World Bank

Making Transport Climate Resilient

Country Report: Ghana

December 2010
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0 Executive summary

This report is the output of the World Bank-financed study on Making Transport Climate Resilient for Ghana, which is a Sub-Saharan Africa initiative to respond to the impact of climate changes on road transport.

The climate scenarios
The study is based on four specific climate scenarios selected by the World Bank to be consistent with the scenarios used in the study "Economics of Adaptation to Climate Change". The scenarios span from a "global dry" future with higher temperatures than today, but with the same rain patterns, to a "wet Ghana" future with more intensive rain than today so that a 10-year storm in 2050 will be up till 35% more intensive than today. The foreseen increases in average temperatures in all scenarios range from 1°C to 2°C by 2050.

The design and maintenance of roads
The largest problems facing the current Ghanaian road network seem to be overloading and missing maintenance and repair. The most influential climate impact on roads will in the future come from changes in rain patterns and only to a small extent from increased temperatures.

A climate-resilient road in the future in Ghana will be very similar to a climate-resilient road today. Ghana has the knowledge and materials needed to design and keep their roads up to standard. The key element to ensuring climate resilience after the initial construction is sufficient maintenance. Without routine maintenance, there is no possibility for a road to meet its design life in today's climate, let alone the future climate. The climate changes predicted do not suggest that the problems in the future cannot be accommodated with today's engineering solutions in Ghana.

The existing design manuals for roads and structures provide a solid base for assuring the best possible road and structures construction in the future. They are systematically being updated to reflect current engineering practices that are relevant in Ghana. The engineering solutions needed to make a climate-resilient road can to a very large extent be found in these manuals, from solutions to hydraulic-related problems such as scour and sedimentation to problem soils and sub-grade problems as well as slope stability and surface drainage solutions. Updates of rainfall and hydrology charts are, however, strongly recommended.
The adaptation measures
The measures to deal with the predicted change in precipitation volumes and patterns will primarily be:

Design:
• Revise parameters used for design storms for drainage systems and structures every 5 to 10 years
• Investigate the need for river training and increased channel maintenance and bridge scour protection
• Design culverts that cause limited damage to roads during floods
• Investigate the use of spot improvements in high-risk areas
• Design gravel roads and community roads with a variety of materials suitable for the climate and topography
• New alignments need to consider likely future changes in the environment taking into account increases in rainfall, groundwater, etc.

Maintenance:
• Continue to expand the database for road maintenance
• Prioritize maintenance and drainage upgrades in areas that are most at risk of flooding and more intensive rain
• Increase the frequency of drainage maintenance that is discussed in the manuals in relationship to the increased frequency of large storms
• Repair and clean channel and drainage structures in high-risk areas before the rainy season
• Allocate more funds for the maintenance of current roads.

Research:
• Encourage further research into more initially robust scour prevention compared to long-term maintenance savings
• Continue improving models for prediction of floods based on the newest available climate data
• Expand methods for slope stabilization and protection
• Append the design manuals with more low-cost engineering solutions for community roads
• Add a chapter to the design manuals focusing on the climate impacts on roads and engineering solutions
• Increase research into the correlation of development in floodplains and flooding in urban areas.

The economic assessment
The costs of adaptation to climate changes in the period 2010 - 2050 are roughly estimated at up till around 1.1 billion USD in 2009 net present value - of which increased maintenance costs are far more important than the costs of changed designs.
The costs to road users due to climate-related incidents may be substantial even with today's climate and are expected to increase up till 30% in year 2050 if measures are not taken. Adapting to climate changes by eliminating the increase in road user costs completely is likely to be a feasible strategy for some new road infrastructures - especially culverts and riverbank protection. For other structures, the specific conditions decide if it is economic feasible to fully adapt to the climate change.

For the existing network, an adaptation strategy is expected to be preferable where adaptation takes place because the life time of the infrastructure is exceeded or in cases where the infrastructure is destroyed by climate- (or other) related incidents. Therefore adaptation should take place gradually over time starting from today, and the timing will follow normal plans for reconstruction of worn out or destroyed roads, so the roads assets over a long period can be adapted to the future climate.

**The policy implications**

The road owners will experience increased costs to maintain the current service levels for both existing and new infrastructure.

Yearly reconstruction costs for existing roads will increase because of a higher risk of damage each year in combination with higher unit reconstruction costs.

New climate-resilient roads are more costly to build so investments budgets have to be increased or the number of new roads to be constructed will have to be reduced.

Design parameters are recommended to be reviewed every 5 to 10 years to continuously search for the optimal balance between climate risks and adaptation costs in the country.

The key element to ensuring climate resilience after the initial construction is sufficient maintenance. Strengthened focus on road maintenance and significantly more spending will be a vital cost-effective adaptation measure. This will also benefit the road users dramatically, but it requires a big change in the current spending patterns in the road sector.

The general implication is that only in exceptional cases it will be economically beneficial to reconstruct or strengthen existing roads and structures before they are damaged/normal life time has expired.

**The proposed strategy**

In the short term (within the next 5 years), the following initiatives are recommended:

- Research is needed in the accuracy of the design parameters in predicting sedimentation and runoff in the varied Ghanaian landscape.
- Based on this research, the design storm parameters for new roads and structures are recommended to be reconsidered to reflect that climate...
change will have an impact in Ghana - after due consideration of an acceptable future safety level versus the uncertain climate risks.

- The design manuals are recommended to be revised so that they clearly present climate-related issues and solutions, e.g. in an additional chapter. Having a chapter dedicated to the climate and environmental impacts on roads would make it easier for the designer to choose quickly and efficiently.

- As the maintenance need will increase according to the expected more frequent heavy rainfall, it is recommended to investigate if it is feasible to change and/or enlarge the drainage system in specific areas prone to erosion and flooding to reduce the risk of total failure and consequential damage and to decrease the climate change-related need for increased maintenance.

In the long term, the following initiatives are recommended:

- Establishment of a process to review climate-related parts of the design guidelines at regular intervals (every 5 or 10 years) to take account of the most updated information on observed climate change impacts and the need to balance climate risks and economic feasibility.

- Establishment of more focused maintenance strategies.

- Further improvement of the hydrology models - this is essential, as it is a common problem that this is lacking.

**Mitigation challenges and measures**

The contribution from the transport sector to climate change in the form of CO₂ emissions comes basically from a combination of:

- Overall demand for transport and mobility, which again depends on economic and spatial development as well taxation regimes for vehicles and fuels

- Supply of transport options available, road transport is the overall dominating motorized mode of transport in most African countries

- Efficiency of transport means available and their utilization and specific energy use.

The general mitigation initiatives in Ghana include:

- Preparation of strategic climate and environmental plans

- Provision of improved bus service – e.g. in form of rapid bus systems on dedicated lanes for commuter traffic to/from Accra

- Taxation of vehicles based on energy use and emission levels according to periodic measurements- with a focus on ensuring necessary enforcement options.
These measures can contribute to offering more environment-friendly motorized transport options and creating incentives to make individual transport use more efficient in a short to medium term.

Other mitigation measures in the long run are recommended to include a stronger focus on:

- Managing spacial/urban planning to create more coherence between habitation areas and the transport system, especially public transport, which can reduce the increase in demand for road transport

- Creating better conditions for non-motorized transport such as bicycles.

Although a country like Ghana needs to increase mobility as a precondition for economic growth measures can be taken to reduce the increase in CO₂ emissions per transported unit without hampering the economic development. More energy efficient transport solutions and vehicles will often also be less costly due to saved energy/fuel costs.
1 Introduction and background

1.1 Introduction

1.1.1 Aim

The World Bank has contracted a study on "making transport climate resilient" as a Sub Saharan Africa initiative to respond to the impact of climate changes on road transport.

The objective of the study is to:

- Establish a knowledge base on the extent and nature of technical and economic challenges that the road sector is facing due to climate change, climate variability and extreme weather events
- Undertake analytical work to deliver guidelines for road transport policy decision-makers on options to protect Africa's transport infrastructure and services
- Contribute to the process of creating awareness on climate risks and how Africa's transport could adapt to climate change.

The work is based on desk research and information on the situation in three case countries selected by the World Bank, namely Ethiopia, Ghana and Mozambique.

This report covers the findings for Ghana based on desk research and data and information collected during a mission in Ghana in August 2010 where a good and fruitful dialogue with key national stakeholders was initiated.

The consultant COWI A/S (Denmark) has been contracted to conduct the study.

1.1.2 Approach

The approach has been:

i. Establishing a consolidated presentation of currently modeled climate change scenarios for year 2050 with emphasis on parameters of particular importance for road transport.

ii. Quantifying the impacts of climate change on road assets and road transport services based on data on existing road infrastructure classified according to standard/quality and climate impact risk.
iii. Developing and preliminary costing adaption measures and presenting needs for changes in the road sector.

Good and robust design practices for transport infrastructure have always depended on sound knowledge of all background conditions including the climatic and hydrological conditions at the actual location for the infrastructure. This ensures that decisions on types of design and specific location can be based on good and transparent understanding of the chosen safety and service level for the infrastructure. The safety level can then be considered together with construction and maintenance costs and the costs/benefits for the transport users and the society in general.

Road projects most often have to state what their environmental impact will be. But it is equally important to ask how the climate and environment can be expected to affect the infrastructure.

Road design and specific climate conditions should always be closely linked. The challenge in many countries, including Ghana, is that climate change will result in a deviation from the observed historical climate conditions and therefore potentially lead to new requirements for design standards if the same levels of service and safety of today shall be maintained for the future.

1.1.3 Outputs

The main outputs and recommendations from the study are summarized in this chapter trying to answer the following main questions:

- What are the current predictions for the future climate and how certain are the changes?
- What are the most important challenges in relation to climate change for road assets and what measures can be taken?
- What are the additional costs for making roads climate resilient?
- What are the most important costs to transport users if road designs are not adapted to climate change?
- What are the recommended measures in a short and long-term perspective?

1.2 Summary of conclusions

1.2.1 Climate change scenarios and predictions

The observed trends in climate change in Ghana so far show:

- Increased average temperatures
- Increased number of hot days and nights
- No trend in precipitation falling in heavy events
- No significant long-term trend in average annual rainfall per month although there is seen a small decrease since a very wet period around 1960.
The specific analyses in this study are based on four climate scenarios for 2050 - chosen by the World Bank and consistent with the scenarios used in the Economics of Adaptation to Climate Change (EACC) project- which illustrate the spread in climate predictions for the country representing the driest and wettest expectations from the available set of all Global Circulation Models and SRES emissions scenarios:

<table>
<thead>
<tr>
<th>No.</th>
<th>Scenario name</th>
<th>GCM climate model applied</th>
<th>IPPC emission scenario</th>
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<tr>
<td>1</td>
<td>&quot;Global Wet&quot;</td>
<td>NCAR-CCSM3.0</td>
<td>SRES A2</td>
</tr>
<tr>
<td>2</td>
<td>&quot;Global Dry&quot;</td>
<td>CSIRO-MK3.0</td>
<td>SRES A2</td>
</tr>
<tr>
<td>3</td>
<td>&quot;Ghana Wet&quot;</td>
<td>NCAR-PCMI/ BCCR-BCM2.0,</td>
<td>SRES A1b/ SRES A2</td>
</tr>
<tr>
<td>4</td>
<td>&quot;Ghana Dry&quot;</td>
<td>IPSL-CM4</td>
<td>SRES B1</td>
</tr>
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</table>

All scenarios result in higher temperatures than today. The "Global Dry" scenario results in significantly more annual (but not more intensive) precipitation. The two "wet scenarios" result only in marginally more annual precipitation, but with higher intensity.

The main findings from the 4 specific Ghana scenarios can be summarized as follows:

- The mean temperature increase will range from 1 °C to 2 °C. The impact is higher asphalt temperature, dust, and increased evaporation.
- The annual rainfall increase will range from - 2% till 18%, most in the south and less in the north. The impacts of more rain are increased runoff, increased river flow, increased soil moisture, and an increased level of groundwater.
- Heavy rain will be more frequent and the design storms for roads etc. will increase with an estimated -1% to 36% in intensity for a 10-year storm and with 0% - 39% for a 100-year storm. The impact is increased frequency of flash floods, erosion, sediment and landslide and a large need for more drainage.
The results of the climate models clearly demonstrate that future rain patterns are complicated to predict and that much still has to be learned to understand what will happen with a higher degree of certainty, which can lead to more substantiated risk assessments when designing infrastructure. However, the climate scenarios demonstrate that Ghana with high likelihood will experience more frequent high intensity rainfall and raising sea levels. If solid adaptation strategies are not implemented the costs of materialized risks can be very high.

The study has - building on the results of the 4 specific climate scenarios - produced a first estimate of new design curves for roads, which are used to estimate the need for enlargement of drainage facilities for roads and for estimates of the increase in precipitation and the frequency of critical storms that exceed the old design level for the existing structures. From a design point of view the two "wet" scenarios result in almost identical requirements to changes in design parameters, whereas the two "dry scenarios" result in requirements as for the climate today.

1.2.2 The current road network
Ghana had in 2008 an estimated classified road network of approximately 66,000 km of which around 13,000 km are paved. 81% of the paved roads and 65% of the unpaved roads are recorded to be in fair or good condition. According to Ghana Highway Authority (GHA) 95% of the 350 bridges for which the condition is known are reported to be in fair to good condition.

All elements of design for all types of roads and structures (paved trunk roads, gravel, community roads) are included in the Ghana pavement design and bridge design manuals, but the rainfall and hydrology charts are from 1991 and may need updating.

The type of road in Ghana varies extremely from a limited number of four-lane high-speed highways to low volume community roads. The success of these roads relies on similar factors:

- The choice of location (alignment), design and construction
- The climate and topography that the road passes through
- The traffic loading; and
- The maintenance.

Many of the current problems that are seen in Ghana are not climate-related, but are amplified by the climate. For example, overloading of heavy trucks will have damaging effects on a road regardless of climate; the damage is amplified when the soils and materials beneath are overly saturated. The same can be said about routine maintenance. Maintenance is a requirement on all roads, and without it roads will deteriorate quicker than their design life.

1.2.3 Climate change impacts on roads
The largest problems facing the current Ghanaian road network seem to be overloading and missing maintenance and repair. The most influential climate
impacts on roads will in the future come from changes in rain patterns and to a smaller extent increased temperatures.

**Change in precipitation volumes and patterns - structures**

One of the main threats to bridges from an increase in precipitation is the increase in peak flow and floods and associated scour and bank erosion. The preferred method to deal with scour would be to account for it correctly in the design phase and implement sufficient countermeasures to handle the expected scour.

The success of a bridge is dependent on its hydraulic capacity, the stability of the channel and its interaction with the bridge substructure.

There is already today a need to invest more into scour protection during initial construction. Maintenance needs to be increased in not only the protection of the substructure from scour, but also by ensuring the hydraulic capacity of the channel by removal of sediment and debris. If maintenance cannot be assured, then it is recommended to invest in more permanent bank and scour protection, or design bridges with larger capacity to handle the sedimentation.

Reinforced concrete pipe culverts are not designed to have capacity for large scale floods greater than 25-50-year return interval, but they should be designed so that the road they are covered by is not washed out during large floods. Culvert sizes should be increased in areas where the potential for damage is greatest, such as in areas with large fills. Maintenance needs to be increased for all culverts in high-risk areas.

**Change in precipitation volumes and patterns - roads**

The design requirements for the new paved trunk roads are on a high level. The problems seen today in the trunk roads are the result of a combination of different factors such as lack of maintenance, poor drainage, and design that cannot accommodate the overloaded traffic. More effort needs to be spent on drainage of the road section. Maintenance becomes even more critical with increased or more intensive rain.

The stability of slopes will be adversely affected by an increase in precipitation. The investment spent on preventing landslides is normally only cost beneficial if it is a vital link. It is better to invest in slope protection measures and use best practices during construction for the lower class roads. Landslides are a natural occurrence and the road design needs to have the least amount of impact to the surrounding environment to lessen its chances of failure. Road location becomes more important with increased flooding, and the suitability of building roads in river valleys needs to be investigated. Slope re-vegetation could be required on all impacted slopes.

Drainage systems should be upgraded in areas that have historically experienced flooding. Investigations should be done to find if it is cost beneficial to upgrade the drainage systems in these areas before a drainage failure occurs, or afterwards during repair or reconstruction.
Sea level rise, storm surge and cyclones
The main effects are that the infrastructure in low coastal areas is exposed to greater risk of being damaged, if protecting measures are not taken, but the situation in the next half decade is not predicted to be that different from today and impacts are of a local nature. Although areas at risk can be found along most of the coast line, the largest risks are found in the eastern part of the coast. Roads are only a minor part of the infrastructure at risk and cannot be considered or protected in isolation, and the costs of climate change measures such as constructing seawalls for the cities cannot meaningfully be considered road costs.

Temperature increases
The main effects from changes in temperatures will be for bridges and bituminous pavements.

Bridges are already designed with temperature gradients in mind. The change in temperature in Ghana over the next 50 years is not expected to require a change in the methodology of designing bridges, but the design temperature should be higher. The increase in maintenance required will not be substantially higher than what it should be already.

Temperature has an affect on the stiffness of asphalt. A poor asphalt mix will have a greater chance of cracking and other deformations if the temperature gradients are not accounted for correctly in the design. The expected life of a newly constructed road is estimated to be about 10 to 15 years for the upper most asphalt layers. Adjustments in pavement design with respect to binder selection can be made at regular service / reconstruction intervals. Designing for different temperature gradients in the future is not considered to have an effect on the cost of resurfacing when this is done within the normal time cycle, as asphalt cost is almost the same for the different types of penetration grade asphalt.

Maintenance needs
Maintenance to the drainage network becomes all the more important with increases in the number of high intensity storms. Routine maintenance, before, during and after the rainy season and after the more frequent very heavy events will help to alleviate total failures requiring replacement. Investments in drainage systems will be quickly lost if they are left to deteriorate or are filled up with sediment.

The maintenance need will increase according to the more frequent heavy rainfall causing a larger and more frequent flow in the system and more sediment from erosion of the surrounding areas or the roadside drain itself. It should be investigated if it is feasible to change and/or enlarge the drainage system in specific areas prone to erosion and flooding to reduce the risk of total failure and consequential damage and for reduction of the climate change-related need for increased maintenance.
1.2.4 Design guidelines

Existing guidelines generally
The predicted climate change in heavy rainfalls seems to follow almost the same pattern in the regions. The big difference in the predicted change is in the average monthly precipitation. The predictions indicate that the southern parts of the country are getting wetter and the northern parts are probably getting drier, but the design storms are predicted to increase in frequency and intensity in all areas.

The existing manuals are good foundations for ensuring the best possible road and structures construction in the future, provided that the rainfall and hydrology charts are updated. The majority of the manuals are taken from other well established manuals such as the AASHTO design recommendations.

The engineering solutions needed to make a climate-resilient road can to a very large extent be found in these manuals from solutions to hydraulic-related problems such as scour and sedimentation to problem soils and sub grade problems as well as slope stability and surface drainage solutions.

Research is needed in the accuracy of the design parameters to predict sedimentation and runoff in the varied Ghanaian landscape. The design storm parameters are recommended to be adjusted to reflect the anticipated more intensive rainfall in the future. A first preliminary estimate of the need for changes in the design parameters is made in the report, but more work is recommended.

Specific recommendations to the manuals
It is suggested to organize the manuals so that the climate-related issues and solutions are presented clearly in an additional chapter. A chapter could be added to the manuals focusing on environmental conditions, similar to what Tanzania Ministry of Works has done with their Pavement and Materials Design Manual. Having a chapter dedicated to the climate and environmental impacts on the roads would make it easier for the designer to choose quickly and efficiently.

The recommendations listed in this report cover guidelines for climate and environmental considerations that should be started immediately in relation to the very first planning considerations and in the later design, maintenance and research.

1.3 Engineering costs of climate change
It is not expected that climate changes in the near future will require large changes to the methodology or economics of classified roads in Ghana. The standards that they are designed for now and should be built at are at a high level.

For new construction, rehabilitation or upgrading the major cost items for roads are shown below together with (for illustrative purposes) the distribution of costs for an asphalt-paved DBST standard road with an average cost of around 773,000 USD per km (2010 costs based on GHA data) including structures. In
addition, an estimate of typical additional construction costs has been made if a new road was to be constructed so it is fully adapted to the predicted climate changes in the applied scenarios in year 2050 compared to the current design standards.

Table 1.1  Road construction cost distribution today and the estimated increase in costs if the roads should be designed to the predicted climate in 2050

<table>
<thead>
<tr>
<th>Description</th>
<th>Percentage of total costs today</th>
<th>Percentage costs increase Global &amp; Ghana Wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>5.7%</td>
<td>0%</td>
</tr>
<tr>
<td>Site Clearance</td>
<td>0.4%</td>
<td>0%</td>
</tr>
<tr>
<td>Drainage</td>
<td>6.6%</td>
<td>10-15%</td>
</tr>
<tr>
<td>Earthworks</td>
<td>12.3%</td>
<td>5-10%</td>
</tr>
<tr>
<td>Sub base, Road Base and Gravel Wearing Course Bituminous Surfacing and Road Bases</td>
<td>45.1%</td>
<td>5%</td>
</tr>
<tr>
<td>Structures</td>
<td>8.2%</td>
<td>5-20%</td>
</tr>
<tr>
<td>Ancillary Works</td>
<td>3.3%</td>
<td>5%</td>
</tr>
<tr>
<td>Day works</td>
<td>0.4%</td>
<td>2%</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>82.0%</strong></td>
<td></td>
</tr>
<tr>
<td>Contingencies + Other Fees</td>
<td>13.9%</td>
<td>0%</td>
</tr>
<tr>
<td>Supervision</td>
<td>4.1%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0%</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Cost Increase Percentage</strong></td>
<td></td>
<td><strong>5.0% - 7.6%</strong></td>
</tr>
</tbody>
</table>

Source: consultant

The largest cost elements of a typical km asphalt road today are by far the earth works and the road base and surfacing. The main cost items which are likely to increase in order to make a typical Ghanaian road adapted to predicted climate change are earth works, the road base, surfacing and the structures, but in the end the actual costs will depend heavily on the specific local conditions. A best estimate is that costs in average will increase between 5% and 8% for a new or newly reconstructed road due to climate change for the same risk profile between now and 2050.

High standard gravel roads are expected to require cost increases in the same areas as paved roads, plus the additional cost of sealing in areas with high gradients and high rainfall. The cost of a new climate-resilient gravel road is expected to increase roughly between 15% and 30%, mostly due to increases in sealing roads.
The costs of making urban roads cannot be judged independently from the general situation for cities and towns. The adequacy of the drainage and sewerage systems is the key determinant for the success of roads in urban areas.

1.4 Economic costs and benefits of adaption

The frequency of disruptions of roads must be expected to increase if adaption measures to climate change are not taken. Although observed information on typical frequencies of disruption and number of people affected cannot be obtained, an attempt has been made to assess the potential costs using standardized, but realistic assumptions about frequency of disruption, number of people affected, waiting times and likely detours.

The costs of climate changes in the period 2010 - 2050 are roughly estimated at around 0 - 1.1 billion USD in 2009 net present value - of which increased maintenance costs are by far more important than the costs of changed designs. Other conclusions are:

- The cost to road users due to climate-related incidents may be substantial even with today's climate and is expected to increase with as much as 30% in year 2050.

- Adapting to climate changes by eliminating the increase in road user costs completely (full adaption) is likely to be a feasible strategy for some new road infrastructures - especially culverts and riverbank protection. For structures the specific conditions decide if it is economically feasible to adapt fully to the climate change. The situation for roadside drainage has to be assessed together with the expected maintenance strategy.

- For the existing network, an adaptation strategy where adaptation takes place as the life time of the infrastructure is exceeded or the infrastructure is destroyed by climate- (or other) related incidents is expected to be preferable.

- For the existing road network the climate changes will incur costs to both road users and the road agency. The major cost item is expected to be increased maintenance in order to keep the roads up to design standards.

1.5 The strategy forward for climate change adaption in the road sector

A future strategy needs to be flexible, adaptive and robust - and acknowledge that the current scenarios and climate models show a large variability in predicted rainfall patterns, which are the most important design criteria for roads and structures.

Taking the mean of the climate scenarios/climate models used in this study as the most likely future development, the long-term increase in engineering costs
due to climate change may be important, but not excessive if dealt with proactively in the regular planning and design processes.

A climate-resilient road in the future in Ghana will be very similar to a climate-resilient road right now. Ghana has the knowledge and materials needed to design and keep their roads up to standard. A key element to ensuring climate resilience after the initial construction is sufficient maintenance.

In the short term (next 5 years), the following initiatives are recommended:

- Research is needed in the accuracy of the design parameters in predicting sedimentation and runoff.
- Based on this research the design storm parameters for new roads and structures are recommended to be adjusted to reflect significant climate changes - after due consideration to an acceptable future safety level.
- The design manuals are recommended to be revised so that they clearly present climate-related issues and solutions e.g. in an additional chapter. Having a chapter dedicated to the climate and environmental impacts on the roads would make it easier for the designer to choose quickly and efficiently.
- As the maintenance need will increase according to the expected more frequent heavy rainfall, it is recommended to investigate if it is feasible to change and/or enlarge the drainage system in specific areas prone to erosion and flooding to reduce the risk of total failure and consequential damage and for reduction of the climate change-related need for increased maintenance.

In the long term the following initiatives are recommended:

- Establishment of a process to review climate-related parts of the design guidelines at regular intervals (5 or 10 years) to take account of most updated information on observed climate change impacts and the need to balance climate risks and economic feasibility.
- Establishment of more focused maintenance strategies.
- Development of reliable and accurate hydrology models, as it is a common problem that this is lacking.
2 Climate risk scenarios for Ghana

2.1 Climate characteristics for Ghana

The overall characteristics for Ghana are illustrated in Figure 2.1.

Figure 2.1 Topographical map of Ghana
Ghana is located in West Africa on the Guinea Coast. At latitudes of 4-12°N, the climate of Ghana is tropical, and strongly influenced by the West African Monsoon.

The rainfall seasons of Ghana are controlled by the movement of the tropical rain belt (also known as the Inter-Tropical Conversion Zone, ITCZ), which oscillates between the northern and southern tropics over the course of a year.

The dominant wind direction in regions south of the ITCZ is southwesterly, blowing moist air from the Atlantic onto the continent, but north of the ITCZ the prevailing winds come from the north east, bringing hot and dusty air from the Sahara desert (known as the ‘Harmattan’). As the ITCZ migrates between its north and south positions over the course of the year, the regions between these northern and southermost positions of the ITCZ experience a shift between the two opposing prevailing wind directions. This pattern is referred to as the West African Monsoon.

In northern Ghana, there is a single wet season occurring between May and November, when the ITCZ is in its northern position and the prevailing wind is south-westerly, and a dry season between December and March when the ‘Harmattan’ wind blows north-easterly. The northern and central regions receive 150-250mm per month in the peak months of the wet season (July to September). The southern regions of Ghana have two wet seasons, one in March to July, and a shorter wet season in September to November, corresponding to the northern and southern passages of the ITCZ across the region.

The seasonal rainfall in this region varies considerably on inter-annual and inter-decadal timescales, due in part to variations in the movements and intensity of the ITCZ, and variations in timing and intensity of the West African Monsoon. The most well documented cause of these variations is the El Niño Southern Oscillation (ENSO). El Niño events are associated with drier than average conditions in West Africa.

Seasonal variations in temperature in Ghana are greatest in the north, with highest temperatures in the hot, dry season (AMJ) at 27-30°C, and lowest in JAS at 25-27°C. Further south, temperatures reach 25-27°C in the warmest season JFM, and 22-25°C at their lowest in JAS.

This means that long term trends are difficult to identify. Rainfall over Ghana was particularly high in the 1960s, and decreased to particularly low levels in the late 1970s and early 1980s, which causes an overall decreasing trend in the period 1960 to 2006, of an average 2.3 mm.

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1 The description of the climate in Ghana builds on the UNDP Climate Change Country Profile for Ghana.
2.1.1 Experienced droughts, floods, cyclones etc in Ghana

There has been experienced several floods in Ghana. Floods originate from both flooding rivers and storm surge from the sea.

In September 2007 there was serious flooding over the White Volta catchment in the northern part of Ghana and in June-July 2010 Tarkwa Municipality was hit by serious damages caused by heavy rainfall and flooded rivers. More bridges were washed away and isolated towns for longer periods. Floods from storm surge occur frequently in the lower White Volta area including Ada.

According to Dr. J.A. Yaro, University of Ghana, the flood plains of the Red and White Volta which flows through the Upper East Region through the Northern Region to the Volta Region was low lying. Due to the impacts of climate change, the flood plain which is clayey due to predominance of ground water laterites in addition to flat topography is vulnerable to flooding anytime there is a heavy downpour. This is more frequent now than it used to be in the past leading to poverty and out-migration in the communities along the river.

![Figure 2.2 A man leaves his flooded house in Ashiaman, in the Greater Accra region, 21 June, 2010](image)

Source: Photo AFP
Figure 2.3 Bridges, soil and houses washed away by flood in Swedru, Central Province, June 2010

Source: Consultant

A study is on-going in the three northern regions for mapping the experienced floods and the flood prone areas. The objective is to raise awareness on climate change and variability, and establish information in the three Northern Regions.

Figure 2.4 Flooding in Lower White Volta Sub-Basin. Experienced in 1999, 2007 and 2008 and the calculated potential flood prone areas

Source: Water Resources Commission 2010
Figure 2.5 Coastal zone of Ghana, defined as land below 30 m. The green line is the 15 m contour line.

Source: Water Resources Commission 2010

2.1.2 Trends in climate change so far
The trend in climate change so far shows:

- slightly increased annual mean temperature (about 0.21°C every ten years),
- significant increased in number of hot days and nights (13% every ten years)
- no real long term trend in mean annual rainfall per month but a decrease of 2.5% every ten years since the very wet period around 1960
- there are no trend in precipitation falling in heavy events
- there are no trend in frequency of tropical cyclones and storm surge.

In the UNDP Climate Change Country Profile for Ghana the recent climate trends (1960-2006) are described briefly as:

Temperature:

- **Mean annual temperature** has increased by 1.0°C since 1960, an average rate of 0.21°C per decade. The rate of increase has been most rapid in AMJ, a around 0.27°C per decade.
- The rate of increase has generally been more rapid in the northern regions of the country than in the south.
- **Daily temperature** data indicate that the frequency of ‘hot’ days has increased significantly in all seasons except DJF, and the frequency of ‘hot’ Nights has increased significantly in all seasons. ‘Hot’ day or ‘hot’ night is defined by the temperature exceeded on 10% of days or nights in current climate of that region and season.
The average number of ‘hot’ days per year in Ghana has increased by 48 (an additional 13.2% of days) between 1960 and 2003. The rate of increase is seen most strongly in SON when the average number of hot SON days has increased by 7.2 days per month (an additional 23.3% of SON days) over this period.

- The average number of ‘hot’ nights per year increased by 73 (an additional 20% of nights) between 1960 and 2003. The rate of increase is seen most strongly in SON when the average number of hot SON nights has increased by 8.9 days per month (an additional 28.8% of SON nights) over this period.

- The frequency of cold days and nights has decreased significantly since 1960 in some seasons. ‘Cold’ days or ‘cold’ nights are defined as the temperature below which 10% of days or nights are recorded in current climate of that region or season.

- The average number of ‘cold’ days per year has decreased by 12 (3.3% of days) between 1960 and 2003. This rate of decrease is most rapid in summer (JJA) when the average number of cold summer days has decreased by 2.1 days per month (6.8% of summer days) over this period.

- The average number of ‘cold’ nights per year has decreased by 18.5 (5.1% of days). This rate of decrease is most rapid in SON when the average number of cold SON nights has decreased by 2.8 nights per month (9% of SON nights) over this period.

Precipitation:

- Annual rainfall in Ghana is highly variable on inter-annual and inter-decadal timescales. This means that long term trends are difficult to identify. Rainfall over Ghana was particularly high in the 1960s, and decreased to particularly low levels in the late 1970s and early 1980s, which causes an overall decreasing trend in the period 1960 to 2006, of an average 2.3mm per month (2.4%) per decade.

- There is no evidence of a trend in the proportion of rainfall that falls in ‘heavy’ events since 1960. A ‘Heavy’ event is defined as a daily rainfall total which exceeds the threshold that is exceeded on 5% of rainy days in current climate of that region and season.

- Observed 1- and 5-day rainfall maxima do not indicate consistent trends.

2.2 Emission scenarios and climate models

2.2.1 SRES emissions scenario by IPCC

IPCC has given four main emission scenarios and more sub-scenarios in the IPCC Special Report on Emissions Scenarios, 2000 (SRES).
The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines.

For Ghana the long-term temperature changes caused by SRES A2 scenario seems to be slightly larger than caused by SRES A1B scenario, which has been used for some studies in the region. The climate changes in the next 40-50 years until 2050-60 seems to be of the same magnitude for SRES A2, A1B and B1 scenarios as presented in Figure 2.6. The change in temperature is lowest in the "optimistic" SRES B1 scenario.

This study covers the period up to year 2040-2060. In this period the climate changes are limited and of the same magnitude for the individual SRES scenarios, while change in temperature seems to accelerate in the period from 2040 to 2100. The average monthly precipitation does not change during the period up to 2100 in any of the SRES.

Figure 2.6 Comparison of climate consequences in Ghana caused by SRES A1B, SRES A2 scenario and SRES B1 scenario. (UNDP Climate Change Country Profile)

2.2.2 Climate models

IPCC used results from 22 climate models (GCM, General Circulation Model) for the fourth Assessment Report (AR4), published in 2007.

The grid size is around 200x200 km (2.5 x 2.5°). These models show different results and have different focus. Therefore it is common to use all or some of the GCMs to find the average consequences, by given individual weight on the
different results and parameters found in the chosen GCMs. It is not recommended to use only one GCM, but to use a weighted average.

In this study it is chosen to use the weighted climate change predictions found and reported by UNDP in the Climate Change Country Profile for Ghana for the general description of the expected climate change in Ghana. More detailed information on the estimated climate change consequences for the four selected climate scenarios for this study is given in Chapter 2.4.

The climate models used by UNDP are a sub-set of 15 from the 22-member ensemble used by IPCC in AR4. The models included are those which had the most complete availability across the different variables required. See the Documentation report for the UNDP Climate Change Country Profile for further details: http://country-profiles.geog.ox.ac.uk.

To illustrate the differences in results from different climate models and the uncertainties related to climate modeling there are given two examples related to Ghana. These illustrations should argue for a relaxed relationship to the accuracy in the results and forecasts based on different SRES and GCM.
Example 1:

Figure 2.7  UNDP illustration of maximum, weighted average and minimum for % change in monthly precipitation (annual average) in Ghana from the period around 1985 until the period around 2060. Results from 15 GCM, as 10 years average for each model. SRES A2 scenario

The models show in all cells big variations and there is no significant trend in any of the cells. In all cells there are models indicating decrease and models indicating almost the same increase in monthly precipitation. On average there seems to be a minor increase (3%) in monthly precipitation.
Example 2:

Figure 2.8 Predicted anomaly of mean monthly precipitation (mm) for the summer rainy season, JJA, using daily data downscaled from three GCMs. SRES A2 scenario and change from around 1990 to 2085. ref.: AR4, WG1 (chapter 11)

The predicted change in monthly precipitation up to 2070-2100 shown above illustrates that the differences are larger than seen for the shorter time horizon until 2050, which is used in this study. The forecasts show very clearly that there is difference in the predicted monthly precipitation in the northern part of Ghana between HadAM3 indicating -20 mm and ECHAM4.5 indicating -60 mm. All three models shows increased precipitation in JJA in the southern part of the country and decreased precipitation in that period in the northern part of the country.

2.3 Climate change characteristics

2.3.1 Climate change in general for Ghana

Following general comments on climate change in Ghana until 2060 are based on the information in the UNDP Climate Change Country Report for the SRES A2 scenario. For specific climate changes related to the four chosen climate scenarios for this study, see Chapter 2.4.

Temperature

- The mean annual temperature is projected to increase by 1.0 to 3.0°C by the 2060s.
- The projected rate of warming is most rapid in the northern inland regions of Ghana than in the coastal regions.
- All projections indicate substantial increases in the frequency of days and nights that are considered “hot” in current climate, but the range of projections between different models is large.
- Annually, projections indicate that ‘hot’ days will occur on 18-59% of days by the 2060s. Days considered ‘hot’ by current climate standards for their season may increase most rapidly in JAS, occurring on 34-99% of days of the season by the 2090s.

- Nights that are considered ‘hot’ for the annual climate of 1970-99 are projected to occur on 28-79% of nights by the 2060s. Nights that are considered hot for each season by 1970-99 standards are projected to increase most rapidly in JAS, occurring on 52-99% of nights in every season by the 2090s.

- Most projections indicate decreases in the frequency of days and nights that are considered ‘cold’ in current climate. ‘Cold’ days and nights occur on less than 3% of days by the 2090s.

- Although the projected mean temperature increases most rapidly in the interior regions of Ghana than near the coast, the projected changes in the daily temperature extremes (‘hot’ and ‘cold’ days and nights) in Ghana are largest in the coastal areas, and smaller inland.

Precipitation

- Projections of mean annual rainfall averaged over the country from different models in the ensemble project a wide range of changes in precipitation for Ghana, with around half the models projecting increases and half projecting decreases.

- Seasonally, the projections tend towards decreases in JFM and AMJ rainfall, and increases in JAS and OND rainfall.

- The proportion of total annual rainfall that falls in ‘heavy’ events tends towards increases in the ensemble projections. Seasonally, this varies between tendencies to decrease in JFM and increases in JAS and OND, but the range of changes projected by the ensemble includes both increases and decreases in all seasons.

- Projected changes in 1- and 5-day rainfall maxima tend towards increases, but projections range between both increases and decreases in all seasons.

Other regional climate change information

- Model simulations of precipitation changes for the Sahelian and Guinea coast regions of Africa are strongly divergent and most models fail to reproduce realistic inter-annual and inter-decadal rainfall variability in the Sahel in 20th century simulations. Our understanding of the processes causing tropical rainfall is insufficient to allow a prediction of the direction of change with any certainty. The IPCC identify this as an area requiring further research to understand the variety of model responses in this region (Christensen et al., 2007).
• Model simulations show wide disagreements in projected changes in the amplitude of future El Niño events. West African climate can be strongly influenced by ENSO, thus contributing to uncertainty in climate projections for this region.

• The coastal regions of Ghana may be vulnerable to sea-level rise. Sea-level in this region is projected by climate models to rise by the following levels by the 2090s, relative to 1980–1999 sea-level:
  
  - 0.13 to 0.43m under SRES B1
  - 0.16 to 0.53m under SRES A1B
  - 0.18 to 0.56m under SRES A2.


The Intergovernmental Panel on Climate Change (IPCC) issued its 2007 report summary on 2 February. It says that sea level has risen 150 mm in the past century and will increase by 300 mm or more by 2100. It also reports that "it is likely that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and heavier precipitation".

2.3.2 Climate change with most influence on roads and transportation in Ghana

The most relevant climate changes related to road and transportation in Ghana are:

• Temperature (and evaporation)
• Rain (intensity/frequency and volume)
• Sea level rise.

The coastline in Ghana is vulnerable for tropical cyclones and storm surge and erosion caused by the rising sea level. The coastal zone and the five large cities located in the coastal zone are all ready today vulnerable to extreme events above the current defense standards of structural protection. The increase in sea level is limited in the period up to 2050, and very little compared to the sea level during storm surge and heavy tropical cyclones. The change in frequency of tropical cyclones and storm surge is very uncertain and most of the infrastructure are prepared for these heavy events or located in safe distance from the coastal zone that is most exposed by the heavy events. Therefore the sea level rise is not the big concern in relation to roads alone. The higher general sea level will influence the slope available for the rivers and by that cause a higher water level in the lower part of the rivers especially during max flow.

Much of the coastline of Ghana is soft, comprising of muddy river sediments and sand, backed by land with low relief and extensive low-lying coastal plains. This is particularly true of the western provinces, which are characterized by the delta for Volta draining the continental interior, and prone to flooding on an
annual basis. The coastline has a series of estuaries and deltas, which shift in response to the frequent floods and deposits of large amounts of sediment. Coastal erosion is a problem along the dynamic coastline. The rate of erosion recorded ranges from 4-12 m/year. People, infrastructure and services in harbor cities such as Ada are in constant need of protection already today.

The numbers of cyclones are too small to draw any significant conclusions regarding trends.

Most of the adaptation measures for reduction of the tread from cyclones and sea level rise will be done for protection of cities and settled areas and not for the roads only. Because of this and the uncertainties and the expected limited change in cyclone events and storm surge/ sea level rise it is chosen not to concentrate on adaptation measures for roads related to the limited change in cyclones and storm surge.

Also the change in temperature is very little and will have a very limited influence on the road structures and the need for operation and maintenance.

The general key figures for the relevant changes in Ghana until 2050 can be summarized as (for the range in the specific four climate scenarios investigated in this study, see Chapter 2.4):

- The mean annual temperature increase will range from 1.0°C to 3.0°C and the number of annual "hot" days will increase from 11% to 18-59% of all days. The impact is change in asphalt temperature. Increase in temperature will cause dust and increased evaporation

- The annual rainfall is almost unchanged. Increase will range from -10% till 10%, most in south and less in north. The impacts of is increased rainfall are increased runoff, increased river flow, soil moisture, groundwater.

- Days with heavy rain will be almost unchanged (~4% to 10%) but the design storms for roads etc. will increase with an estimated 0 - 36% in intensity for a 10-year storm and with 0 - 39% for a 100 year storm. The impacts are increased frequency of flash floods, erosion, sediment and landslide.

The predicted change in temperature in the 4 study specific scenarios until 2050 is up till around 2°C as annual average, which is slightly less than predicted as an average of predictions in the UNDP Climate Change Country Report. An increased temperature influences the general temperature of the roads. Combined with the increase of "hot" days and nights the number of days with high and critical temperature for e.g. the asphalt will increase. Furthermore, higher temperatures will give more frequent occurrence of dust from gravel roads and increased evaporation of rain and moisture in the soil.

The consequences for roads are based on an estimate of the resulting change in basis discharge in the rivers in the most wet and critical months and the increase in moisture of the soil at slopes and beneath the roads.
There are no forecasts available on very short extreme rainfall. There are estimates of the mean average maximum rainfall in 1-day rainfall. The existing design storms used in the drainage design manuals in nearby countries are based on historical 24-hour rainfalls. These data are used to find design curves for shorter and more intensive storms.

In this study, the same calculation method, as used in the drainage design manuals in nearby countries, is used to establish new design curves for year 2050.

### 2.4 Climate change for scenarios in this study

The specific analyses in this study are based on 4 climate scenarios for Ghana representing the span in expected future climate situations from dry to wet according to results from different combinations of emission scenarios (SRES) and GCM models. The scenarios represent a consistent basis between this study and the study “Economics of Adaptation to Climate Change (EACC)".

All proposed measures and recommendations in the report aim to address the range in the future climate resulting from the 4 climate scenarios.

The climate scenarios chosen by the World Bank are:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>GCM-model</th>
<th>Emission scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Global Wet&quot;</td>
<td>NCAR-CCSM3.0</td>
<td>SRES A2</td>
</tr>
<tr>
<td>&quot;Global Dry&quot;</td>
<td>CSIRO-MK3.0</td>
<td>SRES A2</td>
</tr>
<tr>
<td>&quot;Ghana Wet&quot;</td>
<td>NCAR-PCM1</td>
<td>SRES A1B</td>
</tr>
<tr>
<td>&quot;Ghana Dry&quot;</td>
<td>IPSL-CM4</td>
<td>SRES B1</td>
</tr>
</tbody>
</table>

The true "Ghana wet" GCM-sres projection (ncar_pcm1 - A1b) does not produce daily weather data, needed for this study. Therefore the next wettest GCM-sres projection which has daily data available (bccr_bcm2_0 - A2) for Ghana was used instead.

For these four scenarios data and results have been processed by the University of Colorado\(^2\) especially for this study with focus on precipitation, temperature and run-off for the present climate situation and the future situation in the period around 2050 and around 2100. An introduction to the data base and data processing can be found in the appendix.

---

\(^2\) Processed data delivered by a team from Colorado University:
Len Wright, Ph.D., P.E., D.WRE
Anthony Powell
Chas Fant
Alyssa McCluskey, Ph.D.
Kenneth Strzepek, Ph.D., P.E.
There are no information on cyclones or rising sea level and storm surge available for the four specific chosen climate change scenarios.

2.4.1 Key figures for the climate scenarios

Some of the most essential figures for the received climate information are presented Figure 2.9 and Figure 2.10. The focus is on temperature and precipitation in heavy events.
Figure 2.9 Temperature. Annual daily max temperature.

Legend
Mean Annual Max Temperature (deg C) for Ghana

- 46
- 6 - 16
- 16 - 26
- 21 - 22
- 23 - 24
- 25 - 26
- 27 - 28
- 29 - 30
- 31 - 35
- 36

Historical, 1997-2006

"Global Wet": NCAR-CCSM, SRES A2

"Global Dry": CSIRO-MK3.0, SRES A2
"Ghana Wet": (BCCR-BCM2, SRES A2)

"Ghana Dry": IPSL-CM4, SRES B1
Figure 2.10 Precipitation. Annual 24 hours maximum rainfall (pr year)

Historical, 1997-2006

"Global Wet": NCAR-CCSM3.0, SRES A2

"Global Dry": CSIRO-MK3.0, SRES A2
All received climate data has been processed for the purpose of this study, and in the following datasheets the main climate data relevant for this study are summarized for the different climate scenarios:

### Table 2.1 Climate 2050 on average in Ghana, rain and temperature

<table>
<thead>
<tr>
<th>Precipitation:</th>
<th>Hist</th>
<th>GW-NCAR,A2</th>
<th>GD-CSIRO,A2</th>
<th>LW-IPSL,B1</th>
<th>LD-BCCR,A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Mean Rainfall</td>
<td>mm/y</td>
<td>1150</td>
<td>1159</td>
<td>1362</td>
<td>1177</td>
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<tr>
<td>Annual Mean 24 hrs Max. Rainfall</td>
<td>mm/24hrs</td>
<td>42</td>
<td>49</td>
<td>39</td>
<td>47</td>
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<tr>
<td>Annual Mean 5 days Max. Rainfall</td>
<td>mm/5d</td>
<td>85</td>
<td>91</td>
<td>78</td>
<td>92</td>
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<tr>
<td>Annual days with rainfall</td>
<td>days/y</td>
<td>181</td>
<td>178</td>
<td>178</td>
<td>178</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature:</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Mean</td>
<td>deg C</td>
<td>25,9</td>
<td>27,2</td>
<td>27,9</td>
<td>27,2</td>
</tr>
<tr>
<td>Annual Min.</td>
<td>deg C</td>
<td>22,3</td>
<td>23,5</td>
<td>23,9</td>
<td>23,4</td>
</tr>
<tr>
<td>Annual Max.</td>
<td>deg C</td>
<td>29,9</td>
<td>31,4</td>
<td>32,4</td>
<td>31,4</td>
</tr>
<tr>
<td>Annual days with heat waves</td>
<td>days/y</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Making Transport Climate Resilient - Ghana Country Report

Table 2.2  Climate 2000-2050 on average in Ghana

<table>
<thead>
<tr>
<th>Climate Change 2000-&gt;2050 on Average in Ghana</th>
<th>Hist</th>
<th>GW-NCAR,A2</th>
<th>GD-CSIRO,A2</th>
<th>LW-IPSL,B1</th>
<th>LD-BCCR,A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase from 2000 to 2050</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation:</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Annual Mean Rainfall</td>
<td>0</td>
<td>9</td>
<td>211</td>
<td>27</td>
<td>-24</td>
</tr>
<tr>
<td>Annual Mean 24 hrs Max. Rainfall</td>
<td>0</td>
<td>7</td>
<td>-3</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Annual Mean 5 days Max. Rainfall</td>
<td>0</td>
<td>5</td>
<td>-7</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Annual days with rainfall</td>
<td>0</td>
<td>-3</td>
<td>-3</td>
<td>-3</td>
<td>-3</td>
</tr>
<tr>
<td>Temperature:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Mean</td>
<td>0</td>
<td>1,3</td>
<td>2,0</td>
<td>1,3</td>
<td>1,0</td>
</tr>
<tr>
<td>Annual Min.</td>
<td>0</td>
<td>1,2</td>
<td>1,6</td>
<td>1,1</td>
<td>0,9</td>
</tr>
<tr>
<td>Annual Max.</td>
<td>0</td>
<td>1,5</td>
<td>2,5</td>
<td>1,5</td>
<td>1,1</td>
</tr>
<tr>
<td>Annual days with heat waves</td>
<td>0</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
</tr>
</tbody>
</table>

Table 2.3  % Climate change 2000-2050 on average in Ghana

<table>
<thead>
<tr>
<th>% Climate Change 2000-&gt;2050 on Average in Ghana</th>
<th>Hist</th>
<th>GW-NCAR,A2</th>
<th>GD-CSIRO,A2</th>
<th>LW-IPSL,B1</th>
<th>LD-BCCR,A</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Increase from 2000 to 2050</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Mean Rainfall</td>
<td>0</td>
<td>1%</td>
<td>18%</td>
<td>2%</td>
<td>-2%</td>
</tr>
<tr>
<td>Annual Mean 24 hrs Max. Rainfall</td>
<td>0</td>
<td>16%</td>
<td>-8%</td>
<td>11%</td>
<td>2%</td>
</tr>
<tr>
<td>Annual Mean 5 days Max. Rainfall</td>
<td>0</td>
<td>6%</td>
<td>-8%</td>
<td>8%</td>
<td>2%</td>
</tr>
<tr>
<td>Annual days with rainfall</td>
<td>0</td>
<td>-2%</td>
<td>-2%</td>
<td>-2%</td>
<td>-2%</td>
</tr>
<tr>
<td>Temperature:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Mean</td>
<td>0</td>
<td>5%</td>
<td>8%</td>
<td>5%</td>
<td>4%</td>
</tr>
<tr>
<td>Annual Min.</td>
<td>0</td>
<td>5%</td>
<td>7%</td>
<td>5%</td>
<td>4%</td>
</tr>
<tr>
<td>Annual Max.</td>
<td>0</td>
<td>5%</td>
<td>8%</td>
<td>5%</td>
<td>4%</td>
</tr>
<tr>
<td>Annual days with heat waves</td>
<td>0</td>
<td>-100%</td>
<td>-100%</td>
<td>-100%</td>
<td>-100%</td>
</tr>
</tbody>
</table>

In the World Bank study "Economics of Adaptation to Climate Change" (EACC) report from 2010 on the case study for Ghana the change in surface flow as monthly average are given for the different regions. For roads it is the extreme events that are most important for the design, but the average surface flow tells something about the change in daily load on bridges, canals and road protection walls along rivers.
Figure 2.11  Change in monthly average surface flow in the Ghana Dry Scenario (left) and Ghana Wet Scenario (right).

Source: World Bank: "Ghana, Economics of Adaptation to Climate Change", 2010

Figure 2.12  Projected runoff Changes for 2050 by Major Sub-Basin (percent).

<table>
<thead>
<tr>
<th>Sub-Basin</th>
<th>Ghana Wet Scenario</th>
<th>Ghana Dry Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Volta</td>
<td>-10</td>
<td>-30</td>
</tr>
<tr>
<td>Oti Basin</td>
<td>+3</td>
<td>-29</td>
</tr>
<tr>
<td>SW Ghana</td>
<td>+17</td>
<td>+2</td>
</tr>
<tr>
<td>Volta Lake &amp; SE</td>
<td>+51</td>
<td>-16</td>
</tr>
<tr>
<td>White and Red Volta</td>
<td>+8</td>
<td>-30</td>
</tr>
</tbody>
</table>

2.4.2 Design curves for the future climate, 2050

One of the key issues in this study is to find the design storms for the future situation. More of the existing Drainage Design Manuals for countries in the sub Sahara region use design storms based on the 24 hour precipitation for different return periods. In the following tables some of the key results on design curves based on the principles in these sources are summarized. The results are used to establish curves for the future climate situation in 2050 for the chosen four climate scenarios. The main principle for the curves and calculations are similar to the methods used in the design manual for Ethiopia, as there are no similar design manual specifically for Ghana.

Curves for the heavy storms with different return periods are established by two methods. First they are calculated directly from the given predicted future climate data for the four climate scenarios and secondly calculated as "smooth" curves based on the same kind of formulas as the present design storm curves, but with slightly revised parameter values. The direct method gives almost smooth curves, but some single values lay unrealistically far from the smooth curve, why it is chosen to use the formula based heavy storm curves for evaluation of the change in return periods. For the same reason the formula based smooth curves are used as basis curves for design of new structures and enlargement or reinforcement of existing roads, culverts, bridges etc.

Instead of making new design curves for each climate scenario, it is chosen to use the % increase in future storms for each of the four climate scenarios compared to the present/historical storm with the same return period. This percentage is used to assess the need for new design, enlargement, reinforcement etc. for roads, culverts, bridges etc. in the future as a result of climate change. This means that the same relative "reserve" is maintained in the curves used for the assessed future current design standard as in the standard today.

It is also calculated how much the return periods will be reduced for the heavy storms. These figures are used to calculate the cost of more frequent damages, blocking of roads, increased repair and maintenance etc. As an example it can be mentioned that the present 100 year storm in Ghana, will occur once every 18 year in the future (2050), if the predictions for "Global Wet"; NCAR-CCSM, SRES A2, are correct for Ghana - 5 times more often than today. See Table 2.8.
Table 2.4 24 hour maximum precipitation in mm/24h for different return periods, calculated directly and as smooth curves based on common used formulas for extreme events

<table>
<thead>
<tr>
<th>24 hour precipitation depth (mm) vs frequency (yrs), Average in Ghana (directly from GCM data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm/24hrs</td>
</tr>
<tr>
<td>Historical</td>
</tr>
<tr>
<td>&quot;Global Wet&quot;; NCAR-CCSM, SRES A2</td>
</tr>
<tr>
<td>&quot;Global Dry&quot;; CSIRO-MK3.0, SRES A2</td>
</tr>
<tr>
<td>&quot;Ghana Wet&quot;; IPSL, SRES B1</td>
</tr>
<tr>
<td>&quot;Ghana Dry&quot;; Bccr_bcm2_0-A2</td>
</tr>
</tbody>
</table>

Note: formula = "smooth" curves

The increase in 24 hour storms should be used for estimates of the increase in design and for enlargement and reinforcement of roads, culverts, ditches, bridges etc. but as seen in the following Table 2.5 there are some values that seems to be uncertain and not in accordance with the regular pattern for change in precipitation (marked in darker color).

Table 2.5 % change in 24h precipitation for different return periods based on direct data from the GCM

<table>
<thead>
<tr>
<th>% - Change in 24 hour precipitation depth (mm), Average in Ghana (directly from GCM data):</th>
</tr>
</thead>
<tbody>
<tr>
<td>% increase in design values based om Climate Change up to 2050 compared to present precipitation (Future-historical)/historical</td>
</tr>
<tr>
<td>mm/24hrs</td>
</tr>
<tr>
<td>Historical</td>
</tr>
<tr>
<td>&quot;Global Wet&quot;; NCAR-CCSM, SRES A2</td>
</tr>
<tr>
<td>&quot;Global Dry&quot;; CSIRO-MK3.0, SRES A2</td>
</tr>
<tr>
<td>&quot;Ghana Wet&quot;; IPSL, SRES B1</td>
</tr>
<tr>
<td>&quot;Ghana Dry&quot;; Bccr_bcm2_0-A2</td>
</tr>
</tbody>
</table>

Instead of using the direct data from the GCM models, it is chosen to use a smoother pattern for design storms based on formulas for the common pattern for the relations between depth and frequency for heavy storms. The following table is used for increase in design and for enlargement and reinforcement of roads, culverts, ditches, bridges etc.
Table 2.6 % change in 24h precipitation for different return periods based on formulas for smoothing results from the GCM, according to common pattern for precipitation/frequency

<table>
<thead>
<tr>
<th>% - Change in 24 hour precipitation depth, Average in Ghana (based on formula+GCM):</th>
<th>1</th>
<th>2</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>50</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm/24hrs % increase (baseline to 2050)</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Historical</td>
<td>&quot;Global Wet&quot;; NCAR-CCSM, SRES A2</td>
<td>-10%</td>
<td>6%</td>
<td>19%</td>
<td>26%</td>
<td>31%</td>
<td>36%</td>
</tr>
<tr>
<td></td>
<td>&quot;Global Dry&quot;; CSIRO-MK3.0, SRES A2</td>
<td>14%</td>
<td>9%</td>
<td>6%</td>
<td>4%</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>&quot;Ghana Wet&quot;; IPSL, SRES B1</td>
<td>27%</td>
<td>31%</td>
<td>34%</td>
<td>36%</td>
<td>37%</td>
<td>39%</td>
</tr>
<tr>
<td></td>
<td>&quot;Ghana Dry&quot;; Bccr_bcm2_0-A2</td>
<td>-5%</td>
<td>-3%</td>
<td>-2%</td>
<td>-1%</td>
<td>-1%</td>
<td>-1%</td>
</tr>
</tbody>
</table>

Note: formula = "smooth" curves

Table 2.7 Absolute change in precipitation per return period

<table>
<thead>
<tr>
<th>Change in 24 hour precipitation depth (mm), Average in Ghana (based on formula+GCM):</th>
<th>1</th>
<th>2</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>50</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm/24hrs</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Historical</td>
<td>&quot;Global Wet&quot;; NCAR-CCSM, SRES A2</td>
<td>-2</td>
<td>1</td>
<td>5</td>
<td>8</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>&quot;Global Dry&quot;; CSIRO-MK3.0, SRES A2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>&quot;Ghana Wet&quot;; IPSL, SRES B1</td>
<td>5</td>
<td>7</td>
<td>9</td>
<td>11</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>&quot;Ghana Dry&quot;; Bccr_bcm2_0-A2</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: formula = "smooth" curves

The changes in frequency or return period for a given historical storm are given in Table 2.8. This table is used for evaluation of increased frequency of damages etc. and increased need for repair and maintenance.

Table 2.8 Future return period in years for present heavy storm with different return periods.

| New returnperiod - 24 hour precipitation, Average in Ghana (based on formula+GCM): | 1 | 2 | 5 | 10 | 20 | 50 | 100 |
| Future returnperiod in years of a present XX year storm | 1 | 2 | 5 | 10 | 20 | 50 | 100 |
| Historical returnperiod | "Global Wet"; NCAR-CCSM, SRES A2 | 1,2 | 1,8 | 3,0 | 4,6 | 7 | 12 | 18 |
| | "Global Dry"; CSIRO-MK3.0, SRES A2 | 0,7 | 1,4 | 3,8 | 8,1 | 17 | 46 | 96 |
| | "Ghana Wet"; IPSL, SRES B1 | 0,6 | 1,0 | 1,8 | 3,0 | 5 | 9 | 14 |
| | "Ghana Dry"; Bccr_bcm2_0-A2 | 1,1 | 2,2 | 5,4 | 10,7 | 21 | 52 | 102 |

Note: formula = "smooth" curves
The change in return period for present design storm is also illustrated as graph in Figure 2.13.

**Figure 2.13  Change in return period for present design storms**

The figures for present and future 24 hour maximum rainfall are represented in the following graph, Figure 2.14.
Figure 2.14  Calculated design curves for the 24h maximum precipitation in year 2050 and the present 24h maximum precipitation curve

The graph shows that the two "wet" climate scenarios result in relative similar design curves, which can not for any practicable purpose be differentiated. The two "dry" scenarios result in design curves almost identical with the present design curve, indicating no need for change in design basis. The graph shows curves for the present 24h precipitation and the expected future 24h precipitation under different scenarios, and these curves will be used for assessing the design need, based on the %-increase in 24h precipitation from present to 2050 as seen in Figure 2.14 or Table 2.6.

The "current design curve" does not exist for the country as such, as there are no mandatory design standards. Instead individual design curves for different projects and for different regions are left for the designer to decide in the specific project.

2.4.3 Rising sea level, storm surge and cyclones

There are no data available for these issues for the four specific chosen climate change scenarios. Therefore results from other new studies have been reviewed. The conclusion is that specific calculations of the adaptation consequences for roads can not be included in this study. The main reasons are the large uncertainties, the indicated limited change the next 40 years and that adaptation measures will be initiated for other reasons than for making transportation/roads climate change resilient. Many adaptation measures for disaster risk
management are urgently needed for protection of the society and values from damages from the present occurrence of cyclones and storm surge.

In the EACC report it is mentioned that, in Ghana, coastal erosion has been a major challenge for many years and has therefore been monitored in some sites over the years. The rate of erosion recorded ranges from 4-12 m/year.

The sea level rise scenarios are highlighted in Ghana’s Initial National Communication to the UNFCCC under the Kyoto Protocol. Planners acknowledge that sea-level rise impacts are evident, for instance the sandy beaches of the east coast are already eroding at a phenomenal rate of about 8 m/year; and flooding of coastal communities do occur during spring tide. However, the current designs do not take into account the climate related impacts in the shoreline protection design and construction due to the incremental cost.

The Government of Ghana (GoG) has undertaken measures to protect highly vulnerable areas in the eastern section of the coastline along the Keta lagoon. The Government has also identified 17 erosion hotspots along the shoreline, of which 10 have been costed as priority protection projects in the 5-year medium term plan for the period 2010-2013. The total length involved is estimated at 76 km.

In the WB report, Sea-Level Rise and Storm Surges, April 2009, it is estimated that the coastal areas in Ghana affected by a 100 year storm surge will increase with 39%, according to 400 km², in the future because of climate change as change in sea level and storm surge.

Figure 2.15 Coastal zone of Ghana (AECC report for Ghana, WB, 2010)
3 Ghana road network

3.1 Introduction

Roads and Highways in Ghana are administered under the Ministry of Roads and Highways, also sometimes referred to as the Ministry of Transportation. Underneath the Ministry of Roads and Highways, different agencies were created that are responsible for the different transport sectors: Ghana Highways Authority (GHA), Department of Urban Roads (DUR) and Department of Feeder Roads (DFR).

Figure 3.1 Organization of Ministry of Roads and Highways

The Ministry of Roads and Highways was originally created in 1982 out of a need to restructure the at that time total breakdown of Ghana’s road infrastructure. The Ministry has changed names and responsibility a number of times since then. In 1997, the ministry was renamed the Ministry of Roads and Transport and combined the earlier Ministry of Roads and Highways and the Ministry of Communications. In April 2001, a new Ministry of Roads and Highways was created, and in October 2001, the Ministry was restructured and renamed the Ministry of Roads and Transport. In 2005 a new Ministry of Road Transport was created out of the Ministry of Roads and Transport. In 2006,
however, the ministry was renamed as the Ministry of Transportation. In 2009, the Ministry of Transport was created which focuses on maritime and rail transport, leaving all road transport to the Ministry of Roads and Highways. The number of Ministries and their responsibilities has changed often in the last 10 years leaving some difficulty in determining each Ministry’s responsibility for the different transport sectors.

The Ghana Highway Authority was established in 1974 and oversees the trunk roads in Ghana. The trunk roads are classified as shown in Table 3.1.

**Table 3.1**

<table>
<thead>
<tr>
<th>Trunk Road Classification</th>
<th>Labeling</th>
</tr>
</thead>
<tbody>
<tr>
<td>National</td>
<td>N</td>
</tr>
<tr>
<td>Inter-regional</td>
<td>IR</td>
</tr>
<tr>
<td>Regional</td>
<td>R</td>
</tr>
</tbody>
</table>

National Roads link the National Capital with the Regional Capitals, and are typically the roads of most importance in the country. Inter-Regional roads link regional capitals across regional borders, and Regional roads typically link the regional capitals with towns and areas within specific regions.

The Department of Urban Roads was established in 1988 as the agency responsible for roads in the urban environments, such as the local roads within Accra City and the Department of Feeder Roads was established in 1981 and is responsible for the feeder road network.

**Figure 3.2 Total Network Size by Road Class (2000-2008)**

*Source: TSPS II, June 09*
Figure 3.2 shows the increase in the Ghana Road Network from 2000-2008. The trunk road network has stayed relatively stagnant where there have been large increases in the length of both the Urban Road and Feeder Road networks. The Feeder Road network has nearly doubled in size, and the amount of road under DUR governance has six doubled in size since 2000 due mostly to municipalities whose roads have been added to the network.

The summary of the condition of the Ghana Road Network is presented in Table 3.2. From the table it is clearly seen that the paved network is in relatively good condition for both GHA and DFR as of 2008, where the unpaved network shows a much less desirable amount of roads in fair or good condition.

Ghana had in 2008 an estimated classified road network of approximately 66,000 km of which around 13,000 km are paved. 81% of the paved roads and 65% of the unpaved roads are recorder to be in fair or good condition. According to Ghana Highway Authority (GHA) 95% of the 350 bridges for which the condition is known is reported to be in fair to good condition.

Table 3.2 Summary Road Condition 2008

<table>
<thead>
<tr>
<th>Condition</th>
<th>Ghana Road Network</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GHA</td>
<td>DUR</td>
<td>DUR</td>
<td>DFR</td>
<td>DFR</td>
</tr>
<tr>
<td></td>
<td>Paved</td>
<td>Unpaved</td>
<td>Paved</td>
<td>Unpaved</td>
<td>Paved</td>
</tr>
<tr>
<td>Kilometers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>310</td>
<td>2919</td>
<td>1934</td>
<td>3379</td>
<td>110</td>
</tr>
<tr>
<td>Fair</td>
<td>1865</td>
<td>1911</td>
<td>198</td>
<td>180</td>
<td>280</td>
</tr>
<tr>
<td>Good</td>
<td>3805</td>
<td>818</td>
<td>2996</td>
<td>3713</td>
<td>1250</td>
</tr>
<tr>
<td>Total</td>
<td>5,980</td>
<td>5,648</td>
<td>5,128</td>
<td>7,272</td>
<td>1,640</td>
</tr>
<tr>
<td>Percent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>5%</td>
<td>52%</td>
<td>38%</td>
<td>46%</td>
<td>7%</td>
</tr>
<tr>
<td>Fair</td>
<td>31%</td>
<td>34%</td>
<td>4%</td>
<td>2%</td>
<td>17%</td>
</tr>
<tr>
<td>Good</td>
<td>64%</td>
<td>14%</td>
<td>58%</td>
<td>51%</td>
<td>76%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: TSPS II, June 2009

The Ministries have recognized that maintenance of their road network is a key element to maintaining economic growth in Ghana and have substantially increased investment into road maintenance over the last few years. Figure 3.3 shows the increase in maintenance expenditures for the Ghana Road Network. Expenditures for maintenance for GHA, DUR and DFR follow a similar path.
There are many large upgrading projects in the planning stages for the Ghana Road Network. At the African Investment Forum 2010, held in Accra, upgrading of the western and eastern corridors was presented, a length of nearly 1,400 km at an estimated cost of 2,400 Mil USD. In addition, there are plans for upgrading, or developing a large number of bridges in DFR, as well as some large intersection developments for DUR.

Source: TSPS II, June 09
Figure 3.4  GHA Trunk Road Network 2010

Source: GHA
3.2 Current road assets in Ghana

3.2.1 Introduction
A well functioning road is dependent on a number of elements to function correctly. This report has focused on the elements that are most likely to be affected by climate change, and are the most critical to the overall usability of the road network. The main components of the road network considered are: Bridges and Culverts, Pavement Design, Slope Stability, and Surface Drainage.

3.2.2 Bridges and culverts
Ghana Highways Authority maintains a bridge database that has GIS references to the conditions and locations of a large number of their bridges. The quantity of bridges in the feeder road network and urban road network is unknown, however, these bridges are being systematically added to databases as well. As of 2008, of 350 bridges in the trunk road network whose condition are known, 95% were in fair to good condition. It is unknown the number of culverts in the country.

Current design practices
For new bridge and culvert construction it is normal to start by using the Ghana Bridge design manual. Additional design manuals such as AASTHO and British bridge codes are also used as references. The sizing and importance of the bridge dictates the investment in the engineering design.

Bridges are designed to withstand a flood return interval based on their span length. The design storm return interval is suggested by the Ghana Bridge Department in Table 3.3.

<table>
<thead>
<tr>
<th>Bridge Span</th>
<th>Return Interval (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long Span Bridges</td>
<td>100</td>
</tr>
<tr>
<td>Medium Span Bridges</td>
<td>50</td>
</tr>
<tr>
<td>Culverts</td>
<td>15</td>
</tr>
</tbody>
</table>

Source: GHA

Rainfall charts are found in the Ghana Highway Authority Design Manual. The rainfall and hydrology charts were last updated in 1991. It is felt from conversations with the highway authority that these rainfall charts no longer represent the actual hydrologic conditions in Ghana. The Meteorological Agency is in the process of collaborating with GHA to update the design manuals.

3.2.3 Pavement design
Design of pavement structures is based on the methods given by the Ghanaian Pavement Design Manual, and supplemented with other manuals such as
AASHTO and the Overseas Road Notes. The manuals cover design for both paved trunk roads, as well as gravel and community roads. The Department of Feeder Roads has produced shortened versions of these manuals that are specifically orientated towards the needs of designing lower traffic roads in Ghana.

Pavement design covers the design and the structure of the road. This can be broken down into paved or unpaved sections. Paved sections include those roads covered with a bituminous flexible or rigid concrete pavement. The paved roads are typically trunk roads. Unpaved sections typically are covered with a gravel wearing course, or made of an engineered earth surface depending on the design standard. An earth surfaced road is typically made of local materials that are not necessarily graded to specifications or meet any testing standards, most often used on low traffic feeder roads.

The road section for a paved or gravel road follows more or less a similar structure (see Figure 3.5). The most essential difference is the cross fall, the typical cross fall of an unpaved road being 2.0 – 2.5 % and for an unpaved gravel road 4%. Typically, the structure includes the sub grade, capping layer, the sub base materials and a wearing course. The sub base materials and thicknesses are adjusted or left alone depending on the strength and quality of the sub grade. The weaker the sub grade material is, the stronger the sub base materials need to be. These layers can consist of many different materials, and are typically adjusted to suit local conditions, and meet the requirements set in the design manuals for level of standard for the road.

**Figure 3.5  Typical road section**

![Typical road section](image)

*Source: MOT Standard Specifications*
Figure 3.6  Typical elements of paved, gravel, and earth roads

Source: MOT Standard Specifications

Road cross sections typically include shoulders, which are built as an extension of the carriageway, either paved or unpaved. They act as extra accommodation for vehicles and pedestrians. The shoulders are typically made with less structural strength than the carriageway, although they can aid in lateral support of the road layers. Surfacing of shoulders is used in Ghana where found applicable and economically feasible.

Vehicle overloading is a serious problem for the longevity of pavement designs in Ghana. From the years 2005-2008, of 82405 trucks weighed, 23% were overloaded.

It is common for a road upgrading project to follow the alignment of the previous road. In these instances, material from the previous road can be reused in the upgrade if it is found to be of good quality and in sufficient supply. Nearly all new road construction that does not follow an old alignment is constructed first as a gravel road. It is the intention to first build a lower cost (lower design standard) road, and pave or seal at a later time if economically feasible.

Soil investigations are done prior to road design using the testing guidelines explained in the Standard Specifications for Road and Bridge Works of the Ministry of Roads and Transports. The type of testing and frequency is dependent on the level of standard of the road. Preliminary soil and material testing and corresponding design for the higher class trunk roads are of a high level and frequency. The testing and design for the lower level roads is not up to the same standard due to the financial aspects.

3.2.4  Slope stability

Slope stability refers to the stability of the landscape within the immediate location of the roadway. This includes both slopes above and below the road, some which are directly affected by the construction of the road, and others that are naturally unstable. The main impact of the slope stability to the road network is through landslides which are often caused by saturation causing slip failures. Erosion increases the need for maintenance in the drainage structures by the addition of siltation.

The types of landslides affecting roads range from deep seated failures to shallow slope failures, and is discussed in Overseas Road Note 14. The impact from
landslides on roads ranges from temporary partial blockage that can be cleared by maintenance crews, to complete blockages that shut down the road for extended periods of time. A deep seated failure is much more destructive and there is a limited amount of economical engineering solutions for prevention.

There is limited information available on the impact of landslides in Ghana. From discussions with the authorities, landslides are not seen as a major threat for construction or maintenance of roads.

The design of the interaction between the road slopes and the landscape is covered in the MOT Standards and Specifications Manual. Slope requirements used in road construction is dependent on the geology, soil conditions, and evidence of past slope instability, or at the discretion of the engineer. The MOT Standards and Specifications Manual list best practices in relation to earthworks, slope cuttings, and spoils.

### 3.2.5 Surface conditions

Surface drainage covers the drainage of precipitation from the surface of the road, through the sub base layers in the road section, as well as runoff down hillsides and through road side ditches. Surface drainage elements are some of the assets that are most likely to be exceeded by extreme storm events. Many of these elements are designed for short storm return intervals, and quickly exceeded during a large event. In this report, bridges and culverts are discussed under their own heading, even though they are a vital part of surface drainage. Table 3.3 shows the design storms used for designing the most common drainage elements. Side ditches are typically designed for a 5 year recurrence interval.

### 3.2.6 Summary

The road assets in Ghana vary extremely. The success of these roads relies on similar factors, namely:

- Initial design and construction
- Climate and topography the road passes through
- Traffic loading
- Maintenance.

The paved trunk roads are the most vital in the network, and receive a majority of the money used on transportation in Ghana. They have correspondingly higher design, construction standards, and maintenance programs than the lower standards of roads. It is agreed that there is an overall lack of maintenance available for roads in Ghana. The explanation for the lack of maintenance is lack of funding. The majority of money allocated to maintaining roads in Ghana is spent on maintaining the trunk roads, leaving the lower standard of roads in need of routine maintenance.
Many of the current problems that are seen in Ghana are not climate related, but are amplified by the climate. For example, overloading of heavy trucks will have damaging effects on a road regardless of climate; the damage is amplified when the soils and materials beneath are overly saturated. The same can be said about routine maintenance. Maintenance is a requirement on all roads, and without it roads will deteriorate quicker than their design life. An increase in rain will only increase the need for maintenance.
4 Climate change impacts on road assets

4.1 Introduction
In Ghana, the most influential climate impacts on roads will come from:

- Temperature
- Rain
- Seal level rise.

Flooding of the infrastructure may have several causes and the impacts and potential adaptation measures are dealt with in two subchapters organized in relation to impacts from rain generally (see especially chapter 4.3.2 on floods) and more specifically from cyclones and sea level rise (chapter 4.4.2), which leads to a third subchapter summing up the current soft spots in the road infrastructure (chapter 4.5.2). A summary of engineering adaptation measures is included in chapter 7.2.1. Further, some more detailed descriptions of climate impacts can be found in the Annex.

4.2 Temperature

4.2.1 Introduction
In Ghana, the scenario results for change in mean annual temperature go from -1 °C to 2 °C by the year 2050. An increase in temperature is expected to have an impact on:

- Bridges
- Bituminous pavements.

4.2.2 Bridges
Impact of climate change
A rise of 2° C will possibly mean an increase in the expansion and contraction of the bridge materials. This could cause more strain on the expansion joints.

Climate impact countermeasures
Bridges are already designed with temperature gradients in mind. The temperature changes in Ghana are not expected to rise so high that they warrant new engineering methods, but it will require the use of best engineering practice and increased maintenance. The most common method of dealing with bridge material expansion is through the use of expansion joints. The biggest drawback of expansion joints is their need for maintenance to function properly. In order
to ensure longevity of the bridge structure, these expansion joints will require increased maintenance, or engineering solutions requiring less maintenance.

If maintenance is not deemed cost efficient or becomes too costly, then there are bridge designs that do not require expansion joints such as integral bridges. Integral bridges require no expansion joints and are dependent on integral abutment elements which use the surrounding soil in aiding in thermal expansion.

Regarding concrete mixes, there is no available data on the gradient caused by the change of temperature within curing time. The hardening process of concrete is taking place during the very early ages of a concrete structure compared with its total service life. In the earliest stage of concrete life, when it is freshly placed, concrete is very sensitive and could easily get ruined. The method of curing and the treatment of the concrete structure during these first few days or weeks is very crucial for its final performance and durability. The risk of early-age plastic shrinkage cracks or thermal cracking due to temperature gradients may define the need for curing and protection of the concrete. Furthermore, increase in temperature means increase in evapotranspiration, therefore the concrete skin should be protected properly against evaporation until a certain maturity or strength is obtained in order to ensure sufficient strength and durability.

It is not foreseen that special methodology will need to be developed or implemented due to the climate change effects on temperature. These criteria are often stated in the execution specifications for any given project, and there are methods and tools to help the concrete producer to plan and predict the hardening process of a concrete structure under various and changing ambient conditions. Furthermore, there are computer tools that simulate temperatures and early-age stresses within a concrete cross-section during hardening.

Summary
- Temperature rise should be dealt with during design phase
- Need for increase in maintenance should not be substantially increased due to temperature rise.

4.2.3 Pavement design

Impact of climate change
The impact from a 2° C change in temperature over the next 50 years is not expected to have major consequences on pavement design.

The expected service life of a newly constructed road is estimated to be about 10 to 15 years for the upper most asphalt layers. Cracking due to climate change from a rise in temperature should not be expected, but in case it was necessary to adequate the bitumen to new conditions, the use of modifying additives may improve its properties. Plastic deformation is greatest at high service temperatures, increasing the penetration index of the bitumen significantly improves resistance to deformation. Using the right additives in a hot climate could increase the stiffness and resistance to deformation of asphalt pavements.
Climate impact countermeasures

- Serious temperature change is on a scale of 20 to 30 years, which is longer than lifespan of most pavements.
- Adjustments in pavement design with respect to binder selection can be made at regular service / reconstruction intervals.

<table>
<thead>
<tr>
<th>Table 4.1</th>
<th>Climate impacts-temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate variable</td>
<td>Road asset</td>
</tr>
<tr>
<td>Average High Temperature</td>
<td>Bridges</td>
</tr>
<tr>
<td>Pavement Design</td>
<td>Deformation Surface, Cracking</td>
</tr>
<tr>
<td># of very Hot Days</td>
<td>Road Construction/Maintenance crews working days</td>
</tr>
</tbody>
</table>

Source: Consultant

4.3 Rain

4.3.1 Introduction

In Ghana, climate associated with rainfall has the largest impact on roads and bridges. This chapter covers major elements that are directly impacted by rain either through direct contact from rain, soil moisture, or from streams and rivers that the road must cross.

The majority of these road elements are sized based on different frequency values of a 24 hour storm. Table 4.2 shows the increase in precipitation that can be expected under the different climate scenarios. These new values can then be applied using the current guidelines to determine new sizing requirements, and/or more appropriate engineering solutions. Because the values for Global Wet and Ghana Wet scenarios are similar and show the same trend, the worst wet scenario used for this analysis is Ghana Wet, IPSL, SRES B1. The dry scenarios, Ghana Dry, Bccr_bcm2_0-A2 and Global Dry; CSIRO-MK3.0, SRES A2 are showing very small changes in the future equivalent to no climate change.
Table 4.2  Increase in design values based on Climate Change up to 2050 compared to present precipitation

| % - Change 24 hour precipitation depth (mm) vs frequency (yrs), Average in Ghana |
|---------------------------------|---|---|---|---|---|---|---|
| mm/24hrs                        | 1 | 2 | 5 | 10 | 20 | 50 | 100 |
| Historical                      | 0%| 0%| 0%| 0%| 0%| 0%| 0% |
| "Global Wet"; NCAR-CCSM, SRES A2 | -10%| 6%| 19%| 26%| 31%| 36%| 39% |
| "Global Dry"; CSIRO-MK3.0, SRES A2 | 14%| 9%| 6%| 4%| 3%| 1%| 0% |
| "Ghana Wet"; IPSL, SRES B1      | 27%| 31%| 34%| 36%| 37%| 39%| 39% |
| "Ghana Dry"; BCCR_BCM2_0-A2    | -5%| -3%| -2%| -1%| -1%| -1%| 0% |

Increased rain will have the largest impact on the road network of the expected climate changes. Increases in rain will have an impact on:

- Bridges
- Culverts
- Pavement design
- Slope stability
- Surface drainage

4.3.2 Bridges

Impact of climate change

The immediate impact of flooding has been seen numerous times in the last few years in Ghana with a number of bridge washouts that have serious consequences on the communities that rely on them, as well as Ghana’s economy.

Table 4.3 shows new return intervals based on the climate change scenarios. The Ghana Wet and Global Wet scenarios are both showing extreme increases in the recurrence of large storms. Initial presumptions would lead one to believe that this will cause major devastation to bridges in Ghana. However, every bridge is hydraulically different, and its success during flooding events is dependent on many different variables. To get a better estimate of the destruction from climate change, a detailed hydraulic analysis would need to be performed on each bridge. The two "dry" scenarios result in return intervals as today.
Table 4.3  New return period – 24 hour precipitation depth (mm) vs frequency (yrs), average in Ghana

<table>
<thead>
<tr>
<th>Historical return period</th>
<th>1</th>
<th>2</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>50</th>
<th>100</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Global Wet”; NCAR-CCSM, SRES A2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>12</td>
<td>18</td>
<td>Year</td>
</tr>
<tr>
<td>“Global Dry”; CSIRO-MK3.0, SRES A2</td>
<td>1</td>
<td>1.5</td>
<td>4</td>
<td>8</td>
<td>17</td>
<td>46</td>
<td>96</td>
<td>Year</td>
</tr>
<tr>
<td>“Ghana Wet”; IPSL, SRES B1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>9</td>
<td>14</td>
<td>Year</td>
</tr>
<tr>
<td>“Ghana Dry”; BCCR_BCM2_0-A2</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>11</td>
<td>21</td>
<td>52</td>
<td>102</td>
<td>Year</td>
</tr>
</tbody>
</table>

Source: See Chapter 2.4

Floods – June 2010
On June 20, 2010 there was large flooding on the River Akora near Agona Swedru. All of the bridges that connect one side of the town to the other were washed out. Eye witness accounts state that the flooding was the worst in recent history. However, the UN produced Ghana-Floods Situation Report #1 produced 23 June 2010 states that the rainfall of that day was only an average of 24 mm, much less than the record figure of 313 mm registered at Kaneshie in Accra in 2009, where there was little to no damage reported. This is interesting because it shows that it is not only the amount of rainfall that has devastating effects on bridges. There are many other factors and their causes need to be investigated.

From conversations with GHA and DUR, it has been noted that development within flood plains has highly amplified the flooding events. Typically the development is in the form of illegal housing that is set up in relatively flat, easy to build areas near the river banks. When the river rises, its flood plain area is dramatically decreased due to the new structures and the waters rise higher than they typically would. Ghana is currently in the process of removing homes that are determined to increase the risk of flooding.3

3 http://www.alertnet.org/db/an_art/60167/2010/09/4-100542-1.htm
Dahwenya Bridge on the Cape Coast-Accra Highway also experienced flooding on that day. One of the large box culverts was on the verge of being washed out, but fortunately survived the flooding. GHA explained that the road was completely flooded for a period of time putting a complete stoppage to traffic on the highway. However, the damage is relatively small given the size of the flooding event. The flood waters were able to find an alternative route over a low point in the road destroying a portion of shoulder and road, but alleviating the pressure on the box culverts.
The impact from increased rain will mean more frequent flooding in the rivers and streams. The increased flooding will mean an increase in scour, and increased risk that the hydraulic capacity of the bridge is exceeded.

Research has shown that it is not only the hydraulic capacity of the bridge structure that is critical, but also the scour protection for the embankments and footings. If a bridge is designed with scour protection to withstand a 100 year storm, how much protection will then be left after the large flood event? It is unlikely that it is economically feasible to build a bridge that will retain 100% of its scour protection after a large flood event. There is variability on when the most damaging scour events will happen, sometimes it may occur during a peak 100 year flood event, but often times these storms only lead to an increase in flows for a short time period. It may be that the most scour damage comes from higher frequency storms that lead to increased river velocities for a longer period of time. This is dependent on the geology and soil type of the river, as well as the type of bridge foundations used, and accurate results require further research.

**Climate impact countermeasures**

Ghana has recently experienced a large number of bridge failures. There was large flooding in the area, however, the rainfalls were not of a significantly high level, and detailed reasons for the high flooding events and subsequent bridge failures need to be identified.

Bridges are one of the largest economic investments regarding road infrastructure, and their protection should be top priority. It is recommended to investigate bridge designs that allow excessive flood waters to be routed away from the bridge and destroy a section of road instead. It is most often much cheaper and quicker to replace a short section of road with raw materials and asphalt than to replace a bridge with either a steel structure, or concrete box culvert. If a bridge is designed for hydraulic capacity of a 50 year flood, then there should be a design in the surrounding road that allows all excess flow to pass over a section of road. The main priority is to alleviate the hydraulic pressure on the bridge elements.

During the initial bridge design, or design of a replacement bridge, the suitability of the location of the bridge should be thoroughly investigated. Placing a bridge in the midst of an alluvial fan or in an unstable flood plain whose channel is likely to move is not recommended. Investigations should be considered to find if it is more cost beneficial to move a large portion of road, so that the bridge is in a more stable environment.

One of the largest threats to bridges from an increase in precipitation is the increase in floods and associated scour and bank erosion. This issue is related to the use of structural design standards. Although scour may occur at any time, it is usually more significant during high flows when the water is swift and deep. The preferred method to deal with scour would be to account for it correctly in the design phase and implement sufficient countermeasures to handle the expected scour. Scour is a common problem with bridges around the world, and not just isolated to bridges in Ghana. There is ongoing research on the best en-
engineering methods to implement scour prevention. Potential scour can be a significant factor in the analysis of a stream crossing system, which should involve an acceptable balance between a waterway opening that will not suffer undue damage from scour and a crossing profile sufficiently high to provide the required traffic service.

Figure 4.3  Local bridge scour Wukro Agridat Zalambesa road (Ethiopia)

Source: Consultant

Riprap is the most commonly applied material for protection of bridge piers against local scour. However, riprap is not a permanent solution, as it is susceptible to being washed out after floods. Different methods of riprap placement can be used as scour protection. The easiest, cheapest and least effective is the placing of loose fill material (graded rock) around the piers and abutments. This is the most susceptible to being washed away during floods given the loose individual pieces. The preferred method is the use of riprap gabions. The gabion fencing keeps the riprap together as one unit giving it more weight and resilience to be being washed away during floods. A stronger more permanent solution should be investigated if it is found to be cost effective. In some locations, riprap may be unavailable, costly, or physically untenable for installation. There are alternatives to riprap as scour prevention methods around bridge piers such as the use of mats, grout bags, footings, or tetrapods.

As a new alternative countermeasure to riprap for scour protection around bridge piers, wire gabions were investigated experimentally for failure mechanisms, effects of significant parameters on failure and its sizing in a clear-water condition. The dominating failure mechanism was found to be a shear failure. Based on the experimental data, the controlling factors for the stability of wire
gabions as a scour countermeasure at the pier are flow depth relative to pier diameter, length to thickness ratio, coverage, alignment and placement depth of wire gabions. An equation for sizing of a wire gabion is proposed in terms of Froude number and factors reflecting both the effect and limit of significant parameters. Comparison of the equation with those of ripraps shows that smaller wire gabions than ripraps provide an equivalent protection implying cost effective and improved stability.

Regular maintenance before the rainy season and after high water events is required to ensure that there is still some protection left around the bridge substructure. A lapse in scour maintenance between high water events may be enough to permanently damage the bridge. It is suggested to supplement current bridge maintenance programs with a bridge scour action plan based on the US Department of Transportation’s “Plan of action for scour critical bridges.” Scour countermeasures can range from simply placing riprap in the scour voids, to highly technical structures including monitoring devices. The decision for which type of adaptation measures used should be decided upon on a case by case basis using a full life cycle analysis.

Increased protection should be ensured along the banks upstream and downstream of the bridge. Large scale bank erosion can work its way towards the bridge abutments from a far distance. If the banks become unstable, the stability of the abutments is compromised and the superstructure becomes in danger. A potential method of bank stabilization is the use of coir fabric, or other bio-engineering methods. These methods have been proven to be effective in re-establishing bank vegetation and stabilization, although may be ineffective in drought prone areas.

In areas with unstable flood plains, there needs to be an increase in upstream river training to ensure that the channel is directed under the bridge span, and not allowed to meander or braid into different paths. This potentially requires large scale river training, through the use of bio-engineered bank stabilization, gabions, or other suitable methods. River training using these methods is only expected to last 4-5 years, and their maintenance and repair is critical to allow them to direct the river correctly.
Figure 4.4 Large scale river works effort using rock gabions Mekele-Adwa (Ethiopia)

Source: Consultant

In areas where there are multiple channels, such as alluvial fans, it may be cost beneficial to raise the road embankment and use a series of culverts, rather than invest in a limited number of large bridges. The culverts will be cheaper to replace if washed out, and a high number of culverts will help alleviate the flooding problem if the main channel changes course, or if the flood plain experiences severe flooding.

Another consequence of floods will be the sediment deposits left behind near the bridges. This deposit will also need to be removed to ensure the hydraulic efficiency.

A well designed bridge will still require maintenance to meet its 50 to 100 year design life. With an increase in precipitation, it can be expected that the maintenance required will also need to be increased. It would be nearly impossible from an economic point of view to design and build a bridge to be able to withstand 100 years of flooding events without maintenance. The current Strategic Plan in Ghana warrants having rigorous maintenance which will need to be kept and likely improve in order to cope with the severe increases in precipitation. With an increase in precipitation, the most vital factor for bridges survival is maintenance. Any future Strategic Maintenance Program will have to be flexible and robust, otherwise there is little chance that these bridges will meet their design lives under the future climate scenarios.
Summary

• Update design manuals with increase in rainfall as predicted by climate scenarios.

• Upstream river training required where river has opportunity to change its course.

• Invest and research into increased scour protection.

• Research past bridge failures and apply lessons learned into new bridge designs.

• Research relationship between development and flooding in urban areas.

4.3.3 Culverts

Impact of climate change

Some of the factors that usually influence blockage of culverts are size, material type, land use, stream slope, catchment area, number of culverts upstream and blockage of upstream culverts. Especially important factors are the size and stream slope. Generally culverts placed in locations with steep stream slope tend to have more blockages due to the greater ability of steep streams to mobilize debris, and the more mobile nature of the debris type (sediment and vegetation) in the upper parts of the catchments.

Experience has shown that increasing only the culvert size will not automatically make for a more climate resilient culvert. If the culvert capacity is large enough to handle the expected increase in flows, but still fails, then it can be concluded that the failure is coming from another factor such as insufficient inlet control, outlet control, lack of maintenance, underestimation of rainfall runoff, or a combination of all these factors. Like bridges, many of the culvert failures that are experienced are directly related to scour events. If the inlet or outlet control is not designed to handle scour correctly, the culvert itself will be undermined leading to failure of the both the culvert and the roadway section.

Earth drains tend to fail due to accumulated earth and soil and eroded road surfaces. These problems are particularly notable on sections with steep gradient, in “cut and fill” and those that are lower than the surrounding ground level. On such sections, an appropriate drainage system should be designed. Furthermore, drainage structures should be connected and discharged through suitable and regular outlets.

The Consultant did not have access to any culvert´s data base, therefore a detailed analysis could not be assessed. However, it is very likely that with the scenarios used for this study Ghana’s culvert system would be stressed by increase precipitation.

Climate impact countermeasures

Maintenance is one of the most important aspects of a well functioning culvert. The investment in culverts will not be met if they are allowed to fill with debris reducing hydraulic capacity. Maintenance needs to be increased on culverts before the rainy season ensuring that the culverts will have clear conduits. This can be difficult on smaller culverts where access is limited.
Culverts have the potential to be blocked very quickly; maintenance before and during the rainy season is required to clean out accumulated debris. Currently, the minimum size culvert allowed is 600 mm diameter for gradient > 2% and 900mm for gradient < 2%. If experience shows that this sizing is too small to allow routine labor based maintenance, it may be necessary to increase minimum sizing to 900 mm diameter.

Culverts should be designed and constructed so that in case of a flood, the least amount of damage to the road and the surrounding landscape occurs. As shown in Table 3.3 reinforced culverts are not designed to have capacity for large scale floods greater than 15 year return interval, but they should be designed so that the road they are covered by is not washed out during large floods. For the Ghana Wet scenario, the 50 years return period would become the 9 years return period, and the 20 years return period would become the 5 years return period. The easiest approach to cope with increased flow would be to increase the culvert size, or raise the road embankment, but this may not be economically feasible and experience has shown that it will not automatically make a culvert climate resilient. Culvert sizes should be increased in areas where the potential for damage is greatest, such as in areas with large fills and high risk of floods. These are the areas with the greatest potential for damage from floods, because the flood water has no escape, and will erode the road section until it can pass through to the other side. The investment and design in culvert sizing should take into account the cost of potential failure.

*Figure 4.5 Road shoulder erosion caused from overtopping culvert, Cape Coast-Accra Road*

*Source: Consultant*

Where a culvert is not sized to handle large floods, there needs to be insurance that the flood waters are able to easily overtop the road near the culvert and re-enter the stream on the other side of the road causing only local damage to the road fill. Preferably the culvert should be at a low point in the vertical profile.
of the road ensuring all flood water is directed back into the channel, and not allowed to run down the drainage ditches. The culvert needs to be placed near a low point of a sag curve with the top of the culvert headwall equal to the top of the road in nearby location.

Figure 4.6 Eroded culvert outlet protection Mekele-Adwa km 39+038, Ethiopia

Source: Consultant

For low class roads, a drainage swale should be included that runs across the road to direct the flow back into its original channel. This method keeps flood water in the original channel if the capacity of the culvert is exceeded, which is a likely occurrence if using only a 5 year design storm for pipe culverts as required for pipe culverts and low road class. A drainage swale is only suitable where it is acceptable to have a speed barrier. It is most suitable for low class roads. There is difficulty in using this method on a high speed road, making it more critical to use a sufficiently sized culvert on the high speed roads. Although this does not prevent damage to the road, it keeps the damage localized rather than allowing the flows to travel alongside the roadways as seen in Figure 4.6.

The investment in culverts will not be met if they are allowed to fill with debris reducing hydraulic capacity. Maintenance needs to be increased on culverts before the rainy season ensuring that the culverts will have clear conduits. This can be difficult on smaller culverts where access is limited.

Debris at the culvert will attract more debris and sediment increasing the rate of plugging of the culvert. In remote areas where maintenance is limited, or in places that are hard to reach, culverts should be oversized and provided with appropriated gradient to allow for hydraulic capacity and to prevent silting up.
Summary

- Update design manuals with increase in rainfall as predicted by climate scenarios.
- Increase maintenance of culverts, cleaning, sediment removal, and scour repair.
- Size culverts based on potential costs of failure.
- Invest and research into increased scour protection for inlets and outlets.
- Research past culvert failures and apply lessons learned into new culvert designs.

4.3.4 Pavement design

Impact of climate change

The wet climate scenarios are showing significant increases in precipitation for the 24 hour design storms. It is difficult to quantify the difference in impact the different scenarios will have, as many of the impacts of rain are dependent on the road design and amount of maintenance performed.

The Ghana Wet scenario is showing large increases in the intensity of storms. The largest impacts to pavement design come from; loss of gravel, or other wearing courses and saturation of the base materials either through the surface, or from below. The largest impacts to the road section will come from flooding events, where the flood waters do not recede quickly and the road section is saturated for a longer period of time than designed for. See Appendix for further explanation of impacts of rain on pavement design.
Pavement design encompasses all the materials that comprise of the road that vehicles drive on. Rain will affect all parts of the road section, namely the subgrade, capping layers, sub base layers, and wearing course, whether it be gravel, paved, or an earth surface.

*Figure 4.8 Damaged road by flooding in Mopeia, in the Zambezi River basin in Mozambique*

Source: USAID (Photo by Tresja Denysenko)

Climate impact countermeasures

(1) Subgrade

With an increase in precipitation, it can be expected there will be a rise in groundwater levels and soil moisture from flooded areas. It follows that the number of sites with expansive and other problem soils that are detrimentally affected by high moisture content will increase.

GHA has experience dealing with black cotton and other problem soils by for example using chemical stabilizers, geo fabrics, and raising the roadway. An increase in rain may lead to large areas being flooded for a longer period of time than they are currently, and the increased use of these techniques. One of the key mitigations is to avoid these soils in the first place, but often due to other constraints, this is impossible. It is easier, cheaper, and more feasible to deal with future subgrade problems during the initial construction than as a reconstruction option later. There is no option for routine sub grade maintenance as it is covered by the upper layers of road material that would need to be removed in order to reach it.

One of the methods that is currently utilized to deal with flooded areas is raising the road surface using a capping layer. This can be a cost effective method of raising the roadway out of flood prone areas, or areas with high water tables.
Raising the road also helps promote positive drainage away from the road surface. The danger is that you create a dam effect for water that would otherwise move down stream and increase flooding in other areas. If the roadway is raised, then the design needs to incorporate more culverts or free draining rock underneath the road section that gives the water free movement.

Sealing shoulders has also shown to help alleviate the saturation of the sub-grade. High levels of saturation (80% – 100%) could cause distress which will usually result from pore pressure effects under wheel loads and mobilization of plasticity in the fine fractions. To avoid this saturation in wet areas where high levels of saturation is likely to occur, use of low permeability selected lower sub-base and sealed shoulders could be used to protect the sub grade from moisture movements.

**Figure 4.9**  Moisture movements in pavements and sub grades (NAASRA,1987)

Source: SATCC

Typically feeder roads will not have the budgets that allow for the expensive use of chemical stabilizers, or geo textiles. With feeder roads, the most important factor will be the location of the road. Avoiding problem areas is essential to a well functioning earth or gravel road. Where areas cannot be avoided, then the road must be built up above the area through the use of well draining rock. In areas where suitable capping layers cannot be provided locally for feeder roads, the next solution is to use chemical stabilization. As said previously, this is a high cost item; however, it will often be cheaper to use chemical stabilization than to import large quantities of rock material due to the cheaper transport costs of stabilization agents such as lime. The use of chemical stabilizers is not suitable for all soil types, and requires engineering knowledge in how to use them correctly. The use of chemical stabilizers or importing rock material should only be used after the investigation of alternative alignments has been exhausted.

Increases in precipitation and soil measure is expected to require additional use of the following construction techniques:

- Increased subsurface drainage
• Geo-textiles and Geo-net
• Increased use of chemical stabilizers
• Raise road using capping layer and well draining rock
• Sealing shoulders

(2) Sub-base and unbound base layers
There are technical methods discussed in the design manuals in keeping the sub-base layers within their optimum moisture content. An important factor in maintaining the paved wearing course is to insure a waterproof layer preventing water from infiltrating into the base layers. This requires routine maintenance patching, repairing cracking, repairing potholes, etc. There is also a need to maintain internal drainage of the layers. Water must be allowed to freely move through the section and exit into a well functioning surface drainage system.

When permeable base materials are used particular attention must be given to the drainage of the sub-base layer. Ideally, the base and sub base should extend right across the shoulders to the drainage ditches. Under no circumstances should a ‘trench’ type of cross-section be used in which the pavement layers are confined between continuous impervious shoulders.

If the water table is high, raising the road level with the use of large amounts of capping material may be necessary to move the section above poor draining soils and ensure a well draining section.

For earth and lower class gravel roads, the key to keeping the sub base levels dry if used, is similar to that of the sub grade; avoiding areas that will be flooded, or raising the road elevation, as well as ensuring adequate surface drainage away from the road.

In order to maintain functioning sub base layers with increased precipitation, there is a need for:

• Increased maintenance
• Raising road elevation
• Securing drainage (i.e. digging out a ditch and filling it in with high permeable material through shoulder)

(3) Wearing course
Regardless of the wearing course that is used on the road, the key elements to ensure climate resilient roads are adequate drainage, strong sub grade, and proper maintenance.

(a) Paved surface
Increase in precipitation will require an increase in pavement maintenance and repair. It is inevitable that some water penetrates the lower levels. The more water that infiltrates the sub base layers, the greater the chance of damage to the paved surface. Routine maintenance sealing, patching cracks, is essential, preferably in the dry seasons to prepare the surfaces for the upcoming rainy seasons. There has been much research lately into the needs of maintenance for
the paved network in Ghana, and it has been found that maintenance is critical for a well functioning road.

The paved surface is the final step in the road. In order to maintain the paving investment, there must be a well functioning sub grade, sufficient drainage, and routine maintenance.

The following may be needed in areas that experience higher than normal rain-fall amounts:

- Increased maintenance
- Increase in shoulder design strength
- Improved drainage.

(b) Gravel Surface

Ghana Highways Authority explained that currently, there is not a shortage of road building material in the country. In areas where gravel is available, road usage is low and the roads are regularly maintained, gravel roads are still a suitable design solution.

A problem with gravel roads is that they are easily saturated, and the gravel can wash away during flooding events. Gravel roads must be placed out of flood limits if they are expected to serve their purpose. Because they are easily saturated, it is also imperative that there is sufficient drainage away from the road surface, and that they are maintained and repaired before major damage occurs. Gravel loss must be replaced before the depth is too low to act as protection for the underlying layers. If the thickness of gravel wearing course is allowed to be less than 50 - 100 mm the gravel pavement ceases to function, no longer offering protection to the base materials and sub grade below, and the road becomes at risk of serious degrading requiring reconstruction. Ghana Highway Authority has set a plan of re-gravelling at least every 7 years. This plan is dependent on a plentiful source of quality material.

Detailed research should be done for the long term sustainability of gravel roads in Ghana. GHA states that currently, there is sufficient material, but it is unknown for how many years the quantities will be at sufficient levels for maintenance and new construction.

Where it is decided to upgrade a gravel road to a sealed road, no sealing investment will be met unless the road system as a whole is in good working order. This requires a strong sub grade, good drainage, and maintenance.

An increase in rain will most likely require an increase in the following:

- Increased maintenance
- Increased frequency of re-gravelling
- Use of alternative materials and sealing options
- Spot improvements
- Improved drainage.
(c) Earth surfaces

As of 2008, there is over 15,000 km of earth surfaced roads in Ghana, with approximately 30% being in poor condition. DFR has worked extensively with local road contractors on earth road construction methods that are most suitable to the climate and topography of Ghana. A benefit of a lower life expectancy for feeder roads is that their design can be more flexible to current climatic conditions.

Earth surfaced roads are at a disadvantage from climate impacts because there is no to limited surfacing that can divert water away from the road section. As stated in the previous sections, the location of the road and drainage of water away from the road become imperative to a successful earth road. Location is difficult to change after construction, but drainage can be maintained through adequate maintenance and drainage improvements.

Figure 4.10 Poorly draining earth surface road, Uganda

Source: Consultant

Earth surfaced roads can be built using labor-based methods. If the roads are built using labor-based methods, then it follows that they should be able to be maintained using labor-based methods. An adherence to guidelines as well as the following list will help to improve the likelihood of success for a community road.

- Increased maintenance
- Increased drainage.
(d) Vehicle Overloading

Overloading of vehicles is already a major cause for damage to Ghana’s roads. The damages will only be amplified by an increase in flooding and saturation to the road base materials. It may be necessary to extremely regulate the weight limits of vehicles that are allowed to use certain roads during flooding events, or when the base materials are overly saturated for the road design. This would require a large collaboration between the different ministries that are responsible for the movement of goods and people, and those that are responsible for the condition of the roads. Real time monitoring of the road conditions would be required as well as adjusting the traffic of freight and goods. For example, heavy trucks would be required to separate their heavy goods onto smaller vehicles, and large busses would be required to separate their passengers into mini busses. This approach would have obvious financial implications, and its use would be most suited to earth feeder roads whose immediate impact of vehicle overloading is seen when their base materials are overly saturated.

Summary

• Increased maintenance
• Raising road elevation
• Increased drainage
• Increased frequency of re-gravelling
• Spot Improvements
• Sealing shoulders
• Increased regulation of vehicle overloading.

4.3.5 Slope stability

Impact of climate change

Research has shown that heavy amounts of rainfall increases the likelihood of landslides. The Wet climate scenarios are showing increases in heavy rainfall events. Roads located in coastal areas close to the shore will be significantly affected by erosion due to sea level rise.

There is high likelihood that the large increases in rainfall seen in the Ghana Wet scenario will increase the likelihood for landslides and erosion. The frequency of large storms is expected to increase over 500%. Data on landslides was not collected for this report on Ghana that accurately predict the increase in slide activities, but it is very likely that areas which are now slide prone will experience slides more often with the future wet scenarios.

Unstable geology, new road construction, and or poor landuse leading to deforestation will all amplify the negative impacts of the increased rainfall and sea level rise on slope stability.

Currently, GHA feels that landslides in Ghana are not a major issue. There frequency is rare enough that they have not been deemed a top priority.
Climate impact countermeasures

It is usually not cost-beneficial or technically possible to build a road in a mountainous region that is not affected to some degree by slope failures. There are mountainous areas in Ghana; however, the vast majority of the country is fairly flat. Damage to the road is to be expected from slope failures in geologically unstable areas and in areas located close to the sea that can be affected by erosion amplified by sea level rise. There are best practices during construction and remediation that can help to minimize the occurrence of slope failure. There are slope stabilization techniques that can be used to aid in stopping deep landslide movements, and slope protection techniques that can be used to limit slope erosion and shallow slope failures less than 0.5m.

Slope failures should be viewed as a consequence to road construction in unstable locations. Landslide incidents may increase with greater precipitation and sea level rise. Areas that are suitable now for road construction might require additional slope stability methods if the terrain becomes unstable due to future changes in precipitation. Sea level rise can also impact slopes that along the coastline.

The level of slope stabilization used should be based on how critical the road is and the rate of road damage that is acceptable. The road should be designed so that it can be built and maintained at an acceptable cost. There is no data for the costs of maintenance related to landslide damages for Ghana, but for Ethiopia the costs of maintenance of landslide damages in unstable areas have been found to be in the long term, comparable to 10% of the costs of construction.
For Ghana these costs should be expected to be lower due to the flatter topography of the country. The costs of repair works become proportionately higher depending on the design standard of the road; however, high design standards do not necessarily insure that the risk of slope failures is lessened. In very unstable areas where frequent damages occur, it is advisable to design a lower standard of road. A lower standard road will be both cheaper to build and cheaper to repair and maintain when slope failures take place.

_Figure 4.12 Rockfall protection retaining wall Mekele-Abi Adi-Adwa km 52+3, Ethiopia_

Source: Consultant

The cost spent on slope failure preventions should be proportionate to the effort spent investigating the site. There is a risk that high investment slope stabilization projects will not be the correct solution if the required geo-technical information is not known beforehand. If geo-technical investigations find high probability of a significant deep seated landslide, the costs of preventing it is most likely not cost effective, and a new alignment should be investigated. Along new trunk alignments and higher class roads, a more intensive geo-technical investigation is needed in order to quantify the likelihood of slope failures, as the investment and repair of these roads is very high. If the likelihood of the cost of maintaining this road due to slope failures becomes too high, an alternative alignment, or a lower level of standard should be considered.

The cost of an intensive geotechnical investigation is maybe not cost effective on the lower class roads, and using current techniques covered in the design manuals to estimate the stability of the landscape is sufficient.
Slope stabilization can be a costly investment with limited benefits depending on the geology of the area. At a minimum, proper drainage and re-vegetation of the slopes should be provided. Drainage measures have been shown to lessen the movement of slopes when they work correctly; however, if they are allowed to deteriorate due to natural causes, bad design or lack of maintenance, their presence can accelerate the slope movement. Their use and installation should be done with care.

Figure 4.13  Gabions used as bank protection Mekele-Abi Adi- Adwa km 83, Ethiopia

Source: Consultant

Slope protection measures which aid in lessening the rate of erosion are a worthwhile investment that lessen the amount of maintenance and repair later on. Bio-engineering is one of the most cost efficient methods of slope protection. Some form of vegetation should be used on all roadway slopes that will accept plant growth. The vegetation helps to root the soil, preventing excess erosion that will later need to be removed from the drainage system. The use of the Vetiver grass system has been shown to be a highly successful, economically feasible solution around the world on various road projects. The drawback is that the species is non-native to Ghana, however extensive research has shown that the species is non-invasive. The use of a biological slope stabilizing method like this requires approval from the EPA and MRH.

On roads built in flood plains, there needs to be more effort on bank stabilization projects. The photo of the bank erosion on an Ethiopian road in Dire Dawa, Figure 4.14 shows the results of a large flood with high erosive forces. The bank stabilization required to prevent this would be a large investment, most
likely requiring retaining walls either constructed of gabions as seen in Figure 4.15 or concrete retaining walls.

*Figure 4.14  Roadside erosion Dire Dawa Region, Ethiopia*

On the trunk road shown in Figure 4.15 from aerial photo investigations it is found that over 2 km of bank protection would be needed to prevent this type of road destruction. The alternative to bank protection measures is to realign the road higher up out of the floodplain. Although it is easier to design a road that runs through a river valley, the costs associated with flooding may warrant moving the road up along the ridge or higher up out of the floodplain. It is worth delineating the 100 year flood, and determining the impacts of the flood on the roadway. If the road is at high risk from damage due to floods, it may be necessary to relocate the roadway.
It is recommended to continue using slope stabilization methods that are successful in Ghana and continue to adapt newer techniques when climate change conditions warrant.

**Summary**

- Ensure suitability of road location with regards to slope stability.
- Landslide protection should be proportionate to the amount spent investigating the site.
- Ensure proper drainage of all slopes.
- Re-vegetate cut and fill slopes with suitable plantings.

**4.3.6 Surface drainage**

**Impact of climate change**

The Ghana Wet scenarios are showing that the intensity of design storms for 2 to 10 year storms will increase by 26% to 39%. These values alone should not over-stress the current drainage system. What is more important is that the frequency of these design storms can increase up to 333%. This implies that these drainage elements will need to be monitored and cleaned more frequently to insure that there is capacity for these average sized storms.

The main impacts from the increase in rain will be in lack of capacity of the drainage elements. Roadside ditches and inlets may be undersized for the increase in precipitation leading to increased events of flooding on the roads both in cities and rural areas. Water velocities will be higher than designed for leading to increased scour damage of roadside drainage.
Climate impact countermeasures

Maintenance to the existing drainage network becomes all the more important with increases in precipitation. Routine maintenance, before, during and after the rainy season will help to alleviate total failures requiring replacement. Investments in drainage systems will be quickly lost if they are left to deteriorate or fill up with sediment. Maintenance should be prioritized in the areas most likely to experience flooding.

Figure 4.16 Poor roadside maintenance

Source: Consultant

Drainage systems should be updated in areas that have historically experienced flooding. Investigations should be done to find if it is cost beneficial to upgrade the drainage systems in these areas before a drainage failure occurs, or afterwards during repair or reconstruction. The risk of waiting to update the drainage system until after a failure is that during a large storm, the risk of multiple failures occurring at the same time increases. There are drainage systems that have additional storage capacity which could be needed in high-risk areas.

The measures to deal with surface draining from a road sector point of view both in urban and rural areas are principally the same. The drainage systems have to be designed with a capacity which reflects the expected change in intensity of rain with a clear view to balance construction costs with the economic risks and costs to the society of not having sufficient drainage capacity. The requirements for maintenance may also be similar. The road authority is normally in full control of designs outside cities but in urban areas, designs may have to be integrated with other types of planning and it has to be ensured that surface drainage in urban areas is designed to meet drainage requirements from both roads and other uses of space. Handling the increase of water in urban areas generally needs to be the responsibility of the relevant city authorities.

Urban road drainage is a much more complex process than road and highway drainage in open areas. Urban road drainage is typically connected to a drainage network that may be combined with wastewater. This water may then be
treated at a wastewater treatment plant before being released further downstream, or it may be released directly into a receiving body of water. Because the road drainage is connected to an often complex network, the success of the road drainage is dependent on the drainage network downstream being adequately sized. If the drainage is undersized downstream, it will have consequences upstream to the different sources. Therefore, adapting urban road drainage to be climate resilient also requires adapting the urban drainage network downstream of the roads. It is important to reduce the addition of storm water from the roads into the urban drainage network as much as possible. Road drainage can be treated separately before it enters the drainage network using best practices such as sustainable drainage systems. These best practices include items such as adding drainage swales, permeable pavements, and detention basins. Urban road and drainage planning should incorporate other urban development in order to design adequately sized drainage systems.

The design storms should be updated using the information from the climate prediction models.

**Summary**

- Update design manuals with increase in rainfall as predicted by climate scenarios.
- Increase maintenance of drainage systems.
- Increased collaboration in urban areas between DUR and other city utilities such as water and waste water.
- Use best practices of sustainable drainage to reduce storm water into urban drainage networks.
### Table 4.4  Climate change impacts-rain

<table>
<thead>
<tr>
<th>Climate Variable</th>
<th>Road Asset</th>
<th>Climate Change</th>
<th>Climate Change Impact to Asset</th>
<th>Recommended Climate Change Countermeasure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooding</td>
<td>Bridges</td>
<td>+36% to 39% increase in intensity of extreme events</td>
<td>Increase in Scouring, Capacity exceeded, River meandering, Siltation</td>
<td>Update Design Parameters; Increased scour protection during design phase; Large scale river training efforts; Detailed investigations in suitability of site location based on climate change predictions; Increase maintenance (scour protection, siltation removal). Primarily relevant for F in low areas</td>
</tr>
<tr>
<td>Flooding due to change in run off in surrounding areas affecting water in rivers (F)</td>
<td></td>
<td>Increase in run off in rivers in larger areas due to more rain in general</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flash floods following extreme events affecting road drainage (FF)</td>
<td>Culverts</td>
<td></td>
<td>Increased outlet velocities and scouring; Increase of overtopping events; Loss of gravel around culverts due to flooding; Increased siltation</td>
<td>Update Design Parameters; Increased outlet scour protection; Pave areas where frequent flooding occurs; Raise embankment; Increase maintenance (scour protection, siltation removal). Relevant for both F and FF</td>
</tr>
<tr>
<td>Pavement Design</td>
<td></td>
<td>More frequent flooding events; Loss of gravel surfaces</td>
<td></td>
<td>Raise roadway; increases in paving gravel roads, other spot improvements. Primarily relevant for FF</td>
</tr>
<tr>
<td>Surface Drainage</td>
<td></td>
<td>More frequent flooding events, damage to road and drainage systems</td>
<td>Preemptive maintenance; Use storm water systems that can accommodate more siltation, and require less maintenance</td>
<td></td>
</tr>
<tr>
<td>Average annual Precipitation; Groundwater levels</td>
<td>Pavement Design</td>
<td>Up to 27 mm increase precipitation for the annual rainfall, possible increase groundwater levels</td>
<td>Increased saturation of subgrade materials; Gravel loss; Impassable earth surfaced roads: Weakened subgrade materials</td>
<td>Require 4 day soaked CBR testing in all regions; Increased use of chemical stabilizers, geo-textiles; Sealing of gravel roads; Paving of shoulders; Increased maintenance</td>
</tr>
<tr>
<td>Slope Stability</td>
<td></td>
<td>Increases in Landslides, Erosion</td>
<td></td>
<td>Detailed investigations in suitability of site location based on climate change predictions; Increase in slope protection.</td>
</tr>
<tr>
<td>Surface Drainage</td>
<td></td>
<td>Increased siltation leading to increased flooding of the drainage systems</td>
<td>Preemptive maintenance; Storm water systems that can accommodate more siltation, and require less maintenance</td>
<td></td>
</tr>
</tbody>
</table>

*Source: Consultant*
4.4 Sea level rise

4.4.1 Introduction
Sea level rise has an impact on road infrastructure by increasing the rate of erosion and encroachment towards land. Sea level rise can also amplify flooding inland. If the sea level is at an extraordinarily high level, this can create a damming effect to rivers that drain into the ocean causing upstream flooding.

4.4.2 Infrastructures
Impact of climate change
There is very limited information regarding estimates of sea level rise in Ghana related to the climate scenarios considered for this project. The majority of the trunk road network is located far enough inland where it should not be damaged by sea level rise. The largest threat from sea level rise is towards urban infrastructure, as well as sea infrastructure such as ports.

Climate impact countermeasures
The most effective mode of developing new road infrastructure near the oceans to build new roads at a height above sea level and a location where neither sea level rise nor erosion of beach slopes will impact the road. If this is not an option, or there is existing road infrastructure, then the road should be protected similar to roads that are susceptible to flooding from rivers. The countermeasure to sea level rise is dependent on the importance of the road infrastructure that is being affected. On low traffic roads, it may be allowable to have delays where high water overtops the road. In these instances, the most important countermeasure is to protect the pavement structure from erosion. This is possible by increasing the shoulder armoring of the road either with stone or with more thorough engineering solutions. For high traffic roads where closures are not acceptable, more rigorous, costly engineering solutions may need to be applied. An example could be a combination of raising the roadway to a level above a predicted storm event level with increased armoring of the road shoulders using large stone or concrete retaining walls.

It is nearly always required to use erosion resilient materials or engineering designs when raising the roadway in areas that are susceptible to flooding. Raising the roadway will be a waste of resources if the materials are allowed to wash away. Slopes that are prone to erosion along roadways can be armored with gabions, large rock, or retaining walls to slow the damage from sea level rise. It can become a very expensive investment in sea level protection regarding road infrastructure. The coast of Ghana is open to the South Atlantic and receives relatively large swells year round. The erosive force of the ocean can quickly erode any engineering efforts if not sized correctly. It may prove more economically feasible to build a new section of road further inland than attempt to protect it from the ocean.

Roads should not be constructed in risky areas. The direct approached solution to this problem is to monitor land use, because the decision on where to build infrastructure is driven by the locations that the road has to connect. It should be avoided to build more dwellings in areas at risk.
The approach of making infrastructure climate resilient has a different dimension when considering sea level rise. The implications of a considerable increase in sea level would be more devastating on humans than on infrastructures. Regardless of the standards, techniques or materials being used, if the water took over urbanized land sides, the infrastructures located in those areas would be severely damaged, there would be broken links for the infrastructures affected, and the area would be unutilized by population. If such a scenario took place, it would not be reasonable to replace the infrastructure but rather to find safer locations for the population to settle and for the infrastructures to be built, therefore reconstruction should be avoided. Nevertheless, it is recommended to protect the existing urbanized areas at risk with coastal defenses.

Summary

- New road infrastructure should be placed inland enough so that it is out of direct threat from sea level rise
- Develop countermeasures specific to individual locations and roads, e.g. increase elevation of roads, which can not be relocated
- Erosion prone slopes e.g. due to flooding, storm surge and coastal erosion on existing roads can be armored, but the costs may quickly approach building new road infrastructure further inland
- Biggest impact from sea level rise is on urban infrastructure and the inhabitants that live there, so coastal protection such as sea walls, dikes etc. may have to be constructed to protect existing values
<table>
<thead>
<tr>
<th>Climate variable</th>
<th>Road asset</th>
<th>Climate change</th>
<th>Climate change impact to asset</th>
<th>Recommended climate change countermeasure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing sea levels, storm surge</td>
<td>Bridges</td>
<td>Increased water levels in coastal areas and rivers; intrusion of salty water; reduced clearance under bridges</td>
<td>Increase in: scouring, capacity exceeded, river meandering, siltation, salt related damage in low lying areas</td>
<td>Higher elevation of infrastructure; update design parameters; increased scour protection during design phase; large scale river training efforts; detailed investigations in suitability of site location based on climate change predictions; increase maintenance (scour protection, siltation removal); corrosion protection may be needed in low lying areas</td>
</tr>
<tr>
<td></td>
<td>Culverts</td>
<td></td>
<td>Reduced outlet velocities leading to reduced capacity; salt related damage in low lying areas</td>
<td>Higher elevation of infrastructure in low lying areas; corrosion protection may be needed</td>
</tr>
<tr>
<td></td>
<td>Pavement design</td>
<td></td>
<td>Increased saturation of subgrade materials; gravel loss; impassable earth surfaced roads; weakened subgrade materials</td>
<td>Raise roadway; increases in paving gravel roads; relocation of road if higher elevation is not feasible</td>
</tr>
<tr>
<td></td>
<td>Surface drainage</td>
<td></td>
<td>Increased saturation of subgrade materials; gravel loss; impassable earth surfaced roads; weakened subgrade materials</td>
<td>Raise roadway; increases in paving gravel roads; relocation of road if higher elevation is not feasible Preemptive maintenance;</td>
</tr>
<tr>
<td></td>
<td>Slope stability</td>
<td></td>
<td>Increases in landslides,</td>
<td>Detailed investigations in suitability of site location based on climate change predictions; Increase in slope protection.</td>
</tr>
<tr>
<td></td>
<td>Coastal erosion</td>
<td></td>
<td>Erosion of road base and bridge support; Loss of coastal (wet)lands and barrier shoreline protecting roads</td>
<td>Coastal protection (sea walls, dams, dikes etc.)</td>
</tr>
</tbody>
</table>

Source: Consultant
4.5 Nature and extent of climate impacts

4.5.1 Introduction

The climate predictions results show important increases in precipitation for the Wet scenarios that indicate drastic increases in flooding events. Over the last 50 years, 9 out of 10 of the largest natural disasters in Ghana have been flood related. Ghana has in the past been prone to large floods, and will be more so in the future according to the Wet scenarios. An overview of the top 10 natural disasters in Ghana is shown in Table 4.6:

Table 4.6 Top ten natural disasters in Ghana between 1900 and 2010

<table>
<thead>
<tr>
<th>Disaster Type</th>
<th>Year</th>
<th>Total affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought</td>
<td>Oct-1983</td>
<td>12,500,000</td>
</tr>
<tr>
<td>Flood</td>
<td>14-Jul-1991</td>
<td>2,000,000</td>
</tr>
<tr>
<td>Flood</td>
<td>5-Jul-1995</td>
<td>700,000</td>
</tr>
<tr>
<td>Flood</td>
<td>10-Aug-2007</td>
<td>332,600</td>
</tr>
<tr>
<td>Flood</td>
<td>Sep-1999</td>
<td>324,602</td>
</tr>
<tr>
<td>Flood</td>
<td>27-Jun-2001</td>
<td>144,025</td>
</tr>
<tr>
<td>Flood</td>
<td>17-Sep-2009</td>
<td>139,790</td>
</tr>
<tr>
<td>Flood</td>
<td>Jul-2008</td>
<td>58,000</td>
</tr>
<tr>
<td>Flood</td>
<td>20-Jun-2010</td>
<td>25,090</td>
</tr>
<tr>
<td>Flood</td>
<td>Jul-1968</td>
<td>25,000</td>
</tr>
</tbody>
</table>


4.5.2 Current soft spots in the road infrastructure

The term "soft spots" is used to describe areas in the current Ghana road network that are frequent problem areas with large disruptions to the traffic flow.

Road network conditions

MRH has been proactive in assessing the conditions of their road network. Figure 4.17 and Figure 4.18 show the condition of the paved and unpaved road networks from the years 2000-2008. The overall condition of paved roads in good condition has increased over the last 8 years. The unpaved network has had a much more gradual increase in roads in good or fair condition with the number of roads in poor condition starting to increase between 2007 and 2008.
Figure 4.17 Condition of Paved Road Network (2000-2008)

Source: TSPS II

Figure 4.18 Condition of Unpaved Road Network (2000-2008)

Source: TSPS II
From site visits, it was experienced that the roads with higher traffic intensity were generally in fair to good condition regardless of being paved or unpaved, while the lower traffic intensity roads were generally in poor condition. The lower traffic volume on the roads in poor condition could be a direct result of the condition of the road. It is likely that detours are found around these roads in poor condition, hence the low traffic volume.

Besides the exception of the bridges recently washed out in Agona Swedru, the condition of other bridges in the area were assessed to be of fair to good condition. This was generally true for drainage elements as well, such as road side drainage and culverts.

**Flood plains**
A large area of Ghana north of Lake Volta up to Burkina Faso is made up of wide, relatively flat floodplains. Flooding in this region is commonplace, and there have been repeated instances of large damage to both residential and road infrastructure. Much of the flooding is amplified by a lack of water resource cooperation between Ghana and Burkina Faso. Increases in extreme events due to climate change will increase the flooding in these areas.

**Error! Reference source not found.** Figure 4.19 shows the extent of flooding in 2007 that affected 40,000 people and resulted in approx. 250 million GHC of damage of the Kulungugu Bridge linking Ghana to Burkina Faso. The biggest impact of these 2007 floods was on agriculture and housing.
There are many challenges with building roads on floodplains. These include finding local material that is suitable, building on poor sub grade materials, drainage, and water overtopping the roadway. Building a climate resilient road through a floodplain requires adhering to the recommendations described in Chapter 4.3. In addition, roads in floodplains must be built in an approach that does not increase flooding downstream in other areas.
Where possible, it is recommended to avoid building roads in floodplains. With modern GIS and surveying capabilities, it should be possible to delineate probable flood limits. It is suggested to not build valuable infrastructure within these flood limits. This is the easiest and likely most cost beneficial mode of building new roads in flood prone areas. This approach should be taken at a transportation planning level. It is common practice to rehabilitate and reconstruct existing roads in their original right of way. It becomes important to properly plan the location of road infrastructure from the beginning taking account for possible climate changes.

The typical approach to building in floodplains is to build the road so that the road surface is raised above the surrounding floodplain. This ensures a dry road surface but may increase flooding in other areas. The road embankment can serve as a large flood levy, and its construction needs to be at the same level as a flood levy requires for it to withstand large floods, associated with frequent adequate maintenance. The construction of the flood levy/road embankment should be based on the expected erosive forces of the floodplain waters. Where new roads cross a floodplain river basin combined with a bridge, there can be unintended increases in flooding. Roads built in floodplain areas must balance the need to stay dry during the wet season as well as not contributing to downstream flooding by acting as unwanted flood levies. Road embankments should be designed so that water can freely move underneath the embankment through well draining rock. In some areas, it may be beneficial to use series of culverts, however, these areas can become stressed if they are expected to drain large areas of flood plain, and they need to be sized and built accordingly.

Figure 4-20 shows the impact that the N1 road embankment had on the Zambezi River floodplain near the town of Caia in Mozambique. This picture is from a flood event in 2007, and the ferry today is replaced by a new bridge, but the high road embankment is still being used. Figure 4-20 clearly shows how the flood plain boundary has been narrowed by more than twice its original width due to the road embankment.
Figure 4-20  Zambezi floodplain N1 near Zambezi Bridge

Source: RESPOND, UNOSAT, DLR

The narrowing of the floodplain also acts to increase the flood velocity underneath the bridge area which will increase the scour potential and downstream damage in the vicinity of the embankment.

In floodplains and lower lying areas near the ocean, the inundation extent is also associated with rising sea levels in the estuaries of the river basins. The river estuaries around the Volta River Basin and Keta Lagoon are low points in the coastline through which sea water can easily propagate inland. These estuaries are vulnerable to the combined effects of chronic sea level rise, tidal wave action and acute events such as tropical storms. Building roads in these areas must account for flooding coming from both upstream and downstream.

On the Keta Peninsula, the coastal roads are currently placed in or near the highest spots in the landscape. These high spots may however only be a few meters above river/sea elevation. The landscape in this area is so flat that the only way to ensure a road stays dry throughout the year is to build the road up on high embankments. Again, this can be a dangerous method if road embankments are constructed poorly. Road embankments have the potential to decrease the size of the floodplain increasing flooding potential in other areas.

Another challenge of building in floodplains is finding suitable local material. Suitable gravel for wearing and base course may be a large distance away. Importing material quickly becomes one of the most expensive pay items. This adds additional challenges during required re-gravelling or reconstruction, and the use of alternative materials that can be found locally should be thoroughly investigated prior to construction. If poor materials are to be used (no funds for cement or bitumen treatment or for transporting material of a better quality), a
shorter structural design period should be adopted, resulting in a higher rehabilitation (reworking, regravelling and compaction) frequency. Deterioration of these roads will come much earlier and progress more rapidly if the materials used are of marginal quality and the precipitation increases. Some of the problems come from past decisions when road projects focused on providing access for as many people as possible, and where the number of kilometers of completed network was more important than the quality of those roads, which failed to take into account long term consequences.

Low quality of sub grade and increasing traffic loads lead into fast deterioration of roads, a process that in some cases does not even reach the life span that they have been designed for. The procedures for the application and approval of wearing course materials are more stringent than those of the sub grade and base materials. For instance, the required thickness of the wearing course takes into account the need for adequate bearing capacity to carry the traffic and general wear due to traffic and erosion. Uniformity and consistence of the wearing course layer in terms of material properties, layer thickness and compaction are of great importance. The approval method for the base materials and construction should be of equal importance.

It is obvious that in order to reduce transportation costs, the preferable materials to use are the ones found locally, therefore the emphasis and stress is on how to adjust guidelines, specifications and construction techniques to suit the quality constraints for the given traffic volumes. This requires having sound investigation data of the available local building materials.

Designing roads in floodplains where flooding is amplified by neighboring countries water uses is also a challenge. Ghana often experiences flooding due to flood water management in Burkina Faso. Because Ghana lies downstream of Burkina Faso dams and has little say on when the waters can be released, it can be difficult for Ghana to manage this water. There is an initiative currently that aims to create a joint Ghana/Burkina Faso management of the Upper Volta Basin. Calculating the true watershed area and flood potential requires a large study into the joint country watershed management.

Road Design
It is important that all aspects of road design are well integrated, such as pavement design and traffic safety measures. Figure 4.21 and Figure 4.22 show images of traffic safety measures on the N6 Highway outside of Accra. The photos are taken within a kilometer of each other on the same day. Figure 4.22 shows the unintended consequences of traffic diverting themselves around the speed bumps and leading to flooding on a section of the road. This portion of the road is most likely not designed to always be 100 percent saturated and failure in this section is to be expected unless a solution is applied.
Another threat to Ghana’s road infrastructure is through sea erosion. The highest population densities are near the Gulf of Guinea and it becomes necessary to build roads near the ocean. Erosion rates from sea intrusion have been predicted to be between 1 and 10 meters per year. The ranges vary extremely from location to location.
4.6 National design standards in Ghana

4.6.1 Introduction
GHA is in the process of updating their design manuals. They hope to officially update them beginning next year. Currently, the manuals used in Ghana were produced between 1991 and 2007. Engineers that design for DFR have their own set of manuals that are condensed versions of the larger GHA manuals.

4.6.2 Recommendations to the manuals
It is recommended to update the rainfall charts in the design manuals with more recent accurate data. The overall feeling from the Department of Meteorology and GHA is that the rainfall charts no longer represent the actual rainfall conditions in Ghana. It is suggested to supplement the manuals with a section that is focused on the most common climate related issues and economic engineering methods to deal with them.

It is recommended that DFR continue to produce their own versions of simplified design manuals. For the feeder roads, it is imperative that their designs can be flexible to accommodate and integrate new engineering solutions that are cost beneficial as they become available.

Currently, DUR uses the same manuals as GHA. Drainage is one of the most important factors for both urban roads and highways. However, urban road drainage is often more complex when it is connected with other city utilities that are already stressed during a storm event. It is recommended to incorporate best practice designs to the drainage section that will help to alleviate some of the flooding problems. These best practices include items such as adding drainage swales, reducing storm water runoff, permeable pavements, and detention basins. Urban road planning and drainage needs to be incorporated with other urban development and its drainage needs in order to design a drainage system that is adequately sized.

4.7 Maintenance
In April 2008, MRH produced the report “Determination of Maintenance Needs of Ghana’s Road Network.” It was concluded that in order to bring Ghana’s road network (GHA, DUR, DFR) up to good condition, it would require nearly 3 billion USD in the first year. In 2008, the total expenditure for maintenance was estimated around 300 million USD. There is a strong need for finding maintenance methods that are economically feasible and are able to maintain the roads to a good level of service.

The recommendation of the Consultant is summarized below.

4.7.1 Climate change and road maintenance
Strictly speaking road maintenance is not an adaptation measure as the purpose of maintenance is not a function of climate change but applies irrespective of the conditions for the road infrastructure, hereunder impact by climate.
The purpose of maintenance is to ensure the longevity and functionality of the infrastructure investment. The scope of maintenance is therefore a function of all parameters which affect the longevity and functionality of the infrastructure. This includes i.a. geometric, pavement and drainage design, traffic impact and climate. Therefore the local climate shall be taken into consideration when planning and implementing maintenance. It follows that climate change may trigger new requirements and demands to maintenance in order to prevent deterioration of the infrastructure.

Our basis for the following is a postulate that the optimal measure to adapt to climate will be to maintain the roads so that they always are in a (near) perfect condition meaning that their resilience to climate impact is at all times (near) maximum.

- Roads/road sections which, under such maintenance attention, are able to tolerate the climate impact and maintain their longevity and functionality, shall not be strengthened.
- Roads/road sections which, in spite of optimal maintenance, can not tolerate the climate, but suffers from reduced longevity and functionality, should be designated for relevant reconstruction and strengthening.

The proposed adaptation strategy is therefore to maintain the road network as best possible and only when this is insufficient in view of the climate impact, to reconstruct and strengthen the road in appropriate ways.

It follows that maintenance will have a key role in the adaption to climate changes. It will not be possible or even necessary to change or reconstruct the bulk of the road network, primary or secondary, in order to cope with climate changes. Reconstruction of roads may of course be the only solution at certain sites if e.g. there are serious risks of flooding ("soft spots"), mudslides or whatever, but should only be applied when the possibilities for making the roads climate resilient through maintenance is exhausted or there are other reasons like e.g. changes in traffic patterns which will make upgrading of the roads beneficial.

4.7.2 Climate change adaptation strategy
We summarize the basic strategy as:

a) In general the existing road network should remain as is unless changes in traffic patterns make reconstructions beneficial and necessary and unless climate impact is above the design resilience sections of the roads.

b) The strategy is to maintain the roads all the time to a high quality. Only if this is insufficient in relation to the climate impact, reconstruction should be considered.

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4 Although traffic impact is not considered in the following it shall not be forgotten that traffic impact and traffic impact changes in parallel to climate impact plays an important role in the planning of maintenance and reconstruction activities. It means that traffic projections and development plans should be taken into account.
c) Maintenance measures shall be planned to cope with existing climate while reconstructions (strengthening) or upgrading of roads and road sections (soft spots) shall be designed to cope with future climate.

It shall be understood in the following that climate change in practical terms refers to an increase of the climate impact. Climate changes with leads to less impact are not considered directly.

4.7.3 Economy

It should be realized that present road maintenance performance does not meet the proposed strategy: optimizing maintenance so that the roads are always in a very good condition. Implementing the strategy, even under the assumption that climate impact is not increasing, indicates that maintenance costs are bound to increase.

This view is too simplistic however. In the present maintenance regime, there may be ample possibilities for improving efficiency - by improving the decision basis, by adjusting the maintenance organization and/or by changing the technological methods in maintenance.

Basically it will be central for successful adaptation to climate change, that the costs of maintenance are minimized in respect of performance. In other words, economic considerations should have a central role in forming the maintenance strategy. This is even more important as maintenance activities are foreseen to increase for - at least - part of the road network as result of the expected climate changes.

In the following we consider means and measures which may lead to a more efficient maintenance organization. It is also realized that external support in funding of adaptation measures may be focusing on the increase of maintenance costs as result of climate change. We therefore propose a model for how maintenance activities (and subsequent costs) can be linked in a transparent and verifiable way to climate changes (road database).

4.7.4 Overview

Maintenance categories

We consider three principal maintenance approaches:

- Routine maintenance
- Corrective maintenance

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5 It should be noted, that this strategy applies at all times and not in particular in relation to climate change.

6 It follows that the alternative strategy - which assumes that roads are reconstructed to increase their design resilience while maintenance is kept sub-standard, is considered inappropriate and uneconomic.

7 In case of climate changes leading to less impact, strengthening of the roads may not be relevant and to keep the roads in a permanent good condition maintenance activities may even be reduced.
• Conditional maintenance

Routine maintenance is performed according to a predetermined plan, independently of actual road condition. Routine maintenance should be the foundation for the maintenance activities and will if planned correctly in respect of known impact from climate and traffic, ensure that the road is for a large part of the time in good condition. Since routine maintenance is executed before road failure takes place, it will usually be possible to minimize traffic problems as result of the maintenance activities.

Corrective maintenance is performed in response to actual road condition. Corrective maintenance should only be necessary in case of unusual events (flood, mudslides, accidents) but will if routine maintenance is insufficient or absent, often be the common maintenance activity. That is when the road organization only responds to serious failure (closures or difficult pass ability) of the road.

Conditional maintenance is between the other types of maintenance and should apply when the roads is observed to suffer damage, but is still fully functional. Conditional maintenance therefore relevant when routine maintenance is inadequate and will prevent application of corrective maintenance.

Methodologies
Finally we consider two principal technical methodologies:

• Equipment based technology
• Labor-based technology

It should be noted that the optimal approach will depend on the type of roads as well as the type of work to be done. Labor-based technology may be economical for some work/roads but not for other.

4.7.5 Organization of road maintenance

Overall the organization of road maintenance should be designed to achieve its objectives in the most economical way - in order to maximize returns at any given input - and to meet external political objectives relevant for the activities.

Ghana has established a database for the road network, and we suggest that this central database is used for holding relevant information for central and decentralized decision making and analysis of activities.

Road database
Management of the road infrastructure should be based on proper and relevant information as basis for planning, budgeting and decisions. Establishment of a comprehensive centralized road database will be a logical and helpful tool.
The Bridge Management System can be used as an example and built upon to include information such as:

- Road ID
- Road location
- Road category (primary, secondary, bound, unbound surface etc.)
- Traffic data
- Weather data (weather station data, local observations)
- Road condition and pass ability correlated with milestones/GPS coordinates
- Specific temporary problems (flooding, mud slides) correlated with milestones/GPS coordinates
- Identification of soft spots (requiring extensive maintenance and attention) correlated with milestones/GPS coordinates
- Maintenance activities for each road section (planned, required, done)
- Maintenance cost data (actual and standard) broken down in equipment, labors and materials cost
- Technology applied in maintenance activities (labor-based, equipment based (specification)).

The database should be dynamic, that is under continuous update. Data should be assembled through e.g. mobile-internet* means by links to centralized server. The capacity of today's technology makes it possible to preserve all historic data and make them subject to automatic analysis. Of particular interest will be to monitor changing maintenance requirements with respect to changing climate over medium to long periods and subsequent register developments in budget requirements with respect to climate changes.

The purpose of the database is to enable management optimize resource allocation, plan activities and identify urgency of interventions (soft spots). The database will be a tool for planning of budget, staff and equipment requirements and serve as a means for prioritization of activities in case of budgeting restraints.

The establishment of the database will make transparent management possible. It should be considered that decentralized road organizations as well as the public in general shall have access to the database or parts of it to provide all stakeholders with a thorough understanding of the situation. The hope of decentralizing road maintenance on rural roads is that it will enable development of smaller local based maintenance operations. The operations may be com-

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*Internet services based on mobile phones are already widely used in Africa and plays a much stronger role here than most places elsewhere. Collection and submission of data via mobile phones to central serves is a very fast, efficient and cheap way of compiling data and could be ideal for maintaining the database with up-to-date and reliable data.
munity based, and aid in the development of labor based maintenance methods, with the maintenance of roads acting as a source of local income.

**Methodologies**
The technology applied in maintenance is also critical for the economical performance. The key to optimize the choice of technology is economy. Assuming a free market (contracting) and design specifications being open for different technologies to reach the same result, economic considerations will naturally filter out the less economic technologies and promote the more economical technologies.

Equipment based technologies (EBT) means the application of heavy, labor-saving equipment, that is on the balance much equipment and little labors. Labor-based technologies (LBT) also uses equipment, but with more weight on manual work and less on equipment based work. So both technologies employ equipment as well as labor, but the balance is different.

In Ghana the wages are much lower that in the industrialized countries. The economical optimal balance between equipment and labor input will therefore also be different. Equipment is used in the rich countries when it is economical beneficial, not because it is fancy. The same should apply in Africa.

However, much road maintenance in Africa is done by application of heavy equipment which is characteristic for work methods in the rich countries\(^9\). The result is that available cheap labor in Africa are not getting jobs they could have performed economically while labor in the rich countries are being employed in the production of the equipment.

Therefore we suggest that the work activities in road maintenance are analyzed with respect to suitability of labor or equipment based methods. In particular for gravel roads, many work procedures may be economically optimal by application of LBT.

Apart from being economically beneficial for the private investor (the contractor) making him more competitive and therefore also more beneficial to the road organizations, LBT creates cash flow in the small communities who provides the labor. Other considerations can be that LBT is much more robust in respect of equipment maintenance (tractors are much easier to maintain than heavy, hydraulic equipment) and the contractor is therefore not so vulnerable in case of mechanical failures. Dissemination of LBT on a large scale may also create a basis for local industry producing construction equipment for LBT.

Extensive experience from a number of African countries on LBT should be studied to identify work areas where it can be applied to the benefit of society.

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\(^9\) This may to some extent be attributed to the influence by donors who historically has encouraged EBT, perhaps out of interest in supporting their own equipment industries.
5 Costs of climate change

5.1 Introduction
For new construction, rehabilitation, or upgrading, the major work items are as follows:

- General
- Site clearance
- Drainage
- Earthworks
- Sub base, road base and gravel wearing course
- Bituminous surfacing and road bases
- Structures
- Ancillary works
- Day works.

5.2 Current costs
For construction of roads, upgrading and rehabilitation, the costs per kilometer have been retrieved from GHA as listed in the following table.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Cost/km (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Dressing (ST)</td>
<td>773,014.76</td>
</tr>
<tr>
<td>Surface Dressing (DT)</td>
<td>1,251,159.52</td>
</tr>
<tr>
<td>Asphalitic Overlay</td>
<td>1,509,978.92</td>
</tr>
<tr>
<td>Regravelling</td>
<td>290,530.57</td>
</tr>
<tr>
<td>Resealing</td>
<td>634,399.16</td>
</tr>
<tr>
<td>Partial Reconstruction</td>
<td>661,981.73</td>
</tr>
<tr>
<td>Upgrading</td>
<td>773,014.76</td>
</tr>
</tbody>
</table>

Source: GHA 2010

Table 5.2 shows associated cost/km taken from the average cost/km of upgrading from gravel to paved supported by a granular base-course and sub-base. The percentages are based on comparison with other projects done by the consultant in the region. The results are summarized in the following table:
Table 5.2  Cost item percentages for upgrading from gravel to paved road

<table>
<thead>
<tr>
<th>Description</th>
<th>Percentage</th>
<th>Cost/km USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>7%</td>
<td>44,353</td>
</tr>
<tr>
<td>Site Clearance</td>
<td>0.50%</td>
<td>3,168</td>
</tr>
<tr>
<td>Drainage</td>
<td>8%</td>
<td>50,689</td>
</tr>
<tr>
<td>Earthworks</td>
<td>15%</td>
<td>95,043</td>
</tr>
<tr>
<td>Sub base, Road Base and Gravel Wearing Course Bituminous Surfacing and Road Bases</td>
<td>55%</td>
<td>348,490</td>
</tr>
<tr>
<td>Structures</td>
<td>10%</td>
<td>63,362</td>
</tr>
<tr>
<td>Ancillary Works</td>
<td>4%</td>
<td>25,345</td>
</tr>
<tr>
<td>Day works</td>
<td>0.50%</td>
<td>3,168</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>100%</strong></td>
<td><strong>633,615</strong></td>
</tr>
<tr>
<td>Contingencies + Other Fees</td>
<td>17%</td>
<td>107,715</td>
</tr>
<tr>
<td>Supervision</td>
<td>5%</td>
<td>31,681</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
<td><strong>773,015</strong></td>
</tr>
</tbody>
</table>

Source: GHA, ROCKS Database, and consultants own experience on road upgrading projects in the region.

5.3  Climate impact

Rainfall will have the most significant cost impact on Ghana’s road network. Temperature and wind will have minor cost implications that should be dealt with during the design phase, and will not have an overall large influence on the cost of a climate resilient road. For this economic analysis, only the influence of increased rain is investigated.

From the climate change predictions, the data used corresponds to the largest change in 24 hour storm precipitation which is expected to be around 39% for the 100 years storm for the Ghana Wet scenario.

5.4  Costs increases for construction of a climate resilient road

5.4.1  General

The costs associated with the General work item are not expected to increase for a climate resilient road in the future. This work item generally includes costing for accommodation, office space and various other items generally unrelated to climate.

5.4.2  Site clearance

The costs associated with site clearance are not expected to increase significantly with increased rainfall.

5.4.3  Drainage

The cost item Drainage includes: cross and box culverts, unlined side ditches, concrete lined side ditch as well as U-shaped ditches (open and covered).
Drainage is an item that is expected to need an increase in investment in order to cope with the increased flooding events. An increase in culverts may be an associated requirement of raising the roadway. It follows that raising the roadway will create a damming effect, and therefore more drainage structures will need to be installed to alleviate flooding.

On typical road upgrading projects, the minimum size of new culverts is 900 mm. It was common to use smaller diameter pipes in the past, but it is highly recommended to use larger pipes for ease of maintenance. For small watersheds, a 900 mm pipe is most likely sufficient for most drainage needs.

Table 5.3 shows the relationship between culvert sizing and cost increases for standard sizes for a road project done by the consultant in Ethiopia.

<table>
<thead>
<tr>
<th>Diameter mm</th>
<th>Cost/m USD</th>
<th>Capacity increase</th>
<th>Cost increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>500</td>
<td>30%</td>
<td>25%</td>
</tr>
<tr>
<td>1100</td>
<td>600</td>
<td>27%</td>
<td>20%</td>
</tr>
<tr>
<td>1200</td>
<td>750</td>
<td>24%</td>
<td>15%</td>
</tr>
</tbody>
</table>

Source: COWI 2008 for the Wukro-Agridat-Zalambesa Road Study in Ethiopia.

Using data from a recent project on the Wukro-Agridat-Zalambesa Road in Ethiopia, the cost of increasing the sizing of all of the reinforced concrete pipes can be found. To increase the hydraulic capacity by a minimum of 27% namely 900mm to 1000mm and 1000mm to 1100mm, as well as their respective headwalls and outlets would cost an additional 10% to the drainage item, but only an additional 1% to the total cost of the project, an additional 5,000 USD/km.

The remaining drainage items such as ditches and drains are relatively low cost items, but their costs can be expected to increase relative to the increase in costs of culverts, namely 10%.

For a completely new road where minimum sized culverts and drainage elements are used for all crossings, cost is expected to increase comparable to the 25 year storm, 38% for the Ghana Wet. For road upgrading projects, it is assumed that many of the structures will still have the hydraulic capacity for the new design storms, and the increase in price will be on the order of 10-15%.
5.4.4 **Earthworks**

The cost item Earthworks include all the initial excavation and compacted fill, up to top of sub grade level, as well as the disposal of surplus soil. The increased rainfall may lead to increased ground water levels, which may have a negative impact on expansive soils. This will either require the increased removal of problem soils, increased use of chemical stabilizers in the native material such as lime or cement, or increasing the fill embankment height to raise the road surface. It is impossible to estimate the quantities that will be required in the future based on the limited information we have now.

As development in the country increases, more soils problems will be encountered requiring more use of these options.

Price of using chemical stabilization is unknown for the project, but based on average estimated prices for Ethiopia, for a road section requiring chemical stabilization, the increased costs associated are approximately 41,000 USD/km. The cost of raising the roadway one meter for a 2 lane 10 meter wide carriage-way is between 10,000 and 40,000 USD/km. These solutions are not applicable everywhere and it is at the discretion of the engineer to decide when and where they should be used.

Many of these problem soils areas will be able to be determined before climate change impacts are experienced when a 4 day soaked CBR test is used, and are not dependent on increase in rain but on the type of materials the road is built upon. Ghana currently uses a 4 day soaked CBR test for their pavement design, and is experienced in using different types of soil stabilization, and raising the roadway if deemed necessary. For this reason, it is difficult to predict the cost increases associated with this item due to climate change, because the majority of future problems in the sub grade should already be accounted for with current designs. It is expected on average that the Ghana Wet scenario will require between 5% to 10% more investment in earthwork stabilization due to climate change. These are increases associated with climate change; many areas that will experience flooding in the future most likely require some sort of stabilization now.

5.4.5 **Sub base, road base and gravel wearing course and bituminous surfacings**

This cost item includes all the sub items related to the pavement design. The costs associated with this work item vary extremely depending on the pavement design and surface dressing chosen. Most often, a gravel or earth wearing course is the cheapest to construct but at the same time the least climate resilient solution.

In areas with high rainfall, it may be beneficial to seal the roads with a waterproof bitumen, rather than use a gravel wearing course in order to protect the investments to the sub grade stabilization and sub base materials. Gravel wearing course requires high maintenance and re-gravelling in order to maintain a road surface that sheds water quickly and is smooth to drive. The cost increases associated with this item will be directly dependent on the materials and the
slope of the road, therefore there will be big differences on costs. Alternatives should be investigated. There is a large threat to gravel roads from allowing them to deteriorate to the point where they will need to be reconstructed. Cost beneficial analysis should continue to be used to determine the economic benefit of sealing the roads.

The pavement composition has a significant impact on the initial investment cost and future maintenance cost. Bituminous surfacing is the most expensive cost item of road and typically account for 20 to 50% of the total cost. It is unreasonable to suggest sealing every road. It is more cost feasible to seal areas that are most likely to fail, those with high gradients and high amounts of rain, or susceptibility to flooding. Research from Vietnam suggests sealing roads with gradients higher than 6% that receive more than 1000 mm of rain per year.

The cost difference between a bituminous paved road, and a high standard gravel road and an asphalt concrete road vary significantly depending on type of sealant used and unit prices of materials. It is already common practice in Ghana to pave the shoulders, typically with a single surface treatment. Having paved shoulders is a more expensive solution, but helps minimize maintenance and prolong the life of the roadway. The decision on type of sealant used and the option to pave shoulders is a political one based on road use, importance, and economics. It is expected that these will continue to be the driving factors in the future.

Granular materials represent the cheapest sub item of the price for building the sub base, road base and wearing course of a road, but large quantities of the material are required. It is expected that because of the increase in flooding events, gravel roads will require more frequent maintenance and regravelling than under current climate conditions, therefore more material will be required. At the same time, lack of sound material may increase due to major climate events. There may be increase in the cost of paving materials associated with increased rainfall, due to an increase on the amounts used if decided to pave shoulders or sections of gravel roads and increase of regravelling.

Because Ghana typically paves shoulders during road upgrades, it is unexpected that the costs associated with pavement design due to climate change will increase by a large degree. There may be times where it is recommended to use thicker asphalt on shoulders near flood prone areas, or use a sub base material that is more graded specifically to allow better drainage. Even with additional flooding as predicted in the Wet scenarios, it is only expected that cost of pavement design for an upgrading project will increase around 5% under the Ghana Wet scenario.

5.4.6 Structures
The costs of structures is the result of the cost estimate carried out considering the foundation, substructure, superstructure, drainage, riprap protection, expansion joints and construction of temporary road.

The cost increase to structures due to an increase in rain will come from sizing a larger structure for new infrastructure, and adding additional flood protection
to existing infrastructure. It is difficult to increase hydraulic capacity of an existing bridge, it is easier to armor the substructure to help prevent a washout from scouring, or to create flood relief channels away from the bridge infrastructure.

The cost increases associated with retaining walls may increase associated to an increase in erosion due to sea level rise and increase in rainfall. At the same time, slopes that appear to be unstable now will be more unstable in the future with increased rain, and should be avoided in the roadway alignment. If these areas cannot be avoided, it is not recommended to increase the investment of retaining walls and slope protection from their current levels as high investment slope stabilization efforts are often not successful.

Roads that follow rivers or are set in flood plains are subject to similar issues as those set in areas with unstable slopes. There is expected to be increases in flooding events, and the largest cost savings will come from not building roads in areas subject to large flooding events. If there are no other alternatives, then it is expected that there will be some need for increases in the effort of roadside river bank protection. The amount is impossible to calculate as it is completely dependent on the location of the road, which varies for each road.

For new bridge projects, it is expected that the hydraulic sizing will need to increase similar to the increase in the 100 year design storm, around 39%. The cost of this increase in hydraulic capacity is dependent on the design. There may be designs that allow the hydraulic capacity to be increased relatively inexpensively. It is estimated that for complete new bridges, the increase in cost will be around 20%. For road upgrading projects, where many of the bridges are structurally sound and replacement is not necessary, it is recommended to invest in river training and increased scour protection in the form of gabions, or other methods that have been found to be successful in Ghana. For existing bridges, it is expected that the river works will increase 50%, which is typically around 5% of the total cost of the bridge.

5.4.7 Ancillary works
Ancillary works includes items such as guardrails, signage, and landscaping. Landscaping is already a high cost item and is not expected to require increases in investments in the future. It is always recommended to plant some form of slope stabilizing plants on erosion prone slopes. It may be necessary to investigate the use of more flood and drought resilient plants, as well as invest in the necessary agricultural effort and maintenance after they are planted to insure that the landscaping investment is met. If the plantings are allowed to die due to drought, or be washed away in flood events, then there is no sense in using these methods to begin with.

There are expected to be minor costs associated with ancillary works due to climate change, more resilient guardrails, planting, etc., approx 5% for the Ghana Wet.
5.4.8 Day works
Day works covering effective working rates and considering non-working days (i.e. rainy days, Sundays and holidays) has a significant impact on the construction schedule and therefore on the project cost estimate. Increases in flooding disruptions from climate change may play a determinant role on the planning schedule of any construction project. It is impossible to determine in which degree the total cost would be influenced by an increase of temperature and precipitation, but in an attempt to include the extra cost associated to the climate change impacts, the Consultant recommendation is to increase by 2% the cost for the Ghana Wet scenario.

5.4.9 Maintenance
Maintenance is not a work item for most cost estimates of new road construction, even though maintenance is the most important activity that will ensure the longevity and functionality of the infrastructure investment. No climate proofing investments, let alone road investments will be met without sufficient maintenance.

Increased rainfall and associated flooding will put more pressure on all of the road assets discussed above. A large portion of the maintenance required can be done using labor based methods. A climate resilient road will require full time maintenance, rather than annual or biannual maintenance.

The cost of maintenance is expected to climb drastically under the new climate scenarios. The frequency of large storm events is expected to increase by up to six times in the Ghana wet scenario. It is estimated that maintenance budgets, monitoring and repair for drainage elements and structures is expected to need to be increased close to 100% in order to ensure that the existing drainage infrastructure is able to accommodate such an increase. Maintenance related to non drainage structures is expected to increase proportionately to the annual increase in rain, around 39%.

Drainage
The benefit of using larger culverts is that they are easily cleaned using unskilled labor and small tools. Ditches can be cleaned in a similar fashion with the use of small tools and supervision.

Bituminous pavement repairs
Small patching of cracks should be done regularly, and can be easily done manually by unskilled labor with some supervision. If the small cracks are repaired early enough on using manual labor, it may not be necessary to bring out the larger paving machines later for a large repair.

Ancillary works
Gabions and scour protection can be repaired by hand with supervision. Landscaping and slope protection vegetation needs to be tended during the first years to ensure that the vegetation roots itself into the soils.
5.5 Summary of cost increase

For a road upgrading project from gravel to paved, the cost increases taking into account the climate change scenario in 2050 are summarized in Table 5.4.

<table>
<thead>
<tr>
<th>Description</th>
<th>Current cost/km USD</th>
<th>Increase cost Percentage Global Dry</th>
<th>Ghana Wet Global Wet Scenario cost/km USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>44,353</td>
<td>0%</td>
<td>44,353</td>
</tr>
<tr>
<td>Site Clearance</td>
<td>3,168</td>
<td>0%</td>
<td>3,168</td>
</tr>
<tr>
<td>Drainage</td>
<td>50,689</td>
<td>10-15%</td>
<td>58,293</td>
</tr>
<tr>
<td>Earthworks</td>
<td>95,043</td>
<td>5-10%</td>
<td>104,547</td>
</tr>
<tr>
<td>Sub base, Road Base and Gravel Wearing Course Bituminous Surfacings and Road Bases</td>
<td>348,490</td>
<td>5%</td>
<td>365,915</td>
</tr>
<tr>
<td>Structures</td>
<td>63,362</td>
<td>5-20%</td>
<td>76,034</td>
</tr>
<tr>
<td>Ancillary Works</td>
<td>25,345</td>
<td>5%</td>
<td>26,612</td>
</tr>
<tr>
<td>Day works</td>
<td>3,168</td>
<td>2%</td>
<td>3,231</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>633,619</strong></td>
<td></td>
<td><strong>682,154</strong></td>
</tr>
<tr>
<td>Contingencies + Other Fees</td>
<td>107,715</td>
<td></td>
<td>115,966</td>
</tr>
<tr>
<td>Supervision</td>
<td>31,681</td>
<td></td>
<td>34,108</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>773,015</strong></td>
<td></td>
<td><strong>811,743-832,228</strong></td>
</tr>
<tr>
<td>Cost Increase Percentage</td>
<td></td>
<td></td>
<td>5% - 7.6%</td>
</tr>
</tbody>
</table>

Source: consultant

The values listed in Table 5.4 discuss the likely costs in adapting construction to make a climate resilient road taking into account the climate models for 2050. The values may be misleadingly low for the true cost of climate change as they only show the anticipated cost of building or upgrading a road to meet the minimum requirements as stated in the Ghana design. The true cost would need to account for the increase in maintenance associated with the increase in precipitation, as well as the increased risk on existing structures. This is further explained in the Economic assessment.

All new paved road construction can be expected to require similar increases in cost. There is a large variability and uncertainty on the results due to the changeability in the landscape and likely conditions that are expected to be found. Realistic costs of increases to earthworks and sub grade stabilization are completely dependent on what is found during the site investigations for each dif-
ferent project, therefore they are only possible to estimate on a project-by-project basis.

It is not expected that climate changes in the near future will require large changes to the methodology of high standard roads in Ghana. The standards that they are designed for and should be built are at a high level. Climate adaptation methods such as soil stabilization and increased sizing of drainage systems are not guarantees that the road will function without the required maintenance of patching, cleaning drainage structures, etc.

High standard gravel roads are expected to require cost increases in the same areas as paved roads, plus the additional cost of sealing in areas with high gradients and high rainfall.

5.5.1 Methodology and base for broad costs

These cost increases are found using cost items information from the consultants own experience in the region based on the current development costs provided by GHA.

5.6 Economic costs of climate-related incidents

5.6.1 Approach and methodology

In a traditional analysis the costs and benefits (in the remaining of this chapter we use costs for costs and benefits\(^{10}\)) of a project are compared to a basis scenario (or 0-alternative) where the project is not carried through. If the costs of a project are lower than the costs in the basis scenario, the project is economically feasible and should be carried through.

Although climate changes are not a decision the same framework can be used assessing the costs of climate changes. Thus, the costs of climate changes can be estimated as the difference between the costs in a scenario with climate changes compared to the costs and benefits in a scenario without climate changes (or "basis scenario").

In order to make this comparison as accurate as possible it is necessary to have a clear understanding of what the situation is without climate changes, and what impacts the climate changes will have.

Since the climate changes are happening over time, it is necessary to make a clear description of the future in both scenarios; with and without climate changes including the amount of infrastructure, traffic growths and growth in GDP.

Moreover it is necessary to describe how people and governmental agencies (e.g. road administrations) will react to climate changes. It is possible that climate changes could alter the road agency's plans of expanding the road network. Also, road users may alter their behavior due to climate changes by

\(^{10}\) Note that benefits can simply be perceived as negative costs.
choosing different modes of transportation or less climate affected routes in the future.

In the following it is assumed that climate changes will only affect the road agency’s choice of adapting to the climate changes. That is, other choices made by the road agency (e.g. the extension of the road network), road users and others are not affected.

It is also assumed that the effects on infrastructure of climate changes will appear gradually following a linear path.

5.6.2 The user costs of climate-related incidents

The cost of climate-related incidents in the transport sector are - beside the repair and reconstruction cost etc. mentioned earlier in chapter 5 - primarily due to the traffic effects caused by the disruption of road service.

These costs can be divided into two main categories: 1) costs related to detours, and 2) costs related to delays. Detours are the result of major incidents where the road is closed for several days e.g. due to a complete wash away following a heavy rain fall. Delays are minor incidents where the road is closed for some hours e.g. due to water overtopping the road (flash floods).

The main costs for each category and stake holder are summarized in the table below.

<table>
<thead>
<tr>
<th>Table 5.5</th>
<th>Main costs for each stake holder due to detours and delays</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Road users</td>
</tr>
<tr>
<td>Detours / major incidents</td>
<td>Increased vehicle operating costs</td>
</tr>
<tr>
<td>Delays / minor incidents</td>
<td>Increased capital/opportunity costs</td>
</tr>
<tr>
<td>Increased time costs</td>
<td>Increased time costs</td>
</tr>
</tbody>
</table>

Based on the consultant’s experience from several feasibility studies in Sub-Saharan Africa it is assessed that the main costs related to detours are born by the road users as the economic costs of pollution and increased maintenance costs per vehicle kilometer are marginal compared to the vehicle operating costs (VOC) and time costs (VOT) born by the road users. Therefore, the focus on the road user costs in this analysis.

The below table summarizes the applied economic costs incurred by road users in case of typical major and minor incidents.
Table 5.6 Economic costs to road users following typical major and minor incidents

<table>
<thead>
<tr>
<th>2010-prices</th>
<th>Description</th>
<th>USD per vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major incidents</td>
<td>Road closed for several days. Average IRI of detour = 8, VOC = 0.56 USD/km, VOT = 0.01 USD/km</td>
<td>0.6 per km.</td>
</tr>
<tr>
<td>Minor incidents</td>
<td>Road closed for some hours. Traffic wait for road to reopen. Capital cost / opportunity cost per vehicle is 1.55 USD/hour, Driver's and passengers time is 0.59 USD/hour</td>
<td>2.1 per hour</td>
</tr>
</tbody>
</table>

Source: ITP Ghana vol. 6: Report on Transport Model Calibration.

Note: The used time values and vehicle operating costs implies that on average, vehicles will wait if the road is closed for less than 28 hours if the length of the detour is 100 kilometer.

In Ghana, the majority of road disturbances are due to poor conditions of the roads. The conditions of the roads are a direct result of lack of maintenance, and in certain areas amplified by flooding. As described in chapter 4, there have recently been some major flooding events that have destroyed a number of bridges.

The damage from flooding events varies depending on the severity of the storm. Disturbances range from the roadway being flooded and un-drivable for a short period of time, damage to the shoulders from water overtopping the road, to complete washouts of bridges and culverts causing total disruption to the traffic flow.

As Ghana has some relatively flat areas that are susceptible to flooding, it is common that roads lying in floodplains are overtopped by flood waters. The velocities of the water in these locations are often not high enough to cause serious damage to the roadway and results in more of a traffic disturbance until the waters recede.

Unfortunately, no statistical information about the recurrence of these incidents are available, but based on interviews of local road authorities in Accra GHA's design manuals and the consultant's experience a best guess is that a typical culvert and a typical long span bridge may be subject to a major incident (complete wash out) in a 100 year storm while minor incidents (water overtopping the road) occur to culverts in a 25 year storm and to bridges in a 50 year storm.

For roads located in floodplains it is assessed that it is washed away in a 50 year storm and that 2% of Ghana’s roads are located in flood prone areas. For inadequate drainage the design manuals state that the drainage capacity should be sufficient for a 5 year storm so that the affected spots in the network are expected to be partly flooded every fifth year. It is assumed that for the Ghanaian road network there are 0.1 affected spots per kilometer.
A major incident may close the road for up to 3 days before a temporary solution is established for a typical culvert. For bridges it may take as much as two weeks to establish a temporary solution.

*Figure 5.1  Temporary bridge installation in Ethiopia*

Source: Ethiopian Road Authority – Bridge Management Branch

A typical minor incident of water overtopping the culvert/bridge could close the road for 8 hours. The below table summarizes the description of the typical effects on traffic and the yearly risk.

A description of the major and minor incidents is presented in the table below.
### Table 5.7 Examples and description of typical traffic disturbances and effects on traffic

<table>
<thead>
<tr>
<th>Culverts</th>
<th>Bridges</th>
<th>Roads located in floodplains</th>
<th>Surface drainage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Major incidents</strong></td>
<td>Complete washout. Road is totally closed for 3 days until temporary solution is established. Length of detour is 100 km. For another few days the road has limited capacity. Yearly risk without climate changes - 1%</td>
<td>Complete washout. The bridge is totally closed for 14 days until temporary solution is established. Length of detour is 100 km. For another few weeks the bridge has limited capacity. Yearly risk without climate changes - 1%</td>
<td>Partial washout of road. The road is totally closed for 1 day until temporary solution is established. Length of detour is 100 km. For another few weeks the road has limited capacity. Yearly risk without climate changes - 4%.</td>
</tr>
<tr>
<td><strong>Minor incidents</strong></td>
<td>Water overtopping road. The road is closed for 8 hours until water is gone. Yearly risk without climate changes - 4%</td>
<td>Water overtopping bridge. The bridge is closed for 8 hours until water is gone. Yearly risk without climate changes - 2%</td>
<td>n/a</td>
</tr>
</tbody>
</table>

**Source:** Consultant

Note: *Assume a typical trunk road is designed for a 5 year storm where 1/2 of the carriage is allowed to be flooded (see GHA's Design Manual, Table 6.4.1). The AADT of the road is 1,000 and in case the road is flooded on average 150 meters are partly closed for 4 hours. In this time period the average travel speed is reduced from 80 km/h to 20 km/h. including deceleration before and acceleration after the flooded part of the road each vehicle will be delayed for approximately 30 seconds.

Based on the information in the two tables above the cost of a major and minor incident can be estimated. The below table illustrates the costs for each category of incident on a road with an AADT of 1,000 vehicles.
Table 5.8  Typical road user cost of an incident on a road with an AADT of 1,000 vehicles, 2009-prices

<table>
<thead>
<tr>
<th>1,000 USD per incident</th>
<th>Culverts</th>
<th>Bridges</th>
<th>Floodplain roads</th>
<th>Insufficient drainage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major incidents</td>
<td>170</td>
<td>793</td>
<td>113</td>
<td></td>
</tr>
<tr>
<td>- of which VOC</td>
<td>167</td>
<td>780</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>- of which VOT</td>
<td>3</td>
<td>12</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Minor incidents</td>
<td>17</td>
<td>17</td>
<td></td>
<td>0.0030</td>
</tr>
<tr>
<td>- of which capital costs</td>
<td>12</td>
<td>12</td>
<td></td>
<td>0.0021</td>
</tr>
<tr>
<td>- of which time costs</td>
<td>5</td>
<td>5</td>
<td></td>
<td>0.0008</td>
</tr>
</tbody>
</table>

Note: The above values are for 2009. As the value of time is expected to increase with GDP, the costs related to time are expected to be higher in the future. Please note that the delays due to limited capacity on a temporary solution are not included in the calculations above as they are expected to be marginal compared to other costs.

The above table shows that the cost of climate-related incidents may be significant. If a culvert is washed out the typical cost to road users is around 170,000 USD due to detours, while it may be as high as 793,000 USD when a bridge is washed out due to the long period where traffic has to use other routes.

The costs due to water overtopping culverts and bridges for 8 hours are smaller but in the size of about 17,000 USD per incident.

When a riverbank road is washed away the total costs for road users are around 113,000 USD per incident. When water is overtopping a road due to inadequate capacity of e.g. drainage ditches the costs per incident are 3 USD.

5.6.3 The expected road user costs in a scenario without climate changes

Given the yearly risk of major and minor incidents estimated in the table above the expected yearly costs to road user in a situation with no climate changes can be assessed for typical culverts and bridges.

For floodplain roads and inadequate drainages the expected costs has been calculated for one critical spot.
Table 5.9  Expected road user costs on a road with an AADT of 1000 vehicles, no climate changes, 2009-prices

<table>
<thead>
<tr>
<th></th>
<th>Culverts</th>
<th>Bridges</th>
<th>Floodplain roads</th>
<th>Insufficient drainage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total expected costs, 2009</td>
<td>2.4</td>
<td>8.3</td>
<td>4.5</td>
<td>0.0015</td>
</tr>
<tr>
<td>Due to major incidents</td>
<td>1.7</td>
<td>7.9</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>- of which VOC</td>
<td>1.7</td>
<td>7.8</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>- of which VOT</td>
<td>0.0</td>
<td>0.1</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Due to minor incidents</td>
<td>0.7</td>
<td>0.3</td>
<td>0.0015</td>
<td></td>
</tr>
<tr>
<td>- of which capital costs</td>
<td>0.5</td>
<td>0.2</td>
<td>0.0011</td>
<td></td>
</tr>
<tr>
<td>- of which time costs</td>
<td>0.2</td>
<td>0.1</td>
<td>0.0004</td>
<td></td>
</tr>
<tr>
<td>Total expected costs, 2050</td>
<td>3.4</td>
<td>9.3</td>
<td>4.9</td>
<td>0.0035</td>
</tr>
</tbody>
</table>

Note: The above values are for 2009. As the value of time is expected to increase with GDP, the costs related to time are expected to be higher in the future.

*The expected yearly costs in 2050 are based on an average growth in time values of 4.5% corresponding to a growth factor of 5.9 from 2009 to 2050.

The above table illustrates that in 2009 the total expected road user cost due to climate-related incidents is approximately 2,400 USD/year for a typical culvert while it is around 8,300 USD/year for a typical bridge.

For floodplain roads the expected costs are 4,500 USD/year for, while it is approximately 1,5 USD/year per critical spot for inadequate drainage.

In 2050 the costs are considerably higher, as the time value is expected to grow with GDP from 2009 to 2050 corresponding to 4.4% per year on average. In 2050 the expected cost on a road section with an AADT of 1,000 will be around 3,400 USD/year for culverts and 9,300 USD/year for a typical bridge. For floodplain roads the cost is 4,900 USD/year in 2050 while it is 3,5 USD/year for inadequate drainages.

5.6.4 The expected road user costs in a scenario with climate changes

In the future the yearly risk of major and minor incidents is expected to increase due to climate changes. How much the yearly risk of each type of incident will change is very uncertain, but as based on the climate scenarios described in Chapter 2 and the hydraulic analysis in Chapter 4 the change could be as much as 39% by 2050. As described in Chapter 4, much of the existing drainage infrastructure is built with excess capacity, and is not expected to fail for their corresponding ERA design storm in 2050.

As described in Chapter 2, the future climate scenarios for Ghana fall into two distinct groups. One group of scenarios coincides with the present climate and would thus lead to no cost of climate change. The other group of scenarios differs from the present climate but have approximately the same effect on the Ghanaian climate. In that light, the economic effects of climate change are presented for only one representative scenario which represents the group of scenarios where there is an effect on the future climate in Ghana. The full impact of the climate changes will not be felt until 2050.
The below table illustrates the yearly risk of each category of incidents with and without climate changes.

### Table 5.10  Yearly risk of incidents with and without climate changes

<table>
<thead>
<tr>
<th></th>
<th>Culverts</th>
<th>Bridges</th>
<th>Floodplain roads</th>
<th>Insufficient drainage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk in 2009 (i.e. without climate changes)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major incidents</td>
<td>1.0% (100 year storm)</td>
<td>1.0% (100 year storm)</td>
<td>4.0% (25 year storm)</td>
<td>5.0% (20.0 year storm)</td>
</tr>
<tr>
<td>Minor incidents</td>
<td>4.0% (25 year storm)</td>
<td>2.0% (50 year storm)</td>
<td></td>
<td>50% (2.0 year storm)</td>
</tr>
<tr>
<td>Risk in 2050 (i.e. with full climate changes)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major incidents</td>
<td>1.4% (72 year storm)</td>
<td>1.4% (72 year storm)</td>
<td>5.6% (18 year storm)</td>
<td>7.0% (14.4 year storm)</td>
</tr>
<tr>
<td>Minor incidents</td>
<td>5.6% (18 year storm)</td>
<td>2.8% (36 year storm)</td>
<td></td>
<td>70% (1.4 year storm)</td>
</tr>
</tbody>
</table>

Given the expected change in the risk of major and minor incidents the cost of climate-related incidents in a situation with climate changes can be estimated.

The expected yearly cost is estimated for a situation where the climate changes in 2050 are present today. That is, if the increase in the risk of incidents were 39% higher today. This is done in order to show the severity of climate changes with today's price level. In reality the climate changes will appear gradually over time.

The estimates are summarized in the table below.

### Table 5.11  Future expected road user costs with climate changes costs on a road with an AADT of 1000 vehicles, 2009-prices

<table>
<thead>
<tr>
<th></th>
<th>Culverts 1,000 USD per year</th>
<th>Bridges 1,000 USD per year</th>
<th>Floodplain roads 1,000 USD per year</th>
<th>Insufficient drainage USD per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Future expected cost</td>
<td>3.3</td>
<td>2.4</td>
<td>0.0</td>
<td>2.1</td>
</tr>
<tr>
<td>Increase due to climate changes</td>
<td>0.9</td>
<td>0.7</td>
<td>0.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Future expected cost</td>
<td>11.5</td>
<td>11.0</td>
<td>10.8</td>
<td>6.3</td>
</tr>
<tr>
<td>Increase due to climate changes</td>
<td>3.2</td>
<td>3.1</td>
<td>3.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Future expected cost</td>
<td>6.3</td>
<td>6.3</td>
<td>6.2</td>
<td>4.8</td>
</tr>
<tr>
<td>Increase due to climate changes</td>
<td>1.8</td>
<td>1.8</td>
<td>1.7</td>
<td>1.4</td>
</tr>
<tr>
<td>Total expected costs per year</td>
<td>4.8</td>
<td>4.8</td>
<td>4.8</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Note: The above values are calculated for a situation where the climate changes are present in 2009. This is clearly not the case. However, the figures give an understanding of the costs, if we currently were living with the future climate changes.

* The expected yearly costs in 2050 are based on an average growth in time values of 4.5% corresponding to a growth factor of 5.9 from 2009 to 2050.
The above table illustrates that the expected cost of climate changes may be in the area of 900 USD per year for a typical culvert and 3,200 USD for a typical bridge in Ghana if the climate changes were present in 2009. With an average GDP growth of 4.5% from 2010 to 2050 the expected costs in 2050 may be as high as 1,300 USD/year for a typical culvert and 3,600 USD/year for a typical bridge.

For floodplain roads the increased cost of wash aways due to the climate changes are expected to be about 1,800 USD per/year for a critical spot, while the increase is approximately 0.6 USD per year for spots with insufficient drainage. In 2050 the same costs could be 1,900 USD/year and 1.4 USD/year respectively.

Clearly, the costs will vary significantly depending on the specific circumstances for each culvert and bridge. Not only due to variations in climate change related changes of risk, but also due to the length of available detours, the quality of detours, composition of vehicle types etc.

The traffic levels will also have a significant influence on the expected costs of climate changes. The costs of incidents and the traffic level are linear related such that e.g. a road with an AADT of 3,000 will have 3 times as high costs as the example with AADT 1,000.

5.6.5 Summary of conclusion on the user costs of climate-related incidents

The above calculations has illustrated that the road user costs of climate-related incidents may be substantial even with today's climate. The example illustrates that for a typical road with an AADT of 1000 vehicles the additional user costs of climate change - if no adaptation is made - could be as high as around 30%.
6 Economic assessment of adapting to the climate changes

6.1 Costs and benefits of adaptation

In section 5.5 the cost of climate changes were assessed for typical types of infrastructure based on general examples. The examples illustrated that the climate changes will increase the yearly expected road user costs for these infrastructures by as much as 30%. In order to minimize the increase in these costs, an adaptation strategy could be beneficial.

Adapting to the climate changes is economically feasible if the cost of adapting is lower than the cost of "doing nothing". Hence, one way to evaluate an adaptation strategy is to assess, whether the yearly costs of avoiding the increased risk due to climate changes are lower (and thus feasible) or higher (non-feasible) than the increase in the expected cost when doing nothing.

In Table 5.11 this means that if avoiding the increase in expected yearly costs in 2050 is lower than 1,300 USD per year for a typical culvert, the adaptation strategy is feasible.\footnote{Please note that there are many ways to adapt to climate changes. One way is to fully avoid the increased risk of major and minor incidents. But it is possible that a less significant adaptation strategy, where only some of the increase in risk is avoided, is better. In order to keep the calculations general, only the former is evaluated here.}

6.1.1 Adaptation: Making new roads climate resilient

One way to adapt to the future climate changes is to increase the size of culverts, bridges etc. on new/reconstructed roads in order to address the increased intensity in rain fall.

Example: A typical culvert

In order to avoid the increased risk of incident following the climate changes, the size of a typical culvert needs to be increased. The cost of increasing the size of a typical culverts are described in chapter 5 and are summarized in the table below just like the annualized costs are calculated based on the cost information.
Figure 6.1  Example of inadequate culvert sizing when climate changes

Source: Ethiopian Road Authority

Table 6.1  Adaptation costs: Increasing the size of culverts

<table>
<thead>
<tr>
<th></th>
<th>Do nothing</th>
<th>Adaptation: Larger culverts</th>
<th>Difference: cost of adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction costs</td>
<td>5,500</td>
<td>8,250</td>
<td>-2,750</td>
</tr>
<tr>
<td>Life time</td>
<td>50</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>Yearly risk of destruction (major incident)</td>
<td>1.4%</td>
<td>1.0%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Repair costs (including removal costs)</td>
<td>6,600</td>
<td>9,900</td>
<td>-3,300</td>
</tr>
<tr>
<td><strong>Annualized costs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annualized construction costs</td>
<td>662</td>
<td>993</td>
<td>-331</td>
</tr>
<tr>
<td>Annual expected repair costs</td>
<td>92</td>
<td>99</td>
<td>-7</td>
</tr>
<tr>
<td><strong>Total annualized costs</strong></td>
<td>754</td>
<td>1,092</td>
<td>-338</td>
</tr>
</tbody>
</table>

Note:  The annualized costs have been calculated using a discount rate of 12%. Repair costs include a 20% addition to remove old structure.

The table above illustrates that the cost of adaptation are relatively low for the typical culvert. It is estimated that the increased risk of incidents can be eliminated for 338 USD/year which is significantly less than the cost to road users in the “Do nothing”-scenario which is 1,300 USD/year (see Table 6.2 below).

**Other examples**

Similar calculations have been carried out for a typical bridge (20 m length by 9 m wide bridge). This showed that the cost of adaptation for a typical bridge can be estimated to 23,400 USD/year which is higher than the cost of no adaptation which was assessed to be 3,200 USD/year for bridges (see Table 6.2 below).
For strengthening of the protection of floodplain roads the adaptation costs have been estimated to 300 USD/year per km for affected road spots which should be compared to a cost of 1,800 USD/year per km for road users, if nothing is done to avoid climate changes.

For drainage ditches the increase in precipitation influences both the risk of water overtopping the road but also the speed of the water in the ditches. This has a larger impact on the road as materials are more likely to be washed away from the road. It is assessed that the increased risk of having material washed away due to inadequate drainage can be eliminated for approximately 70 USD/year for each affected spot in the road network.

Table 6.2 illustrates that for culverts and floodplain roads the cost of adaptation is cheaper than the additional cost to road users without adaptation. This means that adaptation is cheaper than doing nothing in all cases.

For bridges, the question of full adaptation can not be answered just by looking at road user costs, as a number of issues related to life time with and without climate change may be the determining factor. In fact, the cost of adaptation is up to 10 times higher than the expected avoided transport user costs in the "do nothing" scenario.

Another interesting result is that the climate-related increase in expected road user costs is relatively low for incidents where water overtops the road due to inadequate size of drainage ditches. This suggests that an adaptation strategy is only feasible if the related maintenance savings are sufficient to finance the increase in construction costs.

6.1.2 The existing road network

It is also possible to reconstruct the existing road network in order to make it climate resilient in the future. This can be done by increasing the size of culverts, replacing existing bridges etc.

Ghana is planning to increase the size of it's road network in the next many years and given the limited funds it seems to be unrealistic to assume that the reconstruction of an existing, well-working bridge will be prioritized to construction of new roads.
Thus, it is assumed that on the existing road network, adaptation will take place as the life time of the infrastructure is exceeded or the infrastructure is destroyed by climate (or other) related incidents.

Hence, for the existing infrastructure the costs of the increased risk of incidents will be born partly by the road users who will experience a decrease in the network quality due to climate changes. Note however that the devotion of resources to new roads will increase the network quality, and - presumably - by more than the decrease due to climate changes.

### 6.1.3 Conclusion on adaptation

Adapting to climate changes by eliminating the increase in road user costs completely (full adaptation) is likely to be a feasible strategy for new road infrastructure.

Whether it is the best strategy is not investigated further in this project\(^\text{12}\), but the increase in road user costs compared to the relatively low costs of adaptation indicates that a full adaptation strategy may be the best strategy.

For the existing network, an adaptation strategy where adaptation takes place as the life time of the infrastructure is exceeded or the infrastructure is destroyed by climate (or other) related incidents is expected to be preferable.

Since the road users do not experience any changes from climate changes with full adaptation, the cost of climate changes for new roads are the increased costs for the road agency.

### 6.2 A rough estimate of the total cost of climate changes in Ghana 2010 - 2050

The section above illustrated that adapting to the climate changes are likely to be economically feasible for new roads. Note that the costs of fully adapting are not the same as the costs of climate changes.

In order to assess the feasibility of adaptation we compare a situation with climate changes and no adaptation to a situation with climate changes and with adaptation. When assessing the cost of climate changes we compare a situation without climate changes (and hence no adaptation) to a situation with climate changes and 1) with adaptation if feasible, 2) without adaptation if adaptation is not feasible.

Earlier it was argued that adaptation is not feasible for the existing road network therefore the costs related to climate changes are assessed using 2). For new roads adaptation is likely to be cheaper than no adaptation, and it is assessed that full adaptation for new roads is feasible and will be carried through. Hence, the assessment of the climate-related costs for new roads applies to situation 1) above.

\(^{12}\) An adaptation strategy where the road users face some increase in their costs may be even better.
6.2.1 Costs related to the existing road network

The existing road network is the infrastructure which exists today. If a bridge or other infrastructure is reconstructed because it exceeds its lifetime or because it is washed away, it is assumed that the new bridge will be built climate resistant such that after a reconstruction there are no longer any costs to road users due to climate changes.

Road agency

The road agency incurs changes in four cost items:

1. An increase in the expected yearly reconstruction costs due to a higher risk of wash aways.
2. A higher reconstruction cost when the infrastructure exceeds its lifetime in order to make it climate resistant.
3. A change in the expected scrap value of the infrastructure in 2050 as the higher risk reduces the survival chances of the current infrastructure.
4. Increased costs to road maintenance due to more sedimentation and other factors related to climate.

For the first cost item, the road agency's costs in each scenario (with or without climate changes) can be calculated as the cumulated number of infrastructure items which are expected to be washed out or destroyed in another way due to climate changes x the yearly cost of building this infrastructure.

If e.g. 20 bridges are expected to be destroyed in 2020 without climate changes and 21 are expected to be destroyed in 2020 with climate changes, then the costs in each scenario are calculated as follows:

- Costs without climate changes: 20 bridges x yearly costs of normal bridge
- Costs with climate changes: 21 bridges x yearly costs of resilient bridge.

The second cost item can be calculated as the cumulated number of infrastructure items which are expected to be washed out in both scenarios (with and without climate changes) x the early extra cost of building climate change resilient infrastructure.

That is, if 1,000 bridges are past their lifetime cycle in 2020, then the road agency's yearly extra costs of making these bridges climate resilient are

- 1,000 bridges times the extra yearly cost per bridge to make them climate resilient (see Table 6.2 of adaptation" in section 6.1.1).

The third cost item is the difference in the expected scrap value in 2050 given the risk of wash aways or other climate-related incidents in each scenario with and without climate changes.
The fourth cost item can be estimated as the current optimal road maintenance budget times the necessary increase in maintenance in order to keep roads in an adequate condition. It is expected that the maintenance costs will increase with 100-150% in 2050 due to the climate changes (see section 5.4.9). Therefore the increase in maintenance costs due to climate changes in 2050 can be estimated as the cost of the optimal maintenance strategy without climate changes times 150%.

**Example: Cost items 1 to 3**

In 2001 there were an estimated 2,231 bridges on the trunk road network in Ghana. In order to keep things simple, these bridges are divided into two categories: bridges less than 50 meters with a design life of 50 years and bridges over 50 meters with a design life of 100 years. The basic information for these bridges can be seen from the table below.

**Table 6.3 Summarized data for federal bridges on the trunk road network in Ghana**

<table>
<thead>
<tr>
<th>Bridge category</th>
<th>&lt; 50 meters</th>
<th>&gt;= 50 meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average bridge length</td>
<td>8</td>
<td>79</td>
</tr>
<tr>
<td>Life time</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Number of bridges</td>
<td>2,173</td>
<td>58</td>
</tr>
<tr>
<td>Total construction costs (undiscounted)</td>
<td>296</td>
<td>74</td>
</tr>
<tr>
<td>Age</td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td>Rest life time</td>
<td>25</td>
<td>65</td>
</tr>
</tbody>
</table>

Note: The construction cost has been assessed using an average carriage width of 10 meters and an average construction cost of 1,600 USD/m².

Based on these data the three cost components can be assessed for each bridge category. This is done in the table below. Note that since the remaining life time of the smaller bridges is less than to year 2050, the cost of climate changes due to losses in depreciated is zero since the depreciated value of these bridges is zero in 2050. Likewise, since longer bridges have a life time exceeding 2050, the cost related to building climate change resilient bridges when the current bridges are worn out are zero, as there are no worn out bridges.
Table 6.4  Net present value of cost of climate changes 2010-2050 for existing bridges on the trunk road network in Ghana

<table>
<thead>
<tr>
<th>NPV 2009, Million USD</th>
<th>1) Reconstruction costs</th>
<th>2) Exceeded lifetime costs</th>
<th>3) Depreciated value</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50 meters</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without climate changes</td>
<td>96.6</td>
<td>44.8</td>
<td>0.0</td>
<td>141.3</td>
</tr>
<tr>
<td>With climate changes</td>
<td>141.2</td>
<td>60.1</td>
<td>0.0</td>
<td>201.3</td>
</tr>
<tr>
<td>Difference: cost of climate change</td>
<td>44.6</td>
<td>15.3</td>
<td>0.0</td>
<td>59.9</td>
</tr>
<tr>
<td>&gt;= 50 meters</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without climate changes</td>
<td>3.0</td>
<td>0.0</td>
<td>-0.1</td>
<td>2.9</td>
</tr>
<tr>
<td>With climate changes</td>
<td>4.5</td>
<td>0.0</td>
<td>-0.1</td>
<td>4.4</td>
</tr>
<tr>
<td>Difference: cost of climate change</td>
<td>1.4</td>
<td>0.0</td>
<td>0.0</td>
<td>1.5</td>
</tr>
<tr>
<td>All bridges</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without climate changes</td>
<td>99.6</td>
<td>44.8</td>
<td>-0.1</td>
<td>144.2</td>
</tr>
<tr>
<td>With climate changes</td>
<td>145.6</td>
<td>60.1</td>
<td>-0.1</td>
<td>205.6</td>
</tr>
<tr>
<td>Difference: cost of climate change</td>
<td>46.0</td>
<td>15.3</td>
<td>0.0</td>
<td>61.4</td>
</tr>
</tbody>
</table>

The same calculations have been carried out for the three other types of typical infrastructure. The table below summarizes the cost of climate changes related to each type of infrastructure.

Table 6.5  Net present value of cost of climate changes 2010-2050 for infrastructure on the trunk road network in Ghana

<table>
<thead>
<tr>
<th>NPV 2009, Million USD</th>
<th>Culverts</th>
<th>Bridges</th>
<th>Floodplain roads</th>
<th>Insufficient drainage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Reconstruction costs</td>
<td>1.2</td>
<td>46.0</td>
<td>0.0</td>
<td>1.6</td>
</tr>
<tr>
<td>2) Exceeded lifetime costs</td>
<td>4.0</td>
<td>15.3</td>
<td>0.0</td>
<td>2.4</td>
</tr>
<tr>
<td>3) Depreciated value</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>5.2</td>
<td>61.4</td>
<td>0.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Cost item 4
Increased costs to road maintenance due to more sedimentation and other factors related to climate are related to cleaning of ditches, cleaning of roads after land slides etc. which can not easily be avoided by making the infrastructure climate resilient.

In 2011 Ghana Highway Authority has a target maintenance budget of 434 million USD. It is assumed that this is representative of the full period from 2010 to 2050. Assuming that climate change happens (linear) gradually from 2010 to 2050 the net present value of the increase in maintenance costs to keep the original service level due to climate changes can be assessed to 270 million USD (net present value) in 2009 for the trunk road network.
Conclusion on the road agency's total costs due to climate changes, existing network

Given the information above, the Ghana Highway Authority's future increase in costs due to climate changes from 2010 to 2050 can be assessed to have a net present value of 350 million USD in total.

This is only the cost of climate change on the trunk road network. The trunk road network in Ghana has a length of approximately 13,000 km, while the total road network has a length of approximately 67,000 km. While the trunk road network is roughly 20% of the total network, the Ghana Highway Authorities' share of total road fund disbursement in 2008 was 38%.

Assume that all road assets experience the same increase in costs due to climate changes as the trunk roads. Then the 350 million USD from the trunk road network is only 38% of the total for the entire road network in Ghana. Consequently, the total for the entire road network is approximately 920 million USD.

Road users

In the future, the road users will experience more incidents where roads are closed etc. due to the climate changes.

These costs were calculated in Table 5.8, and given information about changes in risk and the number of each infrastructure the cost to road users due to climate changes can be estimated.

The below table summarizes the number of typical types of critical infrastructure on the federal network.

Table 6.6 Amount of infrastructure on trunk road network

<table>
<thead>
<tr>
<th>Number of affected infrastructure</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Culverts</td>
<td>8,100</td>
</tr>
<tr>
<td>Bridges</td>
<td>2,231</td>
</tr>
<tr>
<td>River banks</td>
<td>254</td>
</tr>
<tr>
<td>Insufficient drainage</td>
<td>1,905</td>
</tr>
</tbody>
</table>

Source: GHA and own assumptions

Note: Only data from GHA, i.e. only trunk road network

Based on the figures from Table 6.6 and the information about road user costs following incidents and the future expected climate changes, the net present value of climate-related costs can be assessed for each scenario, with and without climate changes. The result is presented in the table below.

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The table above shows that the climate change related increase in road user costs on the existing network from 2010 to 2050 is around 20 million USD in net present value. The climate change related increase in road user costs are partly mitigated by the fact that destroyed infrastructure will be replaced by climate resilient infrastructure. If the reconstructed infrastructure was not climate resilient the increase in road user cost would be approximately 3 times higher.

The major contributor to the increased costs is the increased risk of culvert incidents due to inadequate size of the culverts currently in the road network.

**Third party costs**

It is expected that the increase in emissions costs etc. due to detours following incidents are marginal compared to the road user costs, and these costs have not been estimated.

It should be noted that in case the adaptation strategies affect other stake holders in the economy, there may be third party costs. For example, some adaptation strategies (e.g. increasing the elevation of a road) may affect the behavior of the water and divert it to other places, where it may harm crop production or the like.

Such potential costs should be handled as externalities of adaptation in the road sector when deciding whether an adaptation strategy is feasible or not.

### 6.2.2 Costs related to the future road network

Based on information on expected future investments in the road sector in Ghana it is assessed that approximately 150 km. of new road will be built each year in the period from 2010 to 2050.

#### Road agency

Due to the climate changes the new roads will be more expensive and require more maintenance than in the case of no climate changes.

If it is assumed that the future network will look like the current network with regard to number of bridges, culverts etc. per kilometer, the increase in costs related to building the road infrastructure can be assessed using the estimated yearly cost of making the infrastructure climate resilient (see Table 6.2)

---

**Table 6.7 Road user costs due to climate-related incidents on the trunk road network in Ghana 2010-2050, NPV 2009**

<table>
<thead>
<tr>
<th>NPV 2009, Million USD</th>
<th>Culverts</th>
<th>Bridges</th>
<th>Floodplain roads</th>
<th>Insufficient drainage</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without climate changes</td>
<td>155.1</td>
<td>142.1</td>
<td>6.9</td>
<td>0.0</td>
<td>304.2</td>
</tr>
<tr>
<td>With climate changes</td>
<td>165.7</td>
<td>151.5</td>
<td>7.2</td>
<td>0.0</td>
<td>324.5</td>
</tr>
<tr>
<td>Difference: CoCC</td>
<td>10.7</td>
<td>9.4</td>
<td>0.3</td>
<td>0.0</td>
<td>20.4</td>
</tr>
</tbody>
</table>
If it moreover is assumed that the maintenance costs for the new network in the long run are similar to the existing network, the increase in maintenance costs can be also be assessed.

The below table illustrates the increase in road agency costs due to climate changes related to the expansion of the road network.

**Table 6.8 Road agency costs related to the future expansion of the road network in Ghana, net present value in 2009**

<table>
<thead>
<tr>
<th>Increase in construction cost in order to make infrastructure climate resilient</th>
<th>Million USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>- of which culverts</td>
<td>2.4</td>
</tr>
<tr>
<td>- of which bridges</td>
<td>45.4</td>
</tr>
<tr>
<td>- of which bank protection</td>
<td>0.0</td>
</tr>
<tr>
<td>- of which curb and gutter</td>
<td>0.5</td>
</tr>
<tr>
<td>Increase in maintenance costs</td>
<td>54.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>102.9</strong></td>
</tr>
</tbody>
</table>

Note: These figures are for the entire road network in Ghana.

**Road users**

Since the screened adaptation strategies eliminates the expected increases in risks of infrastructure failures, the cost to road users are zero.

That is, the road agency increases the design and maintenance standards such that the road users experience no climate change related increase in costs.

**Third party costs**

Since the adaptation strategies will ensure that the traffic is not affected, no cost for third party is expected.

It should again be noted that in case the adaptation strategies affect other stakeholders in the economy, there may be third party costs. For example, some adaptation strategies (e.g. increasing the elevation of a road) may affect the behavior of the water and divert it to other places, where it may harm crop production or the like.

Such potential costs should be handled as externalities of adaptation in the road sector when deciding whether an adaptation strategy is feasible or not.

**6.2.3 Total costs of climate changes in the Ghanaian road sector when adapting**

The below table summarizes the information from section 6.2.1 and 6.2.2.
Table 6.9  **Total Cost of Climate Changes on the trunk road network in Ghana, 2010 - 2050, NPV 2009, million USD**

<table>
<thead>
<tr>
<th>Million USD</th>
<th>Road Agency</th>
<th>Road users</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Existing network</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Culverts</td>
<td>347.8</td>
<td>20.4</td>
<td>368.1</td>
</tr>
<tr>
<td>Bridges</td>
<td>5.2</td>
<td>10.7</td>
<td>15.9</td>
</tr>
<tr>
<td>Floodplain roads</td>
<td>61.4</td>
<td>9.4</td>
<td>70.8</td>
</tr>
<tr>
<td>Insufficient drainage</td>
<td>0.0</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Maintenance</td>
<td>4.0</td>
<td>0.0</td>
<td>4.0</td>
</tr>
<tr>
<td><strong>Future new network</strong></td>
<td></td>
<td></td>
<td>39.1</td>
</tr>
<tr>
<td>Culverts</td>
<td>0.9</td>
<td>0.0</td>
<td>0.9</td>
</tr>
<tr>
<td>Bridges</td>
<td>17.3</td>
<td>0.0</td>
<td>17.3</td>
</tr>
<tr>
<td>Floodplain roads</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Insufficient drainage</td>
<td>0.2</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Maintenance</td>
<td>20.7</td>
<td></td>
<td>20.7</td>
</tr>
<tr>
<td><strong>Total existing and future network</strong></td>
<td>386.9</td>
<td>20.4</td>
<td>407.2</td>
</tr>
<tr>
<td>Culverts</td>
<td>6.1</td>
<td>10.7</td>
<td>16.8</td>
</tr>
<tr>
<td>Bridges</td>
<td>78.6</td>
<td>9.4</td>
<td>88.0</td>
</tr>
<tr>
<td>Floodplain roads</td>
<td>0.1</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Insufficient drainage</td>
<td>4.2</td>
<td>0.0</td>
<td>4.2</td>
</tr>
<tr>
<td>Maintenance</td>
<td>297.9</td>
<td></td>
<td>297.9</td>
</tr>
</tbody>
</table>

Note: The figures for the future network are downscaled to 38% from Table 6.8 to better facilitate comparison. All figures in this table are for the trunk road network only, which comprises 38% of the total road assets in Ghana.

As seen from the table above, the total costs of adapting to climate changes in the trunk road sector from 2010 to 2050 is expected to be around 407 million USD in 2009 net present value.

Once again, it must be emphasized that the costs for the existing network only apply to the trunk road network which covers approximately 38% of the total road assets in Ghana. Assuming that all other road assets experience the same effects of climate change, the total cost of climate change will be approximately 1070 million USD in 2009 net present value.

For comparison the total expenditures in Ghana in the road sector in 2008 was 502 million USD, thus the total net present value of the costs of climate changes in the road sector from 2010 to 2050 corresponds roughly to two years budget. However, calculations show that the yearly costs by 2050 may be in the size of 630 million USD per year due to the enlarged network which suggests that the costs of climate changes is a significant problem in the future.

Clearly, these estimates are very uncertain for several reasons. Besides the uncertainties about AADT, change in risk etc. which has been mentioned above, it is also unknown how correlated the risks are. If two culverts are washed out on
the same road section the cost are likely to be less than two times the cost of one culvert, as it may be possible to repair both culverts simultaneously.

### 6.3 When to adapt?

In Table 5.9 the expected road user costs per year due to climate-related incidents was estimated for culverts, bridges, floodplain roads and insufficient drainage. This was the expected cost given the current climate without climate changes.

In section 6.1.1 the unit cost per year of improving culverts, bridges river banks and drainages were estimated for typical infrastructures in Ghana.

The table below summarizes the above mentioned findings.

**Table 6.10 Cost of climate-related incidents in 2009 and climate change adaptation, 1,000 USD, 2009-prices**

<table>
<thead>
<tr>
<th></th>
<th>Culverts</th>
<th>Bridges</th>
<th>Roads located next to river banks (per km)</th>
<th>Drainage ditches (per km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected road user costs in 2010 (1,000 USD/year)</td>
<td>2.4</td>
<td>8.3</td>
<td>4.5</td>
<td>0.0015</td>
</tr>
<tr>
<td>Yearly cost of adaptation strategy (1,000 USD/year)</td>
<td>0.3</td>
<td>23.4</td>
<td>0.3</td>
<td>0.07</td>
</tr>
</tbody>
</table>

As seen from the table above - when it comes to culverts and riverbank protection - the costs of adapting new infrastructure to the future climate changes are estimated to be significantly lower than the transport user costs of climate-related incidents today with today’s climate.

This may suggest that the sizing of today's infrastructure may be insufficient seen from an economic point of view. If e.g. strengthening riverside roads today reduces the risk of incidents with just 6% (0.3 / 4.5 x 100) it is feasible to strengthen riverside roads even with today's climate.

This suggests that adapting new infrastructure to the future climate changes may be feasible today.

### 6.4 Economic summary and conclusions

Based on the economic screening of adaptation strategies above and the assessment of cost of climate changes, it can be concluded that

- The cost to road users due to climate-related incidents may be substantial even with today's climate and are expected to increase with as much as 30% in year 2050
- Adapting to climate changes by eliminating the increase in road user costs completely (full adaptation) is likely to be a feasible strategy for some new road infrastructure - especially culverts and riverbank protection. For structures the specific conditions decide if it is economic feasible to adapt fully to the climate change. The situation for drainage ditches has to be assessed together with the expected maintenance strategy.

- For the existing network, an adaptation strategy where adaptation takes place as the life time of the infrastructure is exceeded or the infrastructure is destroyed by climate (or other) related incidents is expected to be preferable.

- For the existing road network the climate changes will incur costs on both road users and the road agency. The major cost item is expected to be increased maintenance in order to keep the roads up to design standards.

- The proposed adaptation measures may be feasible today, as they will decrease the risk of incidents with today's climate.

- The total cost of climate changes in the road sector from 2010 to 2050 is estimated to be approximately 1070 mill. USD in 2009 net present value.
7 Policy implications, engineering measures and strategy for adaptation and mitigation

7.1 Introduction

The total cost of adapting to climate changes in the road sector from 2010 to 2050 is roughly estimated to be up till around 1.1 billion USD measured as net present value in 2009.

Ghana has a very large challenge in building climate resilient roads due to its varied terrain, but a climate resilient road in the future in Ghana will be very similar to a climate resilient road right now. The climate changes predicted suggest that the problems in the future can be accommodated with today's engineering solutions provided that the solutions are reviewed and reconsidered regularly as more information on climate changes becomes available. Basically, Ghana has the knowledge and materials needed to design and keep their roads up to standard.

For the Sub Saharan countries improving cost efficient accessibility and mobility is vital for economic growth and development in the next decades, but it is also possible to develop mitigation measures and contribute to reducing the cause of climate change.

7.2 Policy implications for adaptation

The road owners will experience increased costs to maintain current service levels for both existing and new infrastructure.

Yearly reconstruction costs for existing roads will increase because of a higher risk of damage each year (the average lifetime is decreased) in combination with higher unit reconstruction costs to make reconstructed roads climate resilient when they are damaged/their life time is exceeded.

For the existing network, an adaptation strategy where adaptation takes place as the life time of the infrastructure is exceeded or the infrastructure is destroyed by climate (or other) related incidents is expected to be economically preferable.

New climate resilient roads are more costly - 5% to 8% higher costs - to build so investments budgets have to be increased or the amounts of new roads to be constructed will have to be reduced.
Design parameters for the standard design storm that is used for all drainage systems and structures are recommended to be reviewed every 5 to 10 years to continuously search for the optimal balance between climate risks and adaptation costs in the country. Adapting fully to climate changes so transport users are not affected is likely to be a feasible strategy for some new road infrastructure - especially culverts and riverbank protection. For structures the specific conditions decide if it is economically feasible to adapt fully to the climate change.

Increasing sea levels and the large variation in ocean tides is a challenge for part of the infrastructure and the cities located in low areas. Basically, the choice is either to protect existing road infrastructure by investing in protective coastal defenses e.g. sea walls, or gradually relocate the infrastructure (and the population) to more stable areas. The obvious measure is not to rebuild in areas that have a risk of being destroyed or design protection so that water will be diverted around important areas.

During initial investigations for a new or reconstructed bridge/road or replacement of an existing infrastructure the location should be thoroughly investigated with up to date information on precipitation and flooding risks. It should be tested if the infrastructure could be placed in a more stable environment and if additional construction costs over time are likely to be more than covered by savings from a smaller risk of flooding.

Adequate road maintenance is essential for the lifetime and service level of both existing and new roads. The key element to ensuring climate resilience after the initial construction is sufficient maintenance. Without routine maintenance, there is no chance for a road to meet its design life in today’s climate, let alone the future climate. Strengthened focus on road maintenance and significantly more spending - probably around a 150% increase compared with today - will be a vital cost effective adaptation measure. This will also benefit the road users dramatically but it requires a big change in current spending patterns in the road sector.

The general implication is that only in exceptional cases it will be economically beneficial to reconstruct or strengthen existing roads and structures before they are damaged/normal life time is expired.

Research to strengthen knowledge about the existing climate will be very valuable. This could include areas like hydrological data and models which will improve estimation of design floods or sea level data which can be used for more accurate assessment of the need for coastal defenses. Both types of data are essential for design and investment decisions.

### 7.2.1 Engineering measures

The priority recommendations listed below cover measures and changes that can be started immediately. The following engineering measures are identified:
Design
- Revise parameters used for the design storm that is used for all drainage systems and structures on every 5 to 10 years
- Investigate the need for river training and increased channel maintenance and bridge scour protection
- Design culverts that cause limited damage to road during floods
- Investigate the use of spot improvements in high-risk areas
- Design gravel roads and community roads with materials suitable for the climate and topography that are locally sustainable and economically feasible
- New alignments need to consider likely future changes to environment considering increases in rainfall, groundwater, etc.

Maintenance
- Develop a database for road maintenance
- Prioritize maintenance and drainage upgrades in areas that are most at risk of flooding
- Increase the frequency of drainage maintenance that is discussed in the manuals in relationship to the increased frequency of large storms
- Repair and clean channel and drainage structures in high-risk areas before the rainy season
- Allocate more funds for maintenance of the current roads.

Research
- Further research into more initially robust scour prevention compared to long term maintenance savings
- Continue improving models for prediction of floods based on newest available climate data
- Expand methods for slope stabilization and protection
- Append the design manuals with more low cost engineering solutions for community roads
- Add a chapter to the design manuals focusing on climates impacts on roads and engineering solutions
- Increase research into correlation of development in floodplains and flooding in urban areas.

7.2.2 The strategy forward for climate change adaptation in the road sector
A future strategy needs to be flexible, adaptive and robust - and acknowledge that the current scenarios and climate models show a large variability in predicted rainfall patterns, which are the most important design criteria for roads and structures.
Taking the mean of the climate scenarios/climate models used in this study as the most likely future development, the long term increase in engineering costs due to climate change may be important but not excessive if dealt with proactively in the regular planning and design processes.

In the short run (next 5 years), the following initiatives are recommended:

- Research is needed in the accuracy of the design parameters in predicting sedimentation and runoff in the rapidly changing Ghana landscape.
- Based on this research the design storm parameters for new roads and structures are recommended to be adjusted to reflect significant climate changes - after due consideration to an acceptable future safety level.
- The design manuals are recommended to be revised so that the climate-related issues and solutions are presented clearly e.g. in an additional chapter. Having a chapter dedicated to the climate and environmental impacts on the road would make it easier for the designer to choose quickly and efficiently.
- As the maintenance need will increase according to the expected more frequent heavy rainfall it is recommended to investigate if it is feasible to change and/or enlarge the drainage system in specific areas prone to erosion and flooding to reduce the risk of total failure and consequential damage and for reduction of the climate change related need for increased maintenance.

In the long run, the following initiatives are recommended:

- Establishment of a process to review climate-related parts of the design guidelines at regular intervals (5 or 10 years) to take account of most updated information on observed climate change impacts and the need to balance climate risks and economic feasibility.
- Establishment of more focused maintenance strategies followed by more resources for road maintenance.
- Development of reliable and accurate hydrology models as it is a common problem that this is lacking.

7.3 Mitigation policies and measures

7.3.1 Policies and plans

The contribution from the transport sector to climate change in form of CO₂ emissions comes basically from a combination of:

- Overall demand for transport and mobility, which again depends on economic and spatial development as well taxation regimes.
- Supply of transport options available, and road transport is the overall dominating motorized mode of transport in most African countries.
• Efficiency of transport means available and their utilization and specific energy use.

The general mitigation initiatives in Ghana include:

• Preparation of strategic climate and environmental plans
• Trials with improved public transport services
• Planned changes to taxation regime in the transport sector.

The national Climate Commission have a number of climate change activities which are on-going or completed recently:

• A National Adaptation Strategy focusing on 10 key areas is being developed and it has been forwarded to the Government
• A national Climate Change Policy has been elaborated, which considers both adaptation and mitigation issues and measures
• A number of "policy briefs" for different areas have been elaborated, and the road sector is one of them, and the focus is on mitigation
• A Second National Communication will be ready in the fall of 2010 (the first Communication is about 10 years old).

A National Carbon Plan is also under preparation but it is not yet so advanced.

7.3.2 Mitigation measures

The specific mitigation measures currently considered in Ghana are:

• Provision of improved bus service – e.g. in form of rapid bus systems on dedicated lanes for commuter traffic to/from Accra
• Taxation of vehicles based on energy use and emission levels according to periodic measurements- with a focus on ensuring necessary enforcement options.

These measures can contribute to offering more environment friendly motorized transport options and creating incentives to make individual transport use more efficient in a short to medium term.

Other mitigation measures in the longer run are recommended to include a stronger focus on:

• Managing spacial/urban planning to create more coherence between habitation areas and the transport system, especially public transport
• Creating better conditions for non motorized transport such as bicycles.
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Louis Berger (August 2009): Eastern Corridor Road Project Dodo Pepesu – Nkwanta Road Section, Design Documents.

Louis Berger (August 2009): Eastern Corridor Road Project Dodo Pepesu – Nkwanta Road Section, Design Documents.


Low-cost local road materials in southern Africa


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9 Appendix

9.1 Climate impacts on road assets

9.1.1 Temperature

Bridges
The effect of temperature on bridges is mostly seen in the thermal expansion of the material used. The most common method of dealing with thermal expansion is the use of expansion joints. If the expansion joints are properly sized, a wide range of temperatures can be accommodated. A challenge with expansion joints is that they are a flexible component and require a high amount of maintenance. Some types of joints are themselves an entrance point for water which is able to leak onto substructure elements and accelerate deterioration. The amount of expansion in the bridge depends on the temperature changes, the length of bridge, and the type of material used, (reinforced concrete, steel girder, etc.)

Pavement design
Temperature has an affect on the stiffness of the asphalt. A poor asphalt mix will have a greater chance of cracking and other deformations if the temperature gradients are not accounted for correctly in the design.

The difference in price between the various grades of penetration grade bitumen is not considerable. Designing for different temperature gradients in the future should not have an effect on the price.

9.1.2 Rain

Bridges
The largest immediate impact seen to bridges will come from the increased flow in the hydraulic channels. Flood events have the potential to cause serious damage around the abutment and pier substructure elements that hold the bridge up.

One of the most common causes of bridge failure comes from scour, or erosion of the bank materials. There are three types of scour affecting a bridge:

- Local scour occurs with the removal of materials around bridge piers or abutments.
• Contraction scour is the removal of river bed material from the bottom and sides of the channel that is caused by an increase in speed of the water due to the bridge opening being smaller than the natural channel.

• Degradation scour is a natural process of bed material being removed, but may remove large amounts of material at a time.

During flood events the increased energy of the river removes the supporting soils surrounding the piers or abutments. The piers eventually lose their structural integrity due to the loss of their foundations and collapse. The erosion on the banks occurs in a similar mode. The flood waters erode the soil underneath or behind the abutments made into the existing banks of the river. As the soil is washed away, the abutment loses its reinforcing strength and bridge failure occurs.

Some of the low volume community roads use low cost solutions to span the river. With an increase in floods these can be expected to need replacing more frequently, with a greater disruption in the traffic flow.

A side effect of precipitation and increased flooding is the increase of sedimentation. Sedimentation material can come from anywhere in the watershed subject to runoff and erosion. Erosion is increased in areas with loose soils and little vegetation, which is exasperated by poor land management and drought. Sedimentation affects bridges by raising the water level of the channel upstream of the bridge. As the water level rises, the width of the river increases which adds increases in shear stresses on the abutment walls. The sedimentation is sometimes amplified by the structure itself. If the bridge or culvert is not sized large enough, the water will back up around the structure causing the velocity of the river to slow down, giving opportunity to greater sediment deposits. Once the flood waters recede, a large deposit will be left. If this deposit is not removed, during the next flood there may again be an increase in backwater from not only the undersized structure, but also the increase in sedimentation from the previous flood. It cannot always be expected that a future flood will remove the sediment deposited from the previous storm event.

ERA explained of a situation on road A 7-5 between Sodo and Omorate in the southern part of the country that has experienced an ongoing problem with the success of bridge construction. Originally, the road passed over this section of the Delbena river using 1.0 meter diameter pipe culverts as seen in Figure 9.1. After some time, this was washed away and replaced by a 30 meter long bridge. This replacement bridge was destroyed during a flood in 2000.
And in 2002, a 60 meter replacement bridge destroyed during construction from a flood due to an abutment being washed away as seen in Figure 9.3. After this, a new 105 meter long bridge has been designed for a new alignment in a different location. This bridge is currently in construction.
Figure 9.3  60 meter replacement bridge destroyed during construction, 2002 Road A-75

Source: ERA BMS

ERA BMS explains that the river in this area has increased from being contained by small diameter pipes to now over a 100 meter long bridge. It is not clear what original design parameters were used, or how the river originally appeared.

It can be assumed that the initial under sizing of the culvert has aided in these current problems. The original undersized culvert acted as a pinch point in the channel, causing the flood plain to widen, and the aggradation of the channel. Each replacement bridge has been undersized enough combined with the increase in flooding and sedimentation to increase the original problem. The cost of replacing these bridges is most likely more than building one hydraulically adequate, or even oversized bridge to begin with.

Increased precipitation also has the potential to increase standing water on the bridge platform. If the bridge deck poorly drains the water, there is the risk of hydroplaning. Increase in water on the bridge will also accelerate corrosion of the bridge substructure if water is allowed to leak through the expansion joints on the bridge or through potholes in the AC wearing course.

The above bridge example on Road A-7 is located in unstable flood plains where large floods have the power to move the main river channel out of its existing channel. The rate of the change of the geo-morphology of the rivers in Ghana will occur at a faster rate with more floods, causing more difficulty in choosing the most suitable location for a new bridge.

**Culverts**

Precipitation affects culverts in similar ways as bridges. Culverts are susceptible to scour in the same ways as bridges, and are subjected to similar problems with siltation and aggradation.

Culverts can be more susceptible to sedimentation deposits as Figure 9.4 shows. Due to their smaller opening sizes, they are more prone to plugging from flood debris and sedimentation. When the culverts are partially filled with debris,
their hydraulic capacity is reduced and the potential for failure is increased. A likely scenario for the culvert in Figure 9.4 is during the next storm, the water that is not able to pass through the culvert will overtop the road.

The damage from a flood that overtops the road depends on the size and force of the flood, and the wearing course and stability of the road. If a design storm were to pass through the culvert in the figure above there would be a temporary delay to traffic while the flood waters overtopped the road. The damage from limited overtopping usually results in some loss of pavement near the shoulders, loss of shoulder material, and some increased scouring around the inlet and outlet of the culvert as seen in the figure below. The paved wearing course helps to keep the road intact during overtopping. Due to the siltation of the culvert in the figure above, the likelihood of overtopping and subsequent damage will occur more frequently than the 10-25 year design storm it was most likely designed for.

Depending on the stability of the road section, overtopping flood waters have the opportunity to travel through the roadway as seen in the figure below. This is called diversion potential, and is a common scenario with flooded culverts on gravel roads.

*Figure 9.4  Diversion potential*

![Diversion potential](image)

*Source: USDA*

A study in the northwest of USA found that 50% of flooded culverts on gravel roads led to stream diversion along the roadway. The diverted stream will either travel through the roadway, or along the drainage ditches. Often the diverted stream will travel far enough down the roadway to enter another watershed seen in Figure 9.5. The further the stream is diverted, the more erosion will occur. This erosion is then added to the stream as sediment and potentially will be seen again downstream as deposit at another larger crossing such as the bridge example above.
Figure 9.5  Diversion potential

Source: USDA

Increased flows through the culverts will increase the scour and erosion on the inlets and outlets of the culverts.

Pavement design

(1)  Subgrade
The largest effect of precipitation will be seen in subgrade and sub base materials which are poor draining and/or composed of expansive soils. With an increase in precipitation, there can be expected more swelling of the soils in the wet season. Soils are at their weakest when fully saturated. An increase in seasonal variability of rainfall will lead to more cases of extreme saturation, coupled with drying out of the upper subgrade soils during the dry season. This weakening could lead to cracking of the subgrade, which will be seen as deformation throughout the road structure. An increase in water table will have similar impacts to the road subgrade.

(2)  Subbase layers
The base layers are their weakest when fully saturated, and need to be properly drained. The infiltration of water either from the surface (through cracks in the asphalt or from edge break of the road) or from the water table below will have detrimental effects on the base layers causing weakening of the structure. As for the subgrade there will be a seasonal variation of the sub base layer strength.

(3)  Wearing course
The wearing course can be divided into three different materials, each affected differently by precipitation: Paved surface, Gravel surface, Earth surface.
(a) **Paved surface**

The impact of increased precipitation on the paved surface is seen on the amount of standing water on the surface, and the infiltration of water through the surface into the base layers. One of the functions of a paved bound surface is to act as a waterproofing layer to protect the underlying materials. If water is not quickly drained away from the paved surface, it will settle into the base layers, weakening the structure, accelerating the formation of cracking, and potholes. Standing water on the road surface is also a driving hazard from the increase in hydroplaning and increased braking distance.

(b) **Gravel surface**

An increase in precipitation will lead to faster degradation of gravel surfaced roads. Increases in precipitation will accelerate gravel loss, requiring more maintenance and re-gravelling. Without proper maintenance, sufficient drainage can not be met, leading to standing water on the road surface, which aids in creating large rutting and potholes. Gravel surfaces are also more prone to being washed away during overtopping events due to the loose nature of the wearing course material.

Research in Vietnam (Rural Road Gravel Assessment Program RRGAP) has shown that gravel surfacing becomes an unsustainable mode of surfacing if the region receives more than 1000-2000 mm precipitation/year, or where road gradients are higher than 4%. Gravel surfacing should only be considered when:

- Quality material is located within 10km of the road
- Adequate drainage is guaranteed
- Flooding is only a minor local occurrence
- Rainfall < 1000 mm/year, gradients less than 6%
- Rainfall 1000 - 2000 mm/year, gradients less than 4%
- Rainfall is less than 2000 mm/year.

Gravel surfaces also pose a health risk in very dry areas. If a reduction in precipitation is expected and extensive drying of the gravel road surface occurs, there can be increases in road dust. Road dust has been attributed to health issues, and is an overall nuisance to the road user and inhabitants alongside the roadway.

Research in Vietnam has shown the following are the key factors in contributing to unsustainable deterioration of unsealed gravel roads:

1. High rainfall
2. Flooding
3. Poor quality out-of-specification materials
4. Lack of maintenance
5. Poor drainage arrangements.

1.), 2.), and 5.) are contributed to precipitation which is expected to increase.
Alternatives for gravel wearing course that have been tested in Vietnam (Rural Road Surfacing Research RRSR) include:

- Emulsion sand seal
- Emulsion chip seal
- Steel reinforced concrete
- Bamboo reinforced concrete
- Unreinforced concrete
- Engineered clay bricks
- Concrete bricks
- Dressed stone
- Cobble stones.

The outcome of these alternatives is discussed in detail in the RRSR reports.

(c) Earth surface

A well engineered earth surface will be able to withstand a certain amount of precipitation. They are suitable for areas with up to 2000 mm/yr precipitation, gentle terrain and light vehicle loading up to 100 vehicles per day. The serviceability of the earth surface road will depend on the quality of the earth materials and subgrade, sufficient drainage, and vehicle loading. If the road is not properly designed for adequate drainage, the surface will erode quickly making the road unusable. Certain materials are much more suitable for wet environments than others. Clay materials can become impassable during the rainy season due to lack of traction if too much clay is used near the surface. Earth surfaced roads are usually used only for low volume community roads.

Slope stability

Rain has a large impact on the stability of slopes. The largest impact from rain to the slope stability is seen through landslides and erosion. Intense rainfall is a recognized trigger of landslides, and an increase in the intensity of rainfall will most likely mean an increase in landslides.

A landslide study was conducted in Lao PDR showing that the majority of landslides affecting roads occurred during the rainy season when there is higher groundwater and perched water levels in the roadside soils. The majority of slope failures in above road cuts were observed to originate from the upper portions of the cut slopes. Below road slope failures were observed in localized shallow failures in fill slopes and construction spoil or deeper failure of the natural hillside, some instances associated with river scour.

70% of the roadside slope failures recorded in the Lao study took place above the road. Shallow slope failures occurring above the road are typically less destructive to the road carriageway than those occurring below. Only 4% of the above road landslides resulted in total blockage of the carriageway. The most common result of these above road slope failures was blockage to the drainage system, which could lead to other problems in the road network if not quickly remedied. Slope failures below the road are a much larger risk to the structure of the road carriageway, often resulting in deformation or loss of the road.
also proves more difficult to observe the slopes below the road before there is a landslide as they are often out of sight.

The figure below show the significant damage caused by floodplain scour on a section of road in the Dire Dawa region. The embankments of the road have been completely washed away leaving the carriageway exposed and the resulting road failure.

Erosion from rainfall is a slower process than a landslide event, but over time can be as destructive to a road. Erosion of the slopes can quickly fill up the drainage system with sediment causing blockages and drainage failures.

Erosion is a typically a result of:

- The road side slopes being too steep or too long
- Insufficient compaction of embankment materials
- Concentrated road runoff allowed to drain off shoulders.

**Surface drainage**

Adequate surface drainage is one of the key elements to a well functioning road, which high intensity rainfall and the associated flooding can quickly exceed. The impacts to the road from a drainage system that is not working properly, or has been flooded include:

- Erosion or loss of material of road (especially gravel)
- Loss of structures (bridges and culverts)
- Undercutting of slopes
- Flooded road section.

Increase in high intensity storms also often mean an increase in the amount of erosion and sedimentation that is introduced into the drainage network. If this sedimentation is not flushed through the system naturally, it needs to be removed manually, an often time and labor-intensive task. Sediment that is not removed will cause a blockage and increase the sedimentation build up during the next flood.

### 9.2 Climate scenarios and prediction data

#### 9.2.1 Introduction to scenarios and data

The World Bank has chosen 4 climate scenarios for Ghana representing the span in expected future climate situations from dry to wet according to results from different combinations of emission scenarios (SRES) and GCM models.
The climate scenarios chosen by the World Bank are:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>GCM-model</th>
<th>Emission scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Global Wet”:</td>
<td>NCAR-CCSM3.0</td>
<td>SRES A2</td>
</tr>
<tr>
<td>“Global Dry”:</td>
<td>CSIRO-MK3.0</td>
<td>SRES A2</td>
</tr>
<tr>
<td>“Ghana Wet”:</td>
<td>NCAR-PCM1</td>
<td>SRES A1B</td>
</tr>
<tr>
<td>(BCCR-BCM2.0)</td>
<td>SRES A2</td>
<td></td>
</tr>
<tr>
<td>“Ghana Dry”:</td>
<td>IPSL-CM4</td>
<td>SRES B1</td>
</tr>
</tbody>
</table>

For these scenarios, data and results have been processed by the University of Colorado especially for this study with focus on precipitation, temperature and run-off. The results are presented in datasheets and maps, dated September 14, 2010. The data and maps include estimates for the present climate situation and the future situation in the period around 2050 and around 2100. The description, figures and climate data processing was done by:

Len Wright, Ph.D., P.E., D.WRE
Anthony Powell
Chas Fant
Alyssa McCluskey, Ph.D.
Kenneth Strzepek, Ph.D., P.E.

The following is a direct copy of the introduction to the received text, why the references to figures, pages and appendix etc. goes on the analysis report and not on this MTCR report.

9.2.2 Statistical analysis of historical and simulated future meteorological data for the purposes of quantifying potential changes to climate in Ghana

This letter report describes the requested climate change data and statistics computed for Ghana. The statistics and maps are included in attached zip files described below. To follow your requested items in order:

REQUEST from COWI:

1. Scenarios

Predicted scenario data and maps will be delivered for 4 scenarios for Ghana (defined by Consultant)

Boulder CO and World Bank). The scenarios shall represent a wet and a dry scenario on global level and local level. The climate change projection data should be in accordance with the WB procedures for development scenarios, modeling, baseline and downscaling of climate model results.

14 The maps and spreadsheets with all data and results are available in electronic form at the World Bank office in Washington.
A short and clear text description of the existing climate conditions and characteristic for the country and the expected climate changes for the different regions in the country delivered for each Climate Change scenario in short term (around 2050) and long term (around 2100). The descriptions could be a link to a (WB) report, COWI can refer to.

RESPONSE:

The “Economics of Adaptation to Climate Change (EACC)” process defined “wet” and “dry” using the “Climate Moisture Index (CMI)” as a percent deviation from the historical record. The four scenarios analyzed for the Ghana EACC include:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>GCM</th>
<th>SRES</th>
<th>CMI Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Wet</td>
<td>ncar_ccsm3_0</td>
<td>A2</td>
<td>-17%</td>
</tr>
<tr>
<td>Global Dry</td>
<td>csiro_mk3_0</td>
<td>A2</td>
<td>9%</td>
</tr>
<tr>
<td>Ghana Wet</td>
<td>ncar_pcm1</td>
<td>A1b</td>
<td>49%</td>
</tr>
<tr>
<td>Ghana Dry</td>
<td>ipsl_cm4</td>
<td>B1</td>
<td>-66%</td>
</tr>
</tbody>
</table>

The true "Ghana wet" GCM-sres projection (ncar_pcm1 - A1b) does not produce daily weather data, needed for this study. Therefore the next wettest GCM-sres projection which has daily data available (bcr_bcm2_0 - A2) for Ghana was used instead.

The EACC project is not yet complete, therefore the final Ghana Country report for the EACC project is not yet published. However, a synthesis report that includes Ghana, as well as an EACC Ghana information page may be found at:

http://beta.worldbank.org/climatechange/content/ghana-economics-adaptation-climate-change-study

http://beta.worldbank.org/climatechange/content/ghana-economics-adaptation-climate-change-study

The EACC process includes climate projections through 2050 only. So therefore the “wet” and “dry” definitions are for this period and do not include projected climate changes to 2100. It is possible that a CMI analysis through 2100 would produce a different set of GCM projections.

The following section from the draft EACC report includes the following description of Ghana Climate:

“The climate of Ghana is tropical, and strongly influenced by the West African Monsoon. The rainfall seasons of Ghana are controlled by the movement of the tropical rain belt (Inter-Tropical Conversion Zone, ITCZ). In northern Ghana, there is a single wet season occurring between May and November and a dry
season between December and March. The northern and central regions receive 150-250mm per month in the peak months of the wet season (July to September). The southern regions of Ghana have two wet seasons, one in March to July, and a shorter wet season in September to November. The seasonal rainfall in this region varies considerably on inter-annual and inter-decadal time-scales, due in part to variations in the movements and intensity of the ITCZ, and variations in timing and intensity of the West African Monsoon. The most well documented cause of these variations is the El Niño Southern Oscillation (ENSO). El Niño events are associated with drier than average conditions in West Africa. Seasonal variations in temperature in Ghana are greatest in the north, with highest temperatures in the hot, dry season (AMJ) at 27-30°C, and lowest in JAS at 25-27°C. Further south, temperatures reach 25-27°C in the warmest season JFM, and 22-25°C at their lowest in JAS. Annual rainfall in Ghana is highly variable on inter-annual and inter-decadal time-scales. This means that long term trends are difficult to identify. Rainfall over Ghana was particularly high in the 1960s, and decreased to particularly low levels in the late 1970s and early 1980s, which causes an overall decreasing trend in the period 1960 to 2006, of an average 2.3mm.

The mean annual temperature is projected to increase by 1.0 to 3.0°C by the 2060s, and 1.5 to 5.2°C by the 2090s. The projected rate of warming is more rapid in the northern inland regions of Ghana than the coastal regions. All projections indicate substantial increases in the frequency of days and nights that are considered ‘hot’ in current climate, but the range of projections between different models is large. Projections of mean annual rainfall averaged over the country from different models project a wide range of changes in precipitation for Ghana, with around half the models projecting increases and half projecting decreases. Model simulations show wide disagreements in projected changes in the amplitude of future El Niño events. West African climate can be strongly influenced by ENSO, thus contributing to uncertainty in climate projections for this region. (McSweeney, New and Lizcano, 2008)

Ghana’s economy depends heavily on climate-sensitive sectors including agriculture, forestry and hydro-energy. With irrigation almost nonexistent, Ghana’s agriculture is highly vulnerable to climate variability. About 35 percent of Ghana’s land mass is desert and desertification is already currently proceeding at an estimated 20,000 ha per year (EPA, 2009:179). Ghana’s coastline has a length of 565 km and the coastal regions of Ghana may be vulnerable to sea-level rise. Sea-level in this region is projected by climate models to rise by 18 to 56cm the 2090s, relative to 1980-1999 under SRES A2

Climate inputs specific to Ghana and its river basins, both historic and future, such as monthly temperature and precipitation are used to drive the river basin and water resource model and crop models outlined in section 4. Historic inputs have been gathered using CRU global monthly precipitation and temperature data. Future inputs have been taken from four GCMs forced with different CO2 emission scenarios to represent the total possible variability in precipitation.
In the EACC Global Track study, the National Center for Atmospheric Research (NCAR) CCSM3 and Commonwealth Scientific and Industrial Research Organization (CSIRO) Mk3.0 models with SRES A2 emission forces were used to model climate change for the analysis of most sectors because they capture a full spread of model predictions to represent inherent uncertainty and they report specific climate variables (minimum and maximum temperature changes) needed for sector analyses. Though the model predictions do not diverge much for projected temperature increases by 2050 (both projecting increases of approximately 2°C above pre-industrial levels), they vary substantially for precipitation changes. Among the models reporting minimum and maximum temperature changes, the NCAR was the wettest and the CSIRO the driest scenario globally, based on the climate moisture index.

In line with the Global Track, the climate projections from these two GCMs are used to generate the “Global Wet” and “Global Dry” scenarios for the Ghana country track study. In addition, the climate projections from the two GCM/SRES combinations with the lowest and highest climate moisture index for Ghana are used to generate a “Ghana Dry” and a “Ghana Wet” scenario. Note that in the case of Ghana, the globally “wettest” GCM actually projects a drier future climate for Ghana than the globally “driest” GCM under emission scenario A2.”

2. REQUEST FROM COWI Prediction data

The predicted data from the scenarios will include specific data/figures for at least baseline and medium period (2045-2065) and change in figures (baseline to medium period), given as percentage and specific figures. For selected data there will be prepared specific maps and statistics as listed below.

In addition data on discharge etc. will also be delivered for all scenarios in form of 24-hour peak discharges and monthly discharges.

The presentation of the climate and climate change data and baseline could e.g. be presented with the same layout and extend as the UNDP Climate Change Country Profiles, Ghana (http://countryprofiles.geog.ox.ac.uk).

Historical data (baseline)
For historic information, data by month and year will be for the period 1996 to 2007. For historic information, data by day will be for the period 1961 to 1996.

List of data and information to be delivered in spreadsheets (See also the attached matrix for maps and spreadsheets)
Data showing distribution of (grid size in accordance with the WB decision):

1. (P1) Mean annual total precipitation
   i. Sum of precipitation for the year, and take the mean of all of values (one output, units are in mm)
2. (P2) Mean annual days with precipitation
   i. Count days of rain events in each year, and take the mean of all the values (one output, units are in days)
3. (P3) Mean monthly precipitation each month
   i. Same as 1, but for each month (12 outputs, units are in mm)
4. (P5) Mean annual 24 hours maximum rainfall (per year) (1-year storm)
   i. Max of daily precipitation for each year, and take the mean of all the values (1 output, units are in mm)
5. (P6) Mean monthly 24 hours maximum rainfall (per month)
   i. Same as 5, but for each month (12 outputs, units are in mm)
6. (T10) Mean annual temperature
   i. Mean of daily temperature for each year, then take the mean of the annual means (1 output, units are deg. C)
7. (T11) Mean monthly temperature by month
   i. Same as 10, but for each month (12 outputs, units are in deg. C)
8. (T12) Mean annual maximum daily temperature
   i. Maximum daily temperature found for each year, then take the mean of all the values (1 output, units are in deg. C)
9. (T13) Mean annual minimum daily temperature
   i. Minimum daily temperatures found for each year, then take the mean of all the values (1 output, units are in deg. C)
10. (T14) Mean monthly maximum daily temperature by month Same as 12 but for each month (12 outputs, units are in deg. C)
11. (T15) Mean monthly minimum daily temperature by month Same as 13, but minimum (12 outputs, units are in deg. C)
12. (T16) Mean annual duration in days of heat waves (>= 5 C above average daily maximum) Find heat wave durations for the time series, sum the durations in a year and divide by the number of occurrences in that year, use 5 deg. + the average daily maximum temperature for the same year as the threshold, and use the maximum daily temperatures for comparison (1 output, units are in days)
Statistics
1. Average 24 hour max precipitation for the different regions for different frequency (1, 2, 5, 10, 25, 50 and 100 years) (baseline and 2050). Also as curves, if available.

Matrix of requirements:
Matrix for deliverables (datasheets and maps):

RESPONSE:
All requested data and calculations are presented in Excel worksheets and jpg format graphic files for maps, contained in the following files:

Data:
Discharge Ratios: GHANA DESIGN FLOWS.xls for all scenarios and time periods.

Statistics:
Ghana_Stats_COWI_xls.zip All spreadsheets for all statistics and data.
Maps:

Ghana_Precip_Temp.zip All maps of temperature and precipitation statistics.
Ghanadischarge.zip: Design storm maps.

References


Strzepek, Kenneth, PhD, Professor at the University of Colorado at Boulder, Boston, MA, 2009, Personal Communication.

