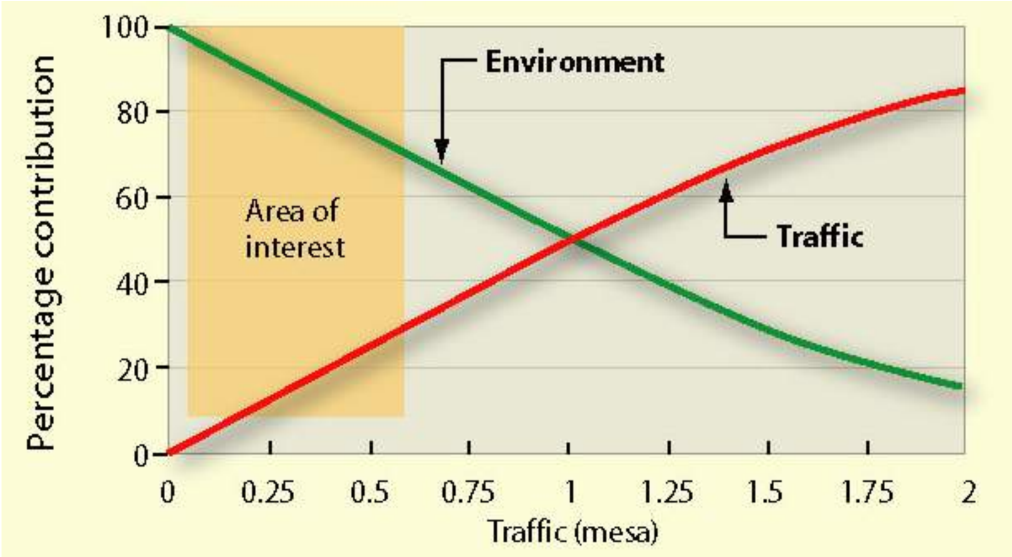
Climate Resilience and Adaptation

Engineering Adaptation Options and Assessment Workshop

T2 Conference, Livingstone, May 2017

Infrastructure adaptation

- Future climate scenarios ae going to be different from current ones – range of stressors
- Relate changes of each stressor to engineering adaptations for infrastructure components
- Climate plays a dominant role in LVR performance



CLIMATE CHANGE

HOTTER
- Expansion
- Evaporation
- Bitumen drying
- Thicker vegetation
- Reaction rates

COLDER
- Asphalt/ bitumen
- Freezing ?

WETTER
- Reduced strength
- Erosion/ deposition
- Drainage
- More vegetation

DRIER
- Contraction
- Erosion (protection lost)

WINDIER
- Trees and signs
- Sand movement
- Loss of fines
- Structures

OTHERS
- Sea level rise
- Storm surges
- Groundwater
- Extreme events

INTENSITY DURATION

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Road issues

- Pavement
  - Subgrade
  - Unpaved
    - Earth
    - Gravel
  - Paved
    - Bituminous
    - Other
- Road reserve
  - Drains
  - Vegetation
- Road environment
  - Slopes
  - Erosion
- Structures
  - Bridges
    - Erosion
    - Structure
  - Culverts
    - Erosion
    - Structure
- Construction
- Maintenance

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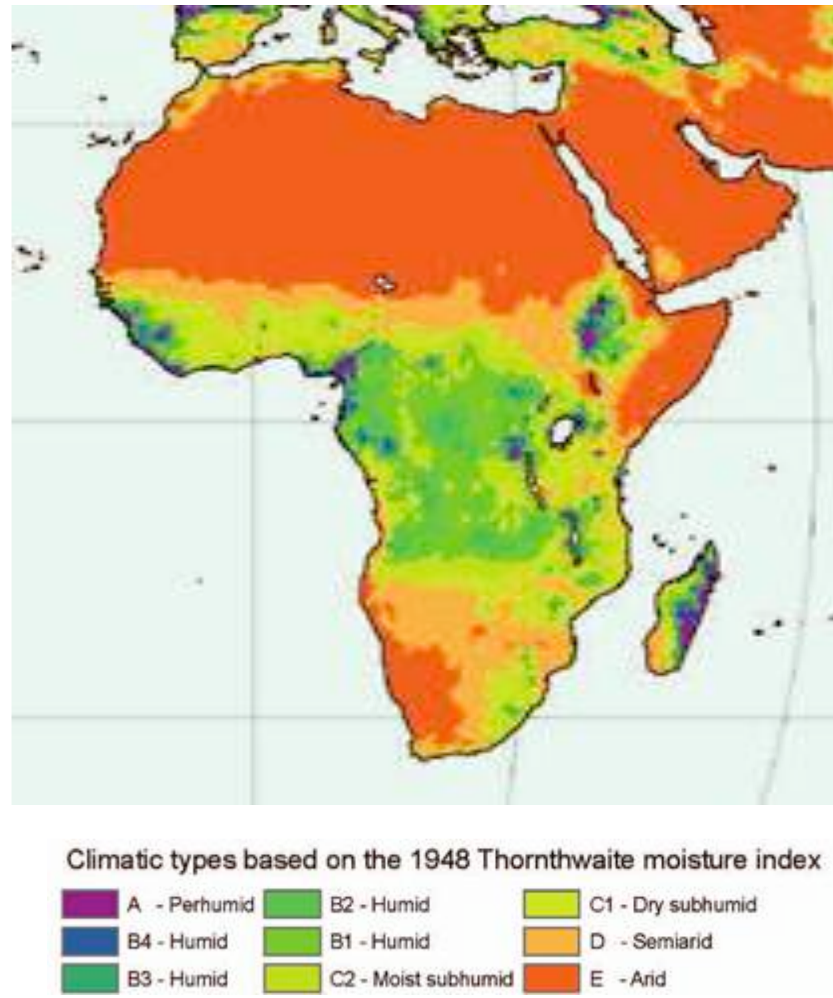
Climatic influences on traditional tools

- ***Climate zonation***

  Use of climate parameters in zonation
  - Thornthwaite’s moisture index.
  - Weinert N-value
  - Geiger-Köppen classification
  - Water surplus areas
  - Return periods
  - Etc.
- ***These are based on temperatures, precipitation, evaporation, etc.***
- ***Will require ongoing modification***



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Status Quo

- We have the infrastructure
- We know climate is going to change
- Some of it will be affected
- What are we going to do about it?

Status Quo

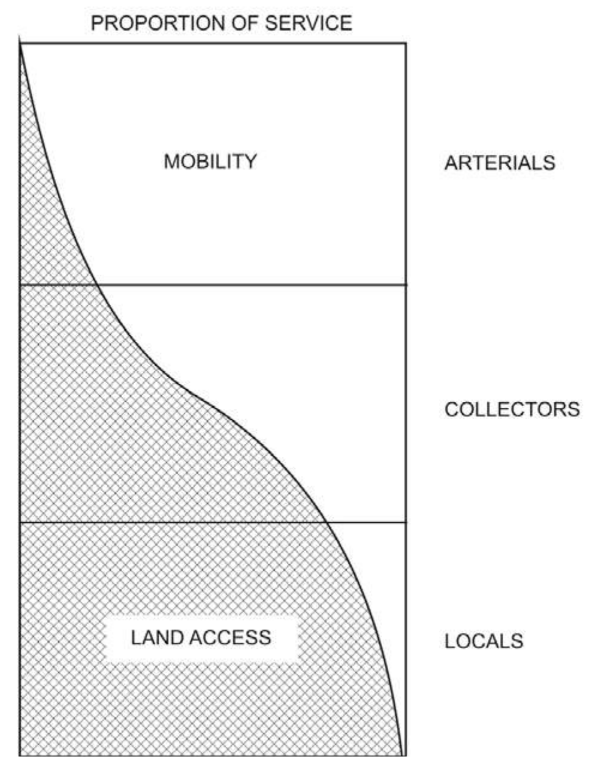
- Identify the potential problems
  - Asset Management problem
  - Discuss later
- Prioritise
- Adapt as appropriate

PRIORITISATION

- Most difficult part – function of available funding
- What is it based on?
  - Loss of life – structures not roads !
  - Inconvenience (Accessibility) – social factor !
    - Usually more a function of river crossings or landslides than road condition
    - Accessibility to alternative routes
  - Cost of closure
  - Cost of repair

Priorities ?

- ***Potential loss of life***
- ***Availability of alternative routes***
- ***Cost and consequences of closure***
- ***Environmental/sustainability issues (i.e. pollution, aesthetics, etc.)***
- ***Cost of repair***
- ***Available funds***
- ***Mobility/accessibility requirements.***



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Mobility versus accessibility

- Different purposes – may overlap
- Different requirements

	Required standards for mobility		
Level of Serviceability	***Max Roughness (IRI units in m/km)***	***Impassability***	***Duration of impassability***
5	***12***	***≯ than 4 days/yr***	***≯ than 1 day***
4	***9***	***Never***	***None***
3	***8***	***Never***	***None***
2	***7***	***Never***	***None***
1	***6***	***Never***	***None***

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Mobility versus accessibility

	Required standards for accessibility		
Level of Serviceability	***Comfortable driving speed (km/h)***	***Impassability***	***Duration of impassability***
6	***N/A***	***> 20 days/yr***	***> 5 days***
5	***15***	***< 20 days/yr***	***Not more than 5 days***
4	***20***	***< 5 days/yr***	***Not more than 2 days***
3	***35***	***Never***	***None***
2	***50***	***Never***	***None***
1	***60***	***Never***	***None***

Choice of serviceability level

- Include issues such as social, traffic and economic considerations
- Needs to be done at a strategic level.
- Based on the inventory of roads - part of the Road Asset Management System

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DISCUSSION

	Required standards for accessibility		
Level of Serviceability	*Comfortable driving speed (km/h)*	*Impassability*	*Duration of impassability*
6	*N/A*	*> 20 days/yr*	*> 5 days*
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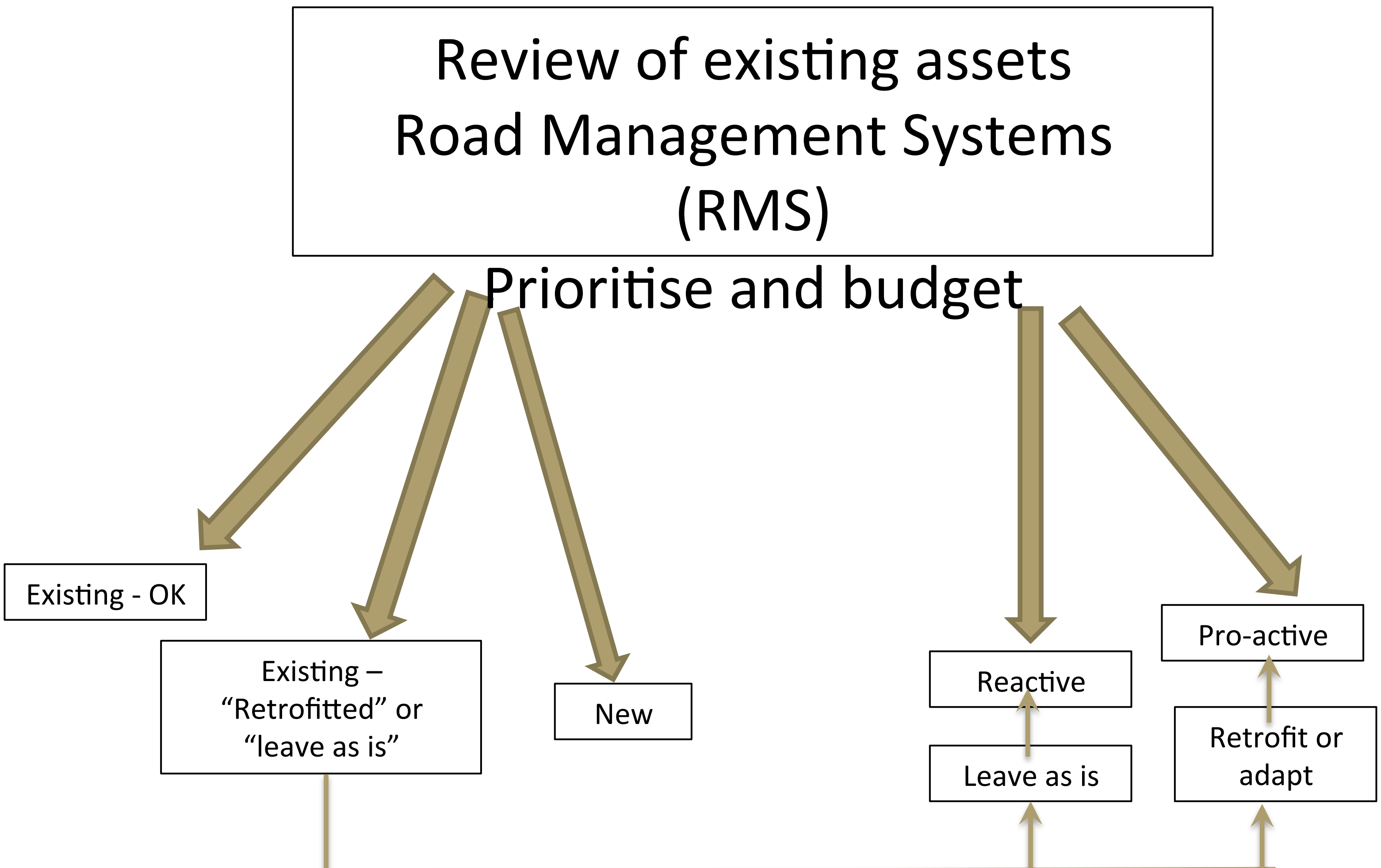
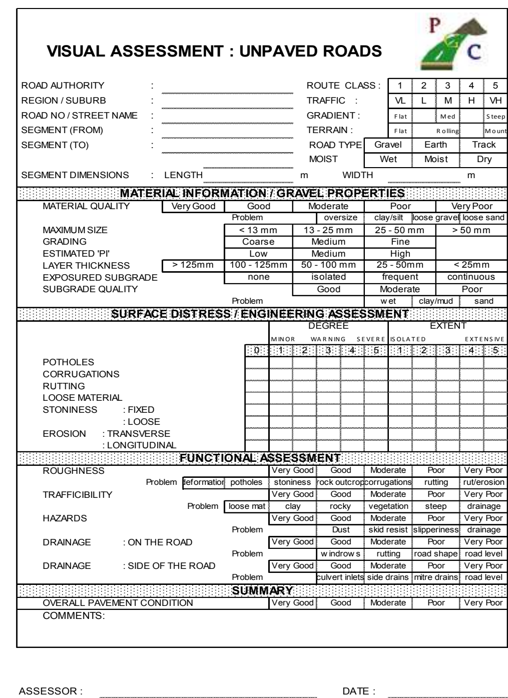
PROCESS


Review of existing assets
Road Management Systems
(RMS)
Prioritise and budget
Existing - OK
Existing –
“Retrofitted” or
“leave as is”
New
Reactive
Leave as is
Pro-active
Retrofit or
adapt

RMS

- Not currently done adequately in most SSA countries
- Climate resilience needs additional information to be collected
- Normally visual assessment of road condition with some measurements (possibly)
- Must also include assessment of potential risk/vulnerability
  - Identify likely problems – according to expected climate changes



VISUAL ASSESSMENT : UNPAVED ROADS

ROAD AUTHORITY :
REGION / SUBURB :
ROAD NO / STREET NAME :
SEGMENT (FROM) :
SEGMENT (TO) :
SEGMENT DIMENSIONS : LENGTH m WIDTH m

ROUTE CLASS :	1	2	3	4	5
TRAFFIC :	VL	L	M	H	VH
GRADIENT :	Flat		Med		Steep
TERRAIN :	Flat		Rolling		Mount

ROAD TYPE	Gravel	Earth	Track
MOIST	Wet	Moist	Dry

MATERIAL INFORMATION / GRAVEL PROPERTIES

MATERIAL QUALITY	Very Good	Good	Moderate	Poor	Very Poor	
Problem			oversize	clay/silt	loose gravel	loose sand
MAXIMUM SIZE		< 13 mm	13 - 25 mm	25 - 50 mm	> 50 mm	
GRADING		Coarse	Medium	Fine		
ESTIMATED 'PI'		Low	Medium	High		
LAYER THICKNESS	> 125mm	100 - 125mm	50 - 100 mm	25 - 50mm	< 25mm	
EXPOSURED SUBGRADE		none	isolated	frequent	continuous	
SUBGRADE QUALITY			Good	Moderate	Poor	
Problem				wet	clay/mud	sand

SURFACE DISTRESS / ENGINEERING ASSESSMENT

	DEGREE						EXTENT				
		MINOR		WARNING		SEVERE	ISOLATED				EXTENSIVE
	0	1	2	3	4	5	1	2	3	4	5
POTHOLES											
CORRUGATIONS											
RUTTING											
LOOSE MATERIAL											
STONINESS : FIXED											
: LOOSE											
EROSION : TRANSVERSE											
: LONGITUDINAL											

FUNCTIONAL ASSESSMENT

ROUGHNESS			Very Good	Good	Moderate	Poor	Very Poor
Problem	deformation	potholes	stoniness	rock outcrop	corrugations	rutting	rut/erosion
TRAFFICIBILITY			Very Good	Good	Moderate	Poor	Very Poor
Problem		loose mat	clay	rocky	vegetation	steep	drainage
HAZARDS			Very Good	Good	Moderate	Poor	Very Poor
Problem				Dust	skid resist	slipperiness	drainage
DRAINAGE : ON THE ROAD			Very Good	Good	Moderate	Poor	Very Poor
Problem				windrows	rutting	road shape	road level
DRAINAGE : SIDE OF THE ROAD			Very Good	Good	Moderate	Poor	Very Poor
Problem				culvert inlets	side drains	mitre drains	road level

SUMMARY

OVERALL PAVEMENT CONDITION	Very Good	Good	Moderate	Poor	Very Poor

COMMENTS:

ASSESSOR : DATE :

ASSESSMENT

- *Climate sensitivity of all components of the road infrastructure needs to be identified during routine road condition assessments*

- ***Two primary parameters:***
  - *Damage – this can normally be repaired rapidly by local works teams*
  - *Collapse – this usually requires significant construction works, often by specialised teams requiring a tendering process and can lead to road closures for an extended period of time.*

ASSESSMENT

- What do we need to assess that is different/ not included normally?
  - Erosion potential – drains, slopes, fills, etc
  - Subgrade material problems
  - Drainage efficiency in the road reserve
  - Drainage from outside the road reserve
  - Slope and embankment stability
  - Construction quality
  - Maintenance effectiveness
  - Others – drift sand, excessive vegetation, etc

ROAD CONDITION ASSESSMENT FORM

PROVINCE: ROAD NAME: TRAFFIC

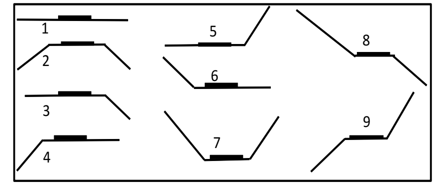
DISTRICT: ROAD CODE: INSPECTOR: DATE: PAGE: 01

STRIP MAP

Village / urban area:		Stream	
Rock Outcrop:	#	River	
Road:		Gully	
Path/Track:		Culvert:	
Quarry		Bridge:	
Gravel pit:		Outlet:	

3		4		5		6	
F:	FLAT	IRR:	IRRIGATED LAND	RO:	ROCK	A	0 -2%
R:	ROLLING	DRY:	DRY FARMLAND	ST:	STONE	B	2 - 6%
H:	HILLY	FOR:	FOREST	GR:	GRAVEL	C	6 -8%
M:	MOUNTAIN	SHR	SHRUB	BO:	BOG / PEAT	D	8 - 10%
		RES:	RESIDENTIAL	CL:	CLAY	E	10 - 15%
				SA:	SANDY	F	>15%

7. PROFILE



Strip Map

Chainage (m)

+200 +400 +600 +800 +200 +400 +600 +800 +200 +400 +600 +800

1. WAYPOINT NUMBER
2. PICTURE REFERENCE No
3. TOPOGRAPHY (F / R / H / M)
4. LANDUSE / VEGETATION (IRR / DRY / FOR / SHR / RES)
5. ROAD SURFACE (CL / SA / GR / LA / BIT / CO)
6. ROAD GRADIENT
7. PROFILE
8. CARRIAGEWAY PROBLEMS
9. ROAD CARRIAGEWAY WIDTH (M)
10. OVERALL ROAD DRAINAGE CONDITION
11. MISSING SIDE DRAIN(S) IF REQUIRED ? (L, R, L+R)
12. MISSING OR DAMAGED CULVERT (MC/DC)
13. CUT (C) OR FILL (F) SLIPS; (S,M,L)
14. FLOOD VULNERABILITY (1-5)

8. Carriageway Problems

1	Poor shape	a Minor
2	Rutting	b Moderate
3	Erosion	c Severe
4	Potholes	
5	Low alignment	

10. Road Drainage Condition

DR 1:	'Good':	No water on the road during rain, no erosion, no silt, good working drainage syst
DR 2:	'Fair':	Some water on the road during rain, some erosion in side drains or half silted
DR 3:	'Poor':	Much water on the road during rain, severe erosion/siltation of side drains
DR 4:	'Bad':	Non existing / non functioning drainage system

13. Cut or Fill Slips

C/F 1	No slips
C/F 2	Minor slips < 3Cu M
C/F 3	Moderate;3-10 CuM up to 25% carriageway
C/F 4	Significant, up to 50% carriageway impacted
C/F 5	Major 50-100% carriageway impact

14. Flood Vulnerability

1. No risk to access
2. Slight risk, little impact on access
3. Moderate risk -
4. High risk of access being compromised
5. Very high risk - severe engineering issue

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Road Number:		**Date:**		**Assessors:**		**Weather:**	

Chainage	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	
GPS and photo No																				
Erodibility																				
Soil																				
Road surface																				
Side drains																				
Embankments																				
Slopes																				
Drainage (in reserve)																				
Road shape																				
Shoulders																				
Side slopes																				
Side drains																				
Mitre drains																				
Drainage (streams)																				
Structure																				
Embankments																				
Erosion																				
Slope stability																				
Cut stability																				
Fill stability																				
Construction																				
Compaction																				
Finish																				
Erosion protection																				
Maintenance																				
Quantity																				
Quality																				

COMMENTS:

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Road Number:	

Chainage	0.1	0.2	

GPS and photo No			

Erodibility			
Soil			
Road surface			
Side drains			
Embankments			
Slopes			

Drainage (in reserve)			
Road shape			
Shoulders			
Side slopes			
Side drains			
Mitre drains			

Drainage (streams)			
Structure			
Embankments			
Erosion			

Slope stability			
Cut stability			
Fill stability			

Construction			
Compaction			
Finish			
Erosion protection			

Maintenance			
Quantity			
Quality			

COMMENTS:

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Choice of serviceability level

- Assessors need to be aware of the possible climate changes
  - Will vary from region to region
  - Must make vulnerability judgements based on the specific stressors and infrastructure

- This includes:
  - The degree of exposure of the road infrastructure to different climatic hazards;
  - The sensitivity of the infrastructure to such changes in climate, and;
  - The adaptations necessary to mitigate the potential for damage (i.e. adaptive capacity).

BUDGET

- Annual allocation
  - Can’t plan without precedent
  - How much ?
  - Gaining knowledge but is it consistent?
- Emergency
  - Usually take from other sources
  - Mostly maintenance funds
  - Other roads then deteriorate
  - Vicious circle

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DISCUSSION

1. Are there any comments on these properties ?
2. Are the major issues covered ?

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Erodibility			
Soil			
Road surface			
Side drains			
Embankments			
Slopes			

Drainage (in reserve)			
Road shape			
Shoulders			
Side slopes			
Side drains			
Mitre drains			

Drainage (streams)			
Structure			
Embankments			
Erosion			

Slope stability		
Cut stability		
Fill stability		

Construction		
Compaction		
Finish		
Erosion protection		

Maintenance		
Quantity		
Quality		

COMMENTS:

ADAPTATIONS

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INCREASED RAINFALL

Also

- Decreased rainfall
- Increased temperature
- Decreased temperature
- Increased windiness
- Sea-level rise
- Groundwater levels

FACILITY	CONSEQUENCE - POSSIBLE PROBLEMS AND DAMAGE	PROPOSED PREVENTIVE MEASURES SUGGESTED REMEDIES
Un-engineered earth roads	-Flooding (excessive surface water) -Softening of material -Impassability	Upgrade to engineered earth road standard
Engineered earth roads	-Flooding (excessive surface water) -Softening of material -Erosion -Impassability	Improve construction processes Improve drainage Upgrade to gravel road (raise riding surface and improve drainage).
Gravel roads	- Erosion -Loss of shape	Improved material selection Improved construction Improved maintenance
Paved roads	- Loss of strength of layer materials -Damage to thin surfacings -Damage to pavement edges	Use appropriate structural designs Ensure high quality construction Use appropriate surfacings Good maintenance (especially of surface cracking and potholes)
Earthworks	- Slope instability -Saturation and weakening of soils -Erosion -Undercutting -Excessive vegetation growth	Good drainage Good design (higher factors of safety) More slope stabilization measures Increased maintenance Bio-engineering techniques to stabilize slopes.
Subgrade soils	-Expansion and cracking -Collapse -Softening -More movement of salts	Correct identification of problem subgrades Correct remedial actions for problems Avoidance or appropriate treatment of problem subgrades Good design Good drainage
Drainage (water from within road reserve)	-Accumulation of water adjacent to road -Erosion of road surface and drains -Softening of materials	Good drainage design Regular, high quality maintenance
Drainage (water from outside road reserve)	-Erosion of embankments and abutments of culverts and bridges -Silting/sedimentation of culverts and bridges -Overtopping of bridges -Damage to bridges	Modify return periods in design Increase culvert and bridge openings Good design Good maintenance Design to minimise effects of debris (removal or upstream barriers/traps)
Construction	-Excessive moisture in materials	Difficult to mitigate against Construct in dry season Greater use of unslaked lime

RESILIENCE

- Some roads are fine – surrounding environment good
  - Raised above NGL
  - Good drainage
  - Sealed shoulders, etc
  - Minimal problems with extreme events
- Others need improvement
  - Costs
  - Phase in over time – based on rate of change - Proactive
  - Mostly problems with extreme events – reactive
- New roads and structures must be designed for the future
  - Resilient
  - Water-proof, temperature proof, flood proof, etc
- Each situation is unique and must be assessed as such !!

Unpaved roads

- Probably less problems than paved roads
- Less permanent surface
  - Usually last between 3 and 10 years
  - Maintained regularly (?)
  - Increased gravel loss from erosion
  - Increased damage when inundated

Earth roads

- Most vulnerable unpaved road
- Also dominant type of road in SSA
  - Local material
  - No proper shape
  - Collects water

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Earth roads

- Minimum requirement – improvement
- Depends on material
- Good gravel road best option

Engineered earth roads

Engineered earth roads

- Depends on material
- If not within specs, we need a full “gravel” road
- Traffic dependent !!

GRAVEL ROADS

- Adaptation
- Costs (+ 30%)

Construction

Shape/drains

Material selection

Maintenance

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Paved roads

- Different set of problems
  - Long-term > 20 years
  - More difficult (and expensive) to maintain
- Structural design critical
- Function of subgrade
- Steady moisture content over time – changes?
- Unique designs for each situation

Paved roads

- CAREFUL DESIGN
- Understand the environment and design for it – moisture, shoulders, drainage, etc
- Maintain the road properly

PAVED ROADS

- Drier and hotter conditions will mostly improve the situation (material strength)
  - More cracking and settlement on clayey subgrades as they shrink
- Wetter conditions will increase problems
  - More expansion as they wet up
  - Dissolution of more salts where present i.e., more pollution
  - Higher pore-water pressures – lower shear strengths

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PAVED ROADS

- Hotter and colder conditions
  - Affect bitumen mostly – softer and harder respectively
  - Quicker oxidation
  - Daily/seasonal moisture movement – condensation, vapour to water (energy release), etc
  - Hotter conditions also speed up chemical reactions
    - Faster weathering/alteration of aggregates in roads
    - Faster stabilization reactions

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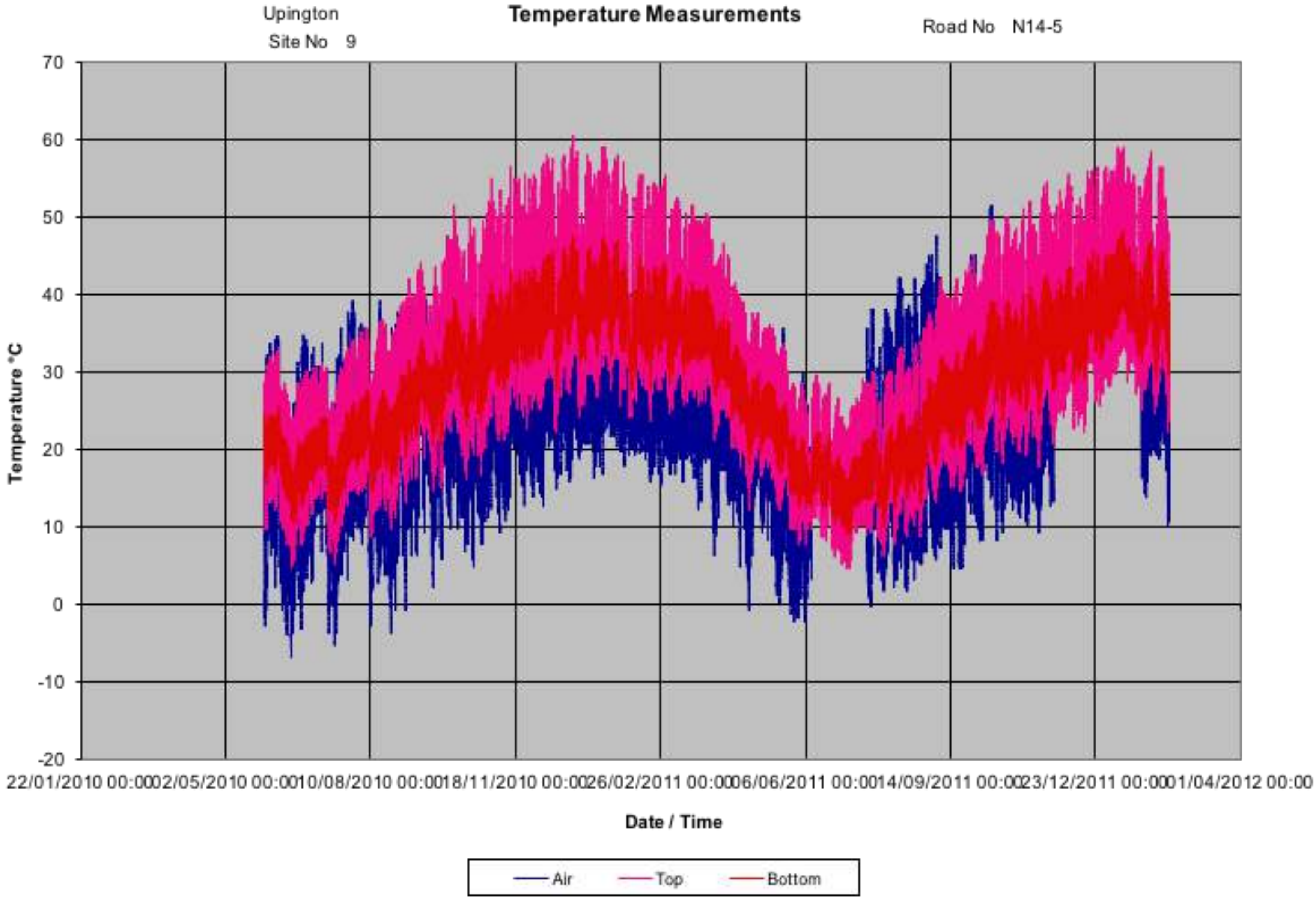

STRUCTURES

- One of the easier problems
- Design is based on return period for a specific storm or flow
- We just need to modify the storm/flow (return period) to handle increased rainfall
- Scour/erosion may require additional work
- Also geometrics

STRUCTURES

- Return periods have been looked at in Ghana (COWI, 2010)
- Indication that 100 year storm will occur every 18 years (2050)
- Need to adapt these with time

STRUCTURES

- Take note of potential for reducing bridge capacity
- Overtopping and damage to structure

EARTHWORKS

- Fill and cut failures with wetter conditions (higher pore-water pressures)
- Cracking in fills and cuts with drier conditions
  - More rapid access of water into structures
  - Rapid failures (tension cracking – drying cracks?)

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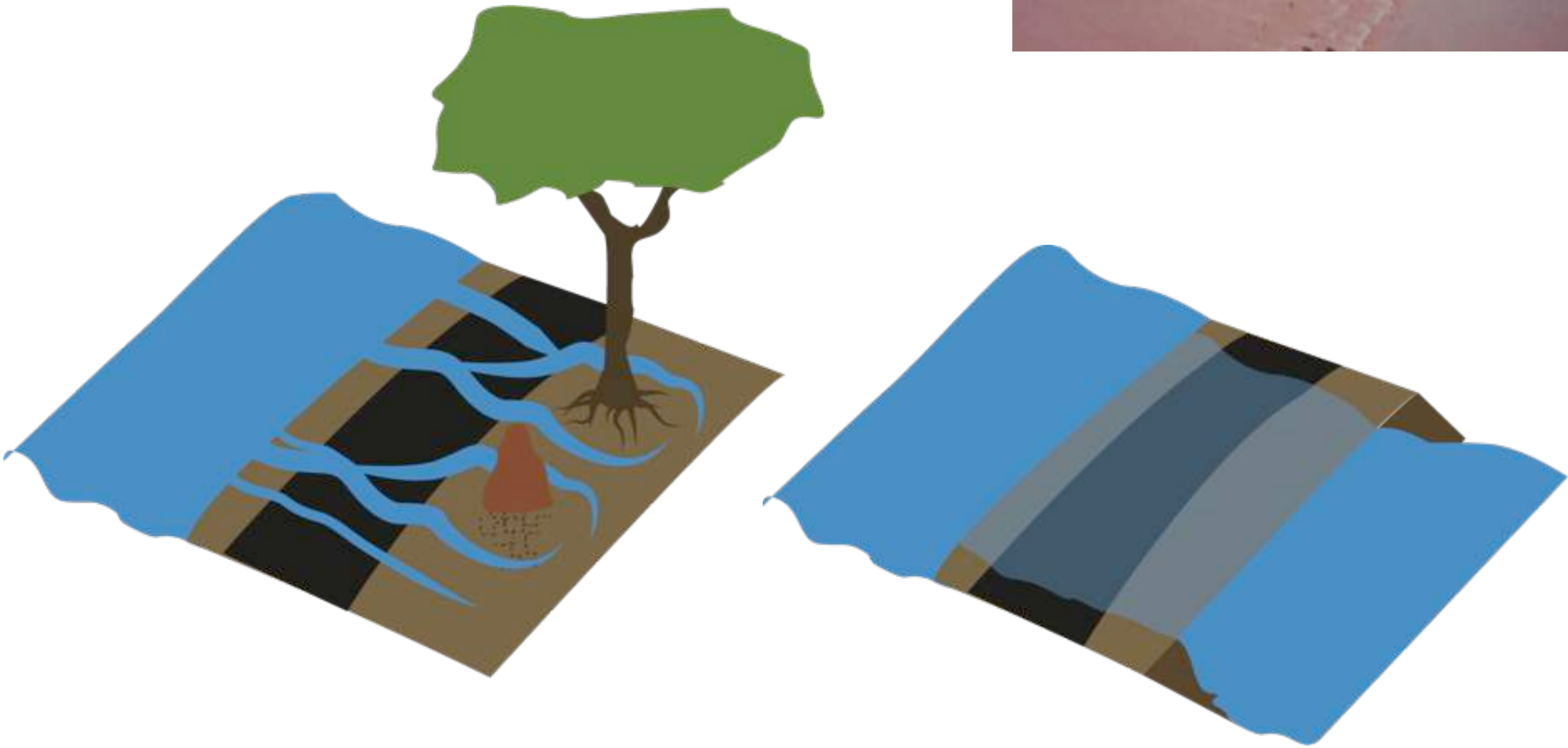
Overtopping of embankments during flooding

- Undercutting of the pavement on the the downstream slope - loss of the embankment supporting the pavement structure
- T*urbulent flow* of the overtopping water causes erosion of shoulders
- Once the shoulders are eroded, the pavement layers are easily eroded

Turbulent flow

Severe problem on natural materials



EROSION & SILTATION

- Increased by loss of vegetation due to drought and fires
- Causes increased siltation/sedimentation
- Requires increased maintenance – often mostly manual
- Also better design considerations

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OTHER ISSUES

- Vegetation
  - Hotter and wetter – more luxuriant – more maintenance
  - Drier – less ground cover – more erosion – more roots in road structure.
  - Susceptibility to fires (drier, windier) and effects of burning (loss of roots/erosion)




- Increased temperatures

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Main problems identified

Problem	Selected countries affected		
	Mozambique	**Ghana**	**Ethiopia**
Shear failure due to excessive subgrade moisture			X
Erosion of wearing course and side-drains on grades		X	X
Slope instability			X
Erosion of embankments near structures	X	X	X
Collapse of structures	X		
Loss of surfacing on low lying roads during flooding	X		
Pavement failures due to raised moisture contents in sub-layers	X (P)		X (U)
Erosion of high embankments and loss of surfacing during flooding	X		
Undermining of embankment due to flooding	X		
Poor road condition - unsuitable gravel			X
Flooding of the road		X	
Impassability due to poor materials and local ponding of water		X	

DISCUSSION

1. Are there any other major problems not included (excluding bridges)?

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Problem
Shear failure due to excessive subgrade moisture
Erosion of wearing course and side-drains on grades
Slope instability
Erosion of embankments near structures
Collapse of structures
Loss of surfacing on low lying roads during flooding
Pavement failures due to raised moisture contents in sub-layers
Erosion of high embankments and loss of surfacing during flooding
Undermining of embankment due to flooding
Poor road condition - unsuitable gravel
Flooding of the road
Impassability due to poor materials and local ponding of water

CONCLUSIONS

- Road adaptations are basically good fundamental engineering
- But we need to identify the potential problems and implement adaptations properly
- Not only design, but also construction and maintenance
- Must identify potential resilience problems during or in conjunction with Asset Management assessments
- Try and avoid future problems before we are too late

Thank you for your attention

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