KING'S COLLEGE
LONDON UNIVERSITY

TECHNIQUES FOR MANAGING ENVIRONMENTAL CHANGE AT THE EARTH'S SURFACE

ASSESSING THE IMPACT OF DEFORESTATION ON SLOPE STABILITY WITHIN THE OVEJAS WATERSHED

CAUCA - COLOMBIA

APRIL 1998

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1. INTRODUCTION

"Soil mass movements are major landform shaping processes in mountainous and steep terrain throughout the world. Only when landslides cause death or injury, or damage structures or settlements do they receive widespread attention. The frequent association of slope failure with residential development, engineering earthworks and certain land management practices is not coincidental. Conditions controlling slope stability may be in a tenuous equilibrium, which can be easily upset by human activities. Many major landslides, however, result from infrequent meteorological or seismic events that induce unstable conditions on otherwise stable slopes or accelerate movement on unstable slopes" (Sidle, 1986).

A good example of factors acting together is the Paez avalanche, which occurred in June of 1994 in the Cauca region (Colombia) where indigenous people were the primary inhabitants. An earthquake of 6.3 on the Richter scale released a series of debris slides and flooding of the Paez and Moras rivers. The magnitude of that event was reported world-wide scale (Annex 1). Geological and topographical characteristics, deforestation and land management practice encouraged the occurrence of more than 1000 landslides of different magnitude in less than five minutes. This region is considered socio-economically marginal, far from state services and forced to clear the moist forest to plant heroin and other illicit crops. (Strong, 1995). The area considered in the current study is located at 80 kms. of the Paez region and it has similar characteristics.

"The occurrence of debris slides is greatly affected by forest cutting. The primal causes of debris slides on a vegetated slope are the increase of soil depth, pore pressure in the surface soil layer and the effect of tree roots. The latter affects the soil strength[1] in two ways, that is, the decrease of soil strength by biological (tree roots) weathering and the increase of soil strength by tree root networks". (Gray & Megahan, 1981; Tsukamoto & Kusakabe, 1984 cited by Tsukamoto, 1987).

The present study compiles the basic information available to the Ovejas watershed area in Cauca - Colombia to assess the impact of hypothetical deforestation on slope stability and to identify the areas presenting higher risks of landslide occurrence. Some of the parameters required to calculate the factor of safety are incorporated into a GIS framework and displayed in maps to locate the risk areas.

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[1] "The term strength is used in three senses in the earth sciences: (1) it may be used for the ability of material to resist deformation by compressive, tensile or shear stress; (2) it may be used for the ability of a rock or soil to resist abrasion; and (3) it may be used to indicate the resistance of loose or unconsolidated mineral grains being transported by a fluid".(Selby, 1993)

2. OBJECTIVE

The objective of the present study is to assess the impact of deforestation on slope stability in the area of Ovejas watershed, located in Cauca - Colombia. The emphasis is on the identification of unstable areas before and after hypothetical deforestation, and the impact of road routes on instability.

3. AREA DESCRIPTION

The Ovejas watershed is situated in Southwest Colombia in the Department Cauca and comprises an area of 106.000 hectares (Figure 1). The terrain is mountainous, characterised by deep gullies and steep slopes (up to 75%). Elevations range from 1000 to 3800 m.a.s.l. The climate is humid and the high rain intensities combined with the steep slope form a serious risk for soil erosion. About 15 % of the area is covered by forest. The Pan-American Highway which crosses the area, provides good access throughout the year to the middle zone, while the dirt roads in the higher and lower zones prohibit good access during the wet months.

Inhabitants belonging to different ethnic groups (mestizos and Indigenous groups like Paez and Guambianos) live in the administrative watershed, mainly small subsistent farmers with an average of 2 hectares of cultivated land. The main crops cultivated are coffee, beans, tomatoes and bananas.

The mean annual rainfall is 2000 mm with a pronounced dry period in July and August (70 and 80 mm respectively). The mean monthly temperature varies little during the year, but differs considerably from place to place, depending on the altitude. The mean monthly temperatures reported vary from 13 ^{0}C (2650 m.a.s.l.) to 21 ^{0}C (1200 m.a.s.l.).

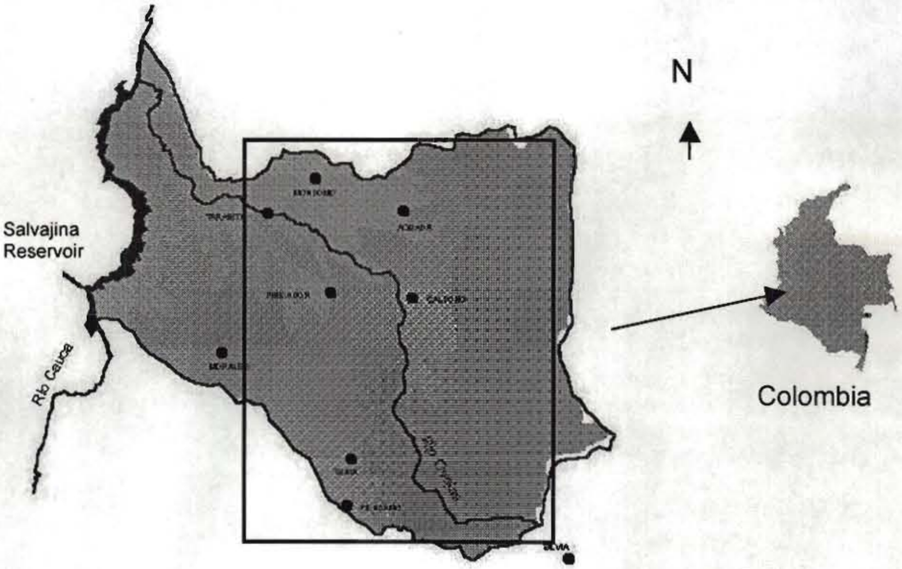


Figure 1. Location of Ovejas Watershed and study area in the box.

4. GEOLOGY

GEMCO (1977) cited by CVC, made a study of age, composition and tectonic activity of different geological groups in the area. Unfortunately, there are no reference maps to guide in the location of each of the identified groups. Here is a brief description of the main geological groups in the area.

Cajamarca Group: Pre-Cretaceous, extends from north to south in the east margin to the town of Silvia and another strip north near the town of Caldono. Esquistos carbonites and quartz, gneiss quartz-feldspar composes the first. The second by quartz, esquistos carbonites alternated with esquistos micaceous. There is a fault in the contact between these two strips and with the surrounding volcanic rocks. The geology is not related with the pedogenesis of this area because the entire area was covered with volcanic ashes.

Doleritic group: Cretaceous, located in the north, composed mainly of feldspars, piroxens and chlorites.

Cauca group: Tertiary, sand stone, doleryte consolidated, andesites and quartz.

Volcanic rocks group: Tertiary rock is sparsely distributed, filling the irregularities of the land.

Popayan formation: Volcanic origin, located in the south-west of the area; composed of andesites, conglomerates and agglomerates of andesites stones.

The soils are from volcanic origin (Oxic Dystropept and Typic Dystrandept) and are considered to be of low fertility due to low effective cation exchange and base saturation.

5. GEOMORPHOLOGY

The information available on geomorphology is included in the CVC report but it is not very extensive (CVC, 1976). The key characteristics are summarised here:

The area can be divided in to three parts: The upper zone (>3000 m.a.s.l.), the Middle (2000 - 3000 m.a.s.l.) and the Lower (>2000 m.a.s.l.). Each one of these zones has its own geomorphologic units, characteristics, materials and climate. Annex 2 shows an extract of their characteristics. In terms of the environmental quality of the landscape, the CVC report states:

"the highest zone is very deteriorated, because of disordered human intervention, deforestation of protective vegetation is encouraging landslides and erosion processes".

The Middle zone has the major concentration of agricultural and cattle activity but is in a better condition. Overgrazing appears to be the major problem in this area.

The lower zone have the highest grade of erosion because of overuse in agriculture and the heavy rain intensity on bare soil before the crop season.

A common pattern in all areas is that the erosion processes are associated with the construction of roads.

6. MAPPING METHODS.

Figure 2 shows the process of mapping the Factor of Safety in the two scenarios mentioned. Eighteen sheet maps of scale 1:25.000 produced by IGAC between 1967 and 1992 containing contour lines, roads and rivers and covering ±70% of the watershed were selected. The maps were digitised using ARC/INFO software (ESRI, 1995) by the GIS unit of the International Centre for Tropical Agriculture CIAT. A digital elevation model (DEM) was built for each sheet map using the contour lines in the Grid module with a resolution of 25 meters per pixel. River vectors were used to enforce the relief. The partial DEM's were joined to obtain a 22.5 by 30 km DEM (67.706.4 has). Figure 3 shows the final version of the DEM.

Hartshorne (1997) presents an evaluation of the influence of digital terrain models in the calculation of Factor of Safety (FOS). He did not find a clear relation between DEM resolution and FOS but suggests using surface texture indices to complement ground truth data. These indices can provide information on the variability and roughness of the terrain models. Carrara (1995) shows with different examples, that uncertainty and errors depend on the quality of the source maps, the accuracy of digitised contour lines and on the algorithms employed for interpolating elevation values or calculating morphometric parameters.

Following the surface module in Grid Module, slope, aspect and watershed delineation coverages were produced. At the same time, the DEM was used to calculate the topographic index, $\ln = Ac/\tan\beta$ (Beven, 1996) (Figure 4). The water table depth was then calculated after normalising the distribution of the topographic index (Figure 7). The local water table can be calculated from the topographic index at each point by the expression:

$$z_i = -\frac{1}{f}\ln\frac{ra}{T_0\tan\beta}$$

Where z_i is the depth of water table, r the effective recharge rate (not considered here), a the pixel area, T_0 the local saturated transmissivity (homogeneous for the whole area with value 1), β the slope angle (in radians for use in GIS systems) and f a constant parameter.

Figure 5 shows the aspect of the area, Figure 6 shows the slope distribution derived from the DEM and Figure 7a details the water table in the study area. Figure 8 shows the map of roads considered to assign a higher safety factor. A 1:50.000 map of soil associations (CVC, 1979) was analyses to extract information about soil depth required in the calculation of the safety factor and a map is presented in Figure 9.

Field observations have not been done yet because of limitations imposed by accessibility, time and resources available.

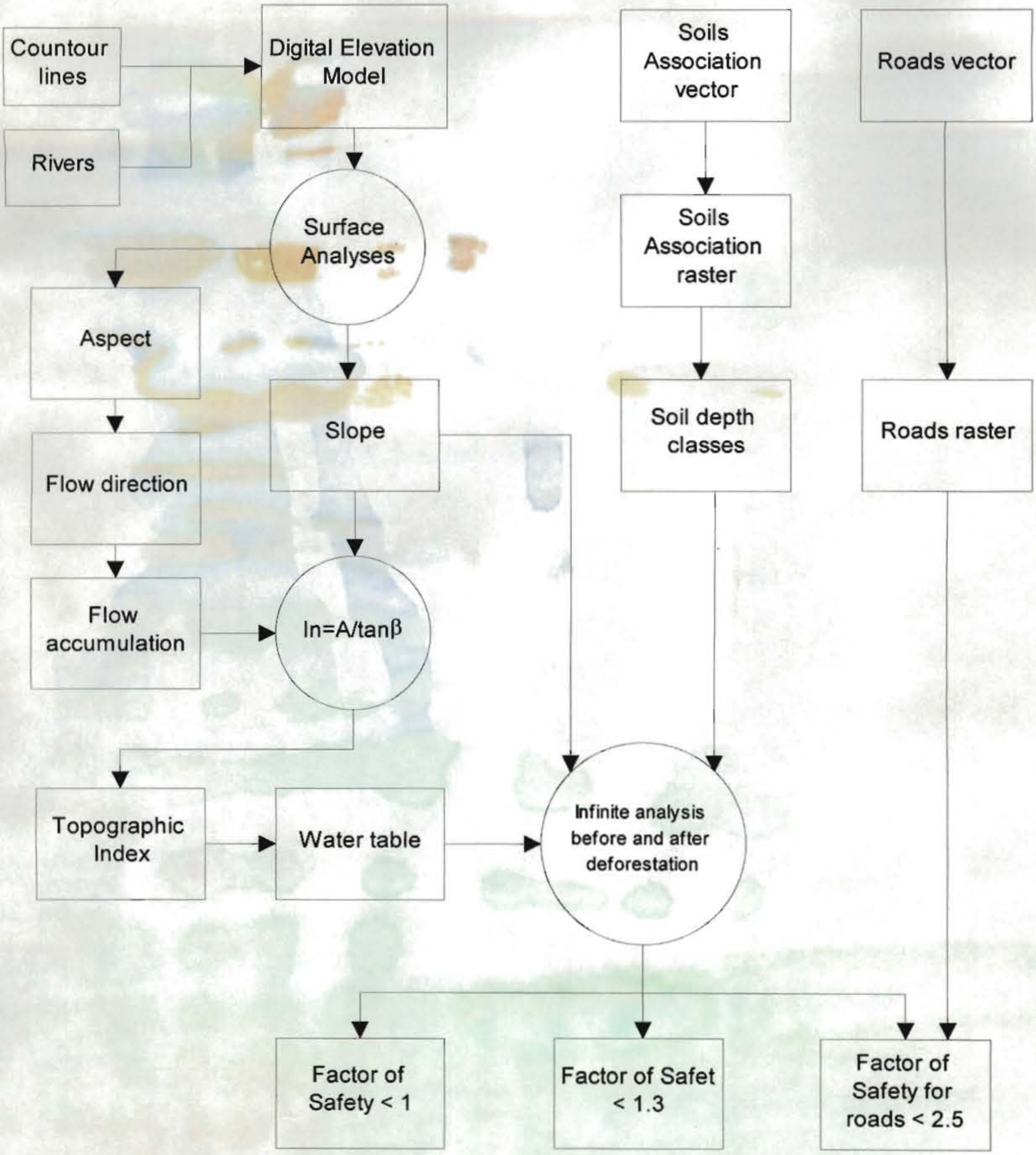
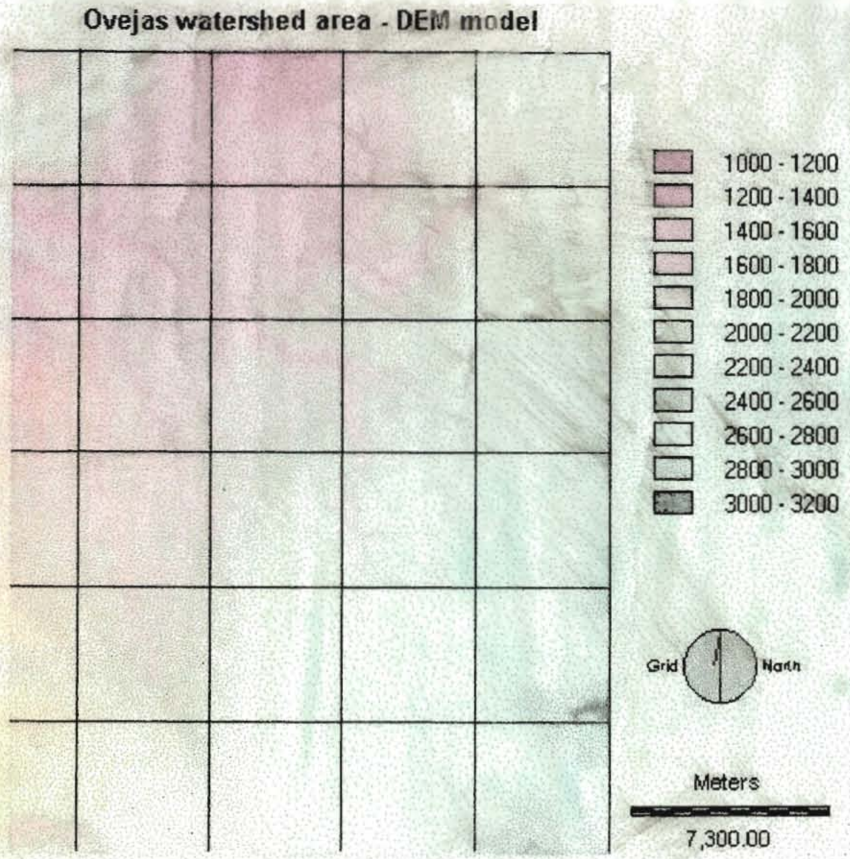


Figure 2. Process of stability analysis.



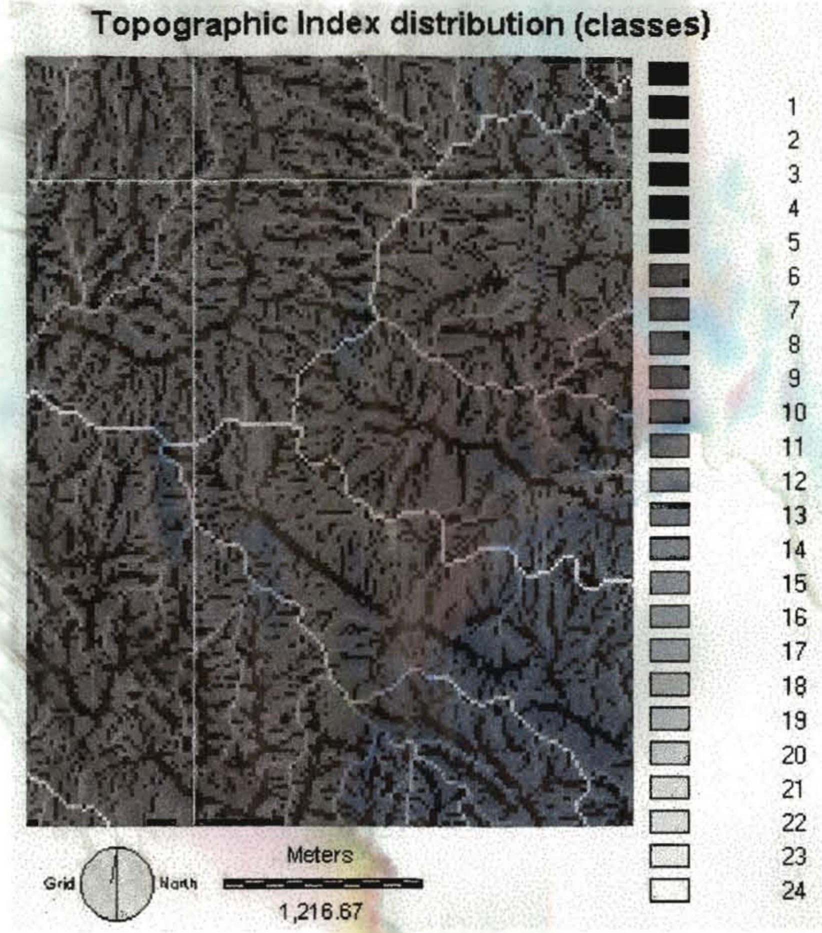
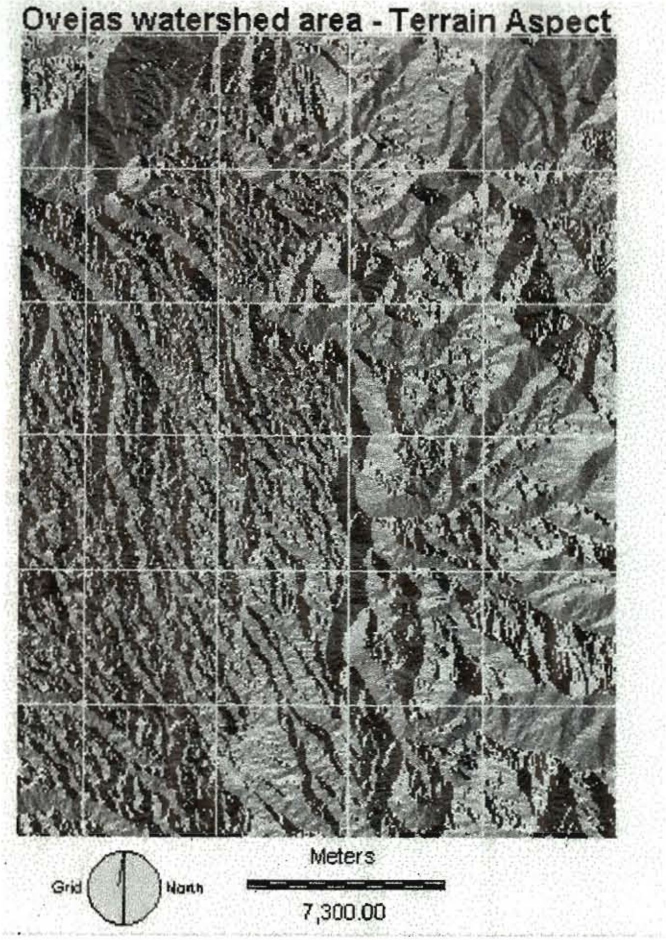


Figure 3. Digital Elevation Model. (left)

Figure 4. Detail of Topographic Index. (right)



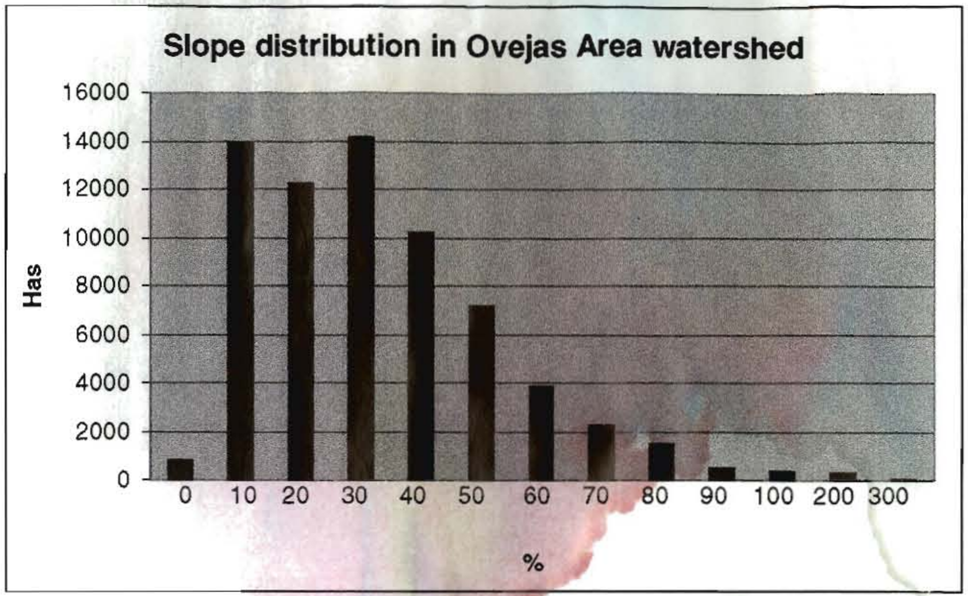
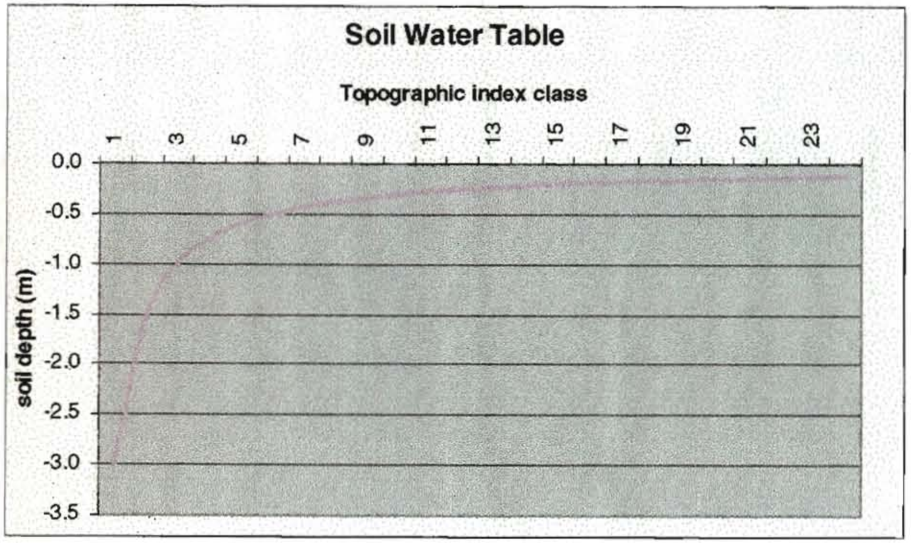


Figure 5. Aspect derived from the DEM

Figure 6. Slope distribution in Ovejas watershed area.



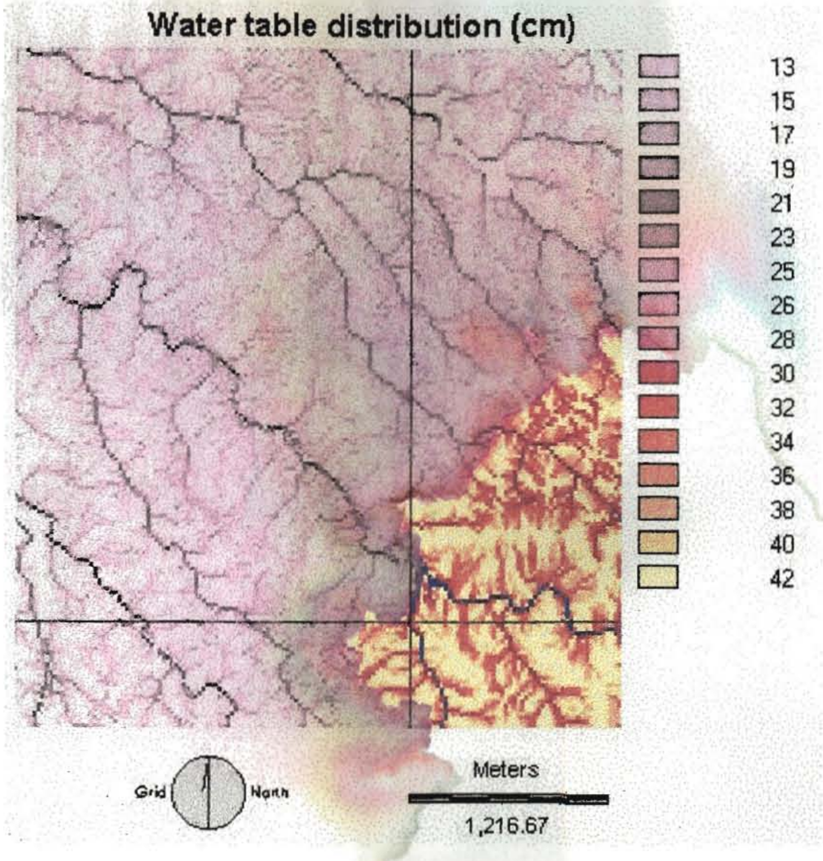
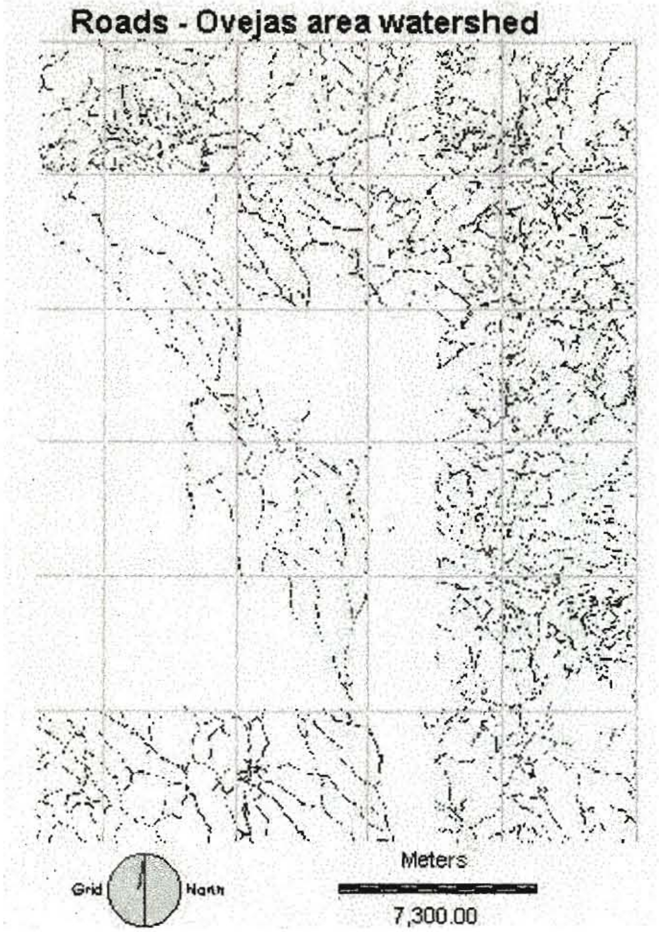


Figure 7. Soil water table after normalisation.

Figure 7a. Detail of Water table distribution.



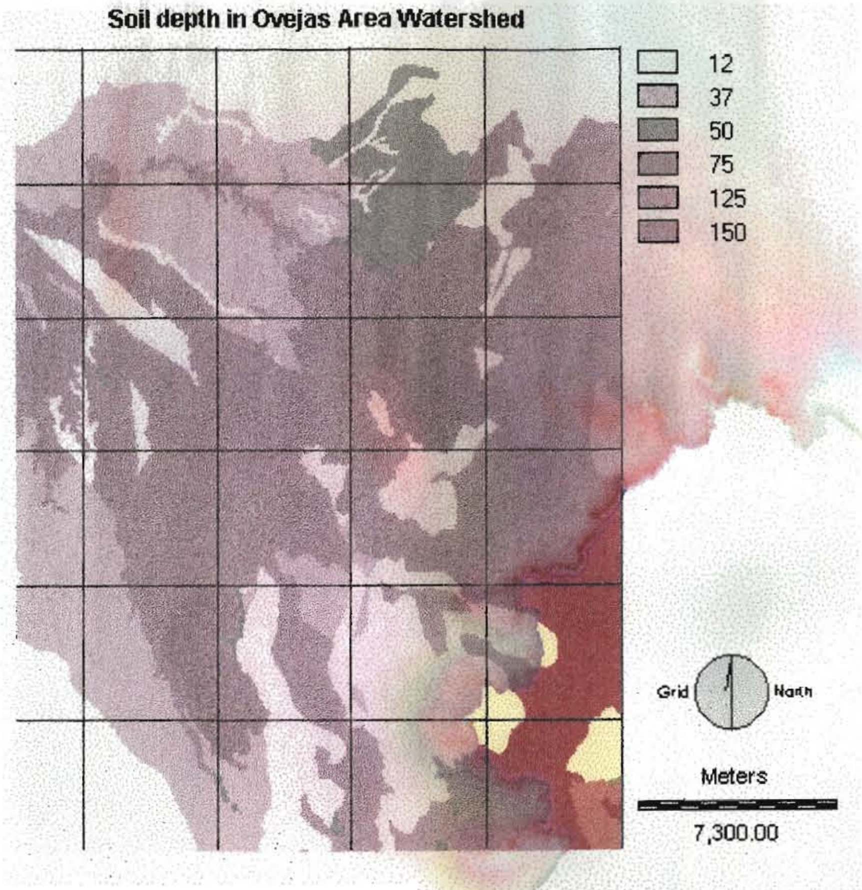


Figure 8. Roads in the study area

Figure 9. Soil depth (cms.) in Ovejas Area watershed.

7. SLOPE STABILITY ANALYSIS

"The stability of a slope against failure is assessed by the safety factor or the ratio of resistance to force. Mass movement will only occur when the disturbing forces become greater than the resistance of the slope-forming materials" (Brunsden, 1979). It is expressed as:

F (factor of safety) = sum of resisting forces / sum of driving forces

"Where the forces promoting stability are exactly equal to the forces promoting instability $F = 1$; where $F < 1$ the slope is in a condition for failure; where $F > 1$ the slope is likely to be stable. There is no such thing as absolute stability, only an increasing probability of stability as the value of F becomes larger. Most natural hillslopes upon which landslides can occur have F values between about 1 and 1.3, but such estimates depend upon an accurate knowledge of all the forces involved and for practical purpose design engineers always adopt very conservative estimates of stability. (Table 1). It can be seen that the greatest uncertainties are usually associated with soil water, especially with its local variability of soil pressure and seepage."(Selby, 1993).

"Three main types of analyses are: (1) planar slip surface (infinite slope) analyses; (2) circular slip surface analyses and (3) noncircular slip surface (other than planar) analyses" (Sidle, 1985). The first was used here to the extended area and the second to a typical cut-road profile.

Figure 10 shows simplified approximation to planar failure in infinite slope surfaces and it can be explained as follows: "If a typical slice of depth z and width b, bounded by the vertical lines IJ and KL, is isolated for attention, then from consideration of the equilibrium of the slice must be equal, opposite and collinear. From a consideration of the equilibrium of the slice by a vertical resolution of forces, the vertical force across the base of the slice must equal the weight W. This can be resolved into its normal and tangential components P and T respectively. For a slice of unit thickness in the strike direction:

$$W = \gamma bz; \qquad P = \gamma bz\cos\beta; \qquad T = \gamma bz\sin\beta$$

Since the length of the slide surface JK is $b\sec\beta$, the average normal and shear stresses produced by P and T are:

$$\sigma_n = \gamma z\cos^2\beta; \qquad \tau = \gamma z\sin\beta\cos\beta$$

In natural hillsides with steady state seepage parallel to the slope, and the groundwater level at distance mz above the slide surface, the porewater pressure u is $\gamma_w mz\cos^2\beta$, and therefore:

$$FOS = [c' + (\gamma - m\gamma_w)\, z\cos^2\beta\ \tan\phi\,]\ /\ \gamma\, z\cos\beta\sin\beta$$

Where:
c' = cohesion (kPa)
ϕ = friction angle (degrees)
γ = unit weight soil (kN/m^3)
γ_w = unit weight water (kN/m^3)
m = water table/soil thickness (m)
z = soil thickness (m)
β = slope angle (degrees)"(Graham, 1984)

Where there is no continuous water table with flow parallel to the soil surface, an alternative form of analyses must be used. The piezometric height (h) is used and is calculated by:

$$FOS = [c'/\gamma z + (\cos^2 \beta - (\gamma_w h / \gamma z)) \tan \phi] \ / \ \cos\beta \sin \beta$$

Solution to the stability equation against changes in slope is shown in Figure 8. The model shows be very sensitive to changes in values of c', m and z. Changes in the FOS against changes in values of β, ϕ and γ were insensitive. The value of m may be reduced improving soil drainage. C' may be modified only by increasing apparent cohesion through a denser plant root network.

Factor of safety with values greater than 1, 1.3 and 2.5 were calculated with the grid maps of slope, soil depth and water table. IDRISI software was used for this purpose. Images are presented in Figures 12 and 13 for two scenarios: before and after deforestation respectively. In the deforested scenario, cohesion was assumed to be 5kPa. Area changes when hypothetical deforestation occurs are presented in Table 3 and are illustrated in Figure 13. Grid lines have been included for geographical reference. The parameter values used in the analysis are listed in Table 2.

Table 1. Values of minimum overall safety factors (after Selby, 1993).

Failure type	Item	F
Shearing	Earthworks	1.3 to 1.5
	Earth-retaining structure	1.5 to 2.0
	Foundation structures	2 to 3
Seepage	Uplift, heave, slides	1.5 to 2.5
	Piping	3 to 5

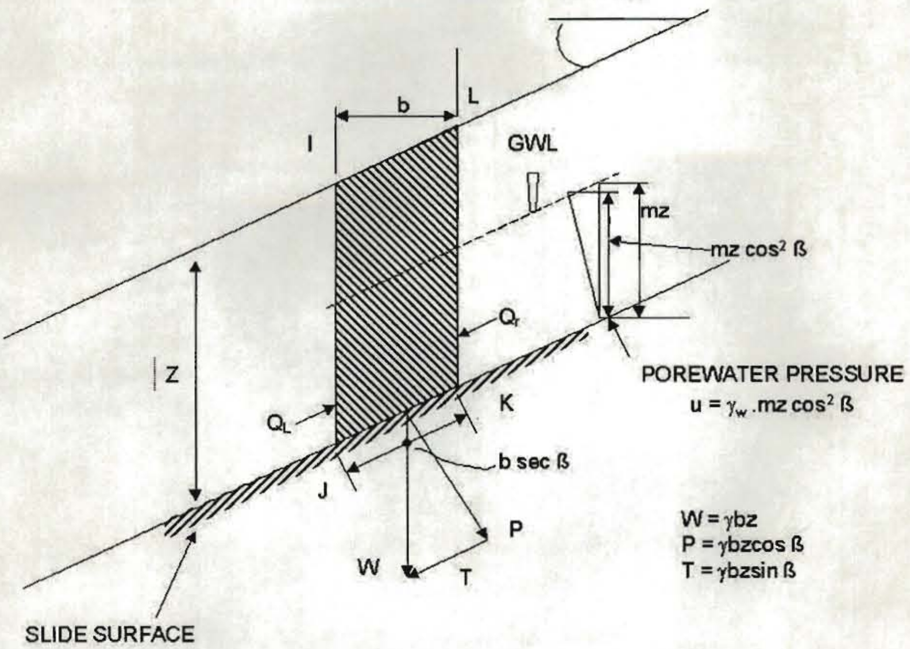


Figure 10 . Planar failure in infinite slopes (after Graham, 1984)

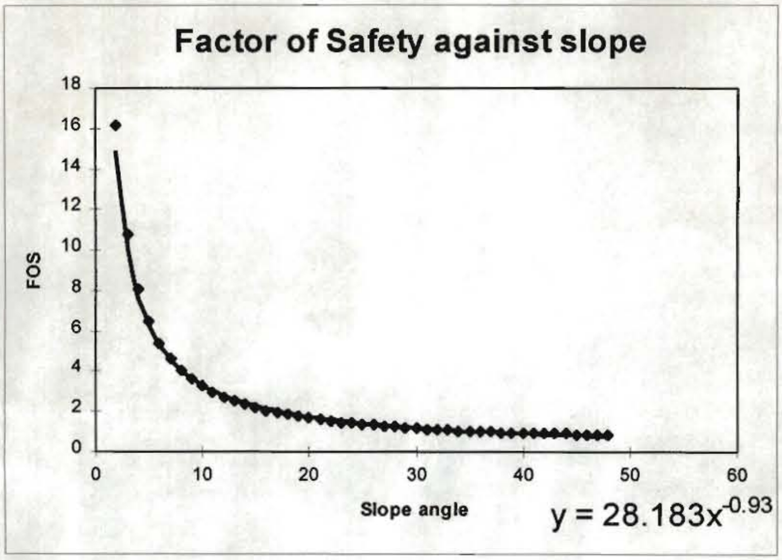

Factor of Safety against slope

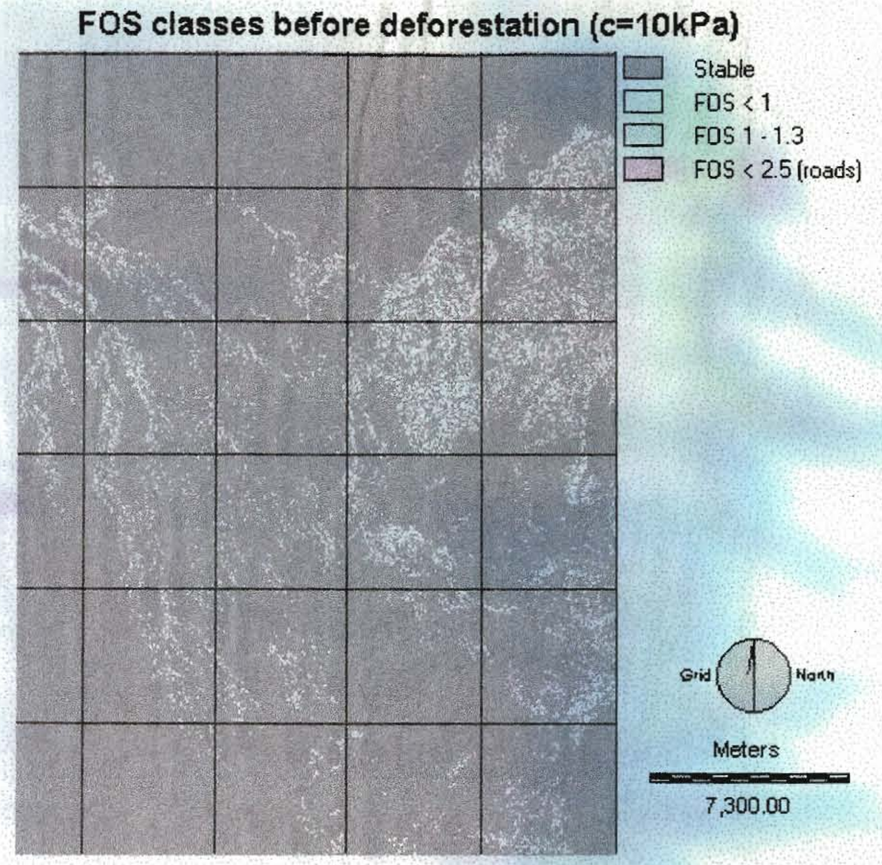
Figure 11. Variation in factor of safety against different slope.

Table 2. Parameters values used in the safety factor analyses.

Parameters	**Total Area**	**Total Area (assuming deforestation)**	**Along Roads**
c' = cohesion (kPa)	10	5	10
ϕ = friction angle (degrees)	20	20	20
γ = unit weight soil (kN/m^3)	16	16	16
γ_w = unit weight water (kN/m^3)	9.8	9.8	9.8
m = water table/soil thickness (m)	Water table map	Water table map	Water table map
z = soil thickness (m)	Depth soil map	Depth soil map	Depth soil map
β = slope angle (degrees)	Slope map	Slope map	Slope map

Table 3. Comparison of FOS areas between two scenarios: before and after deforestation.

	Before Deforestation		**After Deforestation**	
FOS Class	Area (Ha)	%	Area (Ha)	%
< 1	616	1.0	11000	16.3
1 - 1.3	4876	7.2	5494	8.1
<2.5 along roads	712	1.0	976	1.4
Stable area	61502	90.8	50236	74.2
Total	67706	100	67706	100



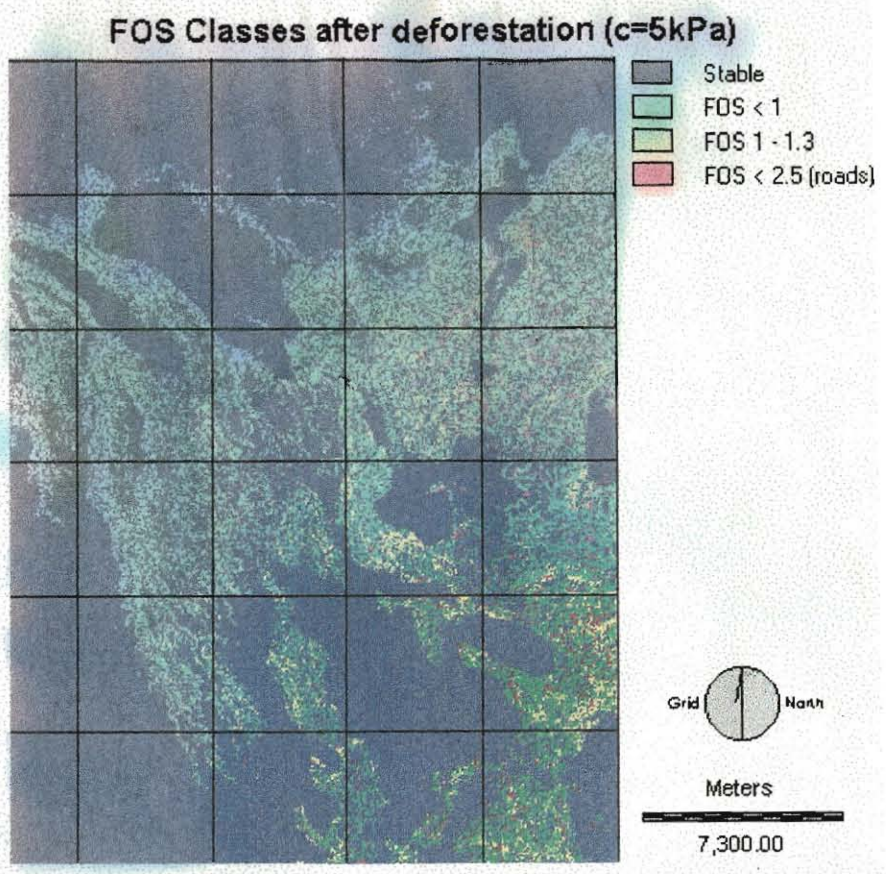


Figure 12. FOS before deforestation.

Figure 13. FOS after deforestation.

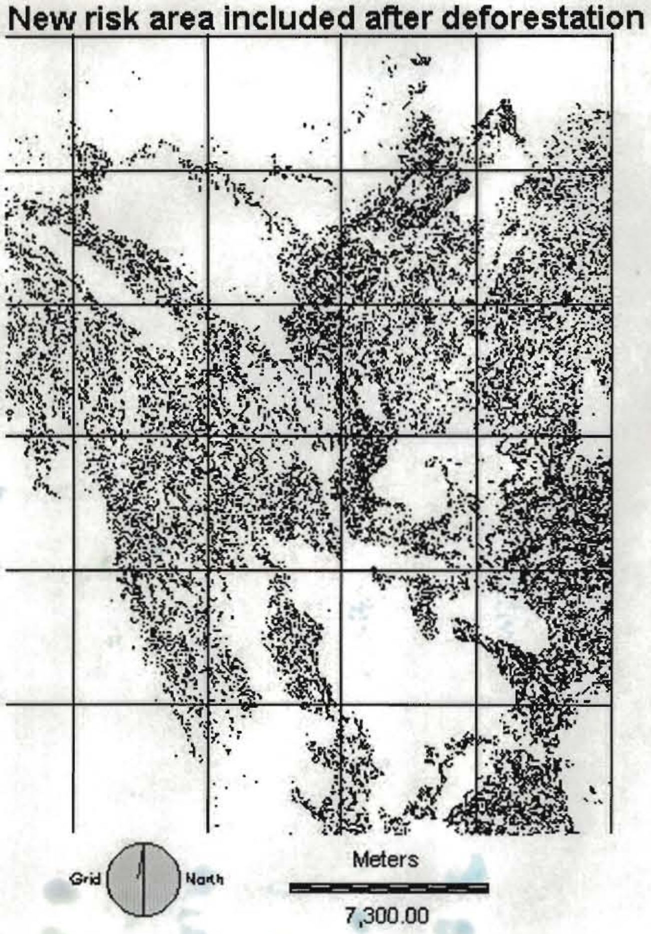


Figure 14. Risk areas incorporated after deforestation.

8. DISCUSSION

In general, the study area is characterised by steep slopes as shown in Figure 6.The Ovejas River divides this area in two different parts. In the West, the middle zone is characterised by a dissected landscape and short length slopes. In the East, the base of the central line of the Colombian Andes is characterised by long slopes and altitude ranges between 1800 and 3000 m.a.s.l. The landscape in this area is more extensive compared to the western zone. It is also less homogeneous with soil depth of more than 1 m. Both features make this area more susceptible to landslides, as is shown in Figure 12.

The Analysis shows that when the C' is reduced, after total deforestation, the area susceptible to landslides increased by 11.000 ha. Figure 15 illustrate that the areas with FOS < 2.5 and between 1 -1.3 increased proportionately less than unstable area (with FOS < 1).

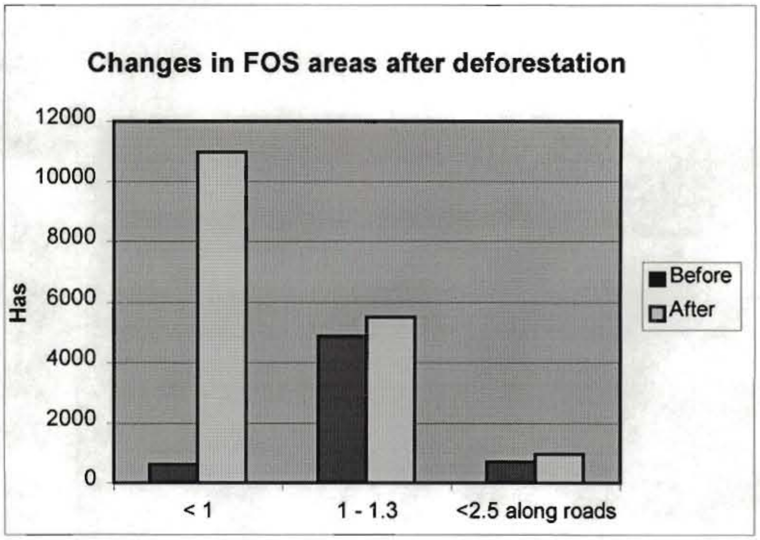


Figure 15. Changes in FOS after deforestation.

9. COMPLEMENTARY ANALYSES

A complementary analysis was carried out on a hillside profile using the SEEP and SLOPE simulation models. They give (between other things), the different FOS according to the different profile characteristics and the slip surface under specific circumstances. Major simplifications were assumed here and the use of this was considered more an exercise to know the capabilities of this tool in the landslide assessment process rather than its application to the current case.

Figures 16 and 17 represents the pressure head and volumetric water content of an hypothetical profile under two scenarios of land use cover: (a) forest and (b) grass. (Steady state mode). Some difference can be evidenced between the two scenarios. Runoff will occur easily in the grass scenario comparing with forest.

Figure 18 shows the framework of landslide analysis according to the Bishop's method and Figure 19 two slip surfaces for two different slip surfaces. The details of a grass slip section are represented in Figure 20 with the correspondent information table.

In developing this exercise, it was evident that high quality of information is required. It is necessary too to make clear explanations of the model outputs. This method requires extensive understanding before it is to be used as a tool of management for the present scheme.

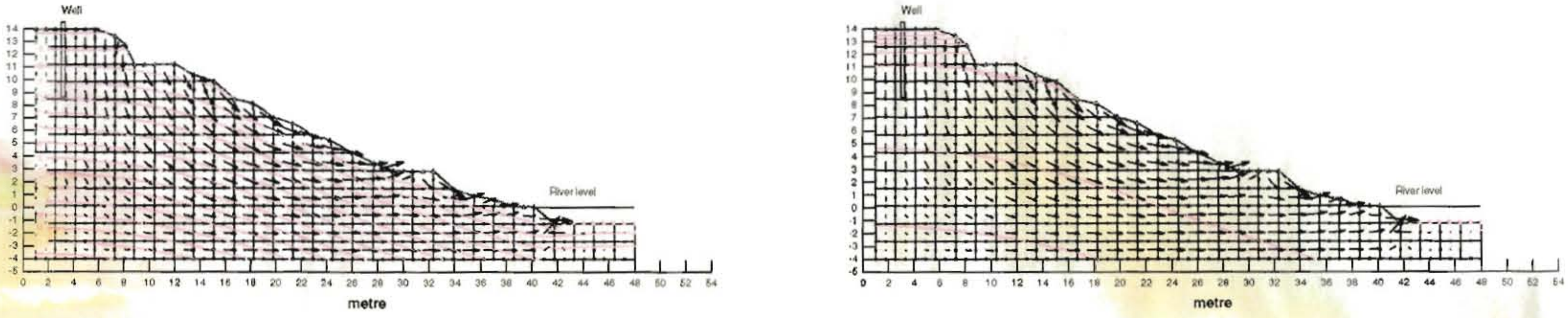


Figure 16. Pressure Head (left) and Volumetric water conten (right) in the grass scenario.

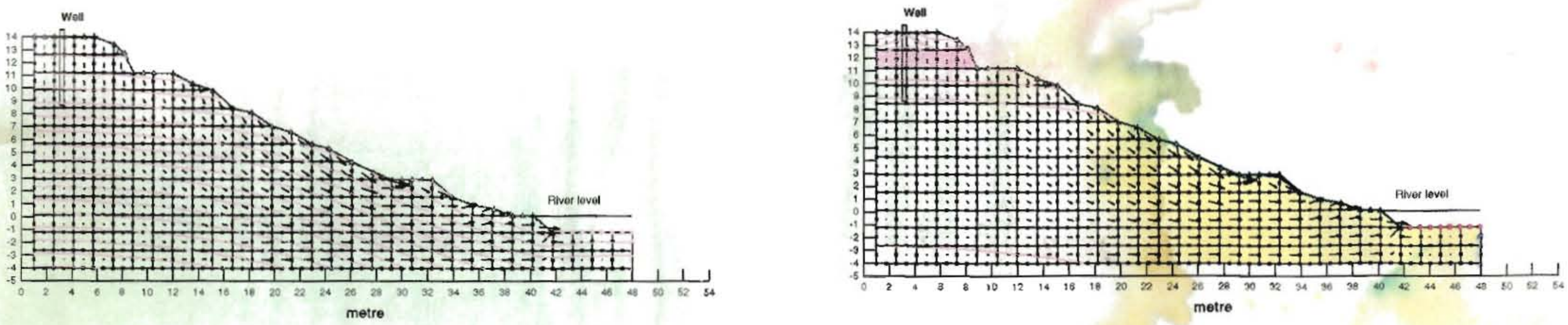


Figure 17. Pressure head (left) and Volumetric water content (right) in forest scenario.

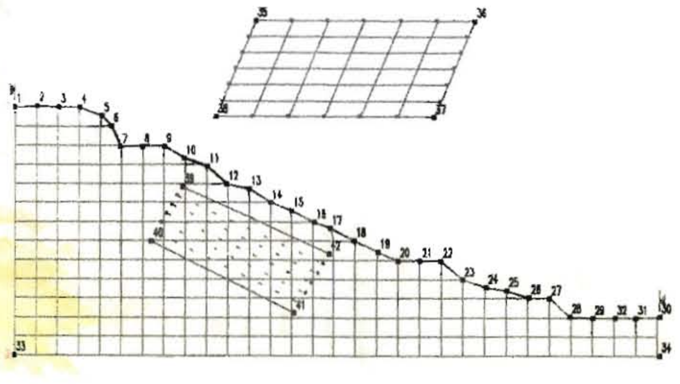


Figure 18. Framework of Bishop's method landslide analysis.

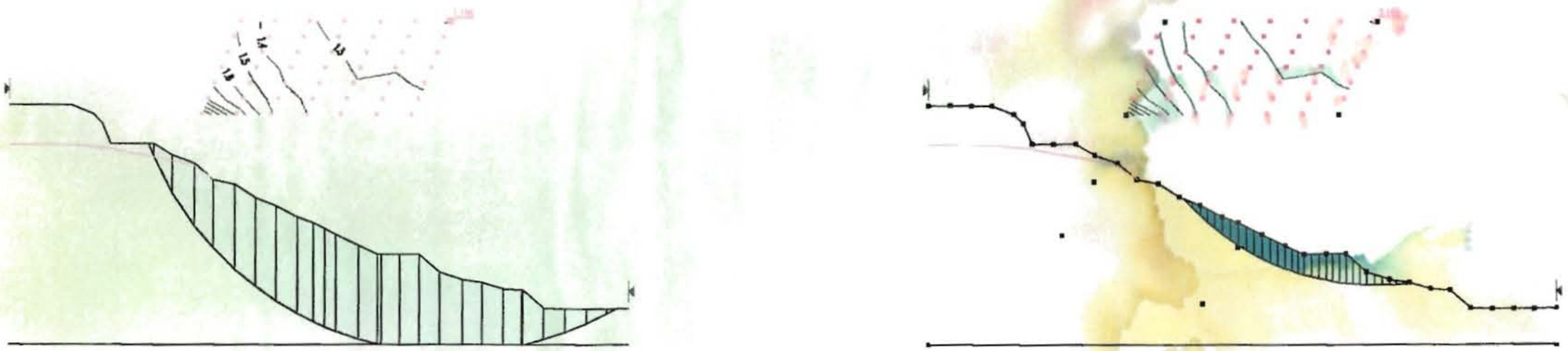
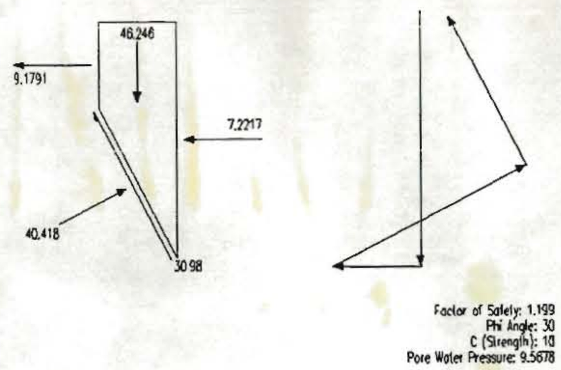


Figure 19. Slip surfaces for two different FOS.

Slice 2	
Weight	46.246
Base Shear Force	30.98
Base Normal Force	40.418
Left Side Normal Force	9.1791
Right Side Normal Force	7.2217
Factor of Safety	1.199
Phi Angle	30
C (Strength)	10
C (Force)	30.805
Pore Water Pressure	9.5678
Pore Water Force	29.474
Pore Air Pressure	0
Pore Air Force	0
Slice Width	1.429
Mid-Height	1.9201
Base Length	3.0805
Base Angle	62.362


Slice 2 - Bishop Method

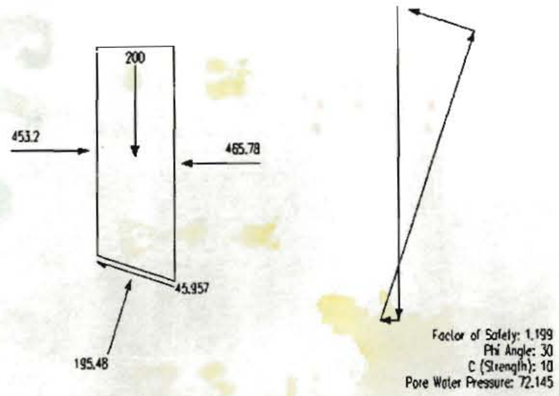

Slice 12 - Bishop Method

Figure 20. Slip surface sections representing the forces involved in the profile.

10. CONCLUSIONS

The method used here is simple and relatively fast and can be applied wherever digitised maps of soils and contour lines are available extending the use of many GIS databases.

Some assumptions considered in the present analysis must be taken into account before reaching a conclusion. The soil depth, one of the most important factors in the stability analysis, is based on a soil general study with a resolution of 1:50000. A sample of no more than 30 profiles was the base of that study. It makes new field observations necessary to adjust the current results. The information used to generate the slope and water table was of 1:25000 scale resolution. Nevertheless, the detail is still coarse for more specific calculations, e.g. quantitative estimate of the amount of landslide debris or expected landslide size and length.

Users of this report must be aware that although this information provides substantial detail, it still has an inherent level of inaccuracy. The assessment report is based on detailed secondary data but limited field observations. Sub-surface and bedrock conditions are poorly known and could only be inferred from very limited bibliographic references. Terrain stability interpretations, site prescriptions and mitigative recommendations, under these constraints depend highly on the local conditions and antecedent landslides.

Future studies must include observations of visible natural landslides in the area or downslope stratigraphic evidence.

11. BIBLIOGRAPHY

Beven, K, Lamb, P, Quinn, R, Romanowicz, R and Freer, J. 1996 TOPMODEL. In Computer Models of Watershed Hydrology, Ed. Singh, V.P. Water Resources Publications.

Carrara, Alberto. 1995 Gis-Based Techniques For Mapping Landslide Hazard CNR-CIOC, Bologna. //deis158.deis.unibo.it/gis/chapt0.htm

C.V.C. 1979 Estudio general de suelos de la parte alta de las cuencas de los rios Piendamo, Cajibio y Ovejas. - Departamento del Cauca. IGAC - Division Agrologica.

Graham, J. 1984. Slope Instability. Edited by Brunsden, D. and Prior, D.B. John Wiley and Sons.

Hartshorne, J. 1997. Assesing the influence of digital terrain model characteristics on tropical slope stability analysis. Innovation in GIS 4. Edited by Zarine Kemp. Taylor and Francis.

Ministry of Forests Act 1995 Hazard Assessment Keys for Evaluating Site Sensitivity to Soil Degrading Processes - Guidebook Forest Practices Code of British Columbia Act.

Selby, M.J. 1993. Hillslopes materials and Processes. Oxford University Press.

Sidle, R.C., Pearce, A.J. and O'Loughlin, C.L. 1986 Hillslope Stability and Land Use. American Geophysical Union - Water Resources Monograph 11 140p

Strong, Simon 1995 White Wash - Pablo Escobar and the Cocaine wars. MacMillan.

Tsukamoto, Y. and Minematsu, H. 1987. Evaluation of the effect of deforestation on slope stability and its application to watershed management. In Proceedings of the Vancouver Symposium, August 1987; Publ. No. 167, 181-189.

Annex 1.

Colombian earthquake emergency

SAIIC (saiic@igc.apc.org)
Mon, 20 Jun 1994 10:51:00 PDT

EMERGENCY SUPPORT NEEDED
Paez People Homeless, Injured, Orphaned, in Northern Colombia

Eighteen Indigenous communities disappeared beneath tons of mud and rock after a massive earthquake registering 6.3 on the Richter scale struck northern Colombia's remote Cauca region which is inhabited primarily by Indigenous people. The quake struck on June 6, with its epicentre close to the town of Torbio, releasing a series of debris slides and flooding of the Paez and Moras rivers. The list of dead, disappeared and injured grows daily.

Indigenous organisations report that government aid to the survivors has been slow and totally insufficient, and that many injured have not received treatment and that people are dying from infection. Official calculations acknowledge 857 deaths and close to 15,000 injured, but there is no precise information on the number of victims or the conditions of the survivors. A leader of the Vitaco Indigenous reserve site of a major avalanche, claimed that at least half of the 4,000 indigenous inhabitants of this locality had been buried.

The National System for Prevention and Attention to Disasters announced that "given the magnitude of the quake' aftershocks, new rockslides could fall from the Nevado del Huila [mountains] which could cause increases in the Paez river's levels." In turn this could result in the flooding of more communities. On the 9 of June, the affected communities were again panicked by tremors with intensities varying from 4.0 to 4.8 on the Richter scale.

Emergency aid provided by Colombians and international organisations has been essential in saving hundreds of unprotected indigenous people's lives. However, the National Indigenous Organisation of Colombia (ONIC) calls for individuals and agencies to take into account, not only the immediate situation, but also the communities future. Of particular concern has been a campaign, promoted by portions of the national press, for the adoption of indigenous children by people outside the region. This is an attack on the autonomy for which indigenous communities have struggled for years.

Additionally, ONIC is concerned with the process of resettling those who have been displaced from their land, stating, "land isn't just a material element, but the essence of their cultures". Its recovery has cost many lives, as well as much pain and suffering. Now, the displaced people find themselves set back to step one. Delimitation of new indigenous reserves is urgently needed. Its also critical to urge governments who are supplying aid that these funds be channelled through indigenous organisations in a way that establishes a true network of solidarity with the affected communities. The Colombian government has been slow to recognise Indigenous organisations jurisdiction within the disaster area.

ONIC's Executive Committee and the Regional Indigenous Council of Cauca (CRIC) is urgently international aid and solidarity. In order to send information regarding the possibilities for support in this state of emergency communicates with CRIC at Fax: 928-233893.

Annex 2.

Geomorphology Description of Ovejas watershed area.

Upper zone (>3000 m.a.s.l.)

GEOMORPHOLOGIC UNIT	LOCATION	RELIEF	COMPOSITION	DRAINAGE	EROSIVE PROCE
Colluvial valleys and glacio-fluvial deposits in very wet 'Paramos'.	Highest hill zones.	Flatness concave and abrupt watercourses.	Organic matter accumulation and volcanic ashes.	Low dense dendritic network.	
Wet and very wet Hillslopes.	East hillslopes of the central line of Colombian Andes.	Sharp and abrupt slopes in different angles.	Volcanic andesites rocks covered by volcanic ashes.	Low dense dendritic network..	Fluvial and ge erosion.
Footslopes in wet and very wet 'Paramos'.	Fall faces of the hills.	Undulated and very undulated landscape with short and irregular slopes.	Volcanic origin.		
Flat inter-mountain areas of cold and wet micro-climate.	Highest areas in the Northeast zone.	Undulated surfaces to lightly inclined.	Bedrock of igneous and metamorphic materials.		Creep slopes, solifl and sheet erosion.

Middle Zone (2000 – 3000 m.a.s.l.)

GEOMORPHOLOGIC UNIT	LOCATION	RELIEF	COMPOSITION	DRAINAGE	EROSIVE PROCE
Hillslopes with cold micro-climate.	East hillslopes of the central line of Colombian Andes.	Vertical cliff face and abrupt.	1- Metamorphic rocks, intrusive igneous and volcanic rocks. 2- Igneous rocks.	1- Dentritic to sub-parallel. Streams with structural control. 2- Low dense dentritic networks.	1- Geologic erosion rock debris mass movements and creep. 2- Solifluction, cree and erosion due t animal tampling.
Cold and wet footslopes.	Footslopes of cliff faces.	Undulated with short and irregular slopes	Heterogeneous materials mixed with volcanic ashes.		
Colluvial valleys with cold and wet micro-climate.	Narrow valleys, terraces covered by volcanic ashes.	Slightly inclined.	Recently sediments.		
Flat inter-mountain areas of cold and wet micro-climate.	Central zone.	Undulated.	Parent material of volcanic ashes with a very wide mantle of volcanic ashes.	Dense dentritic networks.	Organic matter accumulation, creep a hydraulic erosion.

Lower zone (<2000 m.a.s.l.)

GEOMORPHOLOGIC UNIT	LOCATION	RELIEF	COMPOSITION	DRAINAGE	EROSION
Hillslopes of wet climate.	At centre and east of study area.	Highly undulated to abrupt fall faced. With linear and irregular streams.	Metamorphic bedrock (1) in contact with igneous rocks (2) covered with a width mantle of volcanic ashes.	1- Sub-parallel to low dense dendritic. 2- Low dense dendritic.	2- Laminar hydraulic erosion.
Broken Planation surface of temperate wet climate.	East of Santander de Quilichao and Caldono	Highly undulated with irregular and short slopes.	Heterogeneous sediments of Popayan formation with a mantle of volcanic ashes.	Low dense dendritic with narrow valleys and fall abrupt faces with short and deep slopes.	Hydraulic erosion in intermediate levels. Cl faced with landslides debris.
Hills ok sub-humid climate.	North-east of Caldono	Highly undulated, with complex streams running over sediments of Popayan formation.			Hydraulic erosion in intermediate and high levels caused by cree solifluction.
Narrow valleys of temperate wet climate.		Flat			