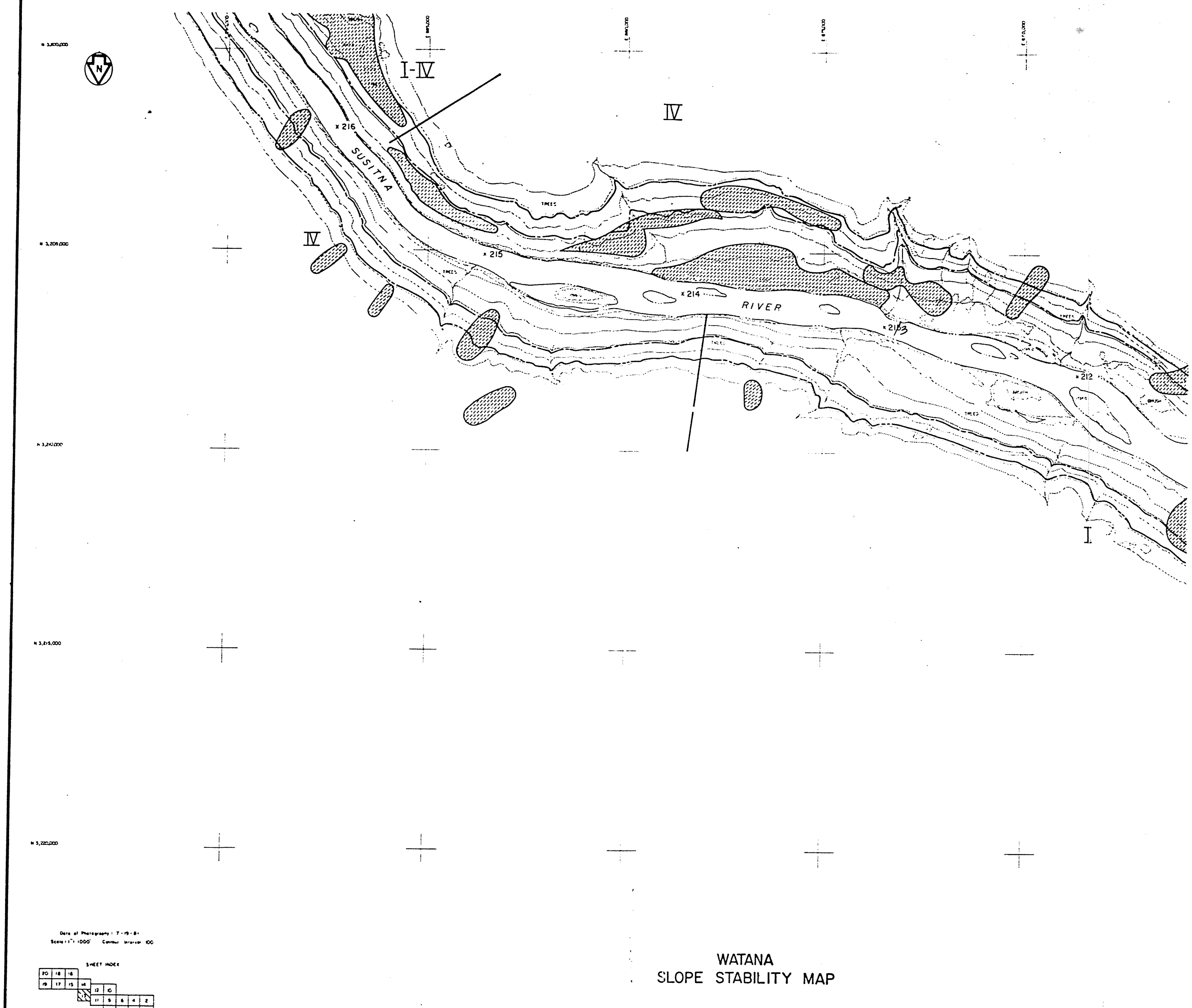
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

FIGURE 5.13

ACRES



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

I	BEACHING
II	FLOWS
III	SLIDING (UNFROZEN)
IV	SLIDING (PERMAFROST)
/I/	DENOTES AREA EXTENT AND TYPE OF INSTABILITY
I(IV)	PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
I-II	BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
	NORMAL MAXIMUM OPERATING LEVEL
	NORMAL MINIMUM OPERATING LEVEL
A x A	RIVER MILES
	SECTION LOCATION
	AREA OF POTENTIAL PERMAFROST

NOTES

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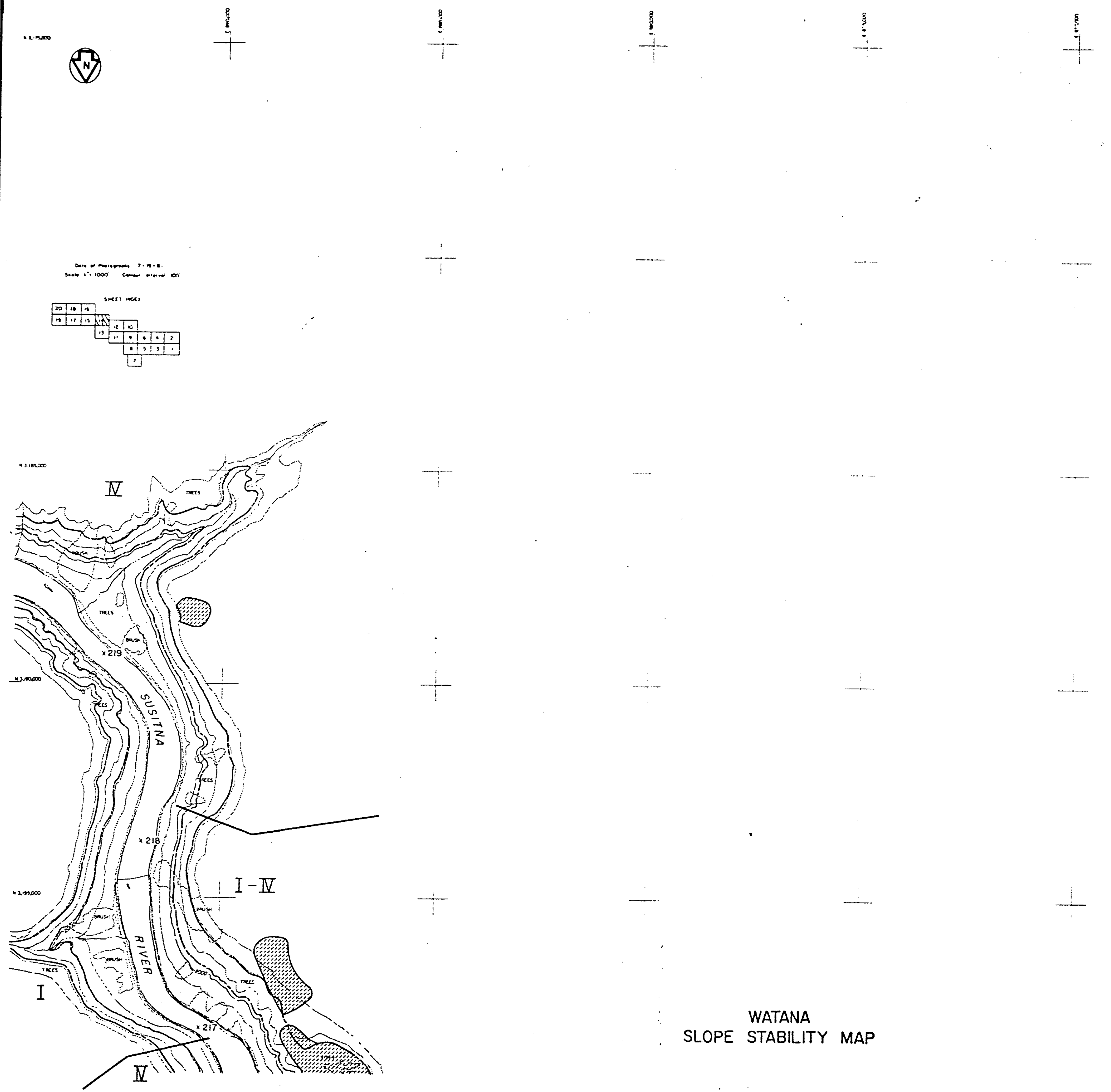
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

WATANA
SLOPE STABILITY MAP

FIGURE 5.14

ACRES



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I — BEACHING
- II — FLOWS
- III — SLIDING (UNFROZEN)
- IV — SLIDING (PERMAFROST)
- /I/ — DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I(IV) — PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I-II — BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- NORMAL MINIMUM OPERATING LEVEL
- x — RIVER MILES
- A A — SECTION LOCATION
- AREA OF POTENTIAL PERMAFROST

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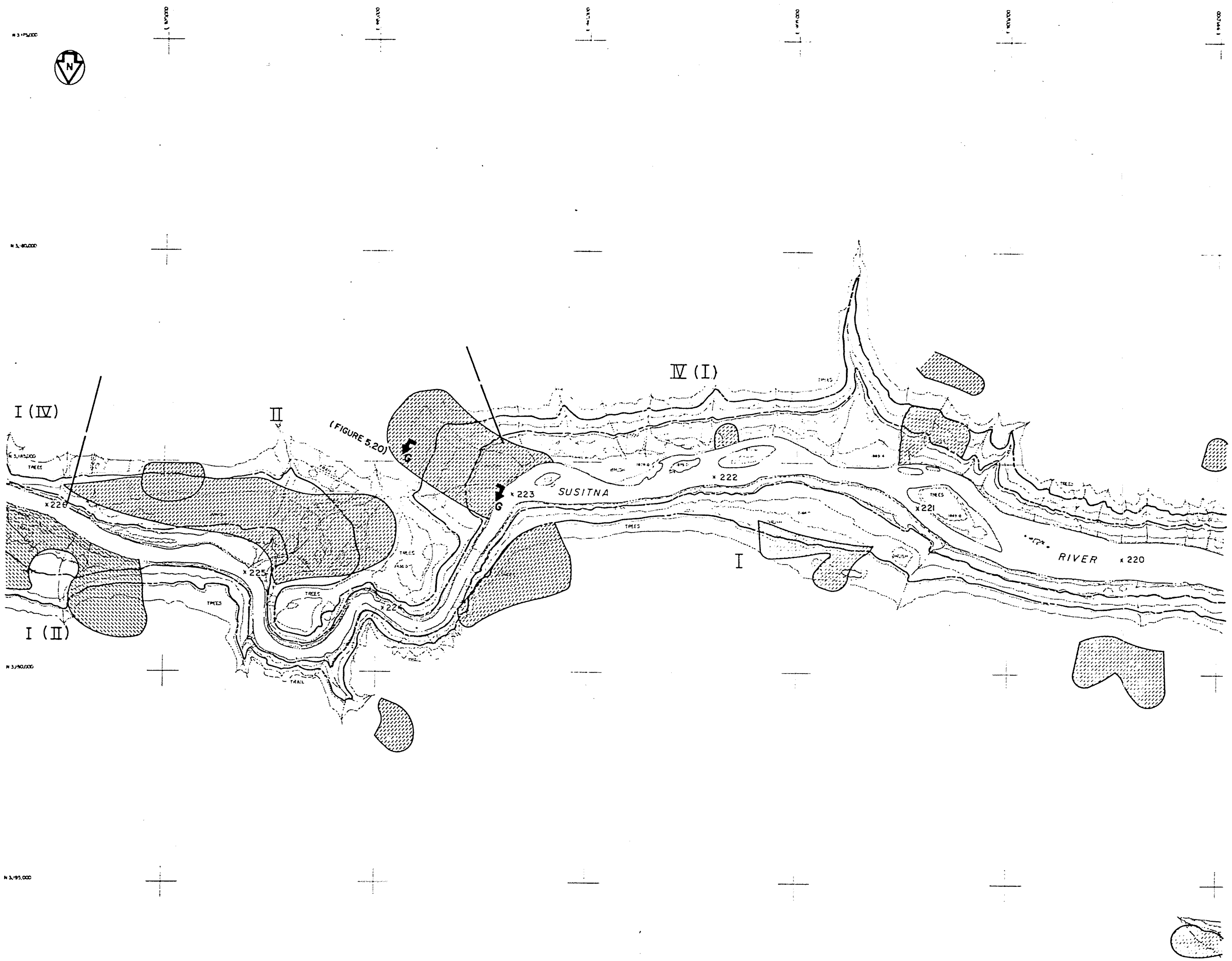
SCALE 0 1000 2000 FEET

WATANA
SLOPE STABILITY MAP

ACRES

FIGURE 5.15



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I — BEACHING
- II — FLOWS
- III — SLIDING (UNFROZEN)
- IV — SLIDING (PERMAFROST)
- /I/ — DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I (IV) — PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I-II — BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- NORMAL MINIMUM OPERATING LEVEL
- A x A — RIVER MILES
- SECTION LOCATION

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SCALE 0 1000 2000 FEET

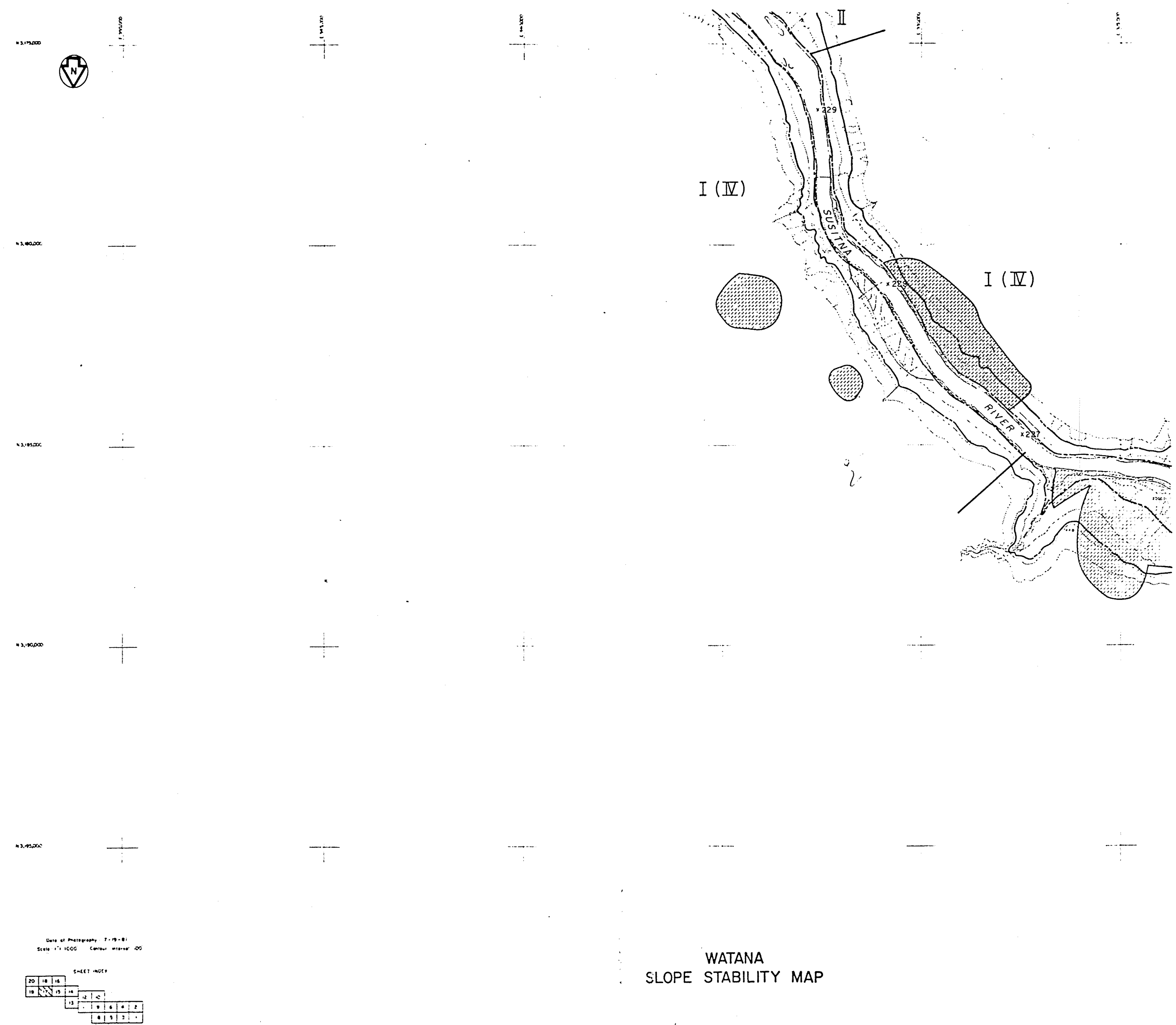
Date of Photography : 7-19-81
Scale 1" = 1000' Contour Interval 100

SHEET INDEX

WATANA
SLOPE STABILITY MAP

ACRES

FIGURE 5.16



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I — BEACHING
- II — FLOWS
- III — SLIDING (UNFROZEN)
- IV — SLIDING (PERMAFROST)
- /I/ — DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I(IV) — PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I-II — BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- NORMAL MINIMUM OPERATING LEVEL
- x — RIVER MILES
- A A — SECTION LOCATION

NOTES

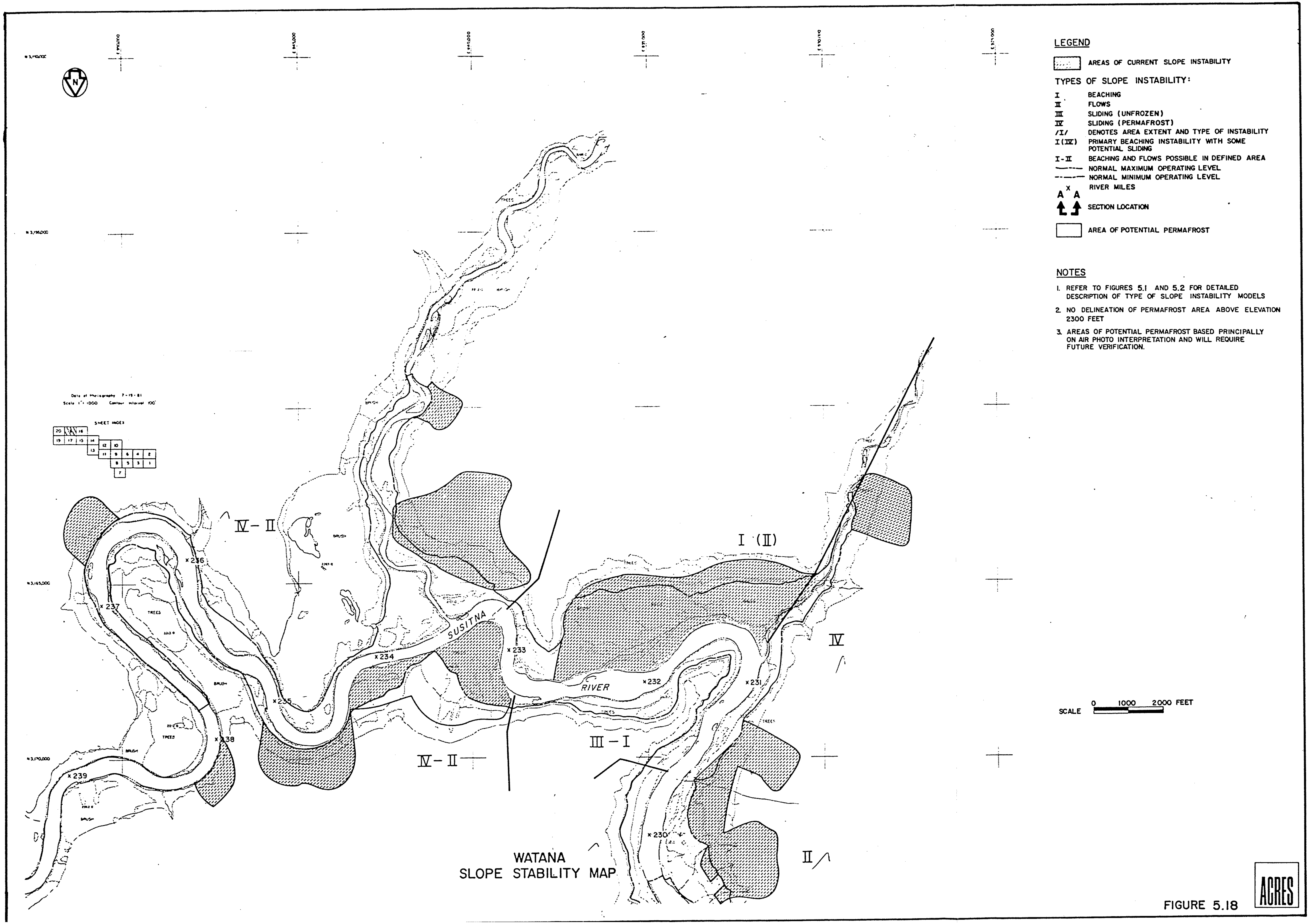
1. REFER TO FIGURES 5.1 AND 5.2 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 2300 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

WATANA
SLOPE STABILITY MAP

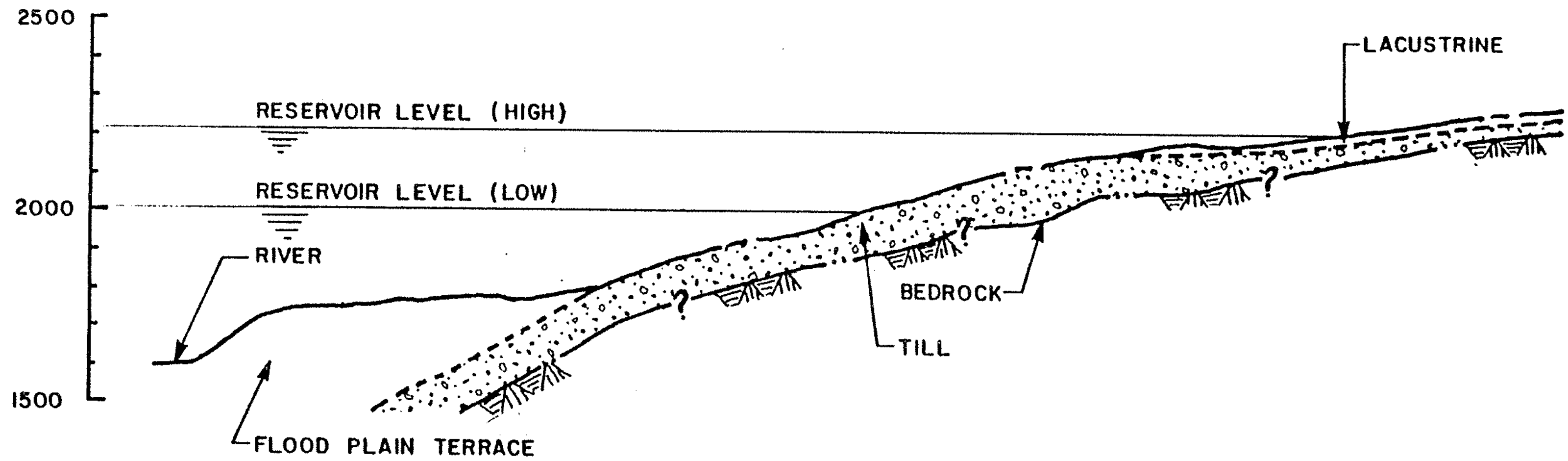
ACRES

FIGURE 5.17



WATANA
SLOPE STABILITY MAP

FIGURE 5.18



ASSUMPTIONS: BASAL TILL, PRIMARILY FROZEN

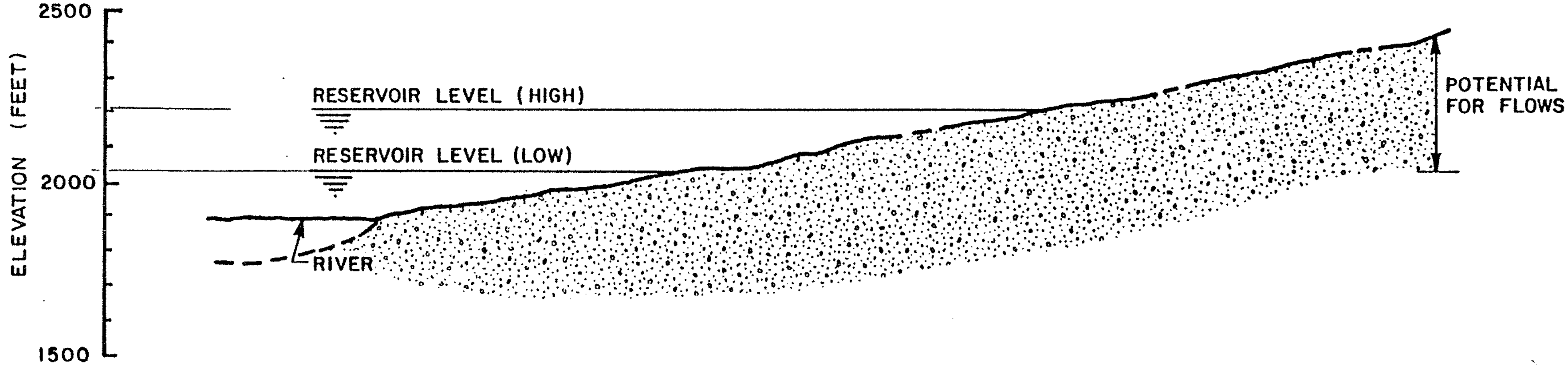
NOTE: SEE FIGURE 5.11 FOR SECTION LOCATION

SCALE 0 500 1000 FEET

SECTION F-F
WATANA RESERVOIR
POTENTIAL ROTATIONAL SLIDES AND FLOWS

FIGURE 5.19

ACRES



ASSUMPTIONS: SANDY MATERIAL, FROZEN

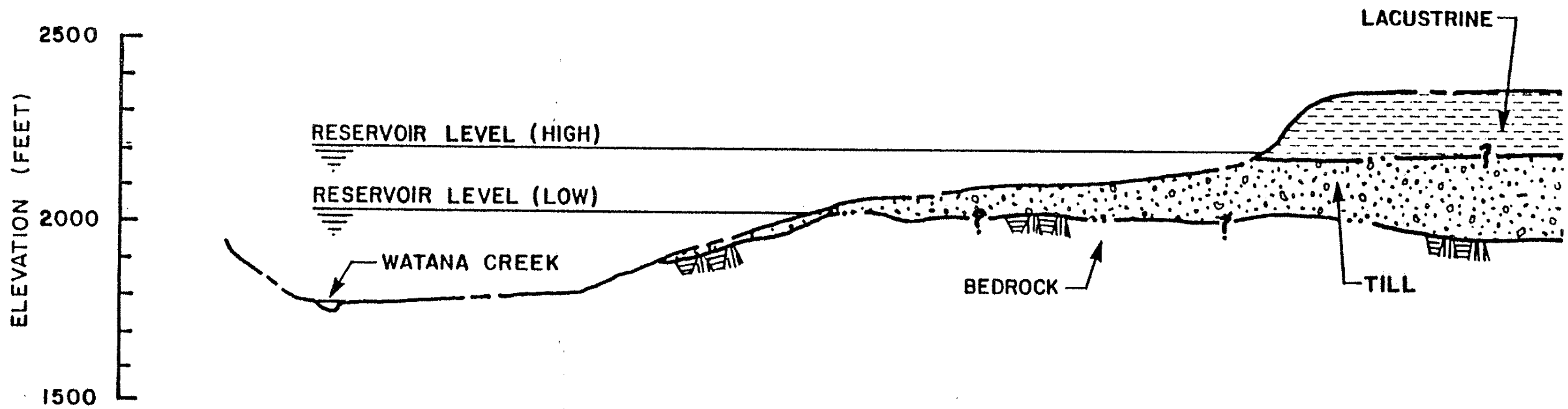
NOTE: SEE FIGURE 5.16 FOR SECTION LOCATION

SCALE 0 500 1000 FEET

SECTION G-G
WATANA RESERVOIR
AREA OF FLOW FAILURES

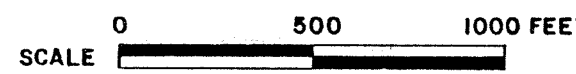
ACRES

FIGURE 5.20



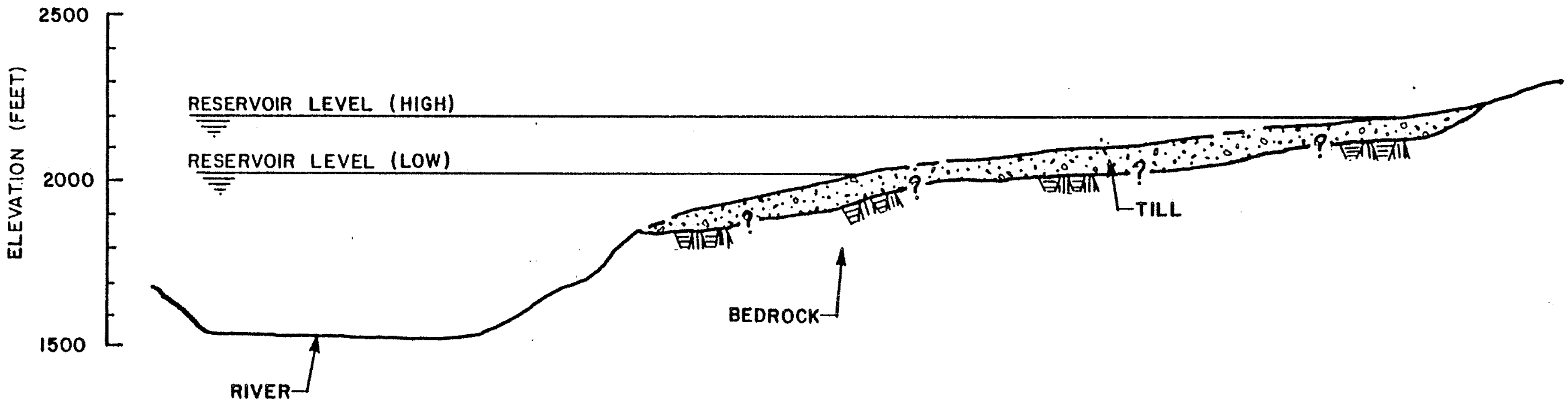
ASSUMPTIONS: STRATIGRAPHY CONSISTS OF GLACIO-LACUSTRINE SANDS AND SILTS, TILL. TILL IS FROZEN, LACUSTRINE MAY BE PARTLY FROZEN.

NOTE: SEE FIGURE 5.7 FOR SECTION LOCATION



SECTION E-E
WATANA RESERVOIR
AREA OF POTENTIAL FLOWS

FIGURE 5.21



ASSUMPTIONS: BASAL TILL, THIN VENEER OF LACUSTRINE MATERIAL FROZEN IN PLACES.

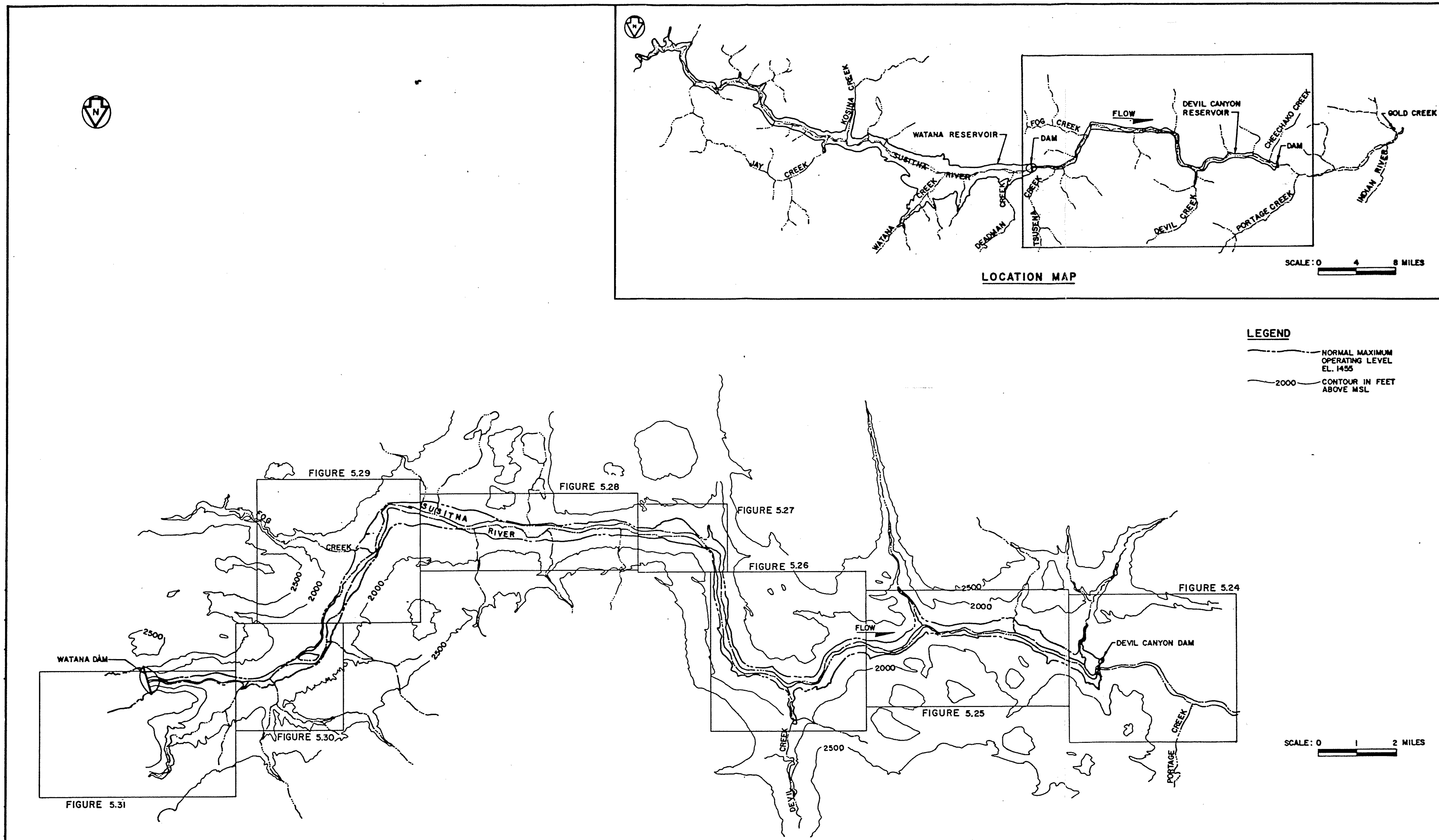
NOTE: SEE FIGURE 5.6 FOR SECTION LOCATION

SCALE 0 500 1000 FEET

SECTION D-D
WATANA RESERVOIR
POTENTIAL BEACHING

ACRES

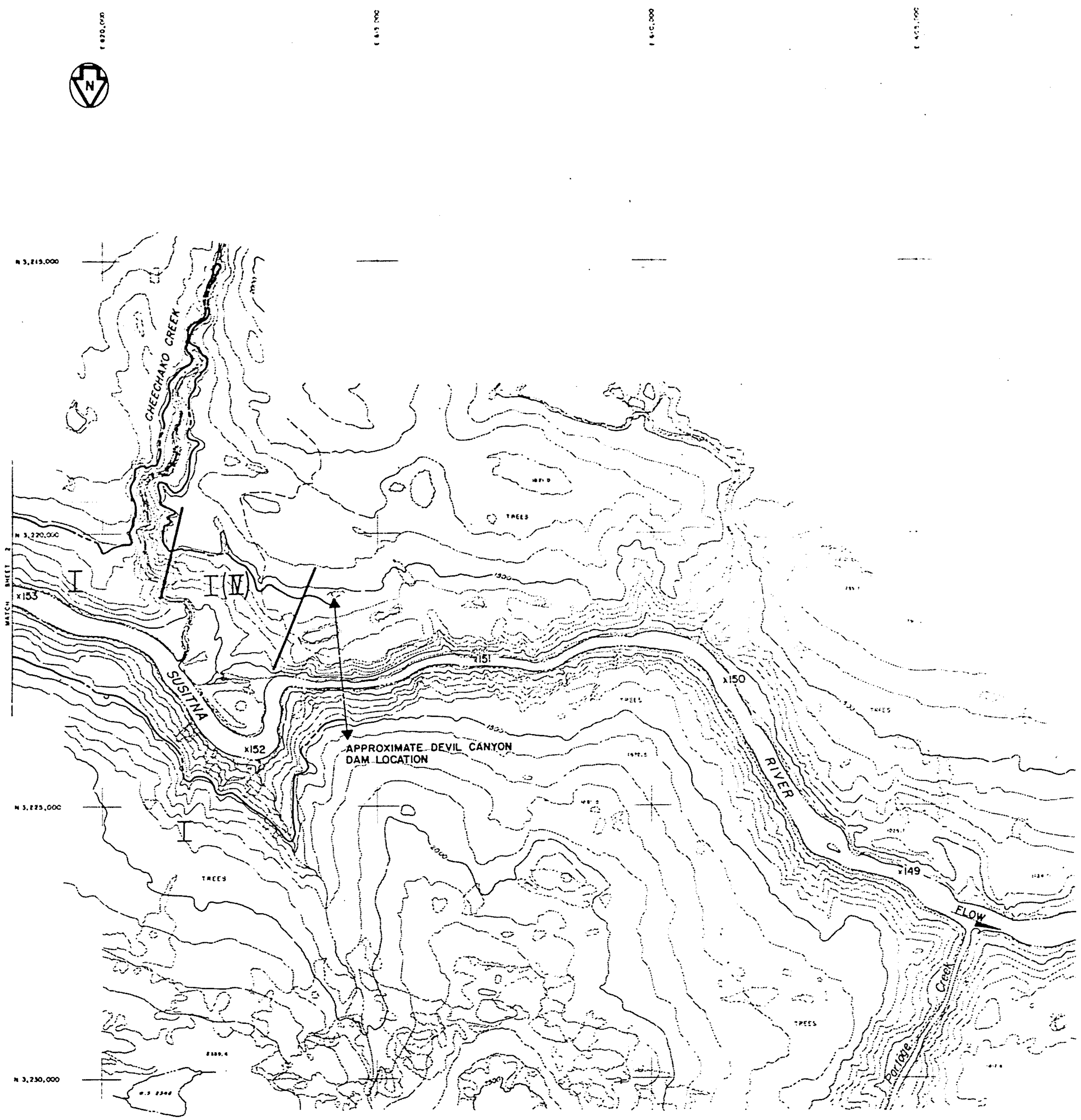
FIGURE 5.22



DEVIL CANYON RESERVOIR
INDEX MAP

ACRES

FIGURE 5.23



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

I	BEACHING
II	FLOWS
III	SLIDING (UNFROZEN)
IV	SLIDING (PERMAFROST)
/I/	DENOTES AREA EXTENT AND TYPE OF INSTABILITY
I(IV)	PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
I-II	BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
	NORMAL MAXIMUM OPERATING LEVEL
	RIVER MILES
A A	SECTION LOCATION
	AREA OF POTENTIAL PERMAFROST

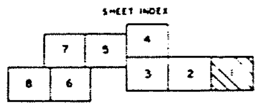
NOTES

1. REFER TO FIGURES 5.1 AND 5.2 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 1500 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION.

SCALE 0 1000 2000 FEET

Date of Photography: 7-19-81
Scale 1"=1000 Contour Interval 100'

SHEET INDEX



DEVIL CANYON
SLOPE STABILITY MAP

ACRES

FIGURE 5.24

LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I BEACHING
- II FLOWS
- III SLIDING (UNFROZEN)
- IV SLIDING (PERMAFROST)
- /I/ DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I (IV) PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I-II BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- RIVER MILES
- A A SECTION LOCATION
- AREA OF POTENTIAL PERMAFROST

NOTES

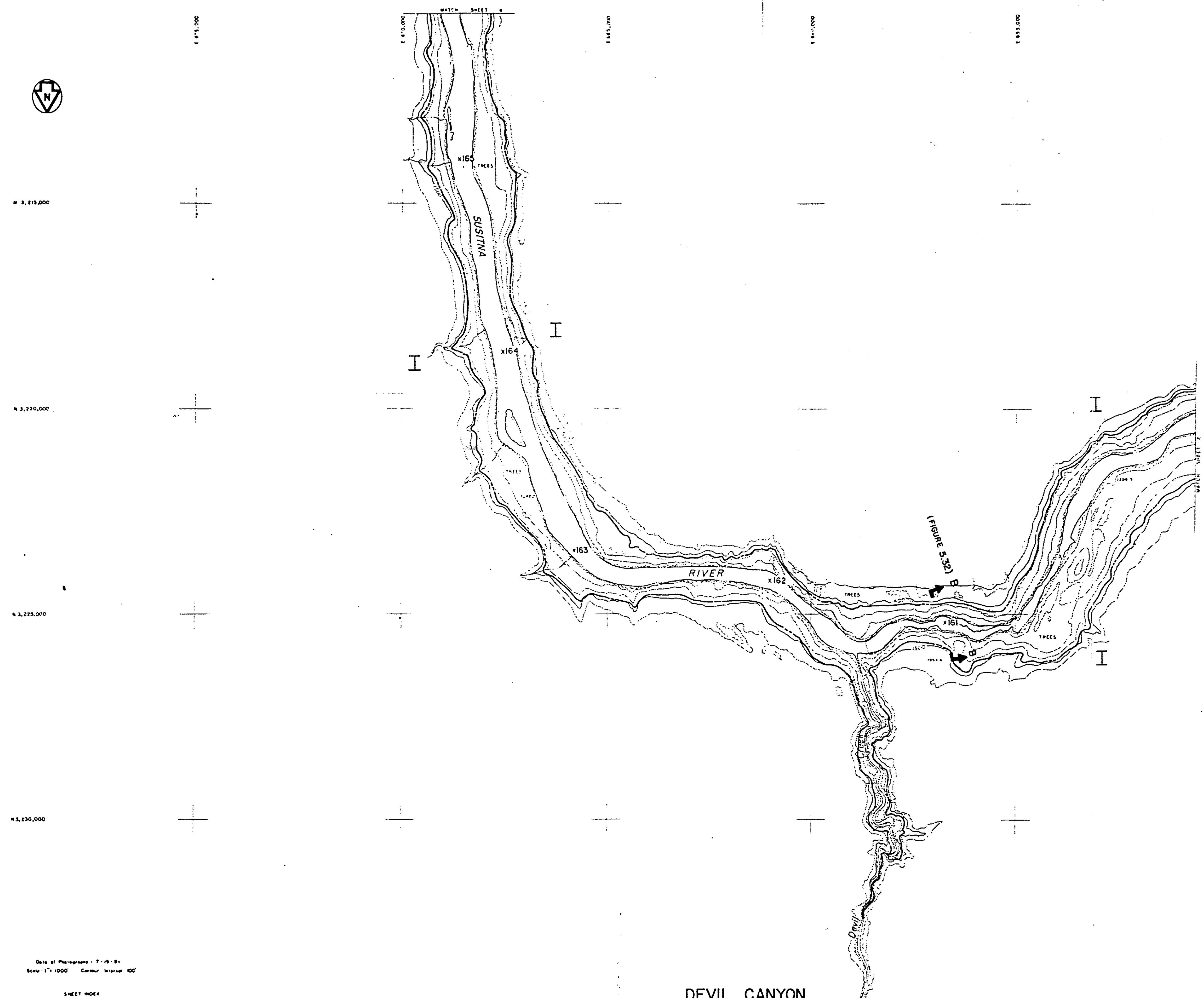
1. REFER TO FIGURES 5.1 AND 5.2 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 1500 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

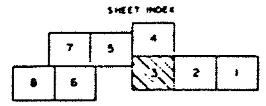
DEVIL CANYON
SLOPE STABILITY MAP

ACRES

FIGURE 5.25



SHEET INDEX



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I — BEACHING
- II — FLOWS
- III — SLIDING (UNFROZEN)
- IV — SLIDING (PERMAFROST)
- /I/ — DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I (IV) — PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I - II — BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- x — RIVER MILES
- A A — SECTION LOCATION
- AREA OF POTENTIAL PERMAFROST

NOTES

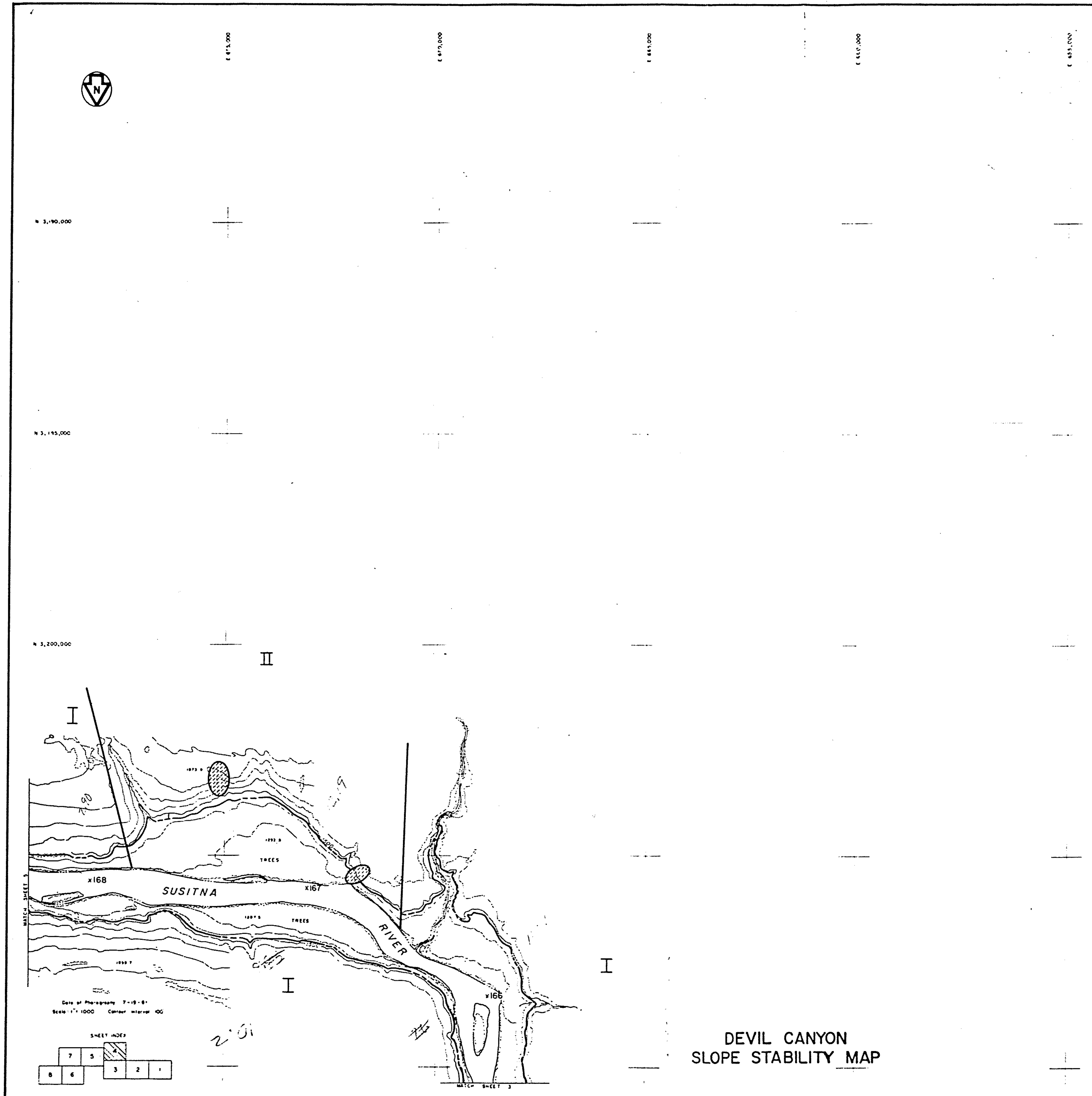
1. REFER TO FIGURES 5.1 AND 5.2 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 1500 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

DEVIL CANYON
SLOPE STABILITY MAP

FIGURE 5.26

ACRES



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I BEACHING
- II FLOWS
- III SLIDING (UNFROZEN)
- IV SLIDING (PERMAFROST)
- /I/ DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I (IV) PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I-II BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- RIVER MILES
- A A SECTION LOCATION

AREA OF POTENTIAL PERMAFROST

NOTES

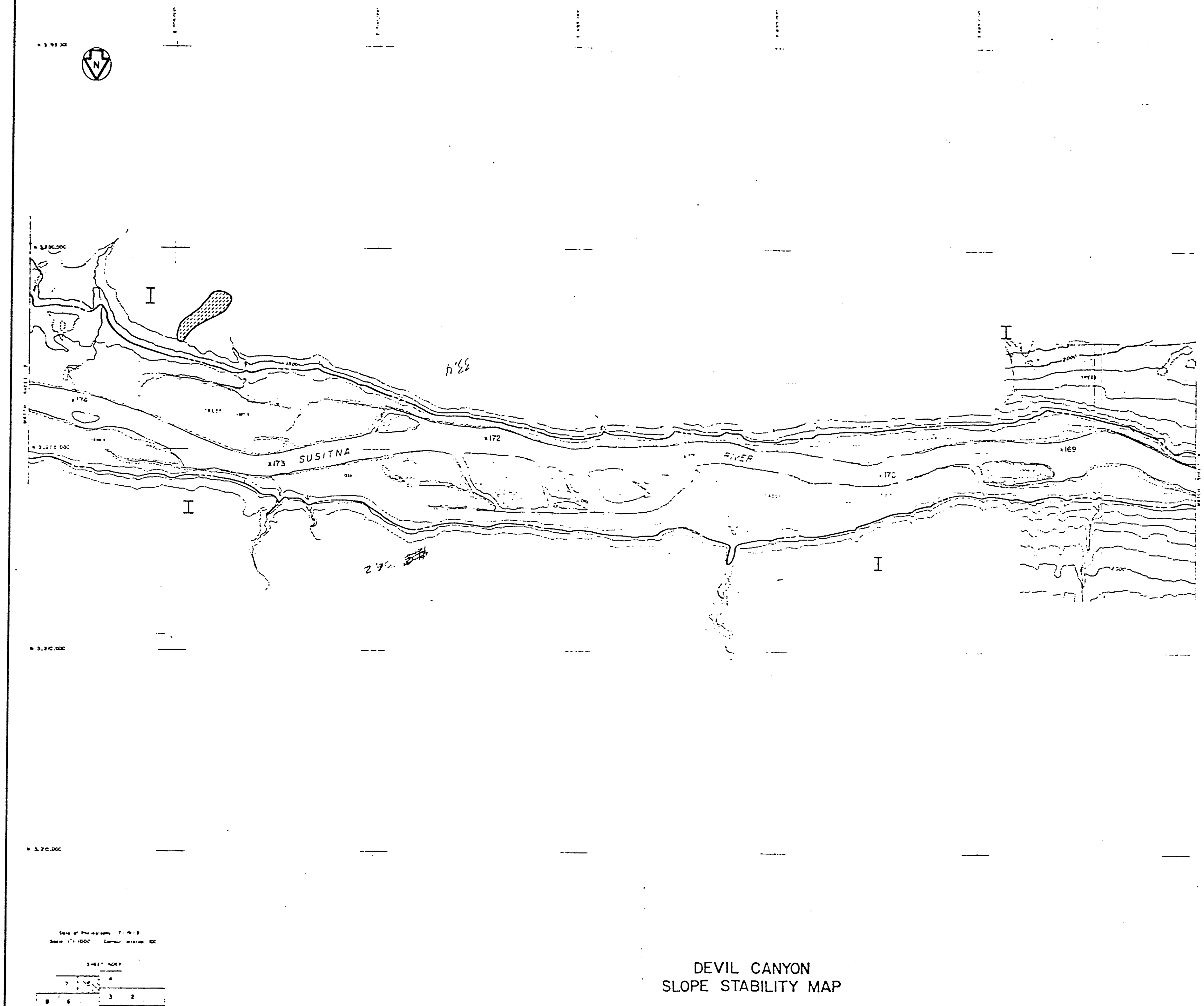
1. REFER TO FIGURES 5.1 AND 5.2 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 1500 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

DEVIL CANYON
SLOPE STABILITY MAP

ACRES

FIGURE 5.27



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I — BEACHING
- II — FLOWS
- III — SLIDING (UNFROZEN)
- IV — SLIDING (PERMAFROST)
- /I/ — DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I (IV) — PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I-II — BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- RIVER MILES
- A A — SECTION LOCATION

AREA OF POTENTIAL PERMAFROST

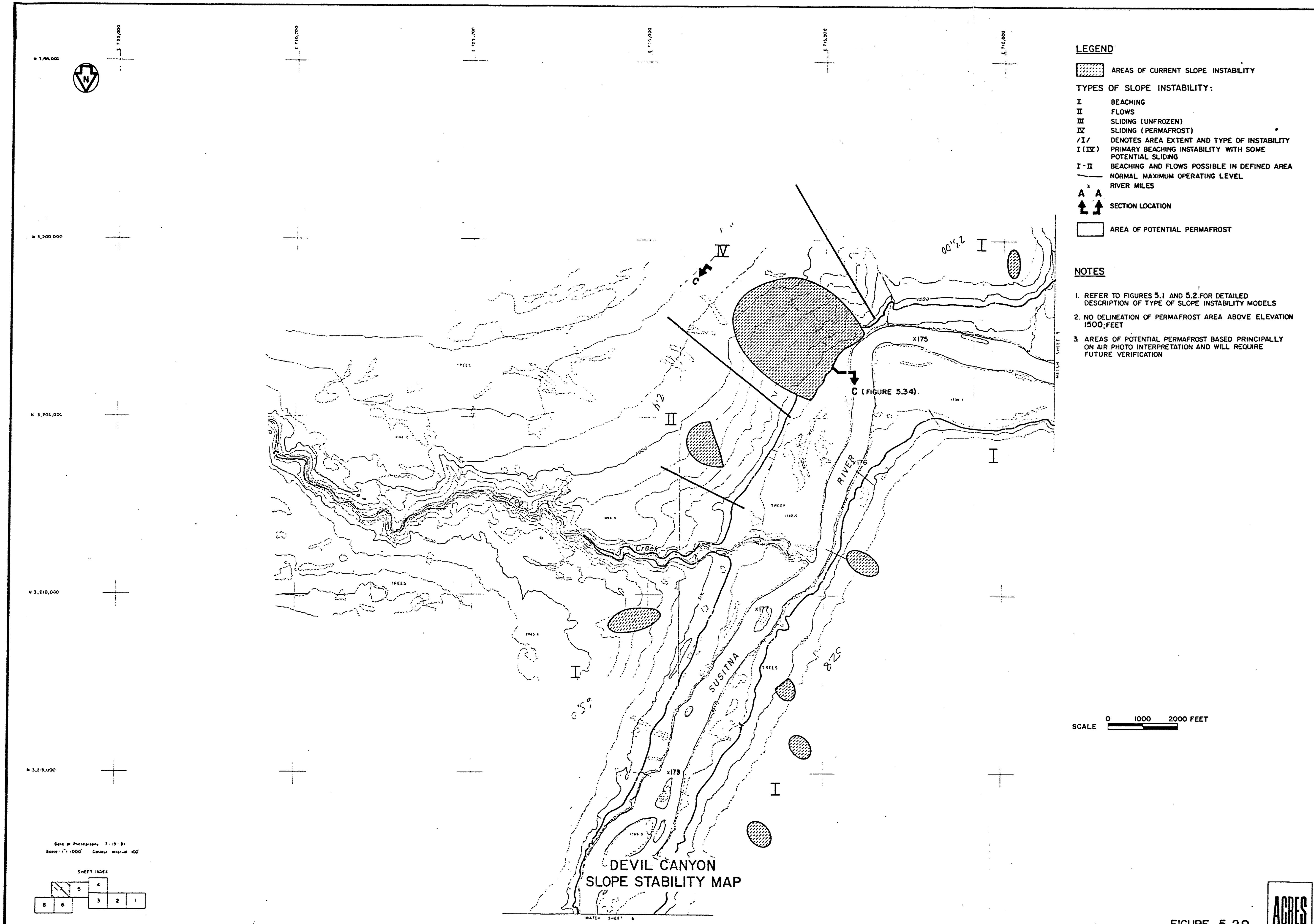
NOTES

1. REFER TO FIGURES 5.1 AND 5.2 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 1500 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

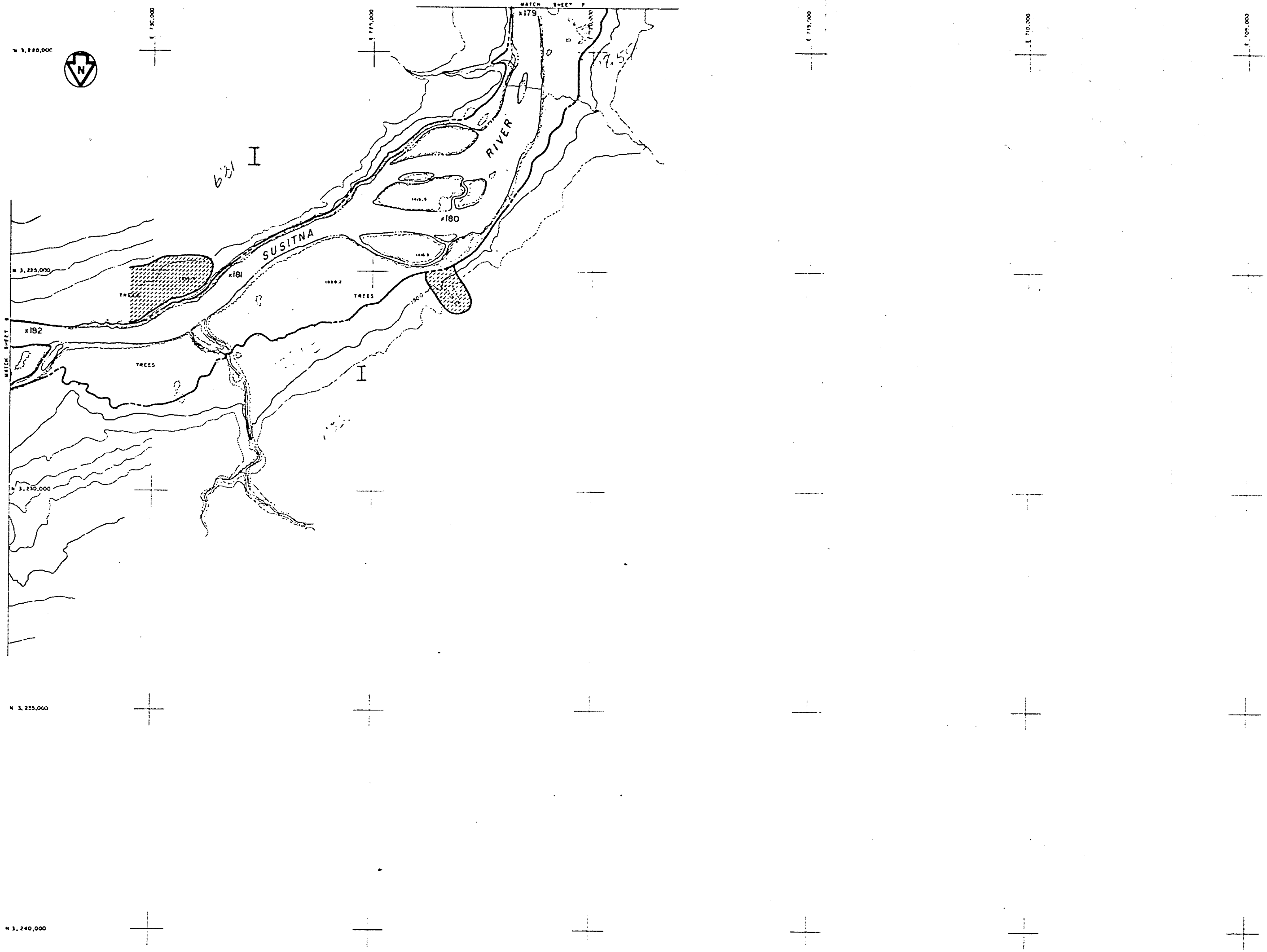
DEVIL CANYON
SLOPE STABILITY MAP

FIGURE 5.28



DEVIL CANYON
SLOPE STABILITY MAP

FIGURE 5.29



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I BEACHING
- II FLOWS
- III SLIDING (UNFROZEN)
- IV SLIDING (PERMAFROST)
- /I/ DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I (IV) PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I - II BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- RIVER MILES
- A A SECTION LOCATION

NOTES

1. REFER TO FIGURES 5.1 AND 5.2 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 1500 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

Date of Photography 7-19-81
Scale 1" = 1000' Contour Interval 100'

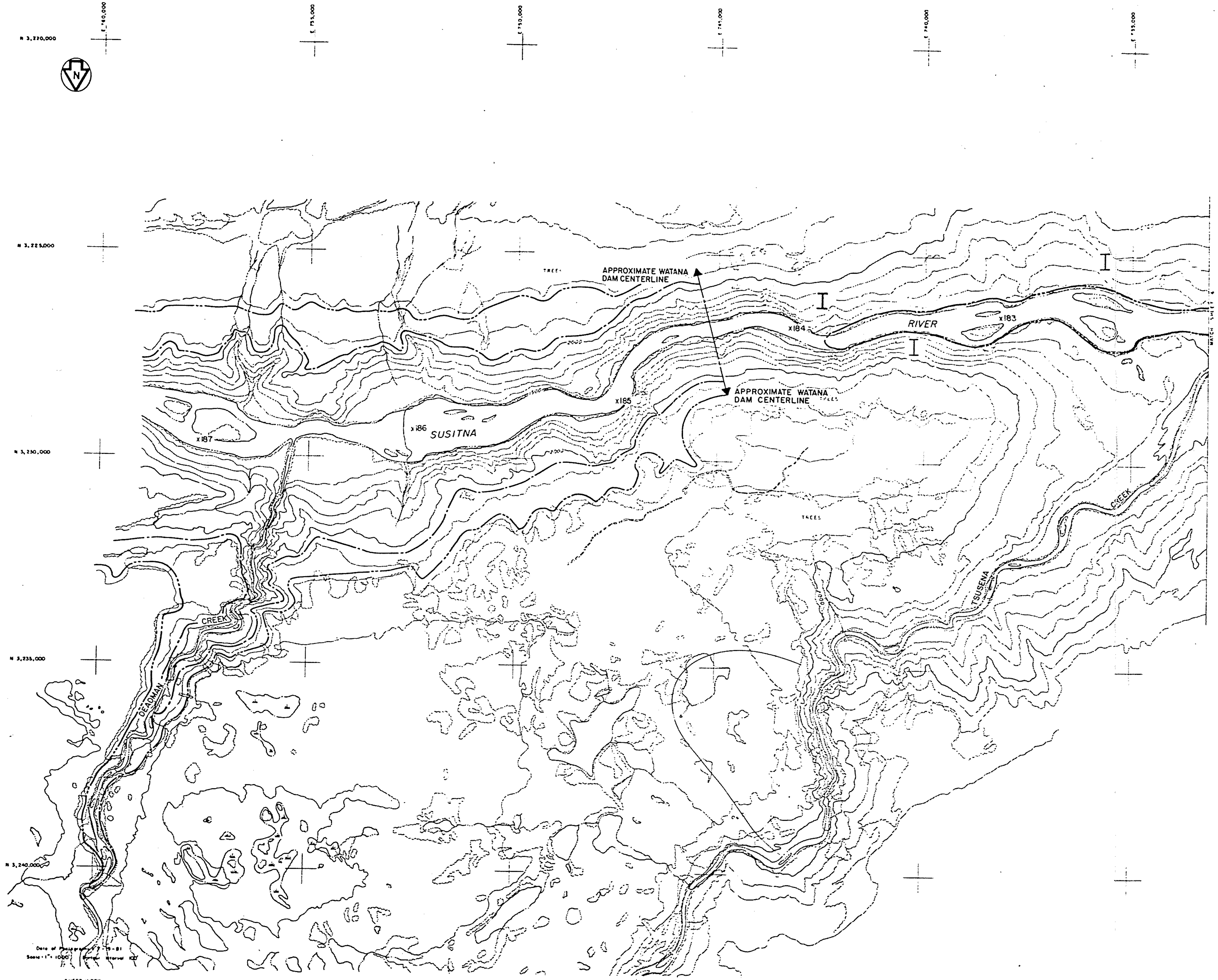
SHEET INDEX

	7	5	4		
8	6		3	2	1

DEVIL CANYON SLOPE STABILITY MAP

FIGURE 5.30

ACRES



LEGEND

AREAS OF CURRENT SLOPE INSTABILITY

TYPES OF SLOPE INSTABILITY:

- I — BEACHING
- II — FLOWS
- III — SLIDING (UNFROZEN)
- IV — SLIDING (PERMAFROST)
- /I/ — DENOTES AREA EXTENT AND TYPE OF INSTABILITY
- I(IV) — PRIMARY BEACHING INSTABILITY WITH SOME POTENTIAL SLIDING
- I-II — BEACHING AND FLOWS POSSIBLE IN DEFINED AREA
- NORMAL MAXIMUM OPERATING LEVEL
- NORMAL MINIMUM OPERATING LEVEL
- X — RIVER MILES
- A A — SECTION LOCATION

NOTES

1. REFER TO FIGURES 5.1 AND 5.2 FOR DETAILED DESCRIPTION OF TYPE OF SLOPE INSTABILITY MODELS
2. NO DELINEATION OF PERMAFROST AREA ABOVE ELEVATION 1500 FEET
3. AREAS OF POTENTIAL PERMAFROST BASED PRINCIPALLY ON AIR PHOTO INTERPRETATION AND WILL REQUIRE FUTURE VERIFICATION

SCALE 0 1000 2000 FEET

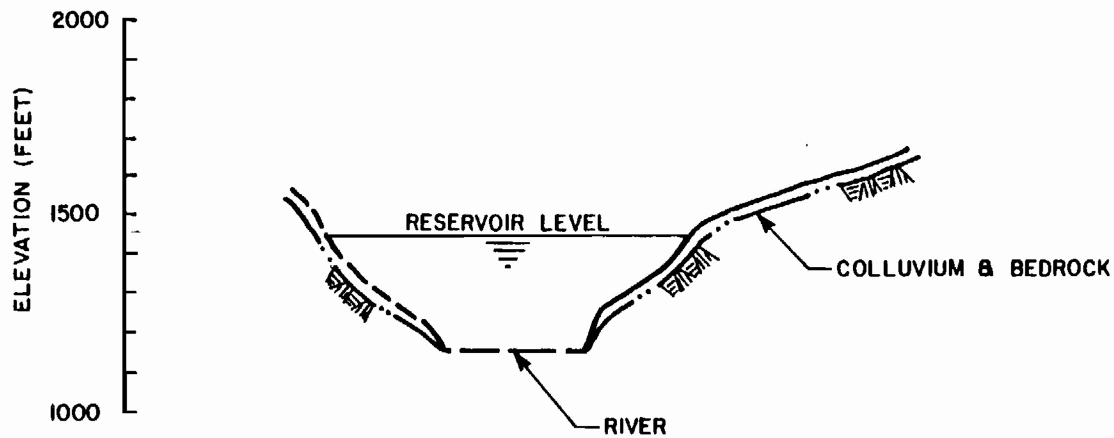
SHEET INDEX

7 5 4
8 6 3 2 1

DEVIL CANYON
SLOPE STABILITY MAP

ACRES

FIGURE 5.31



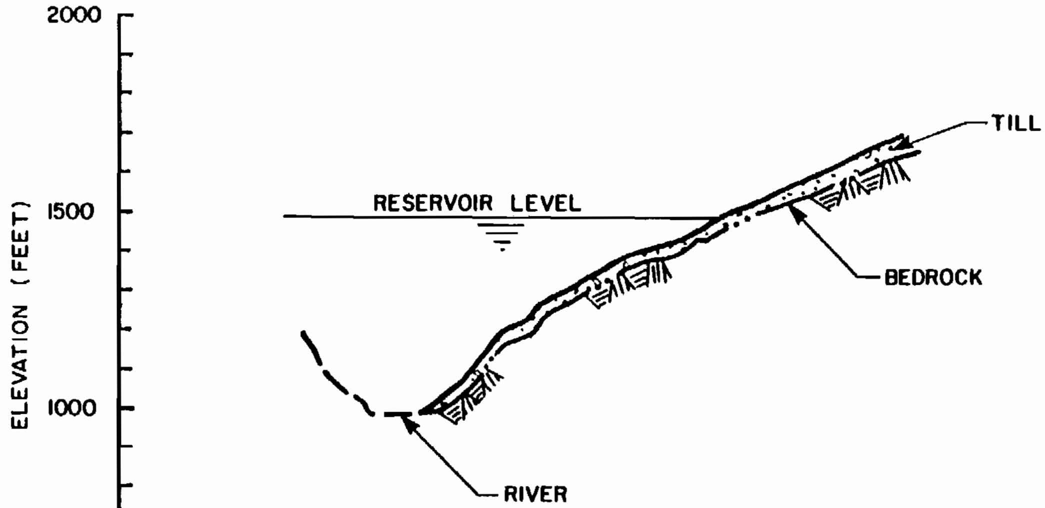
ASSUMPTIONS: COLLUVIUM, UNFROZEN BEDROCK PROBABLY IN CONTACT WITH THE RESERVOIR LEVEL

NOTE: SEE FIGURE 5.26 FOR SECTION LOCATION

SCALE 0 500 1000 FEET

SECTION B-B
DEVIL CANYON RESERVOIR
POTENTIAL MINOR BEACHING

FIGURE 5.32



ASSUMPTION: THIN UNFROZEN VENEER OF SANDY TILL

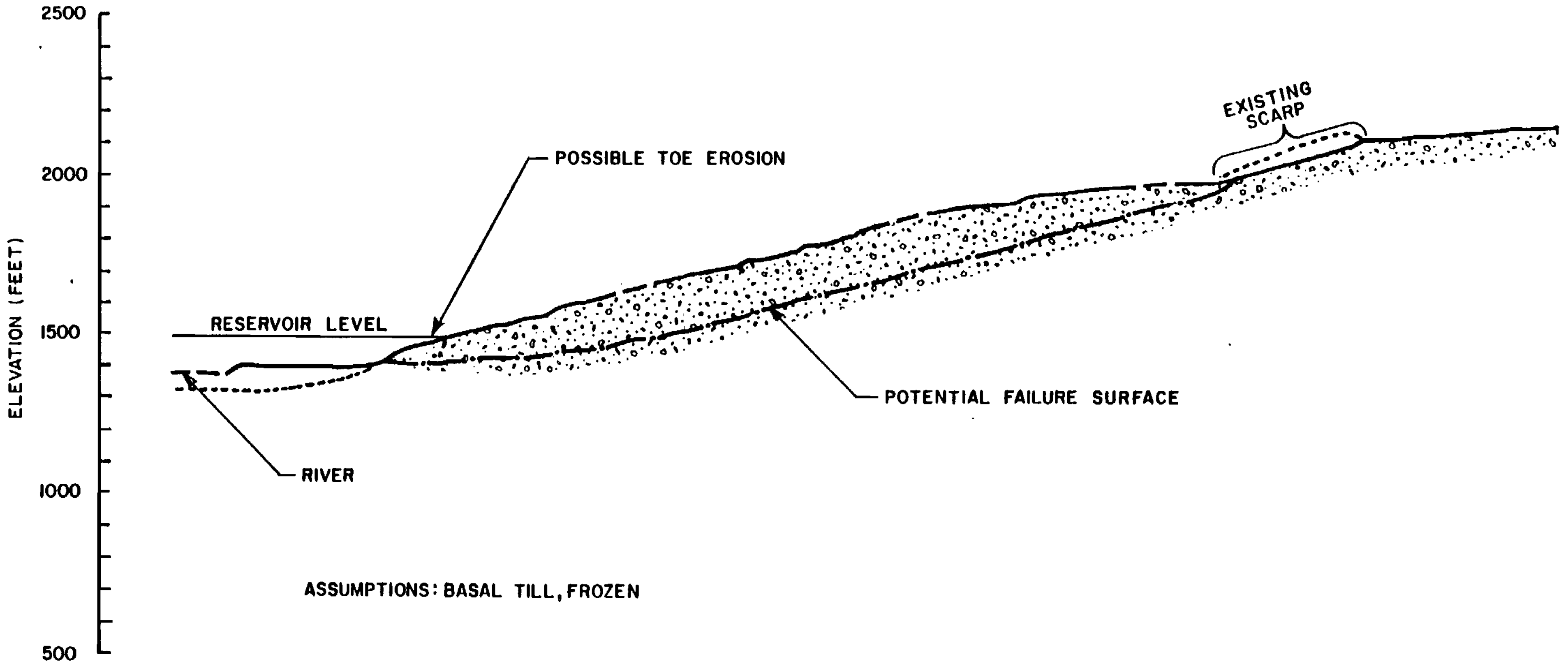
NOTE: SEE FIGURE 5.25 FOR SECTION LOCATION

SCALE 0 500 1000 FEET

SECTION A-A
DEVIL CANYON RESERVOIR
POTENTIAL MINOR BEACHING

ACRES

FIGURE 5.33



NOTE: SEE FIGURE 5.29 FOR SECTION LOCATION

SCALE 0. 500 1000 FEET

SECTION C-C
DEVIL CANYON RESERVOIR
POTENTIAL LARGE SLIDE

ACRES

FIGURE 5.34

6 - RECOMMENDATIONS

It is recommended that typical slope conditions outlined in this report be further investigated during subsequent phases of the project in order to determine:

(a) If potential instability actually exists and the magnitude of this potential for instability at a given location; and

(b) If beaching or sliding will exist at major crossing sites for migrating herds.

This investigation should include drilling, instrumentation and laboratory analysis to confirm the findings in this study. Since only one significant existing landslide has been identified in this study, it is also recommended that further study be directed to this slide with due consideration to excavating a clear channel to the northwest of the existing river channel at this location to preclude blockage of the channel by future sliding. It is anticipated that this excavation could be done during the construction of the Watana Dam when granular material is being excavated from the river channel downstream at the dam. Under no circumstances should material be borrowed in the river stretch below this slide mass.

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