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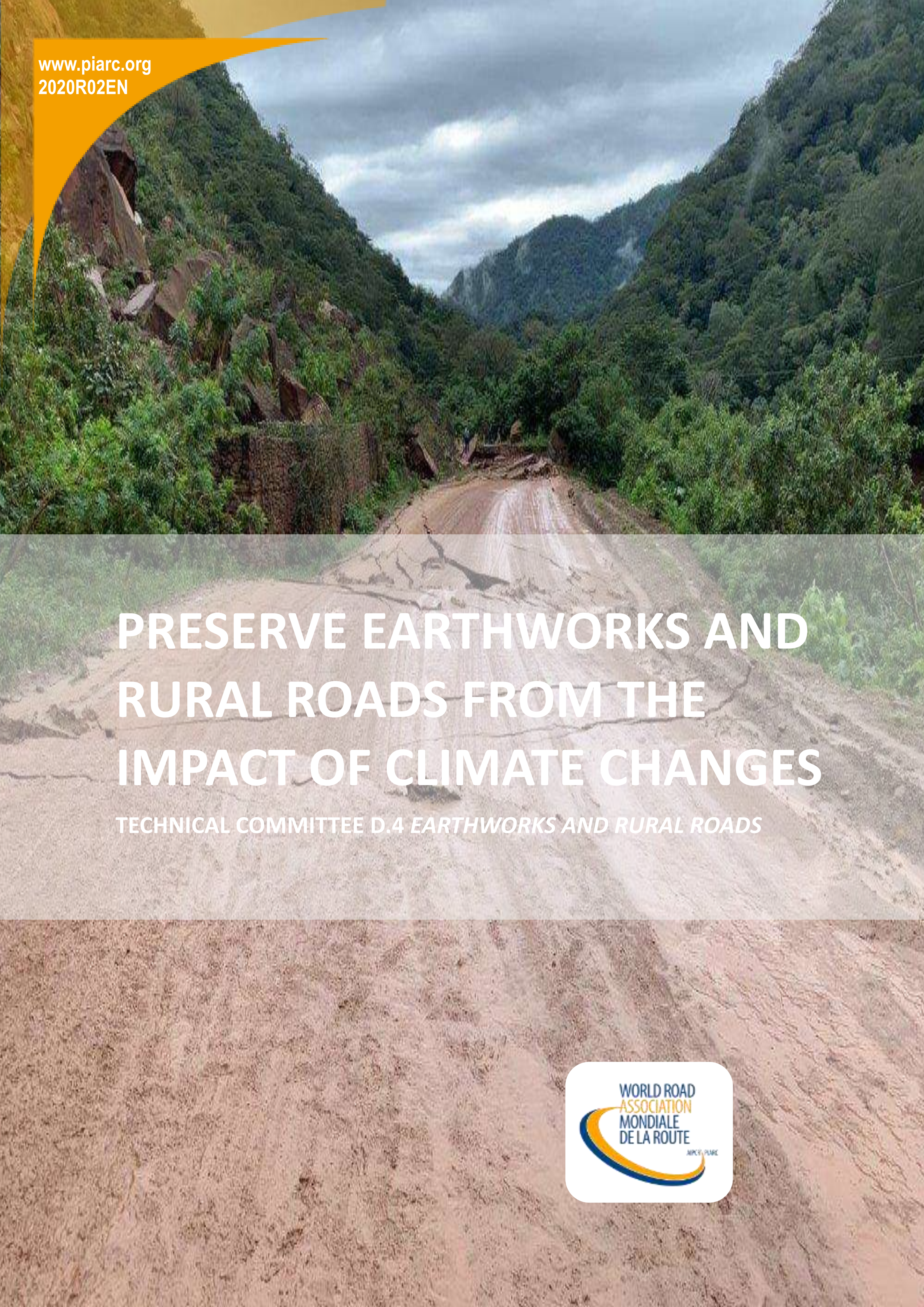

PRESERVE EARTHWORKS AND RURAL ROADS FROM THE IMPACT OF CLIMATE CHANGES

TECHNICAL COMMITTEE D.4 *EARTHWORKS AND RURAL ROADS*

WORLD ROAD ASSOCIATION
MONDIALE DE LA ROUTE

STATEMENTS

The World Road Association (PIARC) is a nonprofit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.

The study that is the subject of this report was defined in the PIARC Strategic Plan 2016–2019 and approved by the Council of the World Road Association, whose members are representatives of the member national governments. The members of the Technical Committee responsible for this report were nominated by the member national governments for their special competences.

Any opinions, findings, conclusions and recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of their parent organisations or agencies.

This report is available from the internet site of the World Road Association (PIARC): http://www.piarc.org

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International Standard Book Number: 978-2-84060-626-0

Front cover © Technical Committee D.4

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TECHNICAL COMMITTEE D.4 *EARTHWORKS AND RURAL ROADS*

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This report was produced by Working Group 1 *Exposure of earthworks structures and rural roads to climate change* of PIARC technical committee D4 (Infrastructure- rural roads and earthworks).

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EXECUTIVE SUMMARY

2020R02EN

PRESERVE EARTHWORKS AND RURAL ROADS FROM THE IMPACT OF CLIMATE CHANGES

This report puts together good practices on the various regional approaches to the impacts of climate change on roads and little hydraulic works. The subject has already been addressed during previous PIARC cycles but more on the general geotechnical aspect.

It includes the definition of the climatic parameters that had to be taken into account, the definition of a rural roads and the terminology of the structure of a road (going from embankments, slopes to the pavement layers).

The report covers:

- The definitions of rural roads, climate parameters, road structures,
- The definition and the description of each cluster and for some of them with some examples of a climate change impact on the elementary compound,
- All the feedback experiences of each country concerning the conception, the works and the asset management taking into account the climate change impacts

Finally, the report identifies and prioritizes future developments of the work on this subject by identifying new topics and additional needs that have been reported for the development of the new PIARC 2020-2023 Strategic Plan.

CONTENTS

FOREWORD

This report concerns the impact of the climate change on earthworks, rural roads and drainage and constitutes the works of the Technical Committee D4 "Rural Roads and earthworks" on issue 1 of its Terms of Reference "Exposure of earthworks structures and rural roads to climate change"

During these PIARC cycle 2016-2019, TC D4.1 has produced this report on best practices concerning strategies to be adopted before and after, taking into account the climate change and the recommendations put forward.

The objectives are to work on rural roads (paved or unpaved) with a technical focus on earthworks. So, the focus on certain specific structures such as embankments, fills or cuts; capping layer, haunches and so on, will be done without forgetting the small hydraulic works (such as culverts).

It was thus taken into account the design, the execution and the management of all these earth structures and small hydraulic works.

There are many PIARC's reports dealing with the climate change impacts on infrastructure. The goal was to come up with a document retracing the various methods implemented in different countries to anticipate the climate change impacts on their infrastructures, and subsequently, to propose an integrating approach that can be broken down in each region.

1. GENERAL EXPLANATIONS

The idea of this report is to summarize the policies, experiences and best practices of the member countries of PIARC on the design and construction of rural roads regarding to climate change. Weather and climate always had a massive impact on the construction and durability of roads and other traffic routes. Weather such as rain, wind, droughts or floods is often causing damages to the roads or earthworks. The road administrations of many member countries adapted their roads successfully to the regional characteristics of their weather.

But nowadays climate is changing. While we can already see differences in climate today compared to the pre-industrial times climate is expected to change even more in the future. With a change in local weather characteristics the way of designing, constructing and maintaining rural roads must get adapted. But as there are member countries of PIARC on every continent and in every climate zone the knowledge of how to deal with special weather characteristics is already available.

Technical committee TC D4.1 set the goal to develop these best practices and to create a guideline for local authorities.

The original output of technical committee TC D4.1 in-between the strategic plan of the years 2016-2019 was to prepare a report which should include the following points:

I. *Investigate and document simulation and modelling tools and techniques to support Road Administrations in managing and responding to adverse conditions as a result of climate change (e.g. drainage and storm water management).*
II. *Investigate and document local practices and techniques for "all-weather" services (dry season, rainy season).*
III. *A report of best practices on before/after strategies.*

The tasks were analysed and led to several new findings

- The term "result of climate change" was arguable and needs a clarification here. The reason for that is that climate change itself is describing the process of transformation of one climatic situation – defined by atmospheric conditions – to another. Due to this change, existing weather conditions can change in strength and number – resulting in extreme weather events.
- Nevertheless, a distinction must be drawn between these extreme weather events – which have always been occurring – and the measurable change of atmospheric conditions – which is a scientifically new state. For more information see also Appendix A – climatic background.
- In practice both are relevant though. An increase in the number of extreme weather events can lead to new challenges for road administrations as they change the needed dimensions of several systems (i.e. drainage). An increase in the number of extreme weather events can also an adapted risk management system needed as the probabilities are changing.

Therefore, both extreme and trend weather events must be considered.

While working with international road administrations and other institutions the TC D 4.1 was surprised because of the high number of empiric studies and experiences.

However, scientific relations between climatic parameters and road parameters are not yet fully clearly quantified. Especially, combined parameters of atmospheric conditions and road material characteristics are still too few.

Because of this, the original output quoted above had to be modified. The task I. “Investigate and document simulation and modelling tools and techniques …” has to be canceled.

The focus of this report is now of the above-mentioned tasks II. and III.

However, once the documentation will be done, how is it possible to transfer the actual knowledge (which is related to actual, local weather conditions) to future climate conditions? This question has to be examined and answered in this report too.

Therefore, the new out output of this report is now defined as follows:

1. The objective is to write a report on best practices, taking into account the climate change and the recommendations put forward.
2. A concept should be investigated an implemented to transfer the actual knowledge to future climate conditions in each country.
3. Climate impacts to be dealt with in this report must be defined.
4. Samples of Best practices are to be collected
5. There should be a separated chapter of hydraulic structures.

2. DEFINITIONS

2.1. CLIMATE PARAMETER TO TAKE INTO ACCOUNT

It is not easy to summarize all the documents produced by PIARC on this subject. However, it is worth noting the following some documents that put our objectives a little more in perspective

First document: PIARC 2012-R04 report *Vulnerability of Geotechnical Infrastructure to Climate Change and adjustments according to geographical context*

The picture below from PIARC 2012-R04 report, summarizes very well the latest works of the experts.

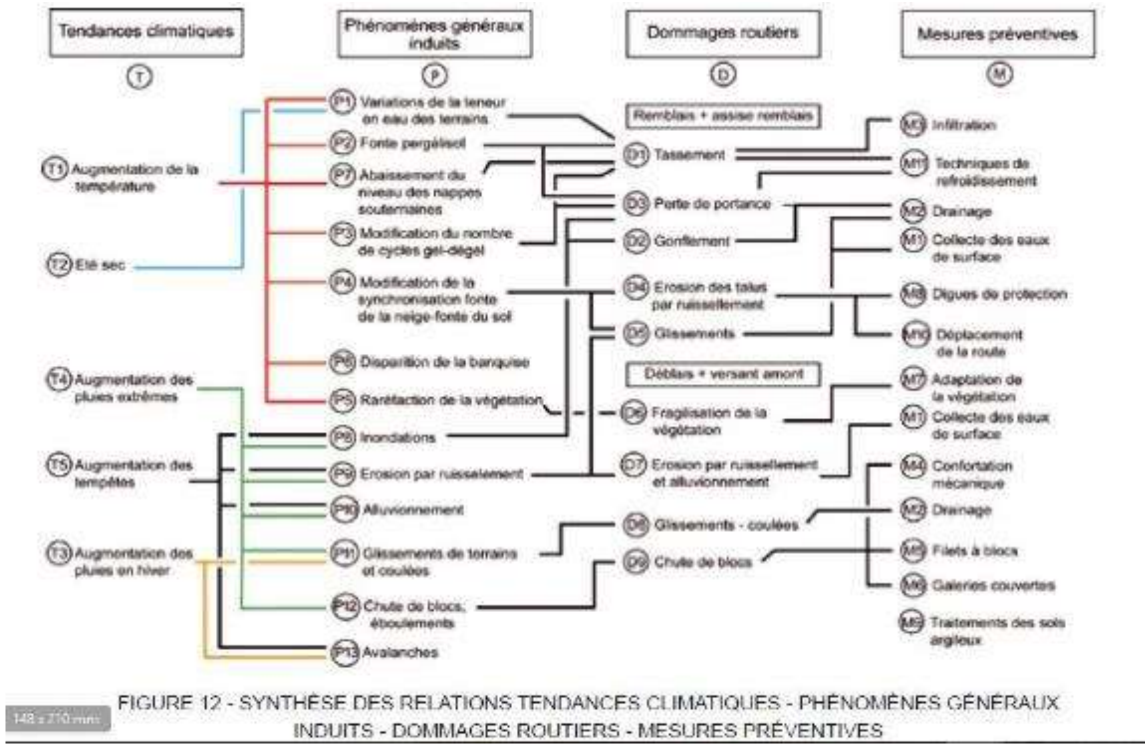

Figure 1: PIARC 2012-R04 report

On the first column, you have the climatic trends: temperature increases, heatwaves, extreme precipitations' increases, increase of storms and winter rain.

In the second column, you have the general induced events such as the variation of soil water content, permafrost melting, decrease in water tables, floods, landslides, rockslides.

In the third column, you have the road impacts such as in embankments (collapsing, swelling, soil erosion, etc.); in fill/cuts and haunches (landslides, rockslides, erosion, etc.)

In the fourth and last column you have the preventive measures such as: drainage; flood barrier, clay soil treatments, covered galleries and even road diversions.

Thus, we can say, that the geotechnical solutions on impacts of the climate change on earthworks and on rural roads are listed and well-known for most of them.

Associated with a variation of a climatic variable depending on the geographical context, one can give a technical solution if it exists (case of the avoidance), this solution requiring a knowledge enhancement, as when one indicates to use a mechanical comfort for example.

Second document: PIARC 2015-R03 EN report: *INTERNATIONAL CLIMATE CHANGE ADAPTATION FRAMEWORK FOR ROAD INFRASTRUCTURE*

The report is available at piarc.org and gives an overview about the future climate challenges and aspects that should be considered by road authorities.

Appendix C of PIARC 2015-R03 EN report is listing all the possible damages of road infrastructure, caused by weather. Appendix C of the mentioned report is in Appendix B of this report.

Third document: *RIVA – Risk analysis of key transit axes of the federal main road network in the context of climate change* published by BASt - Research institute in the department of the Federal Ministry of Transport

The German RIVA, a manual to measure the risk of the federal German road network to get harmed by climatic events, summarizes possible climate factors with the following table:

climatic events				climatic signals
climatic events	thermal events	high temperatures	1	maximum temprature, hot days, summer days, period of hot weather, tropical nights
		changes in temperatures	2	day an night ocillation
			3	freeze-thaw cycle
		low temperatures	4	lowest temperatures, day of freezing, ice days, cold periods
	radiation		5	duration of sunshine
	precipitation events	wetness	6	heavy rain
			7	seasonal precipitation rate
			8	hail
			9	snow and freezing precipitation
		aridity	10	dry season
	gale		11	gale
	frog		12	frog

Figure 2: Climatic events and the resulting climatic signals[1]

The climatic events were divided in the RIVA report into

- thermal events (numbers 1-5, red to yellow colours),
- precipitation events (6-10, dark blue to orange),
- wind and
- fog.

Because of the tasks and the expected output of the work of the TC D 4.1 the Committee had to decide which of the parameters in the above-mentioned reports should be taken into account.

During the meeting of the TC D 4.1 in Bolivia in May 2017 the Committee has defined the following global parameter with regard to the climate impact on rural roads and earthworks:

1 Picture 6, taken from page 24 of the RIVA, published by the BASt in Bergisch Gladbach, Germany

- Temperature
- Precipitation
- Wind
- Flood

Regarding to the defined output of this report the design parameter shown in the following figure are to be investigated:

Rainfall	intensity [mm/h]	The rate at which rainfall occurs expressed in depth units per unit time. It is the ratio of the total amount of rain to the length of the period in which the rain falls
	return period [1 in "n" years]	Estimation of how long it will be between rainfall events of a given magnitude
	duration [minutes or hour]	Duration of rainfall
	Maximum [mm/h]	The rain of a certain amount and duration that can be expected with a known return period
Temperature	temperature impact [°Cd]	The thermal energy transferred into the road structure during an uninterrupted period of hot days or frost days
	air temperature [°C]	The highest temperature measured about 1 meter above ground
Wind	velocity [m/s]	Wind velocity
Runoff	max Quantity [m^3/s]	Portion of the maximum rainfall that appears in roadside ditches or culverts
	max Volume [m3]	The maximum volume of water which has to be stored temporarily during a rainfall period

Figure 3: Design parameters to be investigated in this report

2.2. RURAL ROADS

PIARC defines a **rural road** as an “open country road”, a very general definition. (PIARC Def.)

The German FGSV is defining any road between build-up areas as a rural road as long as it has an importance to the connection between these build-up areas. (FGSV 2012) presented in the Santa-Cruz seminary in November 2017.

With that additional information – that rural roads are outside built-up areas – the actual function of rural roads gets in focus of the definition:

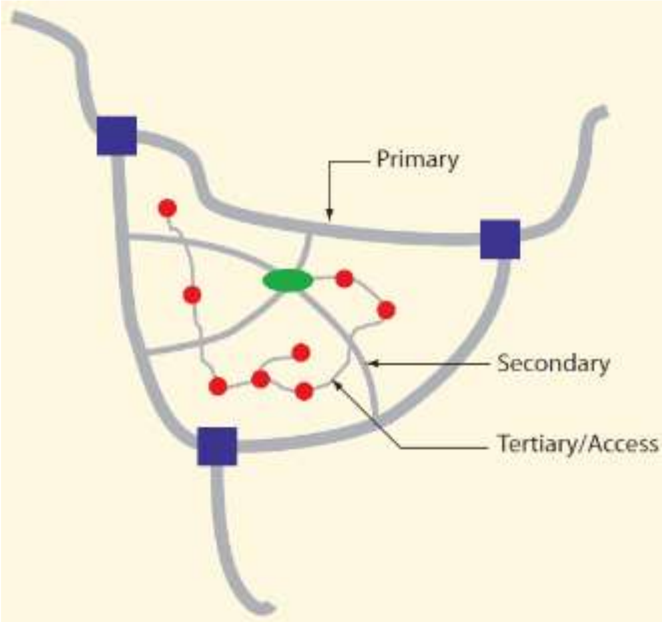

Figure 4: Function of roads outside of built-up areas (In dependence on SATCC Guidelines Low Volume Sealed Roads 2003) [2]

In the graph the three blue squares are major cities and therefore built-up areas. Roads between these major cities have a primary connection function. These rural roads are typically the roads with a wider travelled way and often more lanes. Smaller cities (green dot) are not directly linked to the major cities but have access to the primary rural roads. This access is guaranteed with secondary rural roads. These secondary rural roads are either connecting smaller cities with each other or smaller cities with primary rural roads. The smallest settlements – either single houses or villages – are connected with each other by tertiary rural roads. They also guarantee access to cities or secondary roads.

Note: Furthermore, the importance to connect settlements is essential in this report. Many of these rural roads are secondary and tertiary roads which are single-carriageway roads. They are often the only link between settlements and need a good prevention of damages caused by weather impacts by less maintenance.

Note: Especially primary roads are sometimes dual-carriageway roads with multi lanes in each direction (e.g. motorways). Mostly these roads are very important for the economy of a country. Once one of these roads are out of order high economic losses are to be expected countrywide.

The resilience of these dual-carriageway roads must be much higher and therefore requires a separate consideration maybe in a separate report.

Note: The traffic or axle load becomes unimportant for the definition of a rural road regarding to the tasks of this report. Higher axle loads lead normally "only" to a thicker road structure but due to the impact of climate change the thickness of the road structure is not so important (Perhaps only the thickness of bituminous pavement could be considered.

Definition for this report: Rural road are single-carriageways roads outside of built-up areas.

2 SATCC Guidelines Low Volume Sealed Roads 2003 Figure 1.1

2.3. CROSS-SECTION OF RURAL ROADS

As the member states of PIARC or PIARC itself do not have a standardized definition of the cross-section of rural roads and as there are a lot of different techniques to build rural roads in the different parts and climate zones of the world, this definition of a cross-section is held broad and general.

A rural road comprises two traffic lines, shoulders on each side of it and some drainage system.

Each of the two traffic lines is called **traffic lane** (also sometimes called travelled way). The traffic lane is the section that gets actually used for traffic and carries the traffic load. The dimensions can vary between 2,75 m and 3,50 m for each traffic lane.

On each side of the travelled way, there is a **shoulder**. The shoulder of a road is not for the actual use of traffic but can contribute to the prevention of accidents (hard shoulders). Another suppose is to lead the rainwater to the drainage system and to stabilize the travelled way on both sides.

Shoulders and travelled way together are called the **carriageway**.

Depending on the slope section of the road it contains either one or two side drains. Side drains can be carried out in multiple ways and will be explained in detail at the best practices chapter. The dimensions can vary between 1,00 m and 2,50 m for each shoulder.

Definition for this report: The principal cross-section structure of a single-carriageway rural road is pictured in the following graph:

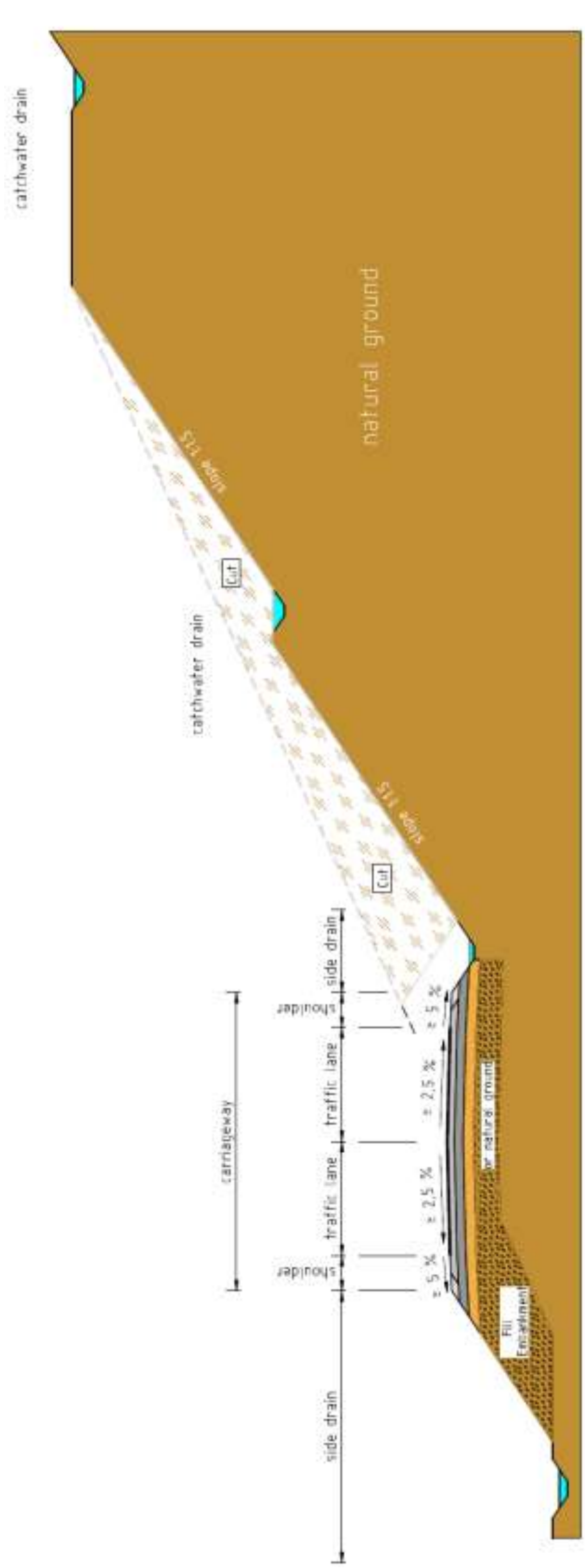

Figure 5: Cross-section of a rural road

2.4. VERTICAL STRUCTURE OF RURAL ROADS

The vertical structure of a road depends strongly on the national manuals on road structures. There is no multinational standardized way of design and use of materials. It depends on locally available materials, technology and knowledge as well as of the supposed use of the rural road. Nevertheless, the following basic layers are included in most of the proper designed rural roads:

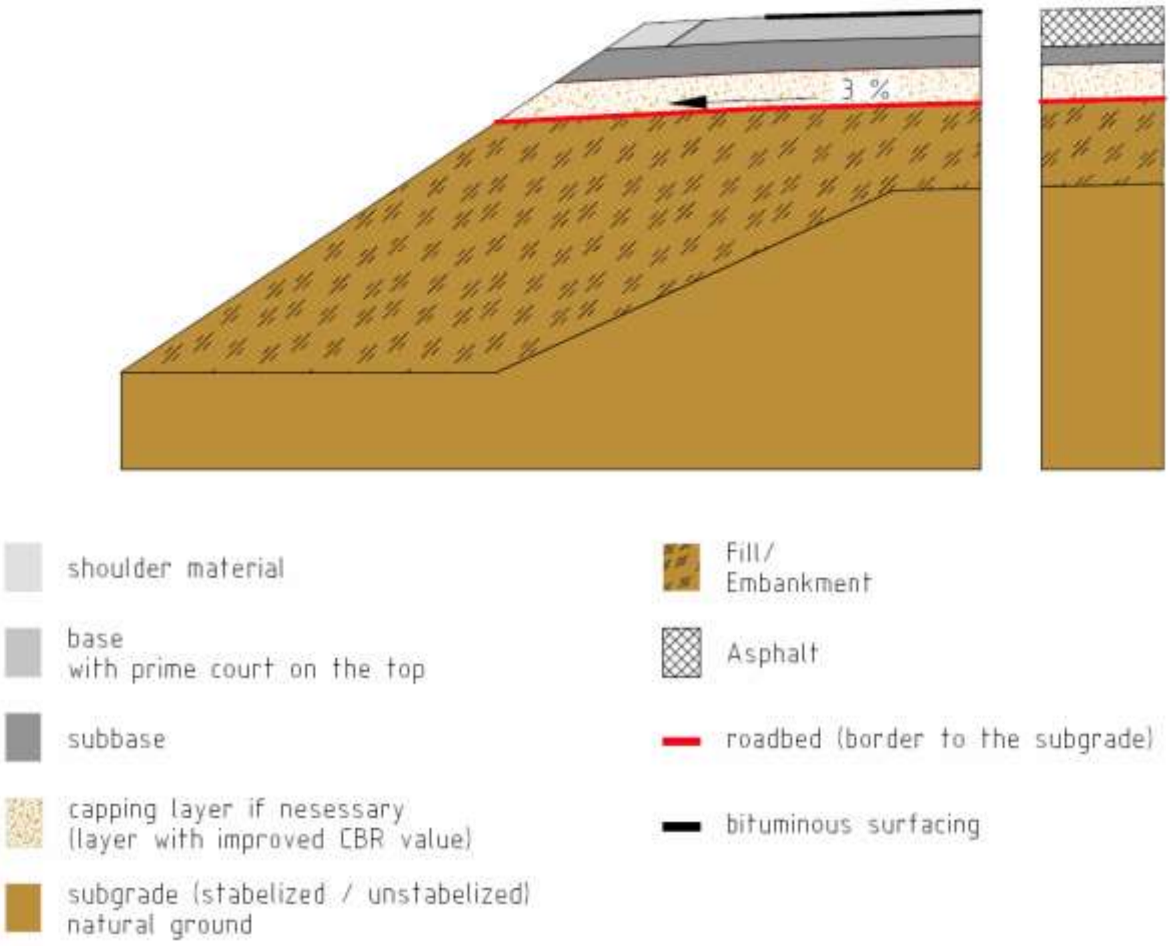

Figure 6: Vertical structure of a rural road

- The **Subgrade** of a road is the lowest component of the actual road structure and not necessarily constructed. While in some cases the subgrade consists of the natural soil of the place the road is built at (clay, rocks, gravel) in other cases the subgrade is part of the road embankment and therefore constructed artificial.
- The **capping layer** (also sometimes called compacted subgrade) can consist of different material and contribute to the maximum payload of the road’s pavement. It is a specific transition layer, part of the upper part of the fill, placed below the superstructure. The intended functions of a capping layer necessitate the use of an appropriate quality of fill material. Due to the definition from Fpr EN16907-01 Capping layers are installed to fulfil two series of functions, when needed:

During the construction works (Short-term functions)

- accurately levelling the platform, in order to facilitate the execution of the superstructure;
- offering sufficient stiffness or bearing capacity, despite weather variations, for a correct execution of compaction of layers or structures above (« anvil » effect);
- protecting the subgrade of the fill or cut, from weather effects;

- assuring good traffic conditions for the equipment needed for building the superstructure;
- eventually, supporting construction traffic for other purposes;
- For some types of capping layers, temporary or permanent traffic restrictions may need to be stipulated.

After the end of construction (Long term functions):

- homogenizing the deformability of the fill or excavation base, as specified by the design of the superstructure (definition of characteristic and/or minimum values;
- improving the bearing capacity of the platform to optimize the combined cost of the "capping layer/superstructure" system;
- offering a thermal protection to fill materials which are sensitive to freeze and thaw or to frost heave;
- contributing to the drainage of the completed structure. »

- The subbase is the layer above the subgrade (or capping layer) and is mostly made of a coarse material as gravel. The reason for this is its free-draining characteristic. Especially in cold and temperate climate zones a coarse material in the subbase is also guaranteeing a frost-proof construction. The subbase can be stabilized as well as non-stabilized. Stabilization means that there was a modifier such as cement or asphalt added to the mixture.
- The base of a road is right below the surface and necessary for draining as well as carrying most of the load on the road. Therefore, the material used needs a higher quality than the subbase and is often artificial (i.e. asphalt). Though it can be built non stabilized, too.
- Prime coat: Must be sprayed immediately (maximum 2 days later) on the top of the untreated aggregate base layer to minimize water losses within the new base. The base must be kept moist to prevent damaging of the first one or to two centimetres by heavy vehicles on site. Furthermore, prime coats are often used to stabilize the surface of the base to support the paving construction activities above.

- The **bituminous surfacing** of roads fulfils several needs:
  - Seal and protect the base and provides strength at the road surface so that the latter can resist the abrasive and disruptive forces of traffic
  - Transmit to the base the vertical and horizontal forces imposed by moving traffic.
  - Protect the pavement from moisture ingress, thus preventing loss of pavement strength, thereby permitting the use of many materials that would otherwise not be appropriate
  - Prevent gravel loss, resulting in elimination of the costs of replacing gravel

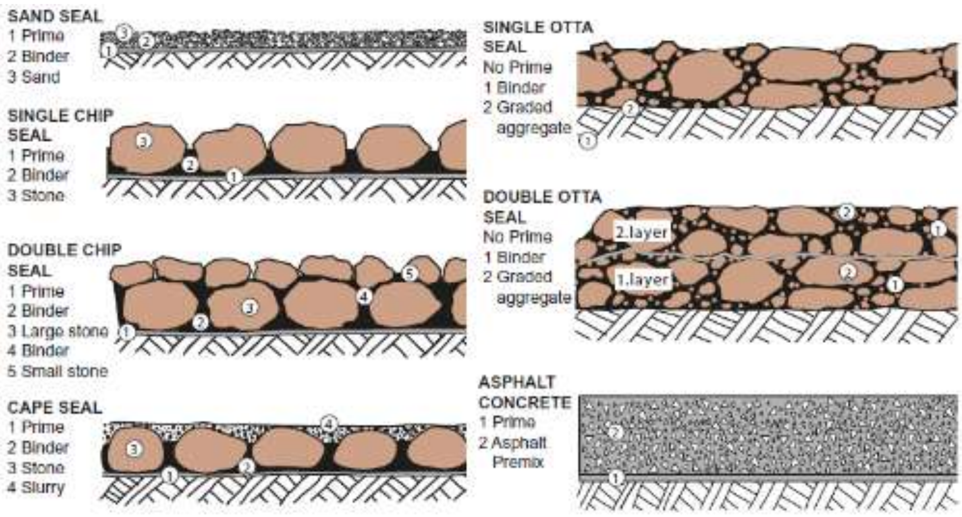

Figure 7: Schematic common types of bituminous seals (In dependence on SATCC Guidelines Low Volume Sealed Roads 2003)

Two principle kinds of bituminous surfacing are common:

1. Bituminous surfacing which only "seal" the base. The following illustration shows various types of seals.
2. Bituminous surfacing by using a thicker asphalt surface layer. Normally used for a higher load capacity. The asphalt surface layer may be divided into sub-layers. Typical sublayers, are as follows:
   - Surface course (also called the wearing course): The topmost sublayer. This is typically constructed of dense graded asphalt concrete. The primary design objectives for the surface course are waterproofing, skid resistance, rutting resistance and smoothness.
   - Asphalt course (also called the asphalt base course):

The hot mix asphalt layer immediately below the surface course. The asphalt course generally has a coarser aggregate gradation and often a lower bituminous content than the surface course.

A part of the asphalt course could be the so-called binder course. The binder course absorbs the dynamic forces. For example, heavy load trucks generate high dynamic forces.

The following illustration shows various types of asphalt layers.

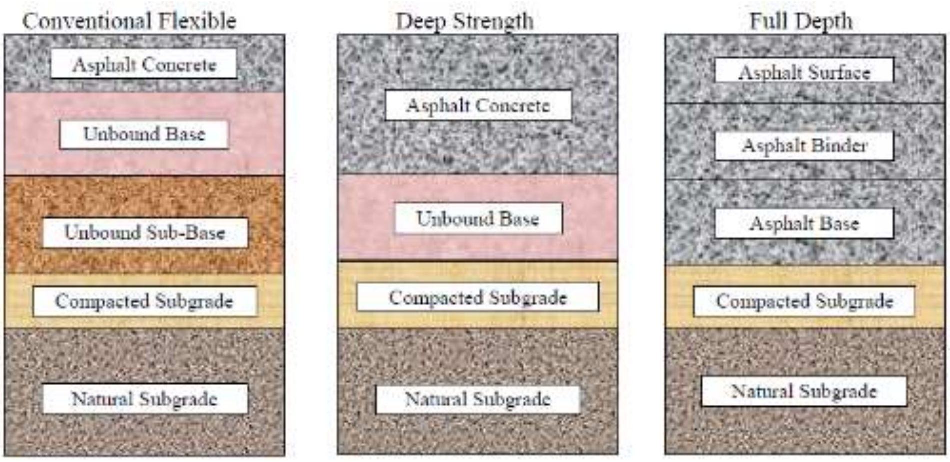

Figure 8: Some common variations Asphalt surface layers (In dependence on the U.S. department of Transportation Publication No. FHWA NHI-05-037 May 2006)

3. APPROACH

3.1. IDEA OF CLIMATE COMPARABILITY

The member countries of PIARC are representing vast parts of the earth. All of them have made different experiences and were establishing own "best practices" for their specific climate due to field studies and realised projects. This knowledge holds great potential. While the scientific analysis of the influence of climatic parameters on road material is not yet available in large numbers, high quality empirical knowledge is available for many specific situations.

Most of the climate parameters can already be predicted accurately with a high probability for even small areas by using existing climate models. And – the data of the existing climate situation is available too.

If now, a climatic parameter (e.g. temperature) is well known in a country today and how related to this temperature, the roads are built today – it is possible to transfer this knowledge to a country which will have the same climatic situation in maybe 50 years.

An example: In Europe the city of Rijeka, Croatia currently has the same temperature as the city of Frankfurt, Germany will have in 50 years.

Figure 9: Schematic Geographical situation of Rijeka, Croatia and Frankfurt, Germany

Based on this the new idea of climate comparability was developed:

- Gather exiting "best practices" examples one building rural roads in as many countries, regions, climate-zones as possible.
- Define the influence of the climate that led exactly to these solutions.
- Parameterize this influence. For example, temperature, precipitation etc.
- Use existing climate models to project the situation for a certain area of interest after a period of 50 years.
- Compare the situation of interest in 50 years with match regions which have already the same situation today.
- Transfer the existing "best practices" examples to the future situation of interest.

Gathering exiting "best practices" examples on rural roads construction should not be done by using enquiries. It has been shown that answering the questions is too complex and difficult for the individual TC-Member.

Getting the information needed must be done during the Technical Meetings all over the world. Step by step and theme by theme.

To do this the concept of clustering the cross-section was developed.

3.2. PRINCIPLE OF CLUSTERING THE CROSS-SECTION

This principle divides the typical road cross-section into different "clusters". These clusters are which are typically affected by weather and need therefore adaptions in design when climate is changing.

The idea behind the cluster concept is that some countries with particular climate characteristics might have special knowledge with an adapted design for these circumstances.

In the future meetings might take place in a country with such special climate characteristics and special experiences with one of the clusters. At these meetings a group of members and regional experts is supposed to set design parameters for an adapted design of the cluster that fits the impacts of climate change.

In a first draft the Technical Committee at their meeting in Port Elizabeth, South Africa on November 23, divided the cross-section into eight clusters:

Cluster							
1	2	3	4	5	6	7	8
Slope	Roadside ditch	Shoulder	Bituminous surfacing	Base	Subbase	Capping layer	Fill Embankment

Figure 10: Cluster of the cross-section

Knowing the impacts (see figure 3) and the clusters (see figure above) the next step was to combine the impacts and the clusters. In other words: What are the climate impact parameters for each cluster?

After many long discussions because of this question, the Technical Committee agreed on the dependencies listed in the following table:

			Cluster							
			1 Slope	2 Roadside ditch	3 Shoulder	4 Bituminous surfacing	5 Base	6 Subbase	7 Capping layer	8 Fill Embankment
Rainfall	intensity [mm/h]	The rate at which rainfall occurs expressed in depth units per unit time. It is the ratio of the total amount of rain to the length of the period in which the rain falls	X		X		X		X[3]	X[3]
	return period [1 in "n" years]	Estimation of how long it will be between rainfall events of a given magnitude	X	X	X				X[3]	X[3]
	duration [minutes or hour]	Duration of rainfall	X		X				X[3]	X[3]
	Maximum [mm/h]	The rain of a certain amount and duration that can be expected with a known return period		X						
Temperature	temperature impact [°Cd]	The thermal energy transferred into the road structure during an uninterrupted period of hot days or frost days	X		X	X	X	X[2]	X[3]	X[3]
	air temperature [°C]	The highest temperature measured about 1 meter above ground								
Wind	velocity [m/s]	Wind velocity Sand and dust storms	X[1]				X[1]			X
Runoff	max Quantity [m³/s]	Portion of the maximum rainfall that appears in roadside ditches or culverts		X					X[3]	X[3]
	max Volume [m3]	The maximum volume of water which has to be stored temporarily during a rainfall period							X[3]	X[3]

Figure 11: Summary of climate impact due to the cluster

1): In combination with temperature impact
2): Only in areas with permafrost
3): The Cluster 7 (capping layer) and Cluster 8 (Fill/Embankment) are affected by climate impact. But it is not easy to separate the impacts on slopes and hydraulic structures (ditches and culverts) from those caused to embankments and the capping layer.

3.3. TRANSFERRING EXISTING KNOWLEDGE INTO FUTURE SITUATIONS

As already explained in the previous chapter 3.1 "Idea of climate comparability", the aim is to transfer today's knowledge into a future climate situation that will occur in a certain region in a few years' time.

A standard cross section was defined and divided into clusters. For each cluster, parameters were defined that describe the climate impact. (See Chapter 3.2 "Principle of Clustering")

Now, for these parameters, "trigger values" must be determined. Special measures must then be taken from these trigger values onwards.

Example “Cluster 1 Rainfall intensity”:

The rainfall intensity is given in [mm/h]. From a trigger value on, the use of geotextiles is recommended. This recommendation must of course depend on the building materials used.

The following illustration clarifies this procedure and the context described.

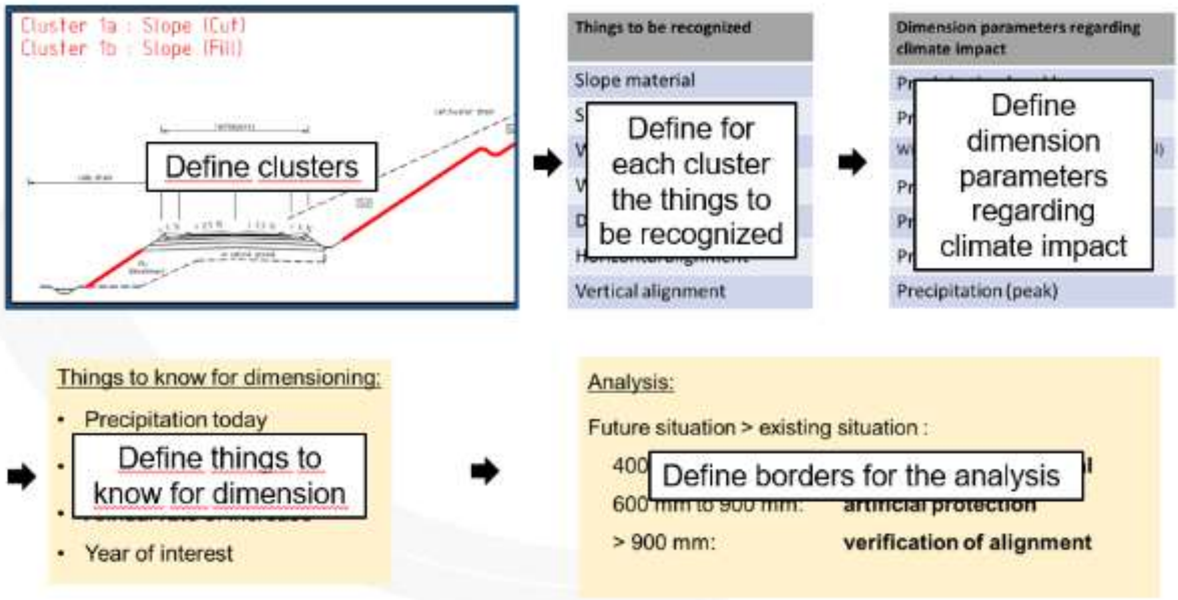

Figure 12: Transfer existing knowledge into future situations

3.4. WORK PROGRAM

In-between the strategic plan of the years 2016-2019, the following work program could be carried out (besides the time needed for the creation of the different questionnaires, their evaluation and the rejection of different ideas to approach the task):

1. Clustering the cross-section (Done in Chapter 3.2)
2. Identify used and proven solutions within each cluster. (Done in Chapter 4)
3. Creating an idea of style sheet (TC D4.1 committee call this sheet "Blueprint") from which the input parameters, the trigger values and the required measures can be derived. (Done in Chapter 6.1)

The work program of the next years could be:

1. *Determine Blueprints for all clusters and the important circumstances, which are interesting for the Administrations. Detailed Explanation due to the word "Blueprint" and for the future working program please see Chapter 6.2.*

4. CLIMATE IMPACTS ON EACH CLUSTER

4.1. CLUSTER 1: SLOPE

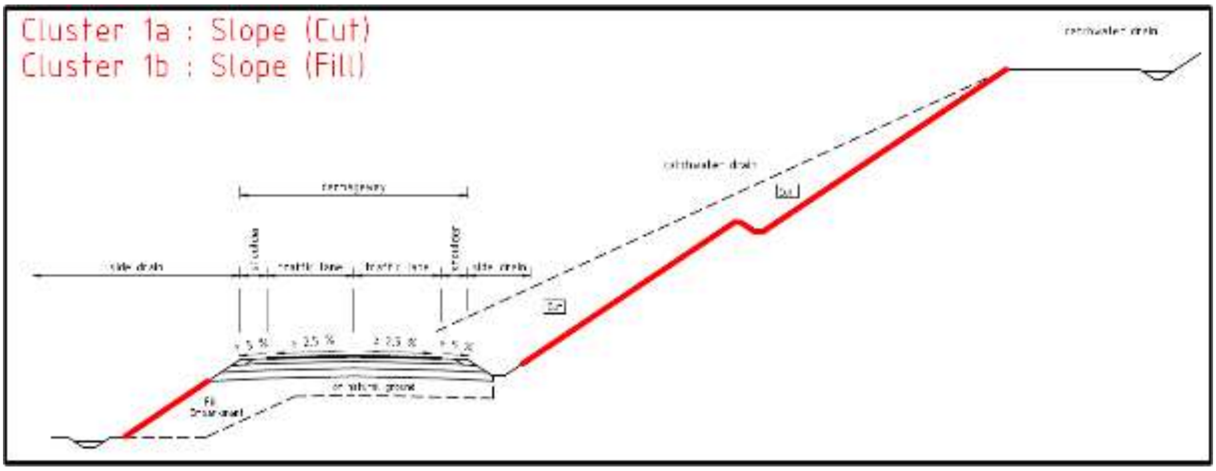

Figure 13: Cluster 1 Slope

For this chapter it should be kept in mind that what affects the slopes will also impact the embankment and may be the capping layer.

4.1.1. Rainfall

Climate impacts: Rainfall intensity
Rainfall return period
Rainfall duration

Hazardous nature: All the mentioned impacts leads to erosion and in the consequence thereof to landslides.

Examples and further explanations:

Landslides are the result of weakened soil due to intense precipitation. Both are characterised through massive and abrupt moving of material. (Howard. B)

Note: The difference between mudslides and landslides lies in their cause. The result is quite similar. Mudslides are the result of rivers or streams taking soil and debris with them.

Landslides are a big risk whenever there is a steep slope close to a road. In countries like Austria and Norway with a very mountainous topography, land- and mudslides are responsible for most of weather-related damages. In Austria 51% of all weather related costs of damages of roads are caused by mud- and landslides or avalanches. (Bednar-Friedl).

They often occur in a very abrupt way. Often the amount of material is so massive that the actual road is hard to recognize after a slide as the following photo shows:

Figure 14: Road in Spain which is completely blocked by a landslide[3]

Landslides are causing at least a comparatively long-term closure of a road. The impact of the slide is furthermore threatening the stability of the road and can destroy a road. Especially very big landslides can even include parts of a road. In that case the whole earthwork and structure of a road can slide away.

Figure 15: Massive landslide in Canada[4]

3 Taken from PIARC TC E1 report of Spain

4 Photo of a landslide in Canada, available online at https://www.nrc.com/search?q= PnyxyvAfm9flfM (last checked on 21.10.2017)

In the photo above, is an example of a landslide where even the road itself was part of the landslide. Landslides mostly happen after long and intense rainfalls. Vegetation and trees in particular can make landslides less likely to happen as they stabilize the underground.

The photo below shows a road embankment that is already damaged by erosion. The reason for that is the same as for the previous photos. A steep grade in combination with a fine material. There is some grass on the surface of the embankment, but it could not protect the embankment of erosion completely. Now as there is a beginning erosion it is likely to continue and to endanger the stability of the whole embankment and therefore of the whole road.

Figure 16: Road embankment damaged by erosion in Canada[5]

Possible Solutions:

To stabilize the surface of the embankment it´s common to use fine-grained soil with some cohesive material. Infiltrating water will be capillarity bound and results in a dense surface. In combination with a not too steep gradient of the slope, the water run off the slope without damaging the surface. However, if the duration and / or the intensity of the rainfall raised the surface will be damaged by the high amount of water.

The first solution is to build a not too steep gradient by using stabilizing vegetation. The example below shows a small hill above a road that got protected from erosion by a dense plantation.

In general, every plant that has a dense rooting and can handle a possibly polluted air is suitable. It should also be able to deal with local climate and not suppress other vegetation in the local environment.

5 Taken from PIARC TC E1 report of Canada

Figure 17: A hill above a small road that got plantation for erosion control[6]

Plantation is not always a suitable option. Especially in very dry areas where natural vegetation is rare most plants could not survive.

Desert regions are often characterised by a low annual precipitation. Nevertheless, this precipitation is often concentrated on just a few days per year. This combination – a dry climate with a lack of vegetation and concentrated heavy rain – is a risk factor for erosion and landslides.

A proper solution can be geotextiles. Geotextiles have the advantage that they protect the surface from being eroded but do not seal the earthwork. As a result, vegetation can still grow on it. However, it does not have to be as dense as without a geotextile to reach the same level of erosion control.

There are different types of geotextiles and they can be made of different materials. Often, they are organic and rot after some years. However, there are also types that can resist water and sunlight for a longer period.

6 Online available at https://farm4.staticflickr.com/3153/2656861027_074fff90c4_o.jpg (last checked on 21.10.2017)

Figure 18: Geotextiles are getting installed at a road embankment[7]

This report recommends the use of geotextiles for erosion control when your climate is known for extreme precipitation events but either soil or climate do not allow a proper protection through vegetation.

When there is a doubt about the success of a plantation project an organic geotextile is also recommended. This geotextile can give vegetation time to develop and still protect soil from erosion. A typical structure of such a geotextile can look like the one below.

Figure 19: Organic geotextile for erosion control[8]

Geotextiles can also offer a good protection for earthworks at coastlines. Many roads are built right at the shore or even on dams through water areas.

7 Online available at http://img.archiexpo.com/images_ae/photo-g/61449-4512211.jpg (last checked on 21.10.2017)
8 Online available at http://2.wlimg.com/product_images/bc-full/dir_39/1141204/jute-soil-saver-jute-geo-textile-1475563619-1434303.jpeg (last checked on 21.10.2017)

Floods can therefore be a risk for the stability of an earthwork. But even the regular surging billows can flush soil away over time. To protect the earthwork from these impacts coastlines often get protected by massive rocks. These rocks absorb most of a waves' energy and build a barrier between water and earthwork.

Figure 20: A road at a lake in Bavaria protected by massive rocks[9]

These rocks alone are reducing the energy of waves but cannot prevent flushing of soil when there is a massive flood. The fine-grained material can be washed out through the gaps between the rocks.

In the photo below you can see that the geotextile is installed on the earthwork, keeping fine-grained material inside. The geotextile and the earthwork as a whole are protected by the rocks at the coastline.

Figure 21: Coastal protection through geotextiles and rocks[10]

While this system is recommended for inland waters and is still sufficient at today's seacoasts it might not be enough in the future. Rising sea levels made Sweden redesign its manuals for road construction close to the coastline.

A first project at the North Sea coast of Sweden was realised in that way.

9 Taken by the city of Bayreuth; online available at http://www.lauterbach-bayreuth.de/files/images/galerie/Wasserbausteine%202.jpg (last checked on 21.10.2017)
10 Online available at http://img.archiexpo.com/images_ae/photo-g/61449-4512211.jpg (last checked on 21.10.2017)

The strategy is to lift up the whole transportation network. New built roads or rehabilitated roads or railways are built higher than the surrounding soil. Sweden wants to react on rising sea levels with that strategy.

The high standards on noise and air quality in Sweden force authorities to combine this additional height of roads and railways with noise protection barriers. Therefore, planned projects in Sweden are more expensive than the traditional design (see enquiry results of Sweden in chapter 7).

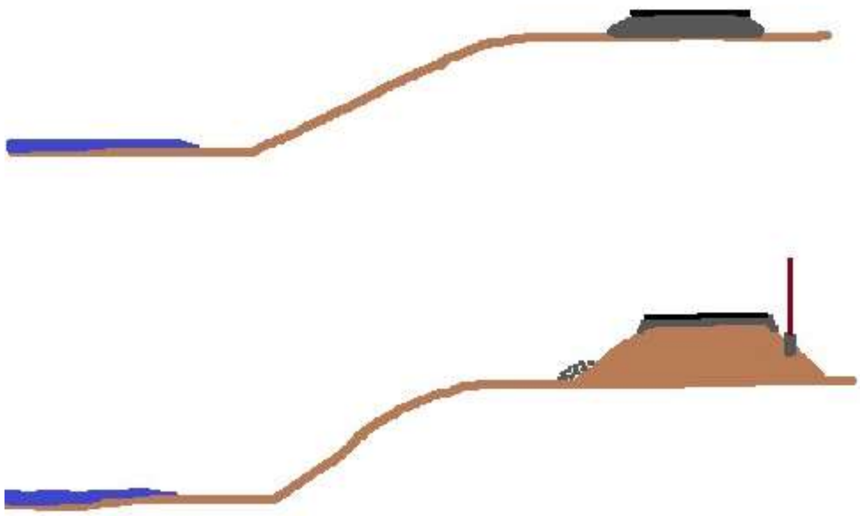

Figure 22: Swedish concept of uplifting coastal infrastructure[11]

Note: Trees are the number one risk for road closures caused by wind in the temperate climate countries. Storms are often falling trees. When these fallen trees are next to a road there is a risk of blocking the road. The following photo shows a blocked rural road in the United Kingdom.

Figure 23: Road in the UK blocked by a fallen tree[12]

11 Own illustration
12 Photo taken by Higgs, Walter; online available at https://www.123rf.com/photo_25896546_road-closed-with-safety-ribbon-uprooted-trees-blocked-forest-road-after-sleet-storm.html (last checked on 21.10.2017)

The road itself or its load capacity are very unlikely to get damaged or influenced by a fallen tree. However, fallen trees are a challenge for road maintenance authorities. Storms are usually not falling single trees but multiple trees at multiple locations. Therefore, clearing work takes more time and roads must get closed for some time. As shown by the use of barrier tape in the above photo.

Catchwater drains:

There are two kinds of catchwater drains with different tasks existing:

- The first kind is the catchwater drain in the terrain.
- The second one the catchwater drain on berm.

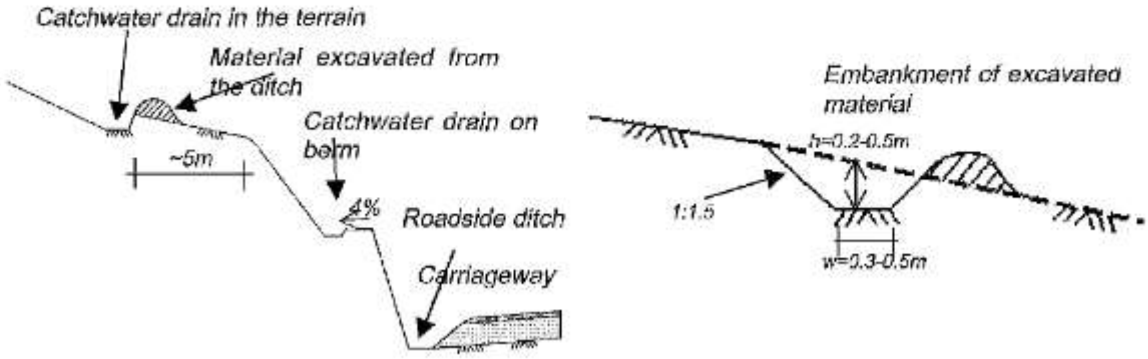

Figure 24: Catchwater drain[13]

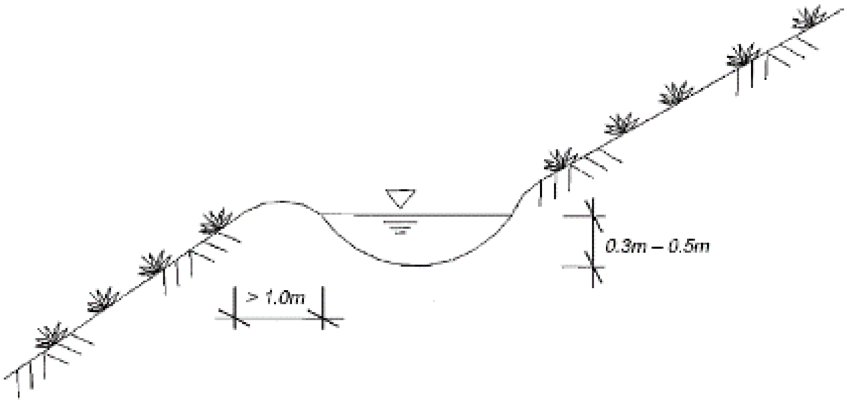

Figure 25: Detail Catchwater drain on berm[14]

Catchwater drains collect the water flowing to the road from higher terrain. They are intended to protect high cutting slopes against erosion and provide relief for roadside ditches. They run more or less parallel to the edge of the slope. Between the edge of the slope and the catchwater drain there should be a margin of safety of not less than 3 - 5 m if possible, so that, in the event of erosion of the valley side of the ditch slope, immediate flooding is avoided which would lead to even greater damage. Most of all, back erosion of the slope edge should not be allowed to place the entire catchwater drain system at risk.

13 Text and Photo taken by FGSV (2003): Access Roads in Rural Areas; Crossing of Watercourses an surface drainage
14 Photo taken by FGSV (2003): Access Roads in Rural Areas; Crossing of Watercourses an surface drainage

The excavated earth can naturally be used to create a small protective embankment on the edge of the ditch on the valley side, thus boosting the protective function of the catchwater drains.

However, special care must be taken to prevent the excavated material -especially loose stones- from falling into the ditch and thus obstructing discharge.

Since catchwater drains must follow the contours of the terrain much more than roadside ditches, special attention must be paid to ensuring that the specified maximum longitudinal slope allowed for the respective type of soil is not exceeded. Otherwise special protective measures will have to be taken (bed stabilization, lining, steps, etc.).

4.1.2. Temperature in combination with wind

Climate impact:	Temperature impact in combination with wrong embankment material.
Hazardous nature:	If it is too dry for too long, the surface of the embankment will dry out. The fine particles are then no longer bound. In combination with wind or rain, the fine particles are washed out or blow away. This process strengthens the erosion and in the consequence thereof to landslides.

Examples and further explanations:

The actual risk for earthworks getting damaged by wind is minimal. The only risk is wind erosion for earthworks that comprise a high percentage of sand or silt and have a lack of vegetation.

To protect earthworks from erosion caused by wind the strategies are similar to precipitation caused erosion:

- dense vegetation
- soil protection by (organic) geotextiles

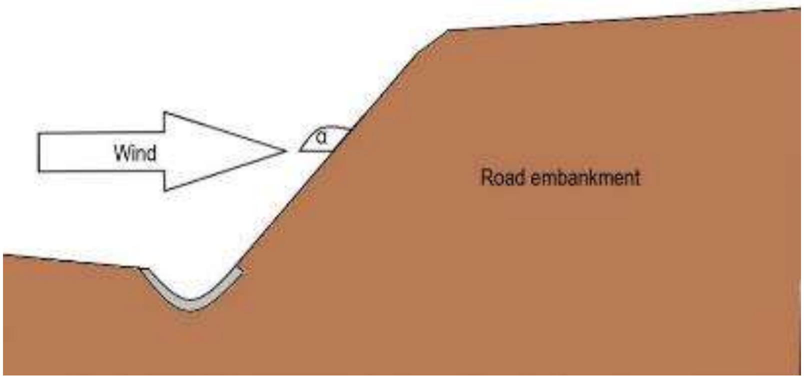

Figure 26: A steep gradient and therefore obtuse angle are a protection against wind erosion – for embankment and road surface[15]

In difference to erosion that is caused by precipitation the gradient of the earthwork plays a minor role. While road embankments with a steep gradient are more vulnerable for erosion caused by precipitation, they are less vulnerable for wind erosion.

The risk of wind erosion is reduced when the angle of the embankment is obtuse compared to the wind direction.

15 Own illustration

Another positive effect is therefore the reduction of sand, dust and snow on the actual surface of the road.

Road embankments – as long as they are designed not too steep – and as long as their sides are protected by vegetation and/or geotextiles are strongly recommended as a technique against impacts of climate change!

4.2. CLUSTER 2: ROADSIDE DITCH

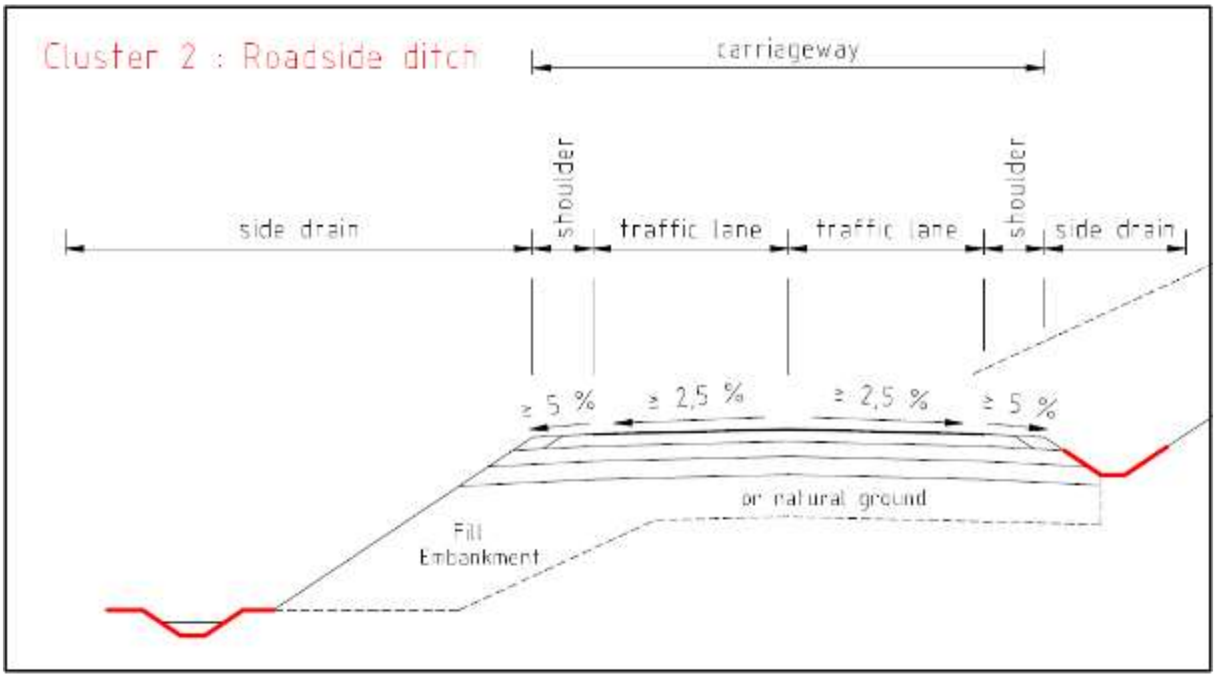

Figure 27: Cluster 2 Roadside ditch

For this chapter it should be kept in mind that what affects the roadside ditch will also impact the embankment and may be the capping layer.

4.2.1 Rainfall and Runoff

Climate impacts:	Rainfall return period Rainfall maximum Maximum run off
Hazardous nature:	If the return period increase, the roadside ditch will convey water much more often. This may result in sealing the ditch to prevent erosion. If the runoff into the roadside ditch increases, the ditch must be either enlarged or the number of water crossing structures (e.g. culverts, small bridges etc.) has to be increase (of course in dependence of the existing terrain).

Examples and further explanations:

Today the maximum amount of expected rain in a specific period of time is still dimensioned by measured amounts of rain in previous periods of time.

In most countries there are many weather stations collecting data about precipitation – often since a long time ago. Statistical methods made it possible to calculate a maximum expected amount of rain for a specific area.

The problem nowadays is that data from the past cannot predict the dynamic change of precipitation caused by climate change. And dynamic simulations on future precipitation are not yet reliable enough. Nevertheless, there is the theoretical possibility to gain more detailed and more reliable precipitation simulations in the future even for regional models. In that way the dimensioning of roadside ditches in the future could be adapted to realistic amounts of water. Therefore, research on precipitation and cooperation with meteorological intitutions has to be aspired.

The change in dimensioning of the ditch is therefore not yet an appropriate theme in this report.

The overall design principle of roadside ditches is to prevent waterflow form the ditch into the vertical structure of the road. To reach this goal, the highest water table in the ditch must be below the roadbed.

For example, the Washington State Department of Transportation figures out:

A roadside drainage ditch primarily conveys roadway runoff. It may also convey offsite flows so the designer should be aware of where water is coming from that shows up in the roadside ditch.

- Minimum ditch depth = water depth to convey the 10 - year design event with a 0.5 foot minimum freeboard between the bottom of roadway subgrade to the 10- year design water surface elevation
- Maximum flow velocity of 5 feet per second and longitudinal ditch slope for grass lined ditches
- Trapezoidal section is preferred but “V” ditch is OK too
- Maximum ditch side slopes of 2:1
- Make sure the 10-year water surface elevation is not equal to the critical depth
- If the depth of flow is less than the critical depth, a hydraulic jump may occur

Notes:

- Freeboard is the vertical distance from the bottom of base course to the 10 - year storm water surface
- Coordinate ditch design with region Hydraulics

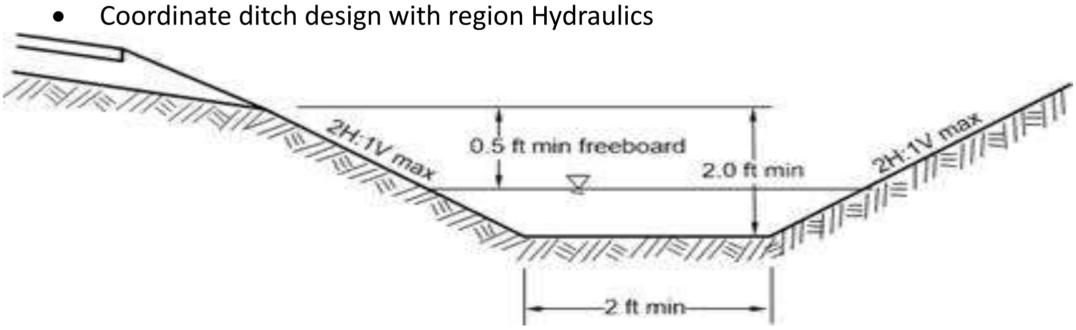

Figure 28: Detail roadside ditch[16]

Additional drainage ditches may be needed at the foot of higher embankments if water flows to the embankment from the adjacent terrain. This can allow moisture to penetrate into the foot of the embankment and cause landslides down the slope. In simple cases, this must be stopped by

16 Photo taken by the Washington State Department of Transportation; Lesson 10: Culvert and Ditch Design (HM Chpt 3 & 4)

providing a sealing (e.g. with water-impermeable soil for the foot of the embankment). [17]

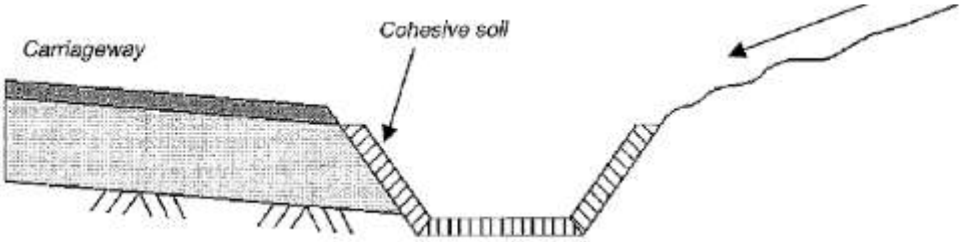

Figure 29: Sealing a ditch with cohesive soil, 10 – 15 cm thick

Plants may also be used to stabilize the foot of the embankment (e.g. live fascines of the kind generally used to secure embankments) or wooden hardwood, rock fill, paving or the like.

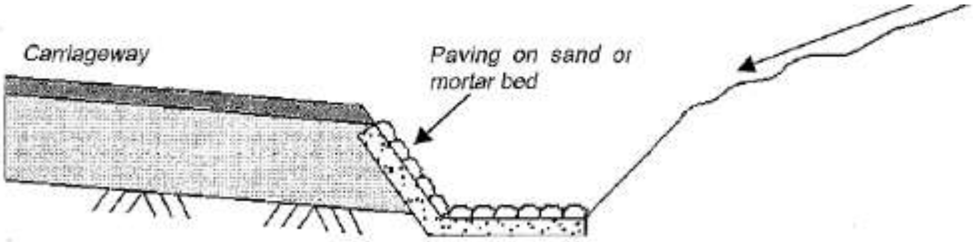

Figure 30: Slope paving, stabilized with mortar

Undercutting the slope with a wall should be used only under cramped conditions, since the support provided by such walls is often overrated. What is more, this solution is very expensive.

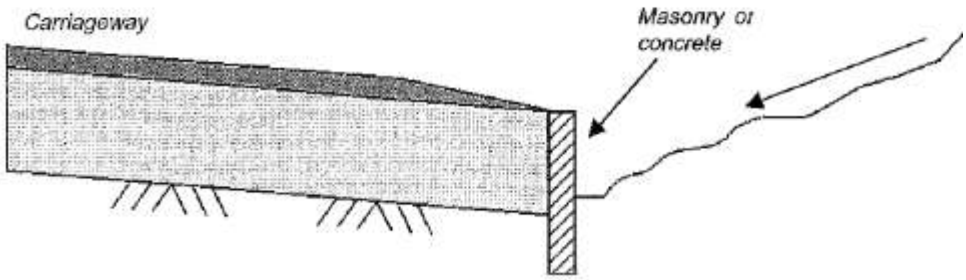

Figure 31: Undercutting slope

Note: Water crossing structures (e.g. culverts, small bridges etc.) are not an essential content of this report because building these structures are common and well known all over the world. And – these structures are not dependent on climate change - but already on adequate dimensioning. But - in Appendix C some additional explanations due to water crossing structures are given.

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17 Text and Photos on this page taken by FGSV (2003): Access Roads in Rural Areas; Crossing of Watercourses an surface drainage

4.3. CLUSTER 3: SHOULDER

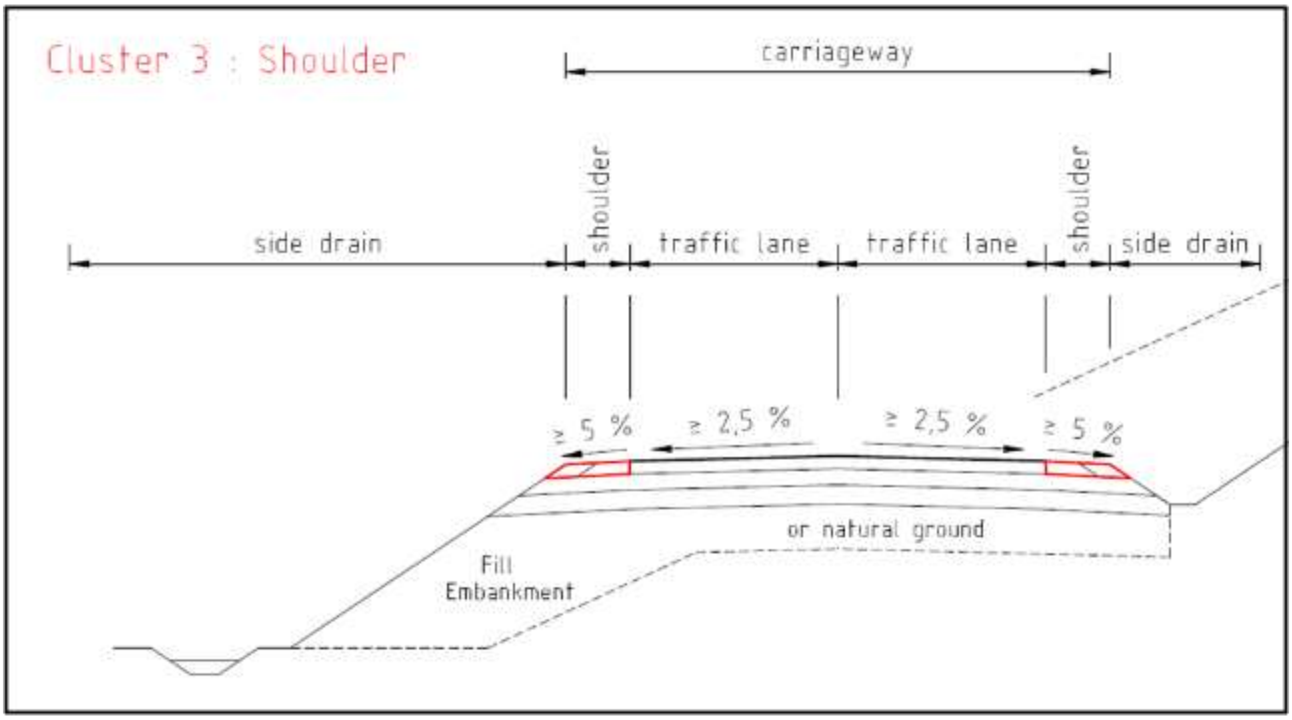


Figure 32: Cluster 3 Shoulder

4.3.1. Rainfall

Climate impacts: Rainfall intensity
Rainfall return period
Rainfall duration

Hazardous nature: All the mentioned impacts leads to erosion on the shoulder surface. This leads to the decision to seal the shoulder or not.

Examples and further explanations:

A sealed shoulder is a road shoulder that has a sprayed seal or asphalt surface. To prevent the erosion shoulders should be sealed.

Note: Of course, sealed shoulders making travel safer, but this is not due to the mentioned climate impacts handled in this report.

The Roads and Highways Department of Bangladesh (www.rhd.gov.bd) for example figures out the following example of shoulder construction:

Note: This is only an example. All over the world different designs are existing.

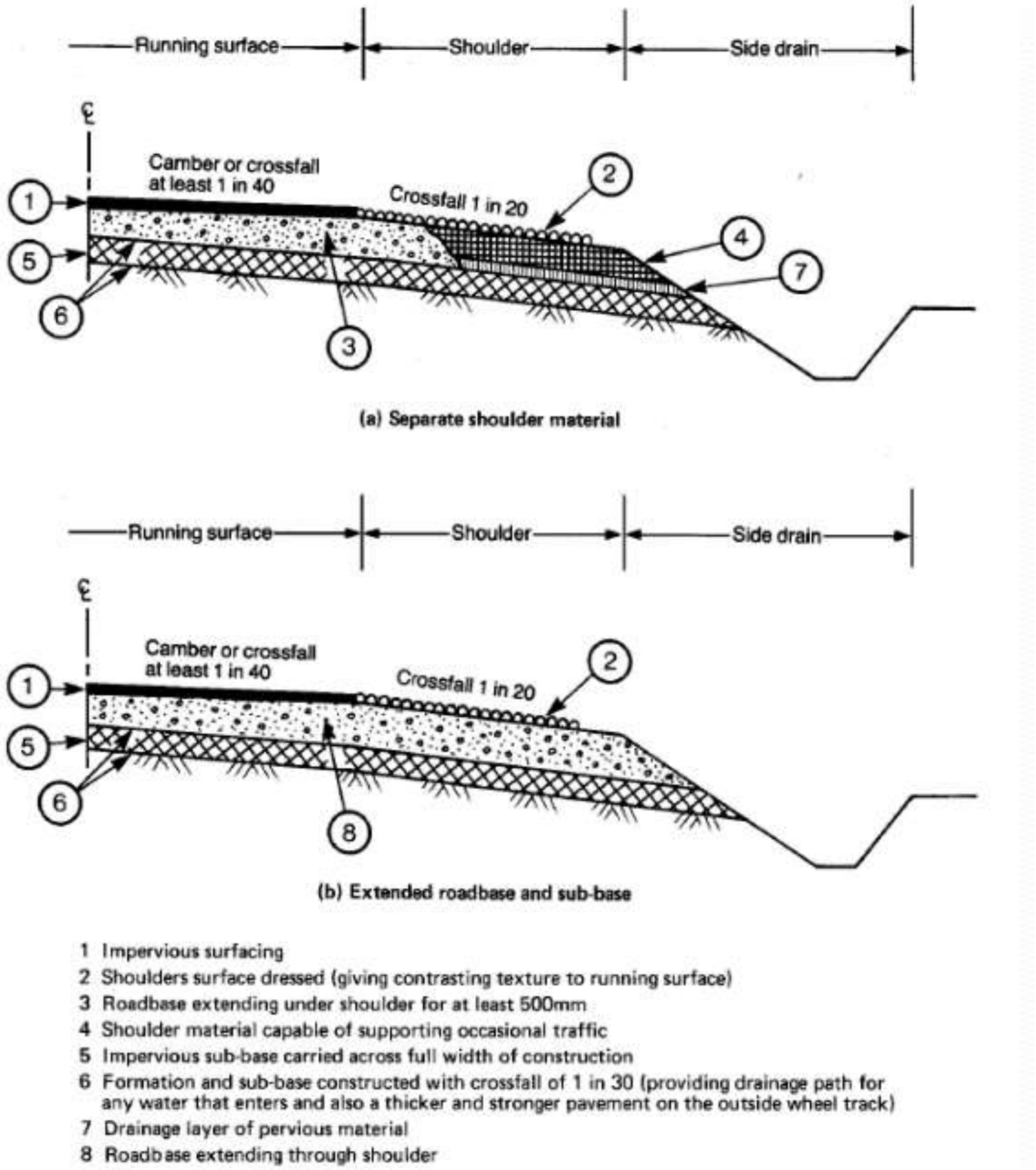


Figure 33: Cross section of road showing shoulder arrangement and roadside ditch

4.3.2. Temperature

Climate impact: Temperature impact

Hazardous nature: If the uninterrupted period of hot days is too long the lower soil layer heats up and the capillary-bounded water in the subsoil can evaporate. This leads to cracks in the road structure.

Examples and further explanations:

The following example was presented by Véronique Berche during the meeting in South Africa 2017, the presentation gave the results of David Mathon's works and the case presented also applied to part of the circulated route:

It is the emergence of cracks systematically after dry periods on departmental / secondary roads in France (Orléans region).

Under the pavement, the soil is always clay more or less plastic, and in most cases, the roads are near forests and there are no high embankments or high cuts (grazing profile of the road).

The structure of the road may be described as a fine layer (may be the pavement surface or bituminous layer) directly above the ground surface.

We note during these last fifteen years an increase in the temperature waves with longitudinal cracks occurring. In these pictures, we can see some examples on secondary roads during the 2013 summer. Summer 2013 was an exceptional summer with very hot air temperatures and droughts, so, you can see longitudinal cracks linked to the shrinkage and swelling of clayed soils

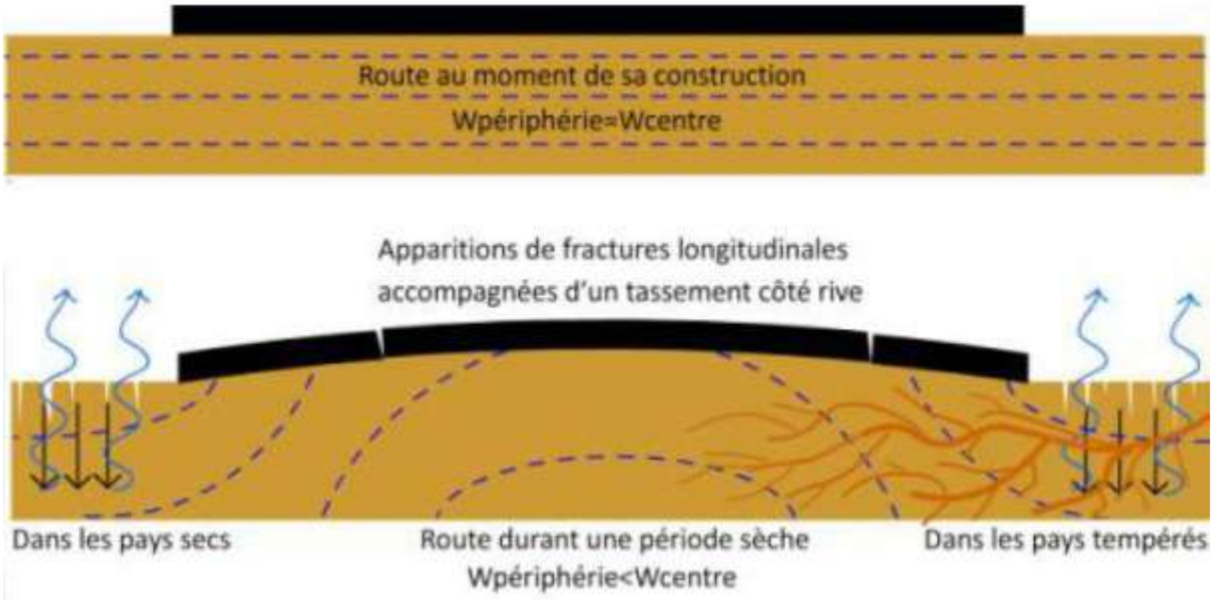


Figure 34: Physical background of tension caused cracks (D Mathon)

In this picture, you can see the effects of temperature increase below and beside the road.

The pavement layers protect the natural soil or the subgrade against evaporation due to hot temperatures. Therefore, there is no protection near the road: shoulders, verges and so on.

Thus, there is evaporation near the road and the water content of the soil decreases in depth until settlement appears.

The water content of the soil in the subgrade is decreased from the extremity up to the centre.

The hydric state decrease of the clayed soil induces a volumetric shrinkage of the soil below the road pavement structure. This induces on the surface of the road, longitudinal cracks and shoulder settlements.

In this picture, we can see the variation of water content in the subgrade and in the soil near the road at different times of the year 2009. Under the pictures of trees, you have the stratigraphic scale and the nature of the different soils: silts in the upper part and just after there is plastic clay underneath.

On the picture on the top left side, it was in May, and it could be considered that the hydric state of the soil was natural just after winter.

In the picture below, we are in July 2009, thus there was a decrease in the water content of the soil beside the road and in the shoulders of the road.

The picture on the right-hand side, was taken in October and it could be seen that there was a deficit in water content even on the extremity of the road.

This is one of the explanations to the longitudinal cracks occurring. And with the climate change, this situation will become more and more frequent. And, during periods of rainfall, the cracks will fill up with water and this will increase the damages on the pavement.

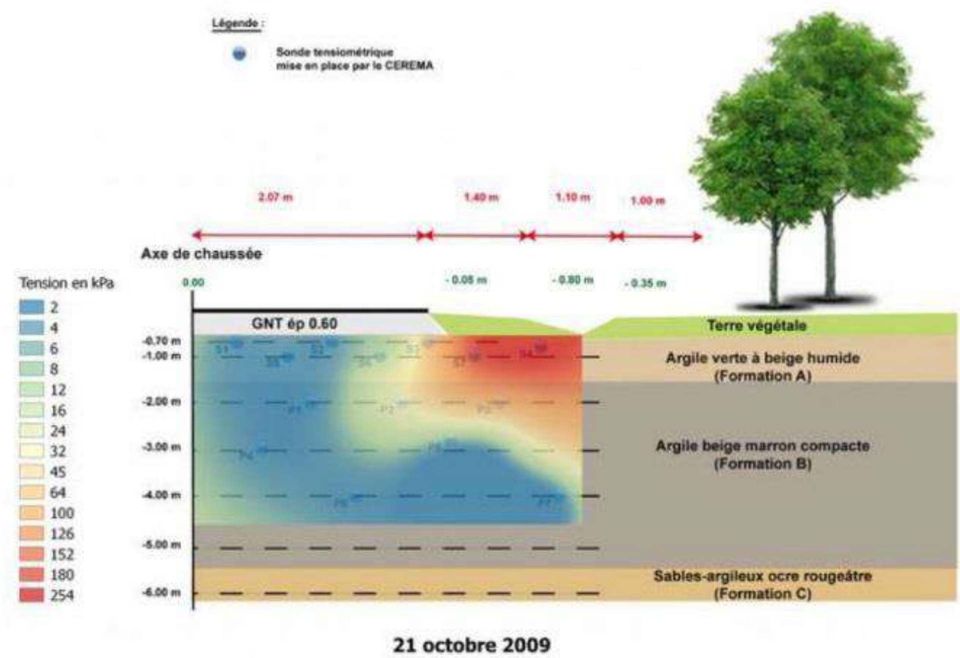


Figure 35: variation of the soil hydric state under a road section (D Mathon)

Year after year, there are dozens of kilometres affected by this phenomenon, and the maintenance and repairs are expensive. The infrastructure manager has been trying to find a less expansive solution to repair this, instead of making a new road in the place of the initial structure.

Here, are the results of one of these tests: using tight screens to limit the side drying out effect.

The question was: how deep will the tight screen be in order to be efficient? In this test, the depth was 2 metres because if deeper, there would be problems of realization and the cost would be more expensive too

And, after one or two years, new cracks will appear on the road. The reason for this is that the trench was not deep enough.

4.4. CLUSTER 4: BITUMINOUS SURFACING

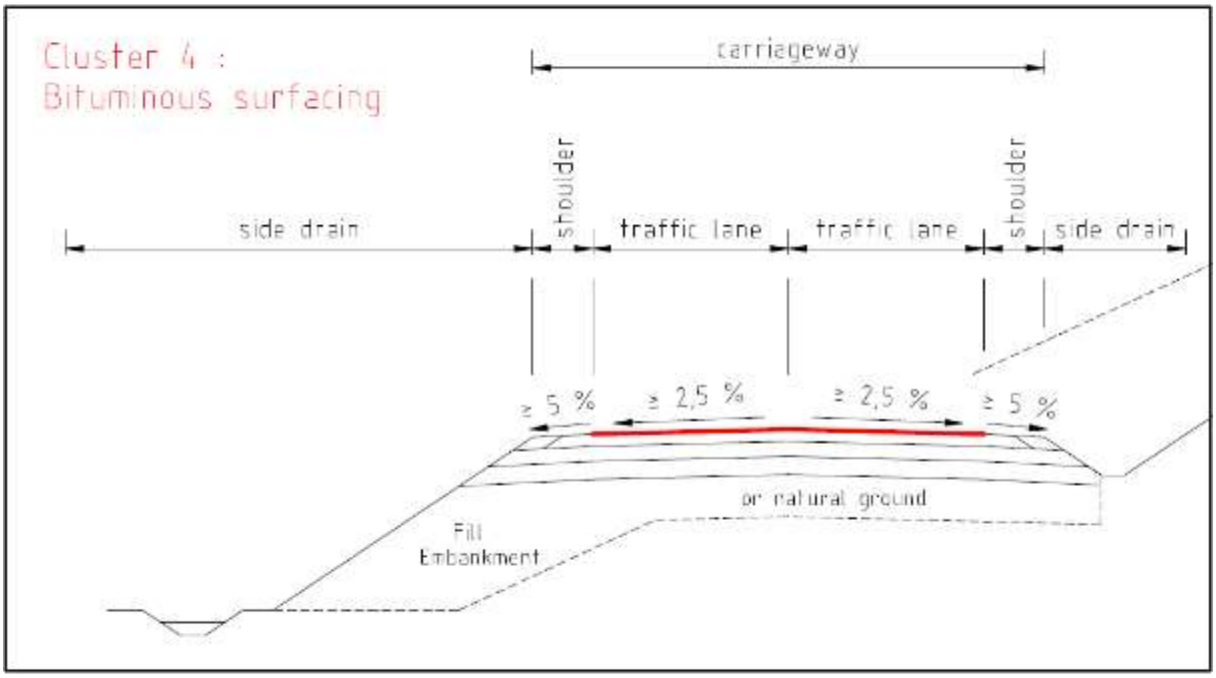


Figure 36: Cluster 4 Bituminous surfacing

Climate impact: Temperature impact

Hazardous nature: If the uninterrupted periods of hot days are too long, the whole asphalt layer could be softened. Because of this, the load-bearing structure becomes unstable and lead to a shorter lifespan of the asphalt layer.

Examples and further explanations:

The effects of extreme temperatures are influencing the surface of the road the most. The surface is under the direct influence of the atmosphere and can therefore heat up or cool down faster than the other parts of a road structure.

In general materials expand or contract under changing temperatures. Both is causing stresses within the material. Rising temperatures lead to an expansion and falling temperatures let materials contract. (Grybosky 1999)

Asphalt in general is a very temperature sensitive material. It consists of bitumen and aggregates. When the surface gets paved the asphalt is very hot with temperatures of around 140°C. At that temperature the bitumen is viscous and the asphalt can get paved. (Asphalt Institute)

There are many different sorts of asphalt which all work proper up to a certain temperature when they start to melt. As asphalt is having a colour that is mostly grey or even black it heats up more than the air when the sun shines.

Most sorts of asphalt begin to melt at temperatures of 70°C. Some others start to become soft even at temperatures of 50°C. Both especially applies to heavy traffic. (Mladic 2013)

In the past decade more and more countries reported melting asphalt roads in summer, such as Canada, the United Kingdom, Poland, India and others. Most of them were facing these problems after struggling with all-time temperature records. (Sims 2016)

Figure 37: melting asphalt road in India in summer 2016[18]

India's summer 2016 heatwave with air temperatures up to 51°C led to many problems with asphalt roads. As the surface began to melt road markings disappeared and people who wanted to crossroads even got stuck in the asphalt.

Consequences in other countries were mostly less dramatic but still caused damages.

In the United Kingdom many asphalt sorts used were not able to resist the heatwave in June 2017. In the United Kingdom even a lot of low volume roads are paved and suffered from the heat as the following photos show.

18 Melting asphalt, taken by Daily Mail, online available at http://i.dailymail.co.uk/i/pix/2015/05/27/14/291B2AFB00000578-0-image-a-49_1432734242184.jpg (last checked on 21.10.2017)

Figure 38: Road in Cambridge shire, United Kingdom with melting asphalt in June 2017[19]

A closer look shows that it is often just the very top layer of the pavement that gets softened enough. Results are still damaging and increasing maintenance costs.

Figure 39: Rural road in the UK with melted pavement[20]

How huge the effect of the sort of asphalt and the darkness of its colour on the risk of melting is can be seen in a photo from Poland:

19 Photo of melted asphalt taken by Taylor, Rebecca, online available at http://i.dailymail.co.uk/i/pix/2017/06/20/12/4192E41700000578-4620562-image-m-115_1497958465644.jpg (last checked on 21.10.2017)

20 Photo of melted asphalt taken by Taylor, Rebecca, online available at http://i.dailymail.co.uk/i/pix/2017/06/20/12/4192E41700000578-4620562-image-m-115_1497958465644.jpg (last checked on 21.10.2017)

Figure 40: Dog stuck in melted asphalt on a road in Poland[21]

The original asphalt sort of this rural road was light grey and obviously more heat resistant than the bitumen that was used to repair the road at some spots. While the people around the dog can stand on the light grey asphalt the dog got stuck in the darker area just next to it. As a dog is very light compared to the weight of any vehicle roads like this are unsuitable for traffic during heat waves.

Beside heat waves forest fires can damage roads, too. Often both happen at the same time. The risk of forest fires rises during droughts and heat waves. In Chile for example both occurred at the same time and led to massive road pavement damages as well as road closures.

Figure 41: Forest fires beside a rural road in Chile[22]

Note: Inn Appendix D some additional explanations due surfacing a road are given.

Countries or regions without dense vegetation often face the problem of sand or dust storms. Forrestal areas reduce the wind velocity and also protect the soil with their roots. Without this protection and without a moist underground wind can move material as sand or dust and blow it on roads.

21 Photo of melted asphalt, online available at http://imgur.com/5KMsFvg (last checked on 21.10.2017)

22 Taken from PIARC Tc D4.1 enquiry result of Chile

This is a common problem in regions as the Middle East, Africa and even parts of Asia and Northern America.

Figure 42: Rural road in Namibia after a sandstorm[23]

Sandstorms are also not damaging the road itself but can make it even unable to be found. Even the palms next to the road on both sides couldn't reduce the wind velocity enough. But still the height of the sand layer seems comparatively low. Another photo from Abu Dhabi shows the possible consequences of stronger storms or the lack of maintenance.

Figure 43: Road in Abu Dhabi after a sandstorm[24]

The road is impassable for most vehicles in these conditions. Abu Dhabi is located at the sea and has no natural vegetation in most areas of the country. As a result, strong winds are often causing sandstorms and are blocking roads.

Countries in the Northern hemisphere are not facing these problems. But instead of sand snow can have a similar effect in winter. Snow – especially freshly fallen and loose – can behave just like sand.

23 Taken from Allgemeine Zeitung Namibia, published on 24.05.2017
24 Photo taken by Amanda, Anna; online available at https://amandainabudhabi.wordpress.com/tag/sandstorm/ (last checked on 21.10.2017)

And as the weight is even lower than the one of sand wind velocities don't need to be high to move snow.

As a result road can also be hard to be seen.

Figure 44: Rural road in Iceland[25]

In the areas where the described influences can occur, roads should always be built on an embankment. This embankment should be at least 0.80 m high. This will have the effect that the wind sweeps the snow or sand over the road.

4.5. CLUSTER 5: BASE

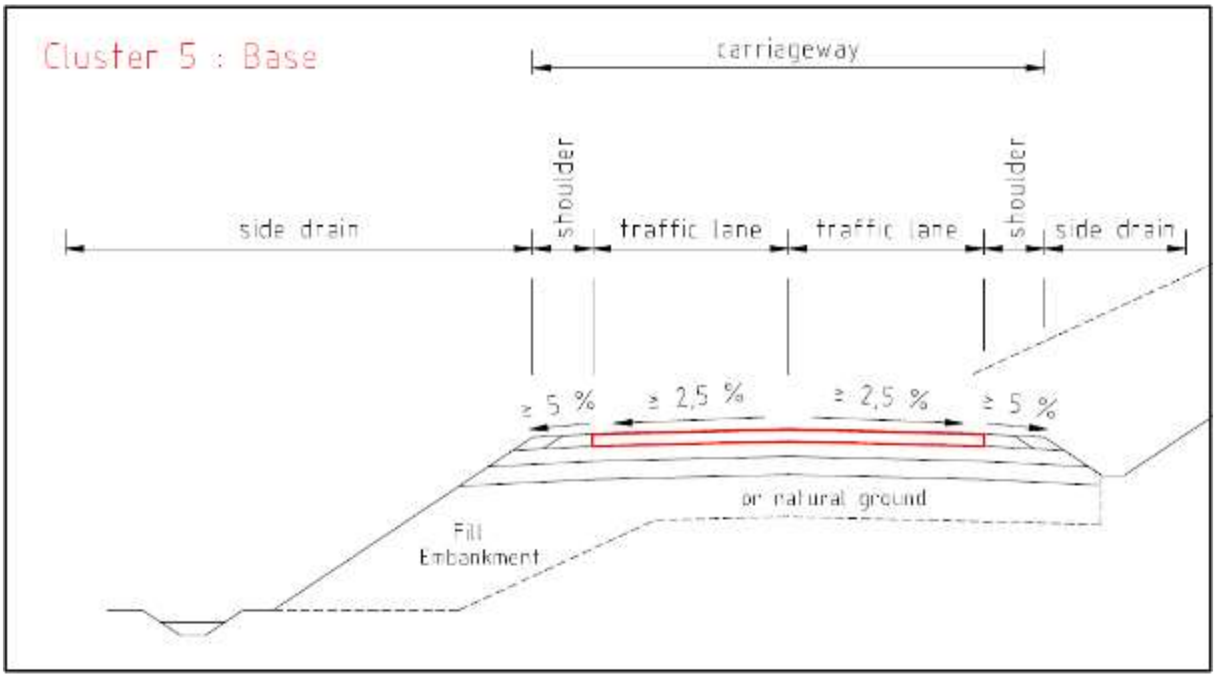


Figure 45: Cluster 5 Base

Climate impact: Rainfall intensity
Temperature impact
Wind (when there is no bituminous surface layer)

25 Photo taken by Milhaud, Michael; available online at https://www.reddit.com/r/Island/comments/32xmt3/the_wind_blowing_snow_over_a_road_in_iceland_at (last checked on 21.10.2017)

Hazardous nature: If it is too dry for a too long time then the surface of the base will dry out. The fine particles are then no longer bound.

In combination with wind or rain or because of the high volume of traffic, the fine particles are washed out or blown away. This process leads to unbind the bigger stones close to the surface. The stones will be ripped out and the load-bearing structure of the base will be destroyed.

All the described effects lead to bumps and/or depressions.

Examples and further explanations:

Of course, the best solution is to surface the road (covering the base with a pavement). If this is not possible, a quality check of the existing surface of the base should be done. This allows a quantitative statement to be made about the condition of the base.

The Canadian ARA for example has developed a simple checklist to judge the current condition of a rural road. The system is very simple and can be used without technical equipment. Its system is divided into two equations: One for sealed roads and one for gravel surface roads.

The Index for gravel roads is called the **Gravel Condition Index**:

In the first step you calculate the Gravel Distress Manifestation Index (GDMI):

$$GDMI = \sum_{i=1}^{n} W_i(s_i + e_i)$$

The GDMI is the sum of different criteria. Each criterion has a weighting (w), a severity (s) and an extent (e).

For gravel roads the criteria have the following weighting w:

Distress	**Weighting Value (w_i)**
Factors Independent of the Time of Rating	
Gravel Supply	3
Cross Section	3
Subgrade Failures	3
Settlements/Distortions	3
Roadside Drainage	2
Maintenance Effort	3
Factors Dependent on Time of Rating	
Rutting	2
Potholes	1
Washboard	1
Surface Drainage	2
Loose Gravel	1
Slipperiness	1
Dust	1
Patching	1

The severity has a value from 1-5. 1 means that the severity is very slight and 5 is for very severe distresses. To estimate the severity the executive staff should have some experience in road maintenance.

The extension also has the possible values 1-5. It describes the percentage of the surface that is affected.

< 10%	1
10-20%	2
20-40%	3
40-80%	4
80-100%	5

As a second step you calculate the Road Condition Index (RCI):

The Road Condition Index describes the driving comfort of the road. To a certain degree the RCI is subjective as it describes a comfort level. A perfect road gets 10 points and a minimum comfort level can get 0 points:

10-8	Very smooth
8-6	Smooth with a few bumps or depressions
6-4	Comfortable with intermittent bumps or depressions
4-2	Uncomfortable with frequent bumps or depressions
2-0	Uncomfortable with constant bumps or depressions

In the last step the actual calculation of Gravel Conditions Index (GCI) delivers the result:

$GCI = (100 \times ((0.1 \times RCI)0.5) \times ((192-GDMI)/192) \times 0.924) + 8.856$

The result of the GCI is a number between 0-100. The following chart explains the meaning of the number:

Time of Improvement	GCI for rural roads
Adequate	>80 points
6-10 years	66-80
1-5 years	46-65
NOW Rehabilitate	40-45
NOW Reconstruct	<40

Note: The calculation of the Index for paved roads is shown in Appendix E.

On the base of this very simple evaluation system the priority for road maintenance can get decided. In general rehabilitation is cheaper than reconstruction.

Therefore, road administrations should focus the maintenance budget on roads with 40-65 points.

The quality of the roads below might be worse. But often the travel quality of these roads is already at a minimum and neither do the costs increase by waiting nor is there a way to prevent a total reconstruction. (Hein 5/24/2017)

4.6. Cluster 6: Subbase

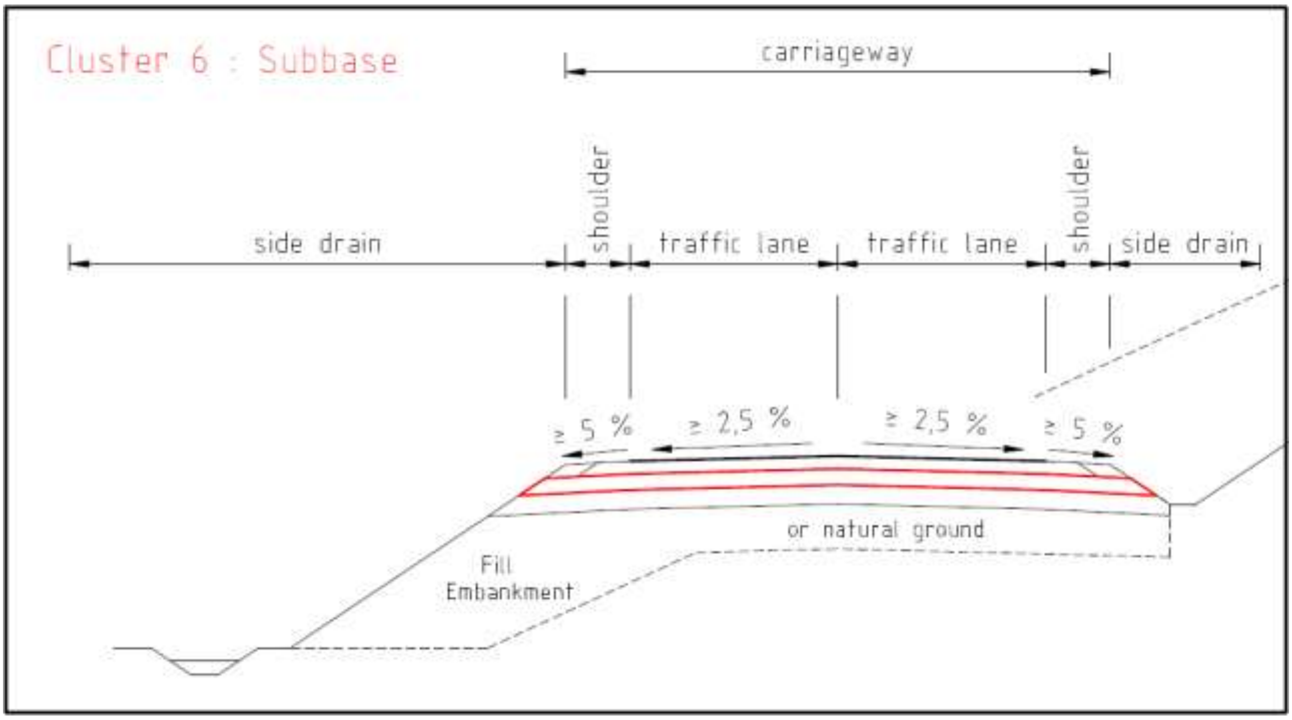


Figure 46: Cluster 6 Subbase

Climate impact: Temperature impact (on Permafrost areas and winter frozen soils)

Rainfall intensity (infiltrations)

Hazardous nature: In the case of permafrost areas, if the uninterrupted period of frozen days is too short the permafrost foundation will warm up and might melt down. This leads to settlements and cracks in the road structure.

Examples and further explanations:

Fine-grained soil as clay is more sensitive to freezing as coarse-grained materials. Therefore, earthworks made of fine-grained materials are more sensitive than earthworks that comprise rocks. (Fuchsschwanz 2015)

One risk for the subbase is therefore to get damaged by freezing. The process of freezing itself is not automatically dangerous for an earthwork. Several factors have to come together at the same time to increase the risk of damages:

- Moisture within the earthwork
- Temperatures below 0°C (in the earthwork itself)
- Traffic load

If one of these 3 factors is not applicable damages of earthwork and road structure are unlikely.

Closure of rural roads can sometimes be an appropriate measure. However, if the rural road fulfils one of the following criteria or conditions, a road closure must be an option to be taken in the last:

- Only access of rural population to medical facilities
- Only connection between inhabitants and workplaces
- Only access of rural population to educational facilities
- Only connection to supplies of daily needs (i.e. food)

If there is moisture and temperatures below 0°C in the earthwork and none of the criteria above does apply, a road closure is appropriate to protect the earthwork!

Especially for roads that are in the planning or get a rehabilitation reduction of the criteria moisture and temperature are in focus.

Frost protection of earthworks[26]:

This chapter is only dealing with the risks of climate change for earthworks. But for a proper earthwork protection the road structure itself – as seen above – is essential, too. The atmospheric temperature is affecting the temperature of the surface of a road the most. The reason for that is the direct contact between the surface and the surrounding air and the influence of sun beams.

Every layer below – the base, the subbase and the subgrade – are affected less than the layer above them. A frost protection layer can be each layer of a road structure that is made of a coarse-grained material like gravel or a mix of sand and gravel. Coarse-grained materials do not store water and can also not draw water from the underground with the capillary effect. Its water content is therefore low compared to the air content. Frost damages are unlikely as the little amount of water can extend into the space filled with air.

Another result of often changing temperatures in combination with moisture can be falling rocks. An example of it can be seen in the next photo. A change in temperature in combination with water or humidity is weakening the rocks until parts of it fall down on the road.

Figure 47: Road in Norway with falling rocks[27]

26 Road structure illustrated by the US department of transportation, available online at https://www.fhwa.dot.gov/engineering/geotech/pubs/05037/images/f009.gif (last checked 21.10.2017)

27 Taken from PIARC TC E1 report of Norway

Falling rocks are not always damaging the road itself. But they increase the risk for drivers and passengers of vehicles and should therefore be mentioned as a possible effect of climate change on rural roads.

4.7. CLUSTER 7: CAPPING LAYER

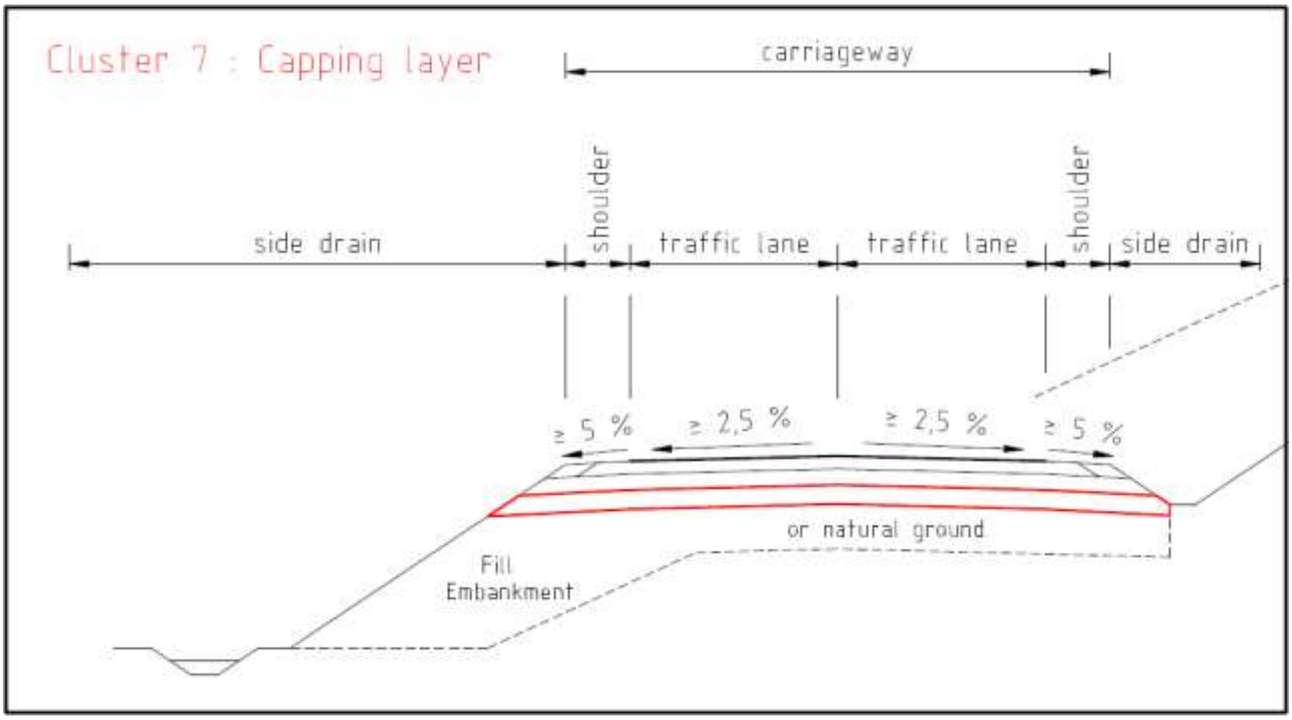


Figure 48: Cluster 7 Capping Layer

Climate impacts: the capping layer may be affected by changes in rainfall and temperature (water passing through non-impervious roadways or ditches, for example) but no cases have been reported as it is not obvious to put problems only affecting the capping layer. Refer to the chapter dealing with shoulder, slope and roadside ditch

4.8. CLUSTER 8: FILL/EMBANKMENT

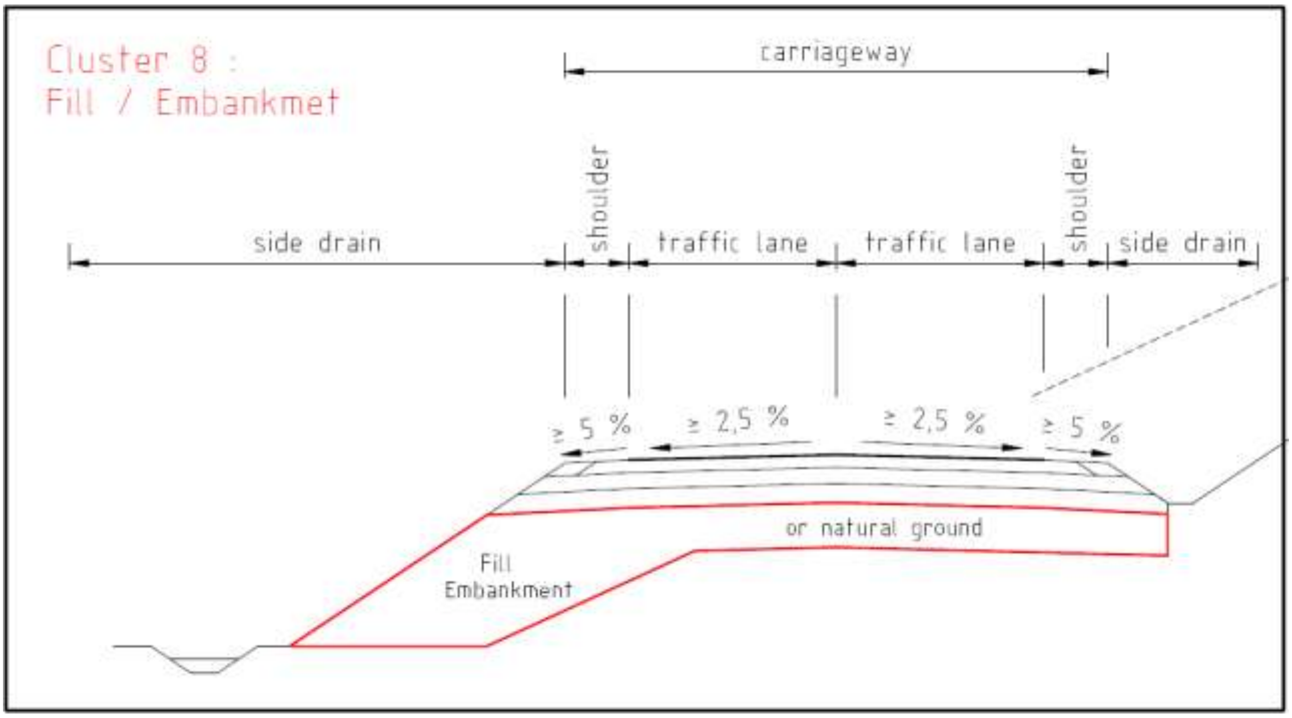


Figure 49: Cluster 8 Fill/Embankment

Climate impacts: Due to the slope of the embankment see comments made on cluster 1 (Slope); to the roadside ditch see comments made on cluster 2, to the capping layer see comments made on cluster 7.

Risk of thawing permafrost

Roads that were built on permafrost soil are located in countries with a very low average temperature. Countries that have permafrost soil can be found on the northern hemisphere mostly Russia, Central Asia (the Himalaya region), parts of China, the Caucasus region, Northern Scandinavia, Canada and Alaska. Due to the lack of landmass on the southern hemisphere only Argentina and Chile do have permafrost there.

Permafrost is – as long as it is not thawing – a very good underground for roads. The reason for that is that even the surface soil has a very high load capacity. Materials like silt, sand, humus and clay do mostly have to get removed from the very top surface in non-permafrost regions as they do not provide an adequate stability. In a frozen state – as in permafrost regions – the expensive removal could get avoided so far and roads were therefore cheap to build.

Therefore, the first step for road authorities with permafrost regions is to check available regional climate models: Even when temperatures are rising globally permafrost will not disappear completely to the end of the century! Technical solutions for a road construction in permafrost regions that are climate change proof are complicated and time-consuming. Therefore, only take action when your permafrost is expected to thaw!

So far there are only two possible ideas of either removing permafrost soil before the construction of a road or replacing roads by bridges.

The People's Republic of China is currently facing thawing permafrost in the Heilongjiang province.

As damages like started to occur in the past few years China began research on thawing permafrost.

More and more roads were built on permafrost and were affected by land subsidence.

As a result of its research China presented two possible solutions:

1. Excavate all permafrost before construction

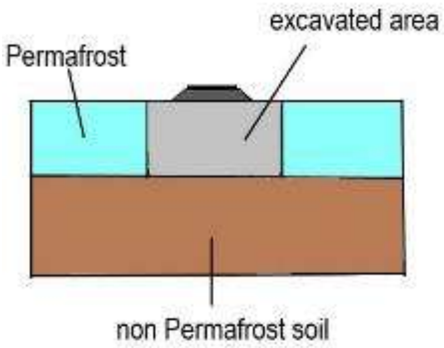


Figure 50: Excavation concept for thawing permafrost

The excavation concept is basically the excavation of all permafrost soil down to stable non-permafrost underground. The left room gets filled with coarse-grained frost proof material like gravel. It is therefore not affected by the surrounding permafrost and has the function of a frost protection layer. As this method needs the intense use of machines (for the excavation of the hard permafrost) and as it needs massive amounts of coarse-grained material in often very isolated areas it is usually not economically affordable. (Wang)

2. Replace roads by bridges

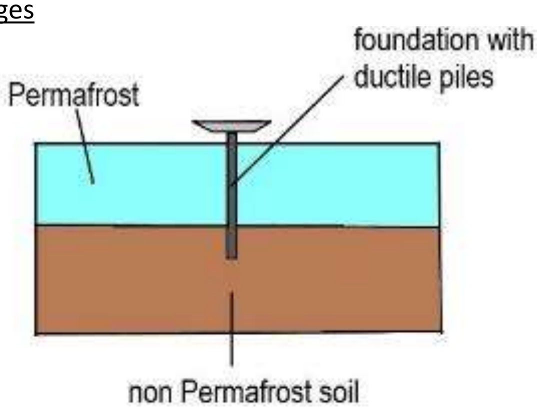


Figure 51: Bridge concept for thawing permafrost

Instead of the excavation of the permafrost another idea is to build the total road as a bridge. This "bridge" is located just above the actual permafrost surface but does have no direct contact – and isn't dependent on its load capacity. Ductile piles are fixed in stable underground and work as a foundation for the bridge. The advantage of this method is the saved coarse-grained material. Nevertheless it is even more expensive than the excavation and can economically only be used for short distances. (Wang)

Countries with permafrost soil do not have any other technology that can deal with thawing

28 Own illustration
29 Own illustration

permafrost. Nevertheless, research is going on. Apart from a reduction in greenhouse emissions there is probably no chance left to preserve most areas with permafrost. Therefore, authorities should focus on the exact areas that are expected to thaw within the next 100 years and try to find affordable ways of building lasting roads.

[30]

Figure 52: Road in Canada in winter with uneven surface due to frost break

Another possibility of damages that look like this is the location of a road on permafrost soil. In areas with permafrost the load capacity of the frozen soil is usually excellent. But it reduces when the soil begins to thaw.

As a result of climate change many areas with permafrost face the problem of damages at the infrastructure. An uneven surface can be an indicator for that as some parts of the underground thaw earlier or stronger than others.

Figure 53: Cracks from melting permafrost at the embankments of the Alaska Highway[31]

As you can see in the photo above melting permafrost is currently already causing problems at the Alaska Highway which was mostly built on permafrost. Parts of the highway were built on it and are now endangered to slide away.

30 Taken from PIARC TC E1 report of Canada
31 Photo of melting permafrost, online available at https://assets.bwbx.io/images/users/iqjWHBFdfxIU/i3pHvoqz6xwA/v0/1200x-1.jpg (last checked on 21.10.2017

5. HYDRAULIC STRUCTURES

Floods can also be a risk for culverts that are placed at earthworks. Heavy rain is expected to increase in many regions due to climate change. Culverts are often not adequately dimensioned for such precipitation events.

On the other hand, road embankments are mostly not designed to dam up a lot of water. The structure can get softened and possibly break.

There are currently two concepts to reducing the risk of blocked culverts:

- *Replacing culverts by bridges:*

The Italian province of Sardinia faced increasing rain and storm events within the past decade. Because of this, many culverts were blocked by debris and embankments collapsed because of the water pressure. Situations afterwards looked like the following example from Sardinia:

Figure 54: Collapsed culvert in Sardinia with a damaged earthwork[32]

Sardinia decided that the risk of another event like this was too high and replaced the culvert by a bridge. This doesn't actually mean a protection of the earthwork but a replacement.

Many other culverts on the island looked like the following one:

32 Taken from PIARC TC D4.1 enquiry results of Italy

Figure 55: Culvert in a river valley in Sardinia[33]

They have been analysing all culverts across the island. Those that were located in valleys that were expected to carry a lot of water in case of heavy rain events were replaced. The same situation on the photo above looks now like this:

Figure 56: Same location after replacement[34]

The resulting costs are of course not affordable for every road and especially not every country. But even for smaller roads in developing countries there are possibilities of constructing cheap bridges to avoid the use of culverts.

African countries and especially the URRAP program are leading in the design of low cost bridges.

33 Taken from PIARC TC D4.1 enquiry results of Italy
34 Taken from PIARC TC D4.1 enquiry results of Italy

- *Change in dimensioning of rain facilities:*

Today the maximum amount of expected rain in a specific period of time is still dimensioned by measured amounts of rain in previous periods of time.

In most countries there are many weather stations collecting data about precipitation – often since a long time ago. Statistical methods made it possible to calculate a maximum expected amount of rain for a specific area.

The problem nowadays is that data from the past cannot predict the dynamic change of precipitation caused by climate change. And as the chapter about regional climate models has been showing it remains difficult. Dynamic simulations on future precipitation are not yet reliable enough.

Nevertheless, there is the theoretical possibility to gain more detailed and more reliable precipitation simulations in the future even for regional models.

In that way the dimensioning of culverts in the future could be adapted to realistic amounts of water. Replacing many culverts by bridges could be superfluously. And this could reduce costs.

Therefore, research on precipitation and cooperation with meteorological institutions has to be fostered. The change in hydraulic works dimensioning has therefore not yet become a good enough practice.

- Other solution (Malaysia: Mister ASHARI presentation PIARC 2013-2016)

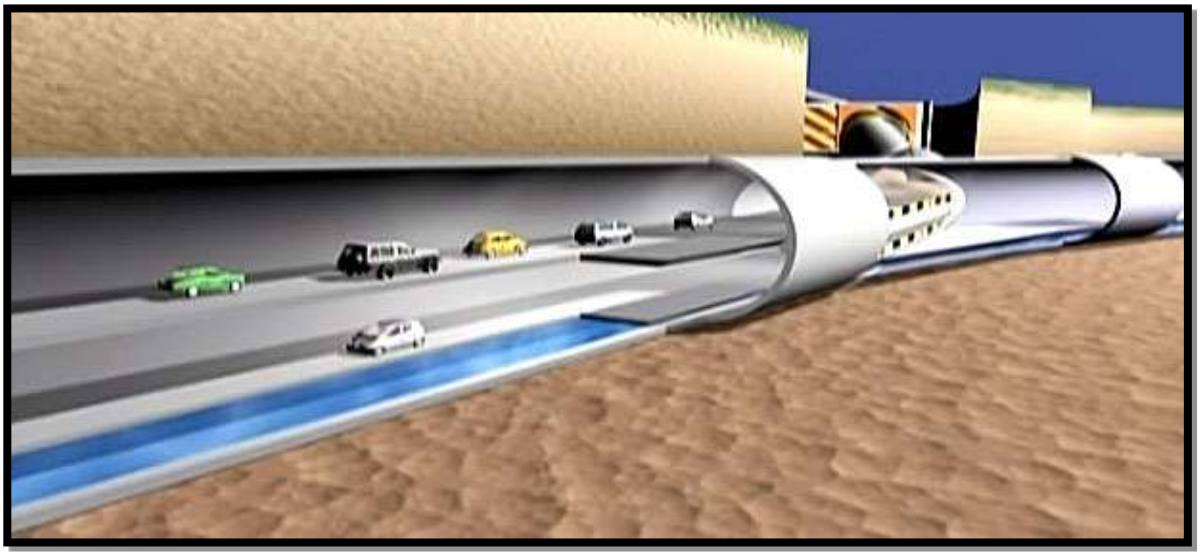


Figure 57: Future solution with flooding impact (Malaysia: Ashari)

As we can see, this is a new infrastructure design that can be likened to a tunnel with three floors. The two upper floors are normally used for traffic, the lower floor can be compared to a hydraulic structure, allowing the flow of drainage water, sanitation. In case of flood, or intense rainy episodes, the central level is cut to the circulation to let the water pass.

If the rains are even stronger, the entire tunnel is closed to traffic and serves as a hydraulic structure to limit the extent of flooding.

This concept needs to be further developed to:

- ensure the safety of road users in case of impoundment of the central level,
- define the cleaning conditions of the "tunnel" after a flood event (presence of mud, debris and other vegetation, ...)
- ensure the resistance of the materials to the impact of the flow more or less loaded with debris of any kind

6. BLUEPRINT

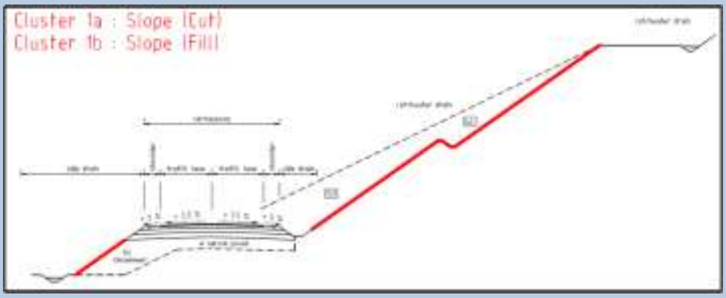
6.1. GENERAL EXPLANATIONS

As mentioned in Chapter 3.4 the aim is to create an idea of style sheet (TC D4.1 committee call this sheet “Blueprint”) from which the input parameters, the trigger values and the required measures can be derived.

The Figure below gives a first impression to reach this aim:

Blueprint TC D4.1

Date:	
member	
country:	
region:	



Things to be recognized for Cluster 1

Rainfall					Wind				
	Year	Max [mm/h]	Year of interest Expected Max	[mm/h]		Year	Velocity [m/s]	Year of interest Expected Velocity	[m/s]
Today					Today				
Future					Future				

Analysis for slope material			Analysis for wind protection slope		
Border [mm/h]			Border [m/s]		
≤ 400		using existing parameter	0 - 8		no change of design
400 - 600		using stabilized material	8 - 11		no use of trees
600 - 900		artificial protection	11 - 14		no use of bushes
> 900		verification of alignment	> 14		protection against wind erosion

Analysis for slope angle		
Border [mm/h]		
≤ 400		slope gradient 1:1
400 - 600		slope gradient 1:1,5
600 - 900		slope gradient 1:2
> 900		slope gradient 1:2

Explanation:
red figures: to be filled out
blue figures: automatically calculated

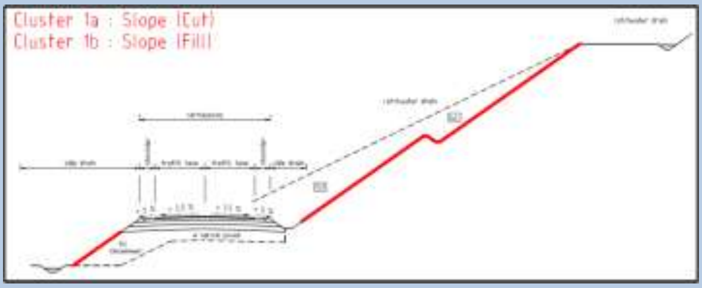
Figure 58: Blueprint – first draft

Filling out the Blueprint should be done in three steps:

1. Members deliver climate data and year of interest

Blueprint TC D4.1

Date:	
member	
country:	
region:	



Things to be recognized for Cluster 1

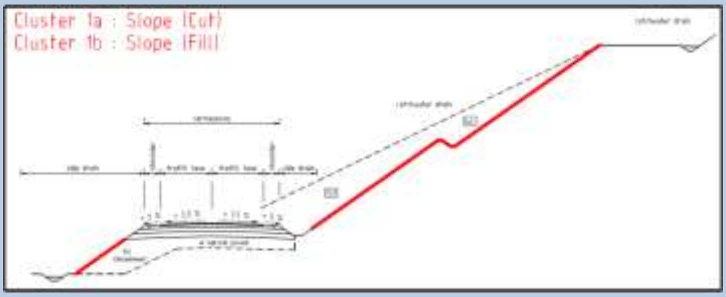
Rainfall					Wind				
	Year	Max [mm/h]	Year of interest	Expected Max		Year	Velocity [m/s]	Year of interest	Expected Velocity
Today	2017	350	2047	[mm/h]	Today	2017	8	2047	[m/s]
Future	2050	410			Future	2050	10		

Figure 59: Blueprint – Step 1

2. The blue figure gets calculated

Blueprint TC D4.1

Date:	
member	
country:	
region:	



Things to be recognized for Cluster 1

Rainfall					Wind				
	Year	Max [mm/h]	Year of interest	Expected Max		Year	Velocity [m/s]	Year of interest	Expected Velocity
Today	2017	350	2047	405 [mm/h]	Today	2017	8	2047	10 [m/s]
Future	2050	410			Future	2050	10		

Figure 60: Blueprint – Step 2

3. A calculated background analysis gives suggestions for the construction

Analysis for slope material			Analysis for wind protection slope		
Border [mm/h]			Border [m/s]		
≤ 400		using existing parameter	0 - 8		no change of design
400 - 600	X	using stabilized material	8 - 11	X	no use of trees
600 - 900		artificial protection	11 - 14		no use of bushes
> 900		verification of alignment	> 14		protection against wind erosion

Figure 61: Blueprint – Step 3

6.2. DETAILED FUTURE WORKING PROGRAM

Further work within the Technical Committee during the working period 2020 - 2023 could now deal with the following topics:

- Regarding the changing climatic influences, determine which construction methods are necessary for the protection of rural roads.
- Determine the border value or the range of the border value based on the specified influence parameters (presented in Chapter 3.3).
- These specifications can then be used to make recommendations for changes in construction methods.
- These specifications should be made cluster by cluster.
- It is recommended to discuss only one cluster at each Technical Committee meeting. As a result, all clusters can be dealt with during the working period 2020 - 2023.

7. CONCLUSION

There is a need for methodology, anticipating the effects of the climate change during the designing and the managing steps.

In conception, we can choose the optimum position of the infrastructure with regards to the position of each risk, what we call « horizontal displacement »: this could be the construction of a new littoral road.

To make this decision, it is advisable to make a mapping of the current and; perhaps, the future potential natural risks such as: landslides, floods and so on.... With this map, it is necessary to see if it is possible to translate the road inland and to higher ground.

The second possibility is to make a vertical translation and therefore to make higher embankments or bridges. For this solution, there is a need of more data or research on:

- the methodology to construct high embankments,
- the possibility to increase the mechanical properties of the soil used in the embankments: perhaps by using hydraulic binders (example: chapter 4.3.2),
- the durability of the treatment when the embankment bases are under water,
- the size of the culverts; drainage system: replacing culverts by bridges (see ch5),
- a new infrastructure concept (see chap 5)

….and so on.

In a managing position, there are two approaches.

The first one, is to define quickly at large scale, the earth structure or drainage system which may have been impacted.

For this, you have to define the major event having impacted the infrastructure and the interrupted transport into systems and components such as: ports, tunnels, bridges, embankments, fills, culverts and so.... Such climate events are defined as events exogenous events in transport infrastructures, characterized by intensity, spatial and temporal occurrences.

Extreme events impact infrastructures: systems and components have different physical vulnerability levels depending on the age of the infrastructure, the materials used, the maintenance... To access the network's physical criticality, we must determinate which climate event will impact which system, how and to which extent.

An example of this approach is given in annex H2 illustrating the methodology set up in Spain.

The second one, is to define more precisely at small scale, the most impacted zones, and work on these specific areas.

Thus, specialized or more detailed studies may be carried out integrating the clusters detailed in the chapter 4. This report only deals with the concept of the construction of these clusters because in order to go further, it is imperative to adapt them to each region as illustrated in chapter 6.1. This is the work that is proposed to continue during the next strategic plan.

In addition to the climatic projections for each zone studied, it would be interesting also to integrate:

- the mechanical state of the earth structure,
- the environment: village or not, risk areas, traffic, and so on

And with all these data, we can begin to prioritize areas requiring the most rapid adjustment / adequation….

Therefore, it must be considered the price, and answer to these questions:

« Should we anticipate and carry out works therefore « zero risk » ?
Or,
« Should we execute sustainable or resilient work that will wear out with time but is reusable without any additional cost?

8. GLOSSARY

Term	Definition
AADF	Average Annual Daily Flow
AC	Alternating Current
APS	Aesthetic Power Supply
B	Magnetic Field
BM	Business Model
BMS	Battery Management System
CAN	Controller Area Network
CBA	Cost Benefit Analysis
CO_2	Carbon Dioxide
CRF	Centro Ricerche Fiat
CWD	Charge While Driving
DBFO	Design Build Finance Operate
DC	Direct current
DEFRA	Department for Environment, Food and Rural Affairs
DWPT	Dynamic Wireless Power Transfer
eBus	Electric Bus
EC	European Commission
ECU	Electronic Control Unit
EFC	Emissions Forecasting Tool
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EMF	Electromagnetic Field
EMI	Electromagnetic Interference
ERS	Electric Road System

9. TABLE OF FIGURES

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APPENDIX A: CLIMATIC BACKGROUND

Since there is a climate record existing for about the last two centuries, we see rising global temperatures. While a change in global temperatures has always been happening in history it never happened as fast as nowadays as you can see in the graph below. (Carlowicz, Michael 2010)

As the consequences of rising temperatures and a climate change do already have an impact on our environment today road administrations have to start preparing their rural roads for it. The consequences of climate change are only expected to grow in the future.

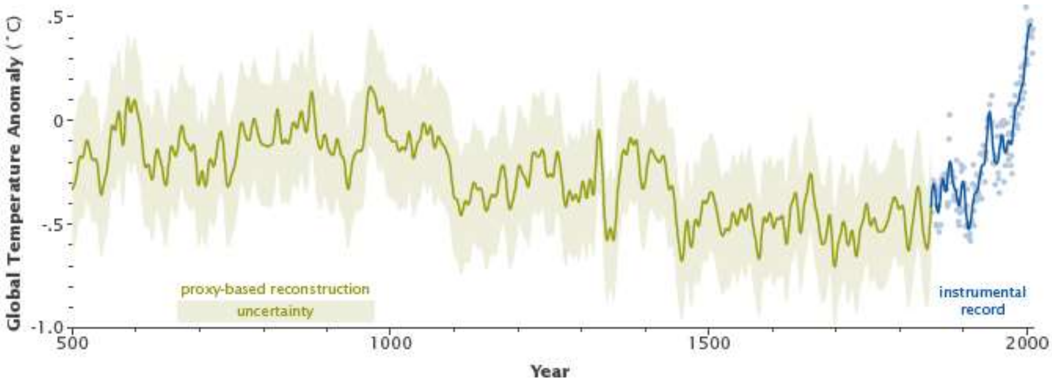

Figure 62: Global average Temperature anomaly (°C) since 500 AD compared to the all-time average temperature[35]

As the consequences of rising temperatures and a climate change do already have an impact of our environment today road administrations have to start preparing their rural roads for it. The consequences of climate change are only expected to grow in the future.

CLIMATIC HISTORY

As the reasons for climate change and the climatic history before the 19th century play a minor role for the best practices of rural roads this report will focus on the climate change of the past 200 years and the expected climate change until the end of the 21st century.

The NASA, the National Aeronautics and Space Administration of the USA, is nowadays being able to monitor global temperatures by satellite technology and has therefore very precise information about temperatures even in very inaccessible areas.

Since we have existing data from the past from a lot of cities with a meteorological office, we can easily compare the change in average temperatures. This time growth rings of trees and samples from glacier ice could provide temperature data in historically inaccessible areas.

From all the existing data the NASA built a global average temperature of the entire 20th century.

The following 3 graphs show the difference in temperatures compared to that global average in the decades 1885-1894, 1945-1954 and finally 2005-2014.

35 Online available at https://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php?all=y (last checked on 21.10.2017)

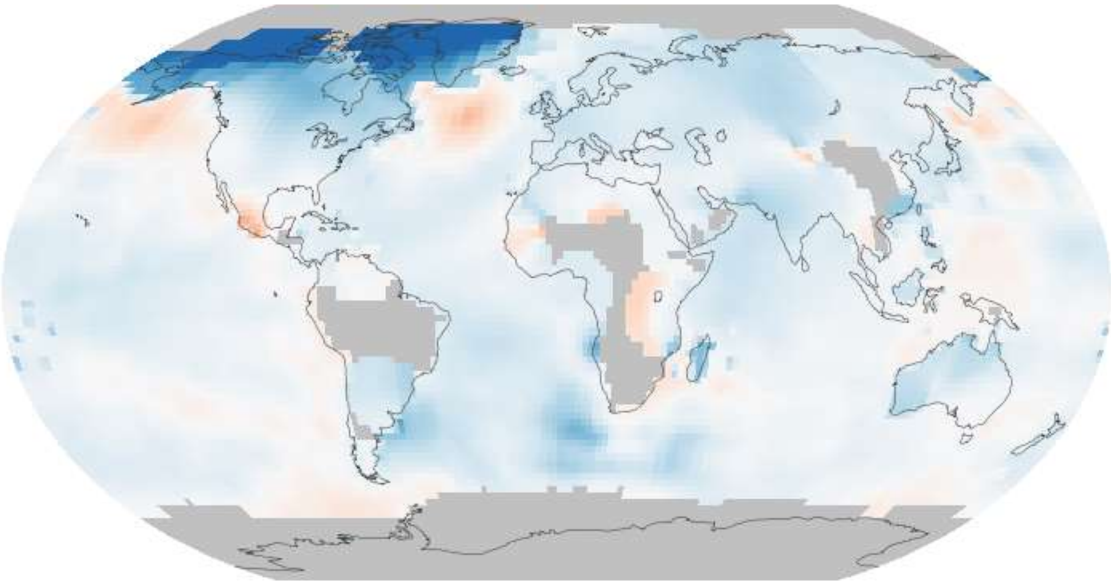

Figure 63: difference to the global 20th century temperature compared to record data from 1885-1894[36]

The graph has no absolute scale, but intense blue means temperatures below the global 20th century average while intense red means higher temperatures. Light shades of these colours mean temperatures between these extremes. As you can see most areas of the world were below the global temperature average. Especially Greenland and Alaska were had much colder temperatures. Data were missing at that time from some areas in South America, Central Africa, China, Antarctica and the North Pole.

Figure 64: difference to the global 20th century temperature compared to record data from 1945-1954[37]

60 years later the temperature data is almost complete as grey spots have mostly disappeared. Extreme colours – both blue and red – are missing which means that the decade between 1945-1954 is quite close to the 20th century average temperature. Compared to the graph before temperatures have clearly risen as there is less blue.

36 Online available at https://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php?all=y (last checked on 21.10.2017)

37 Online available at https://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php?all=y (last checked on 21.10.2017)

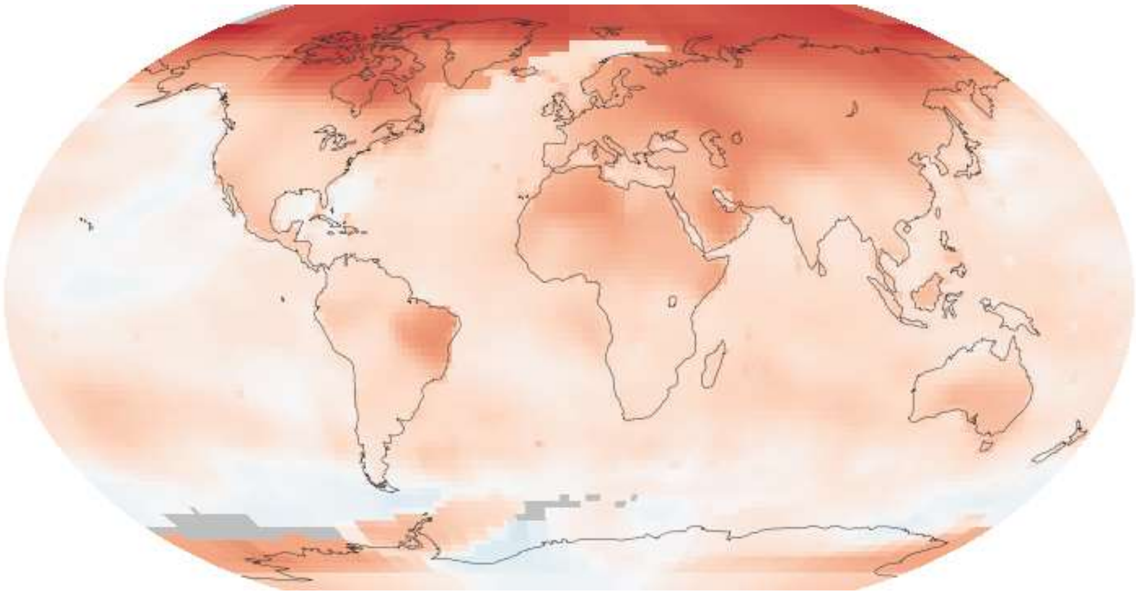

Figure 65: difference to the global 20th century temperature compared to record data from 2005-2014[38]

Compared to both graphs before blue shades have almost completely disappeared. The rise in temperatures is now almost global. But the differences are huge. While the temperatures in Canada, Greenland, Northern Russia and the North Pole have risen the most parts of Southern Africa and Southern America are still not much higher than the 20th century average.

In conclusion there is no doubt left that global temperatures have been rising and as the chapter "climate models" shows they are expected to keep rising. The challenges of climate change are not only rising temperatures but a lot of impacts and effects on environment that can already be seen today.

Consequences of climate change

Since climate change is already significant today some effects on our environment are known:

Sea level rise – Overall the sea live is 10-20 centimetres higher than it was in pre-industrial age. In the past decade the annual rise has increased dramatically and is currently about 3.2 centimetres a year. (NG)

A lot of settlements as well as rural roads are built at the coast or in areas that are already below sea level – protected by dams. For these roads in particular floods caused by a rising sea level are more likely to occur in the future.

Global temperature rise – As already shown in the previous chapter, global temperatures are rising. This has a lot of indirect consequences on weather. But rising temperature itself can damage pavements which are not built for high temperatures. Therefore, rural roads need to get adapted to future temperatures.

Warming oceans – As warming oceans are one reason for the increased number of extreme weather events they are also a risk for rural roads. Hurricanes for example can only arise at sea temperatures above 26 °C. Hurricanes bring very heavy ad enduring rain and a high wind velocity. Both can result in road damages. (GCC)

38 Online available at https://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php?all=y (last checked on 21.10.2017)

For this reason, a higher number of hurricanes, tropical storms and typhoons result in a need for a special preparation for road administrations to protect and maintain rural roads.

Increase in extreme weather events – For the past decades national meteorological administrations are facing an increase in extreme weather events. Heat waves, droughts, heavy precipitation, floods and even snow storms are occurring more often today than they did in the past. (NCA 2017)

When different extreme weather events are occurring at the same place at a different time stresses for rural roads increase as the road has to fulfil more criteria than in the past.

This list of consequences of climate change is not complete but maps all effects of climate change that can be relevant for rural roads.

For more specific explanations about the actual damages of rural roads caused by weather see also chapter 6 – impacts of the aspect "weather" on roads.

CLIMATE MODELS

As road administrations of the member states of PIARC want to prepare their future roads for impacts of climate change and increase the durability of rural roads a detailed prediction of the future climate is essential.

Impacts of extreme weather can be locally limited and therefore global climate models can't deliver enough detailed information to help local administrations facing the future climate challenges.

Nevertheless, the scientific background of regional climate models is based on the principles of global models. Therefore, a common understanding of climate models and a discussion of the quality of their predictions is necessary for all further approach. At the end all road administrations should be able to get all the data they need about the future climate in their region.

IPCC

The IPCC – the Intergovernmental Panel on Climate Change – is the United Nation's organisation responsible for all matters relating to climate change.

The IPCC was established in 1988 and is coordinating scientific research on climate change. As thousands of scientists worldwide are doing research on climate change the main purpose of the IPCC is to review their work, to connect different scientific programs and to publish reports giving guidelines to governments and administrations on how to deal with climate change.

As the IPCC is a non-political but scientific organisation it claims to provide "policy-relevant and yet policy-neutral" results. (IPCC)

The IPCC is regularly publishing IPCC assessment reports, with the first one published in 1990 and the fifth one published in 2014. (IPCC - History) As these reports summarize the state of knowledge of research on climate change they are also a good source to make statements about the quality of climate models today – globally and regionally.

It has to be said that there is more than one scenario for each climate model. The IPCC itself is calculating with a couple of different scenarios. Reasons for different scenarios is an uncertainty in some of the main circumstances: Neither the growth in world population, the growth in world economy, the future energy mix or the technological progress in the elimination of greenhouse gases can be predicted exactly.

As a consequence, even the best climate model delivers a wide range of the possible future climate as it depends on the scenarios.

Global models

Any climate model nowadays is computer based as the complexity of the models since the third IPCC assessment report in the late 1990s has increased even more.

Basically, a climate models are "mathematical representations of the Earth's climate system" as the Australian Department of Environment states. (DoE Australia)

Therefore, scientists try to analyse the atmosphere's physical and chemical processes and interactions to create equations that can – processed by computers – map the development of climate.

In contrast to any weather forecast a climate model is not predicting global weather at a certain moment or period of time. (KSC 2015) But is simulating possible developments of the atmospheric composition in the future and its impact on terrestrial, cryospheric or ocean processes. (p. 603; Randall, Wood)

The main difference between global and regional climate models is the size of the grid cells. While grid cells of global climate models have an edge length of 250-300 km regional models have a higher resolution of their grid cells with mostly 25-30 km and very precise models with an edge length of just 2 km. (Pingel)

The reason for a comparatively low resolution in global models is the enormous computer capacity you need for simulations. Therefore, high resolution simulations can only be done for smaller areas.

Construction of models

The currently most common type of global climate models is called AOGCM, which stands for Atmosphere-Ocean General Circulation Models. The construction of an AOGCM is based on equations. These equations map the laws of physics and chemistry in the atmosphere. But there are still tuneable parameters in these equations which allow the simulation of different climate scenarios.

The main constraint is that the number of degrees of freedom in tuneable parameters is less than the number of degrees of freedom in the observational constraints used in the model evaluation. (p. 596; Randall, Wood)

Tunable parameters are salinity in oceans, soil moisture, level of carbon dioxide as well as others. (p. 604; Randall, Wood)

Climate models – global ones in particular – do not simulate weather itself, for example clouds are taken into account as fixed parameters in these equations.

Reliability and risks

In general, the quality and reliability of climate models has improved since the beginnings in the 1970s and is very likely to improve in the future.

Especially the quality of simulations at continental level or above is already on a very high level, as the following chart shows:

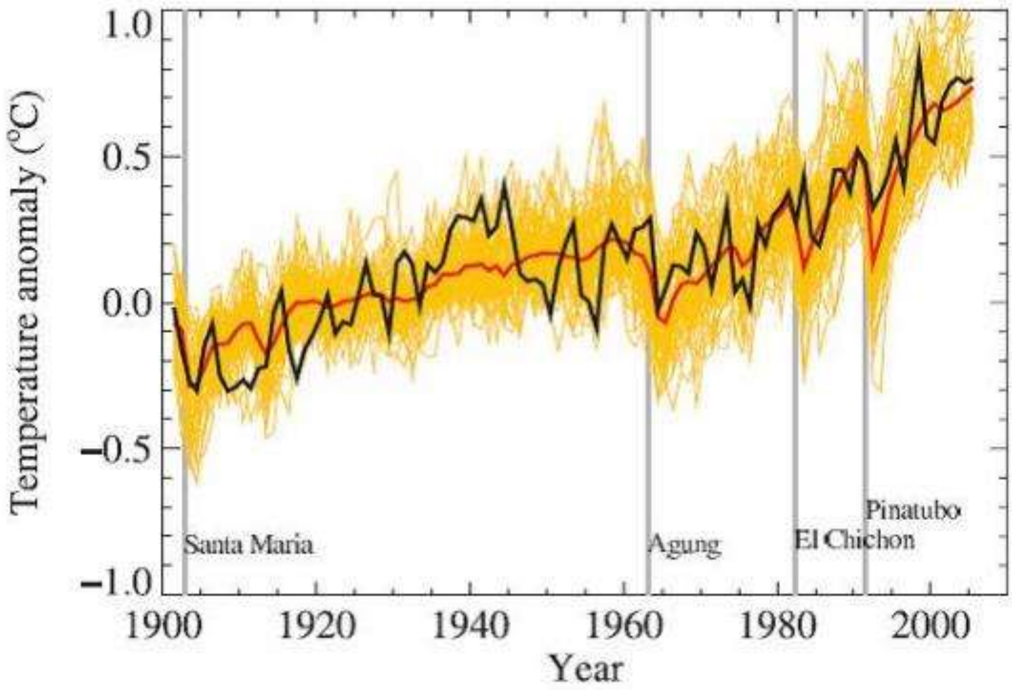

Figure 66: comparison of different climate model simulations (yellow), their average value (red line) and the real temperature anomaly (black line) [39]

A common way to check the quality of climate models is to let them simulate a past period of time of which existing climate data is available. As in figure 10 the 20th century was simulated by different climate models. The average of all simulations (red line) is quite close to the real temperature anomalies (black line).

Nevertheless, the figure also shows one big weakness of climate models: They can't predict unexpected incidents as volcanic eruptions. As the volcanoes Santa Maria, Agung, El Chichon and Pinatubo erupted they had an impact on global temperature. Even if that impact was very small the simulations had to get set back manually at these points. This is possible in hindsight, but never for a climatic prediction of the future. Another weakness is that climate models tend to simulate climate change steadily as the concentration of greenhouse gases increases steadily. But there is still the risk of an abrupt climate change after crossing any threshold – further research on that is recommended by the IPCC. (p. 608; Randall, Wood)

As there is still no consensus over the use of IT capacity between finer numerical grids, the use of more statistic data from the past or the inclusion of more factors in equations global climate models of today provide reliable values for certain variables such as temperature. On the other side the prediction of future precipitation remains challenging. (p. 592; Randall, Wood)

Regional models

Global models build the base for simulations of the future climate. An increase in average global temperatures is a concerning fact. But it doesn't help road administrations to face local characteristics in their region.

39 Online available at https://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php?all=y (last checked on 21.10.2017)

To face these local characteristics and to use the best practices of this report regional climate models should provide the following basic information:

- Change in average annual temperature
- Change in annual precipitation
- Change in number of hot days (>30°C)
- Change in number of cold days (<0°C)
- Probability of droughts, floods and heavy rain events

A regional climate model is basically working the same way as a global model does. The main difference is the resolution. Therefore, a regional model can never work "on its own". The base has to be a working, functioning global model. The grid cells of this global model have an edge length of 200-300 km. A regional model is embedded in this global model and its grid cells have an edge length of 2-30 km.

A regional climate model can look like the following model of Germany:

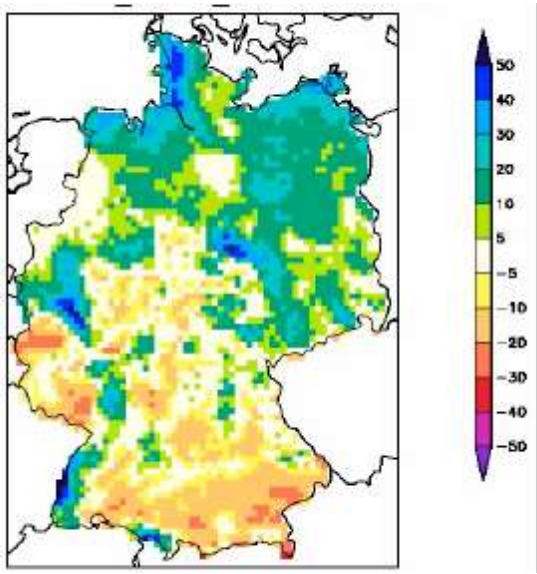

Figure 67: climate model "REMO", showing percentage change of precipitation from 1961-2000[40]

In Figure 11 each coloured dot is one of the grid cells of the regional climate model "REMO". The colour of the dots displays the percentage change of precipitation between 1961 and 2000.

REMO was divided into two parts: The calibration of the model for the period 1961-2000 and the actual simulation of the future regional climate of the 21st century. The resolution of REMO is 10 km per grid cell. (p. 21; Pingel) REMO is not only existing for Germany but for Europe as a whole.

In practice it is common to always check regional climate models by simulating a period in the past first and calibrate the model. After that in the second step a future period of time can be simulated.

In comparison to global models, regional models combine two simulation technologies: The dynamic climate models (AOGCM, see chapter 5.3.1.1) with an additional use of statistic data.

The reason for the use of statistic data is the general lack of precision of regional climate models. There are meteorological stations at many places for many decades. They have been recording local characteristics of weather caused by vegetation, soil structure, topography or waters. These

40 Illustrated by Pingel, Sandra, published in „Regionale Klimaprojektion für Europa und Deutschland", published by the Climate Service Center

characteristics can't be displayed on a small scale by a dynamic simulation. By overlaying dynamic simulation results with existing statistic data regional climate models can have a higher resolution and still a better reliability. (p. 10-11; Pingel)

Today there are regional climate models for every continent:

Europe/western Africa:	Ensembles (collection of several regional climate models, i.e. REMO) available at Danish Meteorological Institute (DMI)
South America/South Asia:	CORDEX initiative (Coordinated Regional Climate Downscaling Experiment)
North America:	NARCCAP (North American Regional Climate Change Assessment Program)
China:	RegCM4
Australia:	NARCliM
Southern Africa:	CORDEX, RegCM4

All of these regional climate models offer data about the expected future annual average temperature and precipitation. The probability of droughts and floods in the future is hard to estimate. But in general it is expected to grow in a lot of regions. (Arndt, Enloe)

For more research on simulation of climate parameters related to road damages a partnership between road administrations or PIARC and meteorological institutions is recommended.

APPENDIX B: CLIMATE IMPACTS DUE TO PIARC

PIARC published a report in 2015 that was called INTERNATIONAL CLIMATE CHANGE ADAPTATION

The impacts listed below are not intended to comprise a comprehensive list, but should act as an initial resource for road authorities to determine their own climate change risks.

- Impacts associated with changing temperatures:
  - heat damage and deterioration of structures and pavements such as softening, deformation and cracking,
  - traffic related rutting and migration materials,
  - thermal expansion of bridge expansion joints and paved surfaces,
  - fire risk,
  - overheating of electrical equipment,
  - corrosion of steel and concrete structures due to increase in surface salt levels in some locations,
  - health and safety risk to road users (e.g. from brake failure) and employees,
  - increased frequency of fog episodes, which reduce visibility and road access,
  - road damage from slush flow,
  - acceleration of the thermal erosion and permafrost melting,
  - changes in travel patterns of network users, e.g. tourism causing a stress on a network with a pre-defined design capacity,
  - longer vegetation growing seasons leading to a reduction in soil moisture and/or increased tree leaf coverage combined with an increased magnitude and frequency of storm events may result in tree fall;

  - damage to pavements, earthworks and structures,
  - overloading of drainage systems,
  - inaccessible networks and assets,
  - deterioration of structural integrity of roads, bridges and tunnels due to increase in soil moisture levels,
  - health and safety risks to workers and the local population,
  - pollution from surface runoff,
  - slope collapse,
  - suspension bridges, signs and tall structures at risk from increasing wind speeds,
  - reduction in summer rainfall levels leading to drainage dilution levels and subsequently effects on water quality,
  - increased wind gust,
  - slope instability leading to landslides, rock fall etc.,
  - changing groundwater levels and height of the water table;

FRAMEWORK FOR ROAD INFRASTRUCTURE. It is available at piarc.org and giving an overview about the future climate challenges and aspects that should be considered by road authorities. Appendix C is listing all the possible damages of road infrastructure that can be caused by weather. It is listing the following points:

- Impacts associated with sea level rise and heightened storm surge:
  - damage to roads, underground tunnels and bridges due to flooding, inundation in coastal areas and coastal erosion,
  - increasing risk of coastal erosion and submersion,
  - damage to road infrastructure and increased probability of infrastructure failures,
  - increased threat to stability of bridge decks,
  - increased damage to signs, lighting fixtures and supports,
  - rising groundwater levels,
  - temporarily or permanently inaccessible networks and assets,
  - more frequent flooding of underground tunnels and low-lying infrastructure,
  - erosion of road base and bridge supports,
  - reduced clearance under bridges,
  - decreased expected lifetime of highways exposed to storm surges,
  - permanent asset loss at coastal sites,
  - health and safety risk to road users and employees,
  - increased salinity of groundwater;

- Impacts associated with changes to snowfall, permafrost and ice coverage:
  - reduced need for snow clearing,
  - safety risks due to snow and ice,
  - changes to soil stability and more unpredictable *'marginal'* days where snow and ice may or may not be risk,
  - increasing ice/snow melt leading to flooding,
  - changing nature and location(s) of avalanche risk,
  - increased risk of drifting snow (when accompanied by increased wind gusts),
  - changes in road subsidence and weakening of bridge supports due to thawing of permafrost (in very cold areas),
  - reduced ice loading on structures such as bridges (in very cold areas, a positive impact),
  - reduced pavement deterioration from less exposure to freezing, snow and ice (positive impacts),
  - landslides due to rapid snow melting,
  - deterioration of pavements and increased safety risks due to an increase in freeze-thaw conditions in some locations (where the temperature hovers around 0°C),
  - reduced pavement friction coefficient,
  - increased disruption to road users as a result of increased frequency and magnitude of snow fall,
  - increased coastal erosion from reduced ice coverage,
  - acceleration of thermal erosion and permafrost melting,
  - increased area of the active permafrost layer and decreased depth of permafrost;

- Other potential impacts:
  - damage to infrastructure from land subsidence and landslides,
  - wind and sand storms,
  - damage to infrastructure due to increased susceptibility to wildfires as a result of drought,
  - damage to infrastructure form mudslides in areas deforested by wildfires as a result of drought,
  - *'summer ice'* – occurs after a prolonged period of no rain when dirt and oil residue builds up on the road. When the first rain event occurs this material becomes incredibly slippery and dangerous (similar to ice on the road),
  - high winds blowing trees/other debris onto network routes,
  - operational constraints at exposed locations e.g. high-sided vehicles,
  - damage to power supply for electrical storms,
  - fog and reduced visibility,
  - increased and/or more variable UV radiation,
  - increasing number of overturned vehicles due to increased wind speeds and storms.

APPENDIX C: WATER CROSSING STRUCTURES

To avoid damages of ditches due to the flow velocity of the following rules need to be observed:

- Build ditches with the same longitudinal gradient as the road itself.

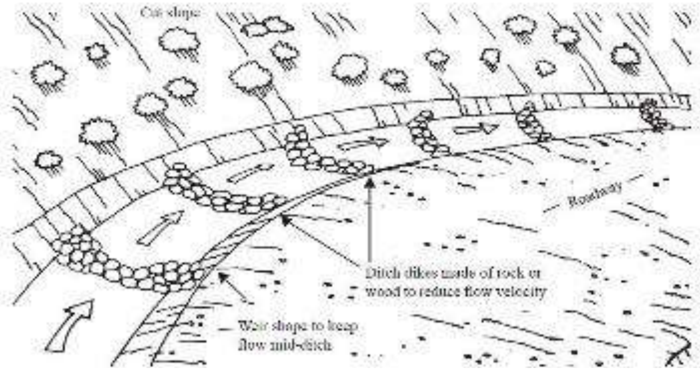

Figure 68: Ditch dikes made of gravel dams

If the longitudinal gradient is higher than 5% ditches need to get reinforced or receive a dense vegetation or ditch dikes to reduce flow velocity.

For Inslope Sections it is essential to have a technique of bringing the collected water from the inner side of the road to the outer side.

There are several options:

- Culverts
- Rolling dips
- Bridge

While bridges need to fit in the local terrain the other two options are independent from that. Especially rolling dips are a very simple and cheap way to realize the transfer of the water.

Rolling dips:

Figure 69: Rolling dip on a rural road with inslope section[41]

41 Photos taken of the Best management practices for low volume roads, published by the U.S. Department of Agriculture

With this technique dips are located periodically. The dip itself drains water from the ditches on the inner side to the outer side of the road.

To avoid erosion ditches should be armed. The lining of a dip can be made of asphalt, concrete, masonry or even heavier rock material as you can see in figure 69 on the right side.

To prevent erosion at the discharge of culverts or rolling dips soil should be protected by vegetation or get armoured.

Figure 70: Discharge of a culvert on armoured underground[42]

Rolling dips are a cheaper way than culverts and unlike culverts they can harder get blocked by debris. Therefore, they are also able to deal with heavy rain events. A problem is its location on the surface of a road. Due to the unsteady gradient of a road with dips the average travel speed is lower. In case of strong precipitation roads might be impassable at the location of dips during the rain. Therefore, inslope sections with rolling dips are recommended only under the following conditions:

- Roads with little importance for heavy traffic
- Located in an isolated area with a lack of maintenance possibilities for culverts
- Due to safety an outslope section is not possible (driving safety, erosion risk)

42 Photo taken of the Best management practices for low volume roads, published by the U.S. Department of Agriculture

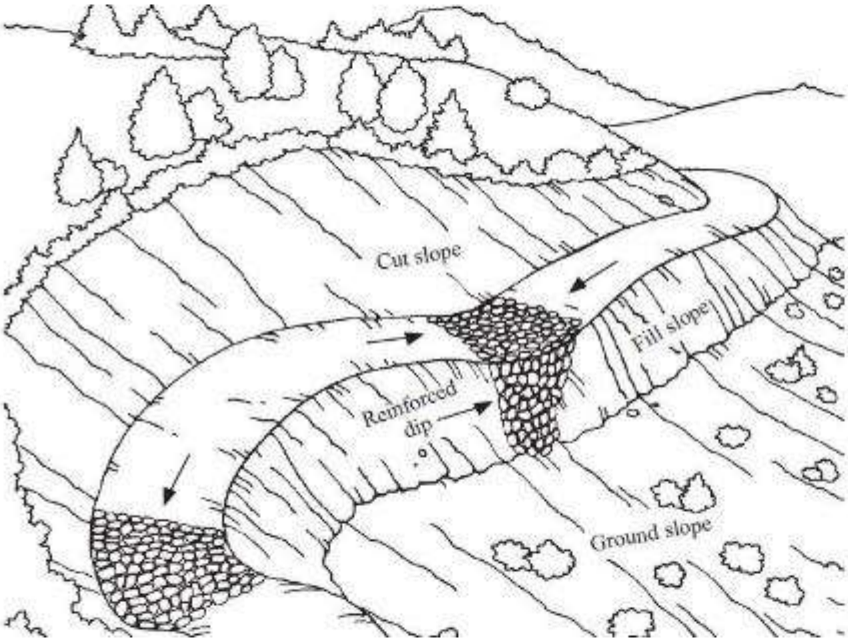

Figure 71: Distances between rolling dips shouldn't be too high[43]

It is also important not to build rolling dips with too much distance in between.

As you can see in the graph rolling dips are never built single to drain ditches of several kilometres of roads. The reason is the amount of rainwater that could be concentrated at just one dip in case of a heavy rain

The dips themselves are reinforced. But the water depth in dips could be too high for traffic and the amount of water that flows into a specific area at the ground slope could be too high.

The following chart shows the recommended distances between rolling dips depending on the material of the road's surface and of the ditches and of the road's gradient:

Recommended Maximum Distance Between Rolling Dip or Culvert Cross-Drains (meters)

Road Grade %	Low to Non-Erosive soils (1)	Erosive Soils (2)
0-3	120	75
4-6	90	50
7-9	75	40
10-12	60	35
12+	50	30

Figure 72: Maximum distances between rolling dips[44]

43 Photo taken of the Best management practices for low volume roads, published by the U.S. Department of Agriculture
44 Table taken of the Best management practices for low volume roads, published by the U.S. Department of Agriculture

As you can see in the title of the graph recommended distances between culverts are equal to the distances between rolling dips.

Bot depend on the characteristics of the soil and the longitudinal road grade. “Soil” in this case is not only soil directly linked to the road or earthwork but also the soil of the location where rainwater gets finally discharged (see “ground slope”).

Longitudinal road gradients of more than 12% should be avoided wherever possible. On one hand high gradients increase the risk of surface erosion. On the other hand, flow velocity gets higher and makes traveling on the road more dangerous.

Instead of rolling dips culverts and bridges can work the same way. Important for culverts in particular is a working maintenance system for clearing them from debris. Otherwise its advantage – a steady and even surface of a road – can become a disadvantage when water dams up and flows on the surface.

Crossing of streams and rivers

Streams and rivers always build a potential risk for roads in general. On one hand they need a special building (i.e. a bridge) to be crossed. On the other hand, they bear the risk of floods that can lead to damages at infrastructure. As the costs of any special buildings are rising with the length of the building this length should be at its minimum. Therefore, the first recommendation for crossings of rivers is about the angle between stream and road:

Always build crossings in a right angle to streams:

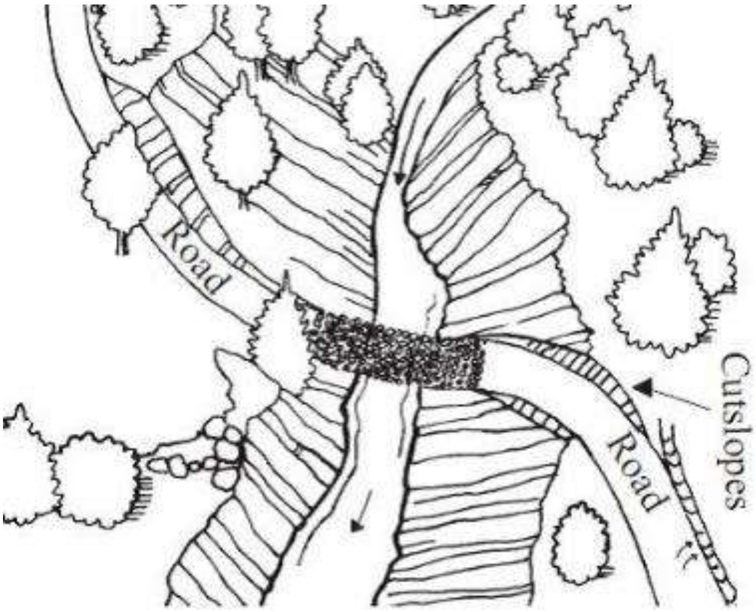

Figure 73: crossing of a stream with right angle[45]

There are several options to design the actual crossing itself. Especially for rural roads the following crossings are suitable:

- Bridges
- Low water crossings
- Dams with culverts.

45 Photo taken of the Best management practices for low volume roads, published by the U.S. Department of Agriculture

Bridges and dams can guarantee a comparatively comfortable ride and are therefore not only for low volume roads. Low water crossings can be designed in two different ways.

Either they are designed as a very low bridge that can get flooded without major damages or it is right on the ground of the stream and gets flooded even at low water periods.

Figure 74: Low water crossing designed and built by the US army[46]

The photo is showing a low water crossing that is flooded even at an average water level of the stream. The crossing was designed by the US army and is made of paving stones that are fixed with concrete.

As vehicles need to drive through a varying level of water this technique is designed only for the use of cars and trucks. Bicycles, pedestrians or motor bikes can only cross the stream at a very low comfort level. As an advantage of this technique can be seen that it is less dependent on regular safety checks. Compared to a bridge there is a lower risk of an abrupt collapse.

<u>Flooded low water crossings are therefore recommended under the following conditions:</u>

- The stream is comparatively small and has a steady flow
- A bridge would overrun the budget
- The road is used by motor vehicles mostly (except motor bikes)
- In case of massive floods, a temporary closure is acceptable

If these points don't apply but a common bridge is not acceptable for some reason a lifted low water crossing can be an option.

46 Online available at http://www.mccoy.army.mil/vnewspaper/newspaper/realmccoy/11232012/images/Water_crossing.jpg (last checked on 21.10.2017)

Figure 75: A low water crossing in the US that is not permanently flooded[47]

This type of low water crossing is based on the principle of a small bridge. Designs are held very simple and have no bridge railing for a certain reason:

Common bridges are not measured to get flooded and can therefore be damaged or even destroyed by strong floods. Low water crossings avoid structures and designs that cause too much resistance to water. They are therefore designed to resist floods but are above the surface at mean-flow conditions.

Unlike flooded low water crossings this design should be preferred under the following conditions:

- The water level is regularly changing between different levels
- The road is used by pedestrians
- A basic maintenance system is established
- Temporary closures due to minor floods should be avoided

The consequences of floods do not only have an impact on rural roads at crossings but to any part of a rural road that is close to water.

A recommendation of this report is therefore to not see a road and its environment as separated issues but to match them.

Climate change should therefore have influence on the choice of a location for a road

- Avoid building roads to close to water if possible
- Avoid building roads on very moisture sensitive ground

While climate change is increasing the risk of floods in many regions people can still reduce the increase by following certain rules. Firstly, areas close to waters, especially streams and rivers should be kept clear of buildings and too dense vegetation and even roads. In that way certain areas are working as retention areas and can reduce the strength of a flood.

47 Available online at http://www.americantrails.org/photoGalleries/cool/25images/07.jpg (last checked on 21.10.2017)

Beside that a road itself should not be built at very steep slopes with fine-grained soil if possible. The risk of landslides is not only dangerous for the road but is even increased by road construction processes that include a massive deforestation.

Figure 76: road crossing watercourse in Chile

APPENDIX D: TYPES OF SURFACING

D.1 ASPHALT

Figure 77: Photo of an asphalt load[48]

Asphalt is a composite of bitumen and aggregate. Asphalt is characterized through its hot temperature before paving (although warm and cold solutions are emerging). At a temperature of more than 140°C all kinds of bitumen are viscous and the composite – asphalt – can therefore get paved easily. Right after cooling down to the specific temperature of use (<60°C) asphalt has its full load capacity. The actual pavement process is therefore no chemical – unlike concrete – but a physical process.

Today asphalt is the most used material for road surfaces and often the base of a road in many parts of the world.

Its advantages are the high availability of its components – aggregate and bitumen. The cost of asphalt is therefore in average lower than the cost of concrete. Nevertheless, asphalt is more common within built-up areas than it is outside on rural roads. The reason for that is that asphalt can easily be removed or cut to repair pipes and cables below a road.

48 Asphalt load, photo available online at http://www.dirt-bandit.com/images/Loaded%20Hot%20Box.JPG (last checked 21.10.2017)

D.2 CONCRETE

Figure 78:: Rural road with a concrete surface[49]

Concrete is another possibility for the surface of rural roads. The actual use of concrete started when countries designed the first highways in the 1920's and 1930's. Concrete has the highest load capacity of the available materials was therefore mostly used for roads with a high percentage of heavy traffic. It can still be used for rural roads with a low volume, too. As in the photo of a rural road shown the surface can be put together of several concrete slabs. On one hand the gaps between the slabs avoid cracks because of expansion. On the other hand, smaller slabs can be built in directly. Otherwise concrete needs several weeks to harden. A period which is often too long for rural roads which guarantee access of settlements to infrastructure. Therefore, concrete plays a minor role as a road surface today.

Concrete reacts sensitively to large temperature fluctuations. As you could already read climate change means also an increase in extreme temperature days. Though it is still hard to predict the exact number of hot days (maximum temperature >30°C) or cold days (maximum temperature <0°C) the effects on rural concrete roads will be noticeable. The surface is under the direct influence of the atmosphere and can therefore heat up or cool down faster than the other parts of a road structure.

In general materials expand or contract under changing temperatures. Both is causing stresses within the material. Rising temperatures lead to an expansion and falling temperatures let materials contract (Grybosky 1999). The higher the spread between minimum and maximum temperatures gets the higher the elasticity of the material has to be. Otherwise, the stress gets too high and the material cracks.

Concrete needs expansion joints not to crack. However, under extreme hot temperatures there is still the risk of "blow ups". When the expansion joints are not big enough concrete panels on the surface can collide and crack. An example for that are the following photos of Austrian highways:

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49 Photo of a concrete surface, online available at http://16745-presscdn-0-7.pagely.netdna-cdn.com/wp-content/uploads/2016/05/Concrete-road.jpg (last checked 21.10.2017)

Figure 79: Blow up at a concrete road in Austria[50]

The photo above is a good example for concrete panels shifting over one another. As a result, there is not only a crack but a bulge. On roads with a high average speed as highways this can lead to terrible accidents. Especially for motorbike riders the risk is high as it happened in Germany in summer 2013. (ONLINE et al. 2013)

Figure 80: Blow up at a concrete road in Austria[51]

But even smaller cracks and splitters as in the photo above cannot only influence safety but also the durability and driving comfort of concrete based roads. Today concrete is not common in use for rural and low volume roads. Therefore most extreme temperature related damages on concrete roads occur on highways. (Fuchs, Sion)

50 and 33 Taken from PIARC TC E1 report of Austria
51

D.3 GRAVEL

Figure 81: Rural road with gravel surface in Indiana, USA[52]

Gravel surfaces are characterized by a more uneven surface than asphalt or concrete. They should therefore only be used for low volume roads. The gravel used is mostly locally found. That's why gravel as a surface has no standardized characteristics. The cost is much lower than for asphalt or concrete. Under dry conditions dust clouds can appear which means a disadvantage.

D.4 DUST / SOIL

Figure 82: Two photos of soil roads in rural areas[53]

Dust or soil roads are the easiest design of a rural road. Often these roads do not have an actual base or subbase but are just compressed soil below the removed humus.

If a road with such a surface gets declared a "dust road" or a "soil road" depends mostly on the

52 Photo of a gravel surface, online available at https://images.hgmsites.net/hug/county-road-in-marshall-county-indiana-via-derek-jensen-on-wikimedia_100597046_h.jpg (last checked on 21.10.2017)
53 Photos of soil roads, online available at http://enviremed.com/wp-content/uploads/2014/02/image001.jpg (last checked on 21.10.2017)

moisture of the underground. Just like gravel roads this type of road can develop clouds of dust.

D.5 HARD CORE SURFACE

Figure 83: Hard core surface on a historic road in France

Hard core surfacing was mostly used in a historic context as it was the primarily used surfacing from ancient times to the 19th century.

Nowadays hard core surfacing is still in use in South America.

D.6 USE OF DRY SOILS

Figure 83: Road in Namibia made of salt[54]

Several countries use materials for construction of roads which don't seem to fit at first sight. The use of dry soils – salt in particular – is common especially in some African and South American regions.

These regions are characterized by huge natural salt resources and a very dry climate. While these conditions might not fit for many regions today, a dry climate could be faced by more regions in the future. This makes the use of dry soils in general – not just of salt in particular – an interesting field of research in the future.

Beside the experiences of especially Namibia and Bolivia research projects could give additional information about the use of dry soils in other regions in the future.

54 Online available at https://kp806.files.wordpress.com/2012/06/namibia-skeleton-coast-salt-road-sign.jpg (last checked on 21.10.2017)

APPENDIX E: QUALITY CONTROL OF EXISTING ROADS

The Index for paved roads is the **Bituminous Condition Index** (BCI):

In the first step you calculate the Distress Manifestation Index (DMI):

$$DMI = \sum_{i=1}^{n} (W_i)(S_i)$$

The DMI is also a sum of different criteria. As well as the DGMI it consists of the variables w and s. W stands for the weighting and s for the severity. The variable e for the extent is missing in this equation.

The following chart shows all relevant criteria for paved roads and the weighting of each:

Distress	**Weighting Value (w_i)**
Surface Distresses	
Raveling	1.0
Bleeding	1.0
Shoulder Disintegration	0.5
Potholes	1.3
Deep Seated Distresses	
Rutting	1.0
Subgrade Failures	1.5
Cracking	0.5
Distortions	1.2
Factors Dependent on Time of Rating	
Patching	1.0
Corrugations	0.4
Streaking	0.3
Joints	0.3

The severity s has a value from 1-5. 1 means that the severity is very slight and 5 is for very severe distresses.

To estimate the severity the executive staff should have some experience in road maintenance.

In the next step the evaluator needs to determine the Road Condition Index (RCI) – just as for gravel roads. The RCI gets determined by test drives on the road section and is subjective to a certain degree:

10-8	Very smooth
8-6	Smooth with a few bumps or depressions
6-4	Comfortable with intermittent bumps or depressions
4-2	Uncomfortable with frequent bumps or depressions
2-0	Uncomfortable with constant bumps or depressions

Finally, the Bituminous Condition Index can get calculated:

BCI = 10 (DMI /10+ RCI) / 2

The meaning of the resulting number (0-100) is the same as for the Gravel road index:

Time of Improvement	BCI for rural roads
Adequate	>80 points
6-10 years	66-80
1-5 years	46-65
NOW Rehabilitate	40-45
NOW Reconstruct	<40

On the basis of this very simple evaluation system the priority for road maintenance can get decided. In general rehabilitation is cheaper than reconstruction.

Therefore, road administrations should focus the maintenance budget on roads with 40-65 points.

The quality of the roads below might be worse. But often the travel quality of these roads is already at a minimum and neither do the costs increase by waiting nor is there a way to prevent a total reconstruction. (Hein 5/24/2017)

APPENDIX F: FUNDAMENTAL EVALUATION OF EXISTING LITERATURE CLIMATE IMPACT FLOOD

F.1 OVERVIEW ON LITERATURE IN DIFFERENT REGIONS

F.1.1 Africa

The climate of Africa is among the hottest in the world in average. Climate zones still are very inhomogeneous among the continent. On both sides of the equator climate is tropical and characterised with hot steady temperatures and a lot of precipitation. In the Northern part of the continent the biggest desert in the world – the Sahara – has a very dry climate. While average temperatures there are still high temperatures can rapidly change between day and night. The southern part is diversified. Mountains, deserts and tropical regions provide a different climate than the maritime regions alongside the coastline.

The United Nations Department of Economics and Social Affairs states the continent of Africa is “the fastest growing in the world” (UN) As this statement is true for the growth in population as well as for the economy Africa is expected to expand its infrastructure throughout the continent. With an often very extreme climate existing experience with road design can be useful – for the continent itself and for the world community.

Ethiopia can be seen as a “typical” African country in some sense: the average GDP growth in the last decade has been 11% a year. The population has also grown and is currently at around 85 million – already bigger as Germany for example. The total road network has a length of just 86.000 km. Even more interesting is the fact that just 11.300 km of the roads are sealed. This means around 87% of all roads in Ethiopia are unsealed. Most of these unsealed roads are in very rural areas and have a low traffic volume (<300 vehicles a day in Ethiopia). (Ayele 11/27/2013) This makes them fit to the criteria of this report and makes Ethiopia worth having a closer look at their experiences. Rural roads in Ethiopia fulfil several important tasks for the development of the country: they offer farmers connection to markets, allow students to attend schools and connect the rural population to health services. (Ayele 11/27/2013) The Ethiopian government therefore recognized their essential meaning for the country. To prepare the existing road network for the extreme climate and increasing traffic volume the government initiated a program called URRAP: Universal Rural Road Access Program. Beside social intentions like the reduction of poverty URRAP has the goal to make rural roads suitable for all weather conditions. Nevertheless these roads are supposed to be affordable and Ethiopia wants to build up structures to be able to maintain rural roads.

With the help of the United Kingdom (UKaid) Ethiopia’s URRAP focused on creating small businesses and adapting existing guidelines for its needs. As a result of the program the access of the rural population to all-weather roads has improved. The average distance in rural areas to the next all-weather road had been more than 11 km and went down to just 6.4 km in 2013 when URRAP wasn’t yet finished. URRAP also provided the technical equipment to build and maintain the all-weather roads. The local population was successfully trained in managing maintenance. Through URRAP the local climate was considered in road design – often for the first time. The following bridge is a good example of a low-cost built bridge that can guarantee road access even during floods:


[55]

Figure 84: Bridge in Ethiopia that is guaranteeing road access during wet season

Today, Ethiopia has its own manual on low volume roads (Ethiopia Design Manual for low volume roads).

The development of climate-optimized construction of roads in Ethiopia is not an exception in Africa. It is actually based on the principles of AFCAP which stands for Africa Community Access Programme. Currently AFCAP is helping ten African countries to develop own standards and guidelines based on their climate and socio-cultural circumstances. The ten countries are Ethiopia, Kenya, Ghana, Malawi, Mozambique, Tanzania, Zambia, South Africa, the Democratic Republic of Congo and South Sudan.

A problem in many of these countries has never been the absence of guidelines and manuals. The actual problem had been that guidelines which were often taken from western countries never fit the needs of rural roads in Africa. Due to the enormous growth in population and limited budgets rural roads in Africa need to be built much cheaper than they are built in western countries. In addition to that the guidelines often didn’t fit for the local climate and existing natural resources. The good news is that more and more African countries are developing own manuals. As the climate in regions like Southern Europe or parts of North America becomes warmer and drier experiences and practices from African countries can become more important.

The most industrialized country of Africa is South Africa. As a former colony which gained independence already earlier than most other African countries road authorities have a long history in South Africa. The SATCC, the South African Transport and Communications Commission is responsible for all design manuals in South Africa. They published own manuals for low volume rural roads. The SATCC is focusing on sealed rural roads. It mentions that research on low volume sealed roads has already been done in Europe and North America in the mid-20th century. But never for the environmental circumstances of Africa. Therefore, the SATCC published its own manual. The main reason for South Africa to favour sealed roads to unsealed roads is the lack of gravel and the lower costs of maintenance.

In Africa cooperation among the continent’s road administrations is very strong. Besides the AFCAP program there is also an association of almost all the African countries. The SSATP – the Sub-Saharan Africa Transport Policy Program – is a council of all the African countries apart the countries with a

55 Taken from the presentation of Ayele, Alemayehu; held at PIARC meeting on 27.11.2013

coastline at the Mediterranean Sea. The SSATP is primarily helping its members to organize and build up effective road administrations and to support the cooperation between its member countries. (Schutte)

F.1.2 Europe

Europe is still the continent with the highest density of population. While its population is hardly growing nowadays its infrastructure has a very dense level. (UN) Africa and parts of Asia are facing an urbanization nowadays. Europe has already had this development in the 20th century. While some regions faced a rural depopulation, rural roads are existing in a high number. Europe is also a centre of research on transportation and a payer of development aid. Most continents today try to adapt their road network to the existing climatic and socio-cultural conditions. European road administrations and research institutions are already taking climate change into consideration. Since 2006 France has its own National Climate Change Adaption Plan (PNACC). Within the years the PNACC got adapted several times and its newest version was published in 20016. Like the already mentioned German RIVA the PNACC also formulates the task to build a system to measure the risk of road networks and segments to get harmed by impacts of climate change. Other Actions of the plan also include the creation of own manuals – unlike the RIVA - with adapted design to prevent negative consequences of climate change for the transportation network. The strategy of the PNACC is similar to the structure of this report: Firstly, to learn more about climate change itself, secondly to analyse its impacts on roads, thirdly to list existing documents. In the fourth steps existing experiences and realized projects build the base of a new manual that gets finally adapted and published. (M Colin)

The third action of the PNACC defines a harmonized methodology to diagnose the vulnerability of infrastructures and land, sea and airport transport systems. The aim of this methodology is to provide managers and planners tools to develop adapted strategies with prioritized measures, to reinforce the resilience of their infrastructures and networks. The next step will be to disseminate the methodology particularly through trainings and seminars, and to establish maps on risks levels for various network types on the French scale.

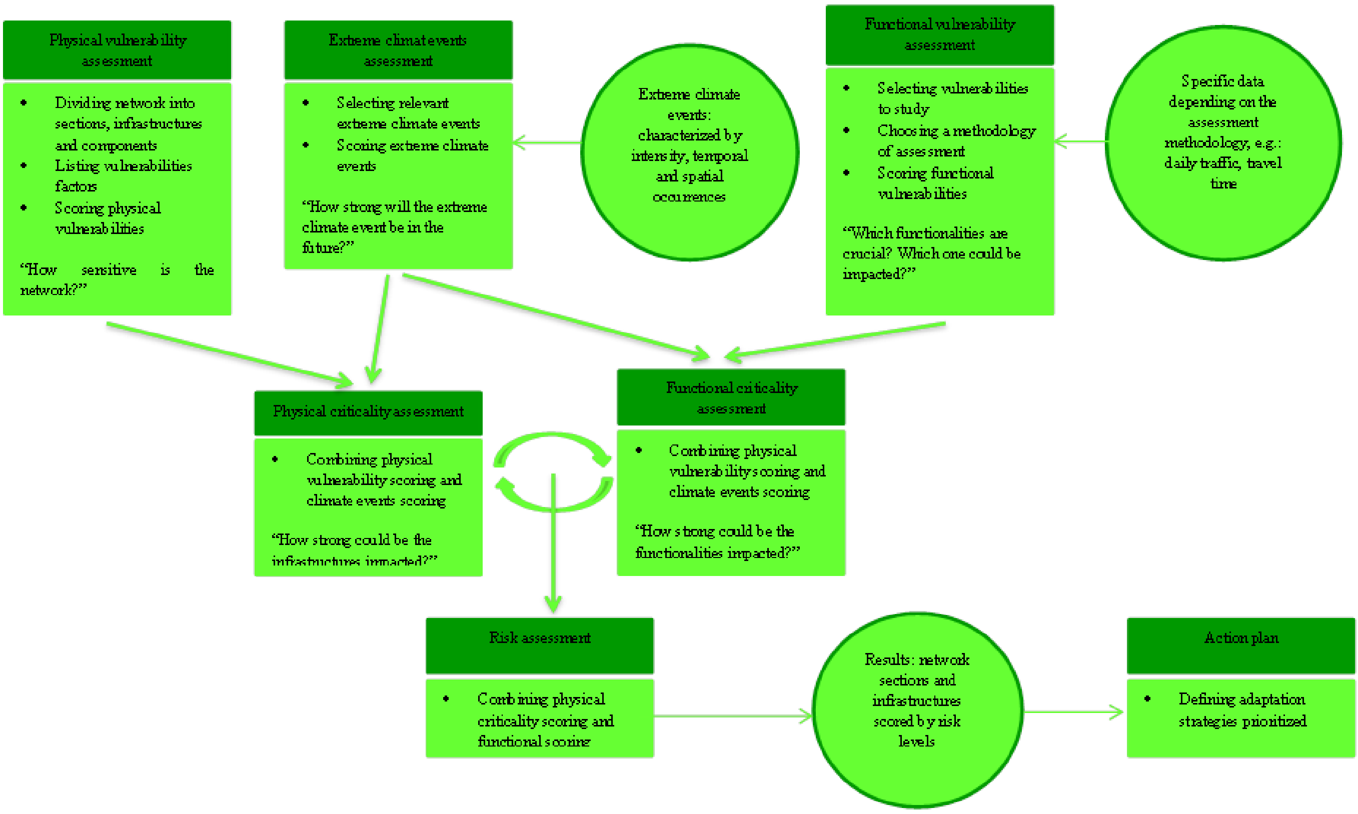

Figure 85: Picture from TRA (proceedings of 6th Transport Research Arena April 18-21,2016 Warsaw, Poland) Adaptation of transport infrastructures and networks to climate change by M Colin, F Palhol, A leuxe

The university of Dresden published own reports on the impact of climate change on infrastructure in general. The BASt – the German federal research agency for transportation – publishes reports on the current state of preparation for climate change regularly. (Auerbach et al. 2014) Apart from that German manuals RAL and RAA (for rural roads and highways) set high standards for drainage and cross slope. Most western and northern European countries are member of the European Union. The EU is aware of climate change and set the reduction of greenhouse gases as one of their major goals. The European Environment Agency, the EEA, published its first report on the challenges of transportation due to climate change in 2014. (Georgi) The report states that all governments of the European Union have started to prepare the transportation to the challenges of climate change. (p. 17; Georgi) The EU strategy on adaption to climate change provides a proper framework to give this preparation within the national members a common direction. Still most countries in Europe are on the first level of the adaption strategy: raising awareness. The necessity of a redesigning of infrastructure due to climate change is not yet common knowledge in Europe. (p. 17; Georgi) The report sees a high potential in the creation of common European guidelines and aggregation of existing knowledge. But just after raising awareness the actual process can begin. The European Strategic Environmental Assessment (SEA) and Environmental Impact Assessment (EIA) are first common manuals to create a risk management for climate impacts on transportation.

The efforts of the EEA and the European commission are important as there already is a lot of knowledge in Europe. Some countries – as Sweden – are already realizing road network projects with a design adapted to climate change. Many countries with a similar topography and environment (i.e. Austria and Slovenia, Denmark and Northern Germany) could profit of each other's knowledge and experiences in that way. Countries in the South as Spain are already facing climate change caused desertification in some regions and an increased precipitation in others. Its climate might be comparable to Northern African countries someday. (Melero Corell) The EUROMED – the European-Mediterranean partnership – is planning to work together in terms of transportation and could be a good platform of exchange.

Another promising cooperation is RIMAROCC. The Risk Management for Roads in a Changing Climate is a cooperation guideline of Sweden, France, the Netherlands and Norway. It is presenting a whole new method of risk management and can be used worldwide. (Bless et al.) The German equivalent is the RIVA. Riva stands for „Risikoanalyse wichtiger Verkehrsachsen des Bundesfernstraßennetzes im Kontext des Klimawandels“. This means that RIVA is a risk analysis system for important travel axis of the German federal transportation road network. (Alfen et al. 2015)

F.1.3 Asia

Most countries in Asia have faced an enormous growth in their population as well as an economic growth. (UN) Japan can be seen as the most developed country in Asia. Its population density is already very high and roads are mostly paved. Japan has a high risk for earthquakes. Earthquakes are not influenced by mankind and are therefore not part of climate change impacts. Some consequences of earthquakes – like Tsunamis or landslides – can also be consequences of climate change caused events. Therefore the manuals of the Japan Road Association and especially its maintenance manuals can be a useful source for the protection of rural roads from these impacts. (JRA 2017)

South Korea has also experience an enormous economic and demographic growth since the second half of XX century.

Another group of countries is Asia is currently growing very fast but is not yet on the same level as South Korea. China and Indonesia can be put into that group.

Another group is about to develop a national road network and is still a very rural and agricultural society. Such as Laos or Bangladesh. Nevertheless, both countries established an own manual for the road design with chapters for low volume roads. Bangladesh and Laos are very good examples as they are both countries with an enormous precipitation. Therefore, the experiences they have made can be interesting for countries which face either an increasing precipitation due to climate change or which face extreme precipitation events in a short period of time.

F.1.4 Oceania

The countries of Australia and New Zealand – both commonwealth nations – were under a strong influence of the United Kingdom. Climate in the UK is very temperate. Australia’s average temperature on the other hand is in average very high but dry in some areas of the country. An example for a very dry region is the centre of the country. Precipitation is rare and never strong. Alongside the northern and parts of the Eastern coast the Australian climate is tropical. Australia’s road administration Austroads has published an own manual for low volume roads in the extreme climate of Australia (“Seal Design Improvement for Low Volume Roads”).

New Zealand and Australia – though their climate is different – have also published guidelines together. The “Road Pavement Design for the Pacific Region” is focusing especially on the use of local materials. The enquiry of TC D 4.1 (see chapter 7) has been showing that availability of adequate material for road construction might become a problem in some regions. Therefore research on alternative materials and cooperation among nations is very useful for this report.

(Larcher 7/1/2009)

F.1.5 America

The continent of America will be divided into the two sub chapters of South and North America. The countries in Central America will be included in the South America chapter. The countries of South America face mostly the same major problems and needs. Often the organizational structure of the administration and socio-cultural issues are similar within South America. The countries of North America – Mexico, the USA and Canada – on the other hand have a different cultural and historic background.

F.1.5.1 South America

South America consists of regions with a very well developed road network and other very rural regions with a low population density. (UN)

And even the standard of the roads is very different among the countries. While in Chile 1 in 4 roads is already paved (24.6%) the more rural country of Bolivia has only 3.43% of paved roads. (Soria 5/24/2017)

These two numbers are exemplary for the huge difference in the road network standards between the coastlines alongside the Atlantic and Pacific Ocean and the very rural inland areas. Wealth and prosperity in South America are comparatively dependent on natural resources and agricultural production. (UN)

Especially big farms and mines are therefore linked to the national road networks between the big cities. Rural roads that are often the only connection for villages and the population on the countryside are in bad conditions. (Aguayo 5/24/2017)

The reason for that is not the high average age of these roads but the inappropriate way of design and construction and a lack of maintenance which let roads become unusable within 8-9 years. (de las Heras)

Several countries started to work out programs to strengthen their rural roads. One of them is Chile. They identified the main problems of the rural roads. All of them were linked to weather impacts. Especially low volume roads haven't been in focus in Chile until then. Chile underestimated the impact weather could have on roads with very low traffic.

As a result of this analysis it started the nationwide rehabilitation program "Programa Caminos Basicos". (Aguayo 5/24/2017)

To make sure that the budget was used just for this type of road they made some specific criteria part of the program: the program was for roads with a daily traffic of less than 700 vehicles and the maximum investment sum was 600.000 $/km. In that way authorities were required to find cheap and suitable ways of creating a long-lasting type of rural road. Rural roads that were still in good conditions received a thin asphalt layer on top of them as a protection against precipitation and moisture.

Other countries in South America as Peru are going a different way. Instead of establishing a nationwide fund program Peru developed its own manuals for rural roads. In Peru a majority of rural roads are not paved. That is why the country developed two separate guidelines. One for the design of paved rural roads (Manual de Diseno de Carreteras Pavimentadas de Bajo Volumen de Transito) and one for the design of unpaved rural roads (Manual de Diseno de Carreteras no Pavimentadas de Bajo Volumen de Transito).

Contrary to Chile unpaved roads are still expected to have a future in Peru. The government focuses on research of cheaper, long lasting designs and improved maintenance management. (Arevalo 5/24/2017)

F.1.5.2 North America

The Applied Research Associates of Canada, the ARA, holds the position that the main goal of maintenance has to be the prevention of a rotting subgrade. As soon as a subgrade starts to rot it is no longer repairable and has to be rebuild as a whole.

That's why water in the subgrade has to be avoided at any cost. Road administrations in Canada and elsewhere have limited budgets. So, the ARA states that roads have to get maintained before there is water in the subgrade. In that way budgets for maintenance can get used in the most efficient way. Otherwise cracked road pavements might get repaired while the subgrade is already too damaged.

ARA established several indices for gravel surface and bituminous surfaces. With these indices (that will be explained in detail in chapter 9) it is possible to determine how soon a road has to get repaired to avoid subgrade damages. (Hein 5/24/2017)

In the USA there are two nationwide administrations which are doing research on rural roads in particular: the Department of Transportation (DOT) and the United States Department of Agriculture (USDA). The DOT is well known for the Federal Highway Administration (FHWA) and the US Forest Service are doing research on rural roads for the USDA in cooperation with the Virginia Tech University and the Conservation Management Institute.

The climate within the United States is characterised by different climate zones. The country has also areas with a high population density and such with a very low population density. (UN) The United States is a country with long distances and partly a very intense agriculture and forestry. That's why the length of the low volume roads (defined as roads with less than 400 vehicles per day in the US) is very long.

As many forest roads are needed for a very high load – timber trucks – their quality is very important. In 2003 the US Forest Service published a manual for these roads in cooperation with other institutions. It is called "Low-Volume Roads Best Management Practices". Apart from forest roads most rural roads in the US are paved. There is still an own manual for gravel roads that has been updated in November 2000. (Skorseth, Selim 2000) The Transportation Research Board has been doing research on concrete surface low volume roads and published several reports on the use and advantages of this technology. (Fuchs, Sion)

F.2 Techniques and procedures mentioned

The recommendations for design and maintenance build a key aspect of this report. Manuals, experiences and reports of many institutions have made their way in. The recommendations though do not claim to be complete and final. On one hand research is proceeding. Even more important is that special situations – either because of topography, available materials, limited time or budget and available staff or machines – can make it necessary to ignore some of the recommendations. As the enquiry of TC D4.1 didn't deliver any tender documents the whole chapter of recommendations is a summary of ideas and concepts and cannot be used for an actual design of a rural road unless tender documents get available during further approaches of TC D4.1. Nevertheless the following recommendations summarize today's knowledge about rural roads that are well prepared for climate change. The actual design of a rural road is the main part of the recommendations – but not the only one. In many countries organizational structures do also provide room for improvement. A proper quality management and regular maintenance can increase efficiency as they save money and increase durability of rural roads. There are also innovative but simple ways to guarantee maintenance and improve the economic situation of the rural population ("Microempresas").

Even if climate change will make weather extreme and more unpredictable not all the recommendations are relevant for all regions in the world. Therefore chapter 10 (special recommendations for different regions) will specify and complete recommendations. Chapter 10 will also focus on recommended next steps in research for these regions.

The first part of the recommendations will deal with quality management.

Quality management is defined as:

"*Management activities and functions involved in determination of quality policy and its implementation through means such as quality planning and quality assurance (including quality control)"*

by the Business Dictionary. Referring to rural roads this means that quality management has several application areas. Firstly, there is the quality control of existing rural roads. Secondly quality management has to make sure that the design of rural roads follows the best possible standards. And thirdly the construction process and use of materials has to fit the standards.

F.2.1. Risk management for existing roads

Beside the quality control of the actual road the risk management is an important component, too. Quality control can only identify damaged parts of a road and set up a priority list of maintenance. But the better way would be to identify endangered road segments right before they get damaged. In that way design adaptions can prevent damages from impacts of climate or parameters of climate change.

In Europe there are currently two projects dealing with risk management of rural roads due to climate change: RIMARROC and RIVA.

At this point it is important to actually understand the meaning of "risk management": Neither RIVA nor RIMARROC can provide recommendations for adapted design or protection measures. The intention of risk analysis instruments like RIVA or RIMARROC is to identify segments that are very likely in focus of negative impacts of climate change or extreme weather. It identifies these segments by the following 4 factors: (Alfen et al. 2015)

- Climatic events as rain or frost (climatic factor)
- Vulnerability of infrastructural elements (i.e. road surface, use of bridges…)
- Consequences of possible impacts (increased number of accidents, economic cost)
- Criticality of the segment (i.e. importance for local population)

Neither RIVA nor RIMARROC can clearly build scientific relations between climatic parameters and road material parameters (i.e. average annual temperature and durability of asphalt surfaces).

The purpose of both guidelines is therefore to improve the use of existing financial resources to improve the design of endangered segments.

F.2.2 Quality management of construction materials

To prevent road damages due to the use of unsuitable materials most countries rely on the results of the CBR – the California Bearing Ratio – to determine the strength of soil and subgrade. Another possible test for the strength of soil is the Proctor Compaction test. As the World Bank states in one of its reports, the majority of countries do not have separate CBR and Proctor requirements for low volume roads. (Pinard 9/29/2006)

Relying on the CBR and the Proctor Compaction test is never an additional risk. But often these two tests rule out materials which are adequate for the construction of low volume roads. To save money and to save high quality materials for highly stressed roads materials should not necessarily get ruled out. High quality materials could run out in some areas in the future. But on the other hand, Laterite is widely common in Africa and Maicillo in South America. Both materials do not fit the CBR test for roads with a normal traffic volume. But both materials are in use for low volume roads for more than 10 years – with sufficient results.

The World Bank sums it up with the following sentence:

“*Make specification fit materials rather than materials fit specification*” (Pinard 9/29/2006)

The huge variance of natural materials does not allow to recommend general strength properties for low volume roads. These properties depend on the used combination of subgrade, base and surface. Other aspects as precipitation and the local criteria for “low volume” play a role, too.

Nevertheless, there are several major recommendations according the use of local materials which do not fit common strength properties:

1. Any potentially used material should be locally available in a huge amount. The reason for that is the effort to determine the quality of the material.
2. The best way to find out the long term robustness of a material is the possibility of test sections in the road network. National road policies should offer possibilities.
3. If a material turns out to be moisture sensitive but has sufficient characteristics apart from that the cape seal technology could be an option.

The Cape Seal technology is a cheap way to protect the road structure of incoming water through the surface. A road with a cape seal gets a thin bituminous layer on its surface. The difference to a paved road is the thickness of the bituminous layer. A Cape seal does usually not contribute to the load capacity of the road. Its purpose is only the prevention of surface erosion and incoming water. Cape Seals are already common in Chile where the road administration stabilizes the already mentioned Maicillo material with it.

Figure 86: Cape Seal on a gravel road in South Africa[56]

Cape Seals are cheaper than common asphalt surfaces and extend the durability of the road structure as it protects it from incoming water and moisture. The Chilean road administrations report an additional lifetime for this type of roads of up to 8 years compared to unsealed roads. (Aguayo 5/24/2017)

56 Photo available online at https://pbs.twimg.com/media/Ck5SE-CWsAAAsfG.jpg (last checked on 21.10.2017)

APPENDIX G: CLIMATE IMPACT FLOOD

Floods are a reason for many road closures as they are a risk in many parts of the world. In Denmark for example floods are the reason number one for road closures that are caused by weather events. (Vejdirektoratet) Especially in areas close to rivers, lakes or the sea floods are a big risk for roads.

Roads that are built close to the shore are influenced by the tides, by waves and can be flooded when storms are occurring. As waves of the Oceans can be very powerful flood events and storms can erode the earthwork of a road at just a single flood event. As the collapse of the road can finally happen in a very short period of time the risk of accidents is comparatively high. While the reconstruction and maintenance of roads with damages due to erosion has often not to happen immediately and is not endangering the safe use of the road damages due to floods mean mostly a total loss. A road that is destroyed by a flood at the shore can look like the following examples in Spain and Norway:

Figure 87: road in Spain destroyed due to erosion caused by a flood[57]

57 Taken from PIARC TC E1 report of Spain

Figure 88: road in Norway destroyed due to erosion caused by a flood. [58]

The reconstruction of roads that were built right at the coastline and destroyed by water is in average very expensive. (Bloemer 2014) The reason for that is the reconstruction of the coastline itself that is often necessary. There is water right beneath the former road even after the flood is gone as you can see in figure 23. Therefore, a water entertainment needs to be installed before reconstruction can begin and the reconstructed coastline needs to be protected against floods. Critical about erosion caused by a flood is the very abrupt collapse of at least parts of the road.

58 Taken from PIARC TC E1 report of Norway

Figure 89: partly collapsed road after flood caused damages of the earthwork[59]

In the previous photo you can see that the coastline itself is still existing. It was built with massive rocks that were solid enough not to get flushed away by the water. Nevertheless, the finer material of the earthwork was washed out by the flood and the road collapsed. Without a sign of warning! This makes it even more necessary to rethink and finally redesign flood protection at coastlines.

Another risk at coastlines lies in debris that waves and floods flush on the roads.

Figure 90: road in Canada with debris flushed on it by a flood[60]

Debris on a road mean an additional risk for traffic on the road and lead to extra closures of the roads. Nevertheless, debris itself is not causing damages to the road as long as it is not too massive. Though debris can lead to permanent obstructions on roads in rural areas with a lack of maintenance. (Marquand) As we have already seen there are also damages that are caused by a mix

59 Taken from PIARC TC E1 report of Norway
60 Taken from PIARC TC E1 report of Canada

of different reasons. An example would be massive floods in rivers. They often erode roads but also bring a lot of debris. The difference to a landslide is often hard to see. Landslides are caused by precipitation and are therefore just the result of softened soil at a hillside. Floods in roads can though also bring a lot of debris, rocks and the results of both can look similar. (Howard)

Figure 91: destroyed road and bridge in Norway due to a flooded river with debris[61]

Rivers often have high flow velocities and can even transport massive rocks over great distances when there is a flood. Therefore roads, bridges and even houses can be destroyed by floods. The risk in even higher as there is the power of the water and the massive debris that is destroying infrastructure alongside the river. Even when the water isn't leaving the streambed itself bridges are endangered when the water level is higher than it usual is or when debris is blocking the culverts.

61 Taken from PIARC TC E1 report of Norway

Figure 92: destroyed bridge in Norway due to a flood[62]

As there is debris on both sides of the destroyed bridge in figure 27 the water was completely flowing over the bridge at the peak of the flood wave. A bridge like the one shown is a total loss.

Debris is not only a problem on the surface of roads but also when it’s blocking culverts. Culverts are a save way for streams to crossroads below the surface. But as soon as these culverts are blocked the water accumulates and the earthwork and road embankment work as a dam for the water – but they are not designed to work as a dam and can get damaged.

62 Taken from PIARC TC E1 report of Norway

Figure 93: Culverts in Sweden blocked by trees and debris[63]

This shows that even a good technical solution to prevent damages from weather events needs proper maintenance to be reliable.

G1.1 Sea level problem

In Sweden, the most problematic impact identified during the enquiry is the rise in sea level.

Sea level rise is one important impact that Sweden has started taken in consideration. There are now planning for a lot of both railway and way-tunnels on the west coast of Sweden. The project is near the Atlantic sea.

The plan contains a series of measures to climate change adaptation facility. For example, the tracks are placed higher up from the soil surface to cope with higher water levels in the future.

Over the years, the project requirements for Varbergs climate adaptation tunnel has been strengthened. There also have a more detailed knowledge of conditions and this has affected the solutions.

The cost will be higher, it is above all the measures for adaptation to climate change and security, which accounts for the increase in costs.

Tunnels with a built roof (concrete tunnels) becomes longer and get more powerful construction. The tracks are placed higher up from the soil surface, which requires higher noise protection and modified foundation for noise barriers

Larger ponds, pumps and larger dimension of pipes to withstand greater water flow.

63 Taken from PIARC TC E1 report of Sweden

Figure 94: Railway plan for Varbergs tunnel in south of Sweden (construction 2019-2024) M Baumann

Building of three metres higher sea the sea could rise by three meters. The risk must Transport Department when a new railway tunnel being built in Varberg. Climate change adaptation raises the price tag for the project, with around 300 million kronor.

The solution will be to the tunnel mouth is connected to the track alignment to the North with a long “built-tunnel”, with shut down covers/doors that will prevent water from entering.

Johan Jansson who work with specialist support in dewatering and been out format climate adaptation of Varbergs tunnel: - Construction with doors that can close out the water, I have not seen before in Sweden, but it is available on several roads around New Orleans in the United States. How did you determine that the tunnel must pass a sea level at just 3.5 meters above the current level?

The challenge is that the water cannot drain into the tunnel. It has an estimated life span of 120 years and must cope with the effects of possible climate change so long term. Even with the current climate, with normal variation, sometime during the 200 years the sea level will rise by 1.8 metres, for example at an extremely low pressure. Wave rinsing could raise the level by a further 20 cm. A worst-case-scenario provides additional 20 centimetres of elevation. To the need for a safety margin of half a meter of unpredictable events. This means that the tunnel with today's climate must pass 2.7 metres higher sea level.

The forecast say that sea levels could rise by one meter to the year 2100 due to warmer climate food. From this they can draw an uplift of 20 centimeters. Thus, the tunnel speed need clear 3.5 metres above today's sea level. The Swedish experts deem that this is enough, maybe even at the top. But it is important to have margins, considering how serious the consequences would be if the sea water flows in.

One should not over-dramatizing consequences of climate change on infrastructure. They have methods of calculating flows and levels and can design projects for them, if they come in early in the planning. And it costs money.

APPENDIX H: MAINTENANCE

Maintenance is one of the main keys for adaption of rural roads to climate change. Many of the weather impacts of Appendix C (see chapters 2.3 and 6) cannot only be avoided by an adapted road design but also by adapted maintenance strategies. PIARC defined road maintenance in 1994 as

"*activities to keep pavement, shoulders, slopes, drainage facilities and all other structures and property within the road margins as near as possible to their as-constructed or renewed condition*" (PIARC 1994)

The World Bank states that more than half of the countries spend only 20-50% of what they should on maintenance. (Burningham, Stankevich 2005) An increase in maintenance spending is therefore recommended but not what this report is focusing on. Big potentials for road maintenance are innovative organizational structures. They become even more important as the challenges of climate change will increase the daily maintenance effort. Daily maintenance efforts are not about the actual structure of a road but the environment. Therefore, maintenance includes drainage cleaning, vegetation management or pothole repair. The World Bank differentiates between 3 maintenance levels. (Burningham, Stankevich 2005)

- Routine maintenance: this one includes mostly environment related maintenance. Routine maintenance should guarantee the passability and safe use of a road. It includes cleaning and clearing (debris), vegetation cutting or pothole repair. Because weather impacts (see chapter 6) are mostly affecting routine maintenance the most room for improvement can be found here.
- Periodic maintenance: Periodic maintenance affects the structural integrity of a road. Therefore staff needs equipment and has to work professionally. Activities can be a repavement for example.
- Urgent maintenance: Urgent maintenance includes all activities that could not be foreseen but that are affecting the passability and safe use of a road. An example is a blocked culvert.

A system to manage the priority of periodic maintenance and rehabilitation has already been presented and recommended in the previous chapter (by the indices GCI and BCI). Often the difference between periodic maintenance and rehabilitation is fluent. The World Bank defines rehabilitation as construction works that affect more than 25% of a road's length. This definition is not in use everywhere though. (Burningham, Stankevich 2005)

Recommendations for maintenance in practice:

- Make sure that <u>responsibility</u> for a road is clear! Every road and even single sections of a road have to be assigned to a specific administration. This administration has to be aware of its responsibility.
- Make sure all <u>affected persons and institutions are involved</u>! Roads are important for local businesses, inhabitants and guarantee access to medical facilities. Closures and maintenance works have to be announced to increase acceptance of the local population. A way of letting the local population take part in maintenance can be <u>micro-enterprises</u> (see chapitre 9.2.1).
- Create <u>maintenance plans</u> and make sure <u>regular funding</u> is guaranteed! Maintenance is causing regular costs but can still reduce the long term overall costs of a road network.
- Develop <u>standards, checklists and manuals</u> for road maintenance! The quality of maintenance is dependent on the skills and knowledge of the maintenance staff. Also provide regular training.
- Build <u>extreme weather taskforces</u> at district level! These taskforces can coordinate maintenance effort after extreme weather events and help to restore trafficability!

What are possible contracting models for road maintenance?

Except for routine maintenance (see above) skilled contractors and professional equipment are necessary for an adequate road maintenance. The contracting model of micro-enterprises (for routine maintenance) will be part of the next chapter. The Polish road administration is leading in developing contractor models for periodic maintenance and has therefore a lot of experience with a high variance of models. (Nowacki 5/24/2017)

- Traditional model: In this model the road administration is providing own staff and equipment to do maintenance for its own roads. This model is common in countries with a strong governmental sector and in very rural areas with a lack of private businesses. The advantage for road administrations is that know-how is kept within the administration and is available all the time.
- Model of diffused orders: The road administration is commissioning a private company for planning and constructing each. The planning can also be done by the administration itself. The contracting construction company receives very precise instructions in what to do and how to do it.
- Indicator model: Here the road administration sets goals and expected effects of the maintenance works. A private company gets commissioned and is free on how to achieve the expected standards. This model requires a high technical know-how in private sector.
- Mixed models: There are several ways of mixing the models above to make them fit the local circumstances.

There is no general recommendation on the choice of contractor models. Each recommendation fits to different circumstances. A general recommendation that can help administrations to choose the right model for its needs requires a road administration to analyse its environment:

- Is there a developed private construction sector in rural areas?
- Is there specific know-how on maintenance in the administration/private sector?
- Do national regulations require a certain contractor model?
- Is there enough capacity to guarantee maintenance by administration staff?
- Can private companies be reliable and still be cheaper in costs?

Other aspects as an intended support of private sector and local population can play a role, too. The more rural a region is the less likely it is to find private companies with fitting equipment and staff. In that case administrations might have to do skilled (construction) works by themselves. There is still an innovative way of supporting un-equipped and unexperienced local population: micro-enterprises for routine maintenance.

H.1 MICRO-ENTERPRISES

Micro-enterprises – in Spanish they're called "Microempresas" – in road maintenance are an attempt of South-American road administrations to let the local population benefit financially and socially from rural roads close to them.

A micro-enterprise is a very small business often consisting of a single person or a family. This micro-enterprise is doing work which neither requires a complex training nor expensive equipment. As the contracts with road administrations mostly apply for local road sections micro-enterprises consist of local population that is doing the maintenance jobs in part-time.

The following explanations and recommendations refer to the experiences of the Bolivian national road administration. (Lazarte 5/24/2017)

Which fields of work can be carried out by micro-enterprises?

Micro-enterprises can fulfil the work of routine maintenance. This routine maintenance includes all works linked to vegetation: mowing works, cutting trees, planting in order to prevent erosion. They can also do cleaning and clearing jobs: cleaning of the surface of the road, clearing of debris and fallen trees or rocks. Here they can also restore the passability of a road after extreme weather events as a part of urgent maintenance. Another important field is the drainage maintenance: keeping culverts and draining channels clear.

What does **a contractor model** with micro-enterprises look like?

Most countries that are supporting the micro-enterprise model first had to adapt their national regulations. Micro-enterprises consist of local population which is mostly unskilled. Because you already know who will get a contract for a specific section an open tender is not possible. For countries like the USA or institutions like the European Union such a model is not possible due to competition law.

It is recommended to include all the local population that is interested to avoid jealousy. Deals should be valid for a longer period of time (>1 year) and should be fixed price contracts. This makes accounting very simple. Contracts should be specific on the works that have to be done and how often they have to be done. Micro-enterprises should have no hierarchies and all members should earn the same amount of money. In Bolivia these points avoided local conflicts and corruption.

When is a micro-enterprise **the best choice**?

A micro-enterprise is the best choice for low developed and very rural regions. For regions with a high rate of unemployment micro-enterprises can contribute to the local economy. The more isolated a region is the more other contracting models would cost due to long distances. Micro-enterprises can also react very fast in case of urgent maintenance.

What are **benefits** for both sides?

Compared to external companies the local population benefits from rural roads and gains access to markets, schools and medical facilities. They are therefore personally interested in keeping these roads in a good state. In case of extreme weather events they can also be at blocked road sections sooner than external companies could. Especially in barely developed regions micro-enterprises are an important income for the population. Compared to agricultural incomes it is guaranteed and steady. The revenues and spending of the members of a micro-enterprise can also help other local businesses to develop. As all members are recommended to be paid equally micro-enterprises can support gender equality. Especially in rural areas women often do not find paid work or earn less than men. To reduce dependence of women there are also projects for women-only micro-enterprises.

Figure 9 6: A micro-enterprise in Bolivia consisting of women only. [64]

What **training is required** for micro-enterprises?

- Micro-enterprises should get a regular technical training. This technical training should include lessons on the functioning of drainage systems and risks of erosion. It should also include practical training with basic equipment that is needed for vegetation works.
- A training of business organization is recommended. Though members of micro-enterprises should be paid equally they still need to organize themselves. This includes working and budget plans and lessons on coordinated teamwork.
- A safety training is necessary! Road accidents are a big risk for even experienced workers. Therefore personal protective equipment should be mandatory to wear (helmet, gloves, safety vest). Micro-enterprises should also be taught on risks of felling trees and how to close roads correctly.
- An additional training in cooperation with forest services is optional. The members of micro-enterprises could be taught in forest nursery on how to establish and maintain plantation. On one hand this increases awareness of environmental issues and helps local forests to prosper. On the other hand the risk of erosion and landslides can be additionally reduced.

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64 Taken from the presentation of Lazarte, Jonathan; held at PIARC meeting in Bolivia on 24.05.2017

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H.2 Risk management for existing roads (asset management taking into account the climate change impact)

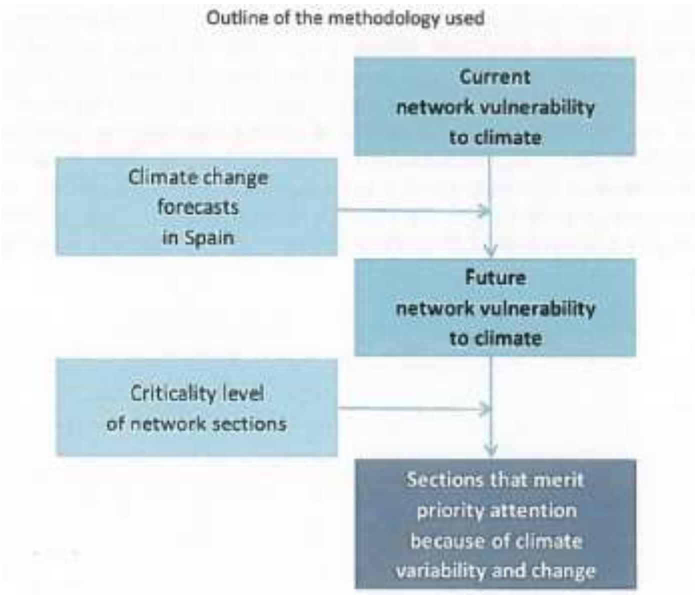
***Spanish example* (Sections of the state-owned inland transport infrastructure network that merit priority attention because of climate variability and change final report June 2018)**

The example presented below corresponds to the methodology used by the Spanish Ministries of Transport and the Environment to identify which parts of the current state-owned inland transport infrastructure require priority attention to adapt to the effects of climate.

In the first stage, the current vulnerability of the state network of inland transport in respect of climate events is evaluated.

Next, an assessment of how vulnerability is affected in the future because of the climate change is estimated. Last of all, the identification of the network sections merited priority because of said vulnerability is identified.

The picture below summarizes the methodology followed.



The characterisation of the road and rail network vulnerabilities was done based on a pre-established typology of impacts. These impacts may in principle be relevant because of their potential effect on traffic conditions and/or the significance of the damage caused in the infrastructure.

Landslides and erosion and falling of materials of ***slopes*** *as a consequence of* ***heavy rain***

Erosion of slopes in ***embankments*** *by the course of a river as a consequence of* ***extraordinary floods***

Insufficient capacity of the ***drainage works*** *due to* ***heavy rain***

Erosion of abutments, undermining of foundations and impacts from debris materials on ***bridges and viaducts*** *due to* ***extraordinary floods***

Development of ruts on the ***pavement*** *as a consequence of* ***high temperature***

Insufficient ***road surface drainage capacity*** *as a consequence of* ***heavy rain***

Impact on the ***road traffic conditions*** *due to* ***wildfires***

Impact on the ***road traffic conditions*** *due to* ***snow***

The next step was to characterise the level of the impact (limited/non-existent, moderate or important) of the current climate conditions on each of the sections defined, using a scale shown on the figure 97.

SCALE OF IMPACTS		
Inexistent/limited effect on traffic and/or on the infrastructure	Moderate effect on traffic and/or on the infrastructure	Important effect on traffic and/or on the infrastructure
1 2 3	4 5 6	7 8 9 10
The effect on the infrastructure and/or its functionality is non-existent or limited throughout the section. Repair is compatible with routine maintenance actions. Road/Rail traffic conditions may be affected by speed limits and/or traffic and/or access control measures during a short period of time (hours).	The effect on the infrastructure and/or its functionality is moderate at some point of the section, requiring modest repairs and/or replacements. Road/Rail traffic delays and/or traffic deviations may be required lasting hours or days.	The effect on the infrastructure and/or its functionality and/or its security is significant or complete at some point of the section. The repair requires the rehabilitation/ reconstruction of one or several infrastructure assets. Road/Rail traffic delays and/or traffic deviations may be required lasting weeks or months.

The level of the impact is graded with 1 when the effect is null, irrelevant or negligible. The numerical scale helps to qualify, within the same level of effect, the nearness to a contiguous level or the frequency of the impact.

Figure 97: scale of impacts

The level of the impact will usually be determined not only by the entity of the weather events, but also by the age of the infrastructure, the design criteria employed, the construction methods used back in the day, and the manner in which the infrastructure has been maintained over the years.

Figure 98 compares the percentage of the road network represented by sections in which each impact may be presented as moderate or important.

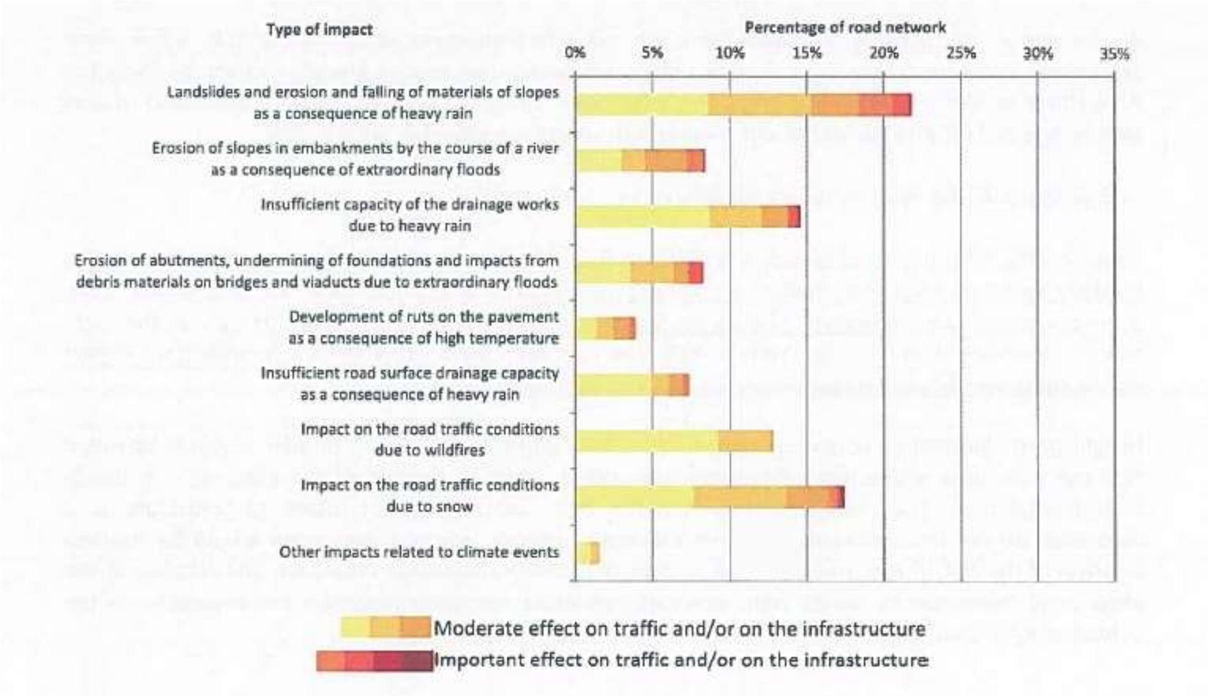


Figure 98: representation of percentage of road network by type of climate impacts

Because of its incidence, the vulnerability of the earthworks stands out, especially the problems associated to landslides and rockslides on slopes.

This work being done, the evolution of the climate was then looked at over a period covering the next 30 years after a choice on the climate models to consider.

Parameters watched more precisely are:

- Change in the maximum daily temperature in 30 years,
- Change in the number of days in a year with minimum temperature below 0°C in 30 years,
- Change in the maximum daily thermal oscillation in 30 years,
- Change in the maximum precipitation in 24 hours in 30 years,
- Change in the maximum wind speed 10 meters from the ground in 30 years

According with these data, the maps of future (in 30 years) network vulnerability taking into account the maximum effect of climate change on the sections of the road network, is presented below:

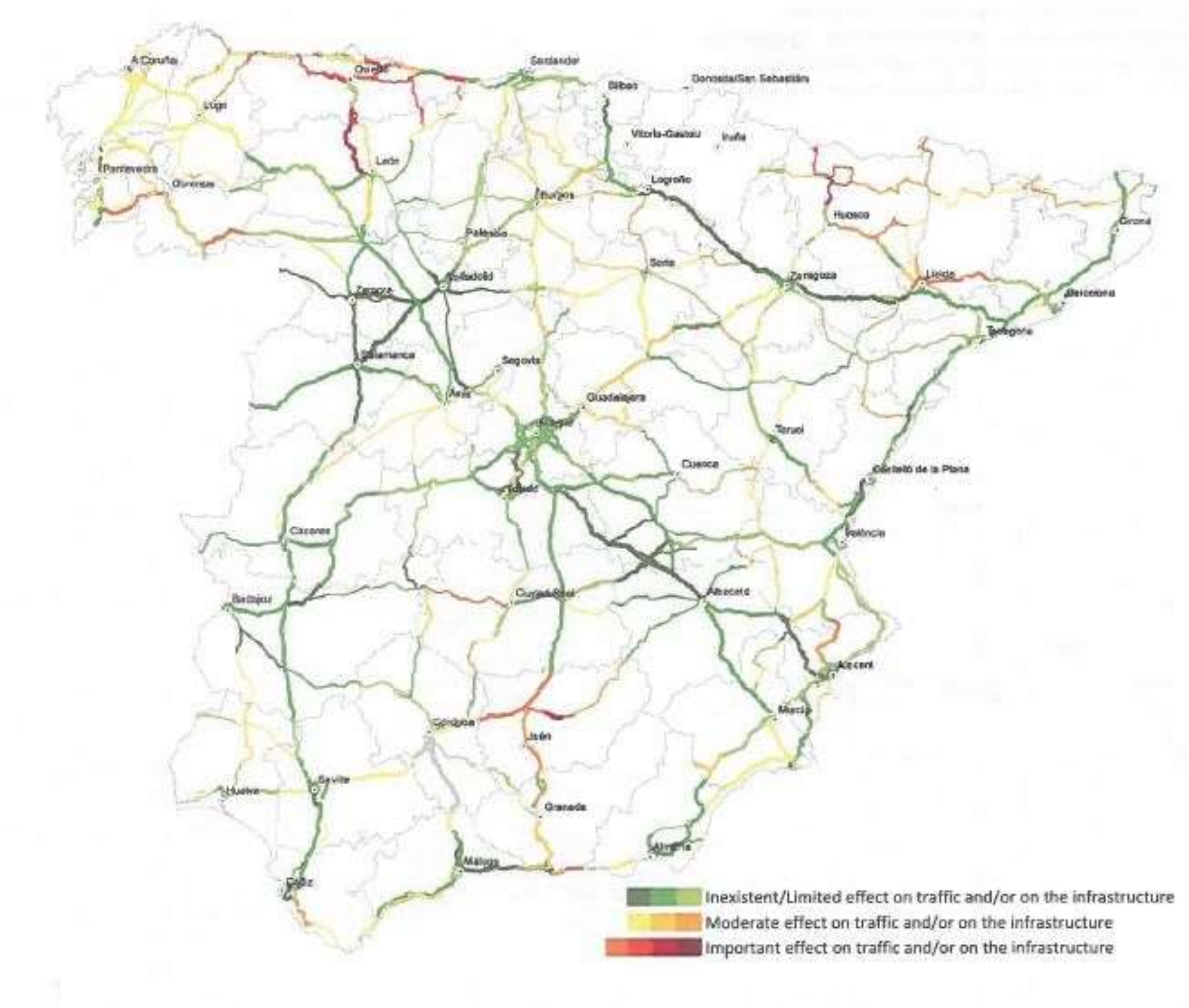


Figure 99: graphic representation of the location of the most impacted area

Thus, we can show the vulnerability of road sections for a current climate and what it will become in the future with projections made at 30 years.

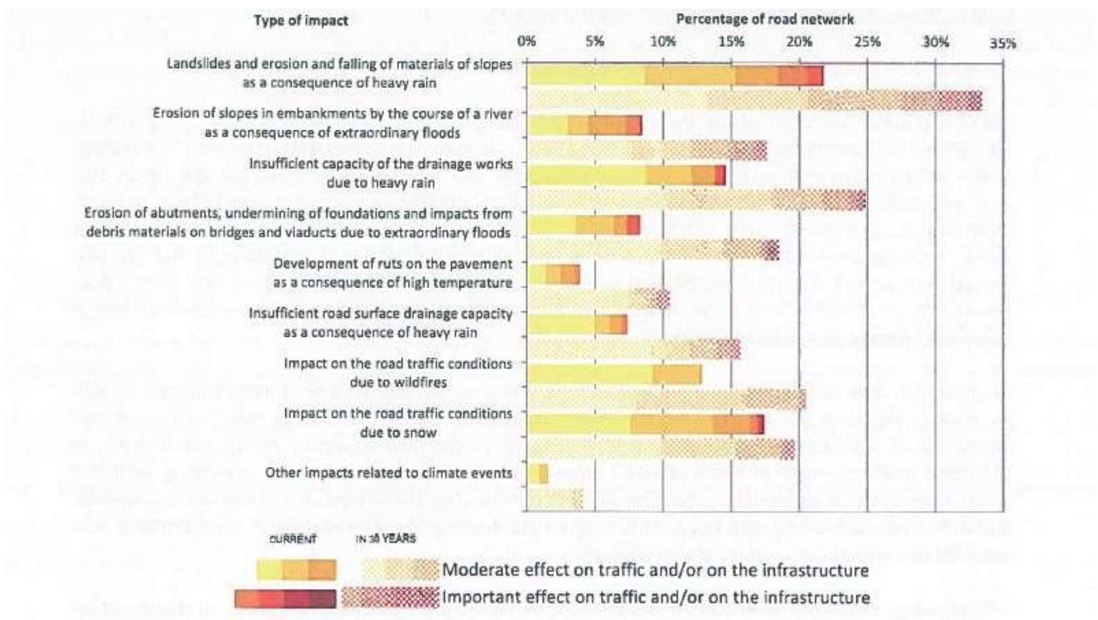


Figure 100: comparison between current and expected impacts with climate change

APPENDIX I: CROSS SLOPES

In most countries there are rural roads including these components in their design. Just very simple roads often miss these structural components as they're often improvised or built without the use of external materials. But there are huge differences in the international design regarding slope. For a common understanding at this point the difference in designing camber gets explained.

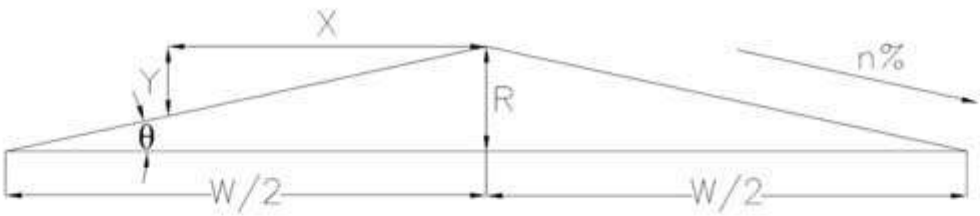


Figure 101: Cross slope as it is most common worldwide, built as a "roof" [65]

The most common way to build out the slope is the one you can see in figure 2. The highest point of the road is in the middle axis of the road. The lanes in both travel directions are inclined towards the side of the road. For the recommendations of this report we always assume this type of slope. It is called the centreline crown slope. It is important to know the way cross slopes can be designed as it is impacting the drainage.

Figure 102: rural road in North America with centreline crown[66]

A centreline crown is draining the water to both sides of the road.

There is another way of designing slopes which is common in Germany for example that should be mentioned at this point:

65 Cross slope „roof", online available at http://www.civileblog.com/camber-types/ (last checked on 21.10.2017)
66 Croos slope „roof", online available at http://www.civileblog.com/camber-types/ (last checked on 21.10.2017)

Figure 103: Cross slope of a road where both lanes are inclined towards the same direction[67]

The so-called cross slope is draining all of the water on the surface of the road at just one side of the road. Therefore, both travel directions are inclined to the same side.

The kind of cross slope with both travel directions inclined to the same side can‘t be seen as the international standard. (p. 106, Kappel 2016) So it will not play a role for the further report unless there is any advantage in a special situation. In that case it will be stated explicitly.

I.1 Impacts of the aspect "weather" on roads

As a report of the Austrian ministry of transportation states 30-50% of all costs of maintenance in Europe are directly linked to weather. (p. 2, Bednar-Friedl) In Austria itself the majority (88%) is related to precipitation. Either directly or in combination with other factors. (p. 2, Bednar-Friedl)

Other damaging factors can be extreme heat or cold as well as wind. Resulting costs are not always caused by the reconstruction of the roads. Economical costs also result from road closures due to weather. Therefore better techniques in design and construction can even pay off for countries.

The following pages sum up weather related road damages and give examples. The examples are also supposed to help authorities to identify the most typical damages at their own road network.

I.1.1 Erosion

A direct way of damages caused by precipitation is erosion. The following photo shows a road that is heavily damaged by erosion.

67 Cross slope, photo by Sascha Pöschl, available online at https://de.wikipedia.org/w/index.php?oldid=167782904 (last checked on 21.1.2017)

Figure 95: road in Central America damaged by erosion[68]

When roads are suffering from a strong erosion as in the shown photo it is very likely that there is no working drainage system at all. As you can see the surface of the road is basically consisting of compressed soil. This soil is fine-grained and can therefore easily be washed out. Another factor which is increasing the risk of erosion is a steep road grade as you can see in the next photo.

Figure 105: steep road grade in Central America[69]

A steep road grade makes standing water on the surface very unlikely. But on the other hand, the flow velocity of rainwater on the road is very high and erosion is a consequence. Therefore drainage should be designed as a cross drain and not along the road itself.

Even roads that are not consisting of compressed soil can have problems with erosion. Usually the erosion of the surface of roads is not relevant when it's made of coarse-grained gravel, asphalt or concrete. But erosion can still damage the road banquet or embankment.

Standing water on unpaved roads can also easily result in road damages as we have already seen. Standing water on soil is softening the road. While this is not critical as long as the road is closed it can lead to damages when vehicles use a softened road. An example for the consequences is shown

68 Photo taken of the Best management practices for low volume roads, published by the U.S. Department of Agriculture
69 Photo taken of the Best management practices for low volume roads, published by the U.S. Department of Agriculture

in the next photo.

Figure106: unpaved road in Central America destroyed by standing water[70]

Sometimes roads are built at the wrong location. The following photo shows a road that was built too close to a small stream. After a while the streambed changed its route and was flowing through the road itself.

Figure 96: rural road in the USA that turned into a streambed[71]

I.1.2 Flood/precipitation Erosion

One of the most important goals of road design is to create a system that is able to drain rain water from the road's surface as fast as possible. Water on the surface of a road is a problem for several already known reasons: possible aquaplaning, penetration of the road's surface and the resulting damages in base and subbase, erosion of surface, earthwork or environment. Most of these problems become more serious and likely the longer it takes to remove the water from the surface. Therefore, this remains a main goal. In addition, a drainage system also should provide a system of channels and ditches to "guide" the water away from sensitive areas as the earthwork or areas with a lack of vegetation and no armed surface.

Before designing a new rural road or rehabilitating an existing one the planners should observe the

70 Photo taken from the Best management practices for low volume roads, published by the U.S. Department of Agriculture
71 Photo taken from the Best management practices for low volume roads, published by the U.S. Department of Agriculture

following points:

1. What does the local topography look like?
2. Is there a rainy season or the possibility to visit the location during a rain shower?
3. Are there waters – natural or artificial – close to the planned route?

Answering these questions will allow road administrations and planners to make a first decision on the cross slope of the road. The following rules and recommendation are from the Best Management Practices for Low Volume Roads published by the US Forest Service. (Keller)

Cross slope

Any road – as low the volume might be – should have a cross slope. A cross slope is the only way to drain the water from the surface of a road to the ditches and other drainage system. The local environment is also very important to make a decision on the different types of cross slopes:

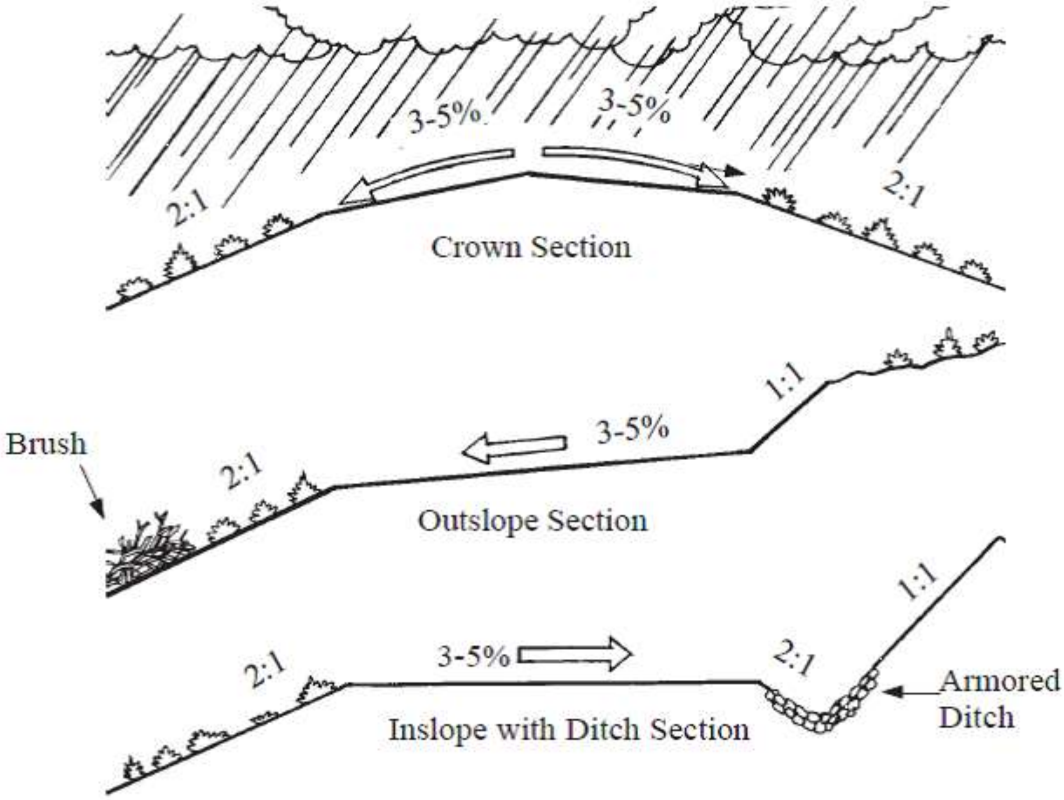


Figure 97: different types of cross slopes[72]

All 3 types have already been explained in chapter 3. Here the areas of application of each will be listed and linked to further recommendations on other aspects of a complete drainage system.

Note: Never build a road without any cross slope! Roads can never drain properly by just their longitudinal gradient!

Crown Sections are mostly used on roads with a width that is big enough for two lanes. Another area of application can be roads that are placed on an artificial embankment and are therefore at the top position in the surrounding environment. The centre of the crown is recommended to be in the middle of the road. In that way the inclination can be the same at both lanes. The inclination is recommended to be between 3-5%.

72 Photo taken of the Best management practices for low volume roads, published by the U.S. Department of Agriculture

Outslopes and inslopes only differentiate by the side on which they drain the water. Outslope sections drain the water to the sloping side of the terrain. Inslopes drain water to the rising side of the terrain. Outslopes can therefore use the gradient of the terrain to drain water off the surface and down the terrain.

Inslopes need to collect the water in channels or ditches and drain it away in a controlled way. Otherwise the rainwater would dam up at the rising side of the terrain and could flow back on the road.

Because of the terrain's gradient ditches are not necessary for outslope roads. But other protection systems are still recommended. Otherwise drained water can't be controlled and can erode parts of the road's shoulders or earthwork.

Outslope Section

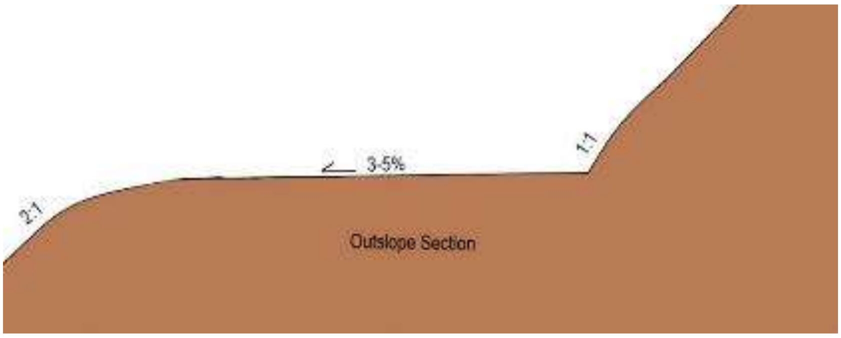


Figure 98: Rural road with outslope section

Outslope sections are the easiest drainage system that can be built at rural roads.

The advantage is that for this design ditches, culverts, pipes or rolling dips are unnecessary. The water drains with the existing topography. As a result, costs of outslope sections are in average lower than for inslope or crown sections. Also, maintenance effort is lower as there are no openings that could get blocked.

What are the risks of outslope sections?

Precipitation drains uncontrollably. Ditches and pipes allow a controlled management of water streams. Outslope sections lead to distributed water drainage. Water that drains off the road can lead to erosion below the road if there is no vegetation. On the other hand, the road is a part of the drainage of the parts of the surrounding environment which are higher than the road itself. Heavy rain can therefore lead to more water on the surface of the road than inslope sections do. Aquaplaning on outslope sections is more likely than on maintained inslope sections.

When are outslope sections recommended?

Outslope sections are a proper solution for rural roads in isolated areas with a natural dense vegetation and a topography that is not too mountainous. Outslope sections need less maintenance compared to crown or inslope sections. They are cheaper to realize. Especially for regions with steady medium precipitation and no seasonal heavy rain events as monsoon they are a proper solution without an additional risk of landslides or erosion.

Note: The recommendations for outslope sections are valid for the outer side of a crown section, too!

Inslope Section

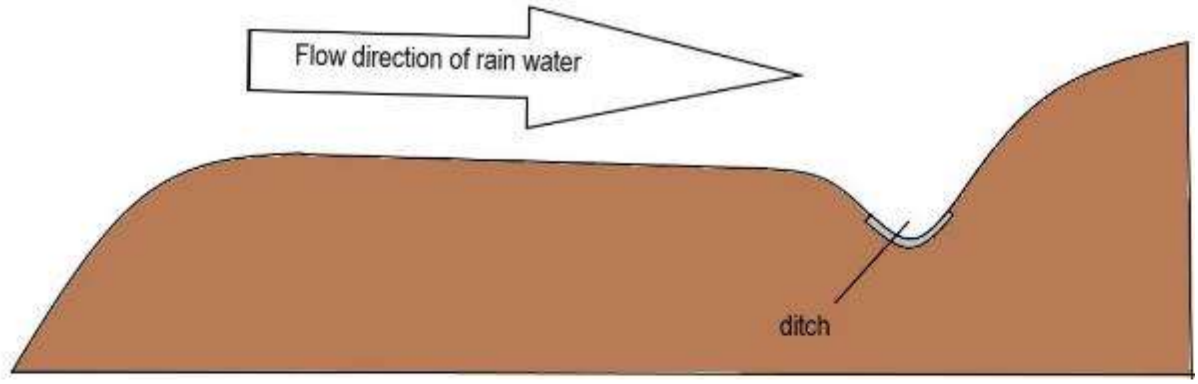


Figure 99: Rural road with inslope section and armed ditch[73]

With an inclination of 3-5% the flow velocity on the road's surface is high enough to drain the water off the road and to prevent aquaplaning. Higher inclinations should be avoided. Firstly, they would be increasing the flow velocity and are therefore an additional erosion risk for the surface. Secondly the water flows into the ditches with too much energy and gets harder to control. With 3-5% the needed size of the ditches is at its optimum.

73 Own illustration

APPENDIX J: TEMPERATURE CHANGES

Fine-grained soil as clay is more sensitive to freezing as coarse-grained materials. Therefore are earthworks made of fine-grained materials more sensitive than earthworks that comprise rocks. (Fuchsschwanz 2015) One risk for the subgrade is therefore to get damaged by freezing. The process of freezing itself is not automatically dangerous for an earthwork. Several factors have to come together at the same time to increase the risk of damages:

- Moisture within the earthwork
- Temperatures below 0°C (in the earthwork itself)
- Traffic load

If one of these 3 factors is not applicable damages of earthwork and road structure are unlikely. Therefore, an immediate measure can be a road closure.

When a rural road does not fulfil the following criteria a road closure of existing rural roads is an option:

- Only access of rural population to medical facilities
- Only connection between inhabitants and workplaces
- Only access of rural population to educational facilities
- Only connection to supplies of daily needs (i.e. food)

If there is moisture and temperatures below 0°C in the earthwork and none of the criteria above does apply a road closure is appropriate to protect the earthwork!

Especially for roads that are in the planning or get a rehabilitation reduction of the criteria moisture and temperature are in focus.

Frost protection of earthworks: [74]

This chapter is only dealing with the risks of climate change for earthworks. But for a proper earthwork protection the road structure itself – as seen above – is essential, too. The atmospheric temperature is affecting the temperature of the surface of a road the most. The reason for that is the direct contact between the surface and the surrounding air and the influence of sun beams. Every layer below – the base, the subbase and the subgrade – are affected less than the layer above them.

A frost protection layer can be each layer of a road structure that is made of a coarse-grained material like gravel or a mix of sand and gravel. Coarse-grained materials do not store water and can also not draw water from the underground with the capillary effect. Its water content is therefore low compared to the air content. Frost damages are unlikely as the little amount of water can extend into the space filled with air. Important is the overall thickness of the frost protection layers below the surface of a road. This thickness is important for the frost protection of the earthwork. The German RStO - a manual for the standardised upper structure of roads – is giving a few rules of thumbs for the needed thickness.

Note: The RStO was made for Germany specifically and is zoning Germany in different frost risk zones. For countries with a very different climate compared to the German one the following thicknesses may only be an orientation to set up an own manual!

74 Road structure illustrated by the US department of transportation, available online at https://www.fhwa.dot.gov/engineering/geotech/pubs/05037/images/f009.gif (last checked 21.10.2017)

The following steps are giving an idea of the criteria that have to be noted:

How big is the traffic load of a road?

This report is dealing with rural roads only. But even they can have a big variety in their traffic load. It should also be mentioned that heavy traffic is wearing out a road disproportionately. The following chart is giving an idea of the basic thickness of the frost protection layers:

	5 / 6 / 7	2 / 3 / 4	1
F2	55	50	40
F3	65	60	50

Figure 100: RStO chart 6; general thickness of frost protection layers in cm depending on traffic load class (1-7) and frost sensivity (F2, F3) [75]

The numbers 1-7 mean the traffic load classes. In general, rural roads can be in any of the classes, depending on the traffic load. Smaller roads with almost no heavy traffic will probably be class 1 roads, rural roads that are used for agricultural or forest services or that connect minor cities are 2/3/4 roads. Only very big roads that are working as highways can be class 5/6/7 roads.

F2/F3 mean the sensitivity to frost of the underground material. Fine-grained materials with high water capacity tend to be F3 soils. Less sensitive underground like a mix of clay with gravel and sand can be a class F2 underground. To be on the safe side the basic thickness can be chosen as 60 cm for rural roads in regions with a regular change between freezing and thawing in winter season.

Add or subtract additional thicknesses for risk factors:

There are other factors that have to be taken into account in addition to the basic thickness of the frost protection layers.

- General regional risk of regular changes between temperatures above and below 0°C:
  Add 5 cm thickness for temperate climate with regular risk of frost in winter season or **Add 15 cm** thickness for alpine climate with harsh winters and a regular change of freezing and thawing!
- Increased risk of frost when the road is located at a northern slope:
  Add 5 cm thickness!
- Groundwater level:
  Add 5 cm thickness when groundwater is higher than 1.5 m below surface!
- Road embankment / road nick influence:
  Add 5 cm thickness when the road is located in a nick!
  Subtract 5 cm when the road embankment is higher than 2 m!
- Drainage system:
  Subtract 5 cm when the road's surface gets drained with channels or pipes at the side of the road!

75 Chart 6 of the German manual RStO

APPENDIX K: ADAPTED ENQUIRY

The idea of creating an adapted enquiry that was designed as a "mask" came up quite early in the process of writing this report. The reason for the low participation in the first enquiry were identified as follows:

- The enquiry was too complex
- Answers required too much explaining text
- One single member was unlikely to be able to answer all the questions

A first draft of the mask is show on the following side.

On the pages after the mask the received answers of the actual enquiry were filled in.

TC D4.1 enquiry **answer of member country:**

description of existing climate

temperatures

regional average maximum		°C
regional average minimum		°C

precipitation

regional average maximum		mm
regional average minimum		mm

current observations regarded to climate change

impacts of climate change on infrastructure

documented Appendix C impacts   see also: International Climate Change Adaption Framework for Road infrastructure

realised projects with design adapted to climate change (please attach **tender documents**)

Questions concerning the "capping layer"

Does the capping layer exist in your country?

If **yes**: Which materials are in use for the capping layer?

If **no**: Is there any layer between the pavement and the subgrade?
If yes: What does this layer consist of?

TC D4.1 enquiry **answer of member country:** **Bolivia**

description of existing climate

temperatures

regional average maximum	24,5	°C
regional average minimum	9	°C

precipitation

regional average maximum	1400	mm
regional average minimum	500	mm

current observations regarded to climate change

impacts of climate change on infrastructure

documented Appendix C impacts see also: International Climate Change Adaption framework for Road infrastructure

floods
landslides, rock falls
permanently or temporarily inaccessible roads

realised projects with design adapted to climate change (please attach **tender documents**)

no adaptions of manuals due to climate change yet
innovative maintenance concepts (microempresas)

TC D4.1 enquiry **answer of member country:** **Chile**

description of existing climate

<u>temperatures</u>

regional average maximum	20	°C
regional average minimum	8	°C

<u>precipitation</u>

regional average maximum	2000	mm
regional average minimum	10	mm

<u>current observations regarded to climate change</u>

summer 2016-17 was the second hottest summer ever recorded
increase of extreme precipitation during periods of warm temperature
increase of droughts with a record of bush fires

impacts of climate change on infrastructure

<u>documented Appendix C impacts</u> see also: International Climate Change Adaption framework for Road infrastructure

Fire risk
Damage to roads, underground tunnels and drainage systems due to floods
Collapse of slopes
Instability of slopes led to landslides of earth, rock falls, etc.
Inaccessible roads permanently or temporarily

<u>realised projects with design adapted to climate change (please **attach tender documents**)</u>

research project for an adaption of hydraulic designs
still no changes due to climate change in practice

TC D4.1 enquiry **answer of member country:** Heilongjiang, China

description of existing climate

temperatures

regional average maximum	4	°C
regional average minimum	-6	°C

precipitation

regional average maximum	700	mm
regional average minimum	400	mm

current observations regarded to climate change

reported thawing of permafrost

impacts of climate change on infrastructure

documented Appendix C impacts see also: International Climate Change Adaption framework for Road infrastructure

changes in road subsidence due to thawing of permafrost

realised projects with design adapted to climate change (please attach **tender documents**)

using bridges or excavate
permafrost
(both options are not economically affordable)

TC D4.1 enquiry **answer of member country:** France

description of existing climate

Depending of the region,

temperatures

regional average maximum		°C
regional average minimum		°C

precipitation

regional average maximum		mm
regional average minimum		mm

current observations regarded to climate change

- global average temperatures increase, extreme hot temperature increase in intensity and duration number of frost day decrease ,...

- Precipitations → decrease during spring and summer, snowfall decrease, increase in drought periods, extreme precipitation increase in frequency and decrease in intensity ,...

- Ground and surface water: surface water flow increase during winter and decrease during summer, annual groundwater level decrease

-Wind conditions models are still uncertain, but extreme winds are expected to be more frequent or intense

- Sea level and swell conditions: pessimistic sea level increase of one meter (pessimistic projection) however sea level at local scale is uncertain; swell models are uncertain

- Biodiversity: birds corridors changes are expected

impacts of climate change on infrastructure

documented Appendix C impacts — see also: International Climate Change Adaption framework for Road infrastructure

Fire risk
Floods and overloading of drainage system
Landslides, rock falls

realised projects with design adapted to climate change (please attach **tender documents**)

Plan National d'adaptation au changement climatique, volet infrastructures et systems de transport, actions 1 et 3

Action 1: potential impacts of climate change on transport infrastructures and systems, on their design, maintenance and exploitation baselines and the needs for precision of climate projections

Action3: Extreme climate events risk analysis on infrastructure, systems and transport services - Concept Compendium

TC D4.1 enquiry **answer of member country:** **Germany**

description of existing climate

temperatures

regional average maximum	11,4	°C
regional average minimum	7,2	°C

precipitation

regional average maximum	1200	mm
regional average minimum	400	mm

current observations regarded to climate change

rise in average annual temperature
all-time record temperatures

impacts of climate change on infrastructure

documented Appendix C impacts see also: International Climate Change Adaption framework for Road infrastructure

heat damage such a melting or cracking of the surface
damages to roads and subterranean tunnels due to flooding
overloading of drainage system
reduced need for snow clearing

realised projects with design adapted to climate change (please attach **tender documents**)

no impact on design manuals yet

TC D4.1 enquiry **answer of member country:** **Italy**

description of existing climate

temperatures

regional average maximum	16	°C
regional average minimum	12	°C

precipitation

regional average maximum	1200	mm
regional average minimum	500	mm

current observations regarded to climate change

-

impacts of climate change on infrastructure

documented Appendix C impacts see also: International Climate Change Adaption framework for Road infrastructure

Fire risk
Damage to roads, subterranean tunnels and drainage systems due to flooding
Increase in scouring of roads, bridges and support structures
Increased slope stability and
landslides
Overloading of drainage systems

realised projects with design adapted to climate change (please attach **tender documents**)

Replacing culverts by bridges due to an increase in extreme precipitation
use of Irish crossings

TC D4.1 enquiry **answer of member country:** **Sweden**

description of existing climate

temperatures	summer		winter	
regional average maximum	15-17	°C	0	°C
regional average minimum	10	°C	-13	°C

precipitation		
regional average maximum		mm
regional average minimum		mm

current observations regarded to climate change

-

impacts of climate change on infrastructure

documented Appendix C impacts see also: International Climate Change Adaption framework for Road infrastructure

Impacts associated with changing temperatures
Impacts associated with prolonged and/or heavy precipitation and storms
Impacts associated with sea level rise and heightened storm surge
Impacts associated with changes to snowfall, permafrost and ice coverage
Other potential impacts

realised projects with design adapted to climate change (please attach **tender documents**)

railway projects at the Swedish west coast are currently carried out with an adaption to rising sea levels. The infrastructure at coasts will be lifted up.

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