Ministry of Environment and Physical Planning
The Government of the Republic of Macedonia

Vulnerability Assessment and Adaptation on Climate Change in the sector Water Resources

Third National Communication to the UNFCCC

Final Version

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As a party to the UN Framework Convention on Climate Change (UNFCCC), Republic of Macedonia has obligation to perform and submit its National Communications. The vulnerability assessment done in the framework of the project Third National Communication to the UNFCCC presents a review of information on the vulnerability to potential changes in climate to ecological systems, socioeconomic sectors, and human health and will update and strengthen the information regarding national circumstances, priorities and strategies.

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Contents

1		National Circumstances	5
	1.1	Introduction	5
	1.2	Climate Change Vulnerability	5
	1.3	Climate Change Adaptation	6
	1.4	Hydrographic Characteristics	7
	1.5	National Protected Areas	10
	1.6	Data Availability	11
	1.7	International Obligations	11
		Water Framework Directive	12
		Major stakeholders	13
		National legislation	14
2		Climate Change Impact Assessment	16
	2.1	Introduction	16
	2.2	Climate Change Related Terms and Definitions	16
		Climate change	16
		Anthropogenic climate change	17
		Climate projection	17
		Sensitivity	18
		Vulnerability	18
		Adaptation	18
		Adaptive capacity	18
		Mitigation	18
		Mitigative capacity	19
		Resilience	19
		Climate change indicators	19
	2.3	Potential Climate Change Impact on Water Resources	20
	2.4	Vulnerability Assessment Methodologies	21
	2.5	Water Sector Tools	24
	2.6	Statistical Trends	26
3		Vulnerability Assessment	34
	3.1	Strumica River Basin	34
		Basic hydrographic characteristics	34
		Municipalities and population	35
		Groundwater	37
		Monitoring	38
		Land use	40

	Erosion	42
	Water quality	42
	Water use	43
3.2	Water Budget	45
	Water balance components for current condition	45
	Projected water balance components	47
	Water balance estimates	48
3.3	Vulnerability Assessment	50
3.4	Adaptation Strategies and Measures	52
3.5	Action Plan	56
	Evaluating criteria	58
	Adaptation measures implementation	58
	Transboundary context	59
	References	61

To live happily is the same thing as to live according to Nature
Lucius Annaeus Seneca

1 National Circumstances

1.1 Introduction

As a party to the UN Framework Convention on Climate Change (UNFCCC), the Republic of Macedonia has obligation to perform and submit its National Communications. Currently, UNDP and the Ministry of Environment and Physical Planning (MoEPP) are implementing the project "Third National Communication to UNFCC" to address global environmental challenges and meet country's obligations under the UN global environmental conventions. This project will provide, on a country basis, a review of state-of-the-art information on the vulnerability to potential changes in climate to ecological systems, socioeconomic sectors, and human health and will update and strengthen the information regarding national circumstances, priorities and strategies. This project also aims to facilitate the integration of climate change risks assessment and ways of risks reduction, as well as to increase the national capacity in producing National Communications and to improve climate change policies.

1.2 Climate Change Vulnerability

The water resources sector is multidimensional and is not limited only to its physical measure, but encompasses other more qualitative, environmental and socio-economic dimensions. The water is unevenly distributed on the planet Earth. Only 2.5% is fresh water out of which 68.9% is in glaciers and 30.8% is groundwater, Figure 1-1. Groundwater accessible to humanity is only with 0.3%. Water scarcity is both, a natural and a human-made phenomenon and is among main problems to be faced by societies in the World in 21st century. Water scarcity is defined as the point at which the aggregate impact of all users impinges on the supply or quality of water under prevailing institutional arrangements to the extent that the demand by all sectors, including the environment, cannot be satisfied fully. Scarcity may be a social construct, a product of affluence, expectations and customary behaviour, or the consequence of altered supply patterns - stemming from climate change for example. The Republic of Macedonia is also facing the problem of water scarcity. To cope with this problem many national documents, such as strategies, programmes, action plans, decrees and laws have been prepared.

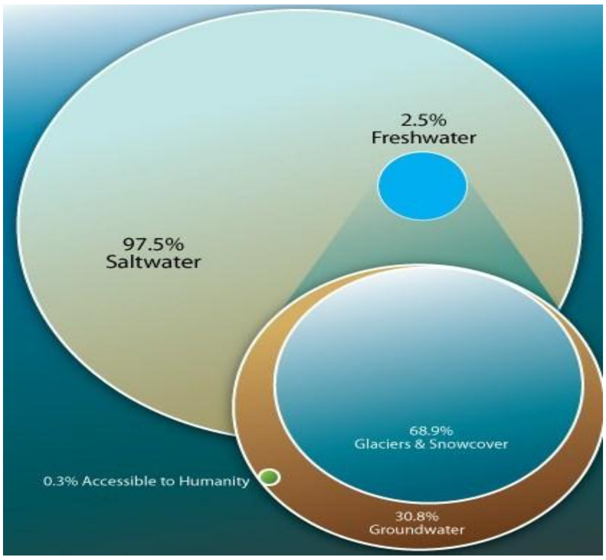

Figure 1-1 Scarcity of water resources on the Earth

Within the first and second national communications on climate change the climate variability was analyzed through its main parameters, precipitation and air temperature with the time series data for the period 1971-2000. Comparison of data for the two periods 1961-1990 and 1971-2000 was analyzed. It was concluded that winters and summers during the second period are warmer compared to the first period. Climate change scenarios up to 2100 on the base of empirical downscaling were developed, as well as one scenario based on the direct Global Circulation Model (GCM) output. According to the obtained results temperature increase of 3.8^{o}C and precipitation decrease of 13% in 2100 is expected in comparison to the reference year 2000.

Hydrological cycle components in the country were also analyzed. The assessed rate of the effective rainfall decrease is about 15% for 2050. Considering this it is expected drastic runoff decrease in all river basins, especially for rivers Bregalnica and Strumica in southeastern part of the country. Developed scenarios on climate change impact and vulnerability assessment in water resources sector show the following: (a) groundwater recharge for Vardar River watershed will continuously decrease, (b) annual mean runoffs for Vardar River will reach the level of 81.8% in 2100 out of 100% in 2000, (c) dry spells and flash floods will be more frequents and sever, (d) eastern part shall experience more water deficiency than the western part, and (e) overall water availability in the country is expected to be reduced by 18% in 2100.

1.3 Climate Change Adaptation

Adaptation measures in water resources sector have been proposed in both previous national communications on CC. The priority measures are: (a) hydrometeorological network modernization, (b) data monitoring, processing and availability establishment, (c) rehabilitation and reconstruction of the existing hydropower and water economy structures and systems, and (d) water management plans development and implementation. Further, the adaptation measures are divided into two groups: adaptation of the supply and adaptation of the demands. All measures are considered as intersectoral and are presented in the Action Plans where the priority measures are those in water supply and irrigation systems, in flood and drought control and protection strategies, in erosion and sedimentation control measures, in water quality measures by construction of waste water treatment plants and waste management implementation.

1.4 Hydrographic Characteristics

The Republic of Macedonia is a land-lock country surrounded by Bulgaria on the east, Serbia and Kosovo on the north, Albania on the west, and Greece on the south. The country lies between longitudes 20^{o}21'31" and 23^{o}02'12" east, and latitudes 40^{o}51'16" and 42^{o}22'21" north, extended to east-west direction of 210 km, and to south-north of 160 km with a border line of 850 km. The country ranges from an elevation 50 m above sea level at Gevgelija in alluvial lowland of the Vardar River in the south, to the high mountainous to the west and north-west where the peaks range from 2.200 m to 2.700 m above sea level. The country consists of 19,1% plain area and 80,9% hilly area. Valleys and plains intersect the mountainous relief structures. The most distinct valleys are those extending along the Vardar River, including the Skopje Valley (1.840 km^2), while the largest plain is the Pelagonija Plain (4.000 km^2) in the south-west at an average altitude of 600 m.

Surface waters are the most important part of the ecosystems in the country. Also, they are most spread in the space and are closest to the area of human activities. Due to the geographic location of the Republic of Macedonia, major part (84%) of the surface waters is domicile. The quantity of surface waters mainly depends on precipitation and snowmelt. Due to topographic, geological and morphological characteristics of the relief the runoff is running into the hydrographic network-rivers, streams and lakes. The karstic areas are the exception, where the water retains longer in the ground and recharge running waters of the river network.

The hydrographic territory of the Republic of Macedonia is divided into four river basins: Vardar, Strumica, Crn Drim and Juzna Morava, Figure 1-2. Vardar river basin is the largest (20.546 km^2 or 79,9%) and gravitates towards Aegean Sea. Strumica river basin is on south-east part of the country (1.520 km^2 or 5,9%), is a tributary of Struma River in Bulgaria, and gravitates also towards Aegean Sea. Crn Drim river basin is on west part of the country (3.355 km^2 or 13%) and gravitates towards Adriatic Sea. Juzna (South) Morava river basin is on north part of the country, is the smallest one (44 km^2 or 0,2%) and gravitates towards Black Sea. This river basin has no significant impact on the availability of the water resources in the country. Water discharging in Republic of Macedonia is performed through the following rivers: Vardar at Gevgelija, Crn Drim at Debar and Strumica at Novo Selo. The major and minor rivers with their watersheds are presented in Table 1-1.

The water potential of the river basins depends of precipitation regime. The average precipitation sum in Vardar river basin is 700 mm, in Strumica river basin is 790 mm, and in Crn Drim river basin is 980 mm. Maximum precipitation sums of 1.400 mm are registered in western part, and the minimum of 380 mm in eastern part of the country.

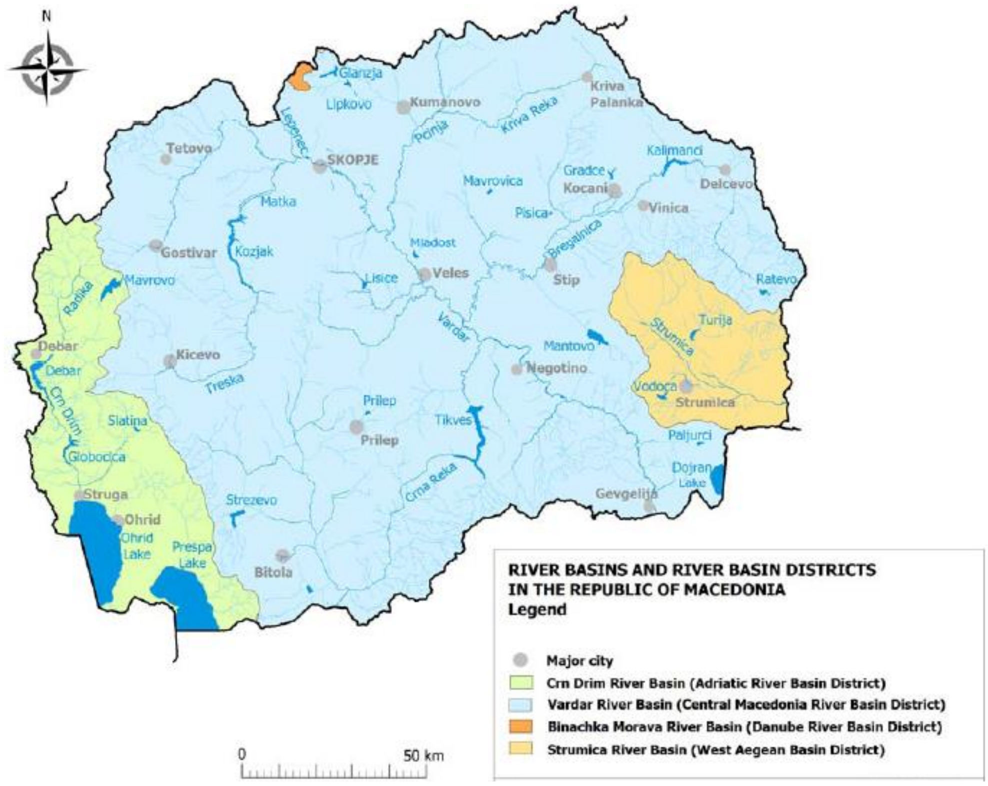

Figure 1-2 Major river basins in the Republic of Macedonia
Source: Water Strategy of the Republic of Macedonia, Government of the Republic of Macedonia, Ministry of Environment and Physical Planning, 2010

Table 1-1

River/Lake		Watershed area (km^2)	Watershed area (%)
1	Major River Basins:		
	Vardar	6.813	26,5
	Treska	2.068	8,0
	Pchinja	2.373	9,2
	Bregalnica	4.307	16,8
	Crna	4.985	19,4
	Subtotal: 1	20.546	79,9
2	Crn Drim	3.355	13,0
3	Strumica	1.520	5,9
	Subtotal: 1 to 3	25.421	98,8
4	Minor River Basins:		
	Dojran Lake	120	0,5
	Cironska & Lebnica	128	0,5
	Juzna Morava	44	0,2
	Subtotal: 4	292	1,2
	Total: 1 to 4	25.713	100

Source: Integrated Water resources Development and Management Master Plan in the Republic of Macedonia, Nippon Koei Co., Ltd. KRI International Corporation, Japan International Cooperation Agency - JICA, 1999

In the Republic of Macedonia 4.414 springs with total yield of 991,9 million m^3/year have been registered, of which 58 have a capacity of over 100 l/s. Only 3 out of these springs are located in the central part of Vardar plain, and all others are in the western region. More significant springs are: Izvor (yield over 3 m^3/s), Studenchica (0,4-4,3 m^3/s), Pitran, Peshnica and Belica (yield over 6 m^3/s) in the Treska river basin, then St. Naum (yield over 10 m^3/s), Biljana, Duvlo, Vevcani (yield over 1,5 m^3/s) and Rosoki (yield over 2,5 m^3/s) in the Crn Drim river basin. In the Crna river basin four springs exist and the largest one is Izvor (yield over 1 m^3/s). In the Vardar river basin, without Treska, 19 springs exist and Rashche is the largest one (yield over 6 m^3/s). Eastern part of Republic of Macedonia is poor with water and only seven springs with very small yields have been registered there. The number of free flowing, tapped and captured springs with data yield is presented in Table 1-2 Tapped springs are located along roads and are used for micro-scale water supply because of their low yield. Captured springs are used for large-scale water supply of cities and villages. The total number of tapped and captured springs is 1.918 with yield of 195,2 million m^3/year.

Table 1-2

Present usage		Total number of springs	Springs with yield data		Total yield	
			number	(%)	(m^3/year)10^6	(%)
1	Free flowing	2.389	2.347	55	434,8	69
2	Tapped	1.645	1.630	38	22,1	3,5
3	Captured	380	288	7	173,1	27,5
Subtotal: 2+3		2.025	1.918	45	195,2	31
Total: 1 to 3		4.414	4.265	100	630	100

Source: JICA, 1999

Three natural lakes, Ohrid, Prespa and Dojran, have also great significance for the hydrographic characteristics of the Republic of Macedonia. The largest one is Ohrid Lake situated at 695 m above sea level with total surface area of 358 km^2 (Macedonian part 229.9 km^2) and with maximum depth of 285 m. Prespa Lake lies at elevation of 853 m with total surface area of 274 km^2 (Macedonian part 176.8 km^2) and with maximum depth of 54 m. Ohrid and Prespa lakes are naturally connected by underground karsts channel and their waters flow through the Crn Drim river basin. The smallest lake is Dojran Lake at an elevation of 148 m with total surface area of 43 km^2 (Macedonian part 27.4 km^2). All three lakes are transboundary. There are also other lakes that are of glacial origin situated in the highest parts of the mountains Shar Planina, Pelister, Jablanitza, Jakupica, Korab and Stogovo.

In Republic of Macedonia have been constructed 21 large and 120 small dams and reservoirs to utilize the hydrological potential of the rivers. Basic characteristics of dams and reservoirs are presented in Table 1-3.

Table 1-3

Dam/Reservoir	River	Dam height (m)	Dam type	Storage (m^3)10^6	Purpose
Vardar river basin:					
Kozjak	Treska	114,0	rockfill	550,0	E, R
Matka	Treska	29,5	concrete	2,6	E
Glaznja	Lipkovska	74,0	concrete	23,6	I, WS, E
Lipkovo	Lipkovska	32,2	concrete	1,2	I, WS, E
Mavrovica	Mavrovica	25,0	earthfill	2,8	I, WS
Kalimanci	Bregalnica	85,0	rockfill	127,0	I, WS, E
Gradche	Kochanska	29,0	concrete	1,8	I, WS
Ratevska	Ratevska	46,0	concrete	10,5	I, WS

Paljurci	Luda Mara	21,1	earthfill	2,9	I, R
Otavica	Otavica	27,0	concrete	8,0	I, WS
Prilep	Oreovachka	36,0	concrete	6,0	I, WS
Tikvesh	Crna	104,0	rockfill	475,0	I, E
Strezevo	Shemnica	76,0	earthfill	119,0	I, WS, E
Suvodol	Sonovirska	33,9	earthfill	7,9	WS, R
Lisiche	Topolka	65,0	rockfill	26,8	WS, I, E
Strumica river basin:					
Turija	Turija	77,5	earthfill	50,3	I, WS,E
Vodocha	Vodocha	44,0	earthfill	27,0	I, WS
Mantovo	Kr. Lakavica	37,5	earthfill	47,5	I, WS
Crn Drim river basin:					
Globochica	Crn Drim	82,0	rockfill	58,0	E
Shpilje	Crn Drim	101,0	rockfill	520,0	E, I
Mavrovo	Crn Drim	54,0	earthfill	357,0	E, I

Legend: E-energy, I-irrigation, WS-water supply, R-retention

Source: Water Economy of the Republic of Macedonia, Journal VODOSTOPANSTO, 1999

1.5 National Protected Areas

In the Republic of Macedonia have been recognized three national parks: Mavrovo (731 km^2) established in 1948, Galičica (227 km^2) established in 1958 and Pelister (125 km^2) established in 1948. All three national parks are heritage sites of nature and culture, Figure 1-3.

Mavrovo National Park is in northwest part of the country. The mountain Bistra (2.163 m) and the lake Mavrovo made the region a year-round tourist center. Mavrovo National Park encompasses numerous rivers, which present a real jewel in the crown of beauty for the mountain landscapes with their wild rapids, and waterfalls. Most impressive parts of the park are the gorges of the Radika River.

Pelister is one of the most southern mountains in the Balkans that has an alpine character. Pelister is also known for its two mountain lakes, which are called Pelister's Eyes. The Big Lake is at altitude 2.218 m above the sea level while the Small Lake is at 2.180 m. The altitude of the park is between 927 m and 2.601 m and is filled with exquisite flora and fauna. Among flora elements, the presence is especially significant of the five-needle pine molica (Pinus peuce) - a unique species of tertiary age being present on only a few mountains in the Balkan Peninsula.

Galicica mountain is situated across the border between the Republic of Macedonia and Albania. The National Park on the Macedonian side of the mountain is situated between the two biggest lakes in the country, Ohrid Lake and Prespa Lake. The floral life in the National Park represents over 1000 species, of which a large number of relicts and endems have the final frontier of its range exactly on the mountain Galicica. Beautiful views across the lakes and neighbouring mountains can be seen from the Galicica peaks. The highest peak is Magaro (2.254 m).

Figure 1-3 Mavrovo, Pelister and Galicica National Parks

1.6 Data Availability

During the preparation of thematic studies and research on water resources related to climate change and vulnerability assessment main problem are data availability, consistency and transparency. Existing monitoring network conducted by the National Hydrometeorological Service (NHS) on climate, surface and groundwater is in continuous reducing process, mainly due to financial problems. Measuring points are reducing, number of measured parameters is reducing, data processing is delaying and etc. Improvement of monitoring network is necessary as well as improvement of data processing, implementation of predictive models and equipment modernization are of highest priority. Modern tools in vulnerability assessment are needed. Training of experts in modern monitoring and data processing technologies is also required. In some cases modern technologies was supplied through some donations and international projects, such as United Nations Development Programme (UNDP), Global Environment Fund (GEF) and Swiss Agency for Development and Cooperation (SDC), but operational costs and sustainability is not provided by the responsible governmental institutions.

It is noted that all very important climate change parameters are not measured at all, such as snow cover and snow melting trends especially on higher altitudes, air temperature trends in mountainous regions, glacial lakes water volume trends, biodiversity change etc.

1.7 International Obligations

The Republic of Macedonia ratified the UNFCCC in 1997. As Party to the Convention, the country has submitted the First National Communication in 2003. It allowed development of expertise in each sector involved in the preparation. For Hydrology and Water Resources sector the assessment of runoff for four representative rivers in the country for the period 1961-2000 was performed as well as the water volume change in three tectonic lakes. It was concluded that the average long term runoff decreases for 10-20%. The most vulnerable regions are east and southeast, and most vulnerable water sectors are water supply and irrigation. In 2004 the Republic of Republic of Macedonia ratified the Kyoto Protocol to the UNFCCC and become Party in 2005. In 2007 the Macedonian Government adopted the National Strategy for Clean Development Mechanism for the first commitment period of the Kyoto Protocol, 2008-2012.

The Second National Communication to UNFCCC was submitted in 2008. In water resources sector projection analyses of the precipitation and runoff was performed till 2050 and 2100. It was concluded decreasing trend for all climatic regions: 15% in mountainous west part of the country, 20% in continental southwest part and 35% to 40% in south and east part. Runoff was simulated by MIKE SHE software tool and the most significant water scarcity was obtained for Bregalnica watershed. The average water shortage for Bregalnica river basin in 2100 will be over 24% in comparison with obtained water shortage of 7% for Treska river basin. Adaptation measures were proposed as well as cross sectoral Action Plan for the period 2008-2011 was proposed. The development and adoption of the Second National Communication on Climate Change represents an obligation for the country according to the UN Framework Convention on Climate Change and the Law on Environment. The Ministry of Environment and Physical Planning is the state’s competent authority for coordination of the activities in the development of the Communication. As a country which does not belong to the group of highly industrialised countries, Republic of Macedonia shares only the common responsibilities of all Parties to the Convention, implying developing and submitting of national communications on climate change, which include chapters on national GHG inventory, climate change mitigation, and vulnerability and daptation to climate change in different sectors.

The mitigation of Climate Change effects has become one of the key priorities in the Republic of Macedonia. Such effects have negative impact on the health and wellbeing of the people and have continuous impacts on the state of biodiversity, indigenous habitats, agriculture and numerous social segments that define the country in wealth of natural habitat, forestry, rivers and lakes. Negative effects from CC impacts are continuously signalled from various domestic institutions, such as Hydrometeorological Service, Public Health Institute, Ministry of Environment and Physical Planning, as well as numerous civil organizations that follow the changes in our environment.

The European Environment Agency (EEA) has prepared a survey of resource efficiency policies in EEA member and cooperating countries (http://www.eea.europa.eu). It is stated that from 2005 Republic Macedonia has candidate status for accession to the EU and has started internal reforms to the economic and legal systems. In that direction the National Programme for adoption of the EU acquis (NPAA) was adopted. The process of harmonization with EU acquis has started in some sectors relevant to sustainable development such as environment and physical planning, forestry, energy, etc. The topic of resource efficiency and natural resources is fount in the publication Sustainable Development, 2010 prepared by the State Statistical Office (http://www.stat.gov.mk/Publikacii/Odrzliv), where the key goals and strategic measures for reaching those goals are elaborated such as: (a) climate change and clean energy, mitigating climate change and its negative effects to society and the environment, (b) sustainable transport, (c) sustainable consumption and production, to decouple economic growth from environmental degradation, and (d) conservation and management of natural resources, to improve management and avoid overexploitation of natural resources.

Water Framework Directive

The European Parliament and the Commission have established the EU Water Framework Directive 2000/60/EC (WFD) to protect all European surface waters and ground waters (http://ec.europa.eu/environment/water/index.html). The concern of this document is not only the water quality and pollution but the ecological integrity with special regard on the hydrology, morphology and biota. With the objective to reach the good ecological status for all water bodies by 2015 the EU Member States are obliged on a common framework to monitor all their water bodies and to apply protection measures and melioration. Further, coherences exist between the WFD and other directives of conservational and water management issues. Within the frame of Birds Directive 74/409/EEC and the Habitats Directive 92/43/EEC wetlands, aquatic habitats, animals and plants are under conservational status and must be protected. The recently decided Floods Directive 2007/60/EC aims to mitigate the effects of floods and obliges the EU Member States to undertake measure and monitoring programmes. The policies and implementation of WFD is also obligation of all EU associate countries.

The whole process of implementation follows several steps. In the first step all countries have to identify all river basins in their national territory and assign them to individual river basin districts. Next step is the analyses of the characteristics of each river basin district, review the impact of human activity on the water resources, analyze the economics of water use, register areas requiring special protection and survey all waterbodies used for human consumption. These issues have to be revised in 2013 and every six years thereafter. According to the results of these analyses management plans have to be developing for all river basin districts. For supporting the implementation of WFD several guidance papers have been elaborated within the "Common Implementation Strategies".

Directive 2007/60/EC aims to assess, manage and reduce the risk of floods within EU considering impacts on human health and life, the environment, cultural heritage and economic activity. The Directive covers all type of floods as along rivers and coastal areas as well as urban and sewer floods. The management measures shall be organized on a river basin district scale. For each river basin a management plan to reduce the probability of floods and the impact of flooding has to be prepared and implemented by 2015. The management measures must take in account water management, soil management, spatial planning, land use and nature conservation and they must not increase the risk of flood in neighbouring countries.

Other key EU Policy Documents related to water are Urban Waste Water Treatment Directive 91/272/EEC, Drinking Water Directive 98/3/EC, Bathing Water Directive 2006/7/EC, Communication on Water Scarcity and Droughts 2007.

The first sentence of the EU WFD expresses most how serious must be the water use and water protection: "Water is not a commercial product like any other but, rather, a heritage which must be protected ..."

Major Stakeholders

Relating to the subject of climate change, sustainable development and efficient use of natural resources the following stakeholders have jurisdiction and responsibilities:

- Government (www.vlada.mk)
- Ministry of Environment and Physical Planning, (www.moepp.gov.mk)
- Ministry of Economy (www.economy.gov.mk)
- Ministry of Agriculture, Forestry and Water Management (www.mzsv.gov.mk)
- Ministry of Local Self Government (www.mls.gov.mk)
- Ministry of Transport and Communications (www.mtc.gov.mk)

- National Committee on CC
- Parliament Commission on Transport, Connections and Environment
- Parliament Commission on EU integration
- Macedonian Academy of Science and Arts (http://www.manu.edu.mk/)
- Electric Power Company (ELEM) (www.elem.com.mk)
- Macedonian Hydro Meteorological Service (UHMR) (www.meteo.gov.mk)

Major stakeholders in the country that are concerned but not responsible are NGOs. The progress in CC issue and related public debate is evident in recent years. Various stakeholders, government institutions and bodies, the NGO sector, Parliament commissions, international foundations and organizations, EU representative offices initiate and/or organize debates, round-table discussions, seminars and conferences. In education and research sector CC issue participation is rather satisfactory but mainly on individual level.

National Legislation

General Environmental Legislation and Action Plans:

- National Environmental Action Plan (NEAP 1) 1996
- National Environmental and Health Action Plan
- Second National Environmental Action Plan (NEAP 2) www.moepp.gov.mk
- Law on Environment (Official gazette 53/2005, 81/05, 24/07)
- Program for investing in environment (Official gazette 81/05)
- Decree for establishing the projects and criteria according to which the environmental impact assessment is required (Official gazette 74/05 – the decree is applying from 01.01.2006)

Air Quality

- Law on Ambient Air Quality (Official gazette 67/2004)
- Book of regulations for the methodology for tracking and confirming the pollutants in the air (Official gazette 9/76)

Waste

- Law on Waste Management (Official gazette 68/2004, 71/04)
- Law for ratification of the Basel Convention (Official gazette 91/2004) www.pravo.org.mk

Waters

- Law on Waters (Official gazette 4/1998, 19/00, 42/05, 46/06) http://www.pravo.org.mk/download/Zakoni/Vodite.pdf
- Law on Water Communities (Official gazette 51/2003, 95/05) http://www.pravo.org.mk/download/Zakoni/Vodni_zaednici.pdf
- Law on Water Management Enterprises (Official gazette 85/2003, 95/05) http://www.pravo.org.mk/download/Zakoni/Vodostopanstva.pdf
- Law on Drinking Water Supply and Urban Wastewater Drainage (Official gazette 68/2004, 28/06) http://www.pravo.org.mk/download/Zakoni/Snabduvanje_so_voda_za_pienje_i_odveduvanje_na_otpadni_vodi.pdf

- Water Strategy of the Republic of Macedonia (2010)
- Water Master Plan of the Republic of Macedonia (WMP). This national document will serve as a base for information and as a framework for operation and planning in water sector. It will be a Digital Master Plan.

  http://www.wmp.gov.mk
- River Basin Management Plans (RBMP). These plans will be developed in 6 years for each river basin in the country, (2011-2017).

Nature Protection

- Law on Nature Protection (Official gazette 67/2004)
- Law on Plants Protection (Official gazette 25/1998, 6/00) http://www.pravo.org.mk/download/Zakoni/Zastita_na_rastenija.pdf

Climate Change

- National Strategy for Clean Development Mechanism (CDM) for the first commitment period of the Kyoto Protocol, (2008-2012) http://www.moepp.gov.mk/WBStorage/Files/CDM%20strategy%20final%20word.pdf

2

Climate Change Impact Assessment

2.1 Introduction

Climate variability and climate change are stochastic forces determining the prospects for human development. Their impacts on different natural and social systems affect all countries directly and indirectly. However, climate change impact on human development cannot be inferred automatically from global scenarios forecasts of key climatic variables. Climate change is global but the effects are local. Water resources are among the most critical for human and economical development, because they are essential for the vital functions of all living beings, plants, agricultural production and for many industrial processes. The interface between climate change, human and water resources is shaped, among other factors, by the differences in local weather conditions, in social and economic coping capacities, and by public policy. People and the communities vary in their vulnerability and capacity to manage incremental climate change risks. Many communities are conducting planning efforts that consider the climate change effects on water resources. Although most of these efforts use processes commonly used in land use planning, some of the climate related elements, such as conducting vulnerability assessments and considering adaptation strategies, are novel and require new types of data and tools. This chapter deals with tools and indicators for the water resources vulnerability assessment. Tools include methods and software/web that can help improve spatial planning and water resources management. The tools described bellow is not a comprehensive list of tools to conduct climate relating planning activities. Rather, these set of tools help communities focus on a set of tools to get started in planning for climate change.

2.2 Climate Change Related Terms and Definitions

Climate change

Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer to millions of years. It may be a change in average weather conditions, or in the distribution of weather around the average conditions. Climate change is caused by factors that include oceanic processes, biotic processes, variations in solar radiation received by Earth, tectonic processes and volcanic eruptions, and human-induced alteration of the natural world. The methods usually used are statistical tests. Climate change may be due to natural internal processes or external forces, or persistent anthropogenic changes in the composition of the atmosphere or in land use. United Nations Frameworks Convention on Climate Change (UNFCCC) defines climate change as: “A change of climate which is attributed directly or indirectly to human activity that alters the global atmosphere and which is in addition to natural climate variability observed over comparable time period". Thus, the UNFCCC makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.

Climate change has influenced on various environmental and social sectors. Especially it has significant impact on water resources. Changes in the water cycle, which are consistent with the warming observed over the past several decades, include: (i) changes in precipitation patterns and intensity, (ii) changes in the incidence of drought, (iii) widespread melting of snow and ice, (iv) increasing atmospheric water vapour, (v) increasing evaporation, (vi) increasing water temperatures, (vii) reductions in lake and river ice, and (viii) changes in soil moisture and runoff. These changes include both interior and costs areas, Figure 2-1. Floods and droughts are likely to become more common and more intense as regional and seasonal precipitation patterns change.

Anthropogenic climate change

Anthropogenic climate change refers to the production of greenhouse gasses emitted by human activity. The IPCC Fourth Report (2007) stated that the post-industrial rise in greenhouse gasses does not stem from natural mechanisms. In other words this is anthropogenic climate change. The most potent of greenhouse gasses are carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). Alarmingly, these are a result of anthropogenic climate change, and the gasses are at the highest levels for over 650.000 years.

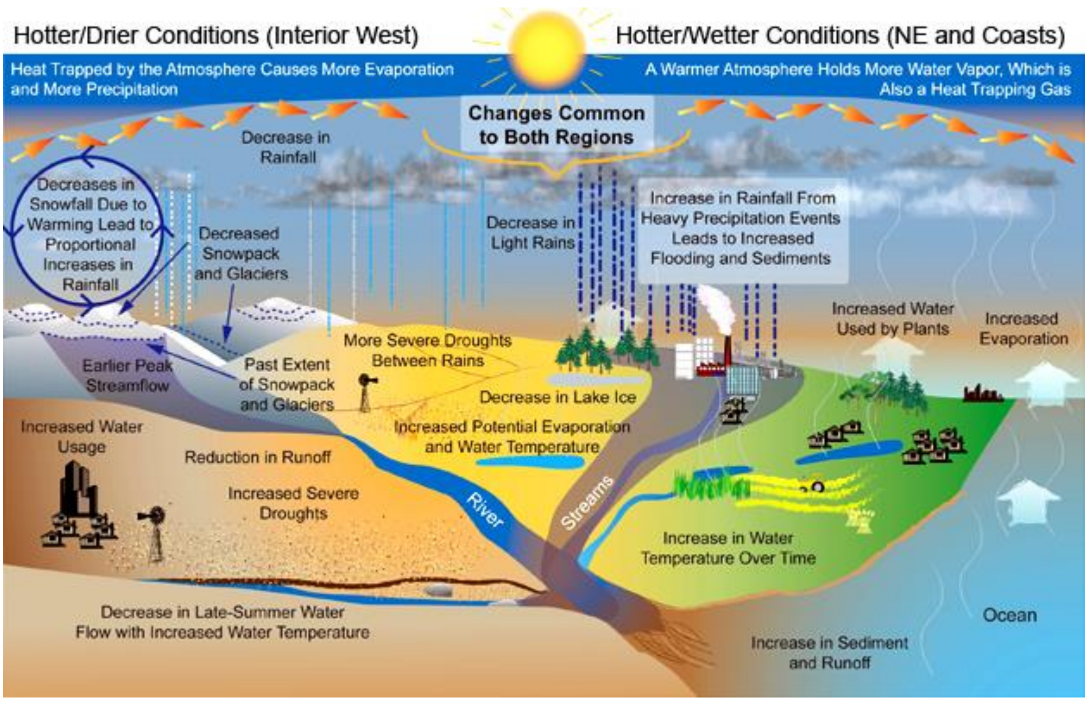

Figure 2-1 Water cycle changes (Source: USGCRP, www.nca2009.globalchange.gov)

Climate projection

Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission of GHG which are based on assumption concerning future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.

Sensitivity

Sensitivity can be defined as degree to which a system is affected by climate variability or climate change. The effect may be direct (e.g., a change of spring yield, surface runoff or crop yield in response to a change in the mean, range, or variability) or indirect (e.g., damages caused by the increase of frequency of flooding or drought).

Vulnerability

Vulnerability is the degree to which a system is susceptible to adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change to which a system is exposed, its sensitivity, and its adaptive capacity.

Adaptation

Adaptation to climate change is mainly about better water management (UNFCCC). The Intergovernmental Panel on Climate Change (IPPCC) defines adaptation as adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Even if the emissions are stabilized soon, climate change and its effects will last many years, and adaptation will be necessary. Climate change adaptation is especially important in developing countries since those countries are predicted to bear the burden of the effects. The capacity and potential for humans to adapt is called adaptive capacity that is unevenly distributed across different regions and populations. Adaptive capacity is closely linked to social and economic development (IPCC, 2007).

Adaptive capacity

Adaptive capacity refers to the potential, capability, or ability of a system to adapt to climate change stimuli or their effects or impacts (IPCC). Adaptive capacity greatly influences the vulnerability of communities and regions to climate change effects and hazards (Bohle *et al*., 1994, Downing *et al*., 1999, Kelly and Adger, 1999, Milleti, 1999, Kates, 2000). Estimates of adaptive capacity is based on premises such as the position of highly managed systems (such as agriculture), given sufficient resources, are likely to be more adaptable than less managed systems. Of course, sensitivity and adaptive capacity vary according to the climate change related stress being considered. Thus, adaptive capacity to gradual changes in mean temperature may be high, but adaptive capacity to changes in the magnitude or frequency of extreme climatic conditions may not be so high (Appendi and Liverman, 1996).

Mitigation

Reduction of emissions of greenhouse gasses is generally referred to as mitigation of climate change. The United Nations defines mitigation as human intervention to reduce the sources or enhance the sinks of greenhouse gasses. These include using fossil fuels for industrial processes or electricity generation, switching to renewable energy, improving the insulation of buildings, and expanding forests and other “sinks” to remove greater amounts of carbon dioxide from the atmosphere. Klein et al. (2007) assessed the options for adaptation and concluded that in the absence of mitigation efforts and measures, the effects of climate change would reach such a magnitude as to make adaptation impossible for some natural ecosystems. For human systems, the economic and social costs of unmitigated climate change would be very high.

Mitigative capacity

The National Human Development Report (2009) defines this term as a country ability to reduce anthropogenic greenhouse gas emissions or to enhance natural sinks, where ability refers to skills, competences, fitness and proficiencies that a country has attained and depends on technology, institutions, wealth, equity, infrastructure and information. Mitigative capacity is rooted in a country's sustainable development path.

Resilience

The Office of Environment and Heritage and the State of NSW in Guide to Integrated Regional Vulnerability Assessment (IRVA) for Climate Change (2013) defines resilience as the amount of change a system can undergo and still retain the same function and structure while maintaining options to develop.

Climate change indicators

The National Oceanic and Atmospheric Administration (NOAA) made an excellent summary of the many lines of evidence that global warming is happening. Many different observations find a distinct human fingerprint on climate change, Figure 2-2. Brief info on each indicator is the following: 1) humans are currently emitting around 30 billion tones of CO_2 into the atmosphere every year; 2) measuring the type of carbon accumulating in the atmosphere it is observed that more of the type of carbon comes from fossil fuels; 3) oxygen levels are falling in line with the amount of carbon dioxide rising; 4) evidence that humans are raising CO_2 levels comes from the measurements of carbon found in coral records going back several centuries; 5) satellites measure less heat escaping out to space at the particular wavelengths that CO_2 absorbs heat, thus finding "direct experimental evidence for a significant increase in the Earth's greenhouse effect"; 6) heat escaping to space is coming back to Earth's surface that is confirmed by observed more downward infrared radiation; 7) increased greenhouse effect resulted in certain warming patterns – the planet is warming faster at night than during the day; 8) another distinctive pattern of greenhouse warming is cooling in the upper atmosphere known as the stratosphere; 9) with the lower atmosphere (the troposphere) warming and the upper atmosphere (the stratosphere) cooling, another consequence is the boundary between the troposphere and stratosphere (the tropopause) should rise; 10) even higher layer of the atmosphere is expected to cool and contract in response to greenhouse warming.

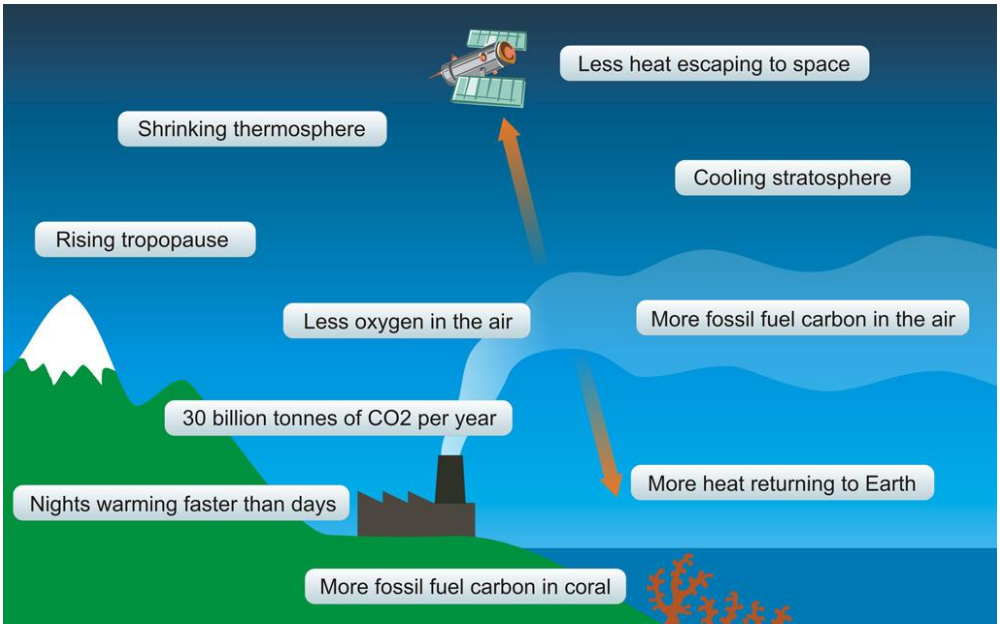

Figure 2-2 Indicators of a human fingerprint on climate change (Source: Global Warming Forum, 2009, http://www.skepticalscience.com/10-Indicators-of-a-Human-Fingerprint-on-Climate-Change.html)

2.3 Potential Climate Change Impact on Water Resources

Global climate change have important implications on water resources that include increases evaporation rates, higher proportion of precipitation received as rain, rather than snow, earlier and shorter runoff seasons, increased water temperatures, and decreased water quality in both inland and costs areas. The consequences of these effects are physical and economical.

Increased evaporation rates are expected to reduce water supplies with greatest deficit in summer, leading to decrease soil moisture and agricultural drought. Agricultural producers and urban areas are particularly vulnerable.

Rising surface temperatures will increase the proportion of winter precipitation received as rain rather than as snow. Snowpack levels are expected to form later in winter and melt earlier in the season, leading to reduced summer flows. Changes in snow pack and runoff are of concern to water managers including hydropower generation, irrigated agriculture, urban water supply, flood protection and commercial and recreational fishing.

Water shortages will cause the price of water to rise. A sufficiently large price increase could affect the extent and pattern of urban growth. One final and important effect is the potential for more frequent and intense interstate water allocation conflicts.

Water resources in the Republic of Macedonia are sensitive to climate change with regard to the quantity and quality. GHG emission scenarios and climate modeling provide different projected values for future water quantity and quality presented in the First (2003) and in the Second (2008) National Communication on Climate Change. Climate change projections for the main climate elements (air temperature and precipitation) are obtained for the periods 2025, 2050, 2075 and 2100 with reference year 1990. Six different climate scenarios for selected subregions were developed, as well as one scenario for the entire country based on the direct Global Circulation Model (GCM).

According to the obtained results, the average air temperature increase is between 2,9°C in 2075 and 3,8°C in 2100. Projected changes in average air temperature for different seasons are: for winter 0,8°C in 2025, 1,7 °C in 2050 and 3,0 °C in 2100, for spring 0,8 °C in 2025 and 3,2 °C in 2100, for autumn 0,9 °C in 2025 and 3,7 °C in 2100, and for summer these projections are 1,4 °C in 2025, in 2050 it is 4,1°C and 5,4°C in 2100.

The average precipitation sum is expected to decrease between 8% in 2075 and 13% in 2100. The available surface water reduces will be for Vardar River between 7,6% in 2025 and 18,2% in 2100 and for Bregalnica River between 10% in 2025 and 23,8% in 2100. Groundwater recharge in Vardar River basin will decrease continuously reaching approximately 57,6% of the current recharge in 2100. In conclusion, the overall water availability in the country is expected to be reduced by 18% in 2100.

Figure 2-3 Location of study area

2.4 Vulnerability Assessment Methodologies

The water resources vulnerability assessment usually is based on three types of indicators, such as flood, drought, and water management. One methodological approach in vulnerability assessment is by GIS-based spatial data for indicators as it is shown in Table 2-1. Three main criteria are considered: sensitivity, exposure, and adaptability. The relation between these criteria indicates that the sensitivity and exposure to climate change is increased, the vulnerability is increased under the same condition, and implies that the vulnerability is decreased by adaptability. National and regional vulnerability of floods and droughts are usually obtained on watershed scale. With the help of the regional vulnerability one can identify the spatial differences in vulnerability in a local scale that can help to prepare adaptation measures.

Table 2-1 List of indicators

Type	Criteria	Indicator
Flood	Sensitivity	Precipitation>80 mm/day
		Maximum precipitation (mm)
		Maximum runoff (m^3/s)
		Summer precipitation (mm)
	Exposure	Elevation (m)
		Population density ($person/km^2$)
	Adaptability	River improvement ratio (%)
Drought	Sensitivity	Annual precipitation (mm)
		Precipitation>1 mm/day
	Exposure	Water requirement density (t)
	Adaptability	Area (km^2)
Water management	Sensitivity	Annual precipitation
		Annual temperature
		Conduit water consumption
		Ground water consumption
	Exposure	Elevation
		Population density
	Adaptability	Conduit water supply rate
		Sewage supply rate

Source: Lonergan et al., 2006, Brooks et al., 2005, World Economic Forum, 2002

Another methodological approach is water balance model development on a watershed scale. Natural watershed systems maintain a balance between precipitation, runoff, infiltration and evaporation. It is necessary to understand the balance or water budget in order to sustain the resource and its environmental and human connections in the watershed. The understanding of the hydrological cycle on a watershed basis is essential for development and implementation of appropriate watershed management policies, plans and procedures. So, water balance model is needed as a baseline scenario for water availability assessment in future including the change of the inflow and outflow components affected by climate change.

The mass balance actually shows the change in storage of the watershed as a difference between the input and output, Figure 2-4. Input waters are precipitation (P) and groundwater inflow (G_{in}), while the output includes evaporation from free surface water (E) and evapotranspiration (ET), streamflow (Q) and groundwater outflow (G_{out}). In many instances the long term difference between groundwater inputs and outputs are small compared to other terms, and in such conditions the water balance can be simplified by assuming the difference between groundwater input and output is essentially zero (G_{in}- G_{out}=0).

Increased evaporation rates and decreased precipitation and snowpack are expected to reduce water supplies. The greatest deficits of water are expected to occur in summer, leading to decreased soil moisture and more frequent and sever agricultural drought. More frequent extreme events, such as floods and droughts, will have serious management implications for water resources users.

Natural watershed systems maintain a balance between precipitation, runoff to lakes, rivers and wetlands, infiltration to the groundwater system, and water which either evaporates from open water surfaces or transpirates from vegetation, completing the natural cycle back into atmosphere.

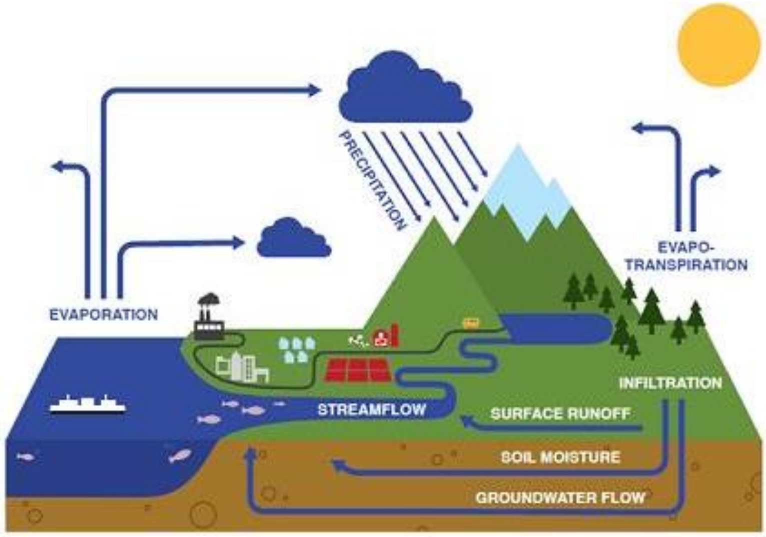

Figure 2-4 Components in water balance

It is necessary to understand this “balance” or “water budget” in order to sustain the resource and its environmental and human connections in the watershed. The understanding the hydrologic cycle on a watershed basis is essential for development and implementation of appropriate watershed management polices and procedures. Natural variations occur frequently in various components of the hydrologic cycle. The risk of occurrence can be estimated by an analysis of the historical records or by application of models. However, vulnerability to a particular problem is a function of hazard perception and planning. Planning on a watershed basis can help to manage risk and reduce vulnerability.

The development of watershed management concepts has generally recognized a hierarchy of watershed management units. A suggested hierarchy is shown in Table 2-2. This hierarchy recognizes that the planning and management focus, and agency involvement are related to watershed size. The level of detail of water budget analysis is also related to watershed size. The hierarchy of watershed scale can range from small catchment and project sites up to large watersheds and regions.

Table 2-2 Hierarchy of Watershed Management Units

Watershed Management Unit	Size (km^2)	Primary Planning Authority	Management Focus	Water Budget (WB) Input
Catchment	0.1-3.0	Property Owner Local Municipality	Site Designs BMP Implementation	Land Use Change Infiltration
Sub-watershed	3.0-25.0	Local Municipality Conservation Authority	Stream and Wetland Classification Management Criteria Resource Protection Strategies	Weekly/Monthly WB Recharge Areas Infiltration
Watershed	25-250	Several Municipalities Conservation Authority Provincial Government	Appropriate Land Use Policies	Seasonal WB Pollution Augmentation
Sub-basin	250-2500	Conservation Authority Provincial Government	Overall Basin Planning	Annual WB Pollution
Basin	2500-25000	Provincial Government Federal Government	Overall Basin Planning	Annual WB Pollution

Source: Site Planning for Urban Stream Protection, Metropolitan Washington Council of Governments, Water Resources Publications, 1995

2.5 Water Sector Tools

The water sector tools described in compendium are mathematical models and software for assessing water resources adaptations to climate change, focusing on regional water supply and demand analysis of water systems. The models summarized here long-range simulation tools such as WEAP and IRAS, short-range simulation models like RiverWare and WaterWare, and spatial tools for river basin water budget modeling such as MIKE BASIN, STREAM and HEC-HMS.

WEAP

Water Evaluation and Planning System

This is a PC based surface and groundwater simulation tool, based on water balance accounting principles, which can test alternative sets of conditions of both supply and demand. The software is relatively easy to use and requires significant data for detailed analysis (http://www.weap21.org/).

RiverWare

This is a general UNIX based river and reservoir modeling application with both operational and planning applications. This system offers multiple solution methodologies that include simulation with rules and optimization. Modeling framework is not spatial, not GIS based (http://cadswes.colorado.edu/riverware/).

IRAS

Interactive River and Aquifer Simulation

This is a PC based surface water resources simulation tool, based on water balance accounting principles that can test alternative sets of conditions of supply and demand. Through data interfacing, IRAS can link to various external modules such as rainfall-runoff and to economic and ecological impact prediction programs. Contacts: RPA Resources Planning Associates, Inc., 231 Langmuir Bldg., 95 Brown Road, Ithaca.

RIBASIM

This a generic model package for simulating the behavior of river basins under various hydrological conditions. The model is a comprehensive and flexible tool that links the hydrological water inputs at various locations with specific water users in the basin. RIBASIM enables the users to evaluate a variety of measures related to infrastructure and operational and demand management (http://www.wldelft.nl/soft/ribasim/int/index.html).

MIKE BASIN

This is a quasi-steady-state mass balance model build on a network model in which branches represent individual stream sections and the nodes represent confluences, diversions, reservoirs, or water users. The ArcView GIS interface has been expanded accordingly (http://www.dhigroup.com/Software/WaterResources/MIKEBASIN.aspx).

STREAM

Spatial Tools for River and Environment and Analysis of Management Options

This is a spatial hydrological model that allows for assessing hydrological impacts due to climate changes and socio economic drivers. It is set up according to a policy analysis framework and ensures a structural approach for an entire river basin including the coastal zone. STREAM is a spatial model and uses data from digital GIS maps and satellite observations (http://www.netcoast.nl).

CALVIN

CALifornia Value Integrated Network

This is an economic-engineering optimization model of California's inter-tied supply system, based on the US Army Corps of Engineers HEC-PRM software. Data on surface and groundwater hydrology, infrastructure connectivity and capacities, operating costs, economic values for water deliveries, and environmental flow constraints are combined with an optimization solver to identify promising integrated water management strategies coving surface water, groundwater, water conservation, water market, water reuse, and desalination water management options. This is a screening model for planning and policy purposes (http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/).

OSWRM

Okanagan Sustainable Water Resources Model

This model is created in system dynamic software STELLA. It simulates water resources supply and demand, including residential/municipal, agricultural, and instream flow requirements. Included are population growth and climate change and how they affect both supply and demand. STELLA software is needed to run the model and is available from ISEE website (www.iseesystems.com).

HEC-HMS

Hydrologic Modeling System

This tool is designed by US Corps of Engineers to simulate the precipitation-runoff processes of watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. A model of the watershed is constructed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed of interest. Any mass or energy flux in the cycle can then be represented with a mathematical model. In most cases, several model choices are available for representing each flux. Each mathematical model included in the program is suitable in different environments and under different conditions. The program features a completely integrated work environment including a database, data entry utilities, computation engine, and results reporting tools (http://www.hec.usace.army.mil/software/hec-hms/).

2.6 Statistical Trends

The statistic trend analysis of time series data related to water quantity and quality is very important part in water management planning and procedures. This analysis is based on data collection and compilation of historical data such as rainfall, temperature, streamflow, stream water level, spring discharge, groundwater level. The time series of any random hydrologic variable exhibit a trend that there is a significant change over time. The trend analysis of hydrological time series is of importance because of the effects of global climate change. Statistical procedures are used for the detection of the gradual trend over time. The purpose of trend testing is to determine if the variable generally increase or decrease.

In the First and Second National Communication on Climate Change the southeastern part of Republic of Macedonia was identified as the most vulnerable. Therefore, this part of the report related to time series data and statistical trend analysis is focused on the identified most vulnerable part of the country. Time series data on basic parameters, air temperature and precipitation, for Strumica and Nov Dojran meteorological stations for the period 1951-2010 are collected and analyzed. In the previous CC National Communications the time series data were analyzed for the period 1951-2000. How much the extension of time series data with only one decade can changed the statistical trends is shown in Figures 2-5 to 2-8.

Analyzing the air temperature data at Strumica shown in Figure 2-5 it is observed increasing trend for the last decade 2001-2010 which resulted to the increasing trend line for the entire observed period 1951-2010. Projecting this trend to 2050 the estimated average air temperature is 12,88^{o}C that is almost the same with the long-term average temperature 12.9^{o}C obtained for the period 1951-2010. Using the trend line for the period 1951-2000 the projected air temperature in 2050 is 11.22^{o}C that is bellow the long-term average temperature and is not reliable estimation which confirms the importance of long time series data. Only one decade extension of historical data has changes significantly statistical trends.

Increasing trends of the air temperatures by the used data at Nov Dojran presented in Figure 2-6 show continuous rise of the temperature in both periods 1951-2000 and 1951-2010. By the use of the obtained regression equations for the period 1951-2000 it is obtained projected temperature of 14,58^{o}C in 2050, and for extended period 1951-2010 the projected air temperature in 2050 is estimated to 15,74^{o}C which is about 8% increase comparing to the long-term average temperature.

Regarding the temperature regime and obtained statistical trends it can be concluding that the trend lines show significant temperature increase for both meteorological stations, Strumica nad Nov Dojran. Long-term average and projected temperatures for 2025 and 2050 are presented in Table 2-3.

Table 2-3

Station	Observed period	Long-term average	Temperature in (^{o}C)	
			2025	2050
Strumica	1951-2010	12,9	12,93	12,88
Nov Dojran	1951-2010	14,5	15,28	15,74

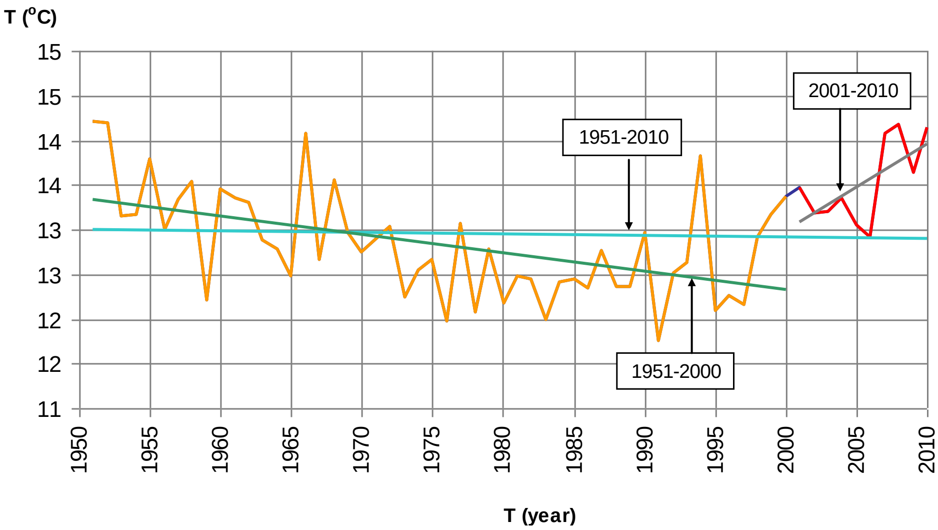

Figure 2-5 Air temperature trends for Strumica

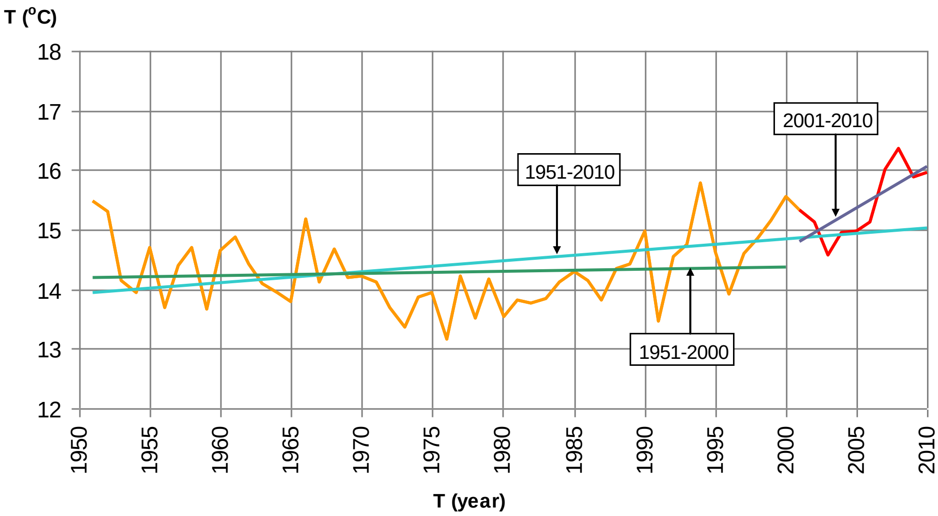

Figure 2-6 Air temperature trends for Nov Dojran

Analyzing the precipitation regime by data at Strumica meteorological station shown in Figure 2-7 it is observed increase of the annual precipitation sums for the last decade 2001-2010 which resulted to less steep trend line for the period 1951-2010. Using trend line for the period 1951-2000 the projected annual precipitation sum in 2050 is estimated to 376 mm that is much less than the long-term average precipitation sum. Using the trend line obtained for the extended period 1951-2010 it is 544,4 mm. The long-term average annual precipitation sum for the period 1951-2010 is 583,1 mm.

Precipitation regime in Dojran Lake region is described by observed data presented in Figure 2-8. Significant increase of the annual precipitation sum is observed for the last decade. In 2002 it is recorded 1041,5 mm and 962 mm in 2009 that is about 40% of the long-term average value. Using the regression equation for the period 1951-2000 the projected annual precipitation sum in 2050 is 432,8 mm, and by trend line for the extended period 1951-2010 it is 677,6 mm while the long-term average precipitation sum is 653,8 mm. This convenient precipitation regime can be explained both by rather wet hydrological period in the country that started in 2000 and by regional redistribution of the precipitation.

Regarding the precipitation regime and obtained statistical trends it can be concluding that for Strumica region the annual precipitation sum will decrease for about 7% in 2050 in reference to the long-term average sum for the observed period 1951-2010. For Nov Dojran it is projected insignificant increase for about 4% in 2050 in reference to the long-term average precipitation sum. Long-term average and projected precipitation sums for 2025 and 2050 for Strumica nad Nov Dojran are presented in Table 2-4.

Table 2-4

Station	Observed period	Long-term average	Precipitation in (mm)	
			2025	2050
Strumica	1951-2010	583,10	558,36	544,40
Nov Dojran	1951-2010	653,80	669,00	677,57

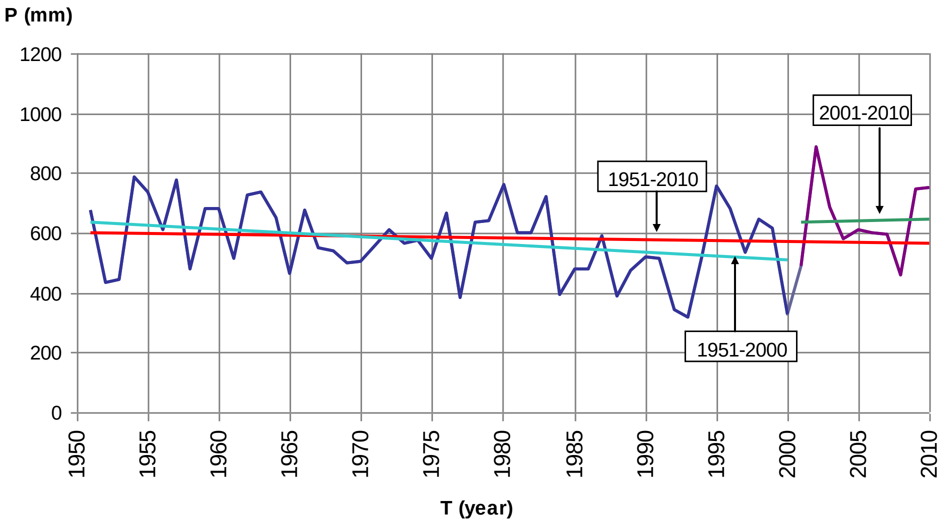

Figure 2-7 Precipitation trends for Strumica

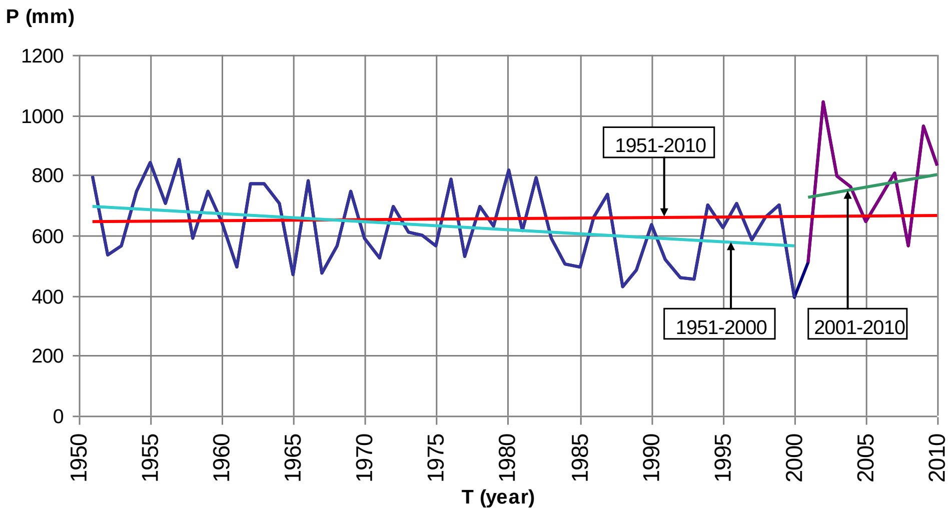

Figure 2-8 Precipitation trends for Nov Dojran

The vulnerability assessment by statistical trends would not be complete if trends of streamflow recorded data are not analyzed. Therefore, two hydrological stations in Strumica river basin, Sushevo in the upper part and Novo Selo in the lower part of the watershed are analyzed, Figures 2-9 to 2-12. Characteristic annual runoff data for

Vardar River are also collected and analyzed for Skopje in the upper part and Gevgelija in the lower part, Figures 2-13 to 2-18. From the presented hydrographs the following concluding remarks can be stated:

- The period of systematic observations and measurements of 1951-2010 is very short period for assessing the statistical trends on long-term basis.
- Recorded annual discharges (minimum, average, maximum) for the last decade 2001-2010 for all analyzed hydrological stations have increasing trend.
- Long-term trend lines for the period 1951-2010 have less gradients comparing to the trend lines for the previous analyzed period 1951-2000.
- Annual average and maximum discharges have rapid increasing trend in the last decade 2001-2010, especially river Strumica at Suševo.
- Recorded characteristic discharges, minimum and average, for Vardar River in Skopje have increasing trends for the last decade, but this has no significant impact on the long-term statistical trend.
- Analyzing the recorded annual maximum discharges of Vardar River in Skopje it is observed decreasing trend. The frequency of recorded flood peaks have changed to lower magnitudes that can be explained by constructed upstream dams and reservoirs and their retention capacities (Kozjak, St Petka and Matka on Treska River).
- Recorded minimum and average discharges of Vardar River in Gevgelija have significant increasing trends which resulted with long-term less gradient of the statistical trend. Using the regression equation for the period 1951-2010 which defines 120,5 m^3/s average runoff in 2000 for the next 50 years is obtained only 65 m^3/s that is about 50% decreasing.
- Maximum discharges have no significant changes referred both to short-term and long-term statistical trends.
- Final conclusion based on the statistical trend analysis of the recorded runoff is that the last decade can be recognized as a hydrological wet period.

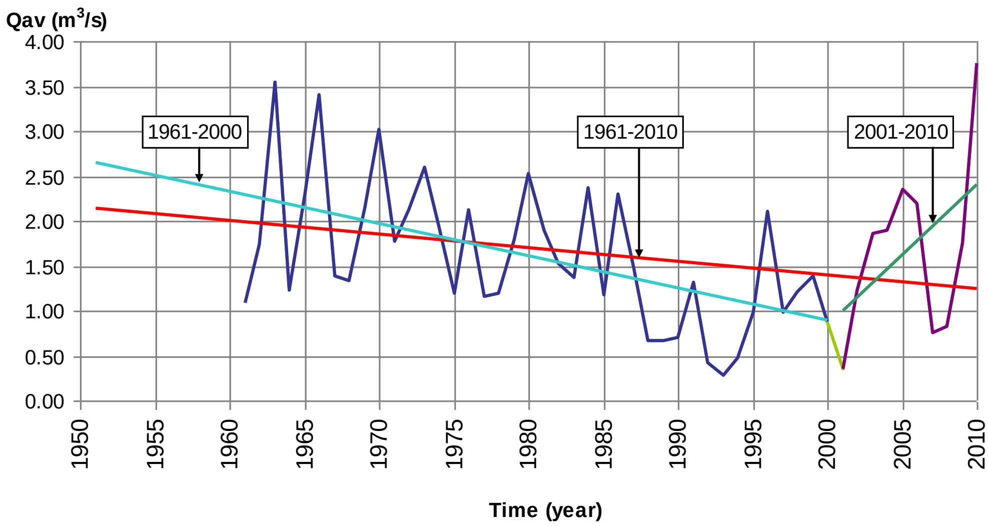

Figure 2-9 Annual average discharges trends for Strumica River at Suševo

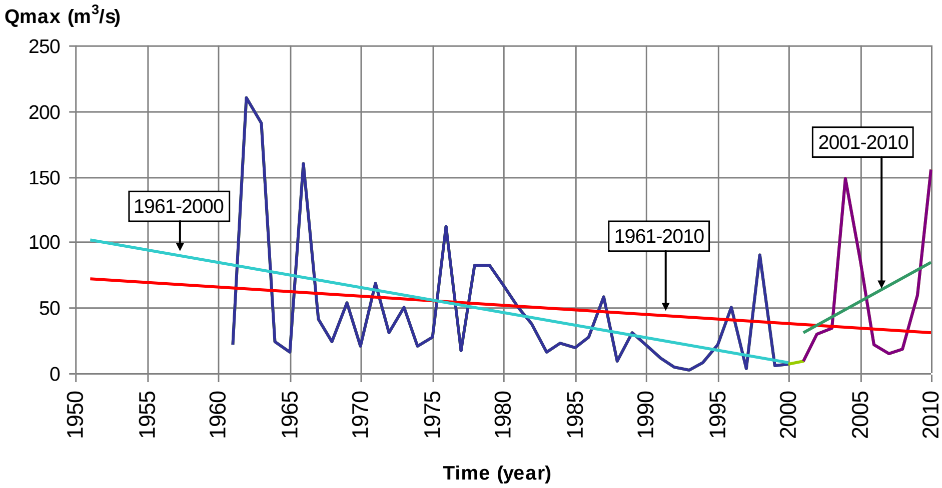

Figure 2-10 Annual maximum discharges trends for Strumica River at Suševo

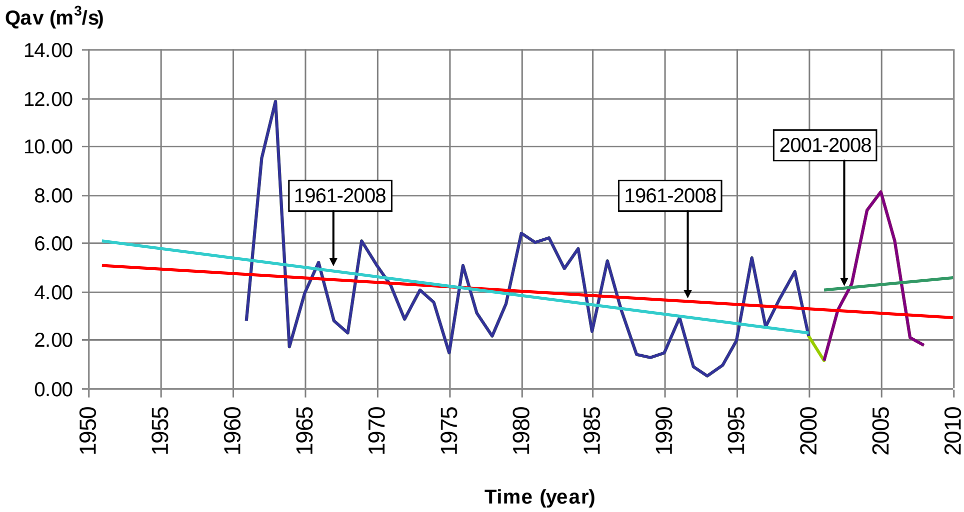

Figure 2-11 Annual average discharges trends for Strumica River at Novo Selo

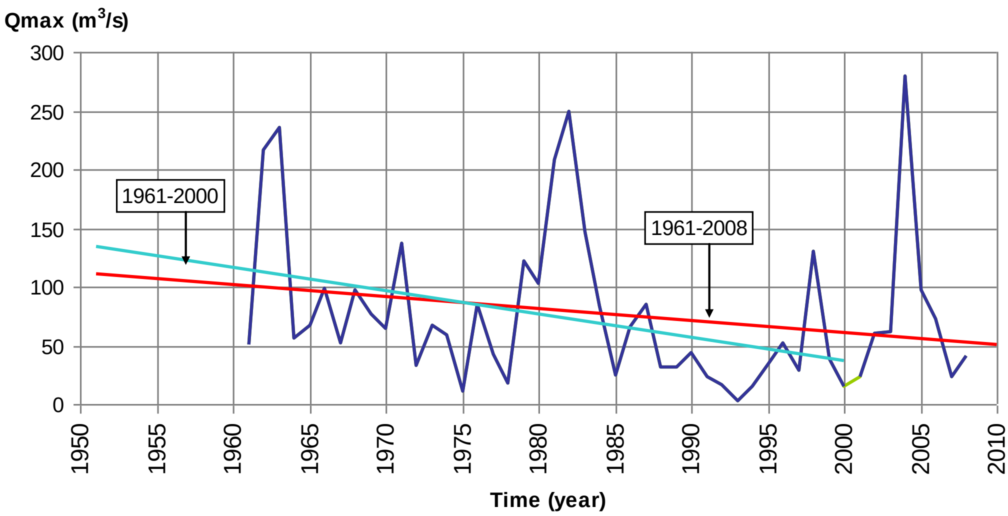

Figure 2-12 Annual maximum discharges trends for Strumica River at Novo Selo

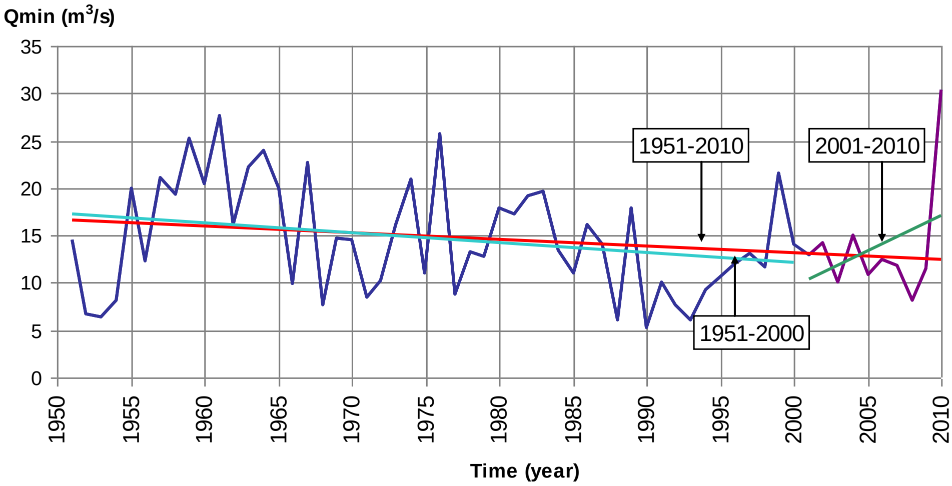

Figure 2-13 Annual minimum discharges trends for Vardar River at Skopje

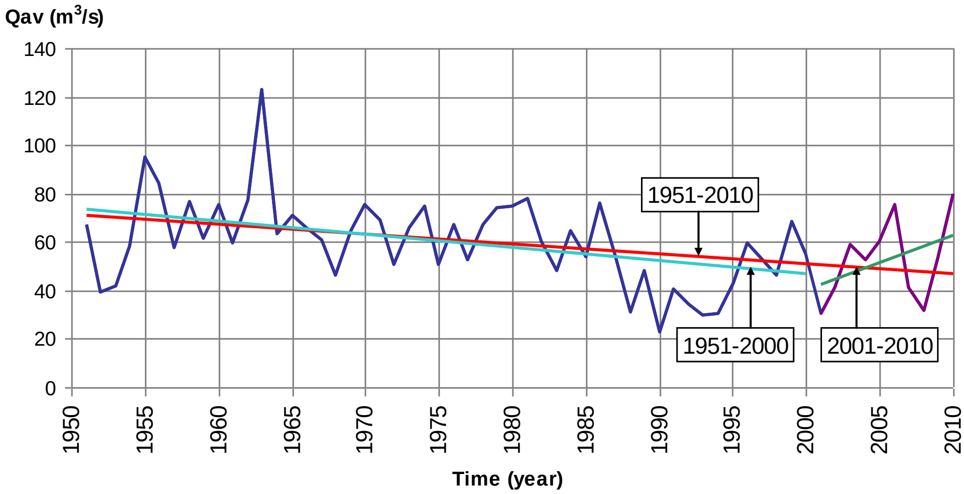

Figure 2-14 Annual average discharges trends for Vardar River at Skopje

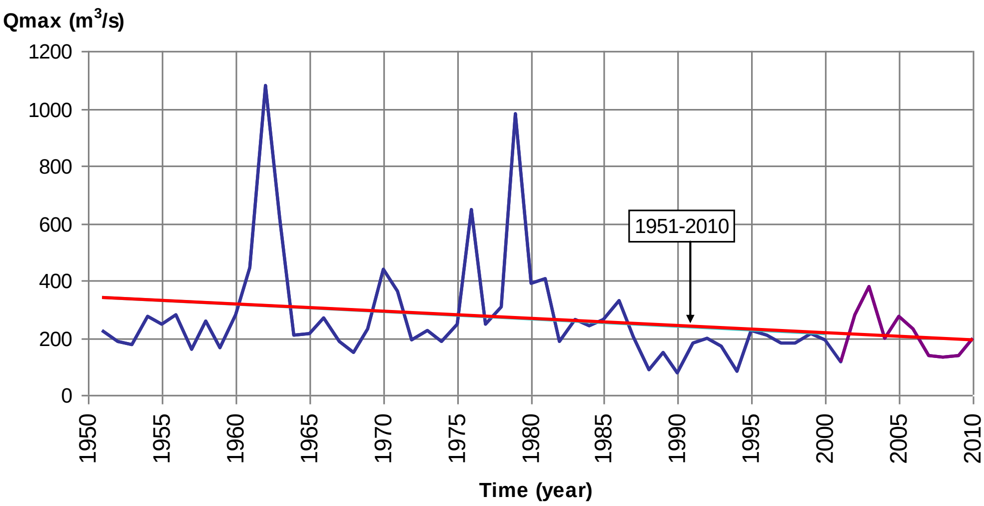

Figure 2-15 Annual maximum discharges trends for Vardar River at Skopje

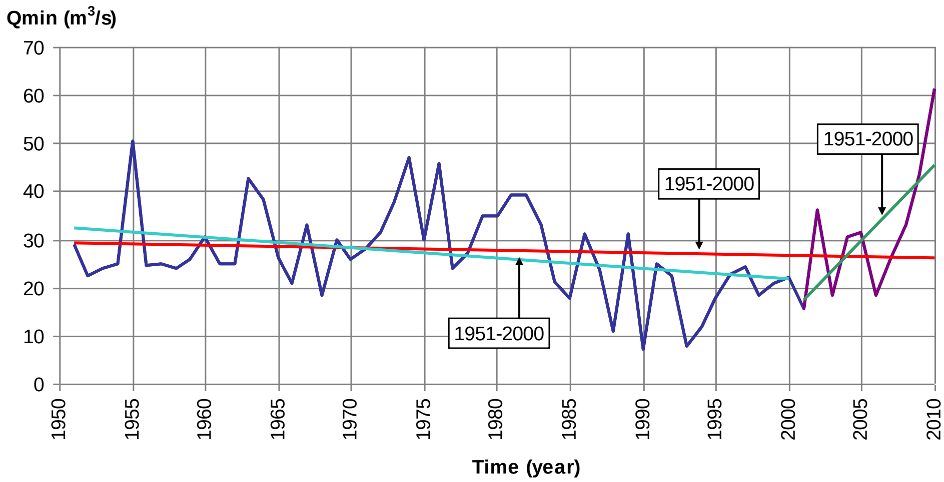

Figure 2-16 Annual minimum discharges trends for Vardar River at Gevgelija

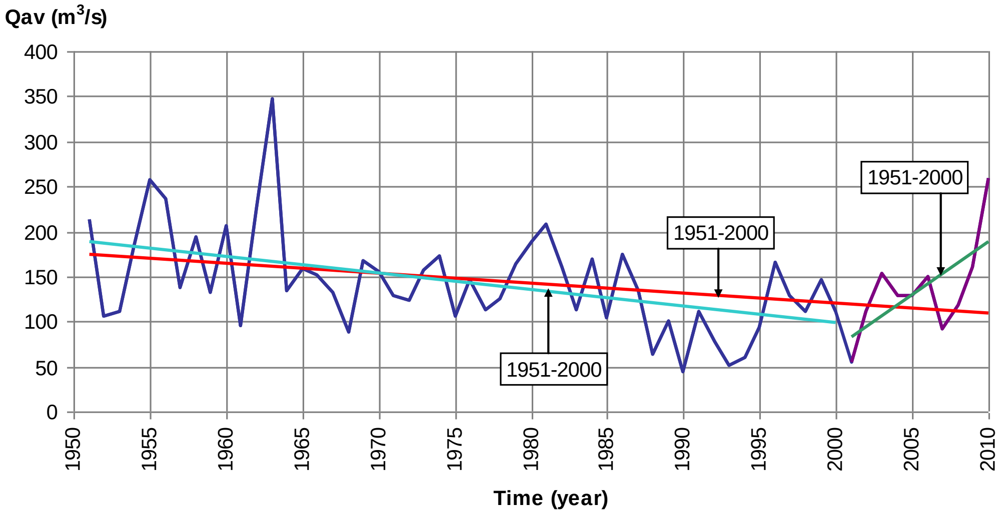

Figure 2-17 Annual average discharges trends for Vardar River at Gevgelija

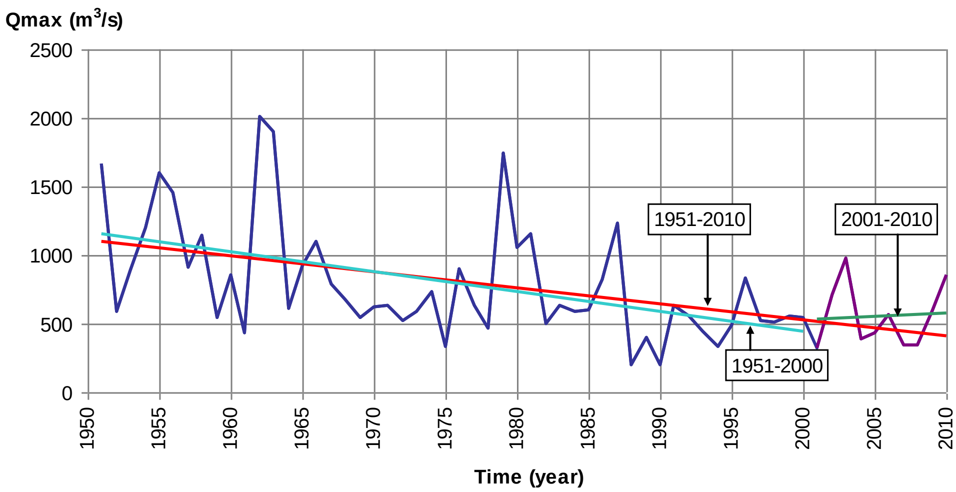

Figure 2-18 Annual maximum discharges trends for Vardar River at Gevgelija

Box 2-1

Statistical trend analysis is typically associated with regression analysis. Creating a trend line and calculating its coefficients allows for the quantitative analysis of the underlying data and the ability to both interpolate and extrapolate the data for the forecast purposes. Excel includes multiple functions for regression analysis such as linear, exponential, logarithmic, power or polynomial. Extrapolation is when the value of a variable is estimated at times which have not yet been observed. This estimate may be reasonably reliable for short times into the future, but for longer times, the estimate is likely to become less accurate, even dangerous, Figures 2-19 and 2-20.

Linear and nonlinear trend lines were obtained to the observed time series data for the period 1951-2010. Extrapolation by polynomial trend lines to future longer period to 2025 and 2050 is less reliable in comparing to the linear ones although the regression coefficients of polynomial regression in some cases are very high. In most cases, especially on precipitation and runoff time series data, linear trend lines as estimates of the observed and future averages are much more reliable than the nonlinear trend lines. By the nonlinear regression equations the future estimates show regional increases or decreases which are far from the projected climate changes for Republic of Macedonia based on direct Global Circulation Model (GCM) output.

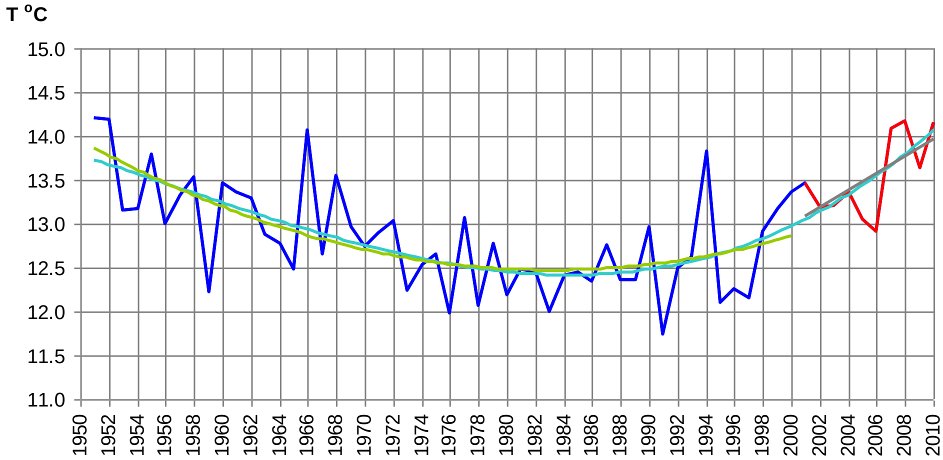

Figure 2-19 Nonlinear trends for air temperature at Strumica

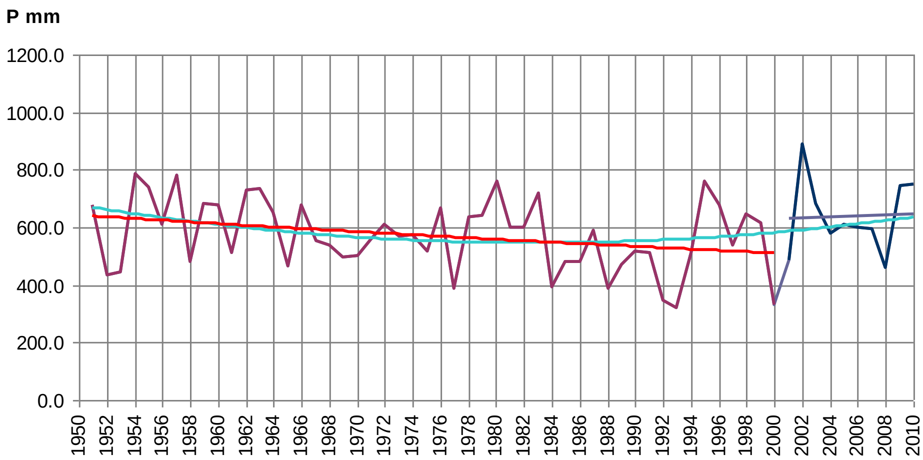

Figure 2-20 Nonlinear trends for precipitation at Strumica

3 Vulnerability Assessment

3.1 Strumica River Basin

Basic hydrographical characteristics

The Strumica river basin is 1.649 km^2 that is 6,4% of the territory of the Republic of Macedonia. The major part of the total watershed (75%) is in Republic of Macedonia, while the remaining is in Bulgaria and Greece. River Strumica takes its source from the Plackovica Mountain at an altitude of 1.540 m asl running south in a deep valley and known as the Stara Reka. It then enters the Radovish valley and runs through the eponymous Radovis. Afterwards the river runs southeast trough the Strumica valley passing through the town of Strumica and turning east to enter Bulgaria south of Zaltarevo. The main tributaries are Turija, Vodocnica, Radoviska and Podareshka. From both sides of the Strumica River there are a large number of tributaries mostly mountainous streams with permanent water flow. River outflow Macedonian border southeast of Novo Selo and inflow Struma River in Bulgaria at an altitude of 186 m asl. It is the Struma's largest tributary. Total length of Strumica River is 114 km out of which 81 km in Republic of Macedonia and 33 km in Bulgaria.

The area of Strumica river basin although is hydrographically well developed is the poorest in water resources and the lack of water affects all segments of human activities: water supply especially in rural areas, industry and irrigation. This also aggravates the water quality and flow rates are often less the biological minimum in the periods when the streams dry up. The annual average of total available water is approximately 132 million m^3 with specific runoff of 3,1 l/s·km^2.

The annual average discharges of Strumica River for the period 1961-2010 at the gauging station Suševo is 1,61 m^3/s, and for the last decade 2001-2010 it is 2 m^3/s. The maximum floods have been recorded in 1962 (210 m^3/s) and in 2010 (155 m^3/s). Data on recent floods in February 2013 are not available yet by the authorized Hydrometeorological agency (HMA). The average discharges at the gauging station Novo Selo for the period 1961-2008 is 3,86 m^3/s and for the last decade 2001-2008 it is 4 m^3/s. The maximum flood 280 m^3/s is recorded in 2004.

This river basin is assessed as poorest in water resources. To meet the water demands for drinking, industry and irrigation, dams with reservoirs are constructed. The largest reservoir is Turija constructed in 1970 and situated 10 km north from Strumica on Ogražden Mountain. The lake water surface is 1,8 km^2 and the reservoir storage capacity is 50 million m^3. Main purpose of the reservoir is irrigation, water supply and hydropower.

Second size reservoir is Vodoča constructed in 1965 and situated approximately 6 km south from Strumica. It covers a water surface area of 1,94 km^2 with storage capacity of 26 million m^3. The water is used for irrigation and water supply.

Smaller reservoirs are: Novoselka near the village of Novo Selo with storage capacity of 500.000 m^3 and with primary water use for irrigation and water supply, Čaušica with storage capacity of 100.000 m^3 which water is used only for irrigation, Ilovica with storage capacity of 500.000 m3 and water use in irrigation and water supply for municipality of Bosilovo, Konče 1 and Konče 2 with water use in irrigation and water supply of the village Konče.

The reservoir near the village of Mokrievo with storage of 26.000 m^3 is used for water supply of nearby villages. The main problem in the watershed of Strumica River is a water shortage. There is a water transfer from the reservoir Mantovo on Lakavica river basin to Strumica river basin. There is no data how much water is transferred on annual basis.

On the north of Belasitza Mountain there are a number of springs and about 10 villages have constructed their own water supply systems. Most of the springs are registered in subwatershed of Strumica and Radoviš, Table 3-1. The waterfalls Mokrinski, Smolarski and Kolesinski are very important water resources for the tourism development in the region.

Table 3-1 Springs' yield in Strumica river basin in (MCM/year)

Subbasin/ Valley	Number	Average	Total	Free flowing	Tapped/ Captured
Radoviš	80	0,008	0,61	0,47	0,14
Strumica	145	0,039	5,59	4,16	1,43

Source: JICA, (1999)

Municipalities and population

General topographic map on Strumica river basin with municipality borders, cities, main rivers and reservoirs is presented in Figure 3-1. In 2004 the Republic of Macedonia was reorganized into 84 municipalities, Figure 3-2. Within the Strumica river basin there are six municipalities which area and population is presented in Table 3-2. According to the State Statistical Office of the Republic of Macedonia the Natural Growth rate for south-eastern part of the country is 0,06% based on data from census in 2004.

Table 3-2 Municipalities in Strumica river basin

No	Municipality	Area (km^2)	Population (2004)
41	Bosilovo	143	14.260
36	Konče	233	3.536
37	Radoviš	502	28.244
40	Vasilevo	231	12.122
43	Strumica	311	54.676
42	Novo Selo	257	11.567

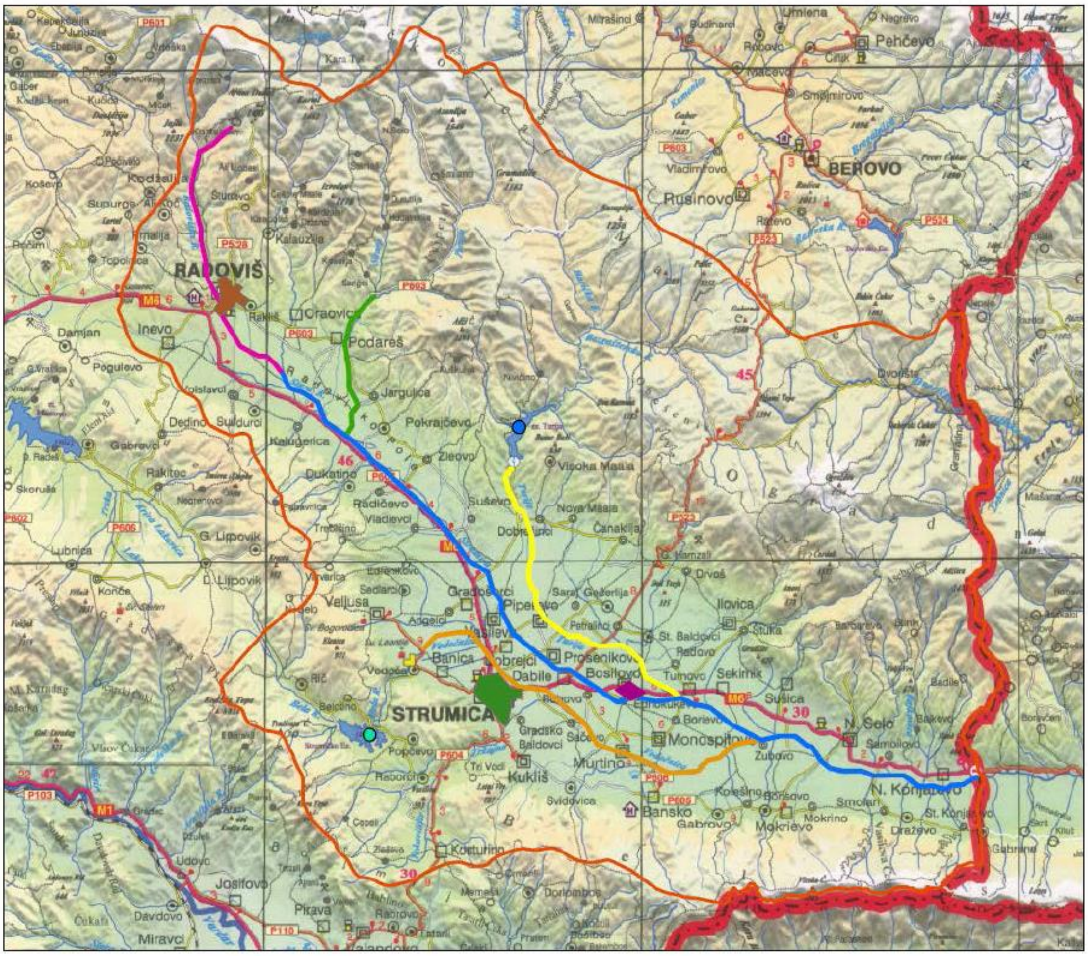

Figure 3-1 Topographic map of Strumica river basin (Source: ARCADIS, 2010)

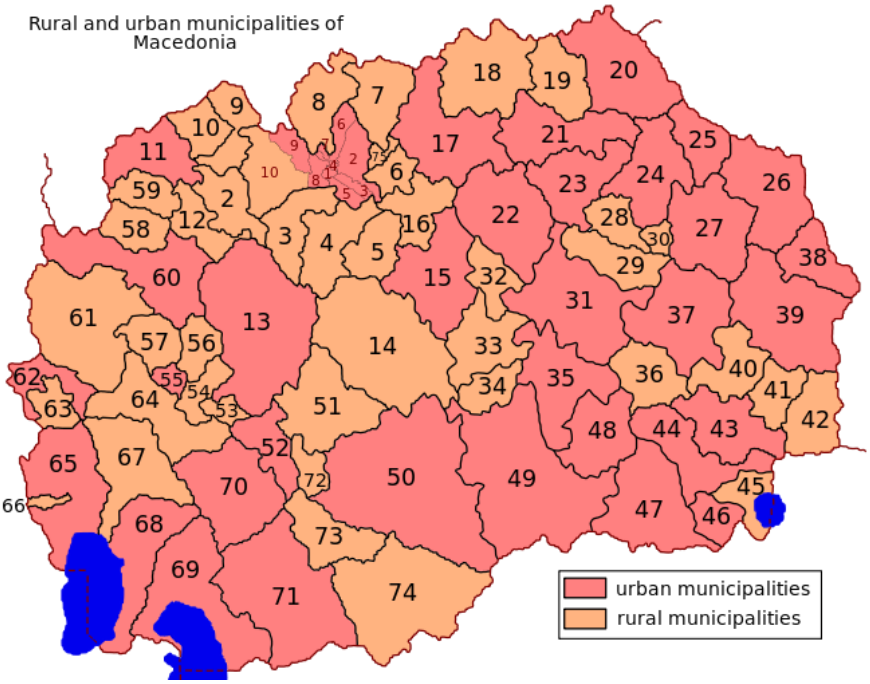

Figure 3-2 Map of rural and urban municipalities in Macedonia

Groundwater

Strumica watershed is characterized with aquifers mainly on northwest to southeast direction with different permeability. There is a compact formation of Quaternary-Pliocene sediments with free water level along rivers Stara Reka, Strumica, Turija, Štuka and others. In the of Quaternary-Pliocene sediments in the central part of Strumica valley (villages Sofilari, Murtino, Dabile, Bosilovo) compact type with water level under pressure is present. Karst-fissure formation is located at the fringe of Radoviška-Strumicka depression. High water permeability is Q=10-50 l/s (T=300-1.500 m/day) and low water permeability is Q=0,5-2 l/s (T=15-20 m/day). Groundwater is used for water supply, irrigation and industry. Geothermal water is also present in Bansko-Strumica.

The report on integrated management of transboundary aquifers in sotheastearn Europe (INWEB, 2007) describes most aquifers as karst aquifers where water moves very quickly trogh large conduits and hence receives little infiltration. This report mentions two transboundary aquifers that lie nearby the Strumica river basin: the Dojran Lake Aquifer and the Sandanski-Petrich Aquifer. Both aquifers are alluvial which exact location and characteristics are not given. The water flow in these aquifers is very slow and when the alluvial aquifers become contaminated, remediation is very difficult.

Geological eras in Strumica river basin are Cenozoic in central part along the main stream, Paleozoic and Precambrian in mountainous parts on both sides of the main stream and small part on south belongs to Mesozoic, Figure 3-3.

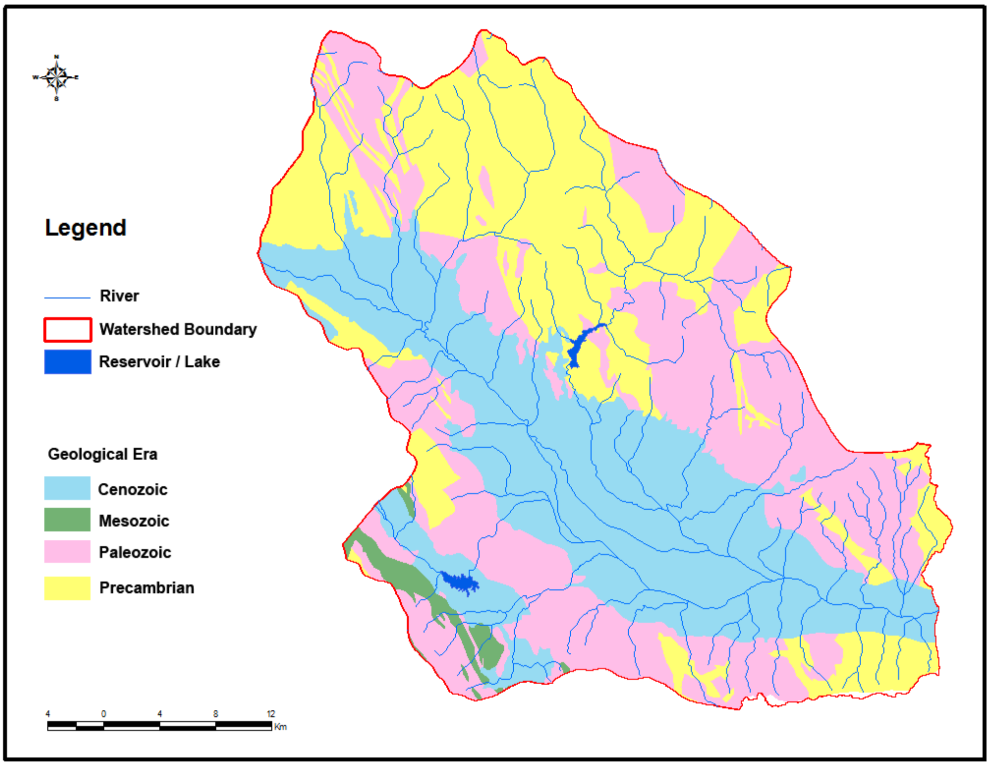

Figure 3-3 Geological eras of Strumica river basin

Groundwater monitoring in Strumica river basin was performed within 23 piesometric wells established in 1953 (villages Sofilari, Murtino, Dabile, Bosilovo, Monospitovo, Novo Selo, Radovish and others). Unfortunately, since 2000 only two of them are operating, Bosilovo and Monospitovo. Organozed groundwater data collection and management is missing, as well as the user cadastre. The estimated static reserves mainly in the aquifers of consolidated type with water level under pressure (artesian) are 850 million m^3.

Monitoring

Monitoring network in Strumica river basin related to water is structures by meteorological stations, hydrological stations and rain gauges. Main meteorological station is established in Strumica (223 m asl), climatological station in Radoviš (380 m asl). Hydrological stations are placed at Smiljanci in the upper part, at Sushevo in central part and in Novo Selo in lower part of the watershed, Figure 3-4. Groundwater is also monitor at villages Sofilari, Murtino, Dabile, Bosilovo, Monospitovo, Novo Selo, Radoviš and others, but unfortunately since 2000 only two of them, Bosilovo and Monospitovo, are in operation.

Rain gauges are established in Podaresh (320 m asl), Veljusa (400 m asl), Gradoshorci (240 m asl), Dobrashinci (280 m asl), Kalugjerica (390 m asl), Kozbunar (1.130 m asl), Kosturino (435 m asl), Monospitovo (207 m asl), Rich (580 m asl), Smolari (380 m asl), Hamzali (290 m asl) and Novo Selo (290 m asl). Short-lasting rainfalls with destructive flood effects are becoming more frequent in Strumica watershed. In Figure 3-5 is presented map of the annual rainfall distribution in Strumica watershed based on which the average annual precipitation 688 mm is obtained. Only the mountainous regions on northeast and south of the watershed have greater precipitation sums over 1.000 mm and the central part in Strumica valley is rather poor with precipitation less than 500 mm annually.

The air temperature distribution within the watershed is presented in Figure 3-6. The average annual air temperature of the entire watershed is 8^{o}C that is less than the long-term average annual temperature 12,9^{o}C obtained for Strumica meteorological station.

Problems on monitoring issue are related mainly to lack of data and/or not availability of data. Some of rain gauges and water gauges do not operate any more due to financial problems, and some do not have systematic measurements and the existing time series data are with significant gaps. For this Third National Communication on CC monthly data on air temperature and precipitation for the period 1951-2010 have be collected for Strumica meteorological station. Runoff data for the period 1961-2010 have been collected for hydrological stations in Susevo and Novo Selo.

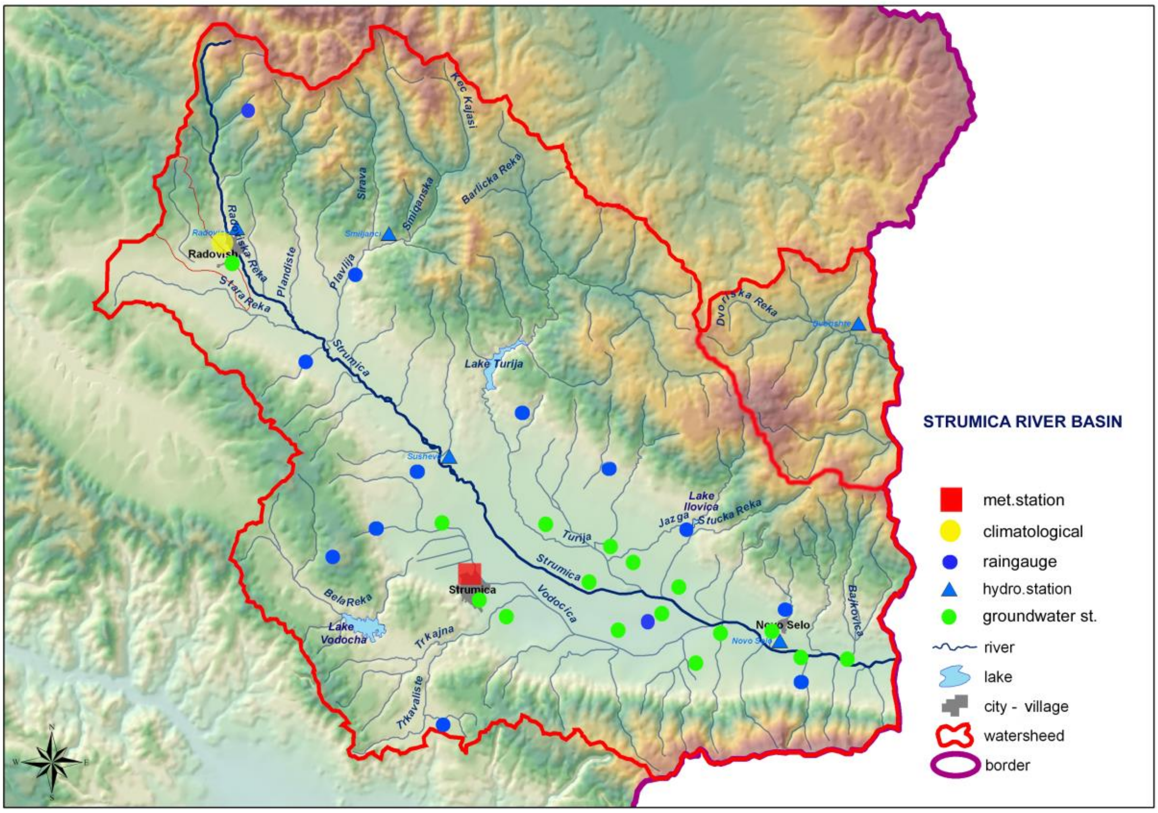

Figure 3-4 Strumica river basin monitoring network

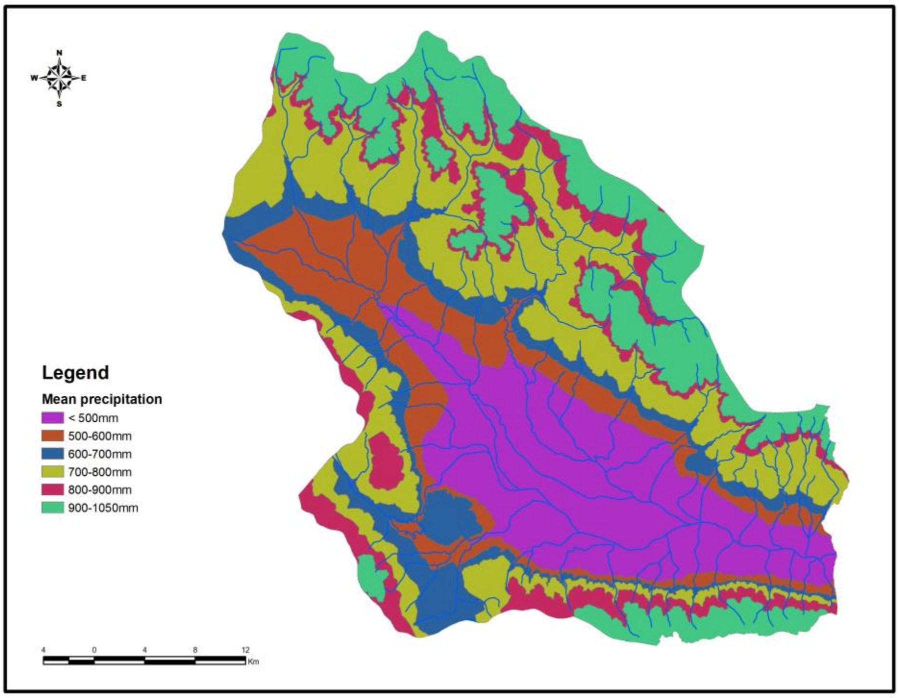

Figure 3-5 Mean precipitation distribution in Strumica river basin

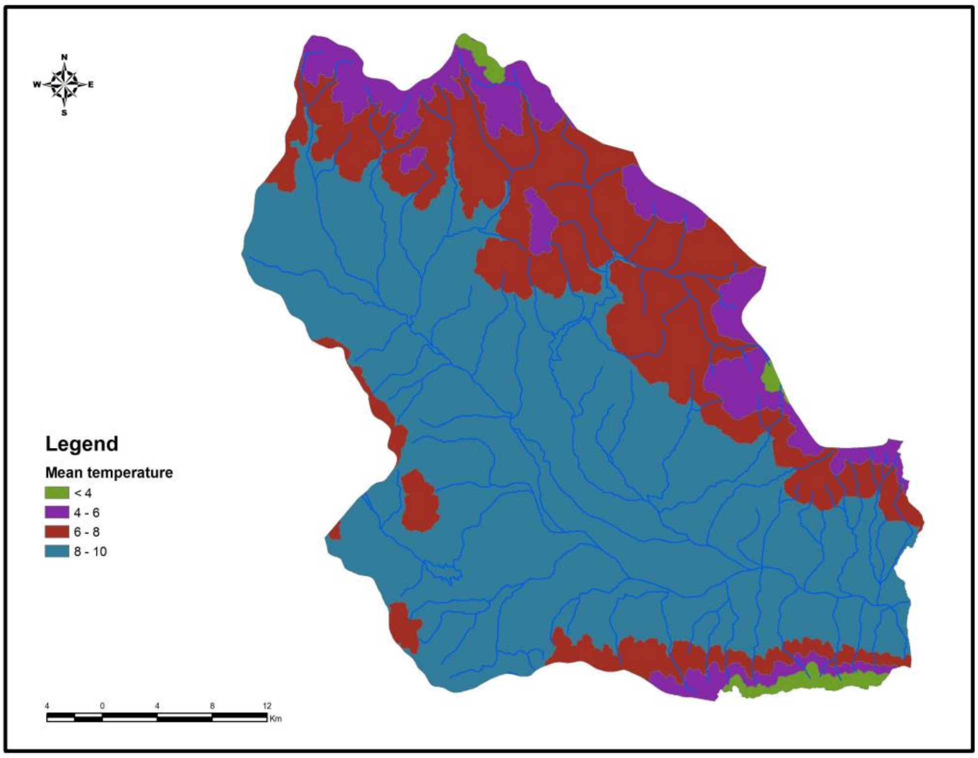

Figure 3-6 Mean air temperature distribution in Strumica river basin

Land use

The main land use type in Strumica River watershed is agriculture. Large parts of this arable land are irrigated. Land covered with artificial surfaces, cities and industry, participate only a very small part. The slopes of mountains Ograzden, Belasica, Elenica, Pljackovica and Plavus are characterized by rich forests. The land use and land cover data are obtained by CORINE Land Cover (CLC) EU database/map which provides comparable digital maps on land cover, biotopes, soil, and acid rain for over 22 countries in Europe. The map was created in GIS ARC/INFO format based on the interpretation of satellite images with land cover types in 44 standard classes. Land cover/use map for Strumica watershed is presented in Figure 3-7 and types of land cover/use are shown in Table 3-3. The broad-leaved forests cover about 60.000 ha, mixed forests cover about 2.300 ha, and pastures participate with 128.000 ha, while the non-irrigated arable land covers about 197.000 ha. By their structure the forests are oak, beech, chestnut, walnut, black and white pine trees and others. The quality forests are between 1.000 and 1.500 m above sea level, while those up to 500 m are mainly degraded or brushes. By water bodies is covered only 1.200 ha.

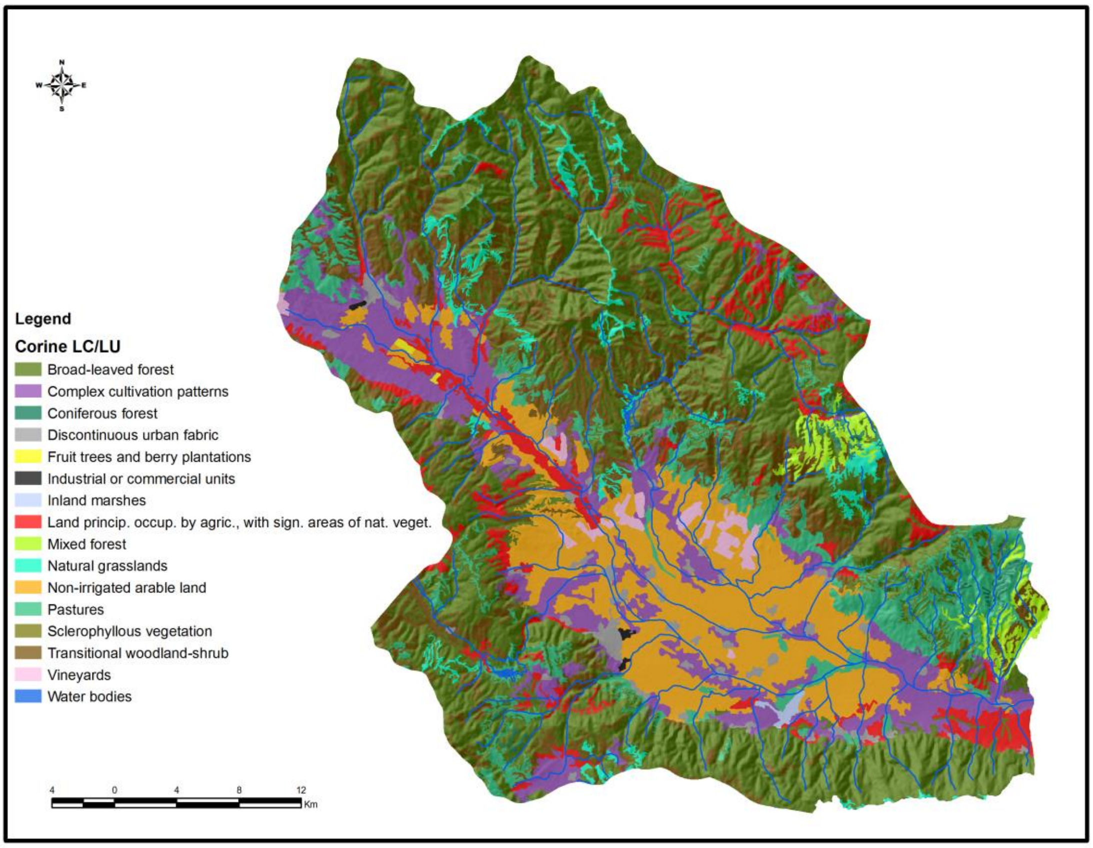

Figure 3-7 CORINE Land Cover map of Strumica river basin

Table 3-3 Corine Land Cover data

Type of land cover/use	Area (km^2)
Broad-leaved forest	599,71
Complex cultivation patterns	53,77
Coniferous forest	1,25
Discontinuous urban fabric	24,63
Fruit trees and berry plantations	0,85
Industrial or commercial units	1,13
Inland marshes	2,27
Land occupied by agriculture, with significant areas of natural vegetation	89,08
Mixed forest	22,75
Natural grasslands	35,28
Non-irrigated arable land	197,29
Pastures	128,31
Sclerophyllous vegetation	0,04
Transitional woodland-shrub	199,61
Vineyards	14,83
Water bodies	1,21
Total:	1372,01

Erosion

In the Republic of Macedonia torrential flows are very often. According to the Erosion map of RM territory is divided in 5 classes of erosion intensity – from class I representing extreme erosion to class V representing very low erosion. The erosion intensity in Strumica watershed is estimated as low (class IV) with erosion coefficient 0,2-0,4. The areas of particular category of erosion intensity are 1.139 km^2 in category IV-V and 381 km^2 in category I-III. Constructed small reservoirs in the watershed have significant sedimentation. The annual sediment yield in Vodoca and Turija reservoirs is estimated to be 37.327 m^3 and 91.578 m^3 with annual erosion rate 0,49 mm and 0,43 mm respectively, JICA (1999).

Water quality

Surface water quality monitoring is performed by Hydro-Meteorological Administration (HMA) in Skopje (rivers, reservoirs and groundwater) and Hydro-Biological Institute (HBI) in Ohrid (natural lakes). Based on the Law on waters (Official Gazette of RM, No. 4/98), the Government of the Republic of Macedonia brought a "Regulation for Classification of Water" (Official Gazette of the Republic of Macedonia No. 18/99). Surface waters, rivers, natural and man-made lakes and groundwater are classified within five classes. This Regulation doesn't apply to mineral and thermal waters. Short description of the quality classification is as follows:

Class I: Very clean, oligotrophic water, which in its natural state, with possible disinfecting, can be used for drinking, production and processing of food product and is suitable for mating and cultivation of noble types of fish (salmonides). The buffering capacity of the water is very good.

Class II: Very clean, mesotrophic water, which in its natural state can be used for bathing and recreation, water sports, production of other types of fish (cyprinid species), or which can be used , after usual methods of purification (coagulation, filtration, disinfections etc.), for drinking, production and processing of food products. The buffering capacity and oxygen saturation throughout the whole year is good. The loadings may lead to slightly increased primary productivity.

Class III: Moderately eutrophic water, which in its natural state can be used for irrigation, and after usual purification methods (conditioning) for industries, which do not need drinking water quality. Buffering capacity of the water is low, but it maintains the (pH value) acidity at a level still suitable for most fish. In hypolimnion occasionally oxygen deficit occurs. The load of harmful substances is evident, as well as microbiological pollution.

Class IV: Strongly polluted (euthrophic) water, which in its natural state can be used for other purposes only after certain processing. The buffering capacity is exceeded, which leads to higher levels of acidity, and which affects the development of the offspring. In the epilimnion there is oxygen saturation, and in hypolimnion there is oxygen deficit. Algal blooms are common. Increased decomposition of organic matter at the same time with the stratification of the water can cause anaerobic conditions and fish death. Harmful substances emitted or released from the sediment (deposits), can affect the quality of aquatic life. The concentration of harmful substances can vary from level of chronic to acute toxicity for the aquatic life.

Class V: Very polluted (hypertrophy) water, which in its natural state could not be used for any purposes. The water has no buffer capacity and its acidity (pH value) is harmful for most of the fish species. Large problems occur with the oxygen regime, namely, saturation with oxygen in epilimnion is present, while, the absence of oxygen in hypolimnion leads to anaerobic conditions. Decomposers dominate over producers. Fish and benthic species are not present constantly. Concentration of harmful substances exceeds acute toxicity levels for aquatic life.

The overall water quality in Strumica watershed is of class III to IV, with quality improvements during springs due to higher levels of flowing water. In Strumica river basin there is only one sampling point in Novo Selo (RIMSYS, SP 64807) near the border with Bulgaria that is the outflow section of this river. Legally required water quality as well as estimated water quality for the period (1996-2025) is presented in JICA (1999). It is noted that if the proposed Water Quality Conservation Plan is implemented, river water quality will be improved to meet the legally required classes.

Water use

The main land use type in Strumica River watershed is agriculture. Large parts of this arable land are irrigated. According to the Expert Report on Water Resources Management (EWRM) data the designed irrigation area is estimated to 16.047 ha out of which 12.437 ha are irrigated by 7 constructed systems. According to this source the incomplete irrigation area is 3.610 ha. According to another source (Statistical Yearbook, 1997) the designed irrigation area is 21.698 ha, the irrigated area is 21.548 ha that show incomplete area of only 150 ha.

Data on water demands in different water economy sectors may be found in NEAP 1, NEAP 2, EWRM and JICA. There are differences in calculated irrigation water demand between those reference studies due to the estimation of total service area. Total water demands in Strumica river basin for irrigation, population, industry and minimum accepted flows for current condition and projected period 2020 are presented in Table 3-4. Total drinking water demands are defined upon the population number. The norms for cities were taken 0,300-0,400 m^3/capita/day, while the rural water supply norm was 0,25 m^3/capita/day. Waste water quantities are estimated to be 6.717.000 m^3/year (EWRM) and 6.937.135 m^3/year (NEAP 2).

Table 3-4 Total water demands in Strumica river basin in (m^3/year)

Population and tourists	Industry	Irrigation	Minimum accepted flows	Total water demands
Current water demands				
11.510.854	32.897.600	117.941.000	13.000.000	175.349.454
Projected water demands 2020				
18.233.400	34.441.700	169.343.000	13.000.000	235.018.100

Source: ERWRM

In Green Growth Project (GGP) developed by World Bank the water demands have been re-estimated. The Municipal water demand growth is taken equal to population natural growth rate. The projected water demands in 2025 are estimated to be 14,8 million m^3/year for population and 35,49 million m^3/year for industry. These projections for 2050 are 15,0 million m^3/year for population and 37,1 million m^3/year for industry. It can be concluded that the previous water demands estimation (NEAP, ERWRM) are overestimated.

The data from the Ministry of Agriculture, Forestry and Water Economy (MAFWE) related to irrigation show decreasing trend of irrigated area starting from 1987. On country level the irrigated area decreased from 78.778 ha in 1987 to only 15.203 ha in 2002 that is decrease of about 80%. Irrigated area is stabilized to around 22.000 ha, Figure 3-8. In Strumica watershed the irrigated area is changeable and depends both on irrigation system technology and on farmers' water demands, Table 3-5. It is shown that out of total planned area of about 12.000 ha in average only about 1.500 ha are irrigated.

Table 3-5 Irrigated area in Strumica watershed in (ha)

System	Total area	Irrigated area				
		2008	2009	2010	2011	2012
Turija	8.600	596	554	826	1227	1162
Vodoča	3.100	265	246	367	545	516
Ilovica	90	13	12	18	26	25
Novoselka	164	6	5	9	12	11
Total:	11.954	880	817	1.220	1.810	1.714

Source: MAFWE

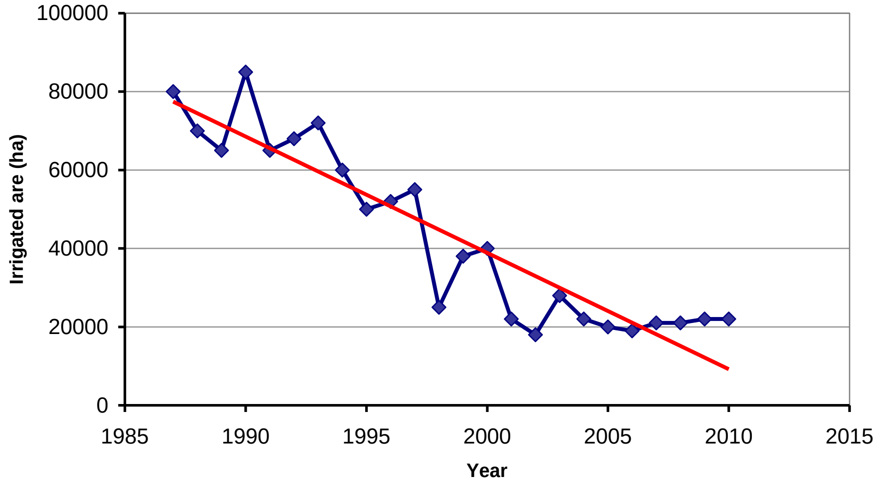

Figure 3-8 Irrigated area for the priod 1987-2010 on country level (Source: MAFWE)

The irrigation technologies in Strumica watershed by municipalities is shown in Table 3-6. It is obvious that surface irrigation participate with over 50% comparing to the sprinkler or drip system.

Table 3-6 Irrigation technologies within the municipalities in (%)

Municipality	Sprinkler	Surface	Drip
Konče	15	40	45
Vasilevo	25	55	20
Bosilovo	24	56	20
Novo Selo	19	50	30
Strumica	29	45	26
Radoviš	18	52	30

3.2 Water budget

The watershed is defined by its surface water catchment area and can be viewed as being composed of two separate but inter-related components; a surface drainage area defined by topography and a subsurface region defined by soil and bedrock features. In spatial terms, the areas and boundaries of each component may not be coincident implying that regional groundwater inputs and outputs to the watershed area may occur. Based upon these factors, a general expression for the watershed water balance on a region basis can be expressed as a change in storage and may be written as input-output=change of storage, or:

$$S_t+(P+Q_{in}+G_{in})-(E+ET+Q_{out}+Q_{ws}+Q_{ir}+G_{out})=S_{t+\Delta t}$$

where the components are:

S_t - initial water storage in the watershed at the beginning of the analyzed period
P - input water in the watershed due to precipitation
Q_{in} - input water in the watershed from another watershed
G_{in} - groundwater inflow
E - output water due to evaporation from free surface water
ET - output water due to evapotranspiration
Q_{out} - outflow water to another watershed
Q_{ws} - used water for population and industry water supply
Q_{ir} - used water for irrigation
G_{out} - groundwater outflow
$S_{t+\Delta t}$ - water storage in the watershed at the end of the analyzed period

In many instances the long term difference between groundwater inputs and outputs are small compared to other terms, and in such conditions the water balance can be simplified by assuming the difference between groundwater input and output is essentially zero (G_{in}- G_{out}=0).

The water balance model that is developed within the Third National Communication on Climate Change presents current condition (2000/2010) year and projected condition (labeled 2025). Average monthly data for the period 1951-2010 were used as well as the projected changes in average air temperature and precipitation based on direct GCM output interpolated to geographic location of Macedonia.

Water balance components for current condition

The precipitation distribution in watershed is obtained by using the recorded rainfall data at Strumica meteo station for the period 1951-2010, Figure 3-9. The annual precipitation sum for Strumica is 583 mm and for the watershed it increases to 688 mm. The average monthly air temperature for the watershed is obtained similarly by the recorded temperatures at Strumica for the same period, Figure 3-10. It is noted that the average monthly temperature for Strumica is 12,7^{o}C and for the watershed it is 8,8^{o}C.

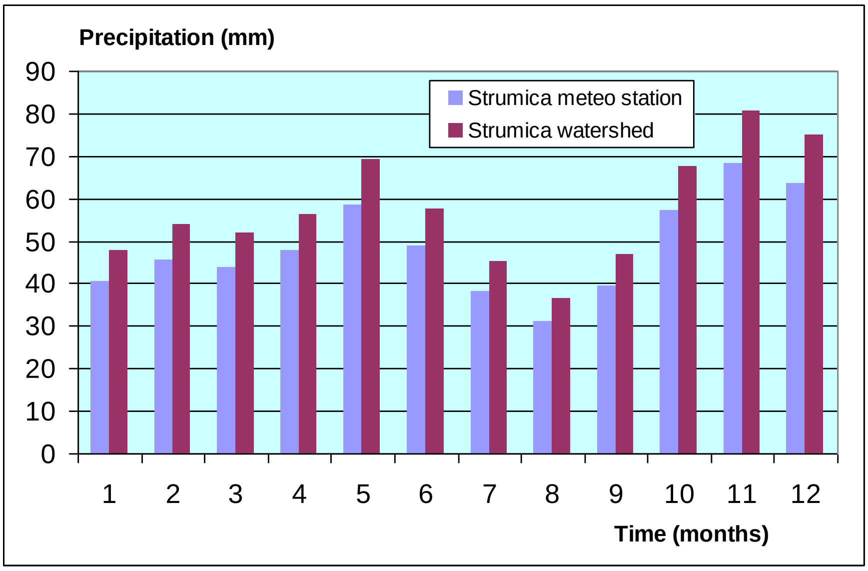

Figure 3-9 Monthly precipitations

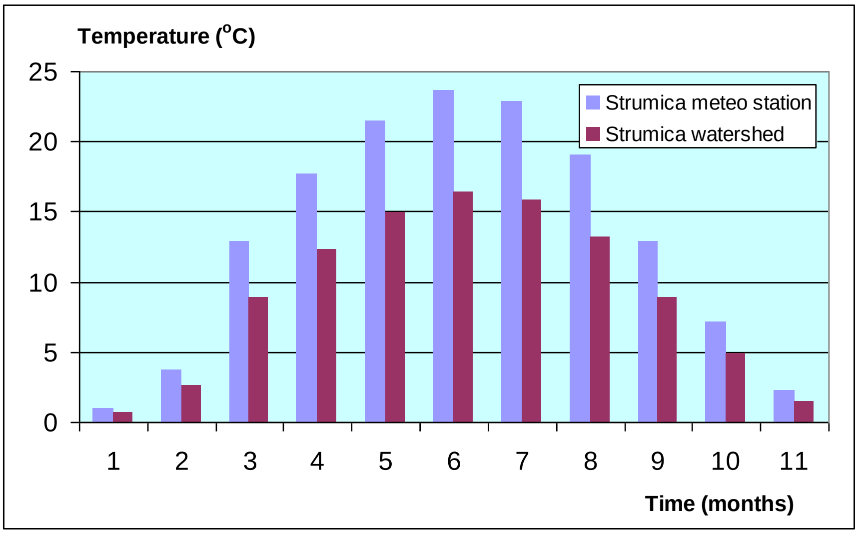

Figure 3-10 Monthly air temperatures

The evaporation from free surface water is computed by Penman based on air temperature data and CORINE Layers data. The computed average annual evaporation is 897,9 mm with minimum in January (12,2 mm) and maximum in July (158,9 mm). Data on evapotranspiration on watershed scale have been computed by data for Radovis and Strumica in "Characteristic of the Climatic-Vegetative-Soil Zones in the Republic of Macedonia" (Filipovski, Rizovski, Ristevski, 1996). The annual evapotranspiration is 677 mm while the minimum (6,9 mm) is in January and the maximum (123,2 mm) occurs in July.

The outflow from the watershed is obtained with recorded data on runoff at Novo Selo that is close to the border with Bulgaria for the period 1961-2008 with average long-term monthly distribution shown in Table 3-7. In Table 3-8 are presented monthly water demands for population and industry water supply and for irrigation.

The initial water storage in the watershed is taken 11,5 million m^3 (MCM) as annual water reserve for drinking water according to the Local Environmental Action Plan (LEAP, 2006) for Strumica region.

Table 3-7 Monthly runoffs of Strumica River at Novo Selo in (m^3/s)

1	2	3	4	5	6	7	8	9	10	11	12	Annual
4,9	7,6	7,9	6,2	4,5	3,3	1,1	0,6	0,7	1,5	3,2	4,9	3,9

Table 3-8 Monthly water demands in (million m^3)

1	2	3	4	5	6	7	8	9	10	11	12	Annual
Population and industry												
2,2	2,2	2,7	3,6	4,4	5,3	5,6	5,6	4,4	3,6	2,7	2,2	44,4
Irrigation												
0,0	0,0	0,0	17,7	17,7	23,6	23,6	17,7	17,7	0,0	0,0	0,0	117,9

Projected water balance components

The annual precipitation sum in 2025 is expected to decrease for 3% and the annual air temperature will increase for 1°C according to the Climate Change Scenarios by GCM. The monthly distribution of precipitation and temperature on watershed level is obtained by data recorded at Strumica meteorological station for the period 1951-2010, Table 3-9. The projected monthly temperatures, evaporation from free surface water and evapotranspiration on watershed level are presented in Table 3-10. The projected evaporation from free surface water is 934,2 mm that is increase of 37,2 mm (4,1%) in reference to the average current evaporation (897 mm). Evapotranspiration projection in the Strumica watershed is 706,8 mm that is increase of 29,8 mm (4,4%) in reference to the average current evapotranspiration (677 mm).

Table 3-9 Monthly precipitation in (mm)

1	2	3	4	5	6	7	8	9	10	11	12	Annual
Strumica meteo station (1951-2010)												
40,5	45,6	43.9	47,7	58,5	48,8	38,3	31,0	39,6	57,2	68,3	63,6	583,1
Strumica watershed (2025)												
46,4	52,2	50,2	54,6	67,0	55,8	43,9	35,5	45,3	65,5	78,2	72,8	667,4

Table 3-10 Monthly temperature, evaporation and evapotranspiration

1	2	3	4	5	6	7	8	9	10	11	12	Annual
Strumica meteo station - temperature in (°C) (1951-2010)												
1,0	3,7	7,9	12,9	17,7	21,5	23,6	22,9	19,0	12,9	7,1	2,2	12,7
Strumica watershed - temperature in (°C) (2025)												
0,7	2,9	6,1	10,0	13,7	16,6	18,2	17,6	14,7	10,0	5,5	1,7	9,8
Strumica watershed - evaporation in (mm) (2025)												
12,2	27,1	57,5	94,6	128,4	143,5	166,6	139,4	88,6	48,4	18,8	9,2	934,2
Strumica watershed - evapotranspiration in (mm) (2025)												
7,0	19,3	44,0	74,5	100,3	111,0	129,6	106,2	65,4	33,8	11,3	4,4	706,8

The projected outflow up to 2025 from the watershed is obtained by the runoff coefficient based on recorded runoff data at Novo Selo for the period 1961-2008. The obtained runoff coefficient in the watershed varies from 0,0153 to 0,152. The average annual runoff at Novo Selo will decrease from 3,9 m^3/s to 3,7 m^3/s or 5,1% based on GCM output.

Water balance estimates

The results out of WB model for the current condition by the use hydrological and meteorological data for the period 1951-2010 are presented in Table 3-11, and for the projected period up to 2025 in Table 3-12. Compared results of both cases/scenarios are graphically presented in Figure 3-11. Analysing the obtained results the following summary remarks are concluded:

1. The water balance estimates are best interpreted as illustrative of the potential character and approximate magnitudes of impacts that may result from specific scenarios of climate change. They serve as indicators of sensitivities and possible vulnerabilities. General Circulation Model (GCM) results are used in this analysis and they are not predictions that the climate will change by specific magnitudes in particular countries or regions.
2. Strumica watershed is vulnerable region in both cases/scenarios, current condition and projected condition up to 2025. During the year vulnerability is dependent of the season. Out of the irrigation season, January to May, there is no water shortage in the watershed.
3. Current condition estimates show maximum water shortage of about 360 million m^3 that is obtained in September. Water shortages are obtained for irrigation season (June to October). The average annual water shortage amounts 257,47 million m^3.
4. By the use of projected water demands up to 2025, the maximum water shortage of 478 million m^3 is obtained in September that is increase of about 25% in reference to the current condition. The annual water shortage is 388 million m^3 or increase of about 34% in reference to the current condition.
5. More reliable data in water balance modeling could be obtained if data on surface water and groundwater consumption in the watershed, especially in irrigation sector, are collected. Without these data the obtained and estimated water balance components may be taken as approximate and even overestimated considering the problems in irrigation and management practices and recent data on significant decrease of irrigated area on country level to only about 22.000 ha and in Strumica watershed to about 2.000 ha. This situation with missing and/or unavailable data should be resolved by better management with the existing irrigation systems, better monitoring, and by mapping/inventory of the individual irrigation wells.

Table 3-11 Water budget of Strumica watershed – current condition

Month/Days	P (MCM)	E (MCM)	ET (MCM)	Q_{ws} (MCM)	Q_{ir} (MCM)	Q_{out} (MCM)	Storage (MCM)
Initial water storage							11,50
1/31	83,73	0,01	10,27	2,22	0,00	13,11	69,62
2/28	94,29	0,03	28,22	2,22	0,00	18,46	115,01
3/31	90,68	0,07	63,71	2,66	0,00	21,05	118,27
4/30	98,67	0,11	106,90	3,55	17,69	15,99	72,80
5/31	121,00	0,15	142,87	4,44	17,69	12,08	16,72
6/30	100,79	0,17	157,16	5,33	23,59	8,45	-77,02
7/31	79,25	0,19	182,84	5,55	23,59	2,95	-212,70
8/31	64,17	0,16	149,64	5,55	17,69	1,55	-322,97
9/30	81,81	0,10	92,48	4,44	17,69	1,85	-357,62
10/31	118,21	0,06	48,29	3,55	0,00	4,05	-295,29
11/30	141,19	0,02	16,34	2,66	0,00	8,19	-181,30
12/31	131,40	0,01	6,50	2,22	0,00	13,14	-71,76
Annual	1.021,34	1,09	1.005,22	44,41	117,94	121,66	-257,47

Table 3-12 Water budget of Strumica watershed – projection 2025

Month/Days	P (MCM)	E (MCM)	ET (MCM)	Q_{ws} (MCM)	Q_{ir} (MCM)	Q_{out} (MCM)	Storage (MCM)
Initial water storage							11,50
1/31	81,22	0,01	10,32	2,63	0,00	12,71	67,03
2/28	91,46	0,03	28,61	2,63	0,00	17,91	109,34
3/31	87,96	0,07	65,26	3,16	0,00	20,42	108,47
4/30	95,71	0,11	110,55	4,21	25,40	15,51	48,47
5/31	117,37	0,16	148,96	5,27	25,40	11,72	-25,47
6/30	97,76	0,17	164,75	6,32	33,87	8,20	-140,85
7/31	76,88	0,20	192,38	6,58	33,87	2,87	-299,68
8/31	62,24	0,17	157,62	6,58	25,40	1,50	-428,55
9/30	79,36	0,11	97,13	5,27	25,40	1,80	-478,78
10/31	114,66	0,06	50,25	4,21	0,00	3,93	-422,51
11/30	136,95	0,02	16,82	3,16	0,00	7,94	-313,48
12/31	127,46	0,01	6,58	2,63	0,00	12,75	-207,99
Annual	990,70	1,13	1.049,25	52,68	169,34	118,01	-388,21

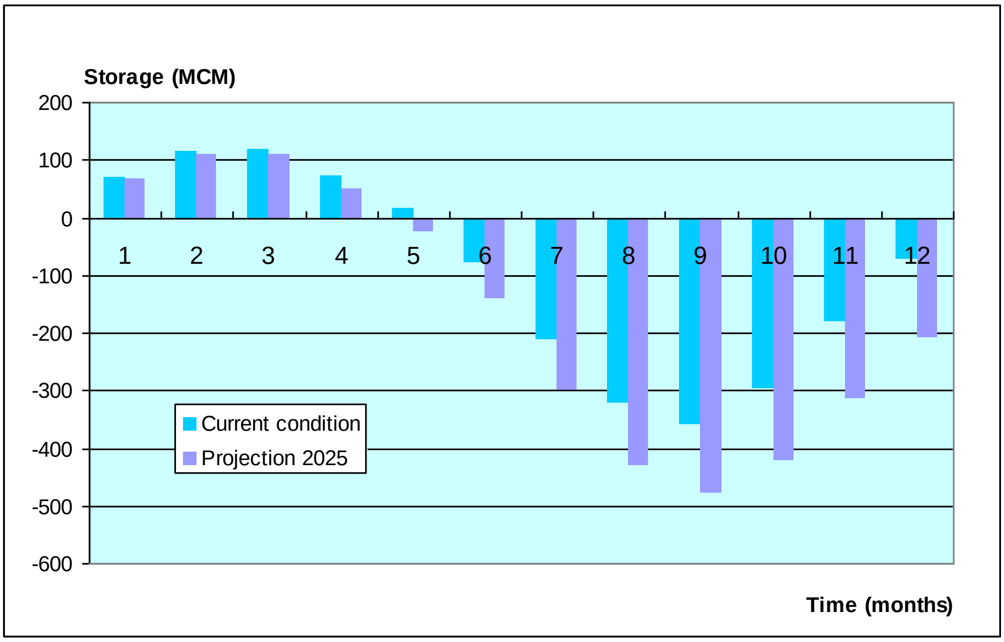

Figure 3-11 Water balance of Strumica watershed

Including the delivered water in the watershed from Mantovo reservoir with an average of 7.25 million m^3 annually for the period 2003-2012 and distributed it from May to October, the monthly water balance for current state show water shortage decrease from 257.47 million m^3 (Storage 1) to 250.23 million m^3 (Storage 2), Table 3-13.

Table 3-13 Monthly water balance

Month/Days	Storage 1 (MCM)	Storage 2 (MCM)
Initial water storage		11,50
1/31	69,62	69,62
2/28	114,97	114,97
3/31	118,17	118,17
4/30	72,59	72,59
5/31	16,36	17,08
6/30	-77,55	-76,10
7/31	-213,42	-211,97
8/31	-323,85	-322,40
9/30	-358,60	-357,15
10/31	-296,33	-295,61
11/30	-182,36	-182,36
12/31	-72,84	-72,84
Annual	-257,47	-250,23

3.3 Vulnerability Assessment

This report on regional vulnerability assessment in south-eastern part of Republic of Macedonia focuses on hydrology and water resources. Considering the important role of water to the ecosystems it is noted that the obtained vulnerability assessment is related to the ecosystems as well. Ecosystems are of fundamental importance to environmental function and to sustainability, and they provide many goods and services critical to individuals and societies. This goods and services include: (i) providing food, fibber, energy and medicines; (ii) processing and storing carbon and nutrients; (iii) assimilating wastes; (iv) purifying water, regulating water runoff and moderating floods; (v) building soils and reducing soil degradation; (vi) providing opportunities for recreation and tourism; (vii) housing the Earth's entire reservoir of genetic and species diversity. In addition, natural ecosystems have cultural, religious, aesthetic and inherent existence values. Water is an essential component of the ecosystems where the humans play important role. Therefore, water availability is an essential component of welfare and productivity.

The assessment of regional vulnerability is necessarily qualitative due to uncertainties regarding the sensitivities and adaptability of natural and social systems. In a number of instances, quantitative estimates of impacts of climate change can be found. Such estimates are dependent upon the specific assumptions of future climate changes, as well as upon the methods and models applied in the analyses. To interpret these estimates, it is important to have in mind that the uncertainties regarding the character, magnitude and rates to future climate change remain. These uncertainties impose limitations on the ability of scientists to project impacts of climate change, particularly at regional and smaller scales.

Developing countries are highly vulnerable to climate change because many are located in arid and semi-arid regions and most derive their water resources from isolated reservoirs or single point systems such as bore holes. These systems by their nature are vulnerable because there is no redundancy in the system to provide resources. There is evidence that flooding is likely to become a larger problem in many temperate and humid regions, requiring adaptations not only to droughts and chronic water shortages but also to floods and associated damages. The climate change impacts depend on the baseline condition of the water supply system and the ability of water resources managers to respond not only to climate change but also to population growth and changes in demands, technology, and economic, social and legislative conditions.

The Water Balance Model (WBM) for Strumica river basin has been developed in two basic scenarios: (i) current/reference condition, and (ii) projected condition up to 2025. The obtained results show that the region is vulnerable in both scenarios. Water shortage, especially in agricultural sector, is significant in summer periods. The problems that have been identified in the region are:

1. The existing irrigation schemes are characterized with poor technical condition of the structures, facilities and equipment, high water losses, low use efficiency, low capacity on cropping pattern changes, and no flow regulation in the convey structures. Reasons for such poor condition of irrigation schemes are poor or even no maintenance, poor quality of the hydro mechanical equipment, small size of the plots, low cost revenues collection, poor implementation of Water Law, bad financial situation of the water management organizations, rural emigration etc.

2. Another problem not only in Strumica watershed but also on country level is unregulated use of surface and groundwater. Most feasible is that farmers use groundwater as a source for irrigation. Having in mind that most of the irrigation systems are not suitable for micro irrigation, farmers find pumping of the groundwater as best option to modernize their irrigation practices. So, by the use of their "own" water source the farmer are controlling the irrigation process according to their needs as well as to the crops needs. How many individual irrigation systems are in Strumica watershed is not known. Therefore, there is an urgent need of mapping/inventory of existing irrigation wells.

3. There is no reliable data on consumed water for irrigation. Most of the irrigation schemes do not have measuring devices on irrigation intakes, river diversions or canal outlet. The price for irrigation water is defined by 1 ha of irrigated area, not on 1 m^3 consumed water. Percentage of the cost revenue collection is different and it varies from 30% to 85%. This low rate of collection of the cost revenues is one of the reasons for bad financial situation of the WMO. The price of water per crop varies in different irrigation schemes and depends on the type of the system (gravity or pumping), climate, soil conditions etc.

4. Climate variability and change in Strumica river basin is evidenced and projected by air temperature increase and precipitation decrease, although the last decade it is observed average annual temperature increase and annual precipitation sum increase. Because of such observed data the last decade may be assessed as hydrological wet period. Since 2002 storms and flash floods in the region have become more frequent and are causing significant damages.

5. The proportion of winter precipitation received as rain is increasing, with declining proportion arriving in the form of snow. Such shifts in the form and

timing of precipitation and runoff are of concern to water managers in a number of settings, including irrigated agriculture, urban water supply, and flood protection. Cropping practices are likely to shift as well, perhaps towards reduced or no tilling technologies, which enhance water infiltration and conserve soil moisture, or towards irrigation technologies that are more efficient at the farm level (although not necessarily at the basin level).

3.4 Adaptation Strategies and Measures

Various approaches or adaptation measures are available to reduce the potential vulnerability of water systems to climate change. The options include pricing systems, water efficiency initiatives, engineering and structural improvements to water supply and irrigation infrastructure, agricultural policies, and urban planning/management. At the national/regional level, priorities include placing greater emphasis on integrated, cross-sectoral water resources management, using river basins as management units. Given increasing demands, the prevalence and sensitivity of many simple water management systems to fluctuations in precipitation and runoff, and the considerable time and expenses required to implement many adaptation measures, the water resources sector in many regions and countries is vulnerable to potential changes in climate.

Adapting to increasing climate variability and change in Strumica river basin may be obtained both by implementing technical and management measures and practices. Technical measures include rehabilitation of the existing water supply systems as well constructing reservoirs for runoff regulation. Better water management requires policy shifts and significant investments that should be guided by the following principles:

1. Mainstreaming adaptation within the broader development context;
2. Strengthening governance of water resources management and improving integration of land and water management;
3. Improving and sharing knowledge and information on climate, water and adaptation measures, and investing in comprehensive and sustainable data collection and monitoring systems;
4. Building long-term resilience through stronger institutions and water infrastructure, including well-functioning ecosystems;
5. Investing in cost-effective adaptive water management and technology transfer;
6. Releasing additional funds through increased national budgetary allocations and innovative funding mechanisms for adaptation trough improved water management.

Close relation to the above principles are mitigation measures. Sector-specific mitigation measures can have various effects on water. The influence of sector-specific mitigation options on water quantity, quality and level can be found in the IPCC Report "Climate Change and Water" (2008), Table 3-14. Water management polices and measures can have an influence on GHG emissions associated with different sectors. Positive effects are indicated with (+), negative effects with (–), and uncertain effects with (?). More information about each sector-specific measure can be found in the IPCC Report "Climate Change and Water", 2008 (http://www.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf). As it is stated in this report, possible water resources conflicts between adaptation and mitigation might arise. Few existing studies (Dang *et al*., 2003) indicate that repercussions from mitigation for adaptation and vice versa are mostly marginal at global level, although they might be significant at regional scale. In regions where climate change will trigger significant shifts in the hydrological regime, but where hydropower potential are still available, this would increase the competition for water, especially if climate change adaptation efforts in various sectors are implemented (such as competition for surface water resources between irrigation to cope with climate change impacts in agriculture, increased demand for drinking water, and increased demand for cooling water in power sector). This confirms the importance for integrated land and water management strategies for river basins.

Table 3-14 Sector-specific mitigation measures

Water aspect	Energy	Industry	Agriculture	Forests	Waste
Quality					
Chemical/ biological	CCS[1] (?) Bio-fuels[2] (+/–) Geothermal energy[5] (–) Unconventional oil[12] (–)	CCS[1] (?) Wastewater Treatment[12] (–) Biomass electricity[3] (–/?)	Land use change and management[6] (+/–) Cropland management (water)[8] (+/–)	Afforestation (sinks)[9] (+)	Solid waste management; Wastewater treatment[11] (+/–)
Temperature	Biomass electricity[3] (+)		Cropland management (reduced tillage)[8] (+/–)		
Quantity					
Availability/ demand	Hydropower[4] (+/–) Unconventional oil[12] (–) Geothermal energy[5] (–)		Land use change and management[6] (+/–) Cropland management (water)[7] (–)	Afforestation[9] (+/–) Avoided/reduced deforestation[10] (+)	Wastewater treatment[11] (+)
Flow/runoff/ recharge	Bio-fuels[2] (+/–) Hydropower[4] (+/–)		Cropland management (reduced tillage)[8] (+)		
Level					
Surface water	Hydropower[4] (+/–)		Land use change and management[6] (+/–)		
Groundwater	Geothermal energy[5] (–)		Land use change and management[6] (+/–)	Afforestation[9] (–)	

Source: IPCC Report (2008)

Notes to sector-specific measures:

1 CCS (Carbon capture and storage) underground poses potential risk to groundwater quality.

2 Expanding bio-energy crops and forests may cause negative impacts such as increased water demand, contamination of groundwater and promotion of land use changes, leading to indirect effects on water resources; and/or positive

impacts through reduced nutrient leaching, soil erosion, runoff and downstream siltation.

3 In general, a higher contribution of renewable energy, as compared to fossil-fuel power plants, means a reduction of the discharge of cooling water to the surface water.

4 Environmental impact and multiple benefits of hydropower need to be taken into account for any given development; they could be either positive or negative.

5 Geothermal energy uses might result in pollution, subsidence and, in some cases, a claim on available water resources.

6 Land use change and management can influence surface water and groundwater quality (through enhanced or reduced leaching of nutrients and pesticides) and the hydrological cycle.

7 Agricultural practices for mitigation can have both positive and negative effects on water conservation and its quality.

8 Reduced tillage promotes increased water use efficiency.

9 Afforestation generally improves groundwater quality and reduces soil erosion. It influences both catchment and regional hydrological cycles (smoothed hydrograph, thus reducing runoff and flooding). It generally gives better watershed protection, but at the expense of surface water yield and aquifer recharge, which may be critical in semi-arid and arid regions.

10 Stopping/slowing deforestation and forest degradation conserve water resources and prevent flooding, reduce runoff, control erosion and reduce siltation of rivers.

11 Various waste management and wastewater control and treatment technologies can both reduce GHG emissions and have positive effects on the environment, but they cause water pollution in case of improperly designed and managed facilities.

12 As conventional oil supplies become scarce and extraction costs increase, unconventional liquid fuels will become more economically attractive, but this is offset by greater environmental costs.

Adaptation strategies and measures are based on the results of vulnerability assessments as well as on development objectives, stakeholder considerations and the resources available. Effective adaptation strategies are a mix of structural and non-structural, regulatory and economic instruments, and education and awareness raising measures. If little or no information is available to perform a structured vulnerability assessment, adaptation strategies and measures should be based on generally available global or local information, like predictions of changes in hydrology, combined with expert and local knowledge.

Given the uncertainty associated with climate change, win-win, no regret and low regret measures should be chosen as a priority. Based on this and the obtained results out of the water balance modelling and vulnerability assessment for Strumica river basin it is concluded that by 2025, and in particular by 2050, the scenarios show that the amount of water available for the environment could be significantly reduced compared to now, given the combination of climate change and changing demands. This will be particularly evident in dry years. Therefore, the following adaptation measures listed by priority are proposed:

- Construction/modification of physical infrastructure
    - Canal linings

- Closed conduits instead of open channels
- Integrating separate reservoirs into a single system
- Reservoirs/hydro-plants/delivery systems
- Raising dam height
- Removing sediment from reservoirs for more storage
- Inter-basin water transfers

- Adaptive management of existing water supply systems
  - Change operating rules for reservoirs
  - Use conjunctive surface/groundwater supply
  - Physically integrate reservoir operation system
  - Coordinate supply/demand
  - Indigenous options

- Policy, conservation, efficiency, and technology
  - Domestic
    - Municipal and in-home re-use of water
    - Leak repair
    - Rainwater collection for non-potable uses
    - Low-flow appliances
    - Dual-supply systems (potable and non-potable)
  - Agriculture
    - Irrigation timing and efficiency
    - Drainage re-use, use of wastewater effluent
    - High value/low water use crops
    - Drip, micro-spray, low-energy, precision application irrigation systems
  - Industry
    - Water re-use and recycling
    - Closed cycle and/or air cooling
    - More efficient hydropower turbines
    - Cooling ponds, wet towers and dry towers
  - Hydropower
    - Reservoir re-operation
    - Additional reservoirs and hydropower stations
    - Low head run of the river hydropower
    - Market/price-driven transfers to other activities
    - Using water price to shift water use between sectors

Another group of measures may be proposed on flood-prone situation. Considering that flooding in Europe and in Republic of Macedonia has become more frequent and more severe, the following measures in prevention and improving resilience can be proposed:

- Restriction of urban development in flood risk zones
- Measures aiming at maintaining dam safety, afforestation and other structural measures to avoid mudflows
- Construction of dikes
- Changing in operation of reservoirs and lakes
- Land use management
- Implementation of retention areas
- Improved drainage possibilities

- Structural measures such as temporary dams, building resilient housing, modifying transport infrastructure
- Migration of people away from high-risk areas

For effective adaptation measures need to be implemented on different time scales. Lon-term measures are related to decisions to address long-term (decadal) climate changes and are based on long-term projections. They usually exceed the scope of water sector planning because they affect the development model and the socio-economic background through institutional and legal changes (for example land use changes). Medium-term measures are related to medium-term (one or two decades) climate change projections and introducing hydrological planning measures such as risk management (for example drought and flood management plans). Short-term measures are related to decisions addressing identified problems mainly under the current climate and hydrological variability. They correspond to measures that can be adopted in the current institutional, legal and infrastructural framework, and usually refer to risk assessment, preparedness and vulnerability reduction (for example revised water allocations during drought). A common problem is a focus on short-term measures. Medium and long-term measures should be fostered, although this is often difficult due to short electoral cycles, funding constraints and high uncertainty associated with medium and long-term forecasts.

3.5 Action Plan

An Action Plan outlines the activities that should be undertaken to cope with climate change and increased water demands. The planned actions are subject to availability of funding and the overall rationale. It lists the proposed projects, and for each the objectives, main activities, expected outputs, intended time frame for implementation, expected cost, and responsibilities. The ultimate goal of an Action Plan is water conservation that is not to prevent water use, but to maximize efficiency and the benefit. Efficient water use is considered the minimal amount of water that is technically and economically feasible to achieve an intended water use function.

The previous Intersectoral Action Plan for adaptation to climate change was developed in Second Communication (2008) where in four major areas were proposed measures. The proposed measures were accompanied by a number of actions, responsible institution/stakeholder, timescale and approximate budget. Most of the actions were short-term (2008-2010) and low category budget (up to 100.000 Euro). Most priority projects in a sector-specific analysis were briefly presented by the following tasks: Goal, Overall development objective, Outcomes, and Project description.

Several constraints and gaps were identifying during preparation of the thematic studies on vulnerability assessment within this study. The most persistent ones are data availability, consistency and transparency. Also there are opportunities and barriers in implementation of the proposed adaptation measures. One very important opportunity is accumulated experience to cope with droughts and floods and existing technologies in water supply and irrigation used in the country. Proper response in the water resources sector as one of the most vulnerable to climate change requires significant financial support. Active use of the EU Framework Research Programmes and allocation of funds in the relevant institutions is recommended. Enhancement of the role of the National Climate Change Committee is recommended for coordination of climate change activities. There are some other barriers such as low investment in research, shortage of well-qualified and trained personnel for adaptation measures implementation, shortage relevant database and GIS layers in appropriate scale and others mainly on systemic and institutional level.

In Table 3-15 are proposed actions/recommendations in water conservation. For local government and regional organizations, this section helps evaluate and identify practices appropriate for the water users. For state-wide associations, organizations, and agencies this section helps organize water management efforts to achieve common goals. Climate changes impacting water resources will have implications for the whole country – business, communities, individuals and environment. This Action Plan sets out the actions by type, clear distinction of the responsibilities, timeframe, financial means for implementation, and constraints through identified possible barriers and risks. These actions must be taken by all stakeholders including Government and public members who must take some responsibility for their well-being and property.

Table 3-15 Adaptation actions for water conservation

Action	Type	Stakeholders	Timeframe	Financing	Constraints	Comments
Modification of existing water supply and irrigation systems to decrease water losses (drip, micro-spray, low-energy, measuring devices)	Capacity building Maintenance Planning	MAWFE Public water management enterprises	Long-term	High budget		Link: Agriculture
Implementation technology for re-use of water (municipal, drainage, waste water)	Policy	MAWFE Public water management enterprises	Medium-term	Medium budget	Finances, Technology aspect	Link: Agriculture Health
Inventory and GIS mapping the existing wells for groundwater use	Capacity building Policy	MAWFE Local municipalities Public water management enterprises	Short-term	Low budget	Low public awareness	Link: Agriculture
Construction system for inter-basin water transfer	Policy Planning	MAWFE MEPP Public water management enterprises	Long-term	High budget	Finances, Access to International funding programs	Link: Agriculture
River basin management plan development including conjunctive surface and groundwater supply	Policy Modelling	MAWFE MEPP Local municipality Public water management enterprises	Short-term	Medium budget		Link: Agriculture
GIS hazard events mapping and risk management (drought and flood)	Policy	MAWFE MEPP Public water management enterprises NGOs	Short-term	Medium budget	Lack of data	Link: Agriculture Forestry Biodiversity Health
Monitoring network improvement (surface water,	Capacity building Policy	MAWFE MEPP HMS Public water	Short-term	Medium budget	Finances	Link: Agriculture Forestry Biodiversity

groundwater, water use, water quality)		management enterprises				Health

Evaluating criteria

The criteria and indicators/sub-criteria of evaluating the proposed adaptation actions are:

- Effectiveness of adaptation
  - Adaptation function (does the measure provide adaptation in terms of reducing impacts, reducing expose, enhancing resilience or opportunities)
  - Robustness of uncertainty (is the measure effective under different climate scenarios and different socio-economic scenarios)
  - Flexibility (can adjustment be made later if conditions change again or if changes are different from those expected today)
- Side effects
  - No regret (does the measure contribute to more sustainable water management and bring benefits in terms of already existing problems)
  - Win-win (does the measure entail side-benefits for other social, environmental or economic objectives)
  - Spill-over effects (does the measure affect other sectors or agents in terms of their adaptive capacity, and does the measure cause other environmental pressure)
- Efficiency/costs and benefits
  - Low-regret (are the benefits from the adaptation measure low comparing to the cost or may be relatively high)
- Framework conditions for decision makers
  - Equity and legitimacy (who wins and who losses from adaptation)
  - Feasibility of implementation (what barriers are there to implementation)
  - Alternatives (are there alternatives to the envisaged adaptation measure that would be less costly or would fewer negative side-effects)
  - Priority and urgency (how severe the climate impacts and adaptation measure would address to other impacts in the area/river basin/country)

Adaptation measures implementation

Implementation of some adaptation measures need water resources models development. There are three basic types of models: hydraulic (biophysical process models describing stream flow, flooding), hydrologic (rainfall-runoff processes), and planning (water resources system models). The questions that can be answered by these models are:

- Hydraulic Model
  - How fast, deep is river flowing (flooding effects)?
  - How do changes to flow and channel morphology impact the sediment transport and services provided (fish habitats, recreation, etc)?
- Hydrology Model
  - How does rainfall on a catchment translate into flow in a river?
  - What pathways does water follow as it moves through a catchment?

    - How does movement along these pathways impact the magnitude, timing, duration, and frequency of river flows, as well as water quality?
- Planning Model
    - How should water be allocated to various uses in time of shortage?
    - How can these operations be constrained to protect the services provided by the river?
    - How should infrastructure in the system, for example dams, diversion works, be operated to achieve maximum economic, social, and ecological benefit?
    - How will allocation, operations, and operating constraints change if new management strategies are introduced into the system?

Transboundary context

Considering that Strumica river basin is transboundary a brief discussion on transboundary cooperation is presented. Transboundary cooperation has two main objectives. First, it aims to prevent, control and reduce transboundary impacts when designing and implementing adaptation strategies and measures. In this way it ensures that unilateral measures do not have unintended effects in riparian countries, in particular that they do not increase their vulnerability. Second, transboundary cooperation can help to enable more efficient and effective adaptation, since some measures that support adaptation in one country can be more effective if they are taken in another country. Prevention of flooding, for instance, can be realized by creating retention areas upstream, perhaps in the upstream country. Transboundary cooperation on adaptation can widen the knowledge/information base, enlarge the set of available measures for prevention, preparedness and recovery and thereby help to find better and more cost-effective solutions.

In transboundary basins, some local measures might not have any transboundary impact and therefore do not need transboundary cooperation. In the case of structural and other measures likely to cause significant adverse transboundary impact, cooperation is required. Moreover, legislative, regulatory and economic measures can benefit from a joint approach.

At transboundary level, common objectives and goals should be defined and major planned measures discussed. Joint bodies are the natural forum for the process of developing and implementing adaptation strategies.

Box 3-1

Predicted impact of climate change vary by region and include increased temperatures and evaporation rates; higher proportions of winter precipitation arriving as rain, not snow; earlier and more sever summer droughts and decrease water quality. The vulnerability assessment of the southeastern part of Macedonia, case study Strumica river basin, is made by water balance modeling. Water shortages are obtained for current/reference condition and for projected condition up to 2025. These shortages currently result in substantial economic losses. Such economic losses, which occur across a range of sectors, from agriculture to energy and recreation, have profound effects on local communities. More frequent shortages imply increased costs to society, although adaptation by water users will mitigate some portion of these costs.

Strumica river basin is very complex from hydrographic development that is shown on Figure 15. By the use of HEC-HMS (Basin model) the watershed is divided into 233 that resulted to a very low ratio between the watershed and sub watersheds (A/n=7). The water potential of each delineated sub watersheds may be obtained by application of daily water balance model for what meteorological, hydrological and water consumption daily data are needed. Daily water balance model is very complex and hard work, but same time the most reliable and accurate water availability assessment in comparison to the monthly and annual water balance models where many parameters are averaged and/or neglected.

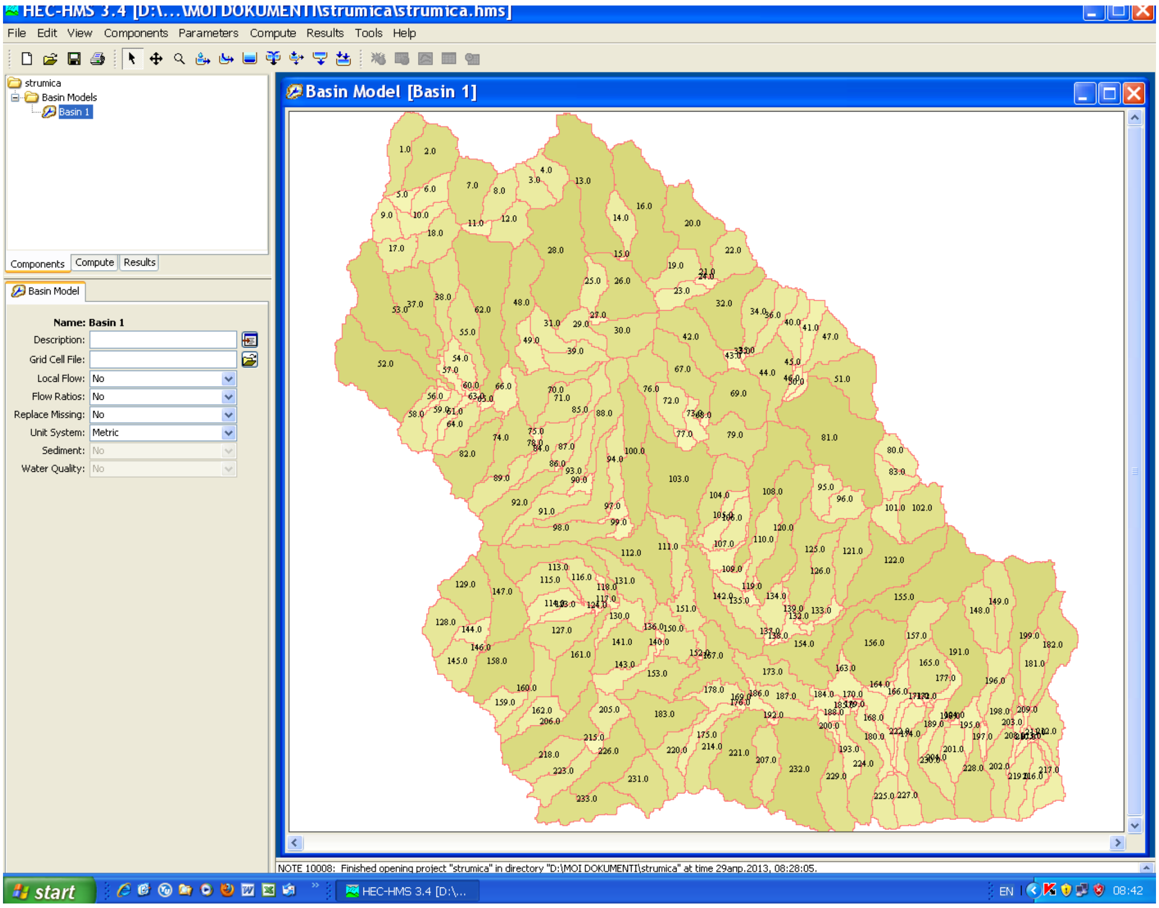

Figure 3-12 Strumica river basin delineation

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