No. 47

REPUBLIC OF PARAGUAY
MINISTRY OF AGRICULTURE AND LIVESTOCK

LAND CONDITION STUDY

FOR THE MASTER PLAN ON THE IRRIGATION AND DRAINAGE PROJECT IN THE ADJACENT AREA TO THE YACYRETA DAM

MARCH 1984

JAPAN INTERNATIONAL
COOPERATION AGENCY

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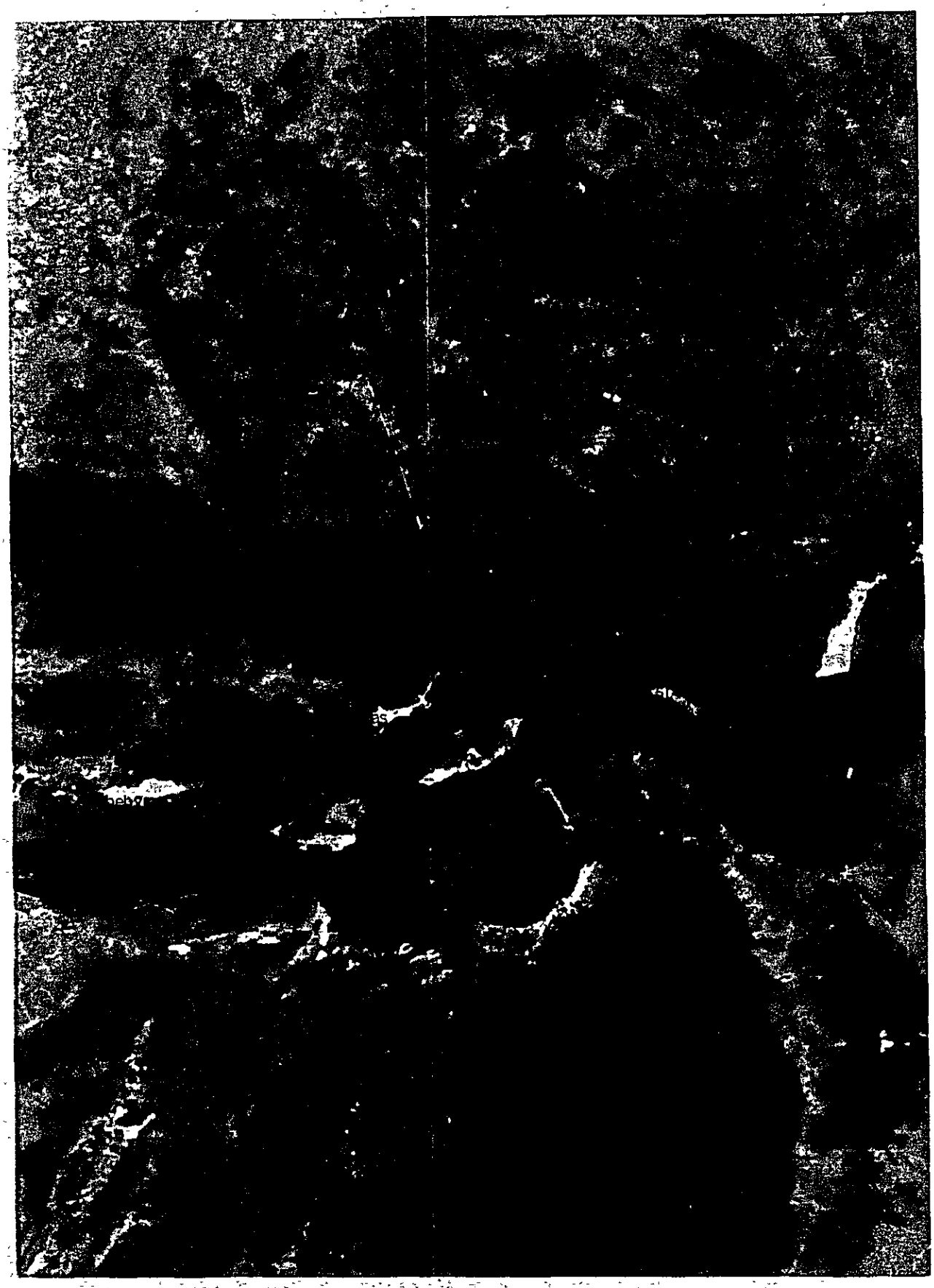


LANDSAT False Color Imagery for the
Adjacent area to the YACYRETA DAM

PREFACE

It is with great pleasure that I present to the Government of the Republic of Paraguay this report entitled Land Condition Study for the Master Plan on the Irrigation and Drainage Project in the Adjacent Area to the Yacyreta Dam.

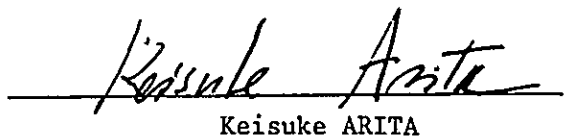
This report embodies the result of a land condition study on the master plan which was carried out from January to March, 1983 and from August, 1983 to March, 1984 by a Japanese survey team commissioned by the Japan International Cooperation Agency following the request of the Government of Paraguay to the Government of Japan.

The Survey team, headed by Dr. Ryohei IMAMURA of Kokusai Kogyo Co., Ltd., had a series of close discussions with the officials concerned of the Government of Paraguay and conducted a wide scope of field survey and data analyses.

I hope that this report will be useful as a basic reference for development of the Project.

I wish to express my deep appreciation to the officials concerned of the Government of Paraguay for their close cooperation extended to the Japanese team.

March, 1984



Keisuke ARITA

President

Japan International Cooperation Agency

SUMMARY

This study, including the interpretation of LANDSAT false color imagery (both analog and digital images), reading and measurement of landform maps, application of available data and field survey, was carried out for the purpose of the preparation of various types of preliminary maps and the land classification which will be used as the basic data for the preparation of the general agricultural development plan for the Adjacent Area to the Yacyreta Dam in Paraguay. The area covered in this plan is the land of approximately 200,000 ha with an elevation of less than about 90 m in the area adjacent to the dam site. Although most of the area is presently a swampy lowland, it seems that the land could be fully used as an agricultural land only by the improvement of the land by drainage because of the topographically and climatologically favorable conditions of the area. Various types of preliminary maps including ones for the change of the land cover, change in the ponding condition, geomorphology, elevation classification, slope aspects, slope classification, relief energy, present land use, vegetation distribution, agricultural form, soil classification, subsurface geology, etc. were prepared as the basic data for the preparation of the agricultural development plan and the land classification was performed by the use of these results.

(1) There is not significant change in the overall land cover of the studied area after 1972. Only some significant changes include the bridge connecting Ayolas and the Yacyreta Island, an airfield located to the northwest of Ayolas, and the access road to the dam site.

(2) There are several areas in the studied area which are ponded throughout the wet and dry seasons. In wet years, most of the swampy lowland in the studied area was found to be ponded .

(3) The landforms in the studied area were classified into hill land, gentle slopes (colluvial slopes, alluvial cones, gently-sloped fans), swampy lowlands, slightly-elevated lands (natural levees, sand bars, sand dunes) and so on.

(4) The elevation of the studied area ranges from 55 m to 120 m, and the elevation class of 70 m to 80 m occupies about 80% of the total area, of which most of the land is the back swamp.

(5) Slope aspects were expressed in 8 directions with the north used as the axis direction. South to west facing slopes generally prevail in the study area.

(6) Slopes were divided into 5 classes, that is, less than 1°, 1-3°, 3-5°, 5-8°, and greater than 8°. It was found that most of the studied area is in the class of less than 1° of flat.

(7) Relief energy was divided into 6 classes in the interval of 5 m, that is, less than 5 m, 5-10 m, and so on. The most of the studied area is included in the class of less than 5 m and hill land were in the class of 10-15 m.

(8) The land use types were classified into 10 types, that is, natural forest, artificial forest, dry (xeric) grassland, wet (hydric) grassalnd, artificial grassland, paddy field, crop field, swamp, river, pond, and others. The wet grassland and swamps occupied the most of the studied area.

(9) The forest types in the study area were classified into hill land, micro relief forest, table land forest (forest on natural levees), river land forest (tall trees) and river land forest (low trees). The river land forest is clustered along the Atinguy River and scattered along the Parana River and the Yabebyry River. Forest types on the micro relief are the small ones scattered in considerably large number on micro relief distributed in swampy lowlands. Table land forest and hill land forest types are widely distributed on natural levees along the Parana River and in hills in the north of the study area, respectively.

(10) The type of agriculture in the studied area is mainly extensive pasture, and paddy fields and crop fields are distributed only in limited areas.

(11) The soil types in the studied area were first classified into fluvisols, gleysols, regosols, planosols, and acrisols according to the FAO criteria. Based on the chemical analysis and the field survey, gleysols, regosols and planosols were subdivided into fine-textured and coarse-textured gleysols, fine-textured and coarse-textured regosols, humic planosols, and planosols. The distribution of soils is characterized by the acrisols in hill lands, planosols and gleysols in the swampy lowland, fluvisols in the lowland along rivers, regosols on natural levees, micro relief and at the margin of hill lands. However, planosols are observed in most of the studied area.

(12) The subsurface geology of the studied area is characterized by sand, silt and clay of the alluvial and colluvial deposits in the lowland, sandstone in the hill lands in the north of the studied area forming a bedrock, muddy sandstone in the hill lands in the east of the studied area, and sandstone, forming a bedrock, on micro relief distributed between Ayolas and the Yabebyry River.

(13) The land was evaluated for classification according to the following four aspects:

1) The land productivity (soil productivity, land productivity based on landform conditions)
2) Safety of land (danger of ponding and flooding),
3) Land development (easiness of forest clearance)
4) Land use potentiality based on physical conditions

The results of the classification show that lands suitable for paddy fields exist on the northern side of an imaginary line connecting the central portion in the east of the studied area and hill lands in the

northwest of the studied area. It is expected that the central part in the west of the studied area could be changed to a place suitable for paddy fields by the land improvement of drainage. These two places occupy the majority of the studied area. Lands suitable for crop fields are distributed at margins of hill lands, on hill lands and on natural levees along the Parana River, the Atinguy River and the Yabebyry River, which occupy about one-third of the total studied area.

Staff Members of the Study

RYOHEI IMAMURA	- Overall responsibility
YOSHITSUGU AKAZAWA	- Land evaluation, vegetation, land use
SHUHEI MIYAKE	- Soils, landform, geology
MASAHIRO SETOJIMA	- Remote sensing, land classification
MAKOTO KANAZAWA	- Interpretation of aerial photographs, remote sensing
HITOSHI ARAKAWA	- Processes of land classification

LAND CONDITION STUDY FOR THE MASTER PLAN ON THE IRRIGATION AND DRAINAGE PROJECT IN THE ADJACENT AREA TO THE YACYRETA DAM, REPUBLIC OF PARAGUAY.

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CHAPTER 1 GENERAL DESCRIPTION OF THE STUDY

1.1 Objective

The study was conducted for two years, as one of the operations for the preparation of the master plan of the general agricultural development project in the neighboring district of the Yacyreta Dam, for the purpose of making various types of preliminary maps.

1.2 General Description of the Studied Area

The studied area, approximately 300 km southeast of Asuncion, capital of Paraguay, covers about 200,000 ha along the Parana River between San Cosme and the Yabebyry River (Figure 1).

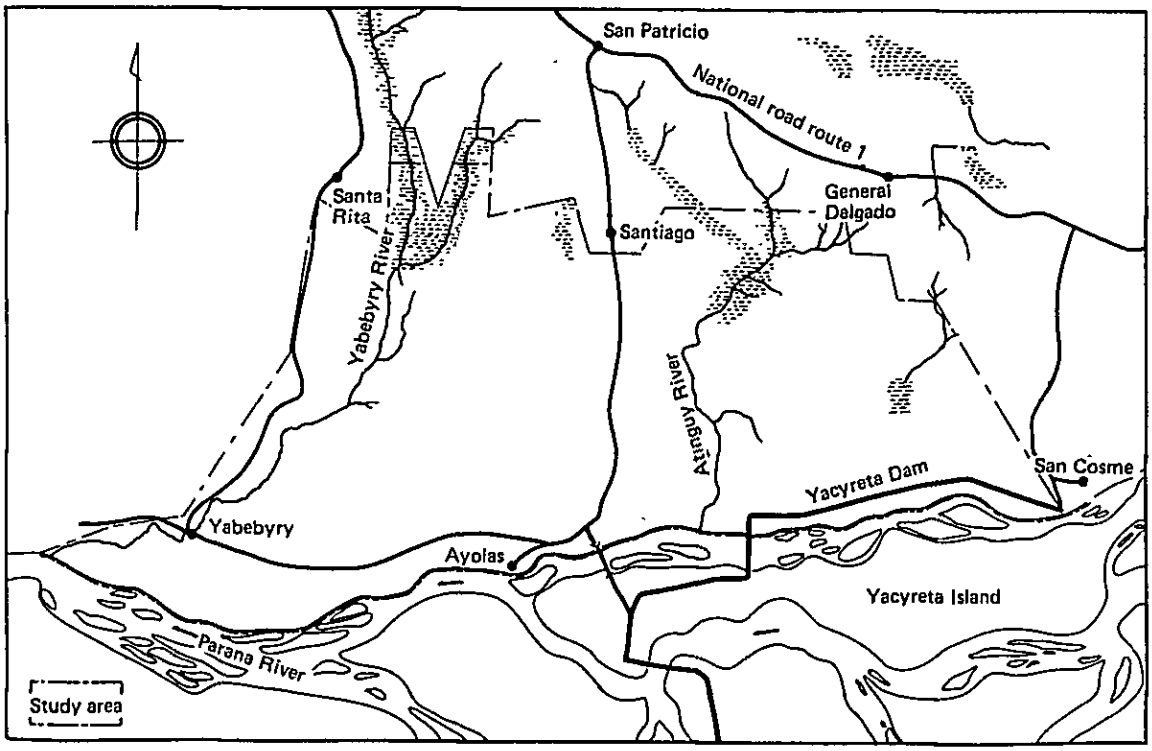


Fig. 1 Map of the Study Area

The area, located in the southeast of a swampy land behind the right bank of the Parana River, is bounded on the east by the foot of a hill land where an urban area of San Cosme is located, on the west by the Yabebyry River and on the south by the Parana River. Located about 70 km to the east of the studied area is Encarnacion, the third largest city in Paraguay. Small cities, such as Ayolas, San Cosme, Santiago, etc. are also located in the vicinity of the studied area.

With the national highway route 1 running east-west in the north of the studied area and the access road for the construction of the Yacyreta Dam crossing it at right angles, the area has a traffic advantage.

Climatically, the area belongs to one of the wettest areas in Paraguay. According to the climatological data* from 1971 to 1980, the Yacyreta district has an annual mean rainfall of 1,515 mm with the minimum amount of rainfall occurring in many places in July through September. Temperature changes greatly in a year, with the daily maximum temperature rising to higher than 40°C in July and the daily minimum temperature sometimes dropping to below 0°C in winter, although the daily maximum temperature in winter sometimes rises to above 30°C.

The landform of the area is a flat land gently sloped to the southwest, except for the foot of a hill land in the east where the city of San Cosme is located, and the lowland is a great swamp land. The soil type in the area is sandy along the Parana River and clayey in the hill land area. The intermediate type of soil is distributed in the swamps.

The type of present land use in the area is mostly extensive pasture land with paddy rice production in limited areas. Pasture is often located in swampy lands.

* Data from the Meteorological Department, Ministry of National Defense.

1.3 Methods and Studied Items

The actual items studied in the present investigation are shown in Figure 2.

1.3.1 The first-year study

The first-year study consists mainly of the preparation operation of the basic data in Japan for the field investigation to be performed in the second-year study. For the understanding of physical conditions of the studied are , the following preliminary maps were prepared, based on the interpretation of LANDSAT false color imagery and the interpretation and measurement of landform maps.

1) 1:500,000-scale map for the change in the ground cover
2) 1:500,000-scale map for the change in ponding conditions
3) 1:50,000-scale map for the classification of elevation
4) 1:50,000-scale map of slope aspects
5) 1:50,000-scale map for the classification of slopes
6) 1:50,000-scale map of relief energy
7) 1:50,000-scale map of land use
8) 1:50,000-scale map of the vegetation of vegetation
9) 1:50,000-scale map for the classification of the agricultural form
10) 1:50,000-scale map for the classification of landforms
11) 1:50,000-scale map of soils
12) 1:50,000-scale map of surface geology

Study year	Contents of study	Study items	Used data	Study method	Study results: Preliminary maps	Study results: Map for the evaluation of classification	Analysis and conclusion
First year	(1) Preparation of preliminary maps based on the interpretation of the LANDSAT imagery, etc. (Examination of accuracy in the second-year study) (2) Study of general conditions of the study area covered in (1) (3) Preparation of the draft second-year study plan (4) Preparation of the study report (interim)	1. Arrangement of basic maps for the study	Landform maps (1:50,000)	Landform maps at the scale of 1:10,000 will be reduced and compiled for areas for which they are available, based on the already produced 1:50,000-scale landform maps	Preparation of base maps for the study (Landform maps at the scale of 1:50,000)		
		2. Preparation of false color composite images from LANDSAT data	LANDSAT imagery (70 mm positive films)	LANDSAT false color composite imagery (Seasonal change in land cover; seasonal change in ponding)	1:500,000-scale LANDSAT color imagery • Map showing the seasonal change in the ground cover • Map showing the seasonal change of the ponding area		
		3. Preparation of preliminary maps		Basically interpretation of LANDSAT false color images	Agricultural form classification map Vegetation map 1:50,000-scale land use map		
				Basically classification of surface conditions based on the interpretation of landform maps	Subsurface geological map Soil map 1:50,000-scale geomorphological map		
				Landform analysis by means of the measurement of landform maps maps	Relief energy map Slope classification map Slope aspect map 1:50,000-scale elevation classification map		Interim report
Second year	(1) Examination, by means of the field study, or preliminary maps prepared in the prepared in the first-year study (2) Completion of preliminary maps (3) Classification of land (4) Preparation of the final report	1. Preparation of base maps for the study	Mapping of base maps for the study (Western side of the studied area	Drawing operations by plotters [The western part of the study area will be drawn at the scale of 1:20,000 → The maps will be reduced and compiled]	1:50,000-scale base map for the study		
		2. Analysis of digital imagery (Classification not based on the ground truth = Unsupervised classification)	Dec. 19, '78 March 17, '81 LANDSAT CCT	Analysis of digital imagery (Clustering)	False color imagery, Unsupervised classification imagery		
		3. Field study	Field survey Aerial photographs (IR photographs at the scale of 1:20,000; November-December, 1972)	Examination for accuracy and modification of each preliminary map by means of the interpretation of aerial photographs and the field survey	Drafting of preliminary maps (1:50,000) Correction		
		4. Analysis of digital imagery (Classification based on the ground truth = Supervised classification)	Dec. 9, '78 March 17, '81 LANDSAT CCT	Analysis of digital images (Unsupervised classification)	Displaied images for the change in the ponding area 1:250,000-scale land cover classification images	Ponding areas frequency map 1:250,000	a, b, c, d

Fig. 2 Methods and processes for the preparation of preliminary maps (I)

Study year	Contents of study	Study items	Used data	Study method	Study results: Preliminary maps	Study results: Map for the evaluation of classification	Analysis and conclusion
		5. Preparation of preliminary maps		Tracing and patterns of preliminary maps Coding of mesh on each map (500 m x 500 m) Computer input Data Compiler Magnetic tape Magnetic tape Transformation of data for mesh color imagery	Reduction of each preliminary map (1:250,000) Completion of each preliminary map (1:50,000) Geomorphological map Elevation classification map Slope aspect map Slope classification map Relief energy map Land use map Map of the vegetation Agriculture form classification map Subsurface geological map Output of printed preliminary maps Mesh color image for each preliminary map	a b c d
		6. Classification of land (1) Classification of land in terms of land productivity	Soils	Classification of land in terms of soil productivity		Classification map of land in terms of soil procuctivity (1:50,000)	
			Slope, Geomorphology, reliefs	Classification of land productivity in terms of landform conditions		Classification map of land in terms of landform conditions	
		(2) Classification of land agricultural development difficulty	Land use, vegetation	Classification of land in terms of the percentage of forested area		Classification map of land in terms of percentage of the forested area (1:50,000)	
		(3) Classification of the safety to flooding and ponding of land	Geomorphology elevation land use	Classification of land in terms of the danger of ponding		Classification map of land in terms of the danger of ponding and flooding (1:50,000)	
			Geomorphology elevation, land use	Classification of land in terms of the danger of flooding			
		(4) Classification of land in terms of physical conditions for the land use potential		Classification of land in terms of physical conditions of land use potential		Classification map of land in terms of physical conditions for land use potential (1:50,000)	
		(5) Preparation of land classification maps by means of color grid images		Compiler For mesh color imagery	Mesh color image for each land classification map		
		7. Summary					Final report

Fig. 2 Methods and processes for the preparation ot preliminary maps (II)

(1) Preparation of 1:500,000-scale maps for the change in the ground cover and ponding conditions

The general condition of the ground cover and the flooded condition were identified for each season by the interpretation of the 1:500,000-scale false color composite imagery and the depicted features were laid on base maps. These maps for a particular season or at a particular time of the year were compared and used for the understanding of the change in the ground cover and the flooded condition for an extensive region including the present study area.

(2) Preparation of 1:50,000-scale maps for the classification of elevation, slope aspects, classification of slopes and relief energy

Each of these maps was expressed in 1 cm (500 m in actual length) square meshes. A map for the classification of elevation was made for the understanding of the terrain condition in the study area and the elevation was expressed at the interval of 10 m.

A map of slope aspects in an important thematic map essential for the estimation of the sunshine duration. Aspects were expressed in eight directions.

Slope is an important factor for the determination of the characteristics of landforms and at the same time it is the factor controlling the human activities of production. The slope gradient was estimated by reading the number of contours in each mesh.

Relief energy is an important factor for the understanding of the characteristics of landforms. It affects the easiness of cultivation. Relief energy was calculated by reading the difference between the highest and the lowest elevation in each grid.

(3) Preparation of a 1:50,000-scale land use map

A land use map is one which shows how land is being used and is the most important source of information for the classification of land.

The study area was classified into such categories as forest, natural grassland, cultivated land, bare ground, swamps, rivers, lakes and ponds and others.

(4) Preparation of a 1:50,000-scale map for the classification of landforms

Landform is the most important factor as an indicator for the evaluation and classification of land. Topographic information is basically composed of information concerning ground surface features and slopes and constitutes a basis for the direct evaluation of land for the selection of suitable locations for agriculture and for the determination of the possibility of cultivation and introductoin of agricultural machinery.

The study area was classified into landform units, such as hills, gently sloping areas (colluvial slopes, alluvial cones, gently sloping alluvial fans), swampy lowlands, and slightly elevated lands (natural levees, sand bars, sand dunes, etc.).

(5) Preparation of a 1:50,000-scale estimated soil map

A soil map occupies an important position as a factor directly controlling the classification of land, and is essential for determining the suitability of land as a farmland, suitable crop varieties, cultivability, necessity of irrigation and drainage facilities and so on.

Based on the soil classification by FAO, the soils in the study area were classified into (1) fluvisols, (2) gleysols, (3) regosols, (4) gleysols, and (5) acrisols.

(6) Preparation of a 1:50,000-scale map of surface geology

The information of geological structure and composition is often directly required for the evaluation of land. The present landforms,

soil types, etc. are controlled by the surface components, i.e., the geological conditions of the land. Therefore, the information on the surface geology is an important indicator for the land evaluation.

The surface geological features in the studied area were classified into alluvial deposits, alluvial fan deposits and colluvial deposits in the swampy lowlands, and clayey sandstone, sandstone, basalt, etc. for the bedrock of hill lands.

1.3.2 The second-year study

The second-year study was performed for the purpose of conducting a supplemental study and corrections of results of the first-year study, classsification of land in terms of physical conditions based on the preliminary maps, and collection of the basic data for the construction of a master plan for the general agricultural development.

(A) Preparation in Japan

1) The area of ponding and ground cover conditions were depicted by the analysis (clustering) of the LANDSAT digital imagery in CCT format.

2) The result of the first-year study was checked for correction by the interpretation of aerial photographs (Infrared photographs taken in 1973).

(B) Field investigation

The study team was organized for the field investigation by technicians specialized, respectively, in the study of the ground conditions, such as soils, landforms, surface geology, etc. and those specialized in the study of the ground cover, such as land use, vegetation, etc. and the present condition of land use, vegetation, soils and others were investigated by the team.

(C) Rearrangement of results in Japan

Preliminary maps were made by the rearrangement of the results of the field investigation, by the classification of the ground features based on the ground-truth by the use of the LANDSAT CCT data, and by the reinterpretation of aerial photographs. The information in preliminary maps were further converted to the mesh information and various types of classification maps were constructed by the use of a computer analysis system.

For the execution of this study, the field conditions were fully considered and the LANDSAT imagery and aerial photographs were fully used for an efficient investigation. A computer evaluation system was employed for the objective classification of land. The results of classification were checked by well-experienced technicians in consideration of the study results in the field. In other words, by following a method for the evaluation of classification by combining the computer and the human judgement, an effort was made for the most appropriate evaluation which would fit to the field conditions.

The actual procedures are shown below.

A. Preparation of preliminary maps

(1) Digital imagery analysis by the use of the LANDSAT data in CCT format

Digital imagery analysis was performed before and after the execution of the field investigation by the use of the LANDSAT CCT data for December 19, 1978 and March 17, 1981. The classification performed before the field investigation is one not based on the ground-truth (unsupervised classification) but one performed after the field investigation is the one based on the ground-trugh (supervised classification).

The unsupervised classification is employed before the execution of the field investigation or when the field investigation cannot be con-

ducted for some reason, while the supervised classification is the one which enables us to judge to which class the unknown data belong statistically. As a result of the above analyses, the ground cover classification images were produced.

(2) Depiction of the change in the ground cover and the area of ponding

The change in the ground cover and the area of ponding in the study area was dipicted by the use of the 1:500,000-scale map for the change in the ground cover and area of ponding prepared on the first-year study and also the results of the anaysis of the LANDSAT CCT digital imagery.

(3) Preparation of 1:50,000-scale maps for the classification of elevation, slope aspects, classification of slopes and reliefs

These maps were constructed by the use of the 500 m square meshes in the first-year study. Since the western half of the study area was newly included in the mapping operation in the second-year study, the topographic measurement was performed again for the area for the preparation of the above maps with the result of the mapping operation used as a reference.

(4) Preparation of a 1:50,000-scale land use map

A field study was performed by the use of preliminary maps prepared in the first-year study and by reference to the interpretation of the 1:20,000-scale IR photographs and the results of the analysis of the LANDSAT digital imagery. A land use map of higher accuracy was thus produced. The land use types were classified into such categories as natural forest, artificial forest, paddy field, crop field, micro reliefs, hilly grassland, lowland grassland, artificial grassland, swamps, rivers, ponds and others (residential areas, airfields, cemeteries.)

(5) Preparation of a 1:50,000-scale map for the classification of landforms

A final map for the classification of landforms was produced by the execution of the aerial photointerpretation, field investigation, trial boring, etc., based on the map for the classification of landforms prepared in the first-year study.

Landforms were classified into such categories as hills, shallow valleys dissecting hill lands, colluvial surfaces, alluvial cones, valley-bottom plains, gentle fan plains, natural levees, back swamps, micro reliefs (high), micro reliefs (low), abandoned river courses, lowlands along rivers, sand bars, sand dunes, rivers, lakes and ponds.

(6) Preparation of a 1:50,000-scale soil map

A 1:50,000-scale soil map was prepared by checking, in the field investigation, and correcting, by the interpretation of aerial photographs, the estimated soil map (estimated from the information on the landform classification map, surface geology map, land use map, etc.) made in the first-year study.

Soils were first classified according to the classification system of the FAO/UNESCO and further classified into smaller categories according to the texture of the surface soil. Soil types found in the study area are fluvisols, coarse-textured gleysols, fine-textured gleysols, coarse-textured regosols, fine-textured regosols, humic planosols, planosols, acrisols, etc.

(7) Preparation of a 1:50,000-scale map of surface geology

A 1:50,000-scale map of surface geology was prepared in the second-year investigation by checking, at the time of the field investigation of soils, and correcting, by the use of the landform classification map and the existing data, the map of subsurface geology produced at the time of the first-year investigation.

The subsurface geology was classified into the following categories:

1) alluvial deposits;
   (a) sand and silt (sandy)
   (b) sand and silt (muddy)
   (c) sand, silt and clay
   (d) silt and clay

2) colluvial deposits
   (a) silt and clay

3) bed rocks
   (a) muddy sandstone
   (b) sandstone
   (c) basalt

B. Analysis of land classification

The analysis of land classification is for the classification of land by the use of certain criteria for the understanding of various land conditions and is essential for any agricultural development project. Land classification was performed in terms of four aspects, i.e., the productivity of land, safety of land, conservation of natural environment and physical conditions for the land use potential.

(1) Classification of land in terms of the land productivity

The land productivity was classified in terms of (1) the soil productivity and (2) the easiness of cultivation which is important in the agricultural management. For the classification of the soil productivity, the suitability of soils for the use of paddy fields and crop fields was determined by reference to the surface soil factors and the study results of chemical composition of soils. The easiness of cultivation and land improvement, if the land is to be

used for paddy rice fields or crop fields, was determined from the topographic viewpoint.

(2) Classification of land in terms of the safety of land

The potential danger of the ground foundation particularly at the time of ponding and flooding was considered and classified.

(3) Classification of land in terms of the easiness of land development (forest clearance)

In addition to the easiness of cultivation in view of topographic conditions as given in (1), the easiness of land development by the forest distribution.

(4) Classification of land in terms of physical conditions for the land use potential

The potential for land use was classified in terms of the general natural conditions by reference to the results of classification of the land productivity, land safety and conservation of natural environment.

1.4 Used Data

1.4.1 Used LANDSAT data

The general explanation of the LANDSAT data will be given in the Appendix of this report. The LANDSAT imagery (LANDSAT 1, 2 and 3) which covers the study area is one given in path 241 and row 79 as shown in Figure 3. However, the coordinate of the image will be path 225 and row 79 for LANDSAT 4.

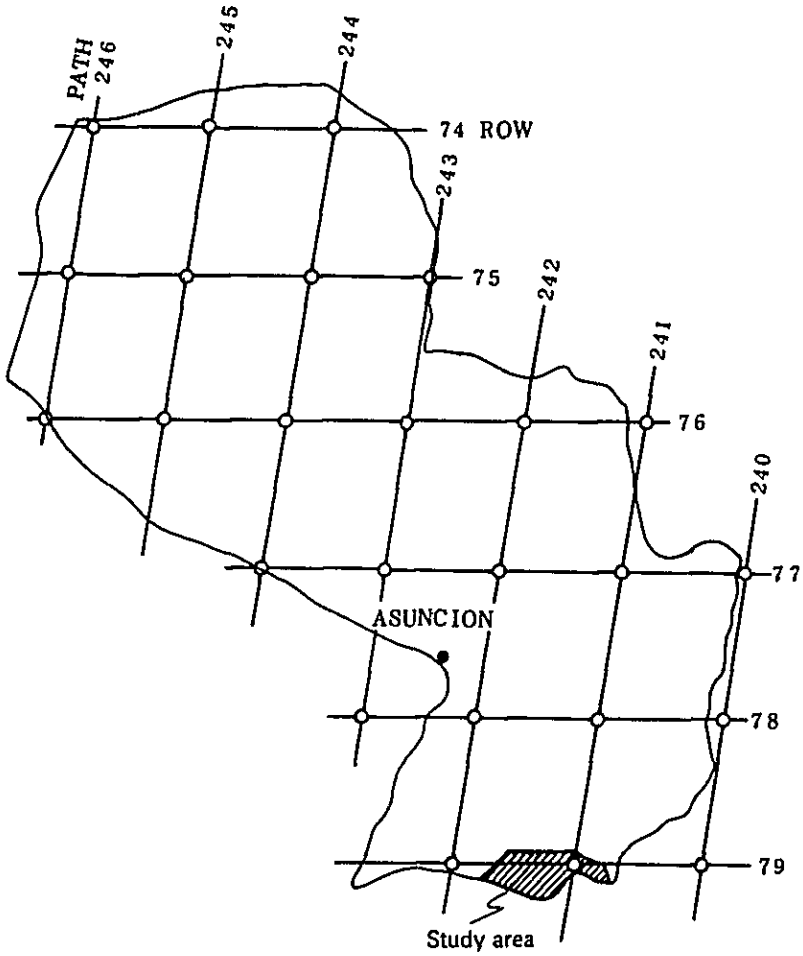


Fig. 3 Map of the Coverage by the LANDSAT Imagery in Paraguay (LANDSAT 1 through 3)

Table 1 LANDSAT images used for the analysis

Path	Row	Date of image	Type of LANDSAT	Type of image used for the analysis
241	79	February 9, 1976	1	False color (1:500,000)
241	79	July 20, 1976	1	False color (1:500,000)
241	79	August 15, 1978	3	False color (1:500,000)
241	79	December 19, 1978	3	False color (1:500,000) CCT
241	79	September 6, 1979	2	False color (1:500,000)
241	79	March 17, 1981	3	False color (1:500,000) CCT
225	79	April 10, 1983	4	False color (1:500,000)
225	79	April 26, 1983	4	False color (1:500,000)

Of these images, ones listed in Table 1 were used after the full consideration of cloud amount and image quality.

Out of the images listed in Table 1, false color images (1:500,000) taken before 1983 were used for the first-year analysis and the false color images taken on April 10 and 26, 1983 and CCT data for December 19, 1978 and March 17, 1981 were used for the second-year analysis. These data were obtained from the receiving station in Brazil (The receiving operation of data from the spacecraft started at the Cuiaba receiving station in Brazil in 1974.).

For the procurement of images in the CCT format, images respectively representing the rainy season and the dry season were selected from among the false color images taken before 1983. The image for the rainy season is the one taken on December 19, 1978 and the one for the dry season was taken on March 17, 1981.

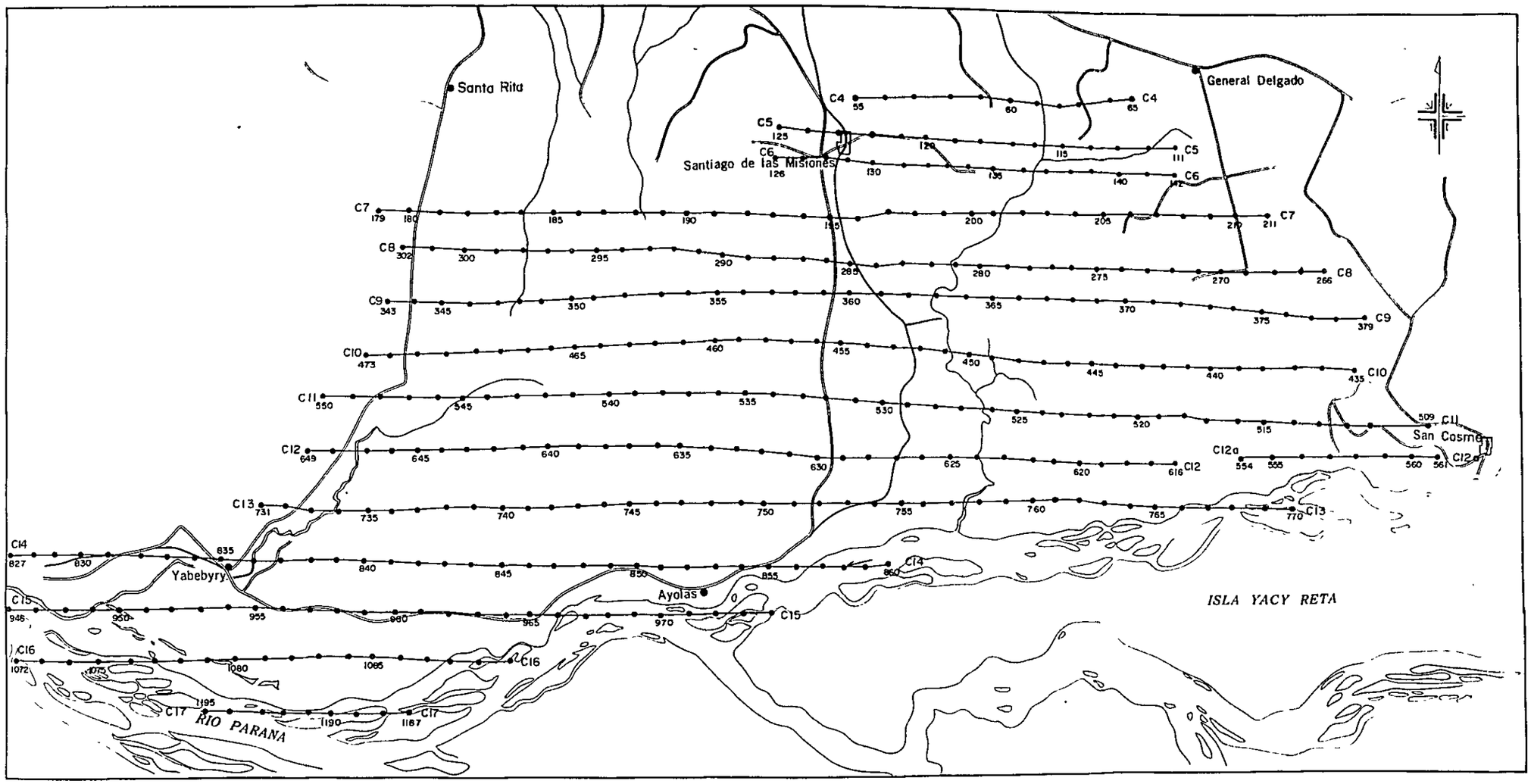


Fig. 4 The Aerial Photographs Index Map

1.4.2 Used aerial photographs

Infrared aerial photographs taken at the scale of 1:20,000 by the Yacyreta Public Corporation (November through December 1972) were used for the field study. The index map of the used aerial photographs is shown in Figure 4. The number of used images for each flight course is given in Table 2.

Table 2 Number of Aerial Photographs Used in each Flight Course

Course No.	Photograph No.	Number of photograph
C4	55 ∿ 65	11
C5	111 ∿ 125	15
C6	126 ∿ 142	17
C7	179 ∿ 211	33
C8	266 ∿ 302	37
C9	343 ∿ 379	37
C10	435 ∿ 473	39
C11	509 ∿ 550	42
C12a	554 ∿ 561	8
C12	616 ∿ 649	34
C13	731 ∿ 770	40
C14	826 ∿ 860	35
C15	945 ∿ 974	30
C16	1070 ∿ 1090	21
C17	1187 ∿ 1195	9
		Total 408

CHAPTER 2 CONTENTS OF PRELIMINARY MAPS AND RESULTS

2.1 General Description

Preliminary maps are used as the basic data for the preparation of the general agricultural development plan in the neighboring district of the Yacyreta Dam. Due consideration was given to the preparation of these maps, so that they could be used fully for the preparation of the rational development plan in view of the importance and urgence of the plan.

These maps were made to be used for (1) the understanding of the natural environment and regional characteristics of the studied area, and (2) the classification and evaluation of land in terms of physical conditions. Ten of the preliminary maps at the scale of 1:50,000 were prepared and shown in the separate collection of maps and at the same time the conceptional map (1:250,000) of these maps is included in the study report.

Table 3 Contents of preliminary maps and study objectives

Preliminary map	Study objectives	Classification items	Relation to classification and evaluation				
			Land productivity		Natural disaster		Conservation of physical environment
			Soil productivity	Easiness of cultivation	Danger of inundati	Danger of ponding	
geomorphology	(1) One of the most important factors in the evaluation of land (2) Evaluation of the easiness of cultivation (3) Evaluation of the danger of ponding and flooding (4) Indices of information for the Subsurface geology, soils, etc.	(1) Hill lands (2) Shallow valleys on the hill land (3) Colluvial slope (4) Alluvial cone (5) Valley bottom plain (6) Gentle fan plain (7) Natural levee (8) Back swamp (9) Slightly elevated a. (10) Micro relief (Low) (11) Abandoned river channel (12) Lowland along the river (13) Sand bar, sand dune		◎	◎	◎	
Elevation classification	(1) Evaluation of the easiness of cultivation (2) Evaluation of the danger of ponding and flooding (3) Understanding of general conditions of landforms	(1) Division into 500 m-by500 m meshes (2) Shown in 10 m unit		○	◎	◎	
Slope aspect	(1) Basic data for the evaluation of land productivity (2) Basic data for the preparation of agricultural management plan	(1) Division into 500 m-by-500 m meshes (2) Shown in eight directions	◌	◌			
Slope classification	(1) Understanding of general conditions of landforms (2) Evaluation of the easiness of cultivation	(1) Division into 500 m-by-500 m meshes (2) Shown in 3 degree unit		◎			
Relief energy	(1) Understanding of general conditions of landforms (2) Evaluation of the easiness of cultivation	(1) Division into 500 m-by-500 m meshes (2) Shown in 5 m unit		◎			
Land use	(1) Understanding of the present condition of land use (2) Indices of information for the physiognomy of vegetation, type of cultural form,etc (3) Indices showing meteorological conditions, soil types, water content of soils, hydrological conditions (4) Evaluation of land for the conservation of natural environment (5) Evaluation of land in terms of physical conditions for the land use potential (6) Basic data for the future land utilization plan	(1) Forest (Natural forest, artificial forest) (2) Natural grassland (Dry grassland, wet grassland) (3) Swamp (4) Artificial grassland (5) Paddy field (6) Crop field (7) Others	◌		◌	◌	◎
Vegetation	(1) General condition of each forest type (2) Evaluation of land in terms of the conservation of physical environment (3) Evaluation of land in terms of physical conditions for the land use potential (4) Basic data for the land utilization plan and environmental conservation plan	(1) Hill land forest (2) Micro relief forest (3) Table land forest (4) River land forest (High) (5) River band forest (Low) (6) Dry grassland (7) Wet grassland (8) Paddy field (9) Crop field (10) Others			◌	◌	◎
Agricultural form classification	(1) General conditions of land management (2) Reference data for the evaluation of land in terms of physical conditions for the land use potential (3) Indices for the evaluation of social and economic studies (4) Reference data for the evaluation of classification of soil productivity	(1) Artificial grassland (2) Natural grassland (3) Paddy field (4) Crop field (5) Rivers, ponds (6) Others	◌				
Soil classification	(1) General distribution of soils (2) Understanding the relationship between soils and crops (Chemical analysis data) (3) Evaluation of the classification of soil productivity (4) Evaluation of land in terms of physical conditions for the land use potential (5) Basic data for the future land utilization plan and agricultural	(1) Fluvisols (2) Coarse-textured gleysols (3) Fine-textured gleysols (4) Coarse-textured regosols (5) Fine-textured regosols (6) Humic planosols (7) Planosols (8) Acrisols	◎	○			
Classification of subsurface geology	(1) Reference data for the preparation of soil maps (2) Basic data for the evaluation of the classification of land from the viewpoint of natural disaster (3) Basic data for the construction plan of service water and drainage water canals and roads	(1) Alluvial deposits [1) Sand, silt (sandy), 2) Sand, silt (muddy), 3) Sand, silt, clay, 4) Silt, clay)] (2) Colluvial deposits (3) Basement rocks Muddy sandstone			◌	◌	

◎ Directly related ○ Indirectly related ◌ Reference data

2.2 Analysis of LANDSAT Imagery

It seems that water basically controls the ecosystem in a swampy area like the studied area. Since plants are the most sensitive to water in such an area, a condition of the macro-scale plant cover would be understood by the analysis of the LANDSAT data for the wet season. In this way, the regional characteristics, hydrological environment and agricultural types in the studied area would be understood. Thus, in this study the LANDSAT data was used as much as possible for the preparation of preliminary maps and the results of the LANDSAT image analysis were reflected on the following operations:

(1) Collection of the basic data for the understanding of the ground cover condition and the preparation of a land use map, a map of the vegetation and a soil map of the studied area,

(2) Understanding of the change in the ground cover in the studied area,

(3) Understanding of the distribution of ponding and flooded areas in the studied area.

2.2.1 Classification of the ground cover and its change

The classification of the ground cover by the use of the LANDSAT data is made possible by the ground cover information based on the characteristics of reflection and radiation from the ground surface. Therefore, in the strict sense, the ground cover classification is not the same as one used for the preparation of a land use map which was made by the intuitional interpretation of texture, hue and pattern of images on aerial photographs and by the judgement of thinking for the analysis and interpretation based on the accumulated experience and information. However, in the studied area, where most of the land is the unused swampy lowland, the ground cover classification by the use of the LANDSAT data is nearly the same as the land use classification by the interpretation of aerial photographs. Therefore, the ground cover condition in the studied area was understood by the preparation of ground-cover classification images by the use of the LANDSAT imagery. At the same time, these images were used as the basic

data for the preparation of a land use map, a map of the vegetation and a soil map.

In the first-year study, the LANDSAT images, taken in two different seasons, February 9, 1976, July 20, 1976, August 15, 1978 and December 19, 1978, were used for the preparation of false color composite images at the scale of 1:500,000 and the calculated image of Band 7/Band 5 which is considered to be one of the indicators of vegetation types. Thus, the seasonal change in the ground cover was mainly delineated.

In the second-year study, the LANDSAT data in CCT format for December 19, 1978 and March 17, 1981 were used for the ground cover classification by means of the digital image analysis, and the temporal change in the ground cover was delineated by the comparison of the two results.

(1) Seasonal change in the ground cover (the case of 1976)

Ground cover maps for the wet and dry seasons were made by the use of the data for February 9 in the wet season and the data for July 20 in the dry season (Figure 5). According to this figure, a large area in the swampy lowland located to the north of Yabebyry and Ayolas is ponded in the wet season. It is also detected that swamps are widely distributed to the west of a point located to the northwest of San Cosme.

In the dry season, a large ponding area to the north of Yabebyry and Ayolas disappears and the disappearance of swamps is also remarkable. Particularly in the wet season, a swamp located to the northwest of San Cosme was found to have receded greatly, and green vegetation mostly of crop field crops is widely distributed on hill lands located to the northeast of San Cosme.

A comparison of images in two seasons shows that most of the swampy area to the north of Yabebyry and Ayolas is either ponded only in the wet season and swampy in the dry season or swampy in both seasons, except for some areas which are completely ponded in both seasons. The images also show that green vegetation prevails in both seasons in the hill lands on the northern and northeastern sides of San Cosme.

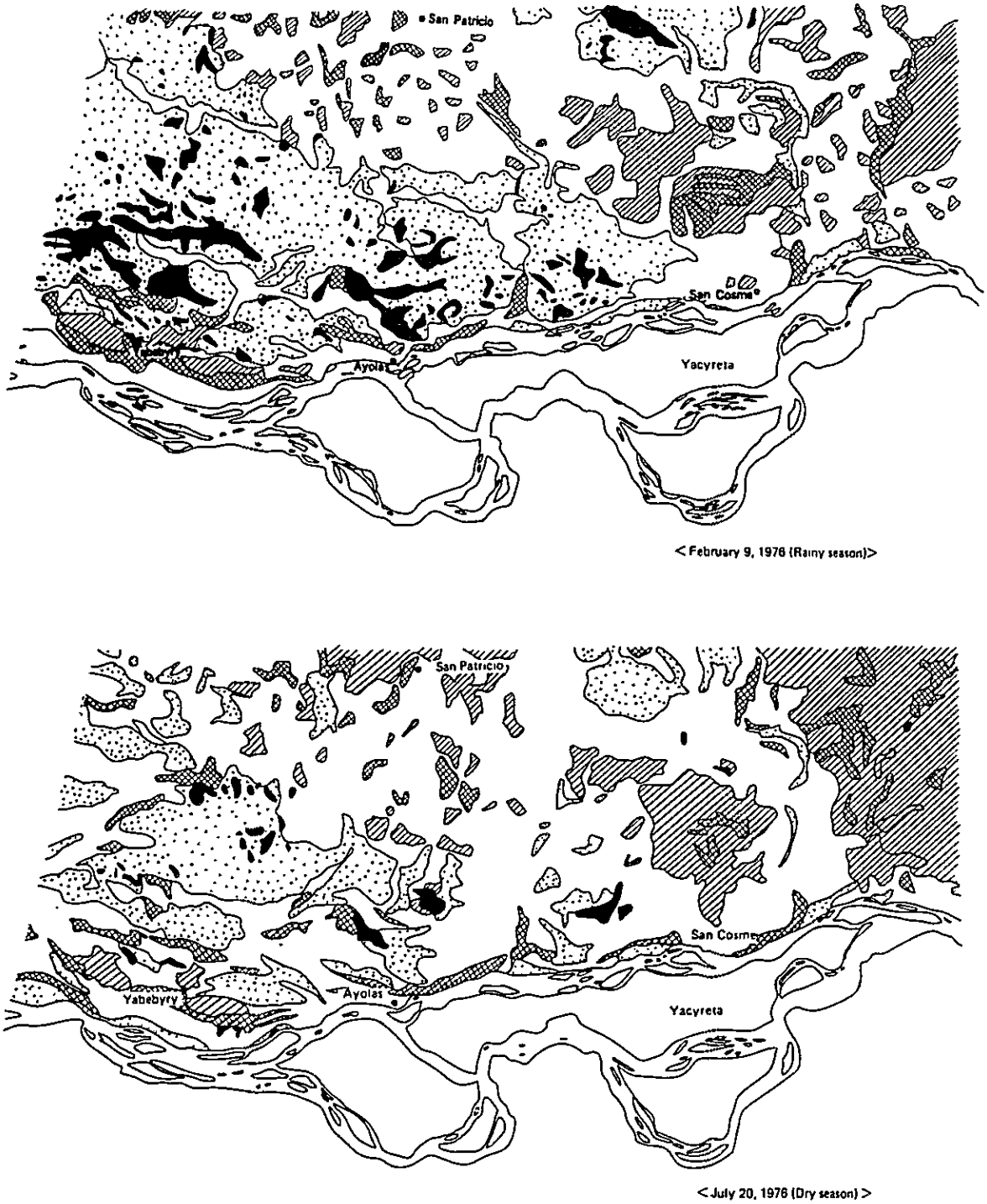


Fig. 5 Land Cover Map 1 (Scale: 1:500,000)

(2) Seasonal change in the ground cover (the case of 1978)

Ground cover maps for wet and dry seasons were made by the use of the LANDSAT images for December 19 in the wet season and August 15 in the dry season (Figure 6).

The ponding area exists widely on the northern side of Ayolas and on the eastern side of San Patricio in the wet season. And the ponding area far greater than the above area exists on the southern side of San Patricio. Only a small ponding area was detected on the northern side of Yabebyry.

In the dry season a green belt of vegetation continuously occurs along the Parana River. A large ponding area on the southern side of San Ignacio almost disappears anc completely ponding areas are scattered only in swamps on the northern side of Ayolas and Yabebyry.

A comparison of images in two seasons shows that completely ponding areas always exist in swamps on the northern side of Ayolas and Yabebyry throughout the two seasons and that in the swamps there are two areas, one which is completely ponded in the wet season and becomes a swamp in the dry season and the other which forms a swamp throughout the season. The images also show that green vegetation (estimated to be agricultural lands) exists all the time in both seasons in the hill lands on the northern and northeastern sides of San Cosme.

Thus, the findings by the analysis of the change in the ground cover between the wet and dry seasons in 1976 and 1978 are summarized in the following two points:

1) A similar general change in the ground cover between the wet and dry seasons was found in 1976 and 1978.

2) In other words, there are areas which are always ponded throughout the wet and dry seasons in the swamps located on the northern side of Ayolas and Yabebyry.

< December 19, 1978 (Rainy season) >

< August 15, 1978 (Dry season) >

Clearly detected Ponding area

Swamp

Agricultural land clearly identified in the imagery

Forest clearly identified in the imagery

Fig. 6 Land Cover Map 2 (Scale: 1:500,000)

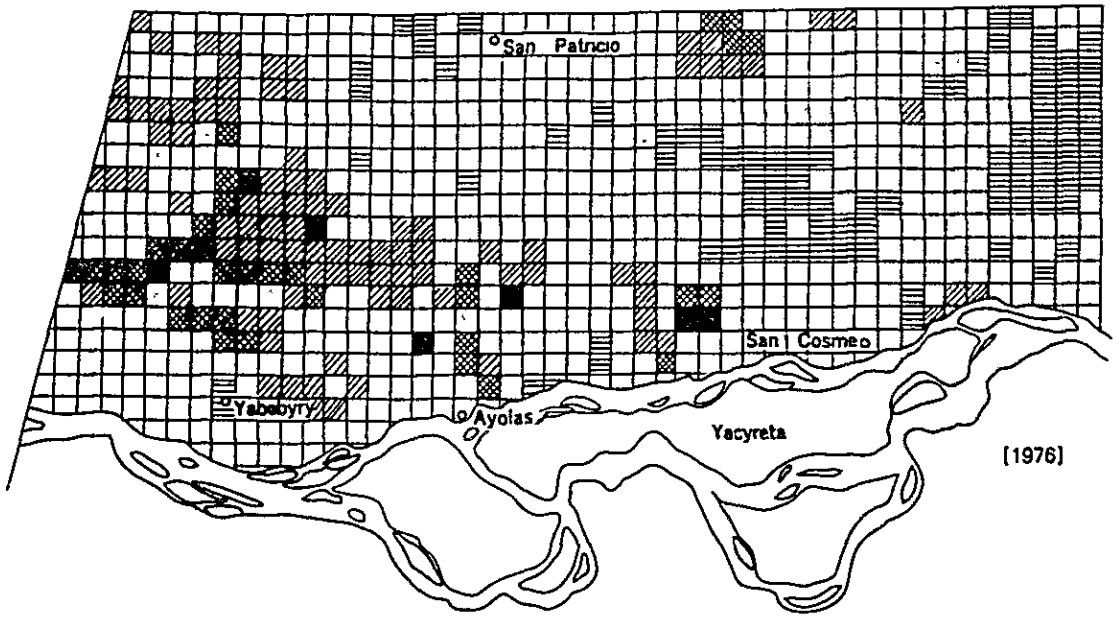


Fig. 7 Change the in the Ground Cover

(Rainy season)	(Dry season)	(Patterns)
Ponding area	Ponding area	
Ponding area	Swamp	
Swamp	Swamp	
Vegetated area	Vegetated area	

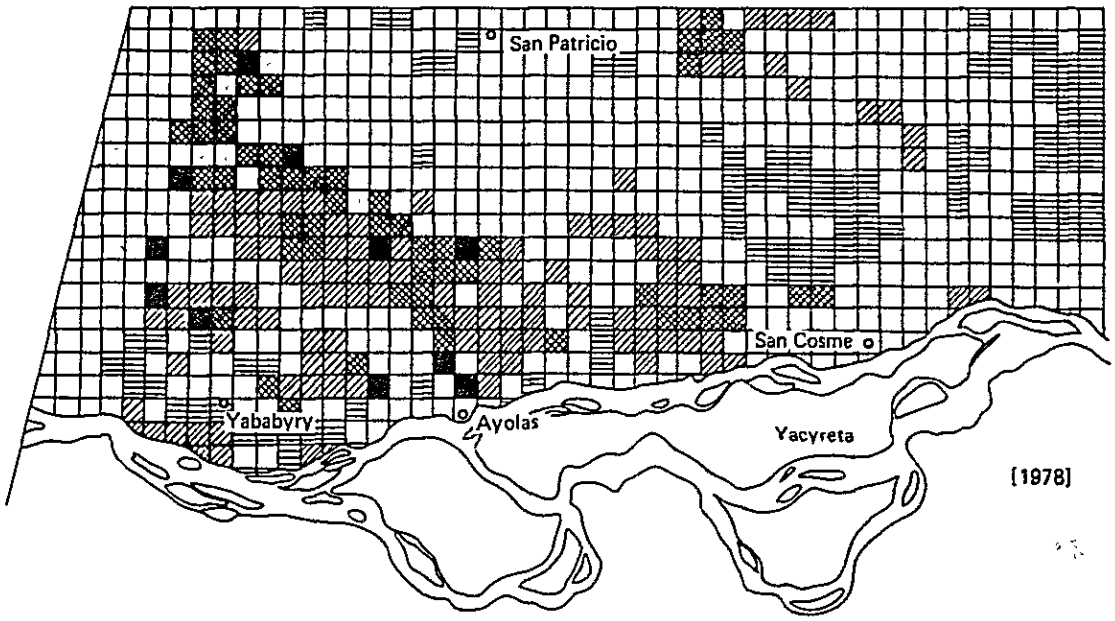


Fig. 8 Change in the Ground Cover

(3) Classification of the ground cover and its temporal change

Representative images for the wet and dry seasons (image of December 19, 1978 for the wet season and the image of March 17, 1981 for the dry season) were selected from among the LANDSAT false color composite images used in the present study and the selected images in CCT format were used for the digital image analysis. The result of the analysis is shown in 1:250,000-scale ground cover classification images (Figures 9 and 10). The digital image analysis of the ground cover was performed in the order as shown in the flow chart in Figure 11. The unsupervised classification was performed before the field survey and the result of the classification was used as the basic data for the field survey. After the field survey, the supervised classification based on the results of the field survey was carried out for the preparation of the final 1:250,000-scale ground cover classification image.

The explanation of the digital image analysis of LANDSAT data is given in the Appendix of this report.

1) Results of the ground cover classification

Classification items of the ground cover and the discrimination efficiency are shown in Table 4.

(a) Results of the classification of the December 19, 1978 image (wet season)

- All ground cover types except for dry grassland were classified at the accuracy of greater than 70%.
- The forest area is extremely limited in the studied area and is seen only on natural levees of the Parana River and in the back swamp in the form of belts and blocks.
- Wet grassland is an area which is ponded in the wet season. The most of the studied area belongs to this type.

- Dry grassland is distributed on hill lands, natural levees and micro reliefs in the back swamp and occupies the second largest area next to the wet grassland.
- Since the distinction between the crop field and the dry grassland of slightly low density is difficult, they were combined and expressed as one type. Crop fields are mostly distributed on hill lands outside the studied area.
- Since the bare ground is not easily distinguished from crop fields after harvesting and thinly vegetated grassland, they were grouped in one type. No large distribution of this type is found in the studied area, except for the Yacyreta Island.

Data of December 19, 1978

Legend	
	Forest
	Wet grassland
	Dry grassland
	Swamp
	Crop field(Including dryness grassland)
	Bare ground(Including crop fild after havesting)
	River
	Pond
	Others

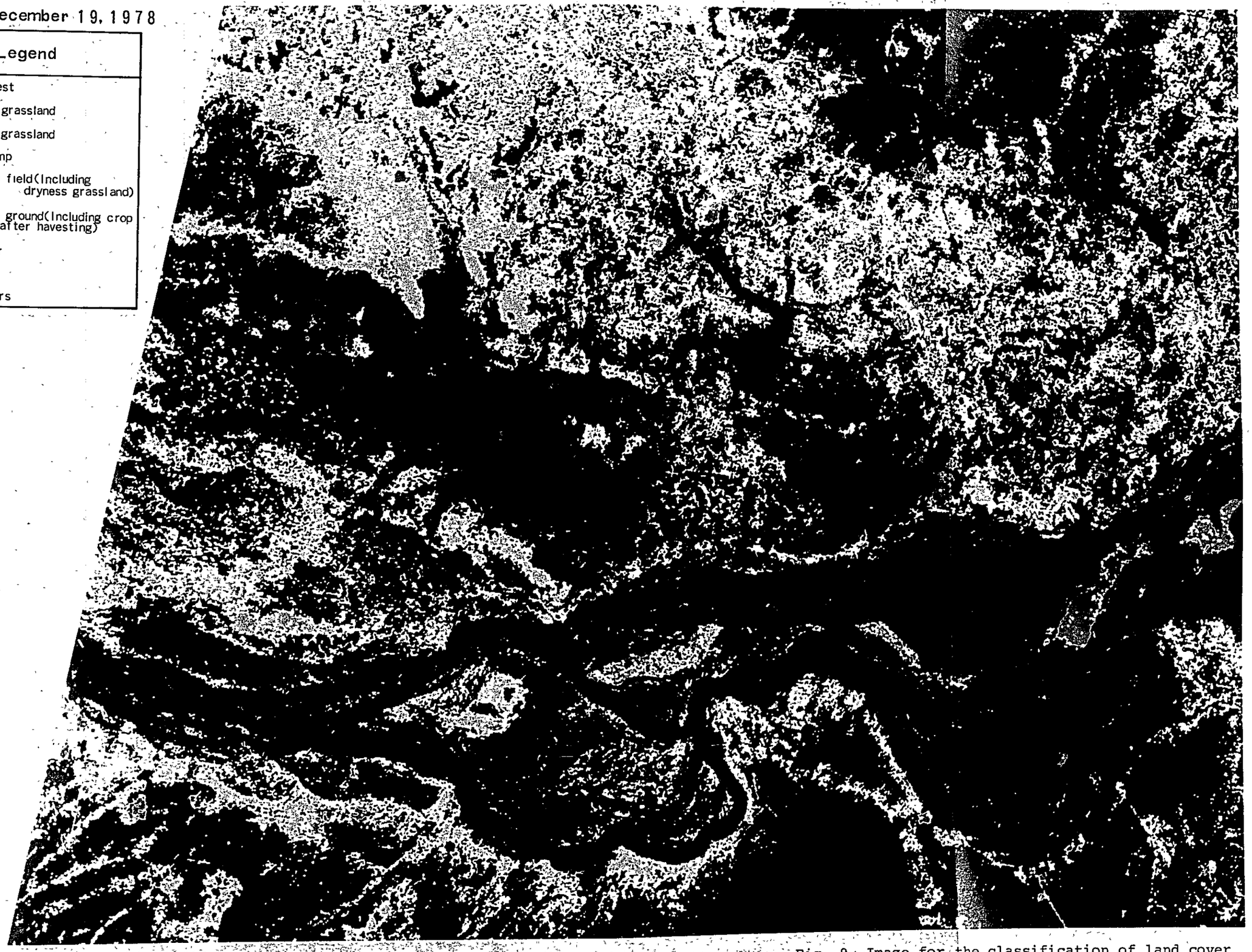


Fig. 9 Image for the classification of land cover (December 19, 1978)

Data of March 17, 1981

Legend

- Forest
- Wet grassland
- Dry grassland
- Swamp
- Crop field(Including dryness grassland)
- Bare ground(Including crop fild after havesting)
- River
- Pond
- Others

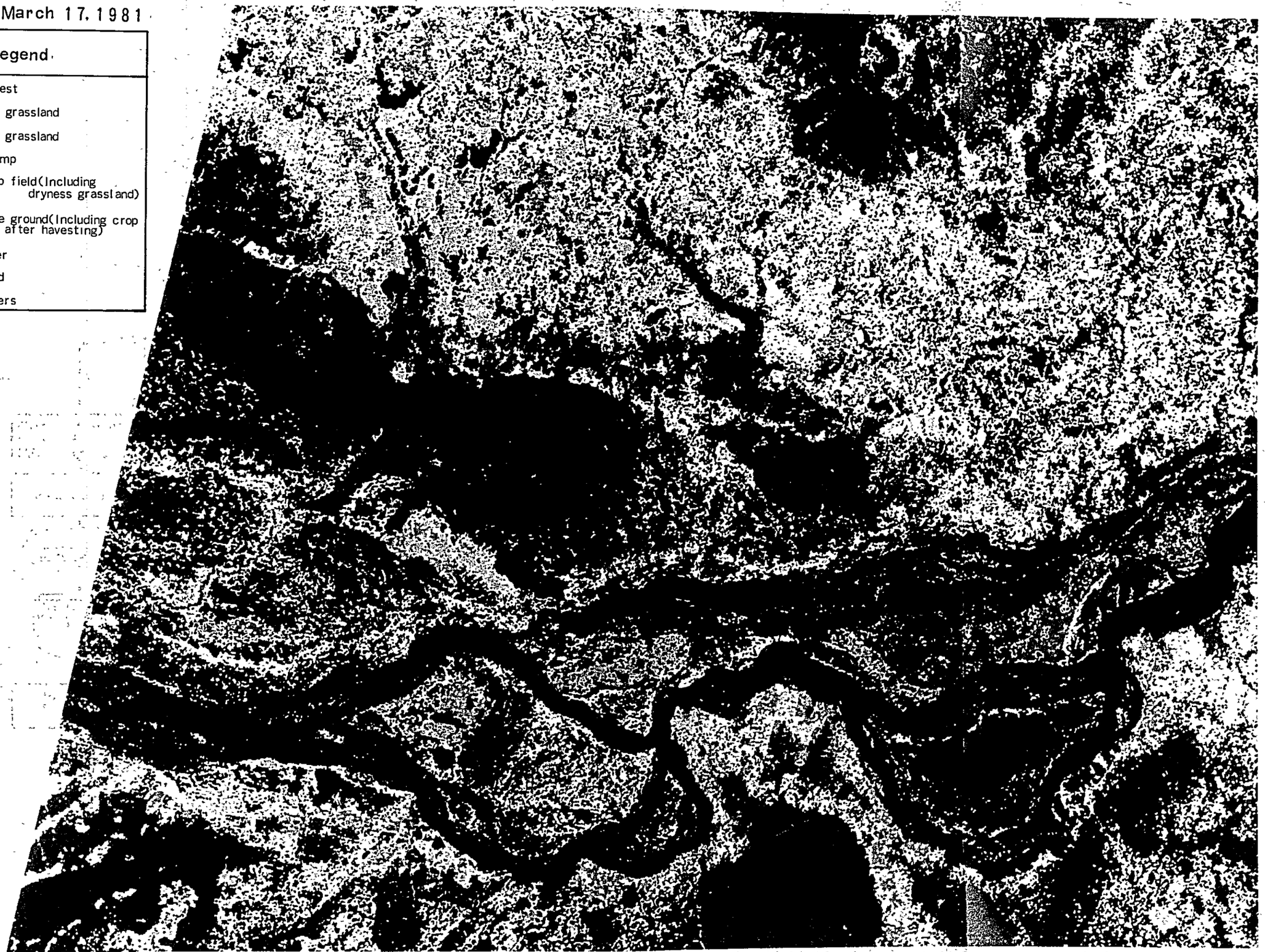


Fig. 10 Image for the classification of land cover (March 17, 1981)

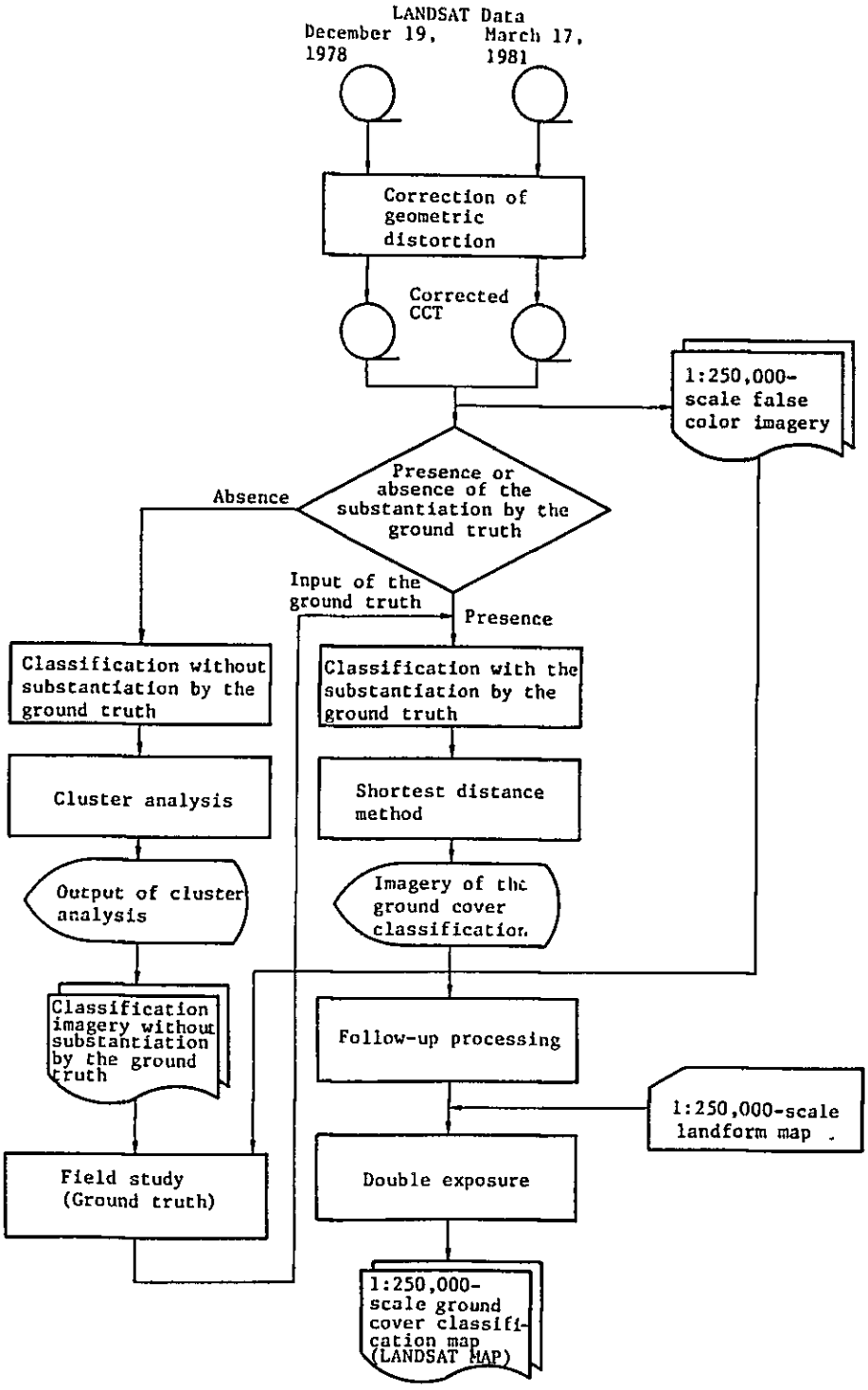


Fig. 11 Flow chart of the ground cover classification

Table 4 Classification items and discrimination efficiency

(A) Data for December 19, 1978 (rainy season)

(Unit: %)

Input items \ Output items	Forest	Wet grassland	Dry grassland	Swamp	crop field (Including dry grassland)	Bare land (Including crop field after harvesting)	Rivers	Lakes and bogs	Others
Forest	97	3							
Wet grassland		91	9						
Dry grassland	2	20	64		12	1			1
Swamp		7		93					
crop field (Dry grassland, etc.)					78	8			14
Bare land (Crop field after harvesting)		13	6			79			2
Rivers							100		
Lakes and bogs		1					9	90	
Others	3	3	11		8	5			70

(B) Data for March 17, 1981 (dry season)

(Unit: %)

Output items / Input items	Forest	Wet grassland	Dry grassland	Swamp	Crop field (Including dry grassland)	Bare ground (Including upland field after harvesting)	Rivers	Lakes and bogs	Others
Forest	94		6						
Wet grassland	3	82	6	9					
Dry grassland		6	88						6
Swamp		7		87				6	
Crop field (Including dry grassland)			16		64	10			10
Bare land (Including upland field after harvesting)					3	97			
Rivers							100		
Lakes and bogs				2				98	
Others	3		6		11	12			68

(b) Results of the classification of the March 17, 1981 image (dry season)

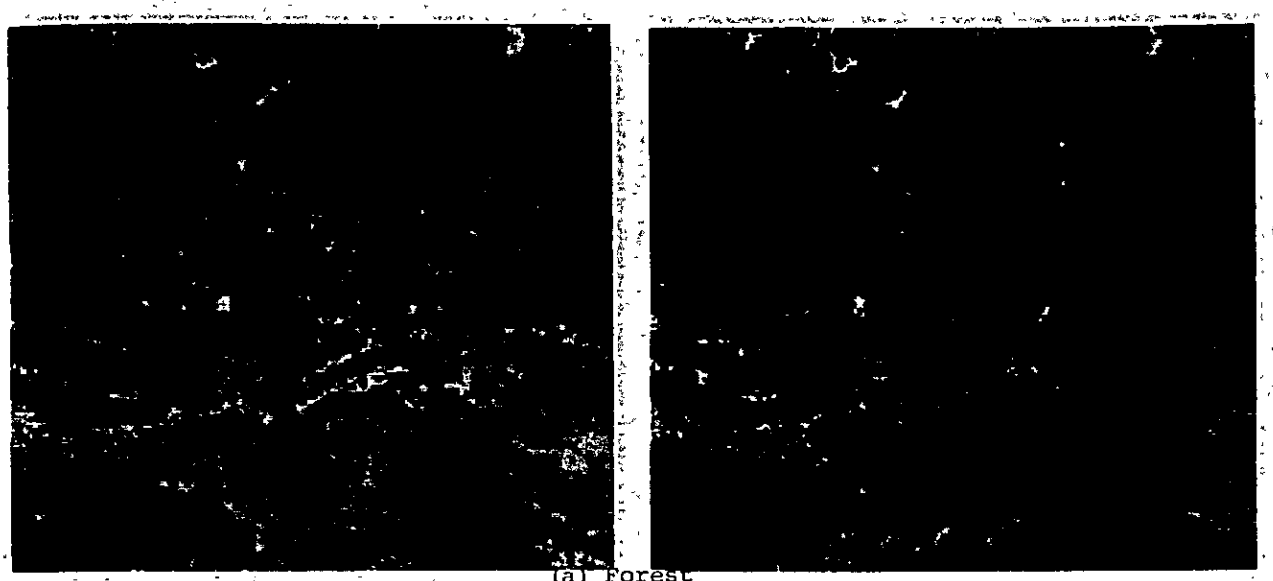
- All ground cover types except for the crop field, etc. were classified at the accuracy of greater than 80%.
- Forest in the studied area is extremely limited and is found only on natural levees of the Parana River and on micro reliefs in the back swamp in the form of belts and blocks.
- Wet grassland is widely distributed in the lowland along the Parana River and in the area between the natural levee behind the river and the hill land at the northern end of the studied area.
- Dry grassland is widely distributed in the natural levee areas of the Parana River, the Atinguy River, the Yabebyry River, etc., on micro reliefs in the back swamp and on hill lands at the northern end of the studied area.
- Crop fields were not clearly distinguished from bare grounds or dry grassland because of the use of images taken in the dry season, and the accuracy of classification of crop fields is lower than that for other types of land use. Most of this type of alnd use is distributed on hill lands outside of the studied area.
- Due to the use of the images taken in the dry season, only the bare ground in the natural levee areas on the eastern side of the Yabebyry River was detected. (This area was classified in the category of crop fields and dry grassland in the wet season.)

2) Temporal change

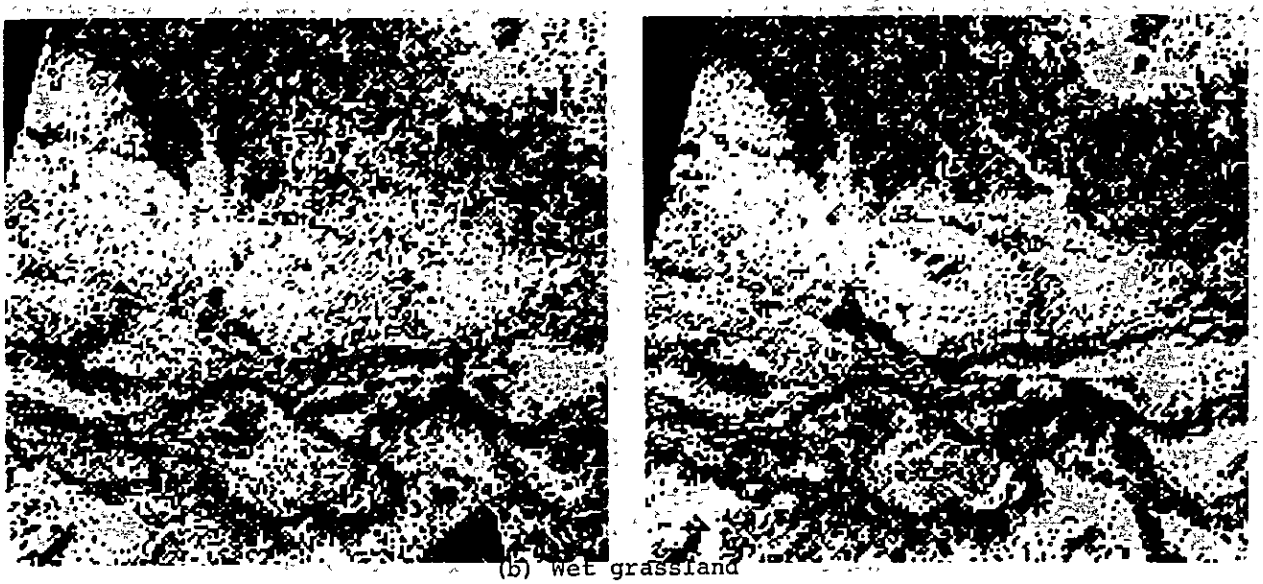
The ground cover classification was made for two different years and the results were compared with each other. The image showing the temporal change of each land use type is shown in Figure 12.

Findings of this analysis are given as follows:

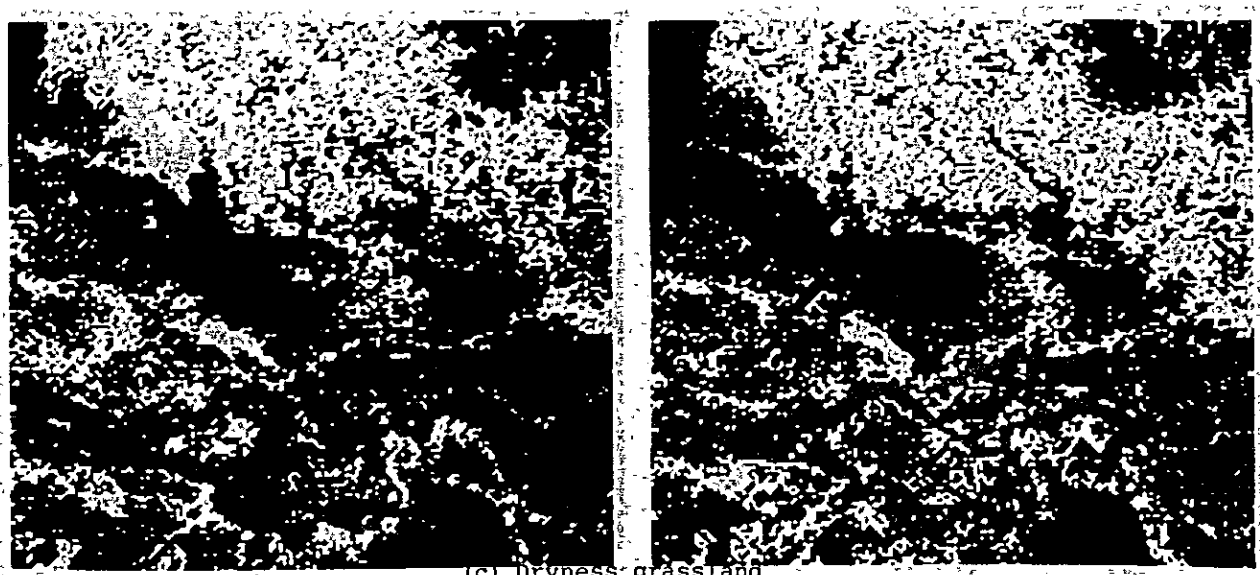
- There is a decrease in forest area from 1978 to 1981 images, although some misinterpretation was probably involved. The decreasing trend in the forest area is particularly remarkable in hill lands to the north and northeast of San Cosme. Forest areas in the back swamp in the studied area also show a slight decrease.
- There is a small change in the distribution area of wet grassland between the wet and dry seasons. But the overall distribution of wet grassland is similar between the two years.
- Dry grassland shows a similar distribution between the two years. Swamps are areas with remarkable ponding.
- In both years, the distribution of large-scale swamps is observed to the northeast of Ayolas.
- Although there is a considerable amount of misinterpretation in the identification of crop fields and dry grassland, the overall change from the wet grassland in the wet season to the dry grassland in the dry season (it is estimated that this grassland has a thinner vegetative cover than the actual dry grassland) is detectable. The identification of crop fields is difficult and the discrimination of the temporal change of the crop field alone is nearly impossbile.



(a) Forest



(b) Wet grassland

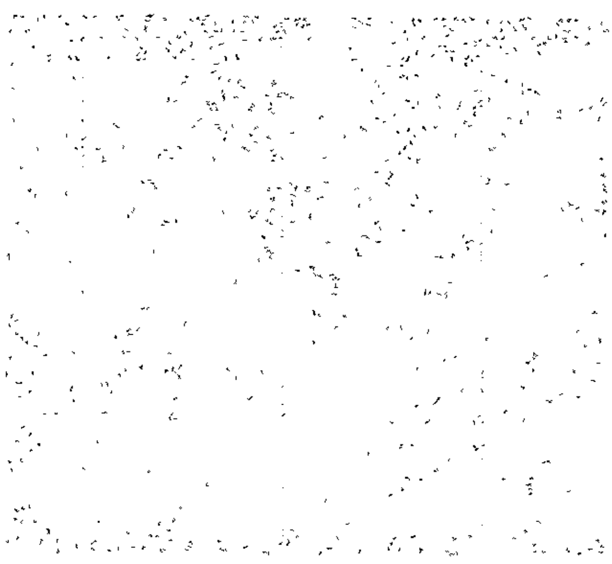
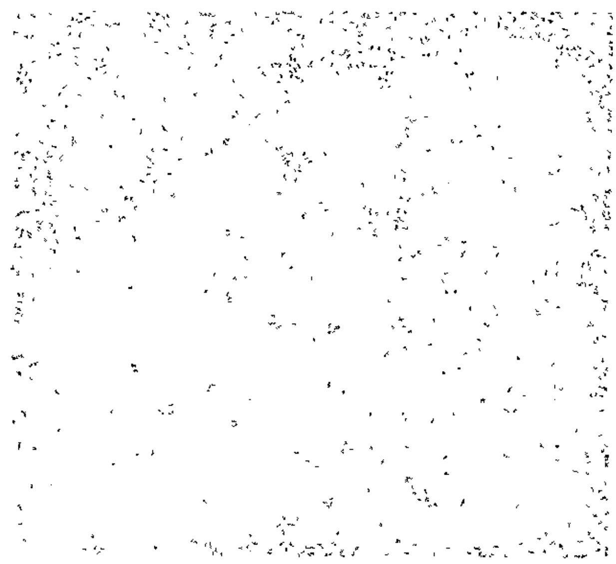
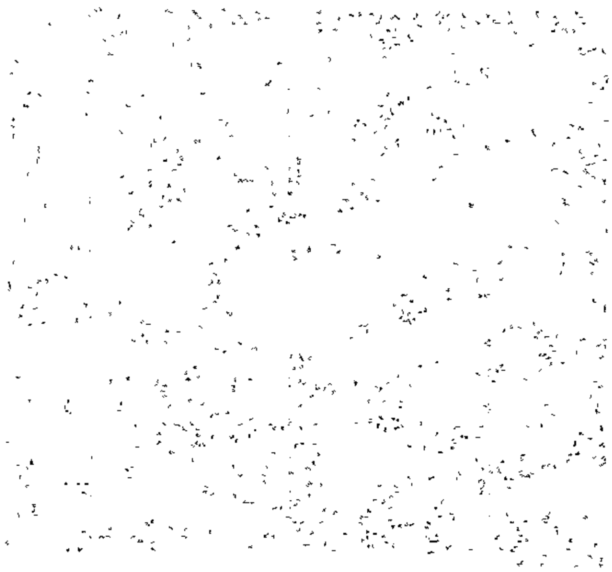
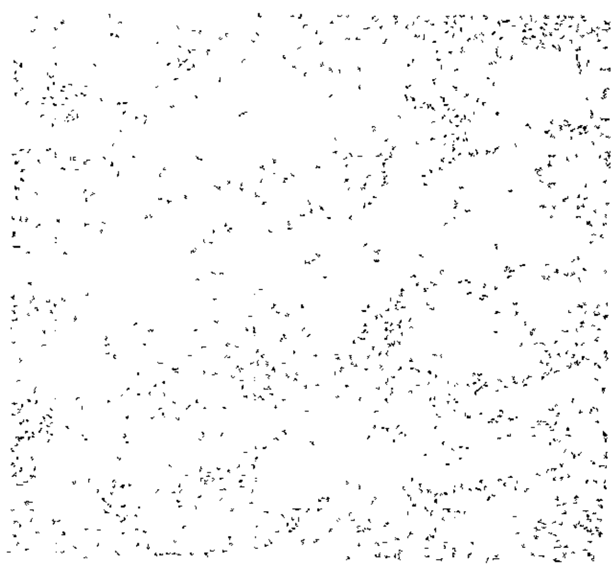
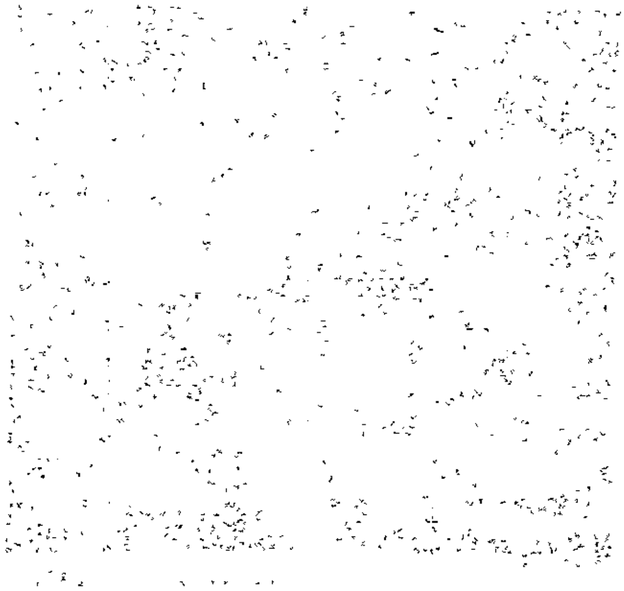
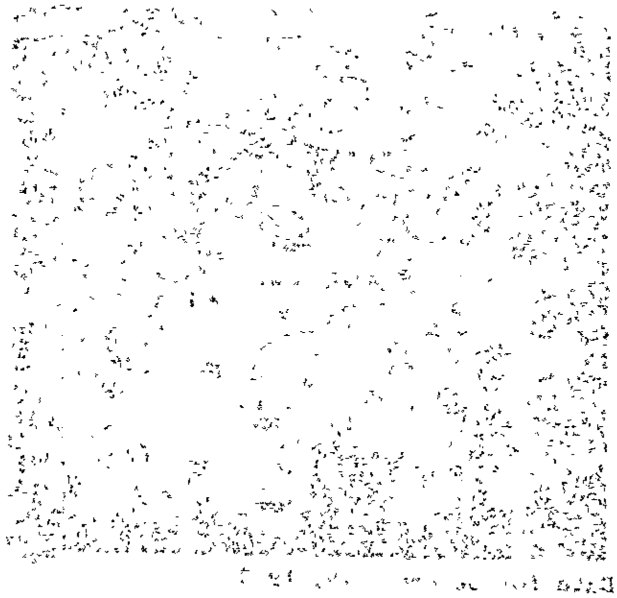


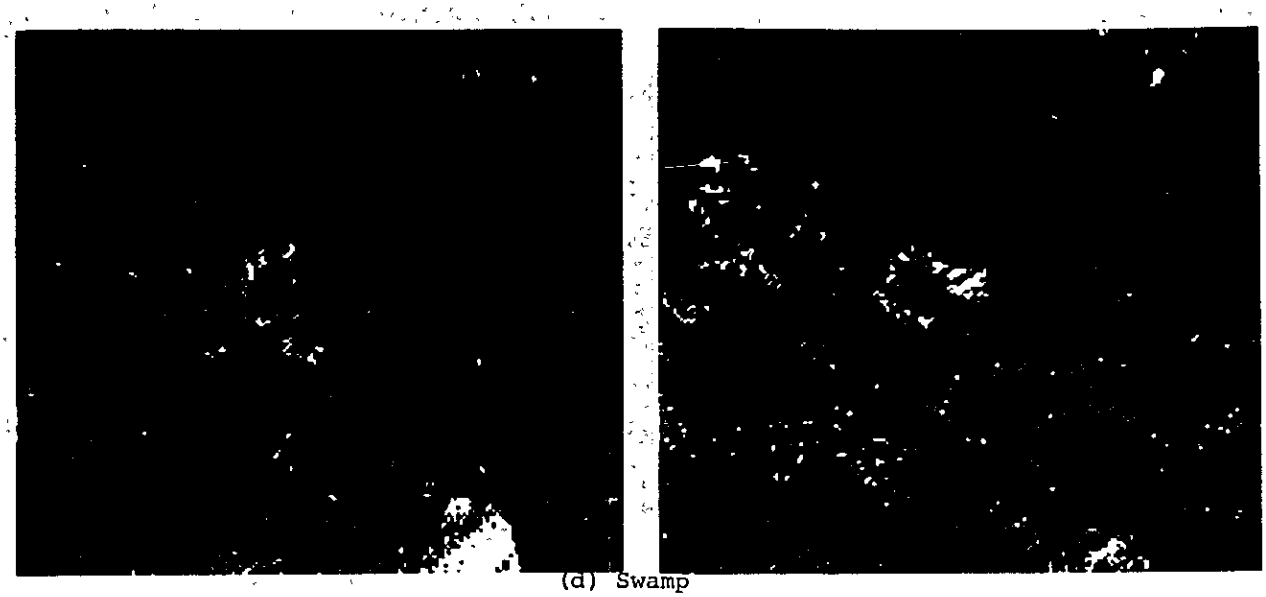
(c) Dryness grassland

Data for December 19, 1978 (Wet season)

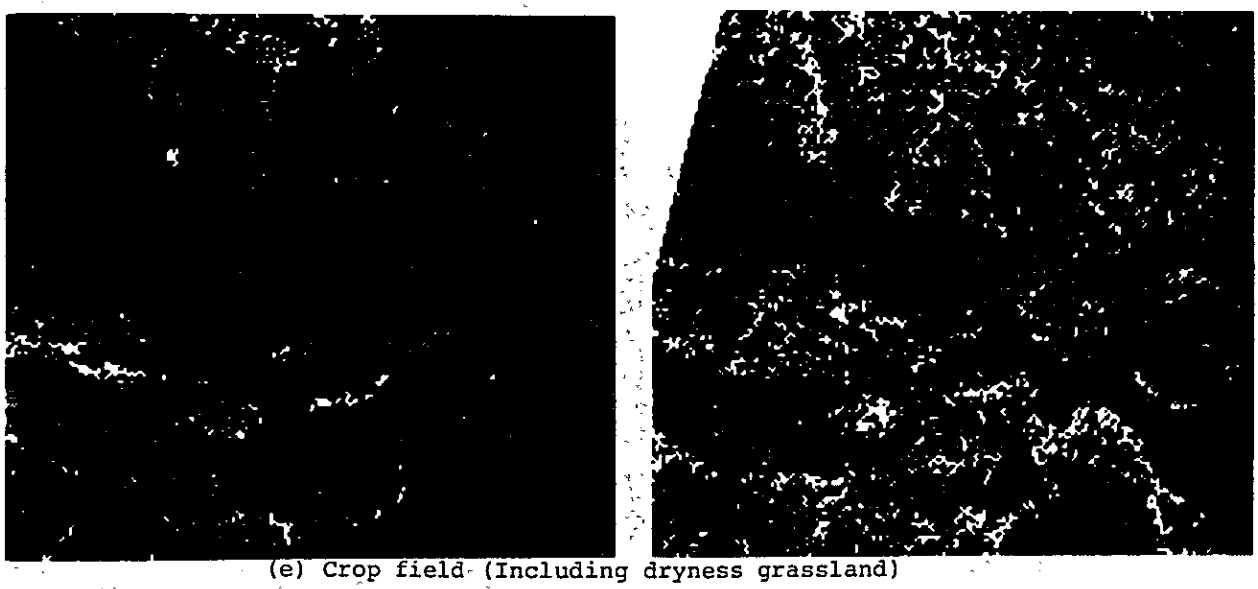
Data for March 17, 1981 (Dry season)

Fig. 12 Images showing the temporal change in the land cover for each classification item

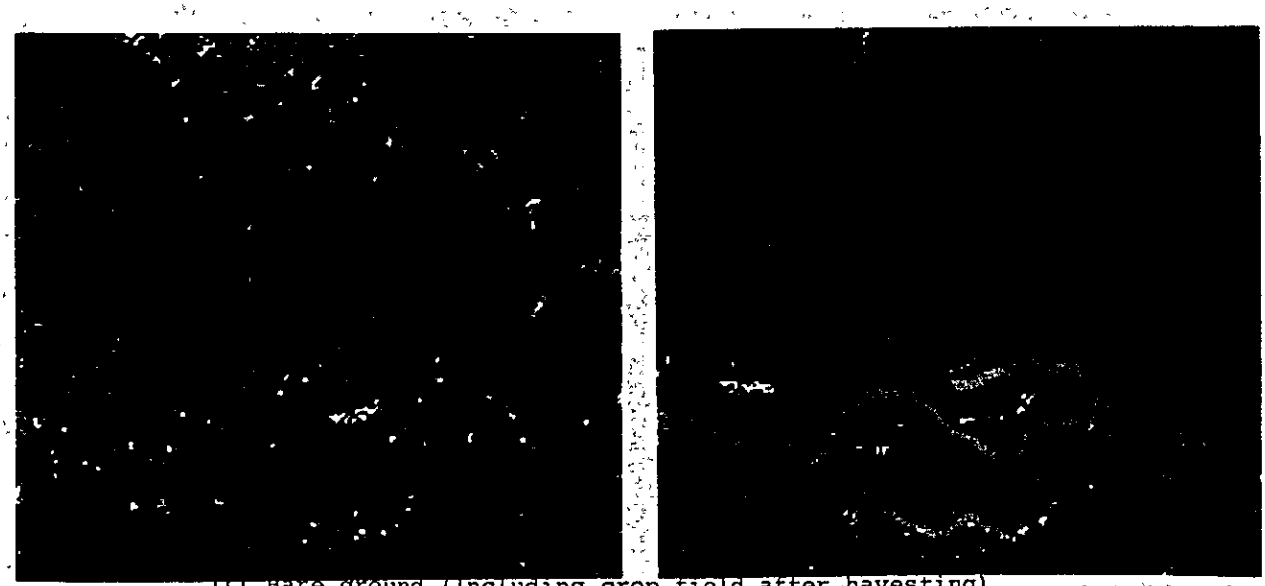









(d) Swamp



(e) Crop field (Including dryness grassland)



(f) Bare ground (Including crop field after havesting)

Data for December 19, 1978
(Wet season)

Data for March 17, 1981
(Dry season)

2.2.2 Change in the ponding area

In a project as this one, in which swamps are improved to agricultural lands by providing irrigation and drainage facilities in wet lowlands, a big problem pertinent to the process of the determination of the scope of the plan is the understanding of the distribution of ponding areas in the swamps caused by rainfall and floods and the depth of ponding and the flooded condition along rivers. Although it is difficult to depict the depth of ponding by the remote sensing method, the distribution of ponding areas can be roughly outlined by the use of images regularly taken, such as LANDSAT images.

In the first-year study, the change in the ponding condition for a large area including the studied area was delineated by the use of 1:500,000-scale false color composite multi-data images. In the second-year study, a more detailed ponding condition was delineated by performing the digital image analysis of the LANDSAT data in CCT format for December 1978 and March 1981. The change in the flooded condition along the Parana River was depicted by the comparison of LANDSAT images taken before and after April 1983. (The entire study area suffered from the great flood in 1983.)

(1) Overall change in the ponding condition

The ponding area was classified into the following two groups based on the interpretation of 1:500,000-scale false color composite images:

1) Completely ponding area (an area which appears black in the false color composite image due to the near-infrared absorption).

2) Ponding area (an area, though ponding, shows a sign of vegetation as indicated in the pale black or dark red color in the false color composite imagery).

Figure 13 shows a ponding area as depicted by the LANDSAT images taken at seven different times between 1976 and 1983. The seasonal change in the ponding condition was obtained by the comparison of images taken in dry and wet seasons in 1976 and 1978.

1) Seasonal change in the ponding condition

The LANDSAT imagery for the wet season (February 9, 1976) shows a large ponding area in the swampy lowlands located to the north of Ayolas and Yabebyry and to the east of San Cosme, while in the dry season (December 19) the ponding areas are scattered only in the areas to the north of Ayolas and San Cosme.

In the wet season in 1978 (December 19), large ponding areas appears to the north of Ayolas and west of San Cosme, while in the dry season (August 15), the large ponding area diminishs and is completely divided by a land into two ponding areas of different sizes, one to the north of Ayolas and the other to the west of San Cosme.

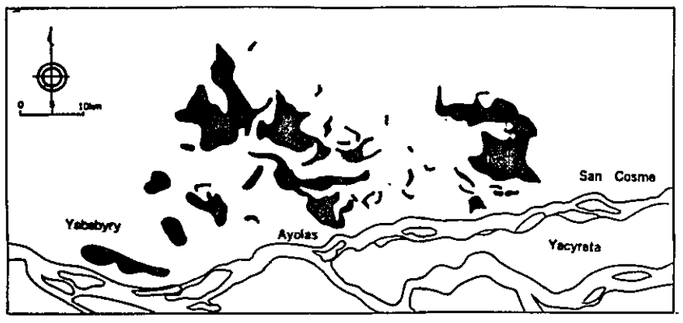
From the above analysis, the following points were clarified:

- Swamps to the north of Ayolas and Yabebyry become ponding throughout the wet season.
- These areas are ponded even in the dry season.

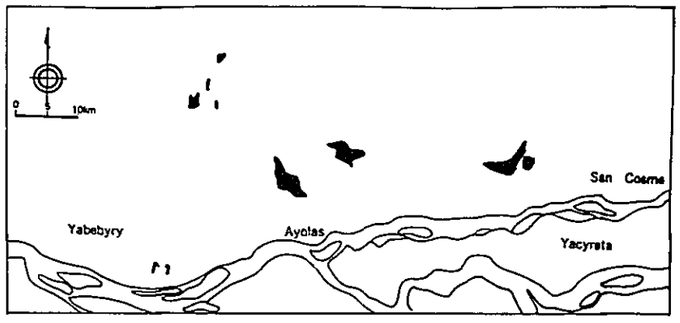
2) Temporal change in ponding areas

The distribution of ponding areas delineated by the LANDSAT images taken from February 1976 to April 1983 is given in Figure 13. As a result of this analysis, the following findings were obtained:

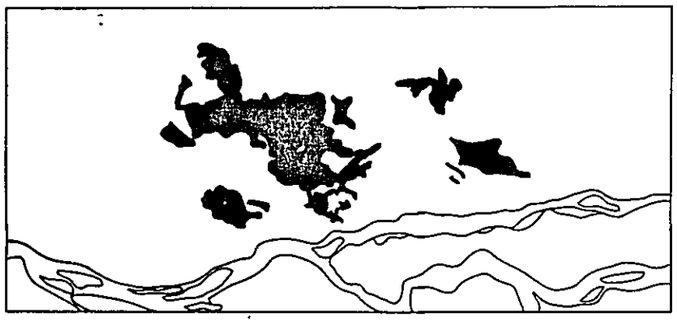
- Ponding areas exist to the east of Yabebyry, north of Ayolas and west of San Cosme in all seasons.
- The ponding areas located in the back swamp between the Yabebyry River and the Atinguy River are grouped into one distributed to the east of Yabebyry and one widely distributed between the river head of the Yabebyry River and the Atinguy River.



February 9, 1976

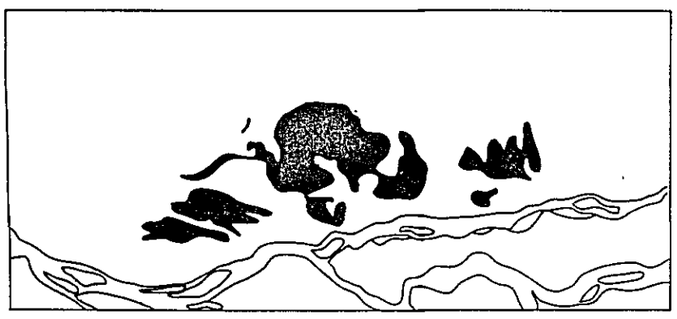


July 20, 1976

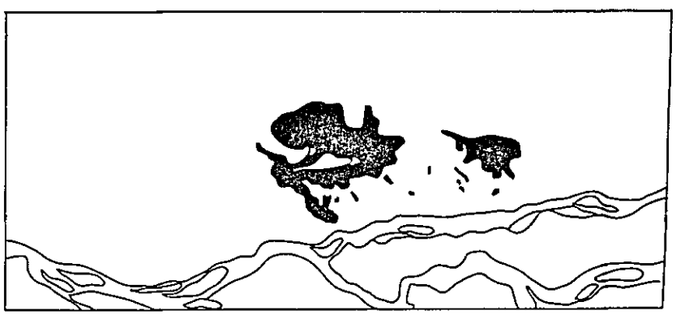


August 15, 1978

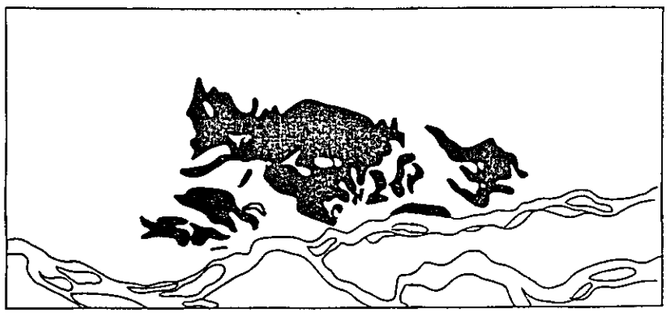
December 19, 1978



September 6, 1979



March 17, 1981



April 26, 1983

(Only areas with marked ponding detected from the LANDSAT imagery are shown)

Fig. 13 Map of Temproral Change in

(2) More detailed change in ponding areas

A 1:250,000-scale image showing the change in the ponding area was prepared by the digital image analysis using the LANDSAT data in CCT format for December 19, 1978 (wet season) and March 17, 1981 (dry season). The result of this analysis is shown in Figure 14.

This image was prepared by the process as shown in the flow chart in Figure 15.

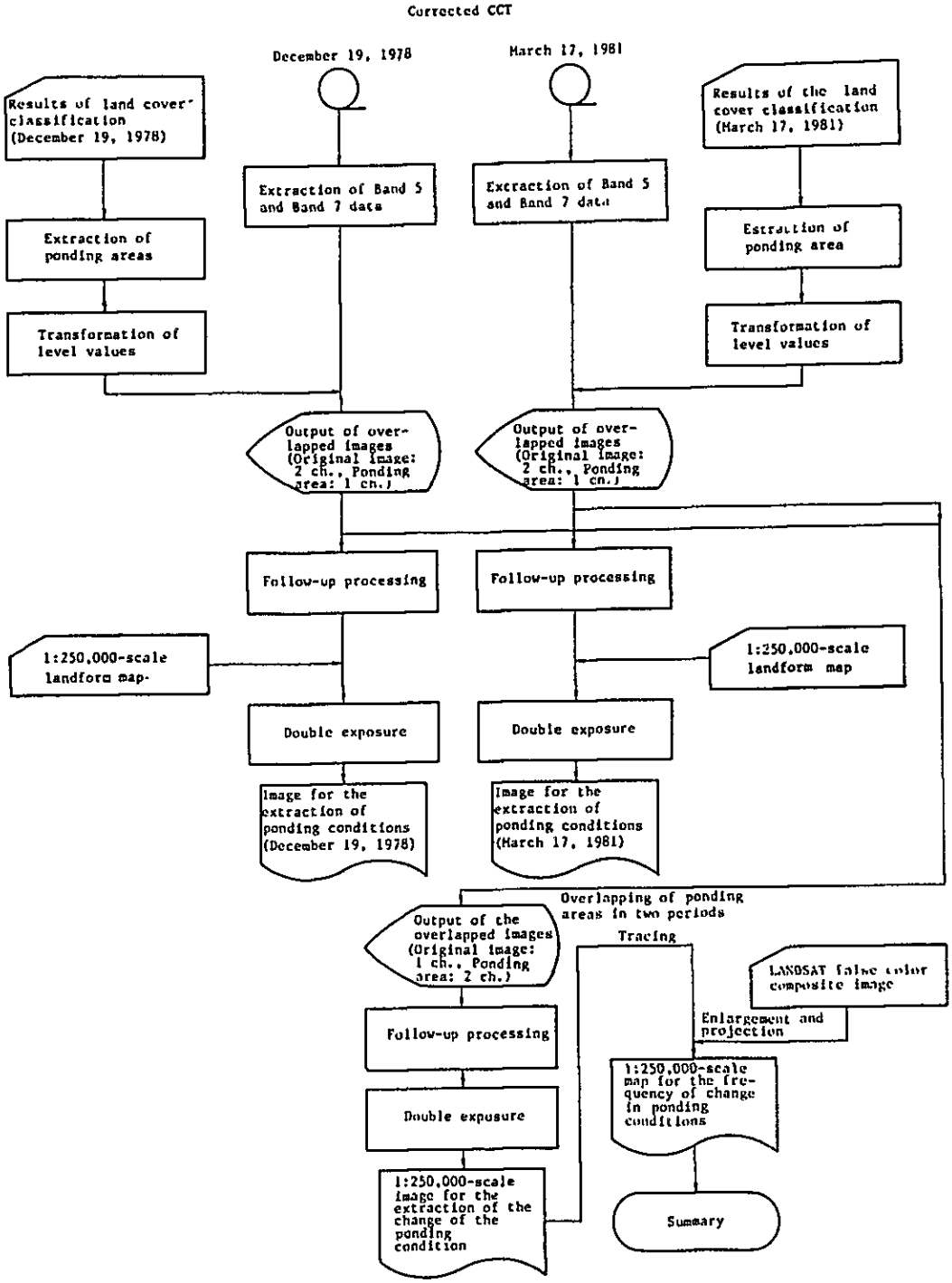


Fig. 15 Flow chart for the extraction of inundated conditions by means of the digital imagery analysis

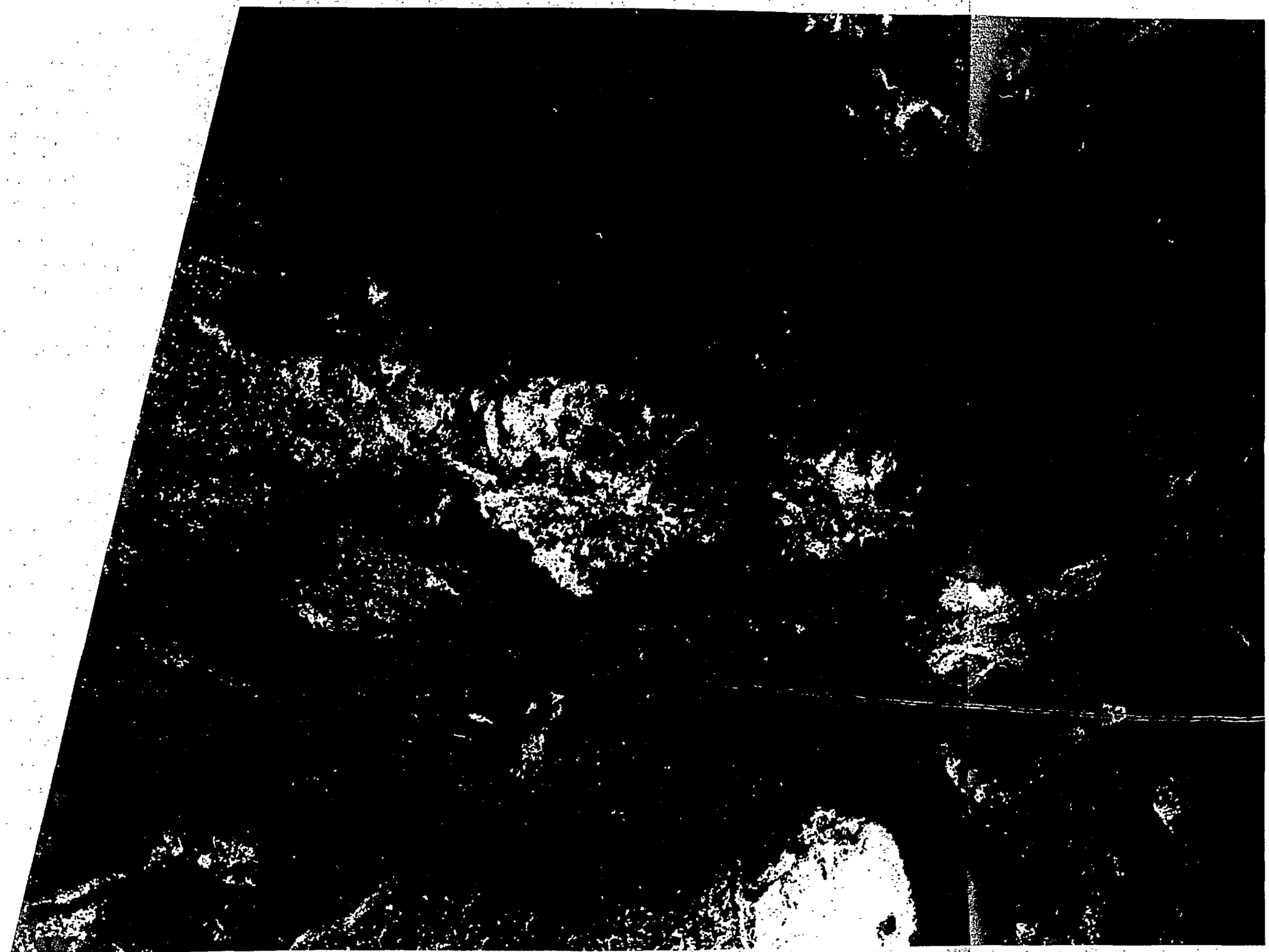


Fig. 14 Image for the extraction of the ponding area

The image shown in Figure 14 was prepared by overlaying the original image (shown in blue) with the ones of the ponding areas for December 19, 1978 and March 17, 1981, where the area in pale blue is the ponding area detected from the December 19, 1978 image and the area in pink is the one detected from the March 17, 1981 image. The white area is the one ponded throughout the two seasons. The findings are summarized as follows:

1) The areas ponded in both seasons in the studied area are found to the northwest of Ayolas, north of Ayolas and on the left bank of the Yabebyry River.

2) Of the ponding areas as stated in 1) above, the one located to the north of Ayolas is especially large.

3) The ponding area to the northwest of Ayolas is a small one, although, as far as the LANDSAT data for December 19, 1978 is concerned, it is spread to a considerably large area. In heavy rain conditions, this would be the extreme outline of the ponding area.

4) The ponding area on the left-bank side of the Yabebyry River showed little change between 1978 and 1981.

In this way, by overlaying the landform map with the results of the digital image analysis of the LANDSAT data and extracting the ponding area in different time, more detailed change in ponding condition was delineated for the studied area.

(3) Frequency of ponding

The frequency of ponding was obtained by overlaying with each other the ponding areas as detected by the interpretation and analysis of LANDSAT imagery for seven seasons from 1976 to 1981. The symbols used in the figure indicate in which season a given area was ponded.

1) The areas ponded for 6 to 7 periods are found to the northwest of Ayolas, north of Ayolas (2 areas), and on the left-bank side of

the Yabebyry River. These areas are considered to be the constantly ponding areas.

2) The areas ponded for 5 periods are distributed roughly around the areas as pointed out in 1) above. These areas are considered to be ponded completely in a particular season of a year.

3) The areas ponded for 4 periods tend to be distributed along the road connecting Yabebyry with Santa Rita and the access road leading to Santa Rosa.

(4) Overall flooded conditions

A comparison in the flow regime of the Parana River between the ordinary discharge time and the large flood period is shown in Figure 17 (Figure 16 shows the flooded area).

1) On the upstream side of San Cosme of the Parana River, little flooded area is observed.

2) A large number of flooded areas are observed between San Cosme and Ayolas. Particularly marked flooding was experienced by the Yacyreta Island where the island was divided into two at the center by the flooded water.

3) On the downstream side of Ayolas, the flooded area is particularly extensive and only the forest on the periphery of a mid-channel sand bar is left as a detectable object.

4) A comparison between the distribution of the flooded area and the landform classification map shows that lowlands along the river, sand bars and sand dunes are completely flooded but natural levees are not.

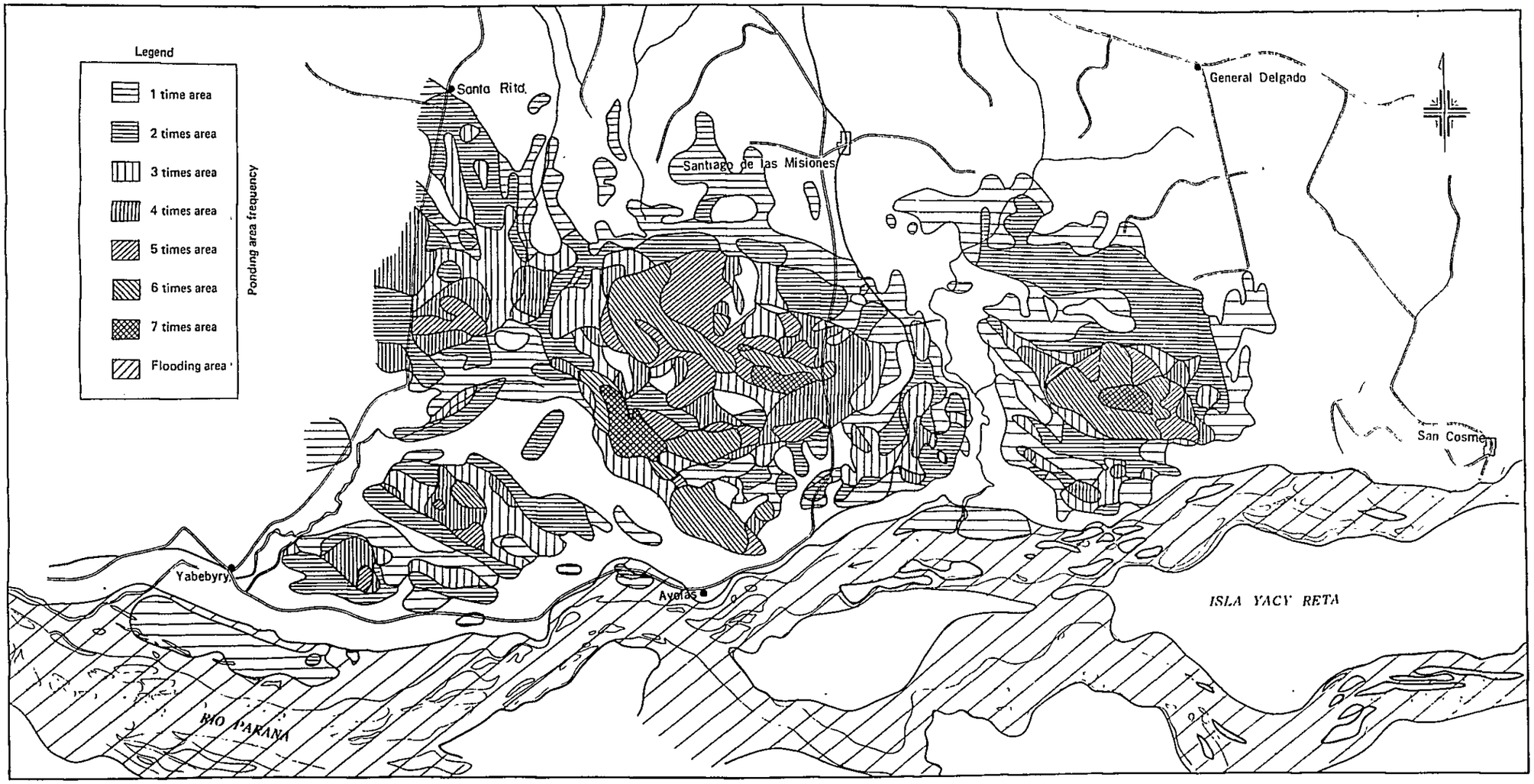


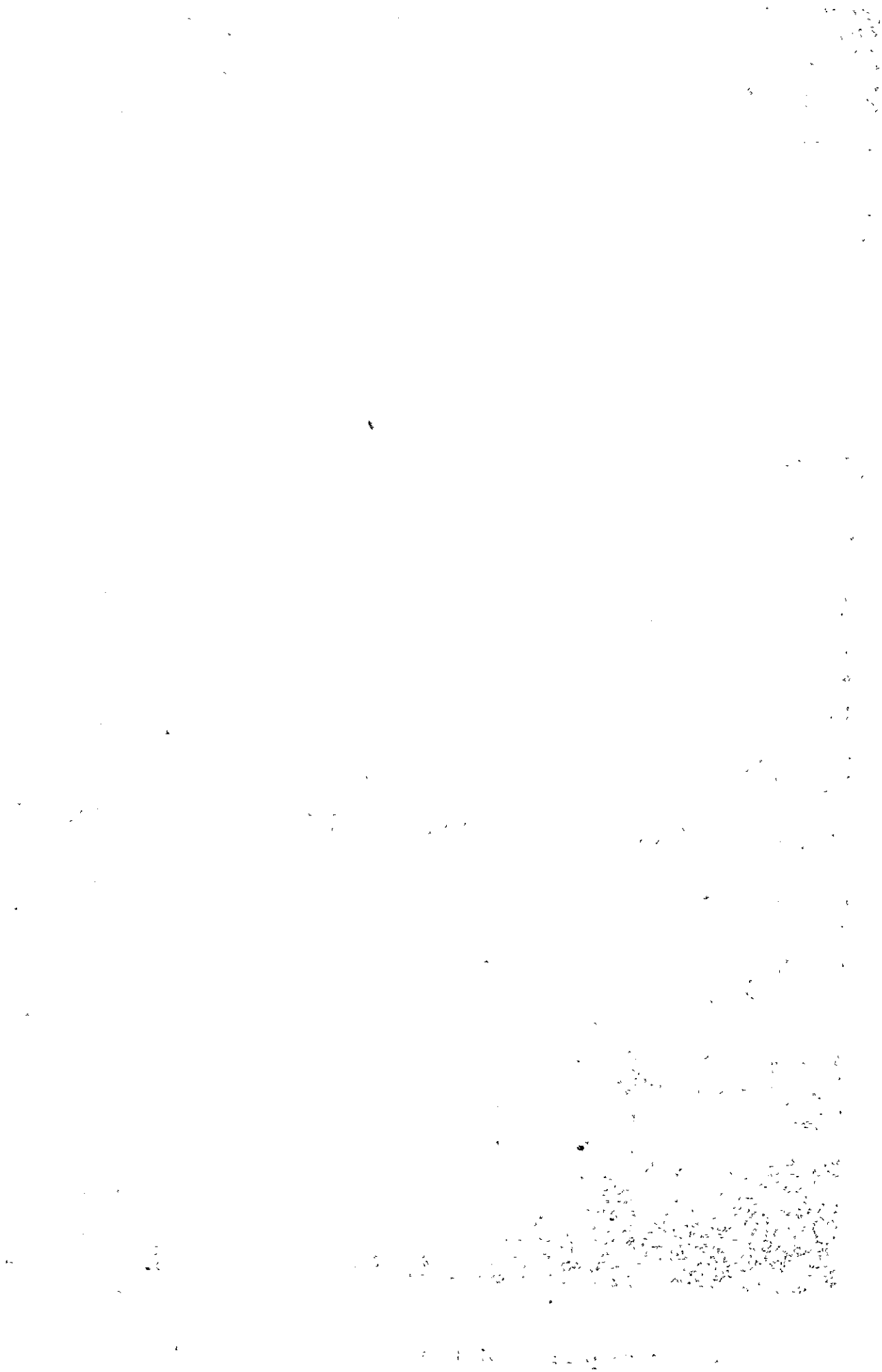
Fig. 16 1:250,000-scale Ponding Area Frequency Map

(February 9, 1976)

(September 6, 1979)

(April 26, 1983)

Fig. 17 Comparison of flow of the Parana River



2.3 Geomorphology

Geomorphology is the basic information for the preparation of soil maps and subsoil geological maps and also constitutes an important factor for the classification of land. In the second-year study, the Geomorphology map (1:50,000 scale) prepared in the first-year study was checked and corrected by the interpretation of aerial photographs and the field survey (Figure 18).

A quick look of landforms in the survey area shows the Parana River running WSW, gently meandering and forming mid-channel bars, such as Yacyreta Island and Talavera Island, etc. The Parana River narrows around San Cosme located at the eastern end of the studied area and forms, by flooding on the right bank side, a huge swampy lowland spreading out from around the narrow portion of the river. In the northern part of this swampy lowland is located gently-sloped hills which consist of a bedrock of sandstone and basalt. The distance between the Parana River and the hill lands is slightly greater than 25 km.

This swampy lowland and hill lands were subdivided as shown below in the Geomorphology map prepared in the present study.

(1) Hill lands

Hill lands are distributed in the north and east of the studied area. Areas with an elevation of greater than approximately 90 m correspond to the hill lands. Due to the advanced dissection of hill lands, they form gentle outline and are used for settlements and crop fields. The bedrock of the hill lands consists of sandstone, basalt, muddy sandstone, etc. and is extremely weathered.

(2) Shallow valleys on hill lands

These are markedly depressed areas on the hill lands forming swamps in many areas and ponds in some areas. They are distributed in extremely limited areas and a few are seen only on hill lands in the northeast of the studied area.

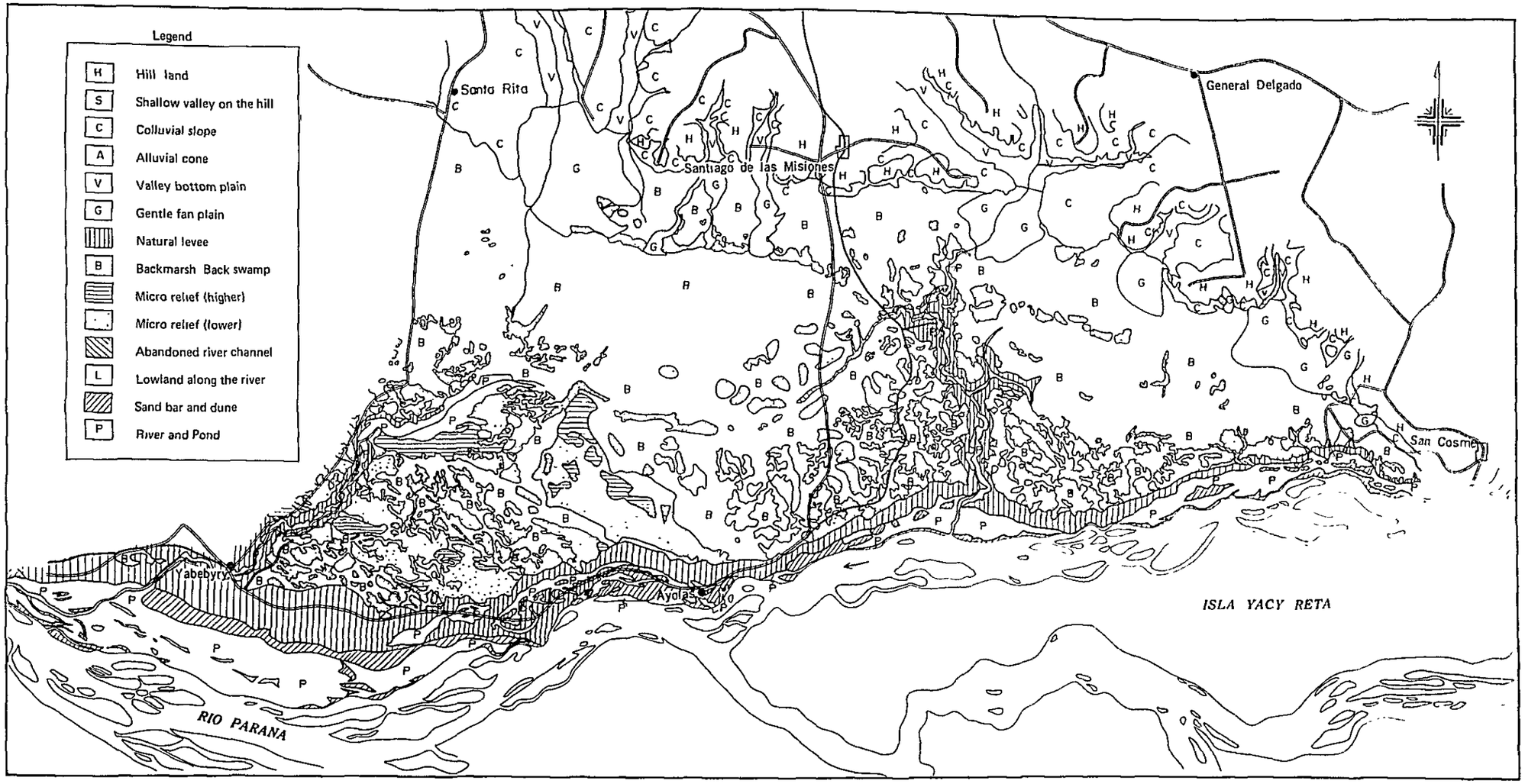


Fig. 18 Geomorphological Map

(3) Colluvial slopes

A depositional landform formed by creeping and rain wash on the lower portion of a slope in the surrounding area of a hill land was classified as a colluvial slope. The surface layer consists of comparatively fine-grained weathered soils and the interfingering portion of this layer with the depositional materials carried by the flood of rivers was also regarded as a colluvial slope. It is distributed in a comparatively clustered form along the hills in the northeast of the studied area.

(4) Alluvial cones

A comparatively steep and new alluvial fan located, in the similar way as a colluvial slope, on the slope of a margin of hill lands is regarded as an alluvial cone. It is only seen in small number around the margin of hill lands in the northeast of the studied area.

(5) Valley-bottom plains

This is a flat plain formed by the depositional process of a river dissecting hill lands and is found in the northern and northwestern parts of the studied area. It was formed by the same process as the one forming the gentle fan plain to be mentioned below, but the difference is that a valley-bottom plain is bounded by hill lands on both sides of a valley limiting its lateral spreading.

(6) Gentle fan plains

An area extending from a valley-bottom plain and having a deposition of materials transported from the upper stream was regarded as a gentle fan plain. It is formed by a muddy deposit and has a high ground water level.

(7) Natural levees

Large-scale natural levees are continuously observed along the Parana River. Narrow ones are also seen along the Atinguy and the Yabebyry Rivers. Although there is a marked difference in elevation between natural levees and the lowland along rivers to be mentioned below, the difference in elevation between natural levees and the back swamp is not very clear. They are formed by sandy deposits and used for crop fields and settlements.

(8) Back swamp

A swamp flat area behind a micro relief such as a natural levee is regarded as back swamp. Of the backmarshes in the studied area, the one located in the center of the western part seems to be flooded all the time and is left without being used. However, back swamps near the hill lands are used for paddy fields and pastures.

(9) Micro relief (high) in the back swamp

Micro reliefs are observed as floating islands in the back swamp. Of these, ones higher than natural levees with the difference in elevation of several meters with the surrounding areas were classified as micro reliefs (high). They are distributed as a projected land to the north of Coratei and as islands on both sides of the Yabebyry River. The surface layer of the lands is extremely sandy like natural levees.

(10) Micro reliefs (low) in the back swamp

These are also micro reliefs but lower in elevation than the ones stated in (9) above. They show a complicated pattern just behind natural levees in the back swamp. It is estimated that these lands were formed in peculiar forms by the repeated erosion and deposition as a number of small rivers changed their courses in the area of sandy deposits continuing behind natural levees. Generally, they are

formed by sandy deposits. With the increasing elevation from the back swamp, the texture of the deposits tend to become coarse.

(11) Abandoned river channels

Out of abandoned river channels, only comparatively new ones with clear channel shapes were regarded as abandoned river channels. And the lowlands along present rivers (to be mentioned later) which are easily flooded at the time of the increased water level and easily deformed are excluded. Abandoned river channels are observed only between natural levees around Coratei.

(12) Lowland along rivers

This is the lowland distributed along rivers in belt forms and easily flooded by the increase in water level. It is characterized by poor vegetation and low temperature. It is formed by the sandy and muddy deposits and is left unused.

(13) Sand bars and sand dunes

Out of the slightly elevated lands in the lowland along rivers, ones lower than natural levees were regarded as sand bars and sand dunes. They were formed by either streams or winds and have various elevations. They are being stabilized by the colonization of trees and other vegetation. But as far as the elevation is concerned, they have a danger of being submerged. They are more sandy than the valley-bottom lowland.

2.4 Elevation Classification

Elevation classification is used as the basic data for the understanding of general landform conditions of the studied area, evaluation of land in terms of the land productivity (particularly, in terms of the difficulty of cultivation), and evaluation of the danger of ponding and flooding. It was prepared by the following procedure:

(1) Expresses the elevation by the mesh method uses the highest elevation as a representative value in the 500m-square grid.

(2) Uses 1:50,000-scale compiled map as a base map.

(3) Elevation classes of the following were used:

1) 50 ∿ 60 m
2) 60 ∿ 70
3) 70 ∿ 80
4) 80 ∿ 90
5) 90 ∿ 100
6) 100 ∿ 110
7) 110 ∿ 120
8) 120 ∿ 130

The results of the classification of elevation are shown in the separate collection of figures and the simplified version is also given in Figure 19. As a result of this classification the following points were found:

(1) The elevation class of 50-60 m is distributed in the swampy lowland near the confluence of the Yabebyry River and the Parana River and in the lowland along the Parana River.

(2) The elevation class of 60-70 m is distributed in the lowland along the Parana River and in the lowland along the Yabebyry River.

(3) The elevation class of 70-80 m is most widely distributed and represents the elevation of the most of the low back swamp.

(4) The elevation class of 80-90 m is located at the margin of hill lands and is distributed in the east, northeast and northwest of the studied area. Micro reliefs to the northwest of Ayolas and natural levees along the Parana River belong to this elevation class.

(5) The elevation class of greater than 100 m is mostly hill lands and is distributed in the east, northeast and northwest of the studied area, in the same way as the elevation class of the above (4).

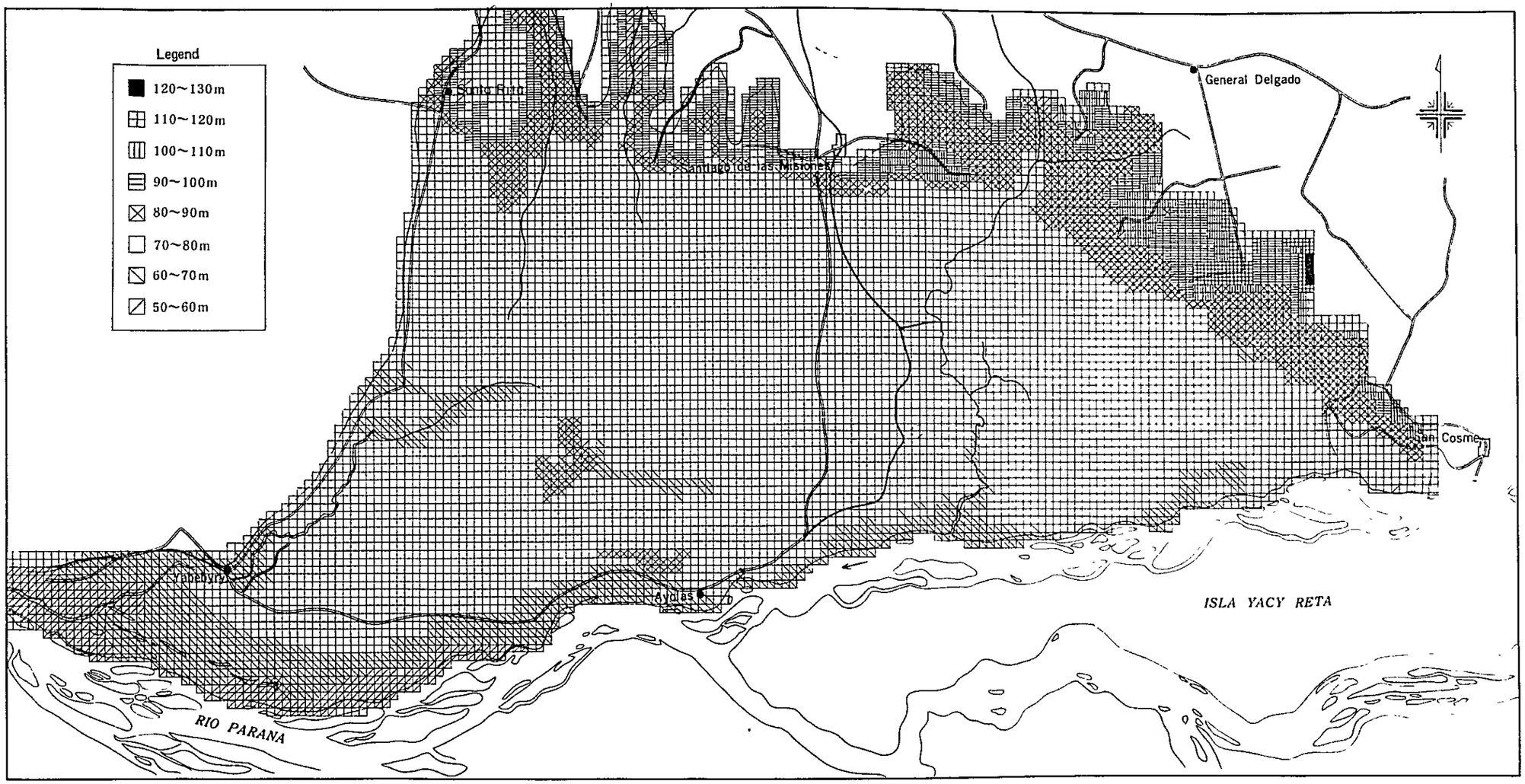


Fig. 19 Elevation Division Map

2.5 Slope Aspects

Slope aspect map was prepared by the following procedure to be used as the basic data for the evaluation of the land productivity and for the preparation of the agricultural management plan:

(1) Uses 500m-square meshes.

(2) The slope aspect is read out on a 1:500,000-scale base map.

(3) 9 classes, i.e., 8 aspects and a flat plane, were used for the classification, using the direction of north as the reference axis.

The result is shown in a separate collection of maps (1:50,000-scale) and, at the same time, a simplified version of the slope aspect map is given in Figure 20.

(1) South-facing slope

South-facing slopes are distributed in the natural levee areas adjacent to the Parana River and around the boundary between the hill lands and the back swamp.

(2) West-facing slope

West-facing slopes are distributed in the hill lands and a relatively larger number of west-facing slopes than the east-facing slopes are found in the studied area.

(3) East-facing slope

East-facing slopes are distributed in hill lands and micro reliefs in the back swamp areas.

(4) Southwest-facing slope

Southwest-facing slopes are mostly distributed on the southwest-facing slopes of hill lands extending to the northwest from San Cosme and in the natural levee areas adjacent to the Parana River.

(5) North-facing slope

North-facing slopes are very few and only rarely seen in natural levee areas adjacent to the Parana River and in micro reliefs in the back swamp.

(6) Flat plane

Flat planes which occupy most of the studied area are distributed in the area between the Parana River and hill lands located in the north and northeast of the studied area.

(7) Other slopes

Slopes facing other than those listed above are only scattered in the hill lands extending to the northwest from San Cosme and in the micro reliefs in the upper stream portions of the Yabebyry River and the Atinguy River.

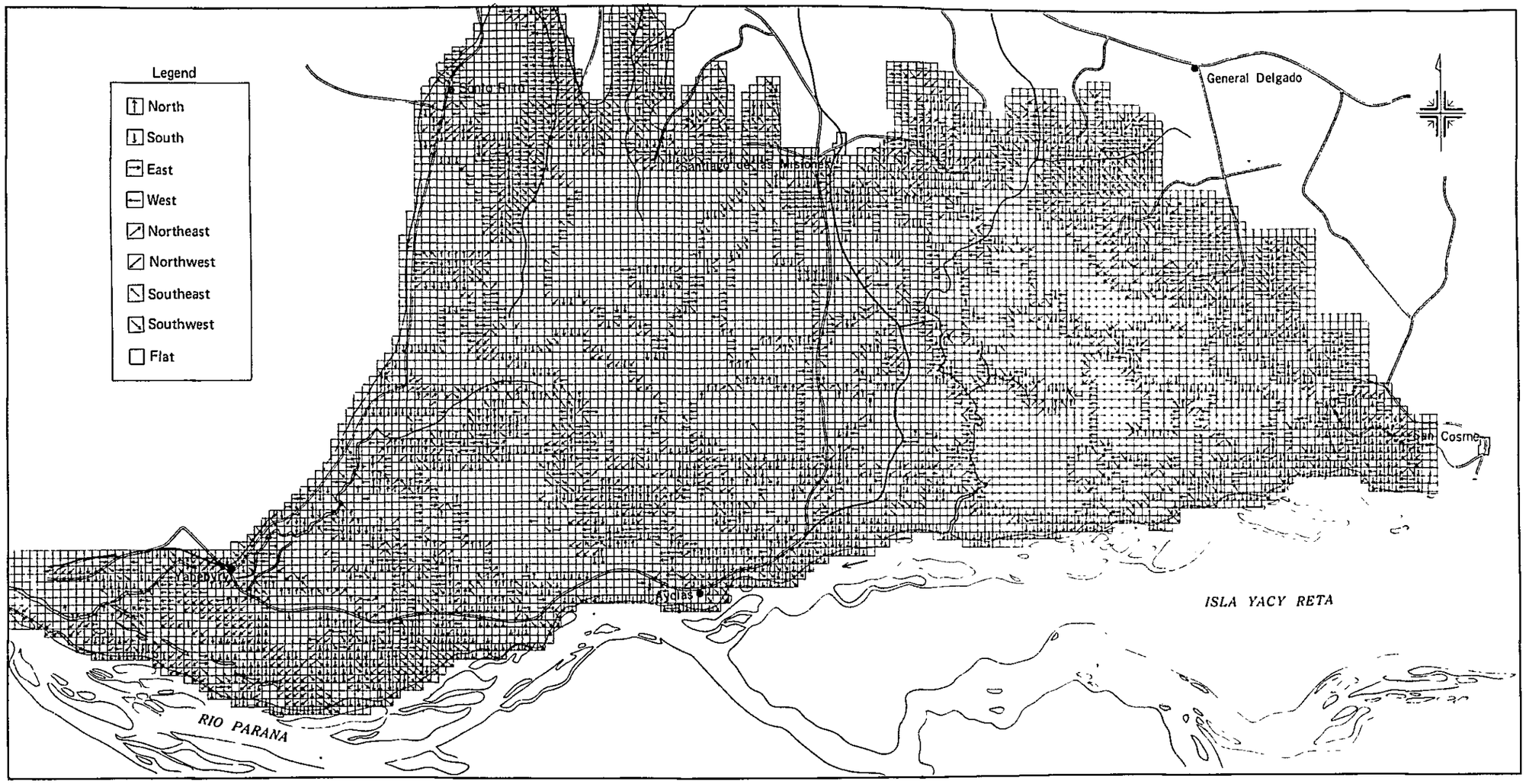


Fig. 20 Slope aspects Map

2.6 Slope Classification

Slope is a factor showing characteristics of landforms and at the same time constitutes the basic data for athe evaluation of land productivity, such as the difficulty of cultivation as a farmland.

A slope classification map was prepared in the following procedure:

(1) Slopes were expressed in the mesh method; the same mesh size as the one used for the elevation map was used for the measurement.

(2) The maximum slope in each mesh was used as a representative value for the mesh.

(3) The following five classes were used for the classification of slopes:

1) Less than 1°
2) 1 ∿ 3°
3) 3 ∿ 5°
4) 5 ∿ 8°
5) Greater than 8°

The result of the study is shown in the separate collection of figures (1:50,000-scale) and a simplified version of the slope classification map is given in Figure 21. The findings are summarized as follows:

(1) The most of the area except for the hill lands had slopes of less than 1° in the studied area.

(2) Areas with slopes of 1-3° are distributed on natural levees along the Parana River, in the hill lands in the north of the studied area, and in micro reliefs along the Atinguy River.

(3) Areas with slopes of 3-5° are widely distributed around the margin of the hill lands and in the natural levees areas along the Parana River.

(4) Areas with slopes of greater than 5° are distributed around Ayolas, on micro reliefs in the back swamp to the northwest of Ayolas, and on hill lands in the northwest of the studied area, and has a tendency of scattered distribution.

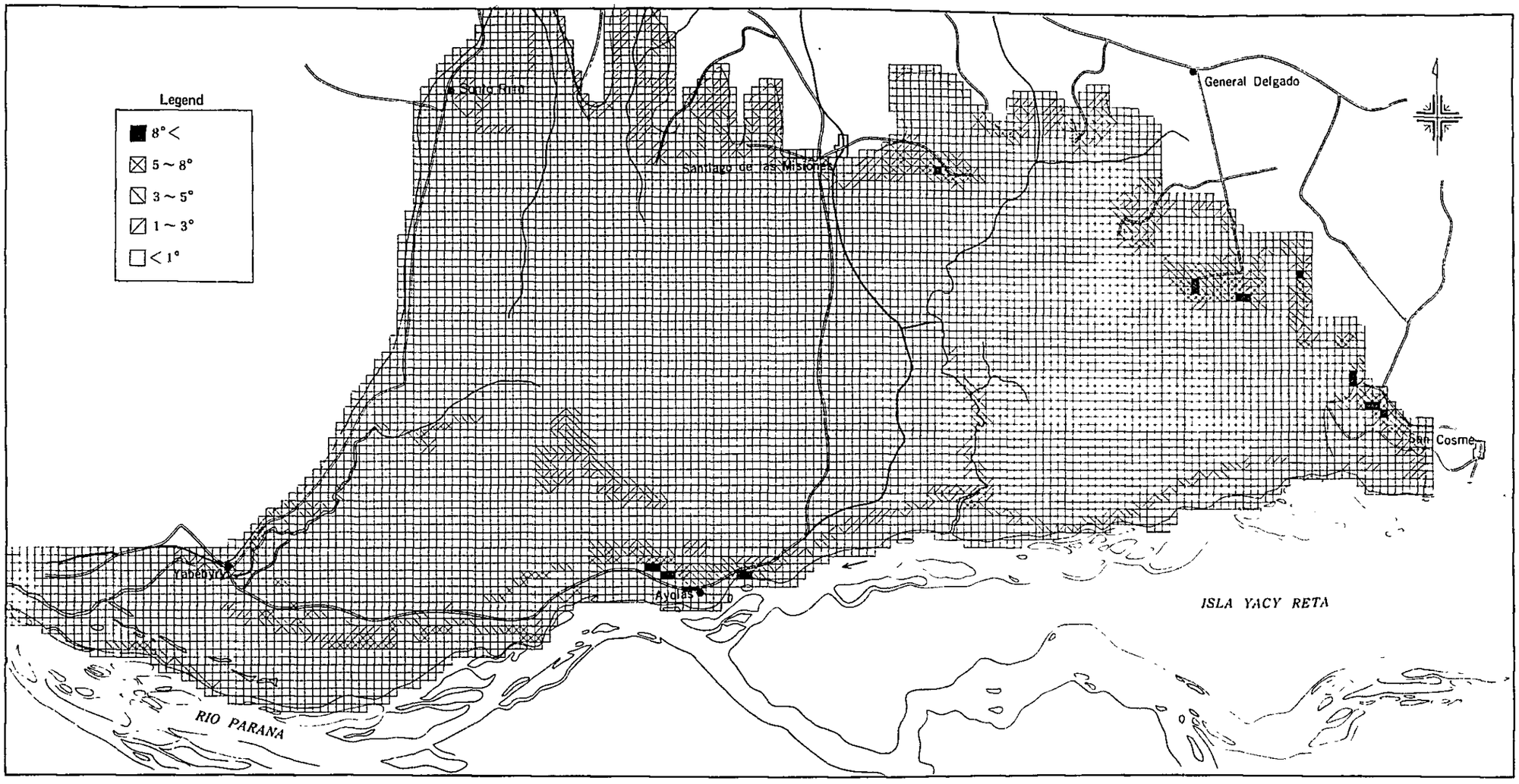


Fig. 21 Slope Classification Map

2.7 Relief Energy

Relief energy were used as the basic data for the understanding of the general characteristics of landforms in the studied area and for the evaluation of land productivity (particularly, athe difficulty of cultivation). Basically, the operation was proceeded with the following things in mind.

(1) Relief energy were expressed by the mesh method and the same mesh size as the one used for the preparation of elevation maps was applied.

(2) The interval of contour lines within the mesh was used for the evaluation of relief energy.

(3) The following 6 classes were used for the classification of relief energy.

1) Less than 5 m
2) 5 ∿ 10 m
3) 10 ∿ 15 m
4) 15 ∿ 20 m
5) 20 ∿ 25 m
6) Greater than 25 m

The results are shown in the separate collection of maps (1:50,000) and a simplified version of the relief energy map is shown in Figure 22. The following findings were obtained by the preparation of the map.

(1) The most of the studied area belongs to the class of less than 5 m, which is distributed in the area between the Parana River and the hill land at the northern end of the studied area.

(2) The area with relief energy of 5-10 m is distributed in the surroundings of the area with relief energy of 10-15 m, on natural levees along the Parana River and on the micro reliefs along the Yabebyry River.

(3) The area with relief energy of 10-15 m occupies most of the hill lands.

(4) The area with relief energy of greater than 15 m is distributed around Ayolas in the natural levees areas along the Parana River, on micro reliefs in the back swamp to the northwest of Ayolas, and on hill lands in the northeast of the studied area.

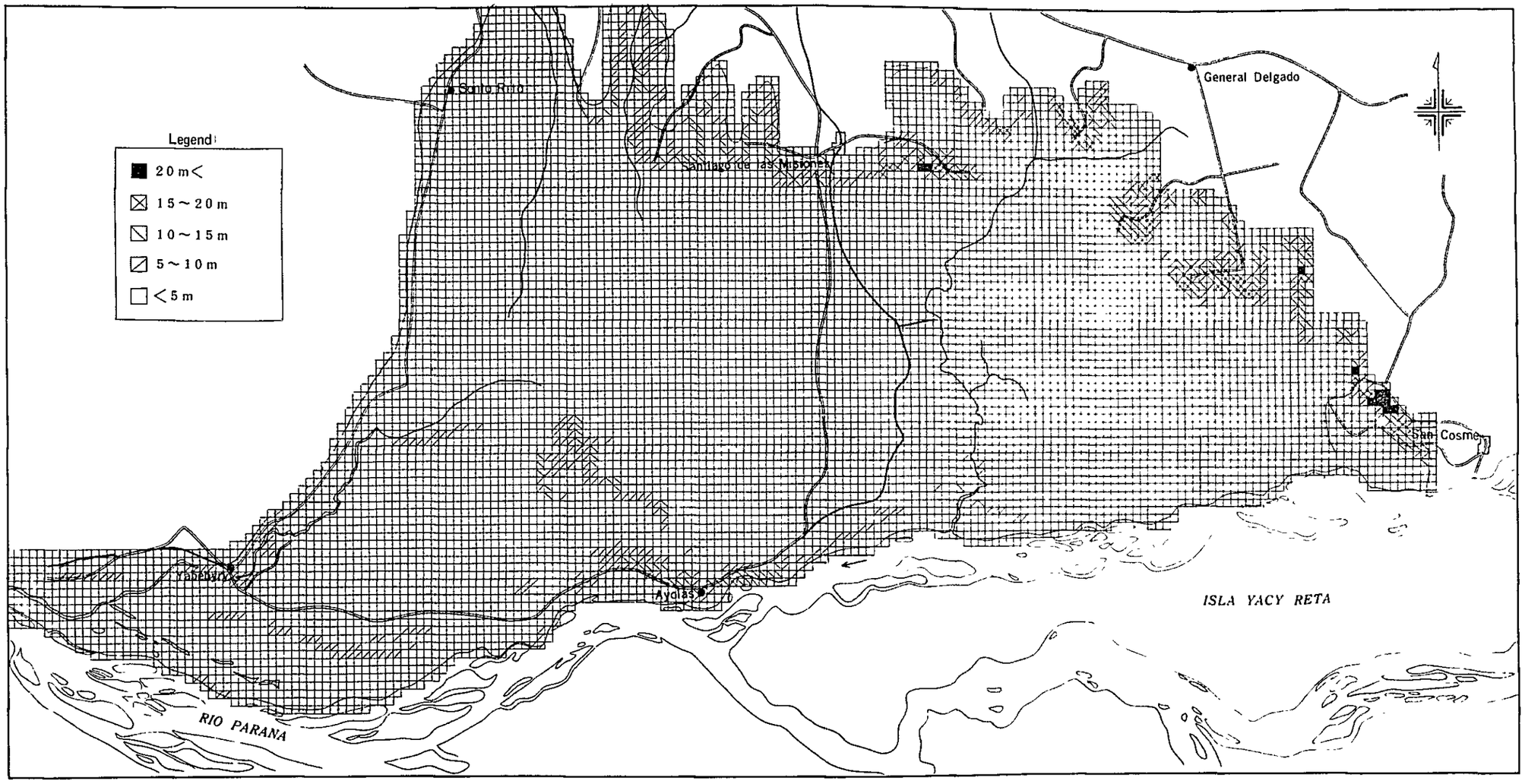


Fig. 22 Relief Energy Map

2.8 Land Use

The land use map is one which shows how the land is being used. It is important not only for the understanding of the distribution of each land use type, but also constitutes the most basic information for the classification of land.

In the first-year study, a land use map (1:50,000-scale) was made for the field survey by the use of the LANDSAT false color composite images and available data. In the second-year study, this land use map was checked and corrected by the LANDSAT digital image analysis, interpretation of aerial photographs and field survey, and the final land use map (1:50,000-scale) was completed as shown in the separate collection of maps. A simplified version of the map is shown in Figure 23.

(1) Forests (natural forests and artificial forests)

Forests in the studied area are largely classified into natural forests and artificial forests. Approximately 90% of the forest area is natural forests and the remainder is the artificial forests. Artificial forests are distributed only along the upper stream of the Atinguy River.

In any season forests show up in bright magenta in the LANDSAT false color composite image and the detailed digital image analysis shows a clearer distribution of forests (Figures 9 and 10). Forests show up in white or greyish white in infrared aerial photographs and are easily differentiated from swamps which appear dark or black because of the absorption of infrared by water.

Forests are distributed on hill lands and micro reliefs in lowlands, along rivers and on natural levees along rivers. Representative locations of forests are:

1) A cluster of forests on a micro relief to the northwest of Ayolas.

2) Forests forming a belt to the west of Ayolas.

3) Forests around the river head of the Yabebyry River.

4) Forests forming a belt along the right bank of the Parana River between Ayolas and San Cosme.

5) The Atinguy River.

6) Forests distributed in clusters on hill lands to the northeast of San Cosme.

Forests in 5) above are gallery forests and swamp forests located on comparatively well-drained natural levees and micro reliefs in the back swamp which are a little higher than the swampy lowland. Forests in 6) above are plateau forests which favor dry soils.

Fig. 23 Land use Map

(2) Natural grassland

Natural grassland is classified into 1) the dry (xeric) grassland which is distributed on micro reliefs and hill lands, and 2) wet (hydric) grassland which favors swampy lowland. The differentiation of these two types of vegetation by the LANDSAT digital image analysis is comparatively easy and they are classified by the use of the near-infrared reflectance as an indicator. They can also be classified in aerial photographs by taking into account the difference of locational conditions (e.g., topographic difference between hills and swampy lowlands) and the difference in the infrared reflectance.

1) Grassland on micro reliefs and hills (dry grassland)

This grassland is widely distributed on the hill lands in the north and east of the studied area, on micro reliefs which are scattered continuously between San Cosme and Santiago, on micro reliefs clustering in the swamp belt bewteen the Atinguy River and the Yabebyry River, and on natural levees along the Parana River.

2) Lowland grassland (wet grassland)

This is the wet grassland which favors swampy lowlands widely distributed in the studied area and occupies about 50% of the area. It appears greyish in infrared aerial photographs and is differentiated from swamps (which are dark in photographs).

(3) Swamps

Areas where hydrophytes and others are luxuriant were collectively regarded as swamps. Because of the super-saturated hydrologic environment, swamps which absorb near-infrared show up in black color in the LANDSAT false color composite imagery. Swamps also appear dark in infrared aerial photographs. A comparison of multi-date LANDSAT images shows that the swamp area changes seasonally (Figures 5 through 8, and Figure 12). The distribution of swamps presented in this report is based on the infrared aerial photographs taken in November

1972. Swamps are relatively widely distributed around the Atinguy River and to the east of the Yabebyry River at this time of the year.

(4) Artificial grassland

This type of vegetation can be identified as such by the interpretation of aerial photographs and the field survey, but cannot be differentiated from the natural grassland on the LANDSAT imagery. In aerial photographs, only the grassland, which gives a very fine texture, constant tonal range and clear edge of the grassland boundary which is a sign of human activities, was classified as the artificial grassland and differentiated from the natural grassland. Representative artificial grasslands are observed in the northern hill lands of the studied area.

(5) Paddy fields

In the studied area the foliage production is the main agricultural practice and the paddy field is used in the three-year crop rotation to increase the fertility of land for the production of good foliage grass. Patterns and tones in aerial photographs would not tell the difference between the paddy fields and the grassland. The distribution was confirmed by the field survey. They are distributed only in the lowland adjacent to the northern and eastern hill lands and along the Parana River and the Atinguy River.

(6) Crop fields

No large crop fields were observed in the studied area. All are small and seen on well-drained sandy soils on hill lands and natural levees.

(7) Others

Residential areas, airfields, cemeteries, and bare grounds are grouped in this category.

As aresult of the above study, it was found that the present land use of the studied area is strictly controlled by the topographic condition In other words, the landform types and the land use types well coincide as shown in Figure 24.

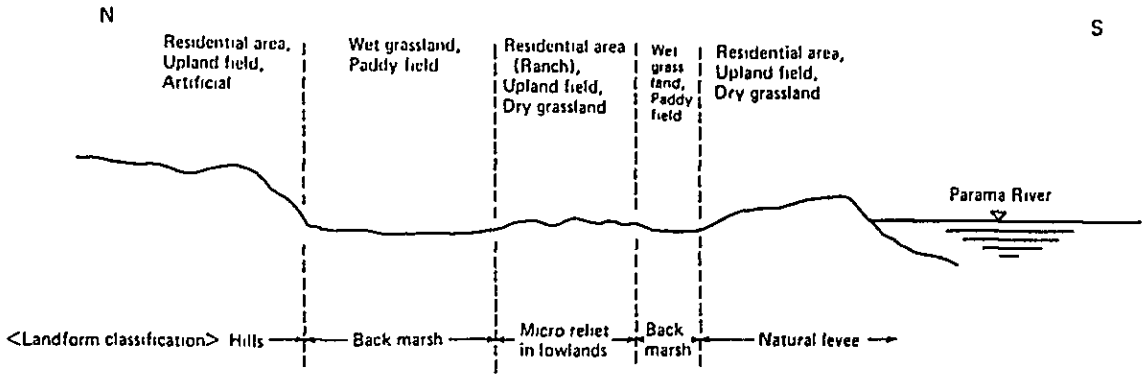


Fig. 24 Relationship between the Geomorphology and the Present Land Use

Table 5 shows the relationship between the landform types and the present land use types.

Table 5 Relationship between landform types and tresent land ues types

Agri-cultural form	Area %	Artificial grassland	Natural grassland	Paddy field	Crop field	River and pond	Others	Total
	Area (ha)	1,625	172,000	6,875	3,275	100	16,500	200,375
	%	0.8%	85.8%	3.4%	1.6%	0.0%	8.2%	100.0%

the relationship between the two is summarized as follows:

1) Hill lands are used for crop fields, dry grassland and artificial grassland. The most intensive land use is observed here.

2) Micro reliefs in lowlands are used only for settlements and crop fields because of the small area and the closeness to the back swamp.

3) Natural levees show advanced land use next to hill lands and are used for residential areas, settlements, and crop fields.

4) The back swamp is mostly left unused because it is ponded in the wet season and only a limited area in the back swamp is used for natural pasture land. Part of the back swamp adjacent to hill lands is used for paddy fields.

2.9 Physiognomy of Vegetation

Vegetation was classified in terms of the physiognomy of vegetation through the interpretation of the result of the LANDSAT digital image analysis and aerial photographs and the field survey based on the aforementioned land use map (1:50,000). The result is shown in the separate collection of maps (1:50,000-scale map of the vegetation) and in Figure 25.

(1) Forest

Forests in Paraguay are distributed on elevated lands and well-drained lands. Soils in the forest can be roughly classified into two types: 1) sandy soil of light color formed from the parent rock of sandstone and 2) terra roxa soil of dark red color which developed from the parent rock of basalt. These soils have the characteristics as listed in Table 6.

Table 6 Characteristics of forest in different soils

Forest in sandy soils	Forest in Terra roxa soils
1. The average height of principal tree species is low.	1. The average tree height of principal tree species is tall.
2. Number of trees per ha is small.	2. The total number of trees per ha is large.
3. Number of usable tree species is small.	3. Number of usable tree species is large.
4. The total average tree volume is small.	4. The total average tree volume is large.

Sandstone and basalt are distributed on the hill lands spreading in the north of the studied area, where forests as affected by the above two types of soils exist. However, since they are mostly the remnants after the logging, no significant change as shown in Table 6 can be observed. On the other hand, in the swampy lowland, a forest exceeding 15 m in the mean tree height is rare and the forest is mostly composed of low trees.

The forest distribution in the studied area is classified into the following types:

1) Hill land forest distributed on hill lands.

2) Forest on micro reliefs in the swampy lowland.

3) Plateau forest and gallery forest on natural levees and micro reliefs along rivers.

All these forest types are located on well-drained elevated lands. In the field survey a representative forest was selected from each forest type distributed in the studied area and trees were studied by applying the 10m-square rectangle (Figure 26).

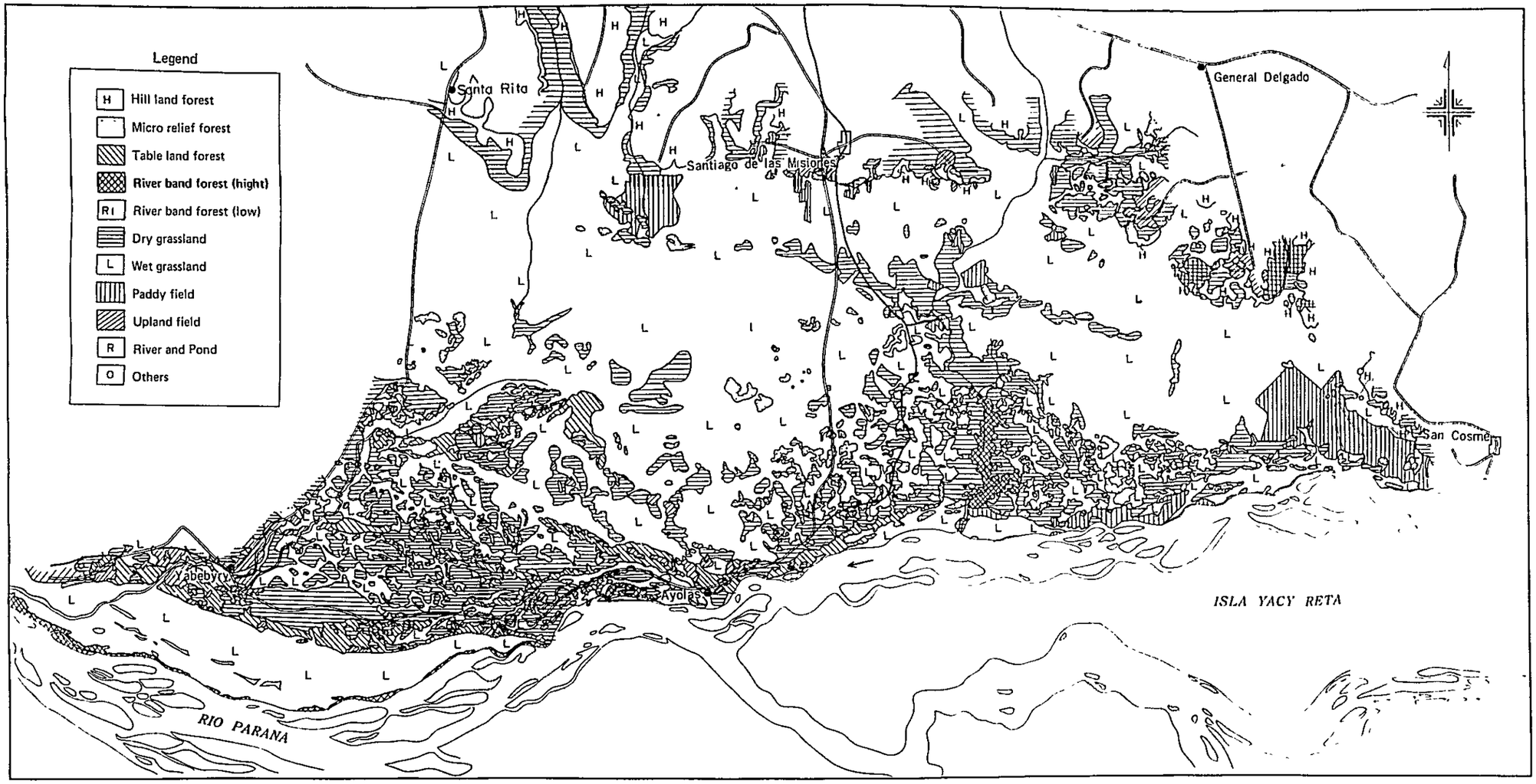


Fig. 25 Vegetation Map

(1) Hill land forest

This is a group of xeric forests distributed on hill lands. The relationship between the diameter at breast height (DBH) and number of standing trees (Figure 26 (A)) shows a balanced distribution of trees in the range of trees from small to large DBH (maximum of about 80 cm), with the number of standing trees of about 1,700 per ha. Trees are concentrated in the tree height class of 25-30 m.

This forest type is distributed on the hill lands in the north and east of the studied area and is particularly concentrated on gentle slopes around Santa Rita.

(2) Forest on micro reliefs

Forests located on micro reliefs were differentiated from the gallery forest. As shown in Figure 26 (B, C), this forest type, as compared with the hill land forest, is characterized by the small DBH and large number of standing trees. Number of standing trees is 2,000 - 3,000/ ha. Trees with the height class of 15-20 m is representative in this forest type. The forest of this tyep is widely scattered in the backmarsh, i.e., a huge area between the hill lands to the north and east and natural levees of the Parana River and occupies only very small area. However, it presents the only esthetic attraction in the otherwise monotonous swampy lowland.

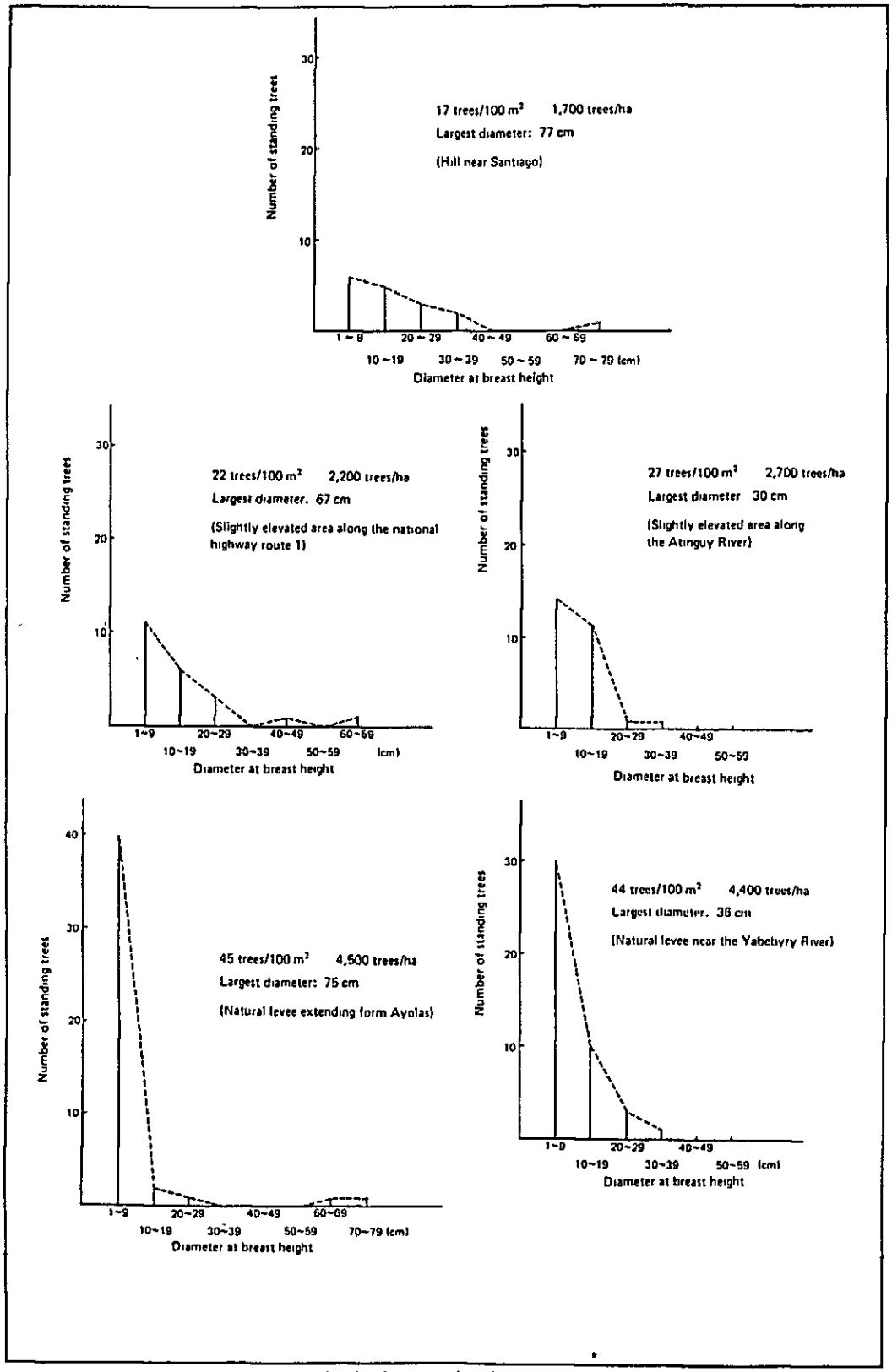


Fig. 26 The Relationship between the Diameter at Breast Height and Number of Standing Tress in Different Physical Environment

(3) Plateau forest

Included in this type of forest are ones on a large natural levee along the Parana River, and ones distributed in a wide area on micro reliefs to the northwest of Ayolas. It is different in structure from the gallery forest to be mentioned below. As shown in Figure 26 (D, E), this type of forest, compared with the above hill land forest and the forest on micro reliefs, is characterized by the small DBH (less than 10 cm) and very large number of standing trees. Number of standing trees is about 4,500/ha with the tree height of 20-25 m. This type of forest occupies nearly half of the total forest area in the studied area.

(4) Gallery forest

Gallery forests were classified into tree forests and low tree forests depending on the tree height.

1) Gallery forest (trees)

This type of forest with the tree height of about 6-10 m is located on micro reliefs along the main rivers, such as the Atinguy, the Yabebyry, and the Parana Rivers. The one along the Atinguy River is clustered and occupies a rather large forest area, although the ones along the Yabebyry River and the Parana River are very small.

2) Gallery forest (low trees)

Of the gallery forests, ones with tree height of 5-6 m were classified in this type. This type of forest is distributed nearest to the water of the Atinguy River, but has a very large number of standing trees, forming a jungle which often makes it difficult to traverse.

(5) Dry (xeric) grassland

The dry grassland includes natural grassland and artificial grassland on hill lands, natural levees and micro reliefs.

(6) Wet (hydric) grassland

The set grassland distributed in the back swamp covers 70-80% of the studied area.

(7) Paddy field

Paddy rice fields are distributed only in the lowland adjacent to the hill lands in the north and east of the studied area and along the Parana River and the Atinguy River.

(8) Crop field

It is distributed only around settlements on hill lands, natural levees and micro relief.

(9) Others

Residential areas, settlements, airfields, cemeteries and bare grounds were grouped in this category.