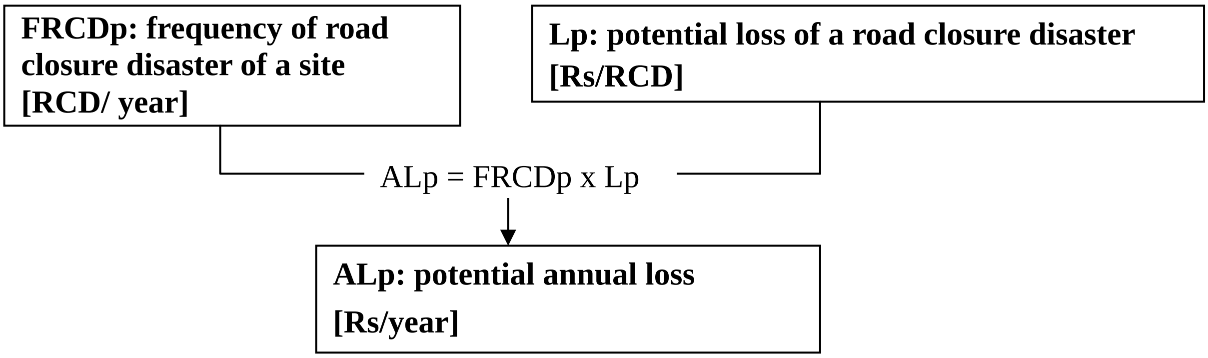
3.3 Risk Assessment of Road Slope Disasters

3.3.1 Outline of Risk Assessment

Road slope disaster risk is evaluated using two risk indicators in this report. One is the frequency of road closure disaster of a site (FRCDp) while the other is potential annual loss of the site (ALp).

Relation of FRCDp and ALp is shown in Figure 3.3.1 below.



RCD: Road closure disaster

Figure 3.3.1 Relation of Risk Indicators

In general, risk is considered as the product of frequency and magnitude. FRCDp is an index which only shows the frequency element of risk. ALp is the overall index which is the product of frequency and the magnitude of risk, evaluated as monetary loss.

(1) Potential Frequency of Road Closure Disaster of a site (FRCDp)

Estimated structure of FRCDp is shown in Figure 3.3.2.

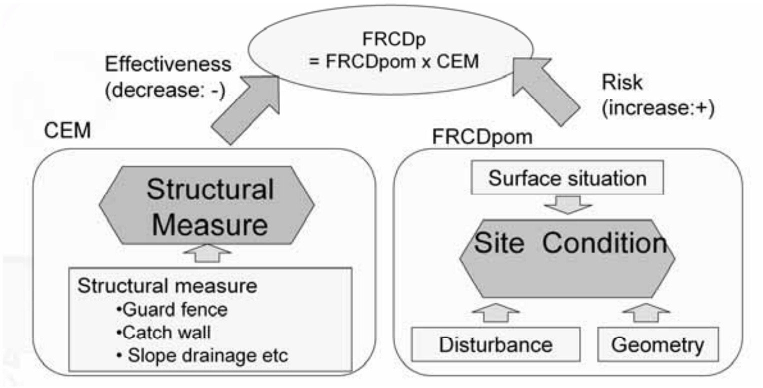


Figure 3.3.2 Estimation Structure of FRCDp

Geometry, surface situation and disturbance are FRCDp factors in the absence of existing measures (FRCDpom). On the other hand, effect of existing structural measures is defined as the coefficient of effectiveness of existing structural measures (CEM). FRCDp is estimated as the product of FRCDpom and CEM.

(2) Potential Annual Loss of a Site (ALp)

Estimation structure of FRCDp is shown in Figure 3.3.3.

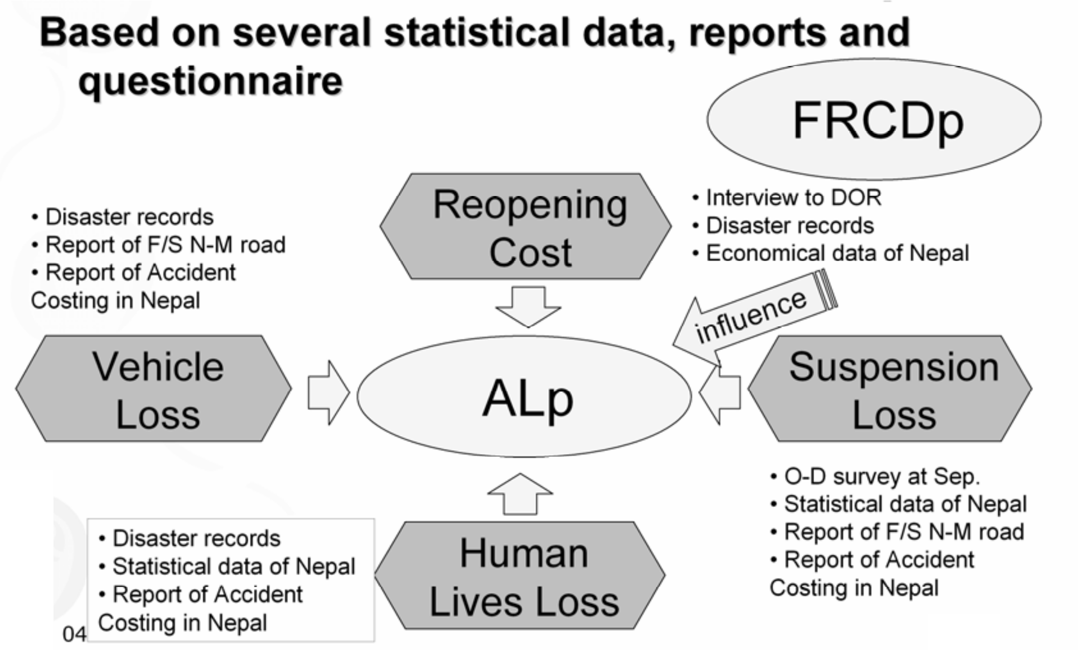


Figure 3.3.3 Estimation Structure of Annual Losses

ALp is the product of FRCDp and potential loss of a site (Lp) as previously mentioned. Lp is composed of four elements consisting of reopening cost, human lives loss, vehicle loss, and suspension loss. Suspension loss is caused by impassable road site, which is composed of losses of waiting, detour, and cancellation.

3.3.2 Workflow

Figure 3.3.4 shows flow of assessment of risk and feasibility of structural measures on N-M Highway.

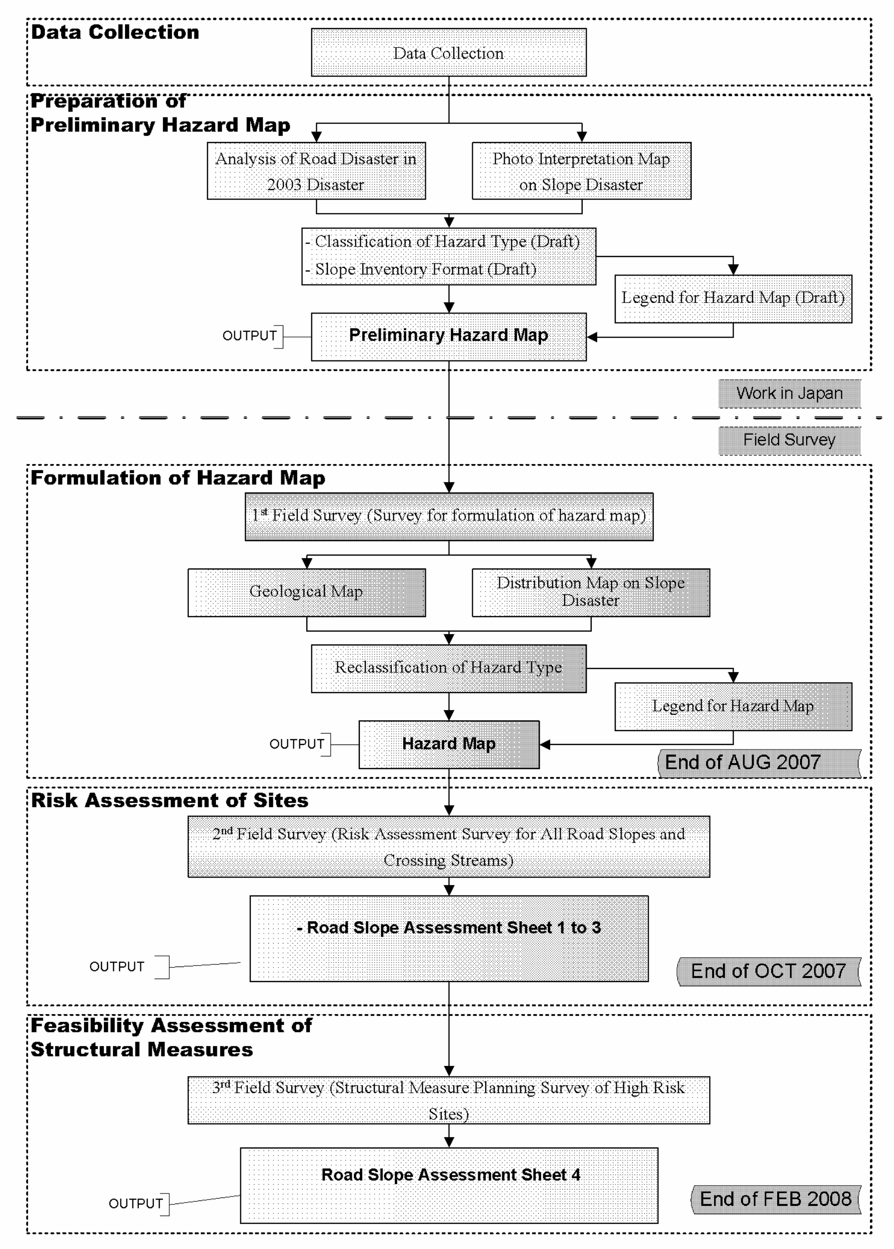


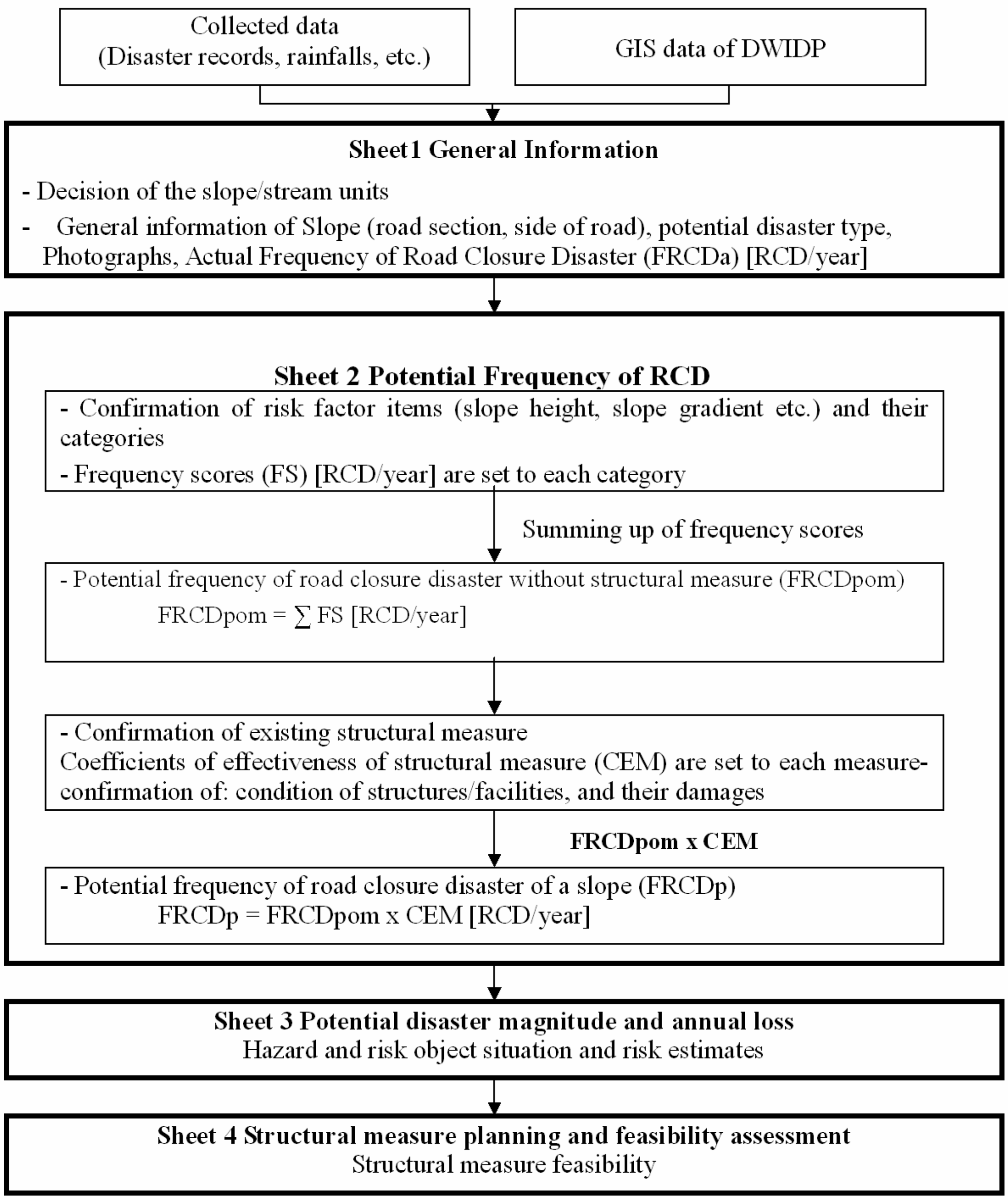
Figure 3.3.4 Flow of Road Slope Assessment on N-M Highway

Hazard map is used as part of input information for risk assessment of sites (road slopes and road crossing streams).

3.3.3 Road Slope Assessment Sheet

(1) Outline

Assessment sheet for risk & feasibility of structural measures (excel spread sheets) are prepared. Figure 3.3.5 shows the flowchart of road slope assessment sheet. Table 3.3.1 shows items required for the assessment of risk and feasibility of structural measures.



Collected data
(Disaster records, rainfalls, etc.)

GIS data of DWIDP

Sheet1 General Information

- Decision of the slope/stream units
- General information of Slope (road section, side of road), potential disaster type, Photographs, Actual Frequency of Road Closure Disaster (FRCDa) [RCD/year]

Sheet 2 Potential Frequency of RCD

- Confirmation of risk factor items (slope height, slope gradient etc.) and their categories
- Frequency scores (FS) [RCD/year] are set to each category

- Potential frequency of road closure disaster without structural measure (FRCDpom)

$$\text{FRCDpom} = \sum \text{FS [RCD/year]}$$

- Confirmation of existing structural measure

Coefficients of effectiveness of structural measure (CEM) are set to each measure-confirmation of: condition of structures/facilities, and their damages

- Potential frequency of road closure disaster of a slope (FRCDp)

$$\text{FRCDp} = \text{FRCDpom} \times \text{CEM [RCD/year]}$$

Sheet 3 Potential disaster magnitude and annual loss
Hazard and risk object situation and risk estimates

Sheet 4 Structural measure planning and feasibility assessment
Structural measure feasibility

RCD: Road Closure Disaster

Figure 3.3.5 Flowchart for Assessment of Risk and Feasibility of Structural Measures

Table 3.3.1 Items in the Assessment Sheet for Risk and Feasibility of Structural Measures

Sheet No. Name (contents of work)	**Description/data**
Risk Assessment of Sites	
Sheet 1. General Information (Screening/ identification of sites to be surveyed)	- Location of site (km post, right/left of road, expected hazard type) - Photographs of site (slope/stream) situation - FRCDa: Actual frequency of RCD of a site [RCD/ year] -FRCDabm: Actual frequency of RCD before structural measures of a site [RCD/year]
Sheet 2. Potential Frequency of RCD (FRCDp) (Disaster frequency assessment)	- Check sheet of hazardous factor items and their categories (item groups are geometry, surface situation, and disturbance), and existing structural measures. - Evaluation results of disaster frequency FRCDpom: FRCDp without existing structural measures [RCD/year] CEM: Coefficient of Effectiveness of structural Measures [ratio] FRCDp: Potential Frequency of RCD [RCD/year] = FRCDpom x CEM
Sheet 3. Potential Disaster Magnitude and Annual Loss (Disaster magnitude identification and risk estimation)	- Sketch of hazard situation and risk object - Evaluation of disaster magnitude LRCpoF: potential Length of Road Closure section of Full width [m] LRCpoP: potential Length of Road Closure section of Partial width [m] - Evaluation of annual losses RCp: potential reopening cost of a RCD HLLp: potential value of human lives loss of a RCD VLp: potential value of vehicles loss of a RCD LTSp: Potential Value of Losses of Traffic Suspension of a RCD Lp: potential loss of a RCD ALp: potential annual loss of a site
Feasibility Assessment of Structural Measures of Sites	
Sheet 4 Planning of Structural Measures (planning of structural measure and feasibility assessment) 4-1 Alternative I High risk reduction 4-2 Alternative II Medium risk reduction 4-3 Alternative III Low risk reduction	- Plane layout of structural measures - Section layout of structural measures - Cost C: cost estimation with 20 years maintenance [Rs] - Benefit /outcome RRR: risk reduction ratio in RCD due to structural measures [Ratio] DAL: Decrease in annual loss due to structural measures [Rs/year] FRCDpwm: Potential frequency of road closure disaster with structural measures [RCD/year] -Feasibility Indicators BCR: Benefit/cost ratio at 12% discount rate [ratio] ENPV: Economic net present value at 12% discount rate [Rs] EIRR: Economic internal rate of return [percent]
Disaster Record	
Sheet 5 Disaster Record (records of when disasters occur after the Inventory Survey)	- Disaster occurrence date - Disaster magnitude - Damage: road closure days, reopening cost, human loss if any, vehicle loss if any - Existing countermeasures

RCD: Road closure disaster

From results of risk assessment survey, high risk sites (road slopes/crossing streams) were selected as priority sites for structural measures. Feasibility assessment of the planned structural measures were done (layout and cost estimate).

(2) Road Slope Assessment Sheet 1: General Information

First of all, the sites where the assessment should be done were specified. Road slope is divided into three slope types (mountainside slope, crossing stream, and riverside slope). Road slope types and their screening criteria for risk assessment are shown in Table 3.3.2.

Table 3.3.2 Screening criteria

Slope Type	Screening Criteria
Mountainside slope	Gradient of mountainside slope > 10 ° And Distance from road to toe of mountainside slope < 10 m
Crossing stream	Wide of crossing stream < 3 m
Riverside slope	Gradient of mountainside slope > 10 ° And Distance from road to toe of mountainside slope < 5 m

In ‘Sheet 1 General information’, following data were arranged.

- Location of site (km post, right/left of road, slope type, expected hazard type)

- Slope type

- Photographs of site situation

- FRCDa: Actual frequency of RCD of a site [RCD/year]

-FRCDabm: Actual frequency of RCD before structural measure of a site [RCD/year]

FRCDa is a current state value (if structural measure is constructed, FRCDa is value of after construction term).

Figure 3.3.6 shows example of road slope assessment sheet 1: general information.

Road Slope Assessment Sheet 1: General Information

Region	Central Development Region						Division Road Office		Bharatpur, Chitwan			
Road name	Narayangharh-Mugling Highway											
Station	from	23	km	960	m	until	24	km	200	m	Length : m	240
Side of Road	Left side of road											
Slope type	Mountainside Slope						Potential Disaster Type (Main)				Slide	
							Potential Disaster Type (Sub)				Slope failure	
Risk Assessment Sheet 1, 2,3	Name of preparer	PATHAK(DWIDP) Satoru NODA(JICA)						Assess ment date	Date		Month	Year
									20		Aug	2007

Photographs

General View

Portion to which attention should be paid

FRCDa: Actual frequency of RCD* of a site	0.100	RCD/year	In case structural measures were done, FRCDa after structural measures period should be input.
FRCDabm: Actual frequency of RCD before measure of a site	0.033	RCD/year	for statistical use only

***RCD: Road closure disaster;** It includes not only the whole road closure but also partial road closures

Note

🟪 Numerical value or terms should be input

🟩 Terms should be input

Figure 3.3.6 Example of Assessment Sheet1 General Information

(3) Road Slope Assessment Sheet 2: Potential Frequency of RCD

(a) Calculation Method of Potential Frequency of RCD

'Sheet 2 Potential Frequency of RCD' was prepared on three different formats for (1) Mountainside Slope, (2) Crossing Stream and (3) Road and Riverside Slopes.

The road slope inventory survey can provide FRCDp as a risk level indicator as shown in Figure 3.3.7. FRCDp is calculated using the following formula.

FRCDp = FRCDpom x CEM

FRCDpom = $\sum$ FS

Where:

FRCDp = Potential frequency of Road Closure Disaster of a site [RCD per year]

FRCDpom = FRCDp of a site without structural measures [RCD per year]

CEM = Coefficient of effectiveness of structural measures effectiveness for FRCDp [coefficient]

FS= Frequency score for FRCDp (FS is assigned to each factor category of each factor item for FRCDp) [RCD per year]

Factor items for FRCDp are set with all considerable factors; factor categories are set from 2 to 4 categories, by referring Japanese road slope inspection manual (Ministry of Construction Japan 1996).

Potential frequency of RCD (FRCDp)

FS: Frequency score of the factor item

Fitted category

Name of factor grope

Factor items for FRCDp	Factor categories for FRCDp				Frequency score for FRCDp [RCD/year]	
Geometry						
Wide of stream: W Frequency score for FRCDp [RCD/year]	3≥W 0.06	5≥W 0.00	10≥W>5 0.00	W>10 0.00	FS1	0.00
	0	0	1	0		
Area of drainage basin: A Frequency score for FRCDp [RCD/year]	$A \geq 0.5km^2$ 0.00	$0.5km^2 > A \geq 0.15km^2$ -0.05		$0.15km^2 > A$ -0.07	FS2	-0.05
	0	1		0		
Area of drainage basin: A Frequency score for FRCDp [RCD/year]					FS3 FS4 FS5	0.04 0.05 0.03
Surface situation						
Dominant vegetation of drainage area Frequency score for FRCDp [RCD/year]	Bare 0.20	Grasses 0.09	Trees 0.09	Unknown 0.07	FS6	0.09
	0	0	1	0		
Dominant materials of stream Frequency score for FRCDp [RCD/year]	Gravel 0.13	Sand 0.01	Silt, Clay 0.01	Bedrock 0.01	FS7	0.13
	1	0	0	0		
Disturbance						
Slope failure situation in drainage area Frequency score for FRCDp [Nos. of RCD/year]	Newly-formed collapses are existing in main valley and branch valleys 0.06	Newly-formed collapses are existing only in main valley 0.06	Newly-formed collapses are existing only in branch valleys 0.05	Newly-formed collapses are existing only in branch valleys 0.07	FS8	0.05
	0	0	1	0		
Trace of debris on or beside the road Frequency score for FRCDp [Nos. of RCD/year]	Trace of debris on or beside the road 0.01		If there are no fitted categories, FS of a factor item is 0.00		FS9	0.00
	0					
FRCDpom: FRCDp without existing countermeasure [RCD/ year]						
					FRCDpom = ∑(FS1:FS9)	0.34
Existing structural measure-type (Description)				**CEM: Coefficient of effectiveness of structural measure**		
Small check dam (5 m height x 2 nos.), Causeway					CEM	0.04
FRCDp of survey site [nos. of RCD/ year]						
					FRCDp = FRCDpom x CEM	0.01

CEM is input by engineering judgment considering predictive hazard magnitude and existing structure's situation

Figure 3.3.7 Calculation Procedure for FRCDp in Road Slope Assessment Sheet 2

(b) Calculation Method

The most suitable frequency scores (FSs) were analyzed by multivariate statistical analysis : minimizing the residual sum of squares between actual value (FRCDabm) and the predicted value (FRCDpom), as shown in figure 3.3.8 and Appendix 3.

Where:

FRCDabm= Actual frequency of RCD of a slope before structural measure is installed [no. of RCD per year]

FRCDpom= potential frequency of RCD of a slope without structural measures [RCD /year]

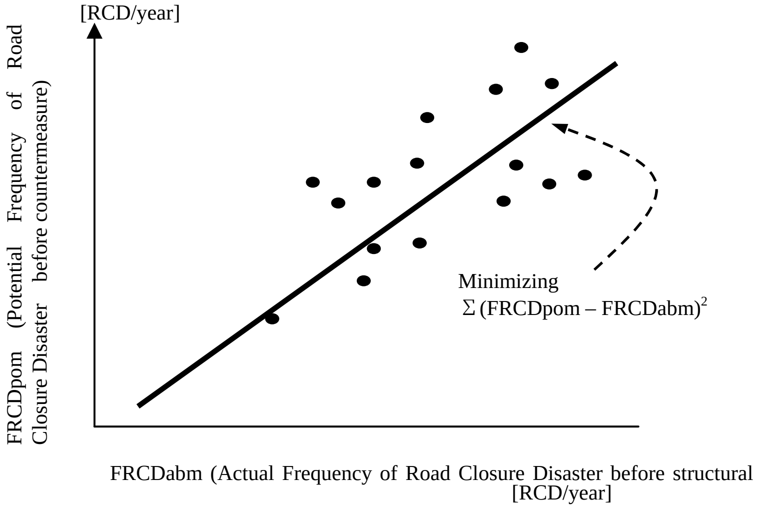


Figure 3.3.8 Illustration for Searching Most Suitable Frequency Scores

The analyzed frequency scores are shown in Figure 3.3.9, 3.3.10, 3.3.11.

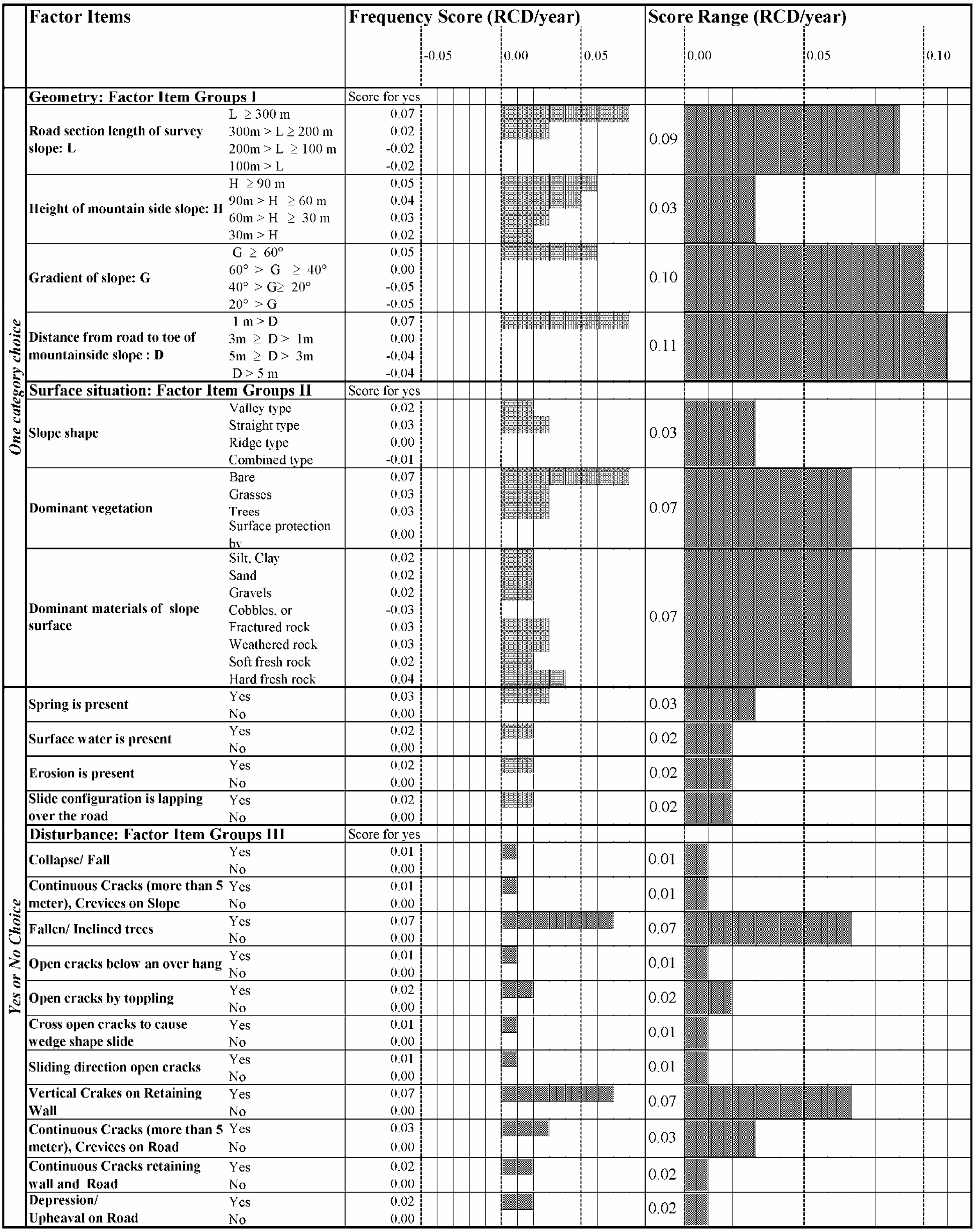
The bigger factor scores are relatively dangerous factor categories in specific factor item.

Score range is difference between maximum and minimum frequency score of factor categories in specific factor item. A bigger score range shows that a factor item has relatively big affection on RCD occurrence.

Table 3.3.3 summarized highly affecting factor items for RCD of each slope types (mountainside slope, riverside slope, and crossing streams).

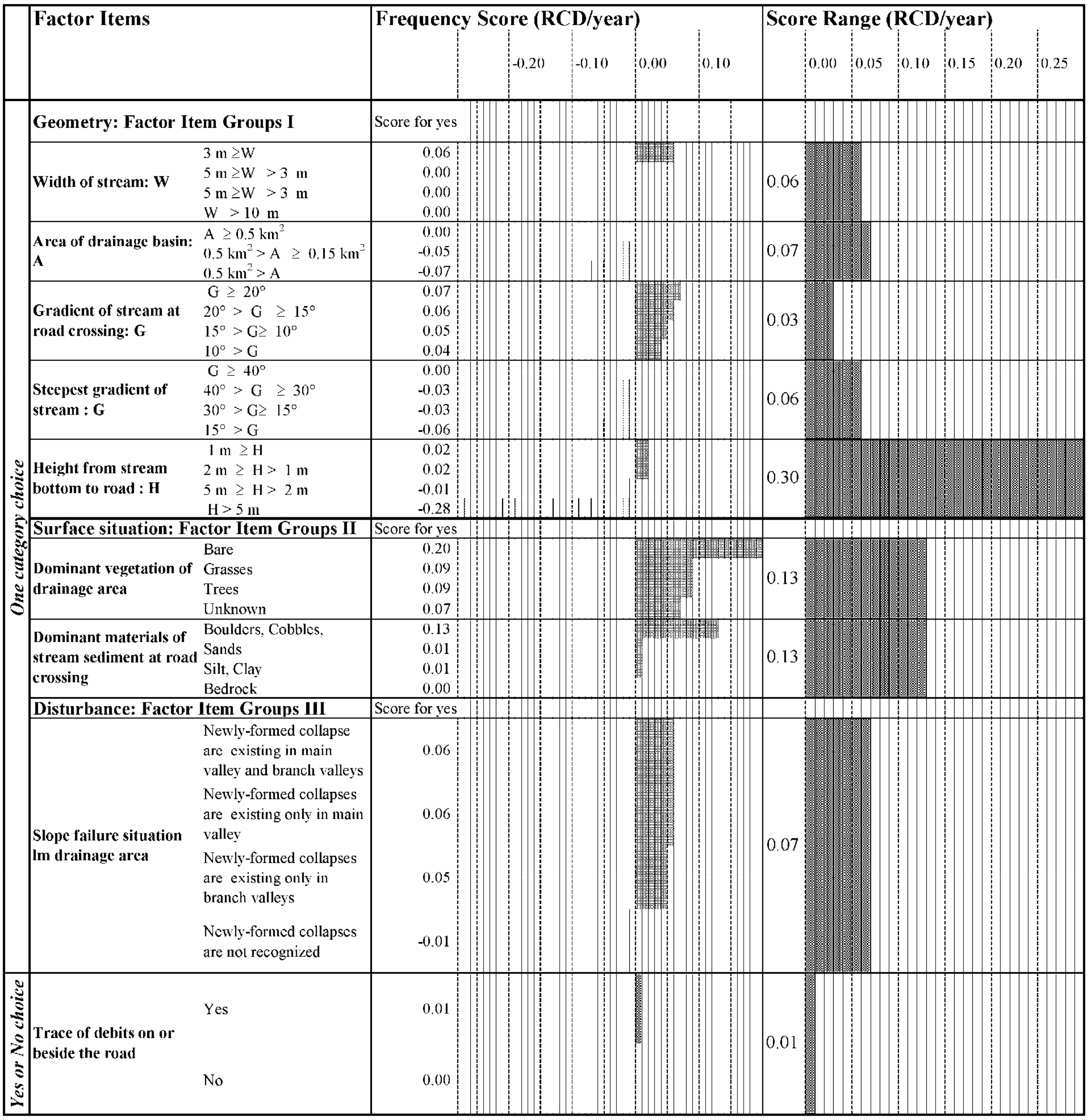
Table 3.3.3 Highly Affecting Factor Items for RCD

Order of top three highly affecting factor items	Mountain side slope	Crossing stream	River side slope
1	- Distance from road to mountainside slope	- Height from stream bottom to road	- Distance from road to toe of mountain side slope
2	- Gradient of slope	- Dominant vegetation of drainage area	- Gradient of slope
3	- Road section length of survey slope	- Dominant materials of stream sediment at road crossing	- Road section length of survey slope



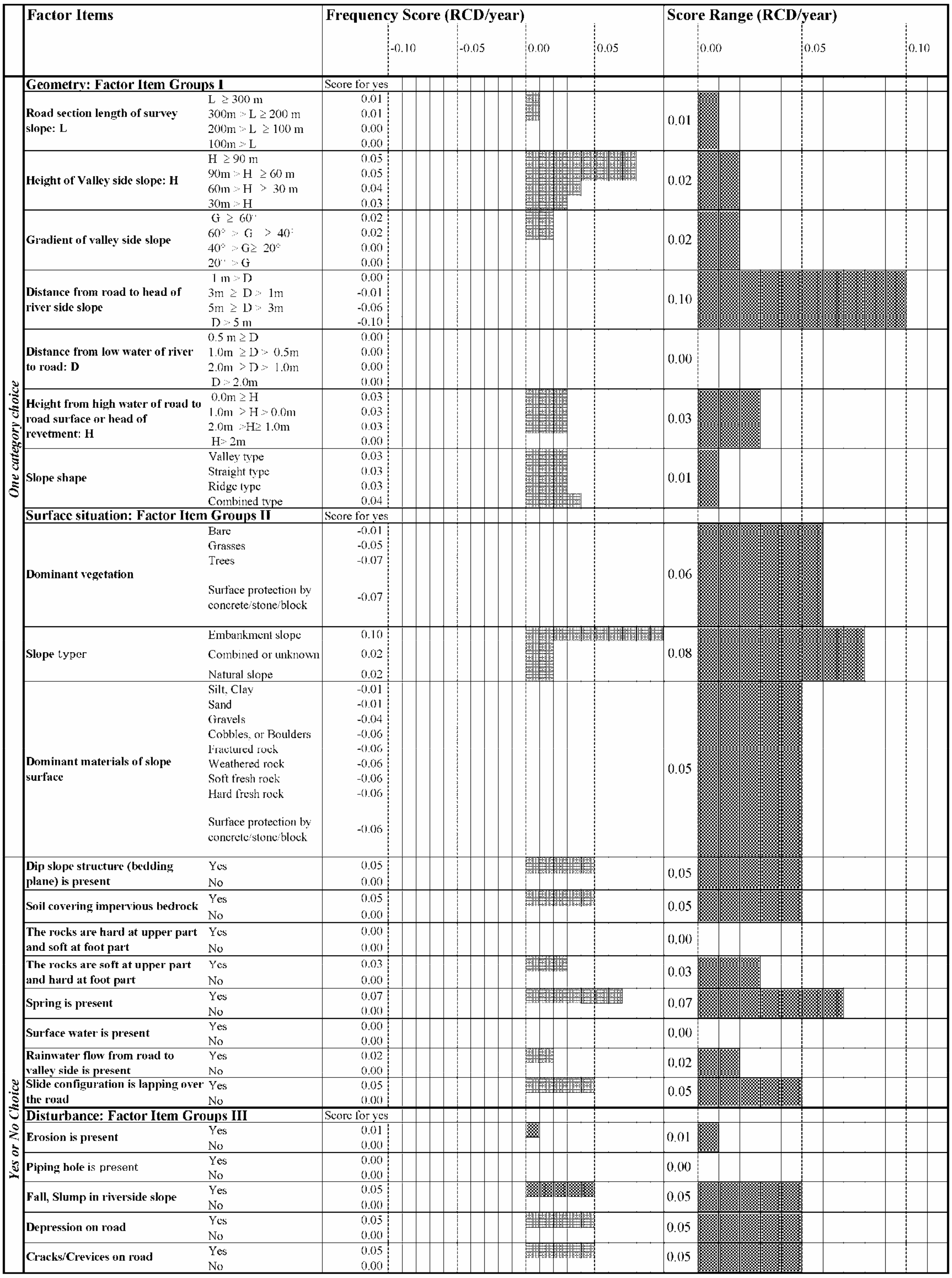
	Factor Items		Frequency Score (RCD/year)	Score Range (RCD/year)
One category choice	**Geometry: Factor Item Groups I**		Score for yes	
	Road section length of survey slope: L	L ≥ 300 m	0.07	0.09
		300m > L ≥ 200 m	0.02	
		200m > L ≥ 100 m	-0.02	
		100m > L	-0.02	
	Height of mountain side slope: H	H ≥ 90 m	0.05	0.03
		90m > H ≥ 60 m	0.04	
		60m > H ≥ 30 m	0.03	
		30m > H	0.02	
	Gradient of slope: G	G ≥ 60°	0.05	0.10
		60° > G ≥ 40°	0.00	
		40° > G≥ 20°	-0.05	
		20° > G	-0.05	
	Distance from road to toe of mountainside slope : D	1 m > D	0.07	0.11
		3m ≥ D > 1m	0.00	
		5m ≥ D > 3m	-0.04	
		D > 5 m	-0.04	
	Surface situation: Factor Item Groups II		Score for yes	
	Slope shape	Valley type	0.02	0.03
		Straight type	0.03	
		Ridge type	0.00	
		Combined type	-0.01	
	Dominant vegetation	Bare	0.07	0.07
		Grasses	0.03	
		Trees	0.03	
		Surface protection by	0.00	
	Dominant materials of slope surface	Silt, Clay	0.02	0.07
		Sand	0.02	
		Gravels	0.02	
		Cobbles, or	-0.03	
		Fractured rock	0.03	
		Weathered rock	0.03	
		Soft fresh rock	0.02	
		Hard fresh rock	0.04	
Yes or No Choice	**Spring is present**	Yes	0.03	0.03
		No	0.00	
	Surface water is present	Yes	0.02	0.02
		No	0.00	
	Erosion is present	Yes	0.02	0.02
		No	0.00	
	Slide configuration is lapping over the road	Yes	0.02	0.02
		No	0.00	
	Disturbance: Factor Item Groups III		Score for yes	
	Collapse/ Fall	Yes	0.01	0.01
		No	0.00	
	Continuous Cracks (more than 5 meter), Crevices on Slope	Yes	0.01	0.01
		No	0.00	
	Fallen/ Inclined trees	Yes	0.07	0.07
		No	0.00	
	Open cracks below an over hang	Yes	0.01	0.01
		No	0.00	
	Open cracks by toppling	Yes	0.02	0.02
		No	0.00	
	Cross open cracks to cause wedge shape slide	Yes	0.01	0.01
		No	0.00	
	Sliding direction open cracks	Yes	0.01	0.01
		No	0.00	
	Vertical Crakes on Retaining Wall	Yes	0.07	0.07
		No	0.00	
	Continuous Cracks (more than 5 meter), Crevices on Road	Yes	0.03	0.03
		No	0.00	
	Continuous Cracks retaining wall and Road	Yes	0.02	0.02
		No	0.00	
	Depression/ Upheaval on Road	Yes	0.02	0.02
		No	0.00	

Figure 3.3.9 Frequency Scores of Mountainside Slope



	Factor Items		Frequency Score (RCD/year)	Score Range (RCD/year)
One category choice	**Geometry: Factor Item Groups I**		Score for yes	
	Width of stream: W	3 m ≥W	0.06	0.06
		5 m ≥W > 3 m	0.00	
		5 m ≥W > 3 m	0.00	
		W > 10 m	0.00	
	Area of drainage basin: A	A ≥ 0.5 km^2	0.00	0.07
		0.5 km^2 > A ≥ 0.15 km^2	-0.05	
		0.5 km^2 > A	-0.07	
	Gradient of stream at road crossing: G	G ≥ 20°	0.07	0.03
		20° > G ≥ 15°	0.06	
		15° > G≥ 10°	0.05	
		10° > G	0.04	
	Steepest gradient of stream : G	G ≥ 40°	0.00	0.06
		40° > G ≥ 30°	-0.03	
		30° > G≥ 15°	-0.03	
		15° > G	-0.06	
	Height from stream bottom to road : H	1 m ≥ H	0.02	0.30
		2 m ≥ H > 1 m	0.02	
		5 m ≥ H > 2 m	-0.01	
		H > 5 m	-0.28	
	Surface situation: Factor Item Groups II		Score for yes	
	Dominant vegetation of drainage area	Bare	0.20	0.13
		Grasses	0.09	
		Trees	0.09	
		Unknown	0.07	
	Dominant materials of stream sediment at road crossing	Boulders, Cobbles,	0.13	0.13
		Sands	0.01	
		Silt, Clay	0.01	
		Bedrock	0.00	
	Disturbance: Factor Item Groups III		Score for yes	
	Slope failure situation Im drainage area	Newly-formed collapse are existing in main valley and branch valleys	0.06	0.07
		Newly-formed collapses are existing only in main valley	0.06	
		Newly-formed collapses are existing only in branch valleys	0.05	
		Newly-formed collapses are not recognized	-0.01	
Yes or No choice	**Trace of debits on or beside the road**	Yes	0.01	0.01
		No	0.00	

Figure 3.3.10 Frequency Scores of Crossing Stream



	Factor Items		Frequency Score (RCD/year)	Score Range (RCD/year)
	Geometry: Factor Item Groups I		Score for yes	
One category choice	**Road section length of survey slope: L**	L ≥ 300 m	0.01	0.01
		300m > L ≥ 200 m	0.01	
		200m > L ≥ 100 m	0.00	
		100m > L	0.00	
	Height of Valley side slope: H	H ≥ 90 m	0.05	0.02
		90m > H ≥ 60 m	0.05	
		60m > H > 30 m	0.04	
		30m > H	0.03	
	Gradient of valley side slope	G ≥ 60°	0.02	0.02
		60° > G > 40°	0.02	
		40° > G≥ 20°	0.00	
		20° > G	0.00	
	Distance from road to head of river side slope	1 m > D	0.00	0.10
		3m ≥ D > 1m	-0.01	
		5m ≥ D > 3m	-0.06	
		D > 5 m	-0.10	
	Distance from low water of river to road: D	0.5 m ≥ D	0.00	0.00
		1.0m ≥ D > 0.5m	0.00	
		2.0m > D > 1.0m	0.00	
		D > 2.0m	0.00	
	Height from high water of road to road surface or head of revetment: H	0.0m ≥ H	0.03	0.03
		1.0m > H > 0.0m	0.03	
		2.0m >H≥ 1.0m	0.03	
		H> 2m	0.00	
	Slope shape	Valley type	0.03	0.01
		Straight type	0.03	
		Ridge type	0.03	
		Combined type	0.04	
	Surface situation: Factor Item Groups II		Score for yes	
	Dominant vegetation	Bare	-0.01	0.06
		Grasses	-0.05	
		Trees	-0.07	
		Surface protection by concrete/stone/block	-0.07	
	Slope typer	Embankment slope	0.10	0.08
		Combined or unknown	0.02	
		Natural slope	0.02	
	Dominant materials of slope surface	Silt, Clay	-0.01	0.05
		Sand	-0.01	
		Gravels	-0.04	
		Cobbles, or Boulders	-0.06	
		Fractured rock	-0.06	
		Weathered rock	-0.06	
		Soft fresh rock	-0.06	
		Hard fresh rock	-0.06	
		Surface protection by concrete/stone/block	-0.06	
Yes or No Choice	**Dip slope structure (bedding plane) is present**	Yes	0.05	0.05
		No	0.00	
	Soil covering impervious bedrock	Yes	0.05	0.05
		No	0.00	
	The rocks are hard at upper part and soft at foot part	Yes	0.00	0.00
		No	0.00	
	The rocks are soft at upper part and hard at foot part	Yes	0.03	0.03
		No	0.00	
	Spring is present	Yes	0.07	0.07
		No	0.00	
	Surface water is present	Yes	0.00	0.00
		No	0.00	
	Rainwater flow from road to valley side is present	Yes	0.02	0.02
		No	0.00	
	Slide configuration is lapping over the road	Yes	0.05	0.05
		No	0.00	
	Disturbance: Factor Item Groups III		Score for yes	
	Erosion is present	Yes	0.01	0.01
		No	0.00	
	Piping hole is present	Yes	0.00	0.00
		No	0.00	
	Fall, Slump in riverside slope	Yes	0.05	0.05
		No	0.00	
	Depression on road	Yes	0.05	0.05
		No	0.00	
	Cracks/Crevices on road	Yes	0.05	0.05
		No	0.00	

Figure 3.3.11 Frequency Scores of Riverside Slope

(c) Coefficient of Effectiveness of Structural Measures (CEM)

The assessment surveyor evaluated the effect of the measures on FRCDp as CEM. CEM is coefficient for calculation of FRCDp as shown in the expression given below.

where

FRCDp = FRCDpom x CEM

FRCDp = Potential frequency of RCD [RCD/year]

FRCD = Potential frequency of RCD without countermeasures [RCD/year]

CEM = Coefficient of effectiveness of structural measures

Table 3.3.4 shows average CEM of Philippines national highway as a reference.

CEM is not set by measure-type. It is differs with strength, scale of structural measures and magnitude of hazard. CEM was set by engineering judgment of assessment surveyor. CEM for multiple measure-types, it is also evaluated by engineering judgment considering compound effect.

Table 3.3.4 Example of Average CEM (Philippines National Highway)

Structural measure type	CEM	Structural measure type	CEM
Mountainside slope		Crossing stream	
Catch wall	0.2	Small sabo dam (less than 10 m height	0.2
Retaining wall	0.1	Riverside slope	
Slope protection by vegetation	0.4	Road drainage	0.05
		Retaining wall/Revetment	0.05

(d) Format of Road Slope Assessment Sheet 2: Potential Frequency of RCD

Three different formats of road slope assessment sheet 2: were used for assessment of potential frequency of RCD by slope types (mountainside slope, crossing stream and riverside slope) and are shown in Figure 3.3.9, 3.3.10, and 3.3.11.

Road Slope Assessment Sheet 2-1: Potential Frequency of RCD (Mountainside Slope)

Road Name	Narayangharh-Mugling Highway	
Station from	1 km	2 m
Side of Survey	Left side of road	

Potential frequency of RCD (FRCDp)

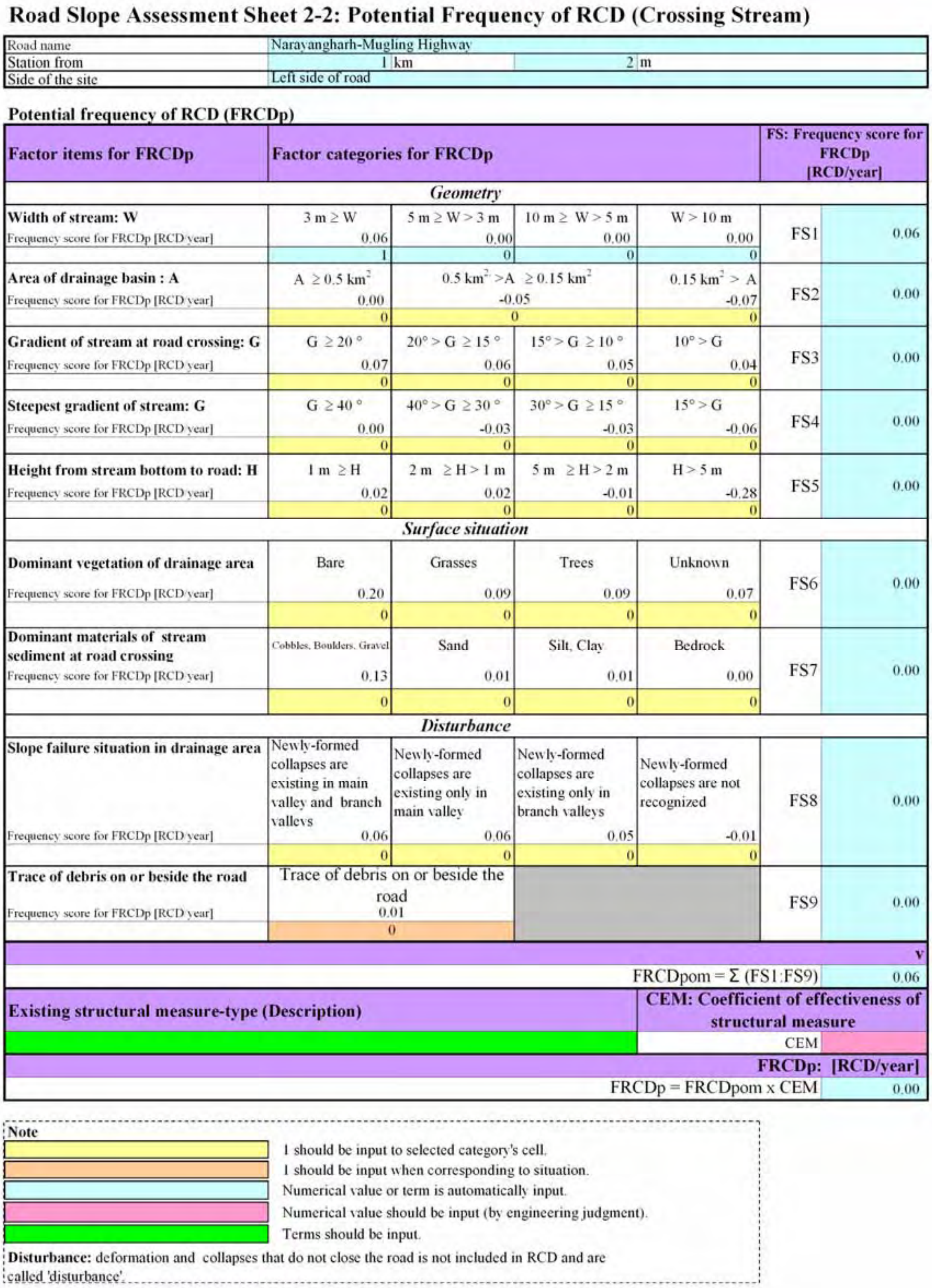
Factor items for FRCDp	**Factor categories for FRCDp**				**Frequency score for FRCDp [RCD/year]**	
			Geometry			
Road section length of survey slope: L Frequency score for FRCDp [RCD/year]	L ≥ 300 m 0.07	300 m > L ≥ 200 m 0.02	200 m > L ≥ 100 m -0.02	100 m > L -0.02	FS1	(0.02)
	0	0	0	1		
Height of mountain side slope: H Frequency score for FRCDp [RCD/year]	H ≥ 90 m 0.05	90 m > H ≥ 60 m 0.04	60 m > H ≥ 30 m 0.03	30 m > H 0.02	FS2	0.00
	0	0	0	0		
Gradient of slope: G Frequency score for FRCDp [RCD/year]	G ≥ 60° 0.05	60° > G ≥ 40° -0.05	40° > G≥ 20° -0.05	20° > G -0.05	FS3	0.00
	0	0	0	0		
Distance from road to toe of mountainside slope : D Frequency score for FRCDp [RCD/year]	1 m > D 0.07	3 m ≥ D > 1m 0.00	5 m ≥ D > 3 m -0.04	D > 5 m -0.04	FS4	0.00
	0	0	0	0		
Slope shape Frequency score for FRCDp [RCD/year]	Valley type 0.02	Straight type 0.03	Ridge type 0.00	Combined type -0.01	FS5	0.00
	0	0	0	0		
			Surface situation			
Dominant vegetation Frequency score for FRCDp [RCD/year]	Bare 0.07	Grasses 0.03	Trees 0.03	Surface protection by concrete/stone/block 0.00	FS6	0.00
	0	0	0	0		
Dominant materials of slope surface Frequency score for FRCDp [RCD/year]	Silt, Clay 0.02	Sand 0.02	Gravels 0.02	Cobbles, or Boulders -0.03	FS7	0.00
	0	0	0	0		
Frequency score for FRCDp [RCD/year]	Fractured rock 0.03	Weathered rock 0.03	Soft fresh rock 0.02	Hard fresh rock 0.04		
	0	0	0	0		
Collapsing/Sliding Structure Frequency score for FRCDp [RCD/year]	Dip slope structure (bedding plane) is present 0.05	Soil covering impervious bedrock 0.05	The rocks are hard at upper part and soft at foot part 0.00	The rocks are soft at upper part and hard at foot part 0.03	FS8	0.00
	0	0	0	0		
Spring/ Surface water / Erosion/ Slide Configuration Frequency score for FRCDp	Spring is Present 0.03	Surface Water is Present 0.02	Erosion is Present 0.02	Slide Configuration is lapping over the 0.02	FS9	0.00
	0	0	0	0		
			Disturbance			
Deformation/ Collapse Frequency score for FRCDp [RCD/year]	Collapse/ Fall 0.01	Continuous Cracks (more than 5 meter), Crevices **on Slope** 0.01	Fallen/ Inclined trees 0.07		FS10	0.00
	0	0	0			
Frequency score for FRCDp [RCD/year]	Open cracks below an over hang 0.01	Open cracks by toppling 0.02	Cross open cracks to cause wedge shape slide 0.01	Sliding direction open cracks 0.01		
	0	0	0	0		
Frequency score for FRCDp [RCD/year]	Vertical Crakes on Retaining Wall 0.07	Continuous Cracks (more than 5 m), Crevices **on Road** 0.03	Continuous Cracks retaining wall and Road 0.02	Depression/ Upheaval **on Road** 0.02		
	0	0	0	0		
					FRCDpom: FRCDp without existing structural measure [RCD/year]	
					FRCDpom = Σ (FS1:FS10)	0.00
Existing structural measure-type (Description)					**CEM: Coefficient of effectiveness of structural measure**	
🟩					CEM	🟥
					FRCDp: [RCD/year]	
					FRCDp = FRCDpom x CEM	0.00

Note

🟨	1 should be input to selected category's cell.
🟧	1 should be input when corresponding to situation.
🟦	Numerical value or term is automatically input.
🟥	Numerical value should be input (by engineering judgment).
🟩	Terms should be input.

Disturbance: deformation and collapses that do not close the road is not included in RCD and are called 'disturbance'.

Figure 3.3.12 Road Slope Assessment Sheet 2-1: Potential Frequency of RCD (Mountainside Slope)



Road Slope Assessment Sheet 2-2: Potential Frequency of RCD (Crossing Stream)

Road name	Narayangharh-Mugling Highway	
Station from	1 km	2 m
Side of the site	Left side of road	

Potential frequency of RCD (FRCDp)

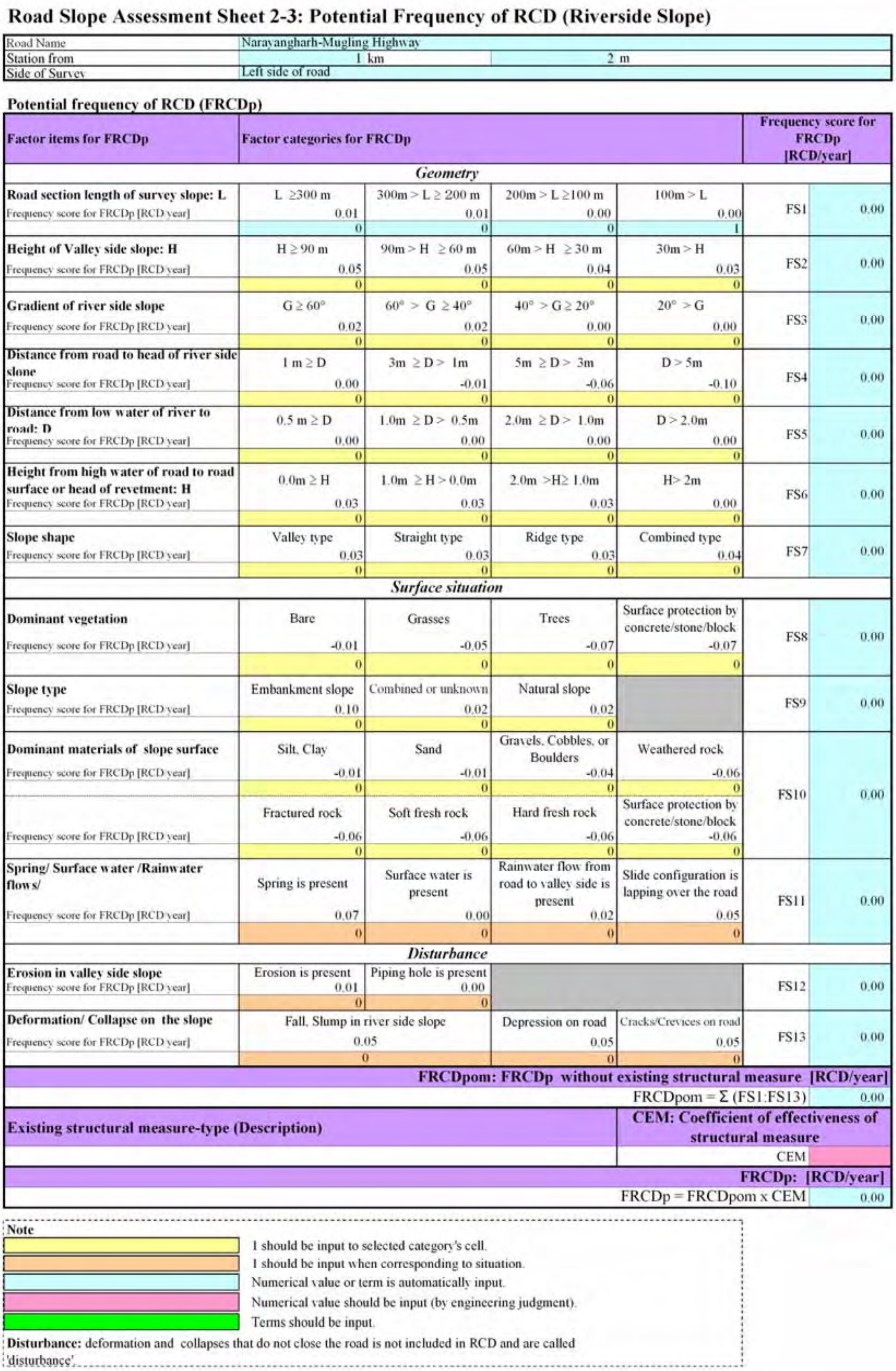
Factor items for FRCDp	Factor categories for FRCDp				FS: Frequency score for FRCDp [RCD/year]	
Geometry						
Width of stream: W	3 m ≥ W	5 m ≥ W > 3 m	10 m ≥ W > 5 m	W > 10 m	FS1	0.06
Frequency score for FRCDp [RCD/year]	0.06	0.00	0.00	0.00		
	1	0	0	0		
Area of drainage basin : A	A ≥ 0.5 km^2	0.5 km^2 >A ≥ 0.15 km^2		0.15 km^2 > A	FS2	0.00
Frequency score for FRCDp [RCD/year]	0.00	-0.05		-0.07		
	0	0		0		
Gradient of stream at road crossing: G	G ≥ 20 °	20° > G ≥ 15 °	15° > G ≥ 10 °	10° > G	FS3	0.00
Frequency score for FRCDp [RCD/year]	0.07	0.06	0.05	0.04		
	0	0	0	0		
Steepest gradient of stream: G	G ≥ 40 °	40° > G ≥ 30 °	30° > G ≥ 15 °	15° > G	FS4	0.00
Frequency score for FRCDp [RCD/year]	0.00	-0.03	-0.03	-0.06		
	0	0	0	0		
Height from stream bottom to road: H	1 m ≥ H	2 m ≥ H > 1 m	5 m ≥ H > 2 m	H > 5 m	FS5	0.00
Frequency score for FRCDp [RCD/year]	0.02	0.02	-0.01	-0.28		
	0	0	0	0		
Surface situation						
Dominant vegetation of drainage area	Bare	Grasses	Trees	Unknown	FS6	0.00
Frequency score for FRCDp [RCD/year]	0.20	0.09	0.09	0.07		
	0	0	0	0		
Dominant materials of stream sediment at road crossing	Cobbles, Boulders, Gravel	Sand	Silt, Clay	Bedrock	FS7	0.00
Frequency score for FRCDp [RCD/year]	0.13	0.01	0.01	0.00		
	0	0	0	0		
Disturbance						
Slope failure situation in drainage area	Newly-formed collapses are existing in main valley and branch valleys	Newly-formed collapses are existing only in main valley	Newly-formed collapses are existing only in branch valleys	Newly-formed collapses are not recognized	FS8	0.00
Frequency score for FRCDp [RCD/year]	0.06	0.06	0.05	-0.01		
	0	0	0	0		
Trace of debris on or beside the road	Trace of debris on or beside the road				FS9	0.00
Frequency score for FRCDp [RCD/year]	0.01					
	0					
						v
					FRCDpom = Σ (FS1:FS9)	0.06
Existing structural measure-type (Description)				**CEM: Coefficient of effectiveness of structural measure**		
				CEM		
					FRCDp:	**[RCD/year]**
					FRCDp = FRCDpom x CEM	0.00

Note

🟨	1 should be input to selected category's cell.
🟧	1 should be input when corresponding to situation.
🟦	Numerical value or term is automatically input.
🟥	Numerical value should be input (by engineering judgment).
🟩	Terms should be input.

Disturbance: deformation and collapses that do not close the road is not included in RCD and are called 'disturbance'.

Figure 3.3.13Road Slope Assessment Sheet 2-2: Potential Frequency of RCD (Crossing Stream)



Road Slope Assessment Sheet 2-3: Potential Frequency of RCD (Riverside Slope)

Road Name	Narayangharh-Mugling Highway	
Station from	1 km	2 m
Side of Survey	Left side of road	

Potential frequency of RCD (FRCDp)

Factor items for FRCDp	Factor categories for FRCDp				Frequency score for FRCDp [RCD/year]	
			Geometry			
Road section length of survey slope: L	L ≥300 m	300m > L ≥ 200 m	200m > L ≥100 m	100m > L	FS1	0.00
Frequency score for FRCDp [RCD/year]	0.01	0.01	0.00	0.00		
	0	0	0	1		
Height of Valley side slope: H	H ≥ 90 m	90m > H ≥ 60 m	60m > H ≥ 30 m	30m > H	FS2	0.00
Frequency score for FRCDp [RCD/year]	0.05	0.05	0.04	0.03		
	0	0	0	0		
Gradient of river side slope	G ≥ 60°	60° > G ≥ 40°	40° > G ≥ 20°	20° > G	FS3	0.00
Frequency score for FRCDp [RCD/year]	0.02	0.02	0.00	0.00		
	0	0	0	0		
Distance from road to head of river side slope	1 m ≥ D	3m ≥ D > 1m	5m ≥ D > 3m	D > 5m	FS4	0.00
Frequency score for FRCDp [RCD/year]	0.00	-0.01	-0.06	-0.10		
	0	0	0	0		
Distance from low water of river to road: D	0.5 m ≥ D	1.0m ≥ D > 0.5m	2.0m ≥ D > 1.0m	D > 2.0m	FS5	0.00
Frequency score for FRCDp [RCD/year]	0.00	0.00	0.00	0.00		
	0	0	0	0		
Height from high water of road to road surface or head of revetment: H	0.0m ≥ H	1.0m ≥ H > 0.0m	2.0m >H≥ 1.0m	H> 2m	FS6	0.00
Frequency score for FRCDp [RCD/year]	0.03	0.03	0.03	0.00		
	0	0	0	0		
Slope shape	Valley type	Straight type	Ridge type	Combined type	FS7	0.00
Frequency score for FRCDp [RCD/year]	0.03	0.03	0.03	0.04		
	0	0	0	0		
			Surface situation			
Dominant vegetation	Bare	Grasses	Trees	Surface protection by concrete/stone/block	FS8	0.00
Frequency score for FRCDp [RCD/year]	-0.01	-0.05	-0.07	-0.07		
	0	0	0	0		
Slope type	Embankment slope	Combined or unknown	Natural slope		FS9	0.00
Frequency score for FRCDp [RCD/year]	0.10	0.02	0.02			
	0	0	0			
Dominant materials of slope surface	Silt, Clay	Sand	Gravels, Cobbles, or Boulders	Weathered rock	FS10	0.00
Frequency score for FRCDp [RCD/year]	-0.01	-0.01	-0.04	-0.06		
	0	0	0	0		
	Fractured rock	Soft fresh rock	Hard fresh rock	Surface protection by concrete/stone/block		
Frequency score for FRCDp [RCD/year]	-0.06	-0.06	-0.06	-0.06		
	0	0	0	0		
Spring/ Surface water /Rainwater flows/	Spring is present	Surface water is present	Rainwater flow from road to valley side is present	Slide configuration is lapping over the road	FS11	0.00
Frequency score for FRCDp [RCD/year]	0.07	0.00	0.02	0.05		
	0	0	0	0		
			Disturbance			
Erosion in valley side slope	Erosion is present	Piping hole is present			FS12	0.00
Frequency score for FRCDp [RCD/year]	0.01	0.00				
	0	0				
Deformation/ Collapse on the slope	Fall, Slump in river side slope		Depression on road	Cracks/Crevices on road	FS13	0.00
Frequency score for FRCDp [RCD/year]	0.05		0.05	0.05		
	0		0	0		
FRCDpom: FRCDp without existing structural measure [RCD/year]						
					FRCDpom = Σ (FS1:FS13)	0.00
Existing structural measure-type (Description)				**CEM: Coefficient of effectiveness of structural measure**		
					CEM	
FRCDp: [RCD/year]						
					FRCDp = FRCDpom x CEM	0.00

Note

🟨	1 should be input to selected category's cell.
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🟩	Terms should be input.

Disturbance: deformation and collapses that do not close the road is not included in RCD and are called 'disturbance'.

Figure 3.3.14 Road Slope Assessment Sheet 2-3: Potential Frequency of RCD (Riverside Slope)

(4) Road slope Assessment Sheet 3: Potential Disaster Magnitude and Annual Loss

(a) Calculation Procedure of Disaster Magnitude and Annual Loss of a Site

Risk is defined as a multiplication of disaster frequency and magnitude. In the assessment sheet 3, risk is assessed as annual loss, which is multiplication of FRCDp (disaster frequency) and Lp (disaster magnitude).

Where

FRCDp = potential frequency of RCD of a site [RCD/year]

Lp = potential loss of a RCD [Rs/RCD]

The calculation procedure of annual loss is shown in Figure 3.3.15 and example of the assessment sheet is presented in Figure 3.3.16.

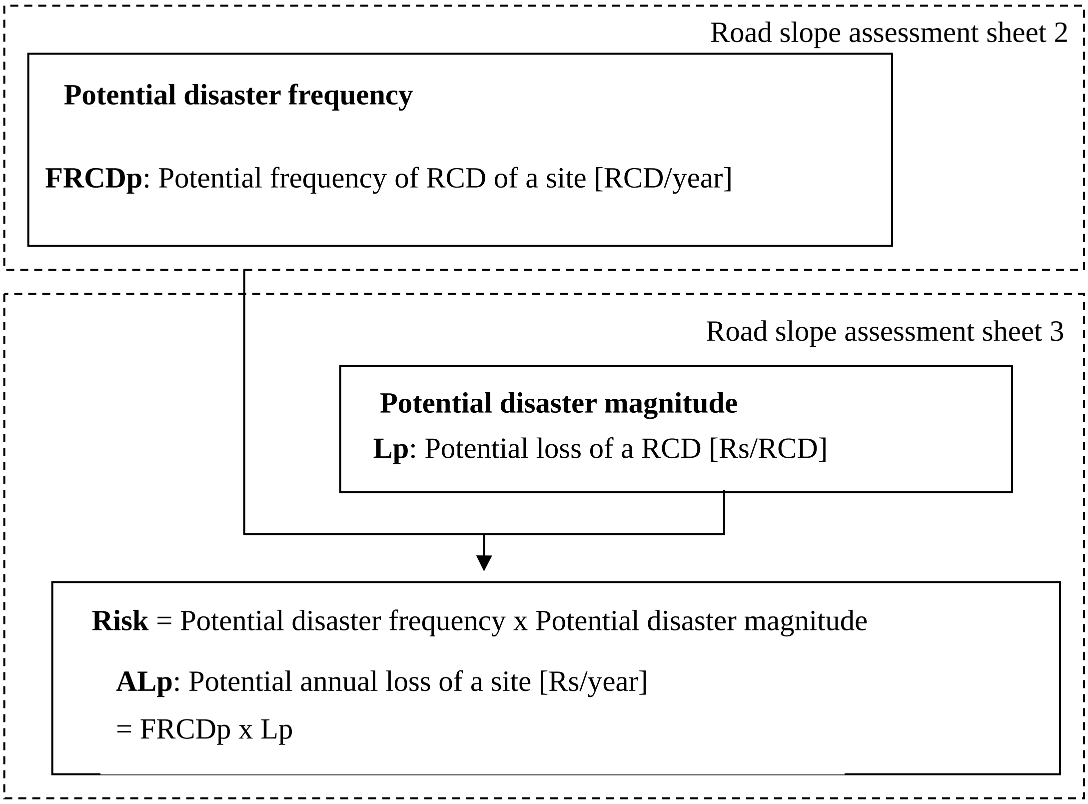
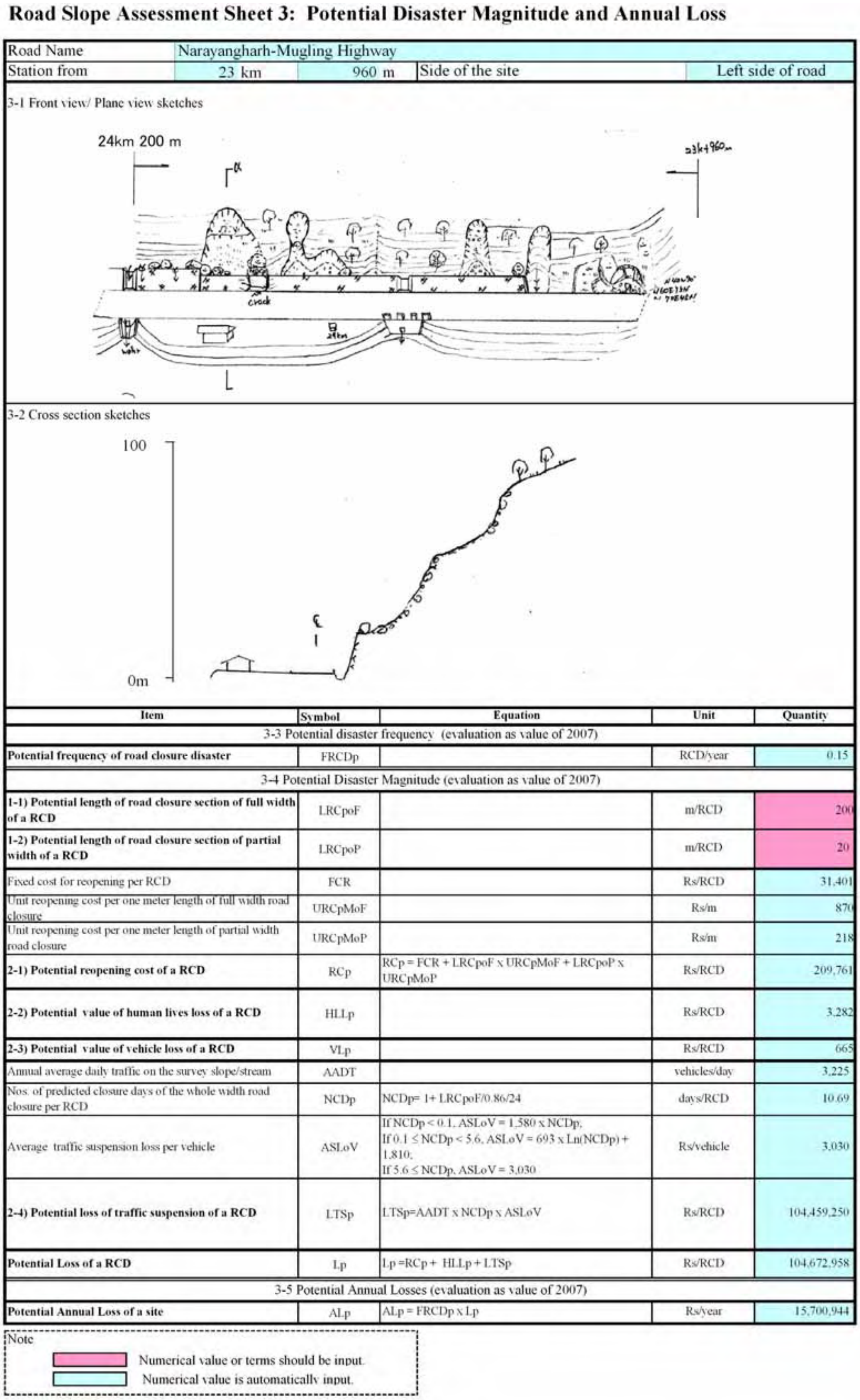


Figure 3.3.15 Calculation Procedure of Potential Annual Loss



Road Slope Assessment Sheet 3: Potential Disaster Magnitude and Annual Loss

Road Name	Narayangharh-Mugling Highway			
Station from	23 km	960 m	Side of the site	Left side of road

3-1 Front view/ Plane view sketches

3-2 Cross section sketches

Item	Symbol	Equation	Unit	Quantity
3-3 Potential disaster frequency (evaluation as value of 2007)				
Potential frequency of road closure disaster	FRCDp		RCD/year	0.15
3-4 Potential Disaster Magnitude (evaluation as value of 2007)				
1-1) Potential length of road closure section of full width of a RCD	LRCpoF		m/RCD	200
1-2) Potential length of road closure section of partial width of a RCD	LRCpoP		m/RCD	20
Fixed cost for reopening per RCD	FCR		Rs/RCD	31,401
Unit reopening cost per one meter length of full width road closure	URCpMoF		Rs/m	870
Unit reopening cost per one meter length of partial width road closure	URCpMoP		Rs/m	218
2-1) Potential reopening cost of a RCD	RCp	RCp = FCR + LRCpoF x URCpMoF + LRCpoP x URCpMoP	Rs/RCD	209,761
2-2) Potential value of human lives loss of a RCD	HLLp		Rs/RCD	3,282
2-3) Potential value of vehicle loss of a RCD	VLp		Rs/RCD	665
Annual average daily traffic on the survey slope/stream	AADT		vehicles/day	3,225
Nos. of predicted closure days of the whole width road closure per RCD	NCDp	NCDp= 1+ LRCpoF/0.86/24	days/RCD	10.69
Average traffic suspension loss per vehicle	ASLoV	If NCDp < 0.1, ASLoV = 1,580 x NCDp, If 0.1 ≤ NCDp < 5.6, ASLoV = 693 x Ln(NCDp) + 1,810; If 5.6 ≤ NCDp, ASLoV = 3,030	Rs/vehicle	3,030
2-4) Potential loss of traffic suspension of a RCD	LTSp	LTSp=AADT x NCDp x ASLoV	Rs/RCD	104,459,250
Potential Loss of a RCD	Lp	Lp =RCp + HLLp + LTSp	Rs/RCD	104,672,958
3-5 Potential Annual Losses (evaluation as value of 2007)				
Potential Annual Loss of a site	ALp	ALp = FRCDp x Lp	Rs/year	15,700,944

Note

🟥 Numerical value or terms should be input.

🟦 Numerical value is automatically input.

Figure 3.3.16 Example of Road slope Assessment Sheet 3: Potential Disaster Magnitude and Annual Loss

(b) Potential Disaster Magnitude

1) Potential Length of Road Closure Section of a RCD

As shown in Figure 3.3.17, at first, the disaster magnitude is evaluated by potential length of road closure section. The definition of length of road closure section of a RCD, which is estimated by a site investigator based on the hazard situation and disaster records in analogous slopes is shown in table 3.3.5.

Table 3.3.5 Definition of length of road closure section of a RCD

Item	Symbol	Unit	Definition
Potential length of road closure section of full width of a RCD	LRCpoF	m	No traffic lane is secured
Potential length of road closure section of partial width of a RCD	LRCpoP	m	At least one traffic lane is secured

Assessment surveyors evaluated the length of road closure section by observing hazard condition and referring to past disaster magnitude of similar slopes.

2) Potential Loss of a RCD (Lp)

a) General

Potential loss of a RCD (Lp) is automatically calculated when the length of road closure section is input in the road slope assessment sheet 3. Lp is a function of nos. of RCD and length of road closure section. And Lp is evaluated at 2007 value.

The unit values or formulas for potential loss calculation is determined using statistical data, existing studies reports of roads in Nepal, and passengers interview surveys including origin-destination surveys conducted in September 2007 under this study. These analyses detail are shown in Appendix 4. The analyzed results are summarized and presented.

Potential loss (Lp) is calculated by summing up four components as shown in Table 3.3.6.

Table 3.3.6 Composition of Potential Loss of a RCD

Lp=Potential Loss of a RCD [Rs/ RCD] Lp= RCp+ HLLp+ VLp +LTSp	RCp =Potential Reopening Cost of a RCD [Rs/RCD]
	HLLp=Potential value of Human Life Loss of a RCD [Rs/RCD]
	VLp=Potential value of Vehicle Loss of a RCD [Rs/RCD]
	LTSp=Potential Losses of Traffic Suspension (detour/waiting/cancellation) of a RCD [Rs/RCD]

b) RCp: Potential Reopening Cost per RCD [Rs/RCD]

Formulas and unit cost for potential reopening cost estimation is shown in Table 3.3.7.

Unit cost is derived from the past costs data of N-M Highway.

The fixed cost (FCR) comprises the loader operator’s salary and allowances, depreciation of loader and overhead costs for operation of site office.

Variable reopening cost of a RCD are unit reopening cost per one meter length of full width road closure (URCpMoF) or Unit reopening cost per one meter length of partial width road closure (URCpMoP). The variable cost comprises the costs of fuel and oil consumptions and cost of labours, and is calculated by assuming the typical road closure disaster debris accumulation volumes of full width or partial width road closure.

Table 3.3.7 Formula and Unit Cost for Potential Reopening Cost

Formula for Loss Estimate	Unit	Unit cost at 2007
RCp=FCR + LRCpoF x URCpMoF + LRCpoP x URCpMoP		
Where RCp: potential reopening cost	[Rs/RCD]	
FCR: Fixed cost for reopening per RCD	[Rs/RCD]	31,412
LRCpoF: Potential length of road closure section of full width	[m]	
URCpMoF: Unit reopening cost per one mater length of full width road closure	[Rs/m]	870
LRCpoP: Potential length of road closure section of partial width	[m]	
URCpMoP: Unit reopening cost per one meter length of partial width road closure	[Rs/m]	218

c) HLLp: Potential Values of Human Lives Lost per RCD [Rs/RCD]

Formulas and unit value for potential values of human lives lost is shown in Table 3.3.8.

ANHD: Average Number of Human Deaths per RCD [persons/RCD]

ANHD in past 10 years (1997 to 2006) is 1/308 (one dead person divided by 308 RCD) [persons/RCD]

Number of RCD is evaluated by the road slope assessment surveys conducted in 2007 under this study, which was based on interviews of DOR staffs and inhabitants along the road.

There were no human lives lost in 10 years, however, in 2003 a truck was buried in the debris at 21 km and the truck driver was badly injured but could escape. The badly injured driver is considered as a dead person in the calculation.

ANHD should be increased promotionally by traffic volume. Traffic volume at 2007 is evaluated about 1.5 times than that of past 10 years, based on the traffic increase of 80% in 10 years (6% per year) of DOR estimation in 2006. Hence, ANHD at 2007 is evaluated as 1.5/308 [persons/RCD].

UHL: Unit Value of Human Life Lost [Rs/person]

The two main components in determining UHL consists of:

- The number of years/days of work lost due to death, and
- The average annual income of dead person

Table 3.3.8 Formula and Unit Value for Potential value of Human Lives Lost

Formula for Loss Estimate	Unit	Unit value at 2007
HLLp=ANHD x UHL Where HLLp: Potential value of human lives lost	[Rs/RCD]	3,282
ANHD: Average number of human deaths per RCD	[persons/ RCD]	1.5/308
UHL: Unit Value of Human Life Lost	[Rs/person]	674,000

d) VLp: Potential Value of Vehicle Loss of a RCD [Rs/RCD]

Formulas and unit value for potential values of vehicle loss is shown in Table 3.3.9.

ANVL: Average Number of Vehicle Lost per RCD [vehicles/RCD]

ANVL in past 10 years (1997 to 2006) is 1/308 (one vehicle lost divided by 308 RCD) [vehicles/RCD].

Numbers of RCD is evaluated by the road slope assessment survey conducted in 2007 under this study, based on interviews of DOR staffs and inhabitants along the road.

One vehicle lost case is in 2003, a truck was buried in the debris at 21 km.

ANVL should be increased promotionally by traffic volume. Traffic volume at 2007 is evaluated about 1.5 times than that of past 10 years, based on the traffic increase of 80% in 10 years (6% per year) of DOR estimation in 2006. Hence, ANVL at 2007 is evaluated as 1.5/308 [vehicles/RCD].

UVL: Unit Value of Vehicle Loss [Rs/vehicle]

The net vehicle damage cost incurred in road accidents is estimated by using following relationship:

Net vehicle damage cost = Average vehicle repair cost
- Custom duties and VAT on spare parts and any salvage
+ Insurance excess (insured vehicles only)
+ Survey fees of accident (insured vehicles only – 10% vehicles)
+ Lost business (commercial vehicles only)

Table 3.3.9 Formula and Unit Value for Potential Value of Vehicle Loss

Formula for Loss Estimate	Unit	Unit value at 2007
VLp=ANVL x UVL Where VLp: Potential value of vehicle lost	[Rs/RCD]	
ANVL: Average Number of Vehicle Loss per RCD	[vehicles/RCD]	1.5/308
UVL: Unit Value of Vehicle Lost	[Rs/vehicle]	147,669

e) Potential Loss of Traffic Suspension of a RCD (LTSp) [Rs/RCD]

Formulas and unit value for potential values of vehicle loss of a RCD is shown in Table 3.3.10.

Table 3.3.10 Formula and Unit Value for Potential Value of Vehicle Loss

Formula for Loss Estimate	Unit	Unit value at 2007
LTSp = AADT x NCDp x ASLoV Where LTSp: Potential losses of traffic suspension of a RCD	[Rs/RCD]	
AADT: Annual average daily traffic	[vehicles/day]	3,225
NCDp: Nos. of predicted closure days of the whole width of the road on the survey site per RCD	[days]	Parameter
NCDp= 1+ LRCpoP/0.86/24 LRCpoF: Potential length of road closure section of full width [m]		
ASLpV : Average suspension loss per vehicles If NCDp < 0.1, ASLpV = 1,580 x NCDp; If 0.1 ≤ NCDp < 5.6, ASLpV = 693 x Ln(NCDp) + 1,810; If 5.6 ≤ NCDp, ASLoV = 3,030	[Rs/vehicle]	

AADT: Annual Average Daily Traffic [vehicles/day]

The value of AADT is presented in the report of DOR Feasibility Study Report of N-M Highway prepared in March 2007. The AADT of 2 ways of N-M highway at 2006 is 3041 vehicles/day. In the report, the traffic volume increase is predicted as 6% per year. Therefore, AADT in 2007 is estimated 3,225 vehicles per day.

NCDp: Nos. of predicted closure days of the whole width of the road on the survey site per RCD [day]

NCDp is determined by using following past data on N-M highway.

ARToDV: average reopening time per debris volume = 0.0258 hr/m^3

Meanwhile,

TVDoF: Typical volume of accumulated debris of one meter length of full width = 33.47 m^3/m.

Actual reopening hour per one meter length full width road closure is

ARToDV x TVDoF = 0.0258 hr/m3 x 33.47 m3/m ≈ 0.86 hr/m

Being the full width road closure is a significant disaster; one day should be added for preparation work and security assurance.

Therefore,

NCDp= 1+ LRCpoP/0.86/24

Where

LRCpoF: Potential length of road closure section of full width [m].

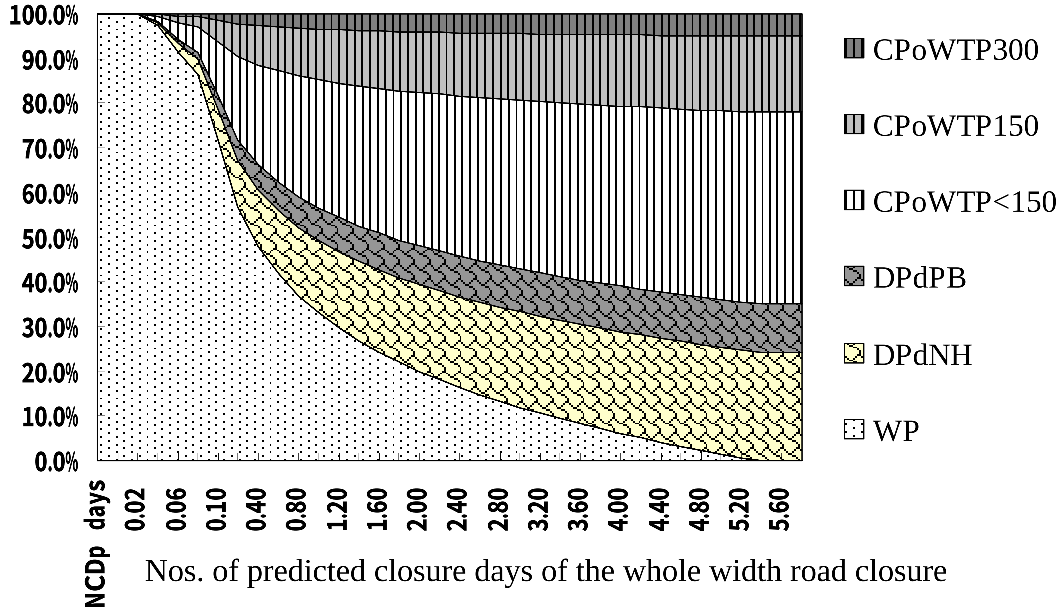
ASLoV : Average Suspension Loss per Vehicle [Rs/vehicle]

Average suspension loss per vehicle (ASLoV) is calculated by summing up three components as shown in Table 3.3.11.

Table 3.3.11 Composition of Average Suspension Loss per Vehicle

ASLpV=Average Suspension Loss per vehicle [Rs/vehicle] ASLpV= AWLpV+ ADLpV+ ACLpV	AWLpV = Average waiting loss per vehicle [Rs/vehicle]
	ADLpV = Average detour loss per vehicle [Rs/vehicle]
	ACLpV= Average cancellation loss per vehicle [Rs/vehicle]

The road users select the option of detour, waiting, or cancellation according to the road closure days. The option is changed by suspension days. In this study the option proposition is determined by passenger interview surveys conducted in September and shown in Figure 3.3.17.



CpoWTP300	Cancellation percentage willing to pay up to Rs 300 instead of waiting (5.0% of non waiting)
CpoWTP150	Cancellation percentage, willingness to pay up to Rs 150 instead of waiting (17.0% of non waiting)
CpoWTP<150	Cancellation percentage willingness to pay under Rs 150 instead of waiting (42.9% of non waiting)
DPdPB	Detour percentage divert to Pokhara-Butawal (10.8% of no waiting)
DPdNH	Detour percentage divert to Naubise-Hetauda (24.3% of no waiting)
WP	Waiting percentage

Figure 3.3.17 Option Selection Proportion to N-M Highway Road Closure of Full Width

Formulas and unit value for average waiting loss per vehicle (AWLpV) is shown in Table 3.3.12.

Table 3.3.12 Formula and Unit Value for Average Waiting Loss per Vehicle

Formula for Loss Estimate	Unit	Unit value at 2007
AWLpV = ∫ NCDp/2 x24 x WP x AVTT		Variable by NCDp
Where AWLpV: Average waiting loss per vehicle	[Rs/vehicle]	
NCDp: Nos. of predicted closure days of the whole width of the road on the survey site per RCD	[days]	Parameter
WP: Waiting percentage	[%]	Variable by NCDp as shown in Figure 3.3.17
UVTT: Unit value of traffic time of a vehicle of N-M highway (waited by vehicle-type proportion of N-M Highway based on unit value of traffic time of each vehicle-type of study on North-South Fast track linking Katmandu to Terai 2007 by DOR)	[Rs/vehicle/hour]	130

Formulas and unit value for average detour loss per vehicle (ADLpV) is shown in Table 3.3.13.

Table 3.3.13 Formula and Unit Value for Average Detour Loss per Vehicle

Formula for Loss Estimate	Unit	Unit value at 2007
ADLpV = DPdNH x UDLdNH +DPdPB x UDLdPB		Variable by NCDp
Where ADLpV: Average detour loss per vehicle	[Rs/vehicle]	
DPdNH: Detour parentage of divert to Naubise or Hetauda (24.3% of no waiting)	[%]	Variable by NCDp as shown in Figure 3.3.17
DPdPB: Detour parentage of divert to Pokhara-Butawal (10.8% of no waiting)	[%]	
UDLdNH: Unit detour loss of a vehicle when divert to Naubise or Hetauda	[Rs/vehicle]	2,400
UDLdPB: Unit detour loss of a vehicle when divert to Pokhara or Butawal - Difference of vehicle operation cost and M-H highway and detour and; - Multiplication of travel time increase and UVTT	[Rs/vehicle]	5,100
NCDp: Nos. of predicted closure days of the whole width of the road on the survey site per RCD	[days]	Parameter
UVTT: Unit value of traffic time of a vehicle of N-M highway (waited by vehicle-type proportion of N-M highway based on unit value of traffic time of each vehicle-type of study on North-South Fast track linking Katmandu to Terai 2007 by DOR)	[Rs/vehicle/hour]	130

Formulas and unit value for average cancellation loss per vehicle (ACLpV) is shown in Table 3.3.14.

Table 3.3.14 Formula and Unit Value for Average Cancellation Loss per Vehicle

Formula for Loss Estimate	Unit	Unit value at 2007
ACLpV = CPoWTP<150 x 75 + CPoWTP150 x 150 + CPoWTP300 x 300		Variable by NCDp
Where ACLpV: Average cancellation loss per vehicle	[Rs/vehicle]	
CPoWTP<150 : Cancellation percentage, willingness to pay under Rs 150 instead of canceling (42.9% of non waiting)	[%]	Variable by NCDp as shown in Figure 3.3.17
CPoWTP150 : Cancellation percentage, willingness to pay up to Rs 150 instead of canceling (17.0% of non waiting)	[%]	
CPoWTP300 : Cancellation percentage, willingness to pay up to Rs 300 instead of canceling (15.0% of non waiting)	[%]	
NCDp: Nos. of predicted closure days of the whole width of the road on the survey site per RCD	[days]	Parameter

As above mentioned, calculation of average traffic suspension loss per vehicle (ASLpV) is done by given formula.

If NCDp < 0.1,

ASLpV = 1,580 x NCDp;

If 0.1 ≤ NCDp < 5.6,

ASLpV = 693 x Ln(NCDp) + 1,810;

If 5.6 ≤ NCDp, ASLoV = 3,030

Where

ASLpV: Average traffic suspension loss per vehicle [Rs/vehicle]

NCDp: Nos. of predicted closure days of the whole width of the road on the survey site per RCD [day]

The proportion of three components of ASLpV is shown in Figure 3.3.18.

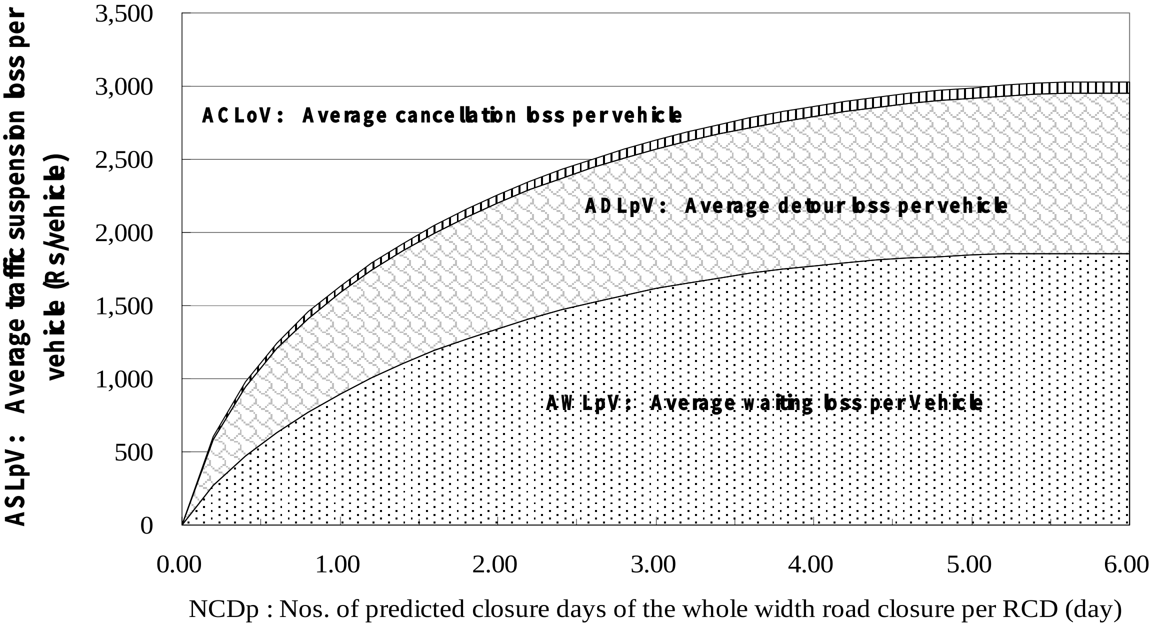


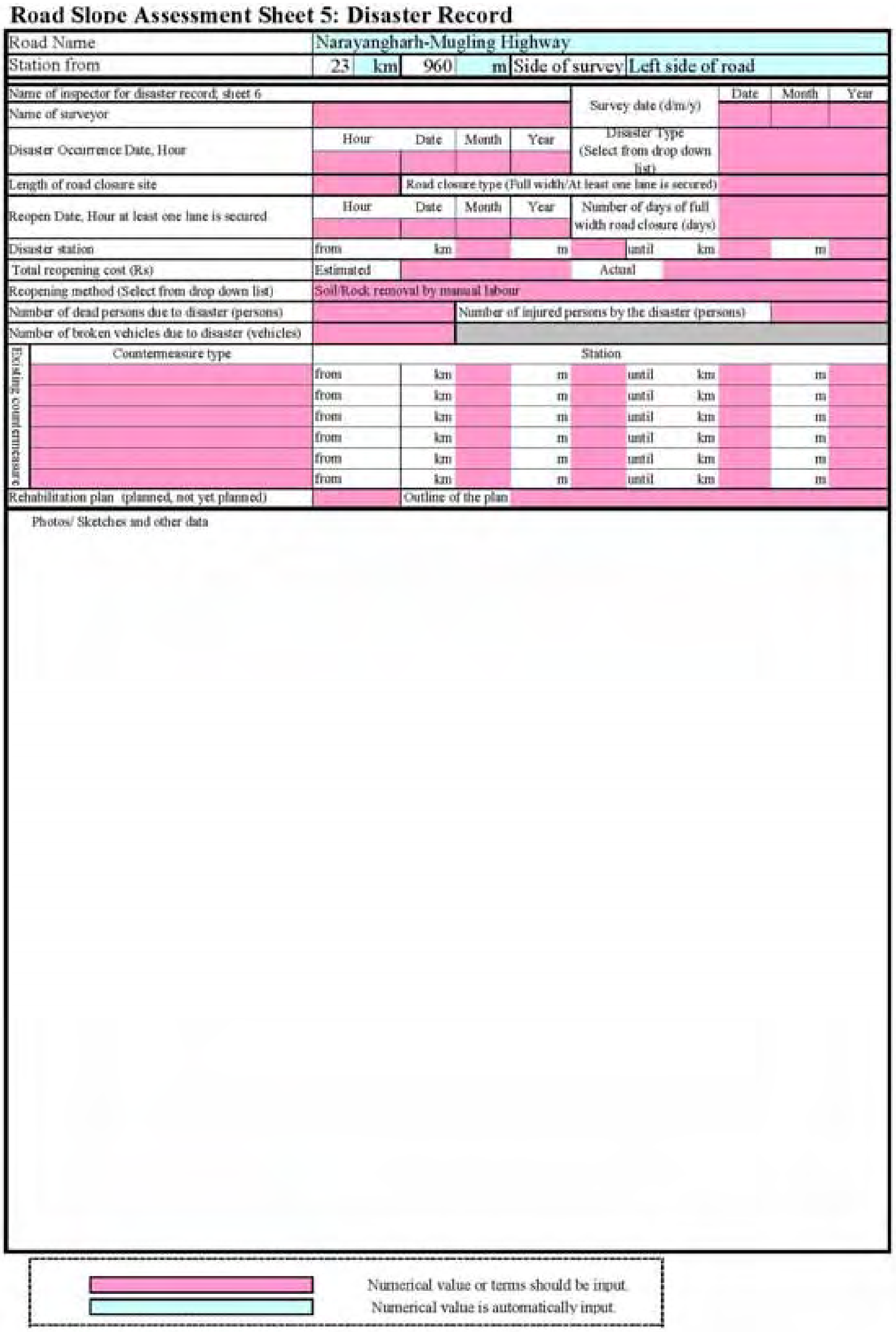
Figure 3.3.18 Proportion of Three components of Average Traffic suspension Loss per vehicle [Rs/vehicle]

(5) Road slope Assessment Sheet 4: Structural Measures Feasibility

The sheet 4: structural measures feasibility is described in Chapter 8.

(6) Road slope Assessment Sheet 5: Disasters Record

The sheet 5: disasters record is prepared for outcome evaluation and precision risk assessment for next stage which is shown in Figure 3.3.19.



Road Slope Assessment Sheet 5: Disaster Record

Road Name	Narayangharh-Mugling Highway									
Station from	23	km	960	m	Side of survey	Left side of road				
Name of inspector for disaster record; sheet 6					Survey date (d/m/y)			Date	Month	Year
Name of surveyor										
Disaster Occurrence Date, Hour	Hour	Date	Month	Year	Disaster Type (Select from drop down list)					
Length of road closure site		Road closure type (Full width/At least one lane is secured)								
Reopen Date, Hour at least one lane is secured	Hour	Date	Month	Year	Number of days of full width road closure (days)					
Disaster station	from	km		m		until	km		m	
Total reopening cost (Rs)	Estimated					Actual				
Reopening method (Select from drop down list)	Soil/Rock removal by manual labour									
Number of dead persons due to disaster (persons)			Number of injured persons by the disaster (persons)							
Number of broken vehicles due to disaster (vehicles)										
Countermeasure type	Station									
Existing countermeasure	from	km		m		until	km		m	
	from	km		m		until	km		m	
	from	km		m		until	km		m	
	from	km		m		until	km		m	
	from	km		m		until	km		m	
	from	km		m		until	km		m	
Rehabilitation plan (planned, not yet planned)		Outline of the plan								

Photos/ Sketches and other data

🟥	Numerical value or terms should be input.
🟦	Numerical value is automatically input.

Figure 3.3.19 Road Slope Assessment Sheet 5: Disasters Record [Rs/vehicle]

3.4 Results of Risk Assessment

3.4.1 Narayangharh-Mugling Highway

(1) Risk Level of Sites

The Team carried out road slope disaster risk assessment survey along N-M highway in August 2007 with the local staff of DWIDP and DOR. The risk of 305 sites (134 mountainside slopes, 78 crossing streams, and 93 riverside slopes) were assessed using the road slope disaster assessment sheets, mentioned in section 3.3. Risk level indicators for the assessment are as follows:

- Potential frequency of RCD of a site (FRCDp) [RCD/year]

- Potential annual loss of a site (ALp) [Rs/year]

Generally, risk is indicated as multiplication of frequency and magnitude of disaster. FRCDp indicates only the frequency component of risk. The ALp is multiplication result of frequency and monetary magnitude of RCD; therefore it can be considered as a comprehensive risk level indicator of RCD.

Figure 3.4.1 Shows categorized FRCDp levels of sites on hazard map.

Figure 3.4.2 Shows categorized ALp levels of sites on hazard map.

Potential disaster sites are distributed along chainage 10 km to 36 km (26 km length section) of the N-M highway. High risk level sites (FRCDp is over 0.1 RCD/year, or ALp is over 1.0 million Rs/year) are scattered entirely along the 26 km stretch of the highway. Among the three slope-types (mountainside slope, crossing stream slope, and riverside slopes), the mountainside slope has the most risky.

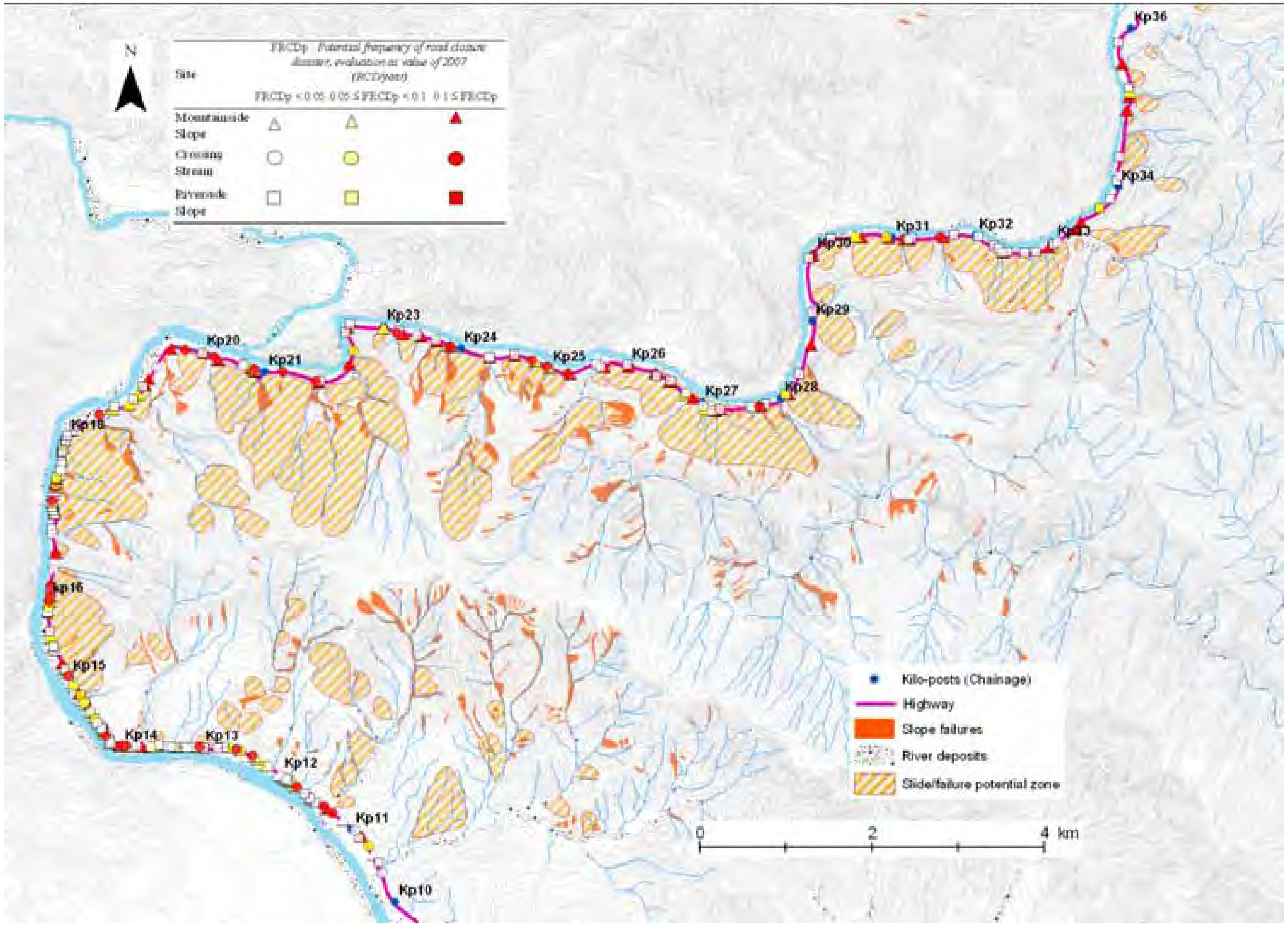


Figure 3.4.1 Potential Frequency of RCD of a site (FRCDp) with Hazard

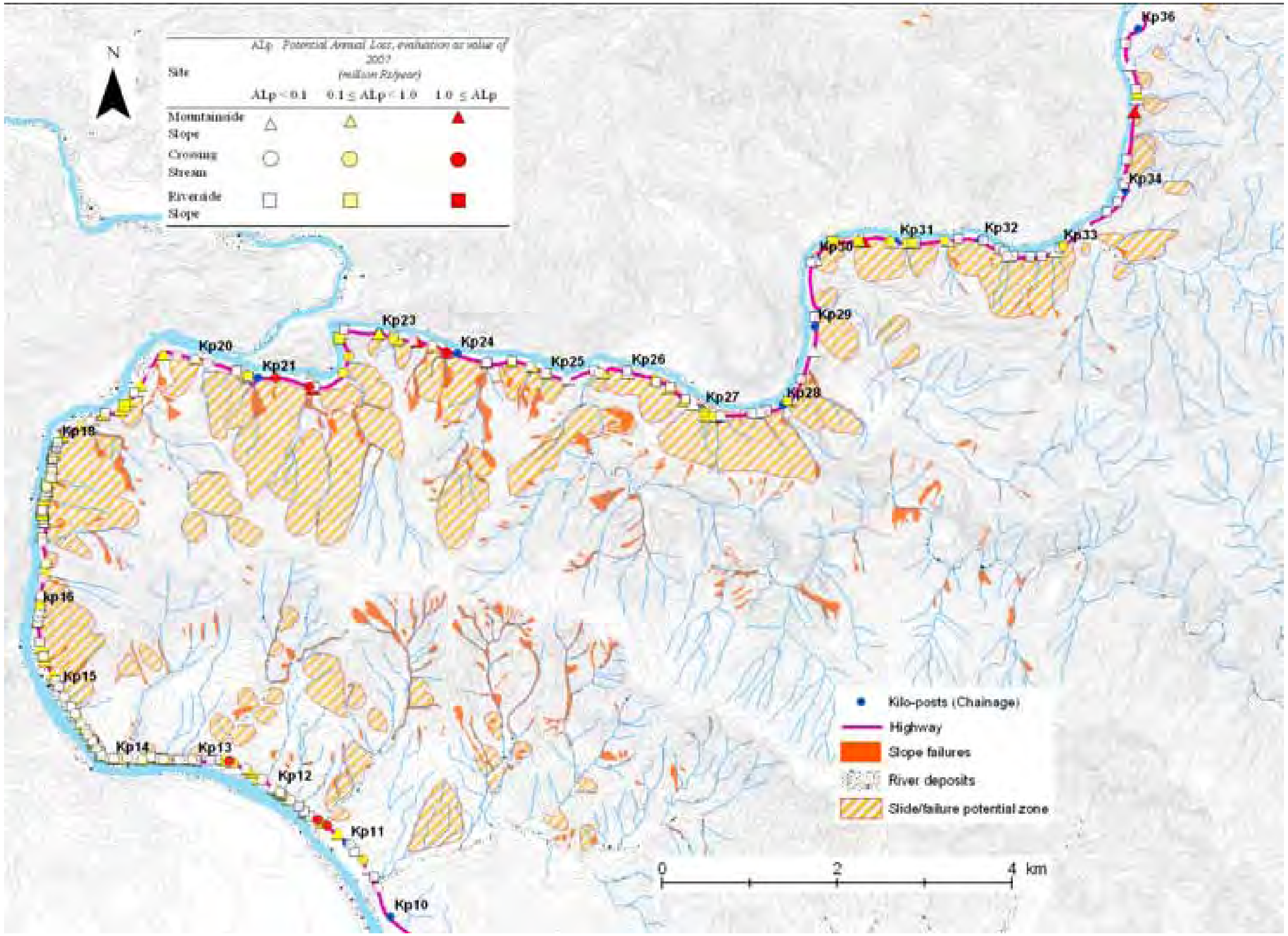


Figure 3.4.2 Potential Annual Loss of a site (ALp) with Hazard

(2) Total Risk of Narayangharh-Mugling Highway

The highway section which has risk of RCD is between CH 10 km and 36 km of N-M Highway.

Figure 3.4.3 shows summary of potential annual loss (ALp) of the N-M Highway. A total of 106.1 million Rs/year of annual loss is predicted based on 2007 market value. Proportions of the ALp by slope-type are: 65.9% of mountainside slope, 32.1% of crossing stream and 2.1% of riverside slope.

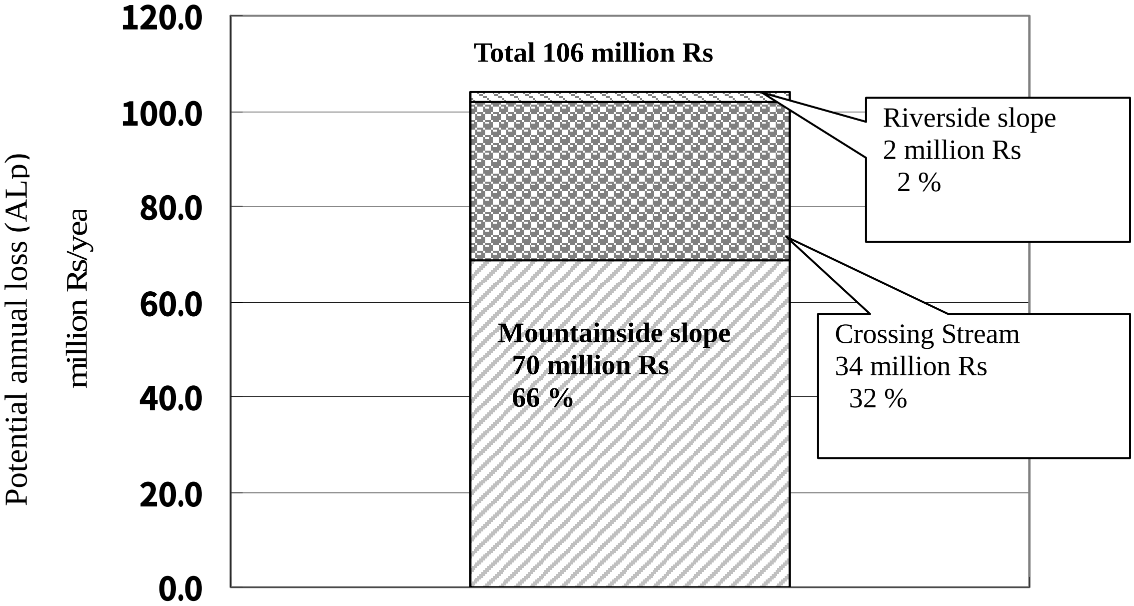


Figure 3.4.3 Potential Annual Loss (ALp) on N-M Highway by Slope Type at 2007 Value

Proportion of the ALp by loss component which is described in section 3.3.3 is shown in Figure 3.4.4. Potential annual loss caused by traffic suspension (ASLp) has big proportion with 99% of the total ALp.

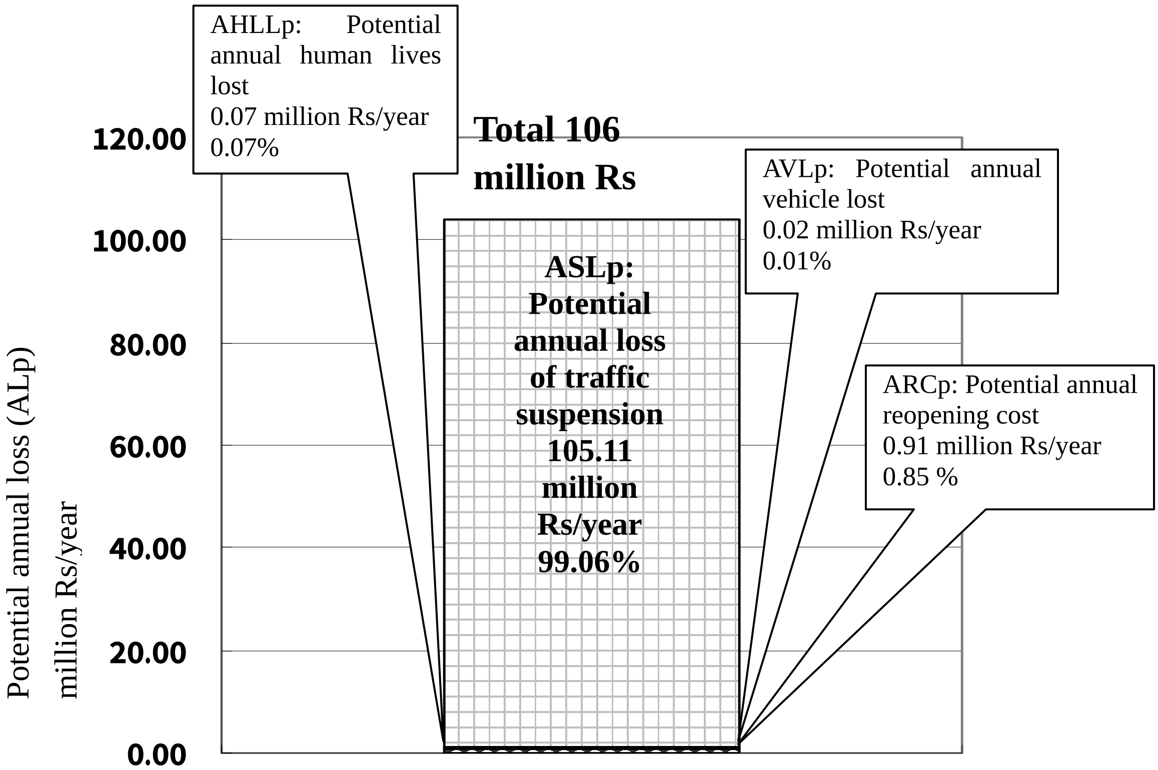


Figure 3.4.4 Potential Annual Loss (ALp) on N-M Highway by Loss Component at 2007 Value

(3) Effectiveness of Existing Structural Measures

Road slope disaster risk estimate results show both potential annual loss (ALp) in 2007 and potential annual loss without structural measure (ALpom). Relation of ALp and ALpom is as shown below, and is described in section 3.3 in detail.

ALp = CEM x ALpom;

Where

ALp: potential annual loss [Rs/year]

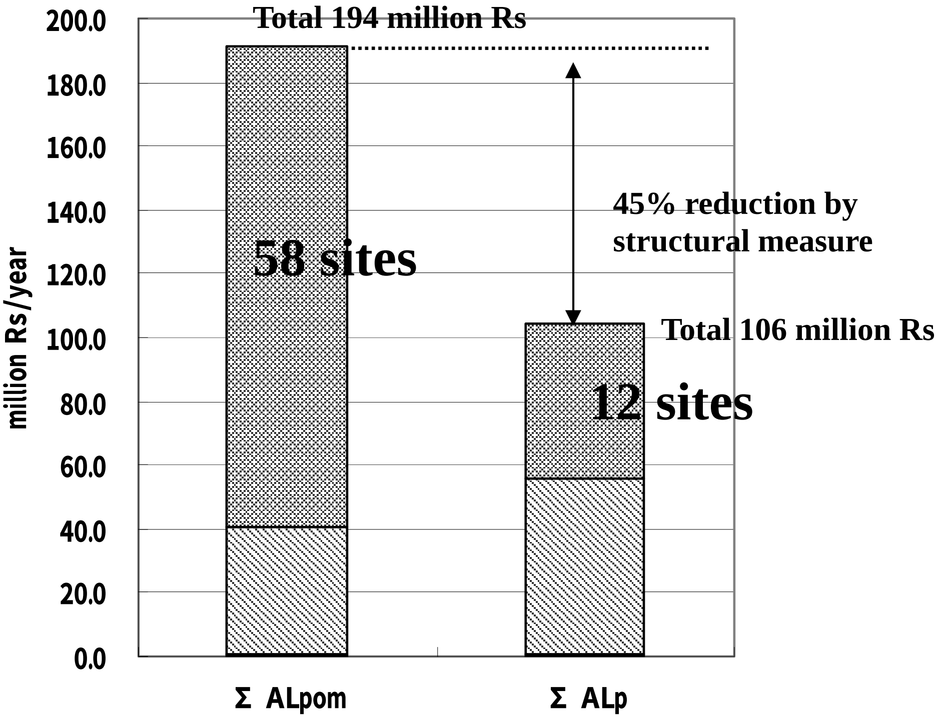
CEM: coefficient of effectiveness of structural measures

ALpom: potential annual loss without structural measure [Rs/year]

Table 3.4.1 is the summary of ALp and ALpom of the N-M highway at 2007 value, and Figure 3.4.4 is the diagram of it.

Almost all the structural measures were installed after 2003 disaster. Therefore, ALpom indicates the risk time point in 2003 by 2007 value.

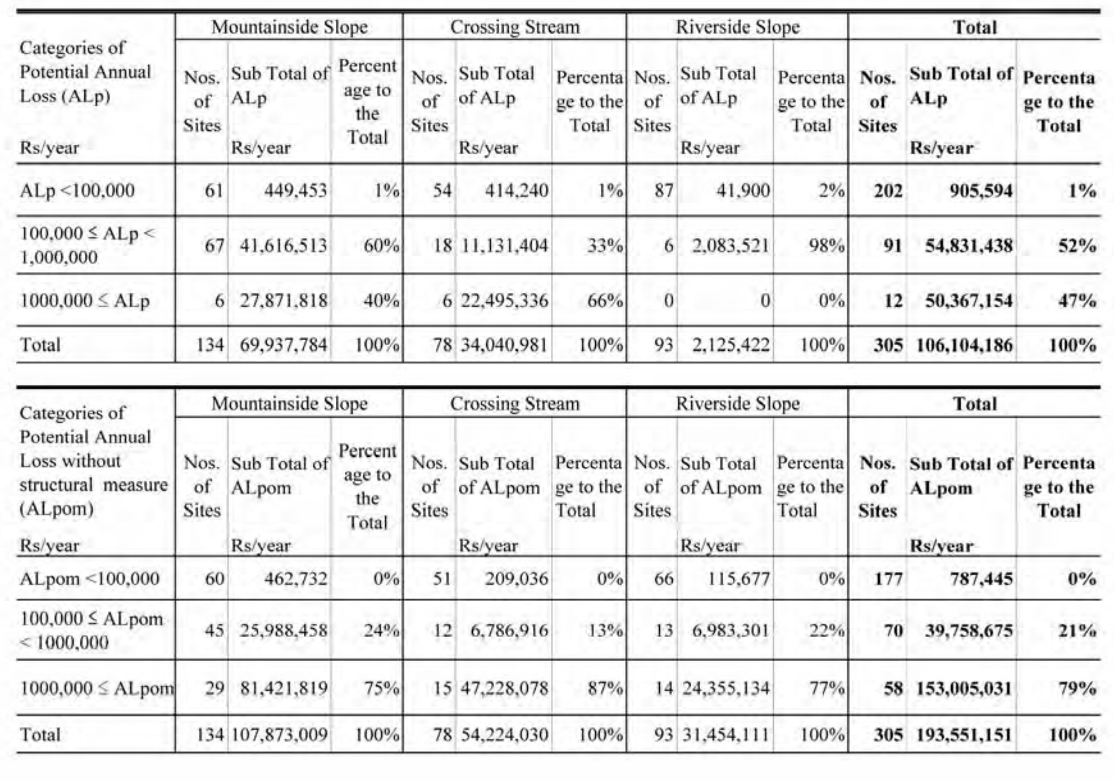
Existing structural measures have decreased 45 % potential annual loss i.e. from ALpom: 194 million Rs/year to ALp: 106 million Rs/year. They decreased high risk sites where annual loss are over 1.0 million Rs/year from 58 sites to 12 sites. Still there are 12 sites having high risk of slope disaster, they are: six (6) mountainside slopes and six (6) riverside slopes.



ALp or ALpom of a site (Rs/year)		Numbers of site	
		ALpom: Potential annual loss without structural measure	ALp: Potential annual loss
▩	Bigger than 1.0 million	58	12
▨	0.1 – 1.0 million	70	91
□	Smaller than 0.1 million	177	202

Figure 3.4.5 Risk Reduction by Existing Structural Measure

Table 3.4.1 Summary of Potential annual Loss (ALp) and ALp without Structural Measures (ALpom)



Categories of Potential Annual Loss (ALp) Rs/year	Mountainside Slope			Crossing Stream			Riverside Slope			**Total**		
	Nos. of Sites	Sub Total of ALp Rs/year	Percentage to the Total	Nos. of Sites	Sub Total of ALp Rs/year	Percentage to the Total	Nos. of Sites	Sub Total of ALp Rs/year	Percentage to the Total	**Nos. of Sites**	**Sub Total of ALp Rs/year**	**Percentage to the Total**
ALp <100,000	61	449,453	1%	54	414,240	1%	87	41,900	2%	**202**	**905,594**	**1%**
100,000 ≤ ALp < 1,000,000	67	41,616,513	60%	18	11,131,404	33%	6	2,083,521	98%	**91**	**54,831,438**	**52%**
1000,000 ≤ ALp	6	27,871,818	40%	6	22,495,336	66%	0	0	0%	**12**	**50,367,154**	**47%**
Total	134	69,937,784	100%	78	34,040,981	100%	93	2,125,422	100%	**305**	**106,104,186**	**100%**

Categories of Potential Annual Loss without structural measure (ALpom) Rs/year	Mountainside Slope			Crossing Stream			Riverside Slope			**Total**		
	Nos. of Sites	Sub Total of ALpom Rs/year	Percentage to the Total	Nos. of Sites	Sub Total of ALpom Rs/year	Percentage to the Total	Nos. of Sites	Sub Total of ALpom Rs/year	Percentage to the Total	**Nos. of Sites**	**Sub Total of ALpom Rs/year**	**Percentage to the Total**
ALpom <100,000	60	462,732	0%	51	209,036	0%	66	115,677	0%	**177**	**787,445**	**0%**
100,000 ≤ ALpom < 1000,000	45	25,988,458	24%	12	6,786,916	13%	13	6,983,301	22%	**70**	**39,758,675**	**21%**
1000,000 ≤ ALpom	29	81,421,819	75%	15	47,228,078	87%	14	24,355,134	77%	**58**	**153,005,031**	**79%**
Total	134	107,873,009	100%	78	54,224,030	100%	93	31,454,111	100%	**305**	**193,551,151**	**100%**

(4) High Risk 12 Sites

The risk level of slopes and stream are classified into three categories, using ALp ranking as indicator Table 3.4.2 shows 12 high risk sites where ALp is over 1.0 million per year. Figure 3.4.6 shows location of six (6) high risk mountainside slopes. Figure 3.4.7 shows location of six (6) high risk crossing streams. Table 3.4.2 List of 12 high risk sites where ALp is over 1.0 million.

Table 3.4.2 Twelve High Risk Sites where ALp is over 1.0 Million

Chainage of starting side	Slope-type	Disaster Type	FRCDp	ALp
			(RCD/year)	(mil. Rs/year)
11 km 280 m (Kahale Kola)	Crossing stream	Debris flow	0.25	5.8
11 km+500 m	Crossing stream	Slope failure & debris flow	0.26	2.1
12 km+600 m (Das Kola)	Crossing stream	Debris flow	0.39	7.7
21 km+200 m	Crossing stream	Slope failure & debris flow	0.34	2.7
21 km+560 m	Crossing stream	Debris flow	0.13	1.3
21 km+610 m	Mountainside slope	Slide	0.15	2.9
23 km+510 m	Mountainside slope	Slide & slope failure	0.24	3.5
23 km+930 m	Crossing stream	Debris flow	0.23	2.3
23 km+960 m	Mountainside slope	Slide	0.24	13.7
24 km+235 m	Mountainside slope	Slide & slope failure	0.19	1.5
30 km+690 m	Mountainside slope	Slope failure	0.24	1.9
34 km+200 m	Mountainside slope	Rock fall	0.55	4.3
Total of 12 sites			3.21	50.4
Percentage divided by total of all 305 sites			15%	47%
Total of all 305 sites			22.02	106.1

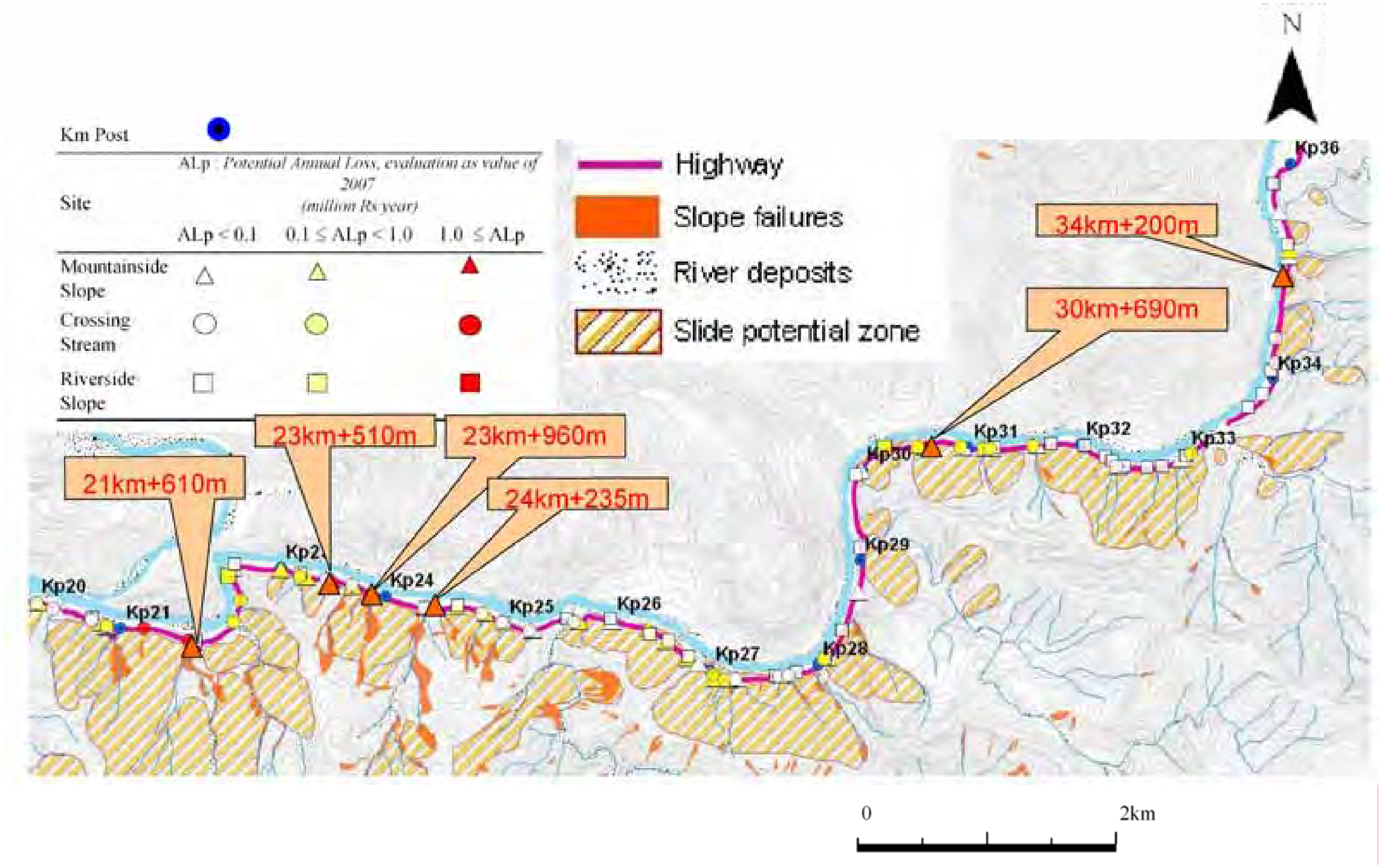


Figure 3.4.6 Location of Six (6) High Risk Mountainside Slopes where ALp is over 1.0 million

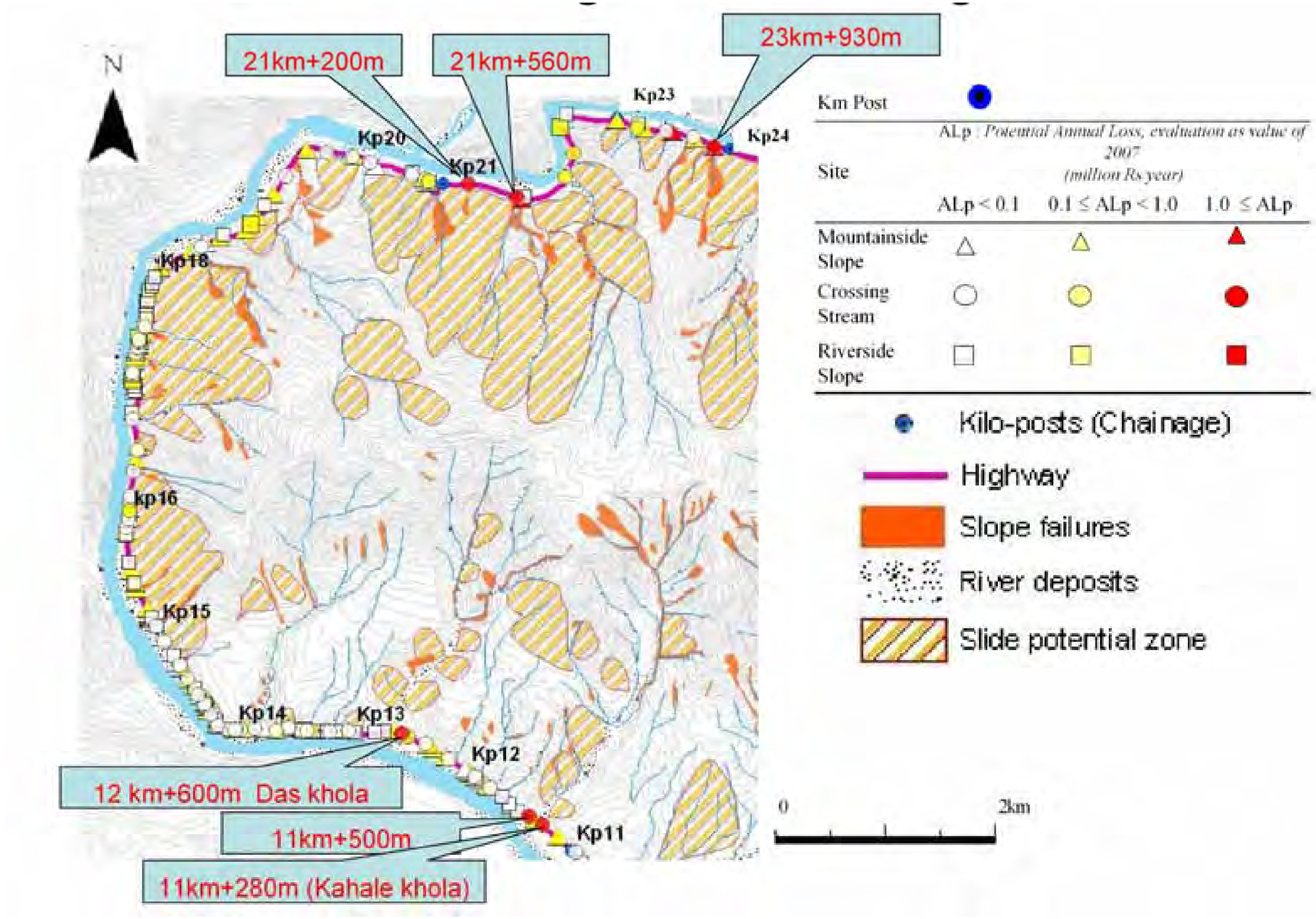
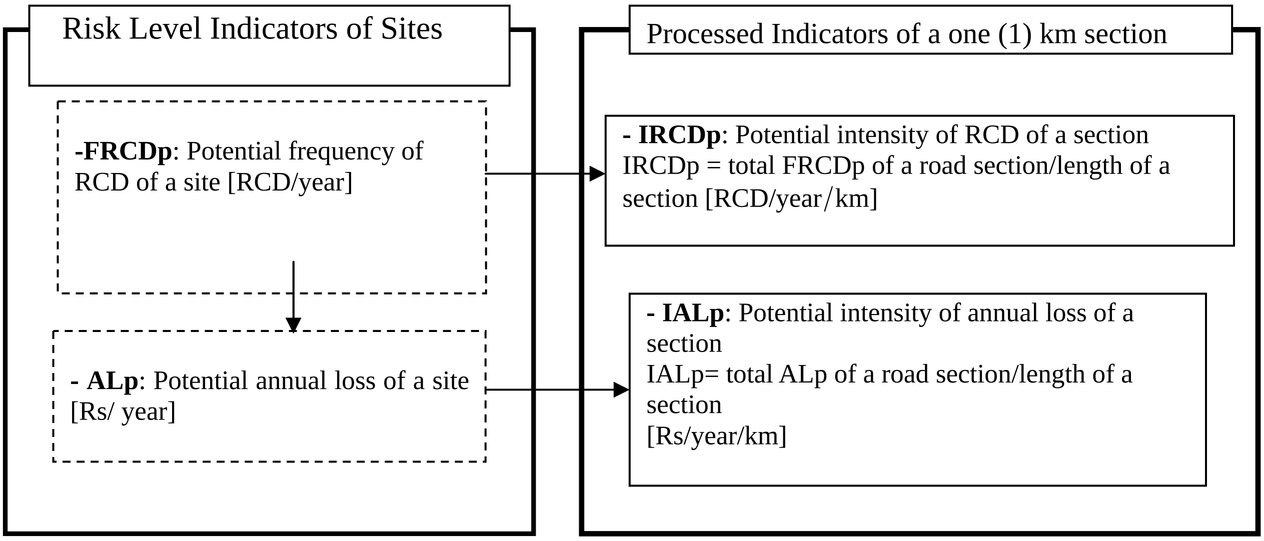


Figure 3.4.7 Location of Six (6) High Risk Crossing streams where ALp is over 1.0 million

(5) Risk Level of Road Section for Every Kilometer

(a) General

For determining high risk road sections, risk level indicators for a site was processed for every kilometer of the road section as shown in Figure 3.4.8



Risk Level Indicators of Sites

-FRCDp: Potential frequency of RCD of a site [RCD/year]

- ALp: Potential annual loss of a site [Rs/ year]

Processed Indicators of a one (1) km section

- IRCDp: Potential intensity of RCD of a section
IRCDp = total FRCDp of a road section/length of a section [RCD/year/km]

- IALp: Potential intensity of annual loss of a section
IALp= total ALp of a road section/length of a section
[Rs/year/km]

Figure 3.4.8 Processing of Risk Level Indicators of a Road Section

(b) Potential Intensity of Road Closure Disaster of a Road Section (IRCDp)

The IRCD of a road section is calculated by the following formula.

$$\text{IRCDp} = \sum \text{FRCDp/LS}$$

Where:

IRCDp: Potential intensity of RCD of a road section [RCD/ year/km]

$\sum$ FRCDp: Total FRCDp of a road section [RCD/year]

LS : Length of a road section [km]

(c) Potential Intensity of Annual Loss of a Road Section (IALp)

The IALp is calculated by the following formula.

$$\mathbf{IALp} = \sum \mathbf{IALp/LS}$$

Where:

IALp: Potential intensity of annual loss of a road section [Rs/year/km]

$\sum$ IALp: Total ALp of a road section [Rs/year]

LS : Length of a road section [km]

the risk of a one (1) km road section is assessed, based on the results of field survey.

(d) Risk Revel of One km Road Sections

Risk level indicators of road section at each kilometer are shown in Table 3.4.3, Figure 3.4.9 and 3.4.10.

High disaster frequency road sections, where IRCDp exceeds 1.0 [Nos. of RCD /year/ km] are: km 11-12, km 13-15, km 17-18, km 27-28, and km 34-35. High annual loss road sections, where IALp is higher than 10 million Rs/ km /year are: km 11-13, and km 23- 25.

Table 3.4.3 Outline of Risk along N-M Highway

km Section	IRCDp: Potential Intensity of RCD of a section	IALp: Potential Intensity of Annual Loss of a section	Top 12 ALp Sites
	RCD/km	Rs/km/year	
km 10 - km 11	0.20	636,349	
km 11 - km 12	**1.28**	**12,553,071**	2 sites
km 12 - km 13	***0.90***	**11,596,374**	1 site
km 13 - km 14	**1.28**	***5,532,572***	
km 14 - km 15	**1.26**	***3,907,911***	
km 15 - km 16	***0.73***	***2,629,073***	
km 16 - km 17	***0.93***	***2,509,015***	
km 17 - km 18	**1.76**	***6,125,221***	
km 18 - km 19	0.49	***2,560,350***	
km 19 - km 20	***0.62***	***3,139,973***	
km 20 - km 21	***0.84***	***2,878,446***	
km 21 - km 22	***0.84***	***8,443,483***	3 sites
km 22 - km 23	0.43	768,427	
km 23 - km 24	***0.94***	**11,427,335**	3 sites
km 24 - km 25	***0.93***	**14,584,536**	1 site
km 25 - km 26	***0.55***	***1,578,079***	
km 26 - km 27	***0.55***	***2,228,505***	
km 27 - km 28	**1.38**	*1,295,980*	
km 28 - km 29	***0.75***	488,570	
km 29 - km 30	***0.50***	18,536	
km 30 - km 31	***0.63***	***2,787,817***	1site
km 31 - km 32	***0.91***	***3,025,898***	
km 32 - km 33	***0.85***	304,143	
km 33 - km 34	***0.73***	28,870	
km 34 - km 35	**1.07**	***4,369,938***	1site
km 35 - km 36	***0.66***	685,373	
km 36 - km 36.1	0.09	3,417	
Average	***0.84***	***4,065,294***	

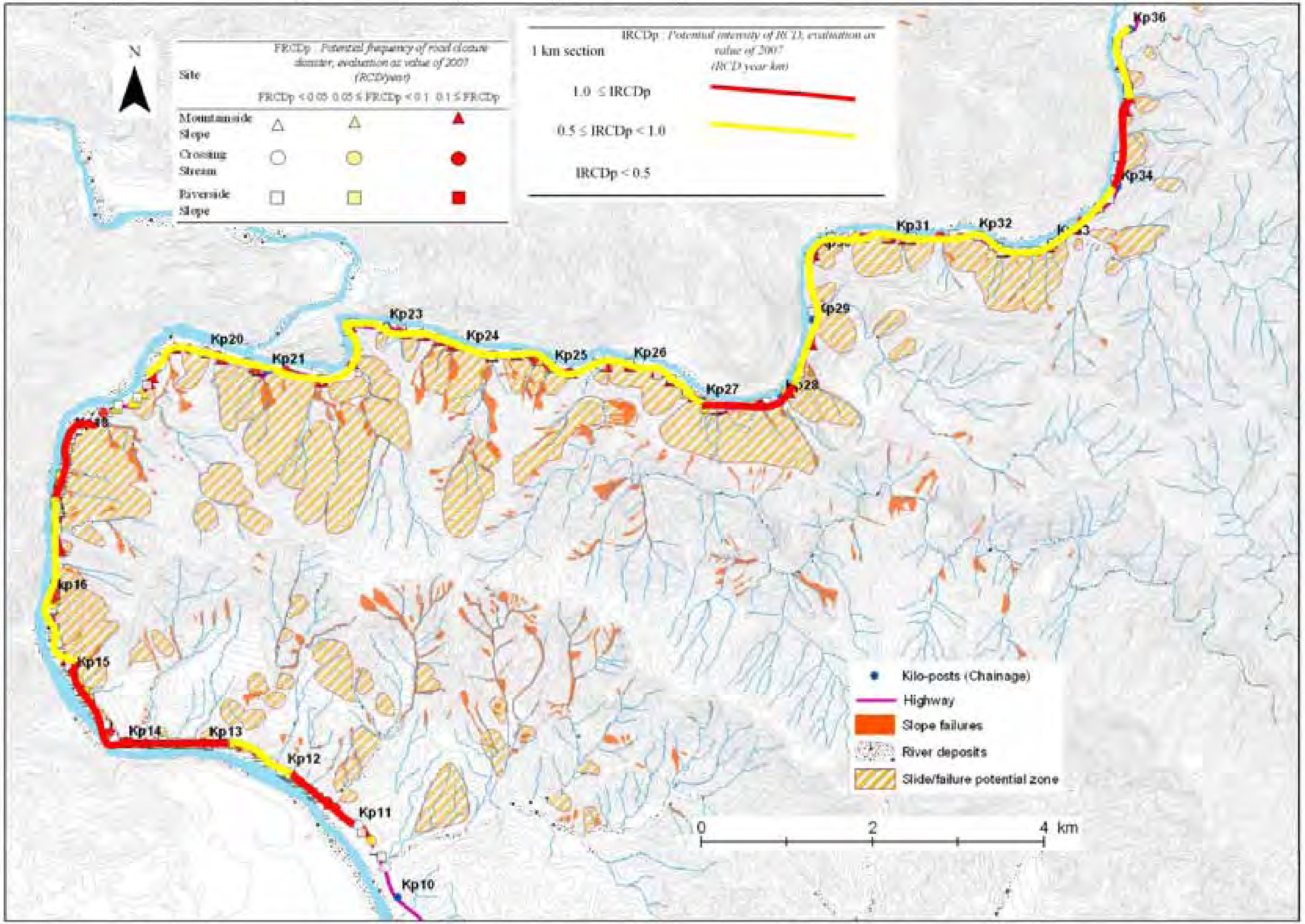


Figure 3.4.9 Intensity of RCD (IRCD)

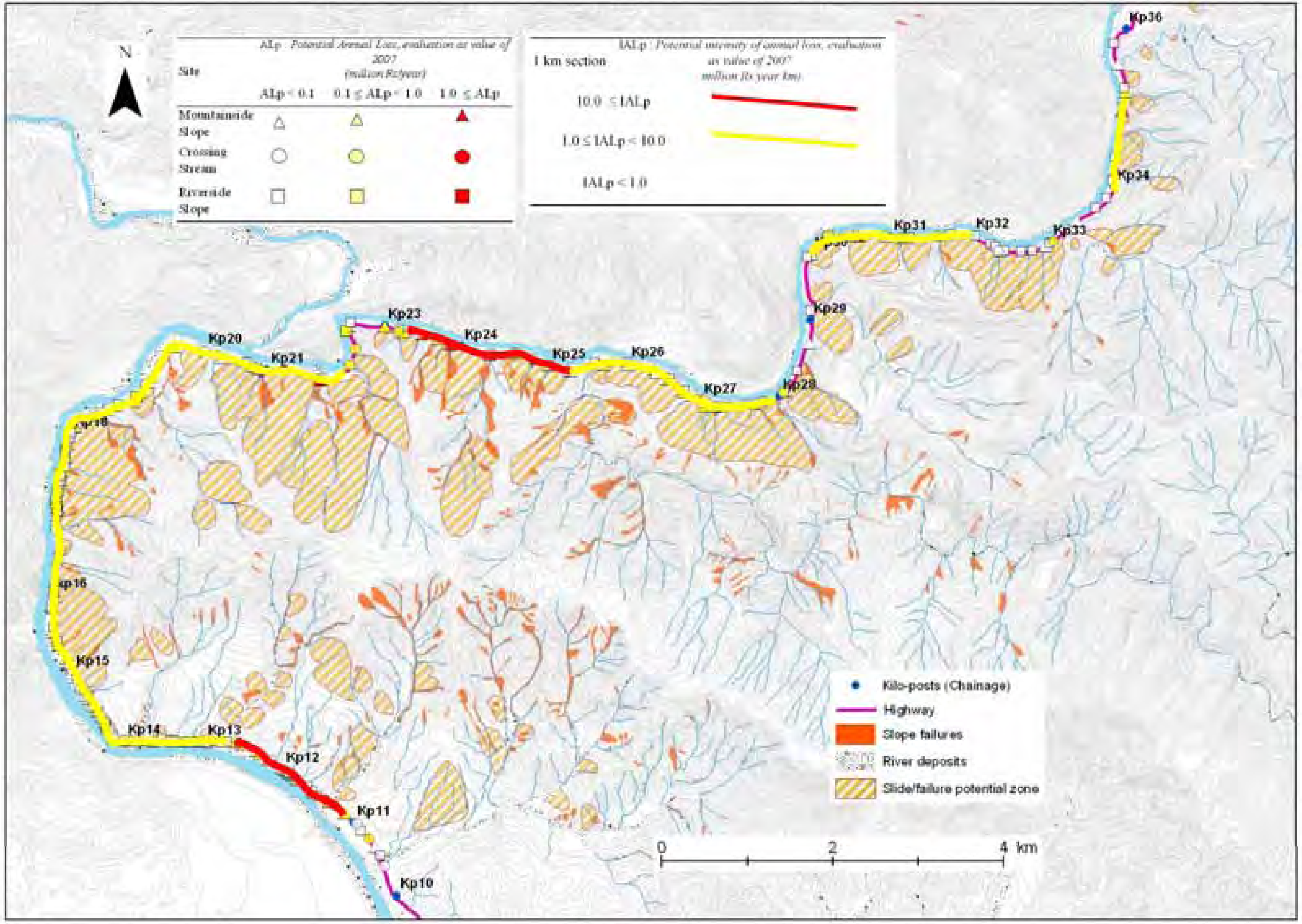


Figure 3.4.10 Intensity of Annual Loss (IALP)

3.4.2 Ruwa Khola/ Marsyangdi Hydro Power Plant

(1) Policy and Flow of Risk Assessment

Hazard with same magnitude has occurred on 31st July 2003, the only one scenario which can be utilized to estimate values of frequency and magnitude of disaster. Consequently, risk is estimated based on this scenario in this study. Flow of risk assessment is shown in Figure 3.4.11.

Risk estimation without existing structural measure

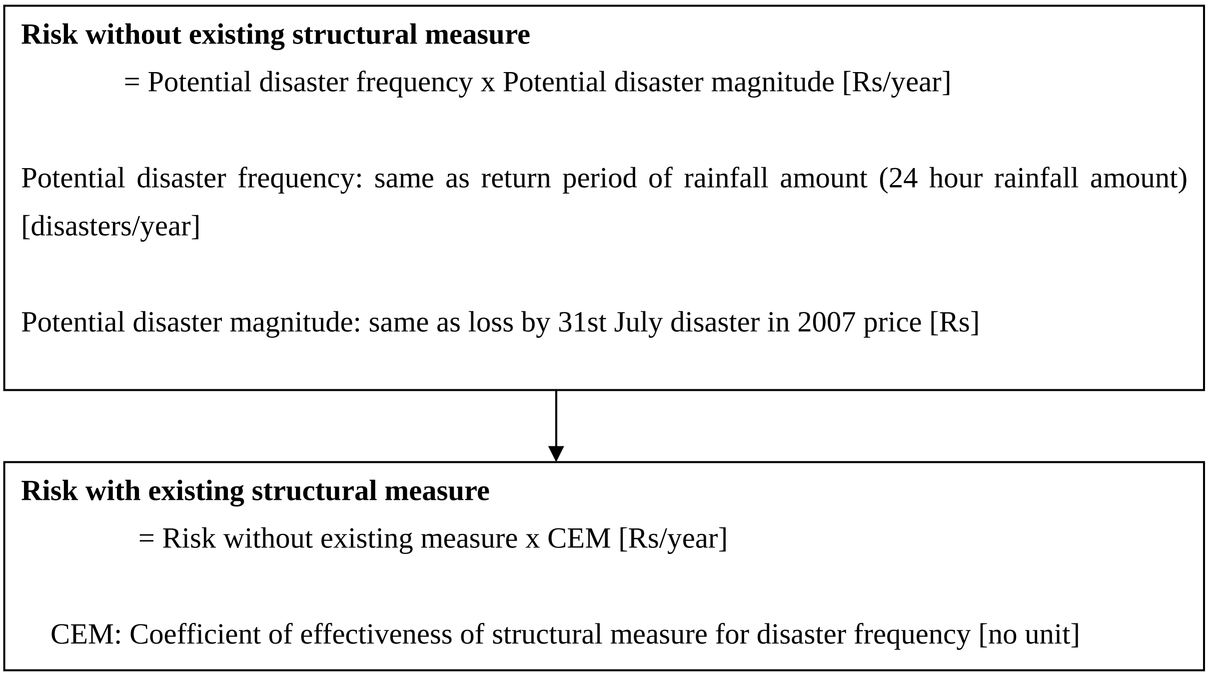
The potential frequency of the disaster is evaluated as the same value of return period of rainfall amount of the disaster on 31st July 2003.

The potential disaster magnitude/potential loss without existing structural measure is estimated as 2007 price of the same damage level in 31st July 2003 disaster, because existing structural measures are installed after 2006 disaster.

Risk is multiplication of the potential frequency and magnitude of disaster.

Risk estimation with existing structural measure

Risk with existing structural measure is evaluated by multiplication of the 'risk without existing measure' and 'coefficient of effectiveness of structural measure for disaster frequency (CEM)'.



Risk without existing structural measure

= Potential disaster frequency x Potential disaster magnitude [Rs/year]

Potential disaster frequency: same as return period of rainfall amount (24 hour rainfall amount) [disasters/year]

Potential disaster magnitude: same as loss by 31st July disaster in 2007 price [Rs]

Risk with existing structural measure

= Risk without existing measure x CEM [Rs/year]

CEM: Coefficient of effectiveness of structural measure for disaster frequency [no unit]

Figure 3.4.11 Flow of Risk Estimation for Ruwa Khola/ Marsyangdi Hydro Power Plant

(2) Disaster Frequency without Existing Structural Measure

The frequency of the disaster is evaluated as the same value of the return period which 16 years of 24 hour rainfall amount, hence, frequency is 1/16 [disasters/year] as per Devghat rainfall gauge station. If the other calculation method of rainfall amount is selected such as the “modified rainfall amount of 6, 12, 24 hour half value”, a smaller return period (refer chapter 3) will be obtained. The 24-hour rainfall amount is therefore adapted as most conservative for the return period.

(3) Disaster Magnitude without Existing Structural Measure

Magnitude of monetary loss during the disaster that occurred on 31st July 2003 is estimated based on results of questionnaire survey on Mugling – Pokhara road conducted on February 2008 (national statistical data, and data form DOR and NER).

Results of monetary loss estimation are tentatively summarized in Table 3.4.4. The monetary losses are finalized and shown in the draft final report prepared on June 2008.

Table 3.4.4 Loss by disaster on 31st July in 2007 Price (Tentative)

Items	Loss (Rs)
Reopening cost (tentative detour road)	40,000
Loss of road and power plant	58,350,000
Loss of vehicle	40,000
Loss of power plant electricity	87,700,000
Loss by traffic Suspension (waiting, detour, and cancellation)	9310,000
Total	**155,440,000**

(4) Risk without Existing Structural Measure

Risk: Potential annual loss without existing structural measure is estimated by multiplying the disaster frequency with the disaster magnitude as follows:

Potential annual loss without existing structural measure

= Potential disaster frequency x Potential disaster magnitude [Rs/year]

where;

Potential disaster frequency: same as return period of rainfall amount (24 hour rainfall amount) [disasters/year] = 1/16

Potential disaster magnitude: same as loss by 31st July disaster in 2007 price [Rs]

= 155,440,000 [Rs/disaster] x 1/16 [disasters/year]

As a result, potential annual loss without existing structural measure is estimated as 9,715 Rs/year.

(5) Risk with Existing Structural Measure

Risk causing Potential annual loss with existing structural measure is estimated by multiplying of “potential annual loss without existing structural measure’’ and “coefficient of effectiveness of structural measure for disaster frequency (CEM)” as follows:

Potential annual loss with existing structural measure
= Risk without existing measure x CEM [Rs/year]
Where;
CEM: coefficient of effectiveness of structural measure for disaster frequency [no unit]

Existing sabo dams have effectiveness of retaining the same scale debris flow of the hazard on 31st July 2003. But, in this site, the volume of debris generated due to slope failure is more than debris control volume of sabo-dams, while a part of existing flow sections is less than the flow section based on the rainfall intensity in 2003. Apart from this, the effectiveness of retaining debris in the sabo dams is reduced by the considerable volume of unstable debris deposited above these dams. Taking these things into consideration, CEM is set as “0.5”.

= 9,715,000 [Rs/year] x 0.5 = 4,875,000 [Rs/year]

Potential annual loss with existing structural measure is estimated
4,875,000 [Rs/year].