Report

NTNU
Norwegian University of
Science and Technology
Faculty of Engineering Science and Technology
Department of Civil and Environmental Engineering

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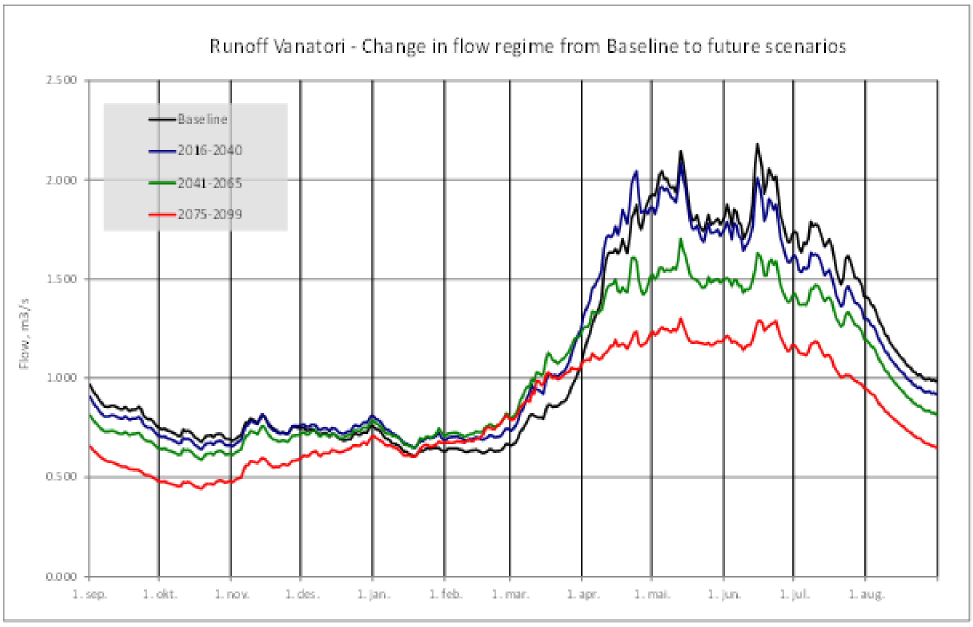
Climate Change and impact on Water Resources and Hydropower The case of Vanatori Neamt in the Carpathian region of Romania



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Executive summary

The project “Intelligene Energy Systems in Protected Areas” was initiated by the Technical University of Iasi (TUIASI) with two Norwegian partners, SINTEF Energy Research and Norwegian University of Science and Technology (NTNU). Additional Romanian partners are the Polytechnic University of Timișoara, the Polytechnic University of Bucharest and the Siret Water Basin Administration. Project funded through the RO06 Renewable Energy Programme developed by EEA Grants 2009-2014.

After careful investigations there has been identified as location for the implementation of the research activities in the Natural Park Vanatori Neamt.

This report is from a study of climate change and its impact on water resources and hydropower potential in the area. This was studied by analyzing climate change data from the Euro CORDEX project in combination with a precipitation-runoff model and a hydropower simulation model.

It was possible to see a clear trend in temperature, increasing nearly linearly up to +1.7 ^{0}C up to the end of the century for RCP4.5 and by 3.5 ^{0}C for RCP8.5. The change in precipitation was less clear than for temperature, with small changes and no consistent trend. From this study, we found seasonal changes in both emission scenarios (Rcp4.5 and Rcp8.5). In general, from January to April both rcp4.5 and rcp8.5 predicts increased precipitation (1% to +20%), and similarly during October – December the precipitation increases from +1% to +12%. However, during the rainy periods (May – September) there is decreased precipitation (-12% to -3%). In summary, for the lowest emission scenario, RCP4.5, there were almost no changes, a decrease of about 1%. For the higher emission scenario, there was a small reduction of 4% for the last 25 years (2075-2099) and +/1 1% before this.

Climate change impacts on hydrology was analyzed by using a HBV Precipitation-Runoff model to convert climate data into time-series of runoff. We found small changes in runoff before 2040, but from then on there was gradual decrease of 10% by 2065 and 25% by 2099. The decrease in runoff is much larger than decrease in precipitation. This is because the increased temperature will lead to higher evaporation.

The impact on hydropower resources was closely linked to the change in hydrology, and like the runoff it was more or less unchanged up to 2040. From here, a gradual reduction was found at 6% by 2065 and 21% by 2099.

The overall conclusion from this study is that it is possible find data and models for doing this type of analysis in Romania. Further studies are also possible, by using the same data sources and models. The results from different climate models and emission scenarios all point to a gradual decrease in runoff and hydropower generation potential in this area. The changes seem to be small up to 2040, from there we estimate a gradual decrease in the order of 20-25% by the end of the century.

CONTENTS

List of Tables

List of Figures

1. Introduction

1.1 Background

The project “Intelligene Energy Systems in Protected Areas” was initiated by the Technical University of Iasi (TUIASI) with two Norwegian partners, SINTEF Energy Research and Norwegian University of Science and Technology (NTNU). Additional Romanian partners are the Polytechnic University of Timișoara, the Polytechnic University of Bucharest and the Siret Water Basin Administration. Project funded through the RO06 Renewable Energy Programme developed by EEA Grants 2009-2014.

After careful investigations there has been identified as location for the implementation of the research activities, the P* area (The Natural Park Vanatori Neamt – the location for the implementation of the research infrastructure), belonging, from a territorial and administrative point of view, to the Commune of Crăcăoani, Neamț County, the North-Eastern Region. The team of researchers involved in the Project aims, among others, at studying, developing and testing a flexible energy management system created by integrating multiple sources of renewable energy, allowing the conservation of energy and including also a distribution grid.

Several types of renewable energy were considered, among then also Hydropower. One important topic regarding hydropower is the long term sustainability, related to possible changes in water resources due to possible land use changes and climate change. This report contains an analysis and documentation of future climate change in the area, and impacts on water resources and hydropower potential. The report can be seen as a supplement to the previously published Chapter 8 in /1/.

1.2 Location, Geography

The research area is located in Neamt county in Eastern Carpathians region, about 100 km west of Iasi. Regionally, the location is within the Danube basin (Figure 1.1) and more specific in the Siret River basin, a tributary to Danube (Figure 1.2).

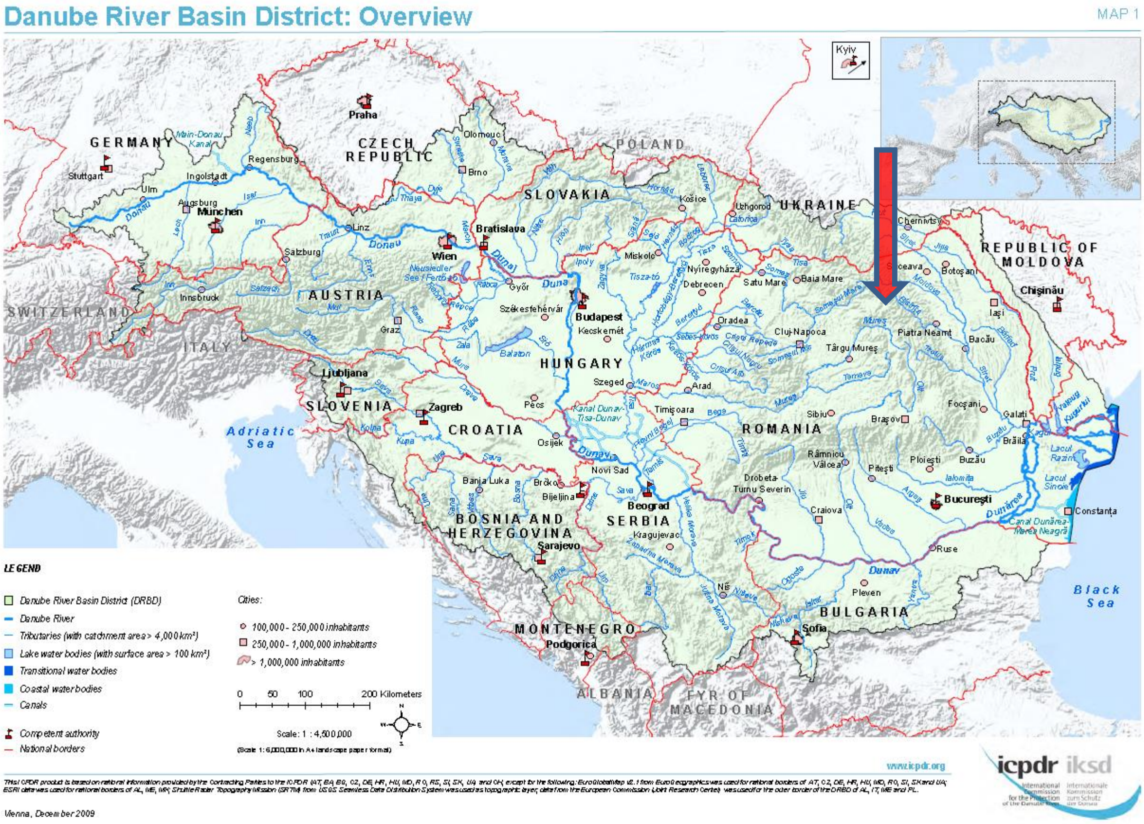


Figure 1.1 The Danube catchment with location of Vanatori Neamt

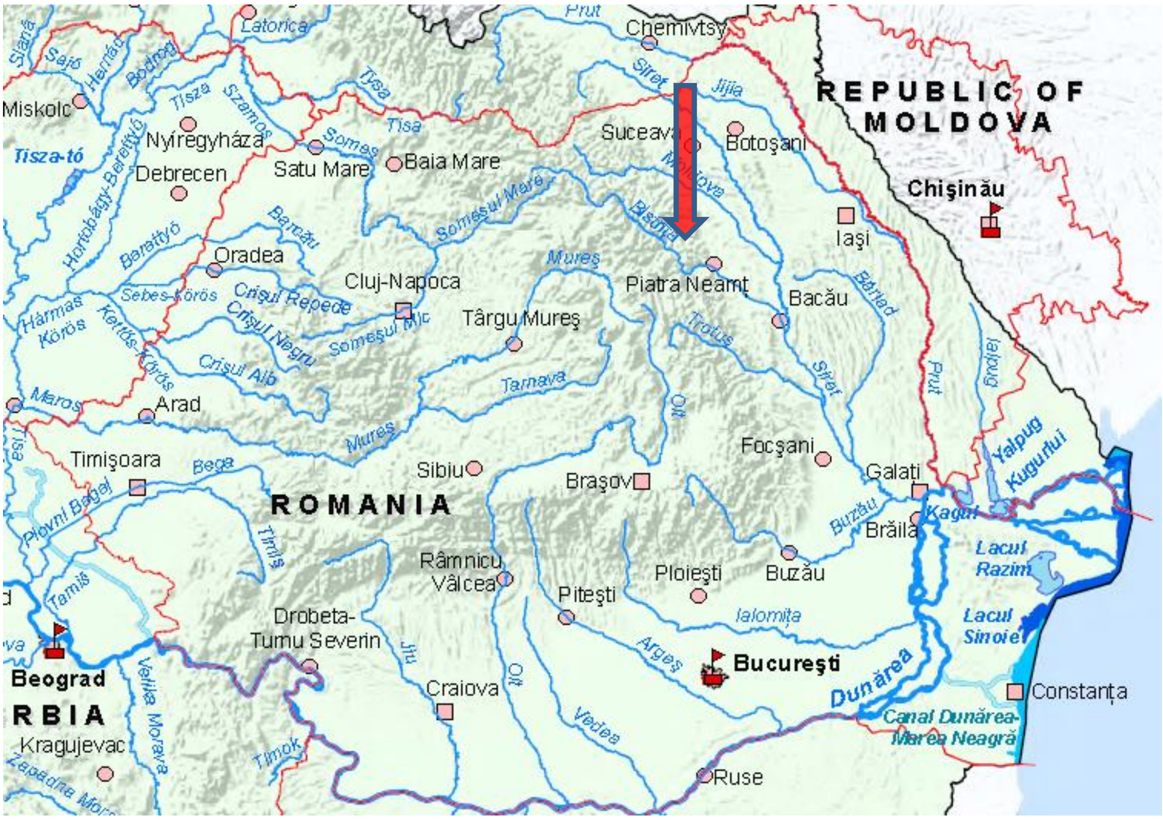


Figure 1.2 Major rivers in Romania with location of Vanatori Neamt in Siret river

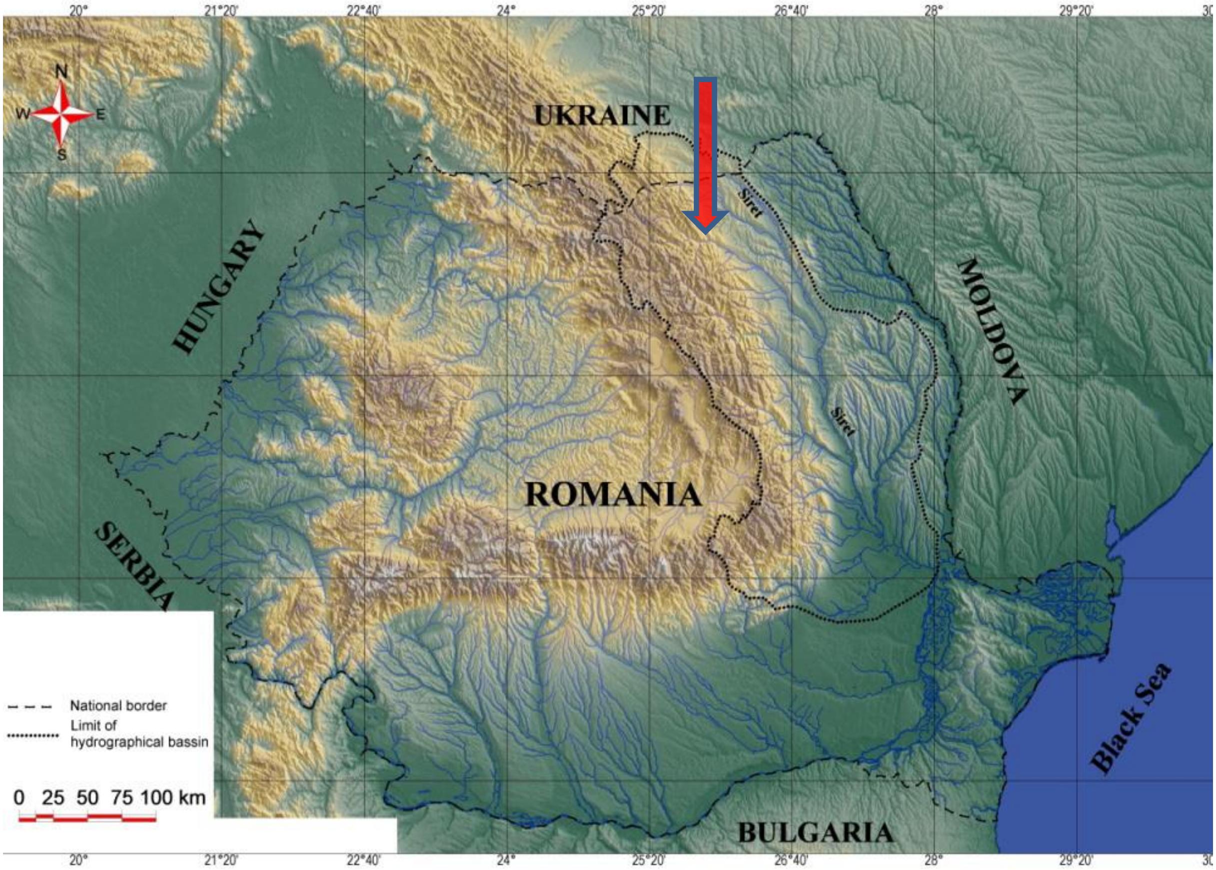


Figure 1.3 Topography of Romania. Arrow indicate location of Vanatori-Neamt

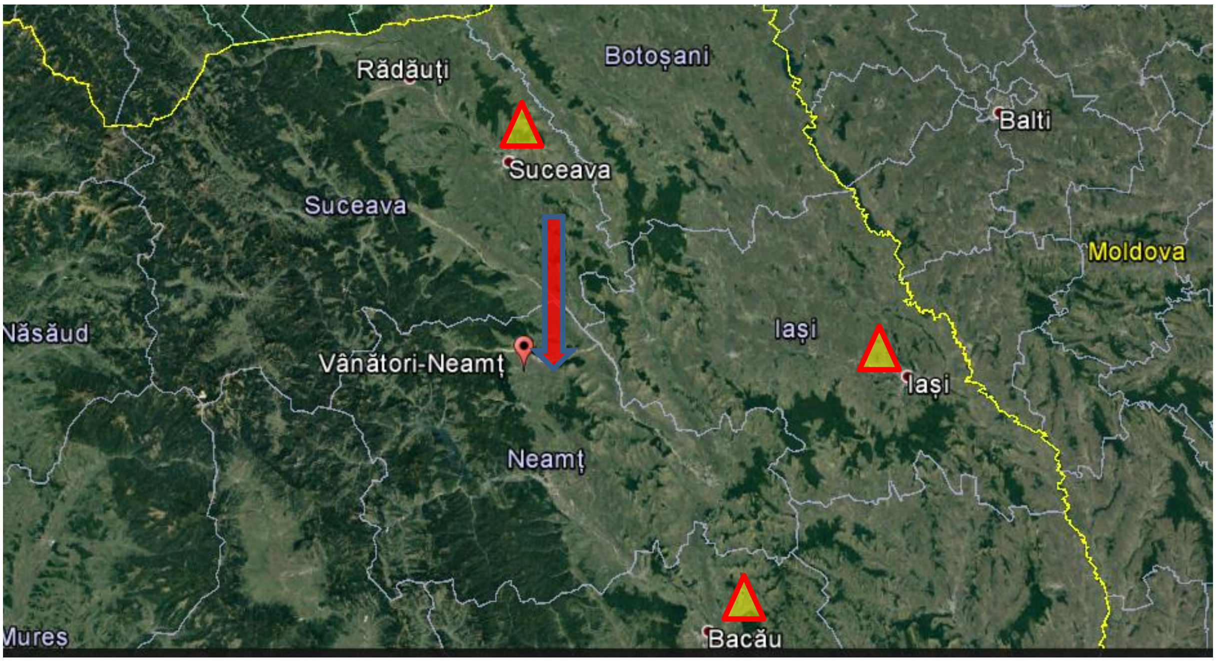


Figure 1.4 Location Vanatori-Neamt national park and three nearby climate stations at Iasi, Bachau and Tosani

1.3 Climate and Hydrology

We could not find a climate station or a hydrological station in the area, but looking at the surrounding region three met stations could be found, data for these are given in Table 1.1 and their location in Figure 1.4. Monthly average precipitation can be found in Table 1.2 and Figure 1.5. We can see that the climate is quite similar at the three climate stations, but since the Vanatori Neamt is located in a more mountainous region there may also be some differences.

Precipitation Stations	TOSANI	BACAU	IASI
Elevation (masl)	161	184	102
Latitude	47.68	46.5331	47.1667
Longitude	26.67	26.9167	27.6331

Table 1.1 Climate stations close to Vanatori

Mean Monthly Precipitation (mm)			
Month	TOSANI	Bacau	Iasi
Jan	23	22	30
Feb	22	23	29
Mar	29	28	33
Apr	52	52	51
May	68	72	63
Jun	90	82	97
Jul	84	78	81
Aug	60	59	58
Sep	43	52	53
Oct	31	32	30
Nov	30	32	35
Dec	28	27	32
Annual	560	559	592

Table 1.2 Annual Precipitation distribution for three climate stations

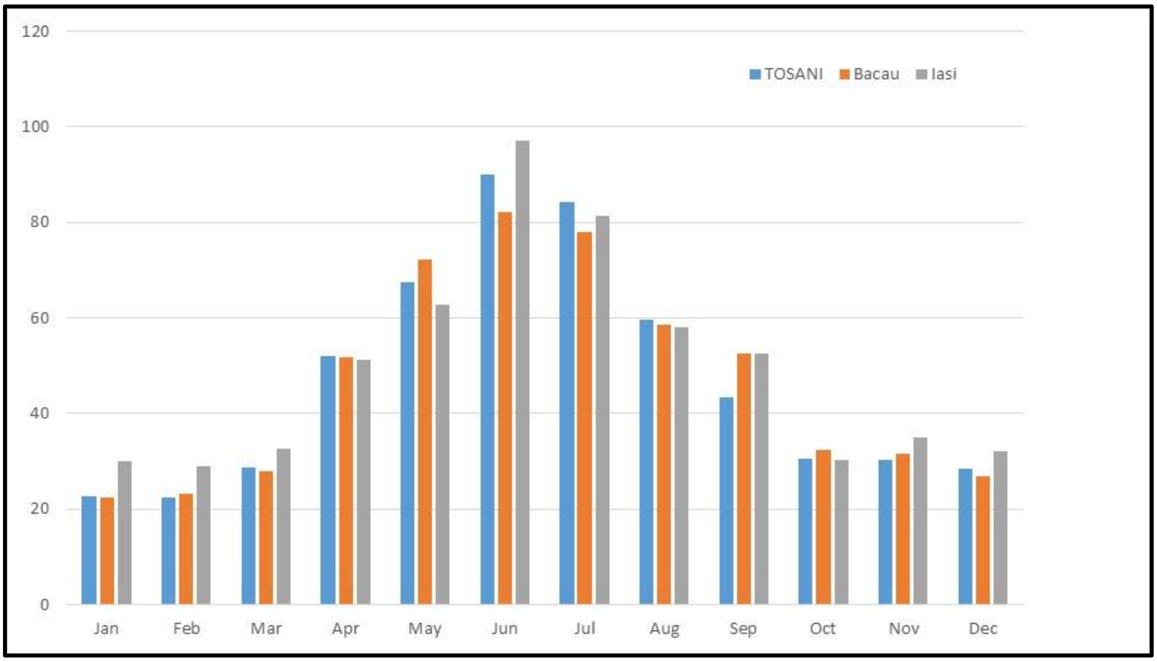


Figure 1.5 Seasonal precipitation distribution for three climate stations

Since none of the available climate stations were located in the Vanatori area, it was decided to use reanalysis data to establish a data series for the current climate. A climate reanalysis gives a numerical description of the recent climate, produced by combining models with observations. It contains estimates of atmospheric parameters such as air temperature, pressure and wind at different altitudes, and surface parameters such as rainfall, soil moisture content, and sea-surface temperature. The estimates are produced for all locations on earth, and they span a long time period that can extend back by decades or more/5/. In this report data from reanalysis was available for the years 1980-2005. In text and tables these data are sometimes called observed or current.

In next chapter we will show the use of various Global Climate Models (GCMs) for prediction of future climate. By comparing with existing climate (reanalysis/observed/current) it is possible to see if and how much the climate is changing. These models are usually also run for the period covered by observed data, and a comparison between observed and GCM simulated data can be used to compute characteristics of change in for example precipitation and air temperature.

Table 1.3 and Figure 1.6 gives a summary of average computed air temperature for four GCM’s, their mean (ensamble) and for comparison the average observed temperature 1980-2005 (computed by reanalysis).

Table 1.4 and Figure 1.7 show the same for precipitation.

Month	CNRM	ICHEC	IPSL	MPI	Ensemble mean	Observed
Jan	1.7	1.9	1.9	1.7	1.8	0.2
Feb	1.8	2.0	2.0	1.7	1.9	-0.2
Mar	3.4	3.2	3.8	4.1	3.6	2.7
Apr	7.9	8.0	7.7	8.8	8.1	7.8
May	12.6	12.9	13.0	13.3	12.9	12.7
Jun	16.4	16.6	16.8	16.4	16.5	16.4
Jul	18.7	18.9	18.7	18.4	18.7	18.7
Aug	18.8	18.6	18.2	18.4	18.5	19.1
Sep	15.6	15.1	14.8	15.4	15.2	15.8
Oct	10.9	10.6	10.2	10.6	10.6	11.5
Nov	6.4	6.0	6.5	5.1	6.0	5.8
Dec	2.6	3.0	3.1	2.8	2.9	1.7
Average	10.4	10.3	10.3	10.4	10.4	10.0

Table 1.3 Seasonal air temperature distribution computed by 4 different GCM's and observed (Reanalysis)

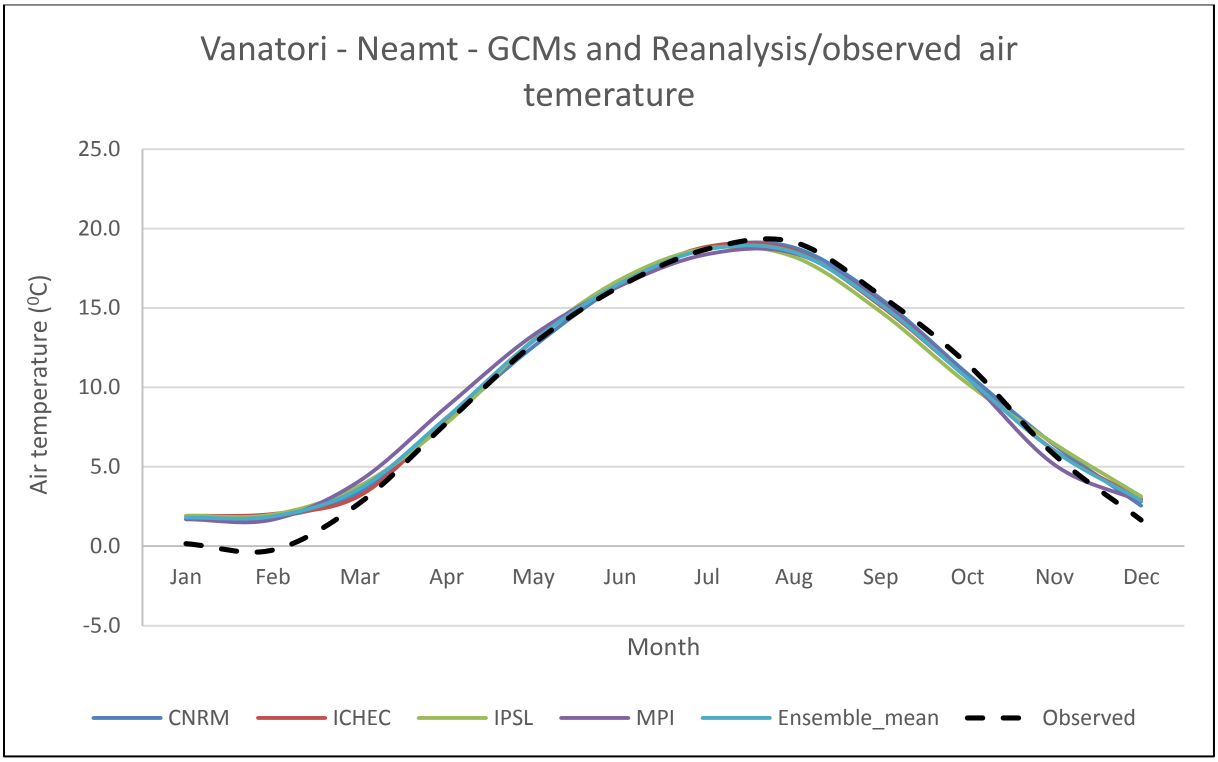


Figure 1.6 Seasonal air temperature distribution computed by 4 different GCM's + observed (Reanalysis)

Month	CNRM	ICHEC	IPSL	MPI	Ensemble mean	Current
Jan	38.94	37.62	42.24	49.67	42.12	48.86
Feb	36.27	39.34	46.70	48.05	42.59	46.10
Mar	57.57	62.32	62.80	56.52	59.80	60.84
Apr	77.85	86.10	78.91	90.20	83.27	74.18
May	130.38	138.55	99.60	130.68	124.80	92.09
Jun	139.10	121.57	140.98	116.24	129.47	96.68
Jul	107.69	97.17	110.07	95.42	102.59	91.97
Aug	70.51	60.06	82.90	79.68	73.29	60.71
Sep	58.57	68.05	61.81	49.95	59.60	52.36
Oct	57.48	59.54	52.45	42.14	52.90	66.84
Nov	42.74	46.10	33.70	46.16	42.18	78.69
Dec	36.21	38.06	38.23	44.39	39.22	64.87
Mid	71.1	71.2	70.9	70.8	71.0	69.5

Table 1.4 Monthly precipitation distribution computed by 4 different GCM's + observed (Reanalysis)

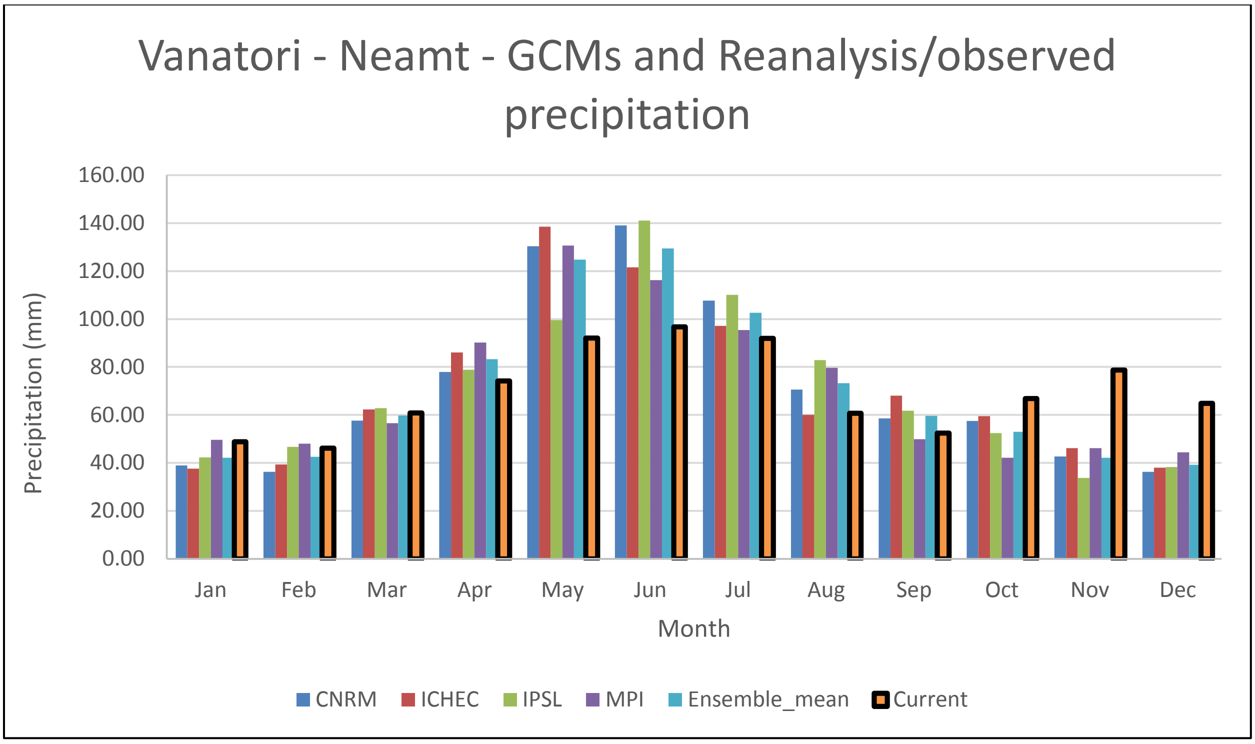


Figure 1.7 Monthly precipitation distribution – Average from four GCM's and average of observed data (reanalysis)

Runoff

No runoff data were available for the Vanatori Neamt area, so it was decided to compute a runoff data series based on the observed (reanalysis) data for precipitation and air temperature. The result is difficult to verify, but a comparison can be made for average runoff, comparing to the map found in /2/, see Figure 1.8. From this map we can see that average specific runoff in Vanatori can be expected to be around 10 l/s*km^2.

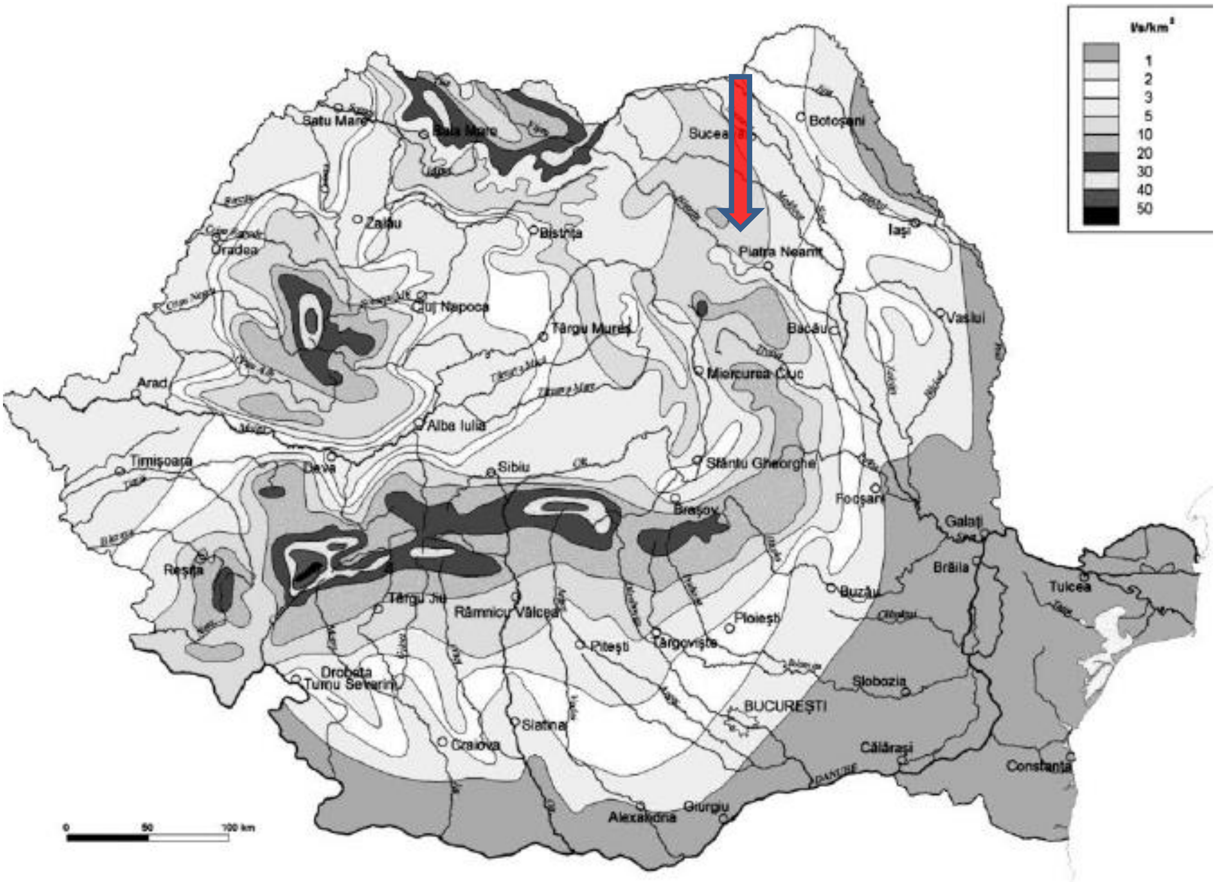


Figure 1.8 Specific runoff map for Romania (From /2/). Location of Vanatori catchment indicated by arrow

2. Climate change analysis

2.1 Methodology

The possible changes of climate in the area have been studied by a methodology which includes the use of many types of models and data. The methodology is outlined in Figure 2.1.

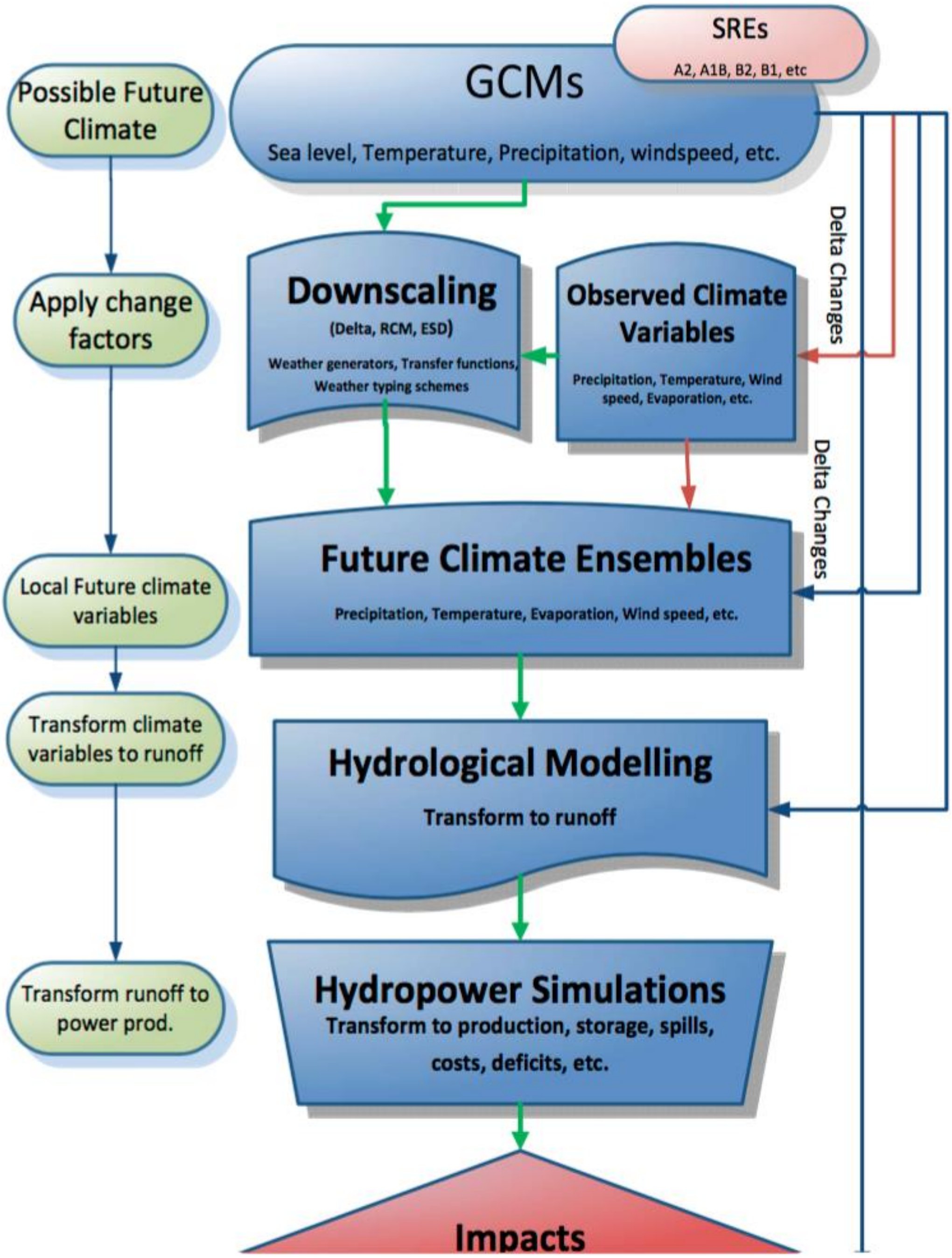


Figure 2.1 Methodology for studying climate change impacts on water resources and hydropower. Figure originally from /3/

The methodology and examples from many case studies was described in /4/ included in the book /1/. In this report, we therefore don't go deeper into the description of methodology for climate change studies, but mainly present results from the application to the Vanatori Neamt area.

Present climate is based on Reanalysis data for Vanatori area as described before. Future climate is computed by different GCM's and further refined by downscaling by Regional Climate Models (RCM) covering the whole of Europe as part of the EURO-CORDEX initiative /7/. The exact location is at coordinates 47.19N, 26.26E and 580 m.a.s.l.

2.2 Global Climate Models (GCMs) used in the study

The future climate has been based on simulations done by 4 different Global Climate Models (GCMs), usually known by their abbreviation. Here is link for each GCM and a short description

1) CNRM-CM5 (https://portal.enes.org/models/earthsystem-models/cnrm-cerfacs/cnrm-cm5)

CNRM-CM5 (Later called CNRM) is the CMIP5 version of the ESM developed jointly by CNRM-GAME (Météo-rance/CNRS) and CERFACS since 1995. The atmospheric component, ARPEGE, is a specific version of the French weather forecast model developed by ECMWF (IFS) and CNRM, adapted for climate simulations. ARPEGE is available for the scientific community with an exclusive aim of research, within the framework of the "Community Climate Model" project. The oceanic component, provided by CNRS/LOCEAN was updated to Nemo 3.2 for version 5. The SeaIce model, Gelato, developed by CNRM and included from version 2, in 1999, is now at version 5. The river routing scheme TRIP, developed by U.Tokyo and adapted by CNRM, was included in version 3 for CMIP3. The surface scheme SURFEX, which involves the Land Surface scheme ISBA and the sea-flux surface scheme ECUME, was developed by CNRM and included for version 5, for CMIP5. The coupler is OASIS3, developed by CERFACS, and the model workflow is developed at CNRM. For CMIP5, CERFACS undertook decadal simulations, while CNRM took in charge the control, academic, historical, scenarios and paleo-climate simulations

2) MPI-ESM-LR (https://portal.enes.org/models/earthsystem-models/mpi-m/mpi-esm)

MPI-ESM (MPG) (Later called MPI) is a comprehensive Earth-System Model, in the sense that it consists of component models for the ocean, the atmosphere and the land surface. These components are coupled through the exchange of energy, momentum, water and important trace gases such as carbon dioxide. The model is developed by the MPI for Meteorology (MPI-M) and based on its predecessors, the ECHAM5/MPIOM coupled model and its COSMOS versions. ECHAM5/MPIOM was used for the simulations contributing to third phase of the coupled model inter-comparison project (CMIP3), and for the MPI-M Millennium project. MPI-ESM1 consists of general circulation models for the atmosphere (ECHAM6), the ocean and sea ice (MPIOM) - coupled by OASIS3 -, the land surface model JSBACH, and optionally includes dynamical land vegetation (DYNVEG), and marine biogeochemistry (HAMOCC). MPI-ESM1 was used as the basis for MPI-M's contribution to CMIP5 and is now used at about 45 institutions world-wide. A model version coupled to an aerosol and chemistry module (HAMMOZ) is developed jointly with partners in ENES.

3) ICHEC-EC-EARTH (https://portal.enes.org/models/earthsystem-models/ec-earth-1/ec-earth)

ICHEC-EC-EARTH release 2 (Later called ICHEC) was developed by the EC-Earth consortium, gathering a number of national weather services and universities from currently 11 countries in Europe. EC-Earth component models are IFS for the atmosphere, NEMO for the ocean, and LIM for the sea-ice, coupled through OASIS. More components and plans for incorporation are under development. EC-Earth current users include KNMI, SMHI , MetÉireann , DMI, Meteorologisk Institutt (Norway), and ETH Zürich. EC-Earth is used in coordinated model intercomparison projects (e.g. CMIP5 and the upcoming CMIP6) to make projections and predictions of near-term and end-of-the-century climate change and variability. The data is downscaled to a local level for Climate Services by partners in different European countries (notably the Netherlands, Sweden, Denmark, Italy, Spain, Ireland). Also many sensitivity studies are conducted.

4) IPSL-CM5A-MR (https://portal.enes.org/models/earthsystem-models/ipsl/ipslesm)

IPSL-CM5 (Later called IPSL) was developed by IPSL, includes 5 component models representing the Earth System climate and its carbon cycle: LMDz (atmosphere), NEMO (ocean, oceanic biogeochemistry and sea-ice), ORCHIDEE (continental surfaces and vegetation), and INCA (atmospheric chemistry), coupled through OASIS. IPSL modelling system also includes an I/O library (IOIPSL), an assembling and compiling environment (modipsl), an execution environment (libIGCM) and a set of post-processing tools. IPSLESM, available in different configurations at different resolutions, is in permanent evolution to reflect state-of-the-art numerical climate science. 80 IPSLESM users are registered in IPSL and associates laboratories while about 200 persons use one or more components separately. IPSL-CM5 is used in about 50 European projects and more than 550 projects access its IPCC result database

2.3 Downscaling by Regional Climate Models (RCMs) – The EURO-CORDEX project

EURO-CORDEX is the European branch of the international CORDEX initiative /5/, which is a program sponsored by the World Climate Research Program (WRCP) to organize an internationally coordinated framework to produce improved regional climate change projections for all land regions world-wide. The CORDEX-results will serve as input for climate change impact and adaptation studies within the timeline of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) and beyond. The CORDEX project /5/ has the vision to advance and coordinate the science and application of regional climate downscaling through global partnerships.

The extent of the EURO-CORDEX region (~ 27N – 72N, ~22W – 45E) is shown in Figure 2.2. Within this region, climate data are computed with a spatial resolution of .11 degree or about 12 km.

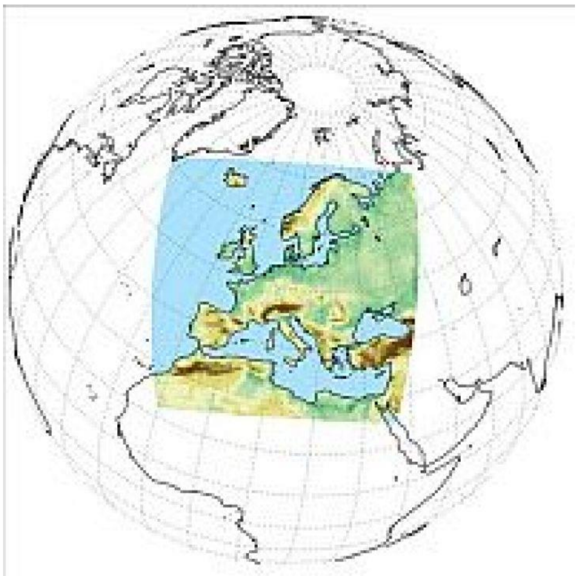


Figure 2.2 The EURO-CORDEX region (~ 27N – 72N, ~22W – 45E)

Within the EURO-CORDEX region the following type of climate data are available for downloading:

- Hindcast (ERA Interim): 1989 – 2008

- Control: 1951 – 2005 (1981 – 2010, 1951-80)

- Scenario: 2006 – 2100 (2011-40, 2041-70, 2071-2100)

The scenarios are based on global climate simulations from the CMIP5 long-term experiments up to the year 2100. They are based on three greenhouse gas emission scenarios (Representative Concentration Pathways, RCPs) corresponding to:

- Peaking radiative forcing within the 21st century at 3.0 W/m² and declining later (RCP2.6)
- Stabilization of radiative forcing after the 21st century at 4,5 W/m² (RCP4.5)
- Rising radiative forcing crossing 8.5 W/m² at the end of 21st century (RCP8.5)

In this study we only utilized data for RCP4.5 and RCP8.5.

2.4 Future climate and climate change in the Vanatori area

The projected future climate was computed for two different emissions scenarios (RCP4.5, RCP8.5) and four different GCMs (IPSL, CNRM, ICHEC, MPI), and simulated up to year 2100. The results were broken down into three different 25-year time periods (2016-2040, 2041-2065, 2075-2099). This was done in order to show the gradual change more clearly. The results, for precipitation and air temperature, were summarized to show monthly averages and presented both as tables and graphs. In addition to results for individual GCMs we also present the ensemble average for the four models and the Baseline which is the present climate (1980-2005). This ensemble average will later be used in the hydrological simulations, and the difference between baseline and future climate will be used to compute the climate change parameters, delta change as % for precipitation and ^{0}C for temperature.

2.3.1 Air temperature

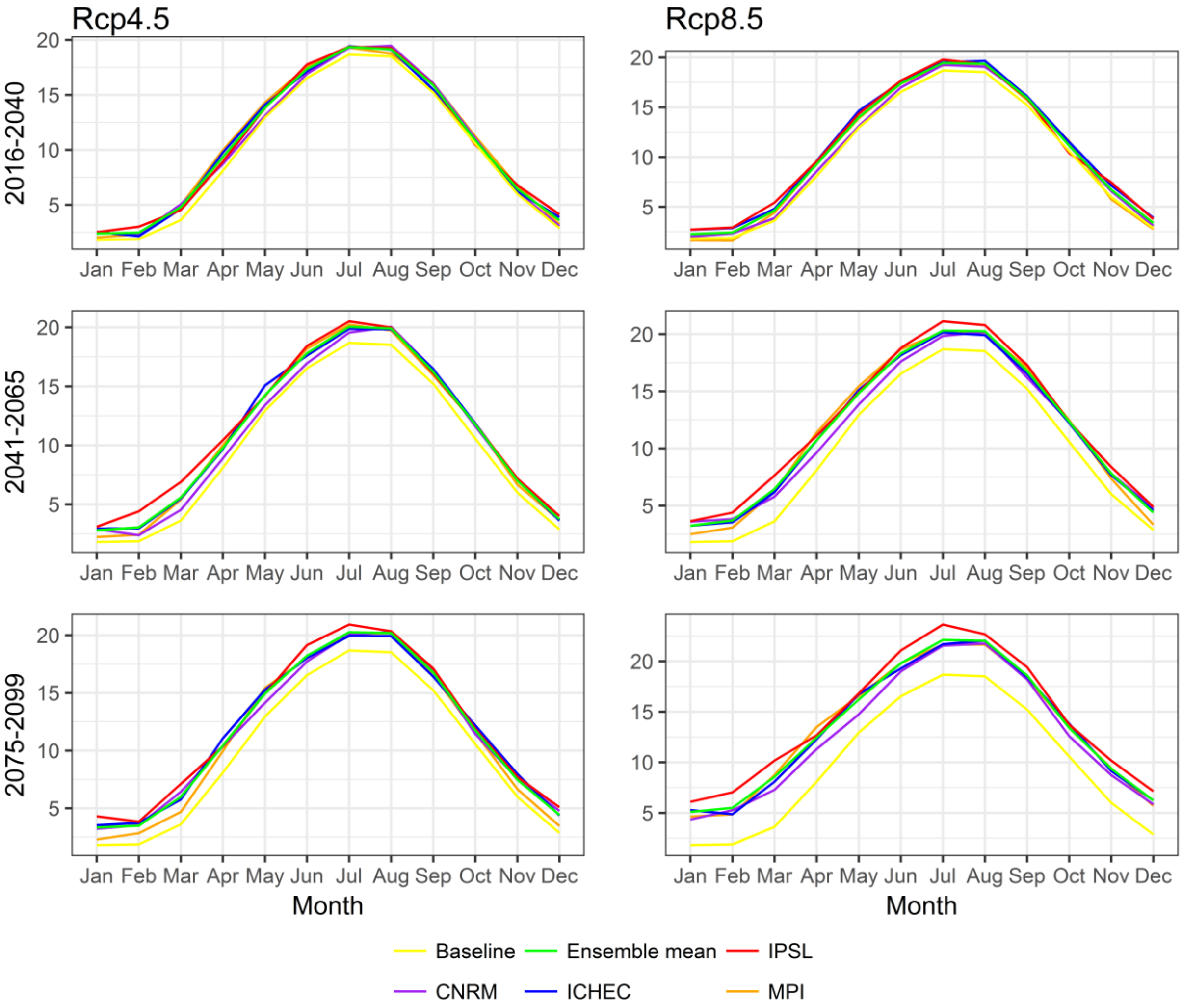


Figure 2.3 Future air temperature in the Vanatori area compared to baseline (1980-2005) for
- Three different future time periods (2016-2040, 2041-2060, 2075-2099)
- Four different GCMs (IPSL, CNRM, ICHEC, MPI) + ensemble mean, GCMs and RCPs
- Two different emission scenarios (RCP4.5, RCP8.5)

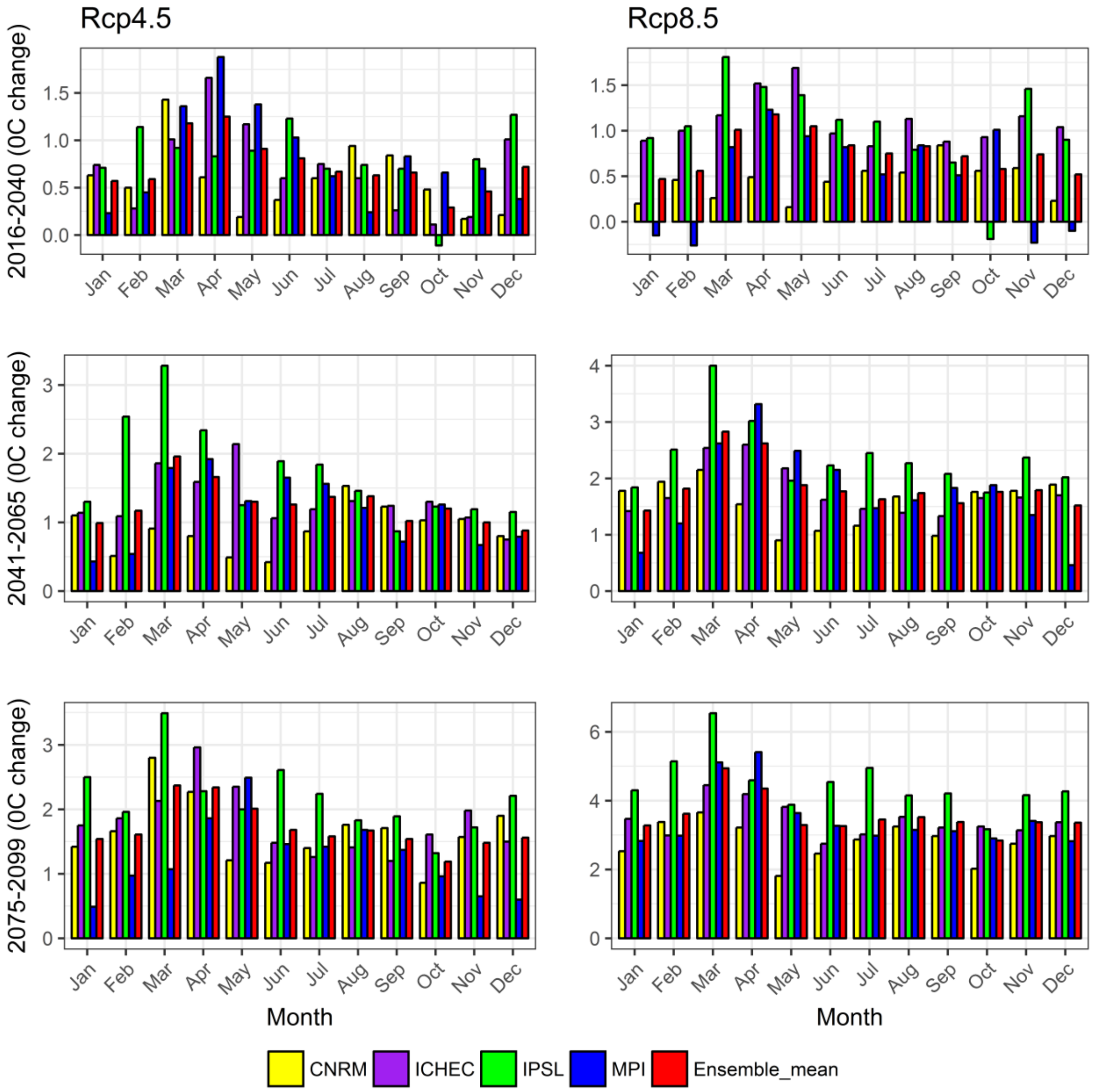


Figure 2.4 Change in air temperature in the Vanatori area compared to baseline (1980-2005) for
- Three different future time periods (2016-2040, 2041-2060, 2075-2099)
- Four different GCMs (IPSL, CNRM, ICHEC, MPI) + ensemble mean, GCMs and RCPs
- Two different emission scenarios (RCP4.5, RCP8.5)

Delta change (^{0}C) for Air Temperature RCP4.5					
Month	CNRM	ICHEC	IPSL	MPI	Ensemble_mean
Jan	0.63	0.74	0.71	0.23	0.57
Feb	0.50	0.28	1.14	0.45	0.59
Mar	1.43	1.01	0.92	1.36	1.18
Apr	0.61	1.66	0.83	1.88	1.25
May	0.19	1.17	0.89	1.38	0.91
Jun	0.37	0.60	1.23	1.03	0.81
Jul	0.60	0.75	0.70	0.62	0.67
Aug	0.94	0.60	0.74	0.24	0.63
Sep	0.84	0.26	0.70	0.83	0.66
Oct	0.48	0.11	-0.11	0.66	0.29
Nov	0.17	0.19	0.80	0.70	0.46
Dec	0.21	1.01	1.27	0.38	0.72

Delta change (^{0}C) for Air Temperature RCP4.5					
Month	CNRM	ICHEC	IPSL	MPI	Ensemble_mean
Jan	1.10	1.14	1.30	0.43	0.99
Feb	0.51	1.09	2.54	0.54	1.17
Mar	0.91	1.86	3.28	1.79	1.96
Apr	0.80	1.59	2.34	1.92	1.66
May	0.49	2.14	1.25	1.31	1.30
Jun	0.42	1.06	1.89	1.65	1.26
Jul	0.87	1.19	1.84	1.56	1.37
Aug	1.53	1.31	1.46	1.21	1.38
Sep	1.23	1.24	0.87	0.72	1.02
Oct	1.03	1.30	1.23	1.26	1.20
Nov	1.05	1.07	1.19	0.67	1.00
Dec	0.80	0.75	1.15	0.79	0.88

Delta change (^{0}C) for Air Temperature RCP4.5					
Month	CNRM	ICHEC	IPSL	MPI	Ensemble_mean
Jan	1.42	1.75	2.50	0.49	1.54
Feb	1.66	1.86	1.96	0.97	1.61
Mar	2.80	2.13	3.49	1.07	2.37
Apr	2.27	2.96	2.28	1.86	2.34
May	1.21	2.35	2.00	2.49	2.01
Jun	1.17	1.48	2.61	1.46	1.68
Jul	1.40	1.26	2.24	1.42	1.58
Aug	1.76	1.41	1.83	1.68	1.67
Sep	1.71	1.20	1.89	1.37	1.54
Oct	0.86	1.61	1.32	0.96	1.19
Nov	1.57	1.98	1.72	0.65	1.48
Dec	1.90	1.50	2.21	0.60	1.56

Table 2.1 Projected change in Air Temperature (^{0}C) for RCP4.5 for 2016-40 (Left), 2041-65 (Mid) and 2075-99 (Right)

Delta change (^{0}C) for Air Temperature at RCP8.5					
Month	CNRM	ICHEC	IPSL	MPI	Ensemble_mean
Jan	0.20	0.89	0.92	-0.15	0.47
Feb	0.46	1.00	1.05	-0.26	0.56
Mar	0.26	1.17	1.81	0.82	1.01
Apr	0.49	1.52	1.48	1.23	1.18
May	0.16	1.69	1.39	0.94	1.05
Jun	0.44	0.97	1.12	0.82	0.84
Jul	0.56	0.83	1.10	0.52	0.75
Aug	0.54	1.13	0.79	0.84	0.83
Sep	0.84	0.88	0.65	0.51	0.72
Oct	0.56	0.93	-0.19	1.01	0.58
Nov	0.59	1.16	1.46	-0.23	0.74
Dec	0.23	1.04	0.90	-0.10	0.52

Delta change (^{0}C) for Air Temperature at RCP8.5					
Month	CNRM	ICHEC	IPSL	MPI	Ensemble_mean
Jan	1.78	1.42	1.84	0.68	1.43
Feb	1.94	1.65	2.51	1.20	1.82
Mar	2.15	2.54	4.00	2.62	2.83
Apr	1.54	2.60	3.02	3.32	2.62
May	0.90	2.18	1.96	2.49	1.88
Jun	1.07	1.62	2.23	2.15	1.77
Jul	1.16	1.46	2.45	1.47	1.63
Aug	1.68	1.39	2.27	1.61	1.74
Sep	0.98	1.33	2.08	1.83	1.56
Oct	1.76	1.65	1.75	1.88	1.76
Nov	1.78	1.66	2.37	1.35	1.79
Dec	1.89	1.70	2.02	0.46	1.52

Delta change (^{0}C) for Air Temperature at RCP8.5					
Month	CNRM	ICHEC	IPSL	MPI	Ensemble_mean
Jan	2.53	3.47	4.30	2.83	3.28
Feb	3.38	2.99	5.14	2.98	3.62
Mar	3.66	4.45	6.54	5.11	4.94
Apr	3.22	4.19	4.59	5.41	4.35
May	1.81	3.82	3.88	3.64	3.29
Jun	2.46	2.75	4.54	3.27	3.26
Jul	2.87	3.02	4.95	2.98	3.45
Aug	3.25	3.53	4.15	3.15	3.52
Sep	2.97	3.22	4.21	3.11	3.38
Oct	2.02	3.25	3.17	2.90	2.84
Nov	2.75	3.14	4.16	3.41	3.37
Dec	2.97	3.37	4.27	2.82	3.36

Table 2.2 Projected change in Air Temperature (^{0}C) for RCP8.5 for 2016-40 (Left), 2041-65 (Mid) and 2075-99 (Right)

2.3.2 Precipitation

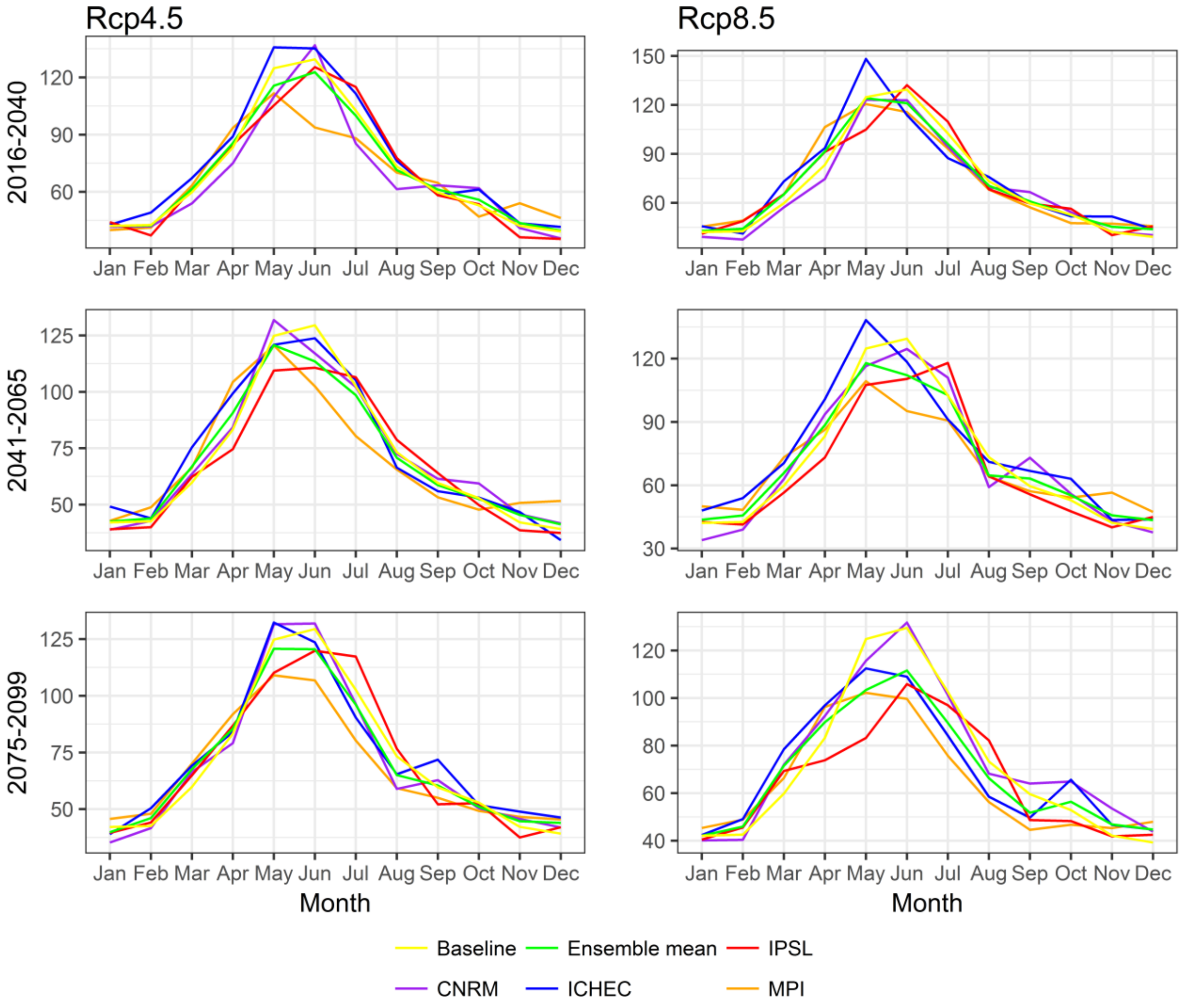


Figure 2.5 Future precipitation in the Vanatori area compared to baseline (1980-2005) for
- Three different future time periods (2016-2040, 2041-2060, 2075-2099)
- Four different GCMs (IPSL, CNRM, ICHEC, MPI) + ensemble mean, GCMs and RCPs
- Two different emission scenarios (RCP4.5, RCP8.5)

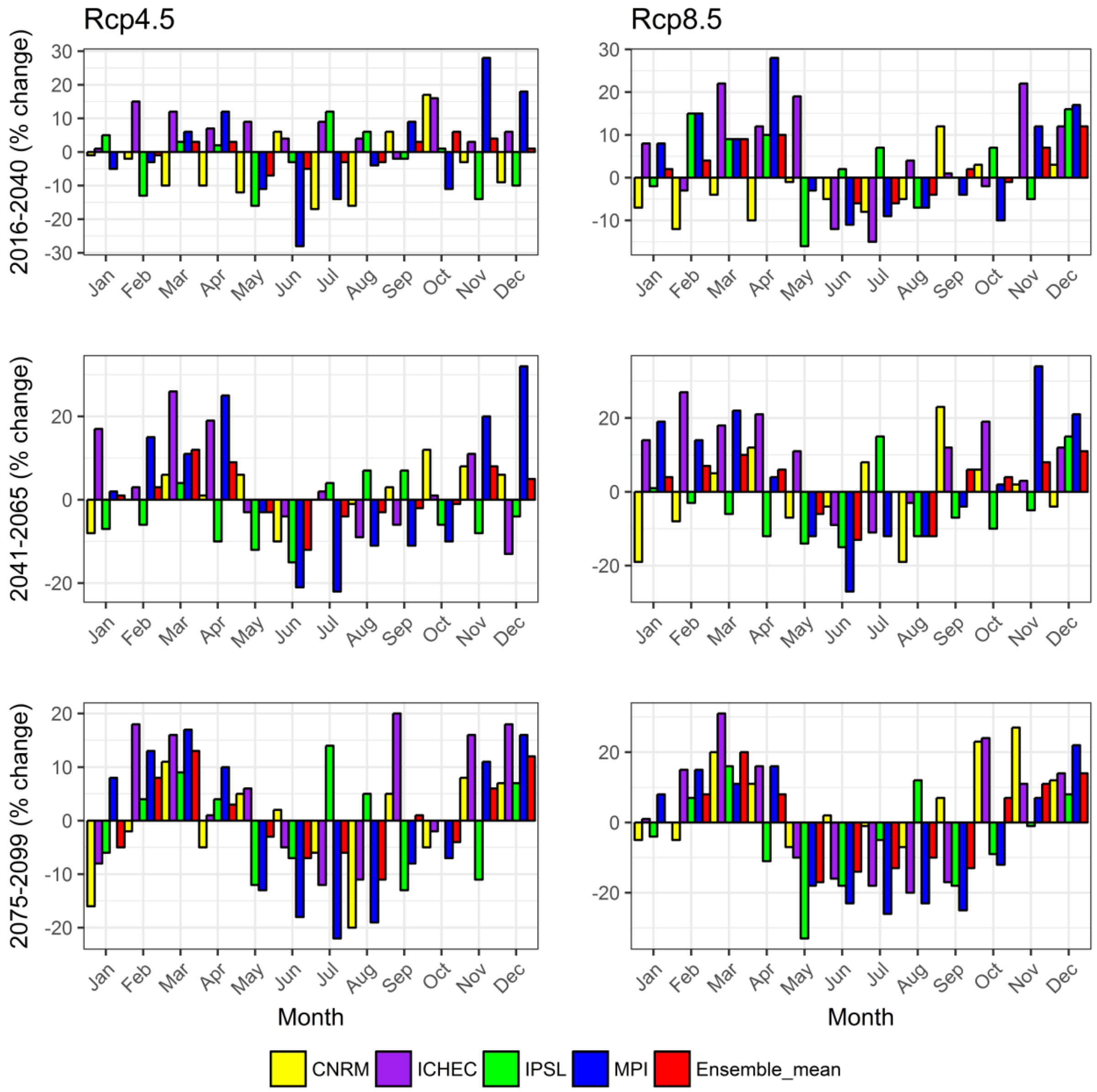


Figure 2.6 Change in precipitation in the Vanatori area compared to baseline (1980-2005) for
- Three different future time periods (2016-2040, 2041-2060, 2075-2099)
- Four different GCMs (IPSL, CNRM, ICHEC, MPI) + ensemble mean, GCMs and RCPs
- Two different emission scenarios (rcp4.5, rcp8.5)

From this figure, we can see seasonal changes in both emission scenarios (Rcp4.5 and Rcp8.5). In general, from January to April both rcp4.5 and rcp8.5 predicts increased precipitation (1% to +20%), and similarly during October – December the precipitation increases from +1% to +12%. However, during the rainy periods (May – September) there is decreased precipitation (-12% to -3%).

Delta change (%) for Precipitation, RCP4.5					
Month	CNRM	ICHEC	IPSL	MPI	Ensemble_mean
Jan	-1	1	5	-5	0
Feb	-2	15	-13	-3	-1
Mar	-10	12	3	6	3
Apr	-10	7	2	12	3
May	-12	9	-16	-11	-7
Jun	6	4	-3	-28	-5
Jul	-17	9	12	-14	-3
Aug	-16	4	6	-4	-3
Sep	6	-2	-2	9	3
Oct	17	16	1	-11	6
Nov	-3	3	-14	28	4
Dec	-9	6	-10	18	1

Delta change (%) for Precipitation, RCP4.5					
Month	CNRM	ICHEC	IPSL	MPI	Ensemble_mean
Jan	-8	17	-7	2	1
Feb	0	3	-6	15	3
Mar	6	26	4	11	12
Apr	1	19	-10	25	9
May	6	-3	-12	-3	-3
Jun	-10	-4	-15	-21	-12
Jul	0	2	4	-22	-4
Aug	-1	-9	7	-11	-3
Sep	3	-6	7	-11	-2
Oct	12	1	-6	-10	-1
Nov	8	11	-8	20	8
Dec	6	-13	-4	32	5

Delta change (%) for Precipitation, RCP4.5					
Month	CNRM	ICHEC	IPSL	MPI	Ensemble_mean
Jan	-16	-8	-6	8	-5
Feb	-2	18	4	13	8
Mar	11	16	9	17	13
Apr	-5	1	4	10	3
May	5	6	-12	-13	-3
Jun	2	-5	-7	-18	-7
Jul	-6	-12	14	-22	-6
Aug	-20	-11	5	-19	-11
Sep	5	20	-13	-8	1
Oct	-5	-2	0	-7	-4
Nov	8	16	-11	11	6
Dec	7	18	7	16	12

Table 2.3 Projected change in precipitation (%) for RCP4.5 for 2016-40 (Left), 2041-65 (Mid) and 2075-99 (Right)

Delta change (%) for Precipitation, RCP8.5					
Month	CNRM	ICHEC	IPSL	MPI	Ensemble_mean
Jan	-7	8	-2	8	2
Feb	-12	-3	15	15	4
Mar	-4	22	9	9	9
Apr	-10	12	10	28	10
May	-1	19	-16	-3	0
Jun	-5	-12	2	-11	-6
Jul	-8	-15	7	-9	-6
Aug	-5	4	-7	-7	-4
Sep	12	1	0	-4	2
Oct	3	-2	7	-10	-1
Nov	0	22	-5	12	7
Dec	3	12	16	17	12

Delta change (%) for Precipitation, RCP8.5					
Month	CNRM	ICHEC	IPSL	MPI	Ensemble_mean
Jan	-19	14	1	19	4
Feb	-8	27	-3	14	7
Mar	5	18	-6	22	10
Apr	12	21	-12	4	6
May	-7	11	-14	-12	-6
Jun	-4	-9	-15	-27	-13
Jul	8	-11	15	-12	0
Aug	-19	-3	-12	-12	-12
Sep	23	12	-7	-4	6
Oct	6	19	-10	2	4
Nov	2	3	-5	34	8
Dec	-4	12	15	21	11

Delta change (%) for Precipitation, RCP8.5					
Month	CNRM	ICHEC	IPSL	MPI	Ensemble_mean
Jan	-5	1	-4	8	0
Feb	-5	15	7	15	8
Mar	20	31	16	11	20
Apr	11	16	-11	16	8
May	-7	-10	-33	-18	-17
Jun	2	-16	-18	-23	-14
Jul	-1	-18	-5	-26	-13
Aug	-7	-20	12	-23	-10
Sep	7	-17	-18	-25	-13
Oct	23	24	-9	-12	7
Nov	27	11	-1	7	11
Dec	12	14	8	22	14

Table 2.4 Projected change in Precipitation (%) for RCP8.5 for 2016-40 (Left), 2041-65 (Mid) and 2075-99 (Right)

3 Impact on water resources

The expected changes in precipitation and air temperature will most probably lead to changes in hydrology and water resources, this could be both positive (increasing) and negative (decreasing), depending on magnitude and direction of change. A change in temperature will lead to change in potential evaporation, and a change in runoff even if precipitation change is small. It is therefore necessary to include both temperature and precipitation changes in order to assess the total impact on hydrology.

The methodology used here will consist of the following steps:

- Select a hydrological (Rainfall-Runoff) model that can be used to convert climate to runoff
- If possible, calibrate the model (parameters) to fit the catchment in question best possible
- Run the calibrated model to compute time-series of flow for the baseline period (1981-2005)
- Run the model for future climate scenarios, using baseline climate + Delta change factors
- Compare future runoff to baseline runoff to see and quantify possible changes

3.1 Model selection

For this analysis we choose to use the HBV Rainfall-Runoff model. Actually it is more correct to talk about it as a Precipitation-Runoff Model since it can handle precipitation also as snow, and it can simulate the snow storage and even glacier storage and melt if needed. The HBV-model has been widely tested and used also in this region, and is known to produce reliable results if input data are good. The model requires the following input data (daily time-series data):

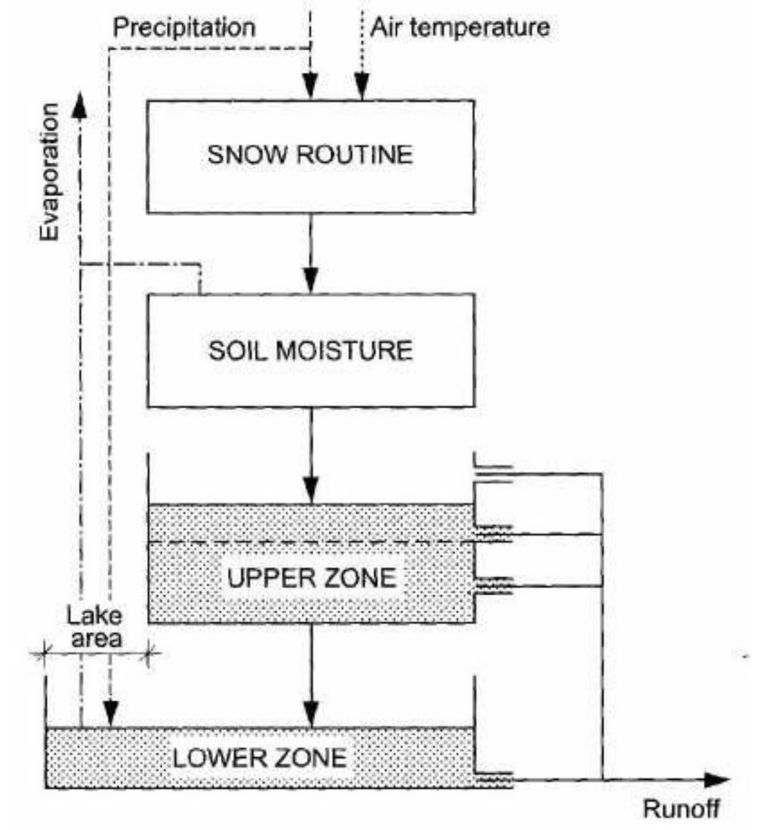
- Precipitation
- Air temperature
- Potential evaporation

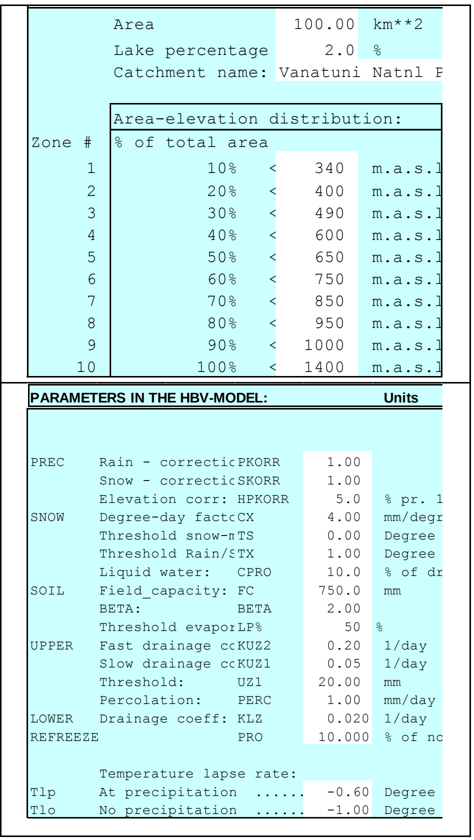
In addition, the model requires topographic data like catchment area, area-elevation distribution, lake percentage and glacier percentage in different heights, if relevant. We here use the “standard” version of the model commonly used for inflow and flood forecasting to most hydropower plants in Norway, see Figure 3.1. The model used here is an Excel-based version developed at NTNU and used for teaching and research applications, but also used in a wide range of operational applications, in Norway and other countries in Europe.

3.2 Model calibration

Usually, this type of models should be fitted (calibrated) to the catchment in question, by running the model with observed climatic and runoff data for a number of years, as a rule-of-thumb at least 5 years. In this case, this was not possible, since we could not get runoff data for catchment in the Vanatori area. But since the model will mainly be used for determining changes in the hydrology, we do not see the lack of calibration as a big problem.

We have defined a catchment of 100 km2 in the area, assuming topography and elevation typical for the Vanatori area. Then, we have selected model parameters by comparing to calibrations from a range of similar catchments and used these for the simulations.





Area	100.00	km**2
Lake percentage	2.0	%
Catchment name:	Vanatuni Natnl P	

Zone #	Area-elevation distribution: % of total area			
1	10%	<	340	m.a.s.l
2	20%	<	400	m.a.s.l
3	30%	<	490	m.a.s.l
4	40%	<	600	m.a.s.l
5	50%	<	650	m.a.s.l
6	60%	<	750	m.a.s.l
7	70%	<	850	m.a.s.l
8	80%	<	950	m.a.s.l
9	90%	<	1000	m.a.s.l
10	100%	<	1400	m.a.s.l

PARAMETERS IN THE HBV-MODEL:				Units
PREC	Rain - correctic	PKORR	1.00	
	Snow - correctic	SKORR	1.00	
	Elevation corr:	HPKORR	5.0	% pr. 1
SNOW	Degree-day factc	CX	4.00	mm/degr
	Threshold snow-m	TS	0.00	Degree
	Threshold Rain/S	TX	1.00	Degree
	Liquid water:	CPRO	10.0	% of dr
SOIL	Field_capacity:	FC	750.0	mm
	BETA:	BETA	2.00	
	Threshold evapor	LP%	50	%
UPPER	Fast drainage cc	KUZ2	0.20	1/day
	Slow drainage cc	KUZ1	0.05	1/day
	Threshold:	UZ1	20.00	mm
	Percolation:	PERC	1.00	mm/day
LOWER	Drainage coeff:	KLZ	0.020	1/day
REFREEZE		PRO	10.000	% of nc
	Temperature lapse rate:			
Tlp	At precipitation	......	-0.60	Degree
Tlo	No precipitation	......	-1.00	Degree

Figure 3.1 Structure of the HBV-model (from /8/) and model parameters used

3.3 Creating a baseline runoff time-series

By running the model with the baseline climate (as described before) we can compute runoff from this theoretical catchment. An example from this simulation is given in Figure 3.2, this is for the hydrological year 1. September 2002 to 31. August 2003. It is usually good to start simulations in the early autumn, when all old snow has melted away in the mountains and before any new snow starts accumulating.

From the figure it can be seen that that air temperature falls below zero in the winter, and the model has periods where snowmelt is contributing significantly to the runoff. Closer checking reveals that the model seems to give reasonable hydrographs for a catchment in this mountainous region, but a real calibration is not possible due to lack of data.

The seasonal distributions of flow can be seen in Figure 3.3 and 3.4. In Figure 3.4 a comparison is made to measured flow in Siret river at the closest gauging station Dragesti, a station with a catchment area of 11811 km^2. Data for Siret at Dragesti have been supplied by the global GRDC database. By comparing monthly average flows (Figure 3.4) we can see that the simulated flows for the Vanatori catchment actually seems quite good. The Siret-Dragesti station and catchment are at much lower elevation than Vanatori, explaining the earlier start of snowmelt and runoff in March-April but otherwise the seasonal distribution is quite similar. Average specific simulated flow is at 11 l/s*km2, this also compares well to what we can see in Figure 1.8.

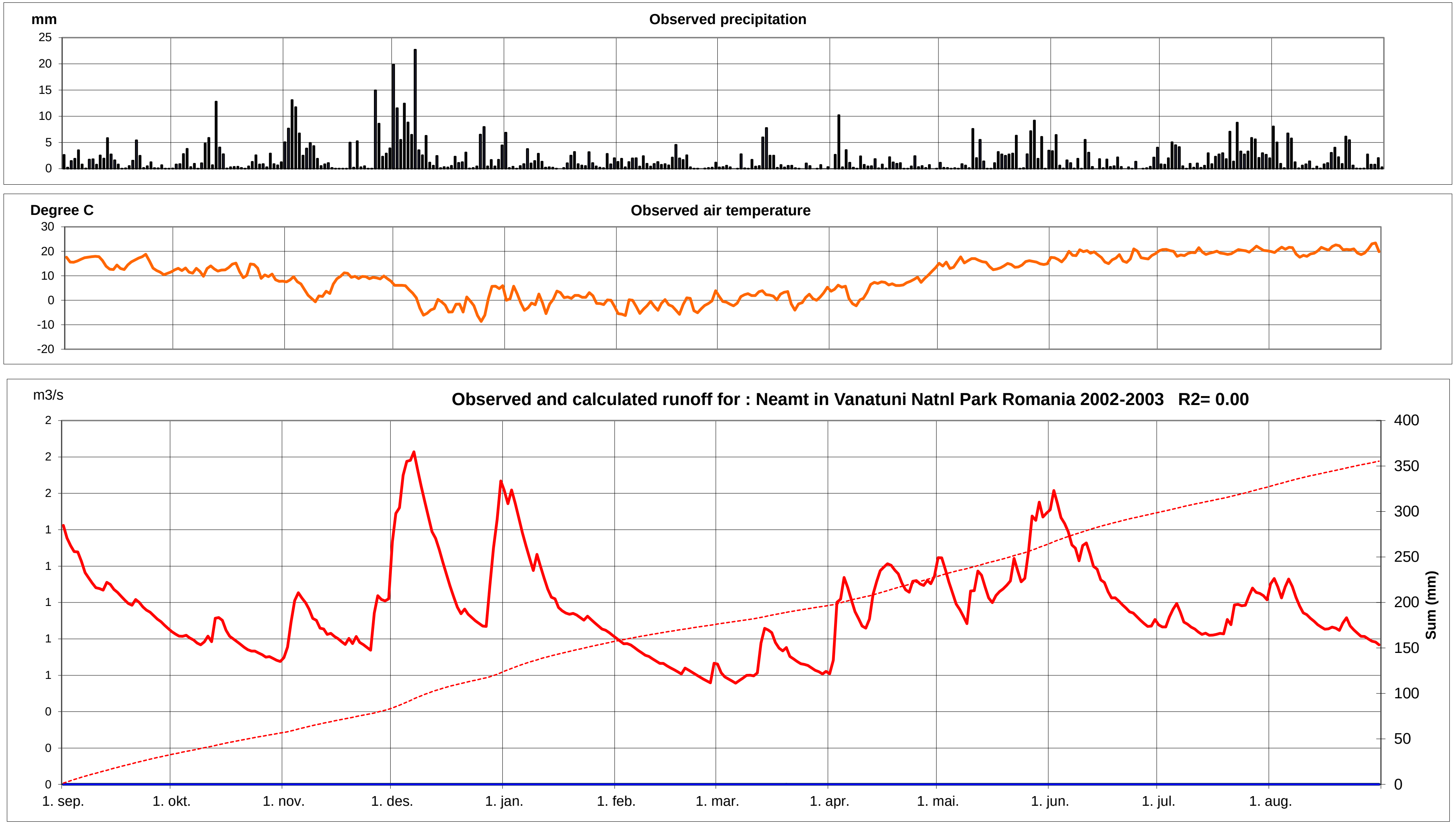


Figure 3.2 Precipitation (upper), temperature (middle) and HBV-simulated flow (bottom) from a 100 km2 catchment in Vanatori area

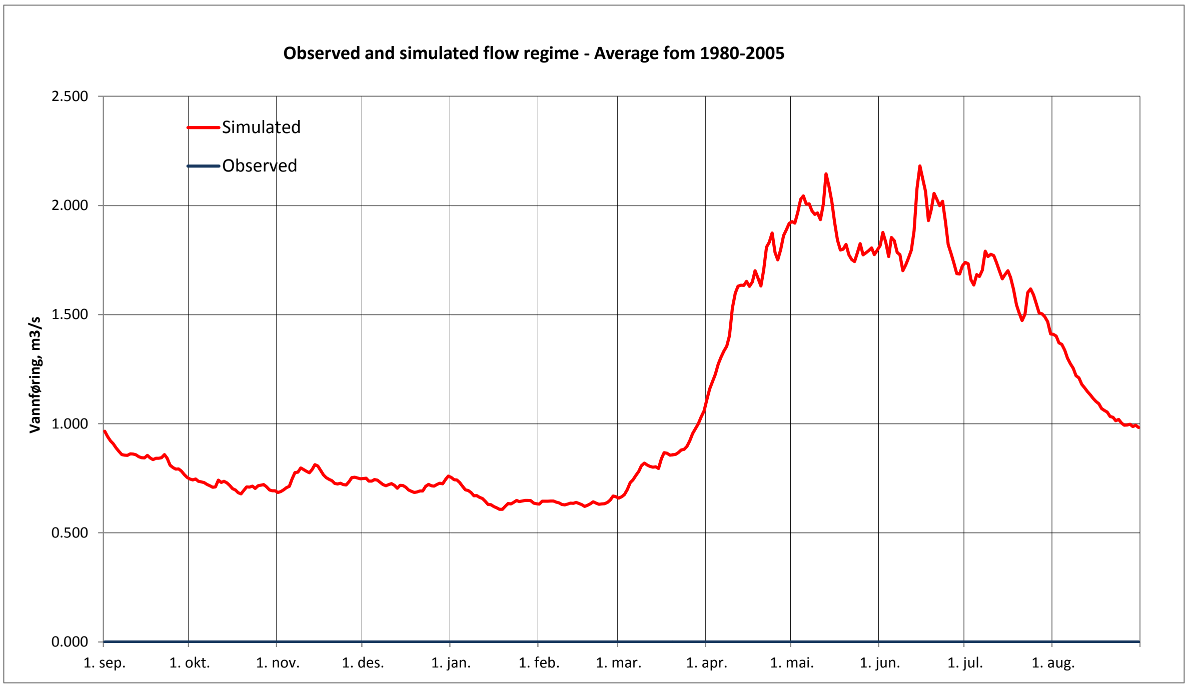


Figure 3.3 Average annual distribution of simulated runoff for Vanatori 1980-2005

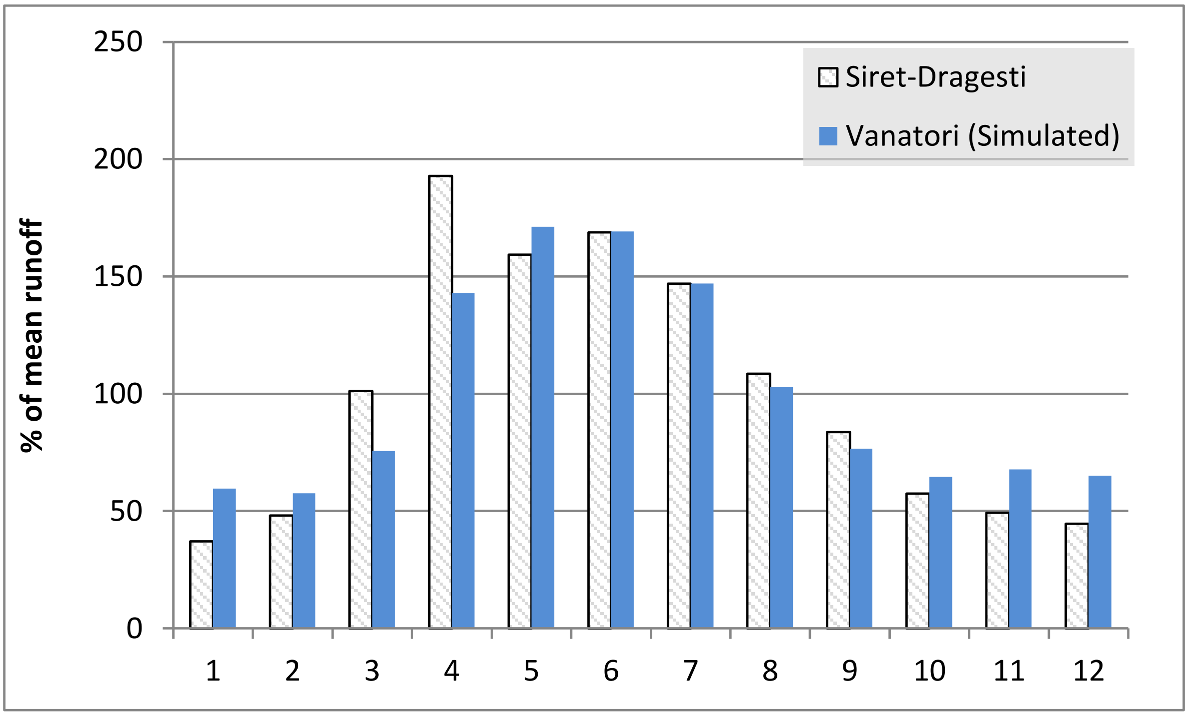


Figure 3.4 Comparison - seasonal distribution of simulated flow in Vanatori and Siret at Dragesti

3.4 Simulating future runoff

With a calibrated and verified HBV-model it is now possible to simulate future runoff for different climate scenarios, and compare these to the baseline computed and documented in Chapter 3.3. The simulations are done by using the Delta-change approach, always using the same baseline climate time-series (P, T and PET) and modifying these by Delta-change factors as computed and documented in Tables 2.1, 2.2, 2.3 and 2.4. The change in potential evaporation is computed by using the Thorntwaite method as documented by Rosenberg /9/. This method makes it possible to compute PET from air temperature and geographical location only, and allows us to quantify the impact of temperature change on PET and thereby on runoff.

In order to limit the number of simulation alternatives we decided to run only one emission scenario (RCP8.5) and use the Ensemble average for all four GCMs. It is, of course, possible to run all the other alternatives with individual GCMs and for RCP4.5. The methodology is the same, and all data have been compiled and presented in the Tables 2.1-2.4.

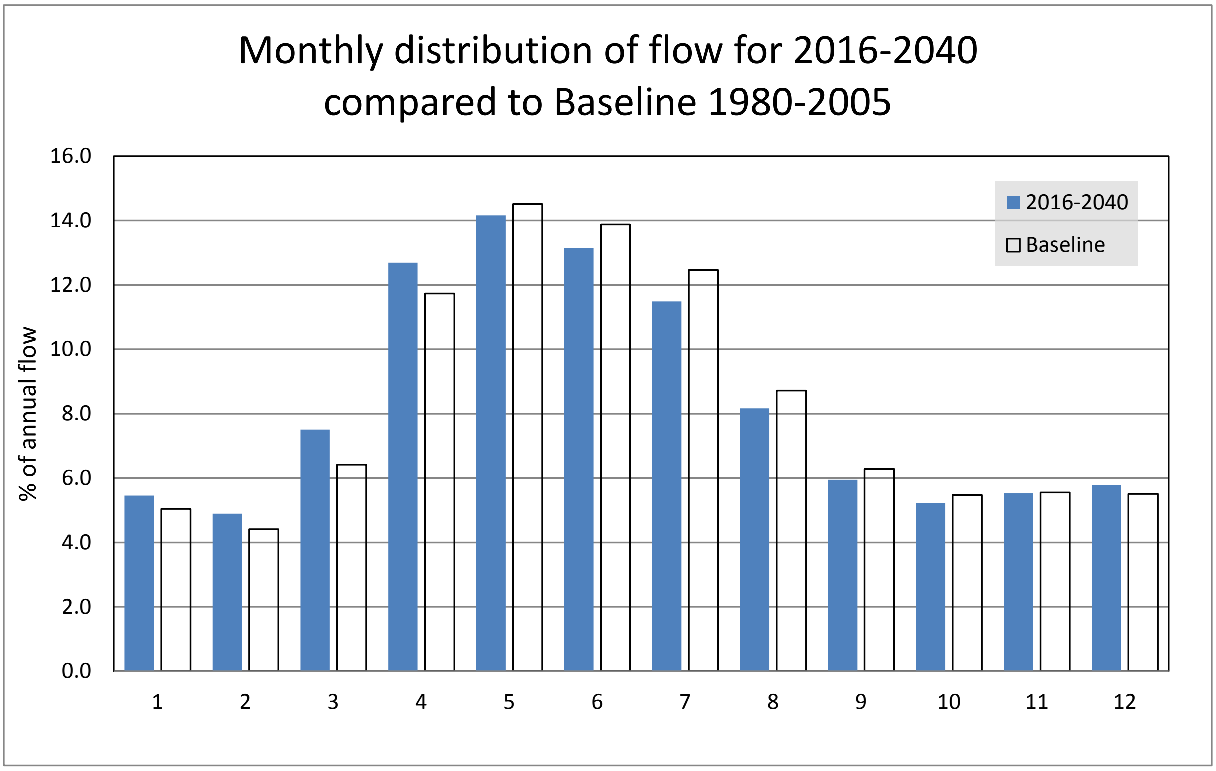
It is difficult to visualize the many different results, but here we focus on two types of diagrams in order to show the difference from Baseline scenario (1980-2005) to the three different future scenarios each covering a period of 25 years: 2016-2040, 2041-2065 and 2075-2099. The two type of diagrams are shown in Figure 3.5, 3.6 and 3.7. For each the upper bar-plot show a comparison of monthly average future flow and the baseline flow, the lower graph show duration curves for each of the two alternatives, computed from 25 years of daily flow. In order to see both high and low flows in the same diagram the y-axis of the duration curves are in logarithmic scale. Data for duration curves are given numerically in Table 3.2. Some more results are given in Figure 3.8 and 3.9.

Change in average flow is summarized in Table 3.1. With the highest emission scenario, RCP8.5, there will be a gradually lower runoff for the area, a small reduction of only 1% in the first 25 years, then increasing to 10% in the second period and up to 25% reduction in the last period, 2075-99. A significant part of the reduction can be explained by increased evaporation due to higher temperature, the rest is because of reduced precipitation.

When the runoff is reduced as shown in Table 3.1, less water will also be available for hydropower generation. The fourth column in the table shows volume of runoff water from a catchment of 100 km^2. A simplified calculation of hydropower potential can be done if head is assumed or known. Here we assume a head of 100m, each m^3 of water will generate approximately 0.25 kWh of energy and the total potential for hydropower generation is shown in the last column. According to this, the climate change could reduce the potential from 8.7 GWh/year to 6.6 GWh/year by 2099. A more detailed and realistic computation of hydropower generation can be found in next chapter.

Scenario	Average flow, Q_m m^3/s	% of baseline	Runoff volume, Mill.m^3/yr	Potential Energy, GWh
Baseline	1.110	100	35.0	8.7
2016-2040	1.104	99	34.8	8.7
2041-2065	1.003	90	31.6	7.9
2075-2099	0.832	75	26.2	6.6

Table 3.1 Simulated runoff and hydropower generation potential for 4 climate scenarios



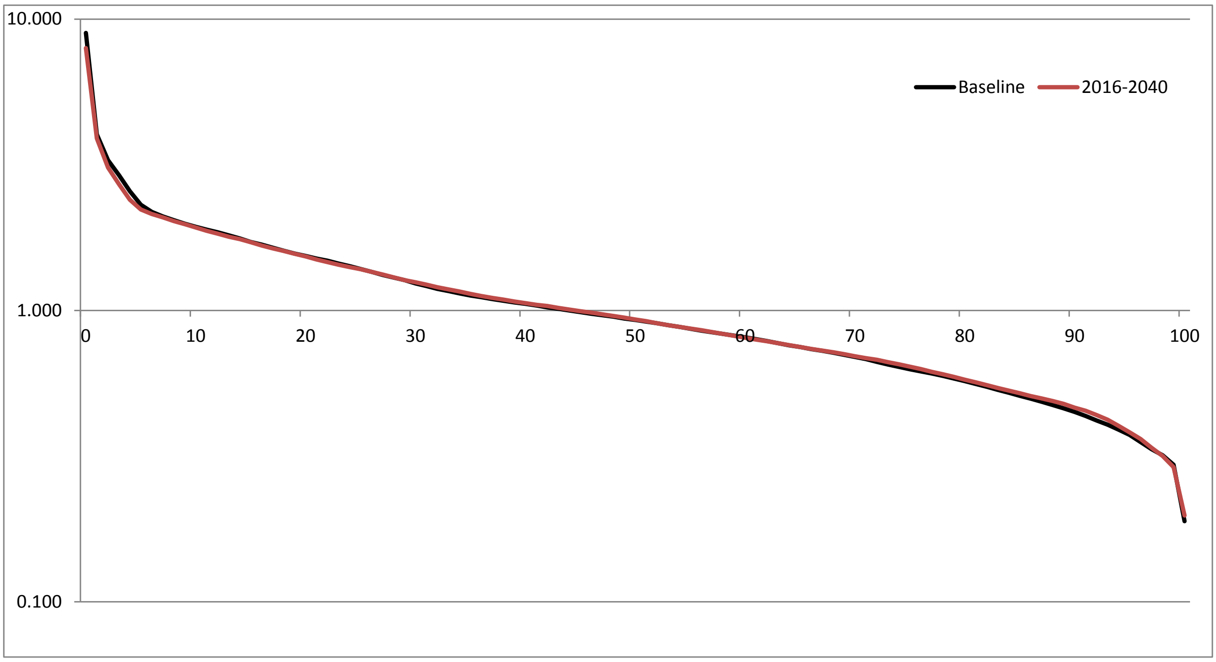
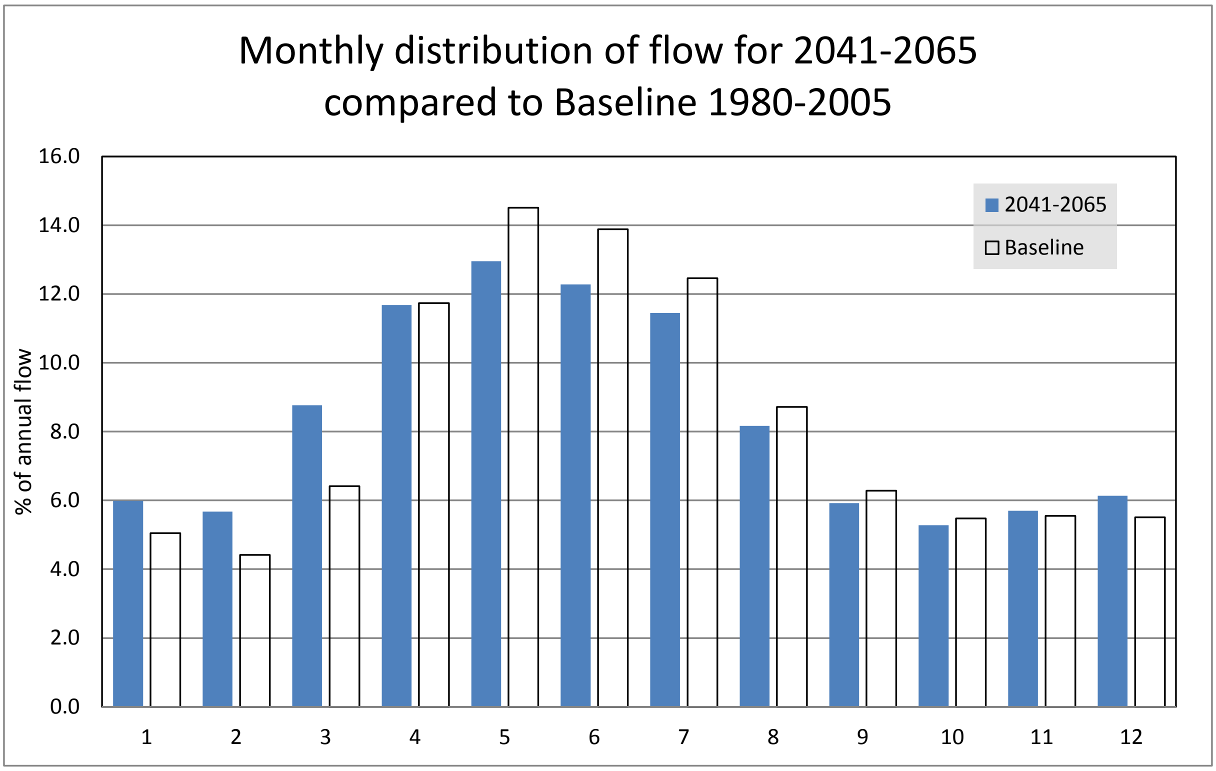


Figure 3.5 Simulated future flow statistics – 2016-2040



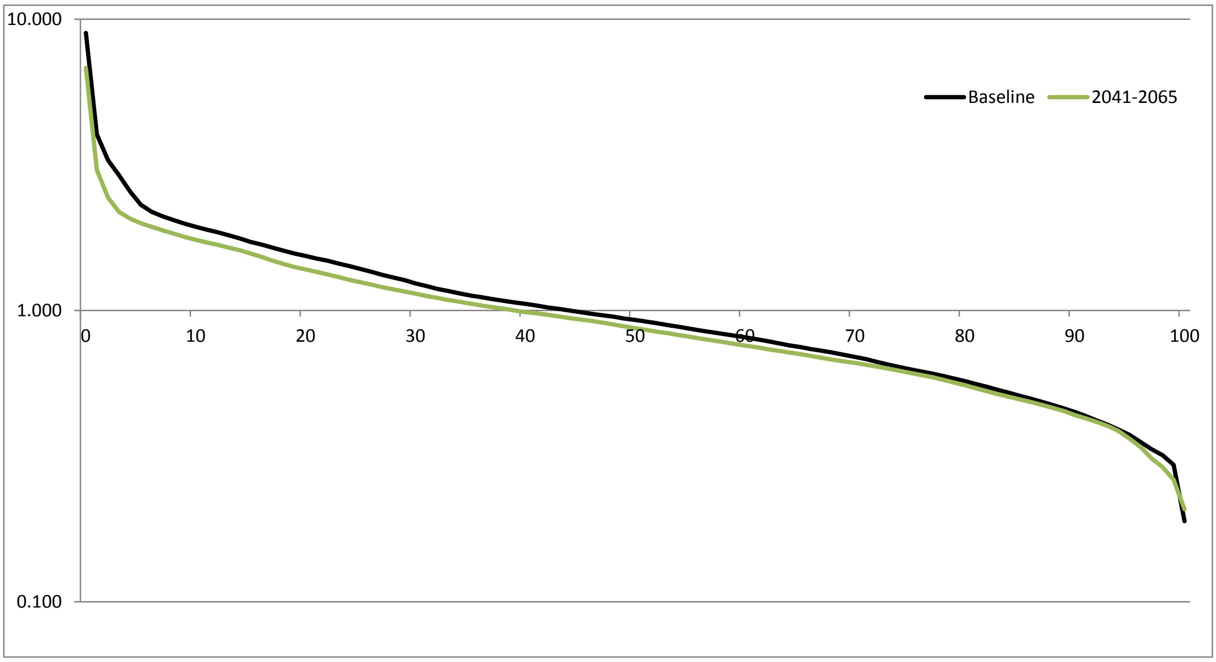
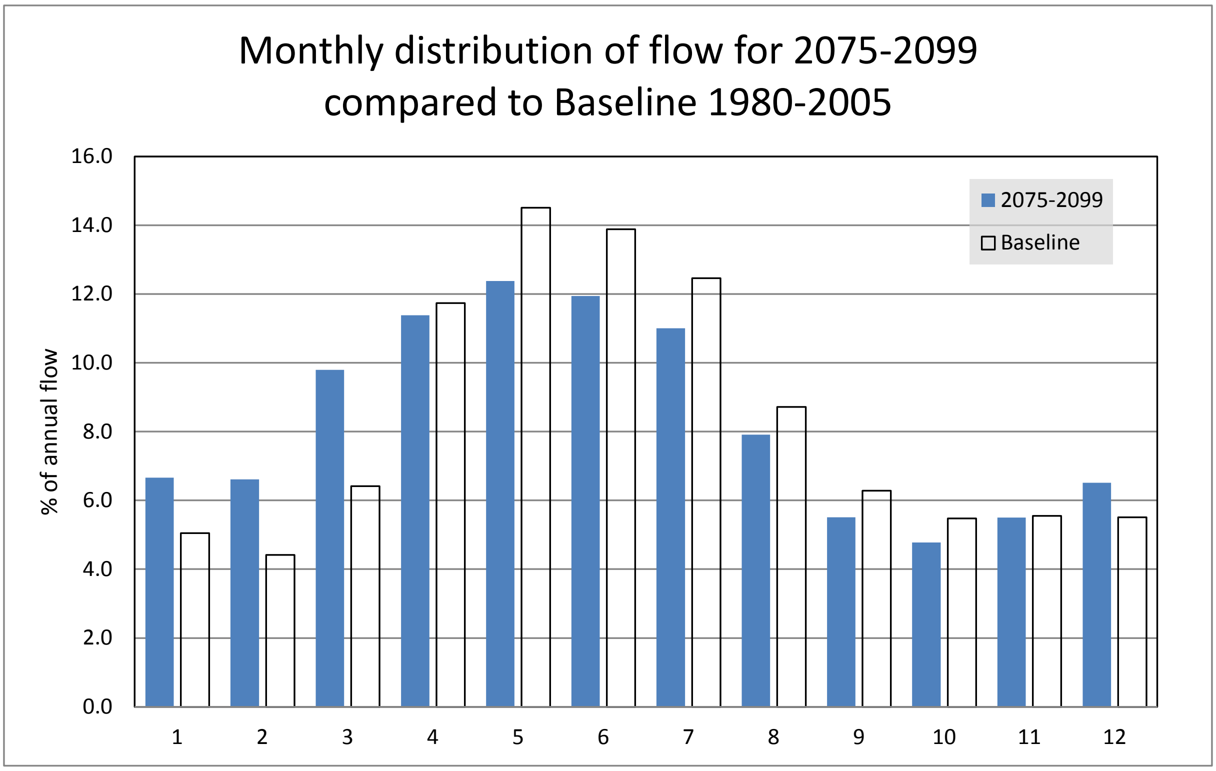


Figure 3.6 Simulated future flow statistics – 2041-2065



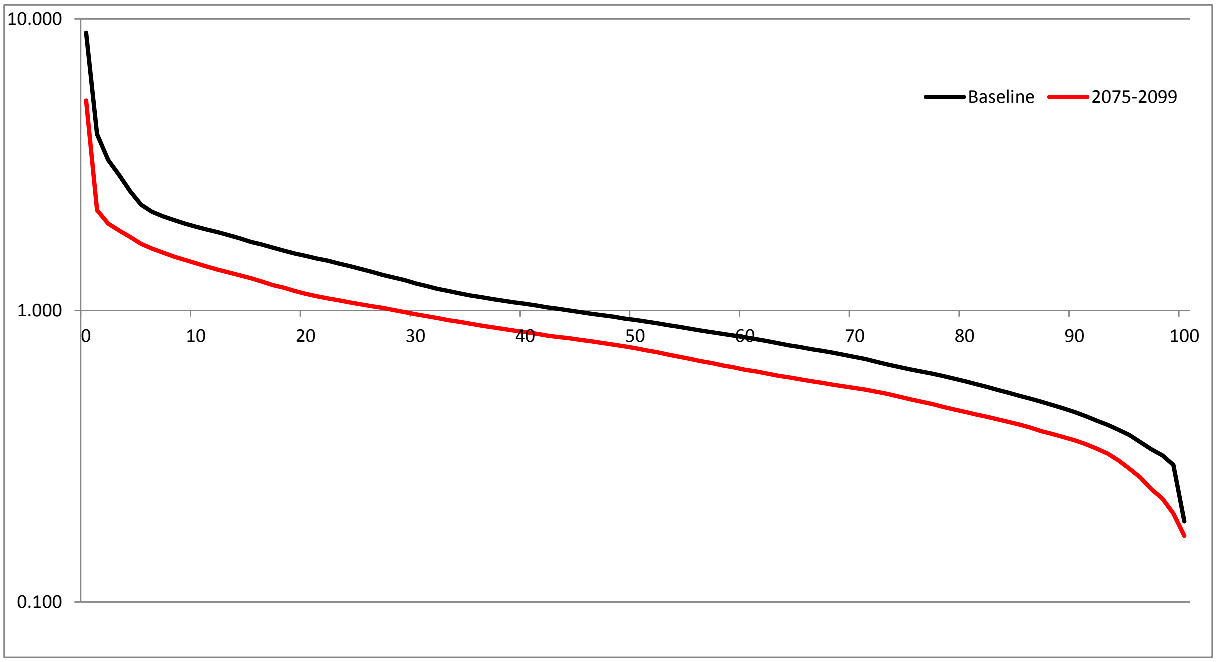


Figure 3.7 Simulated future flow statistics – 2075-2099

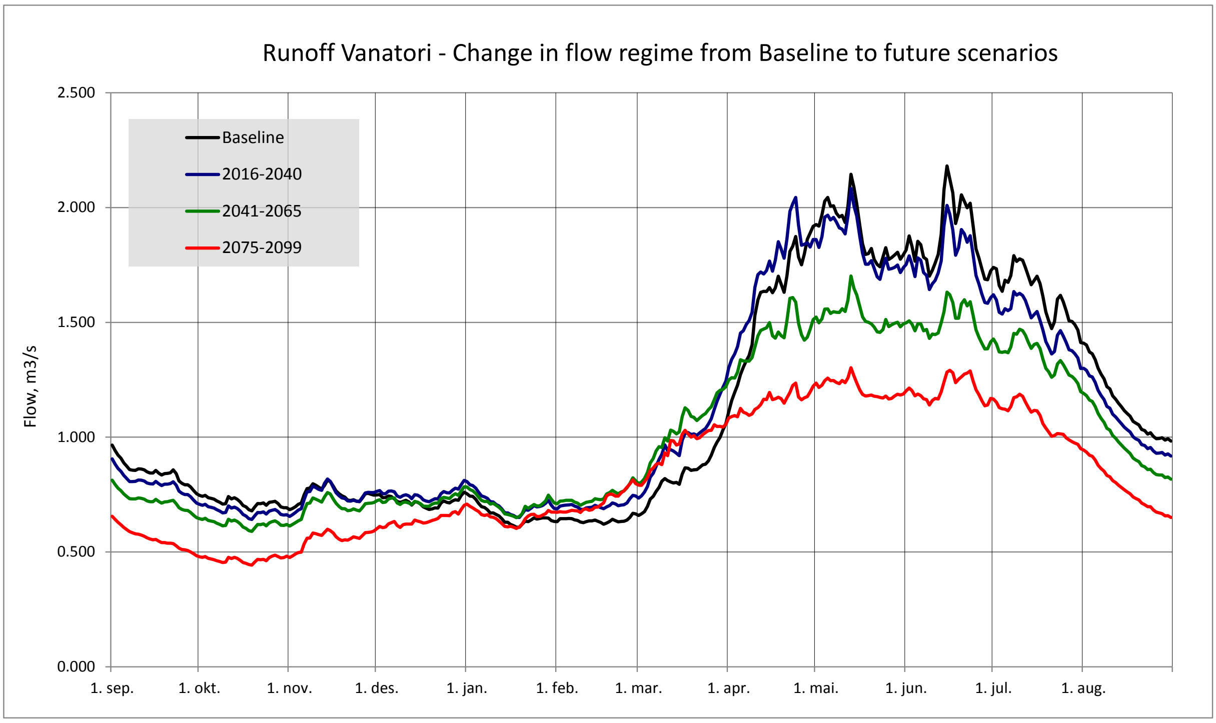


Figure 3. 8 Change in seasonal flow

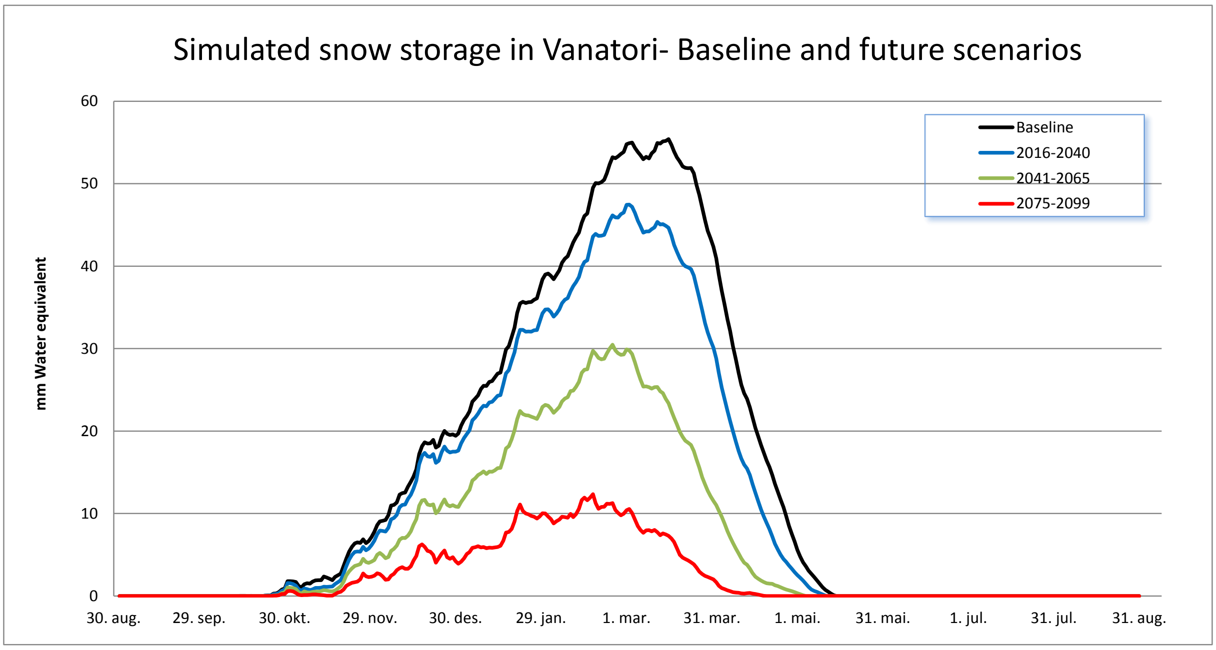
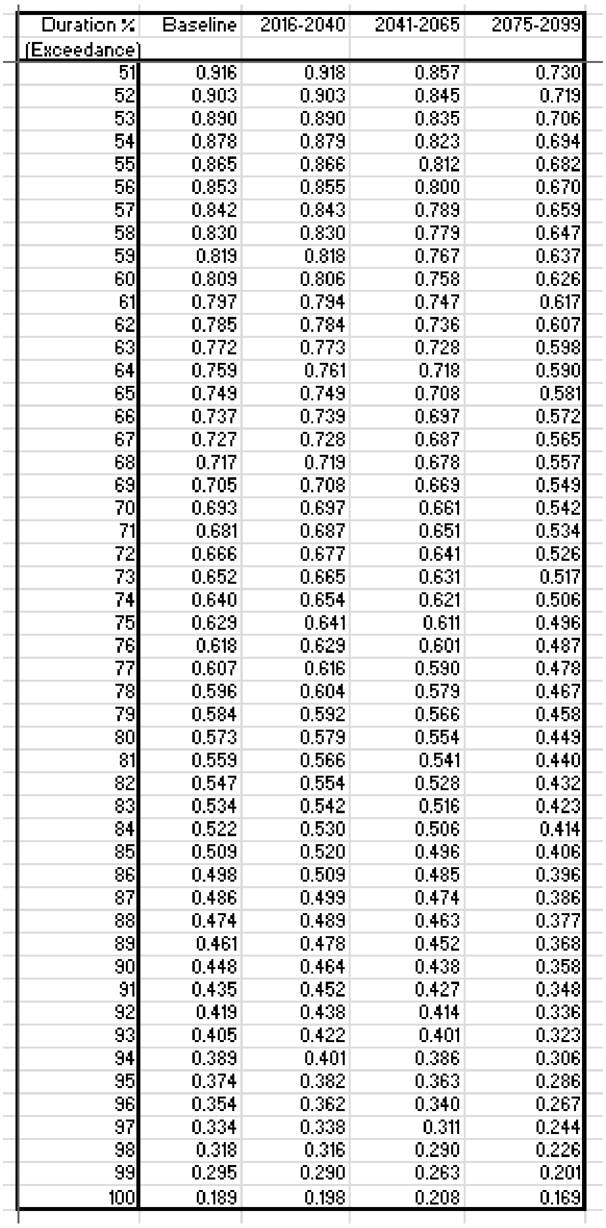


Figure 3.9 Change in snow storage

Duration % (Exceedance)	Baseline	2016-2040	2041-2065	2075-2099
0	8.969	7.949	6.792	5.246
1	4.022	3.894	3.045	2.207
2	3.282	3.098	2.440	1.987
3	2.915	2.716	2.178	1.879
4	2.566	2.400	2.069	1.788
5	2.305	2.222	1.992	1.691
6	2.180	2.144	1.937	1.630
7	2.104	2.089	1.885	1.579
8	2.041	2.028	1.834	1.531
9	1.987	1.977	1.788	1.491
10	1.936	1.927	1.748	1.451
11	1.895	1.877	1.712	1.414
12	1.854	1.834	1.681	1.379
13	1.811	1.792	1.643	1.350
14	1.768	1.756	1.609	1.319
15	1.720	1.715	1.567	1.290
16	1.684	1.671	1.526	1.256
17	1.643	1.635	1.483	1.223
18	1.604	1.600	1.443	1.197
19	1.568	1.565	1.410	1.167
20	1.538	1.532	1.383	1.140
21	1.507	1.496	1.356	1.118
22	1.482	1.467	1.329	1.100
23	1.449	1.437	1.301	1.083
24	1.419	1.410	1.273	1.065
25	1.389	1.385	1.250	1.050
26	1.358	1.357	1.226	1.034
27	1.325	1.329	1.201	1.020
28	1.297	1.301	1.181	1.003
29	1.271	1.270	1.161	0.987
30	1.238	1.249	1.141	0.971
31	1.214	1.225	1.121	0.955
32	1.185	1.202	1.104	0.942
33	1.165	1.182	1.086	0.925
34	1.144	1.161	1.071	0.914
35	1.126	1.141	1.056	0.900
36	1.110	1.122	1.040	0.888
37	1.095	1.105	1.027	0.876
38	1.080	1.089	1.014	0.865
39	1.066	1.074	1.001	0.853
40	1.054	1.060	0.988	0.843
41	1.039	1.047	0.977	0.832
42	1.025	1.036	0.967	0.820
43	1.013	1.021	0.955	0.811
44	1.000	1.008	0.942	0.803
45	0.987	0.994	0.931	0.793
46	0.974	0.983	0.920	0.783
47	0.963	0.971	0.909	0.774
48	0.952	0.958	0.896	0.764
49	0.939	0.944	0.881	0.753
50	0.928	0.931	0.868	0.742



Duration % (Exceedance)	Baseline	2016-2040	2041-2065	2075-2099
51	0.916	0.918	0.857	0.730
52	0.903	0.903	0.845	0.719
53	0.890	0.890	0.835	0.706
54	0.878	0.879	0.823	0.694
55	0.865	0.866	0.812	0.682
56	0.853	0.855	0.800	0.670
57	0.842	0.843	0.789	0.659
58	0.830	0.830	0.779	0.647
59	0.819	0.818	0.767	0.637
60	0.809	0.806	0.758	0.626
61	0.797	0.794	0.747	0.617
62	0.785	0.784	0.736	0.607
63	0.772	0.773	0.728	0.598
64	0.759	0.761	0.718	0.590
65	0.749	0.749	0.708	0.581
66	0.737	0.739	0.697	0.572
67	0.727	0.728	0.687	0.565
68	0.717	0.719	0.678	0.557
69	0.705	0.708	0.669	0.549
70	0.693	0.697	0.661	0.542
71	0.681	0.687	0.651	0.534
72	0.666	0.677	0.641	0.526
73	0.652	0.665	0.631	0.517
74	0.640	0.654	0.621	0.506
75	0.629	0.641	0.611	0.496
76	0.618	0.629	0.601	0.487
77	0.607	0.616	0.590	0.478
78	0.596	0.604	0.579	0.467
79	0.584	0.592	0.566	0.458
80	0.573	0.579	0.554	0.449
81	0.559	0.566	0.541	0.440
82	0.547	0.554	0.528	0.432
83	0.534	0.542	0.516	0.423
84	0.522	0.530	0.506	0.414
85	0.509	0.520	0.496	0.406
86	0.498	0.509	0.485	0.396
87	0.486	0.499	0.474	0.386
88	0.474	0.489	0.463	0.377
89	0.461	0.478	0.452	0.368
90	0.448	0.464	0.438	0.358
91	0.435	0.452	0.427	0.348
92	0.419	0.438	0.414	0.336
93	0.405	0.422	0.401	0.323
94	0.389	0.401	0.386	0.306
95	0.374	0.382	0.363	0.286
96	0.354	0.362	0.340	0.267
97	0.334	0.338	0.311	0.244
98	0.318	0.316	0.290	0.226
99	0.295	0.290	0.263	0.201
100	0.189	0.198	0.208	0.169

Table 3.2 Duration curve for runoff data

4 Impact on hydropower generation

In order to make more realistic analysis of impacts on hydropower, a hypothetical small hydropower plant is assumed utilizing water from the catchment used in Chapter 3. We have assumed the following data for the power plant:

Catchment area:	100 km^2
Head:	100 m
Average inflow	1.16 m^3/s
Capacity	1.5 m^3/s
Total efficiency	0.90
Environmental flow	0.2 m^3/s (Corresponding to minimum observed flow)

More detailed specifications for penstock, turbine, generator and transformer are specified according to typical (default) values for a small hydropower plant of this size in Norway.

The analysis was performed using the software system MPC-2004 /10/, with inflow duration curves as given in Table 3.2 for the following four scenarios, each corresponding to one column in the table.

Baseline (Column 1)	1980-2005
First 25 years (Column 2)	2016-2040
Next 25 years (Column 3)	2041-2065
Last 25 years (Column 4)	2075-2099

The results are summarized in Table 4.1 and in the four graphs on Figure 4.1, 4.2, 4.3 and 4.4.

		Generation, GWh/year	% of baseline
Baseline	1980-2005	4.54	100
Future 1	2016-2040	4.59	101
Future 2	2041-2065	4.29	94
Future 3	2075-2099	3.58	79

Table 4.1 Hydropower generation for the four scenarios

We see that the computed hydropower generation in Table 4.1 is much less than the values in Table 3.1. This is because a more realistic hydropower model is used now, where flood spill and losses due to environmental flows are incorporated in a more correct way. The changes in generation due to changed climate and hydrology) is still quite similar.

The four graphs (4.1 – 4.4) show how the total energy in the flow is divided into four main categories: 1) Hydropower generation (dark blue), 2) Losses in pipes and machines (yellow), 3) Environmental flow (light blue) and 4) Flood spill (purple). The small pie chart inset summarized how the total “raw energy” is divided into these four categories in % of total. For the baseline scenario, for example, 51% of energy is energy generation, 6% is lost as flood spill, 24% as environmental flow and 18% as various losses in pipelines and penstock, turbine, generator and transformer.

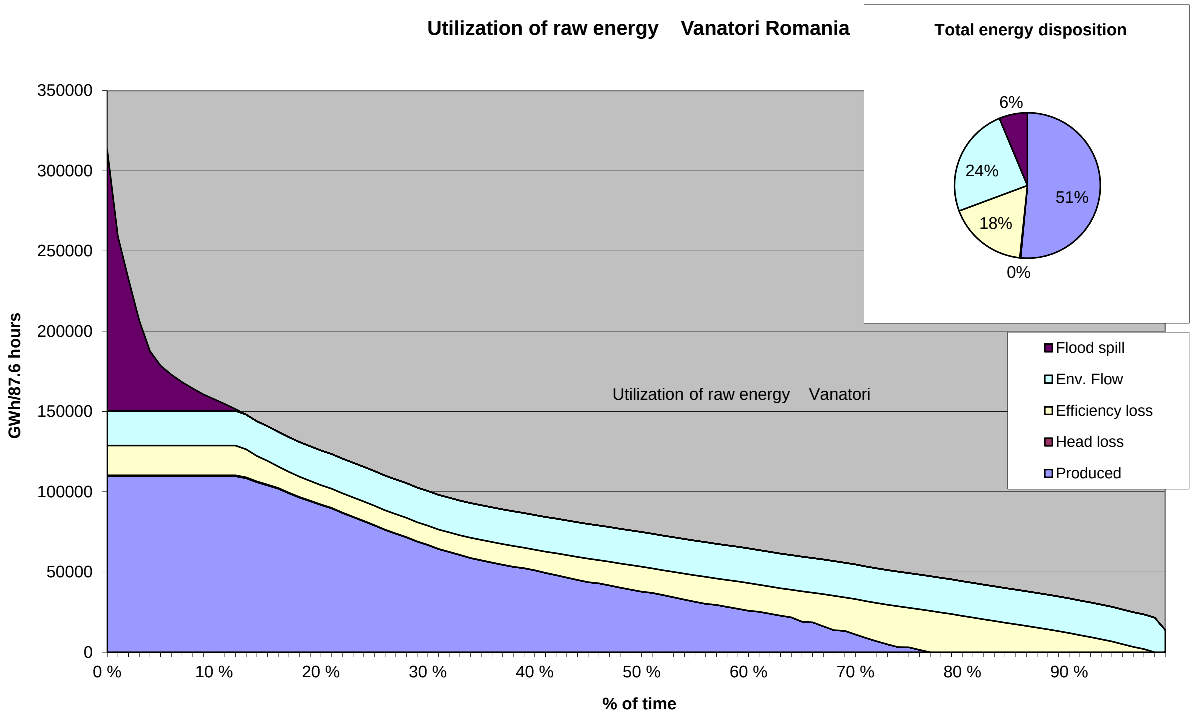


Figure 4.1 Energy utilization in Vanatori HPP - Baseline 1980-2005

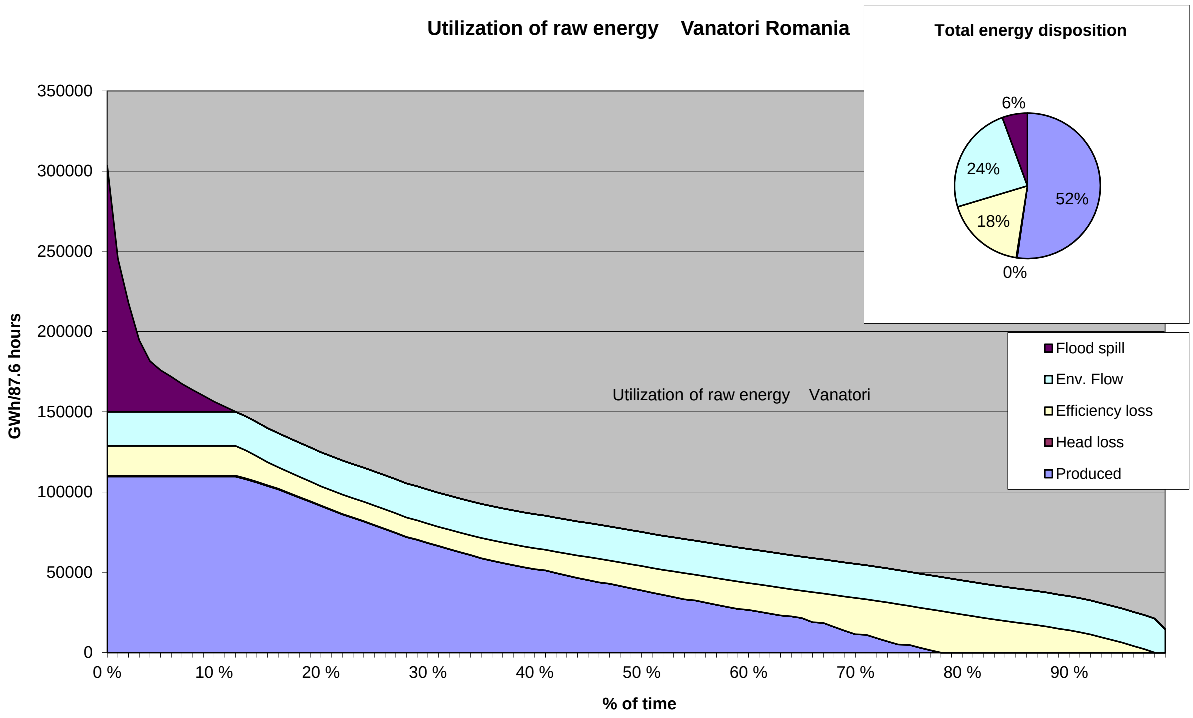


Figure 4.2 Energy utilization in Vanatori HPP - Scenario 2016-2041

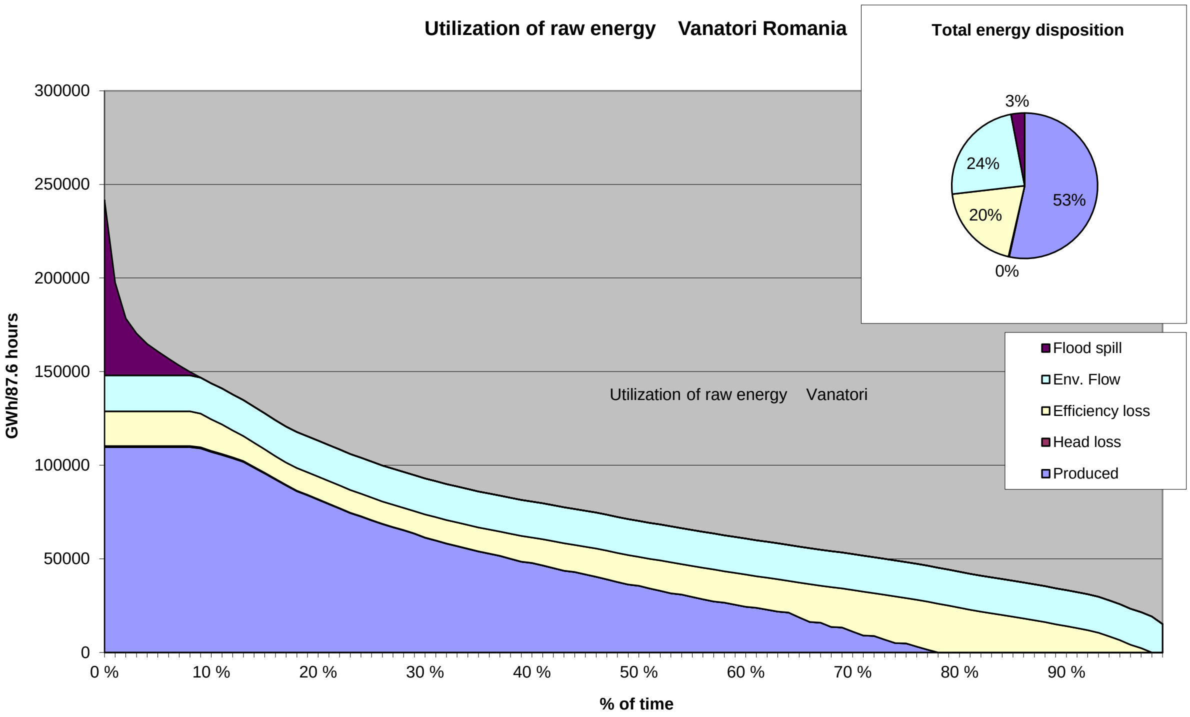


Figure 4.3 Energy utilization in Vanatori HPP - Scenario 2041-2065

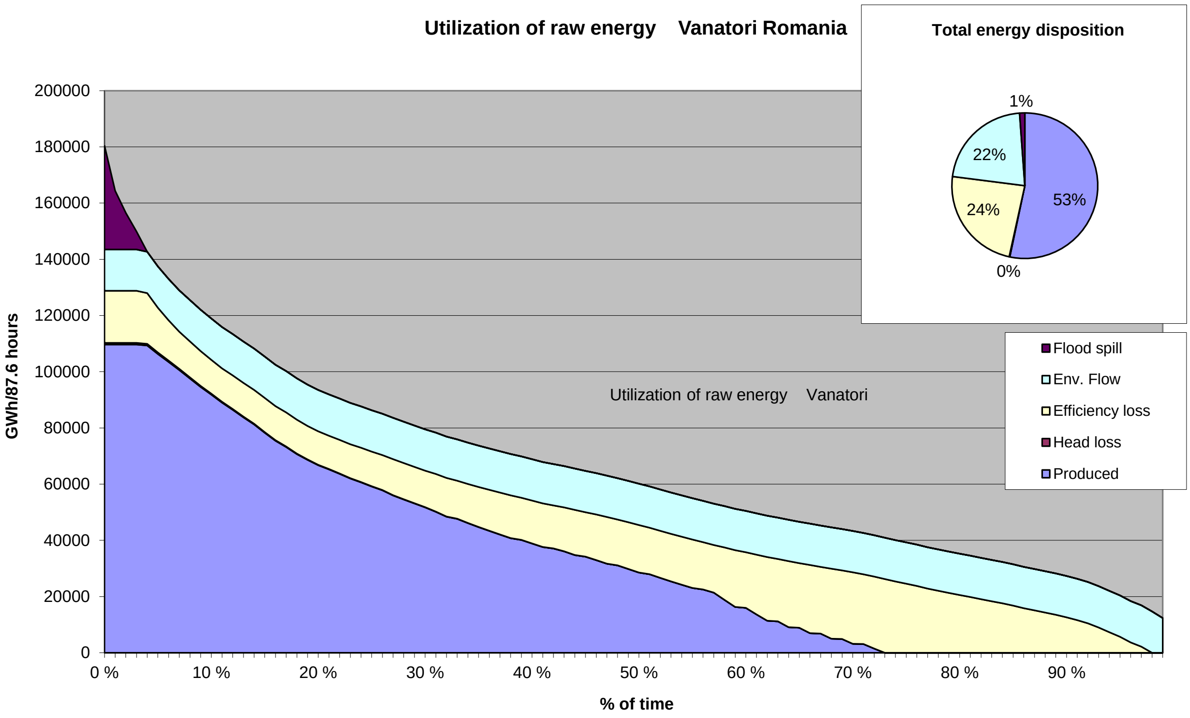


Figure 4.4 Energy utilization in Vanatori HPP - Scenario 2075-2099

5 Summary and conclusions

The possible future impact of climate change has been investigated for an area in the Vanatori Neamt in Romania. This has been one of the activities in a joint EEA-funded research project where NTNU has contributed, together with partners from Romania.

The project results can be summarized under three main topics:

- Climate change up to 2100
- Impacts of climate change on water resources and hydrology
- Impact on hydropower

The climate change study is based on data from the Euro-CORDEX project where we have found downscaled data for present climate (Baseline) and for future climate, for two different emission scenarios (RCP4.5 and RCP8.5) and four different global climate models, from now and up to 2100.

It was possible to see a clear trend in temperature, increasing nearly linearly up to +1.7 ^{0}C up to the end of the century for RCP4.5 and by 3.5 ^{0}C for RCP8.5. Similarly, precipitation data could be retrieved for the same alternatives. The change in precipitation was less clear than for temperature, with small changes and not a consistent trend. From this study, we found seasonal changes in both emission scenarios (Rcp4.5 and Rcp8.5). In general, from January to April both rcp4.5 and rcp8.5 predicts increased precipitation (1% to +20%), and similarly during October – December the precipitation increases from +1% to +12%. However, during the rainy periods (May – September) there is decreased precipitation (-12% to -3%). In summary, for the lowest emission scenario, RCP4.5, there were almost no changes, a decrease of about 1%. For the higher emission scenario, there was a small reduction of 4% for the last 25 years (2075-2099) and +/1 1% before this.

Climate change impacts on hydrology and water resources were analyzed by using a HBV Precipitation-Runoff model to convert climate data into time-series of runoff. The HBV-model was established for a 100 km2 large area and the model was run for four scenarios: Current climate 1980-2005 (baseline) and then for three 25 year periods in the future with climate data, 2016-2040, 2041-2065 and 2075-2095. In addition to the climate data from the Euro-CORDEX dataset, potential evaporation was computed from air temperature data. This analysis was done for only the high emission scenario, RPC8.5. We found small changes in runoff before 2040, but from then a gradual decrease of 10% by 2065 and 25% by 2099. The decrease in runoff is much larger than decrease in precipitation. This is because the increased temperature will lead to higher evaporation.

Finally, the impact on hydropower resources was investigated by creating a hypotethical small hydropwer plant utilizing the water from the same 100 km^2 catchment. The analysis was done by setting up a the hydropower simulation model MPC-2004, simulating generation for the same four scenarios. The baseline generation was found to be 4.54 GWh/year and like the runoff this was more or less unchanged up to 2040. From here, a gradual reduction was found at 6% by 2065 and 21% by 2099. The change in hydropower generation is very closely following the same trend as for runoff.

The overall conclusion from this study is that it is possible find data and models for doing this type of analysis in Romania. Further studies are also possible, by using the same data sources and models. The results from different climate models and emission scenarios all point to a gradual decrease in runoff and hydropower generation potential in this area. The changes seem to be small up to 2040, from there we estimate a gradual decrease in the order of 20-25% by the end of the century.

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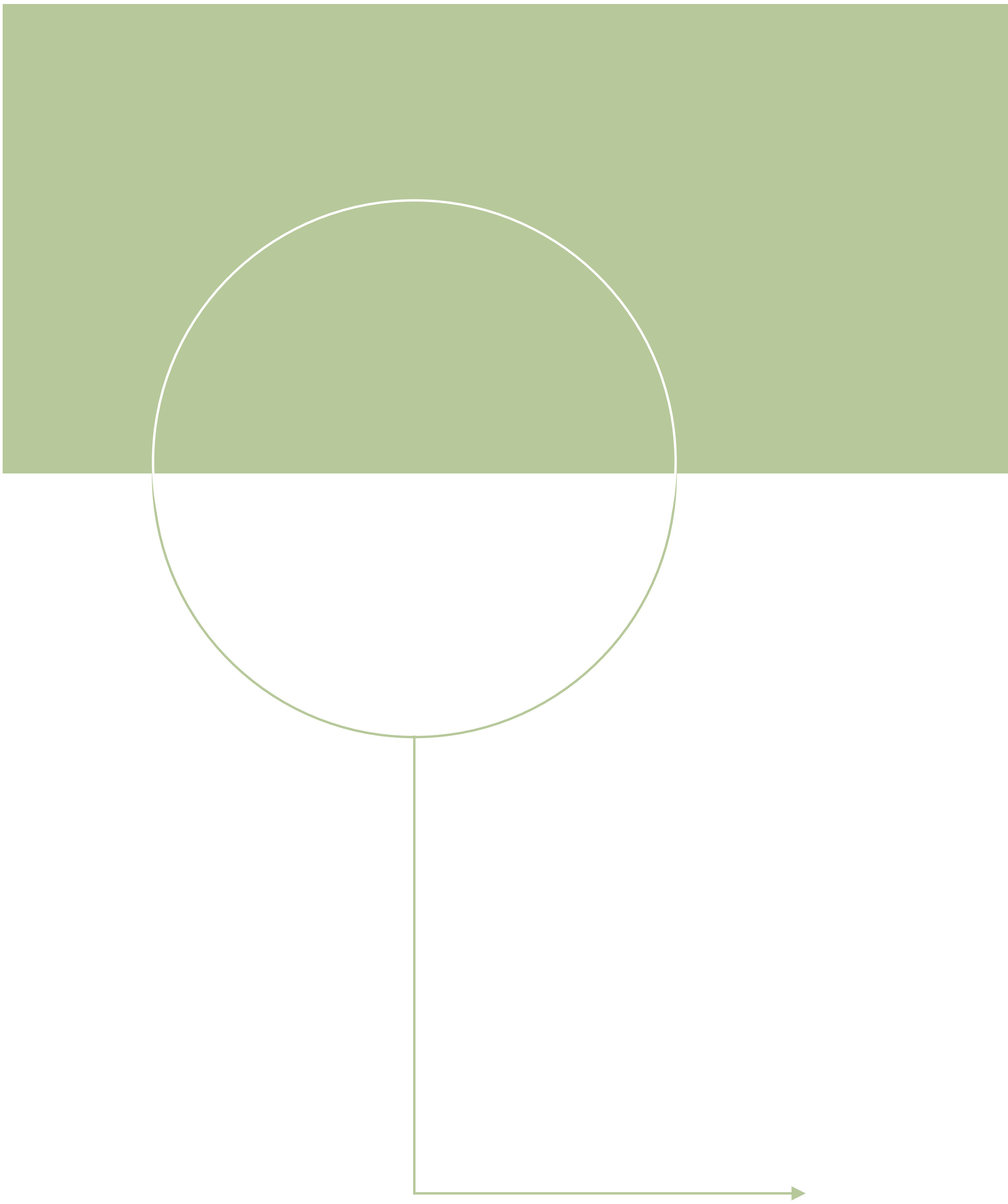

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