Report on the Impact of Climate Change on Road Infrastructure, with a Proposal for Adaptation Measures

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List of Abbreviations

CEDR	Conference of European Directors of Roads
GDP	Gross Domestic Product
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
ISS	The Institute for Standardization of Serbia
PE	Public Enterprise
RAMS	Road Asset Management System
RCP	Relative Concentration Pathway
RIMAROCC	Risk Management for Roads in a Changing Climate
ROADAPT	Roads for today, adapted for tomorrow
UNDP	United Nations Development Program

CONTENTS

1. METHODOLOGY AND DATA SOURCE

1.1 Methodology

The basic approach in the preparation of this report is in accordance with the methodology developed within two research projects funded by the ERANET ROAD program, which was later taken over by the Conference of European Directors of Roads (CEDR):

- RIMAROCC (Risk Management for Roads in a Changing Climate)[1]
- ROADAPT (Roads for today, adapted for tomorrow)[2]

The RIMAROCC project has developed a framework for decision-makers facing the impact of climate change on road networks, based on risk analysis, which includes seven basic steps and 22 sub-steps for identification, analysis, prioritization, evaluation and mitigation of climate change risk (Figure 1).

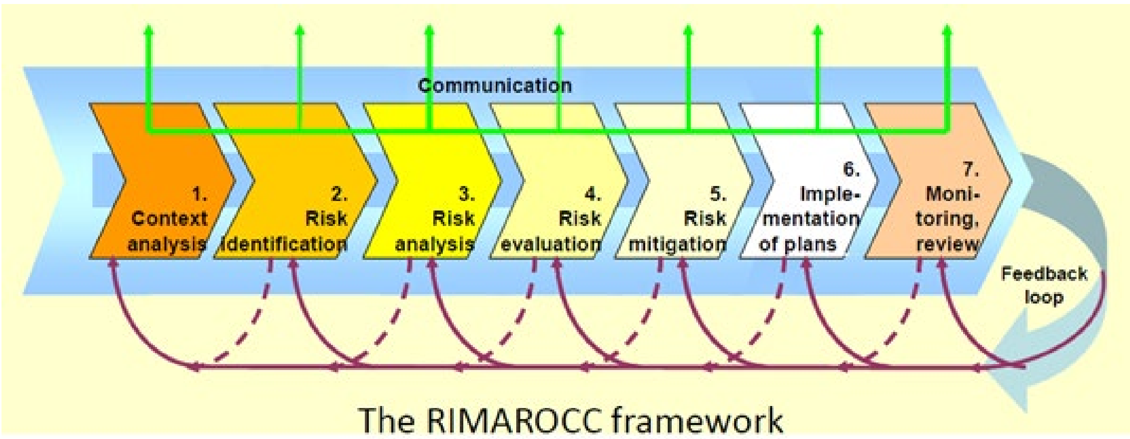

Figure 1. Framework for sensitivity analysis of road networks, developed in the RIMAROCC project

Within the ROADAPT project, guidelines were developed for the preliminary climate change risk assessment of the road network, for a detailed vulnerability assessment, for the assessment of the socio-economic impact and for the selection of adaptation strategies (Figure 2).

1 Bles, T., Ennesser, Y., Fadeuilhe, JJ., Falemo, S., Lind, B., Mens, M., Ray, M., Sandersen, F. RISK MANAGEMENT FOR ROADS IN A CHANGING CLIMATE: A Guidebook to the RIMAROCC Method, Final Report, ERANET ROAD, 2010

2 Bles, T., Bessembinder, J., Chevreuil, M., Danielsson, P., Falemo, S., Venmans, A. Roads for today, adapted for tomorrow ROADAPT Guidelines, CEDR, 2015

1.2 Road network of Serbia

The network of state roads in the Republic of Serbia consists of 16,368.5 km of state roads of the first and second class (Table 1), for the maintenance of which the Public Enterprise "Roads of Serbia"[3] is in charge. In addition, it is estimated that there is about 30,400 km of local roads (municipal roads and streets) for the maintenance and operation of which the local governments [4]are in charge.

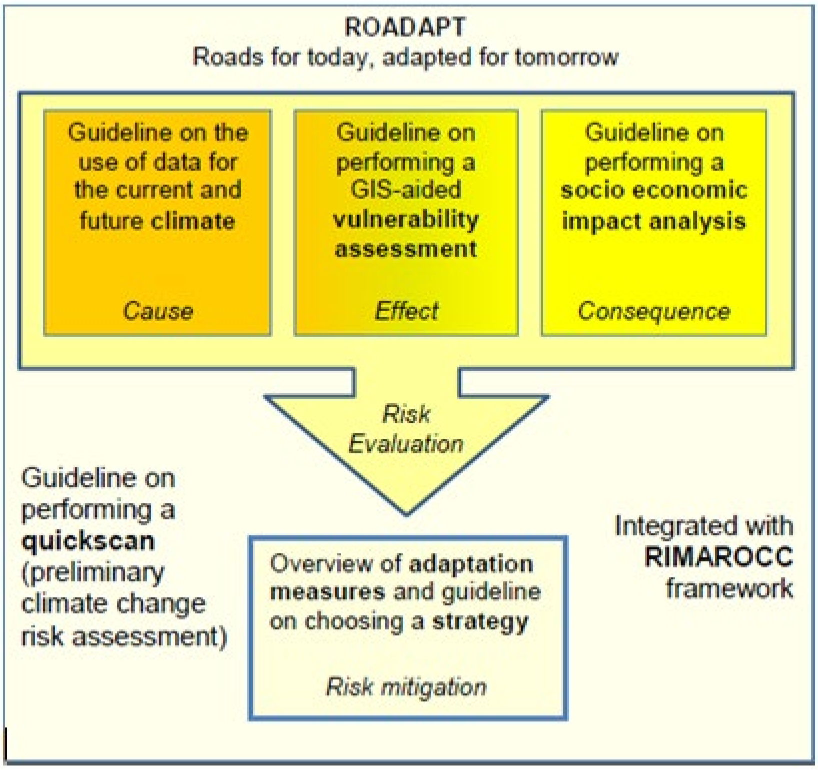

Figure 2. ROADAPT Project Structure

Table 1. State road network in Serbia[5]

State roads	Length (km)
Class IA (Highways)	924.7
Class IB	4,491.7
Class IIA	7,784.5
Class IIB	3,167.6

3 PE "Roads of Serbia" https://www.putevi-srbije.rs/index.php/%d0%be-%d0%bd%d0%b0%d0%bc%d0%b0/%d0%be-%d0%bd%d0%b0%d0%bc%d0%b01, accessed on April 23, 2021

4 Statistical Yearbook of the Republic of Serbia, 2020, Statistical Office of the Republic of Serbia, 2020

5 PE "Roads of Serbia" https://www.putevi-srbije.rs/index.php/%d0%be-%d0%bd%d0%b0%d0%bc%d0%b0/%d0%be-%d0%bd%d0%b0%d0%bc%d0%b01, accessed on April 23, 2021

There are 3,426 bridges with a total length of over 151 km on the state roads of the Republic of Serbia, of which 857 are bridges on highways. Bridges are of different ages, different static systems, from 5 m to 2,212 m long, and built of different materials (wood, stone, concrete, pre-stressed concrete, steel). There are 128 bridges longer than 500 m on state roads.

There are also 107 tunnels on state roads in Serbia, with a total length of 29.2 km, of which there are 33 tunnels on highways. Tunnels are of different ages, different construction technologies and in diverse geological environments. The longest tunnel is Manajle, on the A1 highway (Predejane loop – Vladičin Han loop), 1,815 m long. Most tunnels, 23, are on the Đerdap state road. Sixty-one road tunnels in Serbia are longer than 100 m.

Table 2 and Figure 3 show the structure of traffic loading on the state road network in 2019, based on the annual traffic count reports available on the website of the Public Enterprise "Roads of Serbia"[6]. Data are also available for 2020, but were not taken into account because they were considered unrepresentative due to the impact of the Covid-19 pandemic. As for Class IIA, data are available for only one section and cannot be taken as representative.

Table 2. The traffic load on the state road network

State roads	Data availability		AADT (vehicle/day)		
	Length (km)	%	Min.	Max.	Average
Class IA (Highways)	910.6	98,5	3.933	59.132	16.142
Class IB	3.898,4	86,8	212	28.607	4.473
Class IIA	3.747,8	48,1	158	19.939	2.760
Class IIB	11,2	0,4			16.631

6 https://www.putevi-srbije.rs/index.php/%D0%B1%D1%80%D0%BE%D1%98%D0%B0%D1%9A%D0%B5-%D1%81%D0%B0%D0%BE%D0%B1%D1%80%D0%B0%D1%9B%D0%B0%D1%98%D0%B0, accessed on April 23, 2021

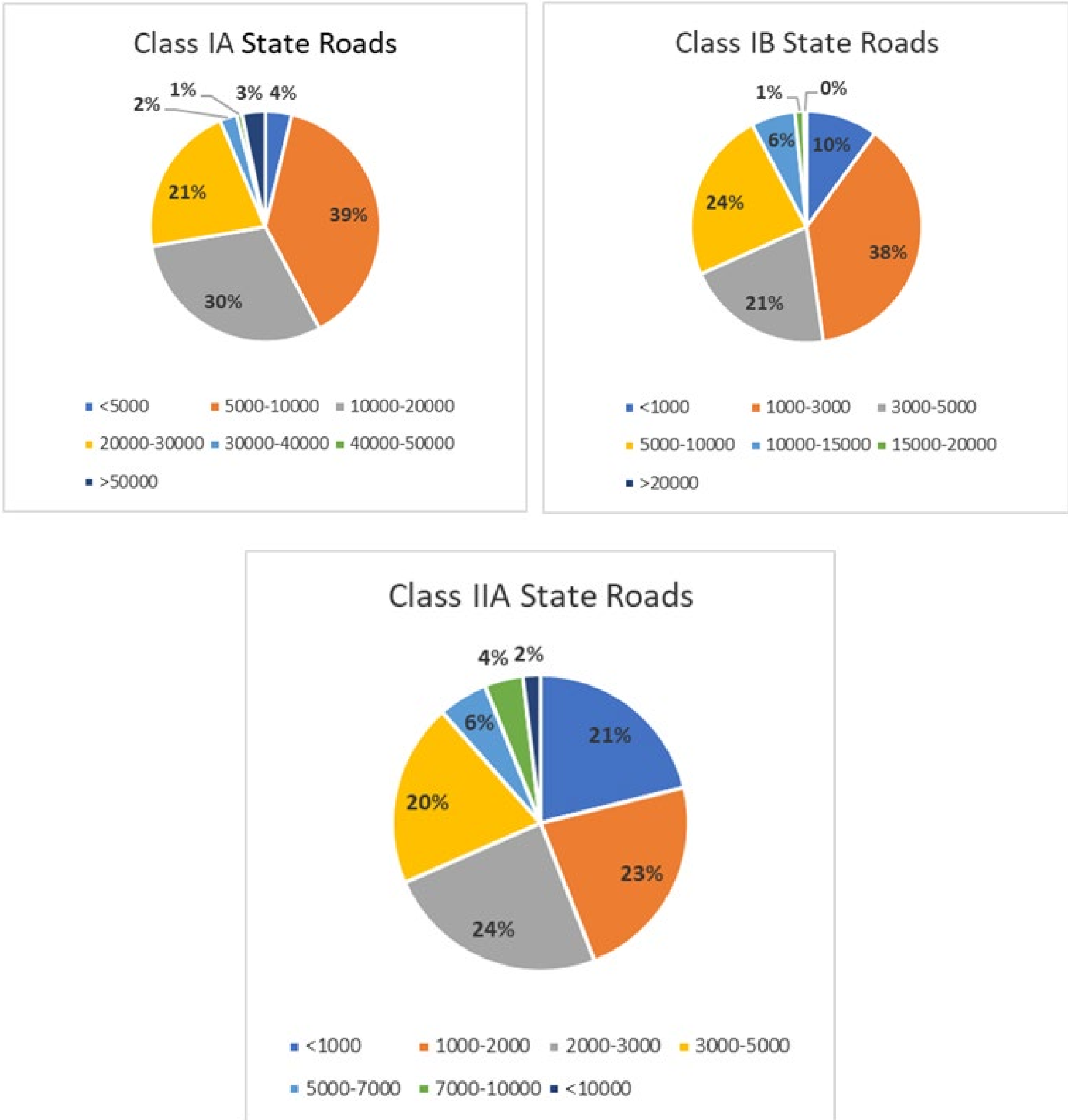

Figure 3. Structure of traffic load on the state road network

On state roads of classes IA, IB and IIA, pavement structures with asphalt layers are predominantly represented, where the basic binder is bitumen whose characteristics depend on temperature. Concrete pavement structures are represented on the network to a negligible extent (less than one percent).

1.3 Availability of road network data

The availability of data on the Serbian road network is relatively limited, which is one of the limiting factors in terms of conducting an analysis on climate change sensitivity. The data are in different institutions, they are very often not up-to-date and available.

In PE “Roads of Serbia”, there are several databases for the state road network:

- Road database
- Bridge database

- Tunnel database
- Landslide database and
- Traffic database.

The degree of keeping these databases up-to-date is very different. Traffic data are updated on an annual basis, which is not the case with other databases, so these databases are practically not used for planning maintenance works on the road network, which is their basic function. A significant problem is the disconnection of these bases, which prevents a comprehensive analysis of the network that would include all roads.

The development of the road database started in the early 1990s. In the period until 2008, several cycles of the condition surveys of the road network were performed. However, this was accompanied by changes in the recording methodology, as well as changes in the road network reference system, which, along with the lack of quality control of recorded data and non-implementation of updates regarding maintenance work, made these data, except for basic inventory data on the network, practically unusable for forming a deterioration model of certain road sections.

The last cycle of recording the condition was conducted in 2018, but again without quality control of the recorded data (in terms of calibration of measuring equipment and performance models of the road structure). The road database has not yet been functional or available. Another problem with these databases is their structure, i.e. the lack of data relevant to the analysis of the effects of climate change, which includes, among other things, historical data on regular, periodic and emergency maintenance works caused by climate-related events. There is also a need to include data from road meteorological stations.

The situation with the availability of data at the level of the local road network is even worse, and as a rule, it is caused by the lack of capacity and resources at the level of local self-government. At the level of local self-governments, inventory data on local road networks are possibly available, without a systematized approach to managing their maintenance.

1.4 Available studies and analyses of the impact of climate change on the road network in Serbia

By 2020, PE “Roads of Serbia” financed the development of nine studies regarding flood risk analysis for Class I and II roads in river basins in Serbia[7]. Table 3 gives a review of these studies, with the road network covered by them. A detailed representation of the studies is given in the report[8].

7 https://www.putevi-srbije.rs/index.php/en/department-for-public-relations?view=article&id=22119&catid=24, accessed on May 09, 2021

8 Report 1- Analysis of the availability of climate and socio-economic information, including climate data, data on risks and impact assessments and information on adaptation measures, DVOPER d.o.o.

Table 3. Studies regarding flood risk analysis for Class I and II roads

River Basin	Length of state roads (km)				Year of development
	Class IA	Class IB	Class IIA	Class IIB	
Kolubara					March 2017
Južna Morava	55.0	92.0	467.0	177.0	April 2018
Sava (without Drina and Kolubara)	332.0	268.0	404.0	287.0	July 2018
Zapadna Morava (without Ibar)	115.0	330.0	563.0	160.0	August 2018
Ibar		244.8	307.9	71.9	November 2018
Drina		239.0	297.0	210.0	2019
Lim		185.6	262.3	17.9	2019
Južna Morava II	278.4	247.9	915.6	400.3	June 2019
Timok		235.7	381.1	307.9	January 2020

The Highway Institute from Belgrade also prepared a Study of the research of snow accumulation on Class I state roads in 2016 for PE "Roads of Serbia". The study analyzed about 4800 km of Class I state roads and concluded that the road network in the length of 678.1 km was exposed to the effect of snow accumulation.

These studies have been prepared based on the current status, or recorded occurrences in the past and do not include the impact of climate projections.

A methodology for assessing the vulnerability of roads to climate change was developed within the World Bank Study *Mainstreaming Climate Resilience in the Road Transport Management in Serbia*[9]. The methodology was applied within a pilot project on the territory of the wider area of Valjevo and included the impact of floods, flash floods, landfalls, flows, landslides, wildfires and snow accumulation on 43 sections of state roads (about 500 km of Class I and II roads).

Within the Climacor II project, a study of the impact of climate change on the Road Corridor X was done[10]. The Study applied a modified Roadapt/Rimarocc methodology for rapid assessment of the impact of climate change based on an expert survey in terms of the most important threats, possible effects (in terms of availability), and probability of occurrence, and finally defined proposed adaptation measures for individual risks.

9 Mainstreaming Climate Resilience in the Road Transport Management in Serbia, GFDRR & The World Bank, 2018

10 http://documents.rec.org/projects/Annex1_OrientEast-MedCorridorAssessment.pdf

The study on the impact of climate change for the City of Belgrade[11] is the only available study that deals with local infrastructure and gives a general overview of the impact on the area of traffic infrastructure in the city.

2. IMPACT ASSESSMENT

2.1 Critical climatic parameters relevant to road infrastructure

The impact of climate change on road infrastructure can be twofold:

- Extreme climatic events can cause infrastructure damage and traffic disruptions in a short period;
- Long-term climate change can jeopardize the durability and functionality of road infrastructure over a longer period and cause more intensive maintenance work.

The impact of rainfall on road infrastructure is multiple and can be analyzed through several separate mechanisms. The parameters that affect the condition of the pavement structure are as follows:

- Average monthly precipitation
- Frequency of precipitation, i.e. the number of consecutive days with significant amounts of precipitation
- Precipitation intensity, maximum annual or monthly values.

The average monthly or annual amount of precipitation is a parameter that is important for assessing the deterioration of the road structure. Higher precipitation causes bitumen-leaching, wetting of the structure, reduction of load-bearing capacity and consequently leads to the need for a higher frequency of maintenance works or to the accelerated deterioration of the road surface (Figure 4). This deterioration is further reflected on road users through reduced driving comfort, increased operating costs related to travel and vehicle costs.

11 Climate Change Adaptation Action Plan and Vulnerability Assessment, City of Belgrade, Secretariat for Environmental Protection, 2015

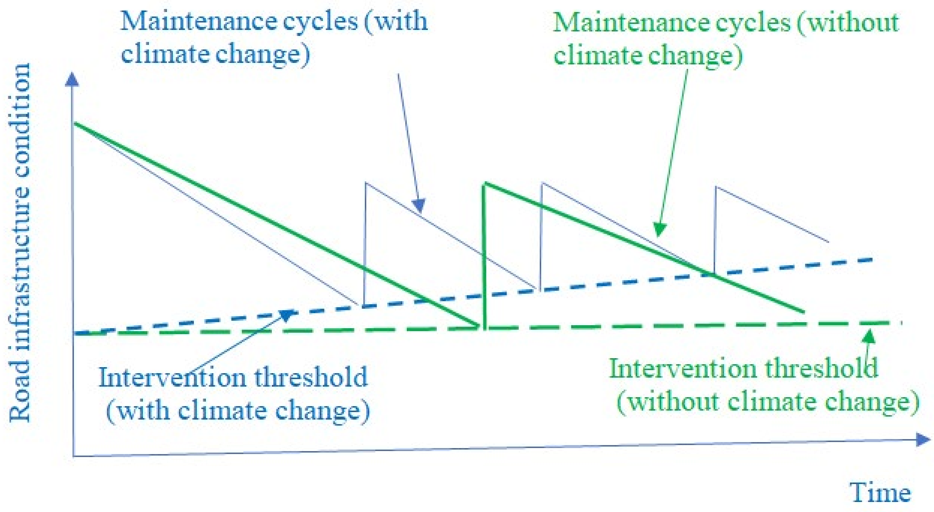

Figure 4. Schematic representation of the impact of climate change on road maintenance costs

However, the amount of precipitation also has an impact on other road facilities in the right-of-way, which relate to the drainage system. In this sense, the key parameter is the maximum intensity of the precipitation. Namely, by increasing these values beyond the expected or designed values, serious damage to culverts and other elements of the drainage system can occur. These damages always lead to distresses on the pavement surface, but also to endangering the safety of driving and passability of that section of the road. Similarly, there can be great damage to bridge structures, especially due to soil erosion under pier foundations, which can lead to great material damage, endangering driving safety and total traffic blockage.

Finally, the frequency of precipitation, i.e. the number of consecutive days with high intensity of precipitation is a parameter that leads to landslide activation and slope instability. During the activation of the landslides, consequently, great material damage occurs on the road structure, pavement and structures, and there may be total traffic disruption and the safety of road users may be endangered.

In a similar context, strong snowstorms affect traffic disruptions and reduce road user safety, and the parameter that can be monitored is wind speed and direction combined with the thickness of the snow cover (i.e. the amount of snowfall).

In terms of accelerated deterioration of the road surface and the damage caused by climate change, in addition to precipitation, another important factor is the change in average daily air temperature, maximum air temperature and the number of consecutive hot days. These parameters affect the change in the characteristics of the bituminous binder, which results in higher pressures on the base and the occurrence of permanent damage to the pavement in the form of ruts and/or cracks. The consequence of these impacts is eventually reflected in reduced time between the two maintenance interventions, the reduction in driving comfort and safety, and an increase in operating costs related to travel.

On the other hand, climate change can also have a positive effect on the pavement structure, in terms of reducing the depth of frost penetration, which can be estimated based on the number of ice days, minimum annual temperatures and average annual temperatures. The impact in this sense is also important because it affects the projected thicknesses of pavement structures, and thus the costs and time of construction. Otherwise, if these changes are not taken into account, certain layers of the road structure may be oversized and unnecessary investments may be made.

Table 4 provides an overview of critical climatic parameters with the main risks to road infrastructure. The extent to which these parameters are significant for a particular section or road network depends on local conditions, which will be discussed in more detail in Chapter 2.4.

Table 4. Climatic events and corresponding risks to road infrastructure

Critical climatic event	Impact on road infrastructure
Extreme precipitation (showers or prolonged rainfall)	• Road flooding • Pavement substructure erosion, landslides • Overloading of the drainage system which causes erosion and flooding • Traffic disruptions and impact on traffic safety
Average rainfall at the season or year level	• Impact on soil moisture level, which further affects bearing capacity and structural integrity of roads, bridges and tunnels • The negative impact of high water levels on the road base • Risk of flooding caused by surface water runoff, landslides, slope instability and road damage if there are changes in the type of precipitation (e.g. rainfall instead of snow during winter and spring ice melting)
Sea level rise	• Flooding of roads in coastal areas • Erosion of road base and bridge supports • Reduced free passage height under bridges • Increased demand for the use of roads used in case of emergency evacuation
Maximum temperature and number of consecutive warm days (heatwave)	• The question of the integrity of the pavement structure: reduction of stiffness of asphalt layers, rutting caused by traffic loading, cracking, bitumen bleeding • Thermal expansion of joints on bridges and in rigid pavement structures • Impact on vegetation in the right-of-way
Drought (consecutive dry days)	• Sensitivity to forest fires that can directly endanger traffic infrastructure • Possibility of landslides in cleared areas affected by forest fires • Pavement substructure consolidation with (uneven) settlement as a consequence • Increased smog • Lack of water for earthworks

Snowfall and snowdrifts	• Traffic disruptions and impact on traffic safety • Snow removal costs • Impact of avalanches on road closures or endangering vehicles • Flooding as a result of snow melting
Freezing (number of icy days)	• Traffic disruptions and impact on traffic safety • Ice removal costs
Melting (number of days with a temperature around zero)	• Permafrost melting that can result in the settlement of buildings and roads • Reduced usability of temporary roads on icy ground
Extreme wind speeds	• Stability of bridges • Damage to signaling, lighting and poles
Fog	• Traffic disruptions and impact on traffic safety • Increased smog

An overview of current knowledge regarding the impact of climatic events on road infrastructure is given in Table 5, which is defined within the RIMAROCC project[12]. The table shows the weighting factors in terms of the impact of certain events on road infrastructure, from 0 – "no impact" to 4 – "primary importance", and the expected intensity of climate change is given using the IPCC scale (Intergovernmental Panel on Climate Change):

++	significant increase
+	moderate increase
+/-	no significant changes
-	moderate reduction
--	significant reduction.

12 Risk Management for Roads in a Changing Climate: A Guidebook to the RIMAROCC Method, ERANET ROAD, 2010

Table 5. Summary of the impact of climatic events and critical climatic parameters for the analysis of the impact on road infrastructure[3]

Weight	Climatic event	Critical climatic parameter	Intensity of changes in relation to the period 1961-1990 (++, +, +/-, -, --)	Projection availability: qualitative, quantitative, or impossible	Prediction certainty	Spatial resolution (grid size, resolution to which it can be applied)	Time horizon (when will it happen?)	Available data / models
4	Extreme precipitation (showers or prolonged rainfall)	Max. precipitation intensity in [mm/h] and [mm/24 h]	Intensity:+ Frequency: -Northern Europe+ -Southern Europe?	Qualitative	Likely	Extremes are visible only on a small network: 50 km (it is difficult to use a smaller network)	Certain statistical trends; happening today	Regional models + local expertise
4	Average rainfall at the season or year level	Average rainfall over 3 months [mm]	Summer / Winter Northern Europe: +/- / ++ Southern Europe: -- / -	Qualitative	Summer / Winter Northern Europe: Likely / Very likely Southern Europe: Very likely / Likely	Main signal for the 250 km resolution, but can be averaged on a fine 50 km grid to get local averages	Already observed	Global IPCC models + regional ENSEMBLES
4	Sea level rise	Sea level rise [m]	++ 21st century (0.2 up to 0.6 m) IPCC assumption: no accelerated ice melting	Qualitative Qualitative if accelerated ice melting is taken into account	>0.2 m is almost certain at the end of 21st century	Global, but not uniform (may vary depending on local sea)	Already happening (melting of polar ice surfaces will not happen over the century)	IPCC scenarios
3	Maximum temperature and number of consecutive warm days (heatwave)	Average maximum temperature [°C] over 24 h Maximum temperature [°C] Heat wave duration [number of consecutive hot days]	South: ++ 21st century Globally 0.8 – 4.0 °C (best-estimate scenario) North/continent.: + ++, even more for extremes ++, 5 up to 30 days	Qualitative Quantitative Quantitative	In Europe almost certain Almost certain Most likely	Main signal for the 250 km resolution. However, in order to gain insight into the extreme values and the influence of the sea, local adjustment is necessary and possible (50 km). The specific situation in cities (higher T (°C) cannot be predicted.	Already happening (data available)	Global IPCC models + regional ENSEMBLES
2	Drought (consecutive dry days)	Drought duration [number of consecutive dry days], [d/year]	++ in Southern, Central and Western Europe	Quantitative Qualitative	Most likely Over half as likely	Good visibility on the 250 km network. finer resolution on regional level improves understanding	Having started	
2	Snowfall and snowdrifts	Max. snowfall over 24 h (m) Snow cover duration (days)	Intensity: + very Northern Europe ? the rest of Europe Frequency – NW/Central Europe Duration:-- all of Europe	Qualitative Qualitative Quantitative	Likely Likely Almost certain	Some understanding on the 250 km network. It is possible to get limited details at 50 km, but with a large margin of error.	Having started	

Weight	Climatic event	Critical climatic parameter	Intensity of changes in relation to the period 1961-1990 (++, +, +/-, -, --)	Projection availability: qualitative, quantitative, or impossible	Prediction certainty	Spatial resolution (grid size, resolution to which it can be applied)	Time horizon (when will it happen?)	Available data / models
2	Frost (number of icy days)	Minimum T (°C) Average minimum temperature [°C] over 24 h Frost duration [number of days per year] Frost index (depth of frost penetration into the soil, Hellman's	+ (low probability that the minimum temperature rises above the average minimum temperature) ++ 1.8 – 4.0 °C -- -- Certain changes throughout Europe	Quantitative Quantitative Quantitative Quantitative	Likely Almost certain Almost certain Almost certain	Some understanding on the 250 km network. It is possible to get limited details at 50 km, but with a large margin of error.	Having started Having started Having started Having started	
2	Melting (number of days with temperatures around zero)	Number of days with temperatures around zero	+ Northern and Central Europe - Southern Europe (research in progress)	Qualitative	Almost certain in Northern Europe	Some understanding on the 250 km network. It is possible to get limited details at 50 km, but with a large margin of error.	Having started	
2	Extreme wind speeds	Maximum speed (km/h)	+ Northwestern Europe ? the rest of Europe - Stormpath moved north (500 – 1000 km)	Qualitative	Likely in Northern Europe Unknown in Southern and Western Europe	250 km network	Not yet recorded	Global IPCC models
1	Fog	Number of days with fog	?	Not yet possible Local effects (e.g. land use) – vertical resolution	Unknown		Locally recorded (pollution reduction)	

- Prediction certainty:

- almost certain (>99%),
- probability of occurence:
- extremely likely (>95%)
- most likely (>90%)
- likely (>66%)
- -over half as likely (>50%)
- unlikely (<33%)
- most unlikely (<10%)
- extremely unlikely (<5%)

2.2 An overview of the most significant hazards in the Republic of Serbia related to climate change

The territory of Serbia is exposed to various types of natural hazards. According to previous studies, about 25% of the territory is at risk of landfalls and landslides, and 35% of the territory is exposed to soil erosion[13]. According to the same source, about 4000 km of roads are exposed to the danger of floods, and their functional classification is not stated. According to the paper[14] more than 17% of the territory of Serbia is exposed to floods and flash floods, 21% of the territory is exposed to droughts, and the risk of forest fires is present in 3.6% of the territory and is increasing from year to year[15]. Figure 5 provides an overview of areas exposed to natural hazards.

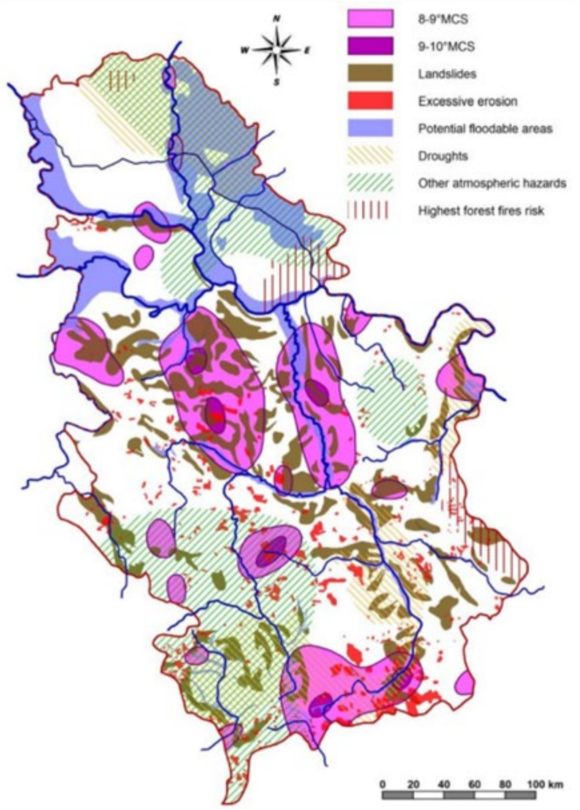

Figure 5. Map of natural hazards in Serbia[16]

This chapter covers the specific impact of climate change on road infrastructure in the Republic of Serbia, through an analysis of extreme events and corresponding effects and consequences in the last 15 years, from 2006 to 2021, based on available data.

13 Novkovic, I., Dragicevic, S., & Manic, E. Natural Hazards and Vulnerability to Natural Disasters: The Case of Serbia. *Risk Measurement and Control in Insurance; Kocovic, J., Jovanovic Gavrilovic, B., Rajic, V., Eds*, 41-62

14 Dragicevic et al., Natural Hazard Assessment for Land-use Planning in Serbia, *Int. J. Environ. Res*., 5(2):371-380, 2011

15 Dragicevic et al., Natural Hazard Assessment for Land-use Planning in Serbia, *Int. J. Environ. Res.*, 5(2):371-380, 2011

16 *Spatial Plan of the Republic of Serbia 2010-2020*. Ministry of Environment and Spatial Planning and the Republic Agency for Spatial Planning. Belgrade

The total damage caused by extreme climatic events since 2000 is estimated at more than five billion euros[17]. The greatest impact in the field of road infrastructure on the territory of the Republic of Serbia is the consequence of the following natural hazards and climatic events:

- Floods (activation of landslides and slope instability, damage to drainage systems, soil erosion under bridge piers)
- Snowdrifts - storms (traffic disruptions and traffic safety)
- Increase in maximum temperatures (durability of pavement structures).

During May 2014, there was a significant amount of precipitation in Serbia, which caused large-scale floods. This is considered to be the most severe flood in the past 120 years, and was caused by the superposition of the negative effects of soil saturation from previous rainfall, high water levels and heavy rainfall. The intensity of precipitation was 250, and even up to 300 liters of rain per square meter. Due to the huge impact of this flood on a larger part of the territory of Serbia, an emergency situation was declared.

The direct effects in the field of road infrastructure were reflected in the damage to bridges and roads and the activation of numerous landslides and slope instability. A team of experts within the United Nations Development Program – UNDP[18] estimated that the total material damage caused by these floods amounts to 1.5 billion euros in all sectors, i.e. 4.8% of Serbia's GDP, of which the damage to infrastructure was estimated at 192 million euros or 12% of the total loss, and the total damage to transport infrastructure was 166.4 million euros (Figures 6 and 7).

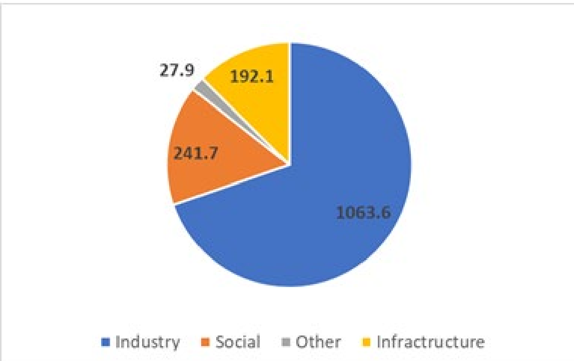

Figure 6. Consequences of the 2014 floods

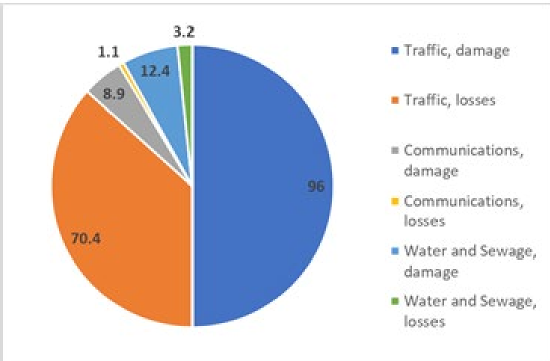

Figure 7. Consequences of the 2014 floods on infrastructure

Within this total amount, 57% of the total consequences represent the value of destroyed physical assets, and 43% refer to losses caused by inability to produce or production downtime due to damage (Figure 6).

In the Republic of Serbia, the activation of landslides and the occurrence of slope instability are directly related, in most cases, to increased rainfall or are a consequence of the human factor.[19]

17 Mainstreaming Climate Resilience in the Road Transport Management in Serbia, GFDRR & The World Bank, 2018

18 Bjelić, M. and Lazarević, M., Financial aspects of natural disasters – Case study of the 2014 floods in Serbia, UNDP, 2015

19 Abolmasov, B. Influence of climate changes to landslide hazard assessment on the road network of Serbia, *Road and Traffic*, 63 (3), 21 – 34, 2017

It is estimated that the 2014 floods caused the activation of over 2000 landslides on Class I and II state roads and over 3000 landslides on the local road network[20]. The estimated needs for the reconstruction of main, regional and local roads, including bridges and culverts, as well as landslide remediation, were around 23.5, 30.5 and 34.0 million Euros, respectively[21].

Previous events related to the consequences of the floods occurred in different regions and at different periods during the year. In 2006, the Sava River had an extremely high water level in Belgrade due to increased rainfall in the Danube, Sava, Velika Morava and Tisa basins, which caused floods that threatened Kladovo and Negotin lowlands.

In November 2007, large floods hit Southern Serbia, especially the Vlasina River Basin, with torrents sweeping away 13 bridges and damaging a large number of roads. Also, in November 2009, large floods affected the Zlatibor and Raška districts, primarily Užice, Arilje, Požega, Sjenica, Novi Pazar, Prijepolje, Nova Varoš, Priboj and Raška. On that occasion, 11 landslides were activated in the area of the municipality of Nova Varoš. At the end of June 2009, Vrnjačka Banja and the surrounding settlements came under water due to heavy rainfall and the overflow of the river Goč. During the flood, 20 local bridges were damaged or completely destroyed. In addition, at the end of December, there was the overflow of the Crni Timok, so a flood protection emergency measure was introduced in the municipality of Zaječar. Figure 8 provides an overview of the length of the road network exposed to floods in the period from 2005 to 2019.

In the period after extreme floods in 2014, the state of emergency was declared in Eastern and Western Serbia, in different months during the year, based on various climatic events. These events were sometimes atypical for a certain season, which further confirms the hypothesis of change of climatic conditions.

In addition to floods, a phenomenon that is significant in terms of road infrastructure and in connection with climate change is snowstorms, which affect safety and total traffic disruptions. For this reason, the state of emergency was in force in February 2015 in the municipality of Sjenica, and in 2012 in 22 municipalities in the territory of Southeast Serbia, Pešter and Western Serbia. In January 2017, total collapse in traffic was recorded on the section of the road E-75 between Leskovac and Aleksinac, due to snowdrifts. In January 2019, the state of emergency was declared on the entire territory of the municipality of Lučani.

20 Jotić, M., Vujanić, V., Jelisavac, B., Zlatković, M., Milenković, S. Landslides and damage to traffic infrastructure in Serbia, *Construction*, 69 (5-6), 215-224, 2015

21 Serbia Floods 2014, United Nations Serbia, European Commission and the World Bank Group, 2014

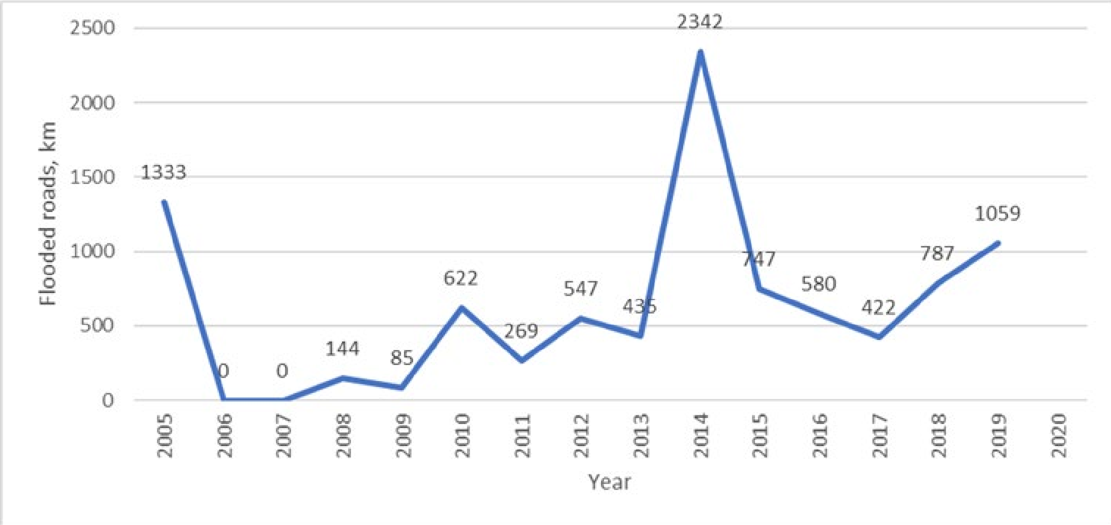

Figure 8. Historical overview of road length exposed to floods[22]

Figure 9. Historical overview of road length exposed to soil erosion[23]

The World Bank's study[24] gives the hazard structure on the roads in the Valjevo District.

Hazard Level	Hazard Category			
	Floods	Landslides	Forest fires	Snowdrifts
Very high	41%	41%	45%	29%
High	32%	21.5%	46%	14.5%
Moderate	6%	14.5%	16%	16%

22 Statistical Yearbooks of the Republic of Serbia 2006-2020, Statistical Office of the Republic of Serbia, 2020

23 Statistical Yearbooks of the Republic of Serbia 2006-2020, Statistical Office of the Republic of Serbia, 2020

24 Mainstreaming Climate Resilience in the Road Transport Management in Serbia, GFDRR & The World Bank, 2018

The works most often needed during the rehabilitation of the road network in the Republic of Serbia affected by climate change are as follows:

- Pavement rehabilitation
- Retaining wall remediation
- Culvert/bridge remediation
- Landslide remediation.

However, there is one big aspect of climate change on the durability of pavement structures and resistance to permanent deformations, primarily of asphalt layers, and influenced by the increase in average and maximum temperatures because of climate change. This impact has not been covered or present in the analyses related to the Republic of Serbia so far, and in the opinion of the authors, it may be of exceptional significance, through several aspects, such as economic, financial, impacts on driving safety and comfort, traffic delays and disruptions caused by the increased volume of maintenance works or accelerated pavement deterioration.

2.3 Expected effects of climate change in terms of climatic parameters until 2100

This chapter covers the climatic characteristics of Serbia of importance for road infrastructure, as well as their projection in order to evaluate the possible effects.

In Serbia, there has been a trend of increased air temperatures that have been accelerated since the 1980s, accompanied by a redistribution of precipitation in terms of extended dry periods, increased frequency of events with extreme precipitation, as well as periods with high air temperatures[25].

Recorded average annual air temperatures in the period from 1960 to 2010 showed a growing trend with an annual increase of 0.04°C, while in some areas in the Eastern and Southeastern Serbia, a trend of temperature decrease of 0.05°C per year is present. The largest temperature increase is registered in the summer months. The amount of precipitation in the period 1946-2006 has a growing trend at the most part of Serbia's territory, while the reduction in precipitation is registered in the Eastern and Southeastern parts of the country. While the annual precipitation increase in the West is 16 mm, a decrease of 8 mm per year is present in the Southeast[26].

Kržić et al.[27] and Rajković et al.[28] provided projections of climatic parameters for two scenarios, moderate (A1B) and intensive (A2), which are based on the IPCC Fourth Assessment Report[29],

25 Vuković, A., Vujadinović, M., Rendulić, S., Djurdjević, V., Rumk, M., Babić, V., Popović, D.: Global Warming Impact on Climate Change in Serbia for the period 1961 – 2100, *THERMAL SCIENCE, 22* (6A), 2267-2280, 2018

26 Sekulić, G., Duška Dimović, D., Kalmar Krnajski Jović, Z., Todorović, N. CLIMATE VULNERABILITY ASSESSMENT – Serbia, WWF (World Wide Fund for Nature), Environmental Improvement Centre, 2012

27 Kržić, A., Tošić, I., Djurdjević, V., Veljović, K., Rajković, B. Changes in climate indices for Serbia according to the SRES-A1B and SRES-A2 scenarios. *Climate Research*, 49: 73–86, 2011

28 Rajković B., Vujadinović M. and Vuković A. (2013) Report on revisited climate change scenarios including review on applied statistical method for removing of systematic model errors, with maps of temperature, precipitation and required climate indices changes; Second national communication of the Republic of Serbia under the United Nations framework convention on climate change. MERZ, Belgrade, Serbia, available at http://haos.ff.bg.ac.rs/climatedb-srb/ (25.04.2021)

29 IPCC (Intergovernmental Panel on Climate Change) (2007) The physical science basis. In: Solomon S, Qin D, Manning M, Chen Z,

for the period from 2001 to 2100. According to these projections, the expected increase in the air temperature at the level of the ground surface at the end of the 21st century is from 3°C to 4°C in relation to the average values in the period 1961 - 1990 (Figure 10), with the increase in temperature more significant during the summer months (Figure 11).

According to both scenarios, a slight increase in annual rainfall until 2040 is expected and then a decline until the end of the 21st century (Figure 12). The number of icy days is significantly and progressively reduced towards the end of the 21st century (Figure 13), and the number of summer days and tropical nights increases significantly.

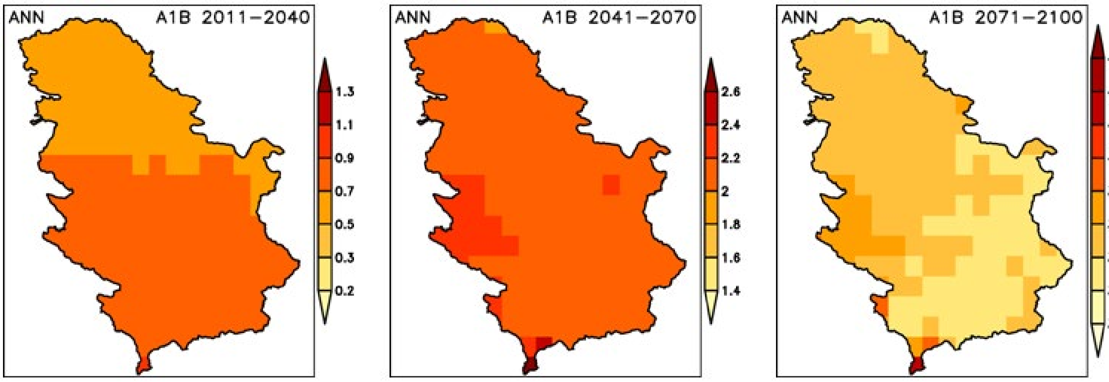

Figure 10. Projection of average annual air temperatures for periods 2011-2040, 2041-2070 and 2071-2100 according to the A1B scenario for the territory of Serbia (spatial resolution 0.25x0.25°)[15].

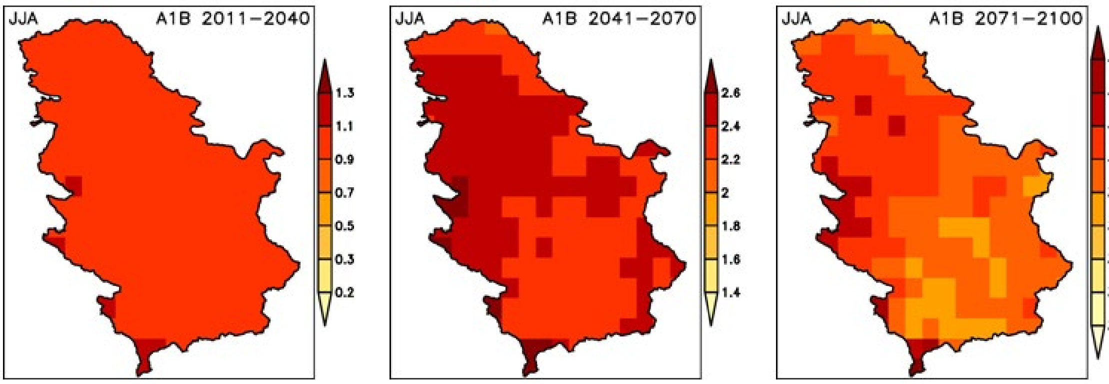

Figure 11. Projection of average air temperatures in the summer for periods 2011-2040, 2041-2070 u 2071-2100 according to the A1B scenario for the territory of Serbia (spatial resolution 0.25x0.25°)[15].

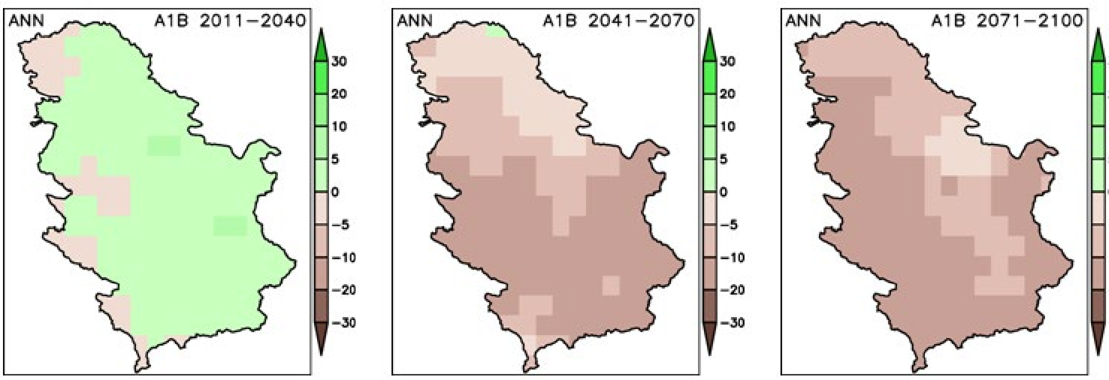

Figure 12. Projection of annual precipitation for periods 2011-2040, 2041-2070 u 2071-2100 according to the A1B scenario for the territory of Serbia (spatial resolution 0.25x0.25°)[15].

Marquis M, Averyt KB, Tignor M, Miller HL (eds) Contribution of Working Group I to the 4th assessment report of the IPCC. Cambridge University Press, Cambridge

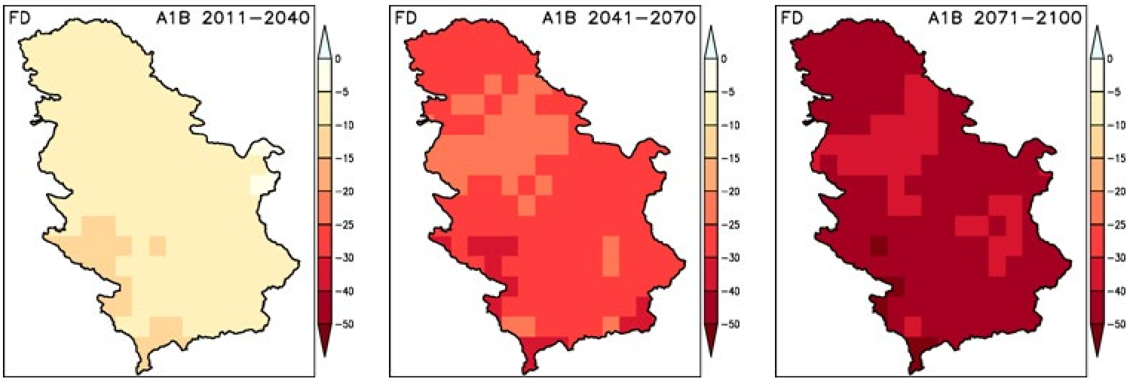

Figure 13. Projection of the number of icy days for periods 2011-2040, 2041-2070 u 2071-2100 according to the A1B scenario for the territory of Serbia (spatial resolution 0.25x0.25°)[15].

The paper[30] gives the analysis of future changes in temperatures and precipitation in relation to the period 1986 - 2005, which is based on the IPCC Fifth Assessment Report[31], applying a set of nine models, with a resolution of geographical width and length of 0.11° and for two greenhouse gas emissions scenarios (GHG), RCP 4.5 (a scenario that implies stabilization) and RCP 8.5 (a scenario that implies a constant increase in GHG emissions).

During the period from 2016 to 2035, an increase in average annual temperatures of up to 1°C is expected according to RCP 8.5 scenario and about 0.8°C according to RCP 4.5 scenario, with changes higher than average in summer and autumn months. In the territory of Serbia, there are no significant changes in the average annual precipitation, but decline in precipitation in the summer period is expected according to both scenarios.

During the period from 2046 to 2065, the average annual temperature of 1.5°C is expected, with a larger increase during the summer months according to the RCP 4.5 scenario, and an increase of 2.1°C with a larger increase in the colder part of the year according to the RCP 8.5 scenario. Average annual precipitation in Serbia can be increased by 4.4% according to the RCP 8.5 scenario, and according to both scenarios, precipitation is expected to reduce during the summer months, which is more pronounced according to the RCP 4.5 scenario and is 5.1%.

During the period from 2081 to 2100, the temperature increase according to RCP4.5 and RCP8.5 scenarios will be 1.9°C and 4.4°C compared to the period from 1986 to 2005, respectively, with the largest increase in the summer months and a slightly larger increase in maximum compared to minimum temperatures according to both scenarios. Accumulated precipitation in the territory of Serbia at the annual level will be higher by 3.5%, or 6.8%, but will be reduced in the summer months by 3.2%, or 4.5% according to the RCP4.5 and RCP8.5 scenarios, respectively.

Figure 14 shows the expected changes in temperature and precipitation in the territory of the Republic of Serbia according to the RCP4.5 scenario.

30 Vuković, A. Vujadinović, M., Rendulić, S., Djurdjević, V., Rumk, M., Babić, V., Popović, D.: Global Warming Impact on Climate Change in Serbia for the period 1961 – 2100, *THERMAL SCIENCE*, Vol. 22, No. 6A, pp. 2267-2280, 2018

31 IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp

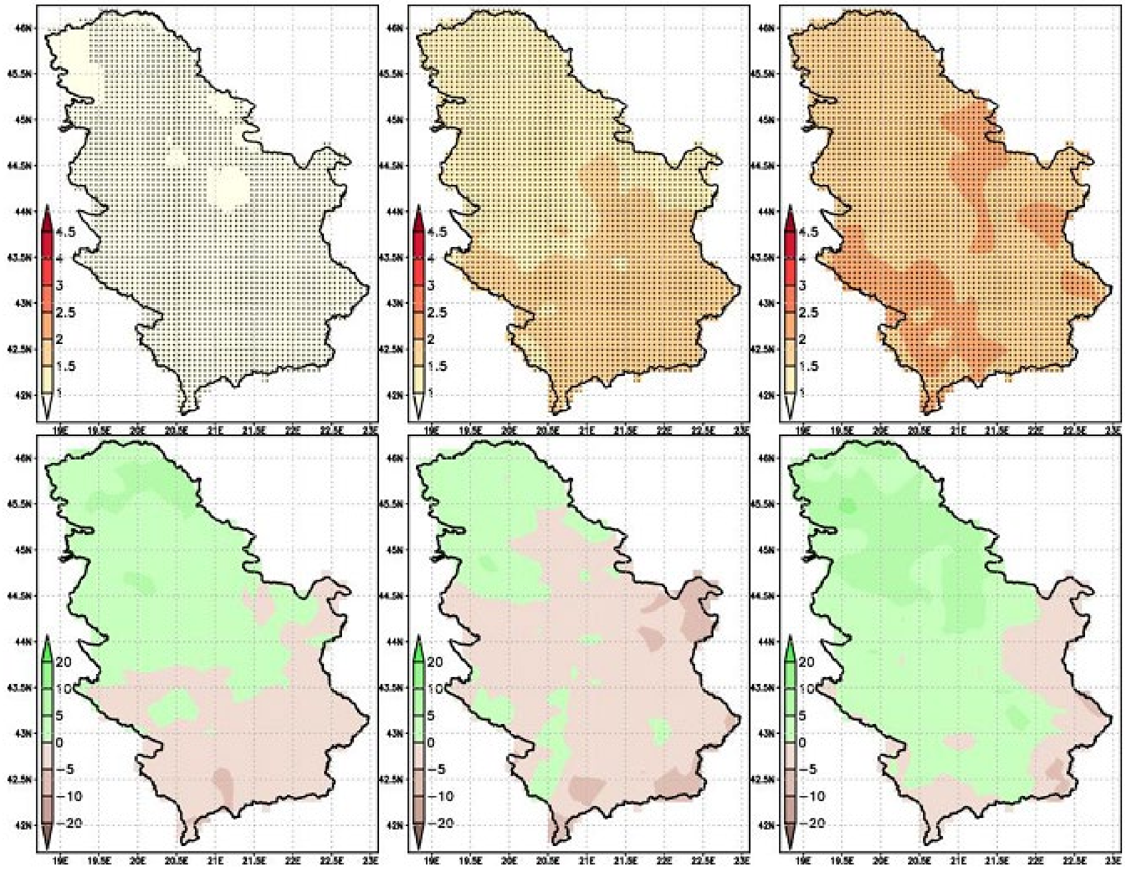

Figure 14. Change in the average annual temperatures in °C (above) and annual accumulated precipitation in % (below) for three time periods: 2016-2035 (left), 2046-2065 (in the middle) and 2081-2100 (right) according to the RCP4.5 scenario

Analysis of registered data and projections for the period from 1961 to 2100 indicates an increase in the average temperature of over 2.5°C according to the RCP4.5 scenario and of over 5°C according to the RCP8.5 scenario, with a decline in precipitation during the summer months and an increase in precipitation intensity, without significant annual change in precipitation. The temperature rise is more pronounced in the central and southern parts of the country.

2.4 Possible effects of climate change on road infrastructure facilities in Serbia

This chapter provides an overview of the possible effects of climate change on road infrastructure in Serbia, based on the broader context presented in Chapter 2.2.

Table 7 shows the impact of climate change on road infrastructure facilities expected on the road network of the Republic of Serbia. Each change is analyzed in the context of the specific impact on a particular road infrastructure facility, as well as through the expected effects of such actions. The impacts of climate change on road infrastructure, observed from a time perspective, can be divided as follows:

- Immediate effects
- Short-term effects (up to 5 years)

- Medium-term effects (5 to 15 years)
- Long-term effects (over 15 years).

In that sense, the same climate change works in several ways. For example, heavy precipitation has immediate consequences in terms of reduced driving safety/comfort, but also long-term consequences in the form of an increase in the pavement rate of deterioration and increased maintenance costs.

Table 7. Impact of climate change on road infrastructure facilities in Serbia

Climatic event	Facility	Effect	Consequence	Time frame
Extreme precipitation (showers or prolonged rainfall)	Pavement structure	Flooding	Reduced driving safety	Immediate
	• Culverts • Drains • Drainage system	Exceeding the maximum projected flow	Possible damage to the drainage system and accelerated local deterioration of pavement	Immediate
	Embankments, slopes	Landslide activation	Pavement fractures	Immediate / short-term
			Driving safety compromised	Immediate
	Bridges	Exceeding the maximum projected flow Soil erosion under pier foundations	Structure fracture or damage	Immediate

Table 7. Impact of climate change on road infrastructure facilities in Serbia, cont.

Climatic event	Facility	Effect	Consequence	Time frame
Average rainfall at the season or year level	Pavement structure	• Wetting of the subgrade and subbase layers • Bitumen bleeding • Reducing soil compaction	Increasing the rate of road deterioration, reducing the time between two maintenance treatments	Medium-term / long-term
Maximum temperature and number of consecutive warm days (heatwave)	Asphalt layers of pavement structure	• Change in stiffness modulus of asphalt layers, fatigue resistance • Higher stresses on the base	Reducing the time between two maintenance treatments, possible occurrence of rutting, bitumen bleeding	Medium-term / long-term
	Bridges	Impact on bridge joints	Damage to the bridge	Medium-term

Drought (consecutive dry days)	Road belt	Increased risk of fire and negative impact on the vegetation cover in the right-of-way	Reduced driving safety due to fire	Immediate
			Possibility of landslides or slope instability as a consequence of fire	Short-term
		Reduced cohesion of fine particles	Increasing the amount of dust on the road	Immediate
Reducing the number of days under the snow cover	Road surface	Less need for winter maintenance	Minor damage caused by the use of salt and other chemicals used in the winter maintenance service	Short-term
Freezing (number of icy days), reduction	Pavement structure	Reducing the depth of frost penetration	Overdesign, unnecessary construction costs	Medium-term / long-term
Snowfall and snowdrifts, strong storms	Road belt	Traffic disruptions	Driving safety compromised	Immediate
	Traffic signals, lighting, etc.	Possible damage	Material damage, reduced driving safety	Immediate
	Bridges	Structural Damage	Endangered stability of the bridge	Immediate / short-term

The impact of climate change is not the same on the entire road network and depends on several factors, including:

- Terrain topography (e.g. plain terrain, hilly terrain, mountainous terrain), and in connection with this is
- Elevation
- Season (summer, autumn, spring, winter)
- Geological features of the terrain.

Having in mind the climate changes that have the greatest impact on the road network in Serbia (listed in Table 7), the following dominant effects can be singled out:

Flooding and damage to the drainage system as a result of extreme rainfall are most pronounced in river valleys (lower altitudes) and in lowland terrain, most often in spring and autumn.

On the other hand, **landslide activation** is more characteristic in mountainous areas, also in spring or autumn.

Regarding the **consequences for the construction of bridges or culverts**, the topography of the terrain is not of greater importance, but consequently, the damage is greater the larger the structure is, i.e. in the lower river basins.

The increase in the average amount of precipitation during the year has an impact on the accelerated deterioration of the pavement surface, where the influence of the season and terrain topography is not of great importance, but the geological composition is, i.e. the deterioration is greater on soil with a lower bearing capacity, which is usually the case in lowland areas and river valleys, in contrast to mountainous areas where rocky soil of higher bearing capacity is expected.

Similarly, **heat waves that affect the reduction of the structure load-bearing capacity** and the occurrence of damage to the asphalt surface in the form of ruts and/or cracks occur in summer. This effect is more characteristic in urban areas and in southern areas. Loss of load-bearing capacity may be more pronounced on a less load-bearing subgrade.

The drought that causes fires, slope instability, increase in road dust, is also an effect characteristic of the summer season and does not depend on other factors, except in the sense that the possibility of slope instability is related to the height of the embankment/cut on a particular section.

Reducing the total number of days under snow cover reduces the need for winter maintenance and this is an effect that occurs in winter, and does not depend on other factors, but is more characteristic in mountainous regions at higher altitudes, proportional to snowfall in that area.

However, **snowstorms** are an effect that occurs in winter but can occur in both flat and hilly terrain.

2.5. Summary overview of critical climatic events on the road network of Serbia in accordance with the RIMAROCC methodology

In accordance with the methodology defined in the RIMAROCC project and the specific guidelines for road infrastructure given within the ROADAPT program, this chapter will highlight the impacts characteristic of considering the effects of climate change on the road network of Serbia.

The risk of a critical event is calculated as the product of the likelihood of occurrence of the event and the corresponding effects.

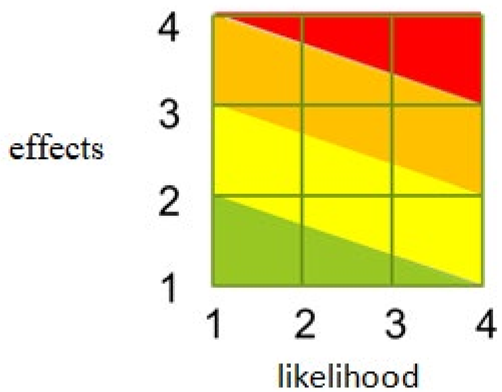

Figure 15. Risk matrix

The consequences of events in terms of road infrastructure are observed as follows:

- *Availability of the section* or road route, length of the section from junction to junction, which will be out of the use or which will be affected by a critical climatic event
- *Material costs/material damage* can be seen through the costs of urgent maintenance and repair of damage during a critical event, but also through the analysis of increased maintenance needs over a longer period of time
- Impact on *traffic safety* can be given in the form of classification, in several categories, with borderline cases ranging from negligible to catastrophic with a high probability of serious body injuries or death
- The consequences for the *environment of the road* can also be seen in the form of classification, from minor to catastrophic
- *The environmental impact also*, in the form of quantitative classification

The availability of the section, i.e. the length of the section and its position in the network is data available in the road database of PE “Roads of Serbia”, and material costs can be estimated on the basis of the valid pricelist of PE “Roads of Serbia”, which is publicly available.

The other three categories can be considered based on expert opinion or conducting an appropriate survey on the target focus group.

For example, in terms of traffic safety, what has potentially the greatest impact is a heavy rainfall that leads to flooding, river overflows, damage to flood defense systems, exceeding the allowable flows on the basis of which structures such as bridges and culverts are constructed. In addition, prolonged droughts and fires, as well as snowstorms, also have a great impact on safety.

On the other hand, the accelerated deterioration of the road and the occurrence of damage affect safety to a lesser extent directly, and to a greater extent indirectly, because more frequent works on the road network and the creation of a construction site zone in the road right-of-way are always potentially dangerous locations, of reduced safety.

The surroundings of the road is also endangered by climate change, in the form of potential disturbance of the landscape, watercourses, impact on the flora and fauna and on cultural heritage. These impacts are most pronounced in the case of large floods, or large-scale fires. In the other analyzed climate events described in Table 7, this impact is not pronounced.

Environmental impacts are increased emissions, increased noise levels and reduced air quality. The negative impact is caused by frequent works on road maintenance and rehabilitation, as well as the occurrence of fires. Road maintenance works typically cause congestion and traffic jams, further increasing this effect, with the intensity depending on the specific location and local conditions.

The **likelihood of occurrence of a phenomenon** can be defined qualitatively within one of the four categories

- Very rarely (once in 50 years or less)
- Rarely (once in 10 to 50 years)
- Occasionally (once in 3 to 10 years)
- Often (more than once in 3 years).

When risks are defined, it is also important to compare them in accordance with the **importance of each section** of the road network and in that way, it is possible to look at the road network as a whole.

The significance of the section is observed through several parameters:

- Road class
- Traffic loading
- Alternative routes (whether they exist and their condition)
- The development of the region in which the section is located, meaning population, industry, tourism, cultural and historical significance and the like.

In this case, the first two categories are the data available (a brief overview shown in point 1.2), and the other two categories need to be assessed qualitatively based on expert opinion.

Table 8 provides a map with basic steps for assessing the risk of the impact of climate change on road infrastructure at the level of the road network.

Table 8. Map of risk assessment of the impact of climate change on road infrastructure at the level of the road

STEPS	WHAT/HOW	Available	Missing data
Identification of the **impact** of climate change on road infra-structure	Historical events	Chapter 2.2	-
	Impact model analysis	Chapter 2.4	Models for the influence of temperature and total precip-itation need to be applied and calibrated for the road network of Serbia
	Consideration of critical parameters	Chapter 2.4	Creating an appropriate data-base on climate change that would allow the evaluation and consideration of parameters necessary for risk assessment
Determining the **probability** of a critical phenomenon	Current data	Data on average air temperatures Data on average precipitation Terrain topography Elevation	Road facility databases are not integrated Integration of road meteoro-logical station data required Integrate and supplement frost depth data
	Projections of future climatic events	Chapter 2.3.	Historical data on emergency maintenance as a consequence of climate change are missing
	Expert opinions	STUDY CORRIDOR 10	Organize an appropriate focus group

Determining the **con-sequence** of a critical phenomenon	Traffic load	PE “Roads of Serbia”	Assign data to a new climate change database
	Property value	PE “Roads of Serbia”	Assign data to a new climate change database
	Road class	PE “Roads of Serbia”	Assign data to a new climate change database
	Alternative routes	-	Road database needs to be updated
	Regional development	-	Road database needs to be updated
Determining **risk**	Probability of occurrence multiplied by consequence	Chapter 2.5	Based on the methodology from Chapter 2.5., a new data-base on climate change is to be created at the level of the road network, for each section

3. ADAPTATION MEASURES FOR FUTURE RISKS AND VULNERABILITIES

For new infrastructural facilities, adaptation to climate change should begin in the initial stages of planning and design. The choice of a corridor for a particular road in the context of climate change is becoming even more important, in order to avoid the risks of landslides, floods and other negative effects.

Climate change requires modification of design guidelines (discussed in more detail in Chapter 4), to ensure sufficient capacity of drainage and erosion protection systems, define appropriate material quality criteria, manage landslide risks, and implement environmental protection measures. In order for these elements to be included in road infrastructure projects, it is necessary to implement them through Terms of References, for which investors are responsible (PE “Roads of Serbia” when it comes to state roads and local governments when it comes to municipal roads and streets).

Certainly, most of the adaptation measures should relate to the existing road network. This includes risk assessment, identification of the most vulnerable structures/facilities and potential risks, and the introduction of risk management related to climate events. To make this possible, it is necessary to update existing databases, review their structure and expand them with missing data, including data related to the impact of climate change at the level of road network sections, as well as to enable the connection of existing databases into a road asset management system (RAMS). All these activities are under the jurisdiction of the Public Enterprise “Roads of Serbia”, which is in charge of maintaining the state road network, and local governments when it comes to municipal roads and streets. In the existing business system of PE “Roads of Serbia”, RAMS information is not used in the right way to form a long-term strategy and medium-term program of maintenance works, which calls into question the way in which the existing funds available for road maintenance is used. On the road network of Serbia, there is a significant part of the sections in extremely poor condition, which increases the risk of the harmful effects of climate change. Systematic application of procedures based on the RAMS condition and loading data of road network sections would help to reduce this risk.

At the level of local self-government, it is necessary to build capacities for the management of local road network maintenance, including the development of databases with a minimum of the necessary information and the definition of appropriate procedures for condition surveys and selection of maintenance treatment.

Table 9 provides an overview of adaptation measures for critical risks caused by climate change on the road network, with the elements to which they relate, as well as the indicative implementation deadline. The table identifies the competent institutions for the implementation of adaptation measures in accordance with their responsibilities. PE "Roads of Serbia" and companies that perform maintenance for state roads and local governments for the local road network in their territory are responsible for adaptation measures related to monitoring, maintenance, reconstruction and management of the road network. The Institute for Standardization of Serbia (ISS), i.e. the Committee on Road Materials, is responsible for the measures related to the change of guidelines and standards, but it is necessary to involve PE "Roads of Serbia" as the main investor in the state road network, which is primarily responsible for its best condition.

Table 9. Review of adaptation measures

Climatic event	Road element	Effect	Adaptation measure	Phase	Jurisdiction	Time frame
Extreme precipitation (showers or prolonged rainfall)	All	All	Ensure efficient operation of drainage systems	Maintenance	PE “Roads of Serbia”, local self-governments	Short-term
			Develop a strategy for temporary diversion	Management		Short-term
			Perform a risk assessment for located landslides	Management		Medium-term
	Pavement structure	Subgrade/subbase erosion	Revise standards for the design of pavement structures taking into account the impact of floods	Regulation	ISS, PE “Roads of Serbia”	Short-term
			Carry out a regular recording of the load-bearing capacity of the pavement structure	Condition monitoring	PE “Roads of Serbia”	Continuously
	• Culverts • Drains • Drainage system	Exceeding the maximum projected flow	Update guidelines for the design of drainage system elements taking into account return periods in line with climate change	Regulation	ISS, PE “Roads of Serbia”	Short-term
			Revise the instructions and conduct regular inspections of the drainage system	Regulation and maintenance		Short-term
			Increase the capacity of the drainage system	Reconstruction	PE “Roads of Serbia”	Medium-term to long-term
	Embankments, slopes	Landslide activation	Update and supplement the landslide database on the road network and map landslides	Management	PE “Roads of Serbia”, local self-governments	Short-term
			Monitor the condition of critical landslides	Condition monitoring		Medium-term
			Apply measures to improve slope stability and erosion protection	Maintenance and management		Medium-term
	Bridges	Exceeding the maximum projected flow Soil erosion under pier foundations	Clean and deepen the bottom under the facility to increase capacity	Maintenance and management	PE “Roads of Serbia”, local self-governments	Short-term
			Perform regular inspection of supports	Maintenance and management		Short-term
			Map areas prone to flooding	Management		Short-term
			Protect pier foundations with gabion walls/concrete structures	Reconstruction		Medium-term to long-term

Climatic event	Road element	Effect	Adaptation measure	Phase	Jurisdiction	Time frame
Average rainfall at the season or year level	Pavement structure	• Wetting of the subgrade and subbase layers • Bitumen bleeding • Reducing soil compaction	Revise standards / procedures for the design of pavement structures taking into account the impact of floods. Revise guidelines for design of asphalt mixtures- include “antistripping agent”	Regulation	ISS, Committee on Road Materials, PE “Roads of Serbia”	Short-term
Maximum temperature and number of consecutive warm days (heat wave)	Asphalt layers of pavement structure	• Change in stiffness modulus of asphalt layers, fatigue resistance • Higher stresses on the subgrade/subbase	Revise standards/procedures for the design of pavement structures Revise standards for materials	Regulation	ISS, Committee on Road Materials, PE “Roads of Serbia”	Short-term
			Identify critical sections and monitor their condition	Maintenance and management	PE “Roads of Serbia”, local self-governments	Short-term
			Periodic maintenance of critical sections	Maintenance and management		Medium-term
	Bridges	Impact on bridge joints	Carry out regular inspections of joints	Maintenance and management	PE “Roads of Serbia”, local self-governments	Short-term
			Repair of joints on critical facilities	Maintenance and management		Medium-term
			Revision of standards for bridge design	Regulation	ISS, PE “Roads of Serbia”	Short-term
Freezing (number of icy days), reduction	Pavement structure	Oversizing during design work, unnecessary construction costs	Revise standards/procedures for the design of pavement structures Revise standards for materials	Regulation	ISS, PE “Roads of Serbia”	Short-term
Snowfall and snowdrifts, strong storms	Road belt	Traffic disruptions	Construction of snow barriers at critical locations	Maintenance and management	PE “Roads of Serbia”, local self-governments	Medium-term
			Develop a strategy for temporary diversion	Management		Short-term
			Ability to inform users via ITS	Management		Short-term
	Traffic signals, lighting, etc.	Possible damage	Construction of snow barriers at critical locations	Maintenance and management	PE “Roads of Serbia”, local self-governments	Medium-term
			Repair/replacement of damaged elements	Maintenance		
	Bridges	Damage on a structure	Increase the recording frequency of critical bridge elements	Management	PE “Roads of Serbia”, local self-governments	Short-term
			Repair of damaged structure	Maintenance		Short-term to Medium-term
			Develop a strategy for temporary diversion	Management		Short-term

4. PROPOSAL/RECOMMENDATIONS FOR SUPPLEMENTING AND/OR DRAFTING NEW LEGAL, PLANNING AND STRATEGIC DOCUMENTS

4.1 Legislative and regulatory framework for the development of road infrastructure projects

This chapter covers the regulations for the field of construction, including planning, design, construction, and maintenance of road infrastructure, as well as a review of the regulation that is closely related to road infrastructure.

In the field of construction, the **Law on Planning and Construction**[32] regulates the conditions and manner of arranging space, arranging and using construction land and construction of facilities. Article 3 defines the principles of planning, arrangement and use of space; among other principles, the following are mentioned:

- Rational and sustainable use of non-renewable resources and optimal use of renewable resources and
- Prevention of technical and technological accidents, protection from fire and explosions, protection from natural disasters, elimination of causes of climate change.

However, the Law deals exclusively with the energy efficiency of buildings, and does not take into account the impact of climate change on other facilities, including transport infrastructure.

Based on the Law, the **Decree on Location Conditions**[33] was passed, which prescribes the manner of obtaining urban, technical and all other conditions for the needs of drafting the conceptual design, construction permit project and as-built drawings. For the Class I and II state roads, location conditions are issued by the Ministry of Construction, Transport and Infrastructure. In terms of climate change, water conditions issued by the Ministry of Agriculture and Environmental Protection – Republic Water Directorate or the relevant body of the Autonomous Province of Vojvodina are particularly important, and for the municipal roads in the watercourse zone, public water management companies, “Srbijavode” and “Vode Vojvodine”. In the Water Conditions, for road infrastructure facilities, among other things, it is required to perform appropriate hydraulic calculations, as well as sizing of facilities based on data on characteristic calculated flows or observed flows and levels based on the opinion of the Republic Hydrometeorological Service of Serbia (RHMZ).

32 Law on Planning and Construction (Official Gazette of the Republic of Serbia, No. 72/09, 81/09, 64/10 – Decision of RS CC, 24/11 (121/12, 42/13 – Decision of RS CC, 50/13 – Decision of RS CC, 98/13 – Decision of RS CC, 132/14 , 145/14, 83/18, 31/19 and 37/19 – other law and 9/20)

33 Decree on Location Conditions (Official Gazette of the Republic of Serbia, No. 115/20)

The Law on Construction Products[34] prescribes the conditions for placing construction products on the market, as well as the preparation of performance declarations. This Law transposed the European Construction Products Regulation[35] into national legislation. Based on this Law, the Rulebook on stone aggregate requirements was adopted[36], as well as the Rulebook on technical requirements for the use of cement and cement-based products in the construction of pavement structures and earthworks[37]. These documents are based on the application of European standards that were almost completely adopted as Serbian standards in the period from 2011 in the field of materials for road construction, but the problem is the lack of national documents that would define quality requirements for certain construction materials. In the field of roads, the Ministry of Construction, Transport and Infrastructure and PE "Roads of Serbia" should initiate the development of these documents in cooperation with the Institute for Standardization of Serbia, so that the quality infrastructure that exists in EU member states can be formed.

In the field of road infrastructure, the framework for design, construction, reconstruction and maintenance is provided by the **Law on Roads** ("Official Gazette of the Republic of Serbia", 41-2018 and 95-2018), with Article 47 defining the protection of public roads from leaching and landslides, while Article 87 determines the facilities for the protection of public roads from torrents and snowfall. Specifically, these two articles are related to the consequences of climate change on infrastructure, and Article 90 specifically defines the manner of risk mapping, identification and ranking of dangerous places. In the law, dangerous places are recognized as sections of the highest risk and black spots for which the manner of identification is prescribed by the Minister (Article 90 paragraph 4). It is also defined that, depending on the class of the road, the manager of the state road is obliged to provide risk mapping projects and identification of sections and places of the highest risk for no longer than 3 years/every 3 years. For local and municipal road managers, this period is 5 years.

Considering that the Minister prescribes the manner of identifying dangerous sections and places, although the law itself does not mention the impact of climate change on road infrastructure, within Article 90, and in connection with Articles 47 and 87, it is possible to include consideration of the impact of climate change on critical road infrastructure, such as landslides, culverts, bridges and embankment slopes, where the mapping of potentially risky structures and sections would be identified, according to the Law on Roads, every 3 and 5 years for state and local roads, respectively.

Regarding road maintenance, the **Rulebook on regular maintenance of public roads** ("Official Gazette of the Republic of Serbia", No. 15/2020), provides specific guidelines for inspections of road infrastructure facilities. Article 4 defines four types of inspections: regular, seasonal, systematic and extraordinary, while Article 6 refers to the key elements of road infrastructure whose condition needs to be monitored, namely the pavement, drainage system, sidewalks, median,

34 Law on Construction Products (Official Gazette of the Republic of Serbia, No. 83/18)

35 REGULATION (EU) No 305/2011, Official Journal of the European Union, 4.4.2011

36 Rulebook on technical requirements for fractioned rock stone aggregate for concrete and asphalt (Official Gazette of the Republic of Serbia, No. 78/20)

37 Rulebook on technical requirements for fractioned rock stone aggregate, as well as the Rulebook on technical requirements for the use of cement and cement-based products in the construction of pavement structures and earthworks (Official Gazette of the Republic of Serbia, No. 26/19)

slopes of cuts and embankments, the occurrence of landslides, signalization and the following structures: culverts, bridges, walls, tunnels and galleries. In particular, Article 11 prescribes the performance of measurements that can determine the instability of embankment slopes and the development of damage to road structures such as culverts, walls and landslides. Article 12 specifically recommends geodetic surveying of subsidence, then the use of benchmarks that monitor the movement of landslides, as well as piezometers for monitoring groundwater levels. Although the impact of climate change is not specifically mentioned, the above-mentioned articles set out how it is possible to monitor the impact of climate change on critical road infrastructure. Regarding the impact of climate change, Article 16 prescribes the measurement of the reduced load-bearing capacity of the pavement structure, which has already been mentioned as one of the consequences of changes in temperature, longitudinal roughness affected by changes in precipitation and humidity, pavement damage, e.g. the formation of rutting can be a consequence of consecutive hot days that affect the properties of bitumen in asphalt mixtures and consequently lead to the occurrence of this type of damage.

Having all that in mind, the Rulebook precisely prescribes the frequency of surveying the condition of road structures and elements , as follows:

- Measuring road roughness every 3 years (every year on the I class state roads)
- Measuring bearing capacity every 5 years
- Measuring damage to pavement surface every 5 years
- Condition surveys of road structures twice a year.

The implementation of this practice would certainly have favorable effects regarding the consideration of the impact of climate change on the condition of road infrastructure structures and facilities. However, the issue of the application of the Rulebook and the availability of the mentioned reports remains. In addition, the Rulebook does not define the manner of making the inventory of facilities, where and how the data is entered, who has access to the mentioned reports, etc. Additionally, a new document that would be the appropriate Rulebook on the maintenance of local and municipal roads should be made.

In the field of road infrastructure, Article 14 of the **Law on Road Traffic Safety** ("Official Gazette of the Republic of Serbia", No. 41/2009, 53/2010, 101/2011, 32/2013 – CC Decision, 55/2014, 96/2015 – other law, 9/2016 – CC Decision, 24/2018, 41/2018, 41/2018 – other law, 87/2018, 23/2019 and 128/2020 – other law) stipulates that the Government submits the National Assembly the Report on road safety twice a year and defines that those reports are publicly available documents. Climate change is not included in this law, but regular monitoring of traffic accidents and their cause is one of the ways of seeing the direct impact of climate change to the safety of road users.

Within the Report entitled Review and Assessment of the Existing Policy, Regulatory and Institutional Framework for Climate Change Adaptation with Recommendations for Development and Promotion of Special Policy and Regulatory Framework, prepared by company Dvoper in 2020, a detailed analysis of including climate change through building facilities is given in the **Law on**

Environmental Impact Assessment ("Official Gazette of the Republic of Serbia", No. 135/2004 and 36/2009), and in this part, this law will not be re-analyzed.

At a strategic level, the General Master Plan for Transport (GMPT) in the Republic of Serbia from 2009 to 2027 gives an investment proposal in the analyzed period of time with regard to the functioning of road infrastructure at the network level, but does not recognize the impact of climate change as a relevant impact when defining the investment strategy.

On its site, the Public Enterprise "Roads of Serbia" provides recommendations for the design of state roads in the form of a document called **Manual for Roads Designing in the Republic of Serbia**[38]. This Manual is comprehensive and takes into account the largest number of road infrastructure elements. However, its application is not obligatory, even on state roads for which the PE "Roads of Serbia" is in charge of maintenance. The degree of application depends on the area to the area.

Chapter 7 defines the relation of the road and the environment. Chapter 7.2 refers to water and soil pollution, and Chapter 7.3 covers the road protection measures regarding environmental impacts, including the measures against erosion, landslides or snow avalanches, winds and snowdrifts, and vibration protection.

Chapter 10, Design of Engineering Structures, specifically section 10.3 **Culverts design**, point two, defines the design flow as a term, but not the way it is determined. In this sense, the influence of change in climate conditions is not covered, but as guidelines suggest that *"the amount of water can be determined by empirical hydrological methods or based on engineering analysis"*, the designer is not limited to use this aspect of impact as reference when dimensioning culverts. Chapter 8, Structural Road Elements, subchapter 8.2. **Pavement Structures**, point 4 defines the impact of climatic, hydrological conditions on the design of pavement structures. In this case, also, the impact of climate conditions is not mentioned, but the designer is left the opportunity to consider this impact doing appropriate analyses. For example, when designing, the number of icy days, average air temperatures, soil frost depth and groundwater level are taken as input parameters, and in that sense, it is possible to design the structure and materials in accordance with the relevant data. In this case, the source of information are the Meteorological annuals of the Republic Hydrometeorological Service of Serbia. In addition to this instruction, the methods that are defined by certain standards are used for the design of the pavement structures[39][40][41]. Additionally, available methods and software that have been developed by road administrations or large concerns such as Shell are used for analytical calculations of constructions. The choice of methods for the pavement design depends on the facility and the designer's preference, but the impact of climate change can be included through the application of certain temperature change scenarios in Serbia in the future and defining the calculation input parameters, as already mentioned.

38 SRDM Manual for Roads Designing, PE „Roads of Serbia", 2012, available at https://www.putevi-srbije.rs/index.php/%D1%81%D1%80%D0%B4%D0%BC-%D0%BF%D1%80%D0%B8%D1%80%D1%83%D1%87%D0%BD%D0%B8%D0%BA-%D0%B7%D0%B0-%D0%BF%D1%80%D0%BE%D1%98%D0%B5%D0%BA%D1%82%D0%BE%D0%B2%D0%B0%D1%9A%D0%B5-%D0%BF%D1%83%D1%82%D0%B5%D0%B2%D0%B0

39 SRPS U.C4.012:1981 – Design and construction of roads – Dimensioning new asphalt pavement structures

40 SRPS U.C4.014:1994 – Design and construction of roads- Dimensioning new cement-concrete unarrayed pavement structures

41 SRPS U.C4.015:1994 – Design and construction of roads- Dimensioning new flexible pavement structures

Rulebook for Construction Structures[42], which includes design of the structures such as bridges, tunnels and other geotechnical facilities within road infrastructure, is entirely based on Eurocodes and its application is mandatory.

After the 2014 floods, a new **Law on Disaster Risk Reduction and Emergency Management** ("Official Gazette of the Republic of Serbia", no. 87/2018) was prepared. It actually deals with the consequences of climate change in the form of extreme climatic events. This law was certainly necessary, and until adopted, a **Guide on Unique Methodology for Assessing Damage from Natural Disasters** ("Official Gazette of SFRY", No. 27 of April 1987), was used, and remains in use.

4.2 Proposal/Recommendations for supplementing and/or drafting new legal, planning, and strategic documents

Recommendations are given within the previous chapter in the analysis of any relevant legal or regulatory document or rulebook. In general, the impact of climate change on road infrastructure is not directly recognized in the mentioned documents, but indirectly there is a way of integrating appropriate analyses, above all, in the phases of design and maintenance.

At a strategic level, there is a need to recognize the importance of this phenomenon not only through emergency acts, but also as an impact that has a constant effect on road infrastructure, both at national and local levels.

42 Rulebook for Construction Structures (Official Gazette of the Republic of Serbia, No. 9/2019, 52/2020 and 122/2020)