A LAND USE - LAND CAPABILITY CLASSIFICATION SYSTEM

FOR NEPAL

A Case Study in Phewa Lake Watershed

by

KESHAR M. STHAPIT

A thesis submitted to the Graduate Faculty of
North Carolina State Univeristy
in partial fulfillment of the
requirements for the Degree of
Master of Science

DEPARTMENT OF FORESTRY

Raleigh

1 9 8 2

APPROVED BY:

Charles D. Harrington

Shamak Khorram

Stanley W. Bond

Jimmy D. Gregory
Chairman of Advisory Committee

ABSTRACT

KESHAR MAN STHAPIT. A landuse - Land Capability Classification System for Nepal: A case study in Phewa-Lake Watershed. (Under the direction of Dr. Jimmy D. Gregory.)

Because of rapidly expanding population, the efficient utilization of land resources to produce food, fodder and fuel is a critical need in Nepal. A scientific integrated approach to land capability classification based on the land's main characteristics of soil, landform and vegetation, is needed to support efficient land use.

Land capability classes are based on the overlay interpretation of maps of landform, soils and vegetation or existing land use. Nine land classes are delineated based on relative degree of high to low productive capacity and low to high degree of limitations, risks of soil damage, erosion hazard and need for conservation measures.

The extensive system of terraces and manual cultivation of steep sloped terrace land plays a significant role in land capability in Nepal. The upgrading of classes by terracing and downgrading of classes by soil limitations, excess wetness and inundation are considered over the classes determined by slope, soil depth, and stoniness.

The system is tested in the Phewa Lake Watershed of Nepal.

BIOGRAPHY

Keshar Man Sthapit was born in Kathmandu, the capitol of Nepal on January 2, 1953. He received a Bachelor of Science degree, majoring in Physics, Chemistry and Mathematics in April 1972 from Amrit Science College, Kathmandu, Nepal, and a Diploma in Forestry in March 1974 from Indian Forest College, Dehra Dun, India.

He joined the Department of Forestry, His Majesty's Government (H. M. G.) of Nepal in April 1974 and transferred to the Department of Soil and Water Conservation in 1975. In the fall of 1980 he enrolled in the Master of Science program in the Department of Forestry, North Carolina State University. He was awarded a scholarship granted by the Resource Conservation and Utilization Project, which is a joint project between the Department of Soil and Water Conservation, H. M. G. of Nepal, and the United States Agency for International Development.

The author is married to the former Subarna Tuladhar and has two daughters, Namrata and Nameeta.

ACKNOWLEDGEMENTS

I would like to thank Dr. Jimmy D. Gregory, the Chairman of my Advisory Committee, whose advice, guidance and criticisms have been truely invaluable. I would also like to thank the other members of my committee, Dr. Stanley W. Buol, Dr. Charles D. Harrington and Dr. Siamak Khorram, for their constructive cirticism and suggestions. Special thanks are also extended to Mr. Pradeep M. Baisyet for making reports and aerial photographs of the study area available from Nepal, without which the project could never have been completed.

Finally, I would like to express my deepest appreciation to my wife, Subarna for her patience and understanding during my two-year absence from home.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

* These figures are at the back.

1. INTRODUCTION

The use of land resources without proper management and without regard to its capability can result in soil erosion on the slopes, floods on the plains, and degradation of the productive capacity of the land. Proper landuse based on the land's capability and utilization of conservation measures to preserve that capability requires careful planning. Therefore, it is important to have a landuse - land capability classification system that is based on the land's capability, conservation measures required, limitations for certain uses, and risks of soil damage and erosion. Such a system is imperative in an agriculture based country like Nepal.

The land surface (topography and soil) is a complex result of geological and geomorphological processes, climate and vegetation and biotic factors acting for a given period of time. Therefore, the capability classification based on soil, landform and vegetation provides a logical approach to land classification relevant to landuse.

Research reported in this thesis has the following objectives:

a. To develop a landuse - land capability classification system for Nepal based on: (1) the inherent capability of the land for agriculture, range or forestry utilization, (2) conservation measures needed to control erosion and (3) limitations, risks of soil damage and erosion hazard for certain land uses.

b. To develop soil, landform and landuse mapping legends for Nepal, necessary for using the landuse - land capability classification system.

c. To test the classification system on Phewa Lake Watershed in west central Nepal.

In applying the system, maps of soils, landforms, and landuse are prepared and the landuse - land capability classifications are generated as a result of overlay interpretation of all the above maps.

The system gives the relative degree of productive potential of the land, limitations, conservation measures needed for certain land uses, risks of soil damage and erosion hazard rather than quantitative figures. This system also considers the manual labor and/or bullock power based agriculture system in Nepal.

2. LITERATURE REVIEW

There are two main types of land classification in practice namely hierarchical or landscape and parametric. In heirarchical classification, lands are classified into natural units and the units have often been arranged into hierarchical sequences and then practical data are related to these units. There are two mutually related systems of formulation of classes in hierarchical classification.

"1. Agglomeration: Grouping things on the basis of their similarities so that classes are built up by aggregation from below. Classes so formed can be agglomerated in higher categories so that a hierarchy is formed.

2. Division: Dissecting wholes into parts on the basis of difference so that classes and units are arrived at by subdivision from above. Classes so formed can be dissected in lower categories so that a hierarchy is formed." (Rowe, 1978)

In parametric classification, lands are classified on the basis of selected inherent characteristics separately and then superimposed to interpret the individual units for the desired purposes.

The hierarchical or landscape systems help to explain the fundamental causes of landscape differentiation, assist reconnaissance and facilitate the appreciation of regions as a whole, whereas parametric systems are more quantitative, less dependent upon subjective interpretation, and are subject to statistical analysis. Also, in parametric systems, it is often difficult to decide on the best parameters to use for classification and the class limits to set for any given land use (Mitchell, 1977).

To understand land and its capability for sustained use, the integrated classification system based on soil, landform and vegetation or landuse is an objective approach to land classification.

It is not possible to review all land classification systems developed in different countries. However, some of the widely accepted and used land classification systems and some recently developed systems of Nepal are reviewed here.

1. Land System of Australia

The Australian Land System approach developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) is a hierarchical land classification system and has three levels of generalization namely site, land unit and land system.

Site:

A site is a part of the land surface which is, for all practical purposes, uniform throughout its extent in landform, soil and vegetation. The site is the smaller identifiable unit.

Land Unit:

The land unit is land surface with a distinctive combination of topography, soil and vegetation. Land units may consist of a single site or a group of geographically associated sites.

Land System:

The land system is defined as an area or group of areas, throughout which there is a recurring pattern of topography, soils and vegetation. It consists of a recurring pattern of land units.

The system is based on the integration of three of the land's main characteristics, topography, soil, and vegetation. The land system is the unit of mapping and the site is the smaller identifiable unit. Within any one land system there is a recurring pattern of topography, soils and vegetation (Christian and Stewart, 1968).

"A land systems map defines those areas within which certain predictable combinations of surface forms and their associated soils and vegetation are likely to be found" (Cooke and Doornkamp, 1974). The simplest criteria for distinguishing between land system is surface relief (Bawden, 1967, cited by Cooke and Doornkamp, 1974). This system is mainly applied to aerial photographs at the reconnaissance level and the interpretation is widely based on landform analysis.

The Australian Land System does "little or nothing to measure or evaluate the important complex of functional relationships between soils, climate, plants, and animals. The accuracy of land system surveys has been questioned on the grounds that little account is taken of local variation and that classification may be based on imprecise criteria and strongly influenced by the more evident contrasts in air-photo patterns" (Cooke and Doornkamp, 1974).

2. Ecological System of Canada

The Canadian Ecological (Biophysical) classification developed by Lands Directorate, Environment Canada is a hierarchical land classification system and "refers to an integrated approach to land survey in which areas of land as ecosystems are classified according to their ecological unity" (Wiken and Ironside, 1977). This system

has six levels of generalization in a hierarchy of ecosystems namely ecoprovince, ecoregion, ecodistrict, ecosection, ecosite and ecoelement.

Ecoprovince: An area of the earth's surface characterized by major assemblages of structural or surface forms, faunal realms, vegetation, hydrological soil and climatic zones.

Ecoregion: A part of an ecoprovince characterized by distinctive eclogical responses to climate as expressed by the development of vegetation soils, water, fauna, etc.

Ecodistrict: A part of an ecoregion characterized by distinctive assemblages of relief, geology, geomorphology, vegetation, soils, water, and fuana.

Ecosection: A part of an ecodistrict throughout which there is a recurring assemblage of terrain, soils, and vegetation.

Ecosite: A part of an ecosection in which there is a relative uniformity of parent material, soil, hydrology, and vegetation.

Ecoelement: A part of an ecosite displaying uniform soil, topographical, vegetative and hydrological characteristics.

The Canadian system is heavily based on a complex concept of an ecosystem. "In simple terms, the ecosystem concept states that the earth operates as a series of interrelated systems within which all components are linked, so that a change in any one component may bring about some corresponding changes in other components and in the

operation of the whole system. An ecosystem approach to land evaluation stresses the interrelationships among components rather than treating each one as a separate characteristic of the landscape" (Bailey, 1980).

The aerial photo interpretation and mapping and description of ecosystems is a sophisticated scientific procedure which is overly complicated for lay users. The system needs highly trained surveyors who understand the nature of the proposed projects so that they can develop the ecological units relevant to the proposed project (Duffy, 1973).

3. Ecological Land Unit System of Nepal

The major ecological land unit system of Nepal developed by Nelson et al. (1980) is a hierarchical land classification system. The system is primarily based on physiography and also climate, vegetation and landform are considered. This system has four levels of hierarchical generalization namely zone, region, land-system and land-types.

Zones:

Zones are land units with similar elevational ranges, climate, vegetation and geological structure.

Regions:

Regions are land units with similar regional precipitation rates and local geological structure.

Land Systems:

Land systems are land units with a repetitive pattern of similar land types.

Land Type:

Land types are the most elemental unit used. They are usually individual slope facets, but in some places because of lack of information, they are rather complex land units with a wide range of properties.

These four mapping levels are very broad and were delineated on 1:250,000 to 1:800,000 scale skylab photography, false color and black and white imagery. Landtype levels are only described and not delineated on the map. Moreover, these mapping units are designed only for reconnaissance surveys for fixing general priorities when selecting project areas.

These three hierarchical integrated land classification approaches do little or nothing to measure or evaluate land capability classes based on potential productivity, limitations for sustained production, risks of soil damage, erosion hazard and need of conservation measures.

Land units of the Australian system and ecosites of the Canadian system potentially appear to be valuable in the reconnaissance level of a land capability classification. However, the lower hierarchical levels of mapping are yet to be detailed in those systems. The landtype of the major ecological units in Nepal is even too broad for the reconnaissance level of land classification. In short, these systems do not meet the objectives of landuse - land capability classification system.

4. Land Capability Classification of the United States

The land capability classification of the Soil Conservation Service, United States Department of Agriculture is a parametric land classification and is perhaps the most widely used and adopted system of land capability classification. The capability grouping of soils is based on their potentialities, limitations for sustained production, risks of soil damage and erosion hazard.

The system recognizes a threefold hierarchy from smaller to larger grouping of: (1) capability units, (2) capability subclasses, and (3) capability classes (Klingebiel and Montgomery, 1961; cited by Cooke and Doornkamp, 1974).

The capability unit is a grouping of soils that have about the same responses to systems of management of common cultivated crops and pasture plants. The subclass is a grouping of capability units having similar kinds of limitations and hazards are recognized: (1) erosion hazard, (2) wetness, (3) rooting-zone limitations, and (4) climate (Klingebiel and Montgomery, 1971). There are eight broad land capability classes.

Class I:

Soils in Class I have few limitations that restrict their use.

Class II:

Soils in Class II have some limitations that reduce the choice of plants or require moderate conservation practices.

Class III:

Soils in Class III have severe limitations that reduce the choice of plants or require special conservation practices or both.

Class IV:

Soils in Class IV have very severe limitations that restrict the choice of plants, require very careful management, or both.

Class V:

Soils in Class V have little or no erosion hazard but have other limitations impractical to remove that limit their use largely to pasture, range, woodland, or wildlife food and cover.

Class VI:

Soils in Class VI have severe limitations that make them generally unsuited to cultivation and limit their use largely to pasture or range, woodland, or wildlife food and cover.

Class VII:

Soils in Class VII have very severe limitations that make them unsuited to cultivation and that restrict their use largely to grazing, woodland, or wildlife.

Class VIII:

Soils and landforms in Class VIII have limitations that preclude their use for commercial plant production and restrict their use to recreation, wildlife, or water supply or to aesthetic purposes.

The USDA system does not consider the terraced agriculture land cultivated by manual labor and/or bullock power on steep slopes. Soil depth, slope and stoniness or rockiness are relatively defined rather than quantified. The system is heavily based on soil classification. Also the environmental situation of land and uses in Nepal

and the socio-economy is drastically different from the conditions under which the classification is applied in the United States. Therefore, the system can not be directly applied in the Nepalese hill agro-ecosystem.

5. Land Capability Classification for Phewa Watershed, Nepal

The land capability classification for Phewa Watershed adopted and modified after T. C. Sheng (UNDP/FAO, THA/76/001, Mae Sa Project Thailand, 1978) by Impat (1980) has eight landuse capability classes: (1) cultivable without terracing, (2) cultivable with terracing recommended, (3) cultivable with terracing essential, (4) pasture, (5) fruit tree, (6) forest land, (7) silvipasture, and (8) protected forest (Table 1). This is a parametric land classification and is based on parent material, soil depth, rock outcrop, slope, run-off class and one or more limitations related to stoniness, wetness or occasional flooding and severe erosion.

This system has not considered the existing terraces, which are extensive and is a major factor determining the land capability classes in Nepal. Also neglected were the slopes greater than 40 percent which were considered as unsuited for cultivation. However, using manual labor and/or bullock power, cultivation is being practiced on steep slopes (above 40 percent) in the Nepalese hill agro-ecosystem. Experience has shown that limits of land slope for cultivation can be raised to 50 percent (Khybri, 1979). Also the system is designed for the Phewa Watershed only and pays less attention to stoniness or rockiness, other types of limitations and climate.

Table 1. Land Capability Classification for Phewa Watershed (Impat, 1980) (Adopted and modified after T.C. Sheng, UNDP/FAO, THA/76/001. Mae Sa Project Thailand, 1978)

Slope degree / Soil Depth %	< 2° / < 3%	2-9° / 3-15%	9-22° / 15-40%	22-30° / 40-60%	30-40° / 60-80%	> 40° / > 80%
Deep (>70cm)	C_1	C_2	C_3	FT	F/SP	PF
	SWE → P	SWE → P	SWE → P	SWE → F/SP		
Moderate (40-70cm)	C1	C2	C3	F/SP	F/SP	PF
	SWE → P	SWE → P	SWE → P	SWE → F		
			P	F/SP		
Shallow (15-40 cm)	C1	C2	C3	F/SP	F/SP	PF
	SWE → P	SWE → P	SWE → F			
	P	P	P			
Very Shallow (<15 cm)	P	P	P	F/SP	PF	PF
				good management essential regardless land use above 40% slope.		

Remarks:

1) C1 - cultivable land without terracing
   C2 - cultivable land terracing recommended
   C3 - cultivable land terracing essential
   P - pasture
   FT - fruit tree
   F - forest land
   SP - silvipasture
   PF - protected forest
2) Soil depth: Effective depth for conservation treatment and plot root penetration.
3) Limiting factors:
   S - Stony
   W - Wet or occasional flooding
   E - Severe erosion

3. CLASSIFICATION SYSTEM

3.0 Introduction

Landform is a natural terrain unit developed under a unique combination of climate, geology and geomorphological processes operated for a given period of time. Landform and substance of the land influence local climate, determines the surface and subsurface hydrologic regime, influence fauna and flora that can survive there, and shape the subsequent development of soil (Rowe, 1971). Therefore, a land capability classification based on soil, landform and vegetation or present land-use is a logical, scientific approach to land classification relevant to land use.

First the following maps are prepared:

a. Soil map including soil depth and stoniness or rockiness,

b. Landform map including slope, and

c. Vegetation and/or landuse map.

Then the land capability map is prepared based on the overlay interpretation of the above three maps.

Three levels of generalization of mapping system are prepared. The level I generalization is for use on 1:250,000 or small scale Landsat or high altitude aerial photographs with minimum ground checking. This level of generalization is designed for broad reconnaissance inventory or for deriving general information on the area. Level I cannot be used for land capability classification, because it is very general for the purpose.

The level II generalization is for use on aerial photographs of 1:50,000 to 1:100,000 scale with moderate ground checking. The Level III generalization is for use on 1:12,000 scale aerial photographs with intensive ground checking. Level II and III mapping will be very detailed and is designed for land capability classification. In Level II mapping, we may not be able to indicate all details of limitations because of scale problems. It is used for general landuse planning. Whereas Level III is designed to indicate almost all limitations, so that more detailed landuse planning for crops, etc. can be done.

The recognizability and mapping of an object is determined by its size, shape and nature and the resolution of the photographs. Therefore, the level of generalization and scale of aerial photographs are not restricted to each other. In other words, if an object covers a large area and has high contrast, even the Level III category can be mapped on 1:250,000 scale imagery or photographs. But sometimes, due to unfavorable conditions the Level II category may not be mapped on 1:12,000 scale photographs. The recommended minimum size of mapping unit delineations for each level of generalization are given in Table 2.

Table 2. Minimum size of mapping unit delineations recommended for use in the landuse - land capability system.

MAP	LEVEL		
	I	II	III
	SCALE		
	1:100,000 to 1:50,000	1:25,000[3]	1:12,000
	hectares		
Soil[1]	30-120	8	2
Landform[2]	20- 80	5	1
Landuse	10- 40	3	1
Land Capability	30- 40	8	2

[1]Soil map includes soil depth and stoniness or rockiness category.

[2]Landform map includes slope category.

[3]Using 1:50,000 scale aerial photos and base maps of 1:25,000 scale, the minimum mapping delineate size of 8, 5 and 3 ha can be followed for soil, landform and landuse maps.

At present, Nepal has almost complete coverage of aerial photographs with scale of about 1:50,000. Therefore, it is recommended that aerial photographs be used for detailed mapping as much as possible and that a 1:25,000 scale contour base maps be used for producing maps, so that objectives between the two levels can be bridged. In this case, the minimum size mapping delineations of 8, 5 and 3 ha. can be used for

soil, landform and landuse maps. By indicating one of nine land capability classes and limitations, the minimum size of land capability class delineated that can be shown will be eight hectares.

The classification system is based on the following criteria:

a. The interpreter must achieve accuracy of more than 85 percent in the land capability classification.

b. The same results in land capability classifications must be obtained from different interpreters from aerial photographs of different dates.

c. Each higher category is an aggregation of only the categories immediately below it.

d. The classification system is applicable to the whole of Nepal.

3.1 Soil Classification System

"Soil is the collection of natural bodies on the earth's surface, in places modified or even made by man of earthy materials, containing living matter and supporting or capable of supporting plants out of doors" (Soil Survey Staff, 1975). Soil supports plants that supply food, fiber, timber and other human needs, and is one of the most important land characteristics that governs landuse. For soil classification, we follow the USDA Soil Taxonomy (Soil Survey Staff, 1975) which is a well organized soil classification system based on the properties of soil profiles, including soil temperature and moisture. The system contains six categories from highest to lowest levels of generalization. These are: order, suborder, great group, sub-group, family and series. There are ten orders; 47 sub-orders,

approximately 230 great groups and multiples of these in sub-group, family, and series (Boul et al., 1980). Order and suborder units; great group and sub-group units and family and series units are used for levels I, II and III mapping respectively.

Thus prepared soil map is integrated with the soil depth class and the stoniness class to give complete soil map used for land capability interpretation. There are four soil depth classes (Table 3) and five stoniness or rock outcrop classes (Table 4).

Table 3. Soil depth classes for Nepal (Modified after Impat 1980).

Symbol	Soil Depth	Description
	----cm----	
d_1	0-15	Very shallow
d_2	15-40	Shallow
d_3	40-70	Moderate
d_4	>70	Deep

Table 4. Stoniness or Rockiness classes for Nepal. (Modified after Impat, 1980).

Symbol	Stoniness or Rockiness	Description
	----volume percent----	
r_1	0- 3	Non stony or rocky
r_2	3-15	Fair stony or rocky
r_3	15-50	Stony or rocky
r_4	50-90	Very stony or rocky
r_5	> 90	Extremely stony or rocky

Soil depth is measured along a vertical axis between the earth's surface and the upper surface of underlying consolidated bedrock known as the R horizon.

"Stoniness refers to the relative proportion of stones over 10 inches in diameter in or on the soil whereas rockiness refers to the relative proportion of bedrock exposures, either rock outcrops or patches of soil too thin over bedrock for use in a soil area" (Soil Survey Staff, 1975).

3.2 Landform Classification System

Landforms are natural terrain units (including geologic elements of rock type and structure and transported or residual soils) that, where developed under similar conditions of climate, weathering, erosion, and mass wasting, will exhibit a predictable range of physical and visual characteristics (Way, 1978). The landform classification system developed for Nepal is given in Figure 1. In developing the system, emphasis was given to the significance of landform in landuse.

The land is classified according to the landform classification system up to the lowest possible level for a given map scale. Since most of the landforms resulting from mass movement occur in the other landform classes viz, plain, hill or valley, this is indicated in brackets after the main landform. If the process of mass movement is still active, the code is followed by "Y" for yes and if not active by "N" for no.

Slope is the basic landform characteristic that governs land capability in the hills or mountains. The landform map is further sub-categorized on the basis of six slope classes as given in Table 5. The resulting landform map is used for the interpretation of land capability classes.

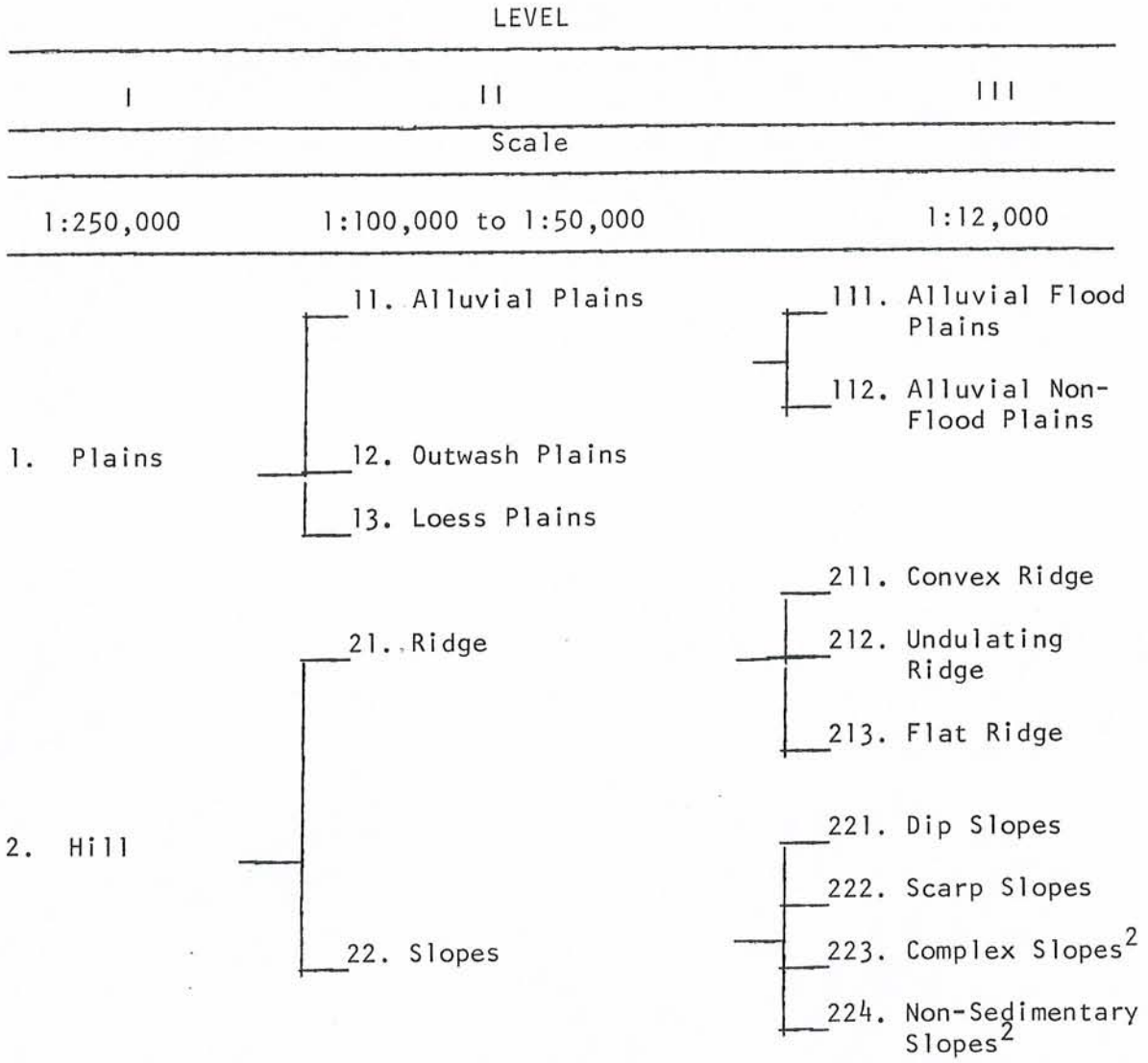


Figure 1. Landform Classification System for Nepal[1]

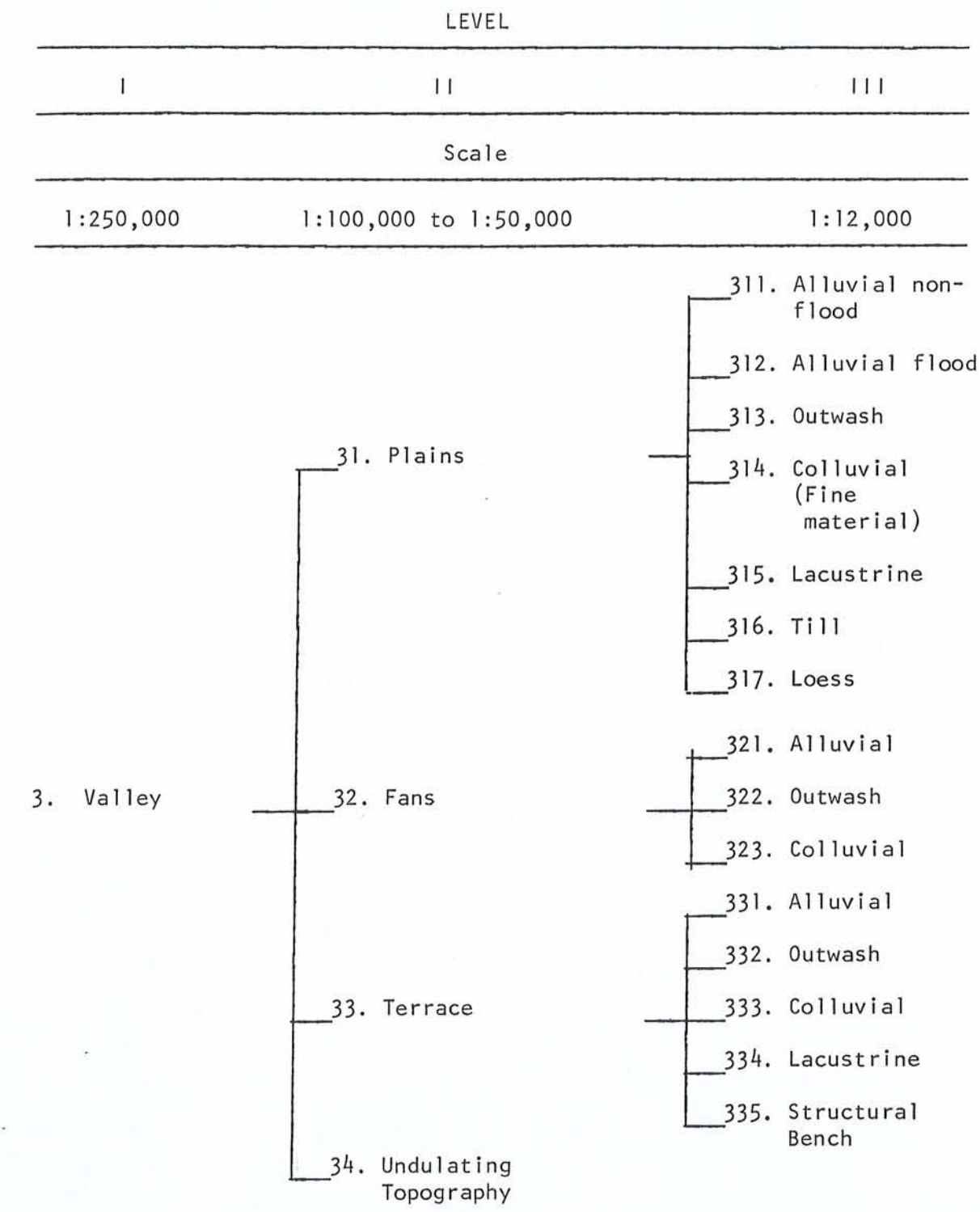


Figure 1. (continued)

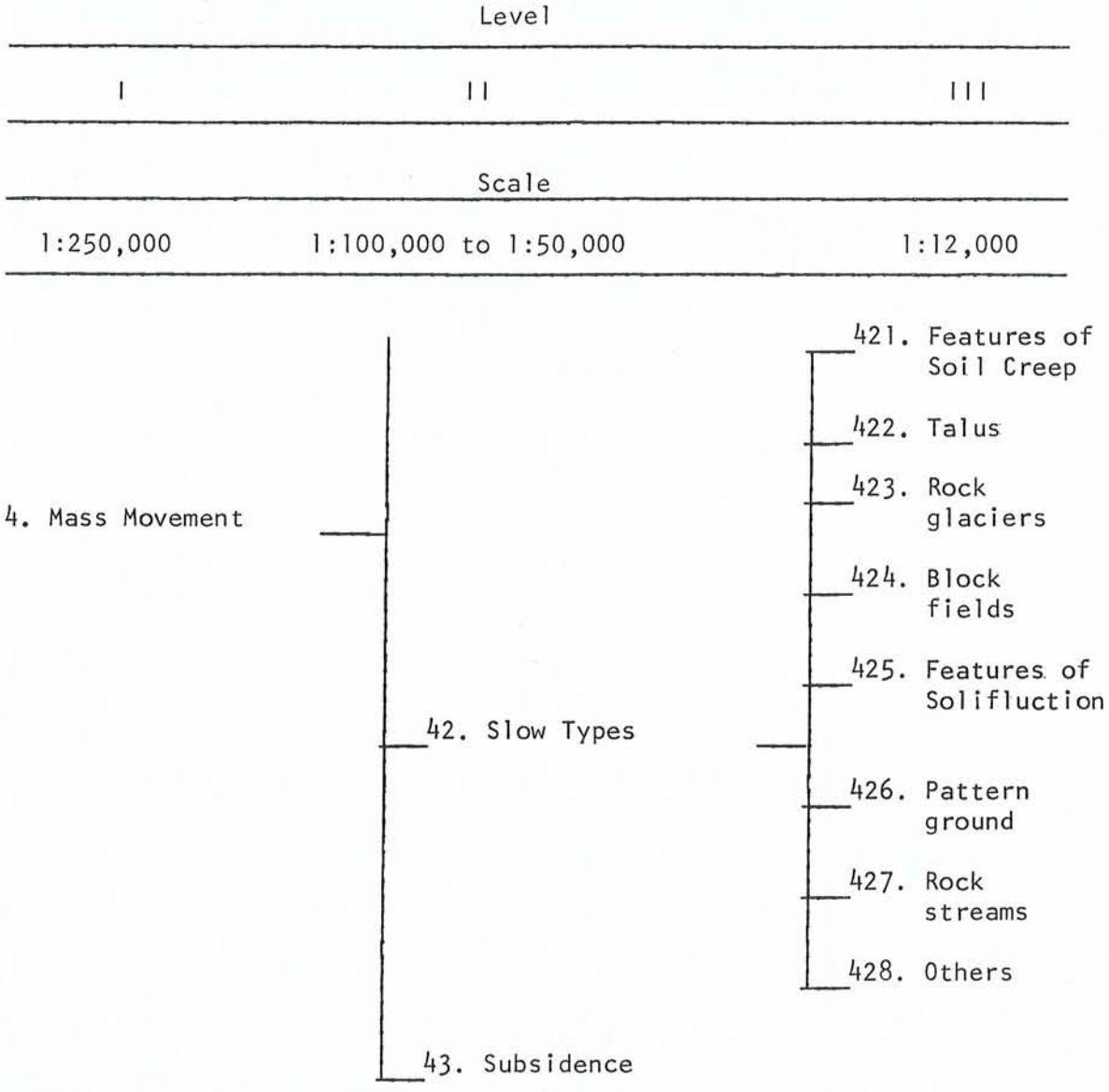


Figure 1. (continued)

[1]For definition of terms see Encyclopedia of Geomorphology (Fairbridge 1968) and Dictionary of Geological Terms (The American Geological Institute 1976) or similar reference texts.

[2]Defined in Appendix 1.

Table 5. Slope classes for Nepal (Adopted from Impat, 1980).

Symbol	Slope	Description
	--Percent---	
S_1	0- 3	Level or nearly level
S_2	3-15	Gently sloping
S_3	15-40	Moderately steep
S_4	40-60	Steep
S_5	60-80	Very steep
S_6	> 80	Extremely steep

In addition to landforms, data on drainage texture and drainage pattern are considered in interpreting land capability classes, but no overlay mapping of the drainage texture and drainage pattern is done. Entire drainage systems from first order streams (the beginning of channelized flow) to the tributaries of major rivers are considered for determining drainage texture and drainage pattern. Aerial photographs are preferred over topographic maps for determining drainage texture and drainage pattern because of the greater detail of drainage systems.

Drainage texture refers to the relative spacing of drainage lines and is categorized into fine, medium and coarse textures (Thornbury, 1969). Drainage texture includes both drainage density and stream frequency. The relationships of photographic scale to drainage texture and distance between first order streams for Nepal is given in Table 6.

Table 6. Average distance between first order streams for drainage texture classes on aerial photos of different scale. (After Way, 1978)

Photo Scale	Drainage Texture		
	Coarse	Medium	Fine
	----------mm----------		
1:12,000	>83	10-83	<10
1:25,000	>40	4.8-40	<4.8
1:50,000	>20	2.4-20	<2.4
1:100,000	>10	1.2-10	<1.2

"Drainage texture is influenced by (1) climatically controlled factors such as amount and distribution of precipitation, vegetation, and permafrost; (2) rock characteristics, including texture and size of fragments released by weathering; (3) infiltration capacity; (4) topography; and (5) stage and number of erosion cycles" (Howard, 1967). Drainage texture is divided into three classes:

Fine Drainage Texture

Distance between first order streams is short, and averages less than 4.8mm on 1:25,000 scale photographs. Fine textured drainage is characteristic of land with relatively high run-off as a result of one or more of the following factors: (1) impervious bedrock, (2) soils of low permeability, (3) fine textured soils, (4) steep slopes, (5) high rainfall coming mostly as intense thunder showers, or (6) scanty or no vegetation. Homogeneous unconsolidated sediment or soft rocks

also favor the fine drainage texture (Fairbridge, 1968; Thornbury, 1969; Way, 1978).

Coarse Drainage Texture

First order streams are over 40 mm apart on 1:25,000 scale photographs and carry relatively little run-off. Coarse drainage texture generally indicates relatively low run-off as a result of: (1) fractured or permeable bedrock, (2) soil of high permeability, (3) coarse textured soil, (4) gentle slopes, (5) low intensity rainfall, or (6) thick cover of vegetation. Consolidated massive rocks also resist erosion and tend to produce coarser texture (Fairbridge, 1968; Thornbury, 1969; Way, 1978).

Medium Drainage Texture

The spacing of first order streams is less than in coarse textured drainage but more than in fine textured drainage. The characteristics of such an area are intermediate compared to areas with fine and coarse drainage textures (Way, 1978).

"A drainage pattern is the design formed by the aggregate of drainageways in an area regardless of whether they are occupied by permanent streams" (Howard, 1967). The different drainage patterns and their characteristics are described by Howard (1967); Way (1978); and Zernitz (1932). "The different drainage patterns can indicate specific rock types, soil materials, rock attitude and structure, and drainage conditions" (Way, 1978).

The drainage pattern determination is followed by stream segment orientation analysis. For stream segment orientation analysis, the number of streams and stream lengths are plotted against their orientation direction of the streams. Direction of stream is measured along the major segment of the stream that is approximately straight irregardless of flow direction. If streams change direction, then each major segment is counted or measured as a unit.

If the number of streams, and also the length of streams, tends to be concentrated in some particular direction, it indicates that the streams are controlled by structure or lithology (i.e. either joint, fracture, fault, or lithologic contacts, etc.) of underlying geology.

Streams across slope indicates structural control showing streams are utilizing fractures, joints, or faults. The tendency for stream direction to be across the slope will indicate that stream cutting may increase the slope gradient which makes the area more vulnerable to mass-movement. If stream direction is oriented more or less along the slope, then the tendency for mass movement in the area will be low as compared to the first case.

The landform classification system is used for extracting information required for land capability interpretation. For example, the alluvial flood plain indicates the productivity limitation of inundation; Fine drainage texture indicates excessive run-off which is a function of climate, geology, soil and vegetation; Similarly rectangular drainage pattern indicates that joints, fractures and/or faults are

at right angles and the presence of those feature suggest potential hazard of potential movement etc., which is important for landuse planning.

3.3 Landuse Classification System

"In a dynamic land management situation, accurate meaningful, current data on landuse are essential. If public agencies and private organizations are to know what is happening, and are to make sound plans for their own future action, then reliable information is critical" (Clawson and Stewart, 1965, cited by Anderson et al. 1976).

Landuse classification is applied to the existing landuse, which governs significantly the determination of the landuse land capability class. The landuse classification developed for Nepal is given in Figure 2. Level I generalization is adopted from Anderson et al. 1976 and the descriptions of the categories have the same meaning except wetland.

Level II generalization is modified after Anderson et al. 1976. The terms with different meanings from that in general dictionaries and those modified from Anderson et al. (1976) are described in Appendix 2 and Appendix Tables 1 and 2.

For use in this system the area is mapped to the lowest level of landuse category for a given scale and the resulting map is used for interpretation of land capability classes.

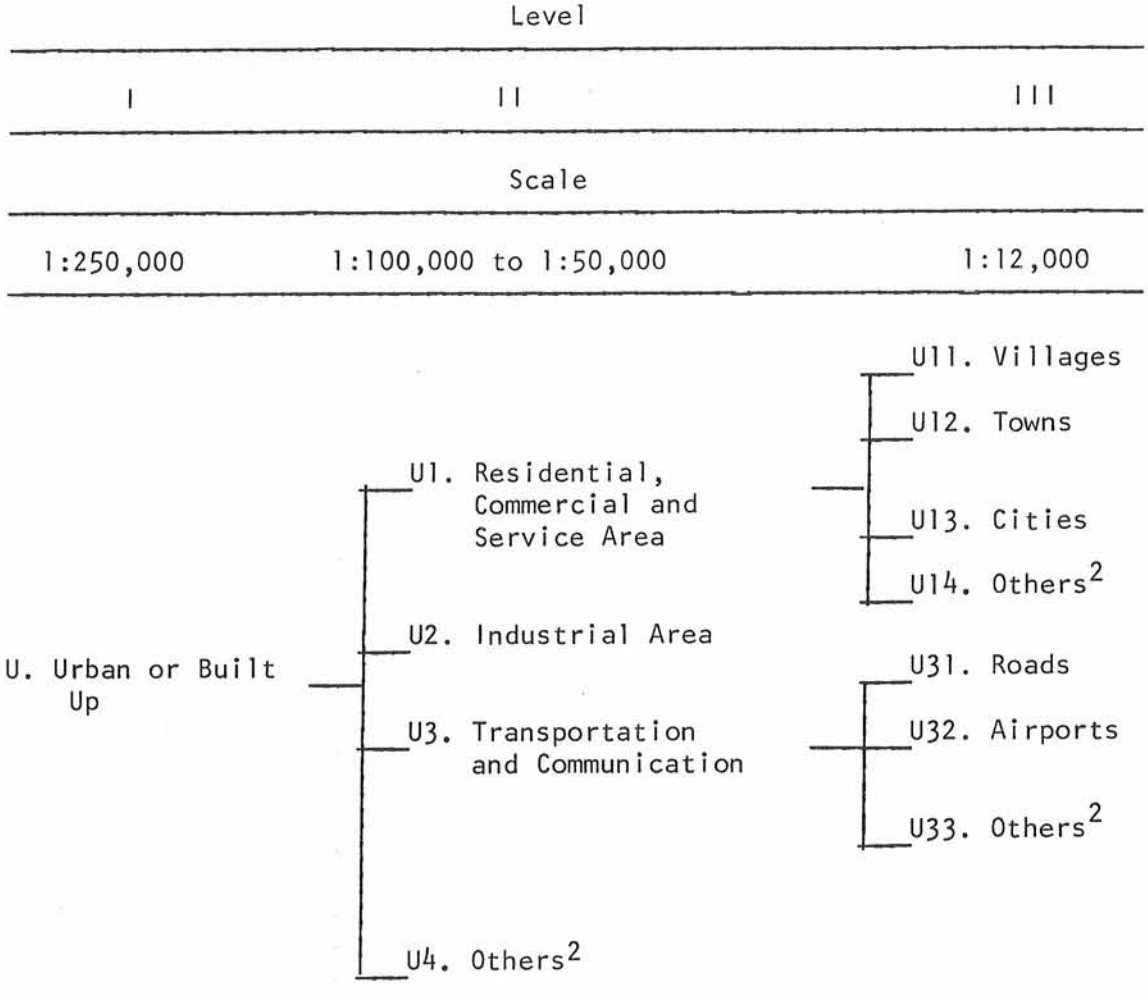


Figure 2. Landuse Classification System for Nepal.[1]

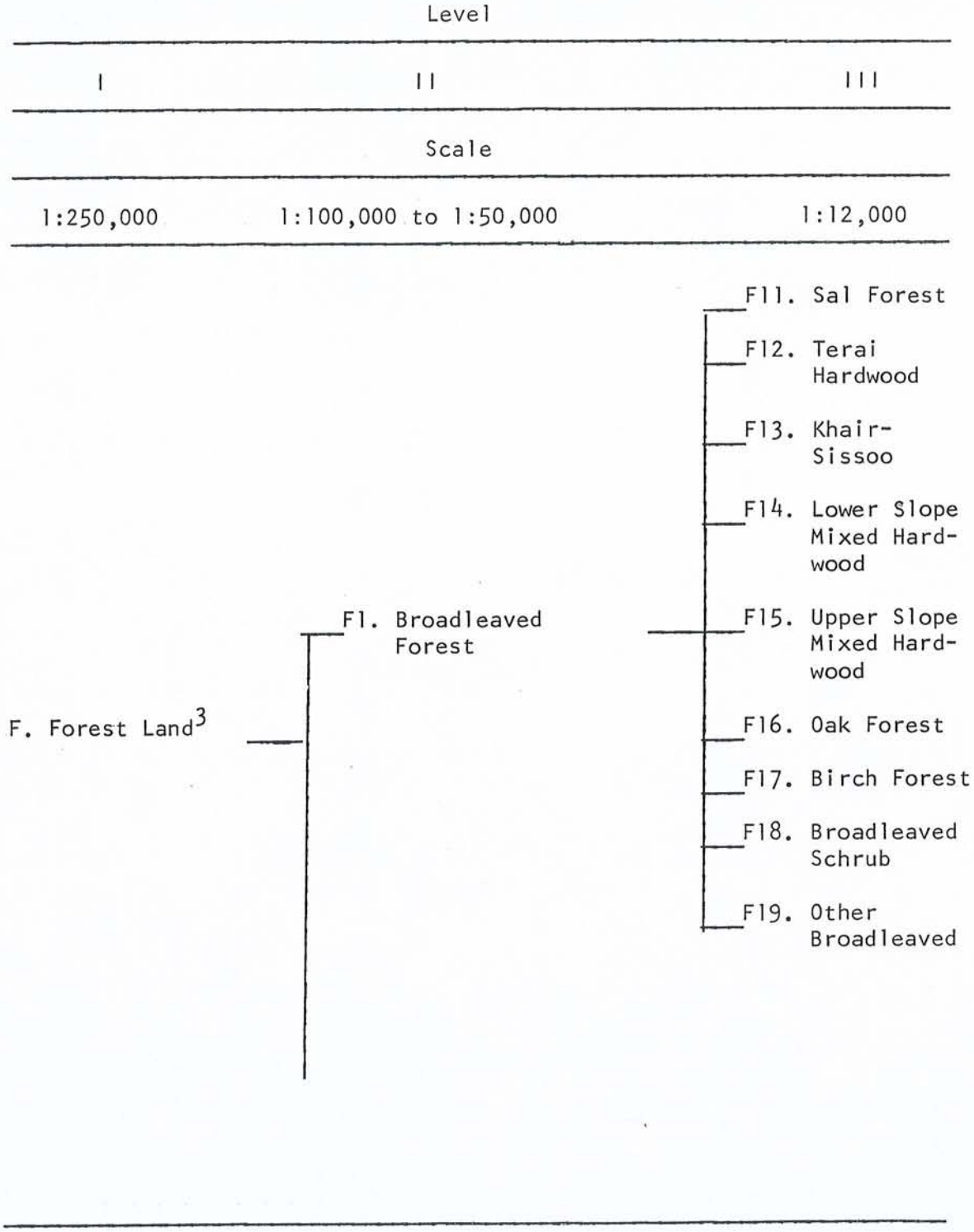


Figure 2. (continued)

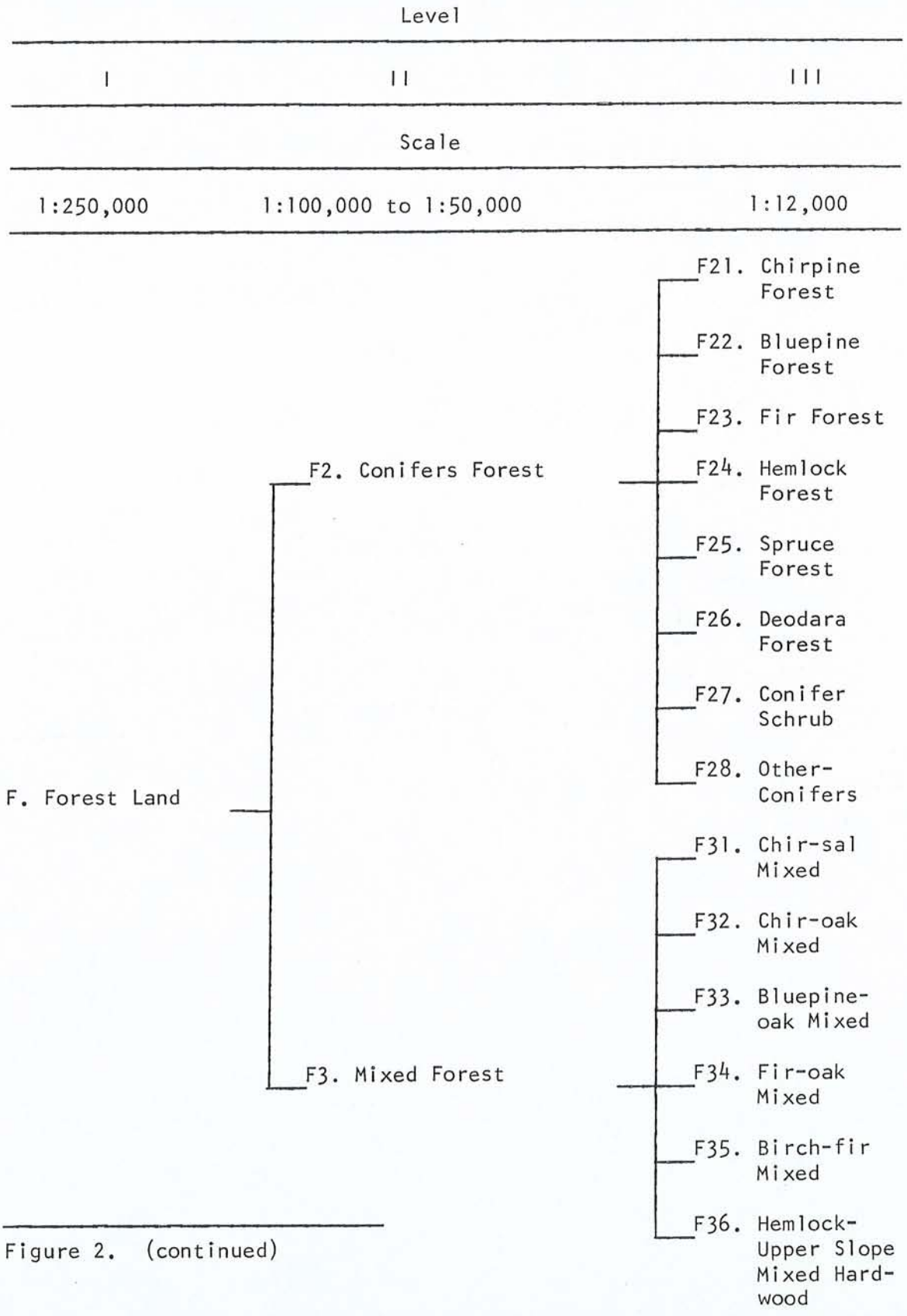


Figure 2. (continued)

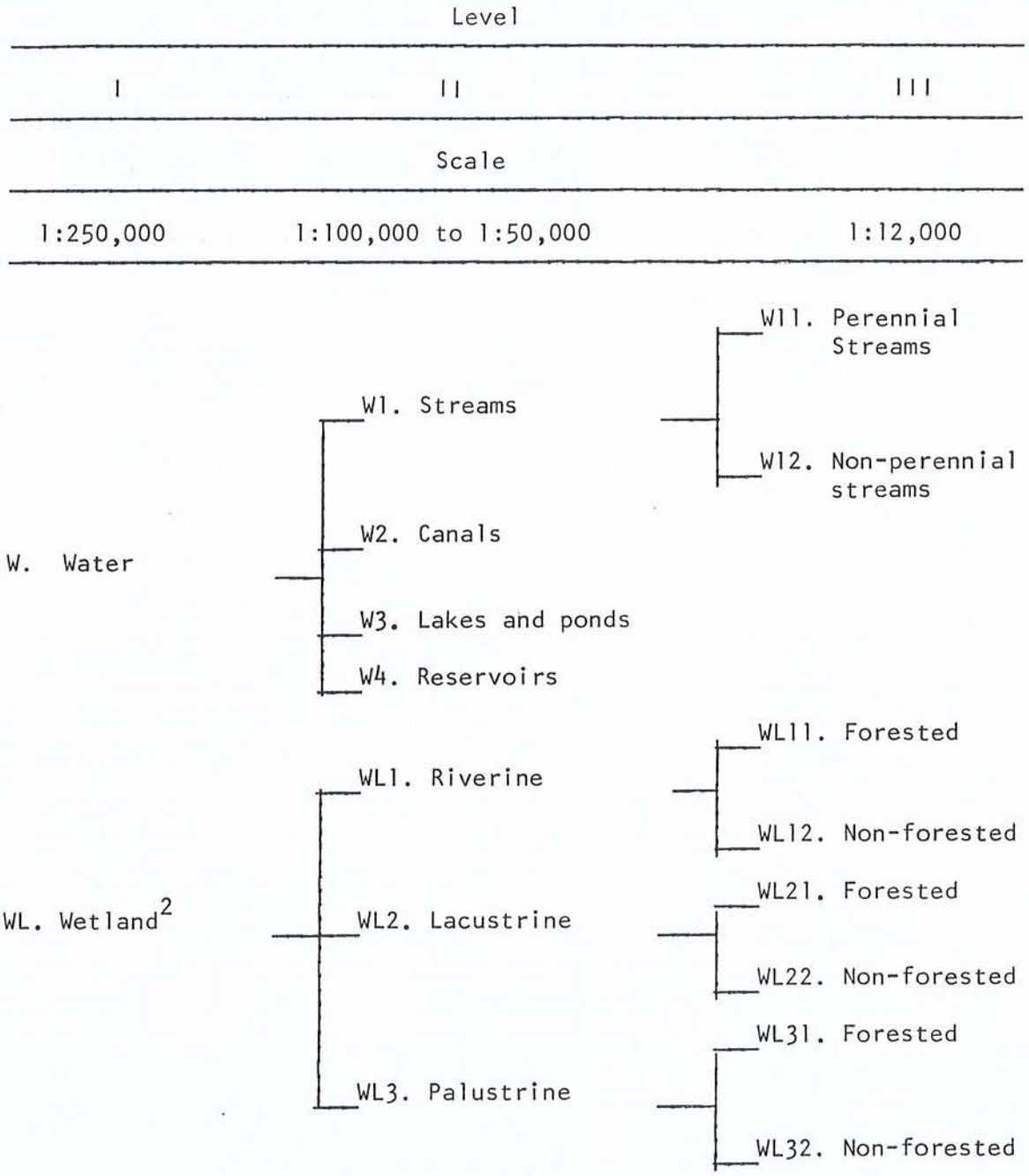


Figure 2. (continued)

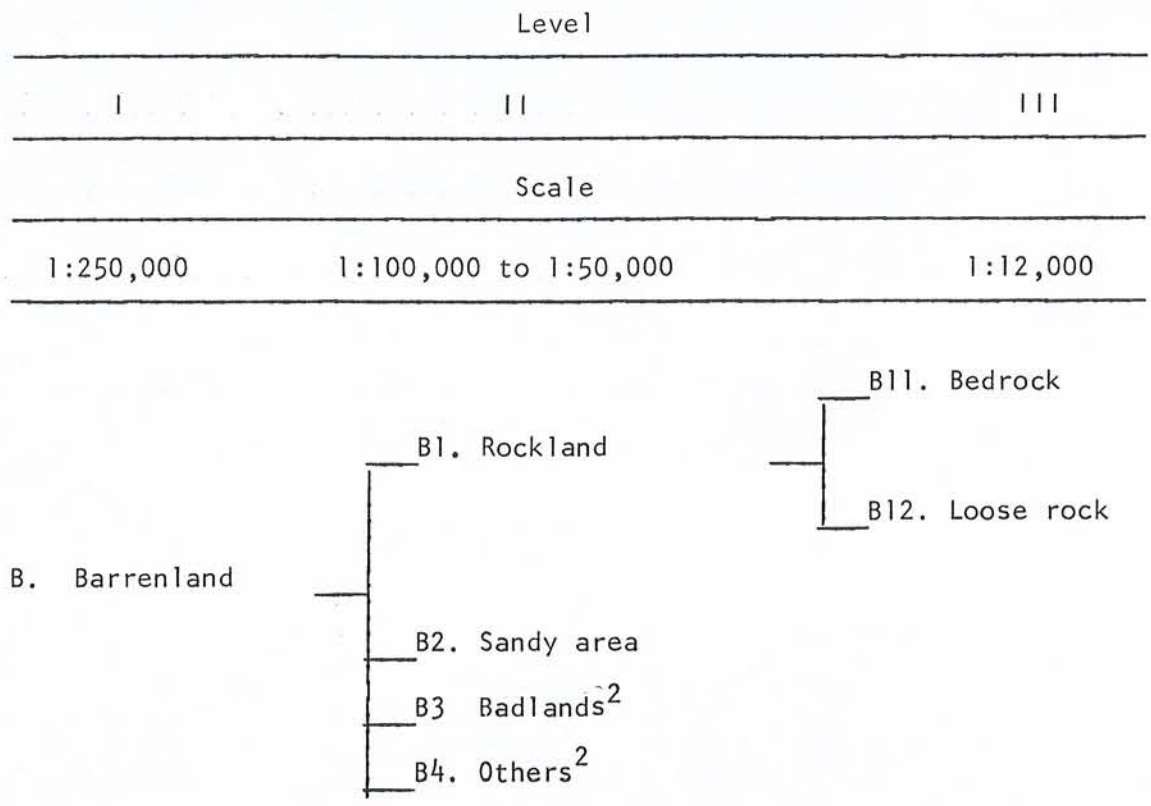


Figure 2. (continued)

[1]For definition of terms see Anderson et al. (1976).

[2]Defined in Appendix 2.

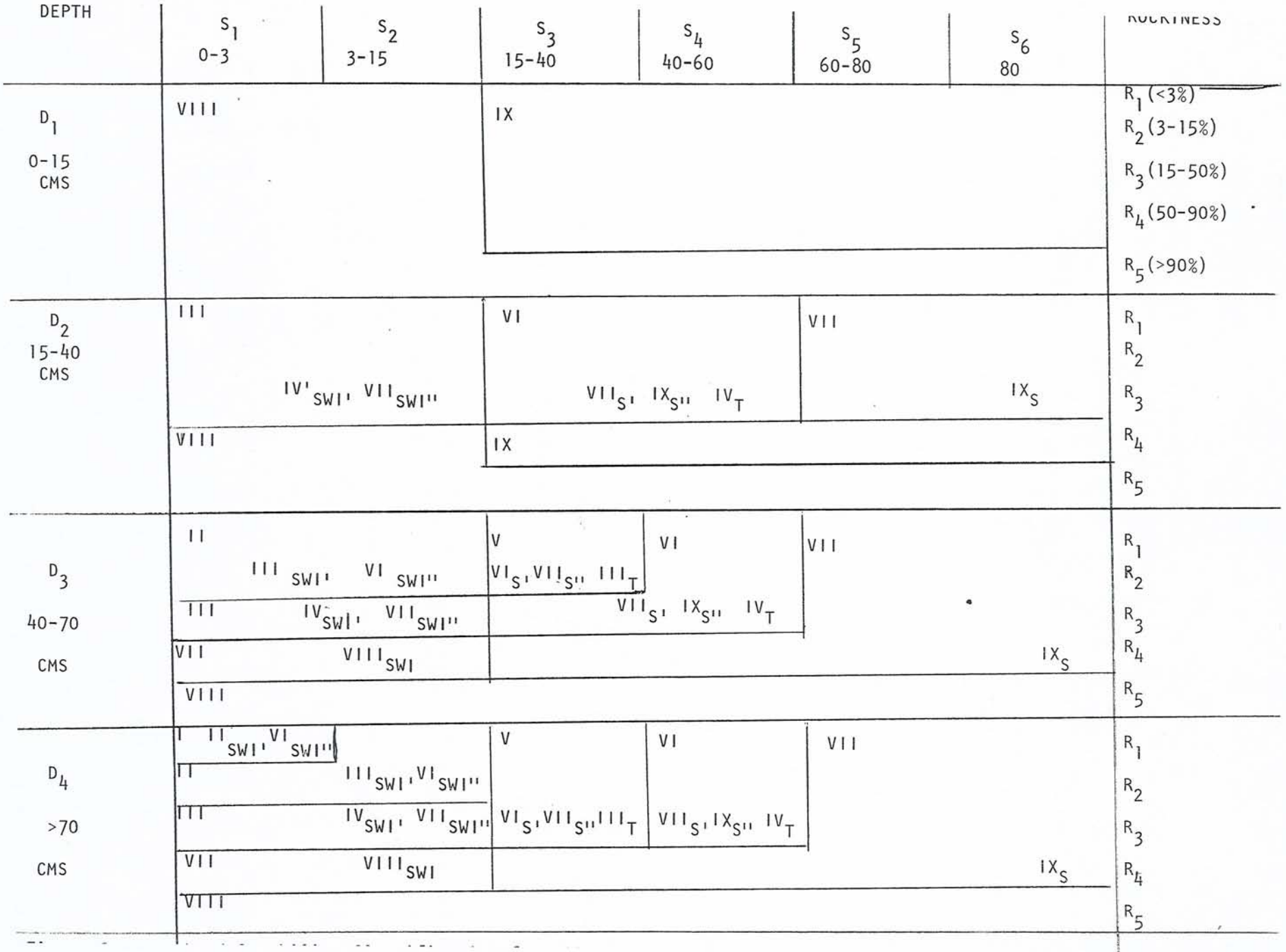
[3]Defined in Appendix Tables 1 and 2.

3.4 Land Capability Classification System

Productive capability, degree of erosion hazard, limitations, risks of soil damage and conservation measures required are the important factors which determine the land capability classes relevant to landuse. Based on the relevant degree of these factors, nine land classes were developed for Nepal. These nine classes range from land class I (cultivable; very high productive capacity; no significant erosion hazard, limitations or risks of soil damage; and no conservation measures required) to land class IX (no economic potential for plant production; severe erosion hazard, limitations, or risks of soil damage and need for conservation measures).

The designation of land capability is the result of an overlay interpretation of the soil map, the landform map and the map of existing landuse. Interpretation is based on the relative degree of productive capacity, limitations and conservation measures for landuse, risks of soil damage and erosion hazard (susceptibility to water erosion).

Classification of land capability is conducted in two steps: (1) one of the nine different land capability classes are assigned to a land unit on the basis of the land's three main characteristics (slope, soil depth and stoniness or rockiness) in combination with the appropriate climatic zone (Figure 3 and 4), (2) then on the basis of four of the land's sub-characteristics: Terracing (T); Soil limitation (S) within the rooting zone such as low permeability, low fertility, high clay content and salinity or sodium etc.; Excess wetness (W);


DEPTH
S1
0-3
S2
3-15
S3
15-40
S4
40-60
S5
60-80
S6
80
ROCKINESS
D1
0-15
CMS
VIII
IX
R1 (<3%)
R2 (3-15%)
R3 (15-50%)
R4 (50-90%)
R5 (>90%)
D2
15-40
CMS
III
IV'SWI, VIISWI''
VI
VIIS', IXS'', IVT
VII
IXS
VIII
IX
R1
R2
R3
R4
R5
D3
40-70
CMS
II
III SWI, VI SWI''
III
IVSWI, VIISWI''
V
VIS', VIIS'', IIIT
VI
VIIS', IXS'', IVT
VII
VII
VIII SWI
IXS
VIII
R1
R2
R3
R4
R5
D4
>70
CMS
I
II SWI, VI SWI''
II
III SWI, VI SWI''
III
IVSWI, VIISWI''
V
VIS', VIIS'', IIIT
VI
VIIS', IXS'', IVT
VII
VII
VIII SWI
IXS
VIII
R1
R2
R3
R4
R5

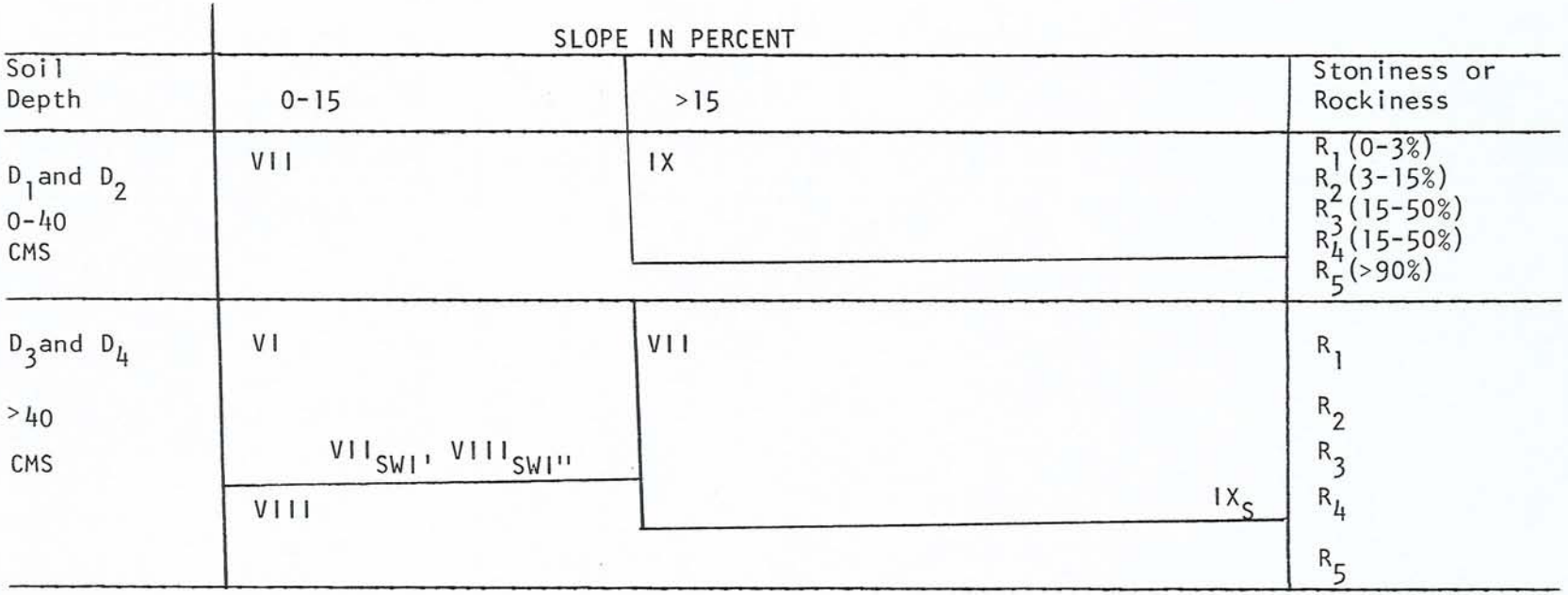


Figure 4. Land Capability Classification for Climatic Zone III for Nepal.

subject to inundation (I) the land capability class is assigned to the proper modified class.

Three climatic zones are categorized on the basis of altitude, broad landform and rainfall:

Climatic Zone I

In this climatic zone where at least three crops, including one paddy, can be grown in a year. Included in this zone are the areas in plains and valleys below 2133 m (7,000 ft) and slopes associated with wide high elevation valleys such as Kathmandu (elevation 1372 m or 4,500 ft) and narrow valleys up to 1981 m (6,500 ft) and 1524 m (5,000 ft) respectively. Zone I areas have average annual rainfall of more than 1016 mm (40 in) or are irrigated.

Climatic Zone II

In this climatic zone at least two crops of either maize, wheat, millet or potatoes can be grown in a year but no paddy. Included in this zone are the areas in valley plains between 2133-2743 m (7-9,000 ft) slopes associated with wide high elevation valleys and narrow valleys between the elevations 1981-2743 m (6,500 to 9,000 ft) and 1524-2438 m (5,000 to 8,000 ft) respectively. Areas in Zone II have an average annual rainfall of 508 mm (20 in) or more and none are irrigated.

Climatic Zone III

In this climatic zone, under the best conditions, only one crop a year of potatoes or millet can be grown. Included in this zone are the valley plains and slopes associated with wide high elevation valleys

between 2743-3657 m (9 to 12,000 ft) elevation, slopes associated with narrow valleys between 2438-3657 m (8-12,000 ft) and areas with rainfall more than 508 mm (20 in).

Although the treeline varies from place to place, for generalization, we consider that areas above 3657 m (12,000 ft) are uneconomical for plant production and are excluded from classification.

The climatic zones I, II and III are indicated in the assigned land capability classes by placing the number 1, 2, or 3 respectively in the front lower corner of the land capability classes designation. For example, land of capability class I in climatic zone 1 is designated as $_1$I.

The land sub-characteristic "terrace" refers to the paddy terrace cropland as defined in Appendix 2. This is a major landuse in the Nepalese agro-ecosystem and plays a significant role in the determination of land capability classes. Land classes V and VI, which are based on the land's three main characteristics are upgraded to III_T and IV_T respectively when terraced and identified with "T" (Table 7).

Table 7. Modification of land capability classes by sub-group characteristics for Nepal.

Land classes without limitation[1]	Down-grading of land capability classes with limitation		Up-grading of land capability classes with terracing
	Economically Correctable	Economically Non Correctable	
I	$II_{SWI'}$[2]	$VI_{SWI''}$	
II	$III_{SWI'}$	$VI_{SWI''}$	
III	$IV_{SWI'}$	$VII_{SWI''}$	
IV	$VI_{S'}$	$VII_{S''}$	
V	$VI_{S'}$	$VII_{S''}$	III_{T}[3]
VI	$VII_{S'}$ or $VII_{SWI'}$	$VIII_{SWI''}$ or $IX_{S''}$	IV_{T}
VII	$VIII_{SWI'}$ or $IX_{S'}$		

[1] Detailed description of land classes see Appendix 3.

[2] SWI stands for soil, excess wetness and inundation limitations respectively.

[3] T stands for paddy terraces.

Three land sub-characteristics, namely soil limitations (S), excess wetness (W), and inundation (I) are considered as limiting factors that reduce the capability of the land and are used for modifying the land capability class determined by slope, soil depth, stoniness or rockiness and terracing. The limitations have been grouped into two categories. The first category of limitations either can be economically corrected under present conditions (fertility, salinity, excess wetness,

inundation) or has moderate effect on productive capacity, erosion hazard or risks of soil damage due to factors such as clay content, low permeability, etc. The second category of limitations either cannot be economically corrected under present conditions (very poor fertility, intensive flooding, high salinity, etc.) or has severe effects on productive capacity, erosion hazard, or risks of soil damage (high sodium, etc.).

Table 7 shows the downdraging of classes with corresponding category of limitations. The first category of limitation is indicated by one (') sign on the right upper corner of the limitations, whereas second category of limitations is indicated by two (") sign. The dominating limiting factor is indicated on the lower right corner of the class number. For example, class III, due to the first category of soil limitations, drops to class IV, then the modified class is denoted by $IV_{S'}$. Where two or more limitations are equally dominant, the limitations are shown in the order of soil (S), excess wetness (W), and inundation (I).

The following assumptions and criteria are considered in assigning land capability classes:

1. Using manual labor and/or bullock power, under proper maintenance of terraces and management of water control, the paddy terraces up to 60 percent slope can be used for culitvation.
2. Land will be well managed and cropped using manual labor and/or bullock power except the land with capability class I and II,

where mechanized cultivation can also be done. Land classes from I to IV are suited for cultivation and other uses including range and wildlife. Land classes from V to IX are of limited use such as forestry, range, wildlife and recreation and are generally not suited to cultivation without deleterious effects on the land.

3. Land is assigned to a capability class based on existing limitations, even though the removal of these limitations are economically feasible. The land capability class will be changed once the limitations are removed.

4. The land capability class assigned is not based on distance to market, size and shape of the land, transportation facilities, location within the field, type of owner and other factors not controlled by the land characteristics.

5. The land capability class is not assigned to landuse such as urban or built up land, water and snow, because these are beyond its scope and those areas are denoted the same as in the landuse map.

The land capability classification system is given in Figure 3 for climatic zones I and II and in Figure 4 for climate zone III.

The properties of the land capability classes are summarized in Table 8 for climatic zones I and II and in Table 9 for climatic zone III. Summarized description of the land capability classes is given in Table 10 for climatic zones I and II and in Table 11 for climatic zone III. Detailed descriptions of the land capability classes are given in Appendix 3.

Table 8. Summary of land capability classes in climatic zones I and II for Nepal.[1]

Land Characteristics	Land suited to cultivation Land Class				Land suited to forestry Land Class			Land not suited to plant production Land Class	
	I	II	III	IV	V	VI	VII	VIII	IX
1. Productive Capacity	Very High	High	Moderately High	Low to Moderately High	High	Moderate	Low	Low or No	Low or No
2. Erosion Hazard	No	Slight or No	Moderate	Severe	Slight or No	Moderate	Severe	No	Severe
3. Limitations and risks of soil damage	Slight or No	Some	Moderate	Severe	Slight or No	Moderate to Severe	Moderate to Severe	Severe or No	Severe
4. Conservation measures required	Slight or No	Some	Moderate	High	Slight or No	Moderate	High	Slight or No	High

[1] Description applies only to the recommended use for the assigned land capability class.

Table 9. Summary of land capability classes in climatic zone III for Nepal.[1]

Land Characteristics	Land suited to cultivation	Land suited to forestry	Land not suited to plant production	
	land class	land class	land class	
	VI	VII	VIII	IX
1. Productive capacity	Low	Low	Low or No	Low or No
2. Erosion hazard	Slight or No	Moderate to Severe	No	Severe
3. Limitations and risks of soil damage	Slight or No	Moderate	Severe or No	Severe or No
4. Conservation measures required	Slight or No	Moderate to High	Slight or No	High

[1]Description applies only to the recommended use for the assigned land capability class.

Table 10. Summarized description of landuse-land capability classes for climatic zones I and II for Nepal.

Capability Class	Description[1]
I	Cultivable; with very high productive capacity; no significant erosion hazard, limitations, risks of soil damage, or need for conservation measures.
II	Cultivable; with high productive capacity, slight or no erosion hazard; some limitations, risks of soil damage or need for conservation measures.
III	Cultivable; with moderately high productive capacity; moderate erosion hazard, limitations, risks of soil damage or need for conservation measures.
IV	Cultivable; with low to moderately high productive capacity; severe erosion hazard, limitations, risks of soil damage or need for conservation measures.
V	Forestry; with high productive capacity; slight or no erosion hazard, limitations, risks of soil damage, or need for conservation measures.
VI	Forestry; with moderate productive capacity; moderate erosion hazard; moderate to severe limitations, risks of soil damage or need for conservation measures.
VII	Forestry; with low productive capacity; severe erosion hazard; moderate to severe limitations, risks of soil damage, or need for conservation measures.

Table 10. (continued)

Capability Class	Description
VIII	No economic potential for plant production; no significant erosion hazard and either slight or no limitations or risks of soil damage if soil depth and/or rockiness are limiting factors or first or second category of limitation if soil depth or rockiness is not limiting factor; slight or no need for conservation measures.
IX	No economic potential for plant production; severe erosion hazard, or need for conservation measures. It has either slight or no limitation and risks of soil damage if soil depth, and/or rockiness are limiting factors or first or second category of limitations and severe risks of soil damage if soil depth or rockiness is not the limiting factor.

[1]Description applies only to the recommended use for the assigned land capability class.

Table 11. Summarized description of landuse-land capability classes for climatic zone III for Nepal.

Capability Class	Description[1]
VI	Cultivable; with low productive capacity; slight or no erosion hazard, limitations, risks of soil damage, or need for conservation measures.
VII	Forestry; with low productive capacity; moderate to severe erosion hazard; moderate limitations, risks of soil damage, or need for conservation measures.
VIII	No economic potential for plant production; no significant erosion hazard; and either slight or no limitations or risks of soil damage if soil depth and or rockiness are limiting factors or first or second category of limitation if soil depth or rockiness is not limiting factor; slight or no need for conservation measures.
IX	No economic potential for plant production; severe erosion hazard, or need for conservation measures. It has either slight or no limitation and risks of soil damage is soil depth and/or rockiness are limiting factors or first or second category of limitations and severe risk of soil damage if soil depth or rockiness is not the limiting factor.

[1]Description applies only to the recommended use for the assigned land capability class.

4. A CASE STUDY IN PHEWA LAKE WATERSHED

4.0 Introduction

The Phewa Lake Watershed covers an area of 12,324 ha. Average annual rainfall is about 3,700 mm (145 in) and mean annual temperature ranges from 12°C in December/January to 25°C in July/August as measured at Pokhara at an elevation of 850 m (2,789 ft). Elevation of the watershed ranges from 850 m (2,789 ft) to 2508 m (8,220 ft). Grey phillitic schist is the dominant rock present throughout the watershed. In the northeastern part of the watershed, the grey phillitic schist is interbedded with carbonaceous conglomerate, in the western part with quartzite schist, and in the southern part with talc rich (red phyllitic) schist. (Integrated Watershed Management (IWM.) Project Report 1980.) Location of the Phewa Lake Watershed is given in Figure 5.

This section is based on the work of Impat (1980), IWM (1980) and the study of 1:65,000 (approximately) scale aerial photographs. Field checking is not possible at this time so the maps and classification results should be considered tentative. Some error due to small scale and quality of the aerial photographs is expected.

4.1 Soil Classification of Phewa Lake Watershed

The soil classification is based on 34 soil profile descriptions, a landuse map (Impat, 1980) and aerial photographs. Because of insufficient number of profile descriptions, soil was classified only to great group and if possible to subgroup level.

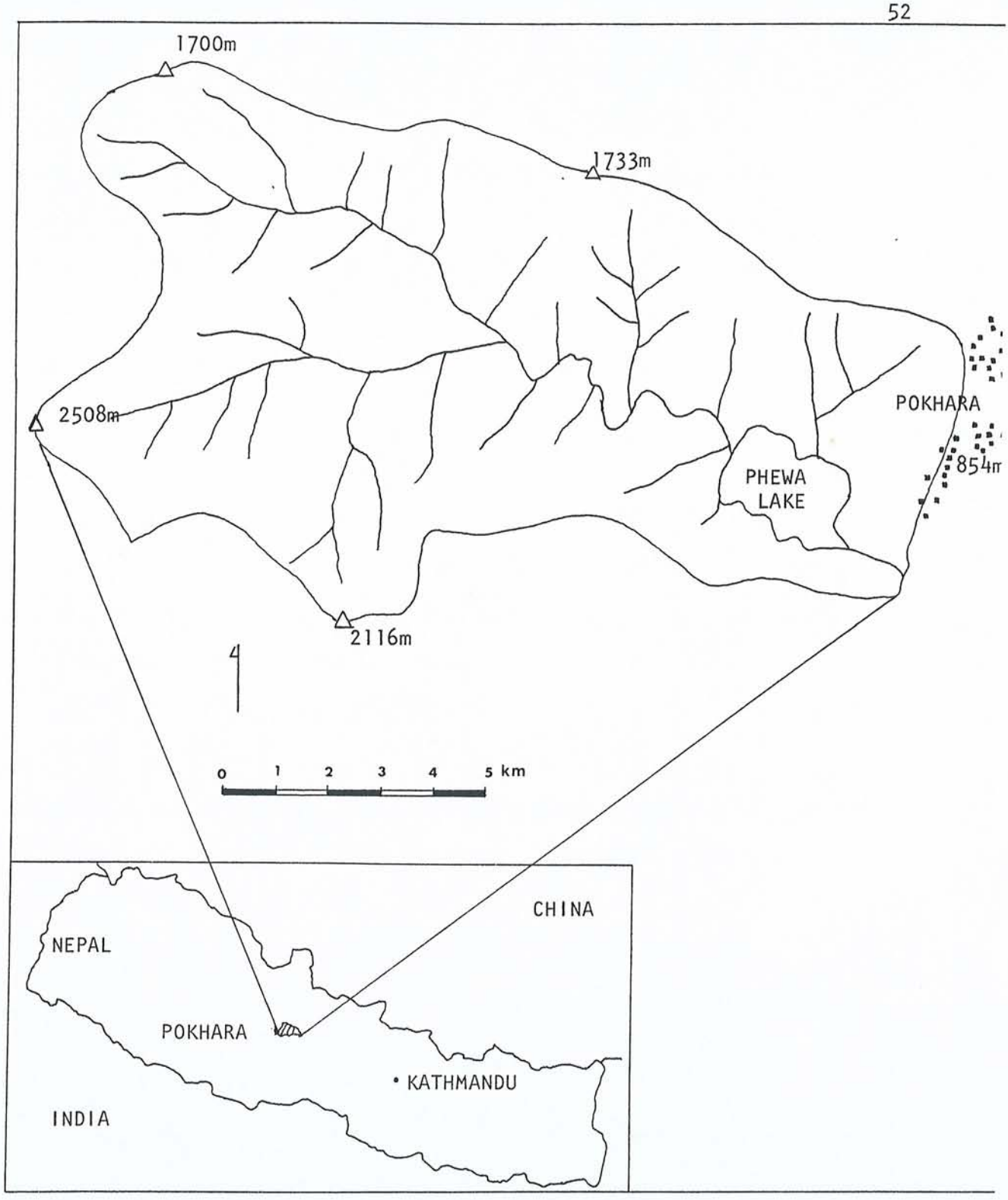


Figure 5. Location of the Phewa Lake Watershed (IWM, 1980).

Udifluvents, Udorthents and Dystrocrepts are the dominant great groups of soils in the watershed. Common subgroups are Typic Udifluvents, Typic and Lithic Udorthents and Typic, Lithic and Umbric Dystrocrepts. Only Udifluvents were mapped to subgroup level.

It is expected that some Udrothents are included with Dystrocrepts and vice versa because of the small scale of the photos and lack of supplementary information. It is not possible to pin point the percentage of inclusion without field checking, but, based on profile descriptions and corresponding landuse it is expected to be below 10 percent.

Clay loam, loam and sandy loam are the predominant topsoils textures of the Dystrocrepts and Udorthents. Sandy to sandy loam and loam are the main topsoils textures of the Typic Udifluvents. Generally, the soils of the watershed have moderate fertility limitations of low available phosphorus and potassium and relatively high acidity. Acidity is not a limitation for paddy even-though the pH is generally below 5.5 (critical value of pH).

The soil map is integrated with stoniness or rockiness and soil depth (Impat, 1980) and is given in Figure 6. Areas smaller than 8 ha are included with an adjacent soil unit that is closest in character.

Udorthents, Dystrocrepts and Typic Undifluvents are denoted by U, D and TUF in Figure 6 and first and second categories of limitation are denoted by ' and '' sign respectively at the upper right corner of the soil group designation.

4.2 Landform Classification of Phewa Lake Watershed

The landform classification is based on aerial photographs, the work of IWM (1980) and the soil map (Impat, 1980). Hills and valleys are the two basic landforms. Convex ridges, dip slopes, scarp slopes and complex slopes define the hill landforms. Similarly alluvial non-flood plains, alluvial flood plains, alluvial fans and outwash terraces are the valley landforms. Two active complex rapid mass movements are recognized in the complex slopes landform.

Due to scale, vegetation cover, quality of photographs and lack of supplementary information, some slopes are not categorized to level III classification and 10 percent of inclusion is expected. Landforms smaller than 5 ha are included into the nearest appropriate category. The landform map based on landform classification system (Figure 1) and slope classes (Table 5) is given in Figure 7.

From measurements on the aerial photographs the drainage texture in the watershed is classified as "fine" indicating high run-off. Here the high run-off is probably due to the steep slopes, high intensity of rainfall, shallow soil depth, sparse vegetation and impervious bed rock. Drainage orientation analysis (Figure 8) indicates a parallel pattern showing that the streams are likely to be controlled by either fractures, joints or faults that run along the slopes and that are mainly oriented NE-SW.

4.3 Landuse Classification of Phewa Lake Watershed

The landuse classification is based on aerial photographs, the landuse map and soil profile descriptions by Impat (1980) and the landuse map by IWM (1980) of Phewa Lake Watershed. The main landuses in the watershed are villages, towns, paddy terraces, upland terraces, lower slope hardwood forests, upper slope hardwood forests, oak forests, herbaceous rangelands, shrub and brush rangelands, lake, streams and barren lands. A zoom stereoscope was used to distinguish the paddy and upland terraces along with landuse mentioned in soil profile descriptions (Impat, 1980). Due to a shadowing effect, scale and resolution problems, some errors are expected in distinguishing paddy terraces from upland terraces on the aerial photographs. In distinguishing paddy terraces, emphasis is given to water resources available. It has been the tradition that people do not make paddy terraces unless they can irrigate for paddy cultivation. Areas smaller than 3 ha are not mapped and 10 percent of inclusion of landuses is expected. The landuse map based on landuse classification system (Figure 2) is given in Figure 9.

4.4 Landuse - Land Capability Classification of Phewa Lake Watershed

The soil map (Figure 6), the landform map (Figure 7) and the landuse map (Figure 9) were overlaid and the appropriate land capability class (Figure 10) was assigned. A land capability class was not assigned to landuses such as urban and water, because these are beyond its scope and these areas are denoted the same as on the landuse map.

5. CONCLUSIONS AND RECOMMENDATIONS

The efficient utilization of land resources can be achieved by proper planning and uses of land based on an accurate landuse - land capability classification. The landuse - land capability classification is based on soil, landforms and vegetation or landuse is a logical scientific approach to land classification relevant to landuse. The landuse - land capability classification system:

1. Classifies the land based on (a) the inherent capability of the land for agriculture, range or forestry utilization, (b) conservation measures needed to control erosion and (c) limitations, risks of soil damage and erosion hazard for certain landuses.
2. Guides landowners in choosing the most appropriate use for the land.
3. Provides guidance to landuse planners.
4. Will facilitate effective planning of research on land management and assist in extrapolating result in extension programs.
5. Permits the compilation of soil, landform and vegetation or existing landuse maps, that can be used for interpretations for other purposes such as urban development, wildlife management, etc.

One of the major problems of the system is it requires considerable amount of time and labor.

The system should be tested in other parts of Nepal, and should be further refined before being extensively used.

The further development of the system should stress:

(1) Quantification of productive capacity, erosion hazard, limitations, risks of soil damage and need for conservation measures.

(2) Consideration of micro-climate such as aspect, rainfall patterns, growing seasons and frost.

(3) Consideration of local socio-economic conditions.

(4) Consideration of irrigatability of land.

The classification system reflects the present needs and socio-economic conditions. As technology progresses, the classification system must reflect the changes to continue to satisfy the objectives set out for landuse.

6. LIST OF REFERENCES

1. American Geological Institute, 1976. Dictionary of Geological Terms. Anchor Press, New York.

2. Anderson, James R., 1971. Land-Use Classification Schemes. Photogrammetric Engineering 37: 379-387.

3. Anderson, James R., Ernest E. Hardy, John T. Roach, and Richard E. Witmer, 1976. A Land Use and Land Cover Classification System for Use with Remote Sensor Data. USGS Professional Paper 964.

4. Bailey, Robert G., 1974. Land-Capability Classification of the Lake Tahoe Basin, California-Nevada, A Guide for Planning. USDA, Forest Service, South Lake Tahoe, California.

5. Bailey, Robert G., 1980. Integrated Approaches to Classifying Land as Ecosystem. Invited paper submitted for publication in Proceedings IUFRO/ISSS Workshop on Land Evaluation for Forestry, Wageningen, The Netherlands. November 10-14, 1980.

6. Bailey, Robert G., Robert D. Pfister, and Jan A. Henderson, 1978. Nature of Land and Resource Classification - A Review. Journal of Forestry. 76: 650-655.

7. Belcher, Donald J., 1973. Land Use and Natural Resources Inventories. Pages 31-45 in Proceedings of the Kodak Seminar, Aerial Photography as a Planning Tool. Eastman Kodak Company, 1974.

8. Bhatt, D. D., 1977. Natural History and Economic Botany of Nepal. Orient Longman Ltd., India.

9. Buol, S. W., F. D. Hole, and R. J. McCraken, 1980. Soil Genesis and Classification. The Iowa State University Press, Ames, Iowa.

10. Buol, S. W., and J. J. Nicholaides, III, 1980. Constraints to Soil Fertility Evaluation and Extrapolation of Research Results. International Rice Research Institute, Philippines.

11. Christian, C. S., J. N. Jennings, and C. R. Twidale, 1957. Geomorphology. Pages 51-65 in Guide Book to Research Data for Arid Zone Development, UNESCO, Paris. UNESCO.

12. Christian, C. S., 1957. The Concept of Land Units and Land Systems. Pages 74-81 in Proceedings of The Ninth Pacific Science Congress, Volume 20 Secretarial, Ninth Pacific Science Congress, Thailand.

13. Christian, C. S., and G. A. Stewart., 1968. Methodology of Integrated Surveys. Pages 233-279 in Proceedings of the Toulouse Conference on Principles and Methods of Integrating Aerial Survey Studies of Natural Resources for Potential Development. UNESCO, Paris. UNESCO.

14. Cline, Marlin G., 1949. Basic Principles of Soil Classification. Soil Science, 67: 81-91.

15. Cline, Marlin G., 1963. Logic of The New System of Soil Classification. Soil Science, 96: 17-34.

16. Bloom, Arthur L., 1978. Geomorphology, A Systematic Analysis of Late Cenozoic Landforms. Prentice-Hall, Inc., New Jersey.

17. Colwell, Robert N., 1971. Monitoring Earth Resources From Aircraft and Spacecraft. NASA, US Government Printing Office, Washington, DC.

18. Cooke, R. U., and J. C. Doornkamp, 1974. Geomorphology in Environmental Management, An Introduction. Oxford University Press, London.

19. Cowardin, Lewis M., 1978. Wetland Classification in the United States. Journal of Forestry 76: 666-668.

20. Cowardin, Lewis M., Virginia Carter, Colet C. Francis, and Edward T. LaRoe, 1979. Classification of Wetlands and Deepwater Habitats of the United States. USDI, Fish and Wildlife Service.

21. Daubenmire, B., 1952. Forest Vegetation of Northern Idaho and Adjacent Washington, and Its Bearing on Concepts of Vegetation Classification. Ecological Monographs, 22: 301-329.

22. Demek, J. (ed.), 1972. Manual of Detailed Geomorphological Mapping. International Geological Union Commission on Geomorphological Survey and Mapping. Krakow.

12. Christian, C. S., 1957. The Concept of Land Units and Land Systems. Pages 74-81 in Proceedings of The Ninth Pacific Science Congress, Volume 20 Secretarial, Ninth Pacific Science Congress, Thailand.

13. Christian, C. S., and G. A. Stewart., 1968. Methodology of Integrated Surveys. Pages 233-279 in Proceedings of the Toulouse Conference on Principles and Methods of Integrating Aerial Survey Studies of Natural Resources for Potential Development. UNESCO, Paris. UNESCO.

14. Cline, Marlin G., 1949. Basic Principles of Soil Classification. Soil Science, 67: 81-91.

15. Cline, Marlin G., 1963. Logic of The New System of Soil Classification. Soil Science, 96: 17-34.

16. Bloom, Arthur L., 1978. Geomorphology, A Systematic Analysis of Late Cenozoic Landforms. Prentice-Hall, Inc., New Jersey.

17. Colwell, Robert N., 1971. Monitoring Earth Resources From Aircraft and Spacecraft. NASA, US Government Printing Office, Washington, DC.

18. Cooke, R. U., and J. C. Doornkamp, 1974. Geomorphology in Environmental Management, An Introduction. Oxford University Press, London.

19. Cowardin, Lewis M., 1978. Wetland Classification in the United States. Journal of Forestry 76: 666-668.

20. Cowardin, Lewis M., Virginia Carter, Colet C. Francis, and Edward T. LaRoe, 1979. Classification of Wetlands and Deepwater Habitats of the United States. USDI, Fish and Wildlife Service.

21. Daubenmire, B., 1952. Forest Vegetation of Northern Idaho and Adjacent Washington, and Its Bearing on Concepts of Vegetation Classification. Ecological Monographs, 22: 301-329.

22. Demek, J. (ed.), 1972. Manual of Detailed Geomorphological Mapping. International Geological Union Commission on Geomorphological Survey and Mapping. Krakow.

23. Department of Regional Economic Expansion, 1970. Objectives Scope and Organization. The Canada Land Inventory, Canada.

24. Dow, Vicki, Hans Kienholz, Misha Plam, and Jack D. Ives, 1981. Mountain Hazard Mapping: The Development of a Prototype Combined Hazards Map, Monarch Lake Quadrangle, Colorado. Mountain Research and Development 1: 55-64.

25. Drescoll, R. S., D. R. Betters, and H. D. Parker, 1978. Land Classification through Remot Sensing - Techniques and Tools. Journal of Forestry 76: 656-661.

26. Duffy, P. J. B. 1978. The Application of Ecological Land Classification to Environmental Impact Assessment. Pages 91-99 in Application of Ecological (Biophysical) Land Classification in Canada, ed. Rubec. 1978.

27. Fairbridge, Rhodes W. (ed.), 1968. The Encyclopedia of Geomorphology. Reinhold Book Corporation, New York.

28. FAO, 1974. Approaches to Land Classification, Soil Bulletin-22. Food and Agriculture Organization of the United Nations, Rome.

29. FAO, 1974. Soil Map of the World. FAO and UNESCO.

30. FAO, 1977. A Frame Work for Land Evaluation, Soil Bulletin-32. Food and Agriculture Organization of the United Nations, Rome.

31. Forest Resources Survey, 1973. Forest Statistics for the Hill Region. Department of Forestry, Nepal.

32. USDA Forest Service, 1976. Land System Inventory. USDA Forest Service, Missoula, Montana.

33. Frayer, W. E., L. S. Davis, and Paul G. Risser, 1978. Uses of Land Classification. Journal of Forestry 76: 647-649.

34. Gilmour, J. S. L., 1951. The Development of Taxonomic Theory Since 1851. Nature, 168: 400-402.

35. Grigg David, 1965. The Logic of Regional System. Association of American Geographers, Annals 55: 465-491.

36. Harrington, Charles D, 1980. A Geomorphic-Geologic Classification System for Landform Elements (Physical Features) of North Carolina. Department of Geosciences, NCSU. (Unpublished)

37. Hills, G. A., 1960. Regional Site Research. Forestry Chronicle 36: 401-423.

38. Hirsch, Allen, Charles T. Cushwa, Dlaus W. Flach, and W. E. Frayer, 1978. Land Classification - Where Do We Go From Here? Journal of Forestry 76: 672-673.

39. Howard, Arthur David, 1967. Drainage Analysis in Geological Interpretation, A Summation. The American Association of Petroleum Geologists Bulletin 51: 2246-2259.

40. Impat, P., 1980. Phewa Watershed: Soil Survey Interpretation and Land Capability. IWM, Department of Soil Conservation and Watershed Management, Kathmandu, Nepal.

41. Iowa State University, Land Use Analysis Laboratory. 1973. A Land Classification Method for Land Use Planning: The Iowa Upper Mississippi Valley. Iowa State University.

42. Ives, Jack D., and Michael J. Bovis, 1978. Natural Hazards Maps for Land-Use Planning, San Juan Mountains, Colorado, USA Arctic and Alpine Research 10: 185-212.

43. IWM, 1980. Plan for the Integrated Development of Phewa Watershed. Integrated Watershed Management Torrent Control and Land-Use Development Project, Kathmandu, Nepal.

44. Khybri, M. L., 1979. Suggestions for Land Capability Classification for the Himalayan Region. Indian Journal of Soil Conservation 7: 1-7.

45. Klingebiel, A. A., and P. H. Montgomery, 1973. Land Capability Classification. USDA, Soil Conservation Service.

46. Lacate, D. S., and M. J. Romaine, 1976. Canada's Land Capability Inventory Program. Journal of Forestry 76: 669-671.

47. Lands Directorate, Environment Canada, 1981. Ecological Land Survey Guidelines for Environmental Impact Analysis. Ecological Land Classification Series, No. 13, Federal Environment Assessment Review Office, Canada.

48. Land Inventory, Environment Canada, 1972. Soil Capability Classification for Agriculture. Department of Environment, Canada.

49. McCormack, R. J., 1971. The Canada Land Use Inventory: A Basis for Land Use Planning. Journal of Soil and Water Conservation 26: 141-146.

50. Miller, V. C., 1968. Aerial Photographs and Landforms (Photogeomorphology). Pages 41-60 in Proceedings of the Toulouse Conference on Principles and Methods of Integrated Aerial Survey Studies of Natural Resources for Potential Development. UNESCO, Paris.

51. Mitchell, Colin W., 1977. Terrain Evaluation. Longman Group Limited, London.

52. Nelson, DeVon, Grant A. Harris, and Thomas E. Hamilton. 1978. Land and Resource Classification - Who Cares? Journal of Forestry 76: 644-646.

53. Nelson, DeVon, P. Laban, B. D. Shrestha and G. P. Kandel, 1980. A Reconnaissance Inventory of the Major Ecological Land Units and Their Watershed Management. IWM, Department of Soil Conservation and Watershed Management/FAO, Kathmandu, Nepal.

54. Orvedal, A. C. and Max J. Edwards, 1941. General Principles of Technical Grouping of Soils. Soil Science Society of America Proceedings 6: 386-391.

55. Perla, Ronald I., and M. Martinelli, Jr., 1976. Avalanche Handbook. US Department of Agriculture Handbook 489. US Government Printing Office, Washington.

56. Perret, N. G., 1969. Land Capability Classification for Wildlife. Lands Directorate, Environment Canada.

57. Rees, W. E., 1977. The Canada Land Inventory in Perspective. Lands Directorate, Fisheries and Environment Canada.

58. Rice, R. M. and J. S. Krammes, 1970. Mass-Wasting Processes in Watershed Management. Pages 231-259 in American Society of Civil Engineers, Proceedings of the Symposium on Interdisciplinary Aspects of Watershed Management, Bozeman, Montana.

59. Rowe, J. S., 1961. The Level-of-Integration Concept and Ecology. Ecology 42: 420-427.

60. Rowe, J. S., 1971. Why Classify Forest Land? The Forestry Chronicle 47: 144-148.

61. Rowe, J. S., 1978. Revised Working Paper on Methodology/Philosophy of Ecological Land Classification in Canada. Pages 23-30 in Application of Ecological (Biophysical) Land Classification in Canada, ed. Rubec. 1978.

62. Rubec, C. D. A. (ed.), 1978. Application of Ecological (Biophysical) Land Classification in Canada. Land Directorate, Environment Canada.

63. Sharma, C. K., 1975. Natural Resources of Pokhara Valley, Kathmandu.

64. Smith, Guy D., 1963. Objectives and Basic Assumptions of the New Soil Classification System. Soil Science 96: 6-16.

65. USDA Soil Conservation Service. 1980. National Forestry Manual. USDA, Washington, DC.

66. Soil Survey Staff, 1975. Soil Taxonomy. US Department of Agriculture Handbook 436. US Government Pringing Office. Washington, DC.

67. Sokal, Robert R., 1974. Classification: Purposes, Principles, Progress, Prospects. Science 185: 1115-1123.

68. Stainton, J. D. A., 1972. Forests of Nepal. Hafner Publishing Company, New York.

69. Steward, G. A. and C. S. Christian, 1968. Survey of the Katherine-Darwin Region (1946). Pages 301-315 in Aerial Surveys and Integrated Studies: Proceedings of the Toulouse Conference on Principles and Methods of Integrating Aerial Studies of Natural Resources for Potential Development, UNESCO, Paris.

70. Stewart, G. A. (ed.), 1968. Land Evaluation. Macmillan of Australia.

71. Strandberg, Carl H., 1967. Aerial Discovery Manual. New York Wiley.

72. Thie, J., and G. Ironside (ed.), 1976. Ecological (Biophysical) Land Classification in Canada. Lands Directorate, Environment Canada, Ontario.

73. Thornbury, William D., 1969. Principles of Geomorphology. John Wiley & Sons, Inc., New York.

74. Way, Douglas, 1978. Terrain Analysis. Dowden, Hutchinson & Ross, Inc., Straudsburg, Pennsylvania.

61. Rowe, J. S., 1978. Revised Working Paper on Methodology/Philosophy of Ecological Land Classification in Canada. Pages 23-30 in Application of Ecological (Biophysical) Land Classification in Canada, ed. Rubec. 1978.

62. Rubec, C. D. A. (ed.), 1978. Application of Ecological (Biophysical) Land Classification in Canada. Land Directorate, Environment Canada.

63. Sharma, C. K., 1975. Natural Resources of Pokhara Valley, Kathmandu.

64. Smith, Guy D., 1963. Objectives and Basic Assumptions of the New Soil Classification System. Soil Science 96: 6-16.

65. USDA Soil Conservation Service. 1980. National Forestry Manual. USDA, Washington, DC.

66. Soil Survey Staff, 1975. Soil Taxonomy. US Department of Agriculture Handbook 436. US Government Pringing Office. Washington, DC.

67. Sokal, Robert R., 1974. Classification: Purposes, Principles, Progress, Prospects. Science 185: 1115-1123.

68. Stainton, J. D. A., 1972. Forests of Nepal. Hafner Publishing Company, New York.

69. Steward, G. A. and C. S. Christian, 1968. Survey of the Katherine-Darwin Region (1946). Pages 301-315 in Aerial Surveys and Integrated Studies: Proceedings of the Toulouse Conference on Principles and Methods of Integrating Aerial Studies of Natural Resources for Potential Development, UNESCO, Paris.

70. Stewart, G. A. (ed.), 1968. Land Evaluation. Macmillan of Australia.

71. Strandberg, Carl H., 1967. Aerial Discovery Manual. New York Wiley.

72. Thie, J., and G. Ironside (ed.), 1976. Ecological (Biophysical) Land Classification in Canada. Lands Directorate, Environment Canada, Ontario.

73. Thornbury, William D., 1969. Principles of Geomorphology. John Wiley & Sons, Inc., New York.

74. Way, Douglas, 1978. Terrain Analysis. Dowden, Hutchinson & Ross, Inc., Straudsburg, Pennsylvania.

75. Weitzman, Sidney, and G. R. Trimble, Jr., 1955. A Capability Classification for Forest Land. Journal of Soil and Water Conservation 10: 228-232.

76. Welch, D. M., 1978. Land/Water Classification. Lands Directorate, Environment Canada, Ontario.

77. Wiken, E. B., and G. Ironside, 1977. The Development of Ecological (Biophysical) Land Classification in Canada. Landscape Planning 4: 273-275.

78. Williams, W. T., 1967. Numbers, Taxonomy, and Judgement. The Botanical Review 33: 379-386.

79. Witmer, Richard E., 1978. US Geological Survey Land-Use and Land Cover Classification System. Journal of Forestry 76: 661-666.

80. Zernitz, Emilie R., 1932. Drainage Patterns and Their Significance. Journal of Geology 40: 489-521.

7. APPENDIX

Appendix 1. Definition of New Landform Terms for Nepal.

Code 223: Complex slopes.

In mountainous areas with slopes of sedimentary rock, quite often scarp slopes are mixed with dip slopes making it practically impossible to differentiate these two in the mapping processes. Complex slopes are defined as those that contain at least 25 percent of land area in each of the scarp slope and dip slope categories. The slope generally has characteristics of both categories.

Code 224: Homogeneous slopes or Non-sedimentary slopes.

Non-sedimentary rock will not have dip, scarp or complex slopes. The characteristics of underlying rock determine the characteristics of slopes. Thinly bedded soft rock like shale also may resemble non-sedimentary rock. Generally, drainage patterns are not controlled by the underlying rock structures.

Code 415: Complex rapid mass-movement.

In the field, two or more types of rapid mass movement usually occur together and differentiation is not feasible. Such situations are categorized as complex rapid mass movement and are among the most common types.

Appendix 2. Description of Landuse Terms for Nepal.

The description of different landuses, which have a different meaning than as defined by Anderson et al., (1976) and or by standard dictionaries are outline here. The terms not defined here have the same meaning as defined by Anderson et al. (1976) or in standard dictionaries or textbooks. The description of forest landuse is contained in Appendix Tables 1 and 2.

Code 14: Others.

All other residential, commercial and service areas, which do not belong to the village, town and city are included in this category. Examples are isolated grain storage houses, service centers or restaurants on highways; educational and religious building or temples and associated areas.

Code U33: Others.

This category includes all minor facilities for transportation, communication and utilities, viz. electric substations, areas used for radio and communication antennas, transportation or water and electricity and railways.

Code U4: Others.

Urban or built up areas not included in the other urban categories falls in this category, viz., urban parks, zoos, stadiums and playgrounds, waste dumps, and areas associated with them such as parking lots, roads, etc.

Code A11: Paddy Terrace.

Paddy terrace is the almost level cropland where paddy can be grown without significant land alteration if climate permits.

Code A12: Upland Terrace.

Outward sloping terrace where land alteration has been done, but significant land alteration is still needed to cultivate paddy. Corn, millet, and potatoes are the main crops.

Code A13: Non Terrace.

Slope cropland without any significant alteration to its natural slope. Corn, millet, and potatoes are the main crops. It needs extensive land alteration for paddy cultivation.

Code A3: Others.

Agriculture land not included in cropland and pasture falls into this category, viz., orchard, nursery, etc.

Code WL: Wetlands.

"Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water" (Cowardin et al., 1979) for a significant part of most years. Wetlands are mostly associated with depressions with low soil permeability. Flood plains, that are seasonally flooded as a function of the hydrologic cycle and where wetness of the flooded period is too short to establish wetland vegetation are not included in this category.

"Wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soils; and (3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year." (Cowardin et al., 1979)

Appendix 3. Description of Land Capability classes for Nepal.

Land Class I

This includes cultivable land with very high productive capacity, no significant erosion hazard, limitation, or risks of soil damage and requires no significant conservation measures.

Land Class I includes the land with soil depth more than 70 centimeters, slope and stoniness or rockiness less than 3 percent and no other soil, excess wetness or inundation limitations. Mechanized cultivation can be utilized in Class I land without significant soil damage.

The land of Class I may be in climatic zones I or II. Under climatic zone I conditions, at least three crops a year can be grown including a paddy and paddy can be cultivated with bunding for water storage. Under climatic zone II conditions, at least two crops of either maize, wheat, potatoes, or millet can be grown without any land alteration, but no paddy can be grown. Cultivation of land Class I requires very low effort and few or no significant conservation measures.

Land Class II

This includes cultivable land with high productive capacity, slight or no erosion hazard, some limitations or risks of soil damage and requires some conservation measures.

Land Class II includes the land with soil depth more than 40 centimeters, slope and stoniness or rockiness either less than 15 percent if no further limitation exists or less than 3 percent if the first category of limitations of soil properties, excess wetness and inundation exists. The first category of limitations is either economically correctible under the present situation or has moderate effect on productive capacity, erosion hazard, and risks of soil damage. Mechanized cultivation can be done, but because of gentle slopes, fair stoniness or rockiness or moderate limitations, this land has slightly greater erosion hazard, somewhat lower productive capacity and is slightly more difficult to cultivate than Class I land.

The land of Class II may be in climatic zones I or II. Under climatic zone I conditions, at least three crops including one paddy can be grown. Paddy cultivation can be done by terracing with risers 2 meters high or less for every 25 meters width (tread) for mechanized or manual cultivation. For manual and/or bullock power cultivation, terracing with lower risers and narrower treads is also feasible. Under climatic zone II conditions, at least two crops of either maize, wheat, potatoes, or millet can be grown without further land adjustment. However, terracing is suggested to protect the productive capacity from erosion. Regular maintenance of terraces is necessary.

Land Class III

This is cultivable land with moderately high productive capacity, moderate erosion hazard, limitations, or risks of soil damage and requires moderate conservation measures.

(3) Land with stoniness or rockiness less than 50 percent, soil depth either 15-70 cm if slope is 15 to 60 percent or more than 70 cm if slope is 40 to 60 percent and severe limitations of soil properties exists.

(4) Land with slope more than 60 percent, soil depth more than 15 cm, stoniness or rockiness less than 50 percent and soil limitations exist.

Climatic zone III

Land Class IX is land with slopes more than 15 percent, stoniness or rockiness less than 90 percent and soil depth either less than 40 cm if no limitation exists or more than 40 cm if soil limitations exist.

Because of great vulnerability of such areas to erosion hazard, under all climatic zones, land Class IX should be strictly protected from biotic disturbance and requires extensive conservation measures to control further degradation. These lands should be used for protection forest and wildlife only. Included in this land class are landforms that resulted from rapid mass movement, and badlands.

7.4. Appendix Tables.

Appendix Table 1. Description of broadleaved and coniferous forests in Nepal (Forest Resources Survey, 1973; Stainton, 1972).

Code	Description	Species that make >75% of basal area	General altitude range
			------meters-----
F 1	Broadleaved Forest	Other than Coniferae order	
F11	Sal Forest	Sal (Shorea robusta)	up to 1067
F12	Terai Hardwood Forest	Asna (Terminalia tomentosa), jamun (Syzygium cumini), gutel (Trewia nudiflora), kala siris (Albizia species), Semal (Bombax ceiba) karma (Adina cardifolia) and Sal (Shorea robusta)	
F13	Khair-sissoo Forest	Khair (Acacia catechu) and sissoo (Dalbergia sissoo)	
F14	Lower Slope Mixed Hardwood Forest	Schima and Castanopsis species	610-1524
F15	Upper Slope Mixed Hardwood Forest	Acer, Aesculus, Juglans, Betula, Fraxinus, Alnus, Prunus, Celtis, and Quercus species.	1524-2743
F16	Oak Forest	Quercus species	1219-3810
F17	Birch Forest	Betula species	2896-4420
F18	Broadleaved Scrub	Short scraggly stunted all broadleaved	
F19	Other Board leaved	Other than above mentioned	

Appendix Table 1 (continued)

Code	Description	Species that make >75% of basal area	General altitude range
			-----meters-----
F 2	Conifer Forest	Coniferae order	
F21	Chirpine Forest	Chirpine (Pinus roxburghii)	914-1829
F22	Bluepine Forest	Bluepine (Pinus excelsa)	1829-3658
F23	Fir Forest	Fir (Abies species)	2134 to treeline
F24	Hemlock Forest	Hemlock (Tsuga species)	2134-3353
F25	Spruce Forest	Spruce (Picea smithiana)	2134-3353
F26	Deodara Forest	Deodara (Cedrus deodara)	1981-2896
F27	Conifer scrub	Short, scraggly stunted all coniferae order	
F28	Other conifers	Other than above mentioned	

Appendix Table 2. Description of mixed forests in Nepal (Forest Resources Survey, 1973)

Code	Description	Species each making ≥ 25% Basal Area
F 3	Mixed Forest	Coniferae order and others
F31	Chir-sal Mixed Forest	Chirpine (Pinus roxburghii) and Sal (Shorea robusta)
F32	Chir-oak Mixed Forest	Chirpine (Pinus roxburghii) and oak (Quercus species)
F33	Bluepine-Oak Mixed Forest	Bluepine (Pinus excelsa) and oak (Quercus species)
F34	Fir-Oak Mixed Forest	Fir (Abies species) and Oak (Quercus species)
F35	Birch-Fir Mixed Forest	Birch (Betula species) and Fir (Abies species)
F36	Hemlock-Upper Slope Mixed Forest	Hemlock (Tsuga species) and species of upper slope mixed hardwood (Appendix Table 1)
F37	Hemlock-Oak Mixed Forest	Hemlock (Tsuga species) and Oak (Quercus species)
F38	Other Mixed	Other than above mentioned conifer species and broadleaved species.