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LANDFORMS IN THE RICE-GROWING AREAS OF THE CAGAYAN RIVER BASIN

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ABSTRACT

Land is the dominant physical resource farmers use. Of the land components that determine the type and productivity of agricultural enterprises, soil and landscape characteristics are most important. Natural landscape facets and soil units develop by parallel genetic processes, and therefore, landforms and soil bodies are often closely correlated locationally. This correlation is fortunate because land features are easily recognized and an approximate interpretation for agricultural use can be made if the association between land features and soil properties is known.

Within cropping systems research projects, there is a need to classify land for two reasons. First, on the basis of land classification, project research is focused on land that is likely to produce the highest payoff. Second, to extrapolate research results it is necessary to describe the characteristics of land on which research was conducted and then to identify other land areas with similar characteristics. This study devised a procedure for rapid land description and determined its utility by classifying land in the Cagayan River Basin.

For the classification, a four-level system was adopted: land system, land subsystem, landform unit, and land surface units. Landform units were regarded as the largest terrain units that would be managed relatively uniformly with respect to the sequence of crops planted and the dates of planting. Four land systems, 9 land subsystems, 30 landform units, and 75 land surface units were recognized. All land in the Cagayan River Basin was mapped to the subsystem level, but only land in the alluvial land system was mapped at the landform unit level. Because rice production is concentrated on alluvial land forms, other land systems were of secondary interest.

Stereograms and photos of selected landforms were used to illustrate physical characteristics of the landform, including common positions of landform unit occurrence in relationship to associated landforms, i.e. the pattern of landform occurrence.

To obtain a limited but objective evaluation of the correspondence between land and soils, soil profile data from 26 soil profiles described along short transects were subjected to cluster analysis. Although the hierarchal system appeared to be satisfactory in this study, additional research is needed to confirm the correspondence between landform units and soil characteristics over a wider range of land systems in which rice is a common crop.

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LANDFORMS IN THE RICE-GROWING AREAS OF THE CAGAYAN RIVER BASIN

Land is the dominant physical resource farmers use. Within areas covering 50,000-100,000 ha, over which the climatic pattern is reasonably uniform, landscape and soil characteristics are the most important land components that determine the type and productivity of agricultural enterprises. Where the effects of climate are uniform, natural landscape facets and soil units develop by the parallel processes of pedogenesis and geomorphogenesis; therefore landforms and soil bodies are often closely correlated locationally. This correlation is fortunate because terrain features are easily recognized and an approximate interpretation for agricultural use can be made if the association between land facets and soil properties is known.

On the basis of terrain features, a hierarchal land classification system can be developed and, for a given region, land classes within that system can be mapped. To aid recognition of landform units, the general relationships between land mapping units and terrain features can be described and illustrated. Two linked benefits should be derived from improved recognition of land classes:

- First, by recognizing important differences in land characteristics, regional agriculturists should be able to make more accurate crop recommendations for given areas. Increased accuracy of recommendations should increase the efficiency of resource allocation in agricultural development programs.
- A second benefit should come from an improved focus of research aimed at increasing regional agricultural production.

More specifically, within cropping systems research programs there is a need to classify land for two reasons:

- to use limited research resources efficiently research should be focused on land classes that are likely to produce the greatest payoff, and
- to extrapolate research results, land areas within the same land class on which research was conducted must be identified.

To be useful in cropping systems research projects, land classification methods must provide sufficient detail to be useful to the research staff in the initial stages of program formulation, and to the extension staff when production is initiated. To meet this requirement, three products are required.

1. maps of land units from which the relative proportions of land in each mapping unit can be determined;
2. stereograms and photos that illustrate the typical recurrent patterns of land units in the landscape with respect to slope, relative elevation, and common terrain features so that recognition in the field is facilitated; and
3. descriptions of representative soil profiles from the major land units on which rice is grown, plus a brief evaluation of the land unit for specified cropping patterns.

The objective of our study was to devise a procedure for rapid land description and to use it in the classification of land in a selected portion of the Cagayan Valley. Before devising a procedure we reviewed land classification approaches used by others. It was not an objective of this study to make a detailed analysis of the correspondence between soils as natural bodies and associated landforms, although some preliminary comparisons were made.

CONCEPTS OF LAND CLASSIFICATION

Because of differences among scientific disciplines, scales of study, and intended applications, a single, widely accepted land classification system does not exist. Geographers have proposed and applied systems based on broad geologic features, usually for small-scale geographic studies. Pedologists, geomorphologists, and hydrologists have formulated land classification schemes that are suitable for large-scale studies. Seldom is terminology consistent across classification systems. In most cases, common geomorphic landform nomenclature such as interfluve, kame, and fan has been explicitly defined for each study.

Classification systems developed by agriculturalists have often been adaptations of geomorphological or geographic classification systems. The land classification systems used by agriculturalists have, in general, been designed to facilitate agroecological inventories or research projects, often to provide a basis for formulating an area development project or establishing land use policies.

In the remainder of this section, selected publications on geomorphology, pedology, and land classification are reviewed. In the first part of the review, the objective is to support the notion that one should expect to obtain at least a strong correlation between the surfaces and the cropping potentials of the soils on those surfaces. In the second part, land classification systems are examined: first, to demonstrate that others have found merit in hierarchal land classification systems as logical methods for describing land, and, second, to determine how a land classification system should be structured specifically for the Cagayan River Basin.

Geomorphic-pedogenic studies

Soil scientists and geomorphologists have examined the influence of landforms on pedogenesis, or, perhaps more correctly, the parallel and interactive processes of pedogenesis and geomorphogenesis. The recognized relationships between landform and soil patterns are used by soil surveyors to locate tentative boundaries of soil bodies on aerial photos and to guide sampling in the field (USDA 1975, Beckett 1978).

From their extensive research, Conacher and Dalrymple (1977) proposed a nine-unit land surface model. They describe diagnostic criteria for each of the nine fundamental land surface units that comprise any landscape. The criteria make possible the field recognition of the units. They present their nine-unit model as a soil-water-gravity model, and claim that it is relevant to studies in pedogeomorphology. In addition to a framework within which pedogenetic studies can be pursued, the land surface units can be mapped and the information from land surface studies can be used for land evaluation. Conacher and Dalrymple discuss both land surface mapping and land evaluation on the basis of land surface units.

Huggett (1975) developed a soil-landscape model that provides a rational basis for the simulation of soil systems. Valley basins form the basic organizational units of the soil systems. The model is three-dimensional. The watershed boundaries on the rim of valley basins, the land surface, and the weathering front at the base of the soil profile are system boundaries. The model builds on concepts such as Simonson's generalized theory of soil genesis (additions, removals, transfers, and transformations) and watershed flow theory (groundwater recharge, throughflow, overland flow). The model assumes that soil and landform evolve simultaneously.

Drawing on experiences from several studies, Webster (1977) stated that "about half the variance in the physical properties of soil in a region can be attributed to differences between classes in a fairly simple classification of soil based on profile appearance, physiography, or geology." About one-third of the total variances of organic matter and pH, but less than 10% of the total variances of available phosporus and potassium, were differentiated by such simple classifications. The physical properties determined in the studies cited by Webster were plastic limit, matric suction, and soil strength (cone index).

Ruhe (1969) associated the soil distribution patterns in Iowa to the evolution of glacial landscapes. The series of studies by Ruhe provides strong documentation of the influence of depositional and erosional geologic processes, previous climatic conditions, and time on the evolution of the soils and landforms.

In a study of three areas in Venezuela, Arnold and Schargel (1978) found that the nature of materials, particularly texture and relative landscape position, yield map patterns common to both geomorphic and pedologic maps, and to maps showing areas of similar cropping potential. They stated that additional refinements in textural profiles and wetness could be used to increase detail of the pedologic maps.

In a study of geomorphic surfaces in Hawaii, Beinroth et al (1974) found that soils occurring down uniformly sloping lava flows differed because of climatic factors, of which an orographic rainfall gradient resulting from a gradual elevation increase was regarded as the most significant factor. Within a band of similar annual rainfall, repeating patterns of soils and land surfaces were evident from their study. Furthermore, soils in two different orders (Ultisols and Oxisols) found in adjoining positions on the same surface had very similar chemical and mineralogical properties. Despite occurring in different soil orders, it is reasonable to assume that adjoining soils on the same surface would not differ greatly with respect to agricultural suitability and management requirements because differences in soil properties were only minor.

In an extensive discussion of the genesis, classification, taxonomy, and geography of soils, Hunt (1972) and Buol et al (1973) cover the relationships of landscape and soil formation and the distributional patterns of soils in the landscape. Hunt makes the distinction between scales of landforms and describes the characteristic major landform elements in each physiographic province of the United States. He emphasizes that an understanding of topography is important because it provides a clue to the kind and thickness of weathered materials that cover the bedrock and to how surface deposits build or modify landforms.

In their discussion of soil genesis, Buol et al (1973) present a state-of-the-art synthesis of parent material, relief and landscape, climate, time, and organism as factors influencing soil development. From their discussion, it is apparent that within an area covered by the same series of climatic sequences, the geologic processes that determine parent material, relief, and time for soil development simultaneously determine the evolution of landscape features. They discuss the relationship between terrain features and soilscapes and their relevance to soil surveying.

The cited studies of Conacher and Dalrymple, Huggett, Ruhe, Arnold and Schargel, Webster, and Buol et al suggest a close relationship between the distributional pattern of natural soil bodies and landforms. More explicitly, within the same geological formation, soils with similar properties should be found on similar land surfaces. This correlation can be applied in the development of a rapid land classification system that can be used to locate and to describe tracts of land with similar land-use potentials. Because of parallels in evolution, soil bodies found on similar land surfaces will often belong to the same or to a closely related family. Soils belonging to the same family will have similar agronomic potential (Johnson 1980). Even where two or more natural soil bodies occur on a single land surface unit, the similarities among the soils would likely not be great enough to place the soils in different soil management groups. A soil management group is a technical grouping consisting of soil series of like profile characteristics that have similar productivities for a defined use (Mokma et al 1978).

Land classification systems

Geographers and agriculturists recognize the importance of landscape-soil relationships and have often incorporated them into low categories of land classification systems. At the high categories in the classification systems, however, broad geologic features differentiate regions.

Under the general term terrain classification, Ollier (1977) described and compared several land system surveys. Three or four hierarchal categories are commonly used. In a discussion of general principles, Ollier pointed out that a high correlation between rock, landform, soil, vegetation, and climate at a site, and between similar sites, is the basic assumption on which the utility of terrain classification is based. He also noted that these correlations, which enable reasonable predictions to be made about land properties at sites not directly inventoried, impart value to terrain classification. According to Ollier, however, only a few rigorous examinations of these assumed correlations have been made.

Australians were among the earliest to recognize a need for systematically mapping land features as a means of inventorying land resources. Way (1978) described the components of the PUCE (Pattern-Unit-Component-Evaluation) scheme used in Australia and compared it to landform mapping systems in the United States. The PUCE scheme, or variants of it, is more formalized than schemes used elsewhere. The four categories in the PUCE system are terrain province, terrain pattern, terrain unit, and terrain component. The first two categories are mapped on a 1:250,000 scale, the third category is mapped on a 1:50,000 scale, and the last category is described in a narrative section. In addition to being mapped, terrain patterns are also described in block diagrams. Characteristics of PUCE units are summarized in Table 1.

From a review of earlier land classification systems, Thomas (1969) synthesized a 6-category hierarchal classification system for resource-inventory applications in agricultural, forestry, and range land development projects. Thomas proposed the following criteria:

1. Site - Sites are fundamental units of relief and are not susceptible to subdivision using morphological criteria. In general they may be mapped only at scales around or greater than 1:10,000.

2. Facet - Facets are relief units exhibiting a high degree of homogeneity and which are genetically single features within landform. A facet is generally only one part of a unit landform (defined below). They can generally be mapped consistently at a scale 1:25,000, but not always at 1:50,000.

3. Unit landform - A unit landform was defined by (others) as a 'terrain feature .... usually of the third order .... that may be described and recognized in terms of typical features wherever it may occur.' This morphological unit is of critical importance in that each unit landform is likely to correspond to a single soil association or catena. The terminology for landform description must be precisely defined for each area. Unit landforms may usually be mapped at a scale of 1:50,000.

4. Landform complex - The landform complex finds no exact parallel in past literature but its existence is recognized by allusions to complex land units and complex unit landforms. It may be argued that such a morphological unit is one of convenience, but certain landforms occur more often as complexes than as simple units. In certain cases it may be necessary to map landform complexes rather than individual unit landforms at scales 1:50,000-1:100,000.

5. Landform system - This category arises out of the definitions of the tract, ... the land system, ... and the recurrent landscape pattern ..... Such systems are defined here solely in geomorphic terms; they exhibit a repeated pattern of unit landforms and/or landform complexes. Landform systems may be mapped at scales 1:250,000-1:500,000.

6. Landform region - This category includes areas within which all the landforms are systematically related through structural or other factors. It corresponds to the major relief unit of Young (1969). A landform region will contain two or more related landform systems.

Thomas did not consider categories that would be mapped at scales smaller than 1:500,000. At such scales the information conveyed would obviously lack detail sufficient to make it useful for planning purposes.

Landscape elements such as alluvial fans and piedmont plains, which could be recognized, named, and mapped, were not enumerated by Thomas. He left the

Table 1. PUCE units and associated characteristics (Way 1978).

Stage in terrain classification	Map scale	Terrain factors used for description	Terrain factors suitable for quantitative expression	
			Factors	Method and scale
Terrain province	1:250,000	Geology	Properties of geologic materials	Air photointerpretation or geological maps 1:1,000,000
Terrain pattern	1:250,000 plus block diagram	Geomorphology; basic characteristics of soil, rock, vegetation common among constituent terrain units, drainage pattern	Relief amplitudes, stream frequencies	Airphoto and/or ground study 1:10,000
Terrain unit	1:50,000	Physiographic unit; principal characteristics of soil, rock, and vegetation	Dimensions of physiographic unit (relief amplitude, length, width)	Airphoto and/or ground study 1:10,000
Terrain component	Usually not mapped but described	Physiographic component, lithology, soil type, vegetative association	Dimensions of physiographic component (relief, amplitude, length, width, slopes)	Measure on site
			Dimensions of vegetation (height, diameter, spacing)	Measure on site
			Dimension of surface obstacles including rock outcrops and termitaria	Measure on site
			Properties of earthen materials throughout profile	Measured in the field or through laboratory procedures
			Quantities of earthen materials	Measured or estimated on site

descriptive definitions for the classes to the adopters of the hierarchal system he outlined. He did, however, describe a classification system for tropical Africa, but because of differences in geologic development and age, the elements within the classification have little relevance to insular Asia.

For a natural resource inventory of Malawi, Young (1969) used geomorphological mapping units to stratify land. In the stratification, four units of scale were used:

1. Major relief units, presented on a scale 1:1000,000, included certain types of landforms, but permitted a wide range of landform characteristics and slope properties.

2. Relief units, commonly of the order of 20-200 km in extent, were described by type and relative extent of landforms and the proportion of slopes in different ranges.

3. Landforms, commonly of the order of 100 m to 2 km in extent, were recognized on the basis of patterns of landform width, maximum slope, predominant slope, and slope shape.

4. Slope units, mapped on scales 1:10,000 to 1:25,000, were the divisions of an individual slope. The slope units, which could be rectilinear, convex, or concave, were described by curvature and angles.

Three landscape categories were included in a land resource classification system used by the International Center for Tropical Agriculture to inventory the agricultural resources of Tropical America (Cochrane 1980). At the highest category, land systems were delineated on 1:1,000,000 LANDSAT prints. Land systems were subdivided into land facets, with a maximum of three facets per land system. The major soils occurring in individual land facets were used as the lowest category of the system. The soils were regarded as descriptive units, not as mapping units. Soils were described at the Great Group level of Soil Taxonomy (USDA Soil Survey Staff 1975).

For an extensive cataloging of Indonesian landforms, Desaunette (1977) suggested that at a general level of classification, broad physiographic regions could be described and mapped at scales between 1:1,000,000 and 1:1,250,000. For reconnaisance level studies, land systems could be described and mapped at scales between 1:500,000 and 1:250,000. For detailed studies, land units within land systems could be mapped at scales between 1:100,000 and 1:10,000 but a land subsystem level, falling between the land system and the land unit level, would be useful in organizing an inventory of land resources.

Desaunette proposed 7 land systems for Indonesia: alluvial, marine, plain, hill, plateau-mountain, volcanic, and karst. Within each land system, several subsystems were proposed. The alluvial system, for example, was subdivided into alluvial-marine, alluvial, alluvial-colluvial, and closed alluvial. Within each subsystem 5 to 8 landforms were commonly described as the basis on which to delineate land units. Within the alluvial-colluvial subsystem, seven landforms were recognized:

- narrow, isolated interhill miniplains;
- broad, isolated interhill miniplains;
- ramified interhill miniplains;
- undulating to rolling interhill miniplains;
- alluvio-colluvial fans;
- colluvial fans; and
- footslope colluvium in strips.

Desaunette suggested that landforms can be used as a quick, diagnostic criteria for agricultural development. Agricultural suitability assessments are similar for land units of the same landform, assuming they are found within the same general agroclimatic zone. The system proposed by Desaunette was applied in a reconnaisance of the land resources survey of the Cimanuk Watershed (FAO/LPT 1976). Applying image interpretation techniques, Malingreau (1976) used landforms in the Cimanuk Watershed in a study of patterns of cropping and water management.

To classify natural resources in South Africa, MacVicar et al (1974) developed a system with the categories: land system, land type, and ecotope. In their system, an ecotope is defined in terms of climate and soil characteristics such that, between two ecotopes, there is a significant difference in the potential yield of a farm enterprise.

- To map ecotopes, scales of 1:20,000 and larger are required. A land type consists of a number of ecotopes.
- For each land type, terrain forms and soil patterns display marked degrees of uniformity. Scales about 1:250,000 are suitable for for land type mapping.
- In the land system category, groups of land types with characteristics sufficiently similar to distinguish them from other groups are combined. Land systems can be mapped at a scale 1:1,000,000 or smaller.

In the systems devised by MacVicar et al, land types and their component ecotopes are the units on which agricultural extension and development programs are focused.

Whyte (1976) has surveyed different land classification methods for integrated resource management and land use planning purposes. Although he presents no conclusions, it is clear that he recognizes the economies of time and funds obtainable by a geomorphological approach to land characterization. He states that landform maps provide information to agronomists, soil surveyors, and engineers engaged in research and development.

Using a land systems approach to land inventory with four levels of stratification, land system units in Nepal were mapped on 1:500,000 satellite imagery base maps (Nelson 1980). The four levels were zones, regions, land systems, and land types. Because of the small size of most land type units, this level was used as a description unit rather than mapping unit.

The elements that make up a landscape have been described by geomorphologists, pedologists, and other scientists. For example, in a study of rice-growing wetlands, Moorman and van Breemen (1978) described six major elementary recurrent landforms: inland valleys, alluvial fans and piedmont plains, meander floodplains, lacustrine floodplains, marine floodplains, and alluvial terraces.

Takaya (1971a, b; 1974, 1980) used geomorphic terms to describe the Chao Phraya Basin in Thailand, the lower Mekong River Basin in Vietnam, and the Komering River Basin in Indonesia. These geomorphic descriptions have been used as structural background on which to base agroecological studies of rice and other crops.

Aiming at land classification applications that are more clearly interpretive for small development areas, Way (1978) described typical landforms found in each of 6 terrain categories: sedimentary, igneous, metamorphic, glacial, eolian, and fluvial. For each category, he illustrates and discusses characteristic land pattern elements, associated soil characteristics, and potentials and limitations for engineering, and other uses.

This review of pedologic and geomorphologic literature suggests that the correlation between landforms, soils, and hydrologic regimes is sufficient to permit a useful and rapid classification of land on the basis of landforms. The review of landscape classification systems suggests that a hierarchal system with large physiographic tracts at the highest category and elementary land surface units at the lowest category is a sound approach to land classification. Land subsystems and landform unit categories should be placed between the highest and lowest categories. Landform units can serve as the basis for mapping unit definition, but users need photographs, stereograms, or sketches to illustrate typical recurrent terrain features within landform and land subsystem units. From the mapped landform units, areas with a complex of land surface soil-hydrologic characteristics similar to those on which intensive agronomic research has been or is being conducted can be identified. Agronomic practice adapted to conditions in intensively studied areas will have a greater likelihood of being adopted in areas with similar land surfaces, soil, and hydrologic attributes than in large areas that are casually identified.

It is apparent that while a landscape mapping approach to land classification has an appeal of rapidity and utility and ease of conveying land recognition to laymen, the resulting descriptions of landscapes and related soil materials should not be viewed as a replacement for a proper soil survey and a documented soil map. A well-conducted landscape mapping project, however, can form a starting point for a rigorous soil survey and studies of soil genesis and taxonomy.

The objective of the study we report here was to develop a land classification system for the Cagayan River Basin. The land areas of primary interest were those on which rice is grown, and more specifically, land with characteristics similar to that found at the Solana site of the IRRI-Cagayan Integrated Agricultural Development Project (CIADP) cropping systems research project. Our study had three purposes:

- It was to provide a preliminary assessment of the soundness of the approach taken to land classification.
- The information collected was to provide the basis for subsequent landform, soil, and agronomic studies.
- As a basis for recommending improved agricultural practices in the Cagayan area, the products from the study were designed to enable agricultural technicians to identify other areas in the basin with land characteristics similar to those in the Solana cropping systems research area.

OVERVIEW OF THE CAGAYAN RIVER BASIN

The Cagayan River drains 25,400 km^2 of which about 12% is level. Rice, maize, mungbean, tobacco, cotton, vegetables, and sugarcane are grown on the level portion.

Landform evolution

The Cagayan River Basin was once part of the sea that covered all but the highest parts of northern Luzon. The southern end of the basin is closed by the east-west oriented Caraballo Mountains. The Cagayan River is joined by many tributaries but the principal ones are the Magat, the Ilagan, and the Chico. All drainage of the Cagayan Valley is northward with the Cagayan River as the master stream. Its head is near Echague and it empties in the Babuyan Channel near Aparri. Except for the Ilagan River, which lies east of the Cagayan, all sizable streams in the basin enter the main stream from the west, a factor that gives the valley an assymmetrical profile.

Throughout the lower surfaces of the basin, marine sediments extend to great depth. Only the uppermost layers are younger strata of river alluvium. In some parts along the edges of the valley, gentle uplift and folding have exposed ancient formations. Meanderings of the Cagayan River, faulting and folding on both rims of the valley, and considerable erosion in the highlands bordering the valley, have produced numerous landform types in the basin.

Sandbars or point-bar deposits and islands are common in the Cagayan River and its larger tributaries. The braided stream pattern, especially, is characteristic in the central and upper valley. In the lower course, the river becomes wide, reaching 400 m at Ilagan and 2 km at its mouth in Aparri. Banks of sand and silt, often a few meters high, occur along its lower course. The valley terminates with a broad sandy beach more than a kilometer wide and about 10 m high along the Babuyan Channel. East of Aparri the beach is surmounted by vegetated sand dunes, some more than 100 m high. Behind the beach lie broad expanses of wetlands that are too swampy and too low for rice cultivation.

Streams flowing from the Sierra Madre Range descend by way of deeply trenched channels, often forming deep cascades and high waterfalls along faults that parallel the north trending fabric of the land. Many of the channels widen and form narrow valleys favorable for wetland rice production.

Stratigraphy of the Cagayan River Basin

The first stratigraphic nomenclature for Cagayan Basin was presented by Corby et al (1951). However, the units were inadequately defined and no type sections were presented. Later the Petroleum Division of the Bureau of Mines recognized seven mappable lithologic units constituting the composite stratigraphic column of Cagayan Basin (Bureau of Mines 1966). The main features of these seven formations are summarized in Table 2.

The general north-south trend of the basin margins is broken in the north by the northeast trending

Table 2. Main features of seven geologic formations in the Cagayan River Basin (Bureau of Mines 1966).

Formation	Location	Rock structure	Thickness	Geologic age
Awiden Mesa	Lubuagan, Kalinga; localized along upper Chico River; Tabuk	Composed of welded tuff and tuffaceous sediments overlain by alluvium; quartz grains form an erosional residue; numerous mammalian teeth and tektites have been found in the formation.	300-600 m	Upper middle Pleistocene
Ilagan	Along Ilagan River, South Ilagan, Isabela; localized along west side of the valley; well exposed on the Enrile and Tumauine anticlines	Great lateral lithological variations of marine shale and sandstones; typical fluvial depositional formation; cobblestone conglomerates are present in the upper portion.	1000-2000 m	Pliocene to Pleistocene
Cabagan	Present almost throughout the basin; exposed in the Buluan River area	Shale with coarse clastic and limestone intercalations in lower portions and reef limestone deposits in upper portions.	1000 m	Miocene to Pliocene
Callao	Callao Canyon along Tuguegarao River at Peñablanca, Cagayan	Reef complex which grades into clastic facies in the deeper part of the basin.	600 m	Middle Pliocene
Lubuagan	Southeast part of the basin; Sierra Madre; Kalinga foothills; along eastern border of the basin	Silty claystone and graywacke beds upper section; coarse sandstones and conglomerates on the middle part and shale and siltstone on the lower part	200-2000 m	Middle Miocene
Ibulao	Exposed in the southeast and northwest parts of the basin.	Reef limestone deposits with claystones and thin interbedded graywacke sandstone in the upper portion	300-500 m	Early Miocene
Dumatata	Observable only in the southwest part of the basin along Dumabato Dumatata rivers,	Basic lava flows, partially metamorphosed agglomerates; tuff brecia; tuffaceous sandstone and silstone; over basement complex.	100-600 m	Pre-Oligocene

Cassigayan-Bajucan high which is essentially a horst block. A similar northeast-trend feature exists in the subsurface of the Ipil area, which is exposed in the San Mariano Embayment, and in the southwest part of the basin. These two features, plus a similar one that may have existed near the central part of the basin in its early history, controlled sedimentation during the formation of the Ibugao, Lubiagan, and Callao formations. The basin gradually developed its present shape during the Cabagan, Ilagan, and Awiden Mesa intervals (Bureau of Mines 1966).

Climate

Most areas in the Cagayan River Basin have a wet season of 5-6 consecutive months in which rainfall is more than 200 mm/month. The rainfall pattern is not uniform over the basin, however, with some areas having slightly longer wet seasons (Flores and Balagot 1969, IRRI 1977). From December to April, when the winds are easterly, the basin receives practically no precipitation. An exception is the northernmost portion, which receives significant rainfall in December and January. The northern coast, which is exposed to northeast winds, receives somewhat higher rainfall. Mean annual rainfall of 2,250 mm for Aparri, 1,720 mm for Tuguegarao, and 1,683 mm for Ilagan have been recorded. Much of this annual rainfall comes from the many typhoons that affect the area.

For the basin as a whole, the precipitation received in the wetlands is much less than that received in the mountains to the east, west, and south. Intense rainfall received from storms is an important factor contributing to the erosion and deposition of surficial materials and therefore to landforms and soils developed in the valley.

MATERIALS AND METHODS

The proposed landform classification system

As generally used, the term landform applies to the recognizable arrangements of the physical land features that make up the surface of the earth. The term includes broad features such as plains, plateaus, and mountains, but also smaller features such as hills, valleys, canyons, alluvial fans, and river terraces. For large areas such as the Cagayan River Basin, the number of different landforms is large but classifiable. A practicable method of organizing the many landforms occurring in the basin is needed. The classification system formulated should be useful to agricultural technicians, scientists, and planners. We proposed a system based on visually recognizable fundamental land units that can be organized into broader classes at higher categories of a hierarchal system.

To classify land in the Cagayan River Basin, an adaptation of a system similar to those used by Thomas (1969), Desaunette (1977), and others was formulated. The organizational structure was strongly influenced by Thomas, and the terminology for landform nomenclature was strongly influenced by Desaunette. Four categories were established: land system, land subsystem, landform unit, and land surface unit.

- Land system. Land systems are subdivisions of broad areas within which recurrent patterns of higher order terrain features are found. Such patterns provide for a natural grouping of lower order terrain features, within which recognition of a limited number of possible component landform units is facilitated. The physical surface features on which land systems are separated are controlled by major geologic processes.

  In the Cagayan River Valley, all land systems were of such extent that they could be interpreted on topographic maps at scales ranging from 1:250,000 to 1:1,000,000 with elevation contour intervals from 100 to 400 m. Black and white (band 6) and composite color LANDSAT prints also aided recognition and delineation. Four land systems were recognized: alluvial, plain, hill, and mountain.

- Land subsystem. Land subsystems are subdivisions of land systems within which the diversity of recurrent patterns of terrain features is decreased. The decreased diversity is introduced by recognizing the effects of secondary geologic or geomorphic processes and lithologic factors that limit the terrain expression resulting from major geologic processes.

  Land subsystems were recognizable on 1:50,000 to 1:250,000 topographic maps with 20 to 100 m contour intervals and on 1:20,000 to 1:50,000 airphotos. The component land subsystems within the four land systems are presented in Figure 1.

- Landform unit. Landform units are terrain features that may be described and recognized in terms of typical features wherever they may occur. They are usually simple in form, resting on a particular rock or superficial deposit, and have soils and water regimes that vary in a consistent way over the whole landform unit. Landform units are products of one or more elementary processes from a complex of denudational-aggradational processes operating on material of similar lithology. For agricultural purposes, the landform unit is sufficiently homogeneous to permit the same or similar sequences of crop species to be cultivated over a year, although cultivars exhibiting particular characteristics that improve adaptation to local environmental gradients (primarily differences in field water regimes) may be planted in subdivisions of a landform unit. Homogeneity of present agricultural use across a landform unit aids in the recognition of the landform unit. The expected homogeneity of the landform unit in future agricultural use imparts significance to it as an agroecological unit.

  Landform units were identified using 1:10,000 to 1:50,000 topographic maps with 5- to 20-m elevation contour interval, or airphotos with scales ranging from 1:10,000 to 1:20,000. The component landform units within each land subsystem are shown in Figure 1.

- Land surface unit. Land surface units are components of landform units. Land surface units are similar to the facets that Thomas (1969) defined as relief units. They exhibit a high degree of homogeneity and are genetically single features within the landscape, having been formed by a single elementary process in a complex of denudational-aggradational processes operating on material of similar lithology. Crests of alluvial fans and central segments of interhill miniplains are examples. Within a land surface unit, crop cultivars of similar duration and plant type would be equally adapted and the optimum management requirements of these crops would be identical. Two or three land surface units are recognized within each landform unit. The component land surface units within each landform unit are presented in Figure 1.

  Land surface units were generally identified and mapped using 1:10,000 to 1:30,000 scale airphotos. Although land surface units can be recognized on 1:10,000 topographic map with 5-m contour intervals, it is difficult to recognize any of them on 1:50,000 topographic maps with 20-m contour intervals.

The hierarchical categories in the landform classification system and the basis on which classes

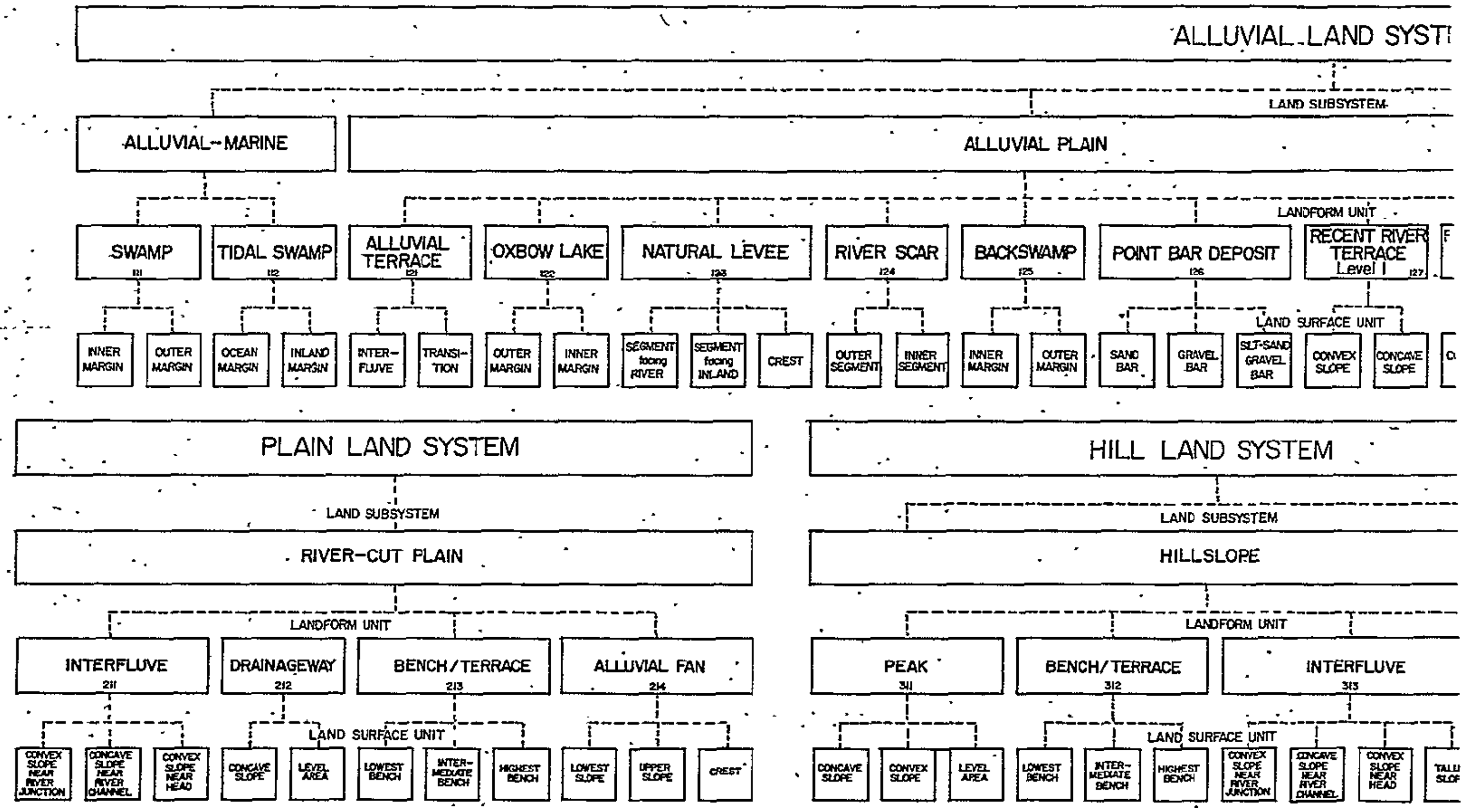
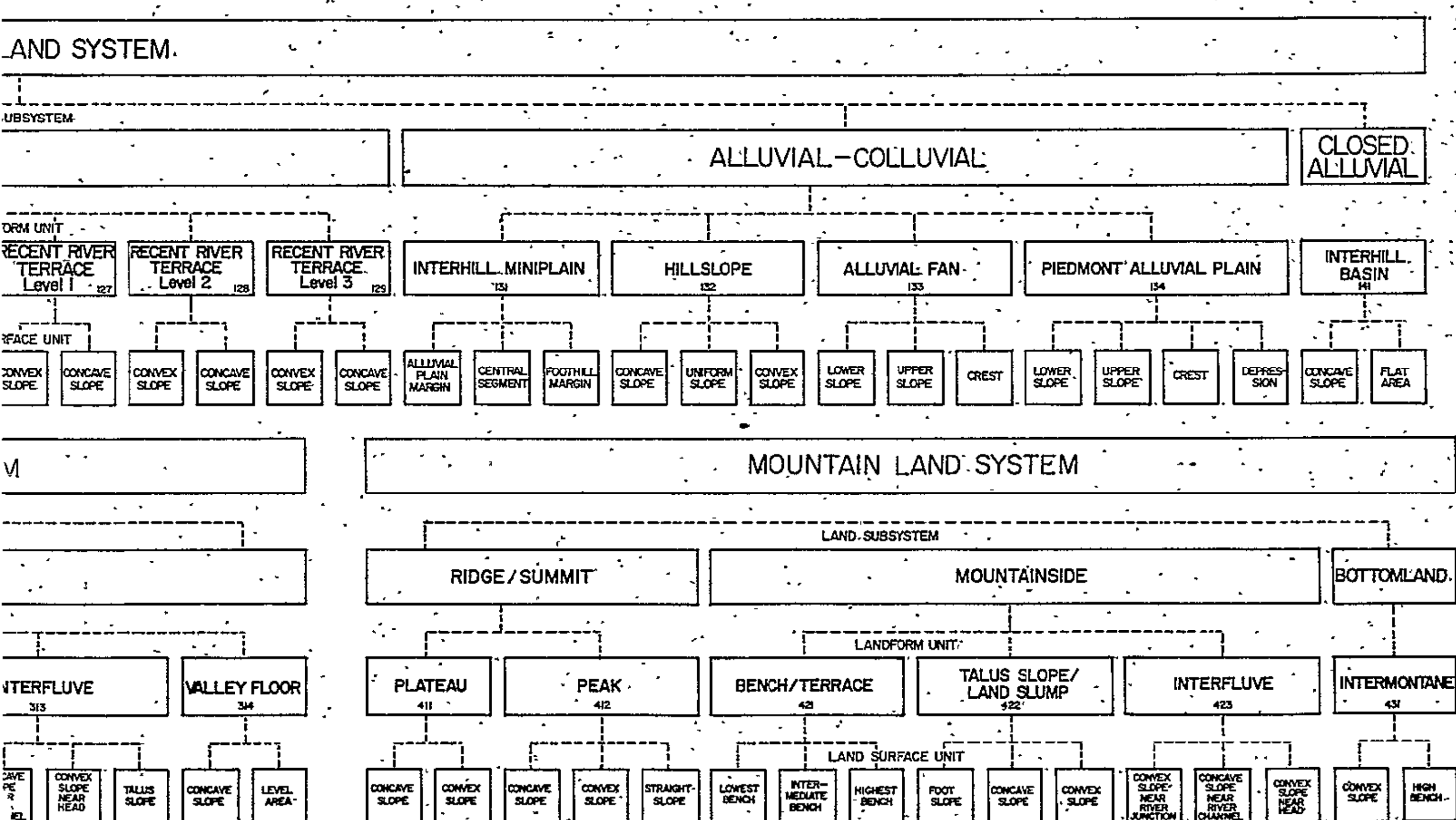


Fig. 1. Terrain classes within the land system, land subsystem, and landform unit categories of the Cagayan River Basin landform classification system. Mapping u



tem. Mapping unit codes are shown for landform unit terrain classes.

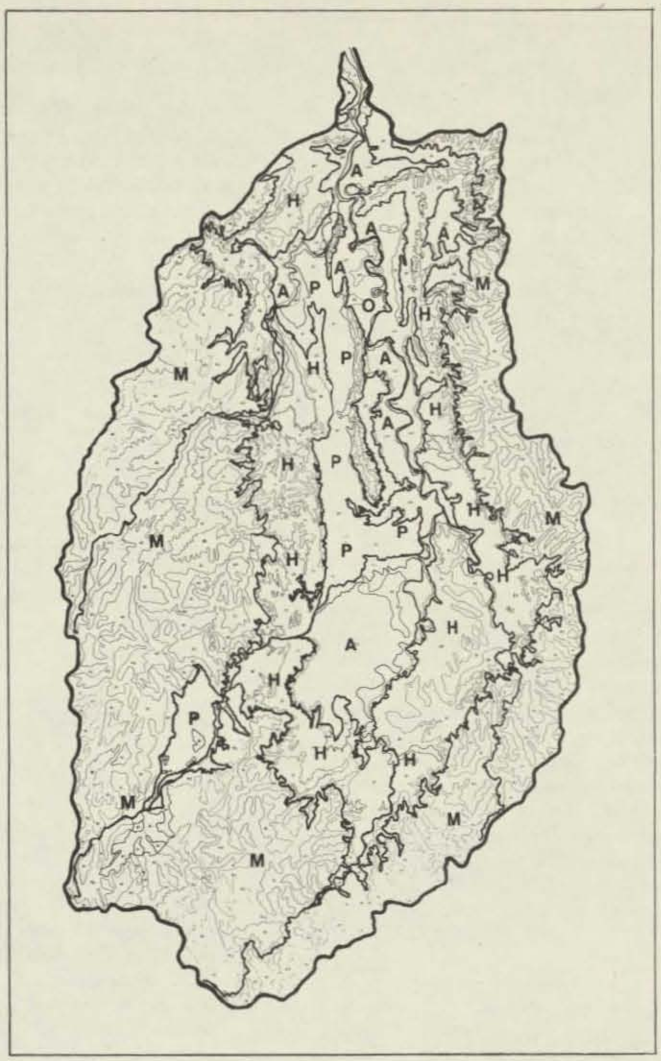


Fig. 2. Land systems and subsystems in the Cagayan River Basin: A = alluvial, P = plain, H = hill, and M = mountain. The initial study area is outlined at top center.

Table 3. Four hierarchal categories in the land classification system formulated for the Cagayan River Basin.

Hierarchal category	Interpreted on
Land system	1:250,000 - 1:1,000 topographic map with 100- to 400-m contour interval
	1:250,000 composite color LANDSAT imagery
Land subsystem	1:50,000 - 1:250,000 topographic map with 20- to 100-m contour interval
	1:20,000 - 1:50,000 air photos
Landform unit	1:10,000 - 1:50,000 topographic map with 5- to 20-m contour interval
	1:10,000 - 1:20,000 air photos
Land surface unit	1:5,000 - 1:15,000 air photos
	1:10,000 - 1:50,000 topographic map with 5- to 20-m contour interval

are interpreted within each category are summarized in Table 3.

Landform mapping procedures

Using 1:250,000 topographic maps and LANDSAT imagery, broad landscape patterns were identified and delineated as land systems. Within land systems, subsystems were identified and mapped by means of photo interpretation techniques. To obtain a three-dimensional impression of the landscape, a mirror stereoscope was used to view overlapping airphotos. Only land in the alluvial landsystem was mapped at the landform unit level.

Boundary of the study area

The initial study area, which covered about 150,000 ha in the north central part of the basin, is outlined in Figure 2. Subsequently, the entire basin was included for mapping purposes, but field studies remained confined to the initial study area.

Recognition aids

In addition to devising the landform classification system, two types of aids were developed to assist potential users with recognition of landform units in field.

- Stereograms were selected and annotated to show examples of major landforms in the land subsystems on which agriculture is important.

- Photographs of selected landforms were used to illustrate some of the common landforms, and their typical positions in relation to other landforms in the same and adjacent land subsystems.

Cluster analysis of soils in landform units

To obtain an exploratory but objective test of the correlation between landform units and soil properties, cluster analysis of profile attributes was used to group 26 soil profiles. Soil profiles were described along seven small transects in the soil study areas identified in Figure 3. Because soil factors that affect crop adaptation were of greater interest than factors that determine the taxonomic placement of a soil, most of the variables used in the analysis were determined in the surface 40 cm, where crop roots predominate.

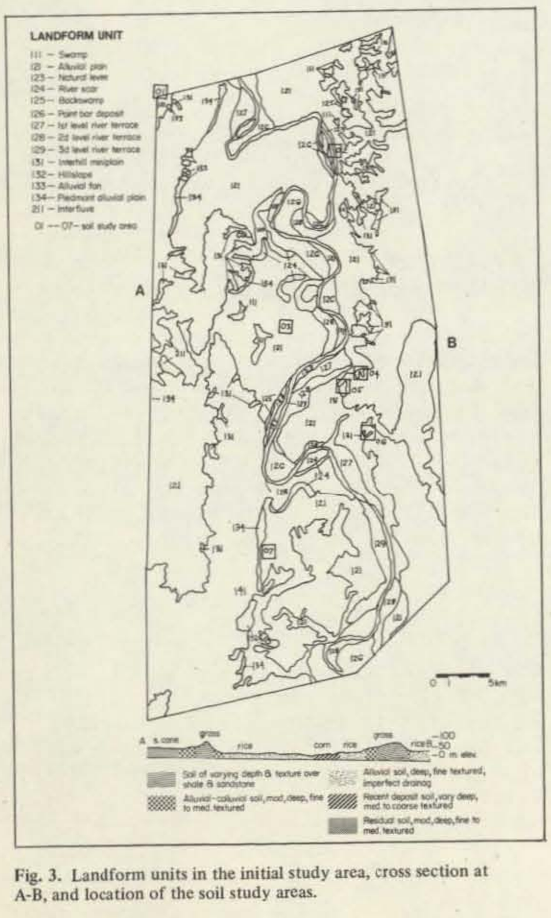


Fig. 3. Landform units in the initial study area, cross section at A-B, and location of the soil study areas.

Three comparisons of alternative clustering procedures were made. First, a comparison of two fusion methods (nearest neighbor and Ward's) was made. In a second comparison, two sets of soil variables, one from the surface horizon only (17 variables) and a second set from the surface and second horizons plus color at 70-cm depth (33 variables), were used to cluster the 26 soils using Ward's method (Table 4). In a third comparison, principal component analysis was applied to the set of 33 variables. From the principal component analysis, the first 9 factor scores were used to cluster the 26 soils using Ward's fusion method.

The CLUSTAN package described by Wishart (1975) was used for all cluster analysis. Except when factor scores were used, fusions were obtained from a similarity matrix of euclidean distances computed from standardized scores of the original variables.

RESULTS AND DISCUSSION

Landform classification and mapping

The predominant characteristics of the 4 land systems, 9 land subsystems, and 30 landform units are listed in Tables 5-10. These tables summarize characteristics of the boundaries between units, topographic and other physical surface features, existing land use and vegetative cover, water availability and flooding hazards, and use suitability. The tables can be used to assist in landform recognition and the evaluation of landforms for alternative uses.

Table 4. Soil variables used in cluster analysis.

	First horizon	Second horizon	At 70 cm
Number of horizons[a]	x		
Hue[b]	x	x	x
Value	x	x	x
Chroma	x	x	
Clay (%)	x	x	
Sand (%)	x	x	
Bulk density	x	x	
Root abundance[c]	x	x	
pH	x	x	
Cation exchange capacity	x	x	
Total exchange bases	x	x	
Exchangeable K	x	x	
Olsen P	x	x	
Total K	x		
Total P	x		
Total N	x	x	
Organic carbon	x	x	

[a]The number of horizons in the profile was placed on a computer card with variables in the first horizon. [b]Hue was coded as 2 for 2.5 yr, 3 for 5 yr, 4 for 7.5 yr, and 5 for 10 yr. [c]Root abundance was coded as 0 for none, 1 for few fine, 2 for many fine, and 3 for many medium roots.

Table 5. Predominant characteristics of four land systems in the Cagayan River Basin.

Land system	Boundary	Typography	Surface drainage	Vegetation
Alluvial	*With highlands*: abrupt change in elevation. *With lowlands*: occurs adjacent to stream; there may be transitional zone; change is often gradual, no definite boundary.	Predominantly level surfaces but irregularities do exist; differences in elevation resulting from irregularities are of minor nature; minor irregularities include such features as lakes and swamps. Elevation - 0-30 m Slope - 0-3% Local relief - 0-2 m	Relatively large river with single or multiple channel flow; general lack of integrated surface drainage; haphazard arrangement of tributaries; very broad interfluves and shallow gullies. Stream frequency - 0-2/km^2 Drainage density - 1-2 km/km^2	Mostly cultivated; minor surface irregularities make vegetative cover variable.
Plain	*With highlands*: irregular identified mainly by change in elevation; there is a transitional or border zone. *With lowlands*: gradual change.	Broad, gently rolling with terrain presenting a smooth appearance; many broad interfluves. Elevation - 30-100 m Slope - 0-8% Local relief - 1-20 m	No major streams; moderately wide interfluves and moderately deep gullies. Stream frequency - 3-4/km^2 Drainage density - 4-10 km/km^2	Predominantly grasses and savannah vegetation; moist bottomland usually covered with trees; cultivated areas are usually planted to sugarcane.
Hill	*With lowlands*: marked isolated hills. *With highlands*: irregular; many closed contours; contours spaced close together.	Relatively rugged; series of straight, nearly parallel ridges; crestline of hill is highly irregular. Elevation - 100-300 m Slope - 5-30% Local relief - 30-300 m^2	No major streams; stream meander at random; numerous intermittent streams; narrow interfluves and relatively deep gullies. Stream frequency - 4-6/km^2 Drainage density - 10-15 km/km^2	Thin forests, grasses, savannah vegetation; patches of cultivated areas; moist low areas thickly covered with trees but usually of no commercial value.
Mountain	Highly irregular; rising more or less abruptly from the surrounding level area.	Very irregular surface; rugged, interconnected hills with steep slope forming continuous ridge. Elevation – more than 300 m Slope - more than 20% Local relief - more than 200 m	Strongly dissected, closely spaced, smoothly curving drainage channels; parallel patterns of streams occur on steep ranges. Stream frequency - 6-15/km^2 Drainage density - 10-12 km/km^2	High elevations predominantly forested; grass and savannah vegetation cover most of the mountainsides at intermediate elevations.

Among the four categories of the hierarchal system shown in Figure 1, land subsystems and landform units were most diverse in the alluvial land system. Figure 2 shows land coverage in the basin according to the 9 land subsystems. The landform units in the initial study area and a cross-sectional diagram showing surface elevations, the general nature of soils and underlying materials, and common crops or vegetative cover are seen in Figure 3.

Between the initial establishment of the hierarchal classification system and the production of the maps and tables to describe the units at the three highest levels, only minor adjustments were made. These adjustments reflected an increased appreciation of the landform patterns as field work and air photo interpretation expanded to cover a broader array of landscapes than encountered initially. These adjustments were regarded as a natural consequence of the procedure, not as a

Table 6. Predominant characteristics of the 9 land subsystems in the Cagayan River Basin.

Land subsystem	Mode of formation/development	Occurences	Boundary	Topography				
Alluvial marine	Alluvial deposition by streams and/or marine sedimentation due to uplifting and recession of sea level, organic deposition.	Usually near the sea. Depressed situation. Limited areal extent, very irregular in shape, tidal marsh near Aparri, many small swamps scattered in several municipalities in alluvial land system.	*With highlands*: very significant abrupt change in elevation. *With lowlands*: not significant, very small change in elevation. Contour line may not be seen particularly in small areas.	Low, depressed position. Microrelief hardly visible, level with very slight difference in elevation between the outer and the inner margins.	Visible standing water; in small swamps; no channels develop; in tidal marshes near the sea, highly integrated, wide but short channel system develops; most swamps have no visible streams.	Grasses and reeds surrounding central water surface; the outer margin of most swamps and marshes are rice paddies and vegetable gardens, fishponds are common.	Severe	Surface and subsurface easily available; quality is questionable.
Alluvial plain	Alluvial deposits of the normal cycle of stream valley development.	Wide, flat, low areas in the basin extending from Bayombong in the south to Aparri in the north, common to nearly all streams with low gradients.	*With highlands*: abrupt change in elevation, may be of almost any shape. *With lowlands*: nonexistent.	Overall level surface; irregularities do not exist; difference in elevation due to irregularities are minor compared to its broad extent	Relatively large streams - single channel streams; meander over the level plain; lack of integrated surface drainage, oxbow takes abandoned channels and river scars are common; very broad interfluves.	Extensively cultivated with lowland rice as dominant crop; maize, tobacco, mungbean, cotton, and other field crops are also grown.	Seasonal; severe flood in areas near major rivers.	Surface water generally available; groundwater available at some depth depending on location with respect to major stream.
Alluvial-colluvial	Alluvial deposition in rapid stream action in combination with colluvial deposition (sheet form accumulation at the base of slope).	At the base of hill and mountain slopes, small valley floors between hills or hillocks.	*With highlands*: significant change in elevation, slope, and surface configuration. *With lowlands*: gradual change of slope from flat to uniform, gentle slope.	Uniform, gently sloping from high land toward lowland; surface irregularities are present.	Many short, intermittent streams of various patterns; some tributaries and some distributaries.	Rainfed rice, sugarcane, orchard in most areas; grass and savannah in some areas.	None in most areas; occasional in transition zone.	Surface water generally unavailable; groundwater usually obtainable at transition zone with alluvial plain.
Closed alluvial	Alluvial deposition with small colluvial deposits near upland boundary.	Found in limited areas in several parts of Cagayan River Basin.	*With highlands*: distinct gradual change in elevation and slope. *With lowlands*: not significant; no adjacent lowland of other landform class.	Basin type topography; slightly sloping to low or central portion, elevation is lower than surrounding upland.	Surface drainage converges to low area; no major streams.	Rice often pump irrigated, diversified upland crops maize, tobacco, mungbean, vegetables.	Seldom to occasional particularly during extremely high rainfall periods.	Surface and groundwater generally easily available.
River-cut plain	Stream dissection, flat or rolling erosion surface produced by streams.	Extensive, elevated plains of low relief between hills and alluvial land systems.	*With highlands*: significant change in relief and elevation *With lowlands*: gradual decrease of elevation and slope with transition zone.	Broad, relatively flat interfluves; low relief intermediate elevation; similar to table land of low elevation, moderately to highly dissected, relatively narrow interfluves, concave and convex shapes.	Many short, intermittent, well-integrated surface drains; no major rivers.	Generally covered with grasses; large area is planted to sugarcane, rice paddies in many small valley floors formed between two interfluves.	None	Confined to valley floors and concave areas fringing alluvial plains; small ponds occur in areas underlain by slightly weathered shale formation.
Hillslope	Uplifted denudational (erosional) processes or mass wasting.	Connection between ridge/summit (crest or hilltop) and valley bottoms (channel).	Areas from the valley bottoms upward may have transition zone with plain alluvial land systems.	Slope may be rectilinear, concave, or complex in plan and profile; many closed contour lines signifying isolated hilltops.	At highest elevation, head of intermittent streams forming radial pattern, areas of headward erosion; many intermittent streams, tributaries, gullies, and rivulets at lower positions.	Generally grass and savannah vegetation; patches of trees near streams; few terraced for rice.	None	Generally none except at footslope or by damming.
Ridge/ summit (mountain land system)	Uplifted vigorous erosional processes.	At highest elevation in the land system.	Prominent because of great elevation and area.	Defined by both its greater height and its greater area compared to other land systems; interconnected contour lines representing ranges or sierras.	Relatively unbranched, intermittent head streams usually in parallel patterns.	Generally thick, moss type forest.	None	None; all intermittent streams.
Mountainside	Uplifted, denudational processes of great volume; mass wasting and slope wash.	Connection between ridge/summit or crest and bottomland.	Areas downward from inflexion point of ridge/ summit to the bottomland.	Steep slopes; rectilinear, concave, or complex in plan and profile.	Many intermittent streams of high gradients forming dendritic pattern.	Generally forest; many areas are denuded and covered with grass and savannah vegetation.	None	May be available at the footslope fringing the bottomland.
Bottomland	Alluvial-colluvial deposition.	Valley floor, floodplains of streams dissecting the mountain land system.	*With highlands*: significant change in elevation, slope, and areal limit.	Lowest elevation in the land system; level terrain.	At least one low grade, permanent stream.	Generally graded for paddy rice in relatively wide bottomlands; small area usually forested.	Slight to moderate; flood only of short duration.	Available.

Table 7. Predominant characteristics of landform units in the alluvial land system of the Cagayan River Basin.

Landform unit	Location/ Hectarage	Topography	Soil: Solum depth	Soil: Texture	Soil: Drainage	Water availability (surface and subsurface)	Flood hazard	Existing land use	Use suitability
Swamp	Scattered in limited areal extent in the alluvial plain land subsystem - Baggas, Solana, Iguig, Tuguegarao, etc., 2,093 ha; mapped.	Depressed area, flat, slightly concave slope; microrelief of 0 - 10 cm.	>100 cm	Clay loam to clay; organic accumulation from decomposed plant debris.	Waterlogged or very poor.	Easily available, water standing on surface at times, high water stable.	Always deeply flooded during rainy season, greater than 100 cm.	Fishpond in permanently water-covered portions; rice paddies and vegetables on relatively dry, outer margins.	Paddy rice fishponds, vegetables.
Tidal swamp	Coastal area near the sea in Aparri, 3,937 ha, mapped.	Flat, usually depressed area between beach ridge and higher landward area; microrelief of 0-10 cm.	>100 cm	Clay loam to sand.	Brackish water.	Slack water, usually salt water inundation.	Flooded by sea and freshwater; often deeply flooded, greater than 100 cm.	Usually fishponds; many portions are covered with thin mangrove forests.	Aquaculture - fishponds, salt, mangrove, forests.
Alluvial terrace	Consists of old floodplains formed by the Cagayan River and other major rivers; 144,416 ha, mapped.	Flat, unidirectional ground surface, generally constant slope; not broken by significant elevations and depressions. Elevation - 5-20 m Slope - 0-4% Microrelief - 0-20 cm	> 100cm	Silt loam to clay topsoil; clay loam to clay subsoil.	Somewhat poorly drained to moderately well drained.	Variable, depending on locality; surface water available from streams dissecting the area, subsurface water available depending on local aquifer. In some areas of Tuguegarao, Enrile, and Solana, subsurface water is available at 10 m depth.	Seasonal flood, depending on location with respect to major river; moderately flooded, 20 to 100 cm.	Rice production area - irrigated and rainfed; other crops include maize, tobacco, mungbean, cowpea, and cotton.	Paddy rice, maize, tobacco, mungbean, cotton, and other upland crops.
Natural levee	Natural embankment of Cagayan River although not well developed in most areas, 205 ha; mapped.	Narrow strip, generally convex slope; steepwater facing the river and gradually decreasing its slope inland from the crest.	100 cm	Has both vertical and horizontal textural variation; coarse on the surface and near the river and gradually becoming finer texture with depth and distance from the river.	Well drained; rapid percolation.	Surface water influenced by river flood; subsurface water generally available in the zone fringing alluvial plain landform unit. Water table greatly influenced by river water regime.	Seasonally flooded.	Upland field crops - maize, tobacco, mungbean, cotton, vegetables.	Suitable for most upland field crops presently grown in the area.
River scar	Near river; former meander now filled with deposits; the town of Enrile is bounded on the south by river scar; found also in Solana, Iguig, Amulong, and other towns. 3,206 ha; mapped.	Level; depressed, oxbow shape area. Elevation - 2-10 m Slope - 0-1% Microrelief - 0-10 cm	>100 cm	Clay loam to clay to depth of more than 100 cm becoming medium texture and finally coarse and gravelly.	Usually waterlogged during rainy season; central portion usually wet even during dry season.	Subsurface water usually available when unconsolidated material is penetrated; water usually stands on the surface particularly on the inner segment.	Easily and deeply flooded.	Bunded mudfish ponds on the inner segment, vegetables are -rown on the outer segment during dry season, in some river scars, outer segments are used for paddy rice.	Mudfish production, but river scars are better left unutilized to serve as buffer strips or reservoirs for floodwater.
Backswamp	Narrow, strip depressional swamp usually situated behind levees or in the concave area near the hill, 185 ha; mapped.	Narrow strip of depressed, slightly concave area. Elevation - 5-15 m Slope - 0-1% Microrelief - 5-15 cm	>100 cm	Clay to clay loam with sandy loam substratum; surface is usually veneered with thin layer of silt deposited by recent floodwater	Waterlogged; slow percolation.	Water stagnates on the surface, subsurface water available from unconsolidated materials at depth; water diminishes rapidly by evaporation.	Easily and deeply flooded.	Usually left unused.	Too small for cultivation, not enough water depth for mudfish; rapid water evaporation.
Point bar deposit	Sediments deposited on the inside of a growing meander loop; occurs also as sand bar island, such as Fugo Island and other small sand islets in Cagayan River; 11,447 ha; mapped.	Flat with irregularities inside the meander loop or as islet. Elevation - 2-5 m Slope - 0-1% Microrelief - 5-20 cm in the form of ridge and humocky topography.	Indefinite	Coarse texture with water-worn gravel of assorted sizes.	Excessively well drained.	Surface and subsurface water greatly influenced by the river.	Easily and deeply flooded.	Maize and peanut are grown in many well developed point bar deposits such as those in Enrile; others are not cultivated and covered with sparse growth of tall grass, mainly talahib.	Peanut, sweet potato, and other root crops, point bar deposits are susceptible to wind erosion.
Recent river terrace Level 1	Close to Cagayan River, represents valley floor abandoned as the river cuts down to the new and lower base level, mapped	Level relatively narrow strip along the river at elevation slightly higher than surface water elevation. Slope - 0-2% Microrelief - 5-20 cm	>100 cm	Fine sand to sandy loam over pure stand.	Well drained.	Surface and subsurface water greatly influenced by the river.	Easily and deeply flooded.	Maize, tobacco, mungbean, peanut, and vegetables.	Suited to most upland field crops: maize, tobacco, mungbean, peanut, vegetables, and cotton.

Table 7 Predominant characteristics of landform units in the alluvial land system of the Cagayan River Basin

Landform unit	Location/ Hectarage	Topography	Soil			Water availability (surface and subsurface)	Flood hazard	Existing land use	Use suitability
			Solum depth	Texture	Drainage				
Recent river terrace Level 2	Similar to river terrace level 1 but farther away from the river at higher elevation; mapped.	Similar to level 1, but 2 to 4 m higher in elevation.	>100 cm	Fine sandy loam to silt loam over sandy loam	Well drained.	Surface water usually not available, subsurface water available at water table depth.	Seasonally flooded.	Maize, tobacco, mungbean, peanut, and vegetables.	Suited to most upland field crops.
Recent river terrace Level 3	Similar to levels 1 and 2 but farther away from the river at higher elevation; has transition zone with alluvial plain landform unit; mapped.	Similar to levels 1 and 2 but 3 to 5 m higher in elevation.	>100 cm	Silt loam/clay loam.	Moderately well drained.	Few intermittent small channels; subsurface water available at water table depth.	Seasonally flooded.	Maize, tobacco, mungbean, and paddy rice at transition zone	Suited to most upland field crops.
Interhill miniplain	Narrow valley floors between hills or hillocks, usually terraced for paddy rice, emerges to alluvial plain landform unit; common between hills on fringing the alluvial plain area on the east and west of Cagayan River Basin; 23,816 ha; mapped	Relatively small and narrow, valley floor slightly sloping from head downward; big alluvial plain, usually graded and terraced; elevation range from 10 m near the alluvial plain transition zone to 30 m near the head, and slope range from 2 to 5%.	50-100 cm	Silty clay loam to clay loam surface, clay loam to clay subsoil.	Somewhat poorly drained	Surface water available and can be stored with earth dam during dry season, subsurface water available at water table depth at transition zone.	None.	Mostly utilized for paddy rice; uncultivated area usually covered with savannah vegetation or grasses.	Suitable for paddy rice, with earth dam for rainwater reservoir
Hillslope	Occurs on all low hills in the alluvial colluvial land subsystem, the slopes of the hills and uplands that form the interhill miniplains are included in this category; 411 ha; mapped.	Either uniform slopes, convex slope or concave slope, elevation varies greatly; slope may range from 15 to 30% or steeper.	20-50 cm	Variable, but unusually silty clay loam to clay loam over clay loam subsoil overlying highly weathered parent material.	Moderately to somewhat poorly drained	No major streams; many intermittent tributaries, subsurface water usually not available except on a few seepage areas.	None.	Usually grass and savannah and small areas. Small area is utilized for paddy rice production, particularly on upslopes of interhill miniplains.	Tree crops and forests.
Alluvial plain	Fan-shaped alluvial deposit made by rapidly flowing streams from hills and uplands out onto a level area, develop in many areas in Cagayan River Basin where streams emerge from mountains onto lowlands; 205 ha; mapped.	Surface slopes smoothly from highland toward lowland, also slopes laterally forming a convex surface.	50-100 cm	Generally coarser-textured soils occur at the head of the fan and finer-textured soils toward the margin, usually clay loam topsoil and silty clay loam subsoil.	Moderately well to well drained in the convex surface portion, poorly to somewhat poorly at the margin of the fan.	Few small surface drainage channels; subsurface water usually available at the margin of fan.	None except at the margin where rainwater may accumulate and stay for short periods	Cultivated fans are usually planted to sugarcane, few rice paddies; uncultivated fans are generally covered with grasses and/or savannah vegetation.	Tree crops, sugarcane, paddy rice at or near lower margin of fan.
Piedmont alluvial plain	Occurs where two or more alluvial fans coalesce or merge; common at the foot of highlands fringing the alluvial plain on the west; 323 ha, mapped.	Each fan has lateral convex surface sloping gently from the head end with depressions between the coalescing fans.	50-100 cm	Same as alluvial fan but with fine-textured soil between two coalescing fans.	Same as alluvial fans; poorly drained at the depression between two coalescing fans.	Same as alluvial fans; subsurface water may also be available at the depression between two coalescing fans.	Water may accumulate at the margin of fans and at depressions between two coalescing fans.	Usually sugarcane on cultivated portions, grass and savannah on uncultivated portions; some paddy rice on margins and depressions.	Tree crops, sugarcane, paddy rice at lower margins and depressions.
Interhill basin	Land surrounded by uplands; largest interhill basin is in Gadu; 1,180 ha; mapped.	Depressional area; level to slightly sloping area, surrounded by highland or upland.	>100 cm	Clay loam to clay.	Somewhat poorly drained.	No major streams; several small, intermittent streams, subsurface water available for pump irrigation.	Seasonally flooded.	Usually paddy rice.	Paddy rice and maize, tobacco, mungbean, vegetables.

Table 8. Predominant characteristics of landform units in the plain land system of the Central River Basin.

Landform units	Location/hectarage	Topography	Soil: Depth of solum	Soil: Texture	Soil: Drainage
Interfluve	Relatively level area between two valleys or two stream channels, of varying width and areal extent; occurs in all parts of Cagayan River basin but significant in the plain, hill, and mountain land systems; in river cut plain subsystem; not mapped	An elevated, relatively level to slightly undulating area between two valleys or stream channels; elevation ranges from 30 to 100 meters.	50-100 cm	Clay loam to clay	Moderately to somewhat poorly drained
Drainage	Narrow but elongated depressed areas surrounded by uplands in the river cut plain subsystems; not mapped	Drains of various widths are found with elevations lower than the surrounding uplands	50-100 cm	Clay loam to clay	Poorly drained
Bench/ terrace	Develops on the side of valleys the river cut plain subsystem; not mapped	Relatively flat or gently sloping surface bounded by a steeper ascending slope on one side and by a steeper descending slope on the opposite side	50-100 cm	Clay loam to clay	Moderately well drained
Alluvial fan	Develops where rapid streams emerge from highlands onto lowlands in river-cut plain subsystem; not mapped	Surface slopes smoothly from highland toward lowland; also slopes laterally forming a convex surface	50 cm	Silty clay loam to clay loam; presence of few waterworn gravels and stones on the surface	Moderately well drained

Table 8 (continuation)

Landform units	Water availability (surface and subsurface)	Flood hazard	Existing land use	Use suitability
Interfluve	No major streams; surface water available onlu during rainy season; subsurface water available at some depth but very difficult to obtain because of high tension exhibited by the soil	None	Generally grass and savannah; cultivated area is predominantly sugar cane	Most upland field crops, including cotton
Drainage	Surface water often available as ponded water; surbsurface water moderately available	Ponded water accumulates after heavy rain	Cultivated area is predominantly paddy rice	Paddy rice, farm ponds
Bench/ terrace	Few or no surface water channels; subsurface water not available.	None	Grass and savannah; rainfed rice in cultivated area	Paddy rice
Alluvial fan	Few small surface drains; subsurface water usually available at the margins of fans	None except at margins where rain water may accumulate briefly	Usually savannah; cultivated area is predominantly sugarcane; few rice paddies built near margins of fans	Tree crops

shortcoming of the underlying structure of the hierarchal system. During field studies and air photo interpretation, however, it was clear that for most agriculturally important land, differences among land surface units within a landform unit were not major factors that affected land use. Moreover, in comparison to locating boundaries between units in higher categories, the boundaries between land surface units within a landform unit were more difficult to locate, both

Table 9. Predominant characteristics of landform units in the hill land system of the Cagayan River Basin.

Landform units	Location/hectarage	Topography	Soil: Depth of solum	Soil: Texture	Soil: Drainage
Peak	Highest part of the hill land system; not mapped	Highest elevation in the ridge/ summit land subsystem; has concave on level surfaces; has isolated, elongated, oval or circular clsoed contour lines	50 cm	Generally coarse textured exposed rock fragments gravelly or stony ground surface	Well drained
Bench/ terrace	Occurs on hillside on the hillslope landsystem; not mapped	Relatively flat or gently sloping surface bounded by steeper ascending slope on one side and by a steeper descending slope on the opposite side	50 cm	Usually clay loam intermixed with gravel and stone in various stages of weathering	Moderately well drained except in the puddled soil on rice paddies
Interfluve	Area between two stream channels on the hillslope land subsystems; not mapped	Narrow, relatively steep area between two stream channels	50 cm	Usually loam with gravels, stones, and rock fragments on the surface	Moderately well drained
Valley floor	Bottomland in the hillslope land subsystem, not mapped	Relatively flat, discontinuous small area	50-100 cm	Silty clay loam to clay loam over clay loam to clay subsoil	Somewhat poorly drained

Peak	Intermittent, unbranched tributaries, subsurface water not available	None	Grass, savannah, and forest.	Forest
Bench/ terrace	Surface water available from intermittent streams; surbsurface water available from a few seepate points	None	A few small areas are utilized for paddy rice; uncultivated parts usually grassed or forested	Forest
Interfluve	Water not available	None	Grass and savannah	Forest
Valley floor	Has minor but usually continuous stream flow; seasonally high ground water	Periodically flooded	Grass and shrub in uncultivated portion; paddy rice in the cultivated area	Paddy rice and other field crops

in the field and on air photos. Because of the uncertainty in locating the boundaries and the limited improvement that separation of land surface units imparted to interpretation, the description and identification of land surface units was de-emphasized for the study. Although an interest was retained in the land surface unit, mapping of classes in this category was considered and important only for special studies.

Two factors may contribute to the greater diversity of landform units recognized in the alluvial land system. First, numerous elementary land-shaping processes are found in the denudational-aggradational complexes operating in the alluvial land system. The denudational-aggradational complexes operating in the plain, hill, and mountain land systems are simpler by virtue of containing fewer elementary processes, mostly of a denudational type, although lithologies on which these processes act are more diverse. Nevertheless, the greater complexity of processes operating in the alluvial land system is reckoned to be a factor causing more landform unit classes to appear in the alluvial land system than in the other three. Second, because of the agricultural importance of the alluvial land system, greater attention may have been given subconsciously to establishing differentiating criteria among landforms within the alluvial area. Some of the landforms described in the plain, hill, and mountain land systems may be landform complexes that would likely be further subdivided if the same degree of refinement were applied to differentiating criteria.

Regardless of the relative contributions of these two factors toward the numeric differences in landform classes within the land systems, the pre-

Table 10. Predominant characteristics of landform units in the mountain land system of the Cagayan River Basin.

Landform units	Location/hectarage	Topography	Soil: Depth of solum	Soil: Texture	Soil: Drainage
Plateau	At elevation of more than 300 m on the ridge/summit land subsystem of the mountain land system; occur on the mountain areas of Nueva Viscaya, Isabela, and Cagayan; not mapped	Level to gently sloping with minor irregularities; has on at least one side of an abrupt descent to lower landscapes	50-100 Over slightly weathered igneous rock (basalt, andresite)	Silty clay loam to clay	Moderately well drained
Peak	At highest elevation on the ridge/summit land subsystem; not mapped	Steep slopes, regular, continuous ridges; becoming steeper at upper margins	50 cm Rock outcrops are common	Loam	Well drained
Bench/terrace	Many parts in the mountain side landsubsystem; not mapped	Relatively flat; narrow, bounded by steeper ascending slope on one side and by descending slope on the opposite side	50 cm	Clay loam over moderately weathered volcanic rocks	Moderately well
Talus slope/land slump	Talus slope is an accumulation of soil, rock fragments boulders, gravels at the foot of a cliff or very steep mountain side; the movement is usually due to gravity aggravated by water saturation during rainy periods; land slumps occur at any place on very steep mountain sides; not mapped	Complex convex shape with microrelief irregularities brought about by accumulation of boulders and rock fragments	No soil profile	Unconsolidated materials	Excessively well
Interfluve	Relatively narrow area between two stream tributaries flowing in the same direction in a mountainside land subsystem; not mapped	Straight sided with moderate slopes; gently rounded crest	50 cm	Loam over weathered fragments	Well drained
Intermontane	Narrow, usually small areal extent, depression surrounded by mountains; not mapped	Basin shape, flat with concave margin	50-100 cm	Sandy loam to silty loam over clay loam sandly clay loam	Moderately well

Table 10 (continuation)

Landform unit	Water availability (Surface and subsurface)	Flood hazard	Existing land use	Use stability
Plateau	No major streams; mostly intermittent tributaries; streams incised deeply subsurface water virtually unavailable or if any, in very localized aquifers	None	Paddy rice, upland field crops and tree crop in the cultivated areas; grasses and savannah vegetation in the uncultivated portion	Paddy rice if irrigation water is available, upland crops, tree crops
Peak	Unbranched tributaries; subsurface water unavailable	None	Forest	Forest
Bench/terrace	Few intermittent streams; subsurface water generally not available except from seepage	None	Paddy rice; grasses and savannah	Forest

Continued on next page.

Table 10. Continued.

Landform unit	Water availability (surface and subsurface)	Flood hazard	Existing land use	Use stability
Talus slope/ land slump	Surface drainage develops rapid flow	None, but serious erosion and/or mass wasting	Usually very sparse or none	Forest
Interfluve	Surface water available from the streams below; surbsurface water not available	None	Grasses, savannah vegetation,	Forest
Inter-montane	Locally narrow stream channel; usually with waterflowing throughout the year; subsurface water generally available	Periodically flooded, briefly	Paddy rice in cultivated areas; very sparse grass and shrub in uncultivated intermontane	Short-season upland crops; or forest

sent hierarchal system appeared adequate for use in conjuction with rice-based cropping systems research. The differentiating criteria separating landform units should be reviewed, however, before they are applied in research and planning activities for other land systems.

Aids to landform recognition

To assist agricultural scientists and technicians with the recognition of landforms in the Cagayan River Basin, photos and stereograms showing representative landform units and their patterns of occurrence in land subsystems, are presented. These aids to landform recognition are restricted, however, to land of current or potential agricultural importance; landforms in the mountain land system are excluded.

Alluvial land system. The stereogram in Figure 4 shows several landforms in the alluvial plain and alluvial-colluvial land subsystems. The river loop has cut the boundary between the alluvial and hill land systems. Components of a hillslope land subsystem are visible in the lower portion of the stereogram.

Recent river terraces, a large recently deposited sand bar, a small backswamp, and an alluvial terrace are visible in Figure 5. In Figure 6, a large backswamp can be seen between a recent river terrace and the edge of a river-cut plain land subsystem.

First-, second-, and third-level recent river terraces are visible in Figure 7. The ground-level photograph in Figure 8 shows the coarse-textured soil on a first-level terrace. At the time of photographing, the land had been plowed and harrowed in preparation for planting maize. Light-colored areas are evidence of sandy material deposited by floodwater 2 months before the photo was taken.

An alluvial terrace, a point-bar deposit, and a small river scar are shown in Figure 9. A closer view of a larger river scar is shown in Figure 10. Components of a hillslope land subsystem are visible in the background. Between the hills and the

Fig. 4. Stereogram showing selected landform units in alluvial plain and alluvial-colluvial land subsystems: point bar deposits (1); sand bar (2); three levels of recent river terrace (3,4,5); convex and concave slopes of second-level recent river terrace (6,7); lower and upper slopes of piedmont alluvial plain (8,9); and small portion of an alluvial plain landform unit (11). Bench/terrace landform units of a hillslope land subsystem are visible (12), and a highly eroded series of small, steep interfluves and valley floors (10) are found between the bench/terrace and the piedmont alluvial plain.

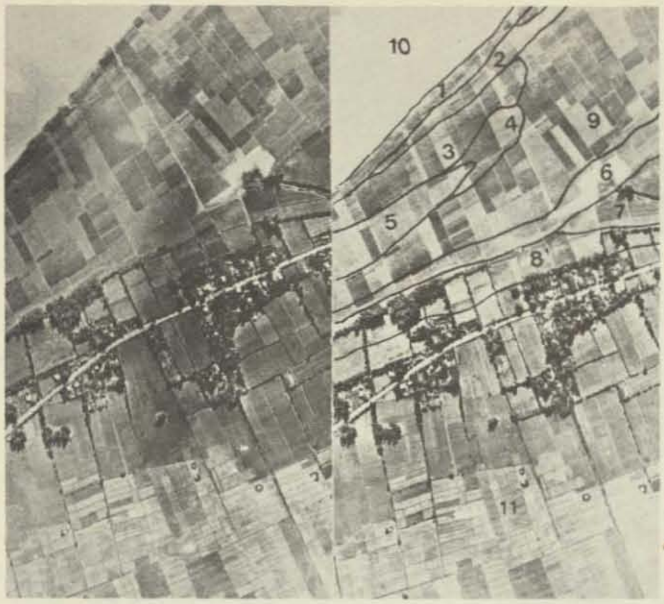


Fig. 5. Various landform and land surface units are shown on this stereogram: concave descending slope (1) of the first-level recent river terrace, concave slope (2), convex slope (3), slight sloping (4), concave slope (5), and a level land (9) with little microrelief on the second-level river terrace; a concave ascending slope (8) flanks level land on the third-level river terrace (7), a small backswamp is found between the second- and third-level river terraces (6); an alluvial terrace landform unit is found above the third-level river terrace (11); a sand bar developed along the Cagayan River is visible (10).

Fig. 6. Inner section of backswamp (1) still waterlogged while the outer section (2) is shallow enough for rice cultivation; upland crops (mungbean, maize, and tobacco) are grown on a second-level recent river terrace (3); scattered tree and shrub vegetation cover the river-cut plain land subsystem (4).

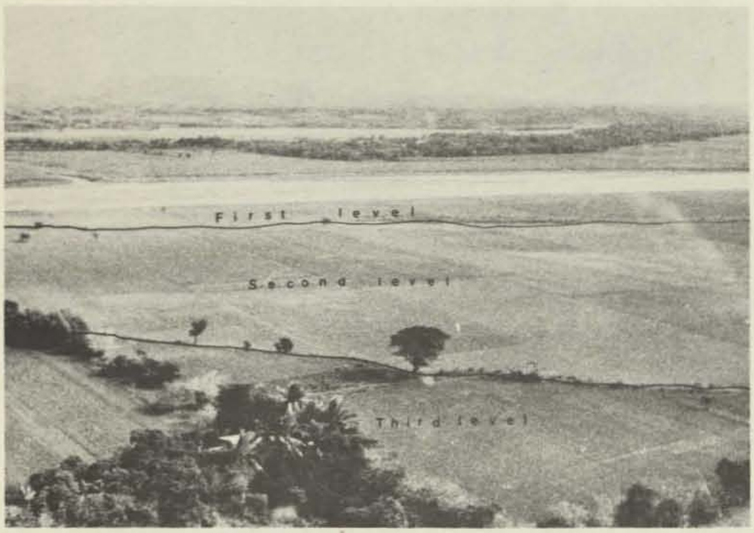


Fig. 7. First-, second-, and third-level recent river terraces.

Fig. 8. Recent river terrace (first level) and newly formed small sand bar next to the river. Light spots are surface sand deposits from an October 1980 flood.

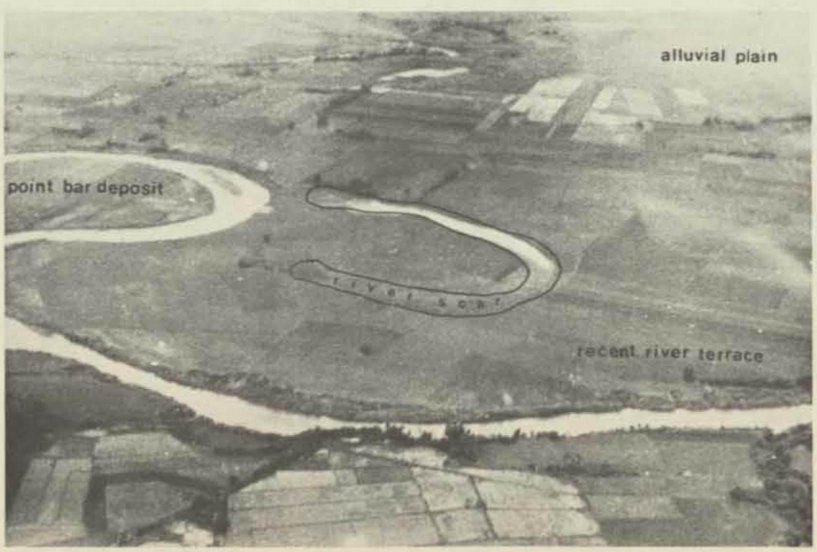


Fig. 9. Alluvial terrace, river scar, point bar deposit, and recent river terrace landform units of alluvial plain subsystem.

Fig. 10. River scar landform unit in an alluvial land subsystem (1); rice is grown in the shallower portions of the river scar; a series of interfluves and valley floors (2) of a hillslope land subsystem is visible at the top of the photograph; a piedmont alluvial plain (3) appears below the hillslope land subsystem, and recent river terraces (4) are found between the piedmont alluvial plain and the river scar.

river scar, strips of piedmont alluvial plains and recent river terraces are visible.

Interhill miniplains and alluvial fans can be seen among components of hillslope and river-cut plain land subsystems in the stereogram of Figure 11. Interhill miniplains may originate as valley bottoms in hillslope land subsystems or as drainageways in river-cut plain land subsystems, and pass through alluvial-colluvial land subsystems as interhill miniplains. At lower elevations, they coalesce with large alluvial terraces in the alluvial plain land subsystem. Between either hillslope land subsystems or the river-cut plain land subsystems and the alluvial-colluvial land subsystem, the boundary separating interhill miniplains and valley bottom or drainageway landforms becomes difficult to locate precisely. The continuum of the drainage system from a hill landsystem, through a plain land system to an alluvial land system, is illustrated in Figure 12. In this photo, the plain land system consists of a narrow band between the alluvial land system and the hill land system.

Fig. 11. Rice fields on an interhill miniplain (1) and sugarcane on an alluvial fan (2) landform unit of the alluvial-colluvial land subsystem; a small section of a river-cut plain land subsystem with sugarcane is visible (3); portions of a hill land system covered with savannah vegetation are also visible (4).

Plain land system. The stereogram in Figure 13 shows a large drainageway and an interfluve in a river-cut plain land subsystem bordering components of a hillslope land subsystem.

Rice fields on several medium to small drainageways are found among interfluves as seen in Figure 14. In Figure 15, a series of rice fields is seen on a large drainageway.

Fig. 12. Three land systems are represented – alluvial, plain, and hill land systems covered with wetland rice, sugarcane, and savannah vegetation. As shown in this photograph, streams draining onto interhill miniplains may originate in valley bottoms of the hill land system and pass through drainageways of a plain land system before entering the alluvial land system.

Fig. 13. A swamp and rice fields (1,6) are found on a large drainageway, sugarcane is found on a bench/terrace (3) and grasslands are found on small interfluves (2) of a rivercut plain land subsystem; valley floor (5) and a series of small interfluves (4) are found on a hillslope land subsystem.

Fig. 14. Rice fields on medium and small drainageways of a river-cut plain land subsystem.

Fig. 15. Rice fields on small (lower left) and large (center) drainageways of a river-cut plain.

Hill land system. Ridges and summits, interfluves, and valley floors are visible in the stereogram in Figure 16. Examples of these landforms are also visible in Figure 17. Two isolated peak landform units are shown in Figure 18.

The stereogram in Figure 19 shows the complex pattern of landforms at a boundary between a hill land system and an alluvial land system. Only a small portion of land in the hill land system has been terraced for rice production. Alluvial-colluvial materials deposited as alluvial fans and piedmont alluvial plains at the base of the hills have been developed for crop production. The piedmont alluvial plain shown in Figure 20 has been left in grass and shrub vegetation.

Cluster analysis

To obtain an exploratory but objective test of the landform classification, alternative clustering procedures were applied to soil profile data. Of the alternative procedures compared, all except the nearest-neighbor fusion applied to a similarity matrix from standardized scores of 17 varia-

Fig. 16. Hill land system showing valley floor (1), interfluves (2), and peak landform units (3).

Fig. 17. Valley floor, interfluve, and peak landform units in hill land system. Hills are eroded sedimentary deposits.

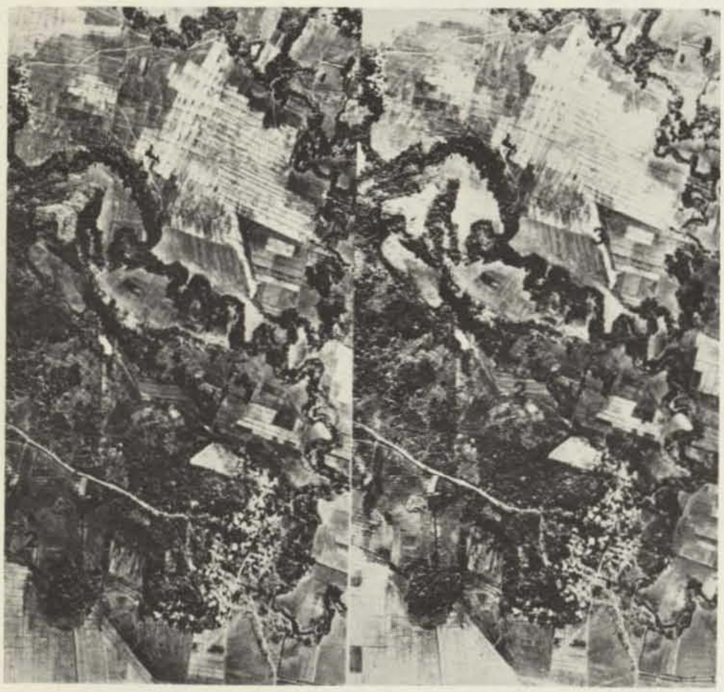


Fig. 18. Two isolated peak landform units of ridge/summit land subsystem.

Fig. 19. Rice fields on alluvial plain landform unit (1,3) and on concave slope of hillslope landform unit (2).

Fig. 20. Piedmont alluvial plain landform unit developed at the foothills.

bles, yielded almost identical dendrograms. Even the nearest-neighbor fusion method created similar clusters provided that clusters were recognized at several fusion levels. The nearest-neighbor method exhibited chaining, which is a common characteristic of this fusion procedure (Webster 1977, de Gruijters 1978).

Because Ward's method applied to a similarity matrix from 17 variables resulted in dendrograms that were almost identical with those obtained from 33 variables after principle component analysis as an intermediate step, the discussion in the remainder of this section will concentrate only on the results from Ward's method applied to the smaller set of variables. The dendrogram generated by this analysis is shown in Figure 21. Clusters below a similarity coefficient level of 2.5 show a clear tendency to place profiles into clusters with soils from the same landform units.

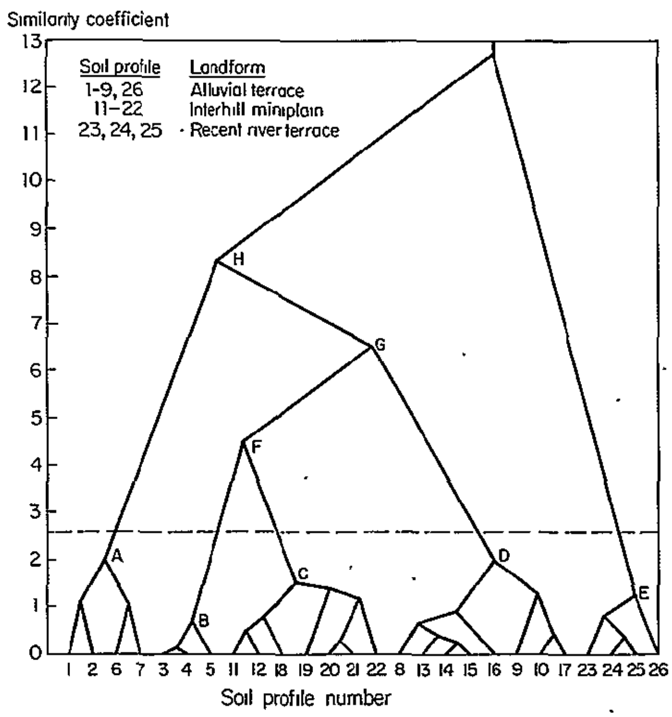


Fig. 21. Dendrogram of 26 soil profiles from Ward's fusion method applied to euclidean metric computed from standardized scores of 17 soil variables. Letters A through H are discussed in the text.

The 7 profiles below nodes A and B came from the 10 positions originally classified as alluvial terraces. Profiles 8 and 9, however, had characteristics that placed them below node D in a cluster containing profiles from interhill miniplains. Both profiles 8 and 9 came from a large alluvial terrace area, but were located at positions where they were periodically influenced by floodwater from a small river draining land in hill and plain land systems. Water from these floods may have deposited material with characteristics similar to the colluvial and alluvial material commonly deposited on interhill miniplains. The remaining profiles below node D, and all profiles below node C, were obtained from interhill miniplain landform units.

Profile 26 was found below node E in a cluster with 3 profiles obtained from recent river terrace landform units. Profile 26 was, however, near a boundary between an alluvial terrace landform unit and a recent river terrace, similar to the land between positions 8 and 11 in Figure 5. Inspection of the profile description and chemical and physical analyses showed that the profile clearly had soil characteristics commonly associated with recent river terrace landform units. The mean values of selected variables, as shown in Table 10, indicate that the profiles in the recent river terrace cluster (below node E) had fewer recognizable horizons and less clay, organic carbon, and total nitrogen than profiles from alluvial terrace or interhill miniplain landforms. Clay content, organic carbon, and total nitrogen as separated below node E, should be closely associated with the physical properties (plastic limit, soil strength, and matric suction) reported by Webster (1977) to covary with land classes based on terrain features. Among profiles from the alluvial terrace and interhill miniplain landforms, however, chemical variables, associated with the source or age (or both) of material perhaps were apparent factors differentiating the clusters.

From Table 8, it is apparent that among the profiles from alluvial terrace and interhill miniplain landform units, (clusters A, B, C, D) the values of many variables overlapped. This overlapping is reflected in the pattern of fusion. As shown in Figure 21, nodes B and C fused to form node F, and nodes F and D fused to form node G. Node G contained all profiles from interhill miniplain landform units and half of the profiles from alluvial terrace landform units. Node A fused with Node G at H. As expected, the profiles below E remained separated until the last fusion.

The early fusion of profiles from the alluvial terrace and interhill miniplain landform units was not surprising. Soils on these two landform units have developed by similar processes. The almost identical agricultural use of these landform units (one traditional rice crop transplanted in August-September and harvested in January-February) also suggested that the soil properties would be similar. The agricultural use of alluvial terrace and interhill miniplain landform units contrasts with the recent river terraces, which are regularly flooded between August and November. Two dryland crops are planted on the recent river terraces, one from December to March and a second from April to July.

On the basis of the small set of profiles in this analysis, a correspondence between soil characteristics and landform units was found, but as expected, profiles from alluvial terrace and interhill miniplain landform units were more similar to each other than to soils from recent river terrace landform units.

CONCLUSIONS

Land is the dominant physical resource used in agriculture, and soil and landscape characteristics strongly influence the type and productivity of crop production enterprises practiced on a given tract of land. Knowledge of the nature and suitability of land for alternative use is important to cropping systems scientists working in support of regional agricultural projects. A land inventory can help scientists identify and quantify land in different land classes and improve the focus of cropping systems research projects. Furthermore, by identifying land areas with features similar to land on which research is being conducted, a classification system can be used to delineate target areas for crop production programs.

Our review of pedologic and geomorphologic literature before our field studies supported the notion that within an area under a single climatic regime, parallel land-shaping and soil-forming processes result in a high correlation between the patterns of landforms and soils found over a landscape. Because landforms are readily observable, a land classification system in which terrain features at several levels of complexity are recognized and mapped can be used to inventory land resources. The correlation between major geologic features, lithologies, and geomorphic and pedologic processes has been used to formulate several hierarchal land classification systems that have been applied in various countries. At the high categoric levels of these systems, terrain features are used to isolate areas formed by similar major geologic processes. At intermediate hierarchal levels, terrain features are used to recognize areas that exhibit similarities in lithologic features and complexes of aggradational-denudational geomorphic processes. At lower categoric levels, terrain features are used to identify landforms that are products of a single or a small set of elementary geomorphic processes.

Most land classification systems have included 3 to 5 categories in their hierarchal structures. For the Cagayan River Basin study, a system containing 4 categories was formulated: land system, land subsystem, landform unit, and land surface unit. Four land systems were recognized: alluvial, plain hill, and mountain. Nine land subsystems were defined and mapped. Thirty landform units were recognized but because rice production is concentrated on alluvial land, only landform units within the alluvial land system were mapped. Initially, a total of 75 land surface units were identified and defined but were neither described in detail nor mapped. At the land surface level, mapped areas became small and boundaries between mapping units were gradual and therefore difficult to locate accurately.

A cluster analysis of soil profiles sampled from alluvial terrace and interhill miniplain landform units showed that at low levels of fusion, separate clusters were maintained for profiles from the same landform unit. From the pattern of fusion, it was concluded that at least for a small number of soil profiles, the cluster analysis supported the presence of a correlation between landform units and soil properties.

Although the hierarchal system appeared to be a satisfactory approach to land classification in the Cagayan River Basin, procedures used to formulate the hierarchal system and define the terrain units within each category should be evaluated in other regions. Additional studies are needed, in the Cagayan River Basin and elsewhere, to determine the degree of correspondence between landform units and soil characteristics, and the correspondence between these soil properties and crop adaptation.

Although air photos were used extensively to aid in mapping, especially beyond the limits of the initial study area, it was apparent that for areas in the order of 200,000 to 300,000 ha, useful maps could easily be obtained from a set of large-scale topographic maps and systematic field visits. Where possible, light aircraft could be used to increase mapping rate and accuracy. To determine the feasibility of classifying landforms in a 200,000-ha tract without the aid of stereographic coverage, a small comparative study should be conducted. At the other end of the spectrum, where landform classification of areas in excess of 1,000,000 ha is required, the possible contribution that computer processing of LANDSAT data can make toward land classification and mapping should be determined. By virtue of a high correlation between terrain features and natural vegetative or agroecological complexes, several computer processing methods may aid in the identification of terrain units within areas pre-stratified on the basis of land systems or land subsystems.

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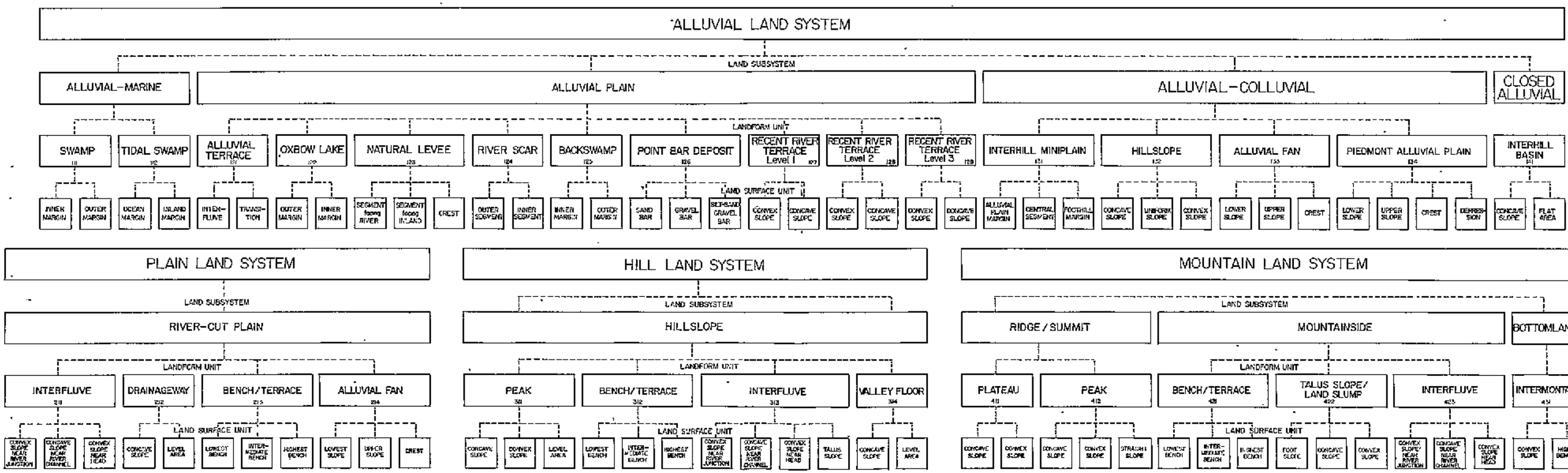

Fig. 1. Terrain classes within the land system, land subsystem, and landform unit categories of the Cagayan River Basin landform classification system. Mapping unit codes are shown for landform unit terrain classes.