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Application for ERS-1 AR Data in Flood Hazard Assessment of Fluvial and Coastal Environments

(EU-ASEAN Philippine Project 2)

Final Report

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(Final Report)

by

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EU-ASEAN PHILIPPINE PROJECT 2

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(EU-ASEAN Philippine Project 2)

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1.0 INTRODUCTION

The Philippines is located near the edge of the Eurasian Continent, which is usually referred to as the 'typhoon belt'. Within this region, the Philippines has the highest occurrence of typhoons at over 20 per year, and as such, floods are an unfailing phenomenon caused by heavy rains and storm surges which normally accompany the strong winds driven by monsoons and typhoons. Whenever floods strike, major damage to human life and property often results, causing partial social paralysis. In bad years, the effects of floods can be so damaging to the economy of the Philippines that a negative gross national product is recorded. It is one of the important national policies to prevent or mitigate disasters due to floods and storm surges in order to improve public security, welfare and land conservation toward the development of the country.

Whenever floods occur in the country, the first and foremost task that will be taken up with top priority is relief, for which flood inundation map together with flood damage statistics are a vital input. Although conventional methods are available for assessing flood damage, there is a need for a rational and scientific approach. Furthermore, traditional groundbased methods are time consuming and unrealistic at times. Accurate, timely and reliable information is essential for monitoring floods and assessing flood damage and in this context, based on previous related works done, it can be said that satellite remote sensing is one of the most powerful tools for these applications.

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The Phil-2 is one of the eight pilot projects under the EC-ASEAN Regional Remote Sensing programme which started July 1st, 1993. The main objective of the project is to investigate the capability of the ERS-1 (European Remote Sensing Satellite) synthetic aperture radar (SAR) in providing basic information in flood hazard assessment of the Bicol Region, one of the flood prone areas in the Philippines.

2.0 NECESSITY FOR ACTIVE MICROWAVE DATA

For the last few years, optical data acquired from the LANDSAT, SPOT and IRS satellites have been utilized for monitoring floods with varied degrees of success depending on the flood, non-flood contrast, cloud cover, as well as the gap between satellite over pass and flood occurrence. However, during typhoon and monsoon seasons, persistent cloud cover is a major technical problem for analyzing optical satellite data over flood affected areas. Based on experience, the chances of acquiring cloud free data over the Philippines is around 15% - 25%. Further, the scattered clouds on satellite images acquired in the optical region limits the use of digital analysis of the data. Hence, cloud-free data which can be provided by active microwave satellite data is very much preferable for accurate delineation of flood affected areas and flood damage assessment. Theoretically, ERS-1 SAR data should be able to compliment optical data and overcome the cloud cover problem in monitoring floods in near real-time. A measure of maximum flood extent resulting from the flood peak is a very important measure for hydrological modelling and the use of multiple-satellites will increase the chances of data availability during peak flooding. In this context, the use of both ERS-1 SAR data and optical satellite data is envisaged.

3.0 THE EUROPEAN REMOTE SENSING SATELLITE (ERS-1)

ERS-1, launched in July 1991 is the first European radar remote sensing satellite. It carries a complete package of microwave remote sensing instruments, including a Synthetic Aperture Radar (SAR), a wind scatterometer, an altimeter and a passive microwave radiometer. The core instrument is the SAR which is useful for a great variety of applications over land, coastal zones and over the ocean. With the exception of SAR, the other instruments are designed for meteorological, oceanographic and hydrological applications. The expected life-time of ERS-1 is 2-3 years, although after more than 4 years in orbit, it is still fully operational. The orbit repeat period is 35 days. the spatial resolution at nadir is around 25 m and the swath width is about 100 km.

The SAR instrument has a frequency of 5.3 GHz (in the C-band) equivalent to a wavelength of 5.7 cm. This active microwave remote sensing instrument sends out a pulse of microwave energy to a target and then measures the return. The strength of the return signal is determined by the surface roughness and the dielectric properties of the terrain rather than the temperature of the material. Here, dielectric properties mainly corresponds to the amount of water medium (soil volume or plant canopy) and the surface roughness relates to the size, shape, and orientation of the observed medium.

4.0 PREVIOUS WORKS RELATED TO THIS STUDY

Research done elsewhere has shown that microwave remote sensing will be of immense importance for flood monitoring. Images from the L-band SAR of SEASAT were investigated to determine its potential in flood mapping, particularly *J.A. Richards et al* (1987) who offered an explanation of enhanced radar backscattering from flooded forests, while *L.L. Hess et al* (1990) reviewed radar detection of flooding beneath the forest canopy. Spacebourne SAR data acquired during Shuttle Imaging Radar-B (SIR-B) program was used to map flood boundaries in Bangladesh (*Imhoff*, 1987). Data from the Side Looking Radar System of the KOSMOS-1500 satellite was used to study the floods in Amon in August 1984 (*Pichgun*, 1989), whilst, Scanning Multichannel Microwave Radiometer (SMMR), although low resolution, provided information on seasonal inundation patterns in large tropical wetlands such as the Amazon River floodplains (*Sippel S.J. et al, 1993*). Aircraft radar systems have also been used for mapping floods. *Lowri et al* (1979) used aircraft mounted X and L band SAR systems to map flood boundaries in Manitosa, Canada, airbourne real aperture and synthetic aperture side looking radar, were used for real-time monitoring flood conditions in China (*Cau Shuhu*, 1991). *K. Blyth* (one of our consultants for this project) *and D.S. Biggin* (1993) monitored floodwater inundation with ERS-1 SAR data in the Thames Valley region of the UK. The 1993 Mississippi River flood in USA has been mapped from ERS-1 SAR data (*Reflections, 1993*) and, ERS-1 SAR imagery was used to study the development and recovery of flooding on Lough Corrib, West Ireland, following a period of high rainfall at the end of 1993 (*J. Matthews & S. Gaffney*, 1994).

5.0 THE STUDY SITE - THE BICOL RIVER BASIN

During the initial planning of this project, the choice of test area was somewhat subjective as there was no way for the proponents to determine with certainty where the next major flood would occur in the Philippines. The probability of one occuring on Luzon Island was good and the Bicol River basin was chosen because there had been a period in excess of 5 years since the last major flood, which was unusual for this area. The choice was fortuitous in that a flood occurred towards the end of 1993 and ERS-1 SAR coverage was obtained.

Much of the information found in this section had been somehow taken from other sources, but whenever ERS-1 SAR data reveal new information, they are being particularly highlighted.

5.1 Geography

The Bicol River Basin (Fig. 1) is a medium-sized river in the southernmost tip of Luzon Island, the biggest island of the Philippines. It has a drainage area of 2,717 km² from the mouth of the river, covering the provinces of Camarines Sur and Albay. The major part of the drainage area is flat alluvial land and tableland with volcanic deposits. The basin has high mountains including volcanoes over 2,000-meters high to the east, and relatively lower mountains to the west. The runoff starts from Mayon Volcano, one of the most famous in Luzon (second only

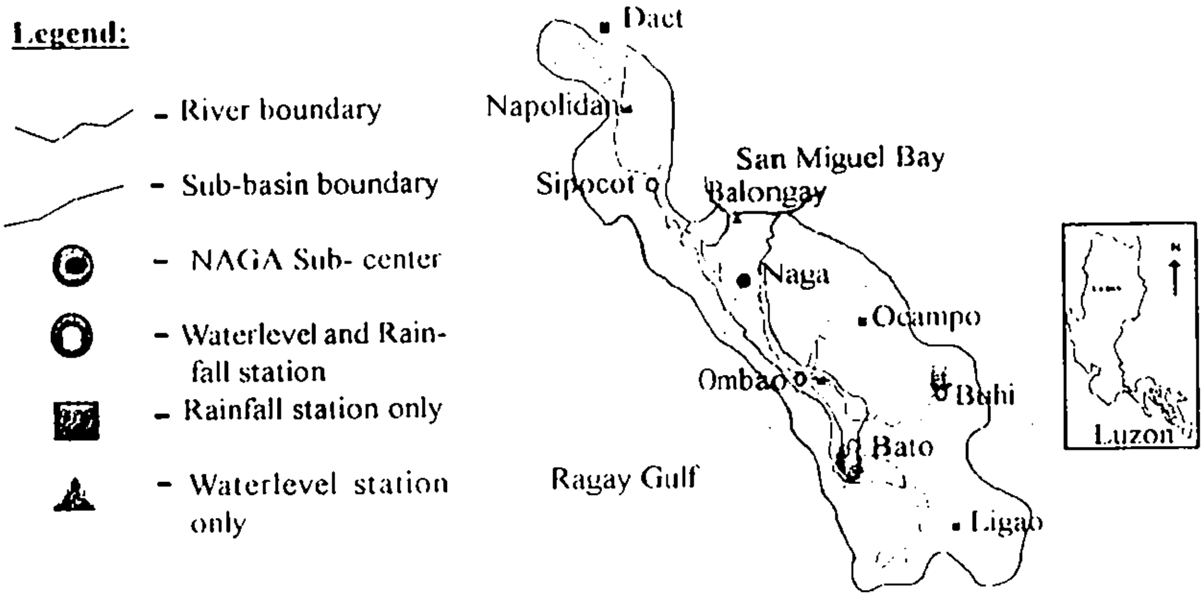


Fig. 1. The Bicol River Basin

to Mt. Pinatubo), with an elevation of 2,421 meters and after being regulated by three lakes, namely; Bato, Baao and Buhi, comes into the main stream of the Bicol River.

The main tributary is the Sipocot River (447 km²), which enters from the west at a point 8 kilometers from the north of the Bicol estuary. Unlike the main stream, the sub-basin of Sipocot is almost all mountainous terrain.

Rainfall in the mountains that are the source of the river, immediately flows down the steep mountain slopes and rapids, and enters the main river course, which meanders considerably across the plain. Then it joins the Sipocot River and enters into San Miguel Bay.

The Bicol River has a very gentle slope. Lake Bato, in spite of its location about 70 kilometers from the mouth, has a minimum water level of only 5.0 meters AMSL. This is 1:14,000 in terms of water slope.

In the case of the Sipocot River, the slope is 1:250 and the fall is 100 meters in about 25 kilometers between Napolidan and the junction with the main stream. The course of the Bicol River, after joining the Sipocot River, widens and finally becomes more than 1,000 meters wide at its estuary.

Since the Bicol River flows so slowly, the tide can reach the upstream of Naga City (about 35 kilometers upstream mountains; plain of volcanic deposits upstream of Lake Bato; and low wetlands extending between Naga City and the river mouth; intermediate wetlands between Naga City and Lake Bato).

5.2 Geology

Monoscopic geologic interpretation procedure was used on the ERS-1 SAR images taking into consideration factors such as textures, patterns, return signatures, sizes and shapes of features on the image. Most helpful were geologic information that already existed (BMGS Report, 1981 and P.T. Dumapit, 1976) prior to this particular interpretation. The result of this analysis nearly coincides with the existing geologic information except for a few contact refinement and a few revisions verified from the image and supported by field verification.

Fig. 2 shows the revised general geologic map of the area. The general geology of the study area consist of:

- Alluvial deposits, principally alluvium, fluviatile, lacustrine paludal and beach deposits, raised coral reefs, stolls and beach sediments. (Recent)
- Pyroclastic and Lava Flow, generally volcanic plain or volcanic piedmont deposits; chiefly pyroclastic and/or volcanic debris at foot of volcanoes. (Pliocene-Quaternary)
- Non active Volcanic Cones, generally pyroxene andesite and dacitic and/or andesitic plugs. (Pliocene-Quaternary)
- Clastic formation, principally Dacitic or Andesitic Flows generally intercalated with pyroclastics. (Upper Miocene-Pliocene)
- Marine calcareous deposits, largely marine clastics overlain by extensive locally transgressive pyroclastics (Tuffaceous Sediments) and Tuffaceous Sedimentary rocks. (Upper Miocene-Pliocene)
- Marine and terrestrial sediments associated with extensive reef limestone and sporadic terrace gravel deposits. (Pliocene-Pleistocene)

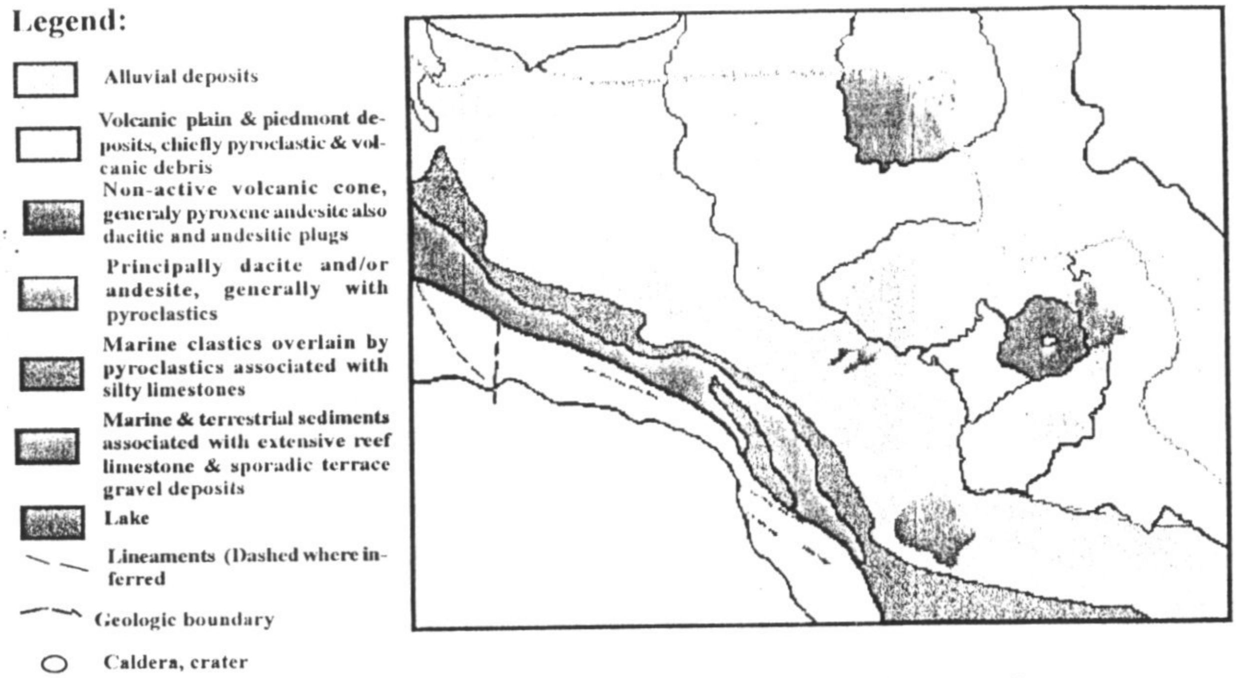


Fig. 2. General Geologic Map of Bicol River Basin

- Faults and other lineaments are very well manifested on both images by distinct conspicuous feature patterns generally trending on a northwest-southeast orientation.

5.3 Land Use

Previous works by NAMRIA and the Swedish Space Corporation of the land use study of the area in 1988 as interpreted from SPOT satellite images and ground truth verification and also works by the National Water Resources Council were used as the basis in the study. Unfortunately, the temporal ERS-1 images provided a very limited opportunity for land use interpretation. In general, response signatures, textures, and patterns offered limited character references. However, shape and size were significant as far as interpretation was concerned. This was well exemplified by the appearance of built-up areas (influenced by human activities) exhibited in both images. Of considerable importance also was the presence of corner reflectors which gave very bright response signals but which were limited only to this type of feature. Nevertheless, detailed ground truthing gave credence to the previous land use studies. With minor revisions, Fig. 3 depicts the general land use of the study area which could be grouped into the following:

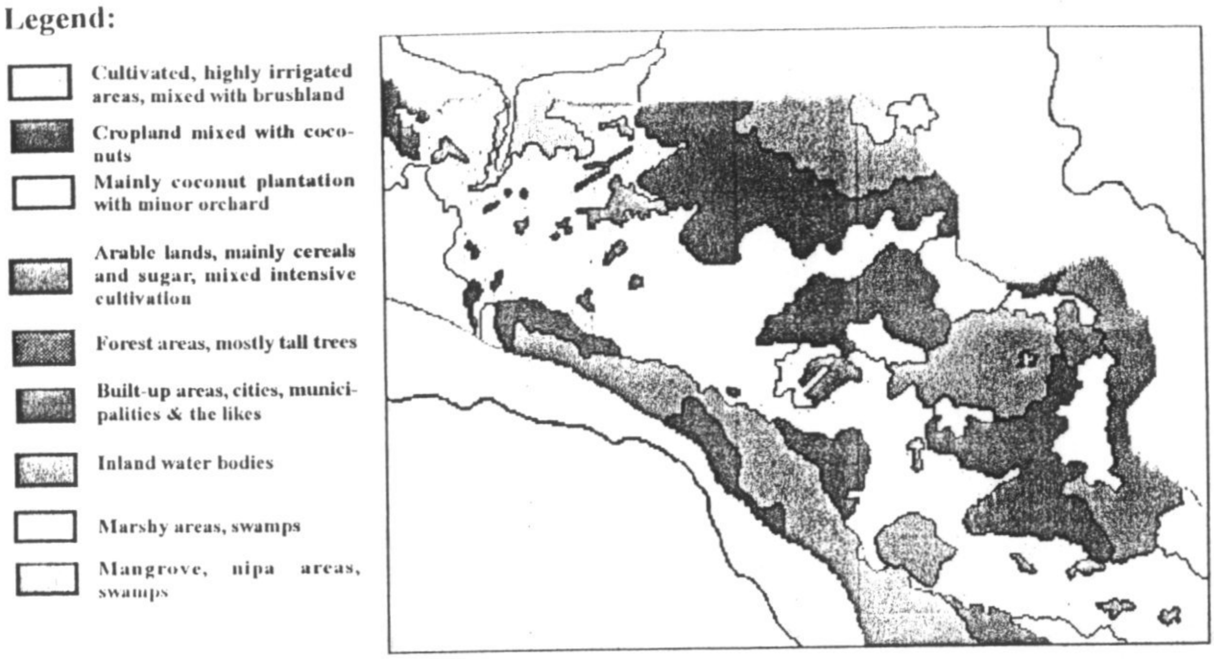


Fig. 3. Land Use Map of Bicol River Basin

- category 1, cultivated areas, principally with rice, mixed with grasses and brushes
- category 2, principally croplands mixed with coconuts and bananas
- category 3, principally coconut plantations mixed with other plantations
- category 4, arable lands, mainly cereals and sugar, mixed with other crops
- category 5, principally forested areas, mostly trees/timber
- category 6, principally built-in areas, characterized by human activities
- category 7, inland water bodies, principally fresh water lakes
- category 8, generally marshy areas, swamps
- category 9, principally mangrove and nipa areas, mixed with brushlands.

5.4 Slope Condition

Previous works by the National Water Resources Council (Framework Plan, Bicol River Basin, Report No. 24-5A, 1983) indicates four slope categories. These were verified and reconciled through field investigations. Unfortunately, not much can be relied upon through monoscopic investigation of the ERS-1 SAR images as

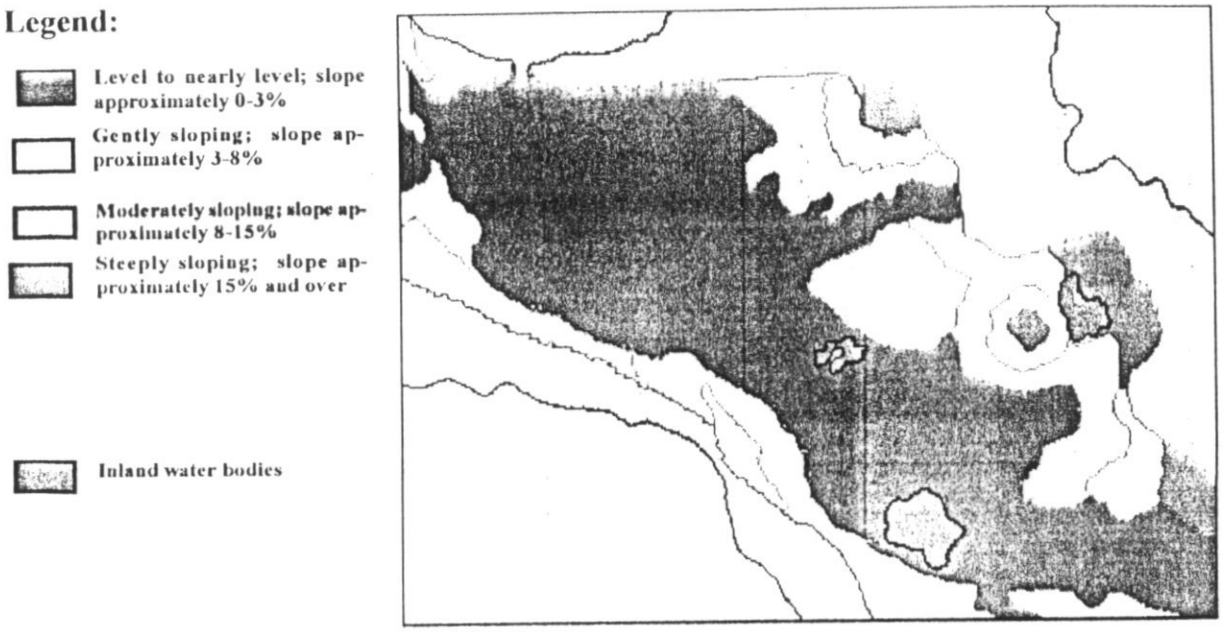


Fig. 4. Slope map of Bicol River Basin

far as slope conditions are concerned. Thus the previous slope conditions were used to satisfy the requirement for correlation. Slope conditions are categorized as follows:

- category 1, includes all level to nearly level lands with slopes ranging from 0 to 3 percent, areas delineated for this category are most suitable for irrigation because of this flat terrain. Generally used for rice production.
- category 2, includes all gently sloping and gently undulating lands with slopes ranging from 3 to 8 percent.
- category 3, includes all moderately sloping and moderately undulating lands with slopes ranging from 8 to 15 percent.
- category 4, includes all steeply sloping, rolling and undulating lands with slopes greater than 15 percent.

Fig. 4 depicts the slope map of the study area.

5.5 Climate

The climate of this basin is of the type having no dry season but has a pronounced rainy season from November to January. The climate is determined by typographical features and is open toward the northeast, to the effects of monsoons, as well as tropical cyclones.

The northeastern monsoons between November and February have a great influence on this basin, while the trade winds are obstructed by part of the Sierra Madre mountain ranges. There are low mountains only to the southwest, therefore, the basin is only slightly affected by southwestern monsoons. Cyclones average two a year.

Average annual temperature is 27°C and temperature differentials between localities are small. Average humidity is 85% at Naga City.

5.6 Precipitation

There is no dry season in this area. There are possibilities of heavy rains in October, November and December, mainly due to the influences of wind direction and topography. The average annual rainfall varies from 2,000 mm in the southwest area to 3,600 mm in the northwestern area.

The highest monthly rainfall was 2,900 mm at Naga City. The most recent heavy rains prior to the December 1993 floods were recorded in October and November 1988. The basin did not experience flood disasters until then. Statistics indicated however, as mentioned earlier, that 1993 could be a wet year for the basin.

5.7 Flood and Storm Surge

Rainfall on mountains such as those in Sipocot river basin reaches the flood plain fast. In the mainstream, however, it flows very slowly towards the estuary due to the low, flat terrain which includes large lakes.

Frequent and heavy floods are caused by storm surges generated in San Miguel Bay. The bay is often subjected to high tides, and, in addition, many violent typhoons pass over the area. The maximum storm surge is estimated to be as high as 2.5-3.0 meters, and the flood tide in San Miguel Bay is about 1.5 meters AMSL.

Therefore, the water level in the bay may reach 4.0 meters AMSL, when the storm surge occurs simultaneously with the astronomical flood tide. When this phenomenon occurs, recession of the flood waters from the upstream floodplain is severely hampered.

5.8 Flood Control Works

The Bicol River Basin Development Program (BRBDP) designed the flood control system for the basin and the Department of Public Works and Highways (DPWH) is in charge of its implementation. Currently under construction are cut-off channels which are intended to straighten the meandering channel in the vicinity of Naga City and to actually by-pass the city. Future programs include major projects such as the construction of dikes in the lower river system and a direct diversion channel from Lake Bato to Ragay Gulf, together with dams in the upper Sipocot River.

6.0 ERS-1 SAR AND SPOT DATA ACQUISITION AND DELIVERY

To date, 35 SAR tapes (33 separate scenes) have been received by the project proponent. Initially, the acquisition of this data was rather haphazard (at least three scenes were of open sea) and coverage of much of Luzon was acquired beyond the area of interest which was eventually selected. Whilst much of this data cannot be used directly in the current study, it could be invaluable as a record of the non-flood situation for the areas covered, should future flooding occur there. Requests for acquisition and processing of SAR images took place directly between PAGASA and ERSIN. Eight (8) scenes have been acquired of the Bicol River Basin (including the sub-catchment of Sipocot) to provide temporal cover of the area.

Two SPOT scenes covering the Bicol River Basin (but not the Sipocot) have been acquired, one from NAMRIA (October 1987) and one from the ESRIN distribution system (February 1994). This was necessary because of difficulties encountered by the investigators in trying to obtain data through the ASEAN distribution system in that delays up to six (6) months were occurring with the local distributor for data acquired through the Bangkok receiving station. No LANDSAT TM data have been available in the Philippines for the Bicol region.

7.0 DATA PRE-PROCESSING

Two areas of concern to the investigators in the initial stage were the inadequate computer facilities at the PAGASA, as well as the long delays occurred between reception of CCT's (and later exabytes tapes) from ESRIN and transporting them to PAGASA. This was aggravated by the inability of PAGASA to display the data because tape reading, sub-scene selection and copying to floppy disks had to be done at NAMRIA or UP for subsequent PC display at PAGASA-WFFC. Attempts were made to read ERS-1 CCT's at the PAGASA Apollo Computer System but to no avail. Another attempt to improve the situation was our request to purchase an Exabyte reader, but funds were not available within the project itself. Data output facilities were also absent at PAGASA, which required that processed data be returned to NAMRIA for hard copy production. Such logistical problems placed severe limitations on the amount of SAR data which could be handled, but which had been addressed to the best of our ability in the early stage of the project.

8.0 GROUND VALIDATION

Visits by the investigators were made to the test area in July and August 1993 to carry out the initial dry period reconnaissance, to establish contact with the local officials, as well as to obtain local map and land-use data. Flood survey was carried out in December 1993, while in October 1994, coastal areas were visited which had been inaccessible after the December 1993 flood.

In November 1994, both European counterparts visited the Bicol area and further land-use data were collected. The position of each site together with reference points such as road junctions were determined by primary GPS. Hardcopy

ERS-1 images of the area acquired before and during flooding were used to select validation areas. The 2-day site visit was considered invaluable for understanding the SAR data in relation to the prevailing land-use and topography and for the application of suitable image processing and interpretation methods. Pictures taken during the each field investigations are in ANNEX 1.

Minor flooding of the lower Sipocot River was reported at the time of ERS-1 SAR acquisition on 01 November 1993 and some may have been present also on the Bicol River, and this has been confirmed and explain later. No ground validation was undertaken for this event but local reports provided some information.

A major flood event occurred in the Sipocot and main Bicol Rivers on 06 December 1993 which was imaged by an early morning ascending ERS-1 pass on that day. This was accompanied by a storm surge within San Miguel Bay which caused further flooding along the coastal area. Ground validation was carried out on 13-15 December 1993. Forty five (45) locations were visited within the 2,717 km^2 basin and photographic evidence of the remaining flood (see ANNEX 1) together with local reporting of peak flood were used to assess floodwater extent in relation to the prevailing land-use. These informations were then compared with water level data which PAGASA collected from 6 telemetered water level stations within the basin.

9.0 MANUAL/ANALOG IMAGE INTERPRETATION

In consideration of all the various data that were gathered and collated, among these are geological, land use and slope information which were derived from previous studies and were later revised with the use of ERS-1 image manual interpretation procedures and fieldwork we were able to create a geomorphological condition analysis of the study area. Temporal analysis of the ERS-1 imageries (flood data & non-flood data) provides significant information about geomorphic conditions in the area. Radar signature differences clearly manifest separation of distinct morphological features such as water bodies and land areas especially in the July 1993 image (non-flood data, Fig. 6) where boundaries are well manifested

Here we could easily delineate permanent water bodies such as seas, lakes, swamps and major river channels from land bodies such as mountain slopes and ridges. Whilst, these features are relevant to the delineation of the influence of the fluvio-marine morphology in the study area, the July image alone can not provide a complete approximate boundary of this area. Intermediate radar signatures midway from dark to black are manifested over most of the area and are not very reliable for monoscopic interpretation. In order to delineate the approximate fluvio-marine extent of the study area, the ERS-1 image of 06 December 1993 flood was utilized (Fig. 7). In this image, the effects of floodwater are strong, controlling the radar signatures. In contrast to the July image where we could observe a homogeneity of the radar return signals from the original scattered dark features (resembling water bodies) in the December image a more regionalized single dark gray response trending NW-SE apparently represents the extent of wet ground (flooded areas). Except for the change from dark to gray of the lakes Bato and Baao further upstream (which was attributed to surface waves due to wind effects) the image demonstrates the distinct geomorphic characteristic of the flood plain in contrast to the surrounding areas. Hence, monoscopic examination of these temporal data and further correlation with geologic, land use and slope information could further enhance the criteria for geomorphic classification which is the key to identifying the probable flood hazard limits of the study area. Geomorphologic survey and analysis provides considerable information on the genetic character and the processes involved in the formation of the various landforms under study. Likewise geologic survey and analysis provides detailed information on the type and physical characteristics of the rocks and sediments deposited in the area. On the other hand, land use and slope analysis provides information on the present conditions existing in the area, be they natural or man-made influences. Land use signifies human response to the natural conditions of the land taking into consideration the physical aspects of soil, water, topography and slope, etc. Fig. 5 depicts the general geomorphological analysis of the study area as analyzed from both the July and December images.

A. Coastal landform - characterized by landforms that are the product of periods of land and sea interaction, where the sea exerts considerable influence in the formation of the coastal geomorphic features such as tidal flats/mudflats

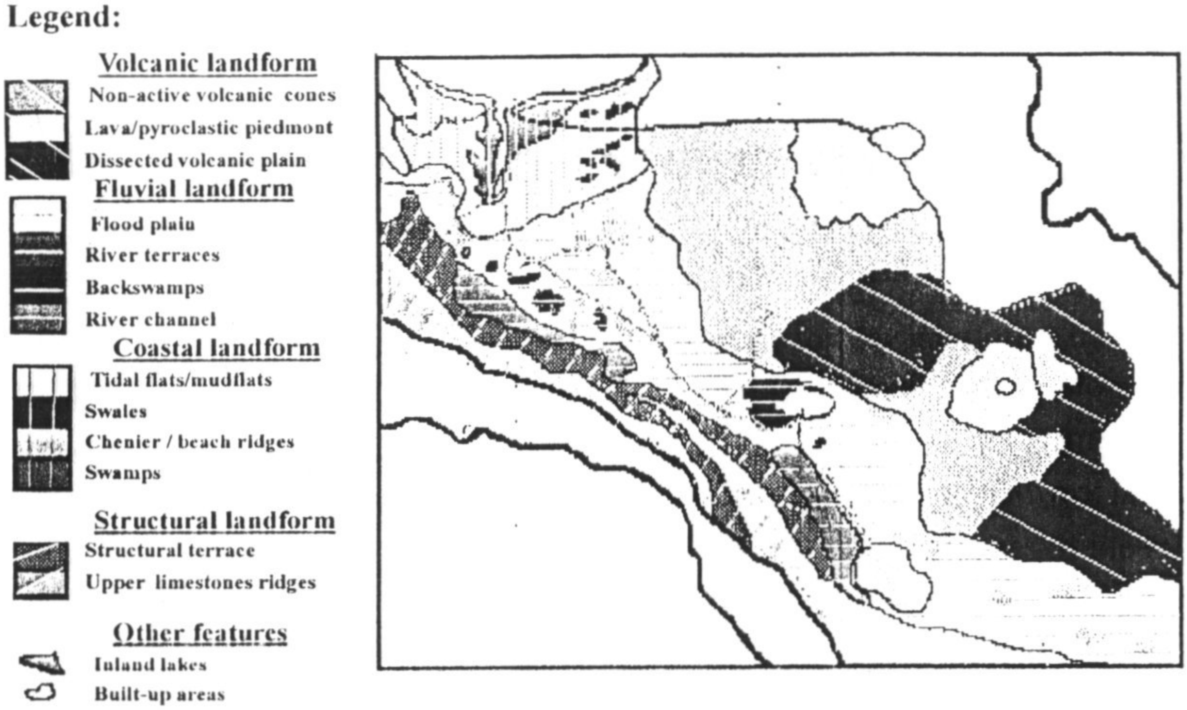


Fig. 5. Geomorphological map of Bicol River Basin
as derived solely from ERS-1 SAR data.

chenier/beach ridges, coastal swamps and swales which are clearly visible on the image. Tidal flats/mudflats register a light grayish color on the image. This is probably due to the response of thick and moderately tall cover of mangrove and nipa palm. Chenier or beach ridges exhibit very bright signatures as their raised topography is attractive to habitation. Houses and fruit trees serve as efficient corner reflectors for the radar signals, hence the bright response. Nevertheless, their pattern of long narrow parallel lines aligned to the configuration of the coast apparently suggest a series of old beach ridges formed through continued land-sea interaction. Coastal swamps and swales register the most distinctive dark signatures, their shape and pattern clearly indicates typical coastal land features. Coastal features such as these (seen on the image and verified on the ground) provide vital information on the history, manner and pattern of their formation, which clearly indicates a series of tidal regressions, storm surges, and fluvial encroachments in the estuarine-deltaic environment in the recent past (quaternary ±10,000 BP). These alternating periods of marine regression and further encroachment by both the river and the sea to maintain equilibrium creates a favorable condition for the formation of such land features. Inasmuch as the materials that constitutes these deposits are water-laid and considering that the processes that were responsible for their formation is still active today, it is logical to assume that these processes will continue to operate in the future, hence future flooding of the area can be expected. Probable flood extent will more or less coincide with the boundary of these landform units.

B. Fluvial landform - characterized by landforms that are products of river action (erosion and deposition). the main morphologic feature is the flood plain which extends several kilometers away from both sides of the main Bicol river. Although much of the drainage network is practically unrecognizable in both July and December images, traces of the main drainage channel are recognizable as dark and narrow sinuous broken lines. This is due mainly to the resolution of the ERS-1 SAR where portions of the channel that are less than 25 meters in width cannot be represented by the picture element of the images. Nevertheless, the pattern, signature, and intrinsic morphologic appearance of the image manifest existing water channels. Features easily recognizable on the images are inland lakes, backswamps and terraces. The flood plain in general is most prominent in the December image exhibiting a dark gray to dark signature except for the two inland lakes which appeared light gray apparently due to surface waves caused by wind effects. In contrast, the lakes as well as the backswamps are very well manifested in the July image by their black signature indicating minor wind effects. The river terraces appeared light gray to dark gray on both images suggesting a different land use pattern which could be likened to the mangrove areas of the coastal swamps. The changes on the temporal images are well manifested by the change in shape and size of the lakes as observed in the field. Likewise, on the December image the extent of the flood plain is very well manifested. Reference signature, textures and patterns of the morphologic features through monoscopic interpretation and concurrent field verification allows the delineation of the probable boundaries of the flood plains. Field investigation of the sediment within the area confirmed alluvial depositions indicative of periodical flooding in the past. In the same manner as the activities in the coastal regions are still active. it is also logical to assume that the extent to which the alluvial sediments have been deposited through se-

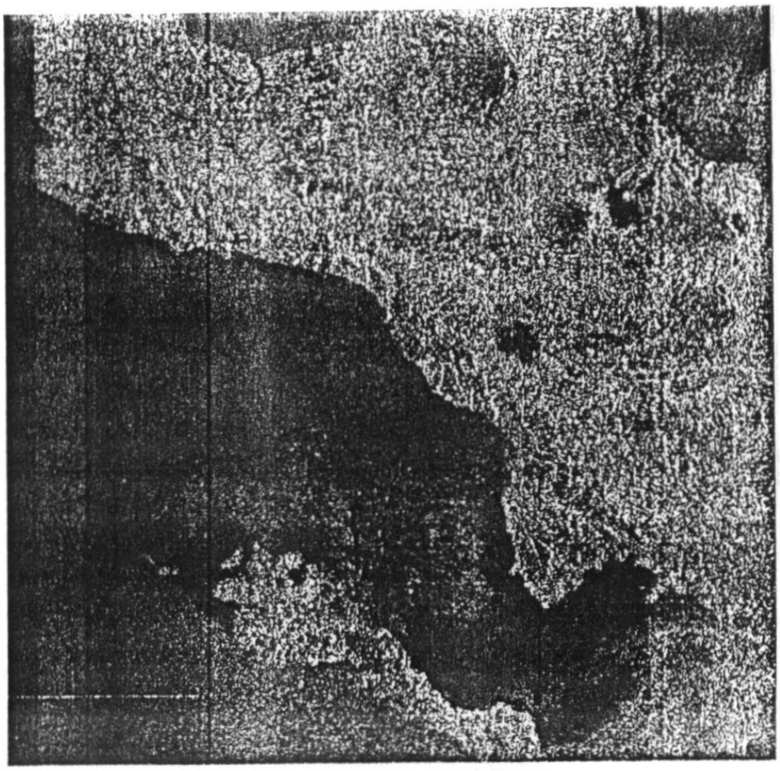


Fig. 6. Full image data acquired 19 JUL 1993
02:14:17 ascending pass

ries of flood events would correspond closely to the probable flood hazard boundary.

10.0 DIGITAL IMAGE PROCESSING & INTERPRETATION

The primary aim of the project is now focused on delineating the flooded regions in the December '93 (Fig. 7) image. Initial examination of the image reveals that there is no clear signature of the floods. As is normal, water bodies - particularly in windy conditions- exhibit very variable backscatter. From the ground data, it is known that both dark and bright areas of the image are underwater. The areas of open water corresponding of Lakes Bato and Baao are bright, as a result of their ability to sustain waves. It must be remembered the time of the satellite pass and the time typhoon pounded the basin coincided, and the surface wind at

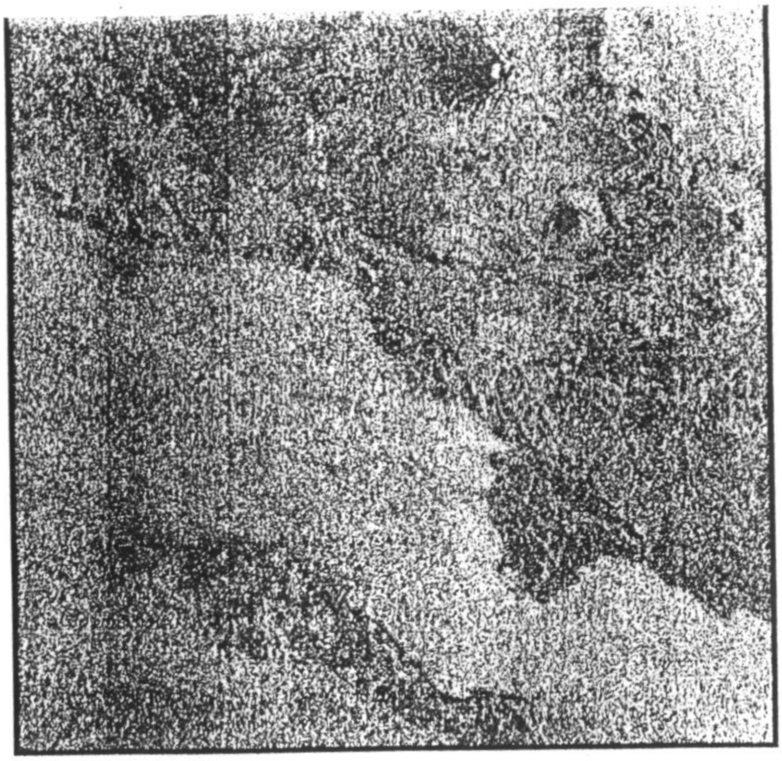


Fig. 7. Full image data acquired 06 DEC 1993
02:14:17 ascending pass

the time was about 36 meters per second southwesterly. But flooded areas away from the lakes show a range of image brightness. Many areas are very heterogeneous, with coconut palms and banana mixed up between rice paddy; the presence of trees would have tended to reduce wind effects. Larger areas of paddy would provide open areas. As a result, interpretation of the image during the floods requires a fairly good knowledge of the pre-existing land cover, because localized wind effects seems to be very important in the analysis. However, it may be possible to infer some information about the extent of the floodbasin by examining textural changes, corresponding to relief effects on the boundaries of the basin, eventhough close examination of the image reveals only weak texture effects visible. This was the principal reason why two of the investigators went to Sheffield University and Institute of Hydrology (Wallingford) in England. Results of such tests will be discussed later.

However, the use of multitemporal data becomes the central point of analysis of this project, as surface cover and land-use appears to have a significant effects on the flood signatures. Methods of change detection were considered, based on the original data and even the enhanced data. Whilst, this did not have a direct bearing on mapping flood extent, it certainly helped to give an estimate of areas under rice production, which in turn helped in the interpretation of signatures of the flood. Methods based on image ratios and their variants, color overlays, and speckle-reduced or segmented images have been considered. All analysis were done on ERGOVISTA PC-based (DOS-based) software, except those that were done in UK. Again the results of these experiments will be extensively discussed later.

It can be noticed that from the flood hydrographs in Sipocot (Fig. 8) and Ombao (Fig. 9) that the flood peak coincided with the acquired ERS-1 SAR image for December (02:14:17). ERS-1 was able to image the basin in the morning of 01 November 1993 (02:11:18) where minor flooding was reported (Fig. 10 & 11). It can be resolved by studying both the images that the inundation observed both in November and December 1993 corresponds to the flood water level for developing relationship between water level/discharge and flood inundation.

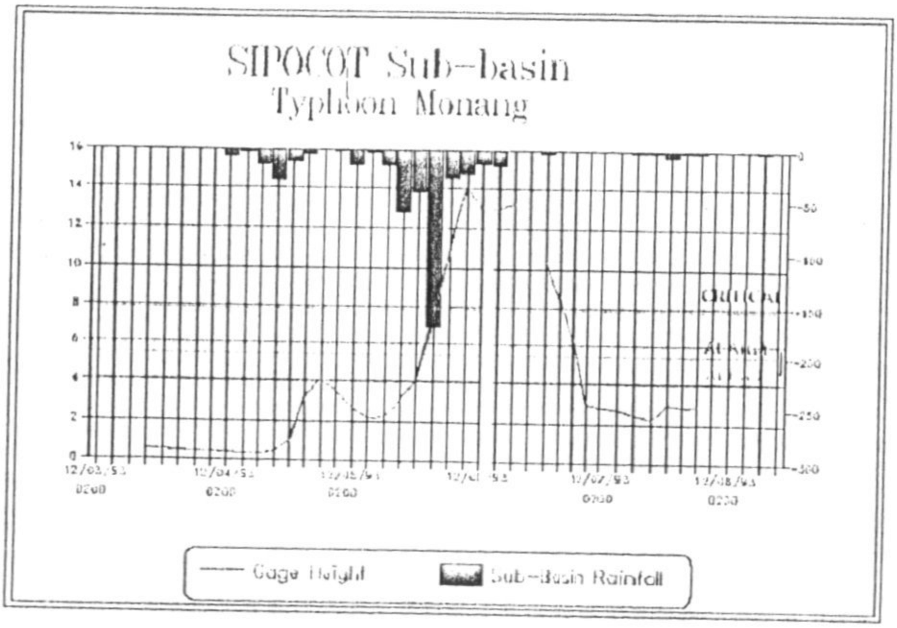


Fig. 8. Flood hydrograph of Sipocot River. Yellow vertical line indicate time of satellite pass. December 1993

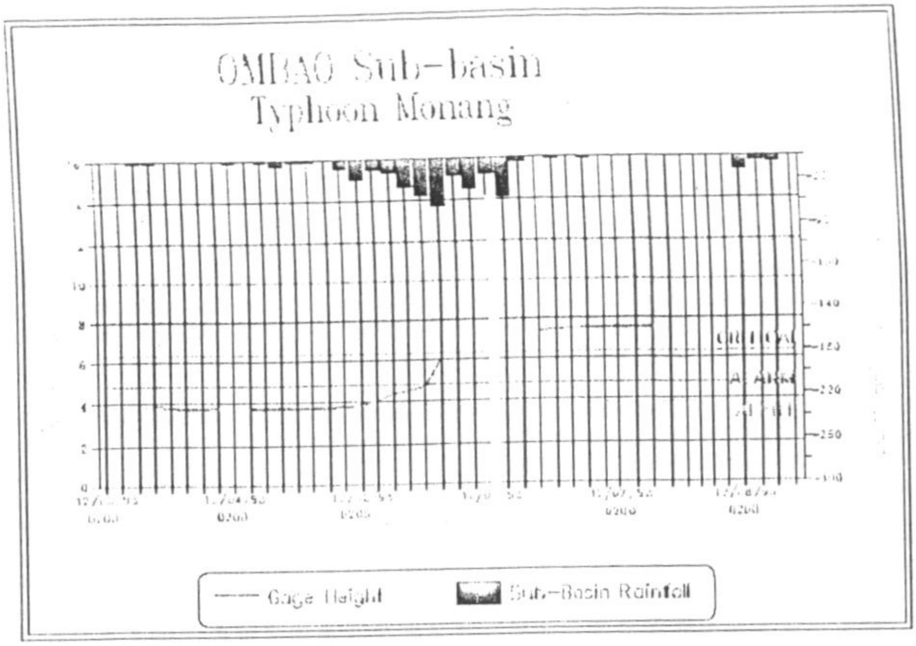


Fig. 9. Flood hydrograph of Ombao River. Yellow vertical line indicate time of satellite pass. December 1993

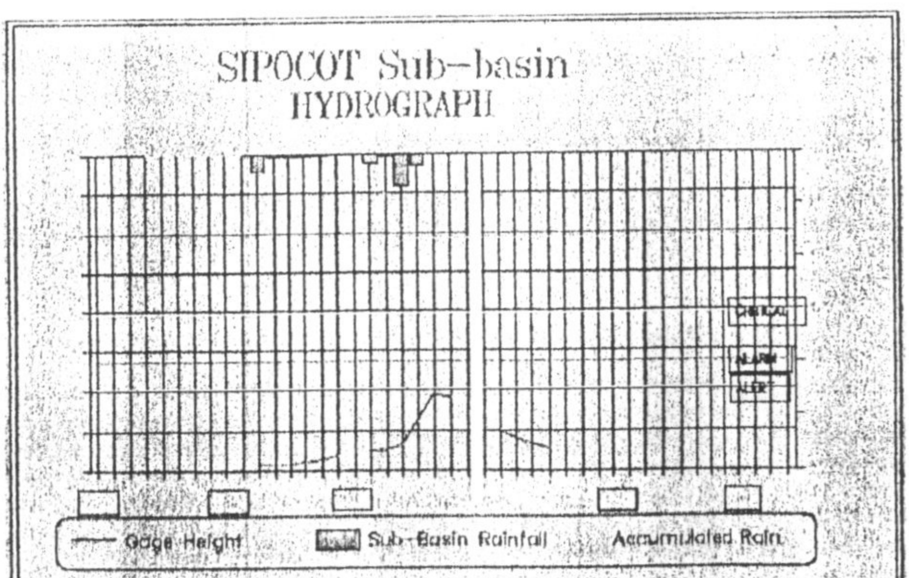


Fig. 10. Flood hydrograph of Sipocot River. Yellow vertical line indicate time of satellite pass. November 1993

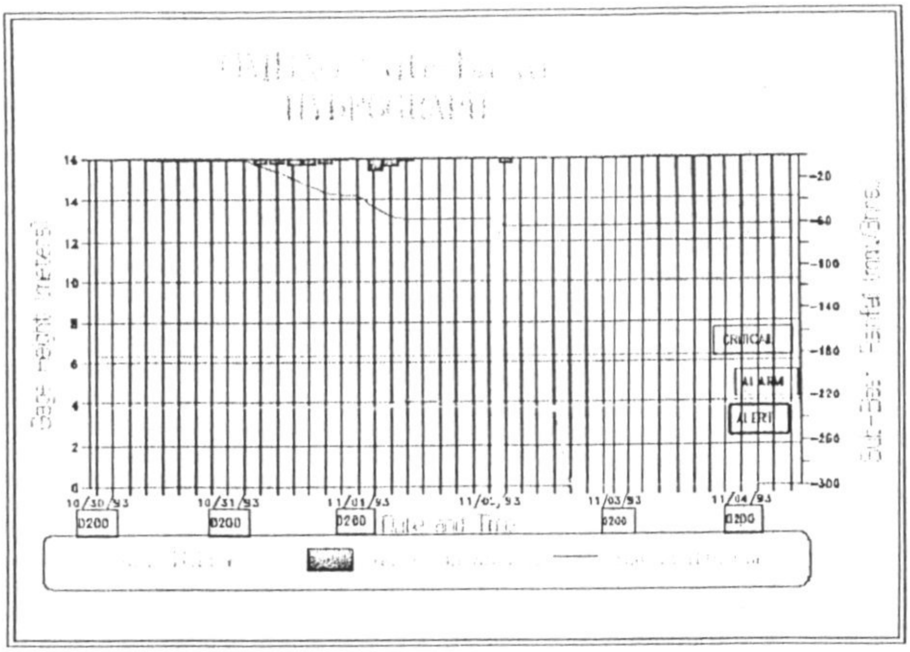


Fig. 11. Flood hydrograph of Ombao River. Yellow vertical line indicate time of satellite pass. November 1993

10.1 Textural Changes Experiment

Using the ERGOVISTA software as a tool for analysis, we experimented two techniques for textural change detection. The most popular technique based on differences in the magnitude of signal intensity between two dates, particularly July and December images, by ratioing and subtraction, seems worthless when the flood image is very much affected by winds of greater than 20 meters per second. However, in the next sub-section, we introduced two dates that had the same data qualities, i.e., both affected by high winds. The second technique which is based on estimates of temporal decorrelation of speckle also did not work, largely due to uncorrelated intensities of the image affected by high winds.

As earlier mentioned, another set of experiments were carried out when two of the investigators visited Sheffield University and Institute of Hydrology in UK towards the middle of February 1995. The latest technique developed by the University itself were annealing and its variations, typically standard annealing, simulated annealing, and finally gamma annealing techniques. Annealing is a filter

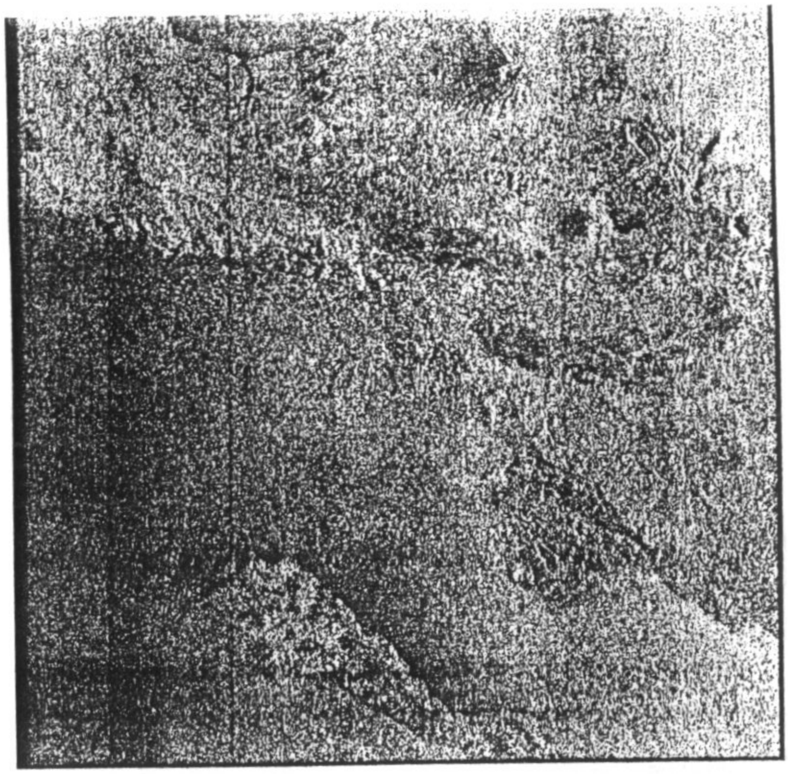


Fig. 12. Full image data acquired 01 NOV 1993
02:11:18 ascending pass

scheme to automatically adapt local image structure, which is available in almost all digital image processing (DIP) softwares, including ERGOVISTA. Standard annealing approaches to image restoration attempt to categorize each image element as belonging to one of a small number of predefined image states or values. Some authors in DIP techniques believe that this procedure is very restrictive for tasks such as radar cross-section estimation. Simulated annealing techniques attempt to present an algorithm which is capable of producing a real-valued output, which is achieved by introducing an edge detection stage for each local image.

Gamma annealing was introduced as a variation of the simulated by assuming that texture, or noise for that matter, are not Gaussian distributed, but Gamma. In effect, all the Gaussian functions in simulated annealing are transformed into Gamma function.

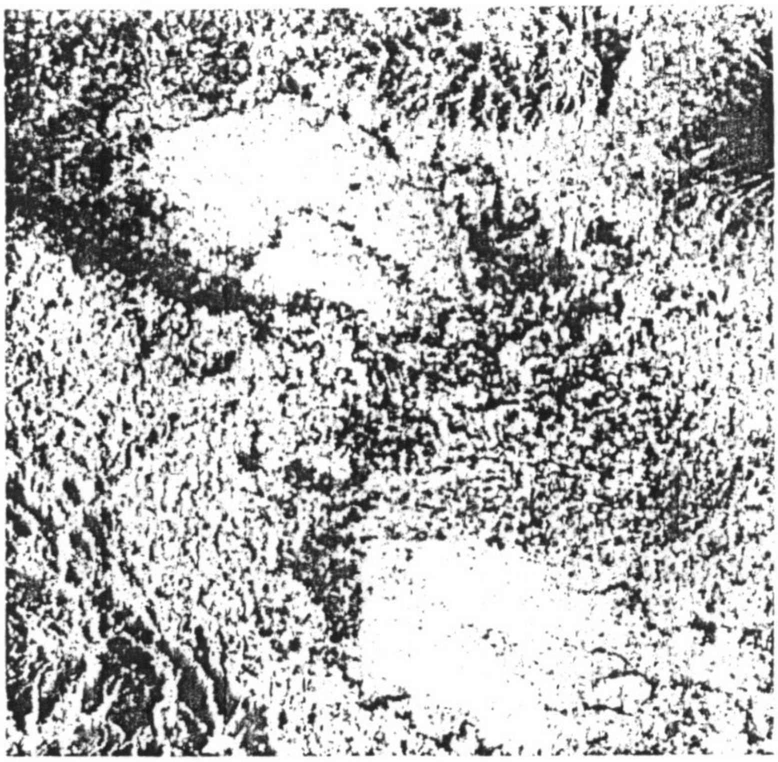


Fig. 13. Gaussian Annealling Application centered at Lake Bato

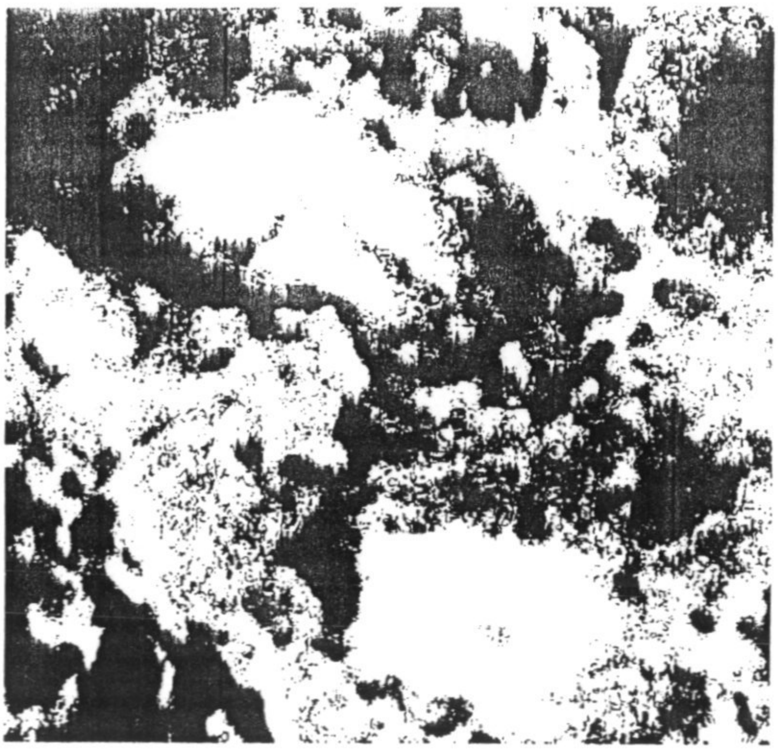


Fig. 14. Gamma Annealing Application centered at Lake Bato

This gives us the opportunity to apply these couple of techniques for the December '93 image which are unavailable anywhere except in UK. The results are presented in Figs. 13 and 14. Again, even our European counterparts conceded that there seems to be over-saturation with such kind of techniques when applied to the December image.

10.2 Multitemporal Analysis

There are three most important SAR images that will be part of the multitemporal analysis; two of which were discussed earlier (December '93, and July '93). The November '93 image (Fig. 12) becomes part of the analysis because of the minor flood that occurred just about the same time, largely in the Sipocot sub-catchment.

Fig. 15 represents the full scene RGB composite image of the three ERS-1 SAR images, not subjected to any filters.

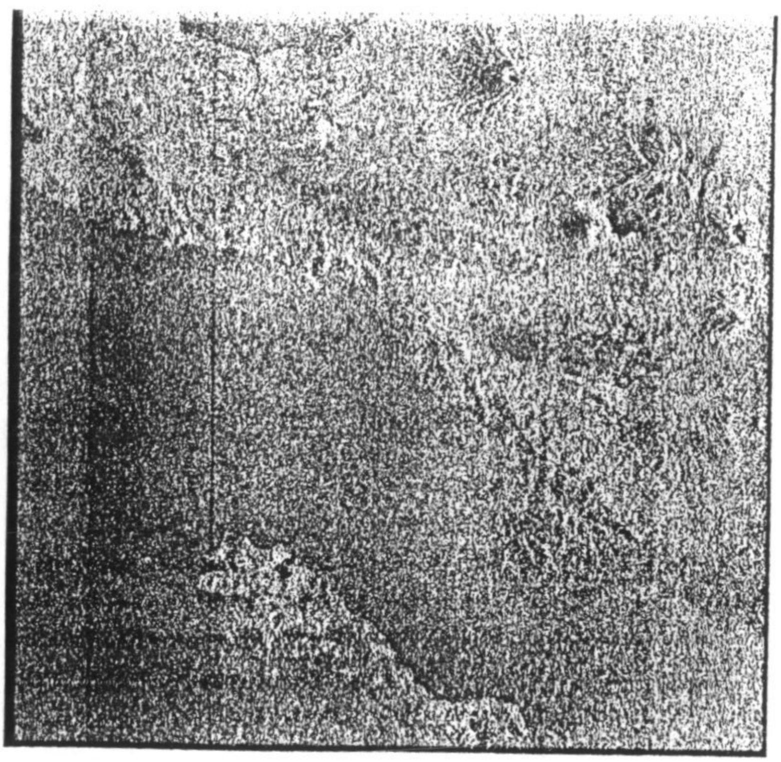


Fig. 15. RGB full scene composite image SAR data
Red=Dec, Green=Nov, Blue=Jul

The rest of the analysis are sub-sectioned due to computer memory capacity (typically 8 Mbyte) to produce detailed false color composites. Two sections were chosen, namely: 1) centered on Naga City (Figs. 16, 17 and 18), and 2) centered on Lake Bato, although most of the explanations will focus on the sub-scenes centered in Naga City, data analyzed for those centered in Lake Bato are also shown, where indicated.

10.2.1 Three (3) Dates RGB Combination

Fig. 19 is a multi-temporal image created by merging three images of ERS-1 SAR. The 06 Dec '93 image is displayed in red, the 01 Nov '93 in green and the 19 July '93 is displayed in blue. This RGB color composite is useful in determining changes between the three acquisition dates. Shades from blue to cyan are areas where changes have occurred on December due to flooding. Shades from brown to magenta are areas under water on the three dates. However, on the December image, the flood water surface is rough from the influence of winds giving the composite image a crimson tone. The subdued shades from gray to green are

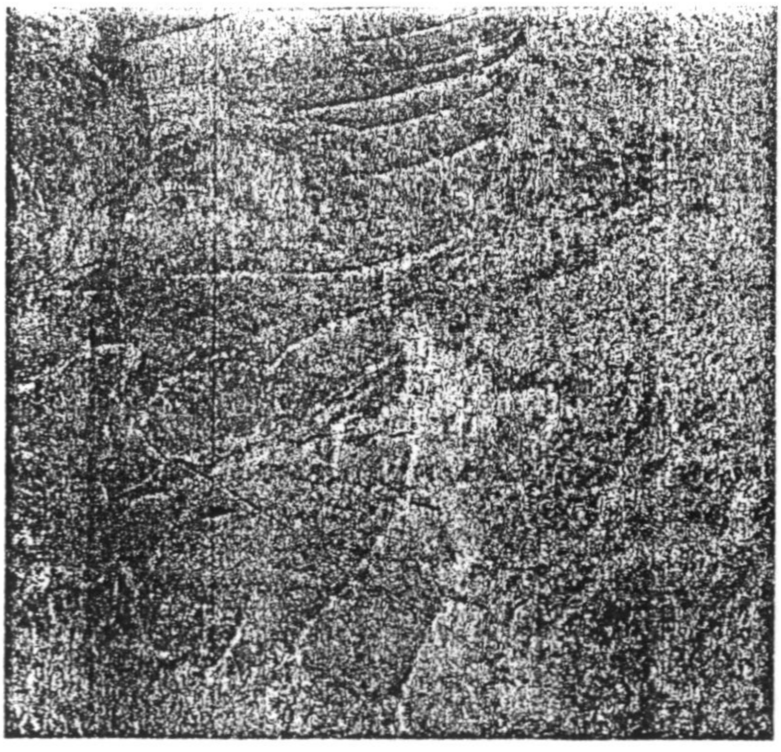


Fig. 16. ERS-1 SAR image sub-scene centered at Naga City (06 Dec 1993)

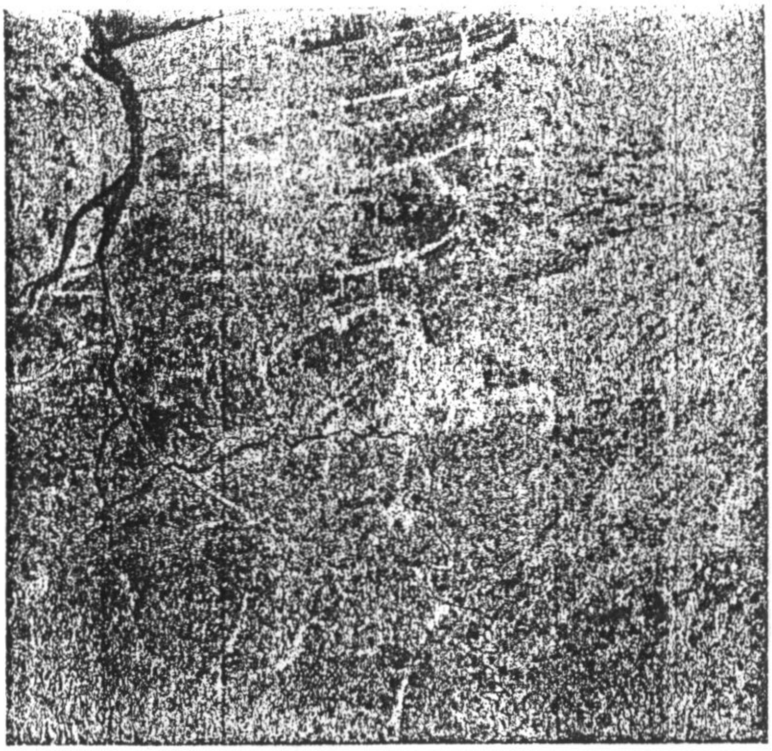


Fig. 17. ERS-1 SAR image sub-scene centered at Naga City (01 Nov 1993)

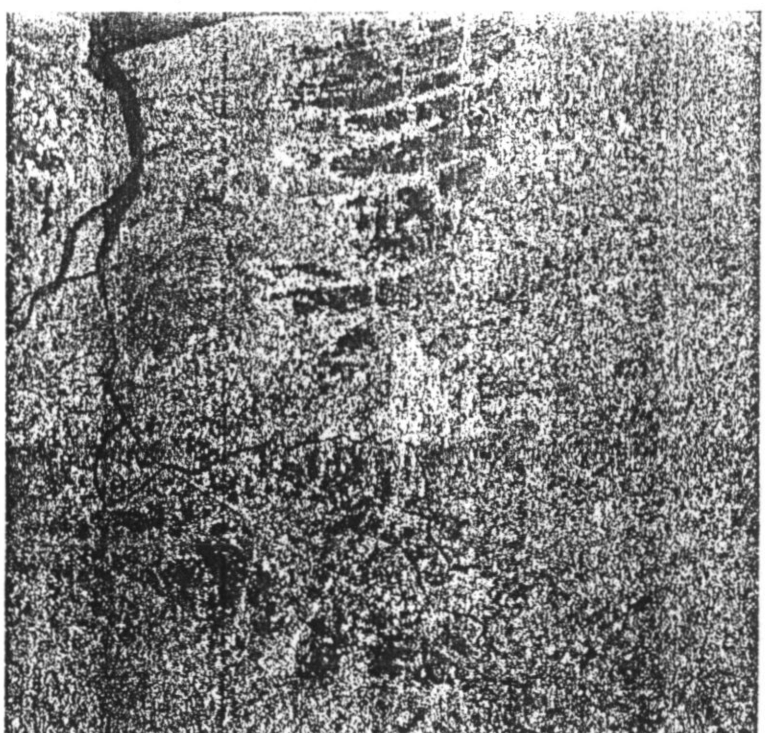


Fig. 18. ERS-1 SAR image sub-scene centered at Naga City (19 Jul 1993)

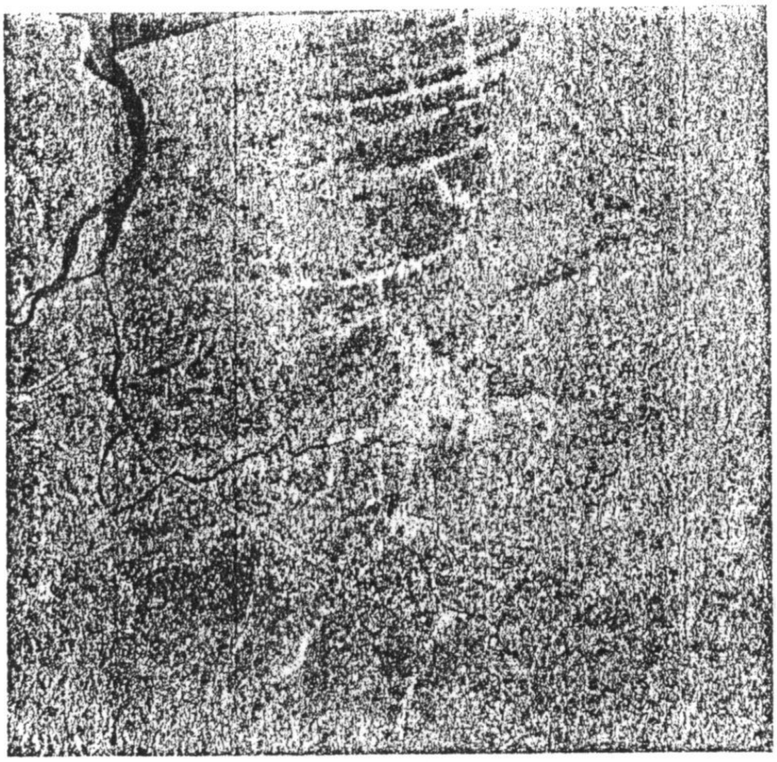


Fig. 19. RGB sub-scene composite image SAR data centered at Naga City
Red=Dec, Green=Nov, Blue=Jul

vegetative areas, where plants have experienced renewed vigour due to wetness.

10.2.2 Two (2) Dates and a ratio RGB Combination

Data from 01 Nov '93 and 06 Dec '93 were merged to create the image in Fig. 20. The 01 Nov image is displayed in red, the 06 Dec image in green and a ratio of 06 Dec image/01 Nov image is displayed in blue. This composite was used to highlight changes between two acquisition dates. Significant changes are in cyan indicating heavy flooding in open areas such as paddy fields and on open water bodies affected by winds. Dark brown are areas where floodwaters inundated the ground surface beneath the vegetative canopies. Bicol River at its estuary, is located on the upper left of the image. Naga City is shown in bright yellow at the center of the image, while other bright clustered yellow areas throughout the image represent municipalities and small villages.

Data analyzed for those centered in lake Bato are also shown in Fig. 21.

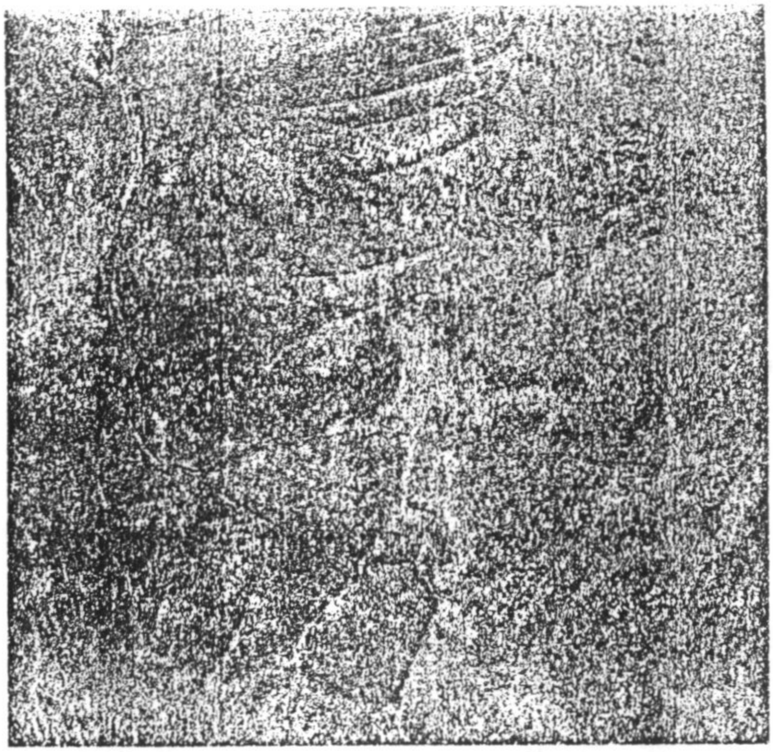


Fig. 20. Image ratioing between Nov. (red) & Dec. (green).
Dec/Nov ratio is in blue. (Naga City)

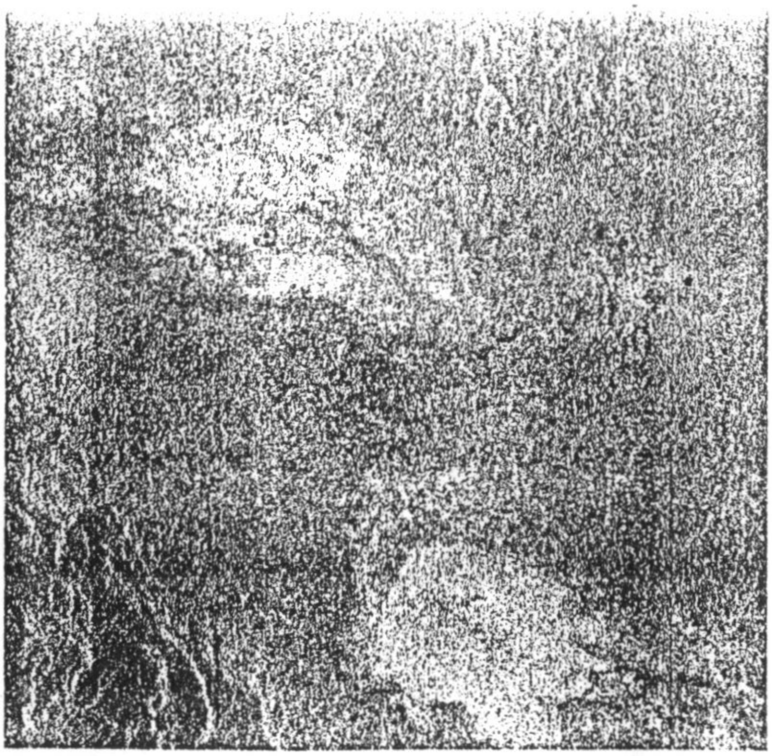


Fig. 21. Image ratioing between Nov. (red) & Dec. (green)
Dec/Nov is in blue. (Lake Bato)

10.3 Integration of ERS-1 SAR Data with Optical Data

A relatively cloud-free SPOT data was acquired two months after the flood (06 February 1994, Fig. 22) which was immediately geometrically corrected. SPOT sub-sectioned images are shown in Figs. 23 and 24, while the ERS-1 SAR (December) counterpart were already being utilized in the previous analysis.

The SPOT multi-spectral data was synergized with ERS-1 SAR data for each sub-section to provide higher accuracy in determining land cover information to better assess the type of areas that were flooded. In these images (Figs. 25, and 26), the SAR data were substituted for the intensity component of the SPOT data. The SAR data determines the intensity of the colors given in the SPOT scene. The intensity hue saturation transformation procedure are defined by the following equations;

$$\text{Intensity} = R + G + B \qquad R = \text{Red}$$

$$\text{Hue} = \frac{G - B}{I - 3B} \qquad G = \text{Green}$$

$$\text{Saturation} = \frac{I - 3B}{I} \qquad B = \text{Blue}$$

It is to be noted that the penetration of cloud cover increased the emphasis of fluvial terrain features and topographical relief, provided high degree of texture, and increased the visibility of roads and lineaments. Bright white spots indicates high return signal or backscattering of incoming radar signals due to corner reflector effects on building, metallic object such as corrugated iron roofing materials, and/or objects orthogonal to the radar beams. Naga City, located in the center of the image, and other municipalities and communities of Camarines Sur are represented as patches of white tones. Green tones indicates open natural water bodies (e.g. Bicol river and San Miguel bay, at the northern portion) and flooded open regions. The granular green tones in Naga City indicates flooded streets from the Bicol river, which runs close to the city. Red indicates areas of substantial vegetative cover. Near the estuary of Bicol river are regions of reddish tone. Flood survey and investigation reveals that these were coastal swamp areas comprising nipa

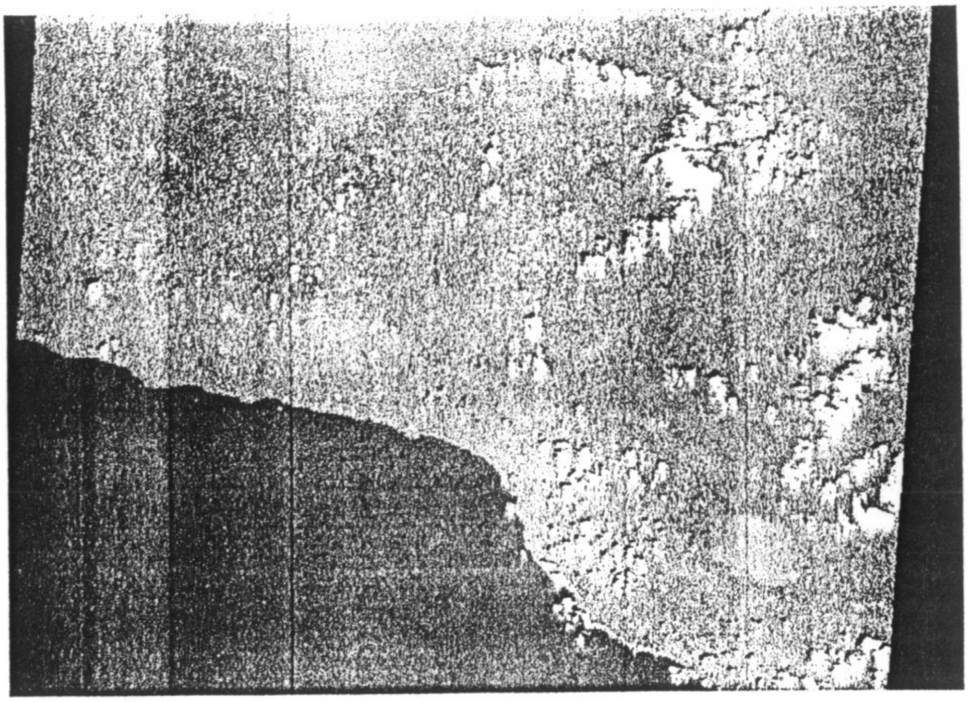


Fig. 22. SPOT RGB composite full scene
(February 1994)

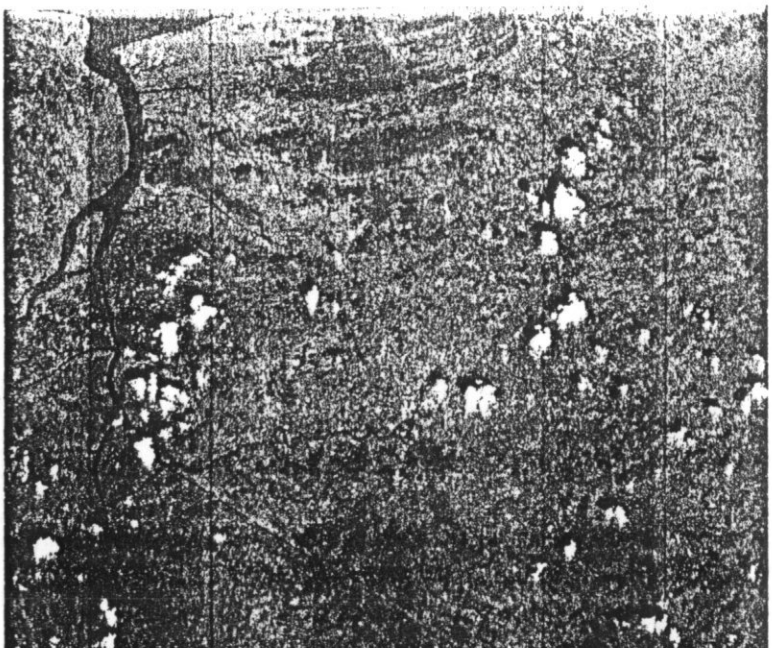


Fig. 23. SPOT RGB composite sub-scene image
centered at Naga City

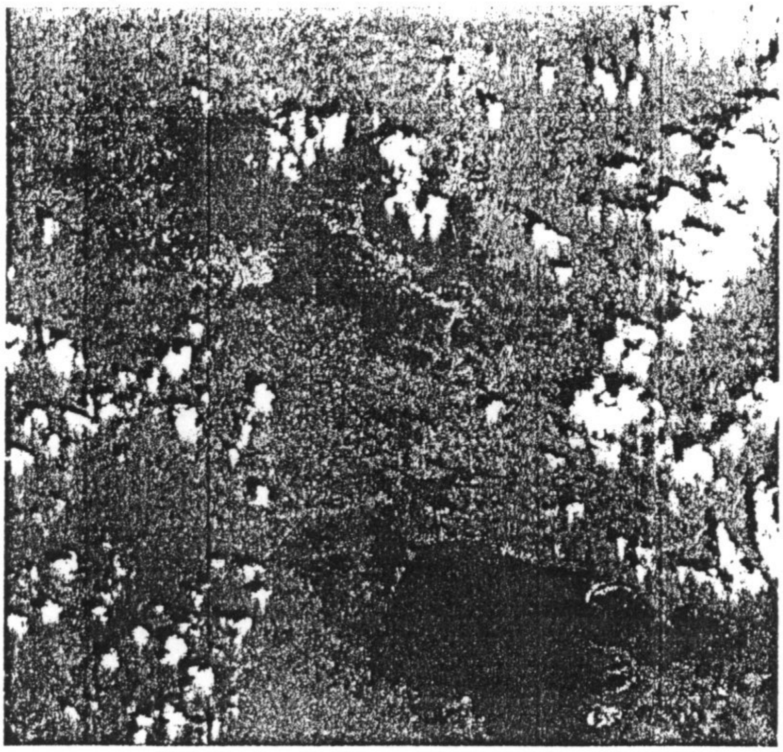


Fig. 24. SPOT RGB composite sub-scene image
centered at Lake Bato

palms, mangrove trees and shrubs with closed canopies. Although these areas were inundated by floodwaters, the radar beam was unable to penetrate through the vegetation canopy giving the impression that it was not flooded. Other areas and regions with tan closed canopies have the same effect as the coastal swamps.

Small patches of green have localized flooding on these regions especially in the Mt. Isarog foothills (northwest portion of the image). Blue tones indicate the cloud shadow in the visible images.

11. INITIAL RESULTS DISCUSSION AND CONCLUSION

For the first time ERS-1 SAR data was extensively used for monitoring floods and assessing extent of floods in the Philippines. ERS-1 SAR data along with other satellite data, increased the repetitive coverage of the flood affected areas. Due to absence of clouds in SAR images, flood assessment and estimation of

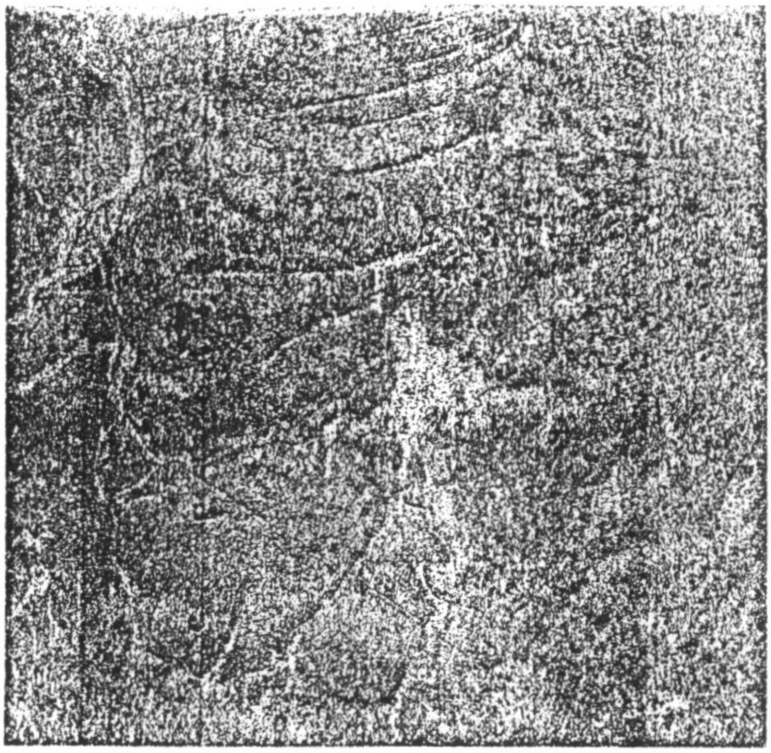


Fig. 25. Intensity-Hue-Saturation transformation composite image centered at Naga City

Fig. 26. Intensity-Hue-Saturation transformation composite image centered at Lake Bato

flood extent was improved. Better results were achieved when ERS-1 SAR data was used in conjunction with other optical satellite data.

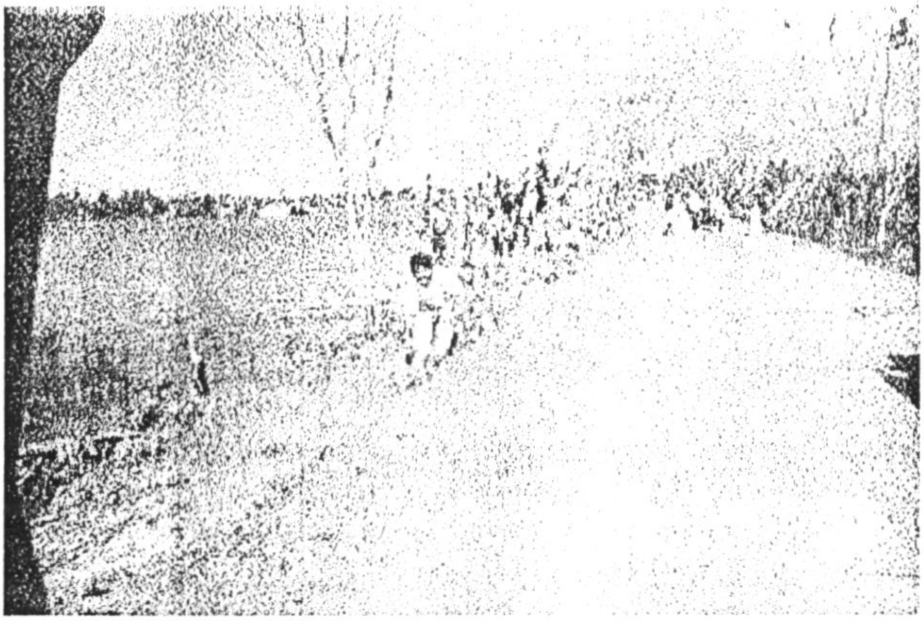
ERS-1 SAR data has shown a great promise in monitoring floods under monsoon and typhoon clouds and wind conditions. The uncertainty and unavailability of cloud free data, as in the case of optical data, is mostly solved but satellite system with improve orbit repeat frequencies are required to better capture many short-lived events. However, ERS-1 SAR data in conjunction with optical data will improve the monitoring of floods. A digital ground data base together with real-time data processing of SAR data in pre-requisite for monitoring and management of floods in real time.

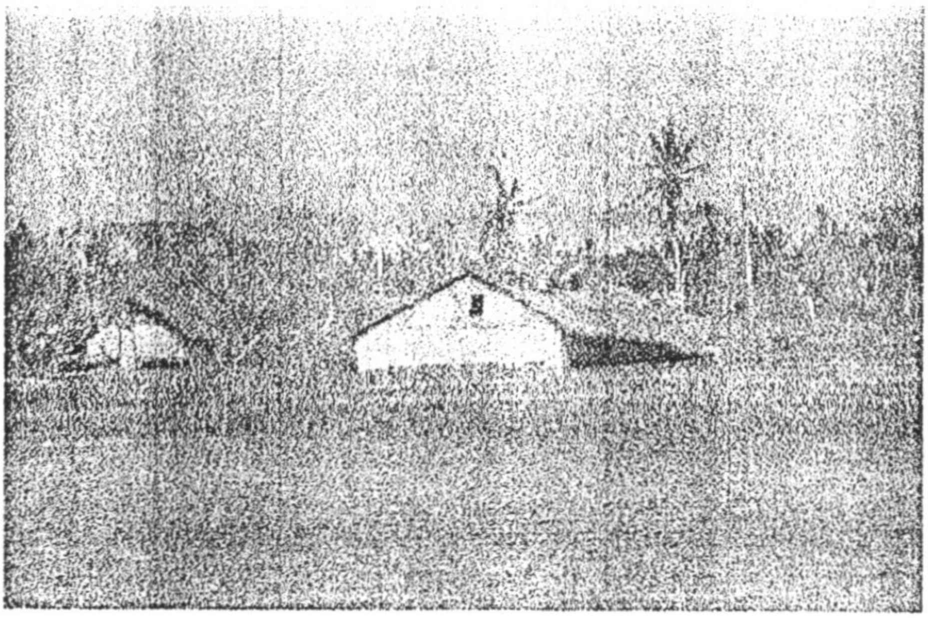
12. RECOMMENDATIONS

In order to properly assess floods, various digital overlays must be developed containing information on existing landuse, landcover, topographical details (slopes), crop details, etc..., using GIS for Bicol River Basin. Satellite data acquired during the pre-flood and post flood were examined to understand the situation in the basin, prior to the effect of the flood wave that passed. In other words, much of the details will come out later as more and more overlays are introduced.

ANNEX

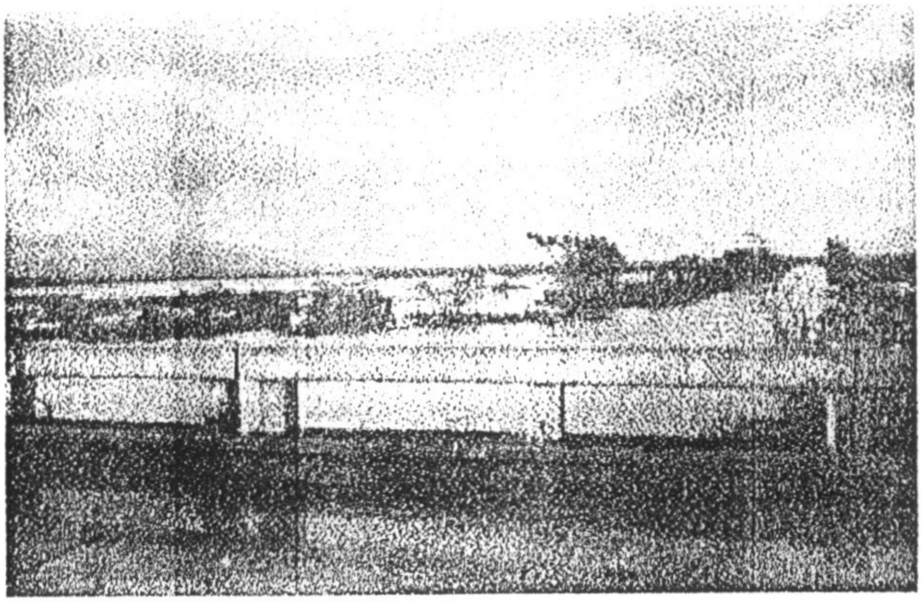
Cabusao, Santa Cruz Municipality in Camarines Sur





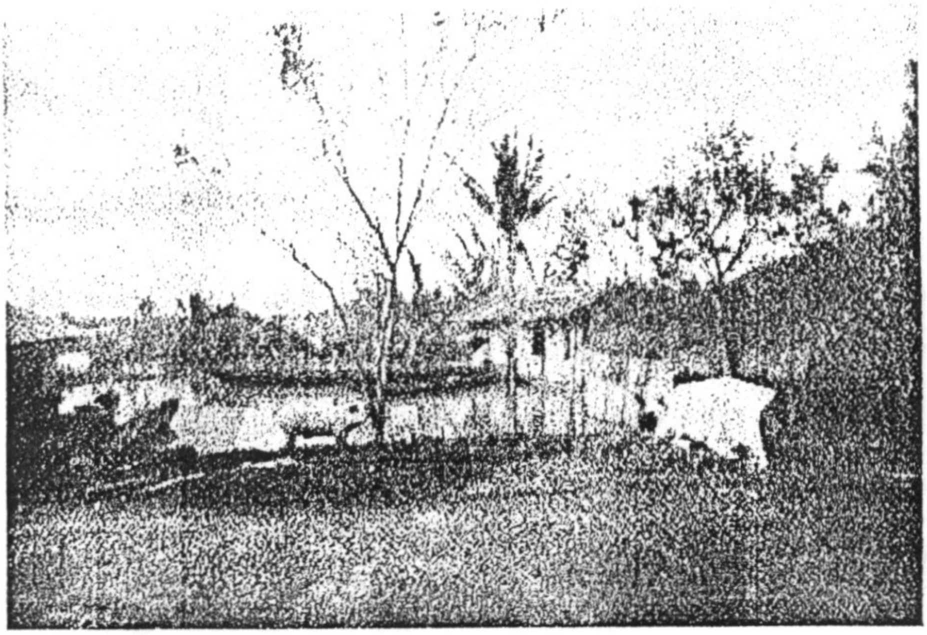
Both places are flat plain alluvial and are basically utilized for agricultural purposes. Ricefields areas are the dominant land cover. There are also coconut and banana plantations. During the Dec. 5, 1993 flood, the rice had just been harvested. It was still under water during the Dec. 13, 1993 ground investigation and field survey. Accordingly, the flood waters reached up to the knee level as per indicated.

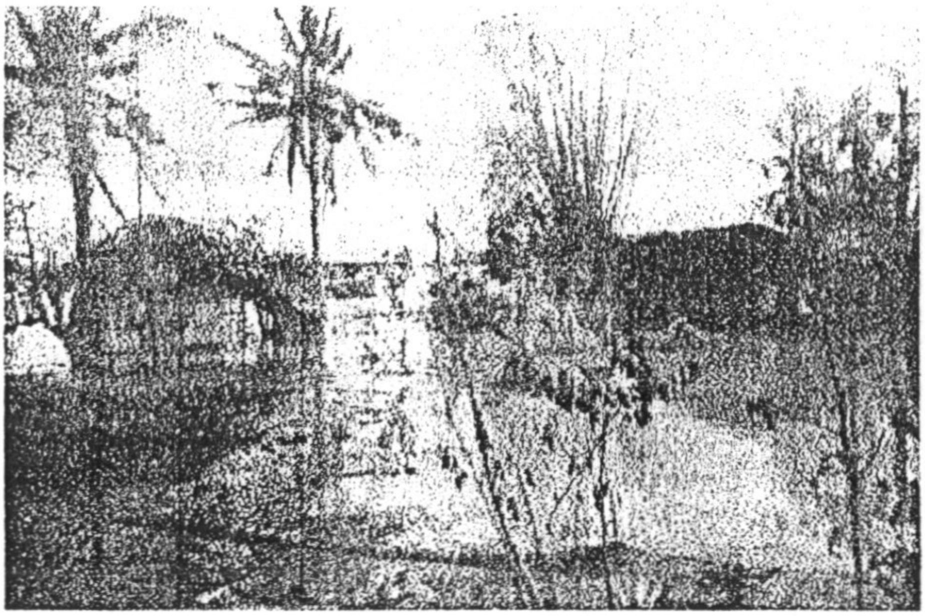
Barangca Bridge, San Fernando
Camarines Sur



The coordinates were taken on top of the bridge that span the Bicol River Development Project (BRDP) canal. Line of trees on both sides of the canal are shown. The adjacent areas are basically utilized for ricefield. Flooding started on Dec. 5, 1993 and it was still inundated during the Dec. 13, 1993 ground investigation and field survey.

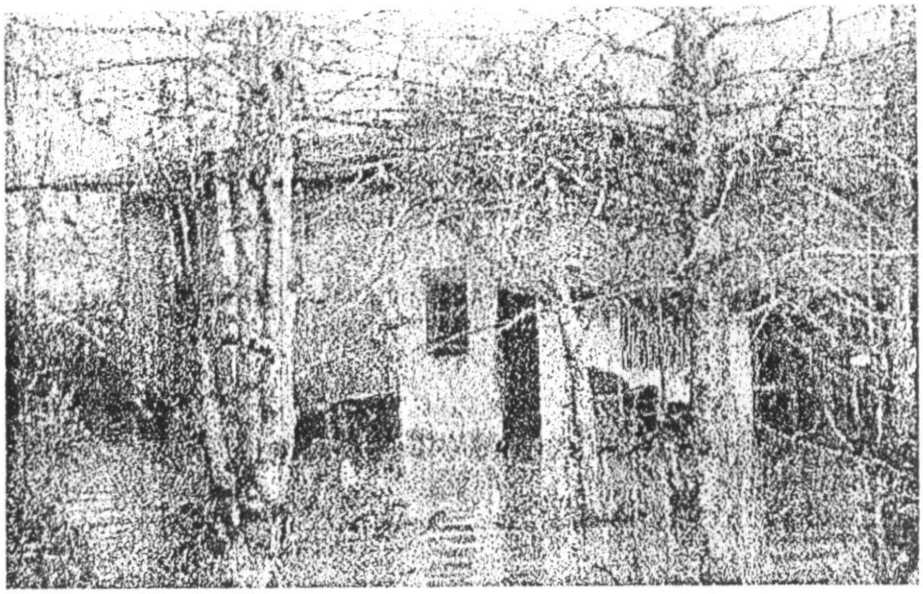
2 Km. from Milaor
Camarines Sur





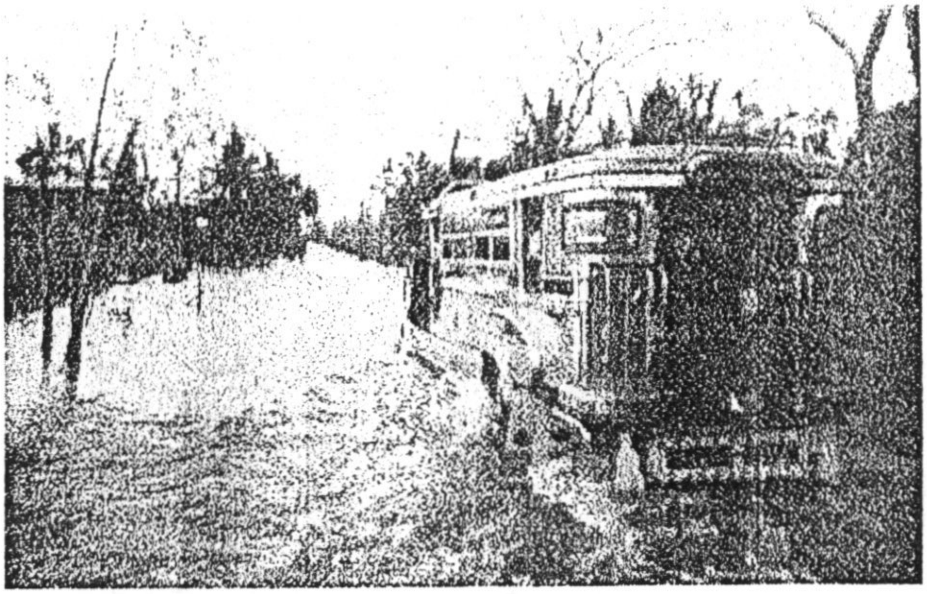
The place is basically a ricefield growing area associated with sparsely located residential houses. It was inundated starting Dec. 5, 1993 and was still under water during the Dec. 13, 1993 ground investigation and field survey.

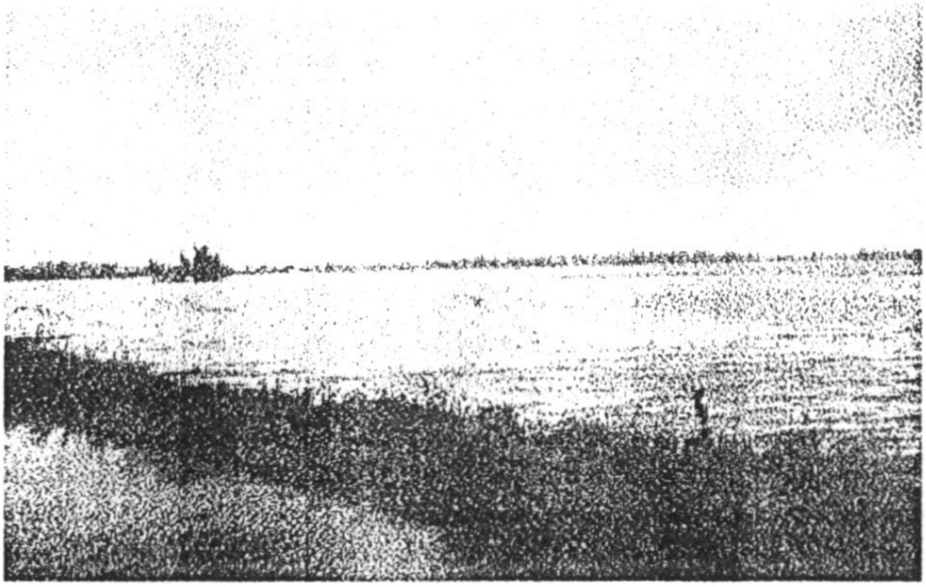
National Highway going to Milaor Camarines Sur



The place is basically a ricefield growing area associated with sparsely located residential houses. It was inundated by flood waters on Dec. 5, 1993 and was still under water during the Dec. 13, 1993 ground investigation and field survey.

Road going to Minalabac
Camarines Sur



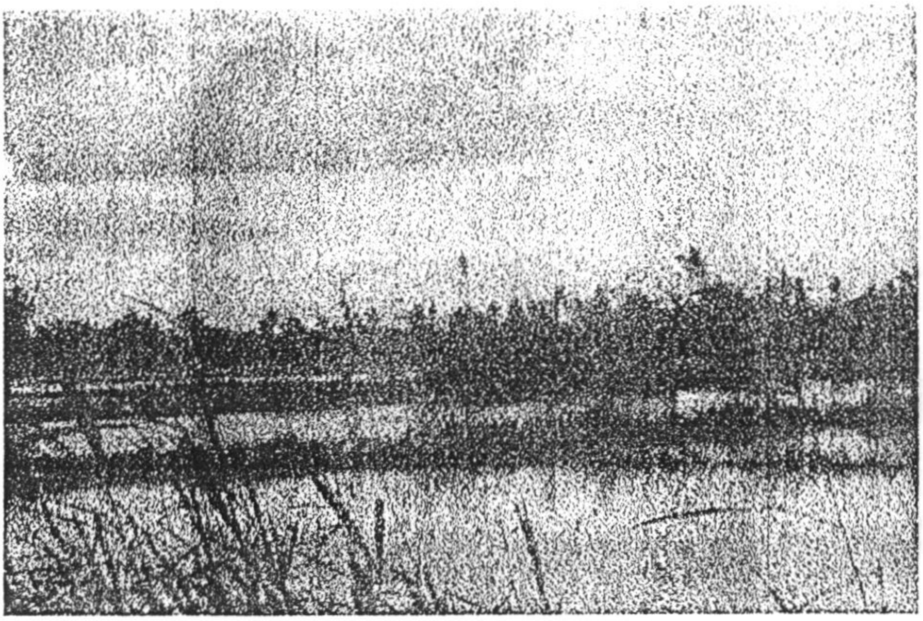


These places are basically ricefield plantation associated with sparsely populated residential area. They are located between Minalabac and Milaor municipalities. Floods inundated the place on Dec. 5, 1993 and the low-lying areas were still under water on the Dec. 13, 1993 fieldwork.

Brgy. Poblacion, Minalabac
Camarines Sur

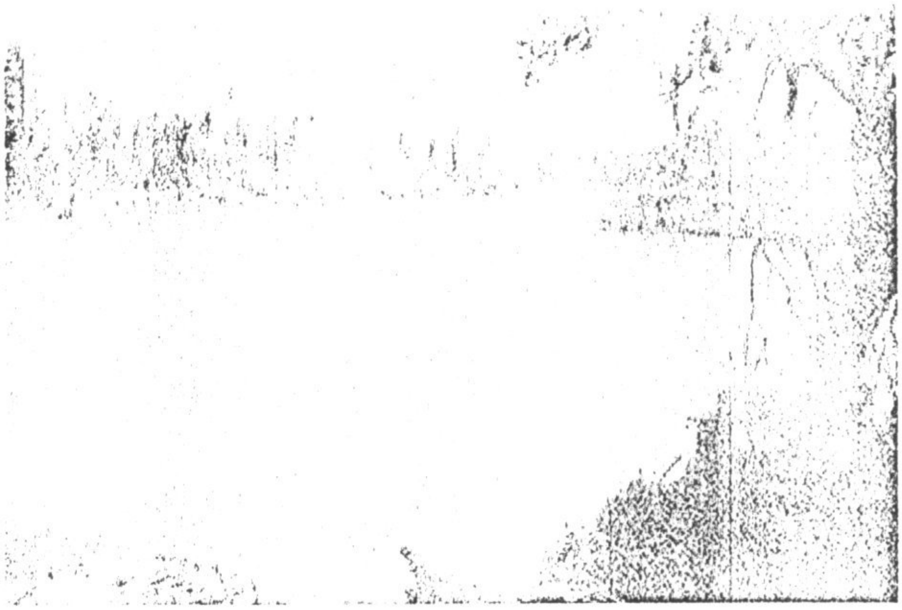
The banks of Bicol river located near the municipal hall of Minalabac. Residential houses comprise the area on one bank of the river, and coconuts and shrubs on the other. Accordingly, the flood waters started to rise slowly at 6:00 p.m. of Dec. 5, 1993 and by 10:00 p.m. the peak of the waterlevel reached a meter deep from the concrete floor of the river embankment. For 2 days, the flood water stayed on until the flood waters started to recede on Dec. 8, 1993. On Dec. 13, field work, the other bank of the river was still under water.

2nd District of Gainza
Camarines Sur



The place is basically a ricefield area.

Pawili River, Boundary of Brgy. Causip and Bagumbayan, Bula, Camarines Sur

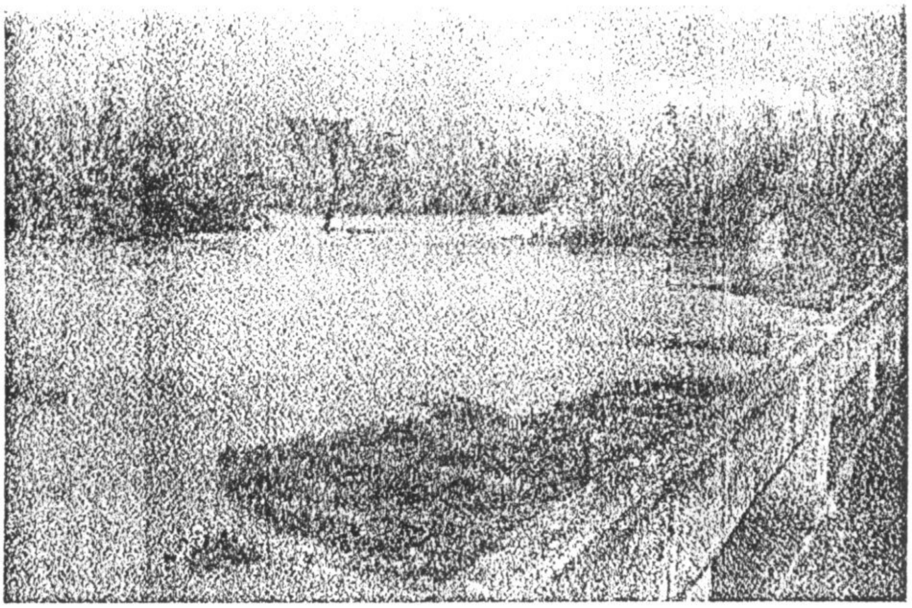


Pawili river started to overflow at 6:00 p.m.of Dec. 5, 1993 and continued to rise until 3:00 p.m. the following day. Water level reached to about 0.8 meter above the natural ground line as indicated. The water then receded slowly for days until the river was back to normal flows on Dec. 12. During the Dec. 14 ground investigation and field survey the ground was still wet while in some regions, ponding of water was still evident.

Buhi Municipality

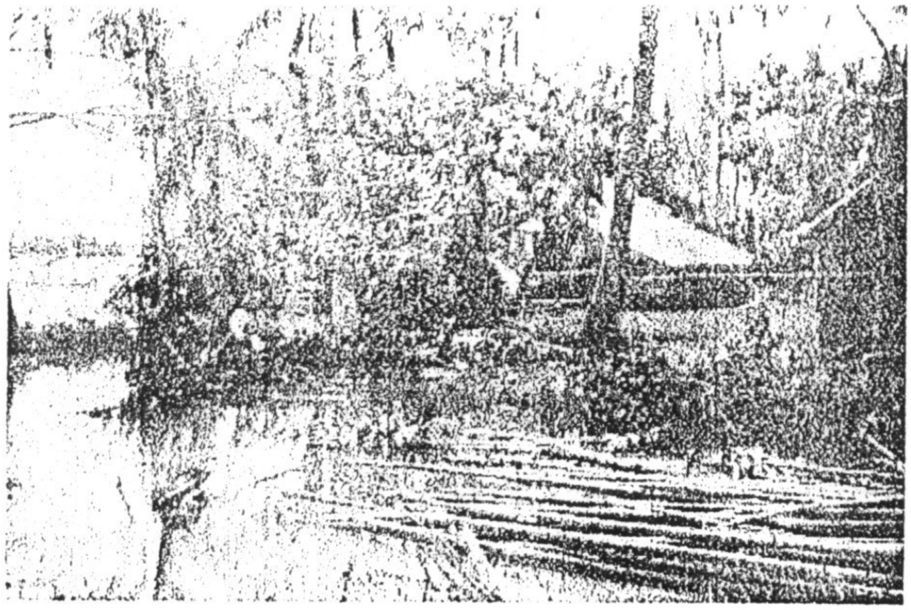
These are basically agricultural areas with rice as the main crop, while houses are seen here & there. The rice crops were newly harvested when the flood struck on Dec. 5, 1993. It was still underflood waters during the Dec. 14 field work. The hills in the background is part of the divide of the Bicol River Basin.

Don Mariano Marcos Bridge, Boundary of Bula and Nabua, Camarines Sur



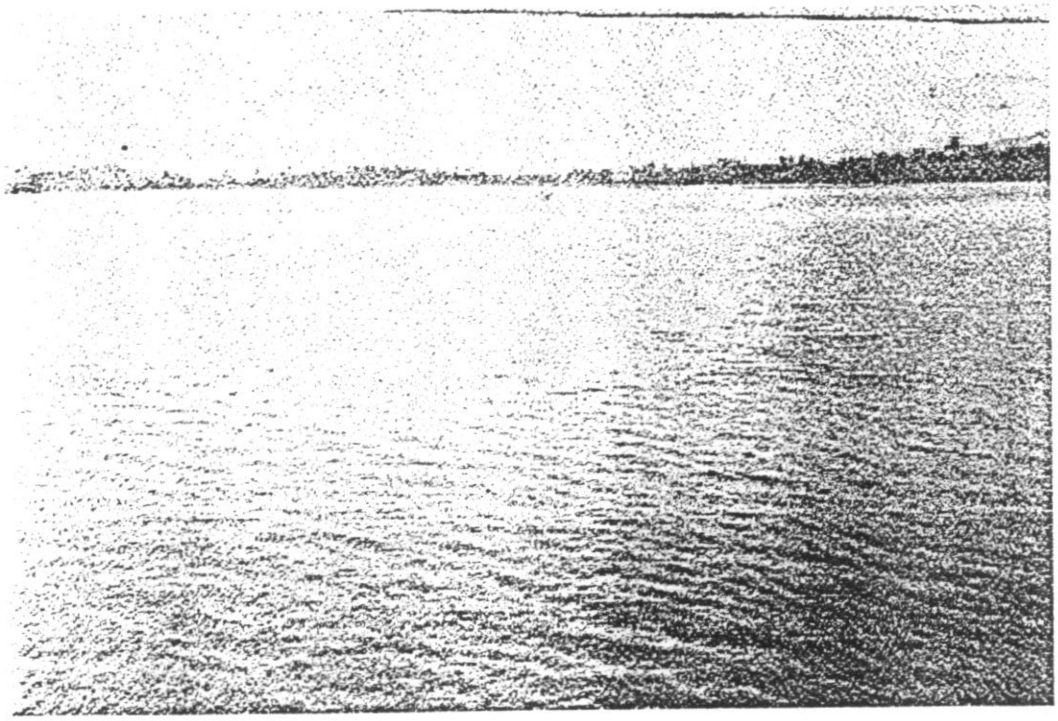
At the bridge over Bicol River, shrubs and brush lined the opposite banks of the river.Adjacent land areas are utilized for rice farming.

Brgy. Madawon, Nabua
Camarines Sur



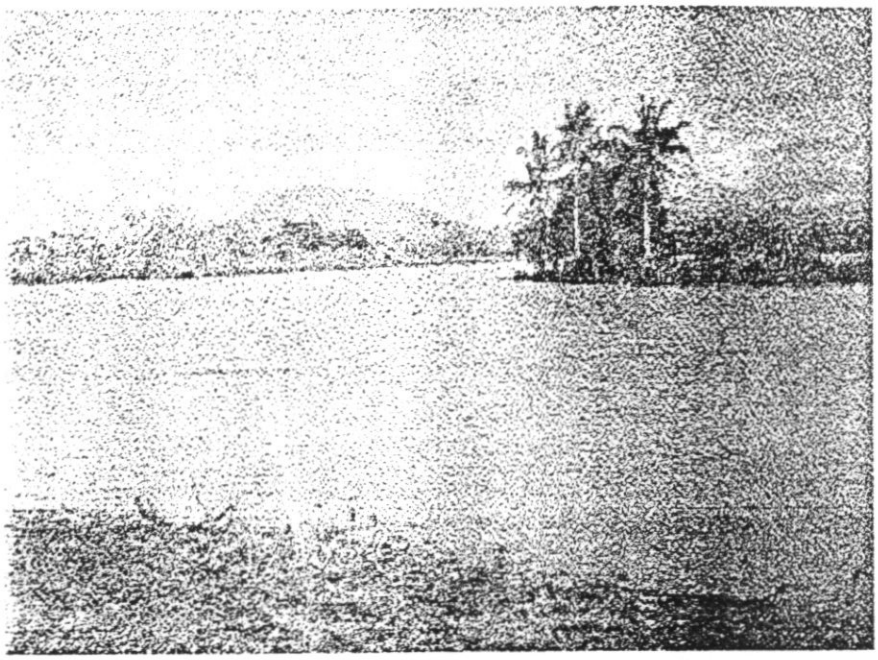
This is an agriculture land utilized for rice, banana and coconut farming. Adjacent areas are still flooded on Dec. 14, 1993 field work. Accordingly, the flood waters started to inundate the area on Dec. 5 due to heavy rainfall spawned by typhoon "Monang" and peaked on Dec. 7 before it receded the following day. Flood waters inundated the area again on Dec. 9 due to heavy rainfall spawned by typhoon "Naning". The area is approximately 4.5 kms. north of Lake Bato.

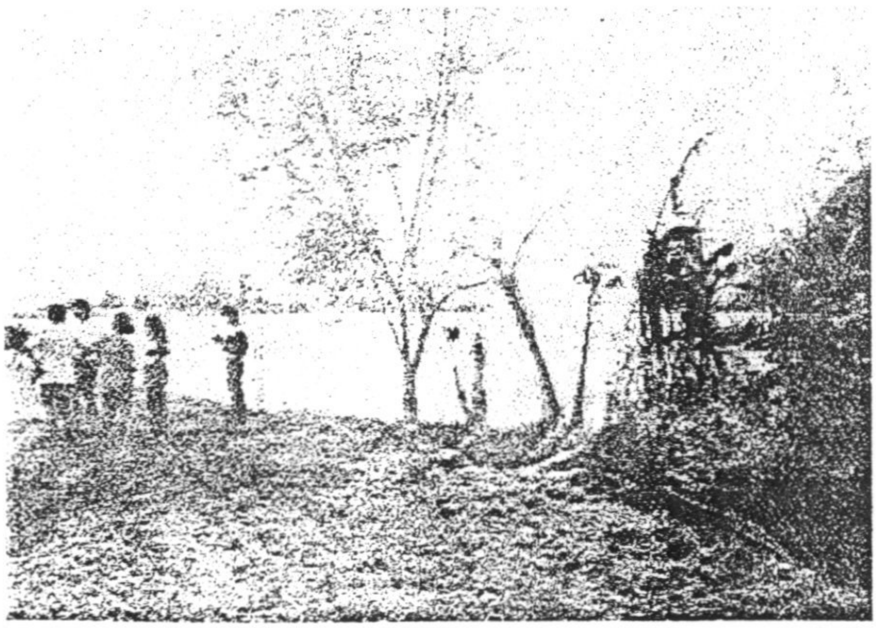
Boundary of Santiago and Santa Cruz, Nabua, Camarines Sur



The place is approximately 100 meters southwest of Nabua municipality and is basically ricefield. During the Dec. 14, 1993 ground investigation and survey it was still flooded, which submerged the area for about a meter. During the period, the rice were already harvested and the land was already prepared for the next cropping.

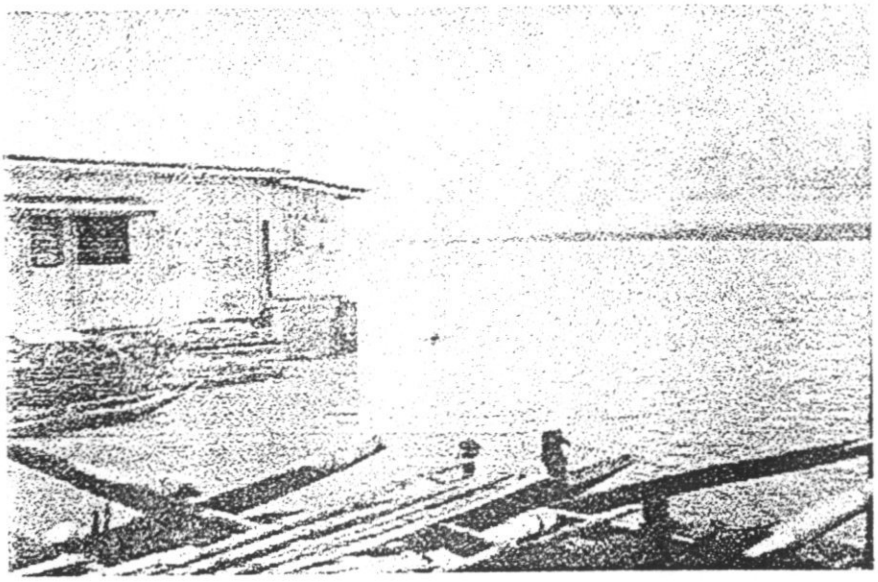
San Vicente Buri, Bato
Camarines Sur





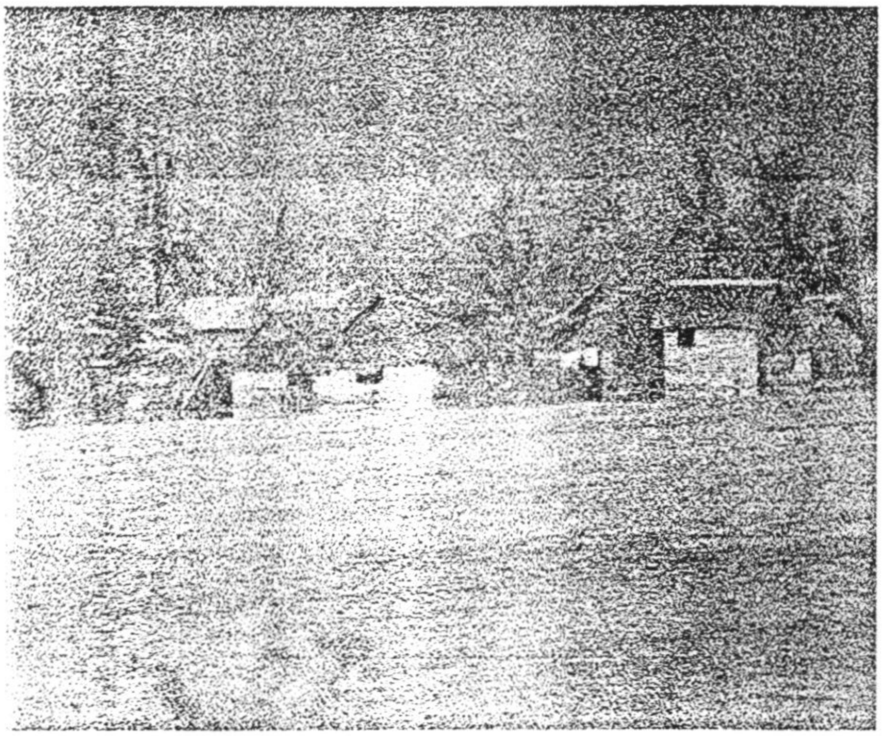
The area is another ricefield. It is associated with shrubs/brush cover in some regions, quite close to Lake Bato. It was still under flood waters during the Dec. 14, 1993 field work, thus increasing the areal extent of the lake. Flood water was murky brown, as seen in the pictures while the adjacent land areas are still saturated.

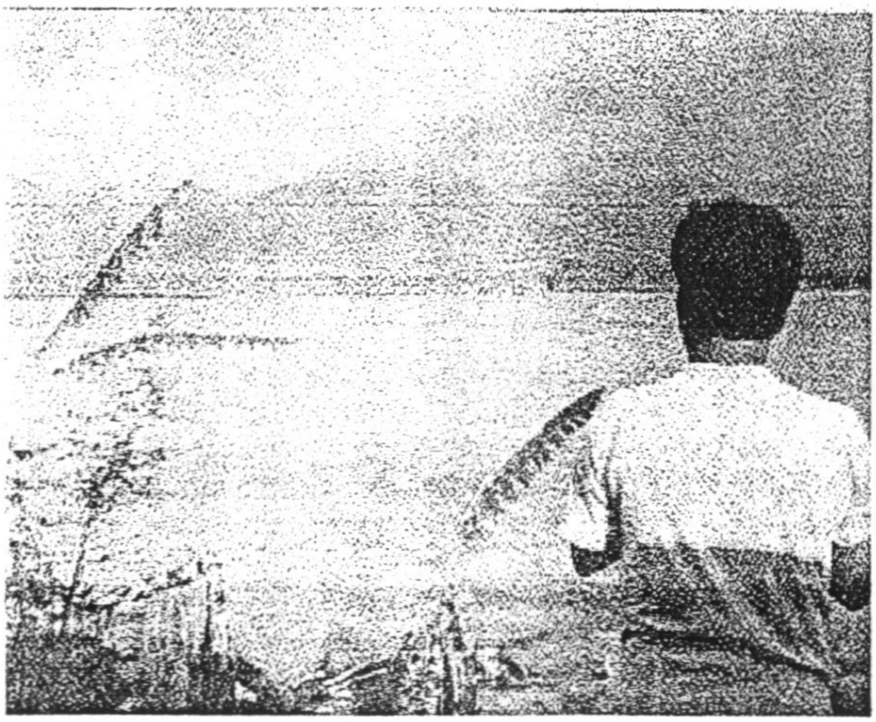
Telemetering Station, Lake Bato
Bato, Camarines Sur



The highway is elevated 2-3 meters above the natural ground level of lakeline. During the Dec. 5, 1993 flood, waters reached a few centimeters below the roadway level. On the Dec. 14 field work, the lake area still extended up to the road embankment. During normal season, however, the lake area is about half a kilometer away from the station.

Between Nabua and Baao
Camarines Sur





Both sides of the highway were under flood waters on Dec. 14, 1993 field work. This place is utilized for rice farming during normal season, and as huge *swimming pool* during flood season.

Natural
Environment
Research
Council