The Study on Comprehensive Disaster Prevention around Mayon Volcano

SUPPORTING REPORT (1)

(Part I: Master Plan)

VII : Forecasting and Warning System

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1. ERUPTION OF MAYON VOLCANO AND OTHER HAZARD

Mayon Volcano belongs to the Bicol Volcanic Chain which extend from north-west to southeast at about 150km west of the Philippines Deep. The Bicol Volcanic Chain comprises sixteen volcanoes, of which three are active. The active volcanoes are Iriga, Burusan and Mayon. The activities of these volcanoes are closely related to the creeping of the Philippines Plate from the east.

Mayon volcano is a stratovolcano with a height of 2462m and has kept a world noted conic shape. Accordingly the steepness of the slope change gradually in general. Elevation 200m is the only point where the slope show slightly large change. The mean steepness of the slope is 1:2.8 for the slope above elevation 200m. Meanwhile the slope lower than 200m becomes as gentle as 1:20. The volcano occupies around 250km, the volume thereof is estimated to be $100km^3$ (Newhall, 1977).

The volcano erupted 45 times during the period from 1616 to 1993 according to the record. The record enunciates that the eruption in the latest two centuries is 43 times. The emitted materials by the eruption are andesitic lava, pyroclastic flow, ash fall, and others. The physical and chemical features of magma are considered to be one of the significant factors which control the type of eruption together with the acquired energy of magma. According to the report prepared by Ramos and others in 1885, the most frequent type of eruption is Vulcanian ,which occurred 20 times out of the adopted sample of 26 eruption or 76.9%. The Strombolian and the Plimnian eruptions are 5 and 1 times respectively. The physical and chemical features might have affected the type of emission. The same report present the frequencies of eruptive hazard, ash fall, pyroclastic flow, and lava flow as follows:

Type of Emission	First Eruption	During Eruption
Ash Fall	16 (84.2%)	21 (100.0%)
Pyroclastic Flow	6 (31.6%)	19 (90.5%)
Lava Flow	2 (10.5%)	13 (61.9%)

The results of the study indicates that most of the eruption initiate with the emission of ash fall. Further, the results enunciates that an eruption not necessarily acompanies dangerous pyroclastic flow and lava flow from the first. However both flows mostly arise before the eruption subside.

Ramos and others in 1985, Magalit & Ruelo in 1985 and Arboleda in 1998 published their study on the ejecta of eruption. Following table presents the ejected volume by major eruptions occurred in 20th century integrating the estimations made by the studies.

Year of eruption	Estimated volume of ejecta
1928	150 million cubic meter
1938	35
1947	25
1968	35
1978	20
1984	70
1993	45

To be noted is the maximum ejecta of 150 million cubic meter in 1928. The eruption in 1900 was medium scale and since then no eruption has been recorded. The stored energy during the period of 28 years might incur the large amount of ejecta in1928. Eruptions with regular interval in 1938, 1947 show decline of ejecta from 150, to 35 to 25 million. The blank of 19 years raised the ejecta to 35 million in 1968 but regular interval of 10 years reduce again the ejecta to 20 million in 1978. Magma might have been activated for some reason and in 1984 the eruption of second largest occurred although only 6 years past since 1978. The regular interval of around 10 years, however, decreased the ejecta to 45 million cubic meter in 1993. The substantial types of volcanic ejecta are ash fall, pyroclatic flow, nuee ardente, lava flow and bomb for Mayon volcano.

1.1 Pyroclastic flow

Pyroclasatic flow is frequent for the eruption of Mayon volcano. Pyroclastic flow accompanies an eruption with a probability of 90.5% as previously mentioned. The frequencies of visit of pyroclastic flow on a slope were studied on the basis of the trace of pyroclastic flow from the crater identified in the report prepared by Newhall. There are 15 eruptions which were accompanied by the pyroclastic flow with identified directions. The distribution of the flow is shown in the following table:

Direction	Frequency and share (%)	
North	2	13
Northeast	3	20
East	7	47
Southeast	9	60
South	6	40
Southwest	7	47
West	2	13
Northeast	2	13

The table enunciate that the southeast slope has received pyroclastic flow most frequently. It implies, however, the west and north slope reserve the possibility to be affected by the flow as well. The Study Team interpreted air photo prepared in 1982 and analyzed the pyroclastic deposition. The results are summarized in the following table.

River Basin	Direction from Crater	Horizontal distance from crater (km)	Lowest elevation (m)	Width of flow (km)	Slope of deposited surface (deg.)
Quirangay	S	5.5	480	0.2	7
Anuling, Budiao	S	5.8	300	4.2	10
Basud	E	8.8	90	1.6	12
Pawa-Burabod	SE	6.0	200	1.3	7
San Vicente	N	8.5	120	1.5	12
Padang	E	7.5	120	1.5	11
Pawa-Burabod	SE	5.0	360	1.3	6
Maninila	S	5.2	420	1.5	8
Nasissi	W	6.0	360	1.0	7

The table shows the travelling distances of historical pyroclastic flow estrimated on the basis of identified deposits. The elevation and slope angle of the site where a pyroclastic flow terminated its travel are also presented. The estimated travelling distances of pyroclastic flow are mostly less than 6.0km in terms of horizontal distance from the crater. However on the north and east slopes there are several traces of pyroclastic flow at 7 to 8.8km apart from the center of the volcano along specific channels. Similar study was carried out by Punongbayan and Ruelo, on the pyroclastic fans formed by the eruption in 1984. This eruption is the largest one in the past 50 years and the data thereof is the most accurate. The features of the pyroclastic fans are as follows.

Incising Channel for Travelling	Direction from Crater	Distance from crater (km)	Lowest elevation (m)	Width of Deposit (km)	Surface slope of Deposit (degree)
Quirangay	S	5.5	480	0.2	7
Anuling, Budiao	S	3.9	580	1.2	10
Basud	E	4.6	400	0.7	8
Pawa-Burabod	SE	6.0	200	1.3	6

The maximum distance from the crater is 6km on the southeast slope of the mountain.

1.2 Lava flow

The variability of the lava flow directions is one of the remarkable character of the eruption . The affected slopes differ from event to event. The frequencies of a slope visited by lava flow were studied similar to that of pyroclastic flow discussed as above. There are 48 traces of lava flow on the slopes surrounding the volcano. As the result, no distinctive specific lava flow prone direction could be identified. Lava flow has arbitrarily visited any slope since 1616. The obtained frequency and the reached horizontal distances (maximum and minimum) from the crater are presented below;

Direction	Visited times	Share (%)	Max. dist (km)	Min. dist (km)
North	4	8		
Northeast	2	4	4.3	3.0
East	11	13		
Southeast	5	10	5.9	4.2
South	8	17		
Southwest	9	19	5.5	3.5
West	7	15		
Northwest	2	4	4.5	3.7

The east slope have received lava flow most frequently. A lava flow on the south-east slope travels longest distance because of the prominent Bonga gully.

1.3 Ash fall

Ash fall tends to scatters all over the mountain slopes. However, there is a case that ash fall has a direction when it is drifted by a strong wind prevailing at the event. Especially during the northeast monsoon, the depth of fallen ash in southwest slope is deeper than other slopes. The volume of ash fall ejected is not estimated but deemed to share 10 to 100% of total ejecta. There is a case that eruption subside after the volcano eject ash fall and no ejection of other material.

In case the scale of eruption is medium or more, the share of ash fall might be as small as 10 to 30% because the material is andesitic with rather high viscosity. The historical record indicates that the depth of the ashes are from a few to thirty centimeter. And it has been seldom that ash fall itself caused significant disaster unless it is washed by a heavy rainfall and concentrate into a river channel to cause a mud flow.

1.4 Mud and debris flow

The slope of Mayon Volcano is steep. Especially the slope between summit and the site with an elevation of 200m is as steep as 1:2.8. The slope of the rest , from 200 to 0m elevation, becomes comparatively gentle , 1:20. Various gullies developed on the mountain slopes have their terminals at the sites with elevations from 400 to 200 meter. Mud and gravel with boulder carried by high flows triggered by heavy rainfall once deposit at these points and form fans. Pyroclastic flows travel mostly along gullies and terminate at fans to deposit debris thereon. Further gullies comprises older deposit loosely consolidated and liable to collapse by weathering and heavy rainfall. Thus, all the slopes are a rich source of mud and debris flow. Some rivers have their origins in the gully like the Basud river and the Pawa – Burabod river. And some are originated in these fans like the Anoling river and the Nassissi river after recurrent river piracy. The rivers of both types are subject to mud and debris flow. Following table present the deposit of mud and debris flow along river channels estimated through the interpretation of aerial photo shot in 1982.

River system	Deposited area (ha)	Deposited volume ($1000m^3$)
Yawa river	294	5,663
Quinari (A)	972	7,356
Quinari (B)	319	1,375
Arimbay	25	125
Padang	56	788
Basud	88	1,575
Bulawan	169	3,375

Mud and debris flow from gullies drags these deposits into the flow and attack the developed areas extending in the areas with lower altitude of 200m.

The precise mud and debris flow (lahar) record is not available because lahar usually occurs together with volcanic eruption or flooding and it might be hard to segregate the damages caused by lahar from ones caused by eruption or typhoon. However some remarkable lahar are recorded. For instance, the fatal casualties brought by the eruption that occurred in February 1993 was 77 in the areas in the southeast slope including the casualty of 7 persons attributable to the succeeding mud and debris flow. The typhoon “Akang” in January 1994 incurred a fatal casualty of 45 by the accompanied mud and debris flow in the same area. In December 1995, mud and debris flow caused by Typhoon “Rosing” killed 7 persons in the same area.

The recorded physical features of mud and debris flow are scarce. However, the height of the wave front is estimated to be 1 to 2m and the travelling velocity to be 20 to 40km/hr on the basis of the slope of the mountain and the deposit.

1.5 Other hazard

The Study Area receives much rainfall through out of the year. Typhoon , N-E monsoon, and tropical monsoon are main causes of rainfall of high intensity . They visit the Study Area in series, so the soil moisture is kept at a high level during any season. It is, however, not seldom that two of them occur simultaneously and the Study Area receives extraordinary heavy rainfall of more than 400mm a day.

Flooding damage is rather insignificant since the river channels have capacities to discharge ordinary flood water because most of the river channels have steep slope. However, flooding of the Ogson river is frequent because of the back water effect of the Nassissi river. Flood water therefrom submerges paddy fields extending along the river for 0.3 to 1.2m for 6 to 24 hours. The same can be seen in the San Vicente river due to the back water from the Quinali(B) river. Heavy rainfall submerges low lying area of Legaspi city twice to trice a year. Inundation with depth of 0.3 to 1m stay on for 6 to 24 hours. Tide with the maximum height of 1.8m affect the depth and duration of inundation. Inundation is a substantial causes which hamper the socio-economic activity of the Study Area.

Typhoon hit the Study Area 2 to 3 times a year on average. In addition to the heavy rainfall, strong wind of a typhoon is the other impediment of the socio-economic activity of the area. Wind have damaged unprepared building, distribution line of electricity and telephone line.

2. PRESENT SITUATION OF THE MONITORING AND FORECASTING

The Government of the Philippines is aware of the situation and has endeavored to mitigate the disaster. The establishment of the disaster forecasting and warning system is one of the measures to be adopted by the government to reduce the vulnerability of the area through the enhancement of disaster preparedness.

Since the forecasting of each hazard requires specific technology, the government relies on the relevant agency in the forecasting and the estimation of the significance of the disaster. The relevant agency in charge of each hazard in the Study Area is listed below.

Volcanic eruption (pyroclastic and lava flow)	;	PHIVOLCS
Mud and debris flow	;	Regional OCD
Rainfall and river water level	;	PAGASA
Typhoon	;	PAGASA

Present situations of monitoring and forecasting on each hazard are briefed as follows.

2.1 Volcanic eruption

PHIVOLCS has managed Lignon Hill observatory to monitor and forecast the activities of Mayon volcano and to disseminate warning to Provincial Disaster Coordinating Council (PDCC) which is mandated to take actions against the impending hazard to protect people in case the hazard is predicted to bring about disaster. The monitoring focuses on the movement of magma through seismic metering system measuring at four sites as follows:

Mayon rest house	;	Northwest
Upper St.Misericordia	;	East
Barangay Anoling	;	South
Lingnon Hill	;	South

Real time seismic data are available at the observatory because the telemetering system by 400MHz radio is introduced. The supervisory control unit with recorder drafts seismic wave on the basis of the gathered data. Volcanic specialists in the observatory monitor the drafted graph for 24 hours. Figure VII 2.1 shows the example of seismograph recorded by the system. To distinguish the wave generated by the activity of magma from others seems not to be easy but a well experienced volcanologist focus their watch on the frequency, degeneration of amplitude and duration to detect the movement of magma. In case any indication is detected, the observatory report the situation through the exclusive radio of 9MHz to the head office in Manila. At the same time the drafted graph is sent through facsimile for more detailed examination. In parallel with the analysis, the observatory carries out ocular surveys of the crater and its vicinity through telescope. Concentration analysis of gas is the other survey to confirm the activity as well since the concentration of sulphur dioxide (SO2) shows remarkable changes if the eruption is imminent. Sampling of gas are made by airplane or mobile. The concentration of sulphur dioxide is analyzed by a gaschromatography. The results of the survey are sent to the head office in Manila and the possibility of eruption is judged and conveyed to PDCC. E-mail has been availed to communicate each other on this matter. Further, the observatory monitor the deformation of mountain by measuring using the installed electronic distance meter (EDM) to predict the timing and the scale of the eruption. The timing and the scale of the eruption are projected referring the swell of the mountain in the head office in Manila. E-mail is effective as well for the communication.

The seismic metering system functions well including data transmission and recording. The maintenance is rather satisfactory. The locations of the existing measuring site are shown in Figure VII 2.2 together with those planned by PHIVOLCS. The specifications of the existing seismic measurement system are compiled and shown in Table VII 2.1.

2.2 Mud and debris flow

Regional Office of Civil Defense manages the existing mud and debris flow monitoring system installed by JICA in 1997. The system detects the occurrence of debris flow by means of the installed wire sensor. A debris flow cuts the wires when it pass through the section in which a wire is installed. The relay box connected to the wire generate signal which indicate the break. The radio transmitter is to transmit the signal to the receiver of the supervisory control unit through 400 MHz radio in the main office of the regional OCD in Legaspi city. The indicator of the unit is to turn on to show the occurrence of the event.

So far 4 wire sensor systems were installed in four rivers as follows.

Monitored river	Number of section wired
Basud	3
Padang	3
Pawa-Burabod	3
Budiao	4

As of now ,all the wires were broken down by the mud and debris flows arose after the system installation.

The locations of the sensor installed sites are depicted in Figure VII 2.3 and the specifications are summarized in Table VII 2.2.

2.3 Rainfall and water level

PAGASA has carried out the rainfall observation for the purpose of flood forecasting and warning for the Bicol river. The upper most reach of the Bicol river fall on the western part of the Study Area. Ligao rainfall gauging station of the flood forecasting and warning system thereof is located adjacent to the Study Area. The real time rainfall data obtained thereby might be available for the forecasting and warning of the Study Area. The system adopts tele-metering system of poling method and the interval of data gathering is set at one hour for normal condition. The interval can be shortened up to 15 minutes by means of manual operation of the control panel in Naga city. In this addition PAGASA has established several observatories in the Study Area. The locations thereof are as follows.

Legaspi	South of the Study Area
Sant Domingo	East
Tabacco	North
Buang	West

Each observatory is facilitated with a set of weather measuring equipment. The main equipment are as follows.

Rainfall	automatic recording
Air temperature	min. and max.(daily)
Air pressurehourly	hourly
Wind	velocity and direction
Relative humidity	min. and max. (daily)

A weather observer stations in each observatory to study data measured therein. The observer disseminates weather forecasting to municipal DCC through telephone referring data and information in wider area like national weather provided by the central office in Manila through the SSB radio installed for the exclusive use of PAGASA.

The observer develops 3 hours rainfall intensity based on the recorded data and send it to central office together with other data for weather forecast through the SSB radio .

The JICA has established five (5) rainfall gauging systems to monitor the rainfall depth in strategic watershed area in 1997 together with wire sensor system which were discussed before. The river basin to be monitored by the system are as follows:

- Maninila river 2km upstream from barangay Maninila
- Pawa-Burabod river 4km upstream from barangay Mabinit
- Padang river 3.5km upstream from barangayBuyuan
- Basud river 5km upstream from barangay San Antonio
- Buang river at Mayon Rest House

The sensor is of tipping bucket type and measuring is of the event report telemeter. Except Maninila system all the measuring equipment are usable . However the defect of 400MHz radio communication impede the system to send valuable data to ROCD. The rainfall sensor in Maninila system was removed by unidentified person. The solar panel of Mayon rest house was broken by the strong wind of typhoon Loleng hit on 22 October 1998. Supplement of dilution water is necessary for most of batteries. During the field survey the sound reaction of the sensor were confirmed.

There are several water level gauging stations established in the Study Area by various agencies. Such stations are:

Benanuan	Ogson river
Nassisi	Nassisi river
Banao	San Francisco river
Legaspi	Yawa river

Almost all are of staff gauges and measurement, recording and data transmission were carried out by manual. The recordings were commenced in late 1950s . However the activities have ceased in early 1980s. Rehabilitation of these stations for flood forecasting purpose might not be effective.

The locations of the gauging stations are indicated in Figure VII 2.4. The features or specifications of the hydrologic measuring system are summarized in Table VII 2.3.

2.4 Typhoon

PAGASA central office in Manila receives and examine the international meteorological information to forecast the course and magnitude of typhoon as follows:

GTS	for weather charts
GMS	for meteorological map
RSM by JMA	for atmospheric pressure chart
TYM by JMA	for typhoon track forecasting chart

PAGASA disseminate the result of the forecasted course to its branch offices and observatories through the SSB radio to inform relevant authorities, agencies and DCCs.

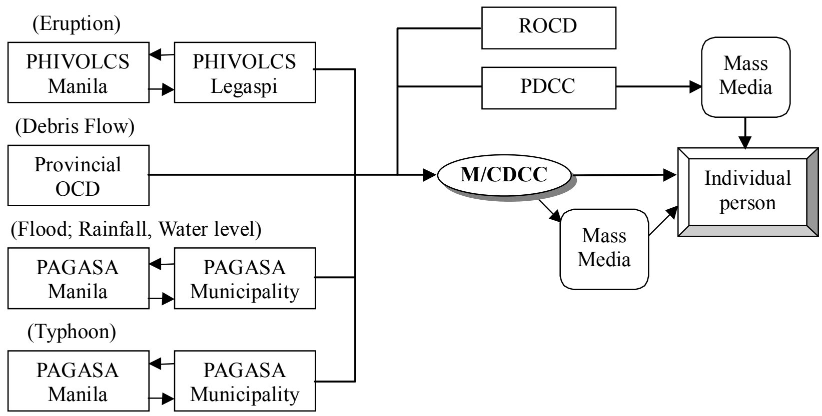
The contribution of local information is limited with regard to the forecasting of typhoon itself. The weather report sent from observatories to the central office, therefore, is the unique participation of the Study Area with regard to the forecasting of typhoon. The weather report is, however, indispensable and is reflected to forecast the local weather to be affected by the typhoon.

3. PRESENT SITUATION OF WARNING SYSTEM

In the Study Area, there is no system which disseminate warning automatically like a flood forecasting and warning system. All the warnings are to be once transmitted to receiver (Regional Office of Civil Defence and Provincial Disaster Coordinating Council) from the relevant agency through manual operation of communication system such as VHF and public telephone . Through PDCC or the local governments receive the warning and prepare to the impending hazard. Provincial disaster managing office(PDMO), the secretariat of PDCC possesses necessary communication facilities; a 24-hour Albay Provincial Radio Communication system, 17 UHF Porta Unit, 2 base units, 2 repeater sets and VHF hand held radio equipment. PDCC through PDMO relay the warning to CDCC and MDCC. CDCC/MDCC relay the warning to barangay DCC through public telephone or house-to-house visit. However for a remote barangay, MDCC expect the warning is received by the BDCC in proper manner through radio broadcast. In barangay, staffs of the BDCC in charge convey the warning and order to evacuate through house to house visit base.

PDCC, on the other hand, makes the warning public through mass media such as TV and radio. People can receive more general information on the hazard by the broadcasting of the mass media.

The following charts illustrate the dissemination flow of warning and order to evacuate.



4. REGULATORY BACKGROUND AND ORGANIZATION

The Calamities and Disaster Preparedness Plan dated 24 August 1988, the Appendix B of the Presidential Decree 1566, provides the details for the creation of the operating unit for evacuation services. It defines the responsibilities and tasks of the local governments: regional, provincial, city/municipal and barangay with regard to the communication and evacuation in case an emergency arises. It also identifies the key organizations which will be involved in the evacuation activities as follows.

Agency	Main functions
PAGASA	monitoring and issues warning on typhoon and flood
PHIVOLCS	monitoring and issue warning earthquake and volcanic activity
OCD	prepares programs for disaster preparedness
PNP	provides security in the evacuation centers
AFP	provides transportation facilities and security
DPWH	provides transportation and communication facilities repairs damaged road and evacuation center

Although no regulatory mandate specified the responsibility on mud and debris flow, ROCD has managed mud and debris flow monitoring system in the Study Area.

DPWH repairs also the damaged river structures because Executive Order No. 124 of 1987 provides the responsibilities of DPWH as follows:

Plan construct, maintenance of infra structure facilities, especially national highways, flood control and water resources development systems

The numbers of staff of each agency in charge of forecasting is identified as follows;

Agency	Total	Forecasting	Maintenance
ROCD	5	1	0
PHIVOLCS Lignon	9	1	1
PAGASA Legazpi	12	1	1
DPWH region V (Legazpi)	205	0	0
DPWH Region V	1,195	0	0

One who has good experiences in the monitoring system resigned in July 1998 and a staff of the agency was assigned to monitor mud and debris flow in spite of a lot of other important jobs and roles.

DPWH did not share the staff for forecasting works because no regulation assign any forecasting works to the agency although Region V (Legaspi) holds ample engineer of 75 person out of 205 staff. It holds electrician and mechanics as well. Collaboration with them might be very useful for operation and maintenance work of the system.

5. PROBLEM OF THE EXISTING FORECASTING AND WARNING SYSTEM

5.1 System for volcanic eruption

Sensor

- The maximum period of one second might be too short considering the possible fall off of wave with high frequency during the propagation in soft material such as loose soil.
- One element (vertical) might not be sufficient because there are waves, horizontal element thereof is most prominent.
- No sensor is installed on the west of mountain and locating accuracy of active magma through the curve of travelling time is affected.
- The highest location of the sensor is Mayon Rest house of only 800m in elevation. This affect the estimation of the ascending movement of magma to some extent.

Recording of measured data for seismic analysis

- Analog data are pen-plotted to monitor and detect abnormal movement of the mountain, which impede a quantitative analysis.

Data transmission to the central office for seismic analysis

- Analog figure is sent to the central office in Manila by means of facsimile for analysis, which is liable to supply inaccurate data due to the deformation of the wave during data transmission.

Air sampling for sulfer dioxide analysis

- Air sampling site is selected arbitrarily in accordance with flight which induce a certain error in the analysis.
- Wind velocity and direction are measured at remote station from the sampling site. And certain error in adjustment is inevitable.

5.2 System for mud and debris flow

Sensor

- The monitored rivers by wire sensor are only the Pawa-Burabod river, Maninila river, Basud river and the Padan river, which were all broken down by the mud and debris flow. There are many other rivers vulnerable to mud and debris flow.
- The maintenance of the sensor is costly because the sensor detect the debris flow when the wire is broken down and should be re-installed after a heavy rainfall.
- Wire sensor is stable and sure to detect a debris flow but cannot afford sufficient lead time for evacuation forecasting and warning purpose. Because the hazard may arrive a barangay within 5 to 6 minutes after the sensor detected the occurrence. The method to afford longer lead time is necessary.

Data transmission and supervisory control unit for telemeter

- The warning signals have been kept turned on for more several months . There are high possibility of malfunctions of data transmission or the supervisory control unit with this regards. Rehabilitation of the supervisory control unit is necessary because the unit is damaged by leakage of rainfall. Technicians for system maintenance is insufficient.

5.3 System for rainfall and river water level

Sensor and monitoring

- The spatial distribution of rainfall is to be studied . However it is apparent that ten gauging stations, telemetered are 6 including Ligao can not provide an accurate rainfall measurement.
- The existing rainfall gauging stations managed by PAGASA are located in urbanized areas with low elevation. The rainfall on the high altitude in the watershed areas should be measured in order to estimate the rainfall effective to forecast and monitor flood and debris flow.

- It might be dangerous to observe manually the staff gauge during flooding. The sensor should be of automatic recording type which afford 24-hour monitoring. In this respect, the effect of changeable riverbed due to silting should be considered.

Data transmission and tele metering

- Manual data collection has considerable difficulty especially under heavy rainfall. Telemetering system should be introduced .
- Ligao station may furnish useful data for flood forecasting because it is telemetered. The poling interval of one hour impede the availability for mud and debris flow forecasting .

Forecasting

- In order to forecast mud and debris flow on the basis of measured rainfall, a certain modeling for decision making is necessary.
- In order to forecast flood on the basis of the measured rainfall and river water level, a certain modeling for decision making is necessary.
- In order to forecast the inundation on the basis of the measured rainfall and tide level, a certain modeling for decision making is necessary.
- Data on the structural conditions of the river channel are not informed to PAGASA and OCD.

5.4 Warning system

Public telephone is one of the substantial communication media to relay the issued warnings from PDCC to C/MDCC and MDCC to BDCC. Public telephone is the most easy communication measure. However, the traffic thereof is not controllable. VHF radio and SSB radio are supposed to be more useful. And the communication among PDCC, CDCC and MDCC relies on VHF radio or SSB. However, the number of barangays which are equipped VHF radio facilities is 21 out of 112 barangays or 19% according to the result of Survey on Calamities and Casualties by the flood and debris flow. The same survey disclosed that barangays which equipped with cellular phone are only three, Donna Tomasa in Guinobatan, Balza and Awang in Marinao. To relay warning to barangay house-to-house visit is still common practice.

6. CONCEIVABLE CANDIDATES OF THE FORECASTING AND WARNING SYSTEM FOR THE STUDY

The installation of following system and equipment are conceivable as in order to reduce the vulnerability of the Study Area through forecasting the impending hazard and disseminating warning to the vulnerable people. Thereby the damage to be incurred by the hazard will be mitigated. The presented system and equipment will be assessed for their merit and demerit in the light of the local conditions and world wide experiences to adopt in the Master Plan to be formulated. The conceivable candidates are as follows:

a. For eruption

(For monitoring of the activity of magma)

Seismic sensor of 3 elements good for the period of 10 second with telemeter. Analyzing and data storing processor with A/D converter.

Graphic terminal with DAT or MO control function.

(For monitoring of de-formation of the mountain)

GPS with a simulation model to assess the deformation

(For monitoring of SO_2)

Automatic gas sampler with simple analyzer and telemeter system.

Automatic wind velocity and direction recorder with telemeter system

b. For mud and debris flow

Optical sensor

Seismic sensor

Supersonic water level gauge

Acoustic sensor

Event reporting type rainfall gauge

Telemetering system is fundamental to all

c. For flood and inundation

Telemetered rainfall and water level gauge

Supersonic type water level gauge and velocity meter

d. For warning system

Inter agency disaster information network with client server

Inter agency disaster information network with web server

VHF radio communication system

Radio paging system and equipment for barangay mail and relevant equipment for barangay

7. ASSESSMENT OF THE CANDIDATE SYSTEM

The selected candidate systems constitute the forecasting, warning and evacuation system of the proposed master plan. The criteria adopted to assess the candidate system to select into the master plan are as follows:

Technical reliability	(accuracy in forecasting and reliability in warning) Accuracy and reliability should be sufficient for evacuation and disaster fighting activity
Compliance to needs	(lead time and quick response) Since the system is to furnish a reliable information for evacuation and disaster fighting activity, the system should afford sufficient lead time quick judgement for those activities.
Availability	(existing infra-structure and system) The proposed system should adapt to the existing local conditions, the existing infra-structure and system should be availed as much as possible.
OMR	(OMR cost and manpower) In order to secure sustainability, OMR cost and manpower input should be considered
Durability	(natural circumstance) The proposed system should be available in a critical circumstance.
Economic aspect	(cost and space) Disaster prevention reduce damage value but does not produce any positive economic value and lesser cost and space are preferable.

The proposed candidate systems are assessed along the criteria as presented in Table VII 7.1. The summaries of the assessment are briefed as follows.

7.1 Eruption of volcano

In order to monitor the eruption of the volcano, three candidate systems are contemplated. The functions or purposes of installation thereof slightly differ one another as discussed in Section 6. And all of them should be installed to establish a complete monitoring system. The result of the assessment should be considered as priority ranking for scheduling.

1. Seismic sensor system
2. GPS and analysing system
3. Gas sampling with wind direction and velocity meter

7.2 Mud and debris flow

Except rainfall gauging system, all the sensor detect the occurrence of mud and debris flow and the lead time of forecasting are inevitably short as compared with rainfall gauging system which predict the occurrence of mud and debris flow. There are some possibility that seismic sensor and acoustic sensor may detect the initial movement of the source of mud and debris flow and thereby longer lead times are afforded. The result of the assessment enunciate the priority order as follows:

1. Event report type rainfall gauging with judgement system
2. Wire sensor system
3. Optical sensor system
4. Seismic sensor system and Acoustic sensor system
5. Super sonic water level gauging system

7.3 Flood and inundation

Rainfall and river water level are main monitoring items to forecast flood. Rainfall gauging is discussed in (2) mud and debris flow. And water level gauging is the subject in this article. Since the rivers are subject to sediment flow, the proposed sensor should free from the river bed change as much as possible. The result of the assessment is as follows:

1. Float type water gauge level gauge with forecasting system
2. Supersonic water level gauge with forecasting system
3. Pressure type water level gauge with forecasting system

7.4 For communication among agencies

Client-server system secure a high data security but requires complicated server management. Webb server system is easy and reliable in server management. Most of the agencies have sufficient experiences in VHF radio communication system. The system cannot afford digital quantitative data transmission. The result of the assessment is as follows:

1. WEBB server system
2. VHF radio system and Client server system

7.5 For warning dissemination to BDCC

Radio paging system is prevailing in the country. However the system does not afford quantitative data communication. Webb server system affords quantitative data communication but operation is complicated and running cost is high. The result of the assessment is as follows:

1. Radio paging system
2. WEBB server system

8. FORECASTING AND WARNING SYSTEM PROPOSED FOR THE MASTER PLAN

Mayon volcano may erupt twice during the target period up to year 2020 considering the average period of 10 years. The proposed comprehensive disaster prevention Master Plan should take the eruption into consideration. In this respect, the proposed forecasting and warning system is planned against eruption, mud and debris flow flood and inundation and typhoon. The proposal for each hazard is briefed as follows.

8.1 Forecasting system for eruption

a) Concept of system planning

The volcanic eruption forecasting system of the Master Plan is formulated under the following basic concept:

- To be forecasted are timing and magnitude of volcanic eruption.
- Timing of eruption is forecasted on the basis of the activity of magma and SO_2 emission.
- The system monitors the activity of magma through locating active magma by means of the curve of travelling time of the measured seismic wave
- The system forecast the magnitude of the eruption through estimating the internal pressure on the basis of the deformation of the slope.

b) Criteria for planning

The adopted criteria to formulate the forecasting plan are as follows:

- Seismic wave should be measured at 4 different sites with same altitude with different directions from the crater of the volcano in order to locate the active magma.
- Seismic wave should be measured at the site with high altitude (higher than 1000m) to make timing forecast accurate.
- Wave of 3 elements should be measured at a site.
- Sensor should detect the wave of boiling magma. In this connection, sensor should conform to a wave with a period of 10 second.
- Displacement of the slope should be measured at 2 different altitudes.
- Displacement of the slope should be measured at 4 different directions from the crater of the volcano to afford accurate estimation of internal pressure.
- SO_2 gas should be sampled automatically.
- SO_2 gas concentration should be adjusted on the base of wind velocity and direction

c) Adopted system configuration

Considering the accuracy of forecasting and the acquired knowledge through experiences following system is proposed.

Sensor	seismograph x 7 4 existing (Mayon Resthouse, Upper S.Misericordia, B.Anoling, Lignon Hill) and 3 additional (B.Canaway, Upper,B. Muladbucad Grandei and U. Banadero EDM and GPS; Existing EDM and additional GPS x 8 (4 directions at about El. 400m and 1000m) gas sampler wind velocity meter wind direction meter

(the locations of the proposed seismograph are depicted in Figure VII 8.1)

Telemeter	for seismograph and wind velocity and direction meter with repeater station
Data processing unit	for seismograph, GPS and gas concentration adjustment with graphic terminal, data filing unit and alarm set.
Gas analyzer	existing gas chromatography

Judgement	Analysis of seismic wave; Amplitude and frequency Time of travelling Analysis of SO_2; Concentration of SO_2 in air Assessment of internal pressure; The FEM analysis on slope deformation

(System configuration of the proposed seismograph system is shown in Figure VII 8.2)

8.2 Forecasting system for mud and debris flow

(1) Concept of system planning

Mud and debris flow forecasting system plan of the proposed Master Plan is formulated under the following basic concept:

- The proposed system should forecast timing, location and magnitude of the impending mud and debris flow
- People in the area to be affected by the impending mud and debris flow is to evacuate in accordance with the forecast and warning made by the system
- The proposed system is to afford information to DPWH for its maintenance works forriver structure and road.

(2) Criteria for planning

The adopted criteria to formulate the forecasting plan are as follows:

- Lead time of 3 hours is required for the first warning.
- Accuracy of 90% and reliability of 75% are minimum requirement for forecasting.
- Existing facilities should be availed to the maximum extent

(3) Adopted system configuration

In the light of the criteria mentioned above, the forecasting system which observe rainfall is adopted. The system judges the occurrence of mud and debris flow on the basis of the observed rainfall. The necessary number of rainfall gauging station to conform to the criteria was estimated by the following formula:

$$N \geq (C \cdot Zd / E)^2 \quad \text{.......} \quad (1)$$

Where N : necessary number of gauging station
C : coefficient of variability of rainfall
Zd : variable corresponding to reliability
E : allowable error

As stipulated in the criteria, the reliability is set at 75%. The table of standard normal distribution , accordingly gives 0.6745 for Zd. For E, 0.1 is adopted. In order to obtain appropriate C, spatial variability of rainfall was studied on the basis of data recorded at Legaspi, St.Domingo, Tabaco, Buang, and Ligao gauging station. At the beginning, the homogeneity of rainfall event was examined by means of correlation analysis. The following table is the obtained correlation matrix.

	Legazpi	S.Domingo	Buang	Tabaco	Ligao
Legaspi	1				
S.Domingo	0.802085	1			
Buang	0.374112	0.437857	1		
Tabaco	-0.26886	-0.26041	-0.14923	1	
Ligao	0.637813	0.519503	0.445268	-0.17907	1

Matrix of Correlation Index of Extreme Daily Rainfall (n = 55)

The daily rainfall data recorded in the period from 1981 to 1995 were studied exept for 1982 when the data at Ligao is missing. The daily rainfall of the days when annual maximum are recorded at any station were selected for the analysis. The correlation matrix imply that the observations at Legaspi, S.Domingo and Ligao are same rainfall event.

Along this line, spatial variability of rainfall was studied for the data recorded at Legazpi, S. Domingo and Ligao. The adopted data and obtained coefficient of variability are presented in Figure VII 8.3. Among the obtained 32 data, the maximum of 0.883 was adopted as the coefficient variability of the Study Area. Applying C of 0.883, N of 36 is obtained. The estimated total watershed area of the gauging stations is 805.5km^2.

Consequent area to be measured by a rainfall gauging station is estimated to be 22.4km^2 . This imply that the rainfall within a circle of 2.67km has a difference of less than 10% from the observed rainfall at the gauging station situated at the center of the circle. The necessary total number of the rainfall gauging station of 41 was obtained assuming the total area of the Study Area to be 908km^2. Since existing 5 stations are available, 36 stations should be established to secure the reliable forecasting. Subsequently the proposed system configuration is as follows:

Event reporting rainfall gauge	: 41 stations (5 existing and 36 additional)
Telemeter supervisory control stations	: 3 stations (1 existing and 2 additional)
Data processing unit	: 1 processor with alarm function, graphic terminal, data recorder and printer
Seismograph	: An experimental sensor with recorder
Acoustic sensor	: An experimental sensor with recorder
Repeater station	: 2 repeater stations on the East and west Slope of the mountain. Existing Ligao repeater station is available.

8.3 Forecasting system for flood and inundation

(1) Concept of system planning

Basic concept contemplated to formulate the forecasting system for flood and inundation is as follows:

- The proposed system should forecast the occurrence of flood and inundation.
- People to be affected evacuate in accordance with the warning on the base of the forecast to be made by the system.
- DPWH organizes the flood fighting team and acts coping against the flood.
- The proposed system forecasts timing and magnitude of impending flood by means of runoff analysis on the basis of the measured rainfall at the stations proposed in (2) and river water level at the strategic points of river and sea water level at Legaspi port.

(2) Criteria for planning

The adopted criteria to formulate the forecasting plan are as follows:

- Lead time of 3 hours is required for the first warning.
- Accuracy of 90% and reliability of 75% are minimum requirement for forecasting.
- Existing facilities should be availed to the maximum extent

(3) Adopted system configuration

The system configuration for forecasting of flood is as follows:

Rainfall gauge	41 gauging stations (common to forecasting system for mud and debris flow)

Water level gauge	7 (Yawa, Quinali B, San Vicente, Nassissi, Oguson, Quinali A and Legaspi port)
Data processing unit	1 personal computer (for runoff analysis) with alarm function, graphic terminal, data recording unit and printer
Repeater station	2 stations; one on the east and one on the west slope of the mountain. Existing Ligao repeater station is available.

Proposed hydrologic monitoring sites are presented in Figure VII 8.4.

8.4 Forecasting system for typhoon

(1) Concept of system planning

The Study Area have been affected by typhoon every year because the area is located along typhoon track. International weather information is imperative rather than local weather condition to forecast a typhoon. PAGASA represent the Philippines and has been furnished the necessary information to forecast typhoon. No modification of the existing system is proposed in this Master Plan.

8.5 Warning system

(1) Concept of system planning

- Existing warning system have functioned well except for the communications between MDCC and BDCC or between CDCC and BDCC. The improvement of the communication is necessary.
- Some information such as rainfall are to be availed to the forecasting of mud and debris flow and the forecasting of flood. These information shall be common to agencies who are responsible to forecast hazards.
- Warning should be disseminated to the people who are in the field

(2) Criteria for planning

- Warning should be transmitted surely to barangay without delay.
- Warning should be transmitted surely to the people working in the field without delay.
- The proposed system should afford the common use of necessary information among the relevant agencies

(3) Adopted system

- Radio paging system between MDCC and BDCC
- Inter agency network WEBB server in addition to existing VHF
- Siren station 17 remote controlled siren stations
  (proposed siren station sites are shown in Figure VII 8.5

8.6 Inter Agency disaster information network

Network should link relevant agencies by means of WEBB server of internet to afford easy and sure communication.

WEBB server should be installed in PDCC, DPWH, PHIVOLCS, PAGASA (Legaspi), CDCC and ROCD.

Table VII 2.1   Specifications of Eruption Monitoring System

No	System	Equipment	Specifications	
1	Seismograph	Sensor	Structure	Pendulum
				Dual coil
			Measurement	1 element
			velocity element	vertical
			Max. period	1.00Hz
			Min. period	0.05Hz
		Transmitter/	Radio	UHF 400MHz
		Receiver	Data	Analog
			Yagi	5 elements
		Antenna	Channel	125Hz
		Controller	discrimination	
			Others	Pen recorder control
			Pen recorder	
		Recorder	Ligao	
		Repeater	Mayon Skyline Hotel	
			Mayon Skyline Hotel	
		Installation	Upper St. Miseriocordia	
			Upper Anoling	
			Lignon Hill	
		Power source	Public electricity	Mayon Skyline Hotel
				Ligao
				Lignon hill
			Solar Battery	Upper Misericordia
				Upper Anoling
2	Monitoring of topographic displacement	Distance meter	Deodolite	Class 1 laser
		Prism	Line 1	4
			Line 2	4
		Benchmark	1	
3	Gas analysis	Sampling	Airplane	
			Vehicle	
		Analyzer	Gaschromatography	
			Wind velocity	
		Adjustment	Wind direction	

Note: A cable data communication is adopted to transmit data from Lignon Hill measurement station to Lignon Hill observatory.

Table VII 2.2 Specifications of Lahar Monitoring System

System	Equipment	Specifications	
Wire sensor	Sensor	Sensor cable	50m
		Junction box	
		Control board	
	Transmitter	Radio	UHF 400MHZ
		Data	Digital
	Antenna	Yagi	5 elements
		Pole	5 m
		Arrester	coaxial
	Repeater Station	Transmitter	
		Receiver	
		Radio	10 W
		Antenna	Yagi 8 elements
	Control Station	Monitor	Pole 15m
		Display	

Table VII 2.3 Specifications of Hydrologic Monitoring System (PAGASA/OCD)

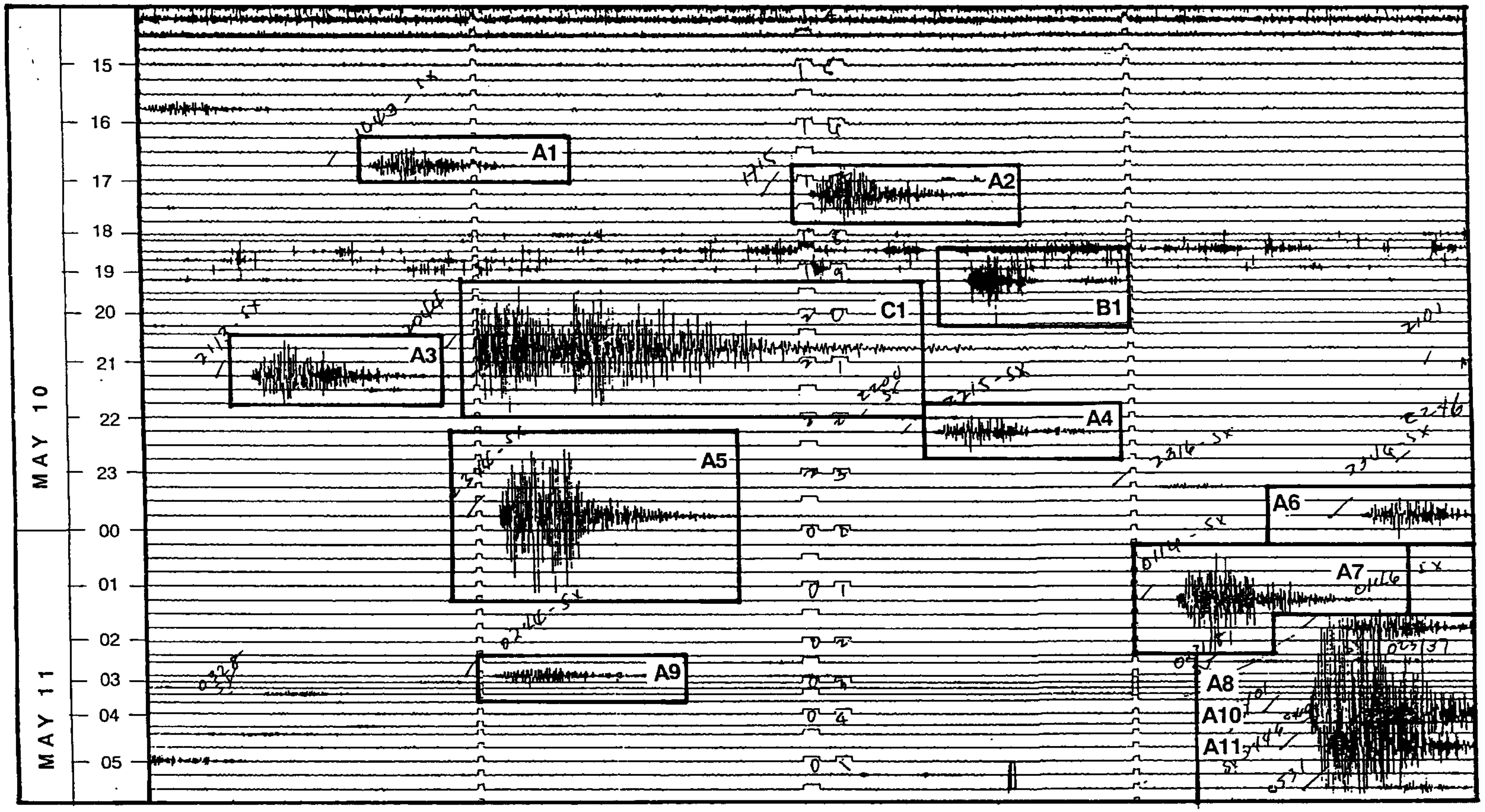
No	System	Equipment	Specifications	
1	Rainfall gauging (1)	Sensor	Tipping bucket	
			Resolution	1.0 mm
			Recording	automatic pencoder
		Data collection	Manual	
		Plotting standard	Interval	6.3 hours
2	Rainfall gauging (2) (Bicol River FFWS)	Sensor	Tipping bucket	
			Resolution	1.0mm
			Recording	automatic pencoder
		Data collection	Telemeter	poling 60,30, 15min.
		Transmission	UHF	400MHz
		Installed site	Ligao	
		Controlled station	Naga	
3	Rainfall gauging (3)	Sensor	Tipping bucket	
			Resolution	1.0 mm
			Recording	automatic digital card
		Data collection	Telemeter	Event report
			Trigger	1.0 mm
		Radio eq.	UHF	400 MHz
		Antenna	Yagi	5 elements
			Arrester	coaxial
			Pole	5m
		Repeater Station	Repeater equipment	
			Radio eq.	10w
			Transmitter receiver	
			Power amplifier	Yagi, 8 elements
			Antenna	15 m
			Pole	coaxial
			Arrester	Maninila
			Installation	Mabinit Buyuan Mayon Skyline Hotel
		Monitoring station	Supervision	16 stations
			Alarm	Alarm Lamp
			Printer	Automatic 09:00 AM Daily Report
			CRT	14 inches 640 dot 400 lines
		Power source	Solar cell	12v, 2.6w
			Battery	Alkaline Storage Battery
4	Water level gauging	Sensor	Staff gauge	
			Resolution	1 cm
			Observation	7, 12, 18 o'clock
			Installation	Legazpi Benanuan Nobonton Malinao

Table VII 7.1 Assessment of Candidate Monitoring System

System	(1)	(2)	(3)	(4)	(5)	(6)	Over All
System for volcanic eruption							
Seismic sensor	B	A	A	B	A	B	1
GPS	A	A	B	B	A	C	2
Gas analyzing	A	A	A	C	B	C	2
System for mud and debris flow							
Wire sensor	A	C	A	C	C	B	2
Optical sensor	A	C	C	B	C	B	3
Seismic sensor	C	B	C	B	B	C	1
Supersonic wl gauge	C	C	C	B	B	C	6
Acoustic sensor	C	B	C	B	B	C	4
Rainfall gauge	A	A	A	B	B	B	1
System for flood							
Water level							
(pressure)	A	A	B	B	C	B	3
(float)	A	A	A	B	A	B	1
(supersonic)	A	A	C	A	B	C	2
System for inter agency communication							
Client server	A	A	A	C	B	B	2
WEBB server	A	A	A	B	B	A	1
VHF radio	C	B	A	A	B	A	2
System to convey warning to barangays							
Radio paging	B	A	A	A	B	A	1
WEBB server	A	A	A	C	B	C	2

Note:
(1) Technical reliability(accuracy and reliability)
(2) Compliance to needs (lead time and quick judgement)
(3) Availability (existing facility, infrastructure and system)
(4) OMR (cost, manpower required to OMR should be small)
(5) Durability (system should function well even under critical condition)
(6) Economy (system should require low cost and small space)

Remarks:
A: high accuracy, longer lead time, high availability high durability ability and low cost
B: medium
C: low

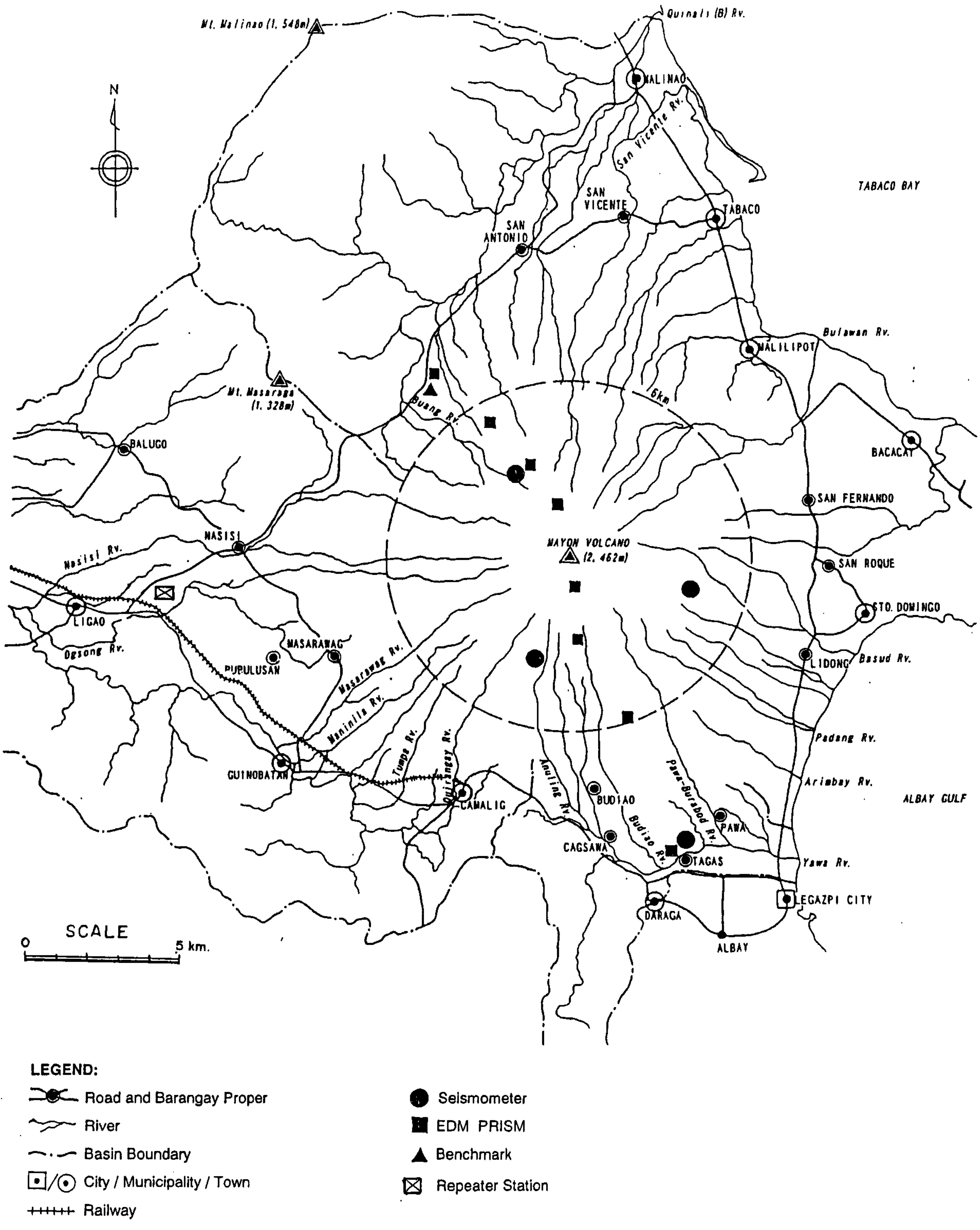


Note: A1-A11 : Seismic waves reflect the movement of magma

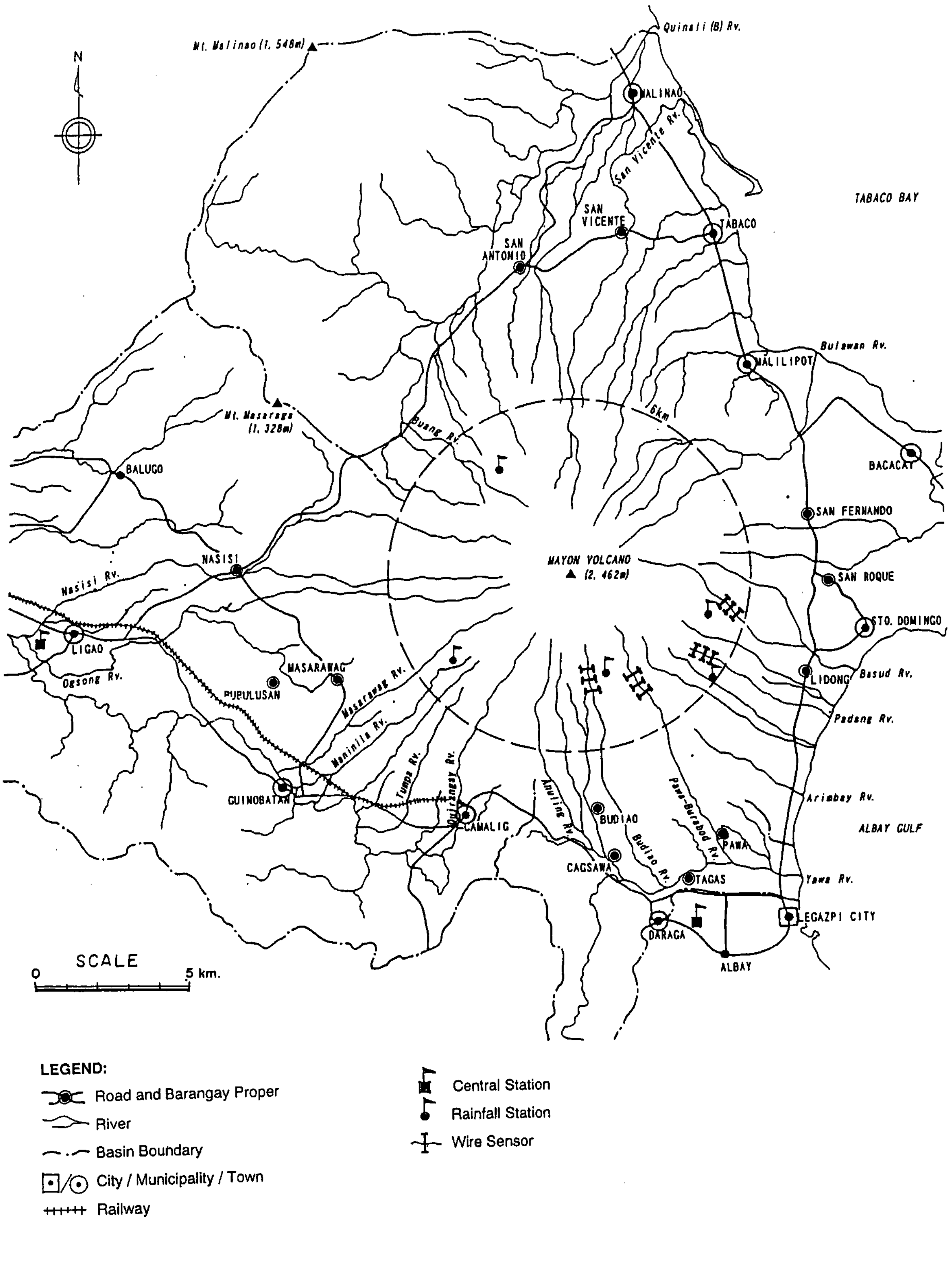
B1 : Seismic wave supposedly reflects the movement of a Heavy Equipment

C1 : Seismic wave reflects techtonic earthquake

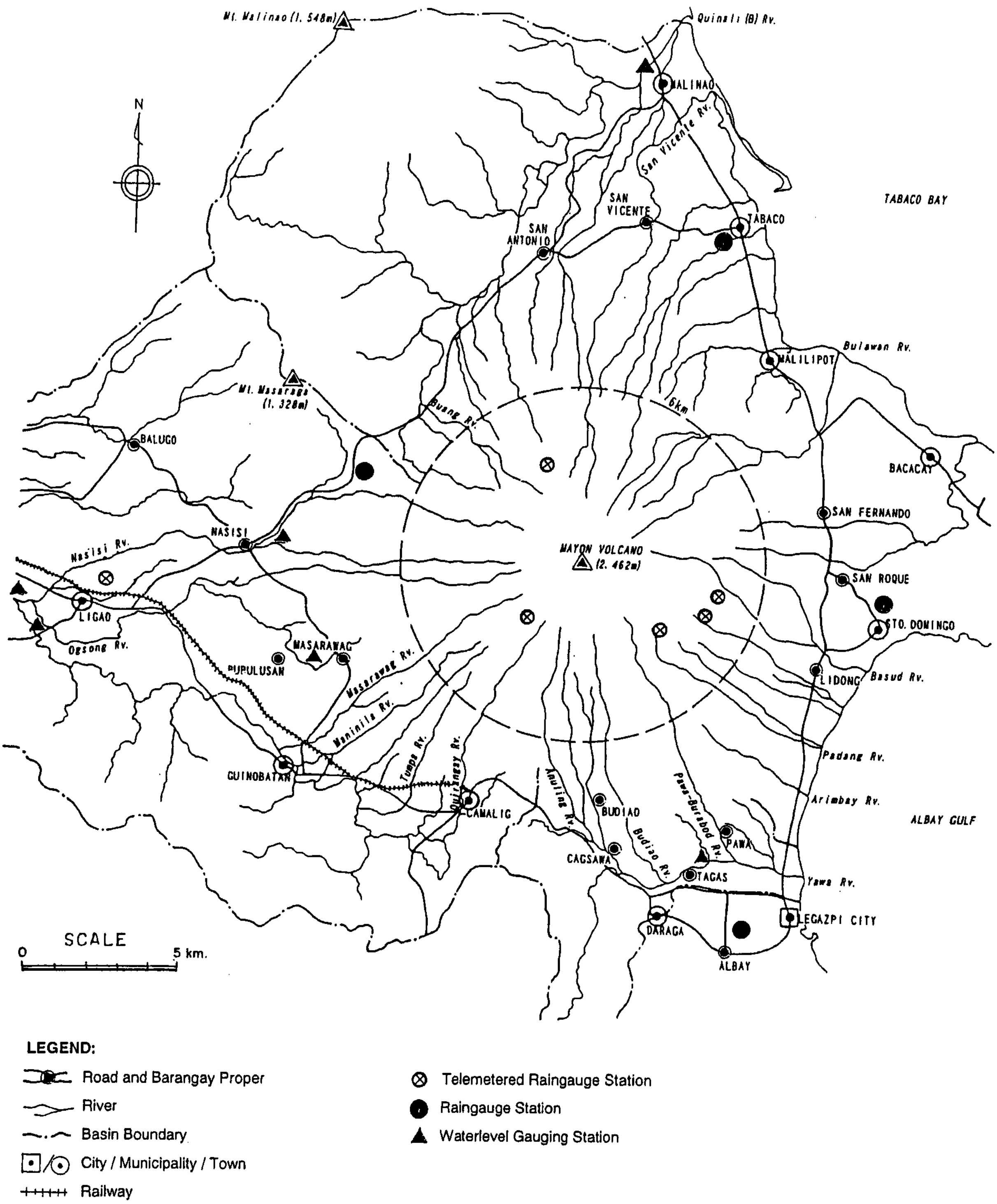
COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	**Figure VII 2.1** **RECOEDED SEISMOGRAPH** (A part of record from 10 May 14:00 to 11 May 05:45, 1998)
JAPAN INTERNATIONAL COOPERATION AGENCY	



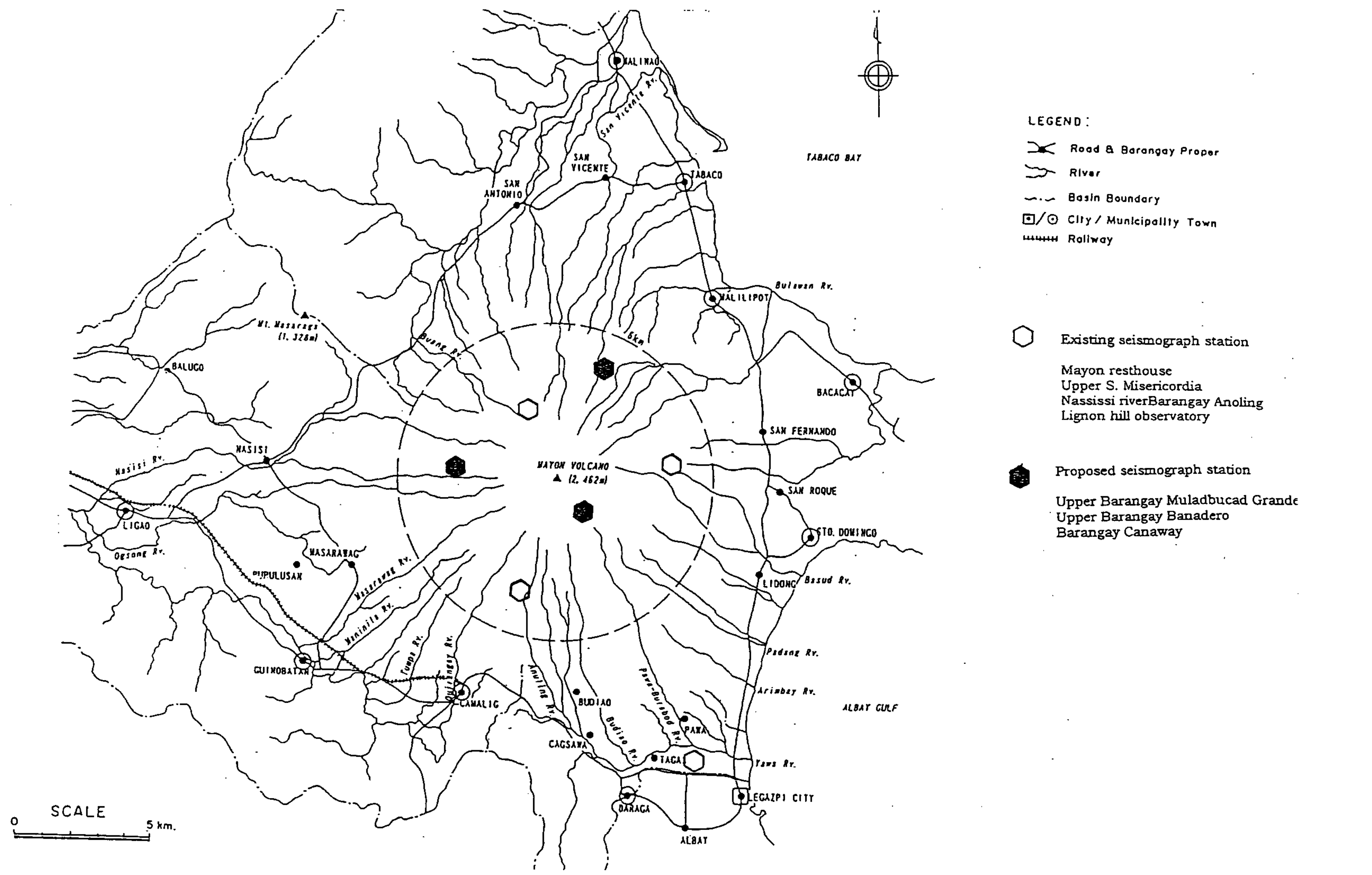
COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	**Figure VII 2.2**
JAPAN INTERNATIONAL COOPERATION AGENCY	**Location of Eruption Monitoring Site (PHIVOLCS)**



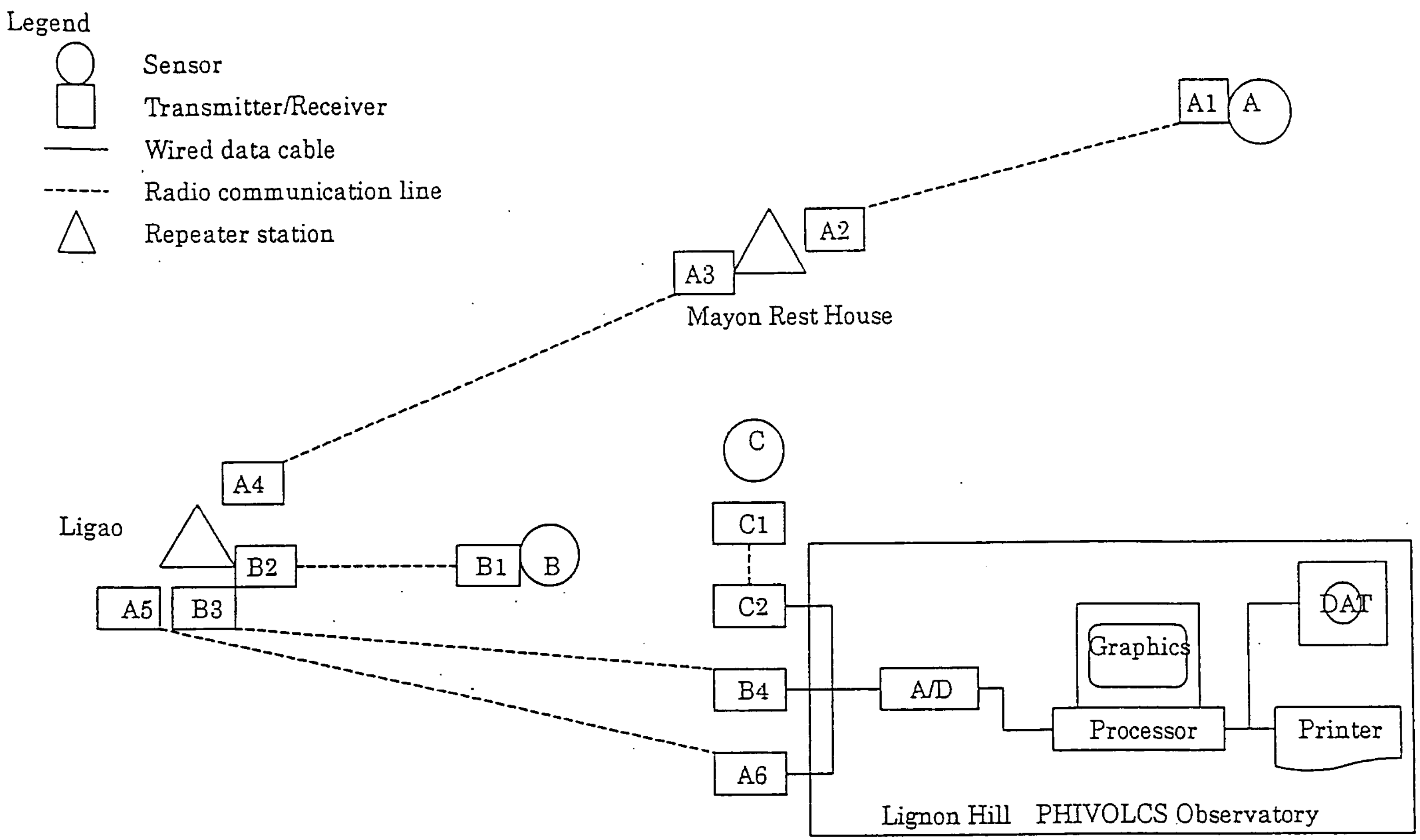
COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	**Figure VII 2.3** **Existing Telemetered Rainfall Gauging Station Site**
JAPAN INTERNATIONAL COOPERATION AGENCY	



COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	**Figure VII 2.4**
JAPAN INTERNATIONAL COOPERATION AGENCY	**Location of Hydrologic Monitoring Site**



COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	Figure VII 8.1 Proposed Monitoring Site of Volcanic Activity
JAPAN INTERNATIONAL COOPERATION AGENCY	

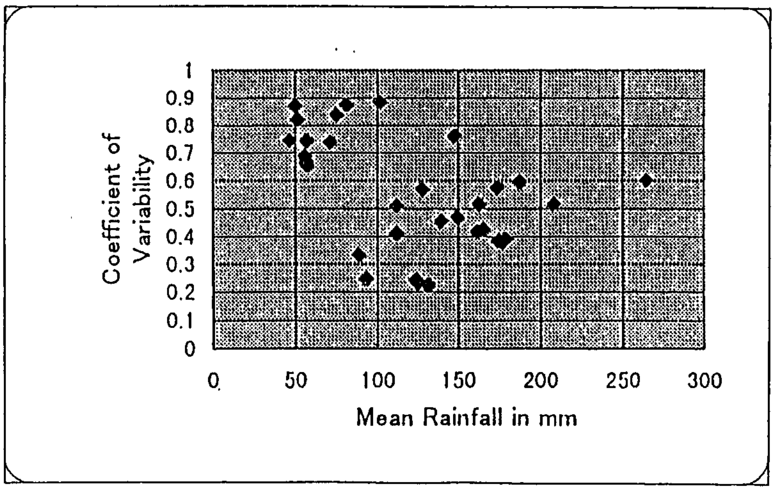


COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES

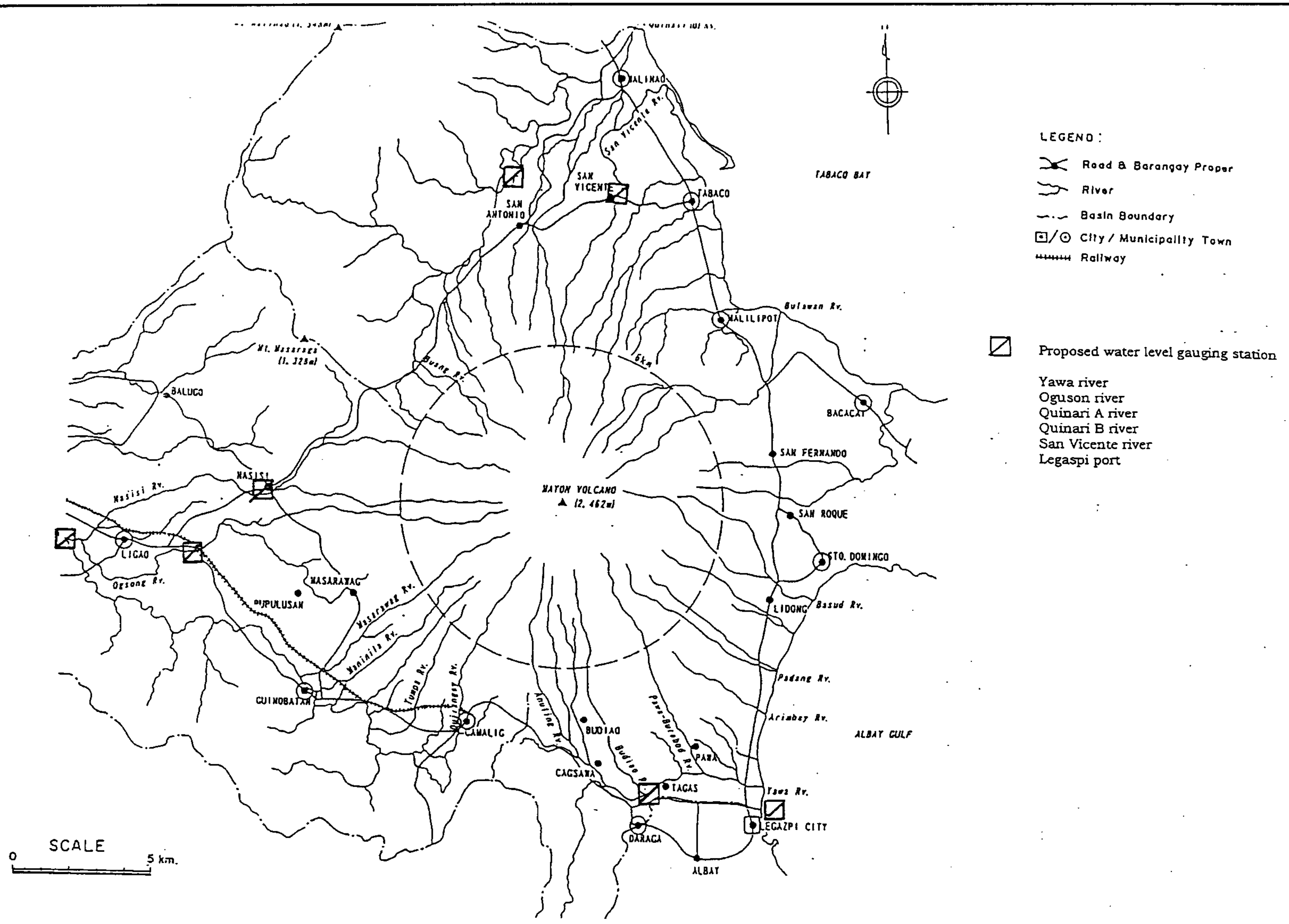
JAPAN INTERNATIONAL COOPERATION AGENCY

Figure VII 8.2
Proposed Seismic Monitoring System

Legaspi	S.Domingo	Ligao	σ	Mean	C. of Var.
229.5	233.2	58.4	99.86987	173.7	0.574956
194.8	229.5	100	67.03405	174.7667	0.383563
170.4	224.8	90.5	67.55228	161.9	0.417247
254.4	143.6	90	83.84207	162.6667	0.515423
44.3	28.4	100	37.59845	57.56667	0.653129
124.6	97.3	4.4	63.01288	75.43333	0.835345
123.2	162.4	50	57.05062	111.8667	0.509988
203.6	174.4	70.5	69.95649	149.5	0.467936
139.9	193.6	50	72.55648	127.8333	0.567587
116.2	183.4	5.6	89.77847	101.7333	0.882488
146.9	128.4	60	45.77558	111.7667	0.409564
92.2	146.2	5.5	70.98049	81.3	0.873069
24.6	29.7	100	42.1372	51.43333	0.819259
220.4	203	18.5	111.8828	147.3	0.759558
111	55.4	100	29.44351	88.8	0.331571
43.8	98.9	25	38.40716	55.9	0.687069
239.4	156.4	100	70.1217	165.2667	0.424294
118.4	156.2	100	28.65263	124.8667	0.229466
33.8	36.1	100	37.57424	56.63333	0.663465
129.6	27.4	57.1	52.57246	71.36667	0.736653
32	21.6	86.2	34.6866	46.6	0.744348
103.2	47.8	20	42.35611	57	0.74309
18.7	31.8	100	43.65116	50.16667	0.870123
172.4	179.2	66.4	63.25356	139.3333	0.453973
114	157.4	100	29.92858	123.8	0.241749
76.7	119.4	84.2	22.79832	93.43333	0.244006
315.2	392	86.4	158.9754	264.5333	0.600965
207.4	223.8	100	67.24354	177.0667	0.379764
134.4	158.6	100	29.44758	131	0.224791
252	251.4	58.6	111.4867	187.3333	0.595125
203	233.4	100	69.91509	178.8	0.391024
217.3	309.9	96.4	107.0621	207.8667	0.515052



COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES	**Figure VII 8.3** **Coefficient of Variability of Rainfall**
JAPAN INTERNATIONAL COOPERATION AGENCY	



COMPREHENSIVE DISASTER PREVENTION AROUND MAYON VOLCANO IN THE REPUBLIC OF THE PHILIPPINES

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Figure VII 8.4

Proposed Monitoring Site of Water Level