A Landslide Risk Rating System for the Baguio City, Philippines Area

by

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University of the Philippines

Submitted to the Department of Civil and Environmental Engineering
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BARKER

A LANDSLIDE RISK RATING SYSTEM FOR THE BAGUIO CITY, PHILIPPINES AREA

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Submitted to the Department of Civil and Environmental Engineering
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ABSTRACT

This research formulates a LANDSLIDE RISK RATING SYSTEM for the Greater Baguio area in the Philippines. It is hoped that the tool will be made a part of the physical/urban planning process when used by engineers and planners and used to address risks posed by landslides given the rapidly increasing concentration of population and the development of infrastructure and industry in the Baguio area. Reports and studies of individual landslides in the area are reviewed in order to discover the causal factors of mass movements and their interactions. The findings of these research works are discussed in the first portion of this paper.

A description of the LANDSLIDE RISK RATING SYSTEM, remedial measures, and recommendations form the rest of the paper. This SYSTEM integrates different hazard (bedrock geology, slope gradients, vegetation) and risk (population, land use) factors. The selection of hazard factors takes into account the results of the analysis of causal factors of mass movements in the area.

This analysis is based on the specific attributes of the subject study area, namely: a relatively extreme topographic relief, variable bedrock geology, and no significant differences in rainfall from one zone to another. The study assumes that the entire Greater Baguio area is subject to a uniform amount of rainfall during any given precipitation event. Although this study is area-specific it can have wider application.

Finally, the paper recommends that in future research work on this subject matter, soil and rock samples from various slopes be subjected to geomechanical testing to facilitate a mathematical analysis of slope failures. This can be the basis for a comprehensive database which can be used to create a Landslide Hazard Map where each slope in the Greater Baguio area can be rated. In addition, it would be beneficial to conduct an analysis of how Hazard Ratings may be reduced when particular remedial measures are in place. A site-specific preventive and remedial slope safety system for every slope in the Greater Baguio area would be the ultimate goal of future work.

Thesis Supervisor: Herbert H. Einstein

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Chapter 1. Introduction

A little over a decade ago, generally little attention was paid to the risks posed by landslides in the urban planning process of most disaster-prone areas in developing countries like the Philippines. However, with the rapidly increasing concentration of population in urban centers and the development of infrastructure and industry, the loss of life and property damage caused by mass movements has grown at staggering rates. This state of affairs is particularly applicable in the greater Baguio area in the Philippines.

In recognition of this situation, this research formulates a Landslide Risk Rating System for the greater Baguio area. It is hoped that the tool will contribute to the mitigation of the abovementioned problem by being made a part of the physical planning process when used by engineers and planners.

This Landslide Risk Rating System integrates different hazard (bedrock geology, slope gradients, vegetation) and risk (population, land use) factors.

At this point, it is instructive to draw the distinction between hazard and risk. Hazard refers to the "probability that a particular danger occurs within a given period of time", while risk refers to the hazard multiplied by the potential worth of loss (Einstein, 1997).

It must be noted that the analysis performed in this study is based on the specific attributes of the study area chosen, namely: an area with relatively extreme topographic relief, underlain by a variable bedrock geology, and without significant differences in rainfall from one zone to another.

The methodological approach offered in this paper is as comprehensive as is possible given the data available to the author. Although it is area-specific, it can have wider application depending on the characteristics of one's study area. This study assumes that the entire Greater Baguio area is subject to a uniform amount of rainfall during any given precipitation event. This is not necessarily the case in many other locations.

Data collection was carried out in the Philippines by members of the staff of Geotecnica Corp., a local geotechnical consulting firm. The methodology, data synthesis, and analysis were subsequently developed and finalized by the author.

The Philippines is an archipelago located in Southeast Asia between the Philippine Sea and the South China Sea, east of Vietnam (Figure 1.1). It is located at 13° 00 N latitude, 122° 00 E longitude. Its capital is the City of Manila. The country's total area is 300,000 sq km with water occupying 1,830 sq km and the land area being equal to 298,170 sq km. It has no land boundaries with surrounding countries and has a coastline of 36,289 km (CIA World Fact Book, 2004). The Philippines has a tropical marine climate, experiencing the northeast monsoon from November to April and the southwest monsoon from May to October. The terrain is mostly mountainous with narrow to extensive coastal lowlands. Its natural resources consist of timber, petroleum, nickel, cobalt, silver, gold, and copper (CIA World Fact Book, 2004).

Figure 1.1 The Philippines in Southeast Asia (http://www.lib.utexas.edu/maps/)

The country is vulnerable to a wide range of natural hazards. It sits astride a typhoon belt, usually affected by fifteen and struck by five to six cyclonic storms per year (CIA World Fact Book, 2004). It is susceptible to landslides, active volcanoes, destructive earthquakes, and tsunamis. Several environmental issues plague the country, including uncontrolled deforestation in watershed areas, and soil erosion.

As of July 2003, the population of the Philippines was approximately 85,000,000 with a national population growth rate of 1.92% for the year (CIA World Fact Book, 2004).

The Philippines is divided into 73 provinces and has 61 chartered cities, one of which is Baguio City. The City (Figure 1.2) is 208 linear kilometers and 250 driving kilometers north of Manila. Its geographical location is 16°24 N latitude and 120°36 E longitude (Mendoza, 1983). Most of the developed portion lies in the northern half of the city. Baguio City extends 8.2 kilometers from east to west and 7.2 kilometers from north to south. It has a perimeter of 30.98 kilometers (Mendoza, 1983).

Figure 1.2 Baguio City (http://www.cia.gov/cia/publications/factbook/geos/rp.html)

Although Baguio City is geographically located in Benguet province, under its Charter it is recognized as an independent city not politically included in any province. It is bordered by the municipalities of Tuba to the south and west, Itogon to the east, La Trinidad to the north and to the northwest is the municipality of Sablan (Figure 1.3).

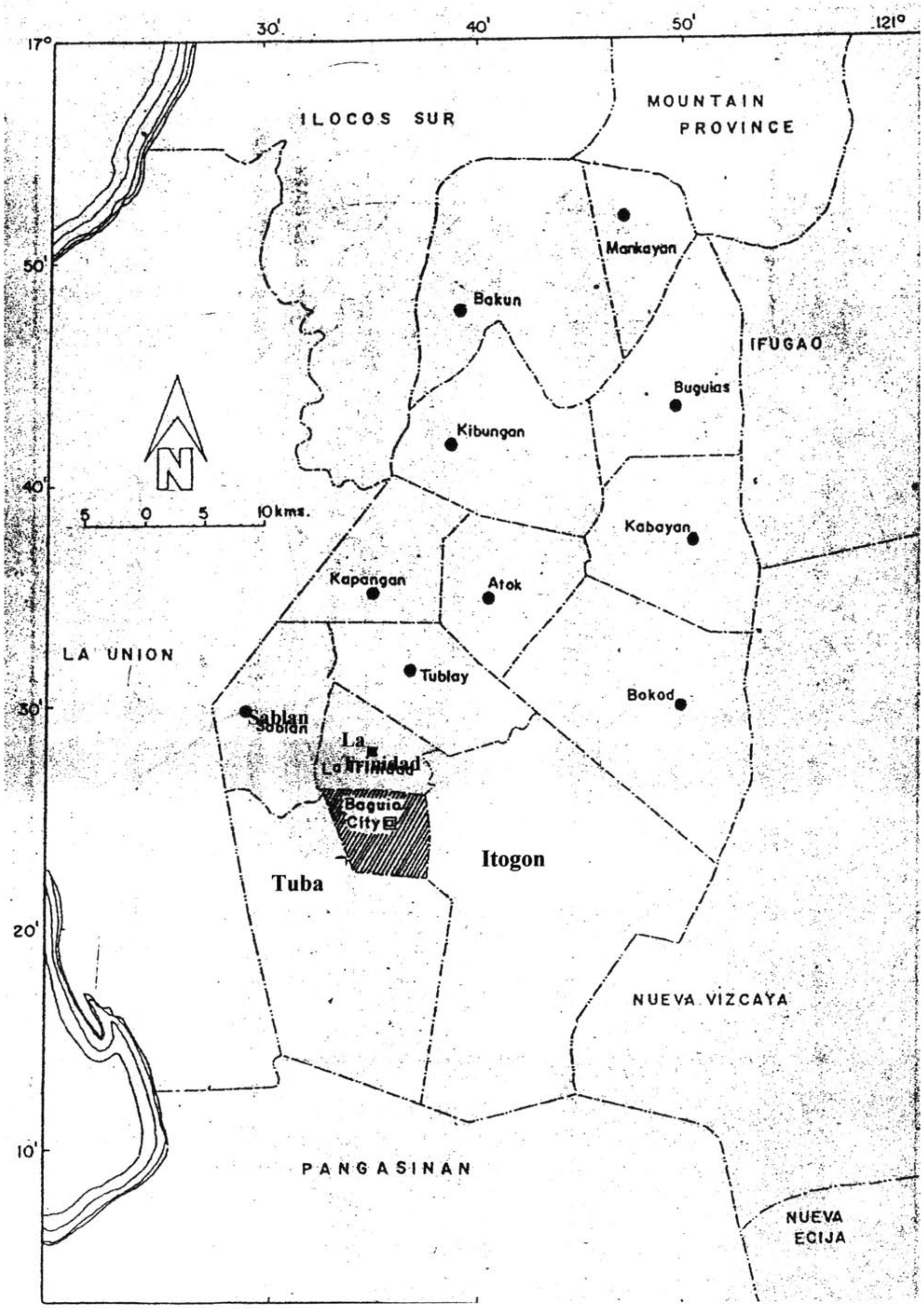
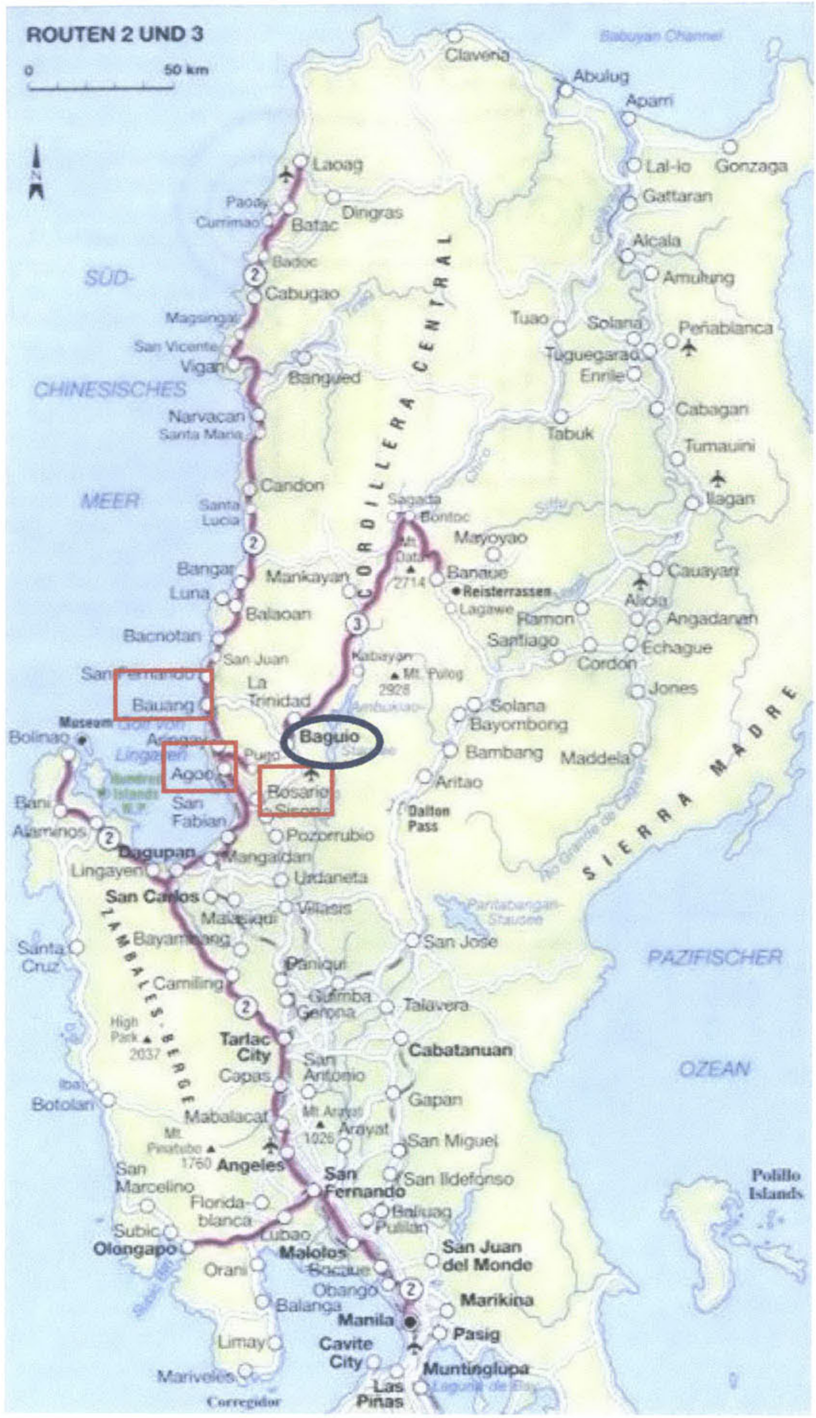


Figure 1.3 Municipalities of Benguet Province Around Baguio (Mendoza, 1983)

Baguio is best known for its climate, unique in the otherwise tropical country. On the average, the temperature is 8 degrees Celsius lower than the temperature in the lowlands (Baguilat & Cabalda, 1985). Generally, the maximum temperature experienced in the area is 26 degrees Celsius (Mendoza, 1983). The City owes this climate to its elevation of approximately 1,500 meters above sea level in the southwest portion of the Cordillera Central mountain range in northern Luzon island (Figure 1.4). This makes Baguio the most popular summer tourist destination in the Philippines.



Source: Polyglott-Reiseführer, Philippinen, Albert G. Schaefer, 1996 Polyglott-Verlag München

Figure 1.4 Map of Northern Luzon

The climate of Baguio City consists of two very distinct seasons, the rainy season from November to April and the dry season from May to October. Average annual precipitation is almost 4,000 millimeters. The City receives the highest amount of rainfall in the country, twice the volume experienced by Manila (Baguilat & Cabalda, 1985). In 1911, the world record 1168.1 mm in 24 hrs (July 14-15) and 2009.6 mm in 2 days, 15hrs (July 14-17) were recorded in Baguio (Jennings, 1950).

The greater Baguio area was originally occupied by the indigenous Igorot and Ifugao tribes, but the city itself was established by the Americans who occupied the Philippines in the early 1900's. The American Governor Luke E. Wright commissioned Architect Daniel H. Burnham, a prominent urban planner, to develop a plan for a health resort where the American soldiers and civilian employees could find respite from the lowland heat. This plan, better known as the Burnham Plan, greatly altered the original mountain settlement and provided the first physical framework for the City. It paved the way for rapid physical development, the undertones of which are still visible today.

The physical framework as embodied in the Burnham Plan integrated road and park systems into one. It envisioned evolving a compact garden city for 25,000 to 30,000 people with Burnham Park at the city center (Figure 1.5). Supporting this development plan was the enactment of a charter approved on September 1, 1909 that provided administrative autonomy for the city. Soon after the city's charter was enacted, Kennon Road (Figure 1.5) was opened to vehicular traffic. The existence of an artery to Baguio City, the Cordillera Region's distribution center, triggered the gold mining boom in the surrounding areas in the early to mid 1930s. Baguio City was the service and operations center for the mining industry and, hence, a direct beneficiary of the economic growth. The events of the Second World War unfortunately left the city in total devastation. Fast paced development, however, ensued following the war years. Such development trends transformed the city into what it is today, a premier urban center north of Manila, performing a multiplicity of roles, as an educational, trade, tourism and administrative center. Baguio City is now part of the Cordillera Administrative Region (CAR). The City has twenty administrative districts among which its 129 barangays (the Philippines' smallest unit of local government) are divided (http://www.baguio.gov.ph/, 2004).

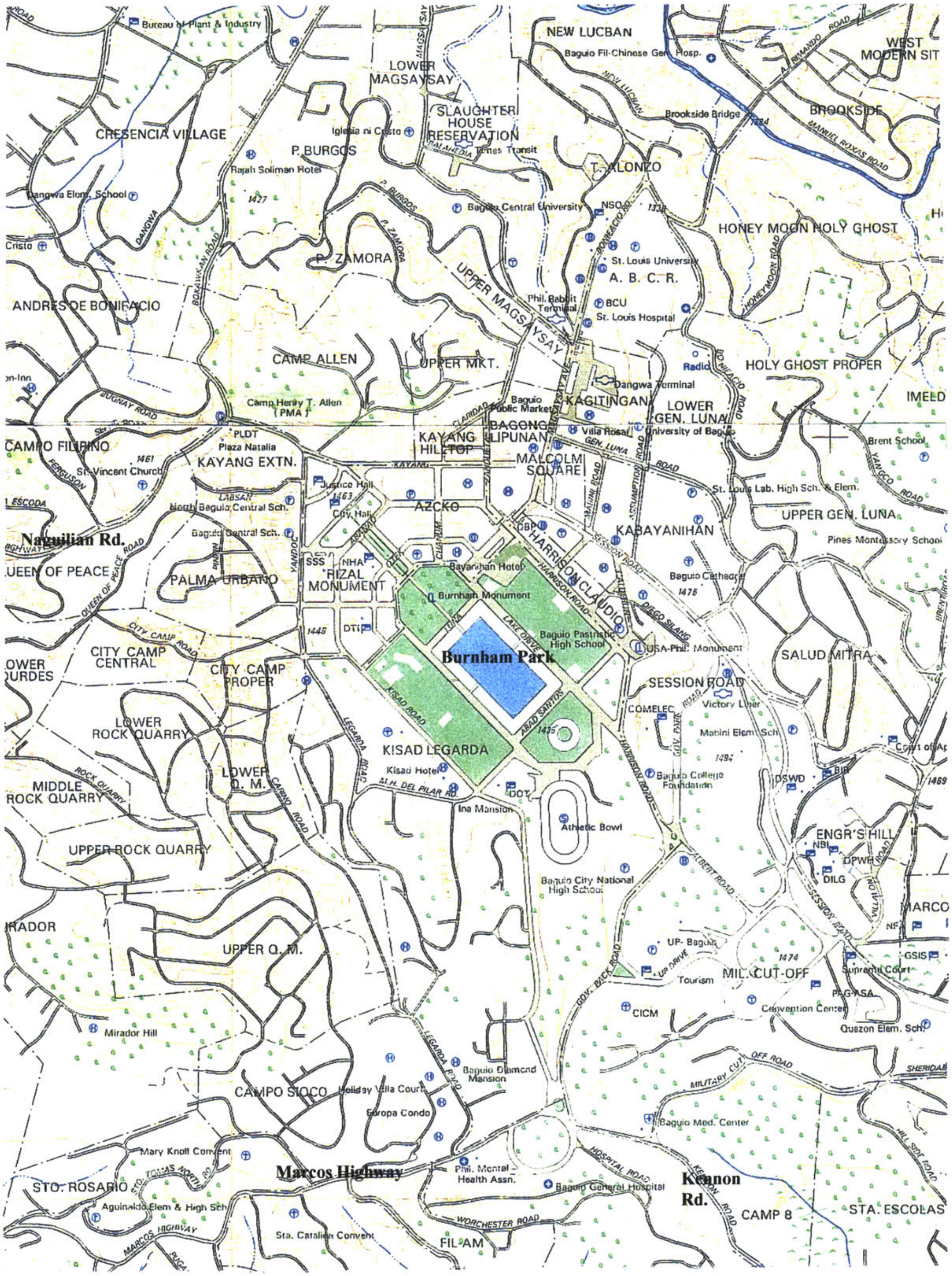


Figure 1.5 Baguio City Proper (Topographic Map of Baguio City, 1995)

Mineral deposits of both metallic and non-metallic ores are found in the City. Within the city limits, metallic deposits of gold and silver are present, while non-metallic resources that include silica and limestone also abound (http://baguio.islandsphilippines.com/, 2004).

In 1982, the population of Baguio City was approximately 128,000. According to a 2000 population census, Baguio is home to 252,386 people with a population density of 5,151 per km^2 (http://www.baguio.gov.ph/, 2004). This constitutes more than a doubling of the population in only 18 years. The population in 2005 is projected to reach 280,192. The city's population is growing rapidly at an annual growth rate of 4.39 percent (more than twice the national population growth rate) or an actual increment of about 7,897 individuals a year (http://www.baguio.gov.ph/, 2004). This puts immense pressure on residential, commercial, institutional and infrastructure land use developments to expand proportionately. This situation is compounded by inadequate and ineffective control over land development. As a result, the traditional role of the city -- that of a mountain resort -- is jeopardized. With a total land area of 49 km^2, and a population density of over 5000 per km^2, Baguio is classified as a highly urbanized city (Mendoza, 1983). Attendant negative results of recent and ongoing developments in the city are rapid loss of open space, destruction of the natural environment, and scarring of the landscape. Risks to the safety of the residents as a result of hillside developments have also increased significantly. Parenthetically, there are far-reaching effects on the city's economy since tourism, which is the City's basic industry, depends so heavily on the natural environment for its viability.

There are three primary access roads to Baguio City from the lowlands, namely, Kennon Road, Marcos Highway, and Naguilian Highway (Figure 1.5). Kennon Road originates at the town of Rosario in La Union province and passes through a narrow and steep valley. Marcos Highway starts in Agoo, La Union, and Naguilian Highway begins in Bauang, La Union (Figure 1.4). Because landslides are most common along Kennon Road, buses and trucks are only allowed to use the latter two routes.

Baguio City is the most commercially active area within Benguet province. Most of the agricultural and mined commodities produced in Benguet go to Baguio City for central distribution. The three arteries thus also serve as very important farm-to-market roads.

In addition to being a center for tourism, Baguio City is an educational hub in the Cordillera Region. The City has seven colleges and universities and several trade and technical schools. More than 100,000 students are estimated to attend these institutions. During peak seasons students and tourists can triple the transient population (Mendoza, 1983).

The Baguio City area is an ideal setting for carrying out a landslide risk study for the following reasons:

- A significant portion of the area experiences mass movements on a yearly basis
- No such comprehensive study has previously been conducted to integrate various factors into a risk rating system.

The main body of this work is divided into two major sections: in Chapter 3, reports and studies of individual landslides in the Baguio City area are presented and analyzed in order to discover patterns and similarities among the landslides on record.

In Chapter 4, the Landslide Risk Rating System, a methodological approach for integrating different hazard and risk factors, is formulated. Detailed analyses of geologic, topographic, geomorphological, and land use maps were carried out in this analysis.

Conclusions and recommendations are presented in Chapter 5.

Chapter 2. Physical Characterization of the Greater Baguio Area

2.1 General Comments

A landslide, even of moderate size, can have effects that are potentially hazardous to people and the environment. Many civil engineering structures are located on or near slopes and are thus subject to slope instability. The instability can be inherent, or the construction process itself can decrease the stability of slopes. However, proper evaluation and analysis of slopes can lead to designs and construction methods that can help prevent instability, or to decisions on whether or not to proceed with the construction at all. Remedial measures may even be identified in order to make construction viable at the site under consideration.

The analysis of landslides is difficult because of the interrelationships of the different causal factors. Nevertheless, it is possible to identify four factors that contribute to the occurrence of landslides:

- Geology
- Topography
- Precipitation
- Vegetation

2.2 Physiography

Baguio City proper is located on a mature surface topography that has been described as a relatively flat upland plateau (Montgomery Consulting Engineers, 1974). Within the city limits the topographic conditions are mild to moderate with rounded hills and mountains. Elevations range from 1300 to 1600 meters above sea level (Mendoza, 1983). Elevation changes and topographic conditions, however, become extreme as one leaves the City proper. The surrounding areas are heavily dissected by young, vigorously eroding river systems, giving the area large elevation differences. To the west, the elevations increase to 2250 meters above sea level to the summit of Mt. Santo Tomas. Along the Baguio-Bontoc National Highway to the north, the elevations increase to 2800 meters to the summit of Mt. Tabayoc. In all other directions, the elevations drop from 1500 meters to sea level within a distance of 30 linear kilometers (Montgomery Consulting Engineers, 1974).

The Baguio plateau is located at the apex of four major drainage systems which drain away from the City radially (Figure 2.1). These drainage systems are the La Trinidad-Baguio system to the north, the Asin-Tuba system to the west/northwest, the Bued River system to the south/southwest, and the Agno River system to the east (Mendoza, 1983).

Figure 2.1 Major Drainage Systems in the Baguio City Area (Montgomery Consulting Engineers, 1974)

2.3 Geology

2.3.1 Regional Geologic History

During the early Cretaceous, the Greater Baguio area was part of a basin whose basement was made up of schists. The basin was filled with a thick sequence of ophiolitic flows and wackes, represented now by the pre-Tertiary metavolcanics/metasediments. An early stage of erosional activity and sedimentation together with volcanism deposited a thick sequence of conglomerates, arkoses, and wackes, and volcanic flows of intermediate composition. Increased and prolonged volcanic activity and sedimentation during the late Eocene added the sequence that is now represented by the Pugo Formation. The Oligocene saw continued building of the Cordilleras. Miocene sedimentary activity and limited andesitic flows followed and are represented by the ZigZag Formation and the Kennon Limestone. Simultaneously, Miocene orogenic disturbance emplaced the Central Cordillera Diorite Complex. Succeeding erosion deposited the Klondyke Formation and the Mirador Limestone. Intense volcanic activity then added the pyroclastics of the Baguio Formation (Fernandez & Damasco, 1995).

2.3.2 Stratigraphy

In terms of stratigraphy, there are seven significant geologic units that are present in the Baguio City area (Figures 2.2 to 2.8). These are (from oldest to youngest) the Pugo Formation (KPpf), the Zigzag Formation (PNzf), the Central Cordillera Diorite Complex (Pcdc), the Kennon Formation (Nkl), the Klondyke Formation (Nkf), Mirador Limestone (Nml), and the Baguio Formation (NQbf). Quaternary Alluvium (Qal) is also found outside the City proper.

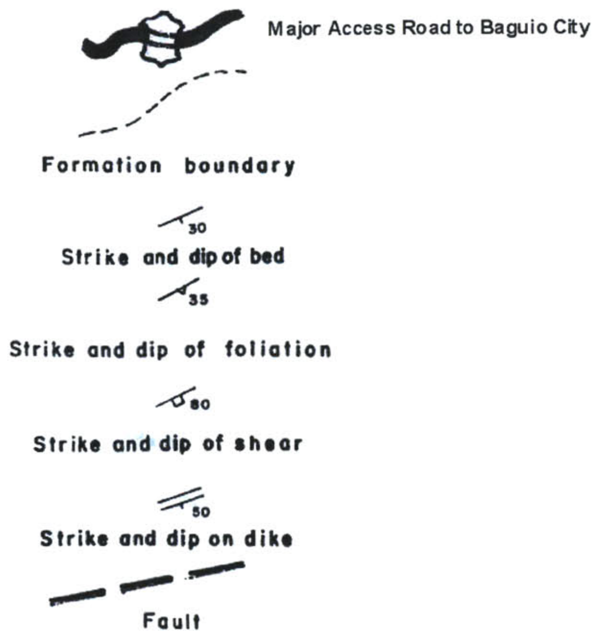


Figure 2.2 Geologic Map Legend of Structural Features

Figure 2.3 Index of Quadrants

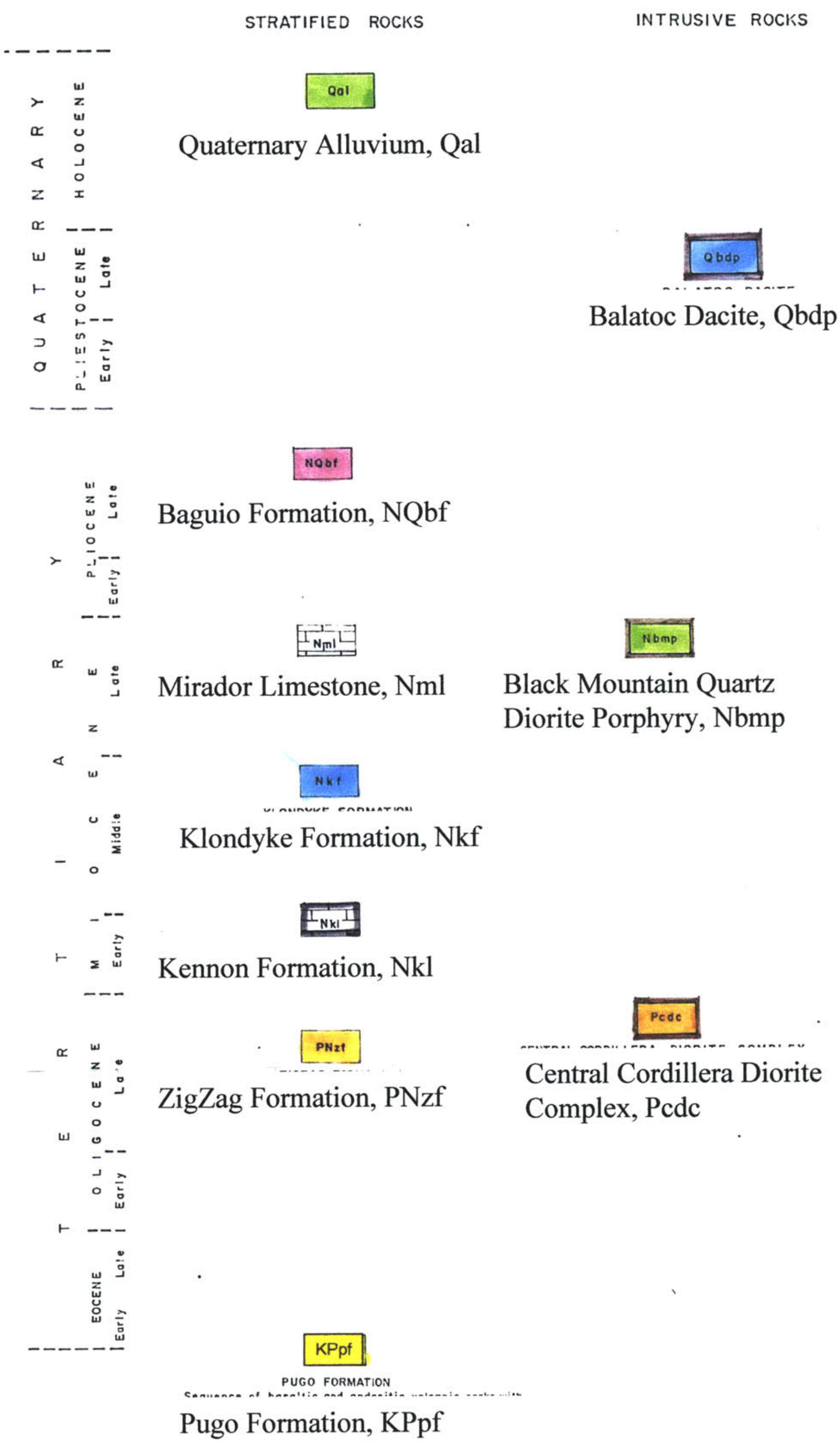


Figure 2.4 Geologic Map Legend of Bedrock Units

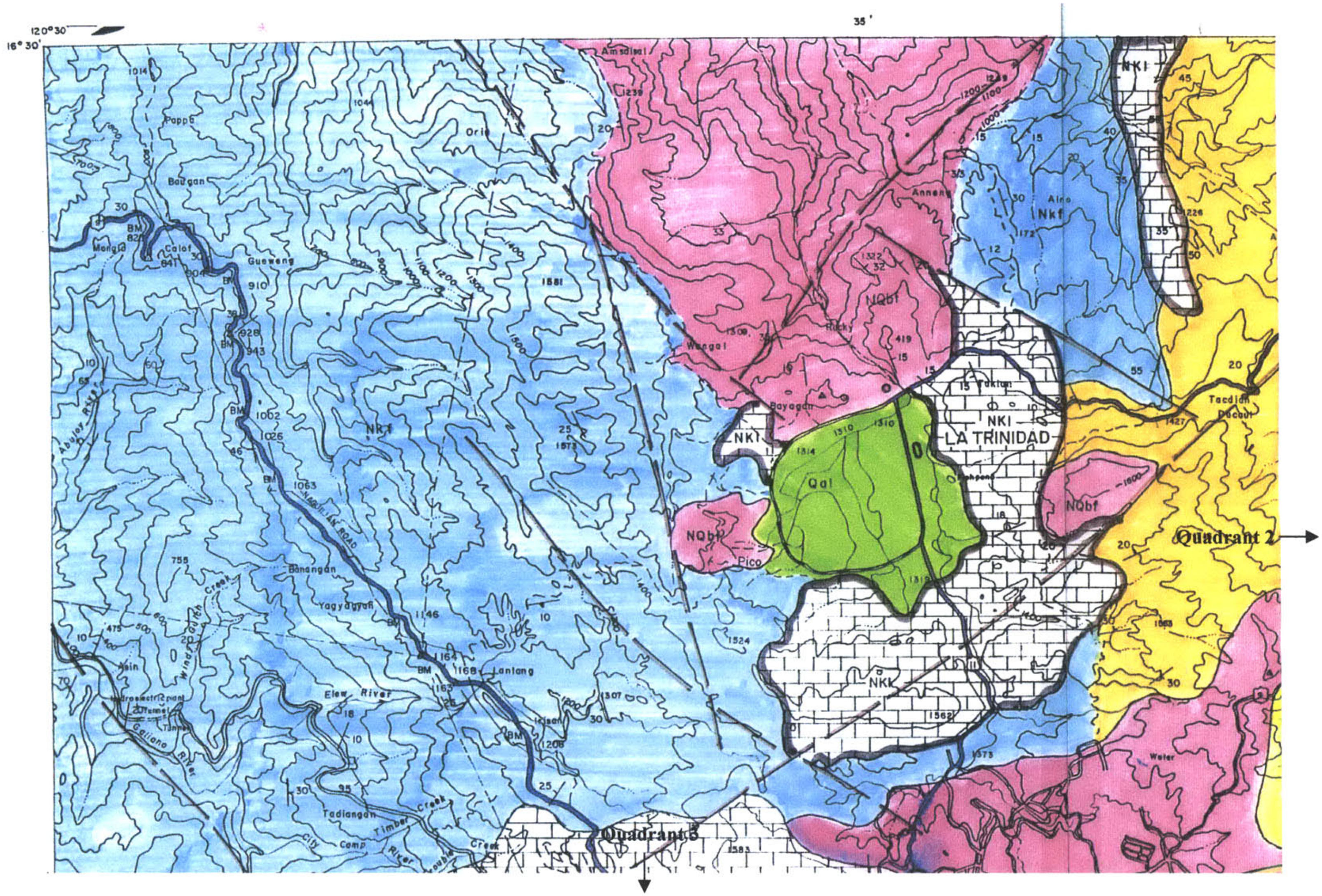


Figure 2.5 Quadrant 1 of Geologic Map of the Baguio City Quadrangle, 1995

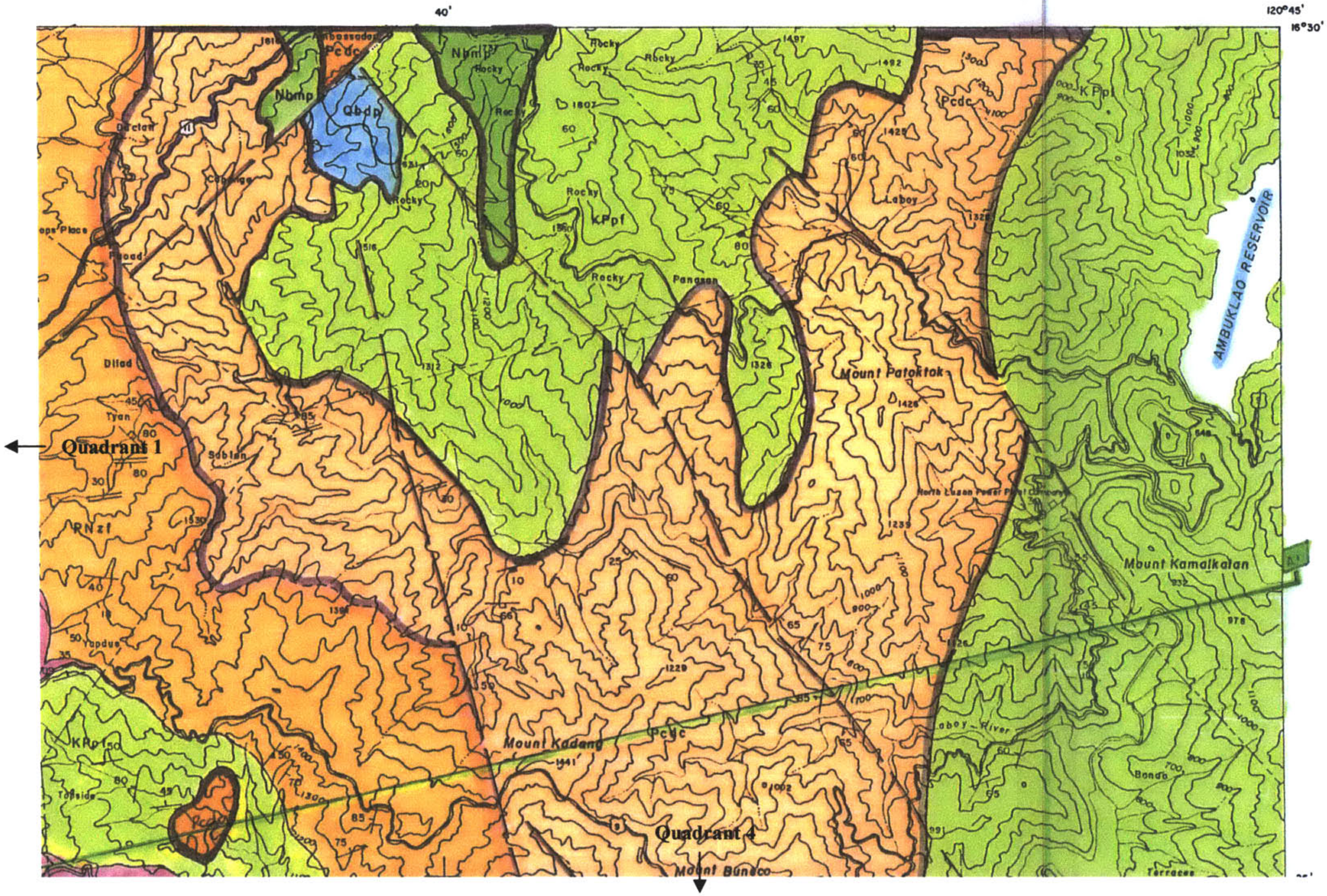


Figure 2.6 Quadrant 2 of Geologic Map of the Baguio City Quadrangle, 1995

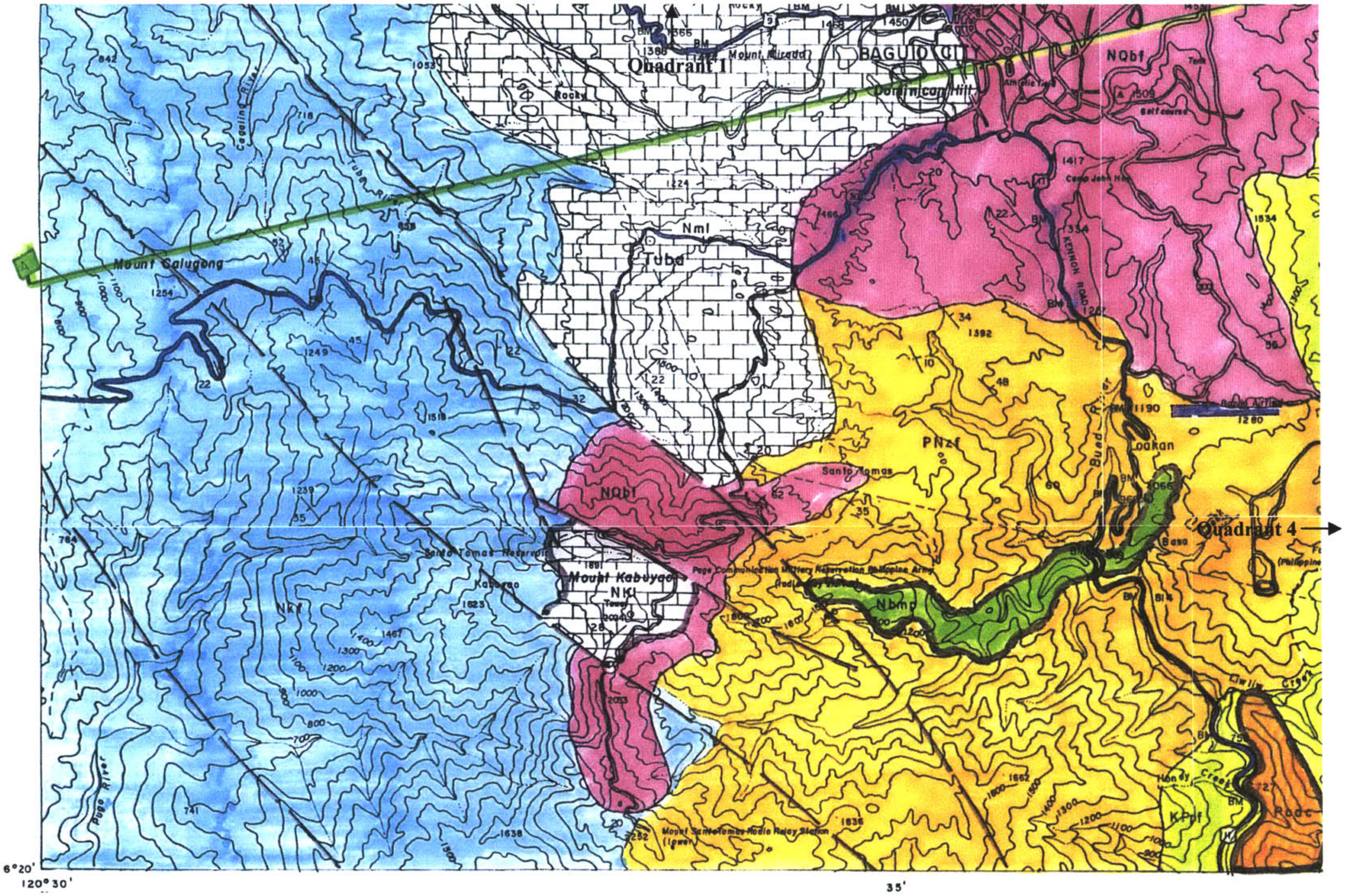


Figure 2.7 Quadrant 3 of Geologic Map of the Baguio City Quadrangle, 1995

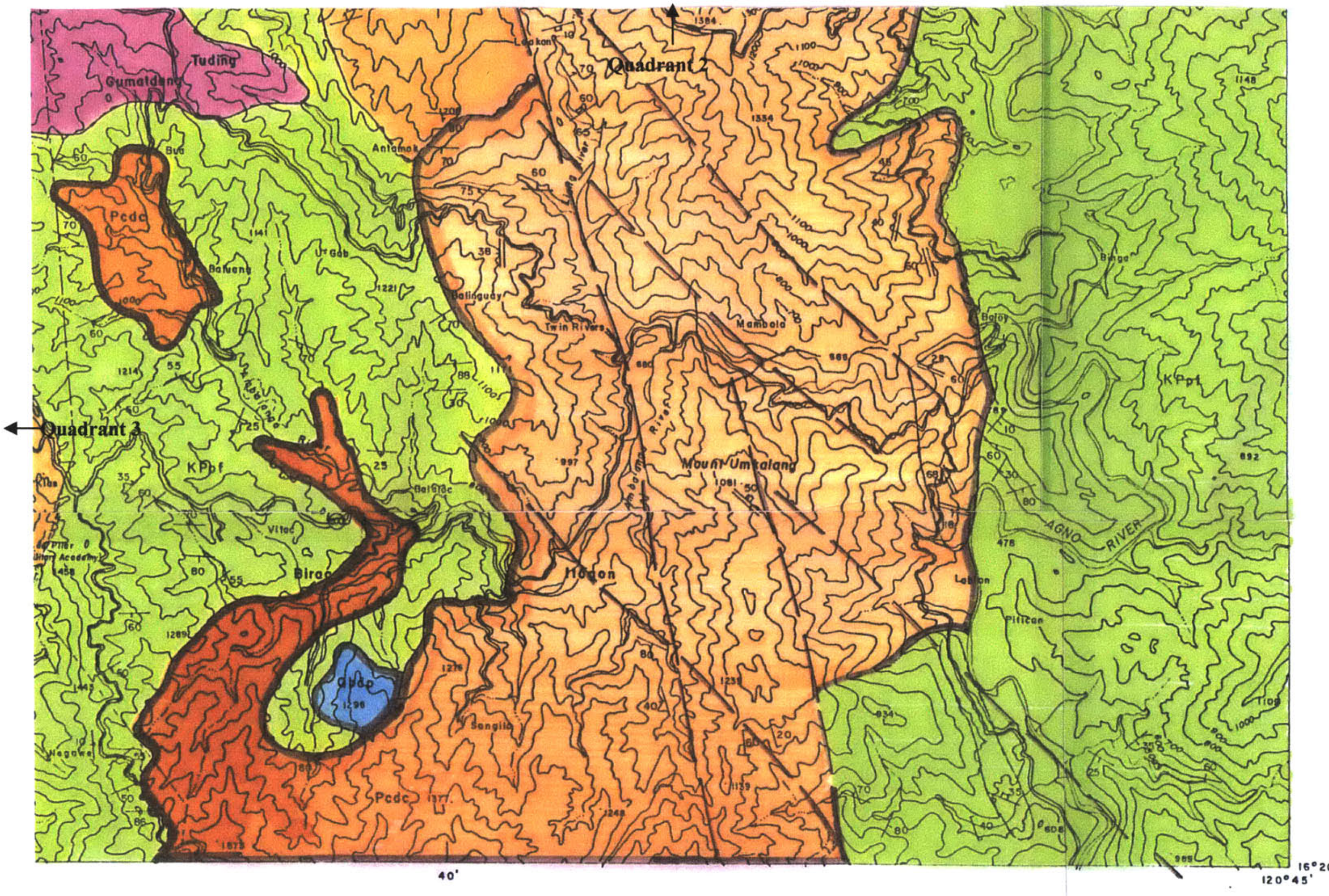


Figure 2.8 Quadrant 4 of Geologic Map of the Baguio City Quadrangle, 1995

2.3.2.1 The Pugo Formation (KPpf)

The Pugo Formation is a stratified rock unit. It is a sequence of basaltic and andesitic volcanic rocks. There are minor interbeds of sandstone, argillites, chert, and pyroclastics (Geological Map of Baguio City Quadrangle, 1995).

2.3.2.2 The ZigZag Formation (PNzf)

The ZigZag Formation (named after the type section at ZigZag View along Kennon Road) is the most widespread unit in the region (Montgomery Consulting Engineers, 1974). It is a sequence of conglomerates, sandstone, and shale with limestone lenses in some areas (Geological Map of the Baguio City Quadrangle, 1995). The elevations of this unit range from 1000 to over 2200 meters above sea level with a thickness greater than 1000 meters. The areal coverage of this unit is in excess of 60 square kilometers (Montgomery Consulting Engineers, 1974).

The upper part of the ZigZag unit is composed of a thick sequence of coarse, well-indurated conglomerate with the ability to form rugged cliffs up to hundreds of feet high, and steep, jagged ridges following the major orientation of bedding (Mendoza, 1983). The ZigZag series outcrops to the north, west, and south of the City proper, and is thus considered to be contiguous under the Plateau. Some hydrothermal alteration may be observed in the southern portion. The entire ZigZag Formation is highly weathered, forming very thick, deep brown residual soil (Montgomery Consulting Engineers, 1974).

2.3.2.3 The Central Cordillera Diorite Complex (Pcdc)

The Central Cordillera Diorite Complex is found predominantly along the eastern flanks of the Baguio Plateau. This unit is an intrusive body consisting of hornblende quartz diorite, pyroxene-bearing diorites, hornblende diorites, monzodiorites, quartz-monzodiorites, tonalites, and granodiorites (Geological Map of the Baguio City Quadrangle, 1995).

2.3.2.4 The Mirador (Nml) and Kennon (Nkl) Limestones

Throughout a significant portion of the Baguio Plateau a large discontinuous mass of biohermal limestone is exposed (Montgomery Consulting Engineers, 1974). This unit rests in angular unconformity on the ZigZag Formation and thus has a similar areal distribution over 32 square kilometers, at elevations from 1100 to 2000 meters above sea level (Mendoza, 1983).

The Mirador Limestone (named after its type section at Mirador Hill in Baguio City) and the Kennon Limestone (named for the type section at Kennon Road) are readily distinguishable by their karst topography. Solution cavities and channels are present along existing fractures, bedding planes, and other zones of weakness (Montgomery Consulting Engineers, 1974). Outcrops of the formations contain sinkholes that are often along major lines of weakness, fault zones, or jointing planes. Crags and pinnacles can be found in these limestones as well (Mendoza, 1983).

Deep red soils (*terra rosa*) form upon weathering of the limestone and grade into the laterites found on the Plateau and on gentle to rolling slopes (Mendoza, 1983). The limestone has a very low primary permeability but localized areas of high permeability are formed when the extremely high amounts of rainfall form secondary, solution permeability (Montgomery Consulting Engineers, 1974).

2.3.2.5 The Klondyke Formation (Nkf)

Superposed on the Kennon Limestone is the Klondyke Formation (with type section at the Klondyke Hot Springs), a clastic sedimentary unit covering an approximately 8 square kilometer area (Montgomery Consulting Engineers, 1974). The Klondyke is a thick sequence consisting of conglomerates, tuffaceous sandstone, volcanic and tuff breccia, some siltstone, and mudstone (Geological Map of the Baguio City Quadrangle, 1995). The Klondyke Formation is 150 meters thick and is also highly hydrothermally altered and forms thick residual soils. It exhibits a high relief with valleys and ridges and is visible along steep cliffs or escarpments. In some areas, fracturing and faulting is quite extensive (Montgomery Consulting Engineers, 1974).

The Klondyke, like the ZigZag Formation, is soft and weathering has progressed to as deep as 30 meters. The large areal extent of these two formations results in almost 80% of Baguio City being covered with residual soil (Rillon, 1992).

2.3.2.6 The Baguio Formation (NQbf)

The Baguio Formation is composed of pyroclastics (tuff, volcanic conglomerate, and volcanic breccia) and is substantially distributed over the surface of the Baguio Plateau. It is considered the cap rock with an areal distribution greater than 20 square kilometers (Mendoza, 1983). The elevations range from 1300 to 1700 meters above sea level but the unit has a maximum thickness of less than 100 meters. Large boulders distinguish this layer from other units (Mendoza, 1983). Outcrops of the unit are always highly fractured and weathered. Completely weathered portions become clays with the original texture of the parent material (Montgomery Consulting Engineers, 1974).

2.3.2.7 Quaternary Alluvium (Qal)

Along the flat-lying valleys and basins on the plateau, Quaternary alluvial deposits are present, covering less than 6 square kilometers (Mendoza, 1983). These are composed of unconsolidated sediments consisting mostly of rock fragments from older rock formations, talus debris, and residual soils (Geological Map of Baguio City Quadrangle, 1995). The deposits can be coarse to very coarse and contain boulders in gorges, canyons, and steep-walled valleys. The major deposits can be found in some small basins in Baguio City Proper, La Trinidad Basin, and Bued River Valley beginning at Camp 7 going north along Kennon Road (Mendoza, 1983).

2.3.3 Geologic Structures

In recent geologic times, the Baguio area has undergone intense tectonic activity. Severe faulting and other zones of structural weakness have had an influence on the orientations of mountain ridges and stream valleys (Mendoza, 1983).

Several of the major faults are oriented in the north-south direction (Table 2.1, Figure 2.9). Minor, subsidiary faulting is also present (Rillon, 1992). The rock on one or both sides of a fault plane may have become shattered during the tectonic rupturing process. This can be a problem in excavations as well as in natural slopes because the weakened ground is exacerbated by rainwater percolating freely into cracks causing elevated water pressures behind the slopes.

Table 2.1 Distribution of Major Faults in the Cordillera Region (Mendoza, 1983)

Province	Type of Fault	Direction
Pangasinan (from Burgos to Bani)	Undetermined	North-South
Benguet 4 km east of Kapangan 3 km southwest of Kapangan	 undetermined undetermined	 N35W N25E – N10E
Abra (Bangued)	Normal	N60E
Ilocos Norte South of Badoc 4 km east of Dumalnog 10 km east of Pasuquin	 Normal undetermined undetermined	 East-West North-South N20E, towards Bangui
Ilocos Sur (Santa)	Normal	N20W

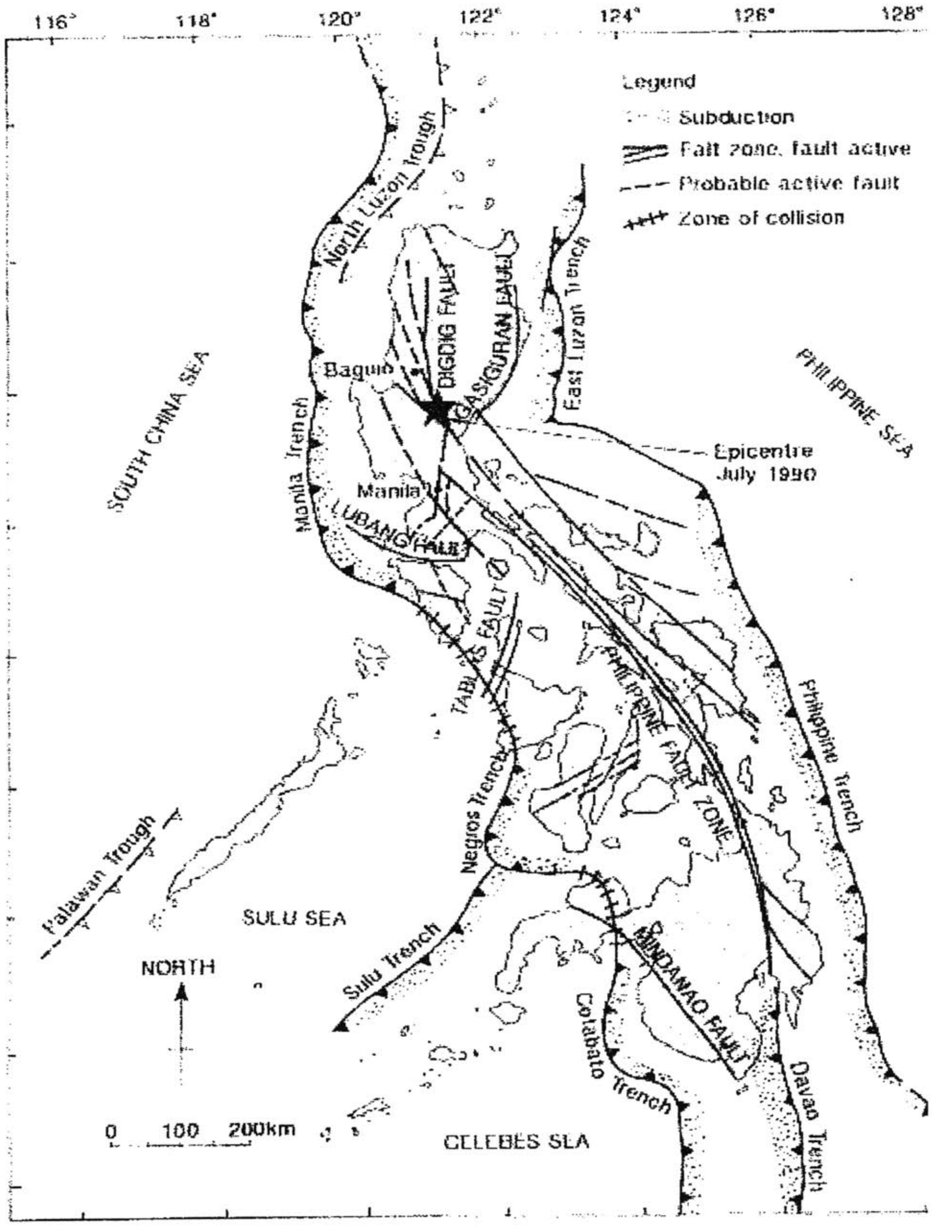


Figure 2.9 Distribution of Potential Earthquake Generating Faults in the Philippines (Rillon, 1992)

2.4 Climate and Surface Hydrology

The most widely accepted scheme for climatological classification of different regions in the Philippines is based on rainfall distribution. This system divides the country into four weather types.

Baguio falls under the Type 1 weather classification characterized as having a pronounced rainy season and dry season (Montgomery Consulting Engineers, 1974). From November to April of each year, conditions are hot and dry. From May to October, rainfall is extremely high, resulting from strong southwest monsoons and tropical cyclones (Figure 2.10). This weather is typical throughout the western side of the country. Average annual rainfall in Baguio City is 3648 millimeters (1950-2003). Variations from this average can be as high as 196 percent. An average of five tropical cyclones, with a maximum recorded number of nine tropical cyclones, affect Baguio every year (Rillon, 1992).

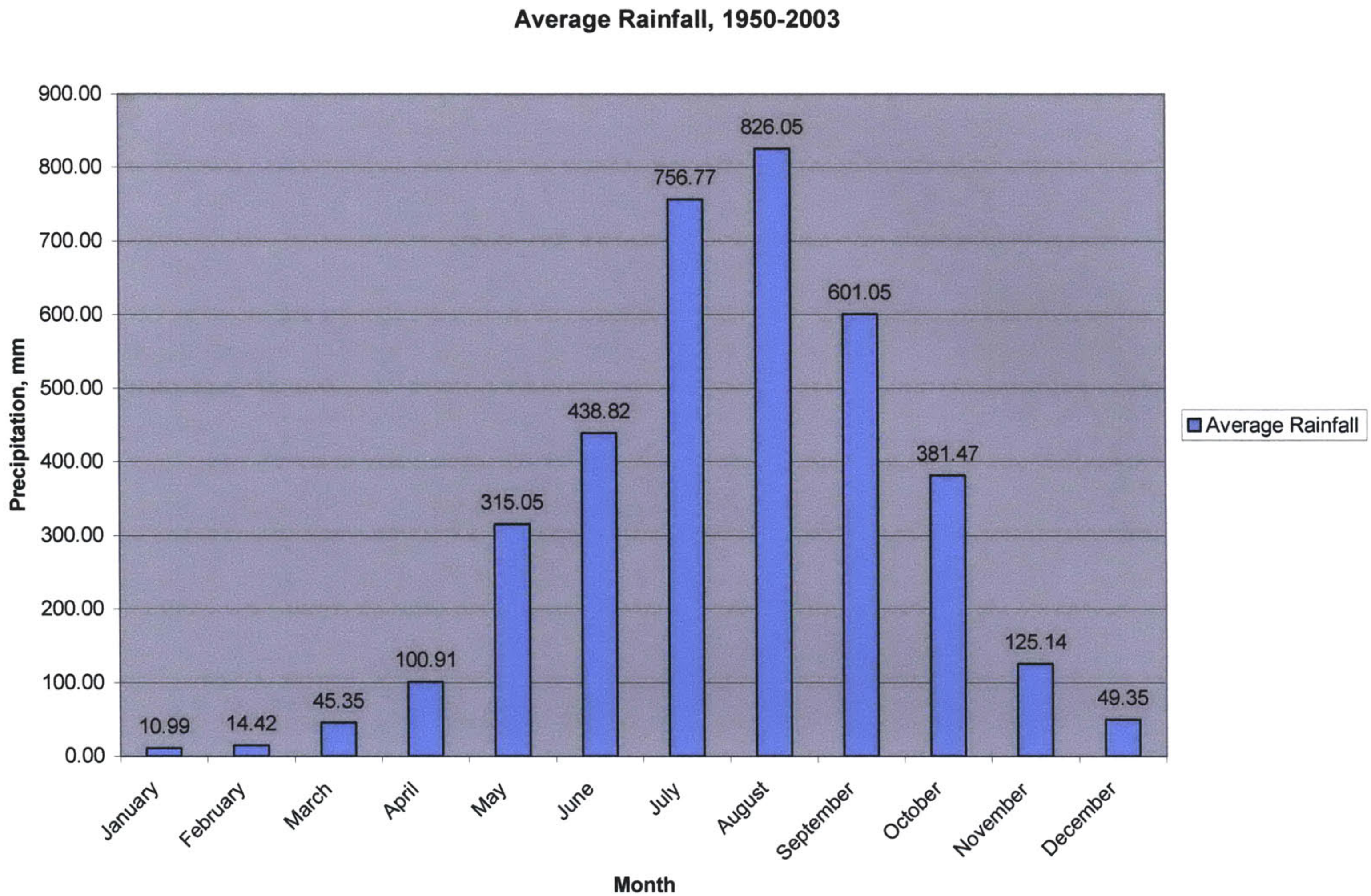


Figure 2.10 Average Monthly Rainfall in the Baguio City Area

Type 2 weather has very extreme maximum rainfall during the months from November to January, but no real dry season. This is typical along the eastern side of the Philippines and is brought about by northeast monsoons and trade winds. Type 3 does not have any pronounced wet and dry seasons. May to October is relatively rainy, but the range between maximum and minimum rainfalls is not large. Type 4 has very evenly distributed rainfall throughout the year (Montgomery Consulting Engineers, 1974). Figure 2.11 shows the portions of the Philippines that fall under each climate Type.

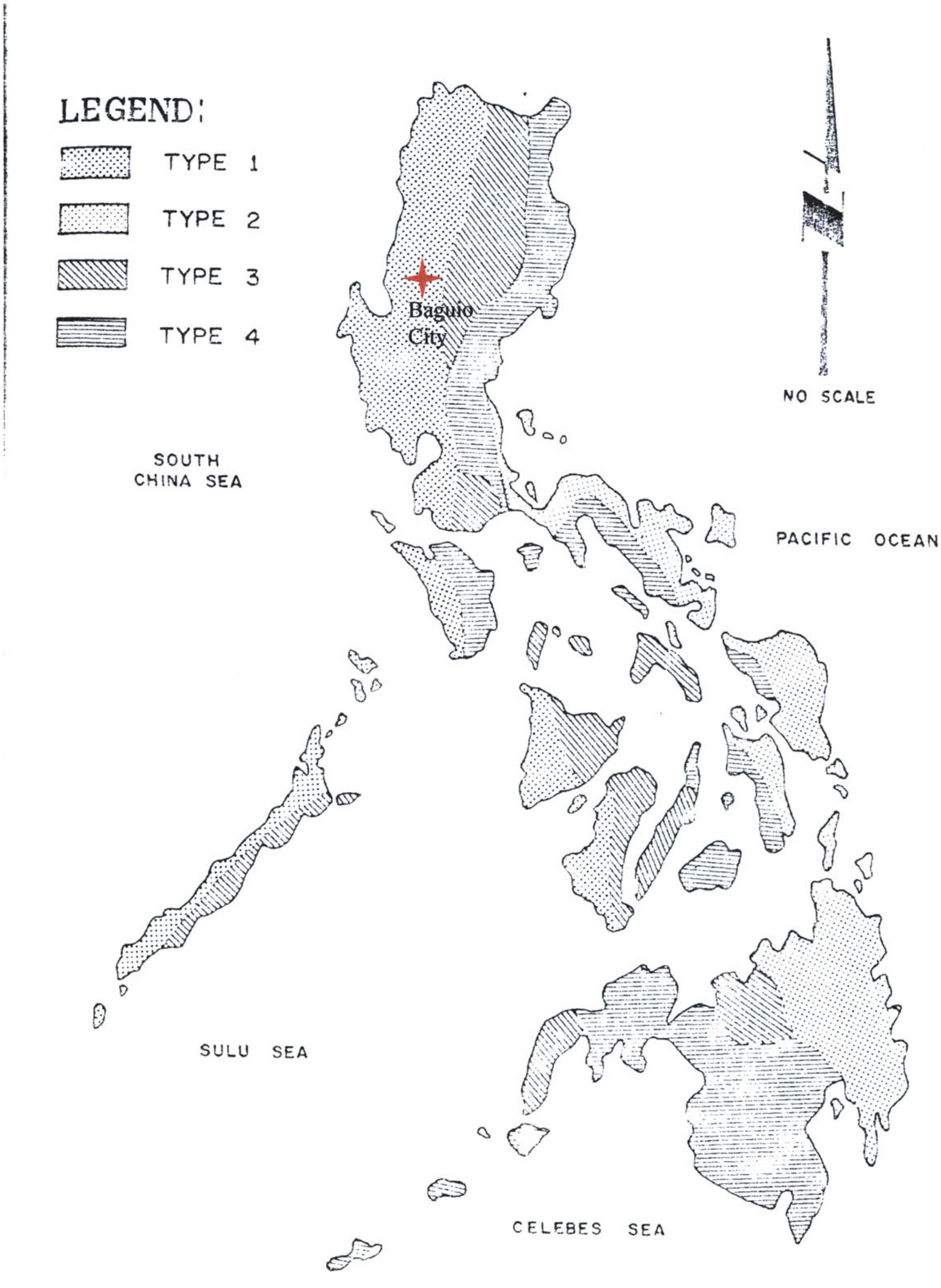


Figure 2.11 Rainfall Distribution Map (Montgomery Consulting Engineers, 1974)

Because Baguio City is situated on a highland plateau, no major rivers pass through it. All drainage occurs radially outward from the periphery of the Plateau. Small streams and creeks serve as the drainage channels from the hills and slopes within the Baguio plateau. As mentioned in section 2.2, the Baguio City plateau can be readily divided into four drainage systems, namely, the northward flowing Baguio-La Trinidad Drainage, the southwest flowing Asin-Tuba Drainage, the south flowing Bued River and the southeast flowing Agno River Drainages. The four systems' total tributary drainage area is 240 square kilometers. Elevations range from 600 to 2250 meters above sea level within these areas (Mendoza, 1983). On the plateau itself, the topography can be described as mild to moderate. However, in the localities at the perimeter of the Plateau the topography is extremely rugged.

From monthly precipitation data, 43% of annual precipitation occurs between July and August. Approximately ninety-one percent of total annual rainfall occurs between May and October.

2.5 Vegetation

The most common vegetational cover is the broadleaf (or short leaf) pine tree that is able to grow in the area because of the cool weather (Montgomery Consulting Engineers, 1974). The pines are a medium-size family of trees, mostly evergreen, of widespread distribution in the temperate areas of the northern hemisphere and some parts of Asia. The family, which contains about 210 species placed in 10 genera, has enormous economic importance as a source of timber and pulpwood, among other products. Members of the family characteristically have helically arranged, needlelike leaves. The genus confined to South China and Southeast Asia is *Keteleeria* (Microsoft Encarta, 2004).

Where manmade terraces have been constructed or where the topography is sufficiently flat, vegetables, rice, corn, bananas, coffee, and fruit are grown (Rillon, 1992).

2.6 Existing Land Use

Population pressure was first experienced in the City in the 1950's (Mendoza, 1983). This was when development began in areas outside the Plateau. Residential areas were built up some distance from the Central Business District thereby concentrating commercial activities in the CBD (Figure 2.12).

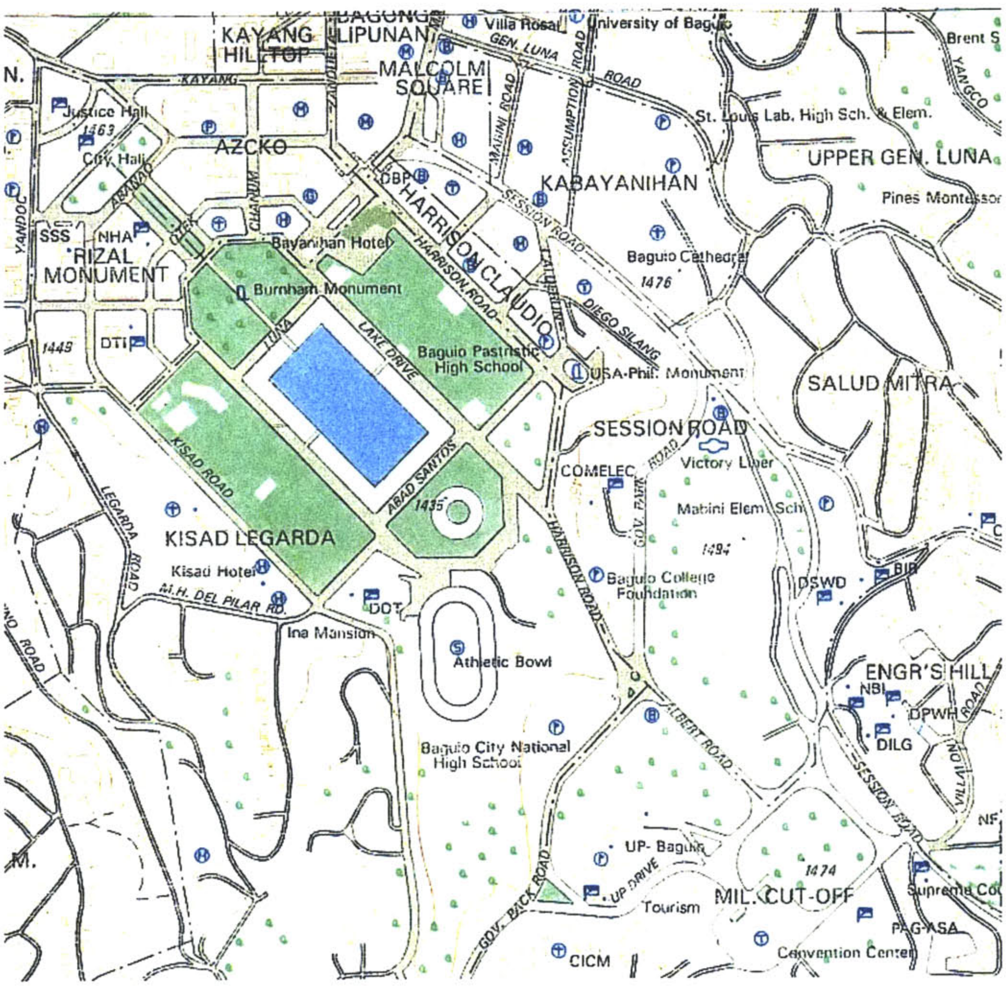


Figure 2.12 Central Business District (Topographic Map of Baguio City, 1995)

Areas with high population density, property, and economic activity that will be adversely affected by disastrous geologic phenomena must be given focus in risk zonation. There are five land-use classifications as adopted from the Benguet Physical

Land Resources Evaluation conducted by the Bureau of Soils of the Department of Agriculture, viz., built-up areas, agricultural areas, grassland/shrubland areas, woodland/forest areas, and miscellaneous land types.

2.6.1 Built-up Areas

These areas are used primarily for commercial and residential purposes. Baguio City Proper is the major population center in Benguet province and in the entire Cordillera Region. Two thousand six hundred hectares (approximately half of Baguio City's land area) are classified as built-up. La Trinidad, which is the capital of Benguet province, is 21.1% built-up (Rillon, 1992). Built-up areas are found mostly on the Baguio Plateau (the portion shown in Figure 1.5), along broad alluvial valleys like La Trinidad, flood plains of major streams, and near access roads and water sources.

2.6.1.1 Commercial

The public markets comprise 20% of the highly developed Central Business District (Mendoza, 1983). Shops, offices, and recreational facilities can also be found in this area, housed in medium-rise buildings. Along the road north to La Trinidad, industrial activity is heavily concentrated.

2.6.1.2 Residential

Housing in Baguio City is of medium to high density with approximately 5,000 people/km^2. Low income housing tends to be located on steep slopes and in landslide areas. Increasing numbers of applications for subdivision development in the steep slopes of the City are being submitted to the authorities that issue building permits (Punongbayan, 1992). A study of the vulnerability of these slopes to mass movements is thus a necessity.

2.6.1.3 Institutional

Institutional land use refers to government housing and reservations, military reservations, and social service facilities (Mendoza, 1983). Health, welfare, and educational institutions are mainly located in downtown Baguio.

2.6.1.4 Open Space

Open spaces consist of steeply sloping areas, inaccessible areas, areas with unsuitable soil and rock outcrops, scenic areas, points of historical interest, and hazardous areas (Mendoza, 1983).

2.6.2 Agricultural Areas

Rice is the primary crop that is planted in paddies or terraces. Other crops that are planted in the Plateau, on mountain and hill slopes, and on river terraces are corn, vegetables, legumes, fruits, root crops, and coffee, among others. Within the BLIST (Baguio-La Trinidad-Itogon-Sablan-Tuba) or Greater Baguio area (Figure 1.3), 1557 hectares are devoted to agriculture. This is only 2% of the total BLIST area (Rillon, 1992).

2.6.3 Grassland/Shrubland Areas

Unforested areas covered with grasses and shrubs are generally found on steep to very steep slopes. These are usually idle land very rarely used for pasture purposes. This type of land comprises the largest percentage of the BLIST area (Figure 1.3), at 57.3% or 56,427 hectares (Rillon, 1992). Because these are idle, future development will most likely take place in this area.

2.6.4 Woodland/Forest Areas

Forest areas in BLIST are found mostly in the municipality of Tuba (Figure 1.3). The total forest area in BLIST is 33,718 hectares or 34.2%. The ideal figure for the entire BLIST area is 60% forest cover (Rillon, 1992). However, deforestation due to illegal logging and slash-and-burn farming practices has made this figure very difficult to achieve.

2.6.5 Miscellaneous Land Types

These include mine pit sites, filling ponds, reservoirs, and riverwash/riverbeds. In total, these areas occupy 750 hectares, which comprise less than 1% of BLIST (Rillon, 1992). Table 2.2 shows the distribution of land use within the limits of Baguio City. Table 2.3 shows the mapping unit legend for Figure 2.13, the land use map of the greater Baguio area shown at a scale of 1:75,000.

LAND USE	BAGUIO CITY	
	Has	%
Built-up	2602	48.35
Agriculture	87	1.62
Grasslands	2406	44.70
Forest	277	5.15
Miscellaneous	10	0.19
TOTAL	5382	100.00

Table 2.2 Land Use in Baguio City Proper (Rillon, 1992)

Mapping Unit No.	Dominant Land Use	Approx. Percentage	Associated Land Use	Approx. Percentage
1	BUILT-UP AREAS Residential & Commercial	100	None	0
2	Residential	80	Vegetables Shrubs Grasses Forest	10 5 3 2
3	AGRICULTURAL AREAS Rice Terrace Irrigated	90	Grasses Shrubs	8 2
4	Rice Terrace Irrigated	80	Grasses Shrubs	15 5
5	Rice Terrace Irrigated	65	Vegetable Terrace Grasses Shrubs Forest	20 5 5 5
6	Paddy Rice Irrigated	90	Vegetable Grasses Shrubs	5 3 2
7	Vegetable Terrace	100	None	0
8	Vegetable Terrace	85	Grasses Shrubs Forest	5 5 5
9	Vegetable Terrace	65	Grasses Shrubs Forest	15 10 10
10	GRASSLAND/ SHRUBLAND AREAS Grasses	85	Shrubs Forest	10 5
11	Grasses	70	Shrubs Forest	25 5
12	Grasses	60	Shrubs Forest Vegetable Terrace	20 15 5
13	Grasses	60	Shrubs Vegetable Terrace Pineapple Banana	20 10 5 5
14	Shrubs	85	Grasses Forest	10 5
15	Shrubs	75	Grasses Forest	20 5
16	Shrubs	70	Grasses Forest Banana	15 10 5
17	WOODLAND/ FORESTLAND AREAS Forest	85	Grasses Shrubs	10 5
18	Forest	75	Grasses Shrubs	15 10
19	Forest	65	Grasses Shrubs	20 15
20	Forest	60	Shrubs Grasses	25 15

Table 2.3 Mapping Unit Legend (Present Land Use Map, Benguet Province, 1980)

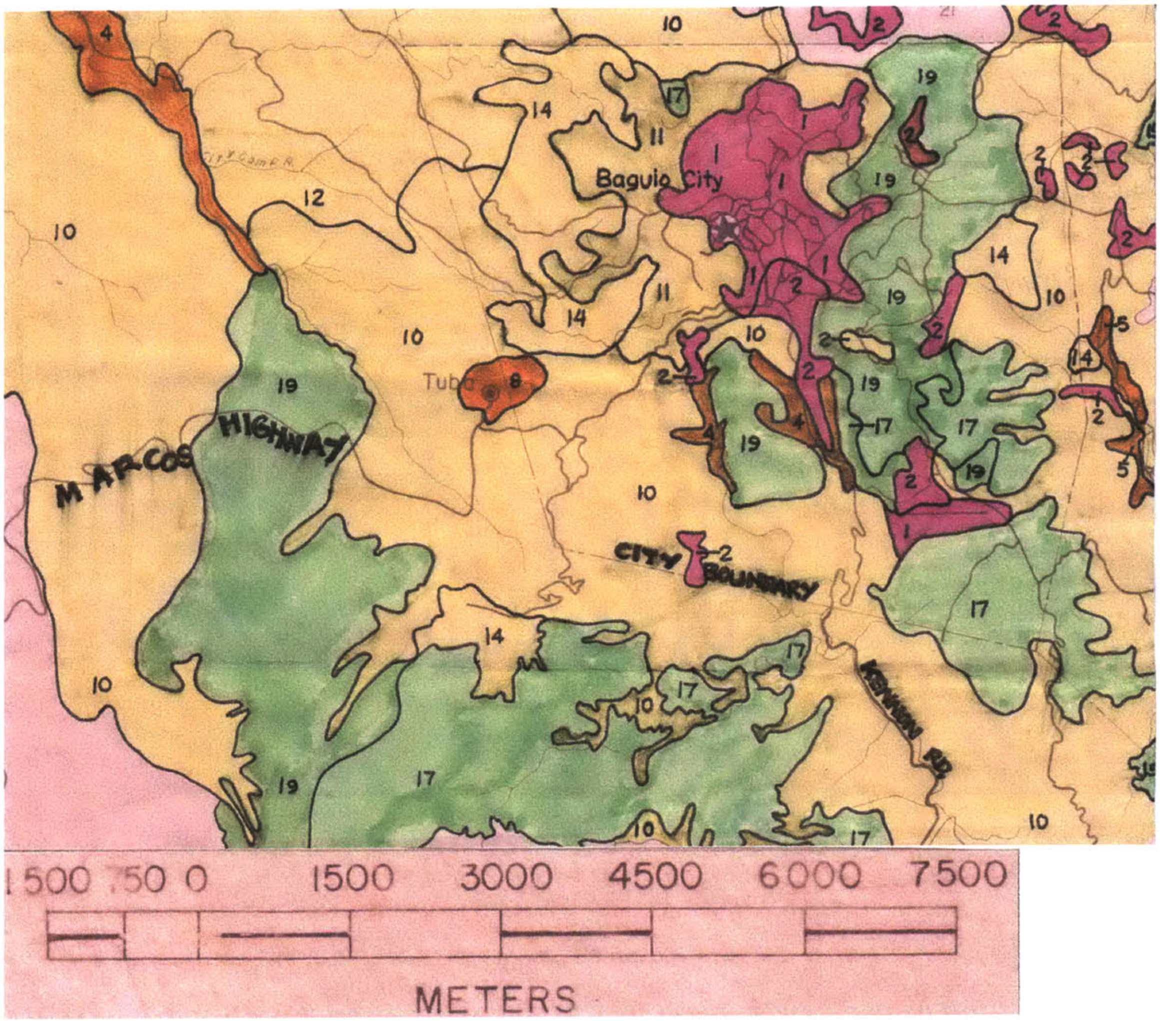


Figure 2.13 Baguio Area Land Use (Present Land Use Map, Benguet Province, 1980)

Chapter 3. Characterization of Major Landslides

Several reports have been written on the major landslides that have occurred in Baguio City. Most of these were government-led studies and investigations. This chapter contains the synthesis of the findings of these reports and field investigations. The objective is to characterize the major landslides that have occurred in the area. The results of this synthesis of data form the basis of the approach proposed in the next chapter for evaluating the vulnerability of a given area to landslides, including a Landslide Risk Rating System for the study area. The rating system may be adapted for use in adjacent locations.

3.1 Mass Movements Within the City Limits

3.1.1 Magsaysay Avenue Landslide

The Magsaysay Avenue area (Figure 3.1) is underlain by agglomerate and weathered tuffaceous sandstone and shale (the Baguio Formation). One to three meters of soil and fill materials can be found in the area. The bedding planes generally strike north-south and dip towards the slope by 20 degrees. During the 1967 rainy season, landslides cut a road section along Magsaysay Avenue and rendered it impassable. Houses were also damaged. The materials involved in the landslides, particularly those at the lower slope and depression, experience occasional soil creep when saturated by heavy rainfall. The materials flow to the creek below the slope and initiate progressive slope failure (Lukban, 1968).

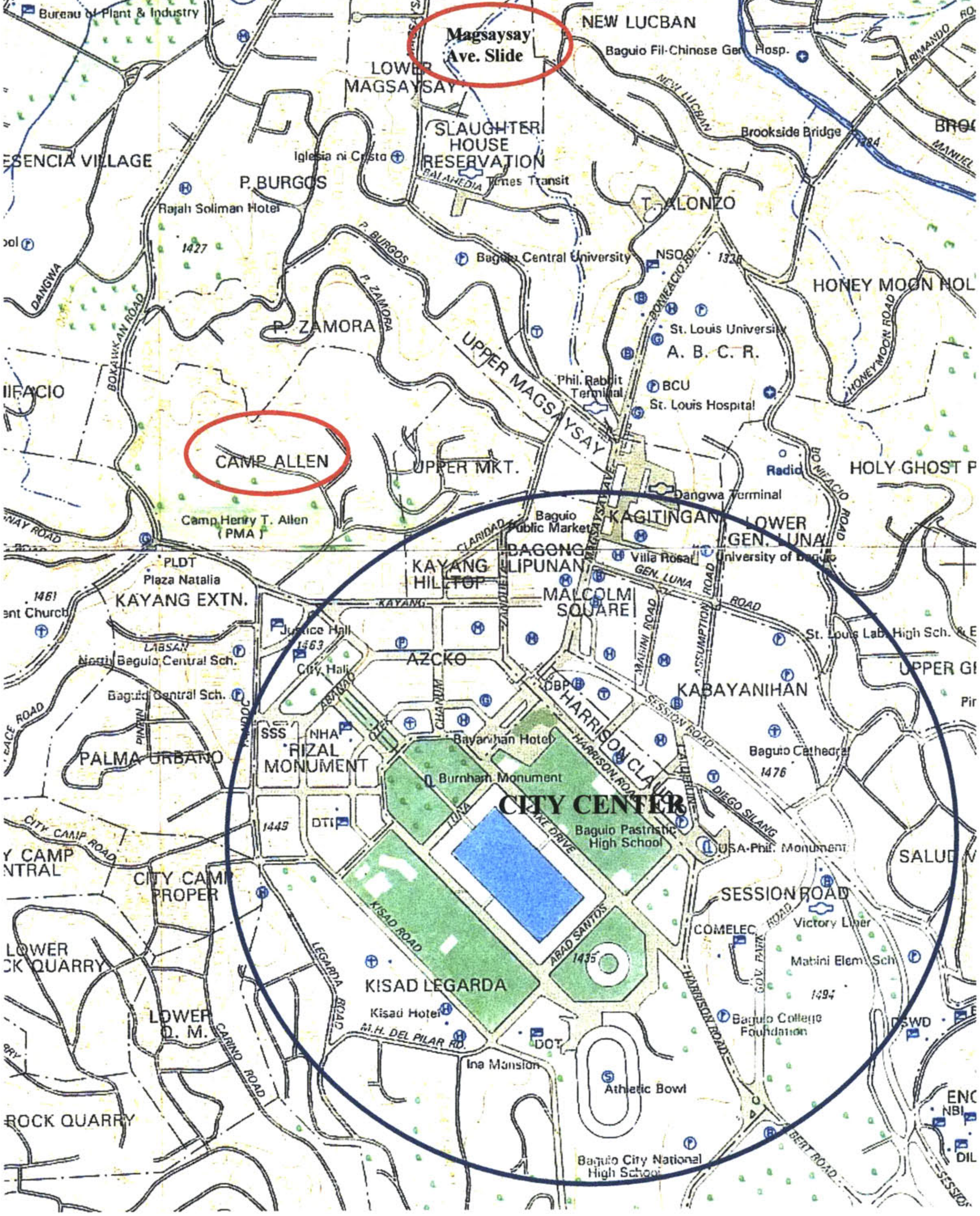


Figure 3.1 Magsaysay Avenue Slide (Topographic Map of Baguio City, 1995)

Several factors are identified as causing the continuing movement of the Magsaysay Avenue landslide:

- The area is within an old landslide system that is bounded by two intersecting faults (Lukban, 1968). These are potential sliding surfaces due to the low resistance of these fault zones to shearing stress.

- The ground movement of 1967 was in an area composed of previously transported slide materials. The old slide partly buried a section of creek (Lukban, 1968). There is, therefore, a possibility that an underground cavity or stream underlies the area.

- Large volumes of rainfall occur in the area during the rainy season. This is accompanied by percolation of water into the disturbed ground. The saturation of the soil results in a corresponding decrease in its shearing resistance as well as exacerbation of the progressive creep of the slope. Localized fault structures and old zones of disturbance further facilitate percolation of water into the subsurface.

- Most roads within the watershed were not provided with adequate drainage. Even during low rainfall surface water flows downslope into the depression in the slide area (Lukban, 1968). During heavy rains, Magsaysay Avenue virtually becomes a canal for the runoff coming from the City center and surface water is brought directly to the old slide area (Figure 3.1).

- Relatively high permeability fill materials were placed in the depression created by the original landslide (Lukban, 1968). Because Magsaysay Avenue is located on the Baguio Formation, the residual soils overlain by the fill are lower permeability clays. This promotes groundwater retention and hydrostatic pressure build-up in the fill leading, in turn, to new slope failure.

- Road filling, benching, and housing construction in the area also disturbed the equilibrium of the slope (Lukban, 1968).

3.1.2 Camp Henry Allen Landslide

Slumping was observed at the southeastern limit of Camp Henry Allen, shown in Figure 3.1 (Mendoza, 1983). The area is also located on the Baguio Formation where the materials involved in the slide are decomposed and highly fragmented tuffaceous agglomerate overlain by a thin layer of residual soil. The residual soil usually does not have a thickness greater than 3 feet (Mendoza, 1983).

The high rate of precipitation was again the triggering factor for the landslide. In addition, the slope was also earlier undercut in order to create space for the construction of houses and other structures. The area has no vegetal cover and surface drainage is inadequate (Mendoza, 1983).

3.1.3 Philippine Military Academy Landslides

There were several landslides that occurred inside the Philippine Military Academy campus (Figure 3.2), namely those at the Parade Ground, Osmena Drive, Melchor Hall, Quezon Avenue, and Quirino Avenue. All these areas are underlain by the ZigZag Formation.

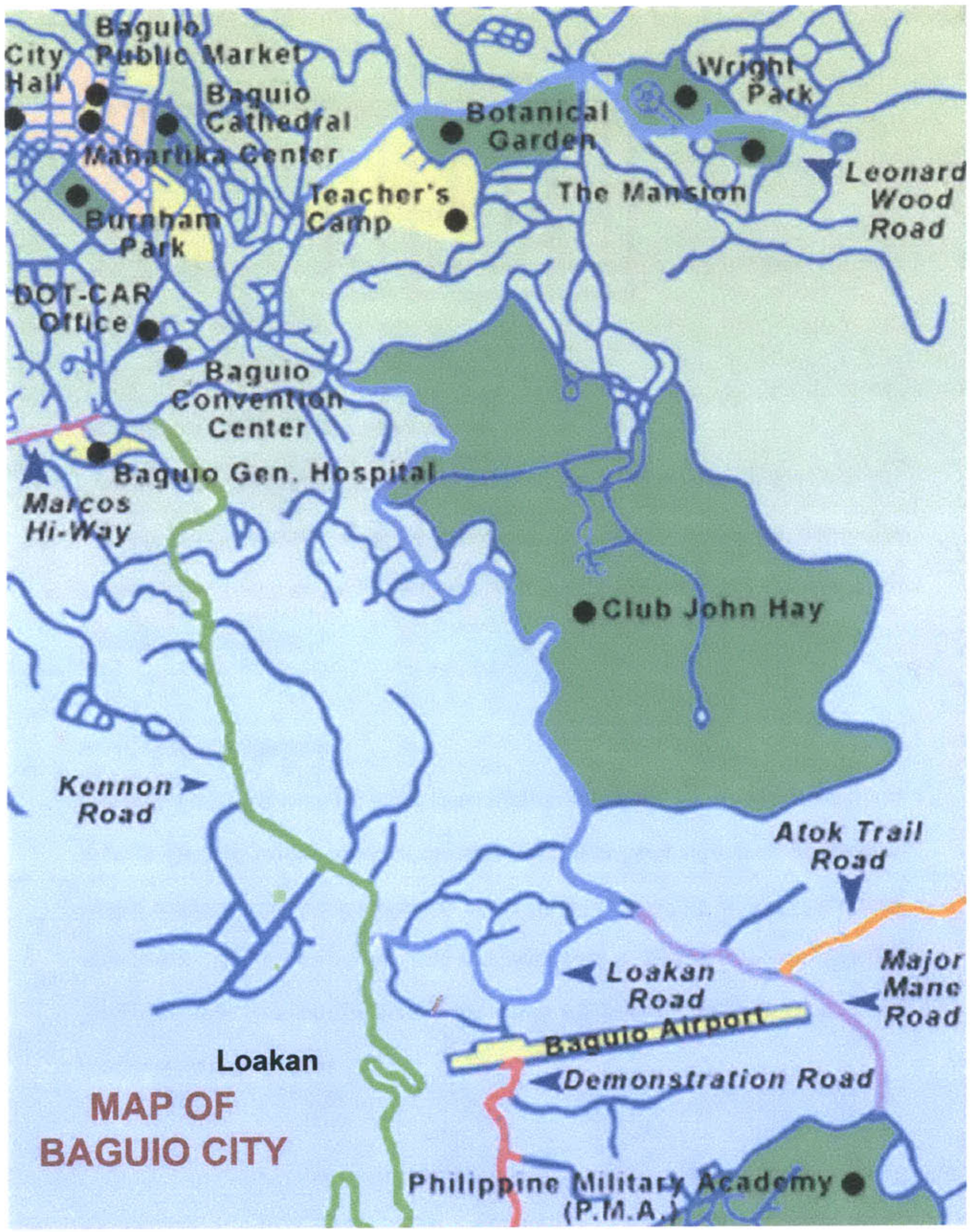


Figure 3.2 Location of Philippine Military Academy (http://www.baguio.gov.ph/, 2004)

Networks of tension cracks were found in all of the landslide areas (Mendoza, 1983). These tension cracks provided pathways for the percolation of rainwater and acted as planes of weakness along which movements preferentially occurred.

3.1.3.1 Parade Ground Landslide

Before this area was filled to become a parade ground, it was a narrow creek gulley. The fill consisted of soil and rocks borrowed from nearby areas. Mendoza (1983) reports that internal drainage may not have been provided for when the gulley was filled. Because the gulley is a natural drainage path, it is to be expected that subsurface water still flows preferentially in this channel.

3.1.3.2 Osmena Drive Landslide

This is also a filled area. The fill materials consist of loosely bound andesite boulders and cobbles mixed with silty material. It is suspected that compaction was incomplete when the fill was placed. Tension cracks in the area occur as circular arcs, indicating that the landslide was rotational. Displacements of the cracks are generally from 4 to 6 inches (Mendoza, 1983).

Atterberg tests performed on the soil fill material show that it is silty with little to no plasticity (Mendoza, 1983).

3.1.3.3 Melchor Hall Landslide

The landslide material in this area is composed of fill mixed with the highly decomposed bedrock of the ZigZag formation. The fine-grained fraction of the soil at the Mechor Hall site is more plastic and less porous than those of the Parade Ground and Osmena Drive areas (Mendoza, 1983).

Vertical displacements along the critical plane of rupture were a maximum of 1 ft. The slide was rotational (Mendoza, 1983).

3.1.3.4 Quezon Avenue Landslide

The material is highly decomposed and fragmented rock of the ZigZag Formation. The slide material is permeable due to the closely spaced fractures present. Several tension cracks also contribute to its high permeability. The soil fraction is clayey silt with high compressibility and medium dry strength (Mendoza, 1983).

3.1.3.5 Quirino Avenue Landslide

A massive retaining wall in this area failed due to the build-up of pore water pressure in the slope behind it. Drainage was not provided for the slope and no weep holes were installed in the wall. The slide material is a largely silty residual soil derived from the ZigZag Formation (Mendoza, 1983).

3.1.4 Barangay Camp 8 Landslide

Tilted houses and bent pipes revealed that subsidence occurred in this area (Figure 3.3), which is underlain by the Baguio Formation. Slumping due to high rates of water seepage and subsequent oversaturation of the soil is evidenced by road cracks. The seepage led to the formation of underground erosion channels and undercutting of the road. Tension cracks were observed to coincide with the faults in the area (Mendoza, 1983).

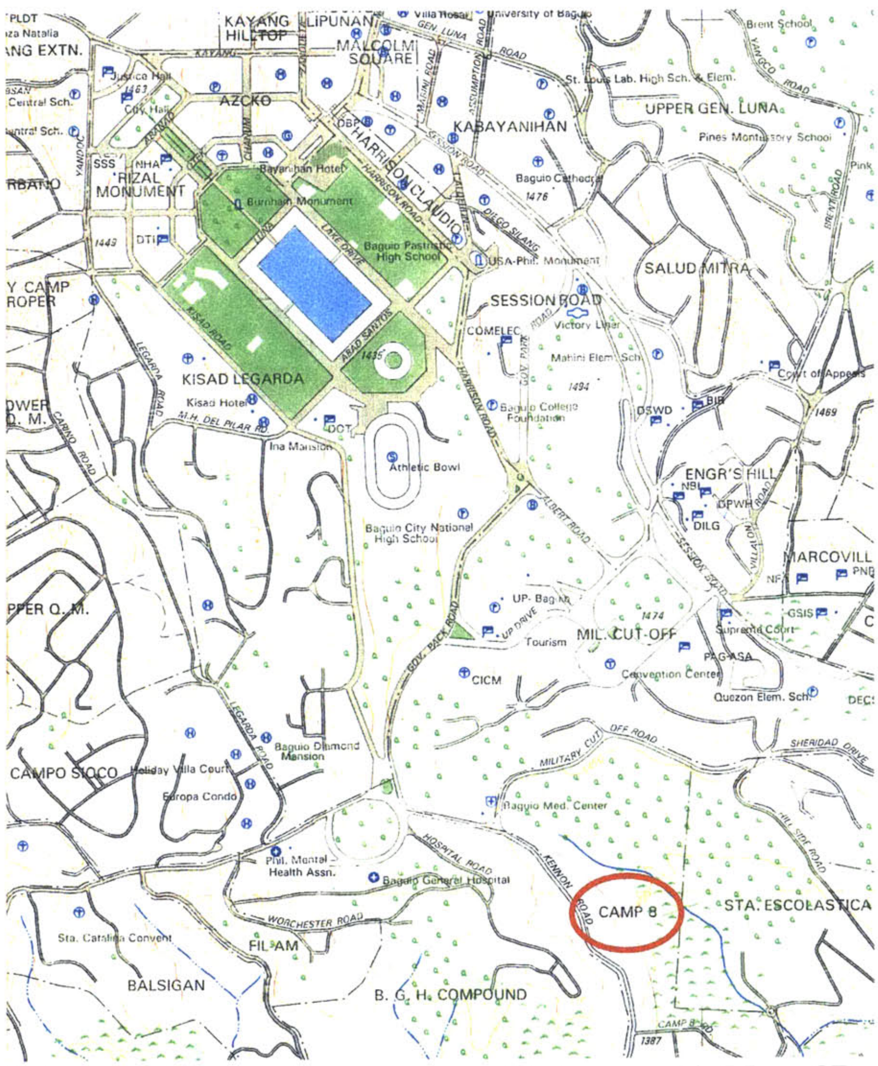


Figure 3.3 Location Map of Barangay Camp 8 (Topographic Map of Baguio City, 1995)

Table 3.1 summarizes the characteristics of the landslides discussed above.

Within City Limits					
Landslide	Date	Weather Condition	Damage	Type	Faults
Magsaysay Ave. (Baguio Formation)	1967	Rainy season	Road section cut and made impassable Houses damaged		present
Camp Allen (Baguio Formation)	1973	Rainy season	2 houses destroyed Cluster of houses north of area in imminent danger		
Philippine Military Academy (ZigZag Formation)					
I. Parade Ground Landslide	Old landslide				
II. Osmena Drive Landslide	Old landslide			rotational	
III. Melchor Hall	Old landslide			rotational	
IV. Quezon Ave. landslide (200m of road section)	Old landslide		Cluster of houses within slide area in imminent danger		
V. Quirino Ave. Hall	Old landslide		Massive retaining wall that failed (no weep holes)		
Barangay Camp 8 (Baguio Formation)	Old landslide		road cracks parallel to road, coincide with faults Cracks on walls of houses, pavements, posts, etc. houses leaning at various angles Bent pipes		present

Table 3.1 Summary of Characteristics of Landslides Within City Limits

3.2 Mass Movements Outside the City Limits

3.2.1 Mines View Park & Cecilio Apostol St. Landslides

Three hundred meters of road section were affected by the landslide in this area (Figure 3.4). Ground instability was indicated by tension cracks and the sudden appearance of springs at the lower parts of slopes (Paderes, 1972). The area is covered with lawn grasses and only occasional pine trees, which are apparently inadequate for slope stabilization. The ground surface is moderately to steeply sloping. Small creek tributaries drain the area (Paderes, 1972).

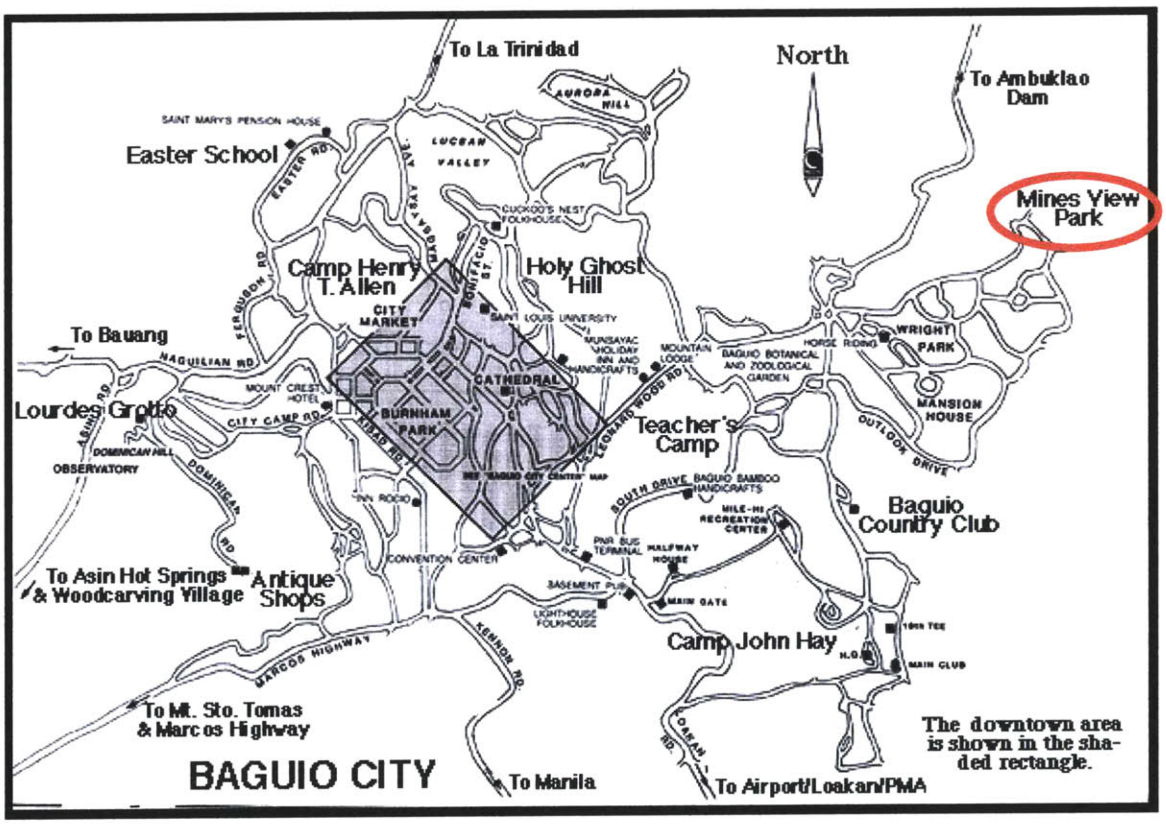


Figure 3.4 Mines View Park Location Map (http://www.baguio.gov.ph/, 2004)

The Mines View Park area is underlain by a thick sequence of pyroclastic rock (the Baguio Formation). The rock is relatively unfractured and moderately competent, with fissures and joints generally tight and far apart. A 2.0 to 4.0-meter thick, slightly decomposed layer of residual soil rests above the bedrock. This residual soil is a mixture of moderately to highly compressible silt and angular detritus of the parent rock loosely cemented in a matrix of clay materials. Atterberg tests of the clay and silt fractions show that the average liquid limit is 20.9%, while the average plastic limit is 20% (Paderes, 1972). Hence, the soils have a very low plasticity index. It would take only a small amount of increase in moisture content to transform this soil from plastic to liquid state.

Paderes (1972) reports that although the soil material is moderately compacted, it is comparatively permeable due to tension cracks caused by previous ground movements.

The following are identified as having caused the landslide in the Mines View Park and Cecilio Apostol St. area:

- The unusually high degree of precipitation coupled with the tension cracks in the area allow for the easy downward percolation of water. This caused piping, as shown by the presence of springs at the lower parts of the slopes.
- Poor surface drainage conditions (Paderes, 1972)
- Lack of vegetation.

3.2.2 Tuding Landslides

The Tuding Landslides derive their name from their location in Barangay Tuding, Itogon, Benguet Province (Figure 3.5). This village is at the eastern boundary of Baguio City (underlain by the Baguio Formation), in the intermediate uplands immediately adjacent to the Baguio Plateau.

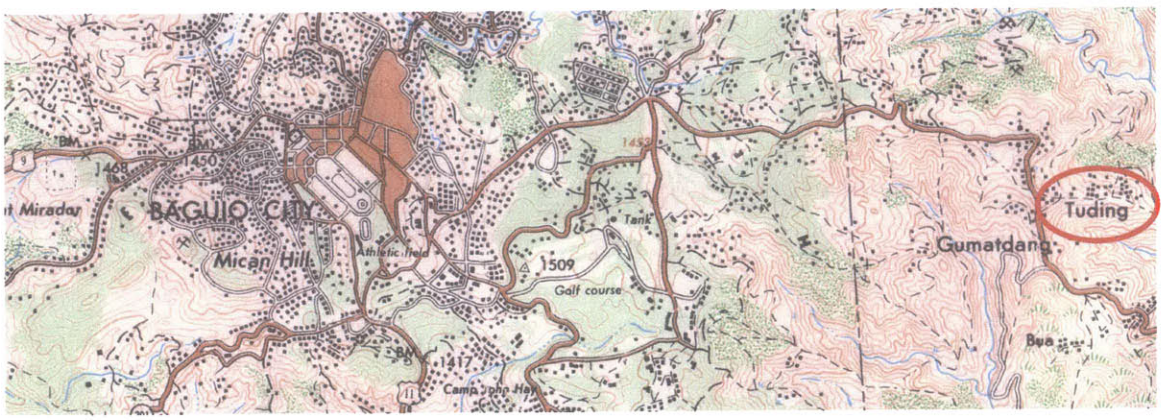


Figure 3.5 Tuding Location Map (Topographic Map of Baguio City, 1977)

3.2.2.1 Landslides I-X

The slides occurred in the later part of June 1985 during and immediately following weeks of heavy rains brought about by typhoons "Kuring" and "Daling". The mines located in the municipality of Itogon and roads from these mines to the City proper were rendered almost totally inaccessible by the landslides. Houses in the area were damaged and some had to be abandoned (Baguilat & Cabalda, 1985).

The highest elevation in the area is 1,550 meters above sea level dropping to 1,300 meters towards the east at slope angles generally greater than 30 degrees (Baguilat & Cabalda, 1985). At high slope angles such as these, the velocity of runoff is increased, as is the rate of erosion.

The reports of landslides at the eastern limit of Baguio City all indicate that the slides occurred almost immediately after prolonged, intense rainfalls. A large portion of the slide-affected area is drained by small tributaries of the Ambalanga River, which is a major tributary of the Agno River (Baguilat & Cabalda, 1985). This resulted in the undercutting/scouring of slopes that was observed in the landslides in this area. Slow and continuous creep is still being observed along the unstable slopes (Baguilat & Cabalda, 1985).

The Baguio Formation, predominantly exposed in the area of the Barangay Tuding slides, is underlain by the ZigZag Formation as seen along creeks at the lower portions of the landslides. Particularly along the landslide-affected slopes, the Baguio Formation was observed to have undergone hydrothermal alteration (silicification, pyritization, argillization) and thus has reduced resistance to weathering. There is a thick cover of residual soil in the area that consists of these highly weathered pyroclastics (Baguilat & Cabalda, 1985).

The presence of fault breccias, gouge zones, faceted spurs, and springs/seepages arranged linearly (preferentially following zones of weakness) indicate that the area is transected by a complex fault system. The faults typically trend NE and NW, with some intersecting within the slide area (Figure 3.6). The NW trending faults are splays of the Philippine fault while the NE trending faults are the conjugate shears of the NW lateral transcurrent faults. This indicates that the major compression is east-west (Baguilat &

Cabalda, 1985). Aside from these fault zones acting as planes of weakness, percolation of water is greatly increased through faults, joints, and bedding planes.

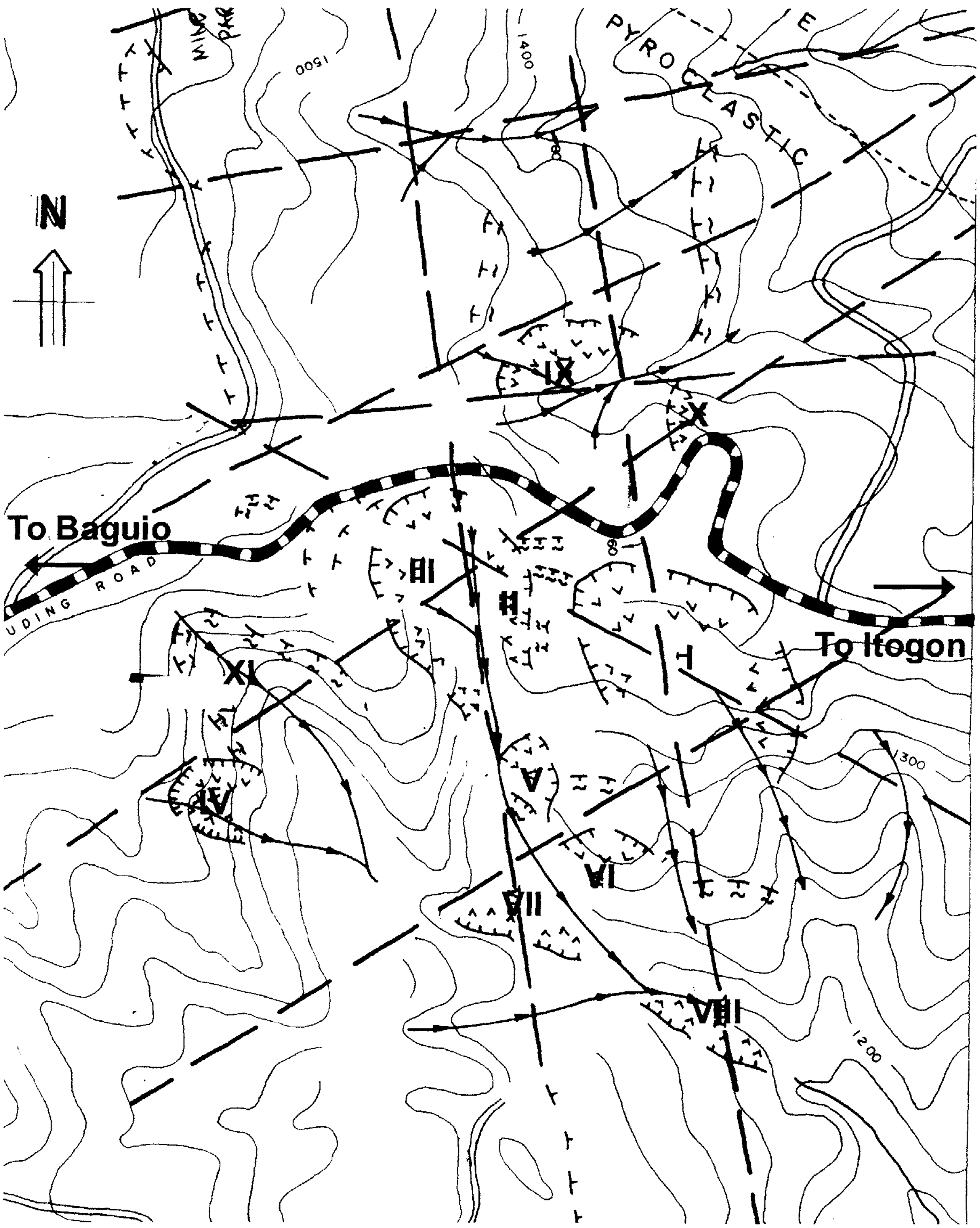


Figure 3.6 Tuding Landslides I – XI (Geotecnica, 1987)

3.2.2.2 Landslide XI at V. de los Reyes St., Outlook Drive

Landslide XI occurred within the area of Landslide IV (Figure 3.6) on July 8, 1986, on the first day of Typhoon Gading. Gading lasted for three days, delivering a total rainfall of 1223.6 mm. The site of Landslide IV is a recurring slide that experienced movement in 1982, 1983, and 1985 (Geotecnica, 1987).

The pre-slide topography is shown in Figure 3.7. It can be discerned from the profile of the ground still covered with trees and grass.

Figure 3.7 Topographic Profile of the Landslide (Geotecnica, 1987)

Figure 3.8 shows the slope failure as seen from its crest. The scar of the failure surface is seen at the left and the right sides of the photograph.

Figure 3.8 View of Slope Failure from its Crest (Geotecnica, 1987)

Figure 3.9 shows the highly weathered pyroclastic rock (residual soil) involved in the V. de los Reyes St. landslide.

Figure 3.9 The Crest of the Landslide (Geotecnica, 1987)

Figure 3.10 shows a close-up of the thick residual soil typical of the pyroclastics underlying the area (Baguio Formation).

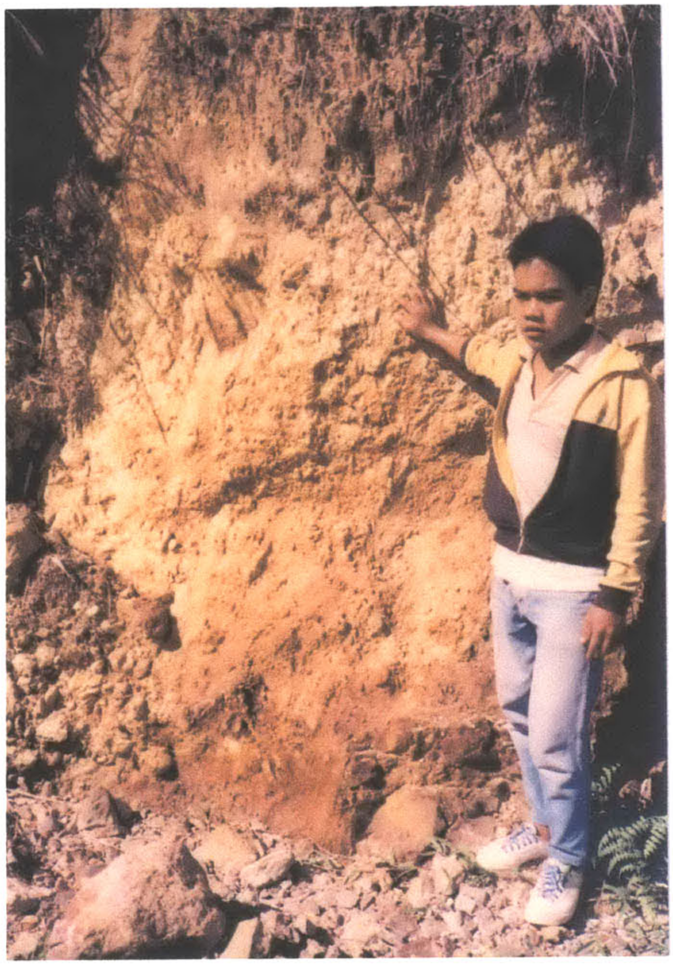


Figure 3.10 Failure Plane (Geotecnica, 1987)

Under the residual soil shown in Figure 3.11, the exposed ground is also in an advanced state of weathering. The house affected by the slide is shown at the top of the photograph.

Figure 3.11 Front View of Landslide (Geotecnica, 1987)

Figure 3.12 presents daily precipitation from June 1 to July 31, 1986. It is recorded that Typhoon Gading delivered unusually high amounts of rainfall from July 8 to 10. Landslides in the area were observed to occur when the cumulative rainfall is greater than 150-200 mm in a 24-hr period (Geotecnica, 1987). Goodman (1993) states that debris flows and slides during the rainy season in the tropics and subtropics occur when precipitation has an intensity of either 70 mm/hr (or greater) or 100 mm per 24-hr period (or greater). Based on these criteria, the apparent triggering factor for Slide XI was the 392.1 mm of precipitation on July 8, 1986.

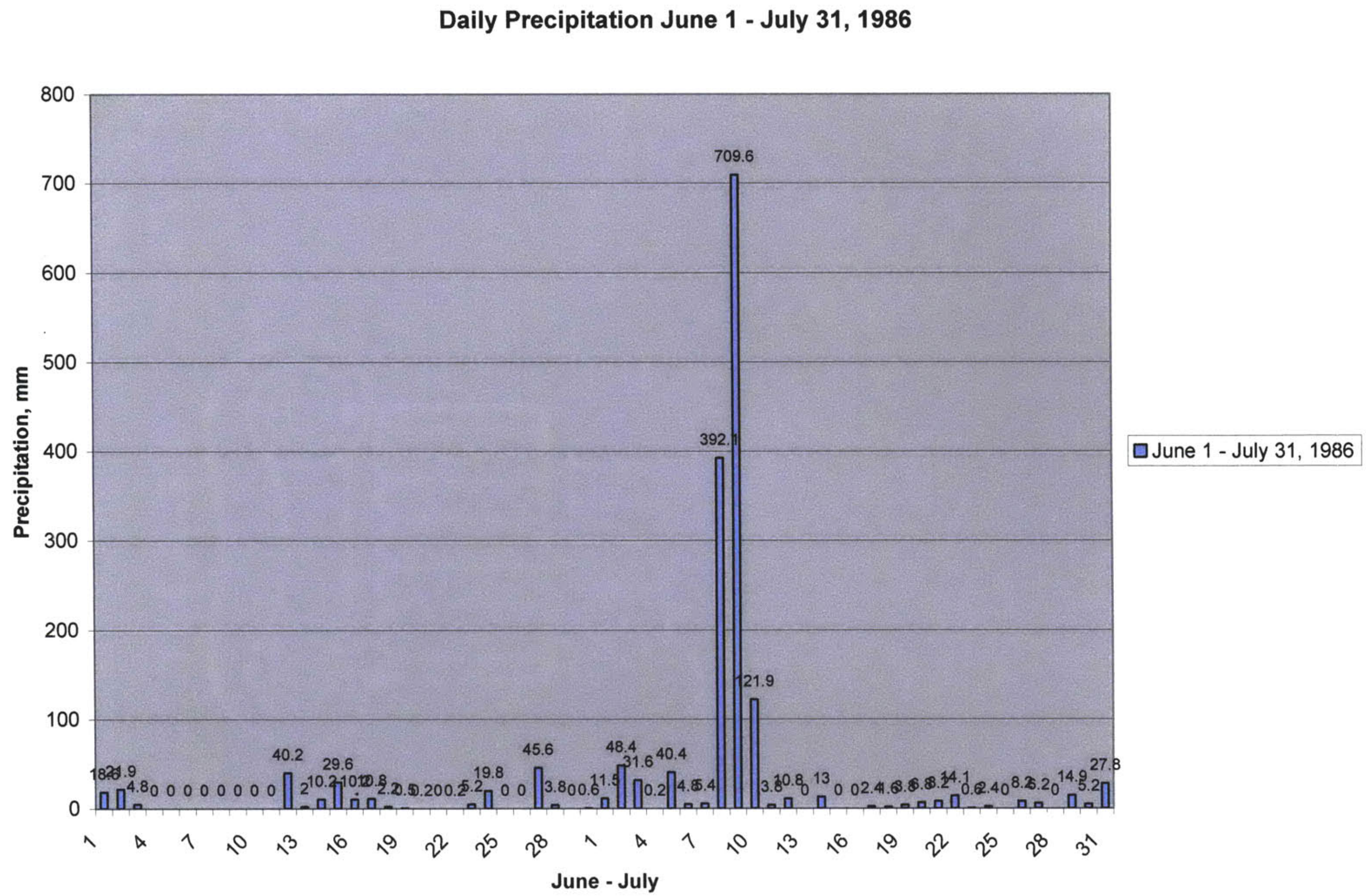


Figure 3.12 Daily Precipitation From June 1 – July 31, 1986

The rainfall percolated into the subsurface through the joints and fissures in the area (Geotecnica, 1987). The soil was thus saturated and a hydrostatic pressure buildup was induced. An attendant decrease in the cohesion of the soils reduced the shearing strength of the slope materials. Moreover, the slope materials where Landslide XI occurred were already at their residual shear strength prior to Landslide XI because it is an old slide area. Pocket penetrometer readings taken on the landslide scarps and nearby rock outcrops range from 30 to 40 tons/sq. m (Geotecnica, 1987), which is indicative of a relatively low value of cohesion.

The presence of intersecting faults in the Tuding Landslide area is likely to have disturbed and fractured the surrounding rock, consequently lowering its strength in comparison to the original strength of fresh rock and making it more susceptible to landslides. The faults also provide zones of weakness along which landslides can preferentially occur.

The Tuding area (Landslides I-XI) is one of the most landslide-prone areas in Baguio City, with the densest concentration of landslides (Geotecnica, 1987).

Table 3.2 summarizes the characteristics of the landslides that occurred outside the Baguio City limits, while Table 3.3 summarizes the results of Atterberg tests done in some landslide areas in Greater Baguio.

Outside City Limits					
Landslide	**Date**	**Weather Condition**	**Damage**	**Geometry**	**Faults**
Bgy. Tuding, Itogon (Baguio Formation)					
I	July 1972	40 days heavy rainfall	10 houses slid downslope	curved scarp, 150m x 100m	Trend:N10W;Dip: 60SW
II	June 1985	during and after heavy rains from typhoons "Daling" and "Kuring"	7 houses abandoned	Arcuate scarp 100m x 30m	
III IV	1969 1982 1983 1985	after heavy rains after heavy rains after "Daling" and "Kuring"	House, garage carried downslope	75m x 100m 50m x 100m	Trend: NE Trend: NE
V	old landslide			discernible scarp with less defined boundaries 10m to 15m	
VI	old landslide			concave erosion scarp 10-20m vertical displacement discernible 75m x 20m	
VII & VIII	old landslide			50m x 15m	
IX	old landslide			75m x 30m	
X	old landslide			10m x 5m	Trend: NE
XI	8 July 1986	during Typhoon Gading w/ July 8 Rainfall = 1223.6 mm	damaged house		Trend: NE

Table 3.2 Summary of Characteristics of Landslides Outside the City Limits

Within City Limits			
Landslide	**Liquid Limit (ave), %**	**Plastic Limit(ave), %**	**Plasticity Index**
Philippine Military Academy			
I. Parade Ground Landslide			
II. Osmena Drive Landslide	45.5	40.5	5
III. Melchor Hall			
IV. Quezon Ave. landslide (200m of road section)	60	55	5
V. Quirino Ave. Hall	57	55.5	1.5
Outside City Limits			
Mines View Park Road & Cecilio Apostol St. (300m of road section)	20.9	20	0.9

Table 3.3 Atterberg Limits of Some Landslides in the Baguio Area

3.3 Earthquake-Triggered Landslides

On July 16, 1990 a magnitude 7.8 earthquake occurred in Luzon island, where Baguio City is located, causing one of the highest numbers of deaths and property damage resulting from a natural disaster in the history of the country. Forty-five seconds of seismic shaking were recorded in that earthquake with epicenter in Cabanatuan City in Nueva Ecija, less than 100 kilometers south of Baguio. Propagation of the main shock was recorded at a depth of 30 km (DENR-MGB Task Force, 1990). Although the earthquake was felt from the Ilocos provinces in the north to the Bicol region in southern Luzon, there was minimal destruction of infrastructure in Metro Manila, which is in Central Luzon. Continuous recording of aftershocks showed that shockwaves from the main shock may have been disseminated and magnified substantially in the fault splays of the Cordilleras. The aftershocks may have been caused by the regional redistribution of stresses following the slip along the Philippine and Digdig Faults during the main shock (Figure 3.13). The daily frequency of the aftershocks decreased dramatically after the main shock and leveled off after two weeks (Bautista, et. al., 1992).

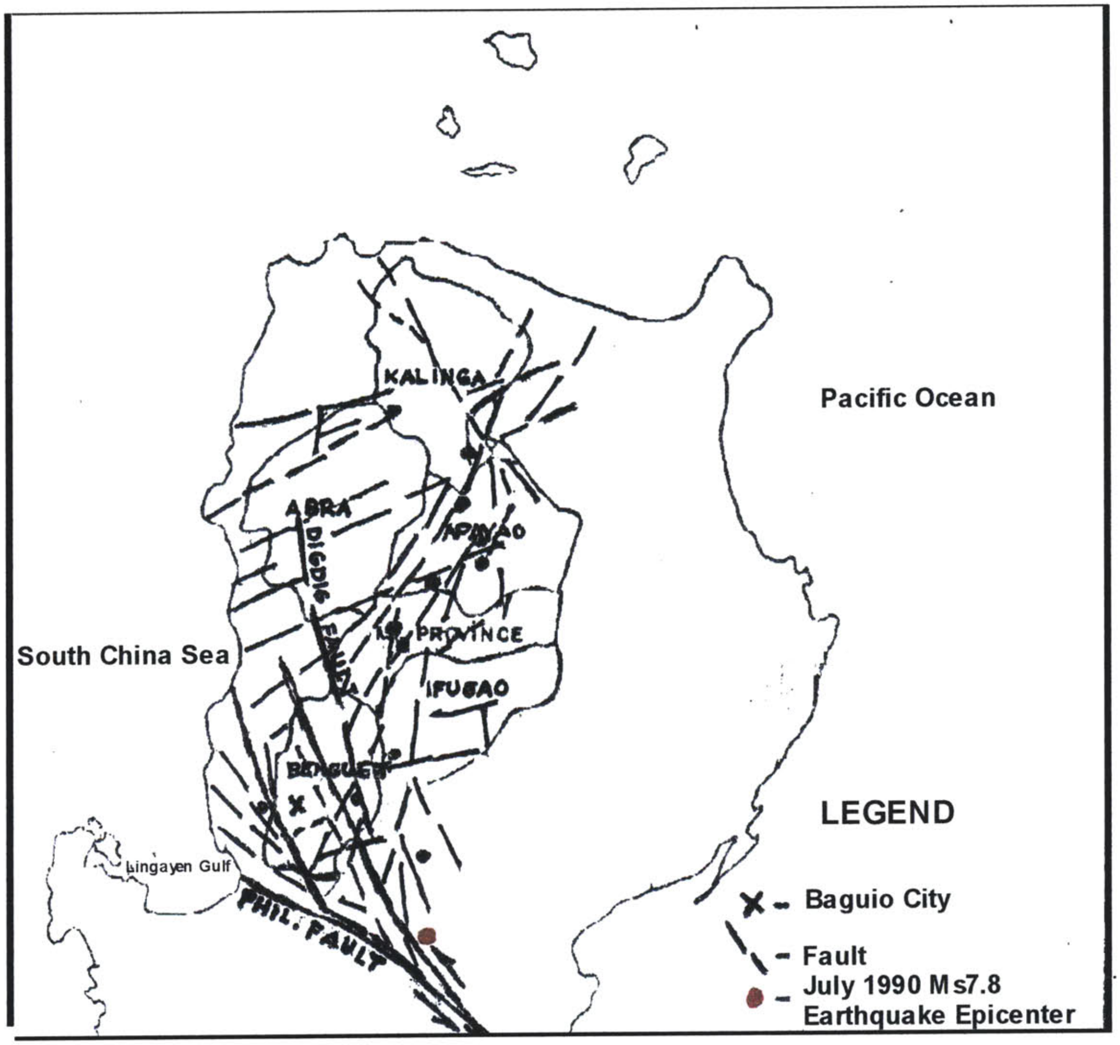


Figure 3.13 Geologic Structural Map of the Cordillera Region, Northern Luzon, Philippines (Geotecnica, 1991)

Although there was considerable damage in Pangasinan, La Union, Nueva Ecija, and Nueva Vizcaya provinces adjacent to Baguio, Greater Baguio was one of the most heavily affected areas in all of Luzon island. Because of the great devastation caused by this natural disaster, the "Inter-Agency Committee on Documenting and Establishing Database on the July 1990 Luzon Earthquake" was created. This Inter-Agency Committee was headed by the Department of Environment and Natural Resources and the Department of Science and Technology.

3.3.1 Tectonic Environment

The 1990 earthquake was caused by the sudden movement of the northwest segment of the Philippine Fault Zone and of its north trending splay, the Digdig Fault (Figure 3.13). Strike-slip displacement reached up to 6 meters along the Digdig Fault (DENR-MGB Task Force, 1990).

The Philippines' tectonic setting makes it extremely susceptible to earthquakes. The country is situated on the Philippine block which is between two opposing plates, the South China Sea Plate and the Philippine Sea Plate. The Philippine Fault Zone formed as a result of the continuous opposite subductions of these two plates under the Philippine block. Both the South China Sea Plate west of the Philippines and the Philippine Sea Plate in the east are squeezing the Philippine block causing its folding and buckling. The subduction of the two plates on either side of Luzon island is converted into strike-slip motion along the Philippine Fault and into the uplift of the Cordillera Mountain Range (Pantucci, 1994). The uplift of the Cordilleras was accompanied by the rejuvenation of the drainage system, progressive steepening of slopes, accelerated erosion, and the undercutting of toe scarps by streams. These phenomena are all characteristic of the Baguio area.

The Cordilleras are dissected by splays of the Philippine Fault, as shown in Figure 3.13. The drainage network in the region preferentially follows these tectonic lineaments (Pantucci, 1994).

The slope destabilization induced by the quake was greatly favored by the region's tectonic history. During their emplacement, batholiths metamorphosed, fractured, folded, and uplifted the surrounding older formations of limestones, conglomerates, sandstones, and shales (Pantucci, 1994). The intrusions resulted in the disturbance of the original structure of the older formations and the lowering of their strength.

3.3.2 Impact of the July 1990 Earthquake

There were 1,666 casualties, 1,513 injured, 16,454 houses damaged, and 8,235 completely destroyed houses as a result of the earthquake (Pantucci, 1994). Damage to buildings, infrastructure, and properties was recorded at 10 billion pesos (approximately 300 million dollars at the time). Ground rupturing caused some of this damage to property, but no deaths (DENR-MGB Task Force, 1990). Four hundred fifty of the deaths were related to landslide occurrences, while 45 more were added to the death statistics when new slope failures were activated during the ensuing 1990 monsoon rains (of August to October 1990) in the slopes that had been weakened by the earthquake in July (Pantucci, 1994).

As a result of the damage to infrastructure, some areas became inaccessible and thus isolated. Damage to transportation and communication systems hampered emergency response and recovery efforts. The delivery of medical supplies and utilities was likewise impaired. Small villages had to be evacuated because of landslide risks, and cultivated lands were damaged. Investment in the area fell, commercial and industrial establishments were closed, farming activity declined, the pre-earthquake construction boom ended because of the landslide hazards, and there was an overall decline in economic growth. Most of the better hotels in the area were severely damaged. Recreational facilities and museums were reduced to rubble. This led to a 15-20% drop in total national tourist revenue in 1991. The tourist industry suffered the greatest losses due to the earthquake (DENR-MGB Task Force, 1990).

The 1990 earthquake brought about surface faulting and liquefaction on a regional scale. Strong ground vibration, earthquake-related landslides, and liquefaction caused most of the damage. There were an unprecedented number of slope failures in Central and northwest Luzon with innumerable landslides in the Cordillera Central and Caraballo Mountains (Pantucci, 1994). Landslide-affected provinces were Nueva Ecija, Nueva Vizcaya, and Benguet (in which Baguio is located). The presence of discontinuities and shear zones heavily contributed to slope destabilization during the earthquake. The effects of the landslides were more intense near the areas of the ground rupture, in areas undercut by streams, near road cuts, and in denuded slopes with steep inclinations and highly fractured rocks. Enormous quantities of sediments were loosened, thus creating further potential for mobilization by monsoon rains for several years (Pantucci, 1994). The erosion cycle is active in the Luzon mountains because of the combination of heavy rains, tectonic uplift, river rejuvenation, and widespread deforestation. The scars left by the landslides will, therefore, probably be visible for decades since the high erosion rates prevent the rapid growth of new vegetation cover.

In the Baguio area, the city buildings and houses were destroyed or damaged due to soil movement and associated cracking. Some homes were swept downslope. Roads were affected by an enormous number of shallow debris slides, as well as some rock falls. There was extensive damage to cut slopes, retaining walls, side drainage, pipes and culverts, and to the surfaces of roads. Marcos Highway (Figure 1.5) was closed to traffic for some weeks after the quake due to a landslide that occurred a few kilometers outside of the City. Very steep slopes along a deeply incised river valley were affected over several kilometers. Deep landslides also occurred along Kennon Road, between which numerous vehicles were trapped. The City was cut off from the rest of Luzon for three days after the earthquake. For at least one month following the quake, Naguilian Road was the only route to the City. The landslides along the road networks caused more damage than the strong ground shaking and brought about more economic dislocation than the earthquake itself (DENR-MGB Task Force, 1990). The large number of landslides along major roads also made it impossible to clear the landslides as they occurred.

At Loakan Airport, the only airport servicing the Cordillera Region, the concrete pavement of the runway was severely cracked. These cracks were approximately 100 mm wide with some smaller vertical movement. On sloping ground, the cracks were associated with slope failures (DENR-MGB Task Force, 1990).

The background of Figure 3.14 shows the landslides in the Mirador Limestone after the earthquake. The mid-ground shows rocks of the Baguio Formation. The foreground of the photograph shows the tension cracks found on Marcos Highway after the earthquake.

Figure 3.14 Effects of the 16 July 1990 Earthquake (Geotecnica, 1990)

3.3.3 Characterization of Landslides Induced by the 16 July 1990 Earthquake

Approximately 100,000 earthquake-induced landslides occurred in part of the Central Cordillera mountain range, the Caraballo Mountains, and in a small zone of the Sierra Madre Mountain Range as a result of the 16 July 1990 earthquake. Less extreme topographic relief and the presence of nearly intact rainforest helped to limit the damage to the slopes of the neighbouring Sierra Madre range. A number of the slides were newly triggered, while a significant number were old slides that were reactivated (Pantucci, 1994). They were observed on moderate to steep slopes, drainage divides, valley heads, and along road cuts (Arboleda & Regalado, 1992).

Landslides occurred northwest and west of the ground rupture along the Digdig Fault and on a narrow zone adjacent to the rupture along the Philippine Fault zone (Figure 3.15). The landslide-affected region is part of the Luzon Central Cordillera Volcanic Belt, which is at the junction of the southern end of the north-south trending Central Cordillera Mountain Range and the Caraballo Mountains (Arboleda & Regalado, 1992). The concentration of the slides along and west of the ruptured fault segment was influenced by (Pantucci, 1994):

- The uplift and intrusion history of the Cordillera batholiths that resulted in numerous steep slopes being locally topped by shattered rocks, as discussed in section 3.3.1; and
- The presence of an intricate network of faults in the most heavily affected zone (Figure 3.13).

Slides occurred predominantly in Intensity VIII and VII (Rossi-Forel scale) zones with marginal occurrence in the Intensity VI zone. Intensity VI on the Rossi-Forel scale is thus designated as the damage threshold (Pantucci, 1994). It must be noted that the Rossi-Forel scale is purely subjective.

The distribution of the slides within the abovementioned Intensity zones is strongly influenced by topographic variations and the local condition of rock formations. In some areas, nearly 60% of slopes collapsed (Pantucci, 1994). Figure 3.15 shows the location of the area affected by landslides.

An Intensity V to VI earthquake on the Rossi-Forel scale is defined as being felt by nearly everyone, with many awakened. Some dishes and windows may be broken, plaster may crack in a few places, and unstable objects may be overturned. Disturbance to trees, poles, and other tall objects is sometimes observed. Pendulum clocks may stop. This intensity range on the Rossi-Forel scale has been correlated with a peak ground acceleration (PGA) of 0.03-0.04g (Bolt, 1993).

Earthquakes of Intensities VI to VII on the Rossi-Forel scale are felt by all, and many are frightened and run outdoors. Some heavy furniture moves, and there are a few instances of falling plaster. The damage to buildings is slight. The peak ground acceleration (PGA) for this intensity level is 0.06-0.07g (Bolt, 1993).

At Intensity VIII on the Rossi-Forel scale, everybody runs outdoors. Damage to buildings of good design and construction is slight, while it is slight to moderate in well-built ordinary structures and considerable in poorly built or badly designed structures. The earthquake is noticed by people driving in cars. The peak ground acceleration (PGA) is 0.10-0.15g (Bolt, 1993).

At Intensities of VIII to IX, the damage is slight in specially designed structures. It is considerable in ordinary substantial buildings and there may be partial collapse. In poorly built structures, damage is great. Panel walls are thrown out of frame structures. Factory stacks, columns, monuments, and walls fall. Heavy furniture is overturned.

People driving cars are disturbed. The peak ground acceleration (PGA) at these Intensities is 0.25-0.30g (Bolt, 1993).

At Intensity IX, damage is considerable in specially designed structures and well-designed frame structures are thrown out of plumb. Damage is great in substantial buildings and there may be partial collapse. Buildings are shifted off their foundations, the ground cracks conspicuously, and underground pipes are broken. The peak ground acceleration (PGA) is 0.50-0.55g (Bolt, 1993).

At Intensity X and greater, some well-built wooden structures are destroyed, most masonry and frame structures are destroyed along with their foundations, and the ground is badly cracked. Rails are bent. Landslides are considerable along riverbanks and on steep slopes. Earth slumps and land slips occur in soft ground. Water is splashed and slops over banks. The peak ground acceleration (PGA) is more than 0.60g (Bolt, 1993).

In the Greater Baguio area, the threshold slide intensity of VI is lower than what is expected from the Rossi-Forel scale, which includes landslides as an effect of earthquakes at Intensity X and greater. This may be because of topographic amplification effects.

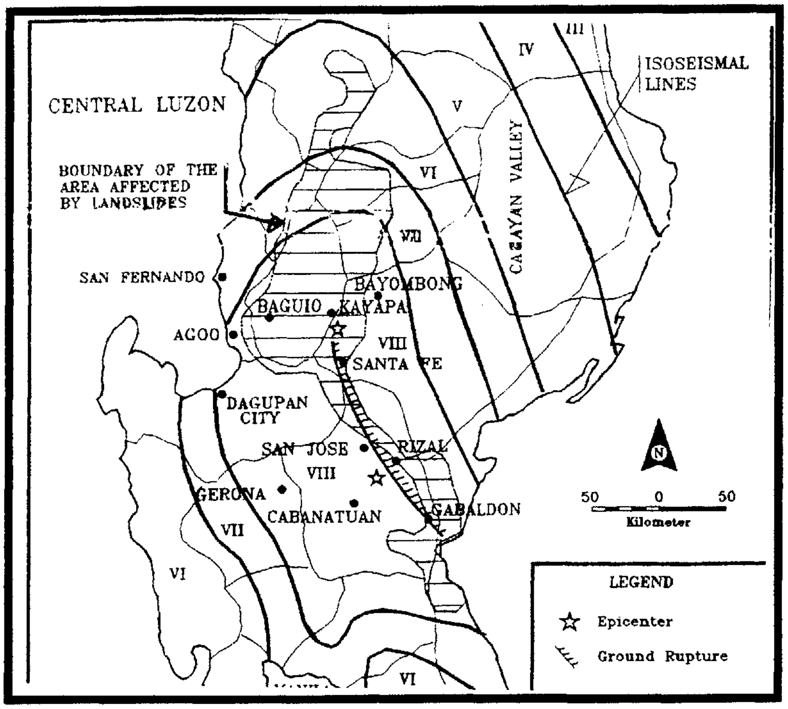


Figure 3.15 Isoseismal Map of July 1990 Luzon Earthquake (Pantucci, 1994)

Within twenty four hours of the main shock, landslides were occurring in patches on approximately 50% of slopes. The slide-affected area was approximately 10,000 sq. km. The landslides were predominantly shallow and translational (Arboleda & Regalado, 1992). A small percentage of the landslides were remobilized old landslides. Because of the variety of local geology and topography, slope failures of nearly all known types were observed (Pantucci, 1994).

The most affected slopes were those that were close to ground ruptures and those close to densely concentrated aftershock epicenters. Fifty to ninety percent of the affected slopes were denuded (Arboleda & Regalado, 1992). Because the earthquake occurred during the rainy season, slopes were subjected to rainfall immediately before and after the main shock. These rains, together with the aftershocks, triggered more landslides.

The slides that were less than 1 m deep were small to medium, with volumes ranging from 1,000 to 5,000 cu. m. They were unevenly distributed due to the extreme variations in the geologic and topographic conditions in the area. The slides generally had triangular, elongated shapes (Figure 3.16). The shallow slides are typical of moderate to steep slopes with limited differences in elevation. The height of the slope was found to have no influence on the occurrence of landslides, but the slope angle is critical in that steeper slopes experienced more landslides. The joint pattern of the parent rock is marginally involved (Pantucci, 1994).

The portions of the mountain shown in the background of Figure 3.16 that have no green cover are all landslides in the Klondyke Formation that were induced by the 1990 earthquake. The slides, being less than 1m deep, typically involved only the residual soil cover.

Figure 3.16 Shallow Slope Failures Observed After 1990 Earthquake (Geotecnica, 1987)

Figures 3.17 and 3.18 show a close-up of one of these landslides. Figure 3.17 shows the crest of a typical slide caused by the July 1990 earthquake, while Figure 3.18 shows the main portion and the toe of the shallow landslide in the residual soil.

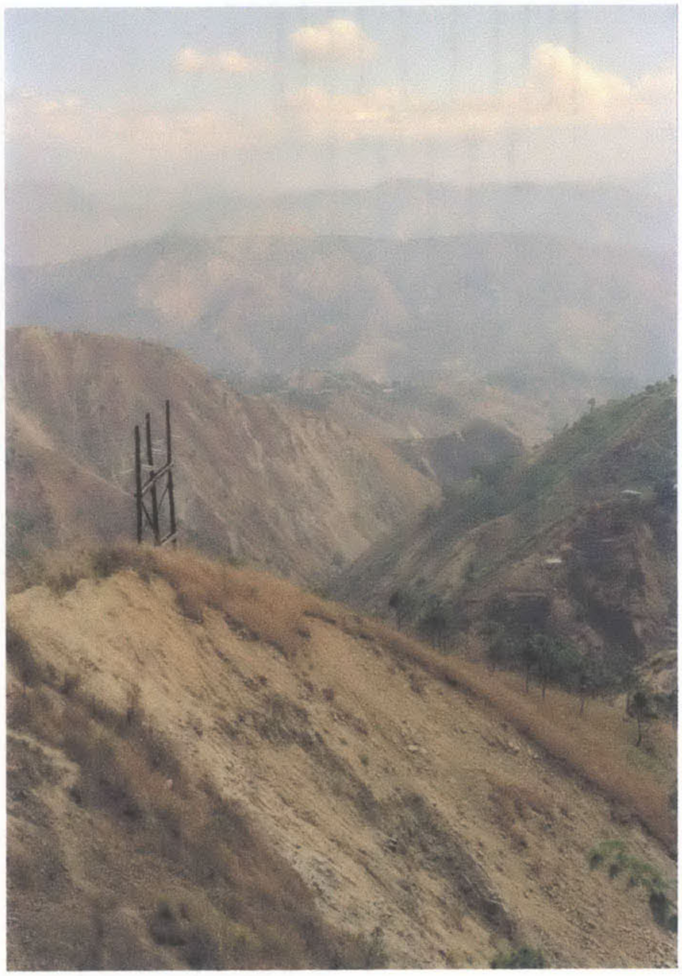


Figure 3.17 Crest of a Typical Landslide (Geotecnica, 1990)

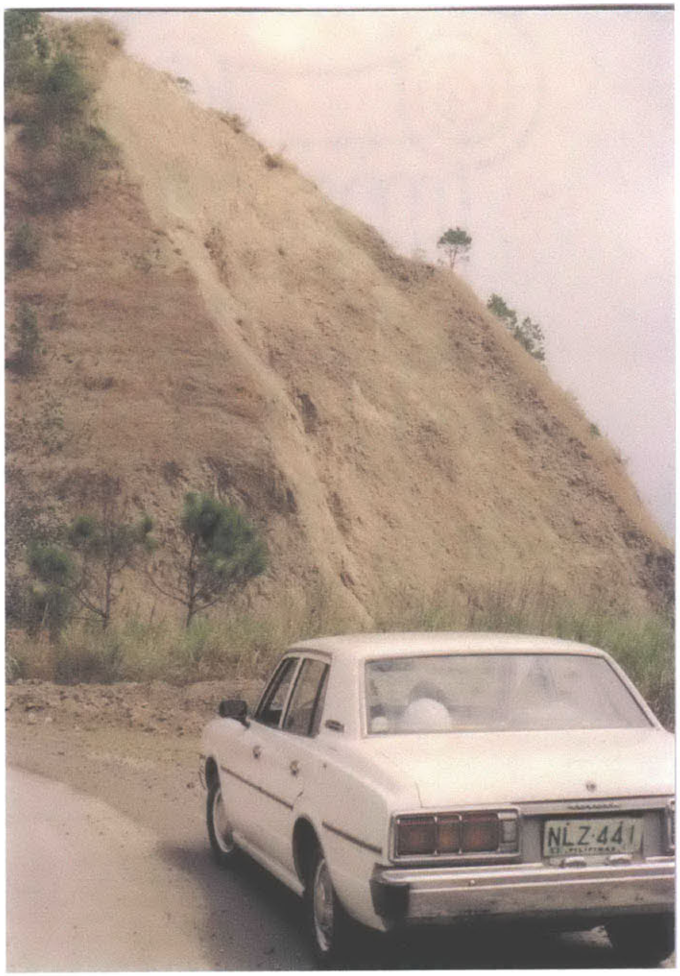


Figure 3.18 Slide Materials and Toe (Geotecnica, 1990)

Sixty-six percent of the landslides that occurred in Baguio City were 1m or deeper. Figure 3.19 shows that 53% of the slides occurred on 14-27 degree slopes, or 25-50% gradient (Arboleda & Regalado, 1992). All slopes steeper than 40° failed (Pantucci, 1994).

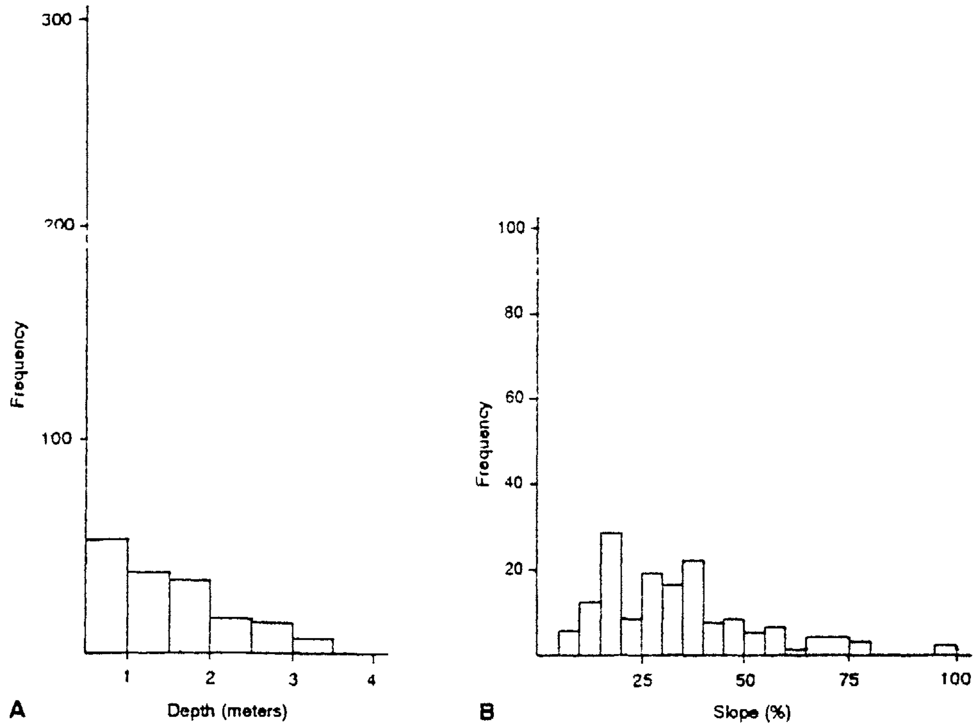


Figure 3.19 Graphs Derived from 150 Landslides in Baguio and Vicinity (Arboleda & Regalado, 1992)

The 2-3m deep landslides consisted of residual soils derived from the highly weathered and fractured rocks underlying the area. Some block slides occurred, primarily along the roads leading to Baguio City, in the ZigZag Formation.

The relatively deeper slides occurred, in some cases, along pre-existing zones of weakness. These slides were comparatively small, with widths ranging from 20-250 m, lengths of 50-700 m, and volumes of 500-170,000 cubic meters (Arboleda & Regalado, 1992). Critical slope height was generally the major controlling factor in the occurrence of the deep landslides, together with the joint pattern and degree of weathering of the parent rock (Pantucci, 1994). The landslide materials that were moved during the earthquake were partly mobilized again during the July-September rainy season.

In comparison to earthquake-induced landslides, older mapped (rainfall-induced) landslides are much larger in terms of affected area (up to 1.3 square km). The rainfall-induced landslides also had a rotational component.

Plots of slope inclination versus depth reveal that as the slope gets steeper, the depths of the earthquake-induced landslides increase (Figure 3.20). This is because the shallow slides involved surficial materials (topsoil) with minimal cohesion. They were, therefore, mobilized even on very shallow slopes once strong ground motion occurred. The deeper slides, on the other hand, were composed of surficial and residual soils as well as bedrock fragments. These materials would have greater inherent cohesion, and thus the more unstable condition of a steeper slope would be needed for the deeper landslides to occur as a result of ground shaking (Arboleda & Regalado, 1992).

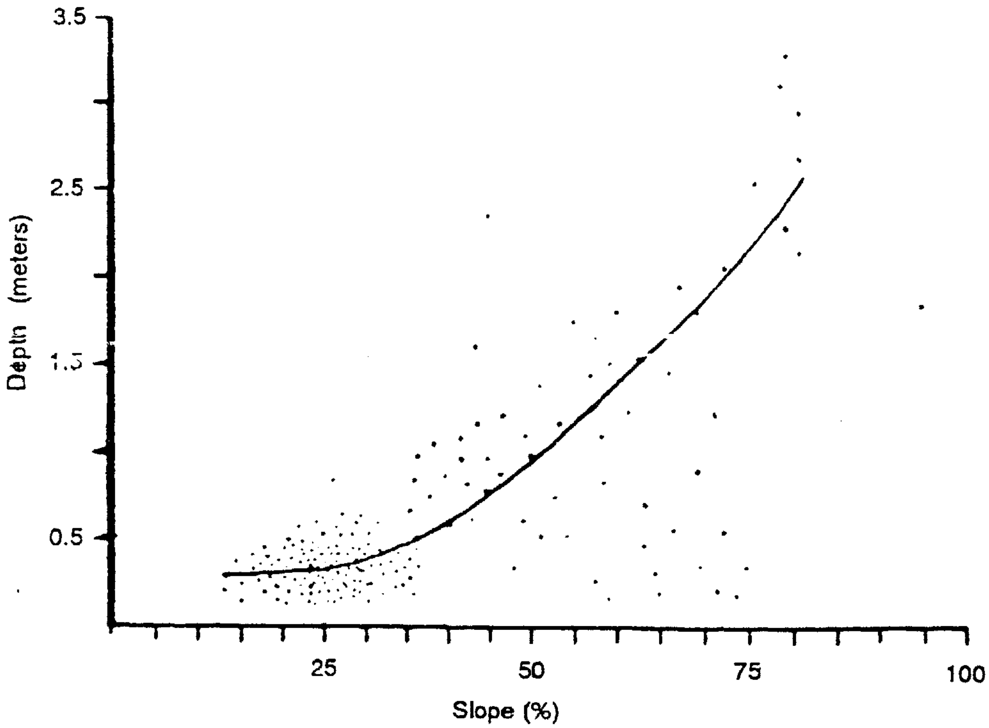


Figure 3.20 Graph of Depth of Landslide vs. Slope Gradient (Arboleda & Regalado, 1992)

Pantucci (1994) used Varnes' landslide classification (based primarily on the type of movement and secondarily on the type of material) to characterize the earthquake-induced slides. Translational slides were found to be the dominant type brought about by the 1990 earthquake. Flows were also abundant in the Central Cordilleras. Falls were common on steep slopes but the quantity of material mobilized in this type was minimal. Coarse, granular slide material was predominant in the deeply incised valleys of the Cordilleras. These materials were accumulated on the footslopes and were later eroded and transported by the heavy rains during the monsoon season (Pantucci, 1994).

Rock slides controlled by joints and discontinuities of the rock mass were characteristic of the movements along Kennon Road (Figure 1.5). Rock block slides occurred along the bedding planes in the rock masses of Kennon Road due to the fact that the construction of the road allowed the bedding planes to daylight. The slide materials included large quantities of rock fragments (Pantucci, 1994).

3.3.4 Seismicity-Related Effects on Slope Failures

The horizontal acceleration caused by the earthquake led to an increase in shear stress and the consequent failure of numerous slopes. The weathering front that separates the residual soil and highly weathered bedrock from the parent rock provides a plane of weakness along which the slopes failed. Physical separation and subsequent sliding are induced along this plane because the differing mechanical properties of the residual soil and the parent rock lead to different response potentials (amplified horizontal acceleration in the zone above the weathering front and attendant increase in shear stress). In some instances, the shaking intensity of the earthquake was too low to trigger outright slope failure. However, the surface soils were loosened and this allowed more water to percolate into the slopes. This led to the failure of these slopes during the rainy season of 1990 (Pantucci, 1994).

In the bedded rock formations, joints and fissures were considerably widened and new fractures were initiated. The shear strength along major discontinuities was, therefore, decreased. Along Kennon Road, this led to large structural failures due to sliding along daylighting planes of weakness (Pantucci, 1994).

3.4 Causal Factors in the Occurrence of Mass Movements

From the reports of both rainfall-induced and earthquake-related landslides that are discussed in previous sections, the following can be identified as the major causal factors of landslides in the Baguio City area:

3.4.1 Geology-related Factors

a. Most of the slide areas are underlain by decomposed or hydrothermally altered materials. Their resistance to weathering and erosion is lowered because of this alteration and degradation. The shearing strength of the altered rock is less than that of fresh rock. In many cases, the sliding of residual soil and weathered rock is along the interface with the unweathered rock, as this interface is a zone of weakness.

b. The tectonic history of the Cordillera Mountain Range contributes greatly to the vulnerability of the area to landslides. The uplift of the Cordilleras rejuvenated the drainage system and led to the progressive steepening of slopes. This causes vigorous, accelerated erosion. The rejuvenation of the drainage system also facilitates the undercutting of slopes by adjacent streamflow.

   The emplacement of batholiths metamorphosed, fractured, and folded the surrounding earlier rock formations. As a result, the original structure of these rocks was destroyed and slopes are locally topped by shattered rocks.

c. Most soil materials involved in the slides are silty, with low plasticity. This indicates that it would take only a small amount of increase in moisture content to transform this soil from plastic to liquid state. Soil in the liquid state would then have less shearing resistance.

d. Many landslides on record occurred in areas where there had been previous mass movements. This could have several implications. Most importantly, old slide materials would already be at or near their residual shearing strength.

Tension cracks formed during previous landslides provide pathways for the infiltration of rainwater and are zones of weakness (potential failure planes). Even in competent rock where fissures and joints are tight and far apart, a thick layer of residual soil would still be rendered permeable by tension cracks.

In old landslide areas, the depression created by the original slide may have been filled. If compaction of the fill was not done properly, the material would have low shearing strength while at the same time having high permeability that would facilitate downward percolation of water. If the relatively high permeability fill is overlying more impermeable residual soils, water would be retained in the fill, leading to the build-up of hydrostatic pressure in the slope. Filled areas may also have buried cavities or streams. If internal drainage was not provided, water may still flow preferentially in the buried cavity or flow channel and again lead to saturation of the slope material and build-up of hydrostatic pressures.

e. A complex network of faults (splays of the Philippine Fault) transects the Baguio area. When the ground ruptured and these faults were produced, the surrounding rocks were disturbed and fractured. This lowered the strength of the rocks. In addition, faults can serve as failure surfaces because they are planes of weakness.

3.4.2 Precipitation-related Factors

The area has among the highest annual precipitation rates in the Philippines. During the rainy season, the amount of rainfall in the area is well in excess of that which has been found to trigger landslides in the residual soils of the tropics and subtropics. The high amount of precipitation during the rainy season causes rises in the groundwater table that in turn result in increased pore water pressures. This decreases the shearing resistance of the slope materials. Intense rainfall also leads to erosion and internal collapse of the soil structure, as evidenced by piping (i.e., in the Mines View Park & Cecilio Apostol St. Landslides).

In unsaturated soils, capillary tension imposes a negative pressure on the soil. However, when heavy rainfall occurs, the soils become saturated and the stability provided by capillary pressure is reversed. Saturation of the soil materials by rainwater also decreases effective stress in the slope and, consequently, the shear strength.

The Greater Baguio area road and surface drainage system is inadequate and the ponding and subsequent percolation of rainwater is, thus, unchecked. This contributes to the rise of the water table and the saturation of the soils.

3.4.3 Human Activity

Human activity plays a large role in increasing the vulnerability of Baguio's slopes to landslides. Much of the Baguio area is denuded due to heavy deforestation. This was brought about by illegal logging and the prevalence of slash-and-burn farming, which is a traditional agricultural practice in the area.

Building construction, road blasting, and blasting associated with mining activities disturb the static equilibrium of slopes. Undercutting of slopes to make room for construction in adjacent areas likewise disturbs slope equilibrium.

3.4.4 Earthquake-related Factors

Ground shaking that is associated with the occurrence of earthquakes (main shocks and aftershocks) can play a significant part in destabilizing slopes. The cyclic stresses produce a horizontal acceleration that increases the shear stress on slopes. While most of the slides that were triggered by the July 1990 earthquake (the earthquake examined in this study) were new, some old slides were also reactivated. In areas where ground shaking was not strong enough to destabilize slopes (due to differing response potentials of the bedrock types), sediments were loosened and the slopes were fully mobilized during the 1990 rainy season. Weakened slopes will be prone to sliding during rainy seasons for many years.

In contrast to normal rainfall-induced landslides in the area, which are mostly rotational and of large volumes, the slides induced by the 1990 earthquake were usually translational and of limited depth and volume. This is because residual soils and weathered rock have significantly different mechanical properties, and thus different response potentials, from intact bedrock. The weathering front that is the interface between intact rock and weathered material serves as the physical plane of separation of the slide materials. The depths of the slides are minimal because the weathering front is usually at depths of between 0.5 to 2.0 m (Pantucci, 1994). The slides are translational because the interface between the soil/weathered material and the parent rock is planar.

Another reason that the earthquake-induced slides were mostly shallow was that the earthquake resulted in the formation of surface faults. These surface faults were planes of weakness along which landslides preferentially occurred. Joints and fissures in the bedded rock formations were considerably widened. This caused the decrease of friction properties along the discontinuities.

The lack of vegetation in the Baguio area is significant in this regard, because most of the earthquake-related slides were shallow. Since vegetation can help stabilize slopes only against shallow landslides, the presence of vegetation would have conceivably made significant reductions in the number of earthquake-related slides that occurred.

Chapter 4. Landslide Risk Rating System

This Chapter proposes a Landslide Risk Rating System which is offered as an aid to rational land-use decision-making, landslide risk minimization, and recommendation of remedial measures. Critical factors must be taken into consideration in the above processes. Such factors include bedrock geology, slope angles, and vegetation. It must be noted that the data available to the author were insufficient to create landslide risk maps or a site-specific preventive and remedial slope safety system. However, the information available was adequate to provide a framework for a preliminary risk analysis tool that can be used by engineers and planners. Despite the limitations of the available data, this approach to slope safety management will afford a more realistic and rational basis for decision-making than is currently in use. It is this author's hope that this framework will assist in the often difficult task of allocating land use.

4.1 General Comments

Although precipitation is identified as the main trigger for landslides in the Baguio City area, it is not included as a hazard factor in this risk rating system, which is designed to be location-dependent. The reason for this is that precipitation, although excessive, is uniform throughout the entire Baguio City area. In determining the susceptibility of particular sites, engineers and planners must note that the Landslide Risk Rating System described in this work factors in relative differences between geographical locations. However, the rainy season occurs annually and precipitation rates are geographically uniform. For this reason it is assumed that all slopes, regardless of location, are subject to the same hazard level due to rainfall.

Three hazard factors are, therefore, defined as being variable across geographical locations and are analyzed in this risk rating system:

- Bedrock geology
- Slope gradient
- Vegetation

A 54 sq. km. area was delineated on the 1:15,000 scale Engineering Geomorphology Map of Baguio City (Appendix B). This map was adapted by C.V. Mendoza in 1991 from the Mines and Geosciences Bureau Map prepared by P.S. Salise. Landslides in Baguio City were mapped using aerial photographs. All the landslides shown on the Engineering Geomorphology Map fall within the designated study area.

4.2 Bedrock Geology

Bedrock geology is the basic contributory variable used in the Landslide Risk Rating System. The rationale for using geology as the base factor is that the engineering properties and behavior of a site vary according to the subsurface materials. In addition, the engineering properties of the residual soils involved in landslides are directly correlated to the parent rock from which the residual soils originated.

To identify the role of bedrock geology in the occurrence of landslides in Baguio City, the area of each bedrock geologic unit lying within the study area was determined. Within each geologic unit, the area affected by landslides was delineated. The percentage (by area) of each geologic unit affected by landslides was computed, with the following results:

	Baguio Formation (NQbf)	ZigZag Formation (PNzf/Mzf)	Kennon Limestone (Nkl)	Mirador Limestone (Nml)	Klondyke Formation (Nkf)	Pugo Formation (KPpf)
Area, sq.km.	**24.361**	**10.768**	**.646**	**14.356**	**2.493**	**1.399**
Landslide Area, sq.km.	**1.449**	**0.692**	**0.000**	**0.641**	**0.017**	**0.170**
% Landslides	**5.95**	**6.43**	**0.00**	**4.47**	**0.68**	**12.15**

Table 4.1 Percentage of Landslide-affected Area by Geologic Units

As seen from Table 4.1 above, the Pugo Formation and the ZigZag Formation have the largest percentage of landslide areas compared to the total area of the rock unit found in the study area.

Based on the above results, it is proposed that the geologic units be rated as follows:

% Landslides	Classification
0 – 3%	Class I
3.01 – 6%	Class II
6.01 – 9%	Class III
9.01 – 12%	Class IV
12.01 – 15%	Class V
> 15%	Class VI

Table 4.2 Classification of Landslide Percentage Areas per Geologic Unit

Under this proposed classification scheme, the geologic units would be rated as follows:

	Baguio Formation	**ZigZag Formation**	**Kennon Limestone**	**Mirador Limestone**	**Klondyke Formation**	**Pugo Formation**
% Landslides	**5.95**	**6.43**	**0.00**	**4.47**	**0.68**	**12.15**
Class	**II**	**III**	**I**	**II**	**I**	**V**

Table 4.3 Geologic Unit Hazard Ratings

Goodman (1993) points out the engineering geologic properties of particular bedrock types that must be taken into account when dealing with landslide mitigation. The characteristics of all types of rock were discussed by Goodman in relation to engineering construction. However, specific types were pinpointed to be particularly susceptible to landslides. These are sandstones in combination with shale, and basaltic and andesitic rocks. This holds particular significance in light of the findings of this study.

The ZigZag formation is primarily made up of conglomerates, sandstone, and shale. Massive sandstones exposed in cliffs tend to develop sheet joints parallel to the valley sides (Goodman, 1993). This leaves loosened slabs of rock in precarious positions. It often becomes necessary to install a supporting structure or rock bolts to prevent rock falls. Where sandstone and shale are found together (as in the ZigZag formation), block slides are common. This is due to the fact that the blocks of harder sandstone slide intact on the shale layer. The remolding of shale by slide movement may convert it into a soft mud that flows considerably farther downslope (Goodman, 1993). The area of an old landslide, therefore, would be susceptible to further movement during the succeeding rainfall event.

The Pugo formation is a sequence of basaltic and andesitic rocks with interbedded pyroclastics. According to Goodman (1993), such basaltic and andesitic sequences often have alternating pyroclastic interbeds or nonvolcanic sediments that contain some impervious layers. The downward progress of vadose water transmitted through the joints in the rock is often impeded by these impervious layers. This causes the accumulation of water in the formation and the subsequent softening and weakening of the underlying material. Increased water pressures in the joints also reduce resistance to sliding. Rock blocks bounded by joints often form in this material as well. When the blocks of basaltic rocks move along the soft foundation of the interbeds, landslides are likely to occur.

Goodman's discussion on the particular susceptibility to landslides of the materials found in these two formations is in agreement with the results presented in Table 4.1.

4.3 Slope Angle

Presidential Decree 705 defines a land-use policy based on slope gradients that mandates that no land of the public domain of 18% slope or greater shall be alienable (transferable to another owner) or disposable (free for use as required). Any forest land of 50% slope or greater may not be used as grazing land (Rillon, 1992).

Five slope classifications were created (by the Department of Environment and Natural Resources) according to gradients: Class I (0-8%)—level to gently sloping, Class II (9-18%)—gently sloping to undulating, Class III (19-30%)—undulating to moderately steep, Class IV (31-50%)—moderately steep to steep, Class V (>50%)—very steep (Rillon, 1992). These are shown in Figure 4.1.

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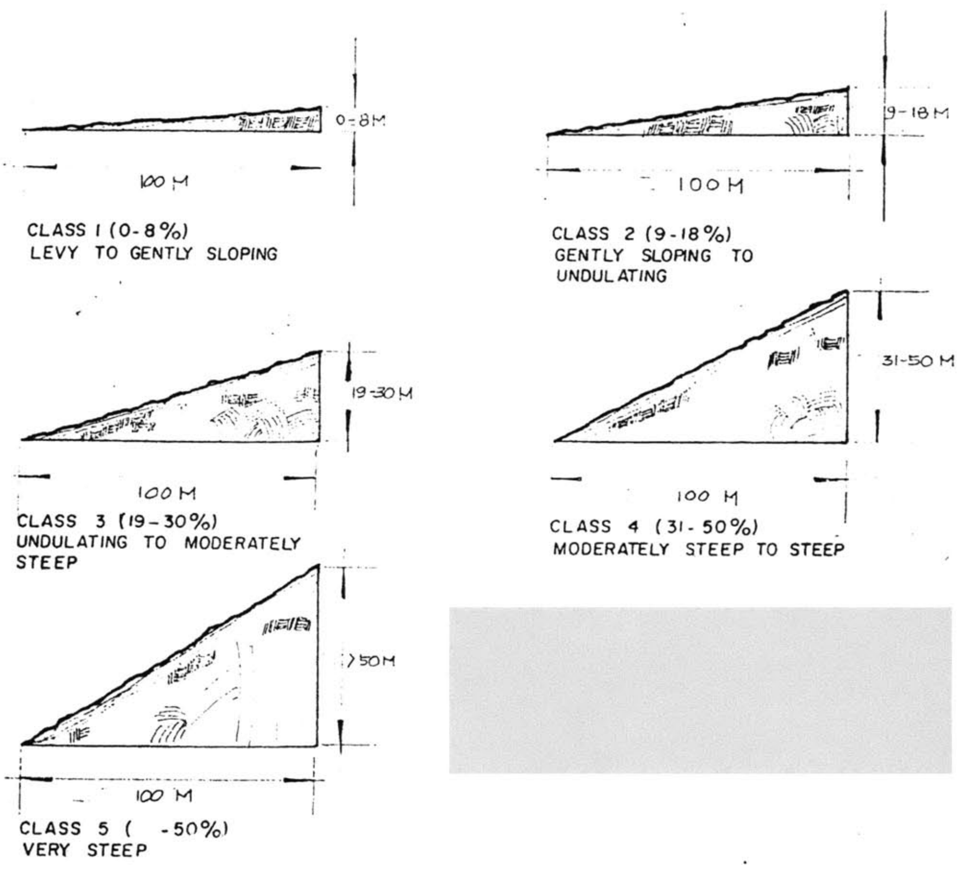


Figure 4.1 Slope Classes According to Percent Gradient (Rillon, 1992)

Greater Baguio (consisting of the municipalities of Baguio, La Trinidad, Itogon, Sablan, and Tuba or BLIST) has a very high relief owing to steep valley walls along river channels draining the area. More than half of the area is calculated to have very steep slopes, mostly found in Itogon, Sablan, and Tuba. Level to moderately steep slopes are present in most of Baguio City and the La Trinidad Valley.

The mean elevation in Baguio City is 1300 meters above sea level. Relief ranges from 900 m along Bued River to 1600 m at Pacdal. The mean slope is 36%, the lowest of the five municipalities. The steepest slopes are found in the Loakan area west of the airport (Figure 3.2) and at Camp 8 along Kennon road, as shown in Figure 3.3 (Rillon, 1992).

The five slope classifications are adopted in the Landslide Risk Rating System in this paper in order to maintain congruence with the existing land-use regulations. The engineer can then determine the gradient of the location being evaluated and assign a class to the slope.

In many cases, steep slopes are likely to be more unstable than flatter slopes underlain by the same type of rock. This is because the component of gravitational force (which acts as the driving force) acting parallel to the surface increases as the slope becomes greater. Runoff velocity also increases with slope and so, consequently, does the erosion rate. However, it was not possible to assume independence of the two factors, geology and slope, in their contribution to landslide occurrence in the Greater Baguio area.

The procedure employed to determine the dependence of topography on geology in the two factors' contribution to landslide occurrence was as follows:

- The percentage (by area) of each slope class found in the geologic units was determined. These results are shown in Table 4.4.

SLOPE CLASS		CLASS I	CLASS II	CLASS III	CLASS IV	CLASS V
GEOLOGIC UNIT	Total Area (sq km)	Area(%)	Area(%)	Area(%)	Area(%)	Area(%)
Baguio Formation (NQbf)	24.36	30.86	52.64	5.70	4.99	5.82
Kennon Limestone (Nkl)	0.65	6.67	0.00	93.33	0.00	0.00
Mirador Limestone (Nml)	14.36	15.19	5.70	79.11	0.00	0.00
Klondyke Formation (Mkf)	2.49	100.00	0.00	0.00	0.00	0.00
ZigZag Formation (PNzf)	10.77	20.55	3.65	40.18	22.83	12.79
Pugo Formation (KPpf)	1.40	0.00	0.00	95.24	0.00	4.76
TOTAL	54.02					

Table 4.4 Percentage by Area of Slope Classes per Geologic Unit

- The percentage (by area) of landslides occurring in each slope class found in the geologic units was determined. These results are shown in Table 4.5.

GEOLOGIC UNIT	Total Area of Landslides (sq km)	Class I Area of Landslides (%)	Class II Area of Landslides (%)	Class III Area of Landslides (%)	Class IV Area of Landslides (%)	Class V Area of Landslides (%)
Baguio Formation (NQbf)	1.45	62.88	7.63	1.55	11.64	16.30
Kennon Limestone (Nkl)	0.00	0.00	0.00	0.00	0.00	0.00
Mirador Limestone (Nml)	0.64	51.75	19.30	28.95	0.00	0.00
Klondyke Formation (Mkf)	0.02	100.00	0.00	0.00	0.00	0.00
ZigZag Formation (PNzf)	0.69	27.24	4.88	28.45	15.85	23.58
Pugo Formation (KPpf)	0.17	0.00	0.00	60.29	0.00	39.71

Table 4.5 Percentage by Area of Landslides in Each Slope Class

• The normalized difference between the percentage of landslides in each Slope Class within a given geologic unit (Table 4.5) and the percentage of each geologic unit occupied by that particular Slope Class (Table 4.4) was determined. These normalized differences are shown in Table 4.6.

	CLASS I	CLASS II	CLASS III	CLASS IV	CLASS V
GEOLOGIC UNIT	Normalized Difference (%)	Normalized Difference (%)	Normalized Difference (%)	Normalized Difference (%)	Normalized Difference (%)
Baguio Formation (NQbf)	103.74	-85.51	-72.75	133.49	180.26
Kennon Limestone (Nkl)	-100	-100	-100	-100	-100
Mirador Limestone (Nml)	240.69	238.82	-63.41	0	0
Klondyke Formation (Mkf)	0.00	0	0	0	0
ZlgZag Formation (PNzf)	32.57	33.59	-29.20	-30.58	84.43
Pugo Formation (KPpf)	0	0	-36.70	0	733.91

Table 4.6 Normalized Difference Between Percentage of Landslides in Each Slope Class (per Geologic Unit) and Percentage of Each Slope Class per Geologic Unit

The normalized differences of 0 shown in Table 4.6 indicate that the expected number of landslides occurred in the particular slope class, given its proportion in the geologic unit. The normalized differences of -100 indicate that no landslides occurred in the geologic unit (within the study area). The negative values of normalized difference indicate that less landslides than were expected occurred in the particular slope class, given its proportion in the geologic unit. The positive values of normalized difference indicate that more landslides than were expected occurred in the particular slope class, given its proportion in the geologic unit.

Based on the results presented in Table 4.6, a modifier will be applied to the classification of geologic units presented in section 4.2. The modified geologic formation ratings are shown in Table 4.7. For normalized differences between -50 and +90, the original geologic class is retained, reflecting the fact that those specific topographies do not contribute to a significant increase or decrease of the occurrence of landslides within the geologic unit. For normalized differences of -50.01 and below, the modified geologic class is lowered by one increment from the original geologic class. This reflects the fact that those particular topographies contribute to a significant decrease of landslides within the geologic unit. For normalized differences of +90.01 and above, the modified geologic class is increased by one increment. This reflects the fact that those particular topographies contribute to a significant increase of landslides within the geologic unit. One exception is gradient Class V in the Pugo Formation. In this case, the modified geologic class is increased by two increments because of the extreme value of normalized difference.

Geologic Class	Gradient Class	Normalized Difference	Modified Geologic Class
Pugo Formation KPpf (Class V)	V	733.91	**VII**
	IV	0	**V**
	III	-36.70	**V**
	II	0	**V**
	I	0	**V**
ZigZag Formation PNzf (Class III)	V	84.43	**III**
	IV	-30.58	**III**
	III	-29.20	**III**
	II	33.59	**III**
	I	32.57	**III**
Baguio Formation NQbf (Class II)	V	180.26	**III**
	IV	133.49	**III**
	III	-72.75	**I**
	II	-85.51	**I**
	I	103.74	**III**
Mirador Limestone Nml (Class II)	V	0	**II**
	IV	0	**II**
	III	-63.41	**I**
	II	238.82	**III**
	I	240.69	**III**
Klondyke Formation Mkf (Class I)	V	0	**I**
	IV	0	**I**
	III	0	**I**
	II	0	**I**
	I	0	**I**
Kennon Limestone Nkl (Class I)	V	-100	**0**
	IV	-100	**0**
	III	-100	**0**
	II	-100	**0**
	I	-100	**0**

Table 4.7 Modified Geologic Classes

4.4 Vegetation

Within each geologic unit, the percentage of landslides occurring in areas covered by each vegetation type was determined. The results are shown in Table 4.8.

In the Klondyke Formation, 100% of the landslides occurred in areas with no vegetation. Similarly, in the Mirador Limestone, 82.46% occurred in denuded areas. In the Baguio Formation, 47.35% of landslides occurred in broadleaf, while 34.41% occurred in denuded areas. In the Pugo Formation, 100% of the slides occurred in broadleaf-covered zones. Since pines grow in undisturbed forest areas, they would be prevalent where development has not yet taken place, i.e., on steep slopes. This accounts for the fact that all the Pugo landslides took place in broadleaf zones. Since the Pugo area is one of steep terrain, it is still almost completely forested. Similarly, the boundaries of the Baguio Formation become very steep (outside the Plateau) and are thus undisturbed and still vegetated with broadleaf. This broadleaf-covered area is where 47.35% of the slides occurred. These results suggest that the contribution of vegetation to the occurrence of landslides is not entirely independent of the topography and the geology in the area. However, in the formulation of the Hazard Rating framework in this study, this dependence was not taken into consideration as it would introduce additional complexity to the framework.

In the Baguio Formation, where vegetation cover of landslide areas is most varied, the smallest percentage of landslides occurred in areas with broadleaf mixed with other types of vegetation. Broadleaf Mix areas benefit from the stabilizing action of the deep roots of the pine trees but are also on less steep slopes where other types of vegetation can grow. A slightly larger percentage of the landslides occur in grass covered areas. This is because the stabilizing effect of the grass roots is not as pronounced as that of the deep-rooted pines (the roots of grasses are shallower, smaller, and can remove less water from the soil). Crop land or agricultural land is third only to denuded areas and broadleaf areas in terms of the percentage of landslides occurring. This is because agricultural land is usually disturbed during the planting process, increasing permeability and allowing for greater percolation of rainwater into the ground.

Table 4.8 Percentage of Slides per Vegetation Type, by Geologic Unit

PERCENTAGE OF LANDSLIDES OCCURRING IN:	Baguio Formation NQbf	Kennon Limestone Nkl	Klondyke Formation Mkf	Pugo Formation KPpf	ZigZag Formation PNzf	Mirador Limestone Nml
Broadleaf	47.35	*		100	*	10.53
Broadleaf Mix	2.33	*			*	
Scrub		*			*	3.51
Grass	5.05	*			*	
Crop/Agricultural Land	10.87	*			*	3.51
None	34.41	*	100		*	82.46

* vegetation data not available

TYPE	CLASS
Broadleaf Mix or Bushes/Scrub	I
Grass or Crop Land/Agricultural Land	II
Broadleaf	III
None	IV

Table 4.9 Classification of Different Types of Vegetation

As can be seen from Table 4.9, hazard classifications are assigned to the different types of vegetation based on the results presented in Table 4.8. Areas covered with Class I vegetation is the least susceptible to landslides, while Class IV is the most susceptible. Vegetation classifications by Barangay (Topographic Map of Baguio City, 1995) are shown in Appendix C.

4.5 Hazard Rating

The resulting Hazard Ratings based on geology and slope gradient (as combined in the Modified Geologic Class), and vegetation type are shown in Table 4.10 below. This is simply one possible rating system that may be derived from the results presented in previous sections. A range of 2 is assigned to each Hazard Rating in order to allow the user to evaluate specific sites, take into account their unique characteristics, and use his or her judgement to differentiate whether the Hazard is relatively high or relatively low for its rating class.

Table 4.10 Landslide Hazard Rating of the Greater Baguio Area

Modified Geologic Class	Vegetation Type	Hazard Rating
VII	IV	97-99
	III	95-96
	II	93-94
	I	91-92
VI	IV	89-90
	III	87-88
	II	85-86
	I	83-84
V	IV	81-82
	III	79-80
	II	77-78
	I	75-76
IV	IV	73-74
	III	71-72
	II	69-70
	I	67-68
III	IV	65-66
	III	63-64
	II	61-62
	I	59-60
II	IV	57-58
	III	55-56
	II	53-54
	I	51-52
I	IV	49-50
	III	47-48
	II	45-46
	I	43-44
0	IV	41-42
	III	39-40
	II	37-38
	I	35-36

Hazard Ratings range from a high of 99 for the most unstable type of slope to a low of 35 for the most stable type of slope.

4.6 Risk Rating

In order to define landslide vulnerability one must first establish a typology of damage related to landslide risk, namely:

- Loss of life
- Loss of property (including capital losses in the form of damage to buildings and civil engineering works, as well as operating losses in the form of disruption of economic activities and services)

The Hazard Rating will be converted to a Risk Rating by using multipliers based on Land Use and on Population.

$$RR = HR * LUM * PM \tag{4.1}$$

where:

RR = Risk Rating

HR = Hazard Rating

LUM = Land Use Multiplier

PM = Population Multiplier

4.6.1 Land Use Multipliers

For Land Use, a multiplier of 1.0 is applied to the most critical Land Use situations. Multipliers less than 1 allow one to reduce the Risk Rating when land use in the area is less critical (Table 4.11). In this study, multipliers were selected ordinally to reflect the relative reductions to the Risk Rating depending on how critical the land use is in the area.

LAND USE	Land-Use Multiplier
Built-up	1
Grasslands	0.95
Agriculture	0.9
Miscellaneous	0.85
Forest	0.8

Table 4.11 Land-Use Multipliers

The most critical Land Use situations in terms of loss of life and property are in the Built-up areas. These areas are used primarily for commercial and residential purposes. Baguio City Proper is the major population center in Benguet province and in the entire Cordillera Region. Two thousand six hundred hectares (approximately half of Baguio City's land area) are classified as built-up. Under the category of Built-up areas, the following types of land use are included: Commercial, Residential, Institutional, and Open Space. For the purposes of this Landslide Risk Rating System, roads and highways are also included in the Built-up classification because of the significant impact of their closure when affected by landslides.

Public markets, shops, offices, and recreational facilities are classified as commercial areas. Industrial activity is also considered a commercial land use. Institutional land use refers to government housing and reservations, military reservations, educational facilities, and social service facilities. Open spaces consist of steeply sloping areas, inaccessible areas, areas with unsuitable soil and rock outcrops, scenic areas, points of historical interest, and hazardous areas. Since these open spaces are within the City proper and are surrounded by other built-up areas, the occurrence of landslides in these spaces would have an impact on property and economic activity. It is clear that built-up areas contain capital-intensive equipment and machinery, civil works, and critical economic activities. The effects of a landslide would thus have the most import, and the Risk Rating must not be reduced.

Grasslands are unforested areas covered with grasses and shrubs and are generally found on steep to very steep slopes. They are usually idle land very rarely used for pasture purposes. Because the land is idle, future development will most likely take place in this area. The Land Use multiplier is thus set at 0.95 in recognition of the fact that grassland areas will most likely be tapped for future development.

A reduction of 10% is applied to the Risk Rating in agricultural areas. Agriculture is a significant component of the region's economy and, thus, is assigned a Land Use Multiplier of 0.9.

Miscellaneous areas include mine pit sites, filling ponds, reservoirs, and riverwash/riverbeds. Since mine pit sites and filling ponds are components of the operations of mines, their destruction by landslides would have some economic impact.

Landslides near reservoirs and riverbeds might lead to siltation and/or damming, and have adverse ecological impact. These are given a Land Use multiplier of 0.85.

The largest reduction factor is applied to forest areas. This is because forest areas are largely undeveloped and, ideally, will remain undeveloped in order to facilitate reforestation of the greater Baguio area. A Land Use multiplier of 0.80 is applied.

4.6.2 Population Multipliers

For Population, the multipliers range from 0.75 - 1.0, with high population in the area in question being assigned a multiplier of 1.0 (Table 4.12). This reflects the fact that the full Risk Rating must be applied in areas with the highest population.

Population per Barangay	Multiplier
0 – 1000	0.75
1000 – 2000	0.8
2000 – 3000	0.85
3000 – 4000	0.9
4000 – 5000	0.95
>5000	1

Table 4.12 Population Multipliers

The Population Multipliers by Barangay are tabulated in Appendix D. Population Data were taken from the National Statistics Office and were the results of the 2003 census.

4.7 Land-use and Building Constraints

A Landslide Risk Rating System is an indispensable tool to define land-use and building constraints which, if applied, will result in the mitigation of the impact of landslides and the prevention of disaster. These constraints are applicable both to zones which are already built up (where adjustment to existing practices is possible) and to areas earmarked for new development. Thus, in the former case, the constraints indicated may lead to the removal of extremely vulnerable structures, to programs of urban renewal in which the risk rating has been taken into account, or to temporarily adjusted land uses. In the latter case, they will simply indicate restrictions on land use and building.

4.7.1 Use of the Landslide Risk Rating System

The Landslide Risk Rating System, provides the engineer with a "go-no go" tool. It is, nevertheless, important to point out that the constraints discussed in section 4.7 do not have an absolute meaning. They are relative from at least two standpoints: 1) they assume the enforcement of the usual building and safety regulations for construction; 2) the constraints are linked to the remedial measures in existence (if any). If remedial measures are installed at a site, the landslide risk will have to be modified and so, consequently, will the constraints.

In light of the above considerations, this Risk Rating System can be generalized for areas outside of the one studied in this work. The relative simplicity of the method does not require the use of sophisticated techniques. It is based on simple data available at every site, which may require only a simple sampling and testing program and the requisite interpretation of data by the engineer.

One of the benefits of applying a tool such as this is that it serves as a basis for improving building codes. Specifically, building codes may be more effectively adapted to local conditions. In addition, building regulations may be modified to take into account variations in geotechnical conditions across a given planning area. Significant savings could, in principle, be achieved by introducing a certain amount of flexibility into building codes.

In conjunction with the Landslide Risk Rating System, instrumentation may be installed to help identify the subsurface conditions and to determine if a slope in a particular site is unstable. For instance, inclinometers can be used to measure horizontal movements in the ground as a function of depth. They can show the location of shear surfaces and monitor the rate of shear displacements (Coduto, 1999). Installation of inclinometers can, however, be very cost-prohibitive and thus other methods may be preferable. For example, monuments may be installed at various locations on the ground surface and their positions over time can be measured with conventional surveying equipment. The monuments are significantly less expensive than inclinometers. Also, unlike inclinometers, drilling rigs are not necessary for installation of monuments.

The position of the groundwater table and measurements of pore water pressures can also be used to assess the stability of slopes. Observation wells and piezometers may, therefore, be installed.

4.7.2 Definition of Constraints

The following is a list of the proposed major constraints which are assigned according to the Risk Rating of each future development site to which the tool is applied. It must be noted that these are merely suggested constraints and that further study must be done in order to arrive at a final set of constraints based on Risk Ratings.

A – No Development

B – No Low-rise Buildings (0 to 2 Stories) and Roads

C – No Medium-rise Buildings (3-7 Stories)

D – No High-rise Buildings (8 Stories and more)

E – No Public Places (i.e., Schools, Markets, Shopping Centers, Theaters, Offices, etc.)

F – No Dangerous Industries and Storage Facilities Which May Cause Explosions or Fire (Chemical Plants, Oil Processing Plants, Gas Storage, Fuel Storage, etc.) and No Capital-Intensive Industries or Activities (Modern Textile Plants, Assembly Plants, Light Industry producing Costly and Sophisticated Products and Components, etc.)

G – No Vital Industries and Services (Electricity, Water Treatment, Hospitals, Telecommunications, Fire Departments, Relief Services, etc.)

The above constraints would be applied as follows:

Risk Rating	A	B	C	D	E	F	G
95 to 99	X	X	X	X	X	X	X
90 to 94		X	X	X	X	X	X
85 to 89			X	X	X	X	X
80 to 84				X	X	X	X
75 to 79					X	X	X
70 to 74						X	X
65 to 69							X

Table 4.13 Application of Constraints Based on Risk Rating

4.8 Remedial Measures

The following general remedial measures are proposed for the slopes in the Greater Baguio area, as determined by the Landslide Risk Rating System. Depending on what remedial measures have been or will be put in place and what Risk Rating has been assigned the particular slope, the engineer can then use his or her judgment to decrease the Hazard Rating of a site.

The determination of which remedial measure is appropriate at a particular site will depend on the site's specific attributes, i.e., which hazard factor predominantly contributes to the instability. Furthermore, this study does not include an analysis of the relationship of the particular remedial measure to the degree to which the Hazard Rating of an area may be reduced.

a. Diversion of the flow of stream and river channels away from roads to prevent undercutting of slopes in road cuts. The toe of an undercut slope may also be stabilized structurally by installing piles to increase the shear strength of the slope.

b. Stringent control of blasting during road construction and mining operations in order to minimize vibrations.

c. Reforestation of denuded areas with fast-growing trees. Vegetation provides protection from erosion, removes water from the ground by the hydraulic pumping action of roots, and provides some soil reinforcement. Although this reinforcement is not adequate to prevent deep-seated slides, it can prevent shallow slides. Because of the amount of precipitation in the Baguio City area, no irrigation systems are needed to maintain the vegetation and no new water need be introduced into the subsurface.

d. Improvement of surface drainage system to reduce downward percolation of rainwater into slopes. This can be in the form of providing appropriate grades so that surface water flows away from the slope. Additional drainage measures can consist of concrete-paved ditches (Figure 4.2) or buried culvert pipes (Coduto, 1999).

Figure 4.2 Concrete-paved Ditch (Coduto, 1999)

e. Slope-stabilization of existing and proposed slopes. The Factor of Safety of a slope is defined as the ratio of the shear strength to the shear stress. Stabilization measures must either decrease the shear stress, increase the shear strength, or both.

   - Cut slopes such as those found along roads and highways often expose daylighted bedding planes in the soft sedimentary rocks in the Baguio area. These can be stabilized by overexcavation and replacement with a compacted fill (with better strength properties than the natural slope materials) to buttress the slope (Coduto, 1999). Such fills would be stronger than the original slope material because they would not contain the weak bedding planes. This is shown schematically in Figure 4.3.

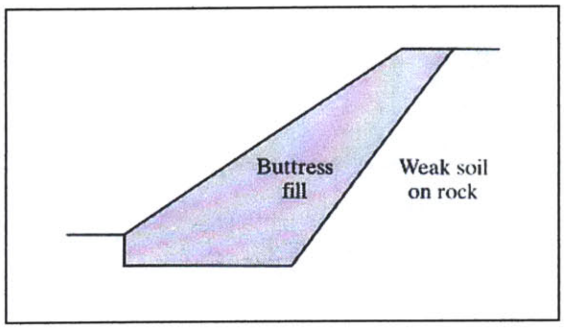


Figure 4.3 Overexcavation and Replacement of Cut Slopes (Coduto, 1999)

- Berms may be placed at the toe of slopes to stabilize existing landslides or unstable slopes. Berms, however, require space that may not be available in congested urban construction areas. The tops of berms, nevertheless, may be level and can be used for development.

- Slopes may be stabilized structurally using retaining walls. These are more expensive than non-structural measures, but may become cost-effective in urban areas where space is not available for berms or the decrease of slope gradients. Retaining walls must be reinforced and provided with weepholes and adequate drainage within the retained slope. Installing weepholes and other drainage measures improves stability by decreasing the pore water pressures (thus increasing the shear strength), and by drying the soil (which increases its strength and decreases its weight).

f. Removal of water already present in the ground using subsurface drains. Some recommended measures are:

- Perforated pipe drains consisting of pipes with holes, buried in the ground to collect the water and remove it from the slope. The pipes should be surrounded by gravel and a filter fabric (Coduto, 1999). The gravel increases hydraulic permeability around the pipe, thereby increasing drainage. The filter fabric prevents fines from entering the pipes and clogging them (Figure 4.4).

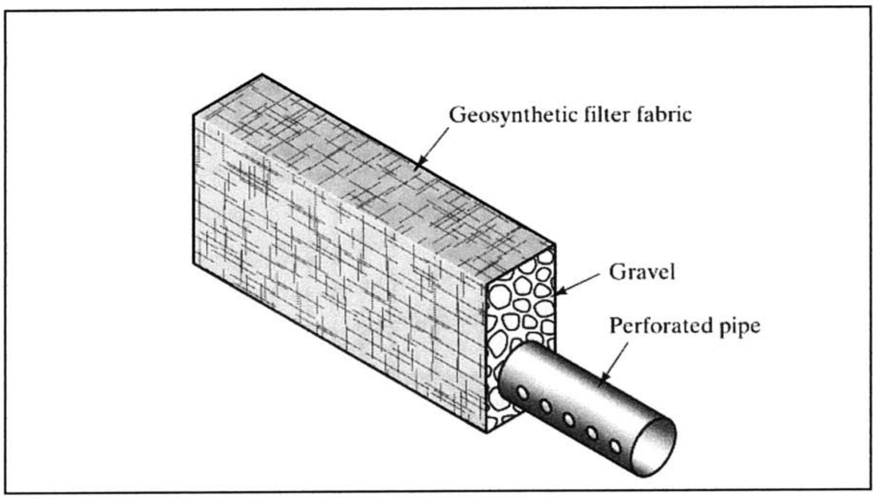


Figure 4.4 Perforated Pipe Drains (Coduto, 1999)

g. Rock bolting in slopes where the planes of weakness daylight.

h. Installation of steel nets, shotcrete, or grout in highly fractured zones where rock bolting would be ineffective. The shotcrete and grout, in addition to preventing rock falls, can prevent downward percolation of water. Tension cracks may also be filled with adequately compacted, impermeable clay to prevent infiltration of rainwater.

i. Review of the strategy for building road networks. Since the addition of highways into Baguio City would not alleviate the landslide problem, tunneling may be the solution for landslide prone areas.

j. Mapping of existing slide areas in geologic exploration reports to minimize the adverse effects associated with building on old slide materials.

Chapter 5. Conclusions

5.1 Summary

The preliminary analysis discussed in this work is based on the result of a synthesis of available data and records regarding landslides in Baguio City, the Philippines. The method used in this study poses some limitations for identifying cause-effect relationships—mainly that geotechnical test data were not available for analysis. With this limitation in mind, one may interpret the initial results presented here as suggesting the following:

First, the main landslide trigger in the Baguio area is precipitation. During the rainy season, the amount of rainfall in the area is well in excess of that which has been found to trigger landslides in the residual soils of the tropics and subtropics. The high amount of precipitation during the rainy season causes rises in the groundwater table that in turn result in increased pore water pressures. This decreases the shearing resistance in the slopes. Saturation of the initially unsaturated soil materials by rainwater also decreases the shear resistance in the slope.

Second, most of the slide areas are underlain by decomposed or hydrothermally altered materials. Their resistance to weathering and erosion is lowered because of this alteration and degradation. The shearing strength of the altered rock is less than that of fresh rock. In many cases, the sliding of residual soil and weathered rock is along the interface with the unweathered rock, as this interface is a zone of weakness.

Third, the tectonic history of the Cordillera Mountain Range contributes greatly to the vulnerability of the area to landslides. The uplift of the Cordilleras rejuvenated the drainage system and led to the progressive steepening of slopes. This causes vigorous, accelerated erosion. The rejuvenation of the drainage system also facilitates the undercutting of slopes by adjacent streamflow. Because of the tectonic history of the area, the original structure of rock formations was destroyed and their strength was decreased.

Fourth, human activity plays a large role in increasing the vulnerability of Baguio's slopes to landslides. Most notably, deforestation is significant in increasing landslide hazards.

Fifth, old landslide areas with materials at or near their residual shearing strength are vulnerable to remobilization during rainy seasons, i.e., when the soil becomes saturated and hydrostatic pressures build up.

Finally, violent ground shaking that is associated with the occurrence of large-magnitude earthquakes play a significant part in destabilizing slopes during and long after the seismic shaking. The cyclic stress generated by the earthquake produces a horizontal acceleration of the ground that increases the shear stress in slopes. In areas where ground shaking is not strong enough to destabilize slopes (due to differing response potentials of the bedrock types), near-surface sediments are loosened and the slopes rendered prone to sliding during the rainy season for many years.

In the second portion of the study, a Landslide Risk Rating System was developed as a tool for engineers and planners to define land-use and building constraints. It is this author's hope that this System will help mitigate the impact of landslides by providing a rational basis for land-use decision-making, landslide risk minimization, and recommendation of remedial measures. Factors that are taken into account in the formulation of the rating system are bedrock geology, slope angles, and vegetation. It must be noted that the data available to the author were insufficient to create landslide hazard maps or a site-specific preventive and remedial slope safety system.

The suggested land use constraints are applicable both to zones which are already built up (where adjustment to existing practices is possible) and to areas earmarked for new development. Remedial measures for the reduction of landslide susceptibility are discussed.

Understanding the causal factors of mass movements, as well as their interaction, is valuable in the design of a Landslide Risk Rating System and of appropriate remedial measures. This is particularly important as population pressure and economic growth drive ever-increasing development in the Greater Baguio area.

5.2 Recommendations

The most serious limitation of this study is the absence of geotechnical test data that can be used in a mathematical analysis of the slope failures that occurred in the Baguio City area. There was a lack of adequate laboratory facilities and site sampling equipment in the region when the reports of landslides were written. Slope stability calculations could, therefore, not be performed to better describe the condition of the slopes. The studies detailed in the reports of landslides were, therefore, limited to visual field appraisal of the conditions of unstable slopes. A limited number of Atterberg Tests were conducted in some areas.

It is, therefore, recommended that in future research work on this subject matter, efforts be made to subject soil and rock samples from various slopes to geomechanical testing. Engineering parameters can then be determined as well as the mode of failure and factor of safety of slopes. A complete register of all slopes and their potential/past failure modes can be compiled. Using this database, a comprehensive Landslide Hazard Map can be created, in which each slope in the greater Baguio area is rated. A site-specific preventive and remedial slope safety and maintenance system for every slope in the Baguio area would be the ultimate goal of future work.

It is further recommended that an effort also be made to relate the type of remedial measure to the Risk Rating of a particular site. In addition, it would be beneficial to conduct an analysis of how Hazard Ratings may be reduced when particular remedial measures are in place or will be installed before construction.

Appendix A. Precipitation Data

(Philippine Atmospheric, Geophysical, and Astronomical Services Administration)

Baguio Synoptic Station	January	February	March	April	May	June	July	August	September	October	November	December	Total	
Year	Precipitation, mm	Precipitation, mm	Precipitation, mm	Precipitation, mm	Precipitation, mm	Precipitation, mm	Precipitation, mm	Precipitation, mm	Precipitation, mm	Precipitation, mm	Precipitation, mm	Precipitation, mm	Precipitation,mm	% Deviation From Mean
1950	14	11.4	114.8	152.7	304	350	1075.7	1504.7	408.7	448.6	43.9	31.5	4460	122.26
1951	19.1	3.6	16.8	59.2	374.1	491	927.4	958.3	591.3	151.4	94.7	11.7	3698.6	101.39
1952	19.1	24.4	31.8	200.4	304.8	347.5	267.7	668.8	305.6	208.8	102.4	56.9	2538.2	69.58
1953	2.8	13.2	36.8	79.8	320.8	462	462	1190.2	274.6	100.6	706.9	45.7	3695.4	101.30
1954	0	1.5	140	103.4	108.5	109.2	245.1	622.3	405.1	411	378	3.6	2527.7	69.29
1955	5.3	0.5	3.6	146.3	222	178.8	449.6	326.1	555.8	197.6	97.3	2	2184.9	59.89
1956	11.9	24.4	178	149.6	325.9	208	309.4	627.1	1199.4	321.6	232.2	25.2	3612.7	99.03
1957	6.1	trace	32	28.4	101.4	816.6	280.9	599.7	810.8	159.5	105.6	11.2	2952.2	80.93
1958	36.8	1.8	2.8	30.7	193.8	728.7	841	305.6	558.3	190.3	10.9	4.8	2905.5	79.65
1959	9.9	trace	93.4	22.4	262.9	261.6	241.1	492.8	264.7	120.1	262.1	9.4	2040.4	55.93
1960	35	113.3	29.4	289.1	348	249.7	275.3	1918.2	270.3	204.7	68.3	20.1	3821.4	104.75
1961	0	0	119.9	63	190.5	574.8	1025.7	611.6	565.2	196.6	72.1	7.6	3427	93.94
1962	3.3	trace	9.1	93	263.9	184.9	1249.2	694.2	832.9	154.2	29.7	7.9	3522.3	96.55
1963	9.7	4.3	9.9	7.9	125.5	1092.5	489.7	383.8	1458	72.2	42.4	20.6	3716.5	101.88
1964	3.2	0.8	18.9	158.4	233.1	520.4	299.9	1870.9	572.3	443.7	202.9	143.6	4468.1	122.48
1965	2.6	22.4	118.6	200.1	459.9	493.3	712.6	371.3	364.8	106.6	24.5	trace	2876.7	78.86
1966	19.6	6.9	45.3	26.8	764.3	241.8	374.3	601.8	956.7	60.1	175.4	37.1	3310.1	90.74
1967	1.8	4.6	12.1	230.9	197.9	1417.9	423.8	1141.1	440.3	1560.3	109.1	0.8	5540.6	151.88
1968	4.2	trace	6.4	51.1	275.5	346.7	1043.7	1672.3	1480.8	31.2	18.6	0	4930.5	135.15
1969	8	0.8	7.2	85.9	354	382.3	1211.8	616.3	894.9	279	52	48.6	3940.8	108.02
1970	21.2	2.9	21.3	68.8	340.6	417.4	405.9	676.8	616	174.5	65.4	50.8	2861.6	78.44
1971	12.7	12.1	4.2	144.4	155.4	496.8	1321.1	756.6	475.8	306.4	46.8	66.7	3799	104.14
1972	18.8	1.9	12.3	80.2	328.3	455.4	4774.5	1040.9	331.9	50.9	46.5	25.6	7167.2	196.47
1973	0.6	trace	1.1	51.5	106.2	372.5	418.7	537.4	225.2	816.2	54.4	13.5	2597.3	71.20
1974	20.1	trace	7.4	97.2	272.4	549.7	389.5	1487.5	332.4	2273.5	536.1	48.7	6014.5	164.87
1975	17.1	trace	3.1	57.9	215.2	224.4	154.3	787.9	477.4	295.5	28.5	43.1	2304.4	63.17
1976	21.6	trace	37.9	21.4	1304.5	1224.8	377.3	677	373	176.3	81.5	7.5	4302.8	117.95
1977	30.2	trace	5.6	30.8	294.8	159.3	694.5	784.2	1274.3	138.8	186.6	trace	3599.1	98.66
1978	0	trace	5.8	64.6	265.9	424.1	613.9	1412.9	583.9	344.8	20	29.7	3765.6	103.22
1979	trace	1.4	1.4	199.3	410.1	239.1	586.7	1078.4	250.2	206.1	20.7	48.1	3041.5	83.37
1980	1	1.9	16.8	4.8	1040.4	4.8	1323.3	237.6	562.2	210.8	885	35.4	4324	118.53
1981	38.6	2.8	0	241.8	248.2	629.5	466.5	1165.4	634.7	196.3	206.4	0.4	3300.2	90.46
1982	0	18.23	33.4	150.97	145.77	282.13	793.73	557.3	268	224.93	72.97	27.73	2575.16	70.59
1983	16.27	9.9	25.8	2.57	104.95	165.43	216	721.83	268.17	149.8	63	0	1743.72	47.80
1984	8.8	0	89.4	130.43	409.35	329.5	315.85	988.65	530.65	237.75	109.65	1.15	3151.18	86.38
1985	3.7	25.3	73.85	205.25	121.8	1213.05	196.05	1029	440.8	283.5	55.9	8.9	3657.1	100.25
1986	6.4	74.63	93.53	5.7	386.7	226.4	1495.7	693.37	757.23	135.7	48.77	11.63	3935.76	107.89
1987	0	0.7	20.47	66.43	198.9	337.33	180.57	469.73	258.5	341.83	5.93	10.67	1891.06	51.84
1988	11.9	18.45	0.05	59.75	153.2	410.6	776.15	243.75	292.1	424.85	21	7.3	2419.1	66.31
1989	18.63	26.97	116.25	67.2	214.63	212.03	827.23	371.3	887.83	247.63	61.97	0.07	3051.74	83.65
1990	trace	0	6.9	15.7	346.9	1088.1	585	1599.9	861.5	109.5	51.5	8.5	4673.5	128.11
1991	trace	10.4	10.6	125.6	124	177.8	586.4	678.7	593.8	1735.3	15.5	1.2	4059.3	111.27
1992	8.3	0.4	67.8	23.6	483.2	317.6	473.4	1403.2	1611.5	1195	21	0.6	5605.6	153.66
1993	1.6	3.6	4	88.4	37.8	1024.3	410.9	431.9	492	584.6	172.4	25.7	3277.2	89.83
1994	23.1	5	94.6	103.5	353.4	193.1	1191.2	719.5	178.6	114.4	97	3.7	3077.1	84.35
1995	trace	4.4	trace	323	220.4	151.1	470.3	704.7	288.9	139.3	102.7	597	3001.8	82.28
1996	3.2	4.6	16.2	87.6	314.2	166.4	1681.7	816.5	356.6	240.7	340.4	719.5	4747.6	130.14
1997	2.2	0.5	24.6	89.1	395.1	218	287	1200	209	106	85.9	trace	2617.4	71.75
1998	trace	0	14.4	44.1	307.1	82.7	289.8	291.9	1031.8	1569.3	85.2	89.5	3805.8	104.32
1999	5.7	0.1	121.1	245.5	293.8	541.3	724.3	1279.3	1694.5	732.5	99.1	44.5	5781.7	158.49
2000	3.6	107.5	151.7	178.7	470.6	249.4	1385.7	697.3	640.6	917.6	51.4	63.6	4917.7	134.80
2001	14.6	39.5	289.8	76	291	451.2	1642	274	842.2	97	61.6	23.2	4102.1	112.45
2002	5	2	0.6	71.2	264.4	411	1883.4	525.6	301.5	224.8	67.3	10	3766.8	103.25
2003	trace	25.4	4.8	46.8	662.7	792.4	721.3	1089.4	303.2	179.3	60.4	4.4	3890.1	106.63
Average	10.99	14.42	45.35	100.91	315.05	438.82	756.77	826.05	601.05	381.47	125.14	49.35	3648.06	196.47

May to October = 3319.21
Percentage of Total = 90.99

July + August = 1582.82
Percentage of Total = 43.39

Baguio Area Climatological Normals	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual Average**
Precipitation,mm	11	11.3	38.7	104.8	288.4	467.3	576.8	817.5	670.9	257.4	142.5	26.6	**3413.2**
No. of Rainy Days	4	3	5	10	19	23	26	27	25	17	9	5	**173**

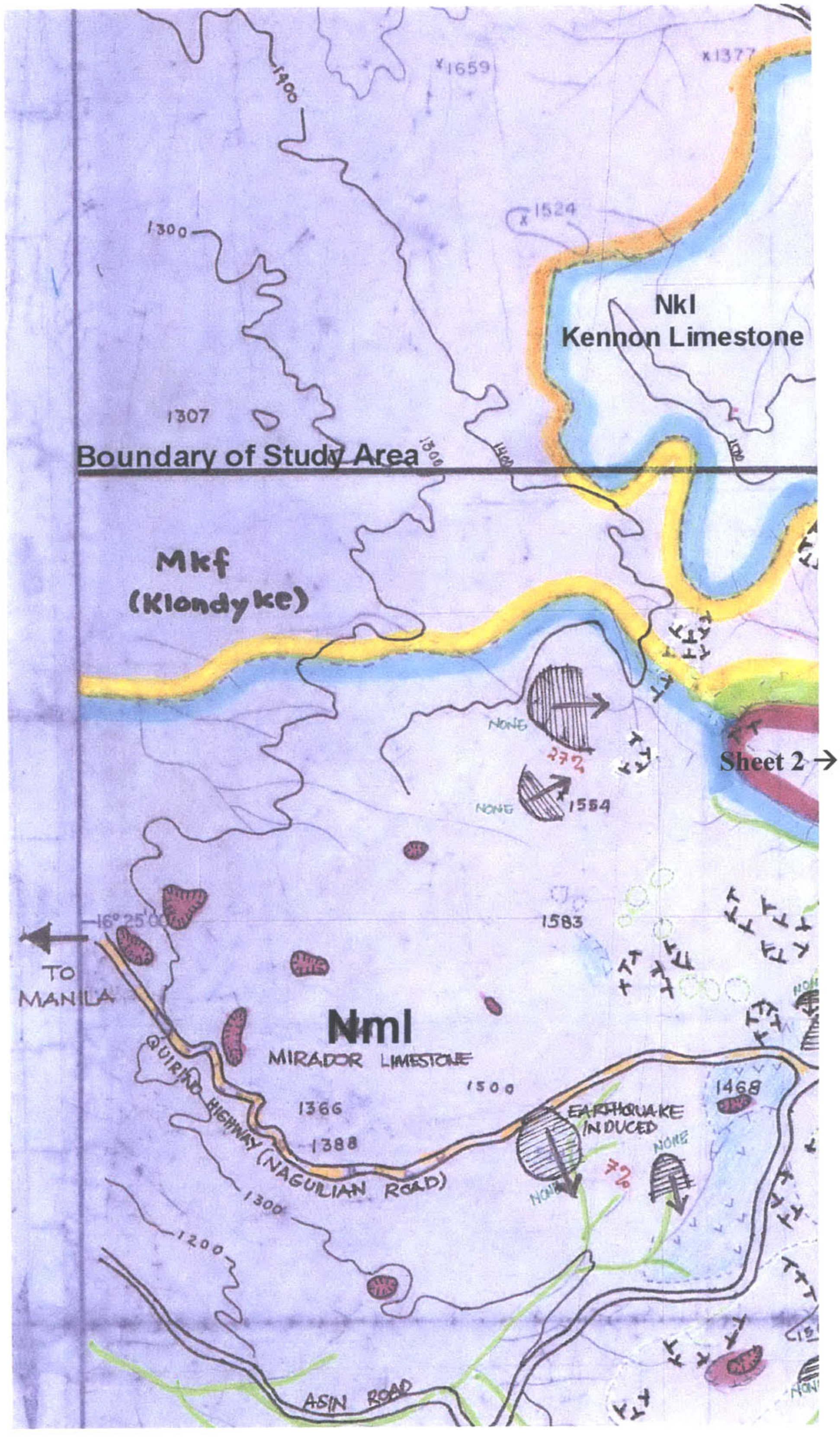
Appendix B. Engineering Geomorphology Map of the Baguio Area

Lithology

Qal	Quaternary Alluvium
Mkf	Klondyke Formation
Nml/Nkl	Mirador Limestone/Kennon Limestone
NQbf	Baguio Formation
PNzf	ZigZag Formation
KPpf	Pugo Formation

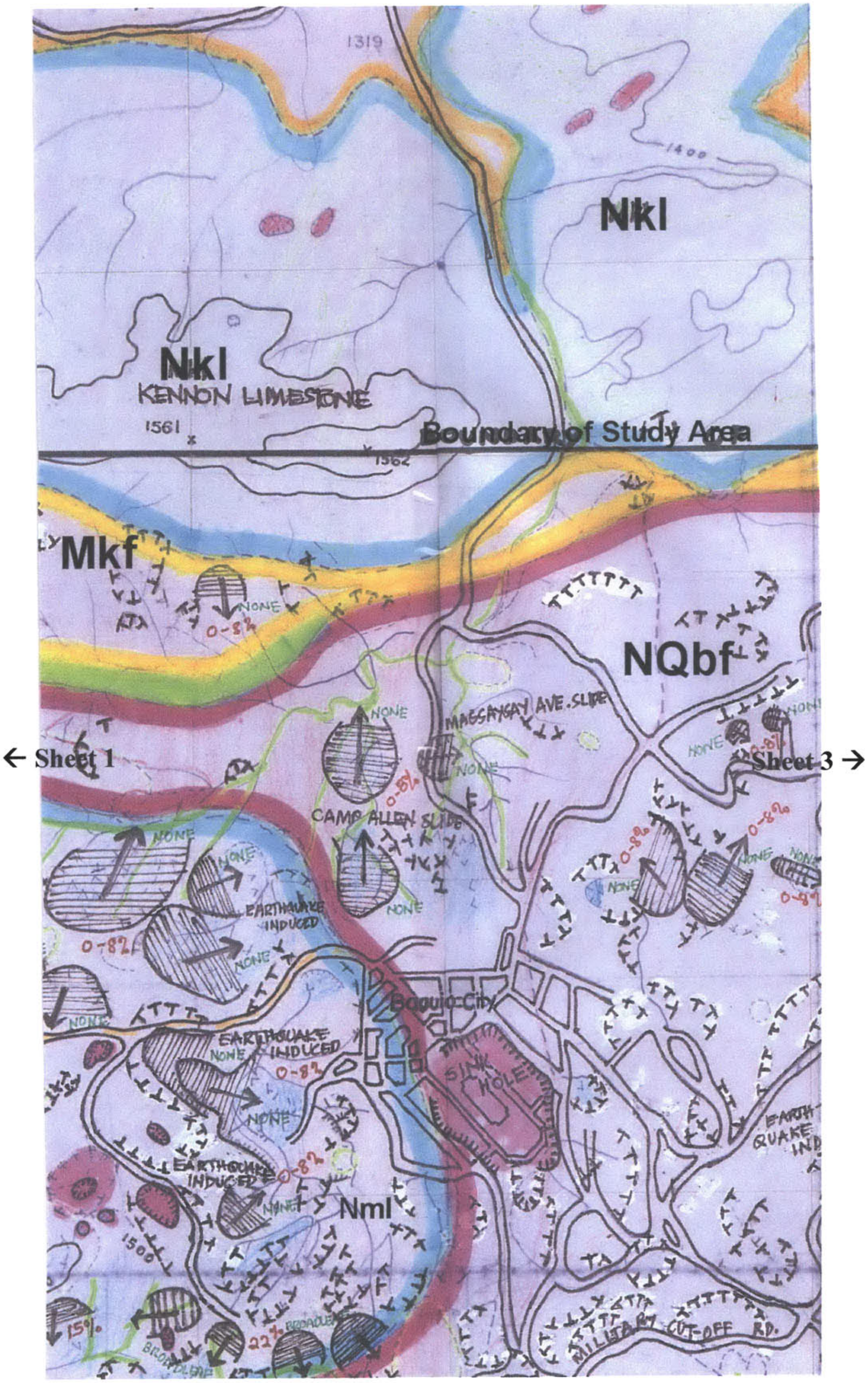
Index to Sheets

Sheet 1	Sheet 2	Sheet 3
Sheet 4	Sheet 5	Sheet 6

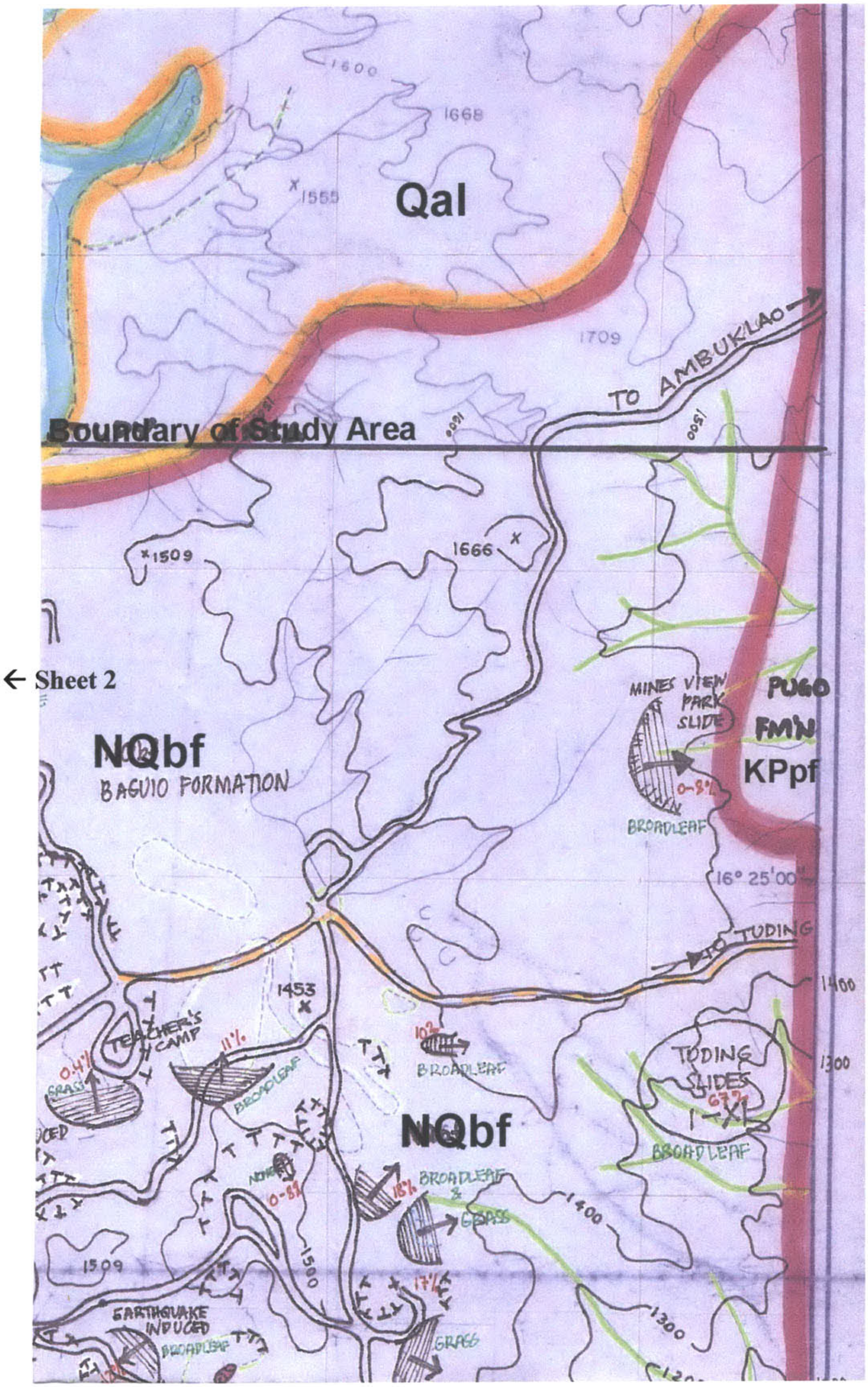


1400
1659
1377
1300
1524
Nkl
Kennon Limestone
1307
Boundary of Study Area
Mkf
(Klondyke)
NONE
1584
Sheet 2 →
1583
TO
MANILA
Nml
MIRADOR LIMESTONE
1500
1468
QUIRINO HIGHWAY (NAGUILIAN ROAD)
1366
1388
EARTHQUAKE
INDUCED
1300
1200
ASIN ROAD

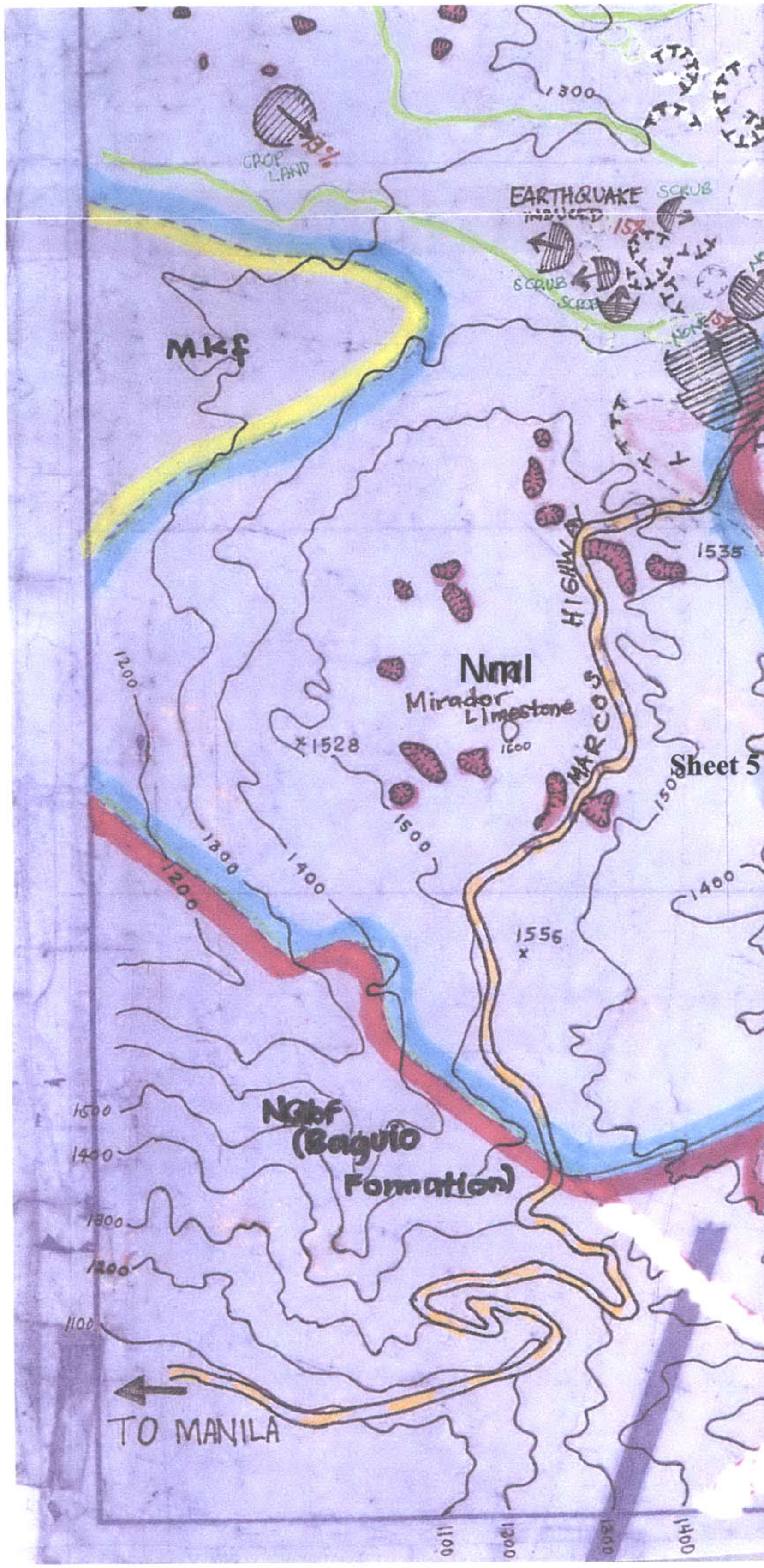
Sheet 1


Nkl
Nkl
KENNON LIMESTONE
Boundary of Study Area
Mkf
NQbf
← Sheet 1
Sheet 3 →
MAGSAYSAY AVE. SLIDE
CAMP ALLEN SLIDE
EARTHQUAKE INDUCED
Baguio City
SINK HOLE
Nml
MILITARY CUT-OFF RD.

Sheet 2

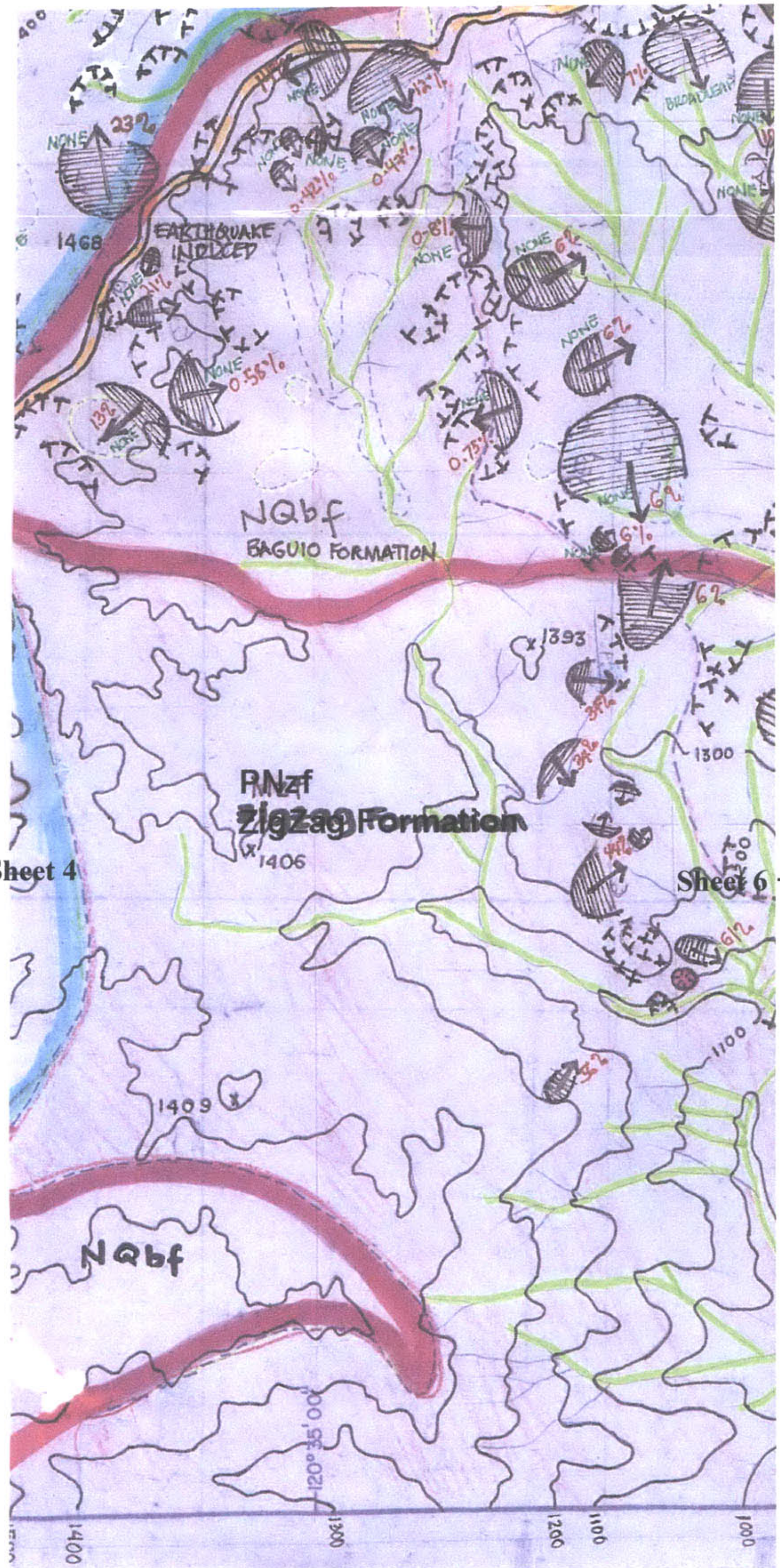

Qal
Boundary of Study Area
TO AMBUKLAO
← Sheet 2
NQbf
BAGUIO FORMATION
MINES VIEW PARK SLIDE
PUGO FMN
KPpf
BROADLEAF
16° 25' 00"
TO TUDING
TEACHER'S CAMP
TUDING SLIDES
NQbf
EARTHQUAKE INDUCED
GRASS

Sheet 3



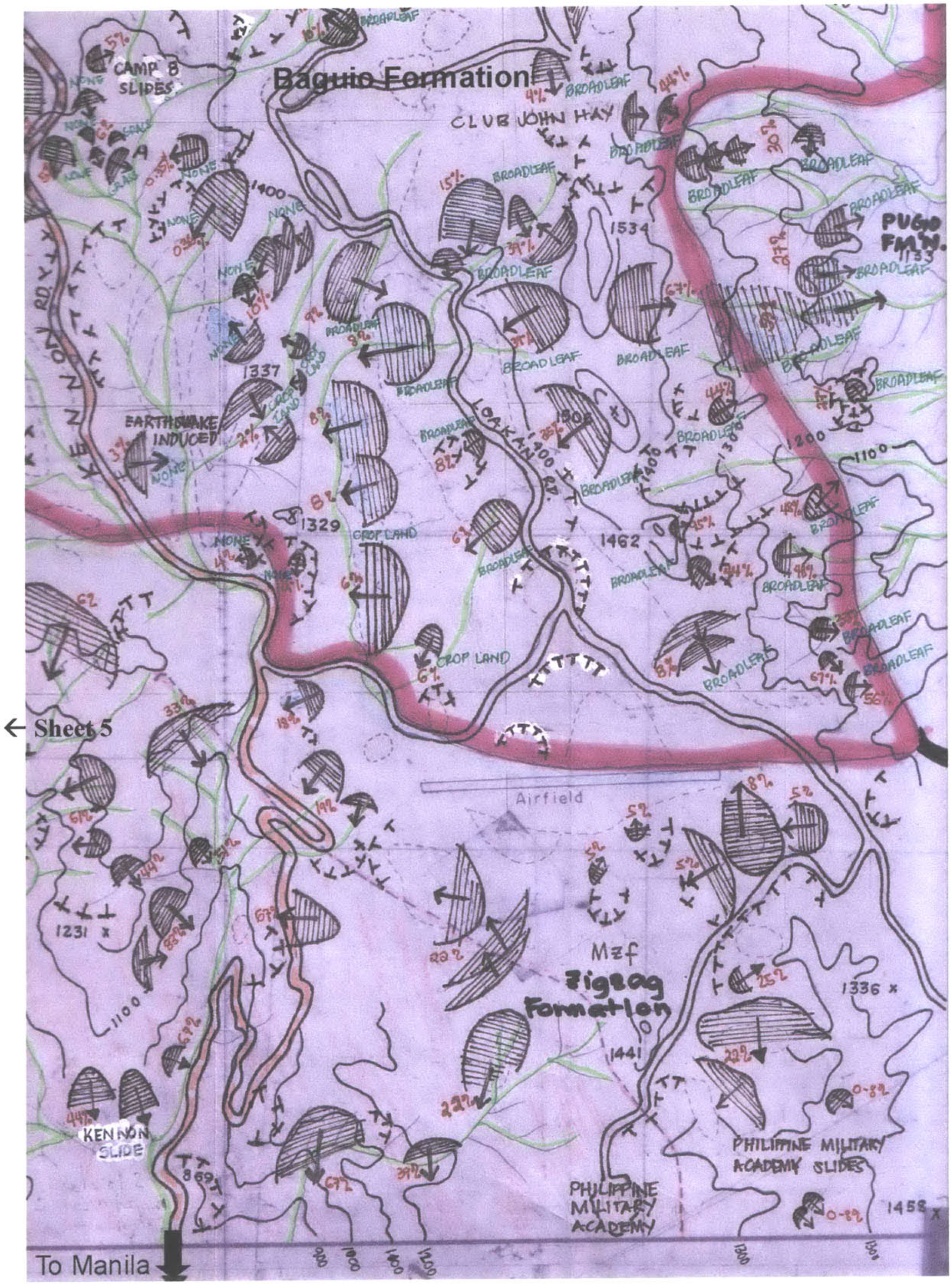
Sheet 5 →

Sheet 4



← Sheet 4 Sheet 6 →

Sheet 5


Baguio Formation
CAMP 8 SLIDES
CLUB JOHN HAY
PUGO FM'N.
KENNON RD.
LOAKAN RD.
EARTHQUAKE INDUCED
BROADLEAF
CROP LAND
NONE
Airfield
Zigzag Formation
KENNON SLIDE
PHILIPPINE MILITARY ACADEMY SLIDES
PHILIPPINE MILITARY ACADEMY
To Manila
← Sheet 5

Sheet 6

Appendix C. Vegetation Classifications by Barangay

(Topographic Map of Baguio City, 1995)

District		Details	Vegetation	Class
I		Lucban		
	1	ABCR	none	IV
	2	Alfonso Tabora	none	IV
	3	Bagong Lipunan	none	IV
	4	Happy Homes	none	IV
	5	Harrison-Claudio C.	none	IV
	6	Holy Ghost Extension	broadleaf	III
	7	Holy Ghost Proper	broadleaf	III
	8	Imelda Village	broadleaf	III
	9	Gen. Luna, Lower	none	IV
	10	Kabayanihan	none	IV
	11	Kagitingan	none	IV
	12	Kayang Hilltop	none	IV
	13	Lower Magsaysay	none	IV
	14	Upper Magsaysay	none	IV
	15	Magsaysay, Private Rd.	none	IV
	16	Malcolm Square	none	IV
	17	New Lucban	none	IV
	18	P. Burgos	none	IV
	19	P. Zamora	none	IV
	20	Sanitary Camp North	bushes/scrub	I
	21	Sanitary Camp South	none	IV
	22	Session Road	none	IV
	23	Slaughter House	none	IV
	24	T. Alonzo	none	IV
	25	Trancoville	none	IV
	26	Honey Moon-Holy Ghost	bushes/scrub	I
II		Campo Filipino		
B				
	1	Camp Allen	broadleaf	III
	2	Campo Filipino	broadleaf	III
	3	Crescencia Village	none	IV
	4	Guisad Central	none	IV
	5	Guisad Surong	none	IV
	6	Bokawkan, Lower	none	IV
	7	Fairview, Lower	none	IV
	8	Upper Market Subdivision	none	IV
E		Pinsao		
	1	Pinsao Pilot	none	IV
	2	Pinsao Proper	grass	II
	3	Pinget	none	IV
M		Quirino Hill		
	1	Q. Hill East	bushes/scrub	I
	2	Q. Hill Lower	none	IV
	3	Q. Hill Middle	none	IV
	4	Q. Hill West	none	IV
	5	Camdas Subdivision	none	IV
	6	Dizon Subdivision	broadleaf	III

TYPE	CLASS
Broadleaf Mix or Bushes/Scrub	**I**
Grass or Crop Land/Agricultural Land	**II**
Broadleaf	**III**
None	**IV**

III				
D1		Irisan	broadleaf mix	I
C		Quezon Hill		
	1	Fairview, Upper	none	IV
	2	Fairview, Middle	none	IV
	3	Fairview, Proper	none	IV
	4	Quezon Hill, Upper	none	IV
	5	Victoria Village	none	IV
IV		City Camp		
F				
	1	AZCKO	none	IV
	2	C. Palma	none	IV
	3	City Camp Central	none	IV
	4	City Camp Proper	none	IV
	5	Dominican Hill-Mirador	broadleaf	III
	6	Kayang Extension	none	IV
	7	Legarda-Burnham	none	IV
	8	Lourde Subdivision Extensior	none	IV
	9	Lourdes Subdivision Lower	none	IV
	10	Lourdes Subdivision Proper	none	IV
	11	Queen of Peace	none	IV
	12	Quirino (Gen. Aguinaldo)	none	IV
	13	Quirino-Magsaysay, Upper	none	IV
	14	Rizal Monument	none	IV
	15	Rock Quarry, Lower	none	IV
	16	Rock Quarry, Middle	none	IV
	17	Rock Quarry, Upper	none	IV
	18	San Roque	none	IV
V				
H				
	1	Bakakeng Central	none	IV
	2	Bakakeng Norte	none	IV
	3	Balsigan	none	IV
	4	Baguio Gen. Hospital Compo	broadleaf mix	I
	5	Dontogan	broadleaf	III
	6	Happy Homes-CPO Sioco	none	IV
	7	I.R. Marcos-La Salle	broadleaf	III
	8	Phil-am	broadleaf	III
	9	Sto. Rosario	broadleaf	III
	10	Sto. Tomas Proper	none	IV
	11	Sto. Tomas School Site	none	IV
	12	SLU-SVP Housing	none	IV
G		Asin		
	1	Asin Road	none	IV
	2	San Luis	none	IV
VI				
J		Loakan		
	1	Camp 7	broadleaf mix	I
	2	Camp 8	grass	II
	3	Loakan-Liwanag	broadleaf	III
	4	Loakan Proper		
	5	Puliwes	none	IV
	6	San Vicente	none	IV
K		Atok Trail		
	1	Atok Trail		
	2	Fort del Pilar (Phil. Mil. Acade	broadleaf	III
	3	Kias		
	4	Apugan-Loakan	broadleaf	III

VII				
P		Sct. Barrio		
	1	Dagsian, Lower	none	IV
	2	Dagsian, Upper	broadleaf	III
	3	Gabriela Silang	none	IV
	4	Happy Hollow		
	5	Hillside	none	IV
	6	Sta. Escolastica	broadleaf	III
	7	Sct. Barrio	broadleaf	III
O		Mines View		
	1	Gibraltar	broadleaf	III
	2	Lucnab		
	3	Mines View Park		
	4	Outlook Drive	broadleaf	III
	5	Pucsusan		
N		Pacdal		
	1	Lualhati	broadleaf	III
	2	M.Roxas-Teacher's Camp	none	IV
	3	Pacdal	broadleaf	III
	4	St. Joseph Village	none	IV
	5	South Drive	broadleaf mix	I
	6	Country Club	broadleaf mix	I
VI				
A		Aurora Hill		
	1	Ambiong	broadleaf mix	I
	2	A. Hill, N. Central	none	IV
	3	A. Hill, S. Central	none	IV
	4	Bayan Park Village	broadleaf	III
	5	Bayan Park East	none	IV
	6	Bayan Park West	none	IV
	7	Brookside	none	IV
	8	Brookspoint	none	IV
	9	Lopez-Jaena	none	IV
	10	Malvar-Sgt. Floresca	grass	II
	11	Modernsite-East	none	IV
	12	Modernsite-West	none	IV
	13	San Antonio Village	none	IV
I		Engineer's Hill		
	1	Cabinet Hill-Teacher's Camp	broadleaf mix	I
	2	DPS	none	IV
	3	Engineer's Hill	none	IV
	4	Gen. Luna, Upper	broadleaf	III
	5	Greenwater Village	broadleaf	III
	6	Marcoville	none	IV
	7	Military Cut-off	broadleaf	III
	8	Salud Mitra	none	IV
	129	Barangays		

Appendix D. Population Data and Multipliers by Barangay

(National Statistics Office of the Republic of the Philippines, 2003)

Population Statistics				Population	
District	Details	No. of Households	2003	2004	2005
I	Lucban				
	1 ABCR	275	1810	1849	1889
	2 Alfonso Tabora	307	1803	1841	1881
	3 Bagong Lipunan	80	328	335	343
	4 Happy Homes	346	1754	1791	1830
	5 Harrison-Claudio C.	62	307	314	320
	6 Holy Ghost Extension	493	2701	2759	2819
	7 Holy Ghost Proper	314	1498	1530	1563
	8 Imelda Village	368	1808	1847	1887
	9 Gen. Luna, Lower	59	779	795	813
	10 Kabayanihan	26	146	149	152
	11 Kagitingan	49	203	207	211
	12 Kayang Hilltop	173	883	902	921
	13 Lower Magsaysay	229	1007	1029	1051
	14 Upper Magsaysay	21	93	95	97
	15 Magsaysay, Private Rd.	312	1131	1155	1180
	16 Malcolm Square	26	109	111	113
	17 New Lucban	472	2516	2570	2625
	18 P. Burgos	547	2580	2635	2692
	19 P. Zamora	350	1976	2019	2062
	20 Sanitary Camp North	347	1641	1676	1712
	21 Sanitary Camp South	389	2054	2098	2144
	22 Session Road	38	188	192	196
	23 Slaughter House	418	2169	2216	2264
	24 T. Alonzo	341	1578	1612	1646
	25 Trancoville	581	1928	1970	2012
	26 Honey Moon-Holy Ghost		3927	4012	4098
II	Campo Filipino				
B					
	1 Camp Allen	445	2012	2055	2099
	2 Campo Filipino	399	1976	2019	2062
	3 Crescencia Village	364	1791	1829	1869
	4 Guisad Central	488	2601	2657	2714
	5 Guisad Surong	311	1495	1527	1560
	6 Bokawkan, Lower	288	1348	1378	1407
	7 Fairview, Lower	659	3765	3846	3929
	8 Upper Market Subdivision	183	964	1005	1027
E	Pinsao				
	1 Pinsao Pilot	655	3440	3514	3580
	2 Pinsao Proper	590	2944	3008	3072
	3 Pinget	1059	5406	5522	5641
M	Quirino Hill				
	1 Q. Hill East	454	2246	2294	2344
	2 Q. Hill Lower	363	1787	1825	1864
	3 Q. Hill Middle	460	2276	2325	2375
	4 Q. Hill West	247	1426	1457	1488
	5 Camdas Subdivision	256	1261	1288	1316
	6 Dizon Subdivision	440	1824	1863	1903

III						
D1		Irisan	3591	18844	19029	19664
C		Quezon Hill				
	1	Fairview, Upper	659	3764	3485	3928
	2	Fairview, Middle	611	3294	3365	3437
	3	Fairview, Proper	187	972	993	1015
	4	Quezon Hill, Upper	514	2443	2496	2550
	5	Victoria Village	449	2287	2336	2386
IV		City Camp				
F						
	1	AZCKO	84	475	466	496
	2	C. Palma	264	1291	1319	1347
	3	City Camp Central	407	1899	1939	1961
	4	City Camp Proper	460	2410	2462	2515
	5	Dominican Hill-Mirador	543	2812	2873	2935
	6	Kayang Extension	348	1709	1746	1783
	7	Legarda-Burnham	202	941	962	982
	8	Lourde Subdivision Extension	225	1188	1213	1239
	9	Lourdes Subdivision Lower	90	471	481	492
	10	Lourdes Subdivision Proper	204	998	1019	1041
	11	Queen of Peace	349	1922	1963	2006
	12	Quirino (Gen. Aguinaldo)	489	2526	2581	2636
	13	Quirino-Magsaysay, Upper	585	3002	3066	3133
	14	Rizal Monument	33	154	157	160
	15	Rock Quarry, Lower	274	1500	1532	1565
	16	Rock Quarry, Middle	367	1823	1862	1902
	17	Rock Quarry, Upper	315	1573	1607	1642
	18	San Roque	166	924	944	964
V						
H						
	1	Bakakeng Central	906	4739	4841	4946
	2	Bakakeng Norte	1054	5266	5379	5495
	3	Balsigan	468	2367	2417	2470
	4	Baguio Gen. Hospital Compound	260	1379	1409	1439
	5	Dontogan	622	3161	3229	3298
	6	Happy Homes-CPO Sioco	244	1275	1302	1330
	7	I.R. Marcos-La Salle	168	910	930	950
	8	Phil-am	85	379	388	396
	9	Sto. Rosario	410	2097	2142	2188
	10	Sto. Tomas Proper	671	3509	3585	3662
	11	Sto. Tomas School Site	115	613	626	640
	12	SLU-SVP Housing	444	2192	2239	2287
G		Asin				
	1	Asin Road	1454	663	7828	7997
	2	San Luis	927	5024	5132	5243
VI						
J		Loakan				
	1	Camp 7	1155	5767	5891	6018
	2	Camp 8	442	2297	2347	2397
	3	Loakan-Liwanag	433	2251	2300	2349
	4	Loakan Proper	1217	5731	5854	5980
	5	Puliwes	475	2374	2425	2477
	6	San Vicente	751	3882	3966	4051
K		Atok Trail				
	1	Atok Trail	185	967	988	1009
	2	Fort del Pilar (Phil. Mil. Academy)	500	3050	3116	3183
	3	Kias	690	3599	3676	3755
	4	Apugan-Loakan	332	1585	1619	1654

VII					
P	Sct. Barrio				
	1 Dagsian, Lower	196	980	1001	1022
	2 Dagsian, Upper	122	587	600	613
	3 Gabriela Silang	459	2309	2359	2409
	4 Happy Hollow	321	1331	1316	1389
	5 Hillside	307	1560	1593	1627
	6 Sta. Escolastica	296	1501	1548	1566
	7 Sct. Barrio	324	1516	1533	1582
O	Mines View				
	1 Gibraltar	1216	6375	6512	6652
	2 Lucnab	181	949	969	990
	3 Mines View Park	244	1304	1332	1360
	4 Outlook Drive	270	1482	1514	1548
	5 Pucsusan	89	517	528	540
N	Pacdal				
	1 Lualhati	170	911	931	951
	2 M.Roxas-Teacher's Camp	139	721	736	752
	3 Pacdal	805	4142	4232	4323
	4 St. Joseph Village	498	2710	2768	2828
	5 South Drive	69	324	331	338
	6 Country Club	378	1998	2041	2085
VIII					
A	Aurora Hill				
	1 Ambiong	308	1693	1729	1767
	2 A. Hill, N. Central	150	765	782	799
	3 A. Hill, S. Central	256	1175	1200	1226
	4 Bayan Park Village	181	855	873	892
	5 Bayan Park East	133	673	687	702
	6 Bayan Park West	236	1157	1182	1207
	7 Brookside	531	2469	2522	2576
	8 Brookspoint	277	1574	1608	1643
	9 Lopez-Jaena	199	1072	1095	1119
	10 Malvar-Sgt. Floresca	166	814	832	850
	11 Modernsite-East	433	2406	2458	2511
	12 Modernsite-West	278	1408	1439	1469
	13 San Antonio Village	254	1555	1589	1623
I	Engineer's Hill				
	1 Cabinet Hill-Teacher's Camp	527	2805	2865	2927
	2 DPS	205	1146	1171	1196
	3 Engineer's Hill	496	2563	2618	2674
	4 Gen. Luna, Upper	176	779	796	813
	5 Greenwater Village	266	1353	1382	1412
	6 Marcoville	194	876	895	914
	7 Military Cut-off	330	1671	1707	1744
	8 Salud Mitra	350	1714	1751	1789
	129 Barangays			273671	

POPULATION RISK MULTIPLIERS

I	Lucban		Population Multiplier
District	Details	2005	
14	Upper Magsaysay	97	**0.75**
16	Malcolm Square	113	**0.75**
10	Kabayanihan	152	**0.75**
22	Session Road	196	**0.75**
11	Kagitingan	211	**0.75**
5	Harrison-Claudio C.	320	**0.75**
3	Bagong Lipunan	343	**0.75**
9	Gen. Luna, Lower	813	**0.75**
12	Kayang Hilltop	921	**0.75**
13	Lower Magsaysay	1051	**0.8**
15	Magsaysay, Private Rd.	1180	**0.8**
7	Holy Ghost Proper	1563	**0.8**
24	T. Alonzo	1646	**0.8**
20	Sanitary Camp North	1712	**0.8**
4	Happy Homes	1830	**0.8**
2	Alfonso Tahora	1881	**0.8**
8	Imelda Village	1887	**0.8**
1	ABCR	1889	**0.8**
25	Trancoville	2012	**0.85**
19	P. Zamora	2062	**0.85**
21	Sanitary Camp South	2144	**0.85**
23	Slaughter House	2264	**0.85**
17	New Lucban	2625	**0.85**
18	P. Burgos	2692	**0.85**
6	Holy Ghost Extension	2819	**0.85**
26	Honey Moon-Holy Ghost	4098	**0.95**
II	**Campo Filipino**		
B			
	8 Upper Market Subdivision	1027	**0.8**
	6 Bokawkan, Lower	1407	**0.8**
	5 Guisad Surong	1560	**0.8**
	3 Crescencia Village	1869	**0.8**
	2 Campo Filipino	2062	**0.85**
	1 Camp Allen	2099	**0.85**
	4 Guisad Central	2714	**0.85**
	7 Fairview, Lower	3929	**0.9**
E	**Pinsao**		
	2 Pinsao Proper	3072	**0.9**
	1 Pinsao Pilot	3580	**0.9**
	3 Pinget	5641	**1**
M	**Quirino Hill**		
	5 Camdas Subdivision	1316	**0.8**
	4 Q. Hill West	1488	**0.8**
	2 Q. Hill Lower	1864	**0.8**
	6 Dizon Subdivision	1903	**0.8**
	1 Q. Hill East	2344	**0.85**
	3 Q. Hill Middle	2375	**0.85**

Population per Barangay	Multiplier
0 - 1000	0.75
1000 - 2000	0.8
2000 - 3000	0.85
3000 - 4000	0.9
4000 - 5000	0.95
>5000	1

III				
D1		Irisan	19664	**1**
C		**Quezon Hill**		
	3	Fairview, Proper	1015	**0.8**
	5	Victoria Village	2386	**0.85**
	4	Quezon Hill, Upper	2550	**0.85**
	2	Fairview, Middle	3437	**0.9**
	1	Fairview, Upper	3928	**0.9**
IV		**City Camp**		
F				
	14	Rizal Monument	160	**0.75**
	9	Lourdes Subdivision Lower	492	**0.75**
	1	AZCKO	496	**0.75**
	18	San Roque	964	**0.75**
	7	Legarda-Burnham	982	**0.75**
	10	Lourdes Subdivision Proper	1041	**0.8**
	8	Lourde Subdivision Extension	1239	**0.8**
	2	C. Palma	1347	**0.8**
	15	Rock Quarry, Lower	1565	**0.8**
	17	Rock Quarry, Upper	1642	**0.8**
	6	Kayang Extension	1783	**0.8**
	16	Rock Quarry, Middle	1902	**0.8**
	3	City Camp Central	1961	**0.8**
	11	Queen of Peace	2006	**0.85**
	4	City Camp Proper	2515	**0.85**
	12	Quirino (Gen. Aguinaldo)	2636	**0.85**
	5	Dominican Hill-Mirador	2935	**0.85**
	13	Quirino-Magsaysay, Upper	3133	**0.9**
V				
H				
	8	Phil-am	396	**0.75**
	11	Sto. Tomas School Site	640	**0.75**
	7	I.R. Marcos-La Salle	950	**0.75**
	6	Happy Homes-CPO Sioco	1330	**0.8**
	4	Baguio Gen. Hospital Compound	1439	**0.8**
	9	Sto. Rosario	2188	**0.85**
	12	SLU-SVP Housing	2287	**0.85**
	3	Balsigan	2470	**0.85**
	5	Dontogan	3298	**0.9**
	10	Sto. Tomas Proper	3662	**0.9**
	1	Bakakeng Central	4946	**0.95**
	2	Bakakeng Norte	5495	**1**
G		**Asin**		
	2	San Luis	5243	**1**
	1	Asin Road	7997	**1**
VI				
J		**Loakan**		
	3	Loakan-Liwanag	2349	**0.85**
	2	Camp 8	2397	**0.85**
	5	Pulinos	2477	**0.85**
	6	San Vicente	4051	**0.95**
	4	Loakan Proper	5980	**1**
	1	Camp 7	6018	**1**
K		**Atok Trail**		
	1	Atok Trail	1009	**0.8**
	4	Apugan-Loakan	1654	**0.8**
	2	Fort del Pilar (Phil. Mil. Academy)	3183	**0.9**
	3	Kias	3755	**0.9**

VII				
P		**Sct. Barrio**		
	2	Dagsian, Upper	613	**0.75**
	1	Dagsian, Lower	1022	**0.8**
	4	Happy Hollow	1389	**0.8**
	6	Sta. Escolastica	1566	**0.8**
	7	Sct. Barrio	1582	**0.8**
	5	Hillside	1627	**0.8**
	3	Gabriela Silang	2409	**0.85**
O		**Mines View**		
	5	Pucsusan	540	**0.75**
	2	Lucnab	990	**0.75**
	3	Mines View Park	1360	**0.8**
	4	Outlook Drive	1548	**0.8**
	1	Gibraltar	6652	**1**
N		**Pacdal**		
	5	8th Drive	338	**0.75**
	2	M.Roxas-Teacher's Camp	752	**0.75**
	1	Lualhati	951	**0.75**
	6	Country Club	2085	**0.85**
	4	St. Joseph Village	2828	**0.85**
	3	Pacdal	4323	**0.95**
VIII				
A		**Aurora Hill**		
	5	Bayan Park East	702	**0.75**
	2	A. Hill, N. Central	799	**0.75**
	10	Malvar-Sgt. Floresca	850	**0.75**
	4	Bayan Park Village	892	**0.75**
	9	Lopez-Jaena	1119	**0.8**
	6	Bayan Park West	1207	**0.8**
	3	A. Hill, S. Central	1226	**0.8**
	12	Modernsite-West	1469	**0.8**
	13	San Antonio Village	1623	**0.8**
	8	Brookspoint	1643	**0.8**
	1	Ambiong	1767	**0.8**
	11	Modernsite-East	2511	**0.85**
	7	Brookside	2576	**0.85**
I		**Engineer's Hill**		
	4	Gen. Luna, Upper	813	**0.75**
	6	Marcoville	914	**0.75**
	2	DPS	1196	**0.8**
	5	Greenwater Village	1412	**0.8**
	7	Military Cut-off	1744	**0.8**
	8	Salud Mitra	1789	**0.8**
	3	Engineer's Hill	2674	**0.85**
	1	Cabinet Hill-Teacher's Camp	2927	**0.85**
		Mean	2155.323	
		Median	1755.5	

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