PRESENT AND POTENTIAL LAND USE MAPPING IN MEXICO

By Héctor Garduño, Head of Physical Resources and Water Uses Group at the Mexican Water Plan, Secretaría de Recursos Hidráulicos., Ricardo García Lagos, General Director, Agrología y Desarrollo S. C. and Head of Soil Studies at the Mexican Water Plan, and Fernando García Simo, Head of the Present Land Use Study, IPESA Consultores.

ABSTRACT

The Mexican Water Plan (MWP) conducted studies of present and potential land use in Mexico using LANDSAT-1 satellite imagery. Funds were provided by the Mexican government and by the United Nations. The World Bank was the executing agency for UNDP fund and assisted also in selecting and hiring foreign personnel.

Present land use studies were carried out all over the country (197 million hectares); nine soil uses were mapped according to the first classification level recommended by the U. S. Geological Survey. Also 6.3 million hectares of land with advanced erosion were detected. Work was executed at a rate of 8 million hectares per month; reliability was 90% and the cost of only 0.1 cents/hectare.

The potential land use study was performed in 45 million hectares at a rate of 4 million hectares per month and at a cost of 0.33 cents/hectare. Soil units according to FAO classification were delineated scale 1:1 million; interpretative maps were also prepared dealing with potential agricultural productivity carrying capacity for cattle, water, erosion risk, and slope ranges.

INTRODUCTION

By the end of 1972, the Mexican Water Plan (MWP) started working with its main objective of developing systematic water resources planning procedures for the country. The Mexican Government made an agreement with the United Nations Development Program in order to make use of foreign expertise when needed. At the same time, it made a commitment of sharing the MWP's experiences with other countries. One fourth of the 4 million dollar project was provided by the UN, and the rest by the Mexican Government. The World Bank was the executing agency for the UNDP funds, providing assistance in selecting and hiring foreign experts.

In Mexico, agriculture is by far the largest water consuming activity. Water resources planning is thus carried out within a physical framework, where the two most important resources are water and soil. This physical framework strongly interacts with a comprehensive socio-economic framework in the planning process.

METHODS

Figure 1 shows the Mexican soil studies stages using LANDSAT Satellite imagery. The MWP defined a work program for a 33 month period project, which included soil inventories as one of the main inputs. Water requirements for irrigated agriculture accounts for more than 95% of the country's total water consumption. Therefore, soil inventories are as import as water inventories for successful water resources planning.

Only the FAO soils map was available for the whole country, as well as many local soil studies covering small areas, when the MWP project was started. Very good present and potential 1:50,000 scale land use maps are being developed in Mexico by CETENAL (Comisión de Estudios del Territorio Nacional). Unfortunately, the FAO soils map is too general, and not suitable for water resources planning. On the other hand, CETENAL maps are excellent but cover less than a third of the country at present time.

The MWP staff defined the objectives for the present and potential land studies and sketched preliminary procedures. Afterwards, two seminars were conducted in Mexico City in order to define the final procedures to study present and potential land use using LANDSAT-1 imagery.1/ A well experienced U.S. Soil Conservation Service scientist and two leading U.S. experts in LANDSAT imagery were selected to participate in the seminars.

The whole country was surveyed with present land use studies and maps scale 1:1 million were prepared, while only 45 million Ha were covered with potential land use studies. The areas to study potential use were selected from regions with less than 10% slope where water is still available for agriculture development.

A short training course on image interpretation for present land use purposes was then given by one of the remote sensing experts, and a Mexican consulting firm conducted the study. In a two-year period the whole country was mapped at a 1:1,000,000 scale with a cost of 200 thousand U. S. dollars, i.e. 0.1 cents/hectare. The areas where potential land use studies would later be carried on were given first priority.

The potential land use study was started 6 months later since present land use information was needed as an input. The other LANDSAT expert and the soil scientist led two pilot studies while adjusting the proposed methodology, along with experienced soil scientist of another Mexican consulting firm. They made six one-week trips to Mexico during the following year to carry on the study. With each trip, they functioned more as a review team, while the leadership and responsibility of the study was turned over to the Mexican soil scientists. More than a fifth of the country was studied in a year with a cost of roughly 150 thousand dollars; i.e. 0.33 cents/hectare. Also 1:1,000,000 maps were finally produced.

The results of both present and potential land use studies have improved the Mexican soil resources inventories as a by-product of the water resources planning itself. The integration of results contributed significantly to improve the regional water resources planning process.

A summary of results of both studies, as well as their integration is presented. Finally, to accomplish the commitment with the United Nations, an outline of a step-by-step handbook to make land use studies using LANDSAT imagery, presently under preparation, is submitted for discussion. Suggestions from the Symposium will help MWP in making a useful contribution to the field of remote sensing technology.

1/ Garduño, H., García Lagos, R., García Simo, F. y Pérez Gavilán, D., UTILIZACION DE LAS IMA GENES DEL SATELITE ERTS-1 EN LA PLANEACION DE LOS RECURSOS HIDRAULICOS, Primer Congreso Panamericano y Tercero Nacional de Fotogrametría, Fotointerpretación y Geodesia, México, 1974.

PRESENT LAND USE STUDY

The objectives of this study were:

1) To survey present land use in the whole country. Special emphasis was placed on irrigated agricultural land and on rainfed areas.

2) To provide basic information to determine potential land use and to compare later the results of present and potential land use studies.

False infrared color transparencies using channels 4, 5, and 7 from LANDSAT were used. The U.S. Geological Survey First Classification level recommendations[1/] were followed with slight modifications to interpret the 200 images that cover the country. Since agricultural land was the main interest of study, images taken during the dry and rainy seasons were used. This made it possible to discriminate irrigated from rainfed agriculture.

The project included intensive low altitude flights and ground-truth trips, as well as comparison with detailed 1:50,000 CETENAL maps. Table I shows the reliability for each present land use mapped.

In southeastern tropical Mexico Skylab IR color photographs were used where cloud-free LANDSAT images were not available. Since only visual interpretations techniques were used, those areas densely covered by vegetation were especially difficult to interpret. Future efforts will also utilize methods which take advantage of spectral computer-aided scanning.

TABLE I. RELIABILITY OF THE PRESENT LAND USE STUDY RESULTS

Land Use	Code	Minimum mapping Unit	More common mixed interpretations	Reliability %
Irrigated cropland	(1)	50 Ha	(2) and (3)	95
Flat rainfed cropland	(2)	100 Ha	(1) and (3)	90
Steep rainfed cropland	(3)	150 Ha	(1) and (2)	85
Range and grassland	(4)	250 Ha	(3) and (7)	85
Woodland (conifer and hardwood)	(5)	250 Ha	(6) and (7)	90
Tropical forestland	(6)	250 Ha	(5) and (7)	85
Shrub/Scrubland	(7)	250 Ha	(5) and (6)	85
Barren land	(8)	300 Ha	(4)	85
Wetland	(9)	200 Ha	(1)	95
Water bodies	(a)	50 Ha		98
Urban areas	(u)	100 Ha		95
Erosion	(e)	300 Ha		85
Average				90

Note 1. The two uses more intensively field checked were irrigated and rainfed land.

Note 2. Water bodies and urban areas were easily identified.

1/ U.S. Geological Survey, A LAND CLASSIFICATION SYSTEM FOR USE WITH REMOTE-SENSOR DATA, Geological Survey Circular 671, Washington, D. C. 1973.

Results

The final results are now being printed in 17 land-use 1:1,000,000 charts (Fig. 2). Each map includes a detailed description for each use, which takes into account regional differences found within the country. A grid formed by squares of one half degree latitude and one half degree longitude was superimposed onto the maps and supporting area statistics were calculated for each land use type on the basis of state, MWP regions and individual charts. The hectares covered by each used with advanced erosion was also computed. Fig. 2-A shows a generalization of results for the whole country.

Comparison with censal figures is usually meaningless due to differences in land use definitions; however, it is interesting to point out that while censal data indicated that an area of 30.0 million Ha is completely eroded, the present land use study detected only 6.3 million Ha of land with advanced erosion.

Duration, Manpower, and Cost

Figure 3 shows the schedule of activities for the present land use study. Once the procedure was defined and the interpreters trained a set of straight forward steps were followed for each one of the 17 land use charts. However, a major change was made in the original methodology, when ground truth proved to need a far greater effort than was at first anticipated.

Table II shows the manpower used in the study and Table III shows an estimate of costs for the whole study which covered 197 million hectares. The reported total cost of U.S. $200,000.00 doesn't cover air checking nor foreign personnel expenses.

TABLE II. MANPOWER REQUIRED FOR PRESENT LAND USE STUDY

Mexican personnel	Man months
Project manager	26
MWP project coordinator	3
Image interpreters	112
Chartographic support assistants	29
Assistants land use area estimation	90
Draftsmen	64
	329
Foreign personnel	
Remote sensing expert	1

TABLE III. COST OF PRESENT LAND USE STUDY

Image and photographic material	8%
Image interpretation	35%
Chartographic support	7%
Ground truth	15%
Land use area estimation	22%
Drawing and reports	13%
	100%

POTENTIAL LAND USE STUDY

Description

The objective of the study was to assess, at an identification and not a project level, areas with high, medium or low agriculture and pasture productivity and water erosion risk.

Since the project also aimed at the development of methodology to be used, two pilot studies covering 6 million Ha were first carried out in a semi-arid and in a humid tropical area. The area covered was of a reasonable size and the ecological conditions different enough as to assure that the methodology could be successfully applied in any other region of the country.

Interpretation of infrared false color and channel 5 images was made using transparencies and prints, both at 1:1,000,000 and 1,500,000 scales, although final results were produced at 1:1,000,000 scale. Overlays with general delineations of present land use maps, geology, rainfall, FAO soil units and infrastructure were used to help image interpretation. Also more reconnaissance flights and ground truth trips with more intensive sampling were required than by the present land use study.

The soil units classification was taken from the 1:2,000,000 scale FAO map, but a far more detailed soil units map was produced after interpreting the images with the aid of the overlays mentioned above as well as the air and ground truth. The potential land use classification mas made according tho Handbook 210 of the U.S.Soil Conservation Service.1/

Finally, interpretative maps were produced for agriculture and pasture use, slope classification, and water erosion risk. A reliability of 80% to 90% was determined by comparing results of the study with available more detailed results of conventional soil surveys.

Results

Figure 4 shows the soil unit delineations obtained following the FAO soil classification system. Image interpretation was determinant in defining more precisely the soil unit boundaries and produced more details than the original FAO map showed.

Potential land use maps were prepared based on the properties of the FAO soil units, yield and production statistics, results from agriculture and livestock experimental stations, field observations, and personal experience of the soil scientists that carried out the study. Estimates of yields were made for the most important crops as well as evaluations of carrying capacity under grass for cattle feeding in each soil unit. Figure 5 shows the general results for agriculture productivity.

Only 17 million Ha were found to have high and moderate agricultural potential productivity. This figure seems low, taking into account that the study was carried out in selected areas according to slope. However, large areas in the south east were classified under present conditions as of low productivity due to seasonal flooding. It is believed that with adequate flood protection and drainage measures, they could easily be considered as areas of high productivity since the soils are deep, flat, and fertile.

The potential range and grass productivity was determined only in 29.7 million Ha since estimates of carrying capacity per hectare were not available in the north western and central regions of the country. Figure 6 shows the general results. A large proportion of the area

1/ Klingebiel, A.A., and Montgomery, P.H. LAND CAPABILITY CLASSIFICATION. Agriculture Handbook No. 210, Soil Conservation Service, U.S. Department of Agriculture, 1973.

was found to have from medium to high productivity (23 million Ha). Most of the land is located in the Gulf coastal plains and on the south eastern regions where most of the country's present livestock production is concentrated.

Finally, Figure 7 shows areas with different degree of water erosion risk. Even though the studied areas lie mostly on flat lands, 69% of the 45 million Ha shows medium to high water erosion risk. This fact points out the need for sound soil conservation programs and policies.

Duration, Manpower, and Cost

Figure 8 shows a schedule of activities for the potential land use study. A line-production procedure was not feasible and separate package studies were carried out in each selected area. The reason for this is that integration of image interpretation, basic data, field notes and personal experience should be borne to a great extent in the mind of the soil scientist in order to finish up a specific area. Hence, one area had to be finished by each team before starting studies on the next one. Two teams were responsible for the whole project.

Table IV shows the manpower used in the study and Table V shows an estimate of costs for the whole study which covered 45 million hectares. The reported total cost of U.S. $150,000.00 doesn't cover air checking nor foreign personnel expenses.

TABLE IV. MANPOWER REQUIRED FOR THE POTENTIAL LAND USE STUDY

Mexican personnel	Man months
2 Team leaders	22
2 Soil scientists	22
2 Image interpreters	22
2 Draftsmen	20
MWP	2
	88
Foreign personnel	
Soil scientist	2
Remote sensing expert	2
	4

TABLE V. COST OF POTENTIAL LAND USE STUDY

Overlay material and image prints	2%
Office work: preliminary delineation, source material analysis and final integration to obtain soil unit maps and interpretative maps	56%
Field reconnaissance trips	26%
Drawing and reports	16%
	100%

THE ROLE OF LAND USE STUDIES IN WATER RESOURCES PLANNING

The comparison of potential and present land use maps shows that 82% of total land now being farmed and rated as high agricultural productivity is being used at present time with irrigated and rainfed flat land agriculture. However, there are 535 thousand Ha of low productivity areas presently being irrigated and 3.6 million Ha with rainfed agriculture of the same productivity class. On the other hand, 3.9 million Ha with high potential agricultural productivity remain unfarmed.

It is also important to point out that 41% of 16.6 million Ha presently being used within the area studied, are in high danger of being eroded. Most of these areas have rainfed agriculture, since most irrigated land lies in areas with low risk of erosion. This was expected, as well as the fact that 15.6 million Ha with medium to high risk of water erosion are not being farmed.

There are large areas in the Gulf coastal plains with low potential agricultural productivity and medium to high risk of water erosion. These areas should be mainly devoted to pasture land, taking care not to over-graze them.

Detailed studies using these results are presently carried on at MWP in order to define future regional water resources development related to agriculture, livestock, and soil conservation.

OUTLINE OF A STEP-BY-STEP SOILS HANDBOOK USING LANDSAT SATELLITE IMAGERY

The MWP soils group is preparing a handbook covering the points outlined below.

Comments and suggestions from the Symposium participants are welcome. It is important to point out that for the sake of clarity it is intended that each step will be illustrated in detail with figures and in a general way, the results for the whole country will also be discussed.

1. Introduction

2. Present land use

   Objectives
   Classification criteria
   Satellite image selection
   Air reconnaissance and ground truth trip
   Interpretation adjustments
   Land use area estimation
   Reliability criteria
   Cost estimates
   Report writing and graphical presentation

3. Potential land use

   Objectives
   Work teams
   Image transparencies and prints
   Basic source overlays
   Classification criteria for soil units and for land capability
   Preliminary soil units delineation in the office

Air reconnaissance and ground truth trips
Adjustments, final delineations, and interpretative maps
Reliability criteria
Cost estimates
Report writing and graphical presentation

4. <u>Examples of interpretative maps worked out</u>

5. <u>Integration of present and potential land use studies</u>

CONCLUSIONS

The use of LANDSAT imagery has made it possible to make land use inventory maps scale 1:1,000,000 in Mexico with an extremely low cost in a two-year period. The Agriculture Ministry is already carrying out a new inventory scale 1:500,000.

The objectives of the present land use study were met, with an overall reliability of 90%. However, only a small fraction of the information contained in the images was used.

The next steps in using LANDSAT in Mexico will include study of dynamic changes in land use, computer aided spectral scanning, more detailed studies of areas of interest at wider scales (1:250,000), etc.

The potential land use maps were developed faster and at a lower cost than would have been possible using any of the conventional methods. A reliability of 90% was also accomplished in these studies.

The integration of both present and potential land use maps is extremely useful in providing orientations for regional development of water resources in agricultural countries with sparse water supplies; it also helps to set forth policies about land redistribution according to capability and water erosion risks.

ACKNOWLEDGEMENTS

Messrs. Gerardo Cruickshank, Undersecretary of Planning at the Water Resources Ministry and Fernando González Villarreal, General Coordinator of the Mexican Water Plan supported and oriented the land use studies.

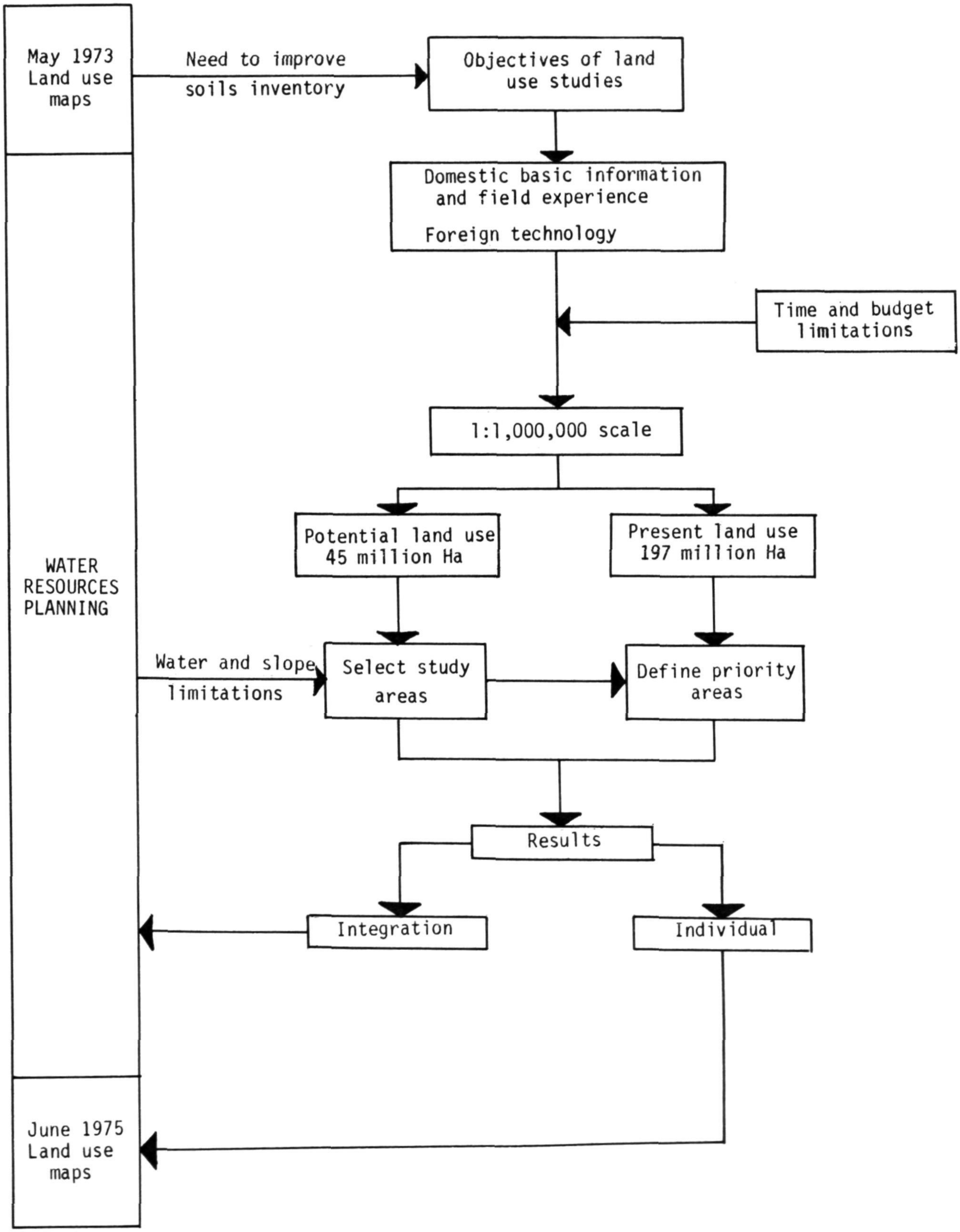
Dr. Donald Lauer in charge of training programs at the EROS Data Center of the U.S. Geological Survey, helped in defining the present land use study methodology, trained the image interpreters and recently made an appraisal of the final results.

Dr. Albert Klingebiel, one of the more experienced U.S. soil conservation scientists, recently retired from the Soil Conservation Service and Dr. Victor Myers, Director of the Remote Sensing Institute at the University of South Dakota, helped in defining the potential land use study methodology and trained Mexican soil scientists on the field. They were also responsible for assistance during the air and field reconnaissance and the reviewing of manuscripts.

Roberto Vital from MWP was in charge of preparing source material, map generalizations and integration of present and potential land use.

The EROS Data Center provided excellent service in processing and sending the images that were required for the study.

Figure 1. Stages of Mexican soil studies as an input to water resources planning



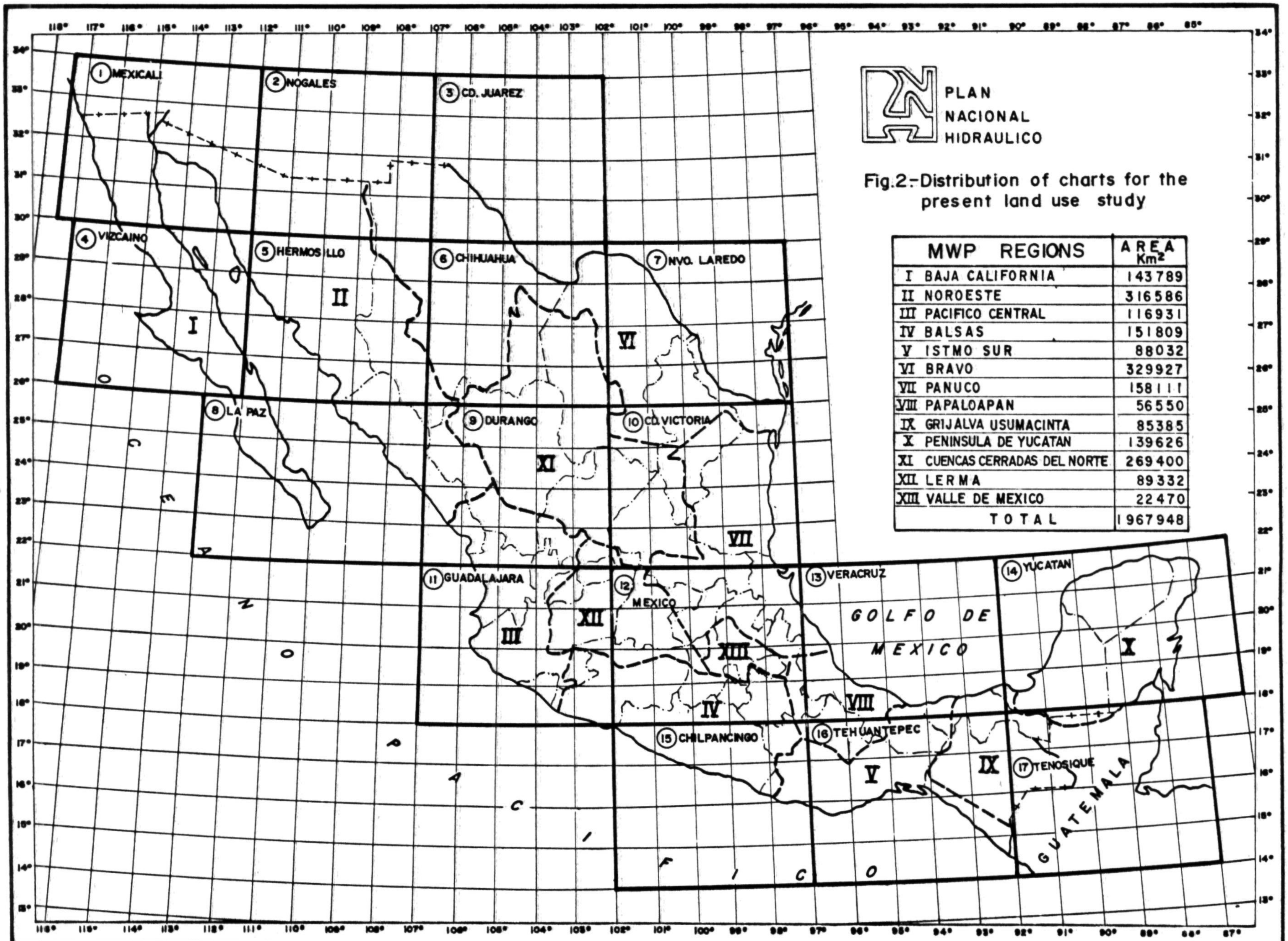
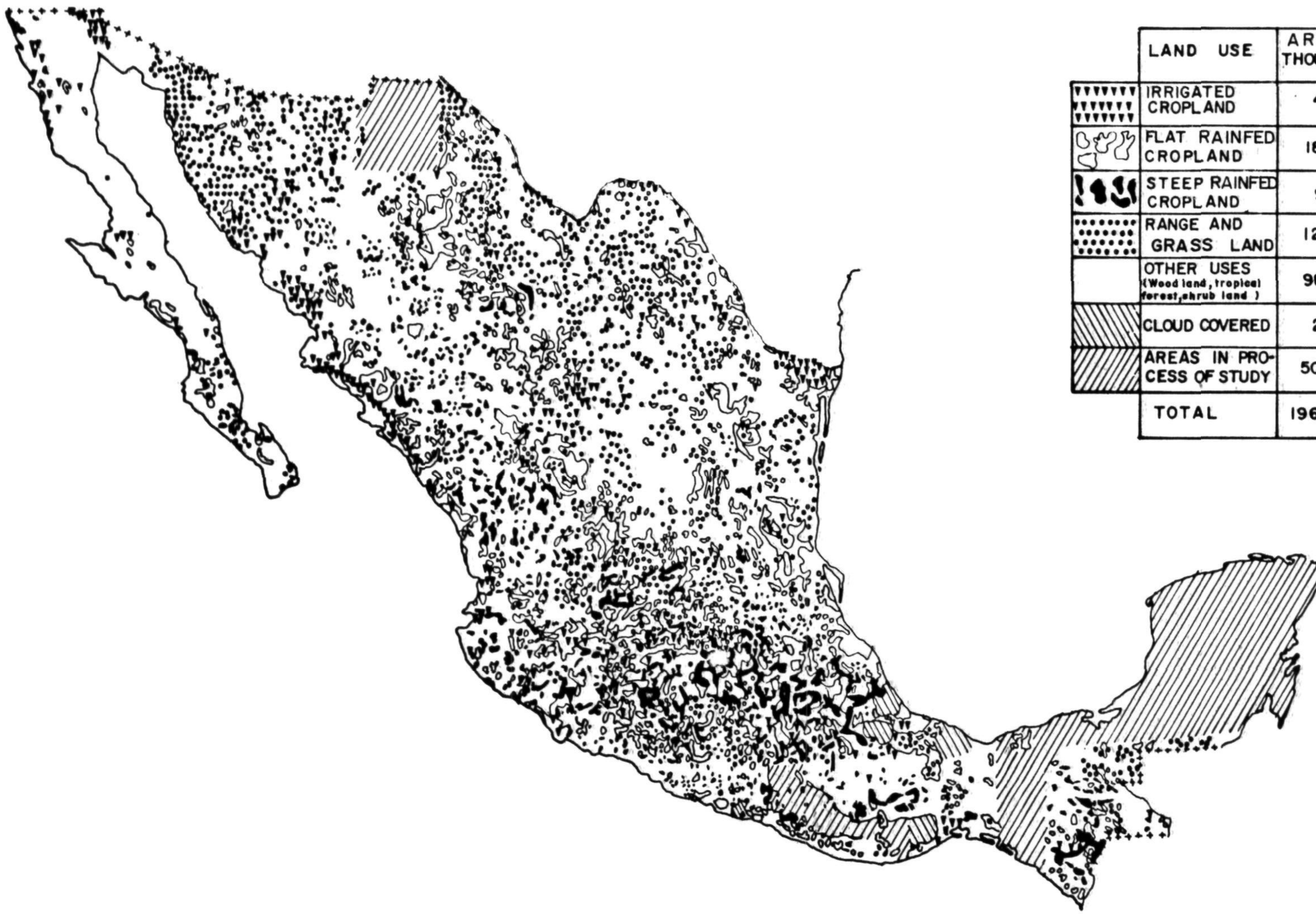


Fig.2.-Distribution of charts for the present land use study

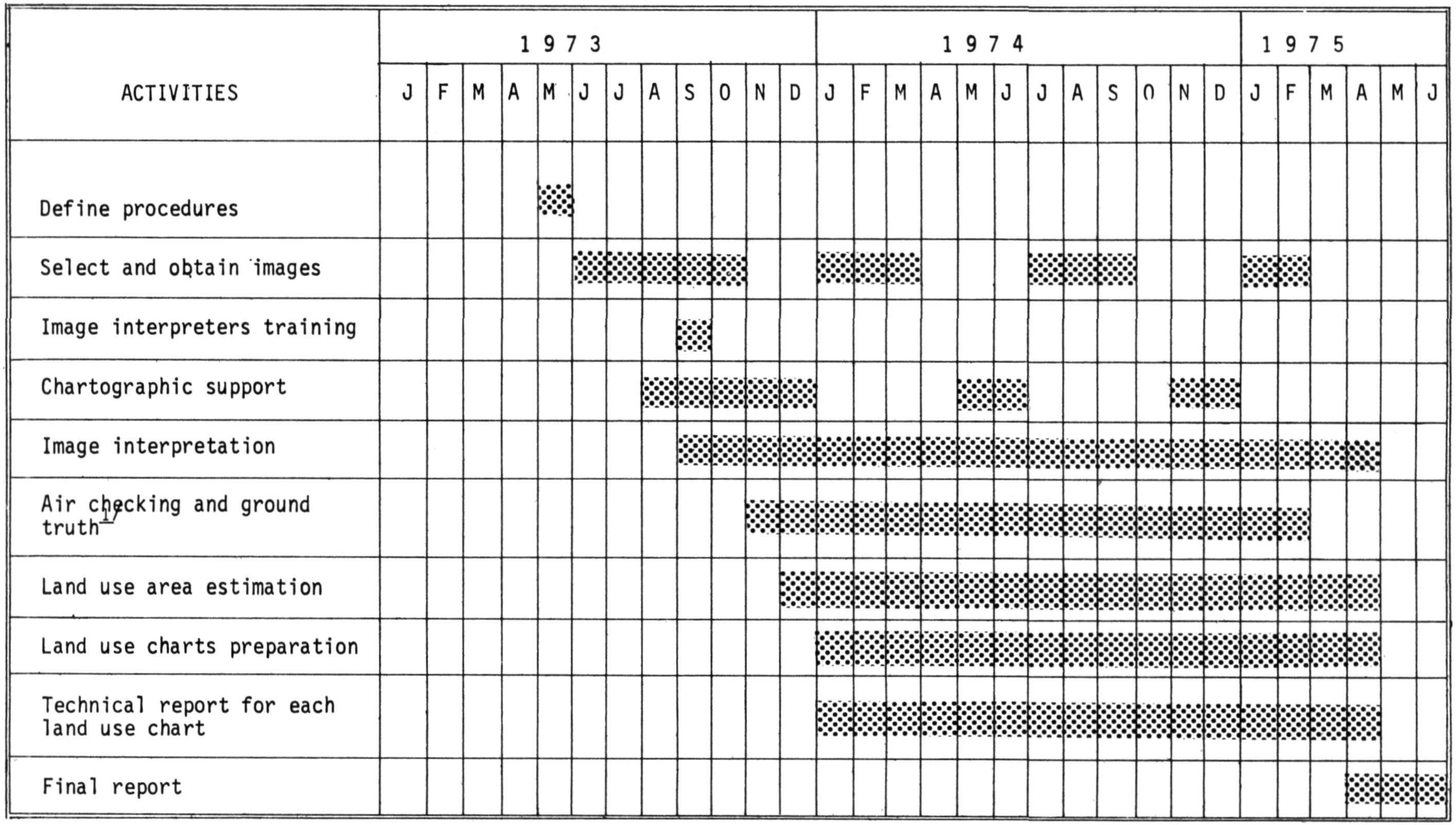
MWP REGIONS	AREA Km²
I BAJA CALIFORNIA	143789
II NOROESTE	316586
III PACIFICO CENTRAL	116931
IV BALSAS	151809
V ISTMO SUR	88032
VI BRAVO	329927
VII PANUCO	158111
VIII PAPALOAPAN	56550
IX GRIJALVA USUMACINTA	85385
X PENINSULA DE YUCATAN	139626
XI CUENCAS CERRADAS DEL NORTE	269400
XII LERMA	89332
XIII VALLE DE MEXICO	22470
TOTAL	1967948



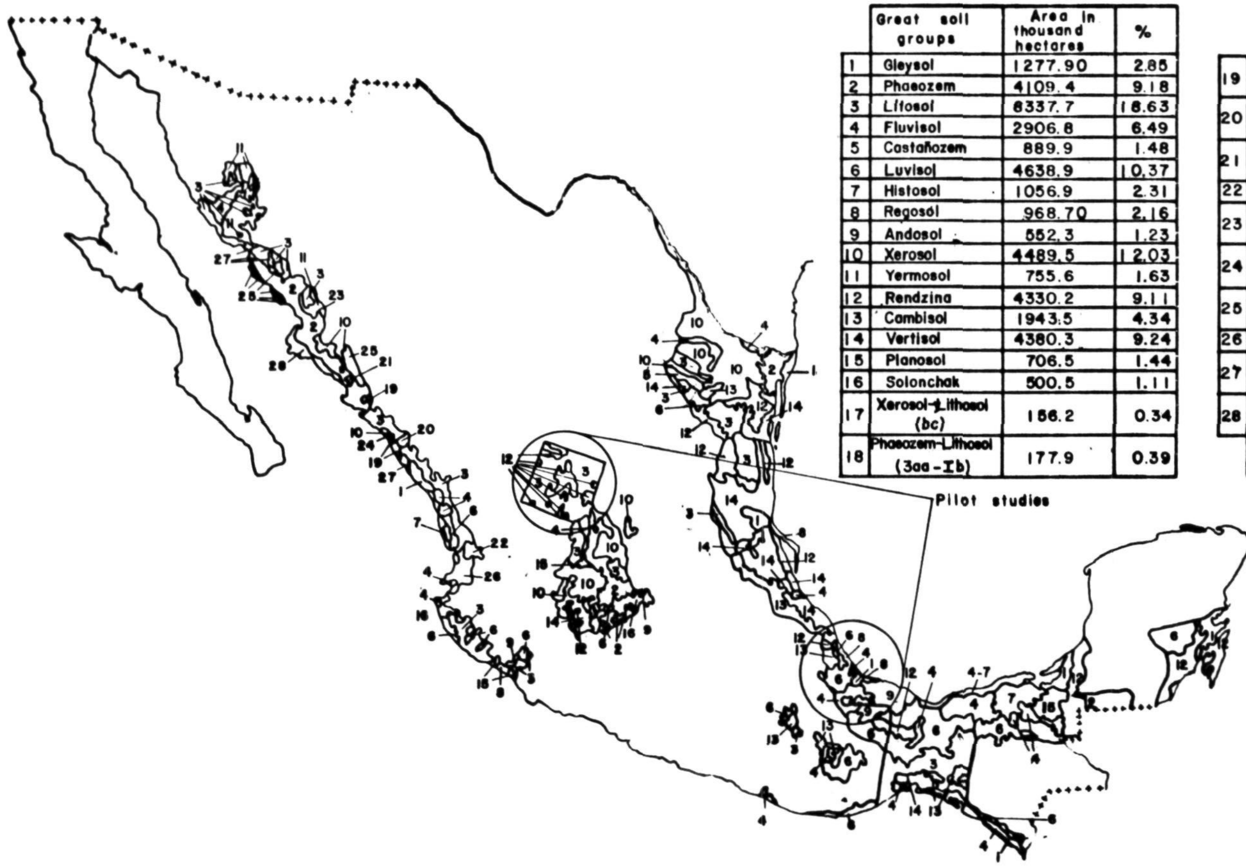
LAND USE	AREA IN THOUSAND Ha	% OF TOTAL TERRITORY
IRRIGATED CROPLAND	4,178.91	2.12
FLAT RAINFED CROPLAND	18,050.14	9.17
STEEP RAINFED CROPLAND	9,935.88	5.05
RANGE AND GRASS LAND	12,290.50	6.24
OTHER USES (Wood land, tropical forest, shrub land)	98,470.0	50.07
CLOUD COVERED	2,875.36	1.47
AREAS IN PROCESS OF STUDY	50,913.13	25.88
TOTAL	196,713.92	100.00

Figure 2-A Present land use study in Mexico

Figure 3. Schedule of activities in the present land use study

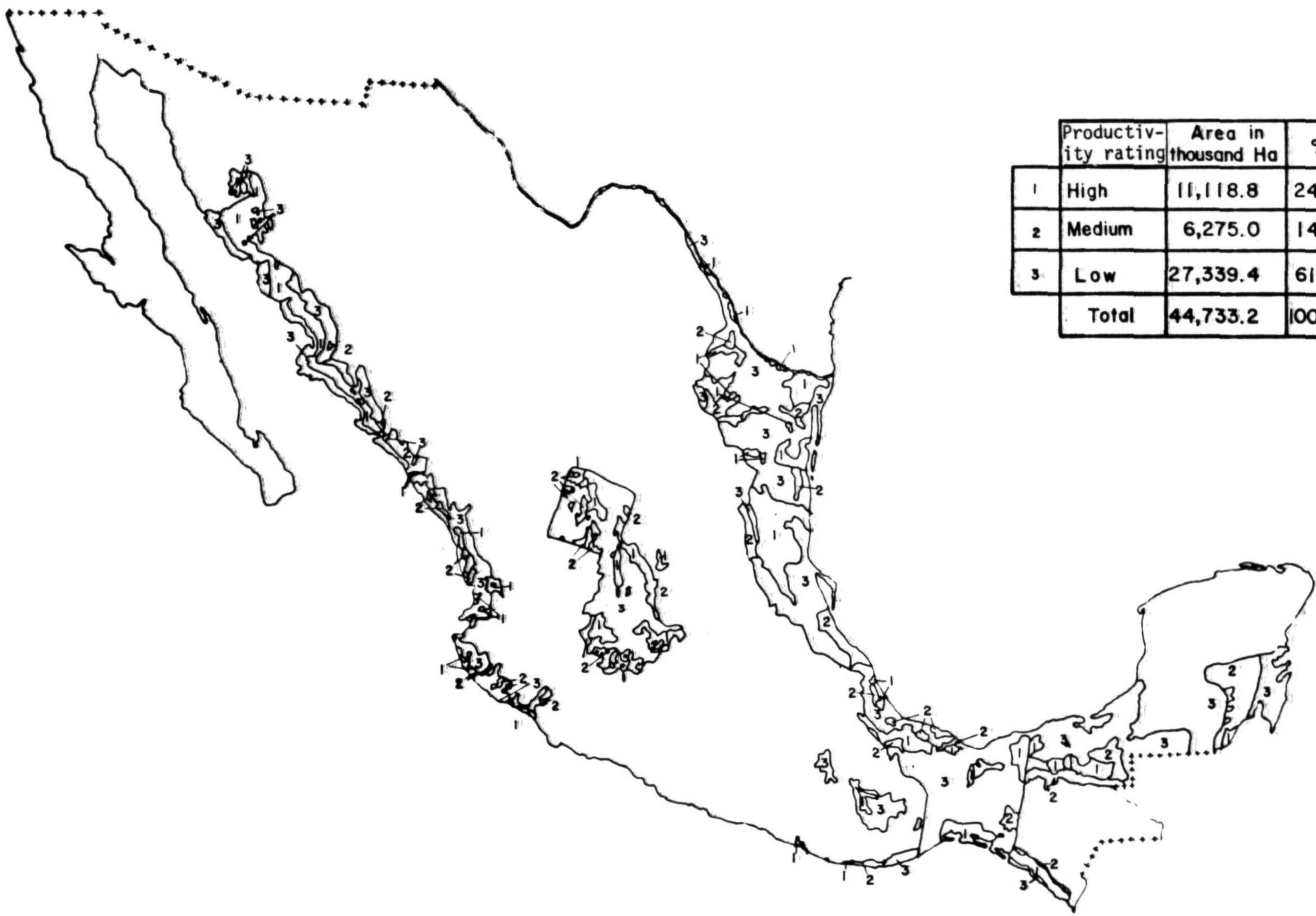


1/ A total distance of 13,500 Km was covered by plane. Ground truth covered 12,500 Km, sampling 4,000 points.



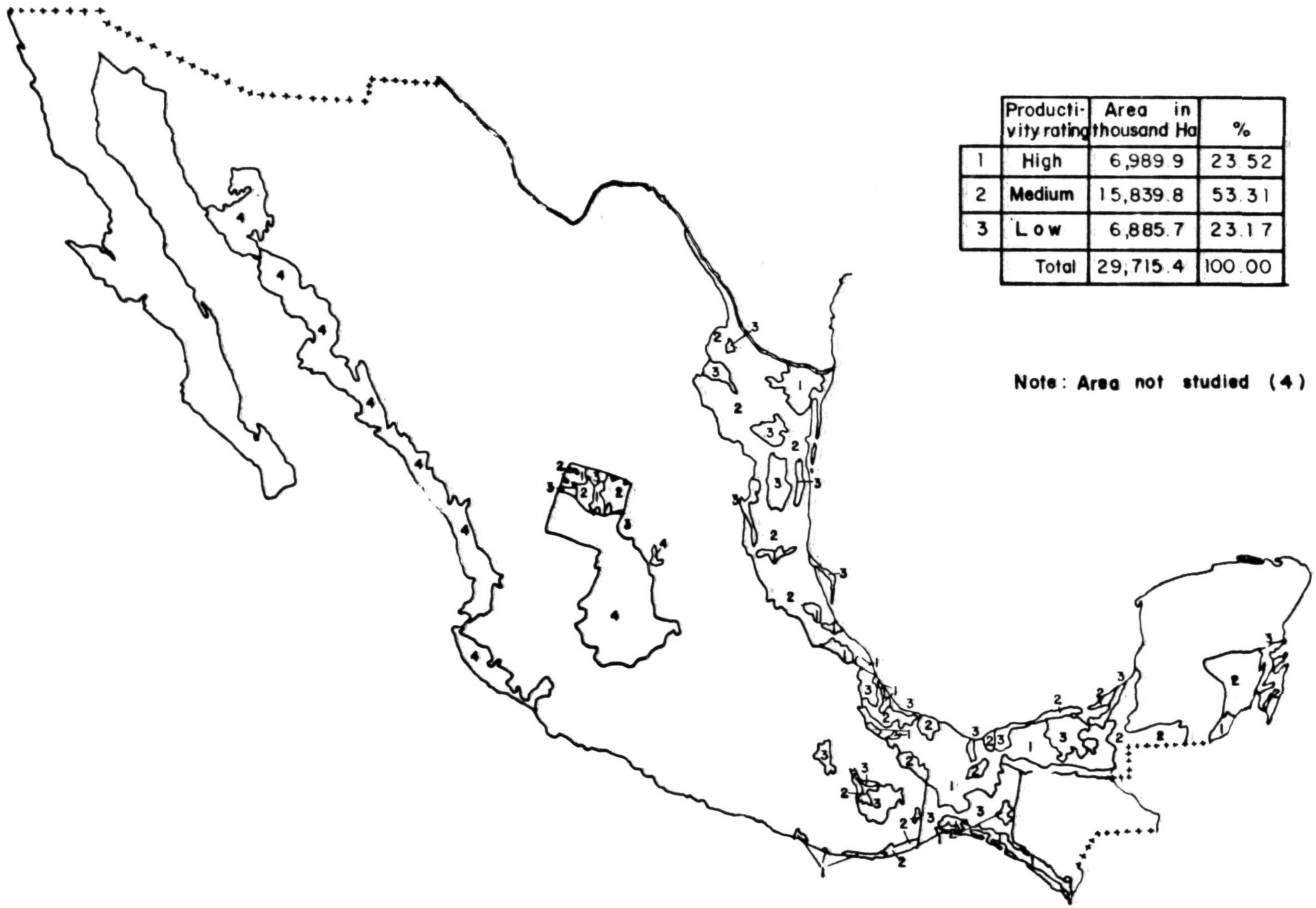
	Great soil groups	Area in thousand hectares	%
1	Gleysol	1277.90	2.85
2	Phaeozem	4109.4	9.18
3	Litosol	8337.7	18.63
4	Fluvisol	2906.8	6.49
5	Castañozem	889.9	1.48
6	Luvisol	4638.9	10.37
7	Histosol	1056.9	2.31
8	Regosól	968.70	2.16
9	Andosol	552.3	1.23
10	Xerosol	4489.5	12.03
11	Yermosol	755.6	1.63
12	Rendzina	4330.2	9.11
13	Cambisol	1943.5	4.34
14	Vertisol	4380.3	9.24
15	Planosol	706.5	1.44
16	Solonchak	500.5	1.11
17	Xerosol-Lithosol (bc)	156.2	0.34
18	Phaeozem-Lithosol (3aa-Ib)	177.9	0.39
19	Phaeozem-Lithosol (3a-Ib)	177.0	0.39
20	Phaeozem-Lithosol (3a-Ic)	151.0	0.33
21	Phaeozem-Lithosol (2a-Ibc)	104.4	0.23
22	Phaeozem-Vertisol	134.6	0.30
23	Lithosol-Phaeozem (b-3a)	310.9	0.69
24	Lithosol-Phaeozem (c-3a)	225.0	0.50
25	Lithosol-Phaeozem (c-2b)	331.0	0.74
26	Lithosol-Luvisol	458.2	1.02
27	Fluvisol - Vertisol ---	57.0	0.12
28	Regosol-Solonchk	605.2	1.35
	Total	44,733.2	100.00

Figure 4 Potential land use studies in Mexico. Great soil groups and associations. Preliminary results.



	Productivity rating	Area in thousand Ha	%
1	High	11,118.8	24.85
2	Medium	6,275.0	14.04
3	Low	27,339.4	61.11
	Total	44,733.2	100.00

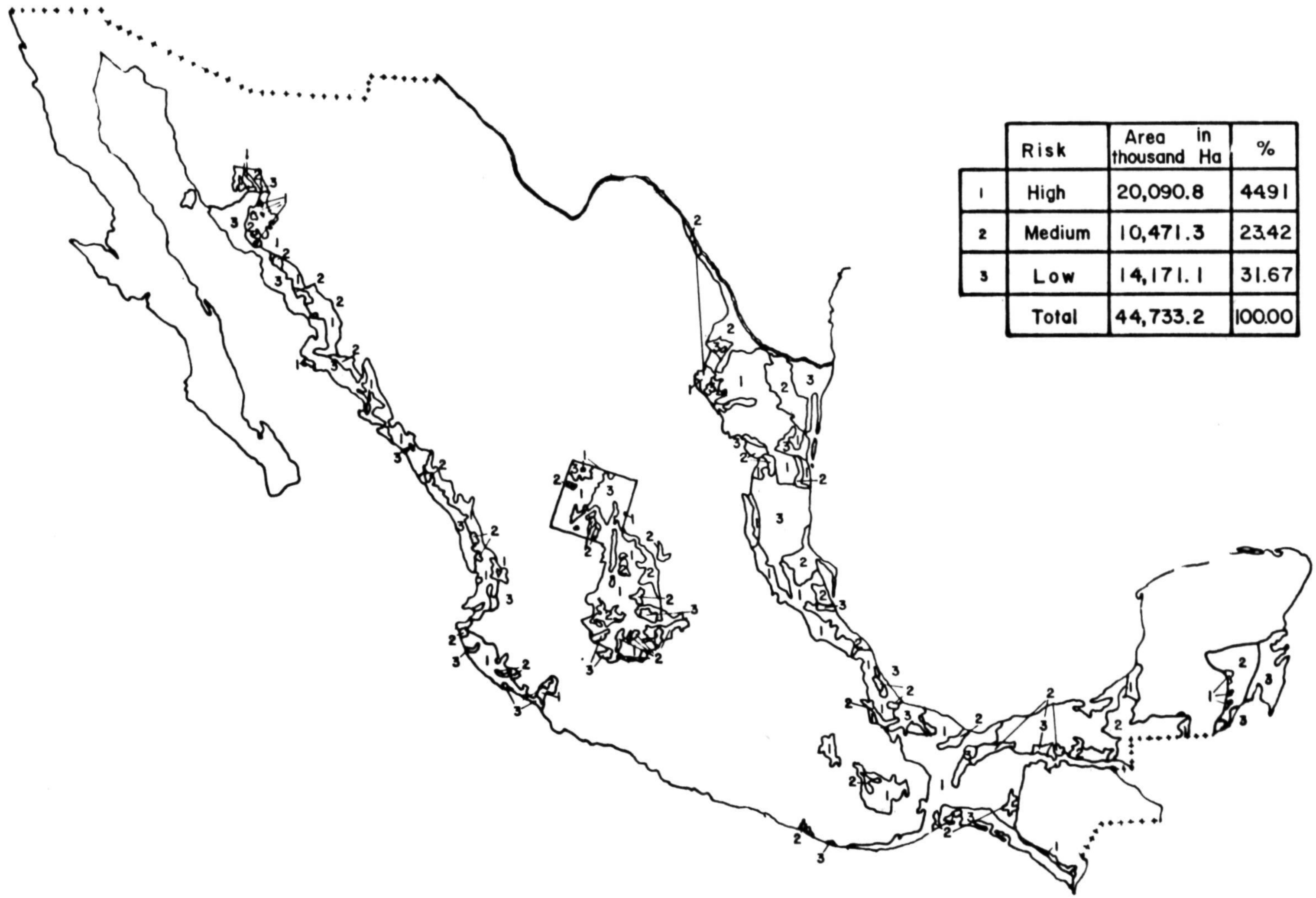
Figure 5 Potential soil productivity for agriculture



	Productivity rating	Area in thousand Ha	%
1	High	6,989.9	23.52
2	Medium	15,839.8	53.31
3	Low	6,885.7	23.17
	Total	29,715.4	100.00

Note: Area not studied (4)

Figure 6 Potential soil productivity for grass



	Risk	Area in thousand Ha	%
1	High	20,090.8	44.91
2	Medium	10,471.3	23.42
3	Low	14,171.1	31.67
	Total	44,733.2	100.00

Figure 7 Water Erosion risk

FIG.-8 SCHEDULE OF ACTIVITIES FOR THE POTENTIAL LAND USE STUDY