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CONSULTING ENGINEERS

IN ASSOCIATION WITH

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Rural Transport Project 2

RURAL ROAD GRAVEL ASSESSMENT PROGRAMME

MODULE 4 FINAL REPORT

DATA ANALYSIS

REF: SEACAP 4
JULY 2005

RURAL ROAD GRAVEL ASSESSMENT PROGRAMME

MODULE 4: FINAL REPORT

JULY 2005

by

Intech-TRL

In Association with

ITST (Vietnam)

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EXECUTIVE SUMMARY

DFID and World Bank are funding the Ministry of Transport (MoT) Second Rural Transport Project (RT2) in Vietnam that is providing basic access roads for communities in 40 provinces of Vietnam (2001 – 2005). Gravel has been the surface usually provided for the project roads. Because of increasing recognition that gravel surfacing is not always the best solution for rural roads in all circumstances in Vietnam, the Government of Vietnam MoT requested studies of alternative surfacings for Rural (District and Commune) Roads in Vietnam under the World Bank and DFID RT2 support. The Rural Road Surfacing Trials (RRST) were planned and are currently being implemented. Subsequently, DFID agreed to fund a scoping study by Intech-TRL within the existing Rural Road Surfacing Research Programme. This sub-study researched the viability of undertaking a national gravel surface performance study in Vietnam; developed appropriate methodologies for the work and proposed a general framework for the Rural Road Gravel Assessment Programme (RRGAP).

The RRGAP Scoping Study revealed that although gravel has been the commonly recommended surfacing in recent rural road rehabilitation programmes, there is little available data on its engineering performance and deterioration. It is evident that Vietnam experiences conditions outside of the envelope of researched knowledge with regard to factors influencing gravel surface performance, compared to most developing countries. In the light of increasing speculation as to the long term cost-effectiveness of gravel surfacing in many locations in Vietnam, this knowledge gap is one that requires urgent attention and which has been addressed by the main RRGAP research.

The main RRGAP investigations, carried out by Intech-TRL at 766 road sites, found serious constraints to the use of gravel in most of the studied 16 programme provinces due to factors relating to material quality, material availability, climate, terrain, drainage provision and maintenance. Overall gravel loss figures indicate that around **58%** of the surveyed sites are suffering unsustainable deterioration, while **28%** are losing material at twice the sustainable rate. From the RRGAP investigations, and consideration of other complementary research and knowledge of the performance of gravel roads elsewhere, the following guidelines are proposed for the restriction and use of gravel as a rural road surfacing in the range of conditions experienced in Vietnam:-

It is recommended that the use of gravel as a rural road surface in Vietnam be restricted as follows:-

1. Rainfall and longitudinal gradient:

- Rainfall < 1,000mm/year : restrict use of gravel to road gradients < 6%
- Rainfall 1,000 – 2,000mm/year : restrict use of gravel to road gradients < 4%
- Rainfall > 2,000mm/year: do not use gravel – material loss and erosion are likely to be unsustainable.

2. Materials Haulage

If the materials haulage distance from source to road site is more than 10km, a detailed infrastructure initial and maintenance cost (whole life cost) comparison of gravel and other technically feasible surface options should be carried out. Furthermore, road user costs, and socio-economic consequences that are currently more difficult to measure, such as dry weather dust emissions, local resource use relating to community benefits (employment etc.) and environmental resource consumption factors, should be included in the surface consideration and decision process.

3. Traffic

Gravel should not be used for roads with traffic expected to be higher than 200 (4 wheel) motor vehicles per day. For expected motor traffic levels of more than the equivalent of 100 motor vpd, a whole life cost evaluation of gravel and other technically feasible surface options should be carried out.

4. Flooding

Gravel should not be used on roads liable to regular or occasional flooding.

The following arrangements should be assured to allow any justifiable use of gravel to be cost affective and sustainable:-

5. Quality Control

There should be improved and adequate testing and quality control arrangements and funding in place to approve gravel material sources, and confirm availability of the necessary quantities for both construction and maintenance needs. Furthermore sufficient material testing must be arranged to ensure that the material placed on site conforms to the specifications and contract requirements, and will not deteriorate under traffic.

6. Drainage

There must be adequate provision in the construction and maintenance of the gravel surface to keep the surface crossfall within the serviceable range of 3 – 7 % to ensure drainage of the rainfall from the road surface. This can be achieved either by mechanical grading or manual reshaping. Soil surfaced shoulders should not be constructed for gravel roads as this risks contamination of the gravel road surface during grading operations, or the trapping of surface water on the road surface as the gravel surface wears down. Shoulders must freely drain away from the road surface, and effective side and turn out drainage must be provided throughout the length of gravel surfaced road, and be maintainable.

7. Maintenance

There should be adequate arrangements in place to **fund** and **organise** the ongoing routine maintenance of the road, particularly the gravel surface, and the periodic maintenance regravelling to restore the material lost due to traffic and rainfall effects.

Discussions of all of these issues are contained in this document.

Application of the RRGAP recommended guidelines will substantially reduce the future use of gravel rural road surfacing in Vietnam, in favour of increased use of other surface types.

A particular problem that should be recognised with gravel is the rapid deterioration when layer thickness falls below a “residual” amount necessary for the surface to continue to perform. There is often insufficient warning of this occurrence to allow regravelling resources to be mobilised before the gravel surface deteriorates to a condition requiring rehabilitation.

The outcomes of the complementary Rural Road Surfacing Trials (RRST) will allow detailed recommendations to be made on the selection, design and use of a range of surfaces, including gravel, and possible stage and composite (variable surface) construction strategies.

Further research, particularly on the relationship between rainfall and gravel loss, could allow these RRGAP guidelines to be refined, suitable for the range of unsealed road surface materials, terrain and climate experienced throughout Vietnam, and for detailed whole life costing relationships to be developed. The database assembled under RRGAP will allow further investigation of factors affecting gravel road performance that were not possible due to the limited resources available for analysis under this SEACAP 4 study.

A programme of national discussion and dissemination of the results of the RRGAP is required to ensure improved and sustainable sector use of unsealed roads in the range of conditions experienced in Vietnam. The results of the RRGAP will also be of interest to other countries and regions with high rainfall, long gravel hauls or maintenance constraints.

Abbreviations and Glossary

ACCESS	Microsoft database software
ADT	Average Daily Traffic
CBR	California Bearing Ratio
cm	centimetre
CPC	Commune Peoples Council
Cong Nong	Light locally made Truck
CS	Crushed Stone
CSIR	Council for Scientific and Industrial Research
DBST	Double Bituminous Surface Treatment
DCP	Dynamic Cone Penetrometer
DFID	Department For International Development
EDCs	Economically emerging and Developing Countries
esa	equivalent standard axles
EXCEL	Microsoft spreadsheet software
GPS	Geographic Positioning System
ILO	International Labour Office
IRI	International Roughness Index
ITST	Institute for Transportation Science and Technology
KaR	Knowledge and Research
kg	kilogram
km	kilometre
kN	kiloNewton
LCS	Low Cost Surfacing
MERLIN	**M**achine for **E**valuating **R**oughness using **L**ow-cost **In**strumentation
MoT	Ministry of Transport
mm	millimetre
m	metre
N/mm^2	Newton/millimetre squared
N/m^2	Newton/metre squared
PDoT	Provincial Department of Transport
PPMU	Provincial Project Management Unit
OM	Operations Manual
PCS	Post Construction Survey
PIARC	World Road Association
PID	Planning and Investment Department
RRGAP	Rural Road Gravel Assessment Programme
RRST	Rural Road Surfacing Trials
RT1/2/3	Rural Transport Project 1, 2 and 3
RTU	Rural Transport Unit
SBST	Single Bituminous Surface Treatment
SEACAP	South East Asia Community Access Programme
SN	Structural Number
TDSI	Transport Development and Strategy Institute
TEDI	Transport Engineering Design Incorporation

ToR	Terms of Reference
TRL Ltd	Transport Research Laboratory Limited
UKDCP	Dynamic Cone Penetrometer analysis software
VOC	Vehicle Operating Cost
VPD	Vehicles Per Day

RURAL ROAD GRAVEL ASSESSMENT PROGRAMME (RRGAP)

SEACAP 4 – Module 4 – Data Analysis – Final Report

1 INTRODUCTION

1.1 Research Programme Background

DFID and World Bank are funding the Ministry of Transport (MoT) Second Rural Transport Project (RT2) in Vietnam that is providing basic access roads for communities in 40 provinces of Vietnam (2001 – 2005). Gravel has been the surface usually provided for the project roads. Because of increasing recognition that gravel surfacing is not always the best solution for rural roads in all circumstances in Vietnam, the Government of Vietnam MoT requested studies of alternative surfacings for Rural (District and Commune) Roads in Vietnam under the support for RT2 by World Bank and DFID. The Rural Road Surfacing Trials (RRST) were planned and are currently being implemented.

During the inception phase of these studies, which included the planning, construction and monitoring of trial road sections in four provinces, it became apparent that already constructed RT1 and RT2 roads could provide a database of information on the actual real-time performance of gravel surfacings in a range of Vietnam road environments. This information would be extremely useful in developing guidelines to allow the use of gravel surfacing in Vietnam where it is economical, sustainable and environmentally appropriate. Such guidelines, in conjunction with information resulting from the Rural Road Surfacing Trials programme, would considerably enhance the ability of rural road practitioners to make informed and cost-effective decisions on surface options for future road programmes, such as the upcoming Third Rural Transport Project (RT3).

Consequently, DFID agreed to fund a scoping study to be undertaken by Intech-TRL within the existing Rural Road Surfacing Research Programme. This sub-study researched the viability of undertaking a national gravel surface performance study in Vietnam; developed appropriate methodologies for the work and proposed a general framework for the Rural Road Gravel Assessment Programme (RRGAP).

1.2 Report Objectives

The objectives of this document are to present, summarise and discuss the findings of the RRGAP Module 4 (Data Analysis). In particular this document

1. Outlines the scope of work completed,
2. Describes the analytical procedures,
3. Presents key relevant data correlation,
4. Discusses the results of the data analysis in the context of selecting and constructing gravel or unsealed roads in Vietnam,
5. Makes relevant recommendations on rural road design selection, construction and management,

6. Makes relevant recommendations on further research.

1.3 Terminology

The word gravel is used within this report to denote any naturally occurring granular material, including laterite gravel as well as granular processed materials such as graded crushed rock aggregate that has been used, or is likely to be used, as a road surfacing material.

2 PREVIOUS WORK

2.1 Scoping Study

The RRGAP Scoping Study revealed that although gravel has been the commonly recommended surfacing in recent rural road rehabilitation programmes, there is little available data on its engineering performance and deterioration. It is evident that Vietnam experiences conditions outside of the envelope of researched knowledge with regard to factors influencing gravel surface performance, compared to most developing countries. In the light of increasing speculation as to the long term cost-effectiveness of gravel surfacing in many locations in Vietnam this knowledge gap is one that requires urgent attention. This is particularly important in view of the large investments planned for the national rural road network and their direct influence on rural development. Guidance is also required on the strategy for the management of the existing gravel road networks.

The RRGAP Scoping Study investigated methodologies for unsealed road condition assessment and identified key issues that need to be accommodated within the main RRGAP programme. Based on these, a modular methodology was proposed for the collection and analysis of rural road gravel surfaces in Vietnam.

Key aspects of this methodology were:

- Guidelines on all survey activities,
- User-friendly road condition data collection pro-formas,
- Its suitability for road condition "snap-shot" surveys,
- Use of standard database software for data storage and manipulation,
- Co-ordination with a proposed RT2 Post Construction Survey (PCS).

Key recommendations arising from the RRGAP scoping study were that:

- Surveys should be integrated with RT2 PCS. The PCS was seen as likely to supply general condition and location data while the RRGAP will supply detailed condition information applicable to a deterioration model.

- The total of surveyed roads should be scientifically valid - the recommendation was for surveys based on a target of 15%-20% of unsealed RT1 and RT2 roads as an initial survey.

- The time scale for survey should be based on a possible target rate of 2 roads per day/team (10 per week) including CPC/PDoT interviews.

- The RRGAP main data gathering activity should be undertaken during the approaching dry season (the scoping study was drafted in November-December 2003).

- The RRGAP should contain both a training phase and robust quality assurance element within it.

- There needed to be a co-ordinated road selection process to identify a representative sample of gravel surfaced road for survey.

It was also recommended that consideration should also be given to:-

- Possible arrangements for CPCs to carry out one day traffic counts on each surveyed road.

- Refinement of existing Vietnam Rural Road vehicle operating cost (VOC) knowledge through complementary investigations.

- Selection of sites from within the RRGAP that would be suitable for long term monitoring in terms of road deterioration, traffic and other road environment impacts. This longer term monitoring, in conjunction with up-dated VOCs, would input to the development of an unsealed road deterioration model for Vietnam.

The Scoping Study was delivered in December 2003 and approved by the RRST Steering Committee on 9th January 2004. The Scoping study forms a general framework for the Rural Road Gravel Assessment Programme (RRGAP).

2.2 Module 1: Project Inception

The Inception phase of the RRGAP was reported in the Inception Document finalised on 23rd August 2004. This document presented the proposed project programme and details of the procedures to be adopted and the relevant contractual arrangements.

2.3 Module 2 : Training

The Module 2, Training Document, was presented for comment on 23rd October 2004. Key aspects of this document were as follows:

- Details of the RRGAP training schedule,
- Hard copy of the training materials,
- Details of the on-site training programme,
- A report on the initial set-up of quality assurance cross-checks,
- An agreed programme for data collection.

2.4 Module 3 : Data Collection

The Module 3 report was presented as a draft working document for comment on 1st February 2005 and summarised the work completed during the data collection phase of the RRGAP. This work included the condition survey of 269 rural road lengths containing 766 profile locations in 16 provinces throughout Vietnam. A large programme of geotechnical index testing was associated with the fieldwork.

The data management procedures associated with collating this large amount of data were outlined and hard copy of the relevant data sets was included within the appendices of the Module 3 document.

3 MODULE 4: SCOPE OF WORK

Figure 3.1 RRGAP Province Locations

3.1 General

Figure 3.1 shows the location of the 16 provinces included in the RRGAP investigations.

Work completed under Module 4 of the RRGAP comprised the following key activities:

1. Data management

2. Key parameter selection

3. Analysis of selected parameters

3.2 Data Management

Data management activities in Module 4 of the RRGAP comprised the following:

Data verification. Data sets were reviewed and cross-checked to eliminate engineering anomalies and obvious mismatches, with particular attention being made to the compatibility of fields linking the ACESS data files.

Query Design. ACCESS query forms where designed as working tools for filtering and searching of the data between linked files.

Report Form Design. ACCESS report forms were designed to output data either to EXCEL files or directly as hardcopy for dissemination purposes.

The structure of other information data sets held in EXCEL files was also reviewed and, where practicable, these were made compatible with those in the main ACCESS database. Verified data was collated and appropriate tables and graphs compiled for interpretation.

Working versions of the RRGAP database will be held on the RT2 website currently being developed for incorporation into the MoT website under the SEACAP 1 project. The data on this website will be available for update, reference and additional interpretation by Vietnam rural road practitioners.

3.3 Key Parameter Selection

The assembled RRGAP database contains a wide range of diverse data sets. Following a review of these data sets is was appreciated that not all of the sets were immediately applicable to the current aims of Module 4 or were capable of providing clear correlations without significant additional data analysis. It was necessary therefore to select key sets suitable for analysis; with the primary objective of defining patterns of road condition and identifying issues influencing that pattern. Criteria for selecting the key parameters were:

1. Adequate data representability,

2. Adequate data verification,

3. Engineering relevance,

4. Suitability for correlation with other data sets.

Data sets not used directly in the current analysis remain available within the RRGAP database for future re-assessment.

The performance of unsealed roads is governed by the behaviour of the surfacing material and road bed in response to the combined actions of the road environment factors, Table 3.1. It follows that an examination of these impacting factors formed a crucial element of the data analysis. Unsealed roads may be considered to deteriorate in three main ways:

- Wear and abrasion of surface material under traffic,
- Erosion of surface by surface water, rain and wind,
- Deformation of the surface and road bed under stresses induced by traffic loading and moisture condition.

Assessment of material loss is a primary issue in deterioration assessment together with other road condition factors, such as potholing, rutting and erosion. In the RRGAP analysis, road condition and deterioration were related to selected road environment factors in order to identify patterns of road surface performance.

Factor		**Description**
Factors assessed in the RRGAP survey	Construction Materials	The nature, engineering character and location of construction materials are fundamental to road performance.
	Climate	The prevailing climate will influence the supply (precipitation, water table), evaporation (temperature ranges and extremes) and movement (temperature gradients) of water. Climate impacts upon the road in terms of direct erosion through run-off, influence on the groundwater regime (hydrology), the moisture regime within the pavement, and accessibility for maintenance.
	Hydrology	It is often the interaction of water, or more specifically its movement, within or on to the road structure that has a major impact on the road performance.
	Terrain	The terrain, whether flat, rolling or mountainous reflects its geology and geomorphology. Apart from its obvious influence on the long section geometry (grade) of the road, the characteristics of the terrain will also reflect and influence the occurrence and type of soil present, type of vegetation, availability of materials and resources (location, type, suitability, variability).
	Sub-Grade Conditions	The sub-grade is essentially the foundation layer for the pavement and as such its condition has a major impact on road performance.
	Traffic	Findings from recent research indicate that the influence of traffic is often less than that from other road environment parameters in low volume roads. However, even for these roads due consideration still needs to be given to the influence of traffic on the performance of the structure.
	Maintenance Regime	All roads, however designed and constructed, will require regular maintenance to ensure that the design life is reached. Indeed good maintenance can often extend the period that the road can function, well beyond the design life. Achieving this will depend on the maintenance strategies adopted, the timeliness of the interventions, the local capacity and available funding and resources to carry out the necessary works.
Factors not assessed in the RRGAP survey	Construction Regime	The construction regime governs whether or not the road design is applied in an appropriate manner. Key elements include: • Appropriate equipment use, • Selection and placement of materials, • Quality assurance, • Compliance with specification, • Technical supervision.
	Axle Loads	The deterioration of paved roads caused by traffic results from both the magnitude of the individual wheel loads and the number of times these loads are applied. For pavement design purposes it is necessary to consider not only the total number of vehicles that will use the road but also the wheel loads (or, for convenience, the axle loads) of these vehicles. For gravel roads the relationship between axle loading and deterioration rates is not well researched. RRGAP data indicate that vehicular traffic on most District and Commune roads is anyway principally light axle loading (Figure 3.8)

Table 3.1 Road Environment Factors

3.4 Selected Road Environment Parameters

Climate: Available **annual rainfall** figures for the selected provinces are summarised in Table 3.2 and the general regional variation is indicated in Figures 3.1 and 3.2. This data was obtained from independent official sources and not directly from the RRGAP survey.

Table 3.2 Annual Rainfall Figures (mm) for RRGAP Provinces

	PROVINCE	1998	1999	2000	2001	2002
North	Dien Bien			2004	2208	3132
North	Vinh Phuc- Low	821	1192	1296	1356	1398
North	Vinh Phuc-Hill	1565	1870	2057	2143	1914
North	Lao Cai	2414	1518	2382		
North	Quang Ninh		2011		3065	2296
North	Hung Yen		1475	1286	2037	1176
North	Tuyen Quang			2265	2007	1697
Central	Binh Thuan	2751	2569	2556	2562	2903
Central	Ninh Thuan			1130	856	583
Central	Quang Nam Coast	3803	4381	3700	2862	2464
Central	Quang Nam - Hill	4603	5203	5781	3578	3289
Central	Dong Nai			2554	2094	1984
Delta	Lam Dong	1988	2159	2356	1412	1803
Delta	Can Tho	1952	1895	1911		
Delta	Tien Giang	1371	1894	1640	1538	759
Delta	Vinh Long	1237				
Delta	Ca Mau	2585	3459	2629	2396	

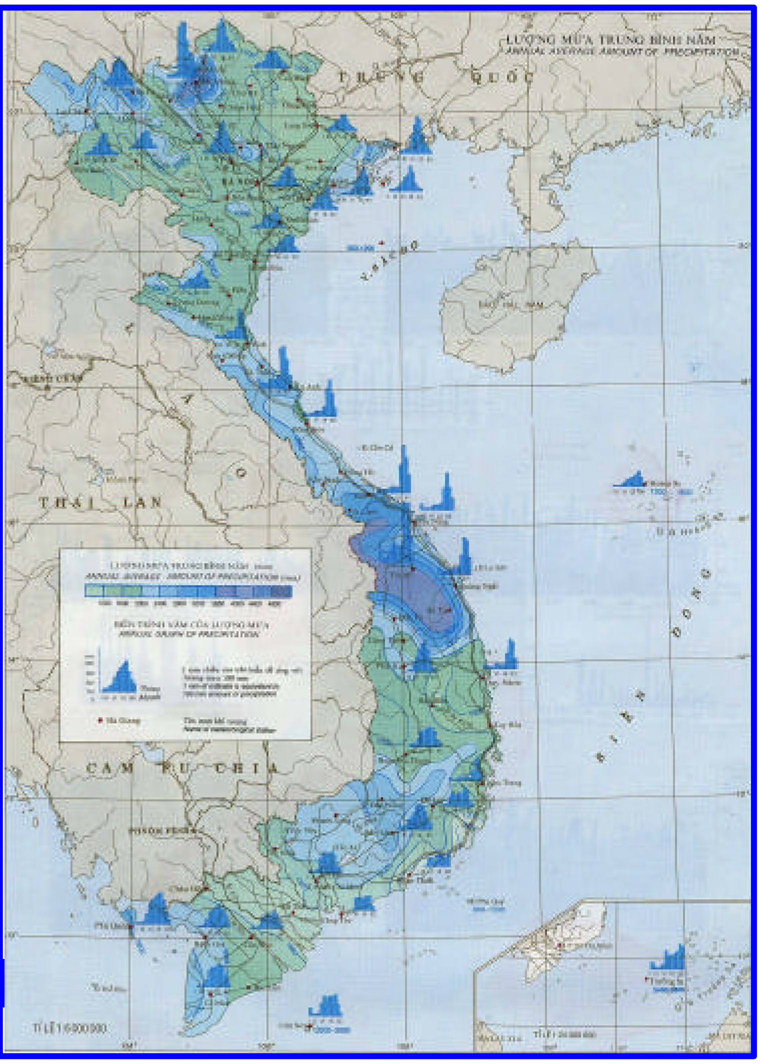


Figure 3.1 Vietnam Annual Rainfall distribution

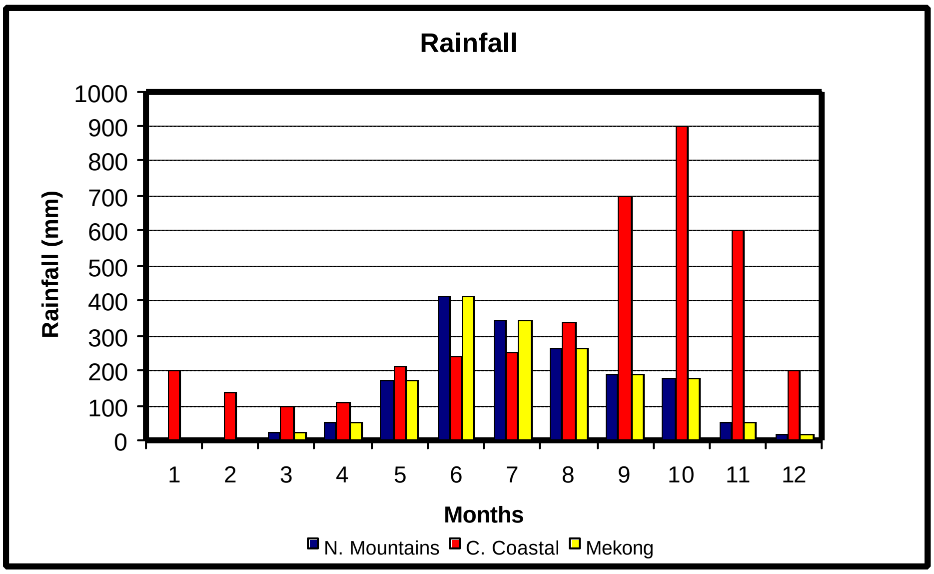


Figure 3.2 Regional Rainfall Variation in Vietnam

Terrain; The field survey teams collected information on the general topographic setting of each road segment under general terrain groups. The overall spread of data is shown in Figure 3.3, whilst the range of terrain types in each province is listed in Table 3.3.

Road gradient was identified as a key influencing factor related to terrain and to road performance, Figure 3.4.

Terrain Groups

1: Delta/Coast

2: Flat/low lying inland

3: Rolling hills

4: Moderate to high hills

5: Inter-montain or high plain

6: Mountainous

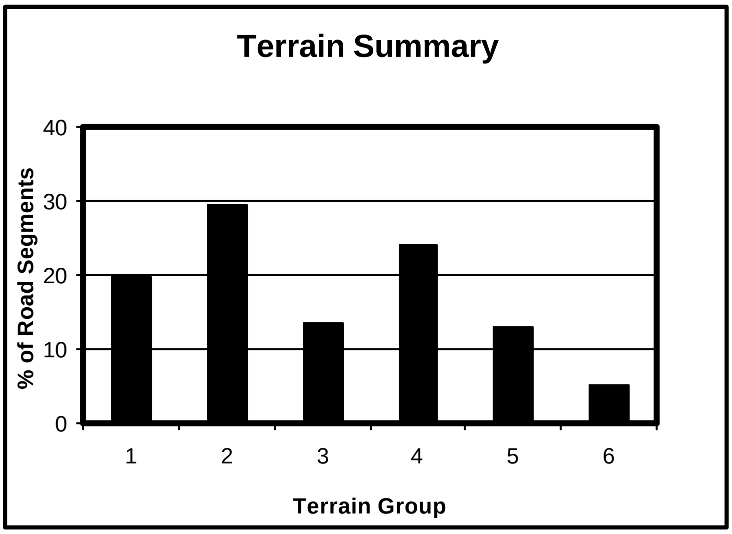


Figure 3.3 RRGAP Terrain Summary

Terrain Groups

1: Delta/Coast

2: Flat/low lying inland

3: Rolling hills

4: Moderate to high hills

5: Inter-montain or high plain

6: Mountainous

	Terrain					
Provinc	**No. of Sites: Terrain Code**					
	1	**2**	**3**	**4**	**5**	**6**
Binh		13	10			
Ca Mau	6					
Can Tho	13					
Dien				10		2
Dong		6		2	10	
Ha Tinh	4	12		2	7	
Hung		20				
Lam				10	1	
Lao Cai				12	3	6
Ninh		8	11		1	
Quang	9	1	11			
Quang			3	11	1	5
Tien	8					
Tuyen		2		19		
Vinh	11					
Vinh Phuc		14		6		
TOTALS	51	76	35	72	23	13

Table 3.3 Terrain Types within the RRGAP Provinces

Gradient Groups

1: Level

2: >0-2%

3: >2-4%

4: >4-6%

5: >6%

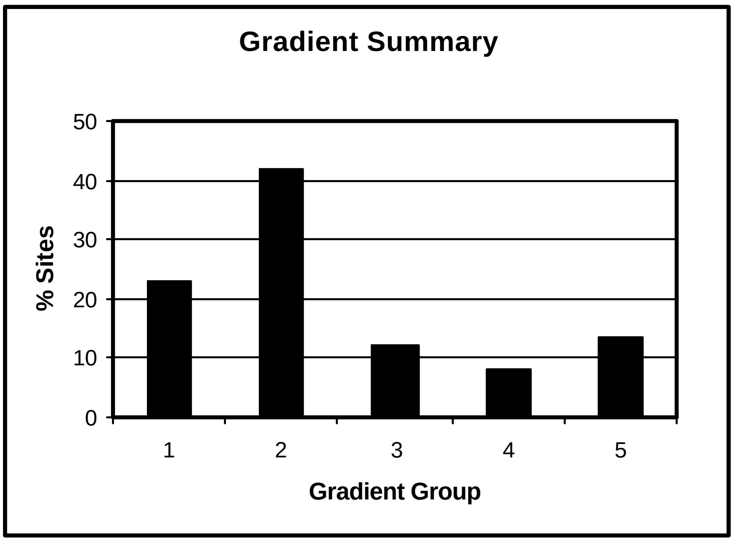


Figure 3.4 RRGAP Road Gradient Summary

Materials: Considerable variation was found in the types of material and combinations of materials utilised to construct the unsealed roads. The original ten-group classification used to collect the data has been modified to suit these variations. The classification employed in the RRGAP analysis is listed below.

1: Lateritic gravel
1R Lateritic material mixed with quarried rock, weathered rock or alluvial stone
2: Hill gravel (Colluvial gravel)
2R Hill gravel mixed with quarried rock, weathered rock or alluvial stone
3 Graded crushed stone
4 Non graded crushed stone (similar to dry or water bound macadam)
5 Alluvial gravel
6 Mechanically or hand mixed clay and gravel.
7 Weathered rock
8 Hand packed stone
10 Undefined

In the above definitions the term "gravel" is expanded to include material described as a graded mixture of clay to gravel and, possibly, small cobble sized materials.

The relative overall occurrence of these materials is shown on Figure 3.5, which indicates the seven principal material groups on which the analysis was concentrated.

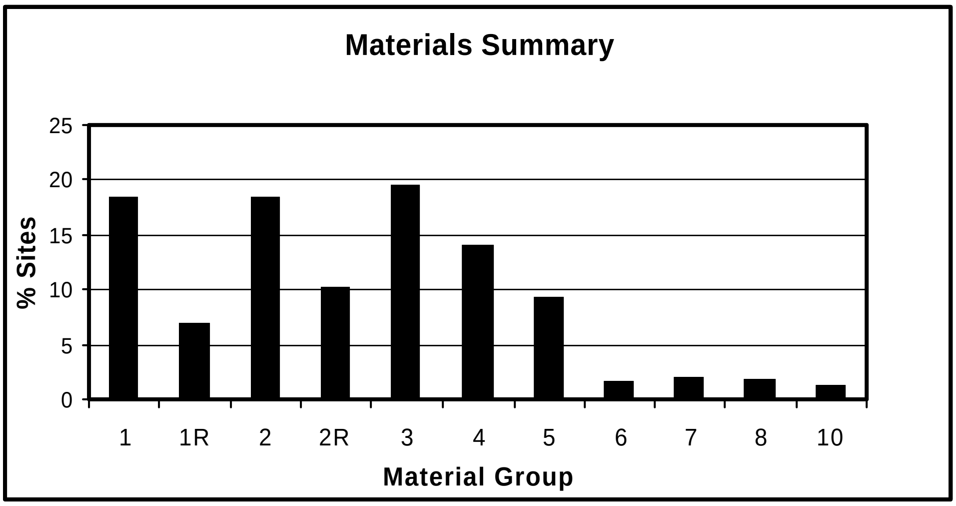


Figure 3.5 Relative Occurrence of Surfacing Materials

Surface and Sub-Surface Hydrology: Flooding of unsealed road surfaces was identified as a potential deterioration factor and Figure 3.6 summarises the range of data recovered. Associated with this is the ability of a road to shed surface water, summarised in Figure 3.7. Tabulated information on ground-water levels, flood conditions and road surface water run-off is included as part of the Module 3 Factual Report.

Construction Regime. No verifiable factual information could be recovered on some key construction factors likely to influence road performance, such as compaction and as-constructed material layer thickness, strength and shape. However, technical compliance with construction **material specifications** could be assessed by comparing these with the RRGAP test results, as listed within the Appendices of the RRGAP Module 3 report. Compliance with road **drainage** requirements could be gauged by assessing data recovered on the existence of side drains, Table 3.4.

Flood Occurrence

1: No flood

2: Occasional flood

3: Yearly minor flooding

4: Yearly major flooding

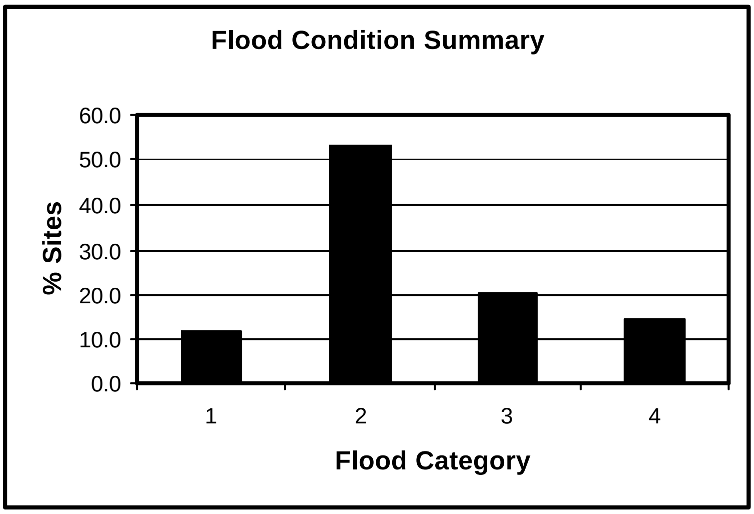


Figure 3.6 RRGAP Survey Site Flood Conditions

Surface Drainage

1: Unimpeded

2: Impeded by road shape

3: Impeded by shoulders

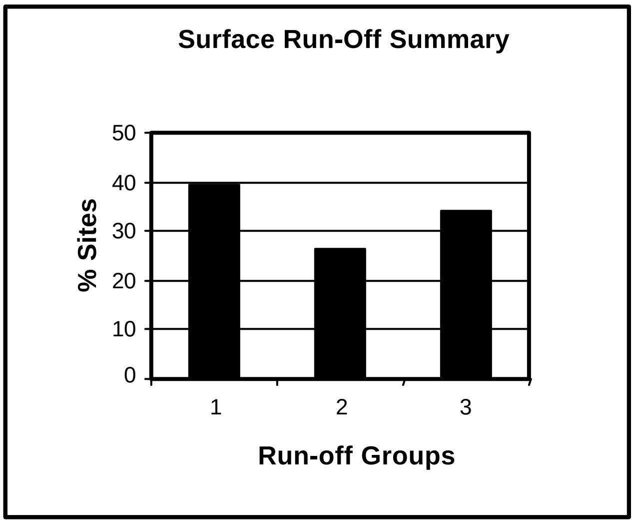


Figure 3.7 Road Surface Run-off Summary

Criteria	No of Sites	% Sites
Side drains not required	619	40
Side drains existing	486	31
No side drains existing at required sites	447	29
% Drains existing where required		**52**

Table 3.4 Existing Side Drainage

Maintenance is a crucial issue in the sustainability of gravel roads due to the high maintenance liability of this type of surface. Potentially valuable information on the actual application of maintenance regimes on the RRGAP roads was obtained from local people. Table 3.5 summarises this information.

Description	Carriageway	Shoulder	Side Ditch: Road Segments	Total Road Segments
Routine maintenance on road segments > 6 months old	46 Road segments (19%)	55 Road segments (23%)	46 Road segments (19%)	238
Periodic maintenance on road segments >18 months old	18 Road segments (11%)	4 Road segments (2%)	7 Road segments (4%)	171

Table 3.5 Summary of Maintenance Programmes on RRGAP Roads

Sub-Grade. The strength of the road sub-grade is acknowledged as influencing road performance and to assess this aspect, the insitu DCP profiles can be used to evaluate relative condition. The evaluation of the DCP profiles has involved a lengthy process of calculation and interpretation, however, before this data can be fully utilised in performance determination further cross-evaluation with road cross-section, groundwater level material type data would be required. A large number of files on individual DCP tests for each road profile site are held within the RRGAP database.

Traffic; A subjective and preliminary assessment of traffic on each road length was obtained by a combination of observation and discussion with PDoTs and local people. Figure 3.8 presents a general summary of this data.

Traffic Assessment

1: 2-wheel traffic only

2: 2-wheel traffic + local light truck

3: Local + minor commercial traffic

4: “3” with heavy trucks

5: Steady commercial traffic

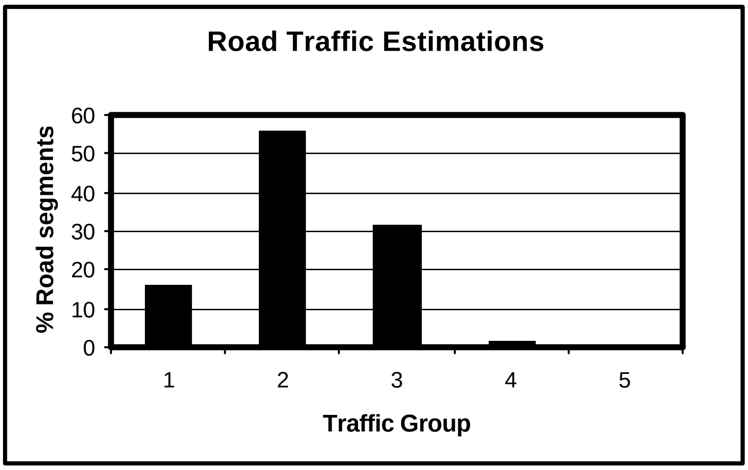


Figure 3.8 Estimated Traffic Summary

3.5 Road Condition Parameters

Particular modes of distress resulting from this deterioration have been selected from the RRGAP database as being significant indicators of performance. These are discussed below.

Material Loss: This was considered to be the principal issue in the RRGAP survey, partly due to the substantial impact on periodic maintenance needs and costs. In most road performance studies or monitoring programmes material loss is assessed by measuring decrease in thickness over periods of time. This allows for an exact measurement of loss. The RRGAP was designed as a one-off condition survey; hence although material thickness was measured it had to be related to design thickness to gain an estimate of loss rather than by exact measurement. This procedure is perfectly adequate to give relative trends in loss but results need to be interpreted bearing in mind the following:

1. As-constructed thicknesses may differ from design thicknesses,
2. Variations in placed thickness due to irregularities in the underlying surface,
3. Difficulty in identification of base of gravel if laid over an existing gravel road.

The use of DCP profiles aided in the interpretation of depth measurements, particularly with regard to (3) above. The figures used in material loss have been adjusted in the light of DCP interpretation, photographic evidence and other relevant criteria such as rut depth and visual appearance. In addition any anomalously high or low figures have been omitted from the detailed evaluations.

A benefit of the RRGAP approach is that it does not involve the monitoring of a specifically staged construction trial, and provides an assessment of outcomes of works constructed under the normal contract operational environment.

Material loss has been calculated for the purposes of this project in millimetres of material lost per year (12 months) and is plotted in terms of loss per site for the whole project in Figure 3.9 and for each province in Figures A1 to Figure A16 in Appendix A of this document

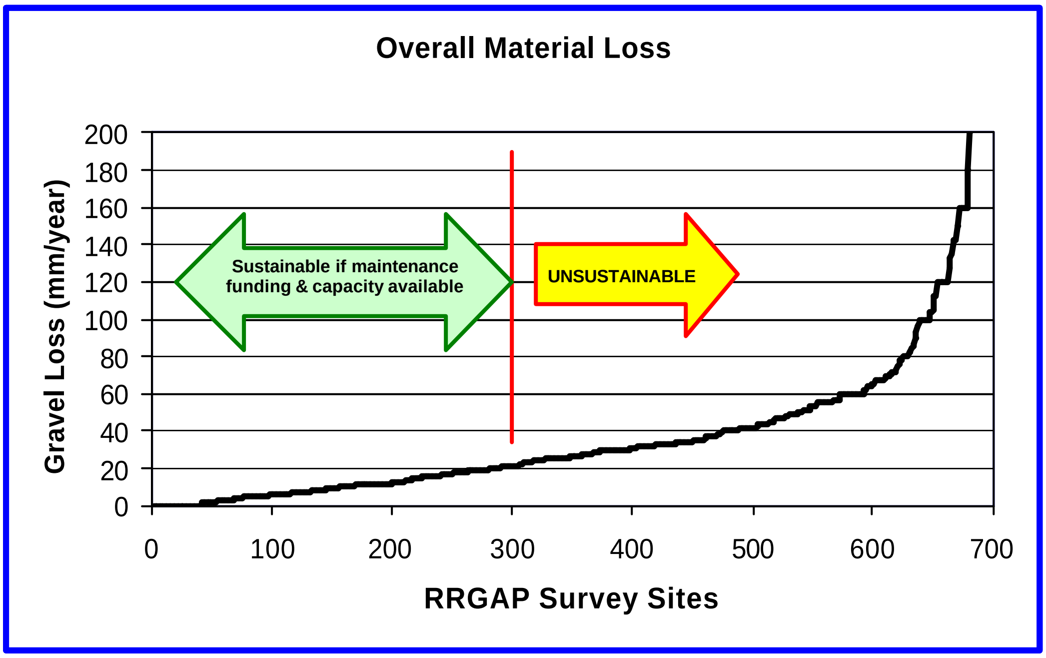
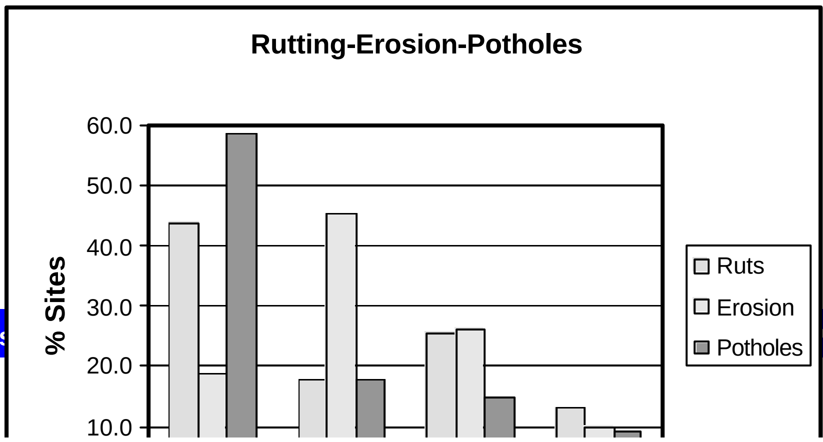


Figure 3.9 Adjusted Material Loss Summary

Erosion. This was seen as a key indicator of road deterioration, both with regard to formation of surface rills and gullies and as a pointer to road roughness conditions. Due to the nature of the survey and project time scale the RRGAP survey did not include direct roughness (IRI) measurements. They are included, however, in the monitoring of the parallel RRST programme. Future gravel road performance monitoring would benefit from roughness measurements, which would allow assessment of VOCs against alternative surfaces.

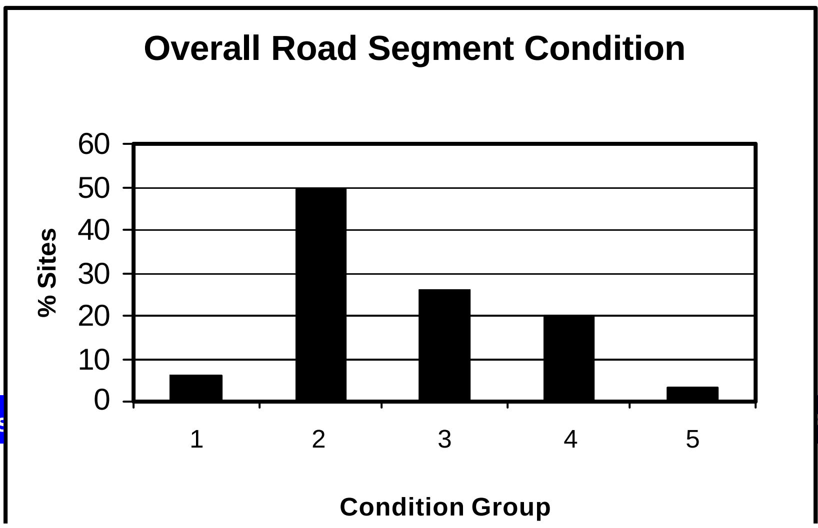
Potholing and **rutting** were also selected as suitable deterioration indicators and a summary of this data together with that for erosion is included in Figure 3.10.



Category	Rutting	Erosion	Potholes
1	None	None	None
2	>15mm	Slight	<2/20m of road
3	15-50mm	Moderate	2-5/20 of road
4	>50mm	Severe	>5/20m of road

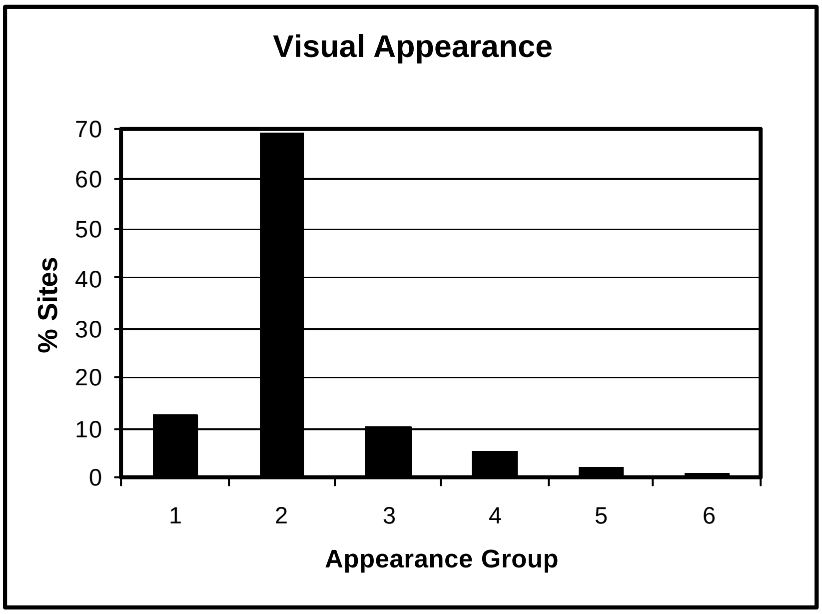
Figure 3.10 Rutting, Erosion and Pothole Data Summaries

Overall Condition; Given that the RRGAP was based on the spot assessment of different conditions along a road, the subjective assessment of the overall condition was a necessary tool for assessing whole-road conditions. **Visual appearance,** together with the site photographs of each profile survey section provided a valuable cross-check on other data sets. Figures 3.11 and 3.12 summarise the data sets.



1	No visible defects; As built conditions
2	A few minor defects
3	Isolated moderate defects - spot repairs required
4	Significant defects - major re-shaping/gravelling required
5	Severe defects - overall road rehabilitation required

Figure 3.11 Overall Road Segment Condition Summary



1	Good surface shape - no stone protrusion
2	Some deterioration/stone protrusion
3	Up to 25% of sub-grade exposure
4	25 to 50% of sub-grade exposure
5	Extensive sub-grade exposure up to 75%
6	>70% sub-grade exposure

Figure 3.12 Profile Visual Appearance Summary

4 DISCUSSION OF KEY ISSUES

4.1 General

Although termed a "gravel" study, the RRGAP survey was in effect a study of a wide range of unsealed surfaces throughout Vietnam comprising; natural gravels; graded crushed stone gravels; mixtures of natural and crushed stone; and non graded stone surfaces akin to water-bound macadam in character. Even within these groupings there is an apparent wide range of grading and plasticity characteristics, hence an overall deterioration model for Vietnam unsealed roads would have to take this variation into account and be based on individual material groups as well as the variable climatic and terrain elements.

Given the added complexity and influence of other road environment issues in Vietnam such as construction quality control and maintenance regime, it was considered more effective at this time not to develop a mathematically based deterioration model. The analysis therefore concentrates on identifying relative deterioration patterns and describing those road environments where unsealed roads are performing best and those where, on current evidence, unsealed roads are obviously performing badly. This approach has allowed key defining factors to be identified that can be used in deciding on the use or non-use of an unsealed road option within a defined road environment.

Relevant data sets were assessed and relationships examined for those that gave clear and valid trends that could be used to develop patterns in road deterioration.

4.2 Road Performance

Material loss and erosion were selected as key factors for determining road deterioration patterns. Material loss trends were evaluated by examining the loss per year over a range of sites, either by material type or by province.

The RRGAP scoping study assessed a number of unsealed road deterioration models none of which were developed in road environments directly comparable with those in Vietnam. During the RRGAP data review process, however, it was appreciated that an existing TRL gravel road deterioration model (TRL, 1984), developed in East African conditions, could be taken as an analytical starting point for a number of reasons:

1. It was based on a small number of relevant road factors,
2. It was not dependant on maintenance or grading,
3. It could be mathematically extrapolated to cover the Vietnam environment.

A range of traffic and rainfall figures appropriate to the Vietnamese environments was put into the model, as shown in Figure 4.1. Based on this figure, in conjunction with engineering judgement and experience, gravel loss of 20mm/year was selected as the limiting figure for road sustainability. This level of loss allows for 100mm of gravel to be lost over a 5 year life without re-gravelling. Depending on the original laid thickness, this would leave from only 50 to 100mm of residual wearing course, which is a reasonable minimum allowable thickness. A deterioration of 20mm/year can therefore sensibly be considered a maximum loss figure for road management sustainability in an environment where periodic maintenance including re-gravelling is not the normal practice due to a range of constraints. A fuller justification for the use of 20mm/year gravel loss as a sustainable limit is included as Appendix C to this report.

Table 4.1 summarises material loss on a province-by-province basis together with terrain, rainfall and erosion condition. In this Table erosion is categorised as being either “slight” or “significant”; the latter being defined as moderate, or worse than moderate.

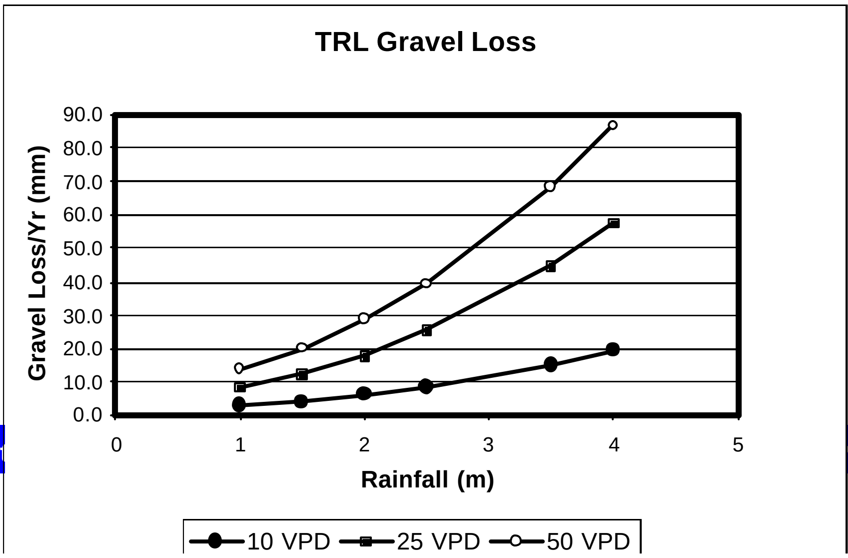


Figure 4.1 TRL Gravel Loss Calculations (Gradient 1-2%)

Key issues with respect to the RRGAP material loss and erosion data are as follows:

1. Overall material loss figures indicate that around **58%** of the surveyed sites are suffering unsustainable deterioration over a five-year design life, while **28%** are losing material at twice the sustainable rate.

2. On province-by-province basis only 4 provinces have greater than 50% of sites below the sustainable loss limit. Of these two, Lao Cai and Bin Thuan also have high erosion figures, resulting largely from the use of unsealed stone macadam surfaces allied to steep terrain.

3. The performance of the road segments as a whole, however, is likely to be slightly better than the above figures for individual survey sites. This is largely because the survey was designed to sample typical surfacing conditions and environments on each segment and not to be representative of the road segment lengths.

4. The overall visual assessment data (Figure 3.11) indicates a composite road performance model comprising the differential "spot" deterioration of short critical lengths separated by lengths of road in better condition. Table 4.2 suggests that this spot deterioration model could account for around three quarters of the roads examined. In addition to which the detailed material loss data indicates an overall general deterioration.

Description of Road Segments	% Road Segments
No visible defects; as-built appearance	6
A few minor defects	50
Isolated moderated defects; spot repairs required	26
Significant defects requiring major re-shaping/re-gravelling	20
Severe defects; overall road rehabilitation required	4

Table 4.2 Summary of Overall Road Segment Conditions

Province	Apparent Gravel			Annual Rainf	Survey Road	Profile Site	Erosion		Terrain					
	Median	>20m m/yea	>40m m/yea				Slight % Sites	Significant	No. of Sites					
									1	2	3	4	5	6
Binh	19	42	21	2674	23	61	35	65		13	10			
Ca Mau	26	67	40	2828	5	15	53	47	6					
Can Tho	40	97	47	1919	13	34	97	3	13					
Dien Bien	21	57	3	2448	12	29	46	54				10		2
Dong Nai	44	90	64	2211	18	42	81	19		6		2	10	
Ha Tinh	**12**	**26**	**8**	**1550**	**25**	**65**	**72**	**28**	**4**	**12**		**2**	**7**	
Hung Yen	21	50	24	1500	20	50	57	43		20				
Lam Dong	62	100	80	1887	11	20	86	14				10	1	
Lao Cai	5	0	0	2105	21	55	23	77				12	3	6
Ninh	**19**	**40**	**7**	**856**	**20**	**57**	**56**	**44**		**8**	**11**		**1**	
Quang	21	50	10	3050	21	49	79	21	9	1	11			
Quang	60	84	68	2457	20	38	41	59			3	11	1	5
Tien	34	88	50	1312	8	17	96	4	8					
Tuyen	34	75	45	1990	21	53	67	33		2		91		
Vinh Long	35	80	33	1237	11	30	97	3	11					
Vinh Phuc	44	79	52	2038	20	42	81	19		14		6		

Notes: Terrain	1	Delta/Coast	4	Moderate to high hills	(grey box)	Non-sustainable loss/poor erosion
	2	Inland flat	5	Inter-montain valley/High Plain	**Bold**	Best performing provinces
	3	Rolling hills	6	Mountainous		

Table 4.1 Overall Apparent Gravel Loss and Erosion Per Province

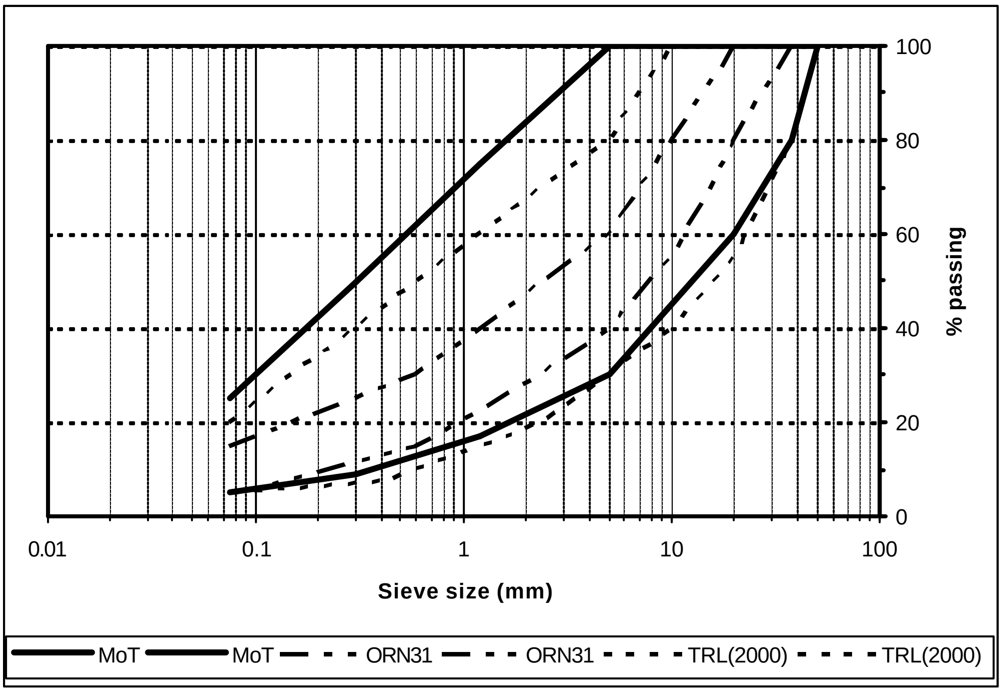
4.3 Material Characteristics

The characteristics of a surfacing material which contribute to satisfactory behaviour of a gravel road have conventionally been considered to be as follows:

It should contain a sufficient quantity of binder in the form of fine grain materials to prevent loosening of the surface, and yet not cause excessive dustiness in dry periods. It should also resist movement of material and thus reduce gravel loss. If the fines content is too high then under wet conditions a substantial loss of strength will occur, leading to excessive deformation and a slippery surface.

The material should not contain a large quantity of coarse particles which can become exposed through trafficking and lead to high surface roughness and create a traffic hazard. Large particles may also prevent efficient maintenance reshaping of a road surface and can lead to pothole deformation if they are plucked out by traffic or during grading. They can also prevent compaction forces being transmitted evenly through a layer, which may result in low densities being achieved with a consequent enhanced risk of road deterioration.

These characteristics are reflected in the standard specifications for gravel surfacing that exist throughout the world that are normally based on grading envelope and plasticity criteria. In this context it should be noted that the current Vietnam MoT/RT2 specification already allows a wide envelope grading in comparison to other specifications, Figure 4.2.



ORN31=TRL Overseas Road Note 31:
TRL(2000) = Relaxed Low Volume Specification (IFG, 2004)

Figure 4.2 Current MoT in Comparison with other Specifications

Evaluation of the RRGAP test results against this specification are presented on province-by-province basis in Appendix B of this document.

Test results have also been evaluated using other plasticity and particle size indices, such as:

Plasticity Product (PP) Plasticity Index **X** % material passing 0.075mm sieve

Plasticity Modulus (PM) Plasticity Index **X** % material passing 0.425mm sieve

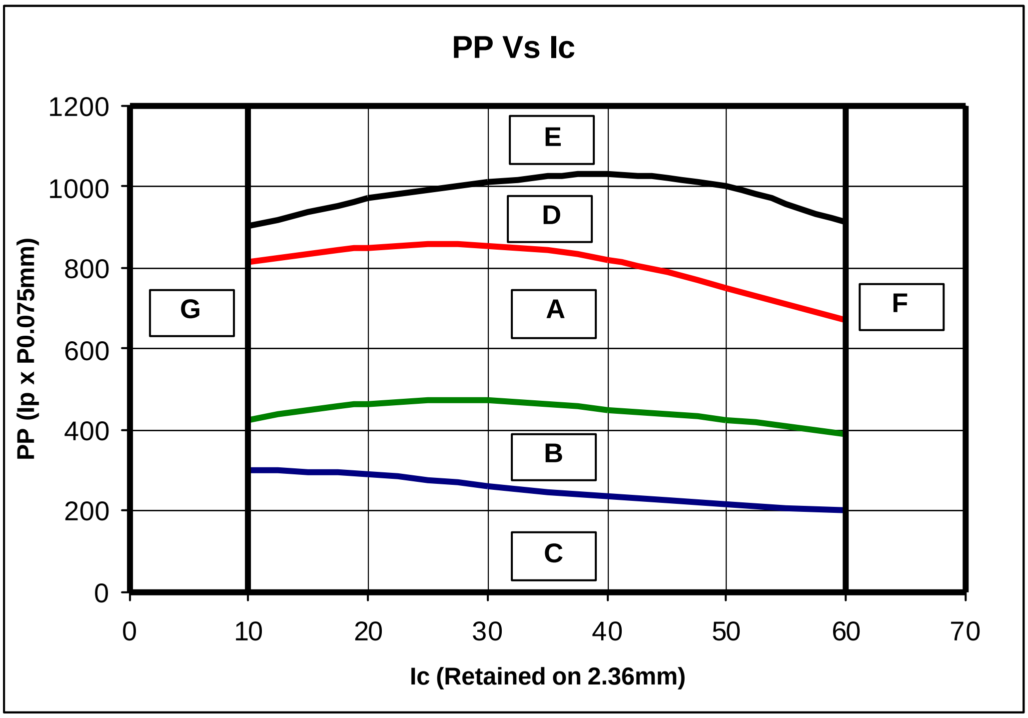
Grading Coefficient (GC) (P26.5mm – P2.00mm) **X** (P 4.74mm)/100

Grading Modulus (GM): (P2.00 + P0.425 + P0.075)/100

Where P= %passing (mm)

Experience has indicated the value of these indices as material assessment criteria and Figure 4.3, which utilises the Plasticity Product value has proved useful in other regions. RRGAP data has therefore also been plotted in this format in Appendix B.

There is a significant variability in the nature and performance of the materials being used as unsealed road surfaces in Vietnam, Table 4.3, Photograph I. The material loss for the RRGAP sites for each of the 7 principal material groups is presented in Figures 4.4 to 4.10 and summarised in Table 4.4. Figure 4.11 indicates the apparent erosion variability related to material type, which is summarised in Table 4.5.



A: Good performance under wet and dry conditions
B Good performance under wet conditions; corrugates in dry conditions
C Lacks cohesion: rapid deterioration with trafiic
D Good in dry conditions; slippery in wet; potholes/erosion
E Poor in both wet and dry conditions
F Too coarse: erodes badly; difficult to maintain
G Too fine; trafficability problems in wet and very dusty when dry

Figure 4.3 Plasticity Product and Particle Size Assessment

Provinces	**Total Site**	**Road Link**	**Material Types Used**									
			Numbers of Sites for Each Material									
			1	**1R**	**2**	**2R**	**3**	**4**	**5**	**6**	**8**	**10**
Binh	69	23	25	30	4	7						
Ca Mau	15	5	4				10					1
Can Tho	34	13					34					
Dien	35	12			2		12		16			6
Dong	42	18	39		7	2						
Ha Tinh	74	25	15	19	10	23			7			
Hung	60	20						54			6	
Lam	29	11	14		9	3	3					
Lao Cai	57	21			3	5		49				
Ninh	59	20			8	30	5		13			3
Quang	62	21			12		25		20			5
Quang	59	20			20		17	1	2	10	7	2
Tien	24	8	24									
Tuyen	54	21	5		26	5	5		13			
Vinh	30	11					30					
Vinh	63	20	7		38		3	1		2		

Notes						
1	Laterite gravel	4	Non graded crushed stone	8	Hand packed stone
2	Hill gravel	5	Alluvial gravel	10	Undefined
3	Graded crushed stone	6	Clay + gravel mix	+R	Gravel mixed with stone/rock

Table 4.3 Range of Materials Used Per Province

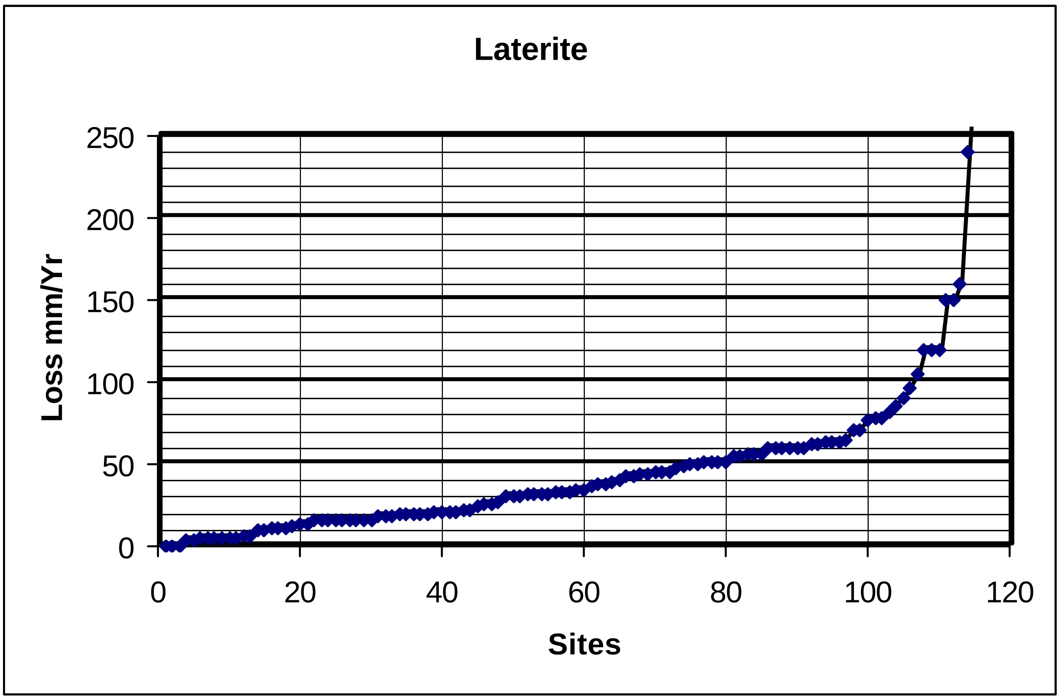


Figure 4.4 Material Loss for Laterite Gravel Surfacing

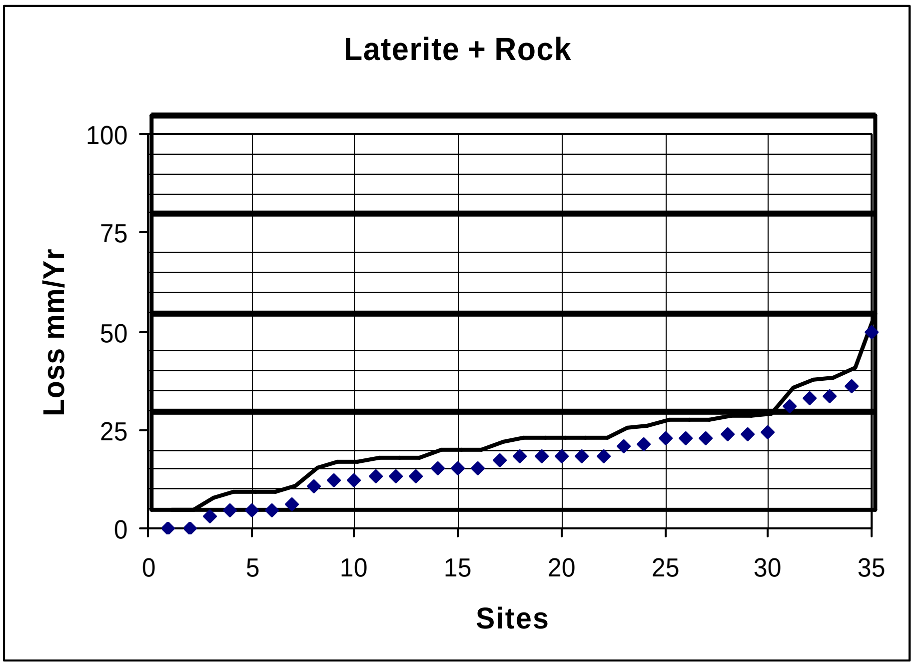


Figure 4.5 Material Loss for Laterite + Rock Surfacing

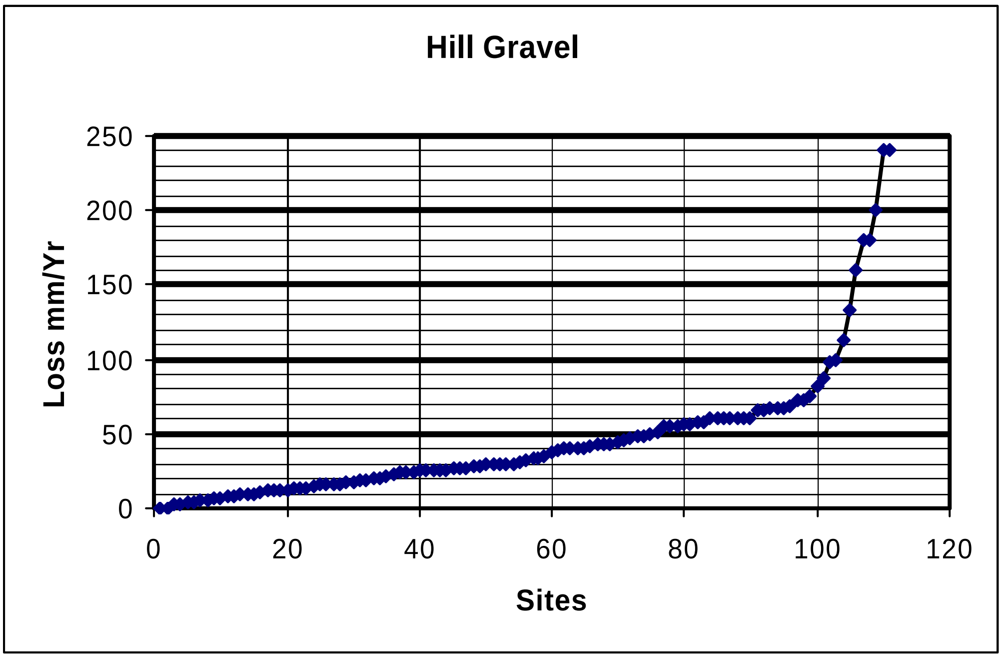


Figure 4.6 Material Loss for Hill Gravel Surfacing

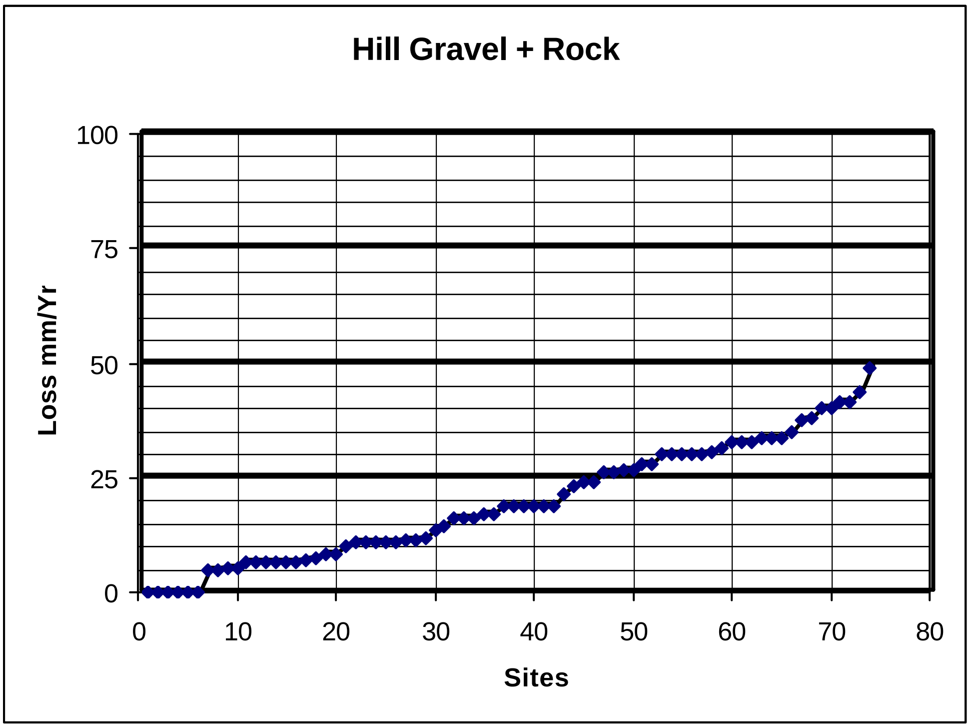


Figure 4.7 Material Loss for Hill Gravel + Rock Surfacing

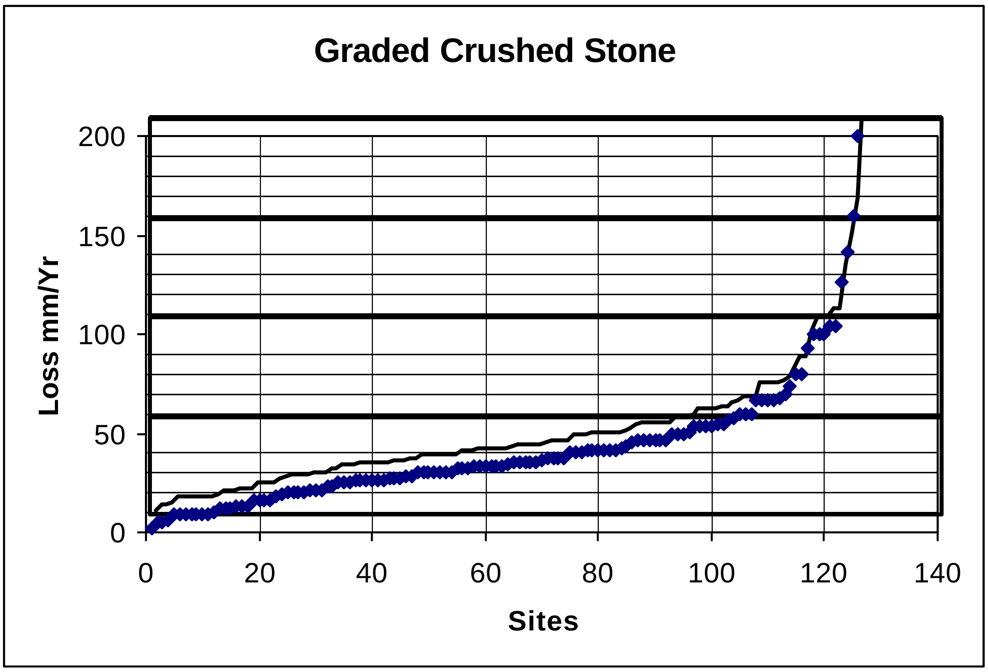


Figure 4.8 Material Loss for Graded Crushed Stone Surfacing

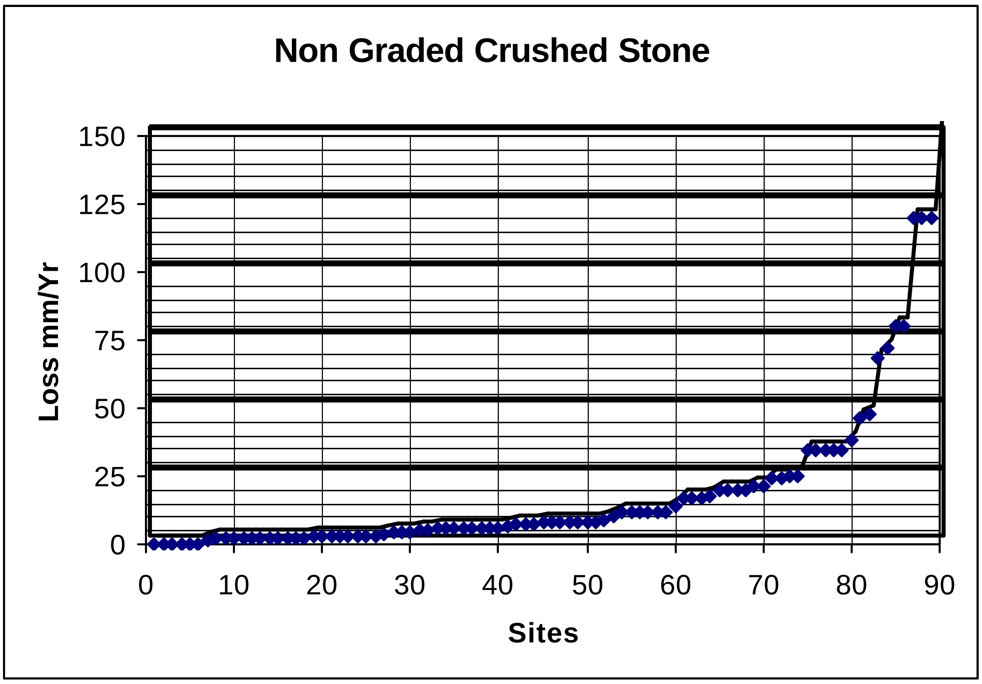


Figure 4.9 Material Loss for Non Graded Crushed Stone Surfacing

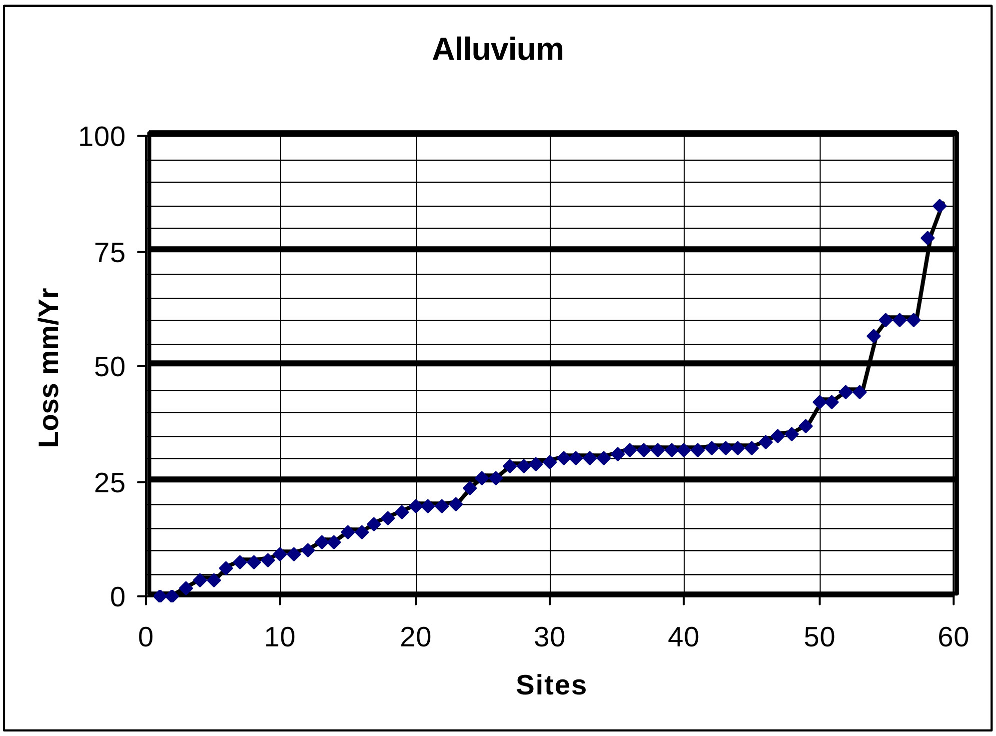


Figure 4.10 Material Loss for Alluvial Gravel Surfacing

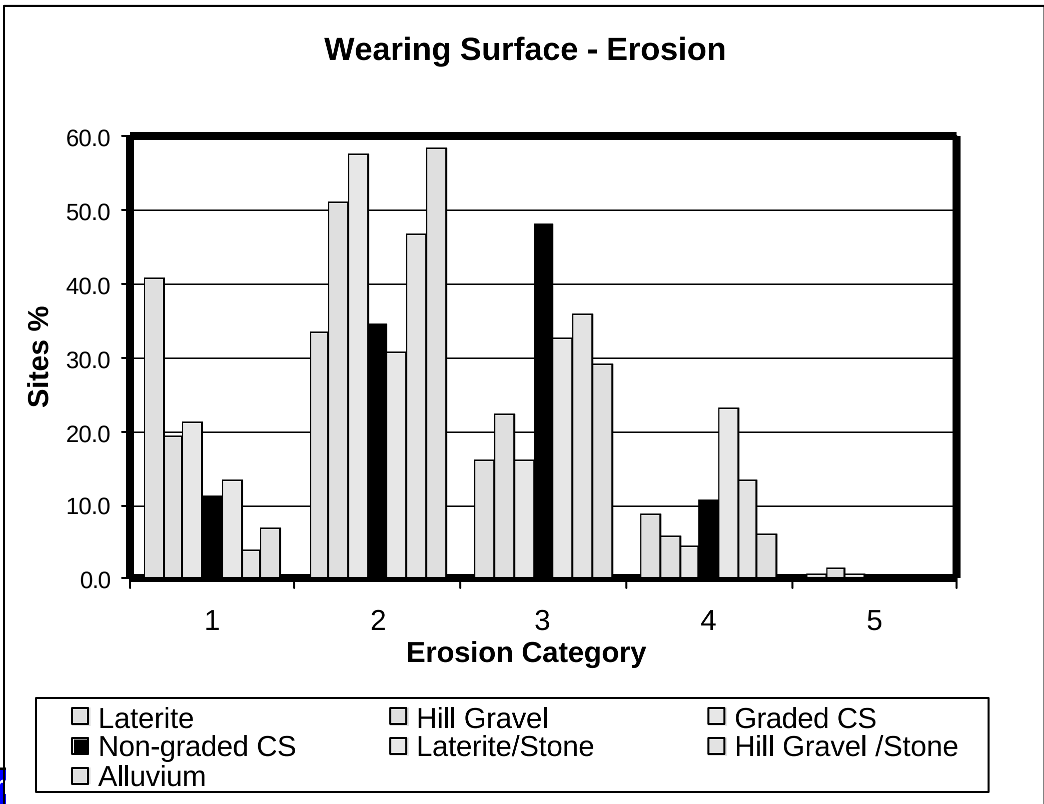


Figure 4.11 Summary of Erosion Related to Material Type

Material Group	Median Loss (mm/year)	% Sites with loss >20mm/year	% Sites with loss >40mm/year	No. of Sites Analysed
Laterite	33	82	43	115
Laterite+Rock	17	34	3	35
Hill Gravel	31	71	41	110
Hill Gravel+Rock	19	42	1	74
Graded Crushed Stone	34	79	34	126
Non-Graded Crushed Stone	8	24	10	90
Alluvial Gravel	19	62	17	60

Table 4.4 Summary of Material Loss Data per Material Type

	1 Laterite Sites	1R. Laterite + Rock Sites	2. Hill Gravel Sites	2R. Hill gravel + Rock Sites	3. Graded Crushed stone Sites	4. Non Graded Crushed Stone Sites	5. Alluvial Gravel Sites
% Slight or no erosion	75	44	70	51	79	46	64
% Significant erosion	25	56	30	49	21	54	36

Table 4.5 Summary of Erosion- Material Type Relationships

Key material related issues to arise out of an examination of this RRGAP data are:

1. Significant amounts of material fall outside the current RT2 specifications for gravel.
2. The naturally occurring laterite, hill gravel and alluvial gravels have a high number of sites (>60%) with greater than 20mm/yr material loss. The implication is that these materials are not suitable for use as an unsealed road surfacing within the majority of Vietnam road environments. Similar comments also apply to graded crushed stone as an unsealed surfacing material.
3. Where natural materials have been mixed with additional crushed rock, weathered rock or alluvial gravel and cobble, then the material loss figures show a distinct improvement.
4. Coarse non-graded stone surfacing performs significantly better than other options in terms of material loss (Photograph II). Given the nature of this surface, which is in many instances close to water bound or dry bound macadam in character, its resistance to material loss is not surprising. However, it does suffer significantly from surface erosion of fines, leaving a rough surface susceptible to localised deterioration.
5. The natural gravel-stone mixtures also have lower than average material loss figure, but as with the non graded stone they also appear to have a higher than average erosion/roughness potential.

4.4 Terrain and Gradient

The impact of terrain, as shown in Table 4.5 and Figure 4.12 indicates that erosion increases significantly between 4% and 6% road gradient. It has been commonly acknowledged that gradients above 6-8% are not usually suitable for gravel surfacing, however the RRGAP data suggest that, for some materials at least, this limiting figure should be lowered to 4% for the high rainfall environments in Vietnam.

	Road Gradient at Survey Point				
	Flat	>0-2%	>2-4%	>4-6%	>6%
% Slight or no erosion	91	67	47	47	26
% Significant erosion	9	23	53	53	74

Table 4.5 Summary of Gradient-Surface Erosion Relationships

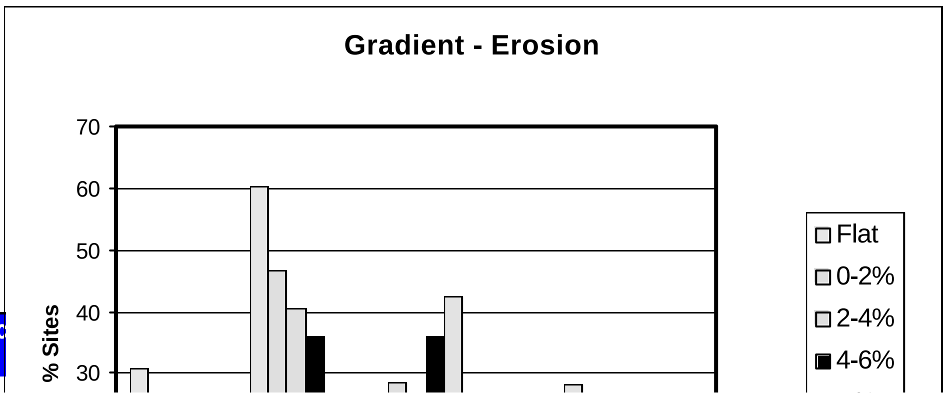


Figure 4.12 Gradient-Surface Erosion Relationships

4.5 Material Haulage

Based on discussions with relevant PDoTs, figures for material haulage for individual road links have been assessed and are presented in Table 4.6 This shows that for provinces in the Mekong delta area material haulage, primarily by boat, can be up to 350km.

Province	Haulage (km)		
	Min	Max	Av
Tuyen Quang	2	19	6
Dien Bien	5	10	7
Dong Nai	4	10	7
Lam Dong	2	10	7
Ha Tinh	2	15	8
Ninh Thuan	1	20	8
Vinh Phuc	2	24	9
Bin Thuan	2	20	11
Lao Cai	7	15	11
Quang Ninh	1	20	13
Quang Nam	4	50	22
Hung Yen	4	70	69
Vinh Long	110	155	135
Tien Giang	135	165	145
Can Tho	160	170	165
Ca Mau	350	350	350

Table 4.6 Material Haulage Summary (km)

The extremely long haulage figures for the Mekong area raises serious issues regarding the current use of inappropriate rural road design options for this region, particularly in the light of their apparent poor sustainability in terms of material loss and poor specification compliance. It cannot be considered a reasonable option to haul marginal material over 100km to construct unsustainable roads. It is likely that a detailed whole life costing of gravel and other surface options would help to justify alternatives when gravel haul distances are more than 10km, particularly when other socio-economic and environmental issues are also considered.

4.6 Construction

Good drainage is considered a fundamental aspect of road engineering in almost all relevant guidelines and design manuals. In a high rainfall country such as Vietnam this aspect of road construction should have a particularly high priority. The RRGAP survey has, however, indicated that drainage, in the form of side ditches and carriageway run-off capacity has not been given a high enough priority either in construction or in maintenance in the Vietnam rural road network, Tables 3.4 and 3.5, Photograph III.

The effects of poor drainage on road performance are indicated by the impact it has on potholing and erosion, Table 4.7.

Road Condition	Impeded Run-off Sites	Non Impeded Run-off Sites
Potholed	53%	24%
Non potholed	47%	76%
Significant erosion	48%	18%
Slight or no erosion	52%	82%

Table 4.7 Summary of Surface Run-off Road Condition Relationships

Construction of gravel roads should also allow for maintenance to be carried out cost effectively. The common practice of placing soil shoulders against gravel road surfaces prevents the gravel from being graded, as such operations would mix the soil into the higher quality running surface. Soil shoulders also help to impede sideways drainage of the surface as the gravel surface wears, thus accelerating the surface deterioration.

4.7 Maintenance

Maintenance is a key issue for the sustainability of gravel roads. Gravel is a low-cost:high-maintenance road surface. Most gravel road design guidelines and network management models either assume or strongly recommend an appropriate maintenance regime that includes both grading and periodic re-gravelling. The high rainfall environment of Vietnam makes this an essential component of unsealed rural road asset management.

Regular routine surface reshaping is required for gravel surfaces to correct minor defects and maintain the crossfall within the range 3 – 7% to shed rainwater. This can be achieved by mechanical or manual methods. Investigations show that due to funding and organisational constraints this activity is rarely achieved. Consequently standing water will occur and accelerate the formation of potholes, ruts and loss of material.

Even more importantly for gravel roads, the loss of material must be replaced by periodic regravelling. This is an expensive operation with costs that increase substantially with material haul distance. If regravelling is not carried out in a timely manner, then the layer thickness will reduce below a critical residual thickness of about 5 – 10 cm and accelerated deterioration will take place. The road will effectively revert to an earth standard and require even more costly rehabilitation. There is often insufficient warning of this occurrence (which can happen within weeks in the rains) to allow funds and resources to be mobilised before the gravel surface deteriorates to a condition requiring rehabilitation. Gravel is thus also a high risk road surface.

The RRGAP data, based on locally based information, indicates that adequate maintenance is not being achieved on the large majority of RT1 & RT2 roads, Table 3.5.

Gravel roads suffering more than 20mm/yr of material loss without appropriate maintenance are largely non-sustainable beyond 4-5 years and may well deteriorate at a significantly greater rate in some in sections within that timescale.

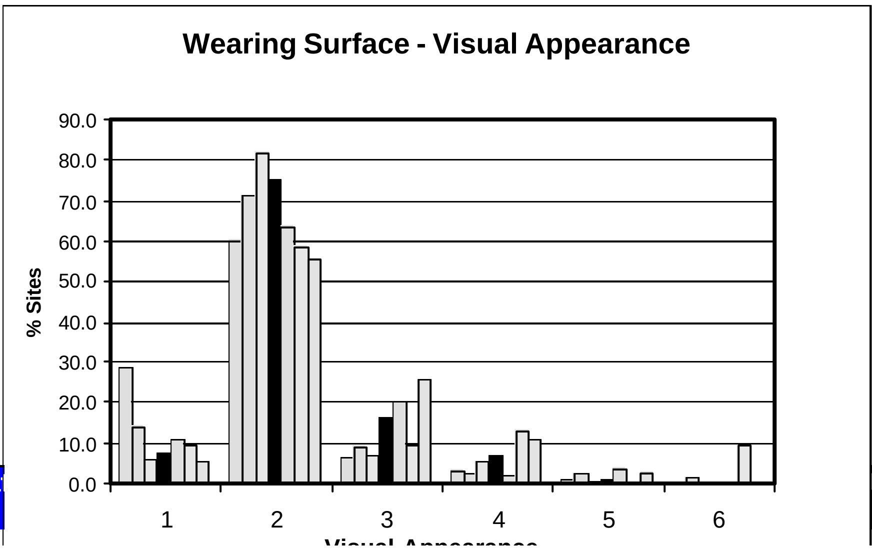
The availability of local materials for maintenance is also an important issue. Commune based maintenance will usually require the availability of suitable materials close to the road. It is unreasonable to expect local communities to support the haulage of materials for the distances discussed in Section 4.5 above. Instead, there is some evidence to indicate that local communities tend to use unsuitable local materials available within shorter hauls, Photograph IV, and thus add to the rate of road deterioration.

4.8 Visual Appearance

Information on visual appearance related to material type (Figure 4.13) would seem superficially to contradict the data on material loss and erosion by implying that the large majority of road segments looked to be in a fair condition. This apparent anomaly should be considered in the light of the following:

1. Unlike most sealed surfaces, the deterioration of a gravel road surface through material loss is not initially a visible feature and only becomes so when the loss approaches a critical stage.

2. There tends to be differential deterioration along the road segments with visible deterioration features, such as rutting and potholing of the road surfaces being concentrated within certain road sections. This results in a "spot" deterioration pattern, as discussed previously.



1	Good surface shape - no stone protrusion
2	Some deterioration/stone protrusion
3	Up to 25% of sub-grade exposure
4	25 to 50% of sub-grade exposure
5	Extensive sub-grade exposure up to 75%
6	>70% sub-grade exposure

Figure 4.13 Site Visual Appearance versus Material Type

4.9 Climatic Effects

In general terms Vietnam is a high rainfall environment with storm concentrations, and hence erosion potential, outside the norm (Intech-TRL, 2003). This undoubtedly has an impact on the deterioration of the unsealed rural roads in Vietnam. However, the relative effects of differential rainfall patterns within Vietnam are difficult to assess from the RRGAP data for a number of reasons:

1. The apparently overriding influences of other factors such as material type and quality.

2. No unsealed road condition information was available from the highest rainfall provinces (Thua Thien Hue and Da Nang; 3,000-4,000mm/year) because the local authorities had already overlaid their RT2 gravel roads with more durable surfacing.

3. The very localised and variable patterns of rainfall.

It may be possible, however, to undertake a more detailed assessment of road location and rainfall data to produce some correlation. An indication of this is the fact that Ninh Thuan, with a low annual rainfall figure of 856mm/year is one the best provinces as regards current road condition.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Current Situation

The RRGAP data on RT1 and RT2 road links indicate that it is likely that over 50% of the unsealed rural road network is either unsustainable in terms of material loss or contains significantly deteriorating road sections.

The previous chapter highlighted the key issues to emerge from the RRGAP with respect to assessed road condition and Table 5.1 summarises the key environmental factors impacting on this condition.

With regard to already constructed RT1 and RT2 and other gravel rural roads, it is clear that there are key factors that could be addressed to improve their condition and sustainability. These are:

1. Funding/resourcing and implementation of appropriate routine and periodic maintenance regimes that includes both re-shaping and re-gravelling activities, where the existing gravel surfaces are deemed to be sustainable.

2. Construction of additional side ditches to ensure that the road surfaces can effectively shed rainwater from the road and disperse it satisfactorily. Shoulders should also be reshaped if necessary to ensure water can be shed from the road surface.

3. Sealing of appropriate road links, e.g. with excessive hauls for periodic regravelling. In a resource constrained environment, a spot improvement strategy of selectively treating problematic lengths within a road link should be considered, e.g. sections liable to flooding or with steep gradients.

Factor	**Description**
Construction Materials	The nature and engineering character of the materials used has been identified by the survey as having the largest single influence on the condition of the surveyed roads. The majority of materials tested are outside specification and therefore are not being using in an appropriate design framework.
Climate	The high and frequently intense rainfall encountered in Vietnam undoubtedly has a significant impact on unsealed road deterioration. However, the localised patterns of this rainfall allied to the over-arching influence of other key factors, prevent the limited rainfall data available from being used as a principal discriminating factor.
Surface and Sub-surface Hydrology**.**	Flooding of rural road surfaces is widespread in Vietnam (Figure 3.6). It ranges from occasional sheet flood to the regular destructive inundations experienced, for example, in the Mekong delta. It is significant that RRGAP provinces in the Mekong had poor surface performance characteristics. Lack of adequate drainage has been identified as having a key impact on unsealed road condition.
Terrain	Road longitudinal gradient has been identified as having a major impact on road surface erosion.
Sub-Grade Conditions	No clear picture has yet emerged form the RRGAP data on sub-grade condition. Further analysis of collected data should be carried out in conjunction with additional investigations into related soil-rock parameters..
Traffic	For the majority of RRGAP roads traffic impacts are likely to be slight (Figure 3.8). The limited data on roads with higher traffic volumes or higher axle loads does indicate increased potholing and rutting.
Maintenance Regime	The apparent lack of programmes delivering effective maintenance to the rural road network is a serious issue that must be taken into account in future selection of suitable rural road options for Vietnam, particularly for high maintenance surfaces such as gravel. This is particularly problematic for provinces with long and expensive material hauls.

Table 5.1 Road Environment Factors Impacting on Current Road Condition

5.2 Future Rural Road Construction in Vietnam

There is a clear need to improve the evaluation of the correct usage of local gravel materials in rural road programmes in Vietnam. It is now recognised that a key objective in sustainable road construction is to properly match the available material to its road task and local environment. Greater use should be made of adapting local non-standard materials within appropriate designs. The RRGAP data has highlighted an apparent mis-match between the design options currently being used and many of the materials being used to construct them. The general options for dealing with this situation are:

1. Modify the material to suit the designs,
2. Modify the design options to suit the materials available,
3. Define areas where the existing unsealed options are suitable.

Options 1 and 2 above are being addressed by the expanding RRST programme which will report later this year on alternatives to gravel, whilst the RRGAP has identified some key factors relevant to Option 3, as outlined in the following paragraphs.

Gravel can only be considered as a serious viable pavement option for Vietnam rural roads on engineering and economic grounds under the following conditions:

1. Where specified quality **material is locally available** in sufficient quantities both for construction and maintenance (probably within 10km of the road). This should be verified with a detailed whole life costing of surfacing options if the materials hauls are longer than 10km. A realistic assessment of the likelihood of routine and periodic maintenance being carried out should be included in the whole life costing, including the risks and consequences of inadequate maintenance.
2. Where road **gradients are less than 4%** in medium rainfall areas (1,000 – 2,000 mm/year). Gravel will probably be unsustainable at any gradient for higher levels of rainfall – 2,000 mm/year is at present an arbitrary figure based on general experience elsewhere and on the policy of the high-rainfall provinces such as Da Nang and Thua Thien Hue to seal their RT2 gravel roads almost immediately after construction. For the few areas of Vietnam that experience rainfall of less than 1,000 mm/year, gravel may be suitable for longitudinal gradients up to 6%.
3. Where **adequate drainage** (crossfall, side and dispersion) can be guaranteed.

4. Where **adequate quality assurance** controls are in place for construction supervision to ensure contract and specification compliance.

5. Where an appropriate **maintenance regime** can be guaranteed as part of a whole-life construction and maintenance specification.

6. Where **flooding** is only a minor local occurrence.

7. Where **traffic** is below 200 motor vpd equivalent. This is recommended from international experience. However it is possible that alternative, more durable, surfaces could be justified at traffic levels below 100 motor vpd in some circumstances in Vietnam.

The above criteria have been incorporated into the Engineering element of a proposed overall "**Preliminary Decision Management System for the Assessment of Gravel as a Paving Option".** This system comprises Operational, Economic and policy elements in addition to the Engineering aspects and is presented in Appendix D to this report.

Apart from assessing gravel performance the RRGAP has raised other important issues, such as:

1. The investigations have indicated the effectiveness of unsealed stone macadam in providing a sustainable surface/road-base, albeit with high surface erosion or roughness penalties. It is suggested that this option would be ideally suited to a staged construction approach, with an appropriate sealing option following-on at a later date from the initial construction. The RRST programme is already trialling stone chip and sand bitumen seal options over dry bound macadam.

2. Other techniques utilising natural stone, without bitumen or cement binder, could have superior performance to gravel, but with reasonable initial costs and lower maintenance liabilities. These surface options include hand packed stone and cobble stone paving. These options should be trialled in the planned expansion of the RRST.

3. Staged construction using gravel as the initial construction material has the disadvantage that significant degradation may occur on the surface unless the seal is applied within 6 months, or at least before the first rainy season. The use of armoured gravel (as trialled in Thua Thien Hue RRST) could be considered in areas where suitable gravel exists, but where other factors such as gradient, flooding or maintenance issues would mitigate against unsealed gravel.

4. Composite construction should be considered as a strategy in future rural road programmes. This involves the construction of different surfacing options along a road link in response to differing environment impacts. In appropriate cases this could involve employing an engineered natural surface option.

5. There is a clear requirement to make PDoTs, contractors and local consultants more aware of the importance of Quality Control and to place more emphasis on effective and contractually empowered construction supervision of rural road projects. At the same time there is a need to advise local contractors on the construction techniques required for the alternative pavement options likely to be mainstreamed from the RRST programme. Some form of advisory unit or panel would be appropriate in this context.

Investing in improved quality assurance and compliance testing of gravel material (where it is viable) would represent very good value for money. For example, even for short gravel hauls, a few hundred dollars (equivalent) per km spent on testing and certification of gravel material at construction stage should be able to prevent gravel loss from the road in service equivalent to about US$500/km/year due to use of poor quality material. The benefit would increase substantially with longer haul distances.

5.3 Supplementary RRGAP Work

The RRGAP research to date has indicated that some additional work appropriate to the ongoing rural road programmes is required; namely

1. A national dissemination workshop and programme for mainstreaming the RRGAP findings.

2. Further detailed research and interpretation of the data to provide background for guidelines on surfacing option selection appropriate to the RT3 programme. Further research of existing data is recommended in the following areas:
   - o Sub-grade – road condition relationships,
   - o More detailed examination of the data from poorly performing road sites,
   - o More detailed correlations between material test data and site road condition.

3. Extrapolation of the existing findings to other provinces to define areas of possible gravel use.

4. Design of an upgraded road inventory procedure for use in candidate road selection for RT3.

5. The selection of suitable sites for long term gravel road performance monitoring. It is recommended that RT2 Year 4 roads be examined for suitable candidates. This will allow the construction procedures to be included in the monitoring process which could then run straight from construction through to working performance. Gravel monitoring is being undertaken on sections included in the RRST programme and similar procedures for could be employed on selected sections of identified Year 4 roads, Figure 5.1

6. A programme of surface roughness (IRI) surveying to supplement the existing RRGAP data using low cost apparatus such as the MERLIN (TRL, 1991)

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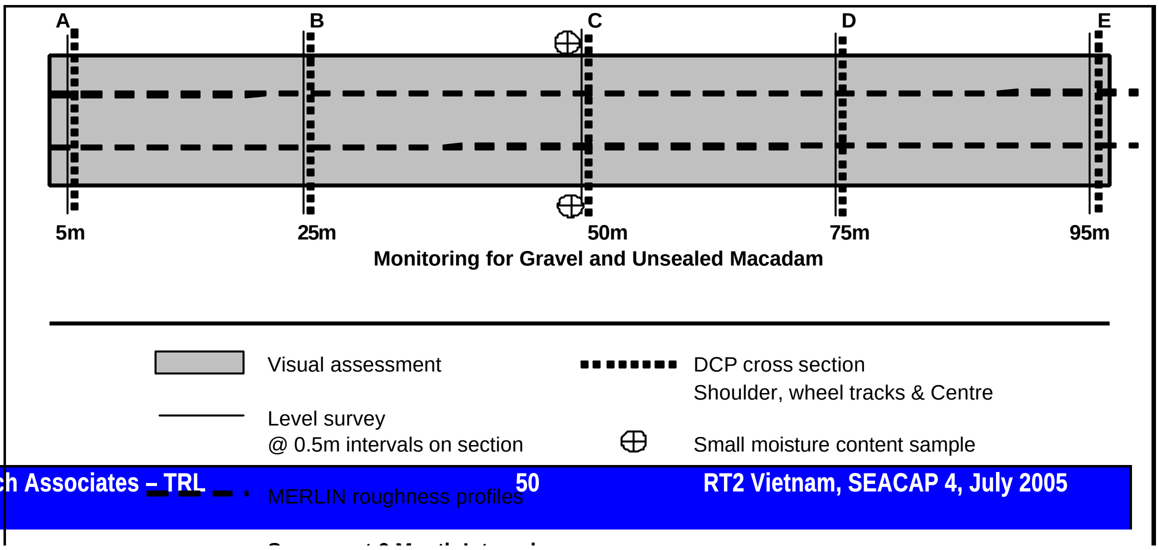

Figure 5.1 Long-Term Monitoring Proposals for Gravel Sections

5.4 Additional Research

In the light of the RRGAP work the following additional research is recommended as part of the overall Rural Road Research Programme.

1. A condition survey of locally funded bitumen and concrete surfaces and overlays on RT1 and RT2 roads, investigating in particular the nature of the surfacing; their current condition; and the road environment factors influencing their performance. This survey is considered a vital add-on to the RRGAP and an essential input to the continuing development of a sustainable rural road strategy that is appropriate to the Vietnam road environments

2. Research into social and economic factors relevant to the use of gravel surfacing for Vietnam rural roads.

3. Investigation and refinement of the rainfall relationship for gravel loss to enable the guidelines on the limits of application to be more soundly based.

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PHOTOGRAPHS

1-A. Laterite Gravel

1-B. Hill Gravel

1-D. Non-Graded Crushed stone

1-C.Graded Crushed Stone

1-E. Alluvial Gravel

Photographs I : Surfacing Material Types

II-A. Eroded Non-Graded Crushed Stone Material. Lau Cai

II-B Road Surface Erosion of Non-Graded Crushed Stone Material. Lau Cai

Photographs II : Non-Graded Crushed Stone Erosion

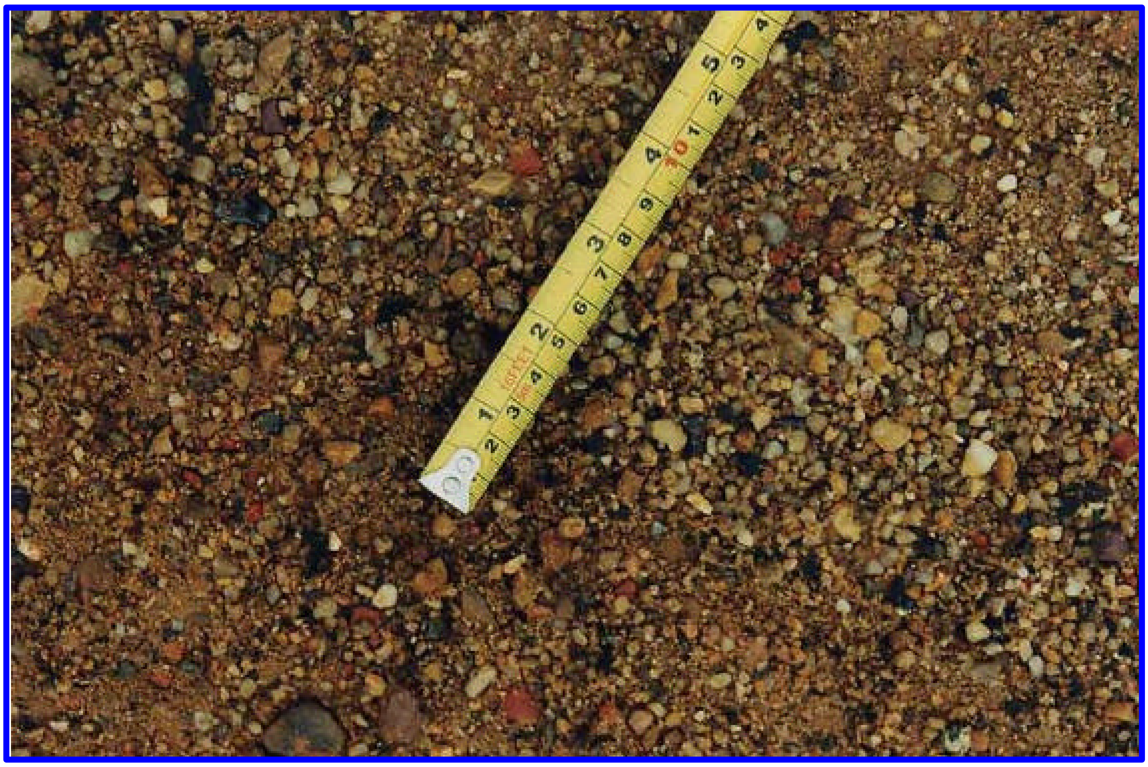

14:35

Photographs III : Impeded Run-off and Poor Side Drainage

Ph
oto

graph IV : Inappropriate Material Use for Maintenance

Photographs V : Gravel eroded within 1 year on steep gradient. However underlying material is stronger, suggesting that an Engineered Natural Surface or other use of the insitu material would have been more appropriate



Photographs VI : Examples of Poorly Graded Gravel

Photographs VII : Lack of Routine Maintenance leads to accelerated deterioration

Photographs VIII : Dust emissions & material loss in dry weather

RURAL ROAD GRAVEL ASSESSMENT PROGRAMME (RRGAP)

Module 4 – Data Analysis

APPENDIX A
MATERIAL LOSS SUMMARY

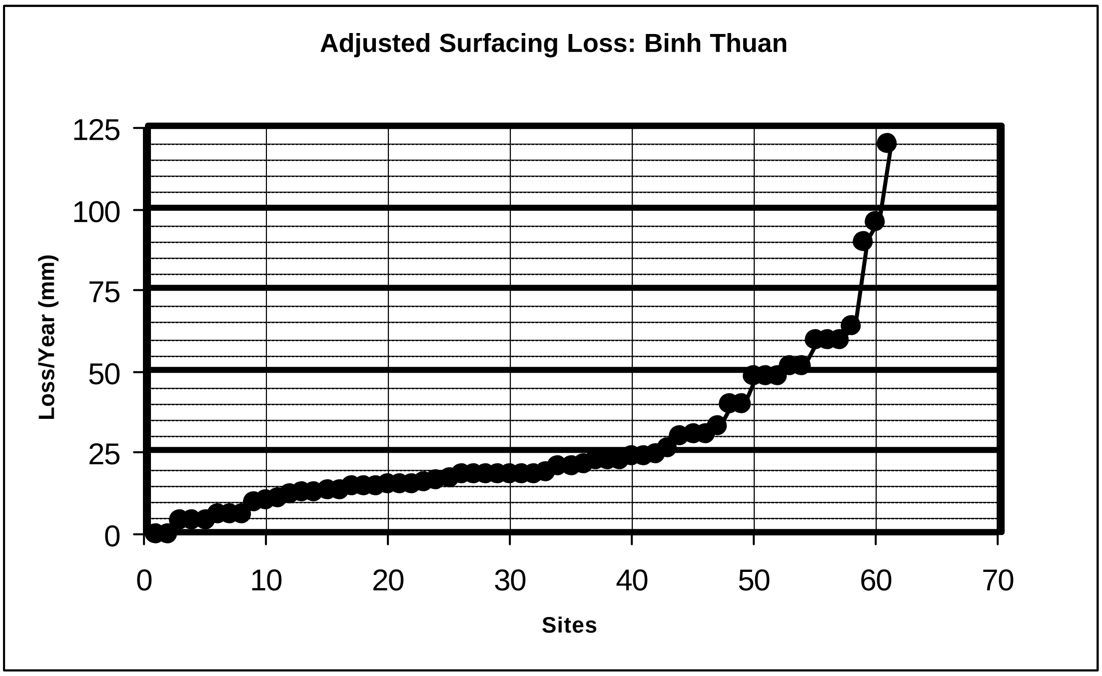


Figure A1 Surfacing Loss Figures for Binh Thuan Province

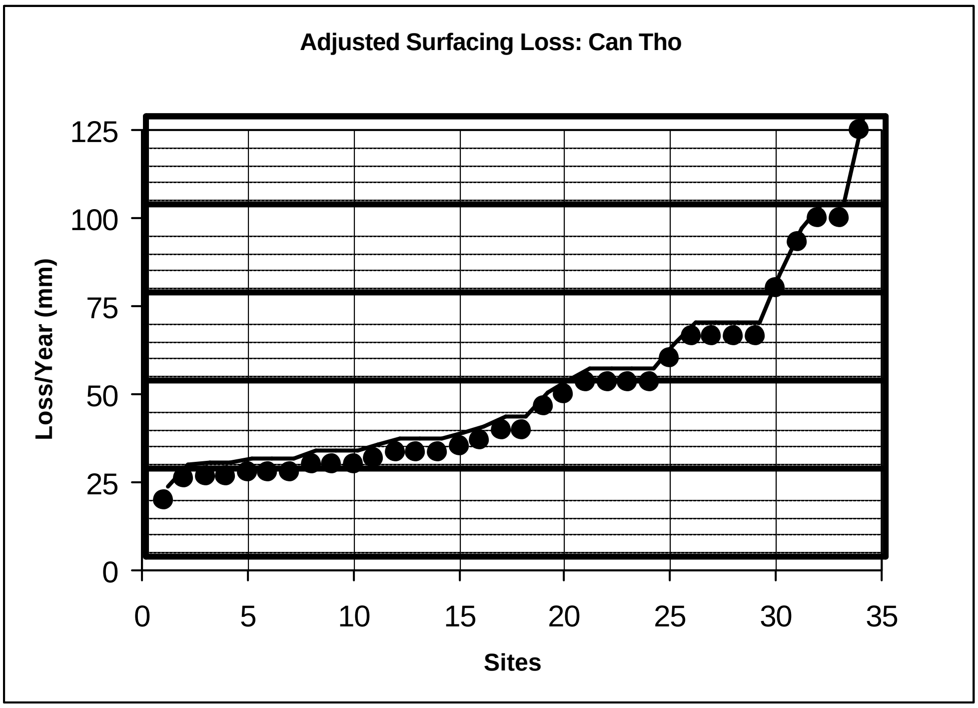


Figure A2 Surfacing Loss Figures for Can Tho Province

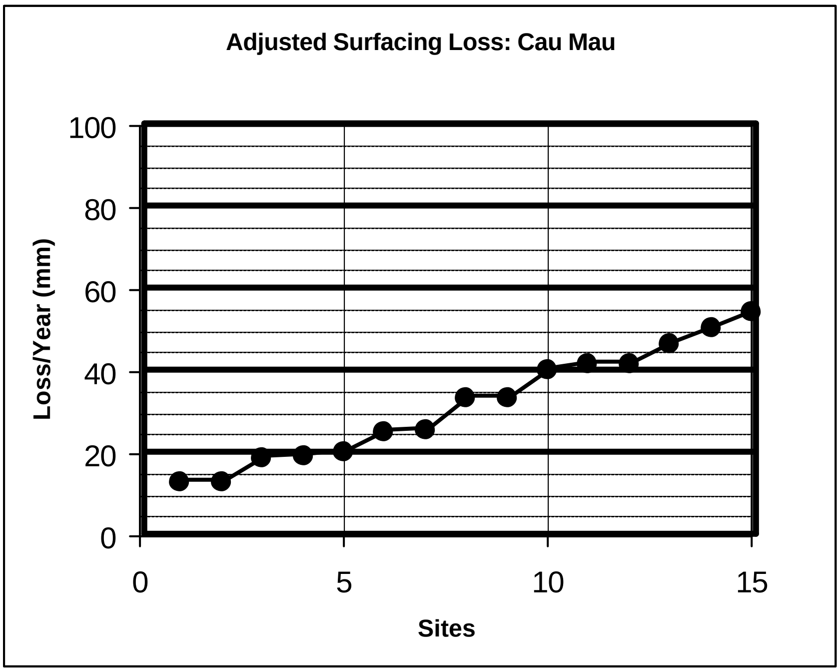


Figure A3 Surfacing Loss Figures for Ca Mau Province

Figure A4 Surfacing Loss Figures for Dien Bien Province

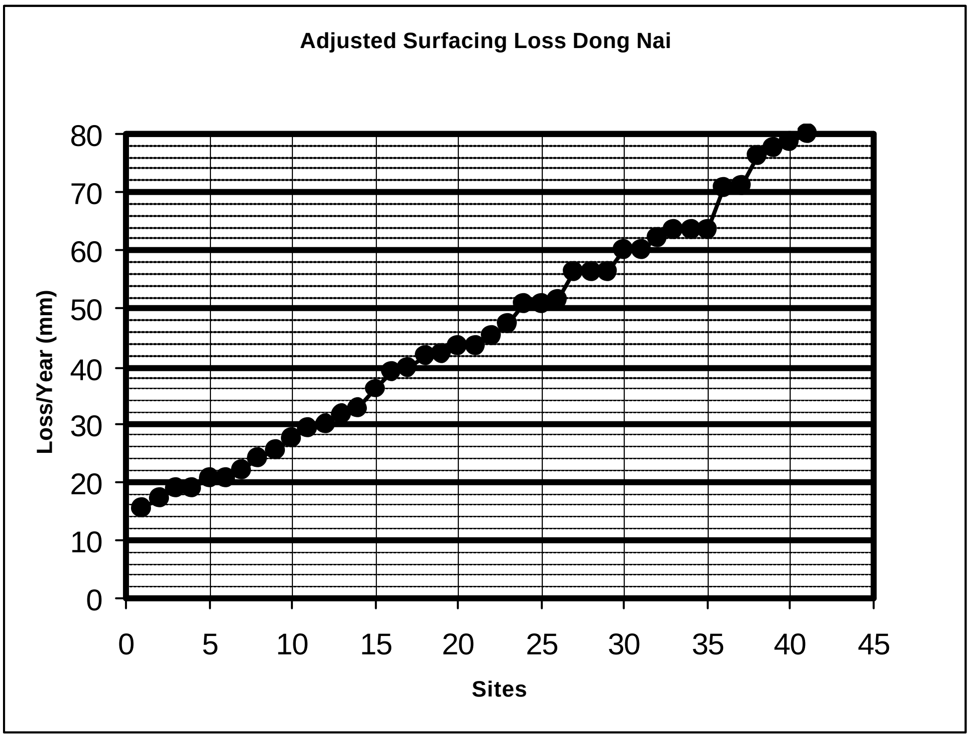


Figure A5 Surfacing Loss Figures for Dong Nai Province

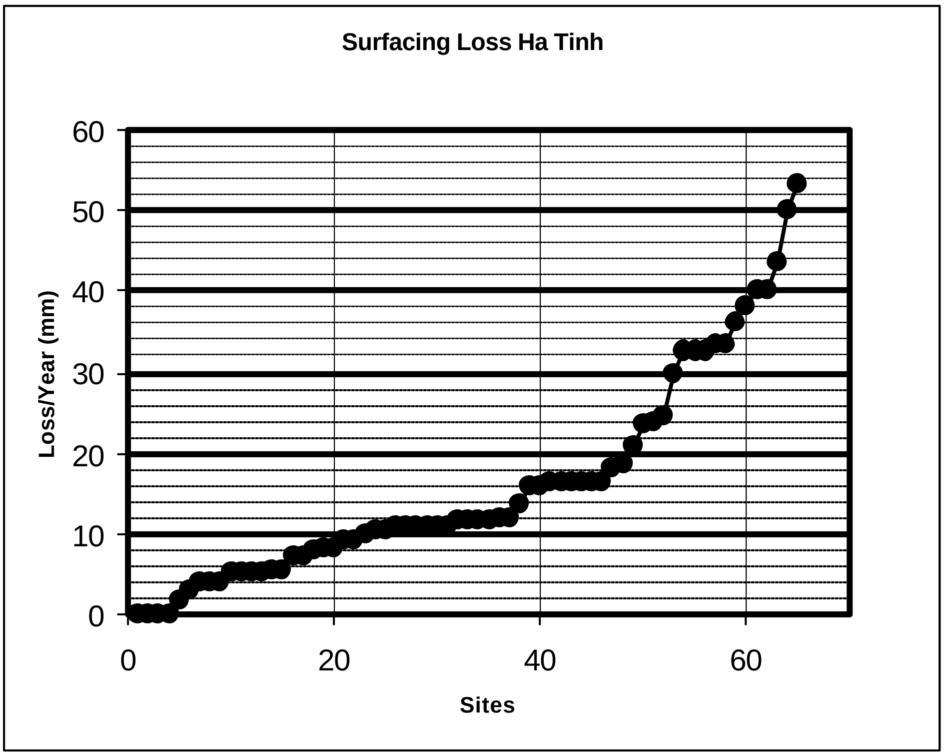


Figure A6 Surfacing Loss Figures for Ha Tinh Province

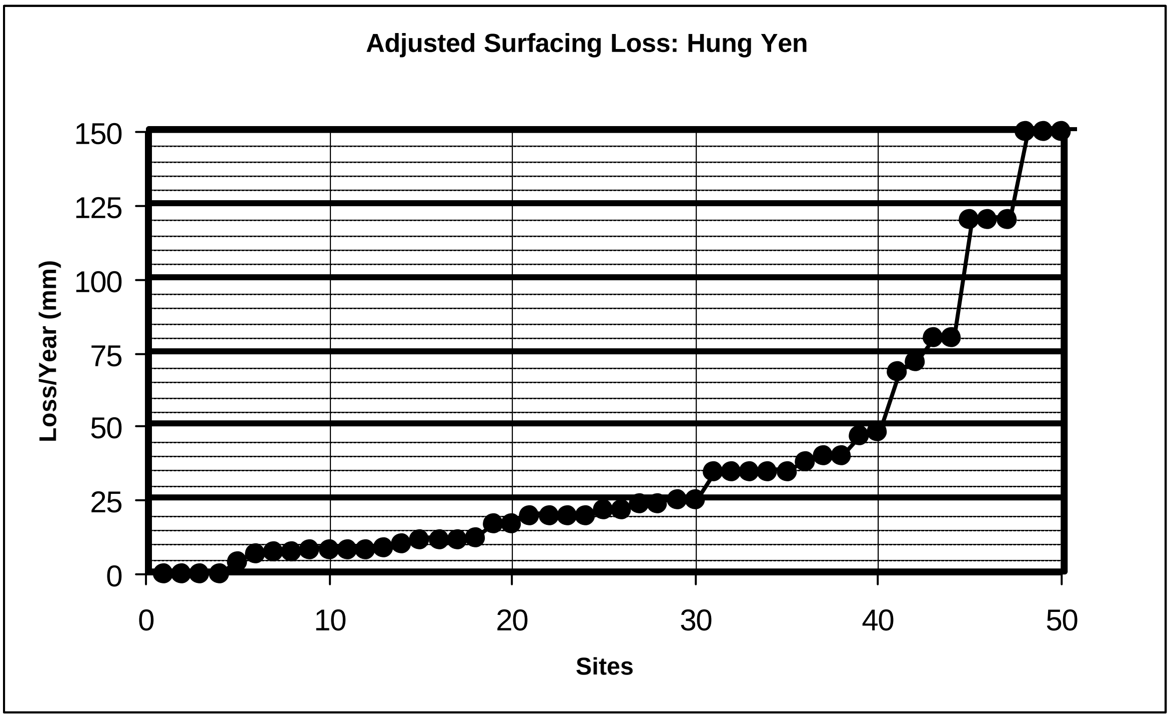


Figure A7 Surfacing Loss Figures for Hung Yen Province

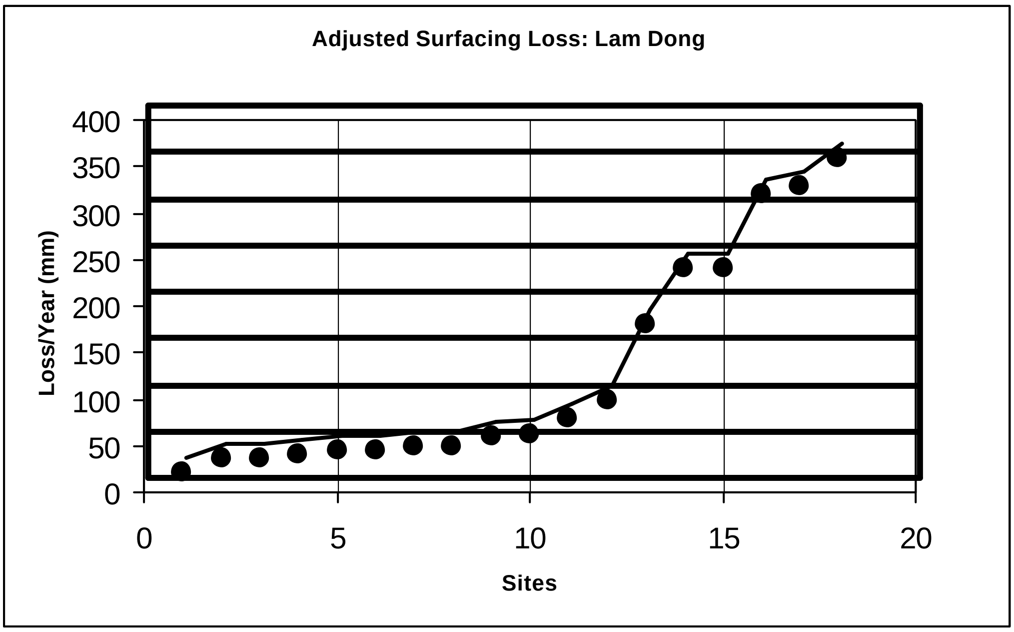


Figure A8 Surfacing Loss Figures for Lam Dong Province

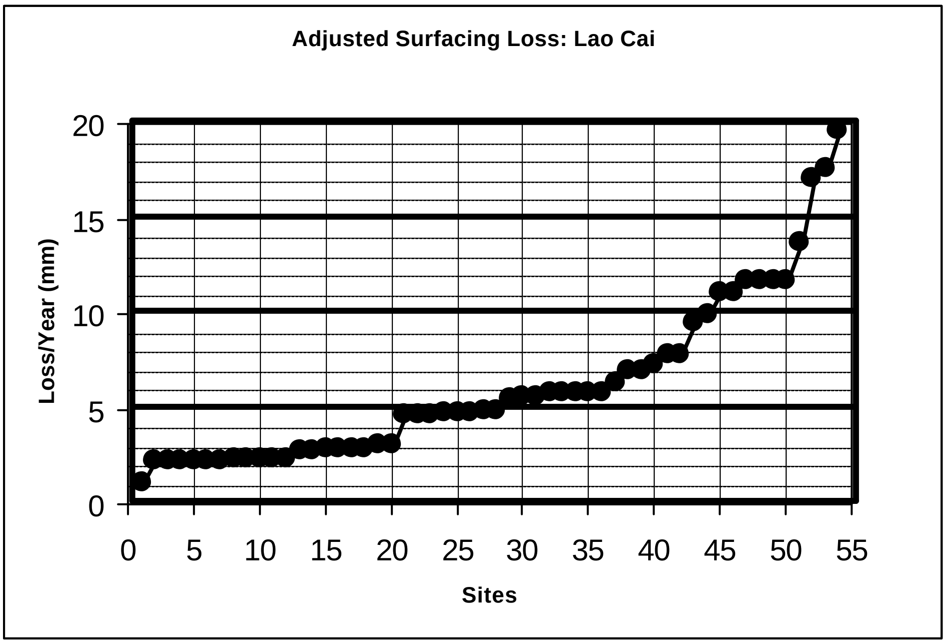


Figure A9 Surfacing Loss Figures for Lao Cai Province

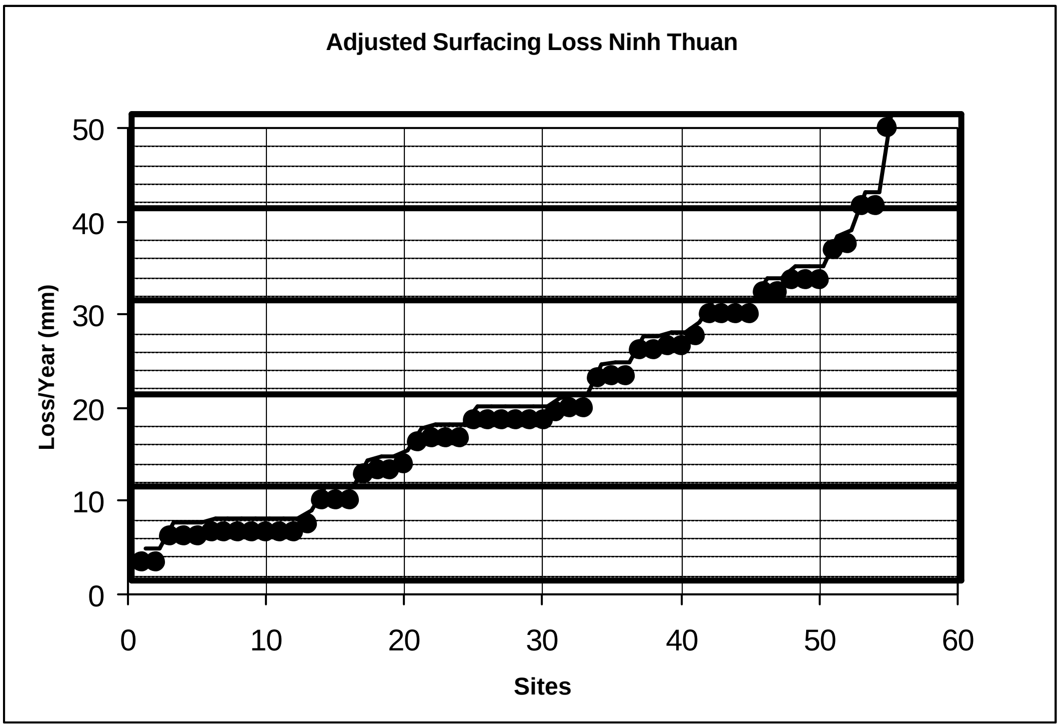


Figure A10 Surfacing Loss Figures for Ninh Thuan Province

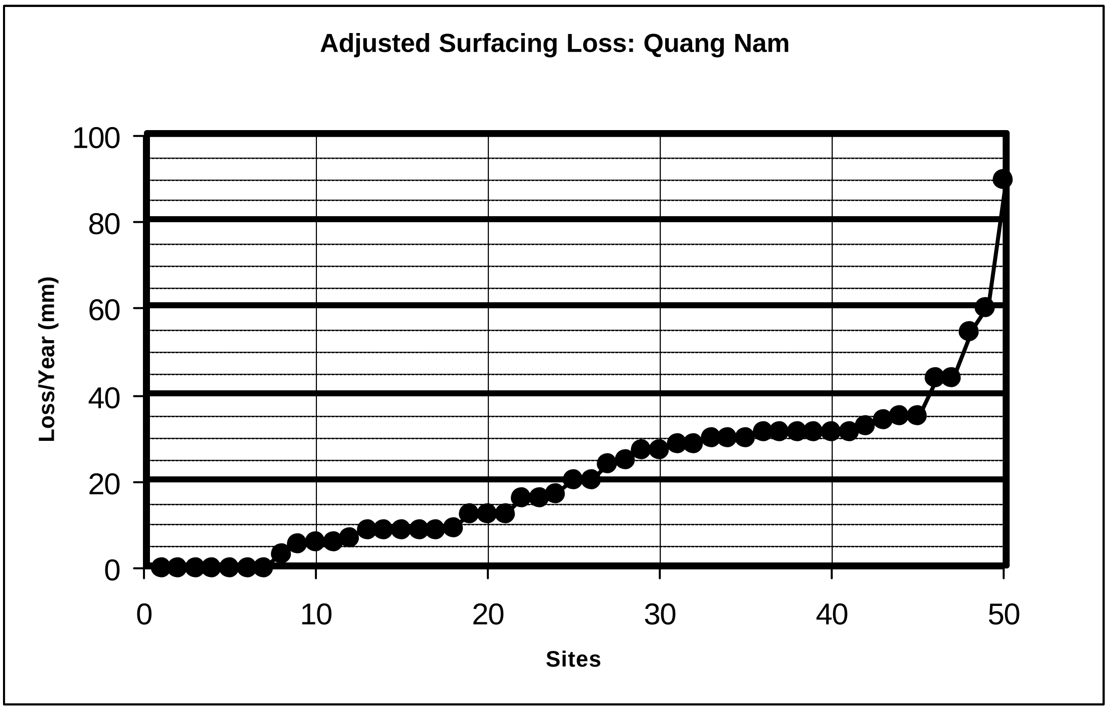


Figure A11 Surfacing Loss Figures for Quang Nam Province

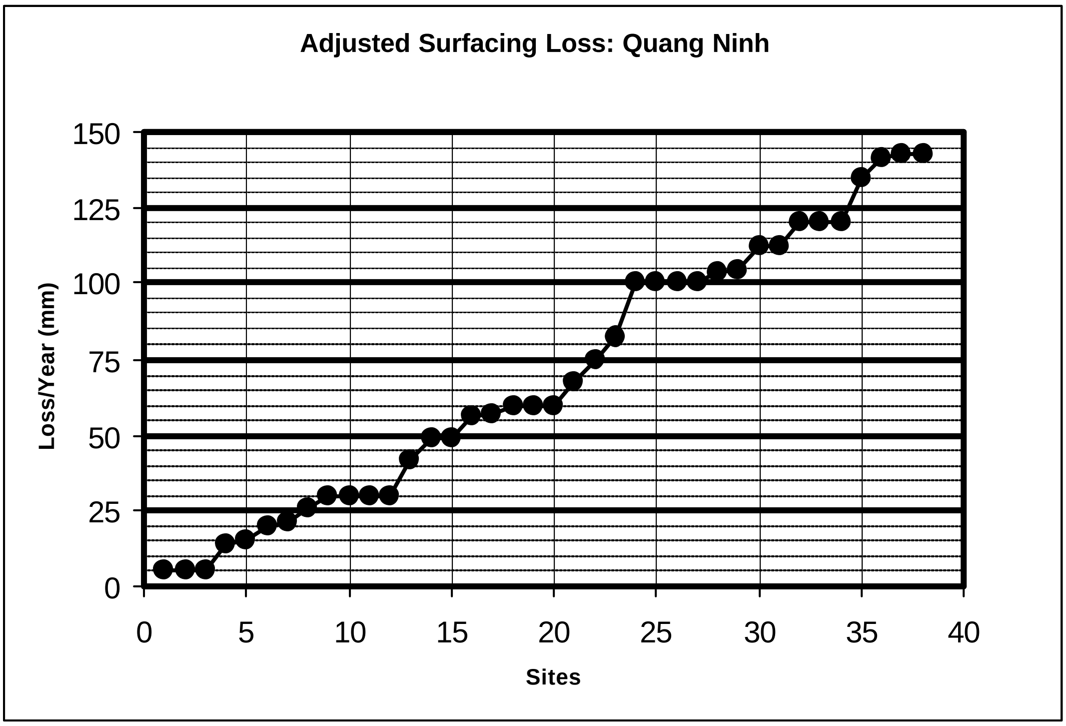


Figure A12 Surfacing Loss Figures for Quang Ninh Province

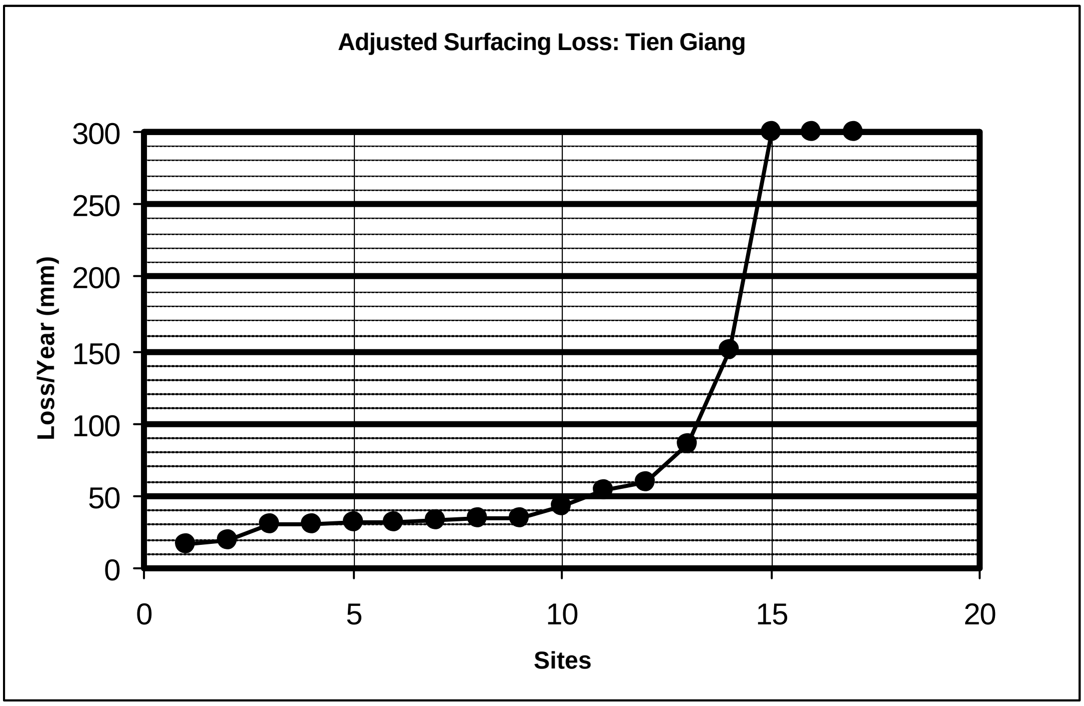


Figure A13 Surfacing Loss Figures for Tien Giang Province

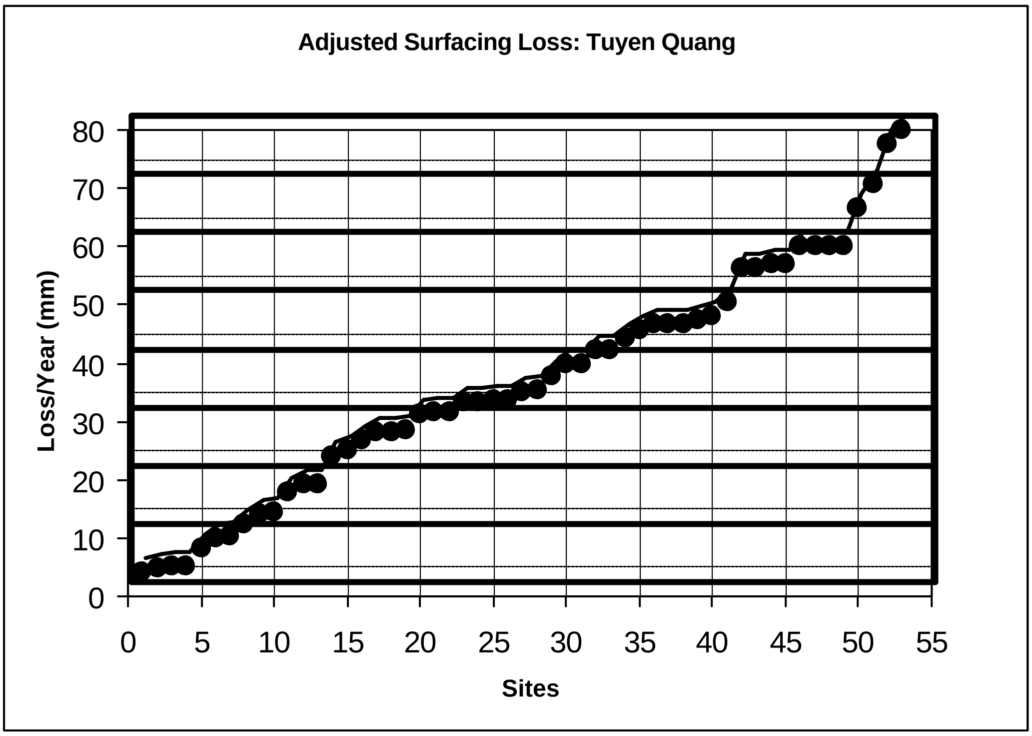


Figure A14 Surfacing Loss Figures for Tuyen Quang Province

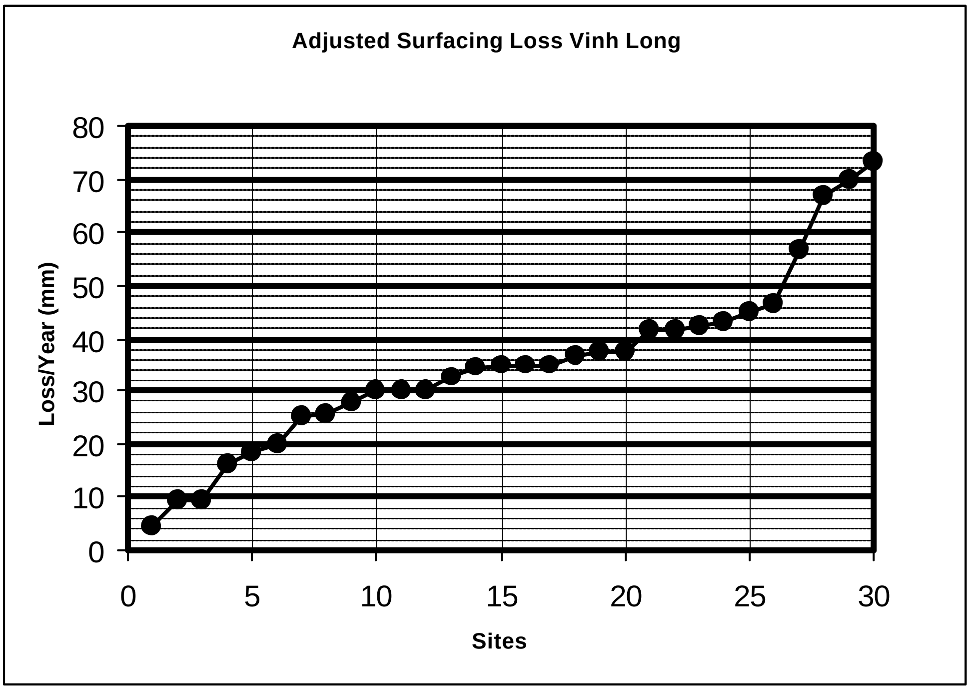


Figure A15 Surfacing Loss Figures for Vinh Long Province

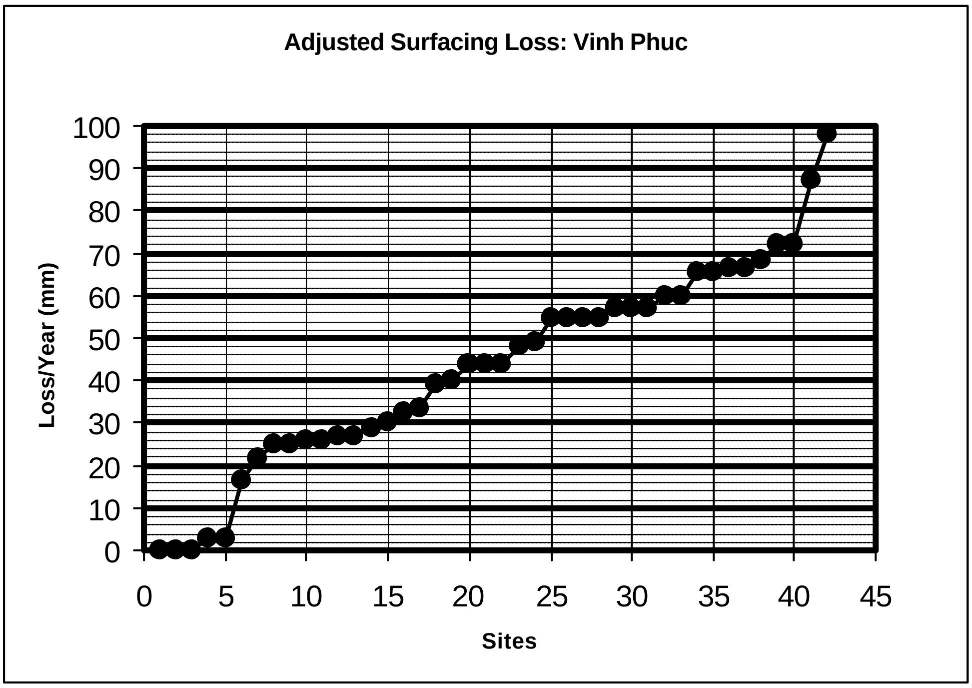


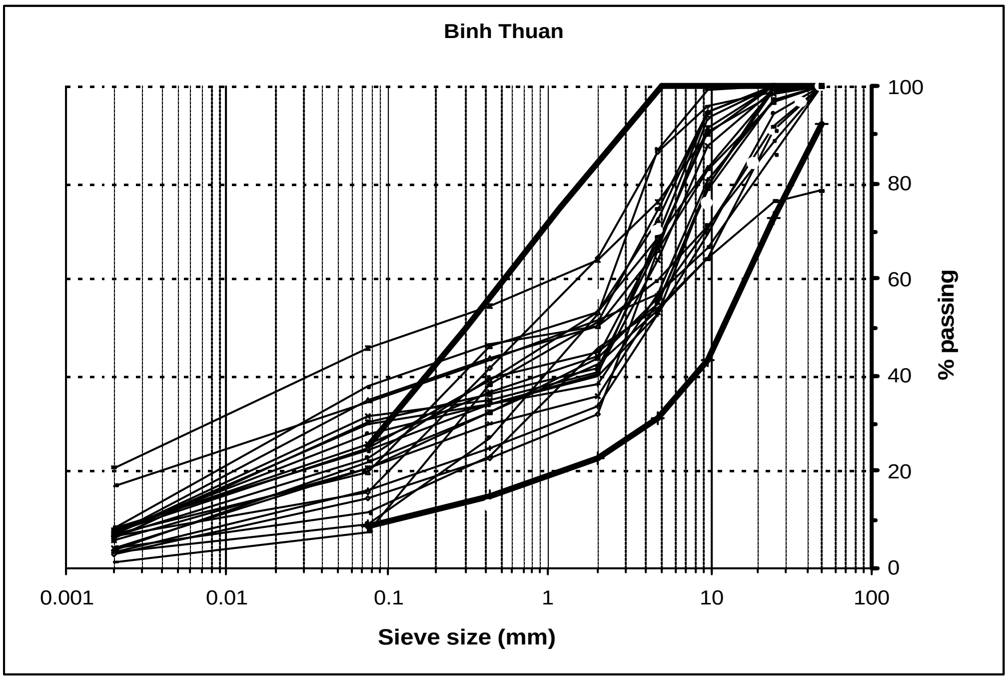
Figure A16 Surfacing Loss Figures for Vinh Phuc Province

RURAL ROAD GRAVEL ASSESSMENT PROGRAMME (RRGAP)

Module 4 – Data Analysis

APPENDIX B

LABORATORY TEST SUMMARY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% passing
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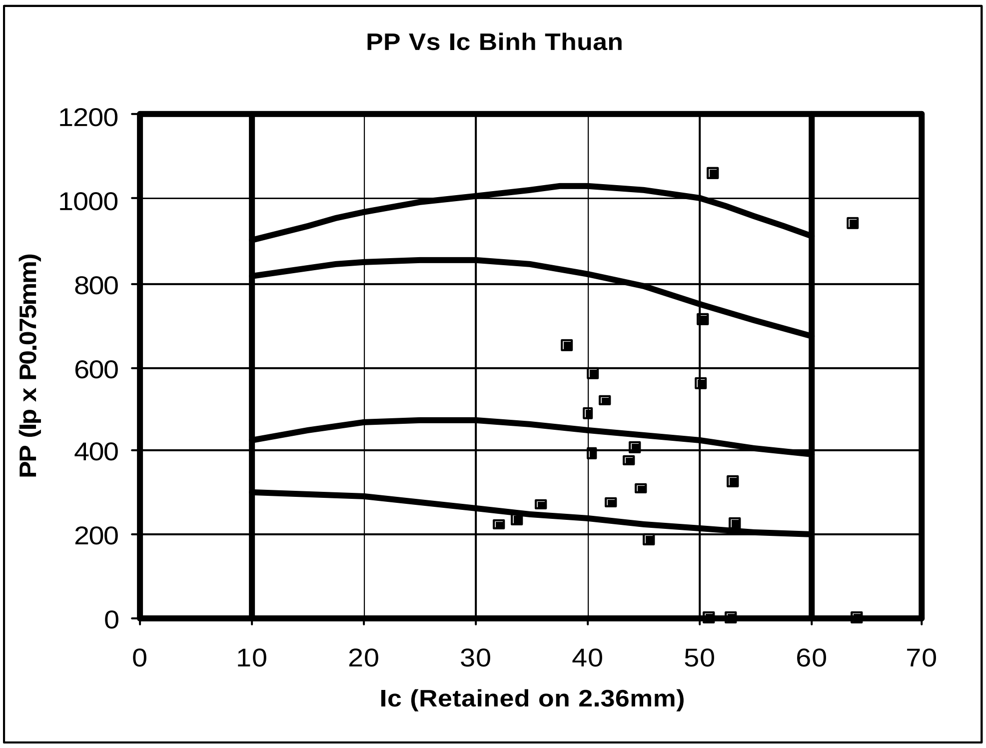
Sieve size (mm)


PP Vs Ic Binh Thuan
1200
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200
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PP (Ip x P0.075mm)
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Ic (Retained on 2.36mm)

Figure B1 Grading and Plasticity Summaries: Binh Thuan Province

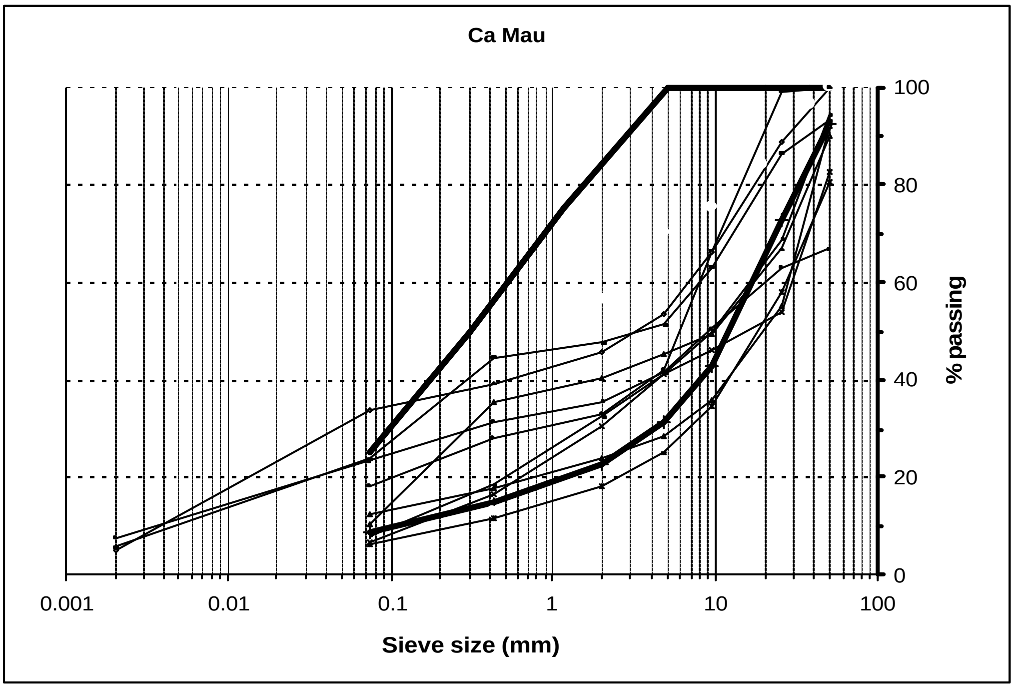


Figure B2 Grading Summary: Ca Mau Province

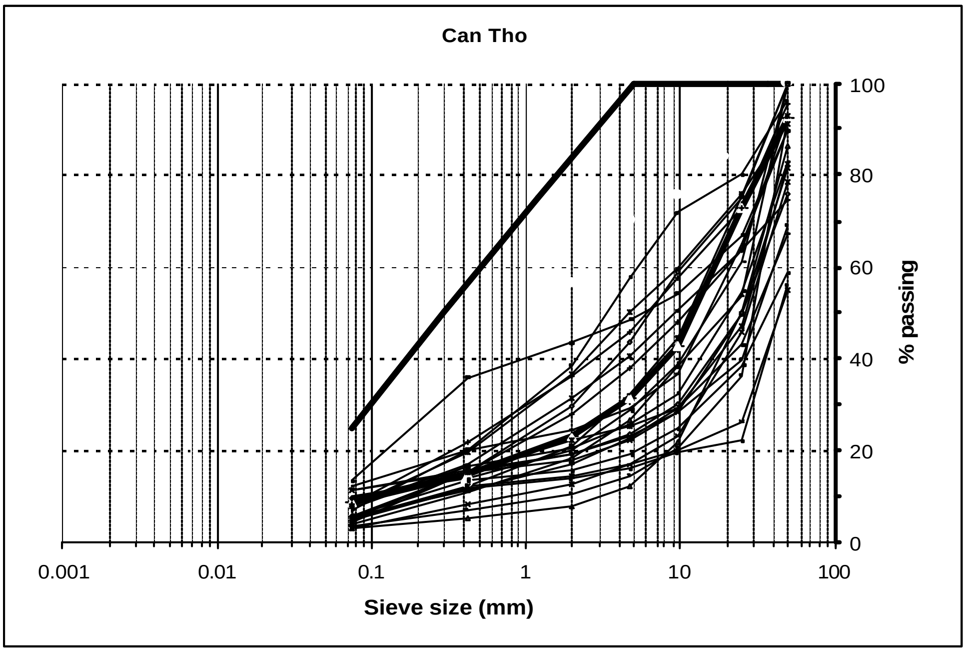
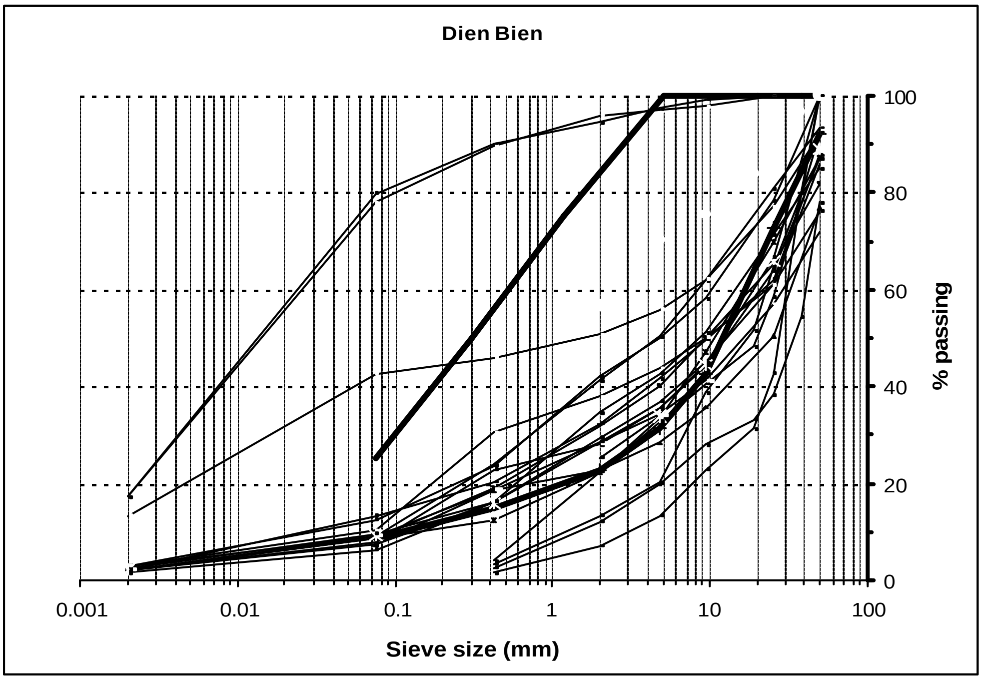


Figure B3 Grading Summary: Can Tho Province


Dien Bien
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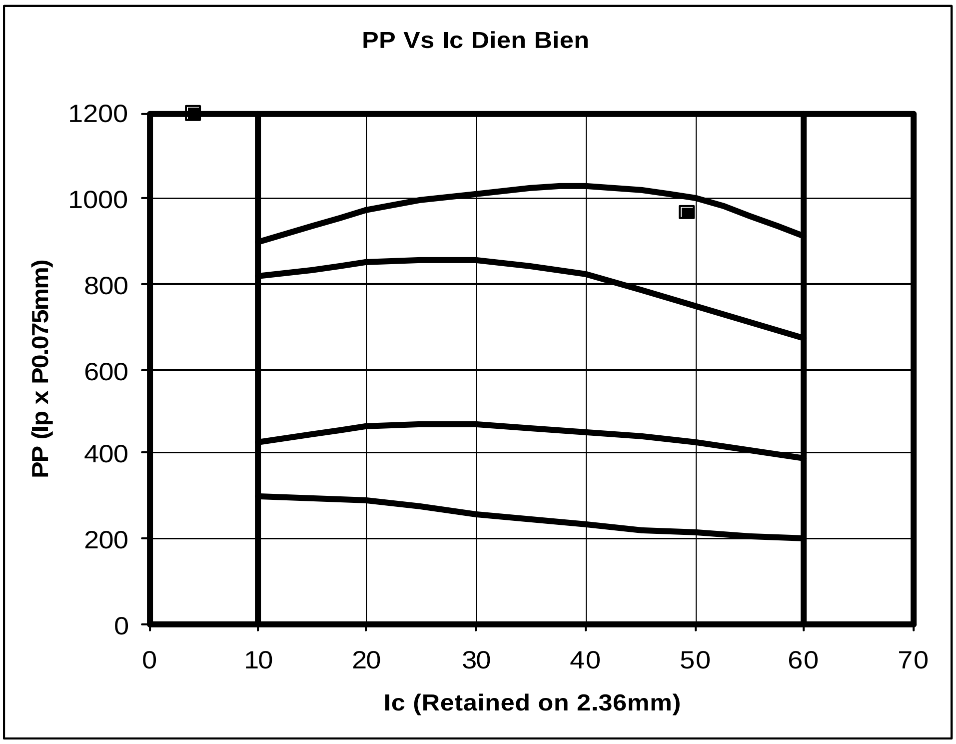
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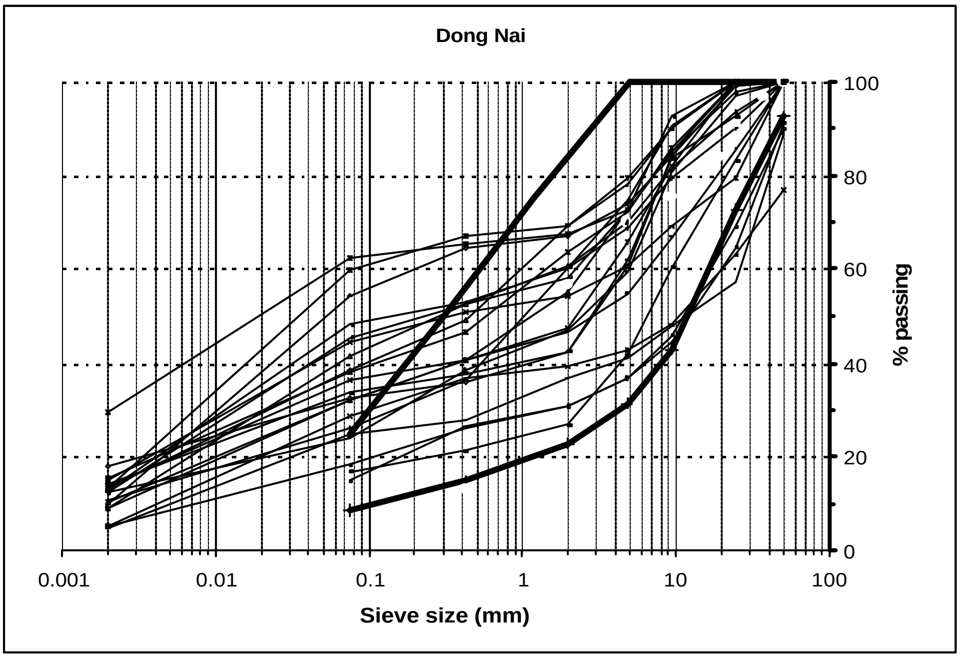
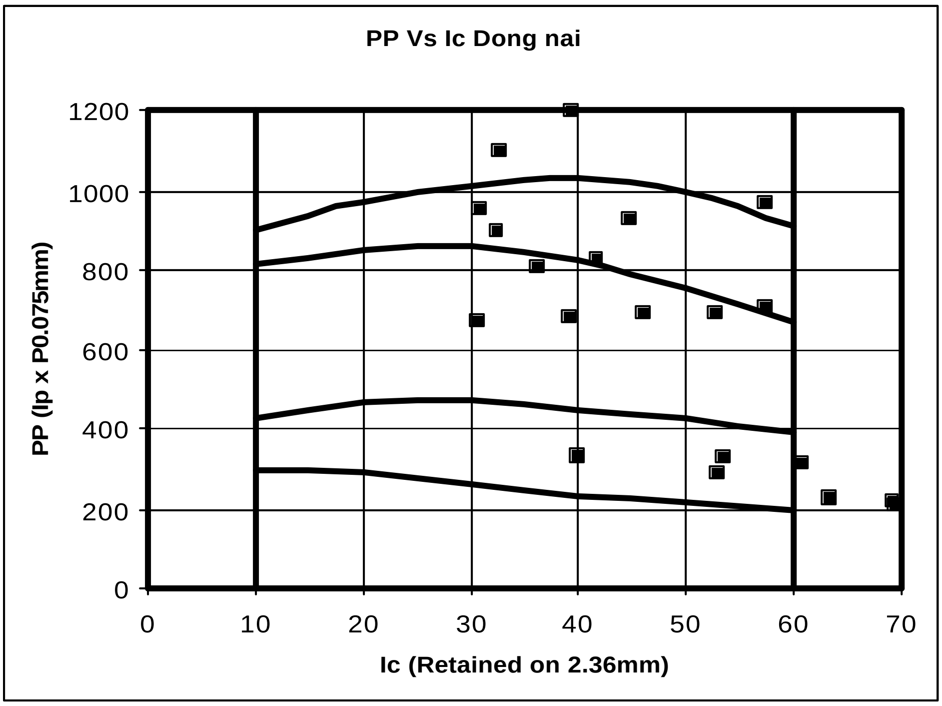
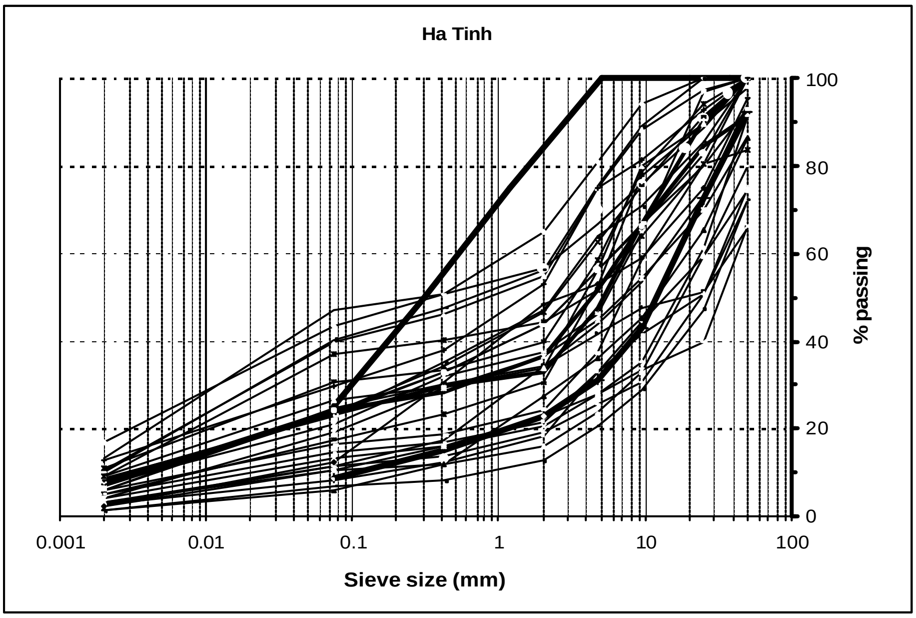
Ic (Retained on 2.36mm)

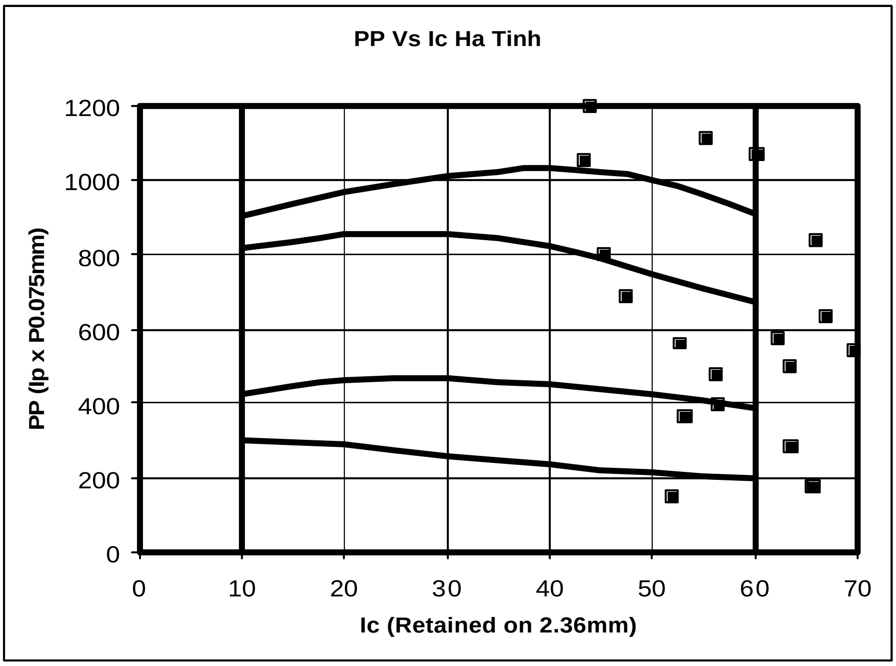
Figure B4 Grading and Plasticity Summaries: Dien Bien Province



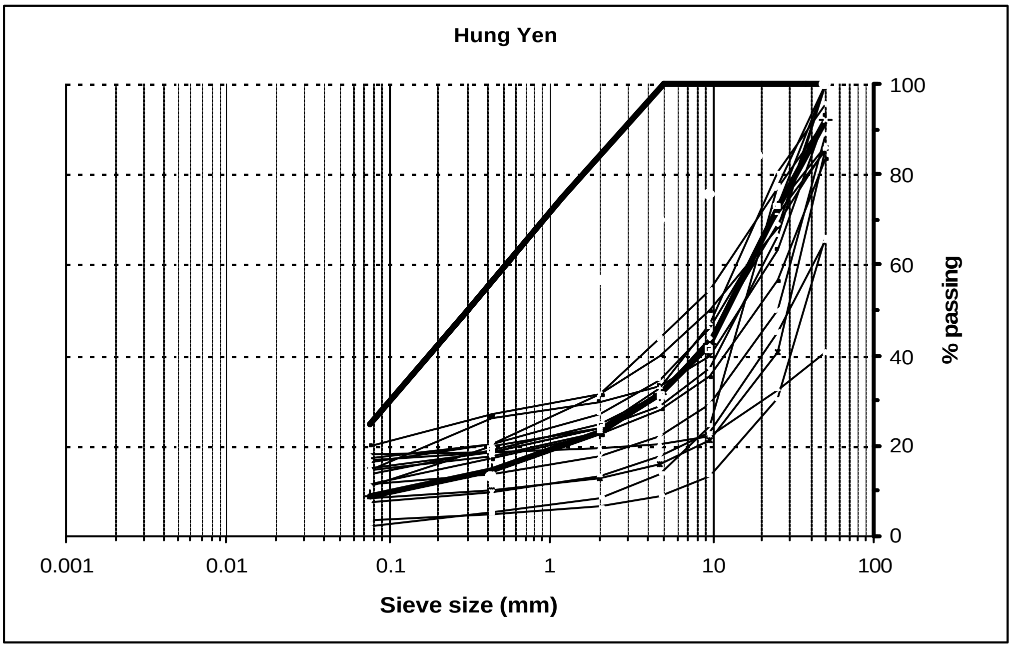


B5 Grading and Plasticity Summaries: Dong Nai Province

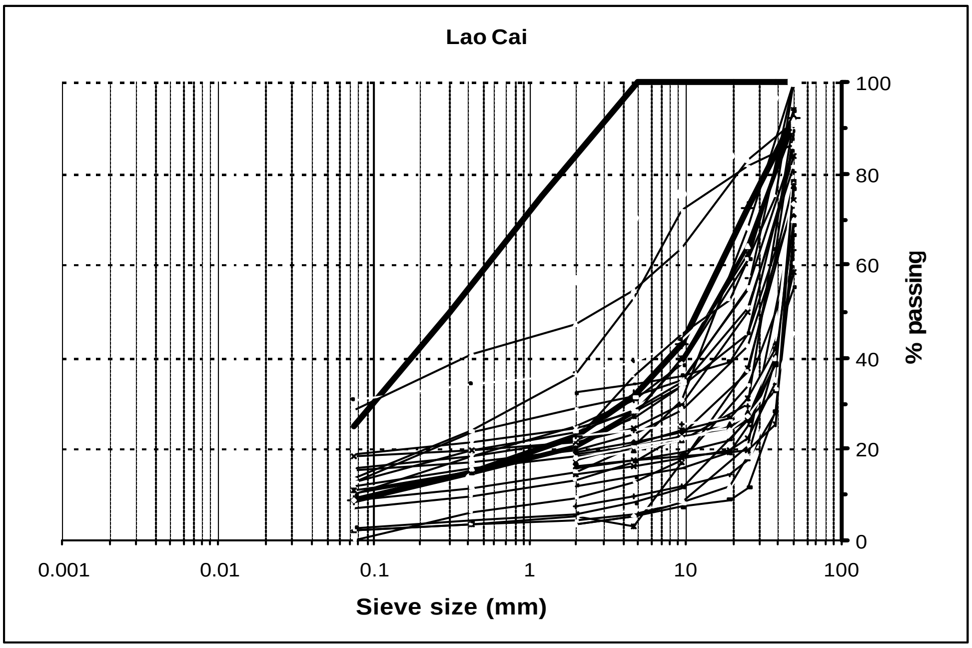




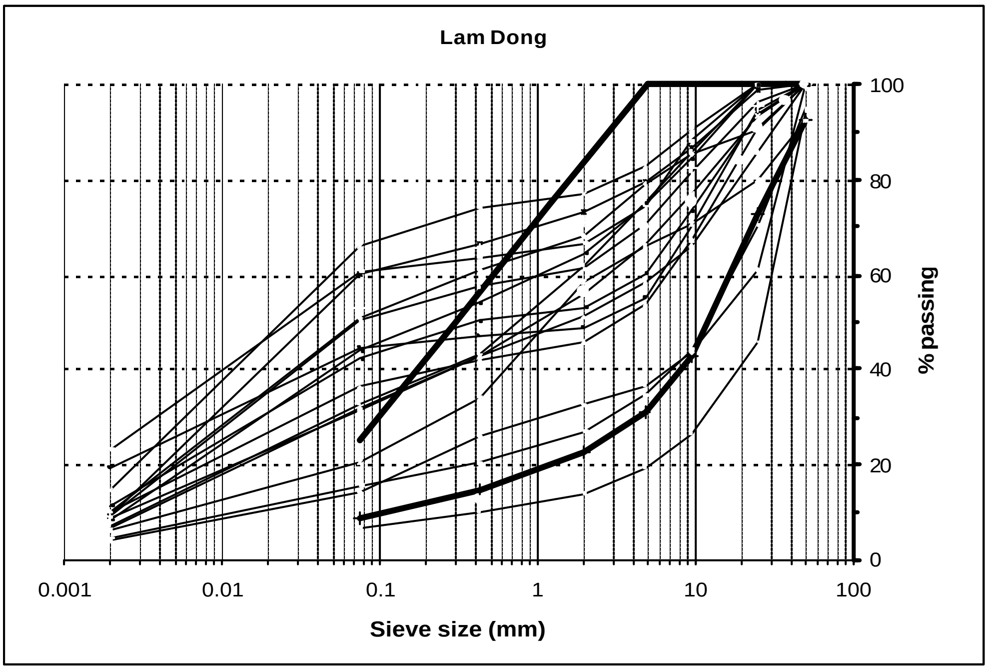
B6 Grading and Plasticity Summaries: Ha Tinh Province



B7 Grading Summary: Hung Yen Province



B8 Grading Summary: Lao Cai Province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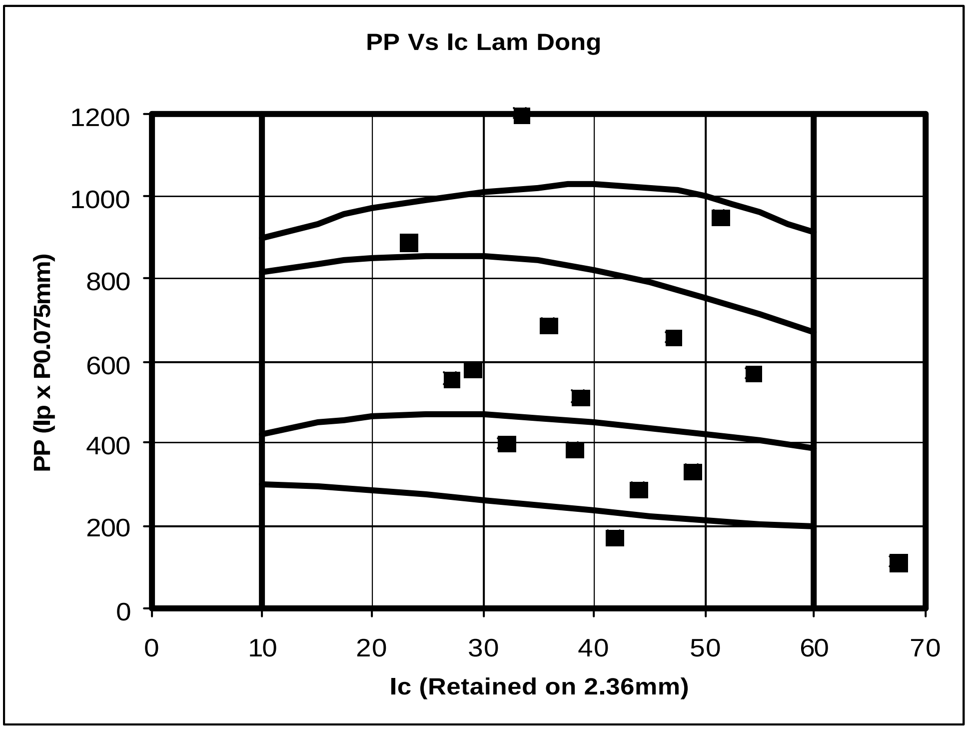
Sieve size (mm)


PP Vs Ic Lam Dong
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PP (Ip x P0.075mm)
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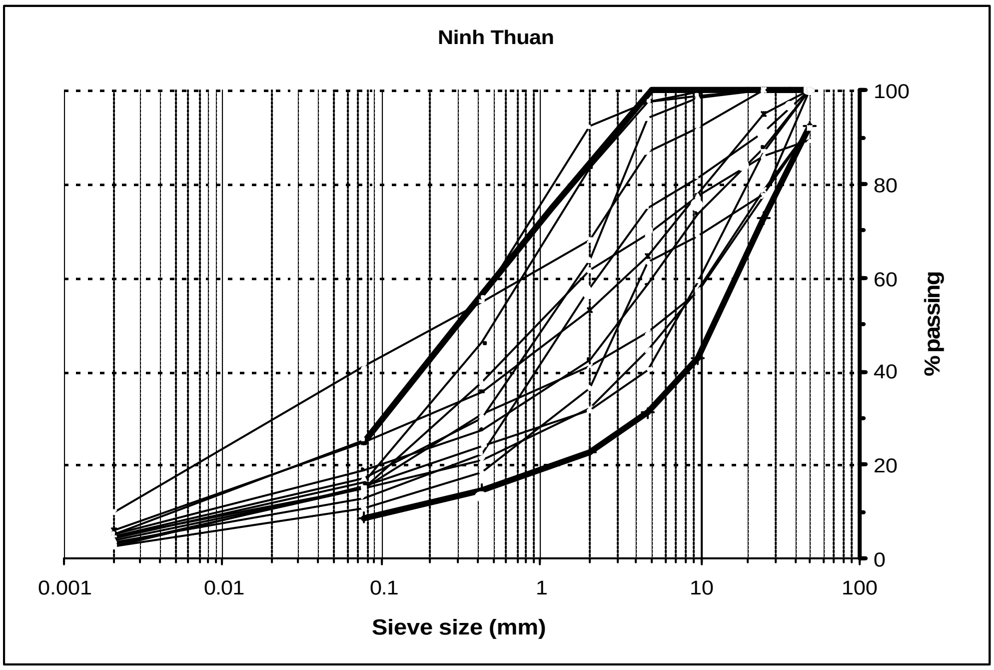
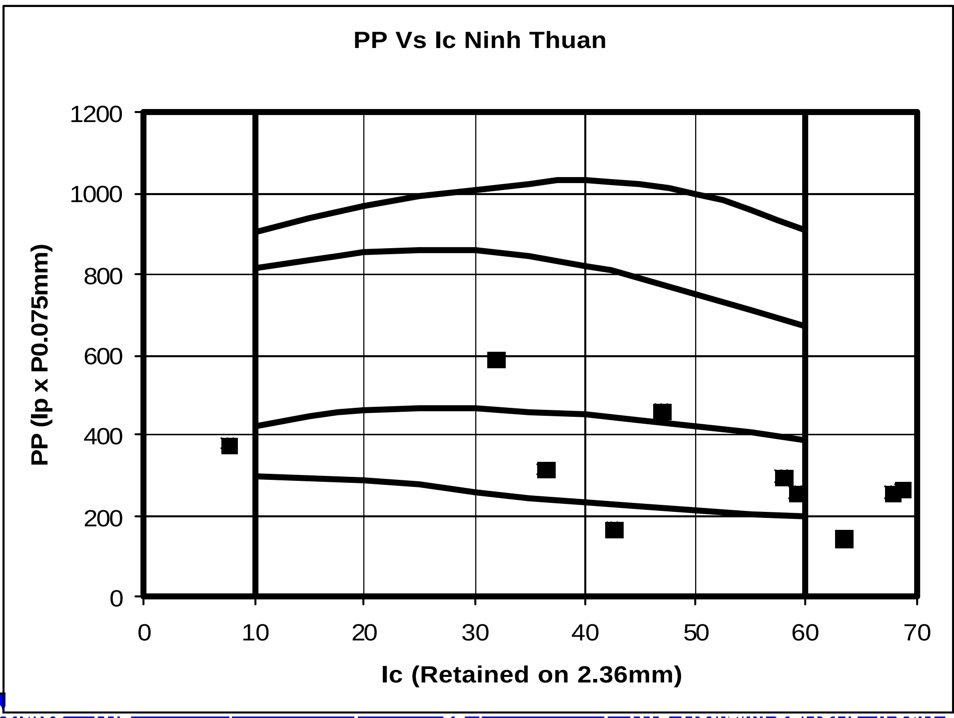
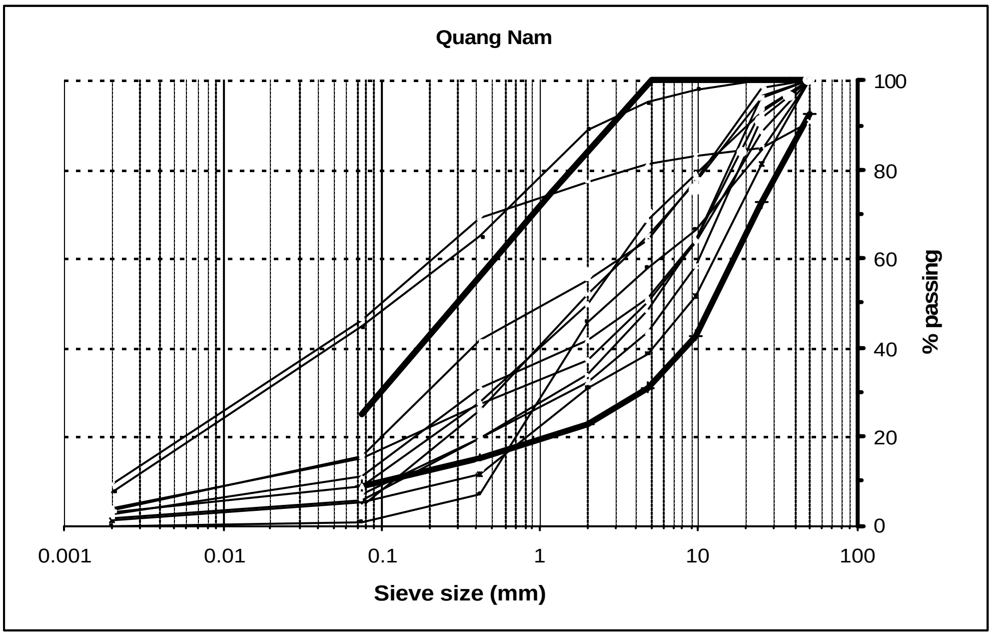
Ic (Retained on 2.36mm)

B9 Grading and Plasticity Summaries: Lam Dong Province





B10 Grading and Plasticity Summaries: Ninh Thuan Province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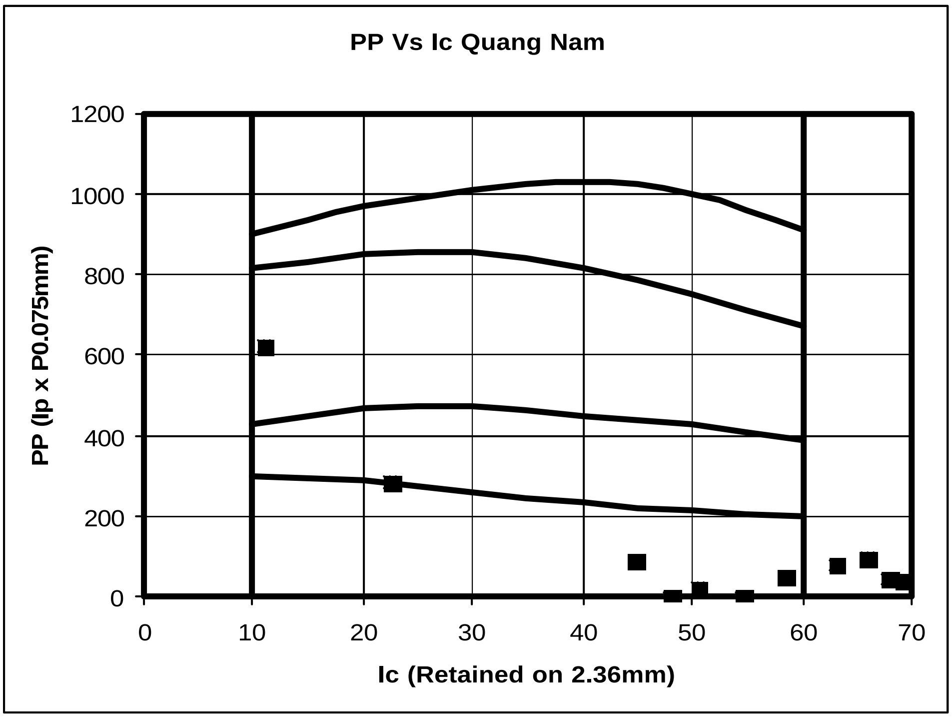
Sieve size (mm)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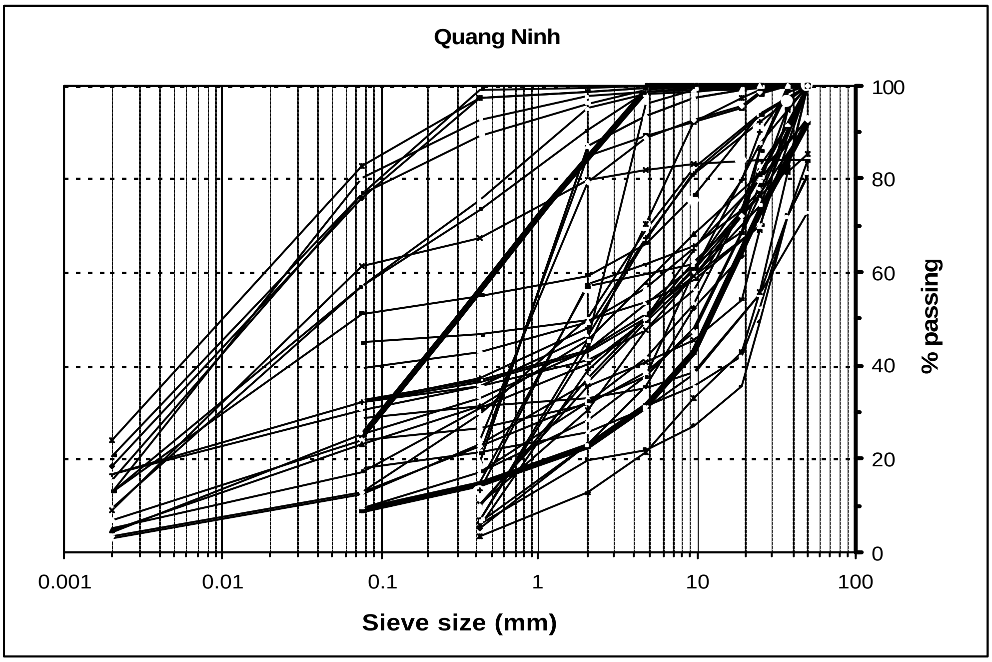
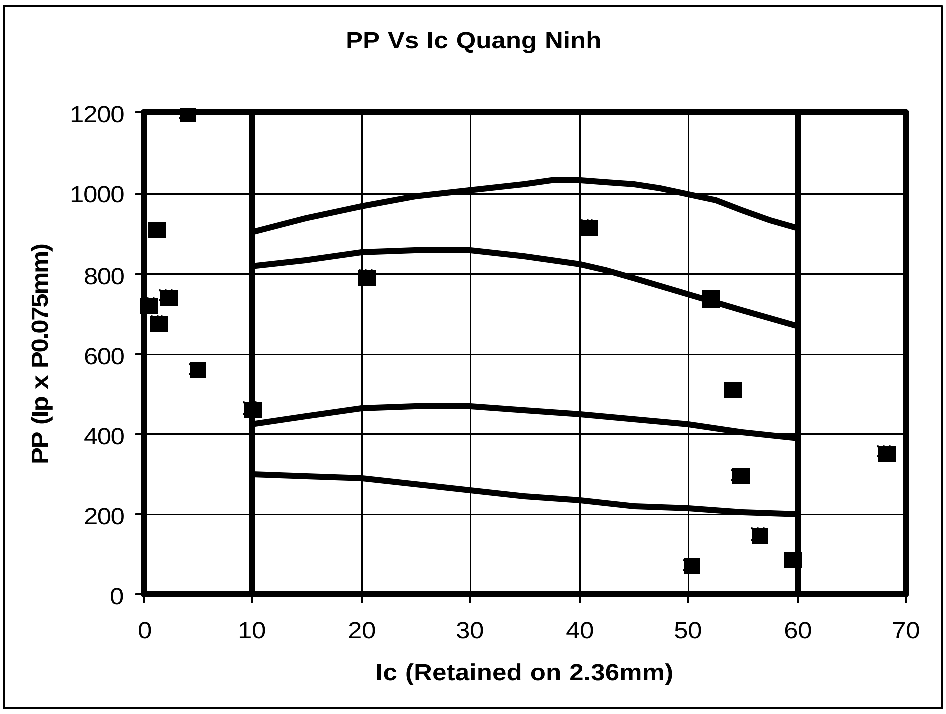
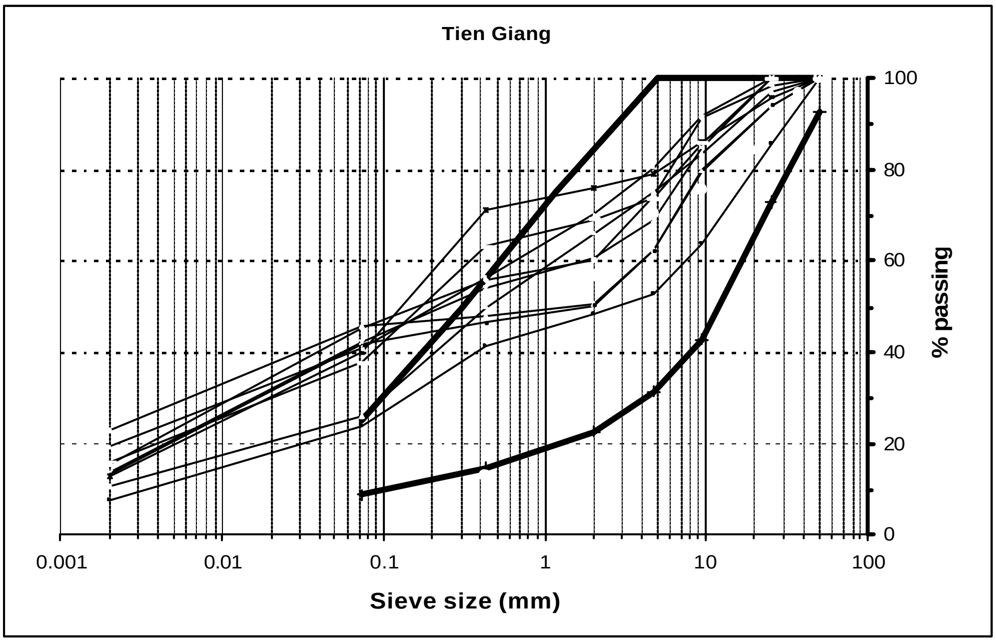
Ic (Retained on 2.36mm)

B11 Grading and Plasticity Summaries Quang Nam Province





B12 Grading and Plasticity Summaries: Quang Ninh Province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0.01
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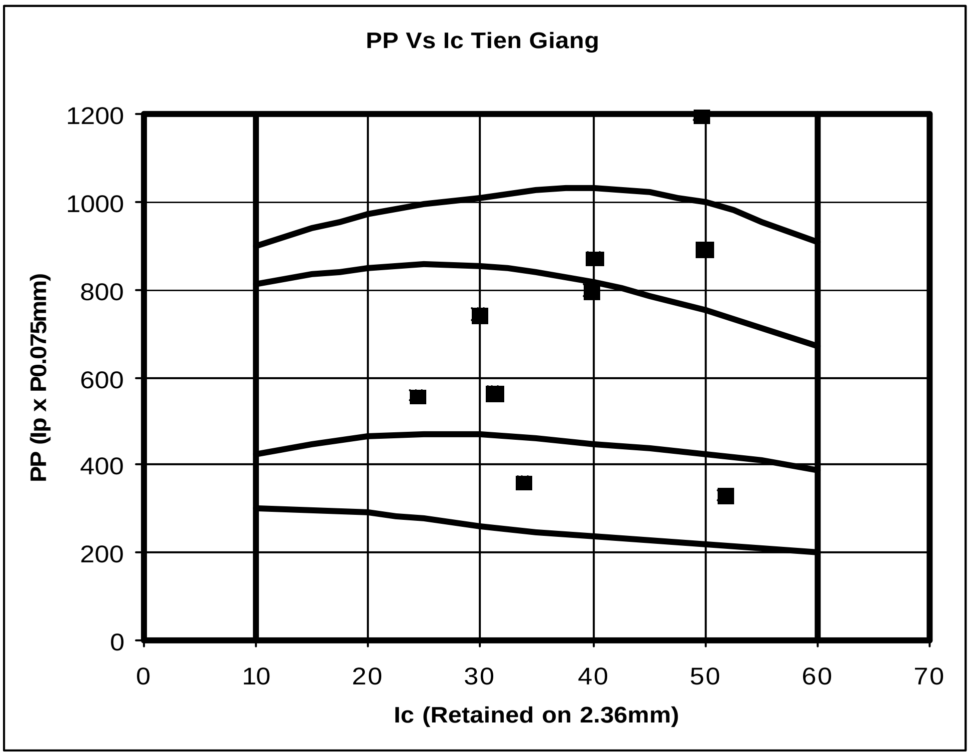
100
Sieve size (mm)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PP (Ip x P0.075mm)
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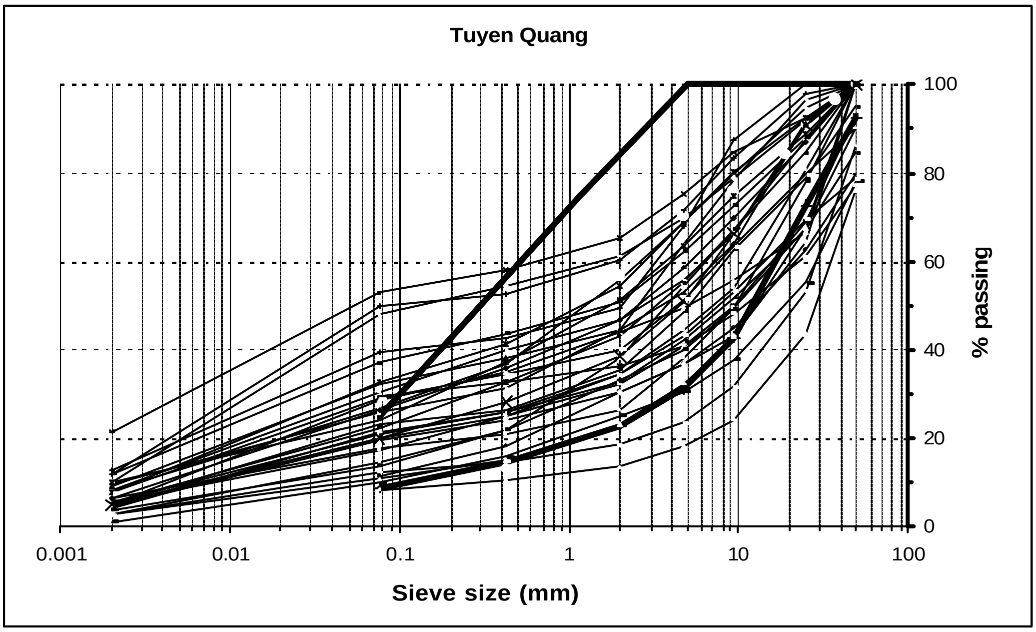
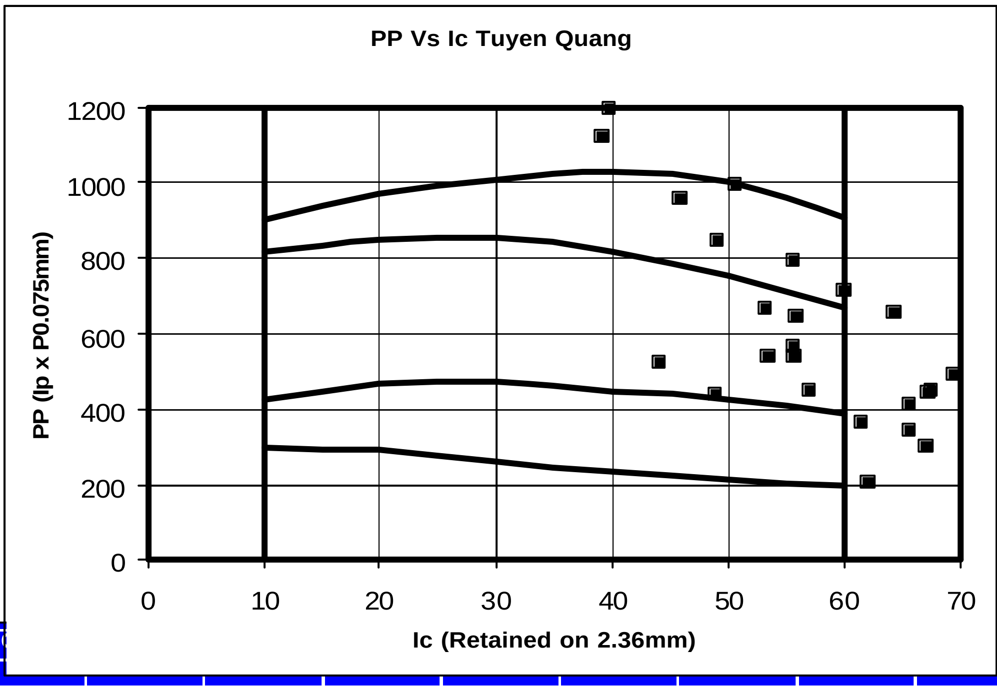
Ic (Retained on 2.36mm)

Figure B13 Grading and Plasticity Summaries: Tien Giang Province





B14 Grading and Plasticity Summaries: Tuyen Quang Province

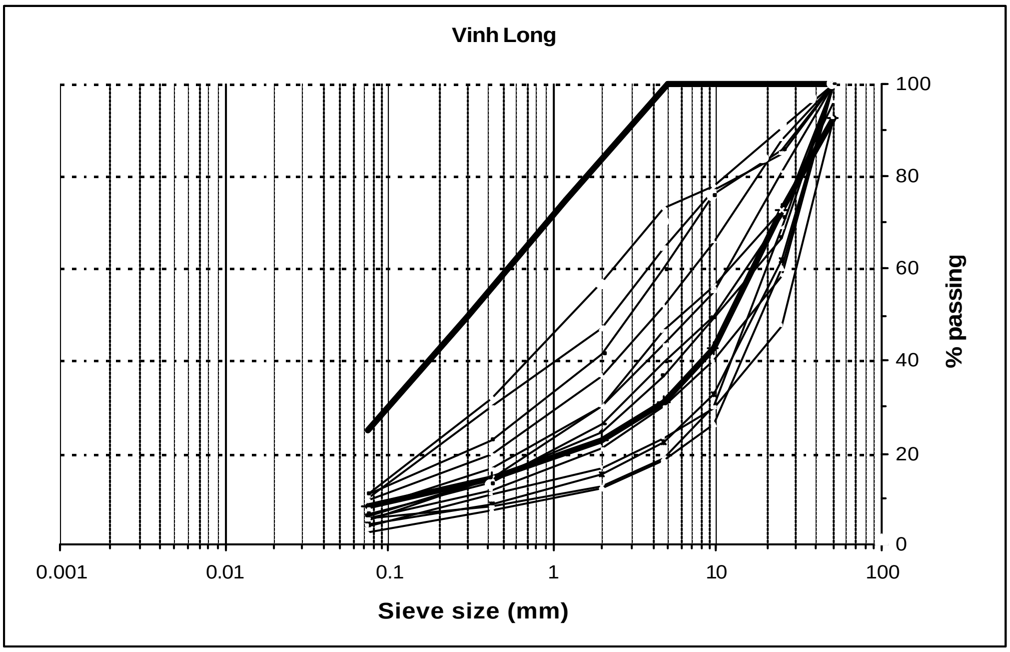
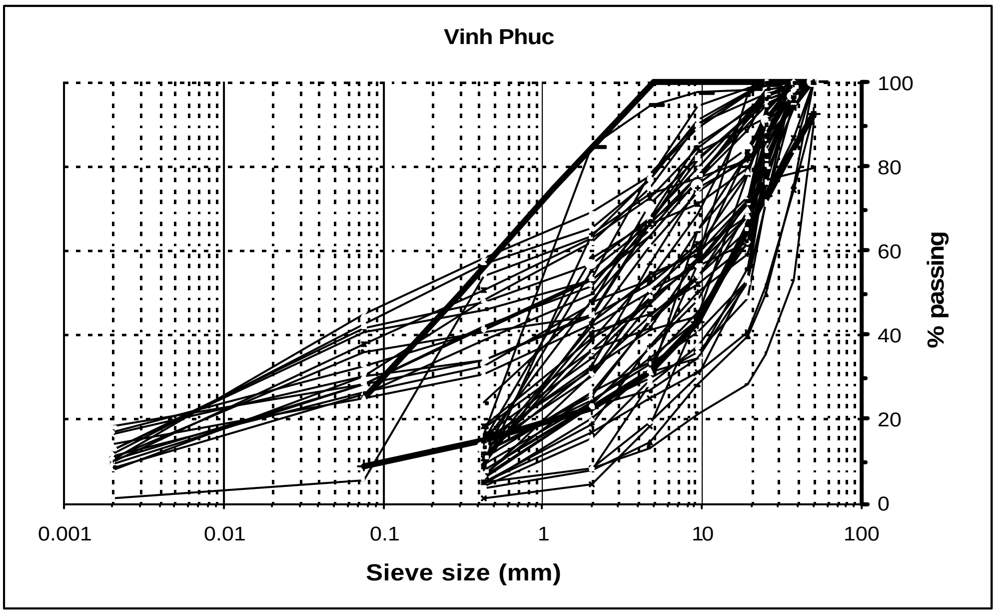


Figure B15 Grading Summary: Vinh Long Province



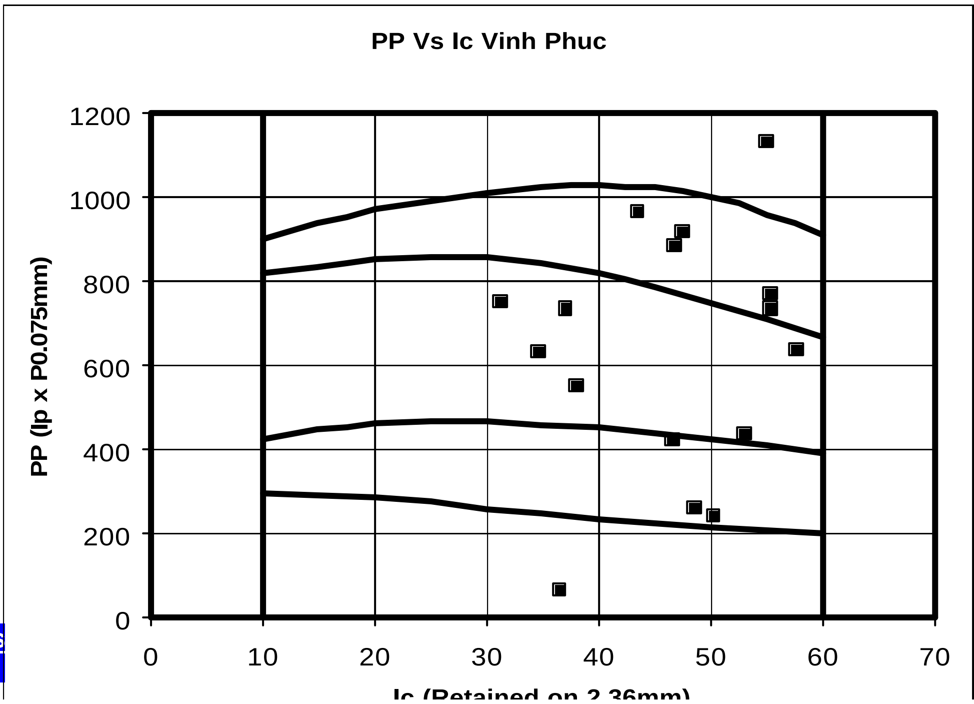


Figure B16 Grading and Plasticity Summaries: Vinh Phuc Province

RURAL ROAD GRAVEL ASSESSMENT PROGRAMME (RRGAP)

Module 4 – Data Analysis

APPENDIX C
SUSTAINABLE GRAVEL LOSS ASSESSMENT

APPENDIX C

Sustainable Gravel Loss Assessment

The assessment of what is a sustainable level of material loss from a gravel rural road surface is necessarily subjective and based on the local physical and operational circumstances for the road.

The assessment should consider the following factors:-

1. The expected rate of loss of gravel from the road surface, depending on circumstances of traffic, material type and quality, gradient, rainfall etc.
2. The financial resources likely to be available to arrange for routine maintenance and periodic regravelling,
3. The organisational capacity to carry out routine maintenance and periodic maintenance re-gravelling, and risks associated with timely intervention (or not),
4. The environmental issues relating to the consumption of a finite resource

The economic evaluation of whole life costs in terms of initial provision and regular and timely maintenance should also be carried out depending on local circumstances.

These factor are considered below.

1. Expected Rate of Gravel Loss

The RRGAP studies have demonstrated that surface gravel loss in Vietnam ranges from about zero to more than 200mm/year in the variety of factors and conditions experienced in the country. Research[1] from other countries has also enabled gravel loss predictions to be made based on experience in generally lower rainfall environments than Vietnam experiences.

Typically an initial gravel surface layer of 200mm is laid on the in situ soil formation/foundation. A gravel loss rate of 20mm/year means that a regravelling operation would be required to be arranged every 5 years when the residual gravel thickness falls to about 100mm. This is a reasonable trigger level to prevent the gravel layer failing over a substantial length of the road. Such an intervention would be required therefore every 5 years indefinitely, or until the road is upgraded to a more sustainable surface.

Gravel loss rates of less than 20mm/year would allow longer regravelling periods. Higher loss rates would shorten the regravelling period; e.g at a 40mm/year gravel loss rate the road would have to be fully regravelled every 30 months.

2. Financial implications

Full routine maintenance of a gravel road should cost about US$200 per km per year (VND3 million). With a haul distance of about 10km, the cost of a regravelling operation to place a 10cm layer on an existing gravel road would cost about US$2,500/km (VND37.5million). With a 20mm/year gravel loss, the total cost of maintenance comes to the equivalent of about US$700/km/year (VND10.5million).

[1] From TRL, see main document text.

Overall costs of full maintenance are shown in the table below based on these figures.

Table – Cost of maintenance for various gravel loss rates

Annual Gravel Loss (mm/year)	Routine Maintenance US$/km/year	Periodic Maintenance US$/km/year	Total Maintenance Cost US$/km/year
10	200	250	450
20	**200**	**500**	**700**
30	200	750	950
40	200	1,000	1,200

Vietnam, like most developing countries, allocates insufficient funds for the full maintenance of its gravel road networks due to general severe funding constraints. Currently there are generally no funds allocated to the maintenance of commune roads. Other developing countries with sizeable gravel road networks, such as Kenya and Zimbabwe, have historically only been able to re-gravel at most about 25% of their gravel road network needs. It is unlikely that Vietnam will be able to mobilise maintenance funding of more than US$700/km/year equivalent for existing the rural road network within the next 5 years. Even if this level of funding were to be available, then there would be justifiable pressure to allocate these funds to the construction of more sustainable surfaces.

It is therefore unlikely that within the next 5 years Vietnam could financially support gravel loss rates of more than **20mm/year** on the rural road network.

3. Operational implications

The nature of gravel road deterioration means that re-gravelling needs to be carried out before the layer thickness reduces to a residual level at which the gravel pavement ceases to function. This is generally accepted to be between about 50 – 100 mm.

At that point in time the re-gravelling operation needs to be carried out to top-up the surface layer. At a gravel loss rate of 20mm/year this needs to be carried out every 5 years. Considerable finances have to be planned in advance for this operation, budgeted for and approved. A contractor has then to be selected and appointed to carry out the work.

The whole process of identifying the need for regravelling, through to implementation of the re-gravelling works can take considerable time; typically of the order of 6 months or more. The problem is that without regular gravel thickness monitoring (not practiced in Vietnam), the time from the realisation that the residual thickness has been reached to failure of the gravel surface can be a matter of only weeks in the rain season.

There is therefore considerable risk that the need for re-gravelling and the timely mobilisation of funds and resources will not be achieved, and the road will revert to an earth standard, requiring reconstruction.

It is unlikely that there will be the operational capacity within the Vietnam rural road management system within the next 5 years to be able to achieve an effective operational system to re-gravel the network at cycles of 5 years or less. Therefore there will not be the operational capability to cope with an annual gravel loss of more than **20mm/year**.

4. Environmental implications

A surface gravel loss rate of 20mm/year represents the loss of 70 cubic metres of material from the road surface of every kilometre of road every year; based on a road surface width of 3.5 metres.

This material is lost to the air causing dust contamination, and to the drainage system, surrounding land and property and watercourses, causing siltation and pollution. There is also the safety aspect of poor visibility for traffic and health risks from airborne particles for travellers and residents along the road. This is particularly an issue in Vietnam where there tends to be ribbon development along rural roads and houses are constructed close to the road.

Gravel, once consumed, is lost from the resource base for ever. Natural gravel is a finite resource and occurs in limited quantities and locations. It is currently not possible to cost this environmental impact with the assessment tools available. It is also very difficult to determine what is a sustainable rate of use for this finite resource.

The environmental impact of gravel loss rates of more than **20mm/year** is likely to be excessively damaging to the environment.

5. Conclusion

From the foregoing considerations, even with a substantial improvement in maintenance capacity, it is unlikely that gravel loss rates of more than **20mm/year** can be supported in a sustainable way on the Vietnam rural road network.

RURAL ROAD GRAVEL ASSESSMENT PROGRAMME (RRGAP)

Module 4 – Data Analysis

APPENDIX D
APPROPRIATE RURAL ROAD SELECTION SYSTEM (Draft)

APPROPRIATE RURAL ROAD SURFACE SELECTION

A Preliminary Decision Management System for the Assessment of Gravel as a Paving Option

The Decision Management System is based on the research carried out in Vietnam under the Rural Roads Gravel Assessment Programme (RRGAP), and Rural Road Surfacing Trials (RRST) by Intech-TRL under DFID and SEACAP support programmes for the Ministry of Transport.

Natural gravel is often the cheapest method of upgrading an earth road to a better quality surface. However, a number of factors mean that in many circumstances in Vietnam, it is not the most appropriate rural road surface.

The Decision Management System guides the user through the objective process of assessing the various factors that influence the suitability of gravel for a specific rural road, or section of the road. Often the varying physical conditions and traffic along a route, including problem sections, will justify a composite approach. This may determine that some sections should be designed with different surfaces, pavement types or standards to achieve the most cost-effective and sustainable use of the limited resources available.

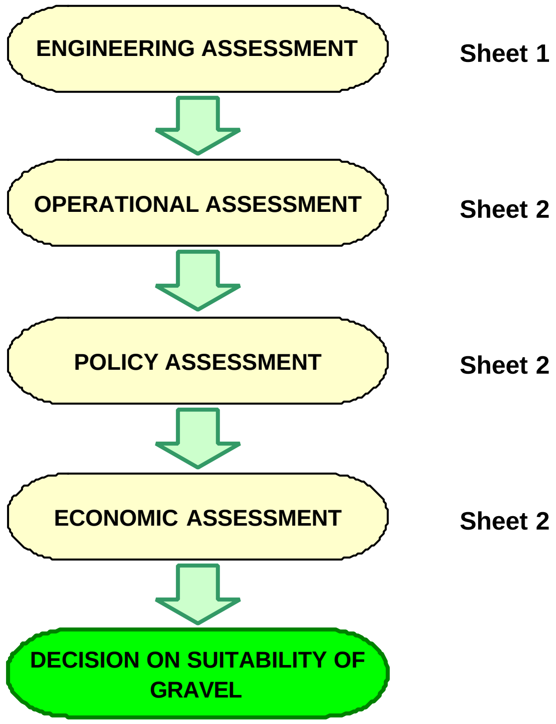
When gravel is assessed not to be the most suitable option, the separate Matrix of Surfacing Options will further guide the user to identify the most appropriate surface options.

THIS IS AN INITIAL DRAFT FOR COMMENTS

Intech Associates - TRL

OVERVIEW OF SURFACE OPTION SELECTION
FOR A RURAL ROAD OR ROAD SECTION

STEP 1 - Consideration of Natural Gravel as a Rural Road Surface Option

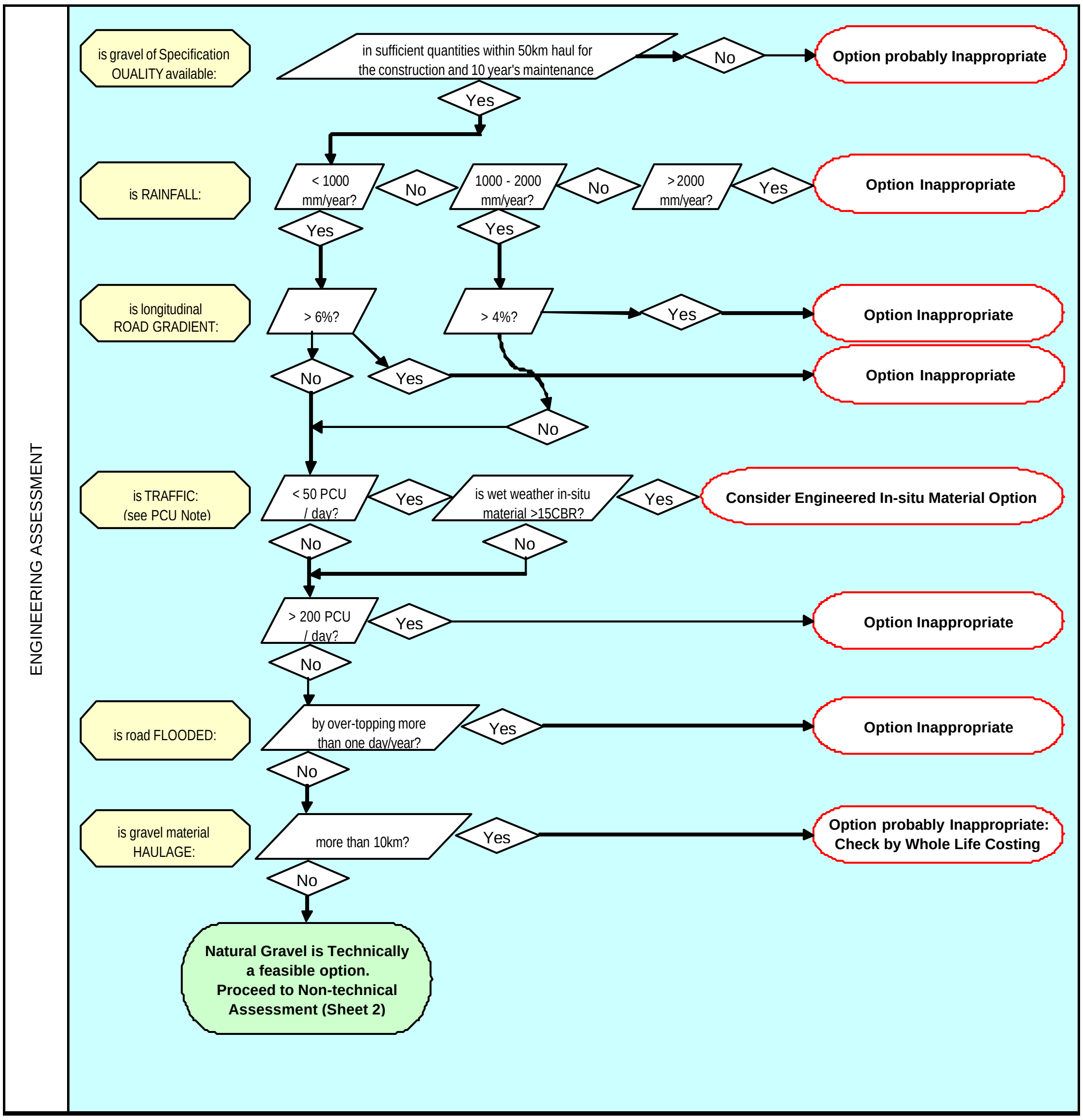


STEP 2 - If Gravel is not suitable, Selection of Appropriate Surface Option

UNDER DEVELOPMENT

Decision Flow Chart for the Consideration of Natural Gravel as a Rural Road Surface Option

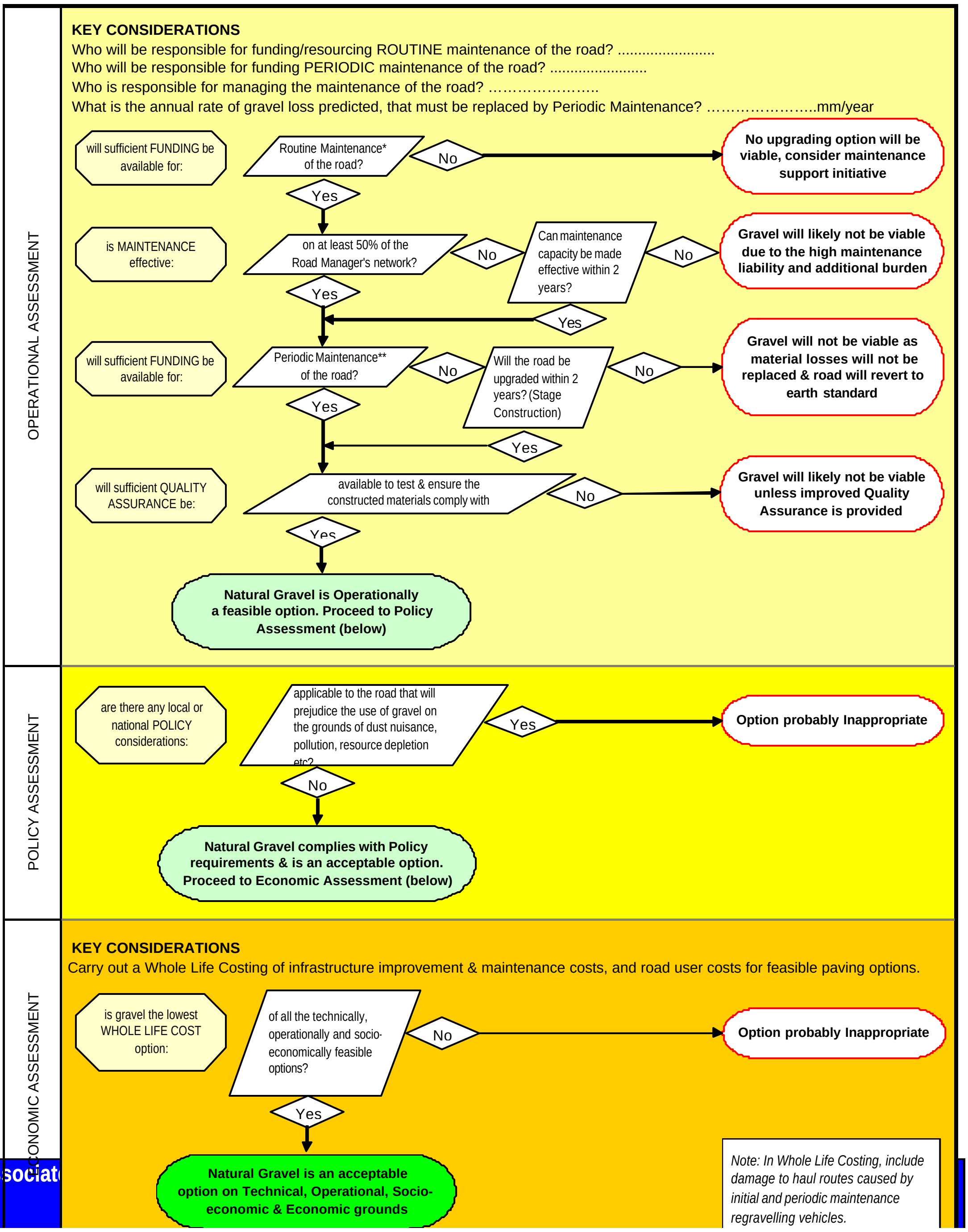
SHEET 1 - Engineering Assessment



NOTES: PCU = Passenger Car Unit (other vehicle types to be converted from traffic surveys and maximum average daily flows for next 3 years).
CBR = California Bearing Ratio - Strength in situ measured by DCP, or to be decided by visual assessment
DCP = Dynamic Cone Penetrometer

Decision Flow Chart for the Consideration of Natural Gravel as a Rural Road Surface Option

SHEET 2 - Operational, Socio-economic and Economic Assessment



NOTES: * Routine Maintenance funding includes voluntary labour contributions by the community

** Periodic Maintenance includes the regular and timely re-gravelling to replace the predicted gravel losses