Geotechnical Hazards Management for Hillside Development

By

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)
SEPTEMBER 2011

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CERTIFICATION OF APPROVAL

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Approved by,

____

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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2006

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

FARAHEEN HAZIRAH BT. KHAIRUL AZHAR

ABSTRACT

Geotechnical Hazards, especially for hillside development is known to be able to cause huge losses if occurred. Though there are many mitigation techniques have been developed, it is more practical if the risks are managed from its root for better control of the hazards and more cost-effective solution. However, it is not possible to provide equal treatment to each risk as the resources are very limited. Because of that, it is important to manage the hazards efficiently in order to optimize resources such as capital and work force besides preventing losses especially in terms of lives and monetary. The outcome of the project is aimed at professional geotechnical/civil engineers, although it will also be useful to the general public, many of whom carry responsibility for slope maintenance as owners of property. This paper describes the effective method in Geotechnical Hazards Management for Hillside Development.

ACKNOWLEDGEMENTS

First and foremost, the author would like to give the special thanks to ALLAH S.W.T for His blessing that enables the author to complete this final year project without any major obstacle. The author also would like to give the special thanks to her supervisors for this research, Assoc. Prof. Dr. Indra Sati Hamonangan Harahap for his kindness, valuable guidance, precious command and advice, his close monitoring for the whole research performance until it is completed. The author appreciates his supervision and full support in helping the progress of this research run smoothly.

The author would also like to thank those who have lent a helping hand in the completion process of this project including the author's parents, post graduate students, SlopeWatch (a non-governmental organization) and the university itself for the wide resources provided for research purpose.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Throughout history, many cases related to hillside development had occur and caused social and economic losses. The most tragic case in this country is the Highland Tower tragedy in December 1993 which had caused 48 death and estimated losses of RM184 million followed by Karak Highway at Selangor-Pahang border (1995), Bukit Antarabangsa (1998), Sandakan Town (1999), Athenaeum Condominium, Ulu Kelang (1999), Taman Hillview Ulu Kelang (2002), Bukit Lanjan (2003), Taman Harmonis, Gombak (2004) and the complete number of landslides occurring in Malaysia is shown on the figure below:

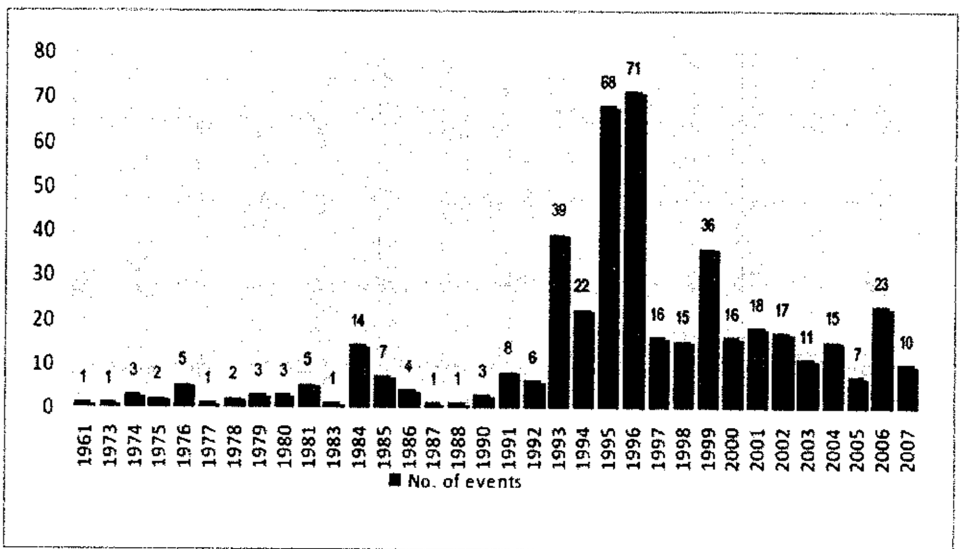

Figure 1.1: Number of Landslide Events in Malaysia from 1961-2007.
(Source: Gue & Wong, 2008)

1.2 Problem Statement

DATE OF OCCURENCE	LANDSLIDE LOCATION (NAME)	CATEGORY	FATALITY (NOS)	DISRUPTION TO TRANSPORTATION NETWORK
11 Dec 1993	Highland Tower	Residential	48	No
20 Nov 2002	Taman Hillview	Residential	8	No
26 Oct 2003	Bukit Lanjan	Highway	-	Yes
12 Oct 2004	Gua Tempurung	Highway	1	Yes
23 Mar 2007	Putrajaya	Public Amenities	-	No
13 Nov 2007	Pulau Banding	Public Amenities	-	No

Table 1.1: Statistic of landslide cases from 1993-2007 according to the categories of the area. (Source: Abdullah et al., 2008)

It is proven from statistics that landslides occurring in residential areas are prone to more fatalities. It is because:

i. There are more population in the area
ii. Hazards occurring more often due to more variety of usage
iii. People in the area are mostly static, compared to people in road/highway area; they are mostly dynamic and on-the-go.

In Malaysia, there are 2 types of Slope Assessment System which are Large Scale Assessment and Small Scale Assessment. The authority that is responsible for Large Scale Slope Assessment is the Public Works Department and the work involves prioritizing slope along roads and highways (Jabatan Kerja Raya, 2006). Meanwhile, the parties that are responsible for the Small Scale Slope Assessment are Department of Mineral and Geosciences Malaysia and Malaysia Center for Remote Sensing and their work is only limited to controlling development in hilly areas (Suhaimi Jamaludin & A. Nadzri Hussein, 2006).

There is no specific slope prioritization system for other areas i.e. residential areas like the one PWD is having for slopes along federal road (Jabatan Kerja Raya Slope, 2010). PWD's slope maintenance management system is described in Appendix 1 - 6.

CHAPTER 2

LITERATURE REVIEW

2.1 Definition of Geotechnical Hazards

Geotechnical hazards are defined as natural events which directly affect the ground or caused ground movements. There are two types of geotechnical hazards which are (Kuwano et al., 2009):

i. Earthquakes and earthquake related hazards
ii. Landslides or slope failure

Throughout this paper, the type of hazards that will be discussed is landslides or slope failure as earthquake and earthquake related hazards are a force of nature and it is uncontrollable though it could be measured. In the other hand, landslides or slope failure is controllable and most of the time, it is human activities who increases or triggers the severity of geotechnical hazards.

2.2 Geotechnical Hazards Management

2.2.1 Definition of Hazards Management

According to Oxford dictionary, hazard is defined as: "*a danger of risk*" while management is "*the process of dealing with or controlling things or people*". According to US National Library of Medicine, hazard management is defined as "*development of systems to prevent accidents, injuries, and other adverse occurrences in an institutional setting*". Thus, geotechnical hazards management can be defined as *"a system developed to prevent natural events which directly affect the ground or caused ground movements."*

2.2.2 Importance of having a proper Hazards Maintenance Management System

A hazards management system need not only address which hazards carries the most critical consequences for mitigation process but it also have to be able to allow the respective parties to select the most cost effective and appropriate maintenance and inspection work and techniques, in order to optimize efforts and cost. Besides, by having a proper Hazards Maintenance Management System, the authorities would be able to decide which slope needs to be mitigated first and which is next. This allows the optimization of time, budget and also manpower.

2.3 Slope Stability Factors

There are several factors influencing slope stability. (Gue & Wong, 2008) They are:

- Soil Properties – Sandy, Clayey, Silty, Rock
- Slope Geometry – Steep Slope or Gentle Slope
- Groundwater Table – Low Groundwater Table or High Groundwater Table
- Slope Maintenance – Proper or Poor Maintenance Programme

2.4 Risk Management Process

2.4.1 Risk Identification

Risk Identification is the process of recognizing the slopes that might be risky within a period of time. In this stage, there is possibility of hazards from all the slopes but still, the severity and probability of the slopes occurring are not known yet.

2.4.2 Risk Analysis

Risk analysis is basically analyzing the possibility of a slope for land sliding within a period of time. The conditions that caused the slope to become unstable and the processes that triggered the movement is the most important factor. There are several methods developed to assess the probability of land sliding. Soeters and Van Westen (1996) and Van Westen et al. (1997) have distributed these methods into a) inventory; b) heuristic; c) statistical; d) deterministic approaches. (Dai et al., 2002)

2.4.3 Risk Assessment

Risk assessment is evaluating the level of severity of the hazard. Level of severity is the level of potential damage or degree of failure of a given element subjected to a given intensity. The method that is largely used to assess risk is based on logical observation and also the statistics of detailed historic record of the location (Dai et al., 2002).

2.4.4 Risk Mitigation

Risk Mitigation is divided into two categories:

i) Reducing the likelihood/probability of hazards occurring

ii) Reducing the consequences of hazards if occurred

The respective authority has the power to decide which category of mitigation will be done whether to reduce the likelihood of hazards to occur, to reduce the consequences of hazards if in case, it occurs, or even both.

2.5 Australia Framework for Landslide Risk Management

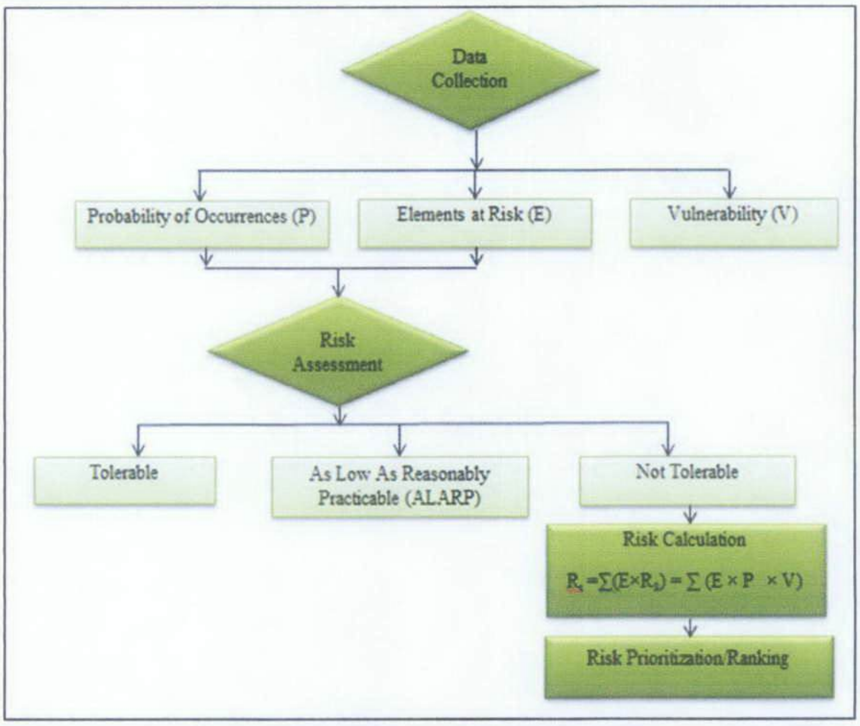

Figure 2.1: Flowchart of project work

The way the system is conducted is first, to use the data collected from the 4 slopes in order to calculate the value of Probability of Occurrences (P), Elements at Risk (E) and Vulnerability (V) according to Australia's Landslide Risk Management method of calculation.

Then, using only the value of P and E, the slope is assessed whether it is in the category of Tolerable, Not Tolerable, or as Low as Reasonably Practicable by plotting the value in the Graph of Societal Risk Criteria.

For the slopes that are in Not Tolerable category, meaning the slope is quite dangerous, they are to be prioritized according to their risk value which shows the higher the risk value is, the more risk it carries. The risk value is calculated using the formula (Lee & Jones, 2004):

$$\sum(E \times R_S) = (E \times P \times V) \qquad (1)$$

The ranking will indicate which slope needs the quickest mitigation and which goes next. The detailed process is shown in the subtopics that follow.

2.5.1 Probability of Occurrences

According to Australia's Landslide Risk Management Concepts and Guidelines 2000, the frequency of land sliding can be expressed by these methods:

i. Observation and experience

   The site is viewed, the geology and geomorphology mapped, and a practitioner forms a judgment as to the probability based on experience.

ii. Inventories

   Involving the statistics of large number of landslides in time and space and using the relative frequency to predict quantitatively, or ranking to predict qualitatively.

iii. Triggering

   The triggering event is identified and the probability of that event equated to the probability of landslide, e.g. rainfall events.

iv. Cause and effect

   A geomorphological understanding is expressed mathematically, eg process rates.

v. Deterministic/Probabilistic

   A deterministic stability model is generated and the inputs are expressed in probabilistic terms.

In a rigorous landslide hazard assessment, probability of occurrence for whether magnitude or intensity can be expressed as an annual probability of occurrence (Pa), such as 1:475 (0.2%) or as a long term probability of occurrence (Px) where 'x' is a given number of years. The equation below shows the relation of Pa to P_x (Van Dine, 1997).

$$P_x = 1 - (1 - (P_a))^x \quad (2)$$

In this case, the method that is used to find P_a is Triggering Method. Rainfall data of the location is recorded for each day in a year. The triggering event to the landslide is the heavy rainfall and it is equated to the probability of occurrence. The approximate annual probability of the recurrence of land sliding, P_a is calculated using the formula (Chit et al., 2004) :

$$P_a = N/T_H \quad (3)$$

Where N = the number of critical rainfall triggering events over the historical recorded time period T_H.

The recorded time period is the number of days in a year which is 365, and the number of critical rainfall is the number of days of heavy rainfall occurring. Heavy rainfall is considered by meteorologists around the world as average daily rainfall that is more than 0.30 inches (7.5 mm) of rain per hour (Weathershack.com, n.d.).

In this case, since the type of probability that is used for the risk calculation is annual probability, only P_a will be calculated.

2.5.2 Elements at Risk

Elements at Risk is defined as the population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides (Australian Geomechanics Society Sub-Committee on Landslide Risk Management, 2007).

The elements at risk will include:

i. Property, which may be subdivided into portions relative to the hazard being considered.
ii. People, who either live, work, or may spend some time in the area affected by land sliding.
iii. Services, such as water supply or drainage or electricity supply.
iv. Roads and communication facilities.
v. Vehicles on roads, subdivided into categories (cars, trucks, buses).

For some cases, other risks may also have to be considered. For example:

i. Environmental, where the elements at risk are environmental (rather than man made), such as forests or water bodies.

ii. Social, where the consequences of the landslide may have an impact on social conditions, such as the cost of disruption to traffic where roads are affected.

iii. Political, where the consequences may not be acceptable in political terms.

The table below shows the group no. with the example of facilities and expected number of fatality. The type of facilities affected is to be determined because it directly distresses the spatial and temporal distribution of population. The type of facilities is also related to the societal requirements for its use, particularly during or following extreme events.

Group no.	Facilities	Expected no. of Fatality
1	a) Buildings with a high density of occupation or heavily used - Residential building, commercial office, store and shop, hotel, factory, school, power station, ambulance depot, market, hospital/polyclinic/clinic, welfare centre.	3
	b) Others - Bus shelter, railway platform and other sheltered public waiting area - Cottage, licensed and squatter area - Dangerous goods storage site (e.g. petrol station) - Road with very heavy vehicular or pedestrian traffic density	3
2	a) Building with a low density of occupation or lightly used - Built up area (e.g. indoor car park, building within barracks, abattoir, incinerator, indoor	2

	games' sport hall, sewage treatment plant, refuse transfer station, church, temple, monastery, civic centre, manned substation)	
	b) Others - Road with heavy vehicular or pedestrian traffic density - Major infrastructure facility (e.g. railway, tramway, flyover, subway, tunnel portal, service reservoir) - Construction sites	1
3	Roads and Open Space - Densely-used open space and public waiting area (e.g. densely-used playground, open car park, densely-used sitting out area, horticulture garden) - Quarry - Road with moderate vehicular or pedestrian traffic density	0.25
4	Roads and Open Space - Lightly-used open aired recreation area (e.g. district open space, lightly-used playground, cemetery, columbarium) - Non-dangerous goods storage site - Roads with low vehicular or pedestrian traffic density	0.03
5	Roads and Open Space - Remote area (e.g. country park, undeveloped green belt, abandoned quarry) - Road with very low vehicular or pedestrian traffic density	0.001
Notes: (1) To account for the different types of building structure with different detailing of window and other perforations etc, a multiple factor ranging from 1 to 5 is considered appropriate for Group No. 1(a) facilities to account for the possibility that some incidents may result in a disproportionately larger number of fatalities than that envisaged. For global QRA, an average value of 3 is taken for the		

multiple fatality factor.   (2) For incidents that involve the collapse of a building, it is assumed that the expected number of fatalities is 100.

Table 2.1: Grouping of Facilities and Expected Number of Fatalities
(Source: Wong et al., 1997)

2.5.3 Vulnerability

Vulnerability refers to the degree of damage (or damage value in absolute or relative terms) which is judged to be likely if the landslide does occur (Australian Geomechanics Society Sub-Committee on Landslide Risk Management, 2007). It is expressed on a scale of 0 - no loss to 1 - total loss.

According to risk management guidelines by Australian Geomechanics Society Sub-Committee on Landslide Risk Management in 2007, Vulnerability is measured by its impact on:

i) Person

According to Finlay et al. (1999), a person's vulnerability lies in the case where a building collapses or burial by debris. If a person is buried, the cause of death is more likely to happen because of asphyxiation rather than crushing impact. When a person suffers from crushing impact, injuries are more likely to occur compared to death.

These factors affected vulnerability values for person:

i. Volume of slide
ii. Type of slide, mechanism of slide initiation and velocity of sliding
iii. Depth of slide
iv. Whether the landslide debris buries the person(s)
v. Whether the person(s) are in the open or enclosed in a vehicle or building
vi. Whether the vehicle or building collapses when impacted by debris
vii. The type of collapse if the vehicle or building collapses.

ii) Property

An estimate of indicative cost of damage, which may include the 'real cost' of the damaged property to the owner itself (Walker, n.d). In determining the weightage for the damage to properties, the rate of movement of slides is less important for structures compared to lives. Slides which move slowly tend to cause less damage than rapid moving slides. This means properties affected by a slower moving slide are expected to have a lower vulnerability than those on a rapid moving slide.

The factors which most affect vulnerability of property are:

i. The volume of the slide in relation to the element at risk
ii. The position of the element at risk, e.g. on the slide, or immediately downslope
iii. The magnitude of slide displacement, and relative displacements within the slide (for elements sited on the slide)
iv. The rate of slide movement

Vulnerability assessment involves the understanding of each affected elements if landslides are about to occur. According to Fell in 1994, vulnerability, v, are considered as follows:

$$v = v_s \times v_t \times v_l \quad (4)$$

Where:

v_s= Probability of spatial impact of a landslide on an element

v_t = Probability of temporal impact (e.g. that the element is occupied during impact)

v_l= Probability of loss of life or proportion of the value of the element

The details for each type of vulnerabilities are described below:

2.5.3.1 Probability of spatial impact of a landslide on an element

This vulnerability value indicates the probability of the impact partially caused from the spatial character of the area itself. The value is measured based on the impacts on three elements; people, buildings and roads.

The table below shows the Example of Vulnerability Values for Destruction of People, Buildings and Roads. The areas of the land slide were classified into 3 Geomorphic Unit which are Hill Slopes, Proximal Debris Fan and Distal Debris Fan.

Geomorphic Unit	Vulnerability Values		
	People	Buildings	Roads
Hill Slopes	0.05	0.25	0.3
Proximal Debris Fan	0.5	1.0	1.0
Distal Debris Fan	0.05	0.1	0.3

Table 2.2: Example of Vulnerability Values for Destruction of People, Buildings and Roads. (Source: Australian Geomechanics Society Landslide Taskforce, 2007)

2.5.3.2 Probability of temporal impact (e.g. that the element is occupied during impact)

The table below is taken from Summary of Hong Kong Vulnerability Ranges for Persons, And Recommended Values for Loss of Life for Land sliding in Similar Situations shows the cases that might occur in case of a landslide and recommended vulnerability value for each of the cases. The value varies for each case as each one of them carries different impact whether to person or properties.

Case	Range in Data	Recommended Value	Comments
Person in Open Space			
If struck by rockfall	0.1-0.7	0.5	May be injured but unlikely to cause death
If buried by debris	0.8-1.0	1.0	Death by asphyxia almost certain
If not buried	0.1-0.5	0.1	High chance of survival
Person in a Vehicle			
If the vehicle is buried/crushed	0.9-1.0	1.0	Death is almost certain
If the vehicle is damaged only	0-0.3	0.3	High chance of survival
Person in a building			
If the building collapses	0.9-1.0	1.0	Death is almost certain
If the building is inundated with debris and the person buried	0.8-1.0	1.0	Death is very likely
If the debris strikes the building only	0-0.1	0.05	Very high chance of survival

Table 2.3: Vulnerability Ranges for Persons, and Recommended Values for Loss of Life for Landsliding in Similar Situations. (Source: Australian Geomechanics Society Sub-Committee on Landslide Risk Management, 2007)

Since Vulnerability is judged by the degree of damage the landslide causes, death is undeniably thee worst damage it could cause. Thus any case that leads to death has the value of 1.0 which is the highest. Other cases that do not lead to death are given reasonable vulnerability value.

2.5.3.3 Probability of loss of life

The table below shows the likely probability of loss of life for slopes according to their slope angle. The angle, ranging from 30° until 60° and above possesses different vulnerability values as shown.

Likely Probability of Death for Different Ranges of Shadow Angle (β) of Affected Person with Respect to Slope Crest								Frequency of occurrence of landslides (of a given slope type) having different ranges of debris travel distances measured in terms of debris mobility angle, α
>60°	55° - 60°	50° - 55°	45° - 50°	40° - 45°	35° - 40°	30° - 35°	25° - 30°	
0.95 (0.95)	0.95 (0.95)	0.95 (0.95)	0.95 (0.95)	0.95 (0.95)	0.60 (0.95)	0.20 (0.60)	0.05 (0.20)	5% of cases with α = 27.5° (±2.5°)
0.95 (0.95)	0.95 (0.95)	0.95 (0.95)	0.95 (0.95)	0.60 (0.95)	0.20 (0.60)	0.05 (0.20)		60% of cases with α = 32.5° (±2.5°)
0.95 (0.95)	0.95 (0.95)	0.95 (0.95)	0.60 (0.95)	0.20 (0.60)	0.05 (0.20)			35% of cases with α = 37.5° (±2.5°)
0.95 (0.95)	0.95 (0.95)	0.95 (0.95)	0.83 (0.95)	0.48 (0.83)	0.17 (0.48')	0.04 (0.15)	0.0025 (0.01)	Vulnerability Factor Calculated

Legend :

0.2 – likely probability of death for a person in a building given the impact of the landslide, at a given range of α and β.

(0.6) – likely probability of death for a person on a road given the impact of the landslide, at a given range of α and β.

Note : The above tables are applicable for toe facilities of a cut slope with an estimated failure volume ranging from 500m³ to 2000 m³. The figures in the top table are based on judgement, having regard to the type of facility, its proximity to the feature and whether it is a toe or crest feature, its location in relation to the reach of the debris (hence accounting for the likely depth of debris at the affected facility) and the degree of protection afforded to persons by the facility.

Table 2.4: Probability of Loss of Life for Different Ranges of Slope Angle. (Source: Wong et al.,1997)

2.5.4 Risk Assessment

There are three types of Risk Based Inspection (RBI) which are Qualitative, Semi Quantitative and Quantitative. However, the type that will be used for this research is Semi Quantitative because:

i) It is more detailed (and more accurate) compared to Qualitative Method

ii) Requires calculation for the specific likelihood score while consequence score is obtained from the tables in the guideline

iii) Not bias towards certain extreme criteria (likelihood or consequence) which means slopes with high likelihood of occurrence do not necessary will be in the Not Tolerable category if the consequence is low.

iv) Less complex than Quantitative Method

The values of Likelihood of Occurrences and Number of Fatalities are needed to assess the risk category. The two values are plotted to the Graph of Societal Risk Criteria as shown in Appendix 10 in order to obtain the risk category of the slope which might be:

i. Tolerable,
ii. As Low As Reasonably Practicable (ALARP) which means not acceptable, but still tolerable, or the worst,
iii. Intolerable.

Risk prioritization will be conducted only for the slopes which are in the Intolerable Risk category. It is because they are in the most dangerous category that they require immediate and huge slope countermeasure works. Since it is almost impossible to do mitigation for all the slopes in that category at the same time, they need to be ranked in the order of the risk they possess.

Calculating the Risk Value (R_t) for all the slopes in the Not Tolerable category, they will be ranked from the highest to lowest value and the highest value will be given the highest priority, followed by the second highest, and so on until the lowest value of risk in the category.

Meanwhile, for the slopes that fall under ALARP or Tolerable category, the risk prioritization can also be applied however, it is not very crucial as periodical inspection of slope condition are already adequate to ensure the slope's safety and detect abnormality. The slopes in ALARP and Tolerable category possess whether very little probability or very minimal consequences or both.

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 Project Methodology

At the initial phase of the project, research on the topic is made. The modes of research may be based on online journals, books, websites, guidelines and also newspaper articles. The current method of slope management system practiced in this country is also studied in depth to obtain comprehensive understanding about the topic.

The next step is research on other systems available in other countries. The systems that were studied are Hong Kong, Australia and Europe landslide maintenance management system. Researches are mostly based on practice guidelines available on the net.

Next, the process is data gathering. The data gathered consists of the nature of the slopes, particularly the material of debris, the slope angle and the function of the surrounding area. The data is mostly obtained from journals online and some are also obtained from researches made by fellow students i.e. final year projects and post graduate.

After the data has been obtained, the most suitable and practical system from the landslide maintenance management system of other countries studied is chosen from discussion with supervisor. The decision is made based on not only its reputation, but also practicality towards this project duration.

After the system was chosen, it is tested to the 4 slopes. After the data is tested with the system, the conclusion of the method is going to be made. The conclusion is whether the method is suitable to be implemented in this country or not.

3.2 Key Milestone

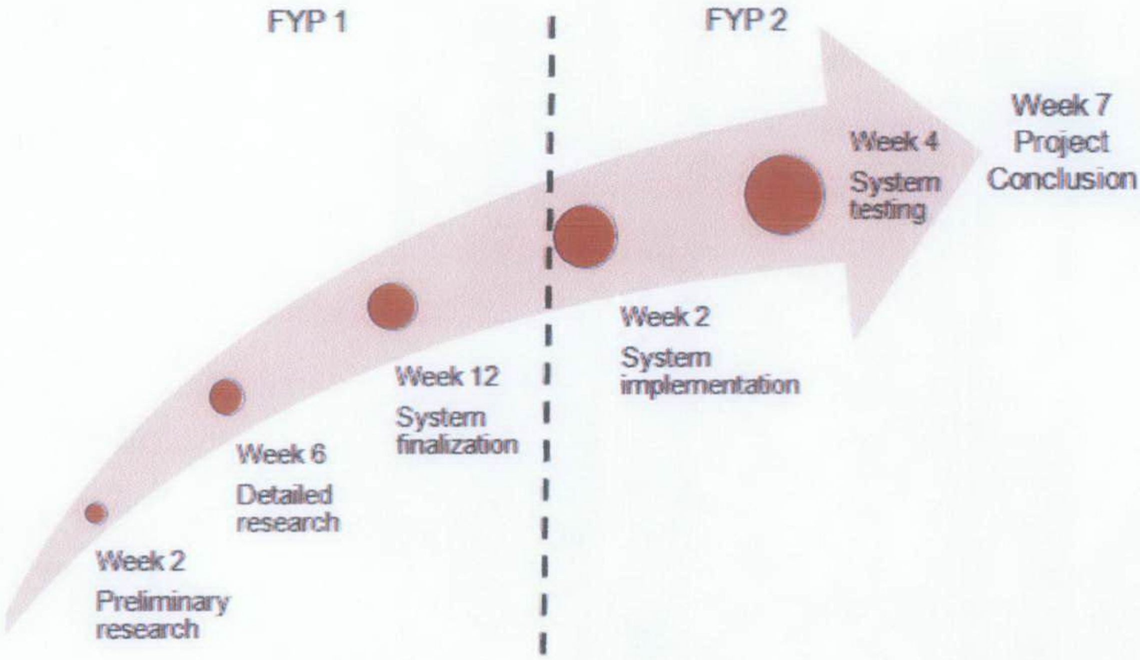

Figure 3.1: Key Milestone for Project

The project started in Week 2 of 1st stage of project with preliminary research conducted using materials from journals, articles, books and presentation papers. By Week 6, detailed research is done by studying the framework and guidelines of Australia Landslide Risk Management. By Week 12, the method is finalized and the data is collected. In Week 2 of 2nd stage of the project, the system is implemented using the data and tested by applying the formula and tables from the guideline.

3.3 Gantt Chart

Detail / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
Selection of Project Topic	■	■													
Preliminary Research Work		■	■	■	■										
Submission of Extended Proposal						■	■								
Proposal Defense									■	■					
Project Work Continues											■	■	■		
Submission of Interim Draft Report														■	
Submission of Interim Report															■

Table 3.1 : Gantt Chart for Project

CHAPTER 4

RESULTS

4.1 Probability of Occurrence

In calculating P, the daily rainfall data is obtained from the Department of Irrigation and Drainage Malaysia, the hyetograph reading as shown in Appendix 6 to 9 is analyzed and represented in tabular form as shown below according to the respective locations which are Universiti Teknologi PETRONAS at Tronoh, Cameron Highlands, Bukit Antarabangsa and NKVE near Bukit Lanjan Interchange. The data was taken from rainfall station closest to the location studied which are Parit Rainfall Station for UTP slope, Brinchang Rainfall Station for Cameron Highlands slope, Bukit Antarabangsa Rainfall Station for Bukit Antarabangsa slope and also Ladang Edinburgh Rainfall Station for Bukit Lanjan slope.

From the reading, the number of times heavy rainfall occurring in a year is calculated in order to obtain the Annual Probability of Occurrence of land sliding for each location.

Slope Location: Universiti Teknologi PETRONAS , Tronoh

Rainfall Station: Sungai Perak, Parit.

Day/ Month	January	February	March	April	May	June	July	August	September	October	November	December
1	1	4	0	0	9	2	0	0	0	15	16	22
2	25	11	0	0	0	0	0	0	0	21	16	0
3	0	0	9	0	0	0	5	112	0	4	6	0
4	0	0	2	0	0	0	0	1	0	0	5	3
5	1	0	0	0	0	0	0	0	0	2	7	0
6	11	0	0	70	0	55	0	0	0	0	7	0
7	0	0	0	0	0	0	4	0	1	18	0	0
8	0	0	0	0	0	0	0	0	0	8	6	10
9	0	0	0	24	0	0	0	14	22	3	0	0
10	1	0	14	0	0	0	0	0	19	17	1	10
11	0	10	3	4	0	0	0	0	47	0	0	4
12	0	6	17	0	1	0	0	0	0	0	14	11
13	0	0	3	0	0	0	0	10	2	0	0	0

14	3	2	30	16	0	0	0	15	7	0	2	1
15	3	0	0	0	57	15	0	0	0	0	67	1
16	0	2	0	0	0	0	0	6	0	0	0	12
17	0	0	0	0	4	0	0	0	0	4	0	2
18	0	0	0	0	0	0	0	13	2	9	54	10
19	0	1	0	0	0	0	0	31	5	11	0	0
20	0	0	6	0	0	0	0	1	0	0	0	0
21	0	0	11	0	2	0	0	4	1	13	12	1
22	0	0	59	5	3	0	0	10	0	45	15	2
23	0	0	0	5	0	0	5	2	0	10	6	1
24	14	0	0	2	13	0	5	2	0	11	0	0
25	0	0	17	9	0	0	4	7	1	0	9	0
26	4	3	19	0	0	1	0	1	15	24	3	3
27	0	0	0	0	0	4	0	4	8	0	46	1
28	2	0	0	14	0	0	0	6	0	26	40	10
29	1		80	57	24	0	2	0	0	0	3	13
30	31		7	2	0	0	22	0	1	1	25	1
31	0		4		0		5	0		10		0

Table 4.1: Daily precipitations for Tronoh area in a year

Calculation:

Based on equation (3),

$P_{AV} = N/T_H$

Assuming average daily rainfall duration of 4 hours,

Thus, heavy rain is when daily precipitation is more than

$$4 \times 7.5 = 30\ mm$$

The number of days of daily precipitation > 30mm = 13,

Hence, N = 13

$P_{AV} = 13 / 365$

$= 0.035$

<u>Thus, the annual probability of occurrence at Tronoh is 0.035.</u>

Slope Location: Cameron Highlands

Rainfall Station: Brinchang

Day/ Month	January	February	March	April	May	June	July	August	September	October	November	December
1	0	4	7	0	26	0	0	0	0	0	6	0
2	3	1	0	2	3	1	4	0	0	12	0	2
3	34	1	0	35	57	0	2	20	0	3	26	0
4	1	0	0	62	57	0	0	1	0	23	13	2
5	13	1	0	27	0	5	0	0	0	0	16	1
6	1	0	0	0	0	1	0	5	21	0	0	1
7	5	12	9	0	0	5	0	23	1	17	17	25
8	3	0	16	0	0	10	13	50	4	33	24	12
9	0	8	4	0	0	7	1	28	0	5	0	2
10	0	8	2	5	13	0	0	0	0	5	3	3
11	3	4	33	7	0	2	0	0	12	0	24	11
12	4	5	4	18	2	0	0	10	1	0	6	3
13	36	10	1	1	0	0	1	53	48	0	15	1
14	6	1	0	5	14	1	0	11	3	0	5	9
15	11	2	75	14	46	19	4	33	15	12	3	19
16	0	8	1	4	6	0	0	3	2	1	1	0
17	0	0	32	16	2	0	0	3	1	14	8	9
18	0	0	20	0	16	2	0	4	7	20	8	3
19	0	0	18	12	14	1	0	3	3	11	15	4
20	0	0	23	1	6	0	0	4	1	15	1	30
21	0	1	37	0	13	26	0	9	21	27	22	1
22	0	0	5	2	2	0	0	21	0	1	3	28
23	0	0	18	3	1	5	24	12	1	0	27	0
24	9	17	7	9	2	0	0	20	0	1	18	0
25	19	16	2	9	0	12	1	7	8	27	18	0
26	16	0	3	7	0	6	0	10	36	5	5	1
27	1	0	0	10	1	0	0	1	10	1	13	1
28	9	0	2	1	0	0	0	62	0	5	4	4
29	14		22	10	0	5	0	7	0	5	31	0
30	27		21	39	0	0	16	0	0	8	2	0
31	9		1		0		0	0		5		1

Table 4.2: Daily precipitations for Cameron Highlands area in a year

Calculation:

Based on equation (3),

$P_{AV} = N/T_H$

Assuming average daily rainfall duration of 4 hours,

Thus, heavy rain is when daily precipitation is more than

$$4 \times 7.5 = 30\,mm$$

The number of days of daily precipitation > 30mm = 19,

Hence, N = 19

$P_{AV} = 19 / 365$

$= 0.052$

Thus, the annual probability of occurrence at Cameron Highlands is 0.052.

Slope Location: Taman Bukit Mewah, Bukit Antarabangsa

Rainfall Station: Bukit Antarabangsa

Day/ Month	January	February	March	April	May	June	July	August	September	October	November	December
1	0	0	3	0	26	0	0	0	0	1	5	0
2	0	0	0	0	**56**	0	0	0	0	0	17	19
3	0	0	**38**	0	**87**	**59**	0	0	0	27	27	**38**
4	0	0	0	0	32	0	0	**70**	13	7	15	0
5	1	6	1	13	0	2	0	0	0	7	2	0
6	25	19	0	**31**	0	2	19	0	0	0	4	0
7	0	0	**40**	7	0	0	17	0	12	10	0	**41**
8	0	0	16	1	0	22	2	0	1	14	0	2
9	0	**41**	0	0	0	0	0	**54**	0	4	0	0
10	0	0	1	0	1	0	0	0	17	9	2	0
11	0	0	8	**34**	0	0	0	0	2	0	7	0
12	0	9	11	16	**41**	0	0	2	0	0	**34**	**36**
13	14	5	0	0	11	0	0	12	23	0	0	0
14	5	0	9	10	**36**	0	0	0	22	0	0	0
15	0	3	0	0	0	0	**65**	7	0	2	3	0
16	1	2	0	**52**	11	0	0	0	22	1	3	9

17	0	1	3	0	0	0	0	2	7	0	15	10
18	0	0	4	14	13	0	0	8	18	0	0	0
19	1	0	14	0	97	0	0	5	22	20	42	0
20	1	0	10	39	17	0	0	2	9	32	2	10
21	1	1	0	1	82	0	0	0	31	32	0	3
22	0	0	18	0	18	0	0	0	3	0	0	27
23	0	3	0	0	11	0	2	0	0	0	15	4
24	1	100	17	26	6	0	2	0	0	0	13	0
25	0	96	8	0	0	0	0	8	19	11	0	0
26	2	0	0	0	0	20	0	0	2	0	0	3
27	0	0	0	30	9	2	91	6	13	0	52	0
28	2	0	5	1	0	0	0	0	0	12	42	0
29	1		5	47	0	10	19	25	0	0	2	0
30	47		9	26	0	2	17	0	1	115	3	0
31	7		0		2		0	0		6		1

Table 4.3: Daily precipitations for Bukit Antarabangsa area in a year

Calculation:

Based on equation (3),

$P_{AV} = N/T_H$

Assuming average daily rainfall duration of 4 hours,

Thus, heavy rain is when daily precipitation is more than

$$4 \times 7.5 = 30\ mm$$

The number of days of daily precipitation > 30mm = 33,

Hence, N = 33

$P_{AV} = 33 / 365$

$= 0.09$

Thus, the annual probability of occurrence at Bukit Antarabangsa is 0.09.

Slope Location: NKVE near Bukit Lanjan Interchange

Rainfall Station: Ladang Edinburgh

Day/ Month	January	February	March	April	May	June	July	August	September	October	November	December
1	0	0	4	0	7	0	0	0	0	0	22	38
2	0	0	0	0	14	0	0	0	0	0	29	28
3	20	0	38	0	7	3	34	13	0	0	11	0
4	9	0	0	0	10	0	0	6	0	0	4	42
5	40	0	2	20	0	1	0	3	0	9	3	0
6	26	0	0	5	0	22	0	0	9	0	1	0
7	0	0	81	1	0	0	0	0	33	0	0	35
8	0	0	17	25	0	3	0	0	0	13	0	0
9	0	0	0	0	0	0	9	3	0	4	0	0
10	0	0	1	2	0	1	0	39	20	0	0	0
11	0	0	5	1	0	0	0	0	0	1	16	0
12	0	0	3	12	32	0	1	0	1	0	4	0
13	5	0	0	0	0	1	0	15	12	0	37	0
14	35	0	4	4	4	0	5	0	60	0	13	0
15	1	0	0	27	51	0	14	29	8	23	2	0
16	0	0	26	54	0	0	0	0	4	1	1	0
17	0	0	20	4	3	3	0	14	0	11	10	13
18	0	4	5	0	13	0	0	0	25	61	0	20
19	0	0	7	0	7	0	0	10	20	26	1	0
20	0	0	7	0	0	0	0	5	1	30	9	44
21	0	0	22	0	42	0	2	0	2	66	0	1
22	0	4	17	0	0	0	0	10	0	0	0	29
23	0	0	0	0	9	6	8	2	0	0	9	2
24	0	13	20	0	6	0	0	0	0	0	0	16
25	0	18	26	1	0	0	0	0	0	3	0	30
26	0	0	0	24	0	71	0	0	12	8	0	0
27	0	0	0	23	17	40	4	0	15	5	46	0
28	0	0	0	34	2	0	0	0	0	3	12	40
29	0		0	37	0	3	18	19	0	0	55	24
30	0		8	2	0	3	26	0	15	0	0	1
31	0		0		6		0	0		24		0

Table 4.4: Daily precipitations for Bukit Lanjan area in a year

Calculation:

Based on equation (3),

$P_{AV} = N/T_H$

Assuming average daily rainfall duration of 4 hours,

Thus, heavy rain is when daily precipitation is more than

$$4 \times 7.5 = 30\, mm$$

The number of days of daily precipitation > 30mm = 26,

Hence, N = 26

$P_{AV} = 26 / 365$

$= 0.071$

Thus, the annual probability of occurrence at Bukit Lanjan is 0.071.

From the calculations that have been made, it is obtained that the annual probability of occurrences, P_a for every location studied is:

i. UTP, Tronoh – 0.035
ii. Cameron Highlands – 0.052
iii. Bukit Antarabangsa – 0.09
iv. NKVE near Bukit Lanjan Interchange – 0.071

The result simply shows that by using Triggering Method, there is a 3.5% possibility of landslide occurring in the slope at UTP in a year, 5.2% of possibility at Cameron Highlands, 9.0% at Taman Bukit Mewah, Bukit Antarabangsa and 7.1% for slope at NKVE near Bukit Lanjan Interchange. The possibility is quite high for all four location as Malaysia is a country which receives rain almost every day in a year although there is a quite distinct different amount of rainfall if compared between the rainy season in November and dry season which is in July.

4.2 Elements at Risk

Based on the table of Grouping of Facilities and Expected Number of Fatalities, the four areas are classified into the facilities they serve:

i. Universiti Teknologi PETRONAS , Tronoh
<u>Group 5 (Roads and Open Space)</u>
Remote area (e.g. country park, undeveloped green belt, abandoned quarry) with very low vehicular or pedestrian traffic density.
Expected Fatalities: 0.001

Figure 4.1: Slope at Universiti Teknologi PETRONAS, Tronoh

ii. Cameron Highlands
<u>Group 3 (Roads and Open Space)</u>
Road with moderate vehicular or pedestrian traffic density.
Expected Fatalities: 0.25

Figure 4.2: Slope at Cameron Highlands

iii. Taman Bukit Mewah, Bukit Antarabangsa
<u>Group 1(a)</u>
Buildings with a high density of occupation or heavily used residential building
Expected Fatalities: 3

Figure 4.3: Slope at Tmn. Bukit Mewah, Bukit Antarabangsa

iv. NKVE near Bukit Lanjan Interchange
Group 2(b) – Roads with heavy vehicular or pedestrian traffic density
Expected Fatalities: 1

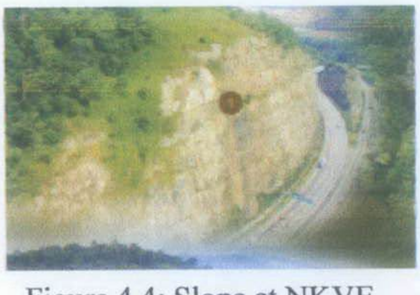

Figure 4.4: Slope at NKVE near Bukit Lanjan Interchange

4.3 Vulnerability

4.3.1 Probability of spatial impact of a landslide on an element

1. Universiti Teknologi PETRONAS, Tronoh

   The slope at UTP is located at a Hilly Slope area, thus the vulnerability values are:

   i. 0.05 for people,
   ii. 0.25 for buildings, and
   iii. 0.3 for roads.

   The possibility of land sliding at UTP's slope will only affect people as there is no building and road close to the slope, so the probability of spatial impact obtained is only taken for people category, thus, the value is 0.05.

2. Cameron Highlands

   The slope at Cameron Highlands is at a Hilly Slope area, thus the vulnerability values are:

   i. 0.05 for people,
   ii. 0.25 for buildings, and
   iii. 0.3 for roads.

   The possibility of land sliding at Cameron Highland's slope involves only people and roads categories as there is no building nearby, so summing up the values, the vulnerability value obtained is:

$$0.05 + 0.3 = 0.35$$

3. Taman Bukit Mewah, Bukit Antarabangsa

   The slope at Bukit Antarabangsa is located on a Hilly Slope area, thus the vulnerability values are:

i. 0.05 for people,

ii. 0.25 for buildings, and

iii. 0.3 for roads.

The possibility of land slide occurring involves all three categories so summing up the values, the vulnerability value obtained is:

$$0.05 + 0.25 + 0.3 = 0.6$$

4. NKVE near Bukit Lanjan Interchange

The slope at Bukit Lanjan is situated on a Hilly Slope, thus the vulnerability values are:

i. 0.05 for people,

ii. 0.25 for buildings, and

iii. 0.3 for roads.

The possibility of land sliding occurring at the location involves only people and road as there is no building nearby, so summing up the values, the vulnerability value obtained is:

$$0.05 + 0.3 = 0.35$$

4.3.2 Probability of temporal impact (e.g. that the element is occupied during impact)

1. Universiti Teknologi PETRONAS, Tronoh

As for the table probability of temporal impact, the possibilities that the slope will cause if any occurrence of landslide are:

i. Not buried – 0.1

ii. Vehicle is damaged only – 0.3

Summing up the values in order to obtain the average Vulnerability Value, the Average Vulnerability Value is:

$$\frac{0.1 + 0.3}{2} = 0.2$$

2. Cameron Highlands

As for the table probability of temporal impact, the possibilities that the slope will cause if any occurrence of landslide are:

i. Buried by Debris - 1.0

ii. Vehicle is buried/crushed - 1.0

Summing up the values in order to obtain the average Vulnerability Value, the Average Vulnerability Value is:

$$\frac{1.0 + 1.0}{2} = 1.0$$

3. Taman Bukit Mewah, Bukit Antarabangsa

As for the table probability of temporal impact, the possibilities that the slope will cause if any occurrence of landslide are:

i. Buried by Debris - 1.0

ii. Vehicle is buried/crushed - 1.0

iii. Building inundated with debris - 1.0

Summing up the values in order to obtain the average Vulnerability Value, the Average Vulnerability Value is:

$$\frac{1.0 + 1.0 + 1.0}{3} = 1.0$$

4. NKVE near Bukit Lanjan Interchange

As for the table probability of temporal impact, the possibilities that the slope will cause if any occurrence of landslide are:

i. Struck by Rockfall - 0.5

ii. Vehicle is buried/crushed - 1.0

Summing up the values in order to obtain the average Vulnerability Value, the Average Vulnerability Value is:

$$\frac{1.0 + 0.5}{2} = 0.75$$

4.3.3 Probability of loss of life or proportion of the value of the element

1. Universiti Teknologi PETRONAS, Tronoh

   Since the slope between Building 13 and Building 5, UTP angle is 23°, 25° is taken for consideration as in the table, 25° is the minimum slope angle. For 25° slope, according to Table 3.4, the likely probability of death for people on the road, since there is no building there, is 0.01.

2. Cameron Highlands

   Since the slope taken as at Cameron Highlands angle is 41° (Khamarrul Azahari Razak et al., 2011) according to Table 3.4, the likely probability of death is 0.83.

3. Taman Bukit Mewah, Bukit Antarabangsa

   Since the angle of the slope at Taman Bukit Mewah, Bukit Antarabangsa is 45-50° (Saravanan Mariappan et al.), the worst case scenario is considered, thus 50° is taken as the slope angle. For 50° slope, the likely probability of death according to Table 3.4 is 0.95.

4. NKVE near Bukit Lanjan Interchange

   Since the slope angle at NKVE near Bukit Lanjan Interchange slope is between 75-80° (Nasiman Sapari et al.,2011), the worst case scenario is considered, thus 80° is taken as the slope angle. For 80° slope, the likely probability of death according to Table 3.4 is 0.95.

4.3.4 Summary of Vulnerability

The summary of vulnerability is the total Vulnerability values which is the product of probability of spatial impact of a landslide on an element, probability of temporal impact and probability of loss of life or proportion of the value of the element. The values are calculated by their respective location.

1. Universiti Teknologi PETRONAS, Tronoh

   From Vulnerability Tables of Table 3.2, 3.3 and 3.4, the value of v_s, v_t and v_l is determined to be:

   $v_s = 0.05$

   $v_t = 0.2$

   $v_l = 0.01$

   Thus, according to equation (4),

   $v = 0.05 \text{ X } 0.2 \text{ X } 0.01$

   $= \underline{0.0001}$

2. Cameron Highlands

   From Vulnerability Tables of Table 3.2, 3.3 and 3.4, the value of v_s, v_t and v_l is determined to be:

   $v_s = 0.35$

   $v_t = 1.00$

   $v_l = 0.83$

   Thus, according to equation (4),

   $v = 0.35 \text{ X } 1.00 \text{ X } 0.83$

   $= \underline{0.29}$

3. Taman Bukit Mewah, Bukit Antarabangsa

   From Vulnerability Tables of Table 3.2, 3.3 and 3.4, the value of v_s, v_t and v_l is determined to be:

   $v_s = 0.6$

   $v_t = 1.0$

   $v_l = \underline{0.95}$

   Thus, according to equation (4),

   $v = 0.6 \text{ X } 1.0 \text{ X } 0.8$

   $= 0.48$

4. NKVE near Bukit Lanjan Interchange

   From Vulnerability Tables of Table 3.2, 3.3 and 3.4, the value of v_s, v_t and v_l is determined to be:

   $v_s = 0.35$

   $v_t = 0.75$

   $v_l = 0.95$

   Thus, according to equation (4),

   $v = 0.35 \text{ X } 0.75 \text{ X } 0.95$

   $= \underline{0.25}$

CHAPTER 5

DISCUSSION

5.1 Risk Assessment

The risk is assessed using the Graph of Societal Risk Criteria where the Probability of Occurrences (P) and Elements at Risk (E) are taken into consideration. Each slope is assessed and shown below.

5.1.1 Universiti Teknologi PETRONAS, Tronoh

P = 0.035
E = 0.001

Plotting the values by interpolating in the Graph of Societal Risk Criteria,

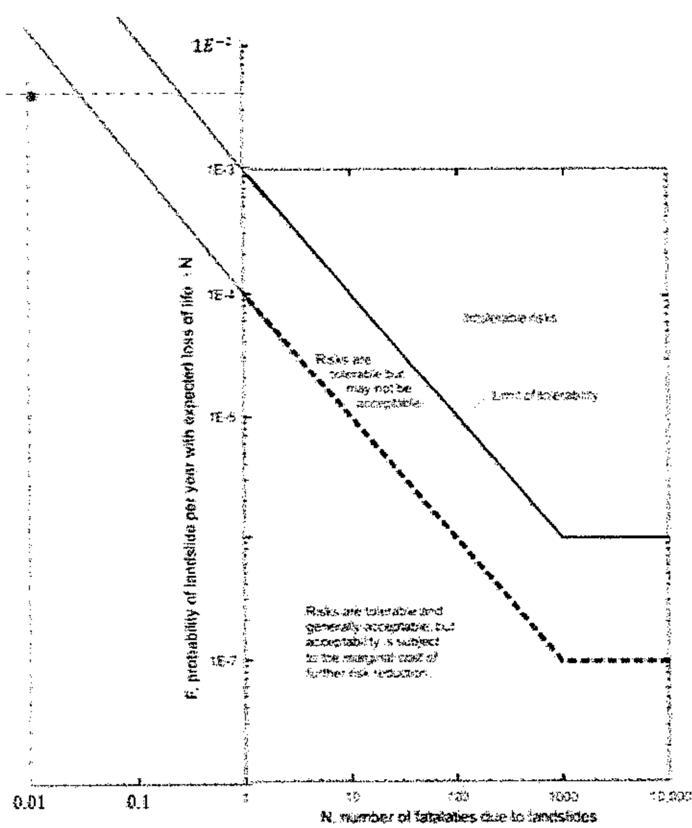

Figure 5.1: Interpolation of P and E for determination of Risk Category at UTP slope

The risk category of the slope is Tolerable, therefore risk value calculation is not needed.

5.1.2 Cameron Highlands

P = 0.052
E = 0.25

Plotting the values by interpolating in the Graph of Societal Risk Criteria,

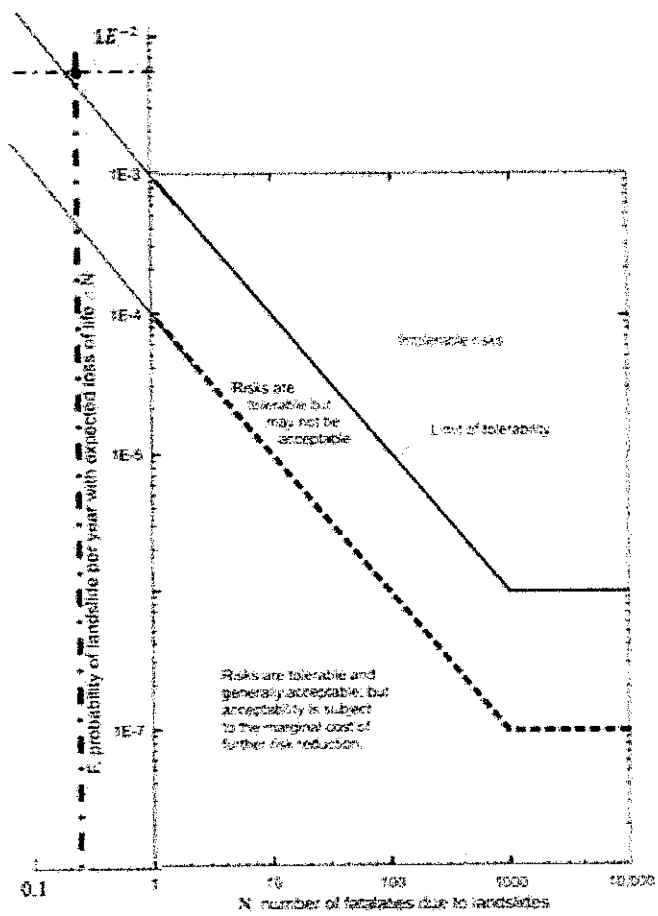

Figure 5.2: Interpolation of P and E for determination of Risk Category at Cameron Highlands slope

The risk category of the slope is slightly Not Tolerable, therefore risk value calculation will be done to rank the slope according to its priority.

Vulnerability Value = 0.29

Based on equation (1),

Risk = $0.25 \times 0.052 \times 0.29$
= <u>0.00037</u>

5.1.3 Taman Bukit Mewah, Bukit Antarabangsa

P = 0.09

E = 3

Plotting the values by interpolating in the Graph of Societal Risk Criteria,

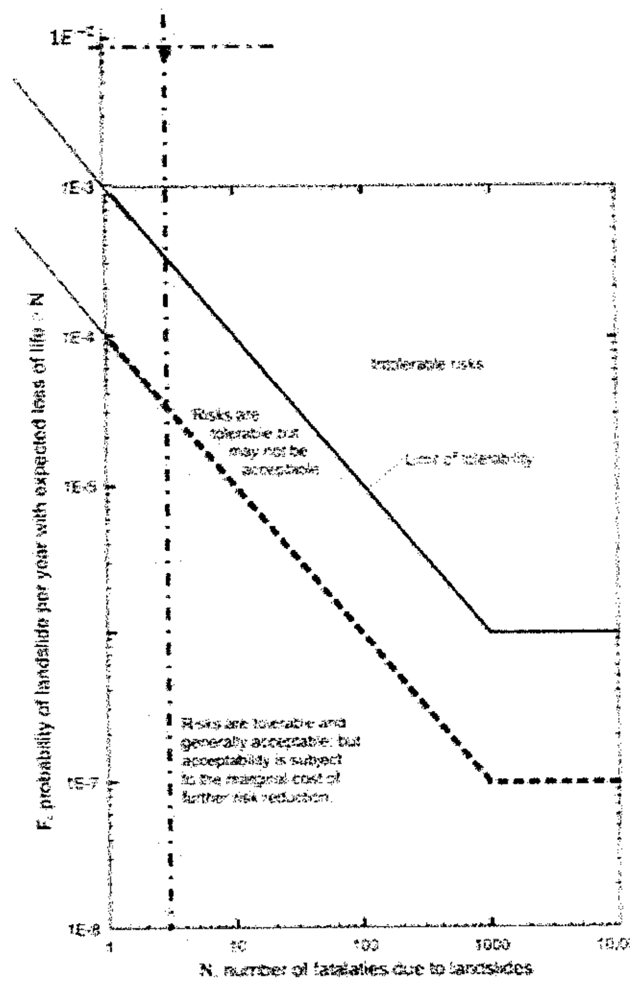

Figure 5.3: Interpolation of P and E for determination of Risk Category at Bukit Antarabangsa slope

The risk category of the slope is Not Tolerable, therefore calculation for risk value will proceed.

Vulnerability Value = 0.48

Based on equation (1),

Risk $= 3 \times 0.09 \times 0.48$

$= \underline{0.13}$

5.1.4 NKVE near Bukit Lanjan Interchange

P = 0.071

E = 1

Plotting the values by interpolating in the Graph of Societal Risk Criteria,

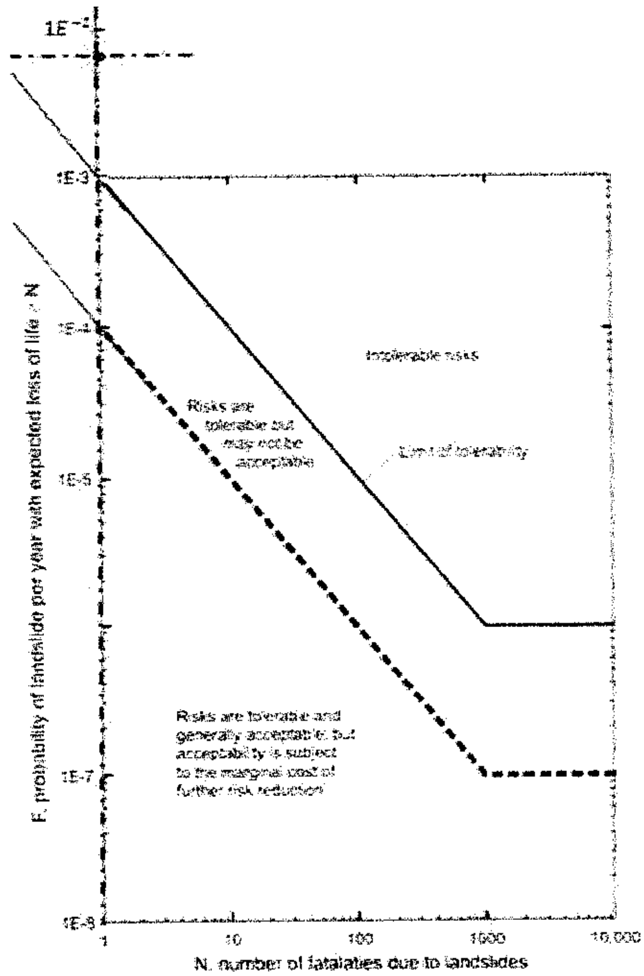

Figure 5.4: Interpolation of P and E for determination of Risk Category at Bukit Lanjan slope

The risk category of the slope is Not Tolerable, therefore risk value calculation will proceed.

Vulnerability Value = 0.25

Based on equation (1),

Risk $= 1 \times 0.071 \times 0.25$

$= \underline{0.018}$

5.2 SLOPE PRIORITIZATION

From the interpolation of the Graphs of Societal Risk Criteria for 4 of the slopes, it is found that the only slopes that fall in the Not Tolerable category are the slopes at Bukit Antarabangsa, NKVE near Bukit Lanjan Interchange, and Cameron Highlands. The slope at Universiti Teknologi PETRONAS, Tronoh falls into the Tolerable category therefore Risk Value calculation does not take place for the slope and it will not be ranked as well.

Ranking the slopes in Not Tolerable category according to their risk values from the highest to the lowest, the result is shown in the table below:

Slope	Risk Value	Rank
Taman Bukit Mewah, Bkt Antarabangsa	0.13	1
NKVE near Bukit Lanjan Interchange	0.018	2
Cameron Highlands	0.00037	3

Table 5.1: Ranking of slopes in Not Tolerable category

From the table, it can be seen that the slope in Taman Bukit Mewah, Bukit Antarabangsa owns the highest priority for slope mitigation/countermeasure, followed by slope at NKVE near Bkt. Lanjan Interchange and then the slope at Cameron Highlands is the lowest in priority.

If all of the slopes are to be mitigated, the slope in Taman Bukit Mewah, Bukit Antarabangsa deserves to be mitigated the earliest, followed by the slope in NKVE near Bukit Lanjan Interchange, then only the slope at Cameron Highlands.

CHAPTER 6

CONCLUSION/ RECOMMENDATION

The result has shown that by using Australia's Landslide Risk Management Guidelines, the most dangerous slope out of the four slope is the slope at Bukit Mewah, Bukit Antarabangsa, followed by the slope at Bukit Lanjan Interchange. Although the assumption was made that the landslide tragedy never occurred yet, it makes sense that the slope in Bukit Mewah is more dangerous than Bukit Lanjan as the tragedy sacrificed 5 lives while Bukit Lanjan tragedy sacrificed none.

The result also shows that the risk for slope in UTP is tolerable, which also makes sense. Though the slope at Cameron Highland falls in the Not Tolerable category, it is less dangerous than the slope at Bukit Antarabangsa and Bukit Lanjan, which is also proven as there is still no tragedy had occurred at the location.

The conclusion is, Australia's Landslide Risk Management is proven suitable to be applied to manage the maintenance of Malaysia's slopes.

After being assessed by this system, the slopes in the Tolerable and ALARP category are further managed by periodical/routine maintenance. It will be beneficial to allow detection if there is any irregularities on the slope that might change its risk category. Meanwhile, as for the slopes in the Not Tolerable category, they should be quickly mitigated in order of their rank of priority. This system does not only allow more effective slope countermeasure, but also optimizing time and budget.

However, this framework still needs to be further analyzed for its suitability in Malaysia condition, some criteria in the tables may need some adjustment for adaptability for condition in Malaysia especially weather, rainfall intensity and severity of landslide cases in Australia in comparison to Malaysia's. This framework has to be examined in-depth before it can finally be used in Malaysia because there might be some differences from the situation in Australia and Malaysia.

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APPENDICES

Appendix 1: PWD's Attribute Scoring Ranges for Cut Slope

HAZARD ATTRIBUTES	POINTS		
	0	1	2
Height of Slope	<12m	12m – 24m	>24m
Slope Angle, f	<45 °	45 ° - 63 °	> 63 °
Slope Cover	>20%	< 20 %	-
Surface Drains	Good	Blocked or Reqd	Need Repair
Natural Water Path	No	-	Yes
Seepage	No	-	Yes
Ponding	No	Yes	-
Erosion	Slight	Moderate	Critical
Slope Failure	No	-	Yes
Surroundings Upslope	No	-	Yes
Soil Type*	Sand/ Gravel	Silt	Clay
Weathering Grade	I	II, III	IV, V, VI
Discontinuities+	I	II, III, VIII	IV, V, VI, VII

* Soil Slope Only
\+ Rock Slope Only

Appendix 2: PWD's Consequences Scoring Range for Cut Slopes

CONSEQUENCE ATTRIBUTES	POINTS		
	0	**1**	**2**
Danger to building occupants	No	-	Yes
Danger to vehicle occupants	< 200 AADT	200 – 1,000 AADT	> 1,000 AADT
Alternative road exists	Yes	No	-
By-pass possible	Yes	No	-

Appendix 3: PWD's Attributes Scoring Range for Embankments

HAZARD ATTRIBUTES	POINTS		
	0	1	2
Slope Angle, f	<45 °	45 ° - 63 °	> 63 °
Height of Slope	<12m	12m – 24m	> 24m
Slope Cover	>20%	<20%	-
Pavement fatigue Cracks	No	Yes	-
Tension Cracks	No	-	Yes
Surface Drains	Good	Blocked or Reqd	Need Repair
Culvert Condition	Good	Need Cleaning	Need Repair
Seepage	No	-	Yes
Ponding	No	Yes	-
Erosion	Slight	Moderate	Critical
Slope Failure	No	-	Yes
Settlement of road	No	-	Yes
Soil Type	Gravel/Sand	Silt	Clay
Surrounding down slopes	No	-	Yes

Appendix 4: PWD's Consequences Scoring Range for Embankments

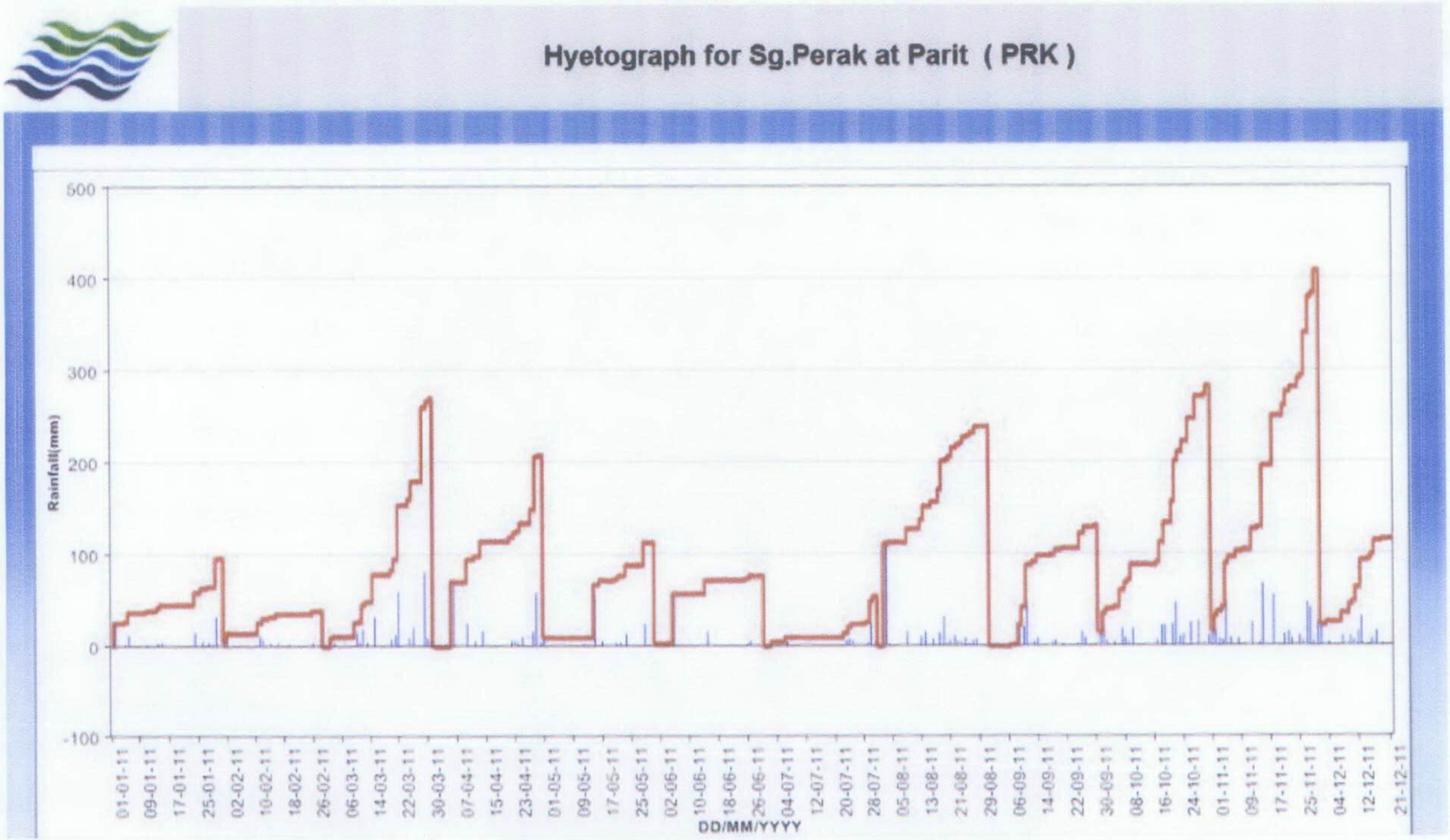
CONSEQUENCE ATTRIBUTES	POINTS		
	0	**1**	**2**
Danger to building occupants	No	-	Yes
	< 200 AADT	200-1,000 AADT	> 1,000 AADT
Danger to vehicle occupants	Yes	No	-
Alternative road exists	Yes	No	-
By-pass possible			

Appendix 5: PWD's Risk Grade and Maintenance Programme Assigned

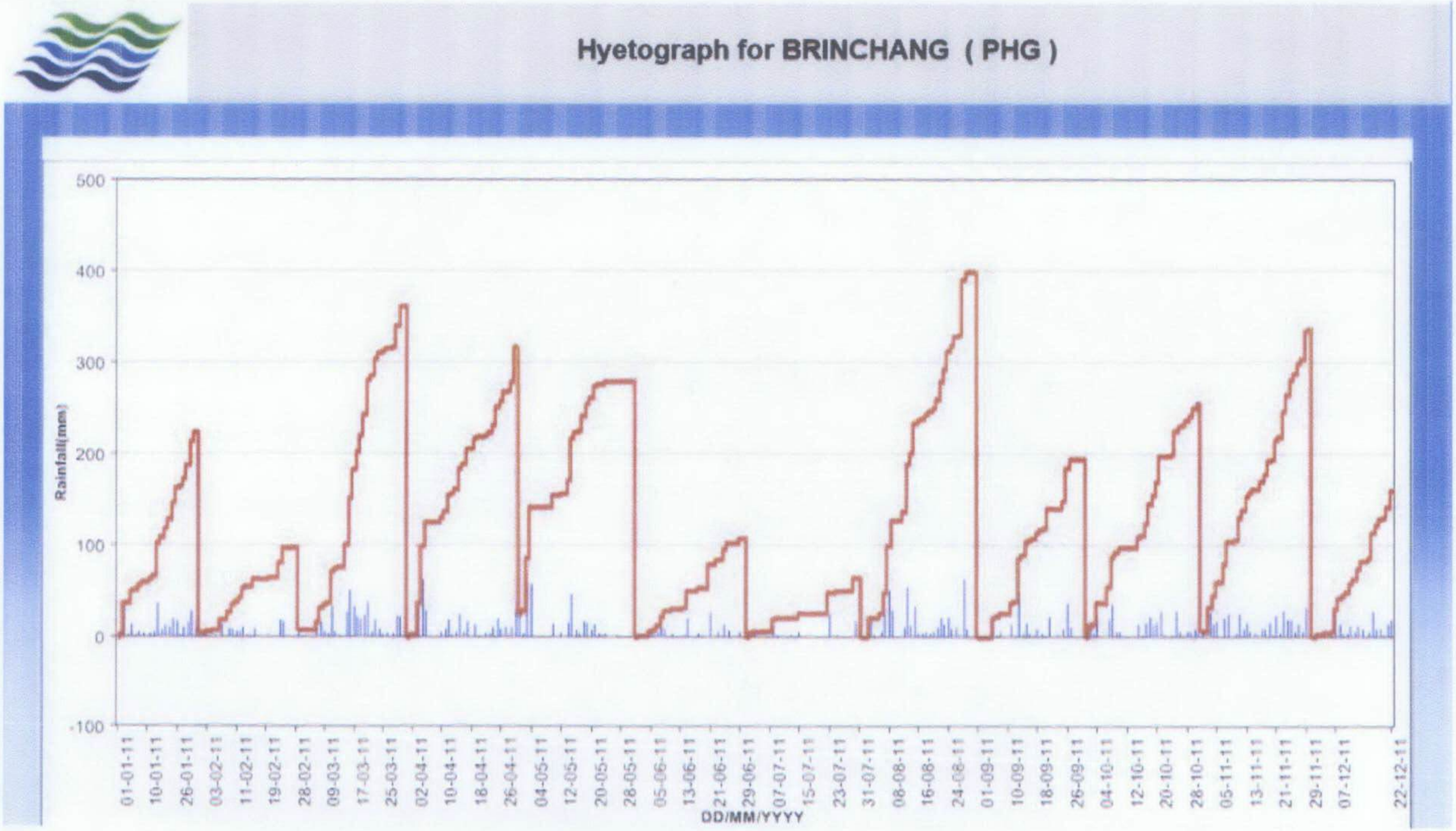
Cut Slope		Fill Slope	
Points	**Risk Grade**	**Points**	**Risk Grade**
76-192	Very High	76-192	Very High
56-75	High	56-75	High
36-55	Moderate	36-55	Moderate
16-35	Low	16-35	Low
0-15	Very Low	0-15	Very Low

Risk Grade	Maintenance Programme
Very High	Countermeasure
High	Regular patrol; Monitoring
Moderate	Periodical Inspection
Low	-
Very Low	-

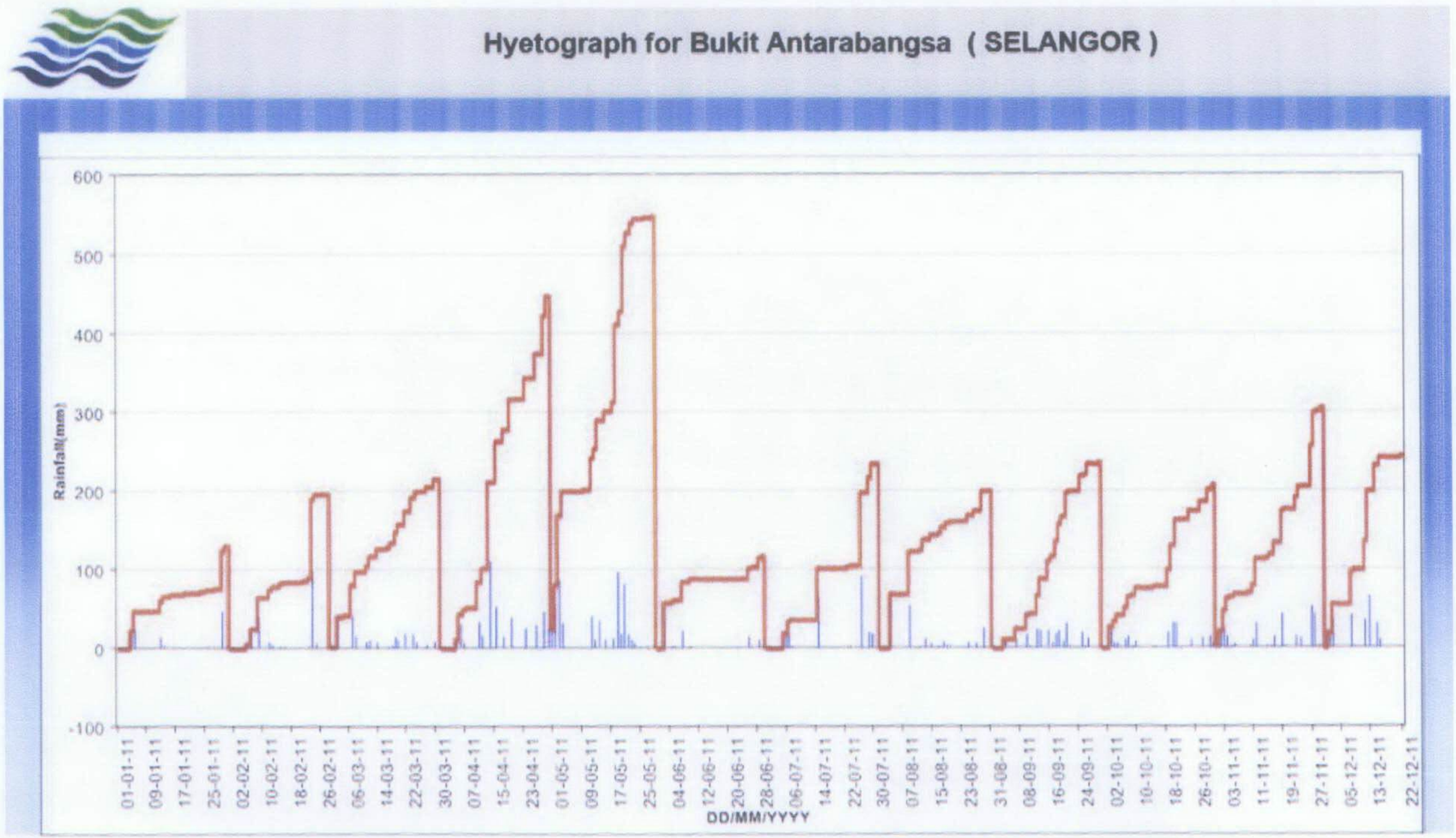
Appendix 6: Hyetograph Reading for Rainfall Station Sg. Perak



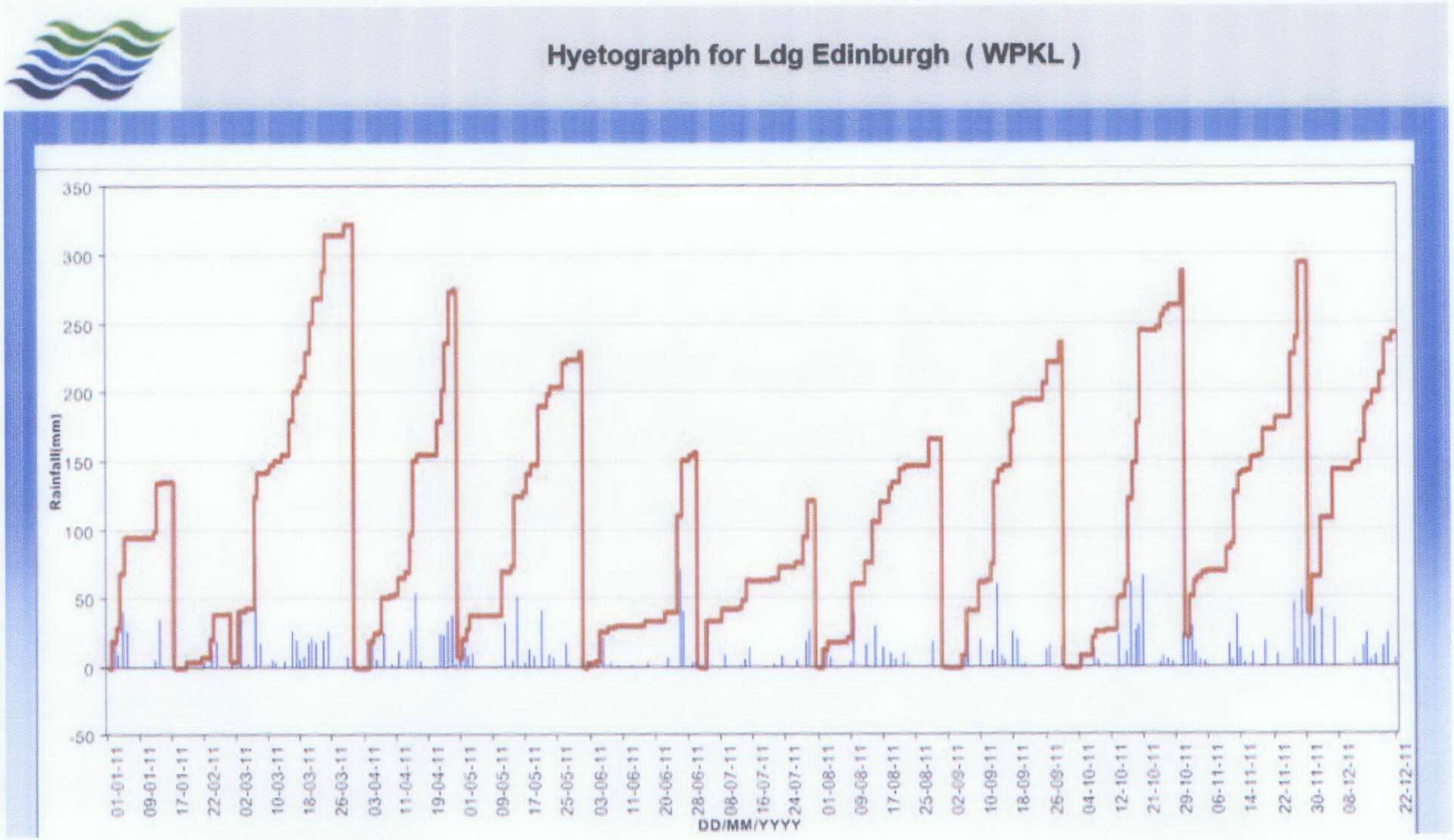
Appendix 7: Hyetograph Reading for Rainfall Station Brinchang



Appendix 8: Hyetograph Reading for Rainfall Station Bukit Antarabangsa



Appendix 9: Hyetograph Reading for Rainfall Station Ldg. Edinburgh



Appendix 10: Graph of Societal Risk Criteria