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ASSESSMENT OF HYDRO-ECOLOGICAL AND SOCIO-ECONOMIC SYSTEMS OF

THE VJOSA RIVER

ASSESSMENT OF HYDRO-ECOLOGICAL AND SOCIO-ECONOMIC SYSTEMS OF THE VJOSA RIVER

under the EU Flood Protection Infrastructure Project – FPIP

Tirana, 2017

Prepared for: UNDP Albania

Prepared by: Dr. **Bart (A.J.) Wickel** and **Stephanie Galaitsi**,
Stockholm Environment Institute, US Center

Revised and approved by Dr. **Eglantina Bruci**, UNDP Albania

With support from: **Liljana Lata** and **Amparo Samper Hiraldo**,
Institute of Geosciences, Energy, Water and Environment, Albania
and the experts Dr. **Liri Muçaj** and **Albana Zotaj**

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Cover Photo: The Vjosa River upstream of Tepelenë (photo by Bart Wickel)

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1. Summary

The ‘Assessment of hydro-ecological and socio-economic systems of Vjosa River Basin Area’ was developed by the Stockholm Environment Institute (SEI) as a sub-task under the European Union (EU) Flood Protection Infrastructure Project (FPIP) for the Vjosa Basin in Albania and directed by the United Nations Development Program (UNDP), as Activity 3.2 with the same title.

The main focus of this project was the development of an application of the Water Evaluation And Planning (WEAP) for the Vjosa River Basin and a set of hydro-ecological and socio-economic scenarios that identify key vulnerabilities to climate change between the years 2015-2050. Understanding specific vulnerabilities within a basin allows planners to propose and prioritize potential adaptation measures, which can be further examined with cost-benefit analyses.

This project was executed in close collaboration with staff from the Institute of Geosciences, Energy, Water and Environment (IGEWE) of the Polytechnic University of Tirana as well various government partner agencies that have provided data. The development of the WEAP application for the Vjosa basin included several capacity building activities to strengthen institutional capacity for model construction and application.

The main objective for this project was the development of an integrated hydrological and water management model to evaluate combinations climate and development scenarios for the Vjosa Basin. Despite being part of a larger project on Flood Protection Infrastructure Project, this modeling exercise does not examine flooding specifically, but rather the broader water management challenges in terms of availability and allocation for the entire Vjosa Basin.

The project was structured around four main activities:

1. The development and provision of appropriately downscaled future regional climate scenarios to assess vulnerability of the basin water balance and specific water dependent sectors to climate change;
2. The collection of available historical meteorological, hydrologic and spatial information needed to construct and calibrate a WEAP model of the Vjosa River Basin and the integration of specific future water resource development scenarios;
3. Evaluation of costs and benefit information for adaptation measures; and
4. Capacity building of IGEWE staff in the development and use of the WEAP model.

This report is the main document for the project and is supported by three technical reports that discuss Climate change scenarios, a cost benefit analysis of the planned Poçem Hydropower project and climate adaptation priorities. The main findings of these technical reports have been integrated into this report.

2. The Vjosa Basin

The Vjosa River drains Albania's second largest river basin (approximately 6,808 km^2) and is one of the longest transboundary rivers in the Balkan area. Approximately one-third of its headwaters are located in northwest Greece, where it is known as the Aoös (Αώος) River (Figure 1).

Figure 1. Location of the Vjosa/ Aoös Basin (blue) on the border of Greece and Albania

In Greece, the Aoös catchment is shared among three prefectures: Ioannina, Kastoria and Grevena. The river's source is situated at 2600 meters above sea level (m.a.s.l.), below the Mavrovouni Mountain in the Pindus mountain range in Greece. The Aoös River flows over a distance of 85 km before crossing Albanian border. In Albania, it continues as the Vjosa River, and flows over a distance for 190 km before discharging into the Adriatic Sea north of Vlora city, where it intermittently shapes and nourishes the Narta lagoon. In Albania, the Vjosa catchment has a mean elevation of about 885 m, and it is shared among seven districts: Ersekë, Përmet, Gjirokastër, Tepelenë, Mallakastër, Fier, and Vlorë. Because the river has not been subjected to large damming or channeling schemes, it is considered one of the rare remaining natural flow regimes in Europe.

The Aoös/Vjosa River has three main tributaries, the Sarantaporos in Greece, and the Drinos and Shushica in Albania. The Sarantaporos River, springs from Grammos Mountain and drains a catchment area of approximately 914 km^2. The Drinos River is the largest tributary of Vjosa with a catchment area of about 1320 km^2, of which 256 km^2 are located in Greece. It springs from Elates Mountain (1257 m.a.s.l.) in Greece, passing through a wide gravel riverbed near Dropulli area. After entering Albania, it joins the Vjosa River is near Tepelenë city. The Shushica River, with a length of 80 km and a catchment area of about 587 km^2, flows between the Kurveleshi Mountains and the Cike-Lungare mountain chain in Albania and joins the Vjosa downstream of Selenice.

2.1 Natural Characteristics

2.1.1 Geomorphology

The Vjosa River runs through a diversity of landscapes. The mean catchment slope is 28%, while the riverbed slope is about 4%. In Greece, the elevation of the Aoös ranges between 2636 to 400 m.a.s.l. In Albania the elevation ranges from 2500 m.a.s.l. to sea level (CNR Cereg, 2015) (Figure 2).

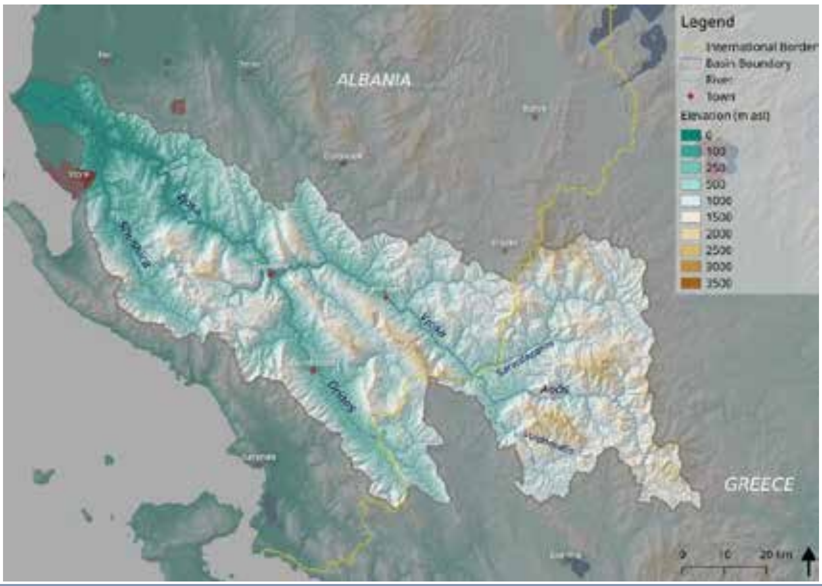


Figure 2. Digital Elevation Model (DEM) of the Vjosa/Aoös basin and its main tributaries

The lower course of the river is characterized by low gradients and is surrounded by a wide, flat floodplain with terraces shaped during the Quaternary Period, which started roughly 2.59 million years ago. This region includes the Myzeqe flood plain located near the city Vlora, the Kota valley, which forms part of the Shushica River tributary basin and the Drinos valley with the areas of Gjirokastër and Dropulli. The gradients of the river in these zones are very low, up to 5° (CNR Cereg, 2015). The river's middle course has hills composed of strongly fragmented terrigenous sedimentary rocks, eroded by Vjosa tributaries over time. These include areas with very high slopes around the highland of Kurveleshi, and at the mountains of Nemerçka, Lunxheri, Bureto, Postnan and Melesini. There are gorges and deep canyons in Bënçë, Këlcyrë, and Langaricë. The river's upper course is surrounded by large mountains, with abrupt crests and very steep slopes, the result of the water erosion and limestone terrain (karst). In Greece, the Aoös tributary Voidomatis flow through the Vikos Gorge, listed as the deepest canyon in the world by the Guinness Book.

2.1.2 Geology

The Aoös River sub-basin is part of the Ionian geotectonic zone which stretches from the Ionian Islands towards the west side of the Pindus mountain range and on south to the Gulf of Missolonghi in Greece. The Ionian zone is very plastic and active due to the high portion of limestone, with a sequence of large anticlines and synclines of general direction NW-SE which is also the general orientation of the Pindus Mountain range.

The Vjosa Basin geology in Albania is dominated by sand and gravel alluvial deposits in the river valley. These alluvial deposits are formed by: Neocene's deposits composed by sandstone, siltstone, conglomerate and partly marlstone, Flysch deposits, Karstic calcareous deposits, and ultrabasic rock. The Vjosa River is characterized by a wide braided sandy gravel layer and a strong river dynamics. The course and the cross section of the river changes rapidly over the years. Table 1 shows the changes in measurement of water level H at Ura Leklit station over the course of six years (see Section 4.3 for a description of this information).

Table 1. Changes in H (m) at Ura Leklit Station from 2002-2005

DATE	H(m) at Ura Leklit Station	Q(m^3/s)	Wet cross section	Average Velocity	Maximum Velocity	B
07/04/2002	1.2	9.63	15.5	0.62	1.28	22
28/05/2002	1.2	14.2	17.9	0.79	1.16	23
08/07/2005	1.19	10.3	15.2	0.68	1.28	22
04/09/2007	1.18	4.23	11.5	0.38	0.73	21

2.1.3 Climate

The average climate of the Vjosa Basin can be characterized as Mediterranean, with dry and hot summers, and mild and wet winters. The western part of the Vjosa basin, due to lower elevation and the proximity to the sea, is warmer than the eastern part. The mean temperatures values vary from 11 to 14°C along the river's valley, and from 6 to 10°C in the mountainous area. Mean maximum temperatures in the upper, middle and low areas of the catchment, may respectively vary between from 12 to 18°C, from 14 to 20°C, from 18 to 21.5°C (Mucaj 2016) (Figure 3).

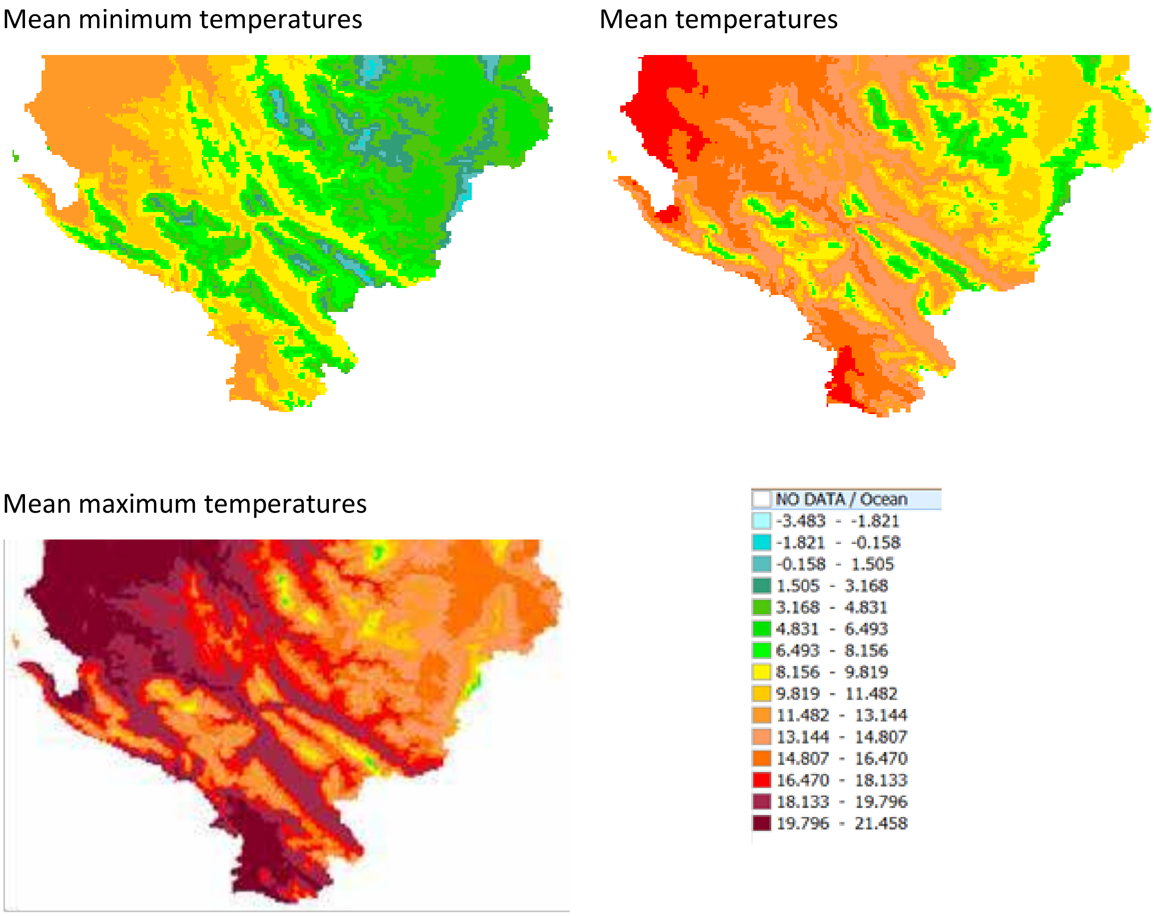


Figure 3. Distribution of annual averages of Tmin, Tmean and Tmax, period 1985-2005. (Mucaj, 2016)

The hottest months in the region are June, July and August with daily mean temperatures between 20 to 24°C. The highest mean maximum values vary from 26 to 33°C and the absolute maximum observed values are 41.6°C in Fier (July 6, 1988) and 43.5°C in Selenice (July 18, 1973). The coldest months are from December to February, with a daily mean temperatures of less than 5°C. The absolute minimum observed temperatures are -10.5°C in Tepelenë (January 14, 1968), -19.8°C in Ersekë (January 4, 1979) and -13.1°C in Përmet (January 15, 1968). Figure 4 shows the average seasonal variability (1951-2010) for different locations in Albania over the course of a year.and -13.1°C in Përmet (January 15, 1968).

Figure 4 shows the average seasonal variability (1951-2010) for different locations in Albania over the course of a year.

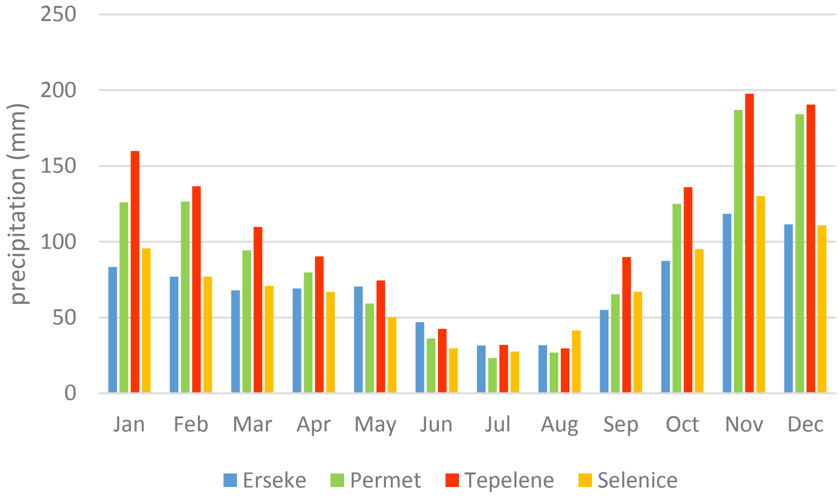


Figure 4. Monthly rainfall distribution in the Vjosa basin (average 1951-2010)
Source: IGEWE Archives

Additionally, Figure 5 shows the rainfall distribution near Ersekë, in the upper part of the basin near the Greek border. The annual averages show a minor peak in precipitation in May, a pattern that is also seen in nearby Korça, just outside the basin's boundary (IGEWE archives), that is an indicator of continental climate.

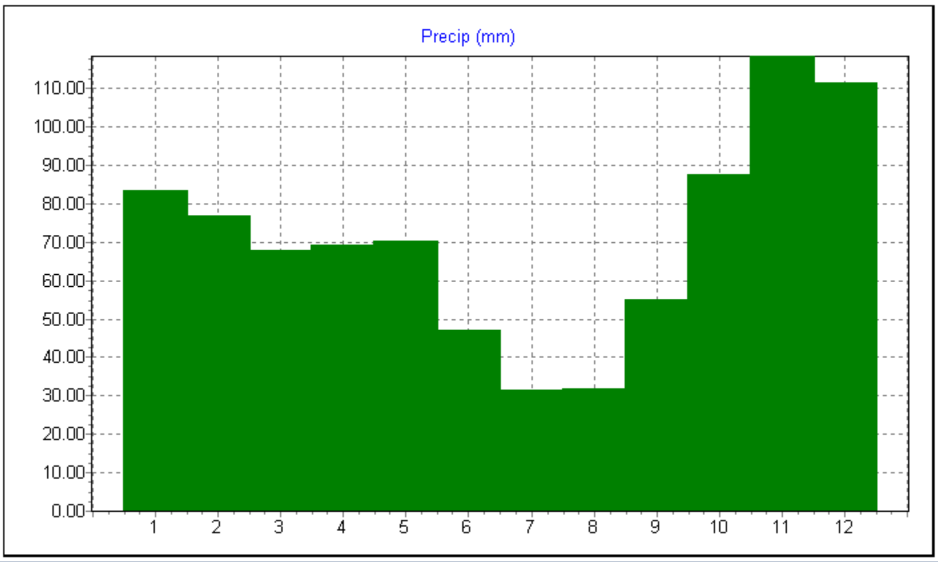


Figure 5. Precipitation distribution for Erseke area (1951-2010)
Source: IGEWE Archives

Average annual rainfall ranges from 950 to 1600 mm in the river basin (Mucaj, 2016). The minimum in precipitation occurs typically during the summer months (June, July and August) and the maximum in November and December. The number of rainy days ranges from 85 to 100 days a year.

The highest historical 24 hours observed precipitation in Vjosa Basin are as follows: Gjirokastër 288 mm on November 13, 1956, Përmet 240 mm on November 15, 1962, Brataj 220 mm December 31, 1970 and Nivicë 196 mm December 5, 1969. Total amounts of rainfall in Vjosa catchment, especially in the Drinos and Shushica sub-catchments, are among the highest observed in Albania.

The Greek part of the catchment is mountainous and pre-mountain. The mean annual precipitation is 1965 mm. The highest precipitation of the Aoös catchment is in Konitsa, with 70 to 120 days of rainfall and five days of snow per year. The highest mean temperature is 29.7 °C and lowest mean -9 °C (Seferlis et al 2008).

2.1.4 Hydrology and Hydrogeology

The annual average discharge of Aoös River is about 70 m^3/s, which includes flow from the Sarandoporos tributary (18 m^3/s annual average discharge). The annual average discharge of the Vjosa River in its outlet into the Adriatic Sea is about of 195 m^3/s and minimum flow during summer time is of 33 m^3/s. The annual average discharge of Drinos River in Hormovë 39 m^3/s and Shushica River has an annual average discharge 19 m^3/s (Seferlis et al. 2008)

The deep karsts aquifers of the Aoös/Vjosa River sustain a constant baseflow in the river generally throughout the dry season. On the Greek side, the Aoös River catchment comprises three hydrogeological units: Timfi, Amarantos, and Arenon Grammou, all karst. These three units provide a mean annual water volume (coming from several springs) of about 169 MCM (Seferlis et al. 2008).

On the Albanian side, different hydrogeological units include several natural springs, wetlands in river's lower course and the Narta Lagoon (Figure 6). The region's deep karst aquifers supply a constant abundant flow even during the periods of lower precipitation in the summer.

Figure 6. Narta Lagoon
Sources: CNR Cereg, 2015, IGEWE 2010

A detailed hydrogeological map for Albania can be found on the website of the Albanian Geological Survey at www.gsa.gov.al/alb/products/Hidro_200.html.

2.1.5 Biodiversity

The Vjosa/Aoös catchment has a high ecological and aesthetic value due to the presence of rare flora and fauna. The various landscapes have more than 1000 plant species.

In the Greek part, the Aoös river catchment is relatively isolated, with favorable microclimatic conditions for the existence of abundant species. The National Park of Vikos-Aoös includes Balkan flora endemics such as *Aesculus hippocastanum, Erysimum cephalonicum, Abies borisii-regis, Bupleurum karglii*, Campanula hawkinsiana, etc.). Rare Macedonian fir (*Abies borisi-regis*) and plane-trees and willows, maples, linden-trees and hornbeams grow along the riverbed in Albania.

The fauna includes birds, mammals, amphibians, wolves, foxes, wild rabbit, wild goat, browns and different fish. Some of the more notable species are *Myotis blythii*, *Ursus arctos*, *Lutra lutra*, *Lynx lynx*, *Rupicapra rupicapra balcanica*, *Triturus carnifex*, *Bombina variegata*, *Testudo hermanni*, *Testudo marginata*, *Elaphe quatuorlineata*, *Elaphe situla*, *Vipera ursini* and *Salmo macrostigma*.

One of the important biodiversity locales is the Narta lagoon in the north-western part of Vlora district. The Lagoon is a wetland covering over 26.70 km^2 with an average depth of 0.7 meters. It is artificially connected to the Adriatic Sea by to channels that cross a chain of dunes of 500 ha. During the dry summer time, the water quantity and quality drops.

Salt tolerant vegetation grows on the north and north-eastern shores of Narta lagoon, for example, *Arthrocnemum fruticosum*, *Polypogon monspeliensis*, *Juncus acutus*, *Juncus maritimus*, *Agropyrum litorale*, *Tamarix dalmatica*, *Limonim vulgare*. (PHARE 2002). Associations of *Phragmites australia*, *Typha latifoglia*, *T.angustifoglia*, along the riverbanks and in fresh and brackish water ponds are gradually replacing this type of vegetation. The fauna comprises macrozoobentos such as the bivalve *Cardium edule* and the crustaceans and invertebrates such as *Cerithium vulgatum*, *C.rupestre*, *Palamon elegans* and *Palaemonetes varians*. The fish species are Muglidae (*M.cephalus* and *L.saliens*), the Sparidae (*Sparus aurata*, *Dentex dentex*, *Boops boops*); sea bass (*Dicentrarcus labrax*); eel (*Anguilla anguilla*).

2.1.6 Conservation

Table 2 describes the protected areas in the Vjosa basin, according to the Ministry of Environment of Albania, shown in Figure 7, below.

Additionally, in Greece, the Aoös River flows through the Northern Pindos National Park. Its 1,969,741 km2 are protected by a number of laws of decrees (Sorotou, 2014). The Vikos-Aoös Geopark is a UNESCO Geoheritage site (UNESCO, n.d.).

Table 2. Protected areas in Vjosa River basin

Name	Category	Legislation	Location	Area (ha)
Kardhiq	I Strict Natural Reserve	Decision of the Council of Ministers no.102,date 15.01.1996	Gjirokastër	1,800
Bredhi i Hotovës-Dangëlli	II National Park	Decision of the Council of Ministers no. 1631,date 17.12.2008	Përmet	34,361
Bredhi i Sotirës	III Natural Monuments	Decision of the Council of Ministers no.102, date 15.01.1996	Gjirokastër	1,740
Zhej	III Natural Monuments	Decision of the Council of Ministers no.102, date 15.01.1996	Gjirokastër	1,500
Piskai-Shqeri	IV Protected Area and Managed Ecosystem	Decision of the Council of Ministers no. 102, date 15.01.1996	Korçë, Kolonjë	5,400
Gërmenj-Shelegur	IV Managed Nature Reserve/National Park	Decision of the Council of Ministers no.102, date 15.01.1996	Kolonjë	430
Pishë Poro	IV Managed Nature Reserve/National Park	Reg. no. 1, date 27.7.1977, MB	Fier	1,500
Levan	IV Managed Nature Reserve/National Park	Reg. no. 1, date 27.7.1977, MB	Fier	200
Balloll	IV Managed Nature Reserve/National Park	Reg. no. 1, date 27.7.1977, MB	Berat	330
Vjosë-Nartë	V Protected Landscape	Decision of the Council of Ministers no. 680, date 22.10.2004	Vlore	19,738

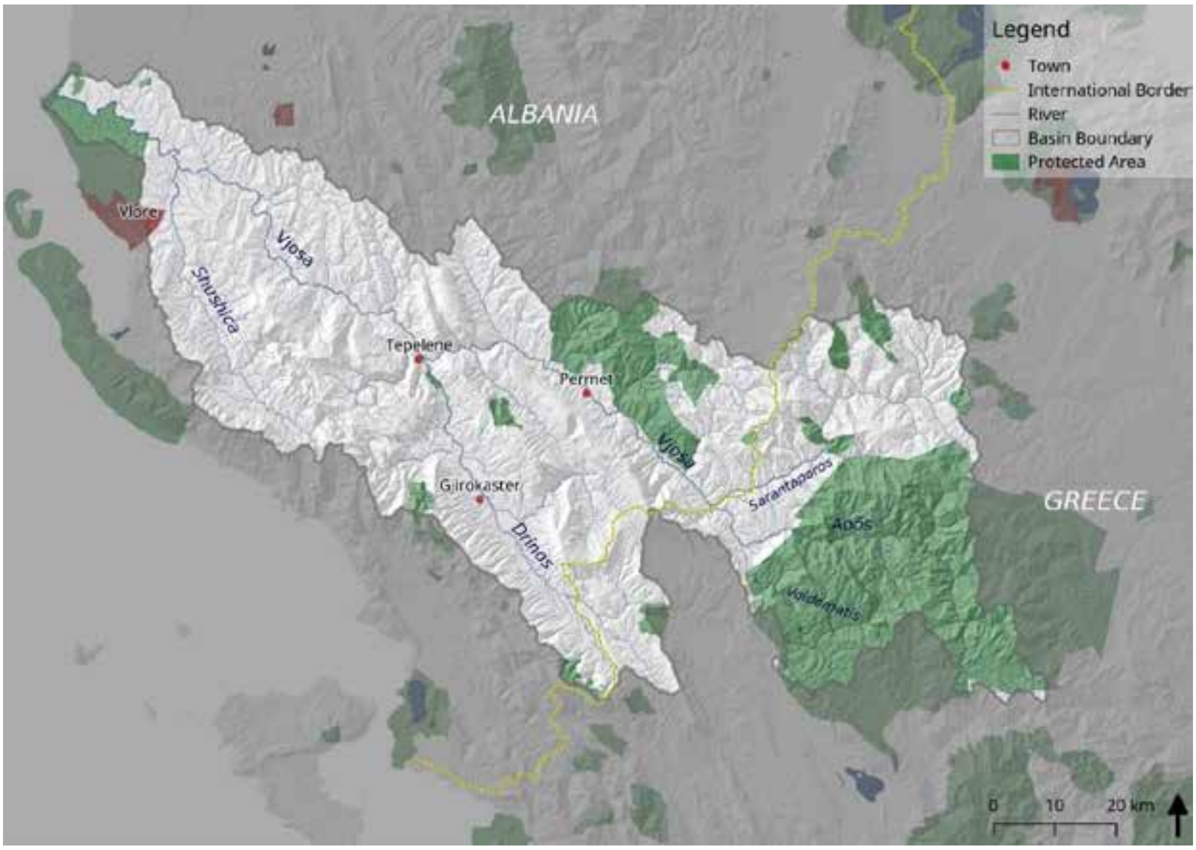


Figure 7. Protected areas in the Vjosa basin

2.1.7 Population

In Greece, the Aoös watershed area between Ioannina, Kastoria and Grevena prefectures had an estimated population is about 35,000 inhabitants in 2001, with density of about 14.4 inhabitants/km². The population is mostly concentrated in the lowlands of Aoös catchment, including scattered settlements along the valleys of Aoös River and in its main tributary, Sarantaporos River (Seferlis et al. 2008).

In Albanian side, five prefectures intersect the Vjosa River basin: Gjirokastër (59%), Vlore (22%), Fier (10%), Korçë (9%), and Berat (less than 1%). At the time of writing, the Albanian population in the Vjosa basin is about 200,000 inhabitants, mainly concentrated in eight cities (Gjirokastër, Libohovë, Përmet, Këlcyrë, Leskovik, Tepelenë, Memaliaj and Selenicë), and several small villages. The average density of population in the Vjosa basin is lower than in other parts of Albania. In the west part of the basin (the lower area) the population density is about 100-250 inhabitants/km², while in the upper area of the basin is about 10-15 inhabitants/km² (CNR Cereg 2015).

There has been a decrease of the population in the Vjosa basin within the last 35 years due to international migration (mainly Greece, Italy, Germany, the United States, etc.). Simultaneously, there is internal migration from mountainous villages to the Albania's urban areas, including in the Vjosa's lower catchment. This urban migration caused a 70% decrease of the population in the mountainous areas and produced a slight increase about 10-15% of the population in the main cities situated in the west side of Vjosa basin. Overall, the basin's population is declining (CNR Cereg 2015) (Figure 8).

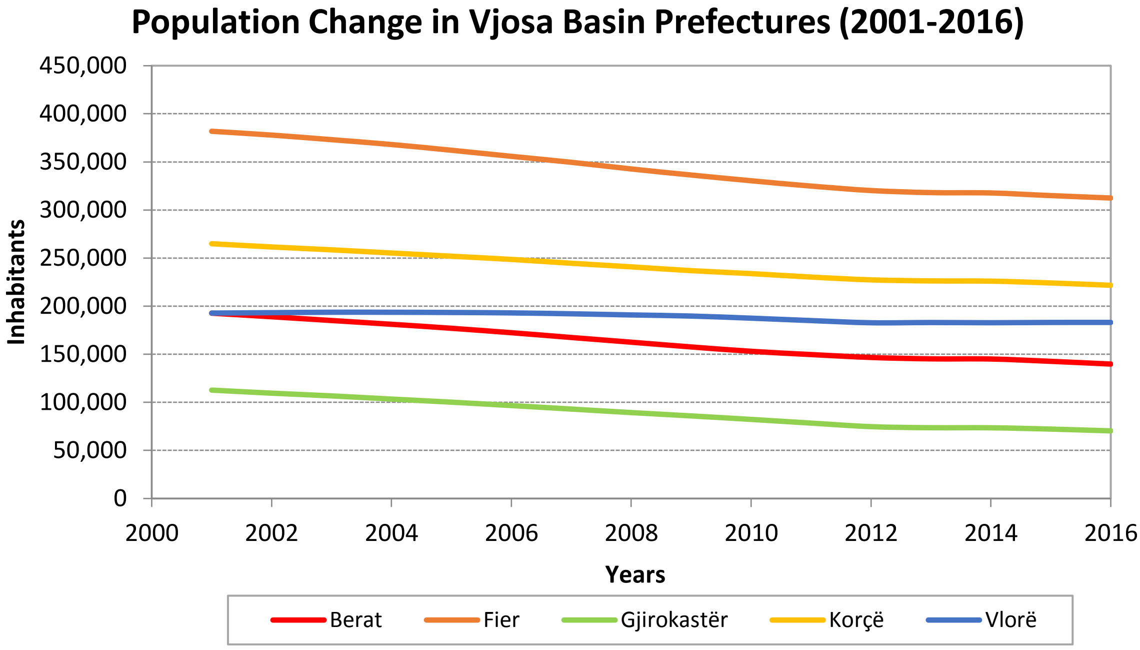


Figure 8. Changes in population in prefectures with area within the Vjosa basin, from 2001-2016. (Albanian Census. 2011)

3. WEAP Model Development

3.1 Introduction

This project uses the Water Evaluation and Planning (WEAP) platform, a software designed and managed by the Stockholm Environment Institute (SEI). WEAP is used around the globe to model and evaluate water availability and demand under current conditions and to assess potential future impacts of development and climate change scenarios on natural resources.

WEAP simulates water supply, demands, management priorities, and existing infrastructure and infrastructural constraints within watershed models. The spatially-based models can incorporate climatic and land use conditions that determine water supply, and this allows the model to investigate various changes within system in to consider the various outcomes of uncertain futures, whether climatic, managerial, infrastructural or demographic.

The WEAP interface contains five components:

Schematic: the initial interface in which points of water supply (e.g. rivers, ground water, reservoirs, etc.) and demand (e.g. irrigation, drinking water, industrial use etc.), and management infrastructure (e.g. dams, reservoirs, canals, diversions, etc.) can be created.

Data: database where the nodes drawn in the schematic can be characterized with physical and political constraints. Elements can reference values in other elements, input values from Excel documents and contain coding to determine values dynamically, among other features.

Results: represents model results in graphs, tables, and dynamic maps. Here the users can review total system demands, percentages of coverage of total demand, reservoir performance through time, and supply for each catchment object among other results options.

Scenario Explorer: allows for comparison of different scenarios. A range of scenarios can be generated based on different possible management strategies or changes in climate change or land use, etc.

Notes: support documenting all data entered and ensuring data sources are recorded. This can be particularly helpful when models are shared among multiple users.

A full description of the WEAP model can be found in the User Guide, developed by SEI and available on the WEAP website.[1]

Like any model, the accuracy and applicability of WEAP model results are directly related to the data available to characterize the system. For more information about WEAP, see Yates et al. (2006a) and Yates et al. (2006b).

3.2 Model Development Approach

SEI collaboratively developed the WEAP model for the Vjosa basin with the project team at IGEWE. Through sequential capacity building activities, the team members have been able to participate in constructing the model and entering the appropriate data to characterize the water supply and water demand nodes. Depending on its application, WEAP can run at daily to yearly time steps. For the current project we decided to develop a WEAP application at a monthly time step, primarily due to the available data.

[1] www.weap21.org

3.2.1 Delineation of Catchments

The structure of the Vjosa WEAP model is determined by the streamflow gauges used for calibration points. Though at the current time only three flow gauges can be used for calibration purposes (see Section 4.3), the modeling team decided to divide the WEAP model into catchment areas within the watershed based on all six operating gauging stations, in case data for the omitted three stations becomes available in the future. In addition, a seventh catchment in the model incorporates the lower part of the Vjosa before the river's outlet to the sea. These delineations divide the production of water within WEAP (in catchment nodes) into the areas that correspond to the catchment areas above the respective streamflow gauges. This allows direct comparisons of the flow in the modeled river with the historic observed data at the gauging stations.

Using QGIS, the locations of the streamflow gauges and the digital elevation model (DEM) of the region enabled the delineation of the Vjosa basin into seven catchments conventionally named according to the names of the streamflow gauge stations. The catchments are: Çarshove/Çarshova (including a large area in Greece), Përmet, Ura e Leklit (including a small area in Greece, also referred to as the Drinos catchment, since it demarcates the Drinos tributary), Memaliaj, Vodicë/Vodica (also referred to as Lumi i Shushicës because it is the Lumi i Shushicës tributary), Poçem and Lower Basin (the outlet of the river to the sea, no gauging station available) (Figure 9).

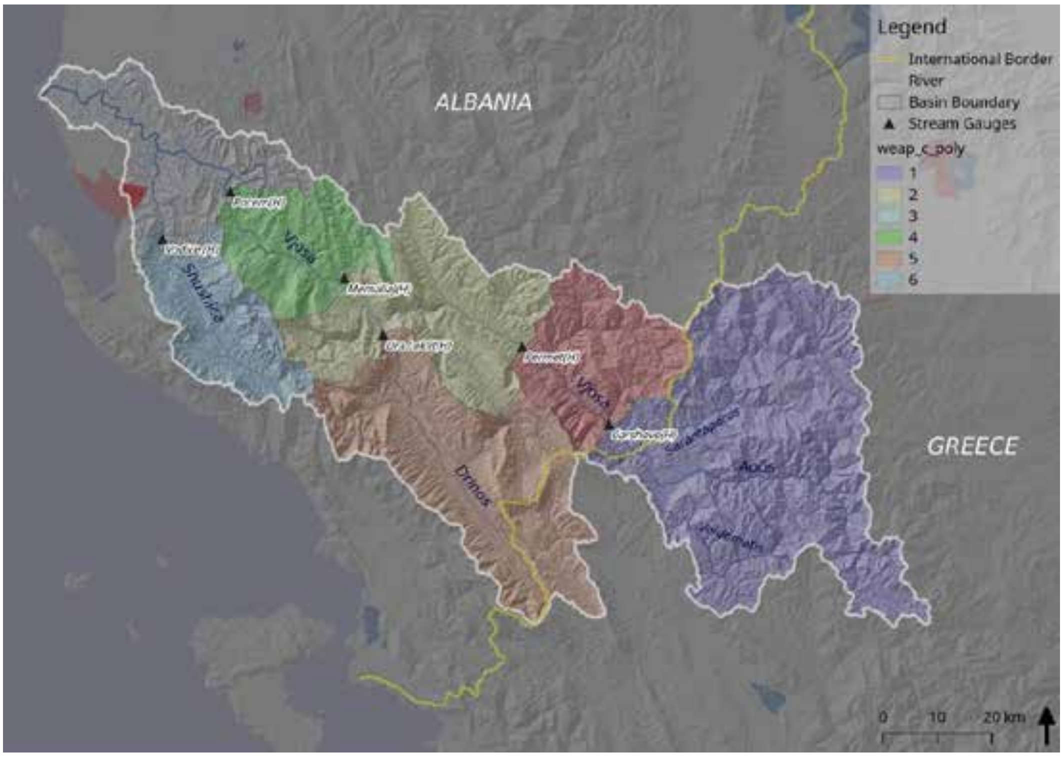


Figure 9. Delineated catchments for the six discharge stations that had data available for the WEAP model

The GIS shapefile was projected in the WGS 1984 (geographic) coordinate system in order to display in WEAP. The completed WEAP schematic (Figure 10) shows the catchment and demand site nodes within the seven catchment areas, named for the streamflow gauge directly downstream from them (or in the case of the two tributaries, Lumi i Shushicës and Drinos).

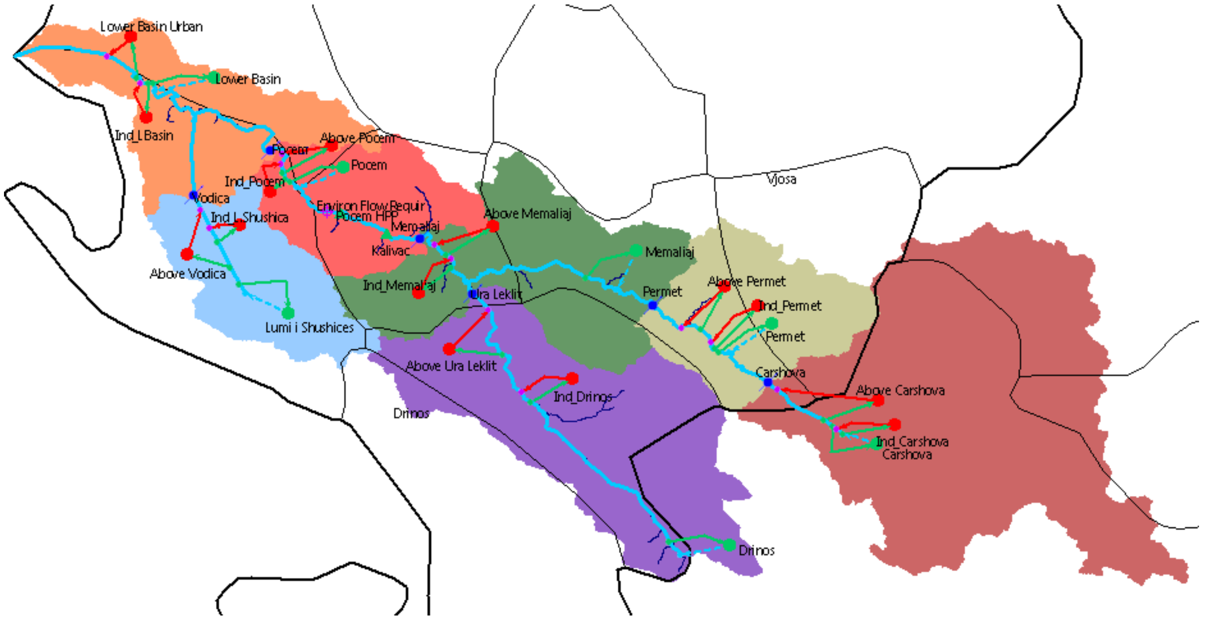


Figure 10. WEAP model schematic

To use the Përmet streamflow gauge as an example, the beige region on the map represents the area where precipitation would be directed to flow into the river section between the upstream gauge in Çarshovë and the Përmet streamflow gauge. The water measured at the streamflow gauge in Përmet can be derived through the following equation:

$$\begin{aligned} Flow\ at\ Permet \\ &= Upstream\ Gauge\ Values\ (river\ flow\ at\ Carshova) \\ &+ Immediate\ Upstream\ Additional\ Streamflow\ (Permet\ catchment\ inflow) \\ &- Immediate\ Upstream\ Consumption\ in\ Demand\ Sites \end{aligned}$$

Where "immediate upstream" means WEAP nodes physically located in the beige catchment area upstream of the Përmet stream gauge (Figure 10).

3.2.2 Catchment Nodes

Catchment nodes in WEAP (green circles) represent the total area of each delineated catchment and use a hydrological model to transform precipitation and other climatic data into runoff for the river. The Vjosa hydrology is characterized by many springs and intermittent karst creeks. The quantity of groundwater resources and the connections with the surface waters are totally unknown. However, literature provides some estimations based on the dry season flow, and stating that the contribution of the groundwater to the surface water is around 30% of the total discharge (Zaimi 2016). The WEAP model simulates this groundwater contribution as part of the dynamic hydrological system that is ultimately dependent on rainfall.

The Rainfall Runoff Soil Moisture model (Yates et al. 2005a, Yates et al 2005b), embedded in the Vjosa WEAP model, calculates runoff using a two-bucket method that simulates both base flow and shallow surface flow. This is meant to capture the runoff from the shallow soils (upper bucket) as well as from the karst springs (lower bucket).

Modeling catchment objects requires a large amount of data, particularly climatic data, like precipitation and temperature, and land use data, which often needs to be estimated. Because the precipitation and temperature data points are entered with respect to the overall delineated catchment areas, a single value for each is needed for each time step, for each area. Because the available meteorological stations represent points, both temperature and precipitation data had to be interpolated to produce appropriate values for catchment areas of the model. The interpolation methods used Thiessen (ArcGIS) or Voronoi polygons (QGIS) to generate average values across the catchment. Figure 11 and Figure 12 below show the results of the interpolation for the respective catchments for the historical calibration period (2002-2008).

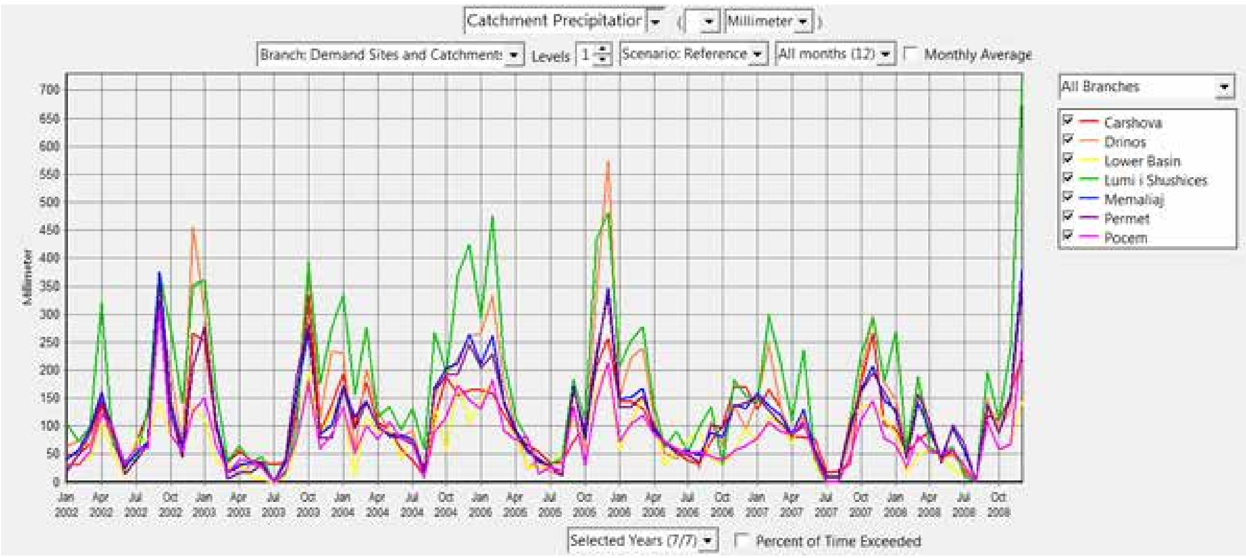


Figure 11. Interpolated precipitation data 2002-2008

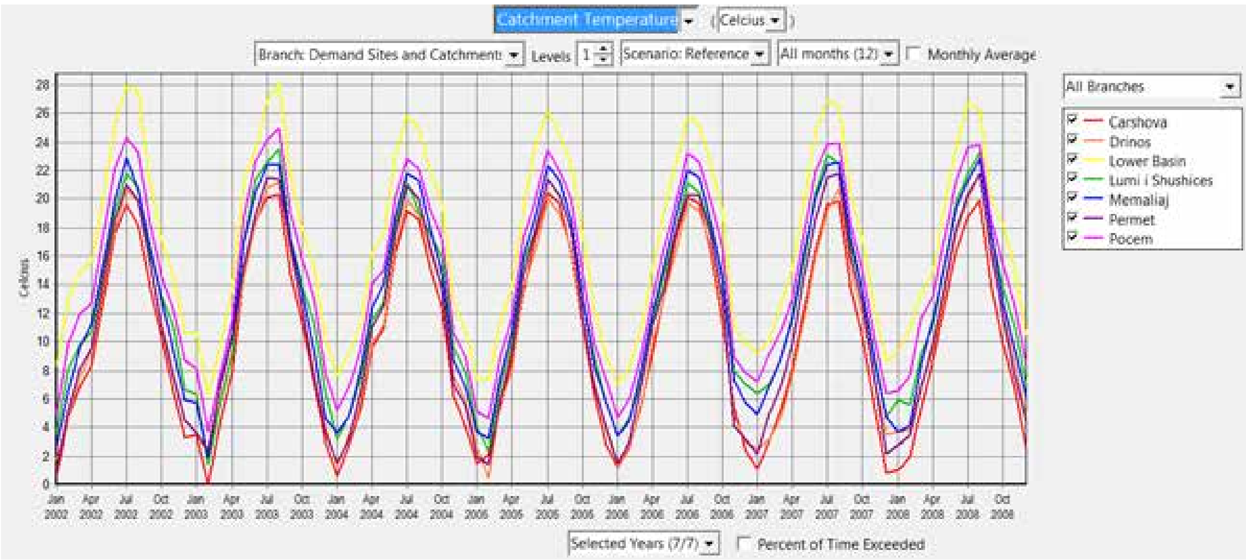


Figure 12. Interpolated temperature data 2002-2008

Other climatic data, such as wind speed and cloudiness factor, in case these are not available can be estimated, but will reduce model accuracy somewhat.

The catchments include data about the land use types represented in their boundaries, because different land use types may release water differently. The land use categories for the Vjosa WEAP model are detailed in Section 4.2.2. The exercise for calculating the area of each land use type for each catchment has been performed, and the land use data will be entered for each catchment as “share” of the total area (the tutorial has been provided to IGEWE in a separate document).

The characteristics of the various land use types within the catchment control how the land use types release or retain the water that falls in the catchment area as precipitation. These parameters include monthly values for crop coefficients (kc) and runoff resistance factor for each land use type, as well as soil water capacity, root zone conductivity, preferred flow direction, initial soil moisture values and preferred flow direction for each land use type. The overall catchment has additional parameters: the freezing and melting temperatures of snow, deep water capacity, deep conductivity and initial soil moisture values for the lower bucket. Many of these values are particularly difficult to measure over large areas, and thus are usually characterized within the calibration process, which alters these parameter values to enable WEAP to simulate the streamflow as closely as possible to the historic data. The calibration process can only be performed after all the system's supplies and demands have been entered for the historic calibration period. Section 0 describes the results of the calibration process for the Vjosa model.

3.2.3 Demand Sites

Many urban areas in the region use local springs for their water supply. In WEAP, there are modeled their water demands as withdrawing water from the river because the karst springs are modeled within the overall hydrology, not individually represented. Presumably, were this water not withdrawn, it would continue flowing into the river. Therefore, the springs are part of the same river system, so when we model the demand sites as withdrawing from the river, it is considered to be the same water as withdrawing from the karst springs that feed the river. The water balance remains the same. This will support model accuracy at the streamflow gauges.

In Figure 10, above, note that by having the respective supply (green catchment objects) for each area proceed the respective demand (red demand site objects) in each area, this simplifies the model considerably, and could lead to errors having to do with water availability in specific locations. However, in the absence of more specific location data, this methodology will provide an approximation of the Vjosa basins water provisions based on a larger scale water balance.

3.2.4 Reservoirs

The Vjosa has many reservoirs, but the majority are not on the main branch of the river. Since streamflow data are currently available only on the main branch of the Vjosa and two tributaries (the Drinos and Shushica), the smaller tributaries are not built into the model and thus many of the reservoirs are not represented in the current version of the model. Figure 13 shows the location of some of these reservoirs.

With more accurate information, however, smaller reservoirs and their impacts can be modeled at a future stage. The current model only includes two reservoirs, Poçem (not yet constructed, modeled within a scenario according to the available engineering plans) and Kalivaç, which did not have available data.

Figure 13. Reservoirs in the Vjosa Catchment
Source: Shapefile “Dams_original” from Zotaj 2016

4. Data collection for the Vjosa WEAP Model

4.1 Introduction

Data collection for WEAP is generally structured around distinct categories of data types:

1. Physiographic/spatial data
2. Hydrological data
3. Meteorological data
4. Water use/demand data
5. Climate Scenarios
6. Development Scenarios

The hydrological model and its calibration in WEAP depends on items 1 through 4. Depending on the local context of water use, (item 4), the model would require additional information on:

- Storage – natural and artificial
- Dam operations
- Environmental flow requirements

For the climate scenarios (item 5) are selected a series of downscaled Global Circulation Models (GCM) which are thought to most accurately capture the range of potential future climate conditions for the Vjosa basin. These are described in Section 6.1.

For item 6, there are developed a set of infrastructure development scenarios that capture potential expansion of hydropower capacity, rehabilitation and or expansion of irrigated agriculture and changes in basin population. These are described in Section 6.1.

The data for items 1-4 are described below. The information was gathered from sources including the following:

- The review of the literature, published and unpublished data available at the national research institute of IGEWE, under Polytechnic University of Tirana.
- Data collected, through the collaboration with the central ministries and institutions such as the Albanian Ministry of Environment, Ministry of Agriculture, Ministry of Energy, INSTAT, etc.
- Agricultural demand data collected by the Irrigation Boards of Gjirokastër.
- Information gathered from/with the collaboration of university departments such as: Department of Environmental Engineering, part of the Civil Engineering Faculty within Polytechnic University of Tirana, and some Albanian private companies, etc.

4.2 Physiographic/spatial data

4.2.1 Elevation/hydrography

Physiographic data for the basin are largely derived from a global hydrologically corrected DEM Digital Elevation Model (DEM) developed by Lehner et al. (2010), which is freely available.[2] For the project were combined the 5-degree tiles at a spatial resolution of 90 m that cover the Vjosa basin for elevation (DEM), hydrologically corrected elevation (CON) drainage directions (DIR), all of which are readily available for download from the HydroSHEDS website.

[2] hydrosheds.org

Using ArcGIS software are calculated the basin outline and flow accumulation/drainage network and used to delineate the catchments of the Vjosa, as described in Section 3.2.1.

4.2.2 Land Cover

Land cover data was derived from the EU CORINE 2006 dataset, which occurred during the calibration period of the model (2002-2008).[3] This dataset provides 44 land cover classes at a scale of 1:100 000 for the years 2000, 2006 and 2012. The minimum mapping unit of CORINE is 25 ha. Five meta-categories in CORINE are "artificial surfaces", "agricultural areas", "forest and semi-natural areas", "wetlands", "water bodies".

For input into the Vjosa WEAP model, were simplified the classification values of the 2006 CORINE dataset into 10 types (Table 3) (where N/A denotes that the value did not appear in the Vjosa watershed).

Table 3. CORINE Land use classes in 2006 (left) and WEAP generalized land use classes (right)

Code	CORINE Land Use	Vjosa WEAP Land Use
1	Continuous urban fabric	Artificial, non-agricultural vegetated areas
2	Discontinuous urban fabric	Artificial, non-agricultural vegetated areas
3	Industrial or commercial units	Artificial, non-agricultural vegetated areas
4	Road and rail networks and associated land	Artificial, non-agricultural vegetated areas
5	Port areas	N/A
6	Airports	Artificial, non-agricultural vegetated areas
7	Mineral extraction sites	Artificial, non-agricultural vegetated areas
8	Dump sites	N/A
9	Construction sites	Artificial, non-agricultural vegetated areas
10	Green urban areas	N/A
11	Sport and leisure facilities	Artificial, non-agricultural vegetated areas
12	Non-irrigated arable land	Arable land
13	Permanently irrigated land	Arable land
14	Rice fields	N/A
15	Vineyards	Permanent crops
16	Fruit trees and berry plantations	Permanent crops
17	Olive groves	Permanent crops
18	Pastures	Pastures
19	Annual crops associated with permanent crops	Heterogeneous agricultural areas
20	Complex cultivation patterns	Heterogeneous agricultural areas
21	Land principally occupied by agriculture, with significant areas of natural vegetation	Heterogeneous agricultural areas
22	Agro-forestry areas	N/A
23	Broad-leaved forest	Forests
24	Coniferous forest	Forests
25	Mixed forest	Forests
26	Natural grasslands	Scrub and/or herbaceous vegetation associations
27	Moors and heathland	Scrub and/or herbaceous vegetation associations
28	Sclerophyllous vegetation	Scrub and/or herbaceous vegetation associations

[3] www.eea.europa.eu/data-and-maps/figures/corine-land-cover-types-2006

29	Transitional woodland-shrub	Scrub and/or herbaceous vegetation associations
30	Beaches, dunes, sands	Open spaces with little or no vegetation
31	Bare rocks	Open spaces with little or no vegetation
32	Sparsely vegetated areas	Open spaces with little or no vegetation
33	Burnt areas	N/A
34	Glaciers and perpetual snow	N/A
35	Inland marshes	Wetlands
36	Peat bogs	N/A
37	Salt marshes	Wetlands
38	Salines	N/A
39	Intertidal flats	N/A
40	Water courses	Waters
41	Water bodies	Waters
42	Coastal lagoons	N/A
43	Estuaries	N/A
44	Sea and ocean	N/A
48	NODATA	N/A
49	UNCLASSIFIED LAND SURFACE	N/A
50	UNCLASSIFIED WATER BODIES	N/A
255	UNCLASSIFIED	N/A

Using the open source QGIS software, the CORINE land use data were summarized and aggregated data to the delineated WEAP catchment objects.

Table 4 provides a summary of the generalized land cover type distribution for the entire Vjosa basin. It is clear that relatively natural land cover types dominate, largely due to the variable topography and inaccessibility of the basin.

Table 4. Summary of generalized land cover types for the Vjosa basin (Albania and Greek sides) and their estimated surface areas derived from the CORINE 2006 dataset

Land Use Type in Vjosa Basin	Area (km^2)
Arable land	324.18
Artificial, non-agricultural vegetated areas	67.79
Forests	2344.94
Heterogeneous agricultural areas	829.7
Open spaces with little or no vegetation	480.23
Pastures	167.01
Permanent crops	74.33
Scrub and/or herbaceous vegetation associations	2469.53
Waters	46.13
Wetlands	2.7
Grand Total	6806.54

4.3 HYDROLOGICAL DATA

Observed streamflow data form a critical component of the WEAP model since it is the main reference for the model's calibration. Only if the model is calibrated can it be used for evaluation of future scenarios.

4.3.1 Summary of stage-discharge observations and rating curve

For the Vjosa River, water level and stream gauge measurement data for six gauging stations (see Figure 9) was extracted from a SQL server database which was developed within the framework of the World Bank project on Disaster Risk Mitigation and Adaption, completed between 2008 and 2013.

These water levels were recorded in relation to a benchmark called the “zero graph level” (see for more details the Appendix A.1). For the current dataset the rating curves are based on average stream conditions, which could introduce a significant error in discharge values.

Once a rating curve is established, water level measurements that are adjusted to the reference level, can be directly translated into discharge values.

For each station, a preliminary relationship between stage and discharge (potential function) was established and plotted in a log-log chart. The correlation coefficient that is established by the linear regression line of this plot provides an indication for the quality of the rating curve. The log-log and linear regression line for the Përmet station on the main stem of the Vjosa and the Vodice station on the Shushica tributary is illustrated by Figure 14.

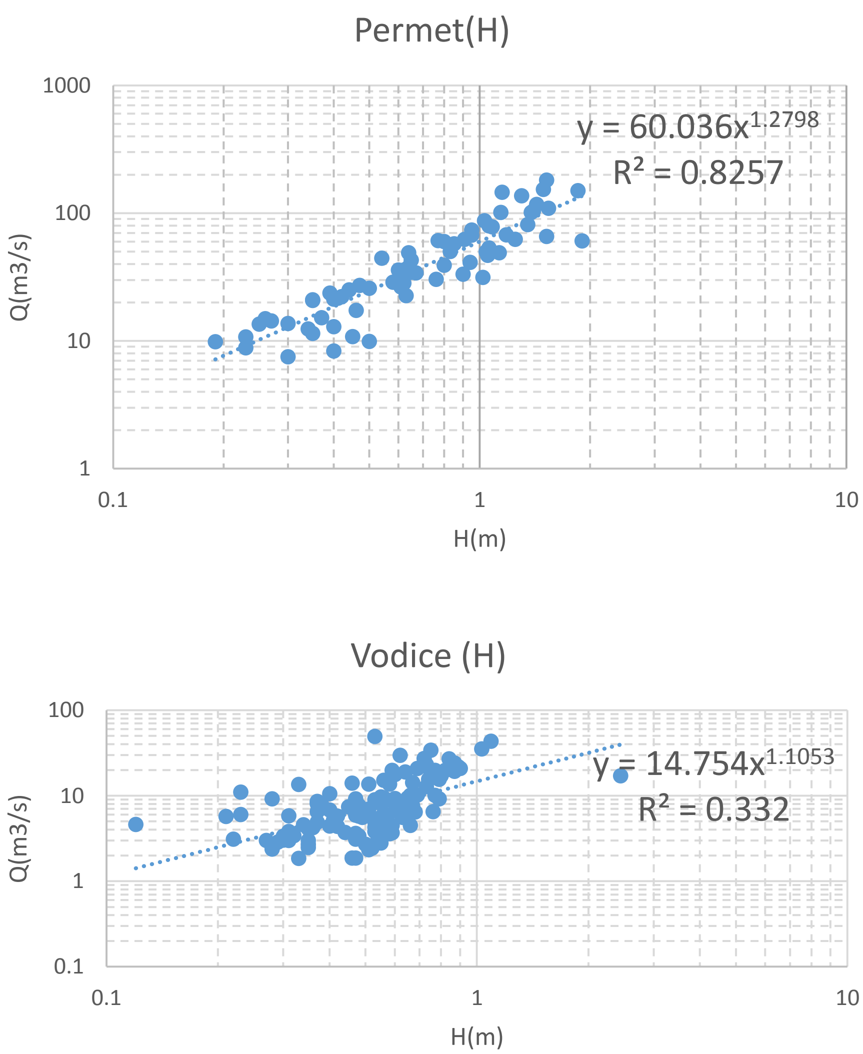


Figure 14. Stage-Discharge relationship for the period 1992-2008 for the Permet and for the period 1992- 2006 for Vodice

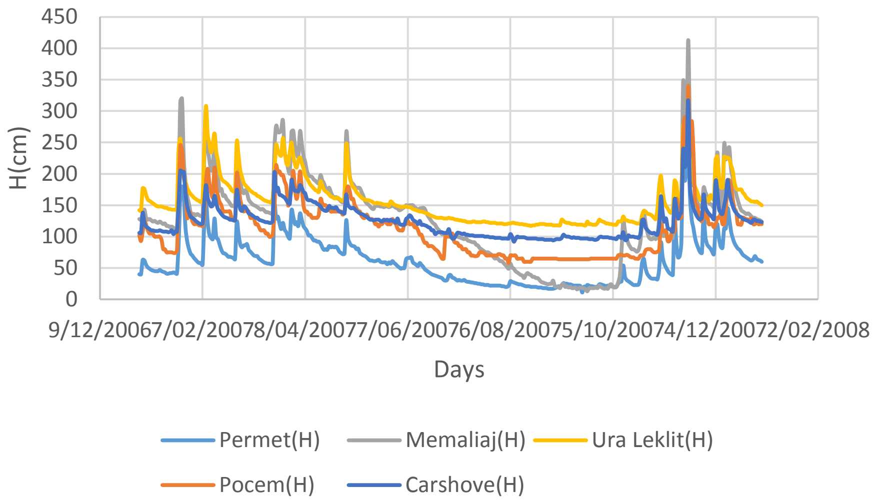


Figure 15. Water level observations at the selected stream gauges for the years 2006-2007

A review of these water level records, which were adjusted to benchmarks, show a very similar pattern in variation (Figure 15). One aspect that draws immediate attention to the Memaliaj station is the a-typical recession curve (falling curve of the hydrograph) during the dry season/summer (June-October of 2007). This could be due to issues with the calibration of the station or a difference in river bed characteristics at the sites.

The correlation coefficients for all stations, is provided in Table 5. The Përmet station, though it has fewer measurements overall, shows a satisfactory correlation coefficient of 0.82, while Vodica station shows a poor correlation coefficient of 0.33 (Figure 14). This indicates problems with the calibration of the streamflow measurements. This issue could be fixed if better information on stream conditions during the measurements are provided. Part of the issues with this station seem related to the very low discharges and potential issues with positioning of the gauge to capture low flows. Hence, it is impossible to derive a rating curve in Vodica and the station will be excluded from the study. As a result Shushica River will not be calibrated.

Table 5. Name, location, period of availability of water level data and number of the stream gauging measurements that were selected within the Vjosa basin for this study

NAME	Lat	Long	Begin date	End date	Correlation	Number of Stream Gauging measurements
Carshove	40.11	20.54	01/01/1993	31/10/2008	0.8	75
Memaliaj	40.35	19.97	01/03/2003	31/10/2008	0.86	21
Permet	40.24	20.35	01/01/1992	31/10/2008	0.82	72
Pocem	40.49	19.73	01/01/1992	30/06/1993	0.69	27
			01/01/2003	31/10/2008		
Ura Leklit	40.26	20.06	01/03/2001	31/10/2008	0.84	49
Vodice	40.42	19.58	22/07/1992	1/12/2006	0.33	126

Based on the available data, were deduced three rating curves in Çarshovë, Përmet and Ura Leklit and two in Pocem and one in Memaliaj for their distinct periods of record. This set of rating curves by station incorporates the changes in the river's cross section due to the river dynamics over the years. A methodology was developed to select the suitable periods to outline each of the rating curves by location.

The approach for choosing the number of years for each rating curve by station was based on an analysis of the change in the correlation over a log-log plot whilst adding extra years to the graph. Whenever the correlation started to drop following the addition of a new year's data, that year was identified as the breaking year. Hence, the first rating curve will be developed with the data from the beginning of the historical records until the year before the breaking year.

No proper method for low or high flow extrapolation of rating curves was conducted because the necessary time and cross section data was not available. Nevertheless, the rating curves were extended further from the last stream gauging measurement in the low and high part of the curve. Moreover, no data about the bankfull stage or detail river cross section including flood plain was available. Hence, these stage discharge relationships are only appropriate for modelling purposes that use a monthly time scale. Finally, it is important to remark that we are introducing significant error to the gauge records due to the extrapolation in the high flow (sometimes we extrapolated discharges 10 times higher than the last measurement), which will be smoothed by the monthly average.

4.3.2 Discharge conversion and hydrograph consistency analysis.

The discharge time series was implemented to change the rating curve equation according to the years of the time series. The rating curve equation takes the form

$$Q = A(H - B)^C$$

Where

Q = streamflow discharge volume
A = Rating curve constant
B = constant which represents the gauge reading corresponding to zero discharge
C = Rating curve constant
H = Stage for discharge

The consistency of the hydrograph was evaluated from upstream to downstream stations and potential data issues were identified for several stations. For example, Çarshovë systematically showed greater discharge values than the downstream stations of Përmet and Memaliaj and equal or greater discharge to Poçem. Based on knowledge of the basin, this is likely due to a bad reference of the benchmark in the rating curve or the water level time series. It is impossible to overcome this problem due to a lack of consistency in the archive regarding the benchmarks for each station. In the case of Çarshovë, it seems that the reference was wrong in the majority of the years. In the case of Memaliaj, a combination of bad quality data mixed with a wrong benchmark value and an inappropriate monitoring location in a turbulent area may be causing the data discrepancies. The Përmet water levels showed a good shape but the discharge measurements seem low, indicating that there might be a problem with the reference in the rating curve.

After the analysis, was concluded that the stations that can be used in the WEAP model are Përmet, Ura e Leklit and Poçem. Çarshovë and Memaliaj should be further studied with IGEWE experts to determine if other methods can reconstruct the correct reference values. The downstream catchments for the Lumi-i-Shushicës tributary and the river reach between Poçem and the outlet to the sea have no streamflow gauges, and the data cannot be calibrated. The results in these areas are highly uncertain, and for this reason are not represented in this report. Table shows that these three stations approximate the long term averages and long term maximum discharges.

Table 6. Comparison of long-term average and maximum discharges for three gauging stations in the Vjosa basin

	Q(m^3/s)		
	Përmet	**Poçem**	**Ura Leklit**
Q average Data	44.2	130.3	29.6
Q average Report	75.0	155.0	36.6
Q max Data	911.4	2021.8	791.1
Q max Report (Poçem Dorez)	734.0	1800.0	636.0

Source: Lushaj et al. 2003

4.4 METEOROLOGICAL DATA

The meteorological data used for the WEAP model are also derived from the SQL server data base, implemented within the framework of the World Bank Disaster Risk Mitigation and Adaption project. Under this project, the original meteorological booklets were digitized from 2002 to 2011. The stations used for this study were selected based on a combination of location and availability of time series. The quality of the data of all parameters and stations included in the Table 7 was thoroughly checked and some data was excluded or completed based in the quality check results.

Table 7. Summary of meteorological stations in the Vjosa basin that were selected for this study

ID	NAME	Latitude	Longitude	Precipitation	Temperature (Tmax, Tmin)	Relative Humidity	Daily values
1	*Brataj(T)*	40.27	19.67	x	x		x
2	*Fratar(P)*	40.51	19.81	x			x
3	*Kelcyre(T)*	40.31	20.19	x	x		x
4	*Krahes(P)*	40.43	19.85	x			x
5	*Kuc(T)*	40.18	19.84	x	x		x
6	*Llongo(T)*	39.84	20.37	x	x		x
7	*Nivice(T)*	40.24	19.89	x	x		x
8	*Permet (S)*	40.24	20.36		x	x	x
9	*Polican(S)*	40.13	20.35		x	x	x
10	*Selenice(T)*	40.53	19.64	x	x		x
11	*Tepelene(T)*	40.29	20.02	x	x		x
12	*Ioannina*	39.37	20.51	x	x		
13	*Vovoussa*	39.54	21.06	x	x		

At the station names:
T - means there are data for Temperature and Precipitation
P - there are data only on Precipitation
S - there are data available for Temperature, Precipitation and others (humidity, etc.)

4.4.1 Precipitation

Precipitation data is one of the most important inputs for the WEAP rainfall-runoff model. For this study, we compiled data from meteorological stations in the Albanian and Greek parts of the basin (Figure 16).

For Albania, complete datasets for the years 2002-2008 came from the 9 precipitation stations Brataj, Fratar, Këlcyrë, Krahës, Kuç, Llongo, Nivicë, Selenice and Tepelenë. In Greece, precipitation data came from stations Vovoussa (in the Vjosa basin) and Ioannina (which is about 15 km south of the basin).

4.4.1.1 *Precipitation in the Vjosa basin in Albania*

For each year in the calibration period (2002-2008), cumulative precipitation and double mass curves graphs were created, plotting meteorological stations against each other (Figure 17 provides an example of Nivicë precipitation data plotted against Brataj precipitation data) to identify missing data and potentially anomalous data points.

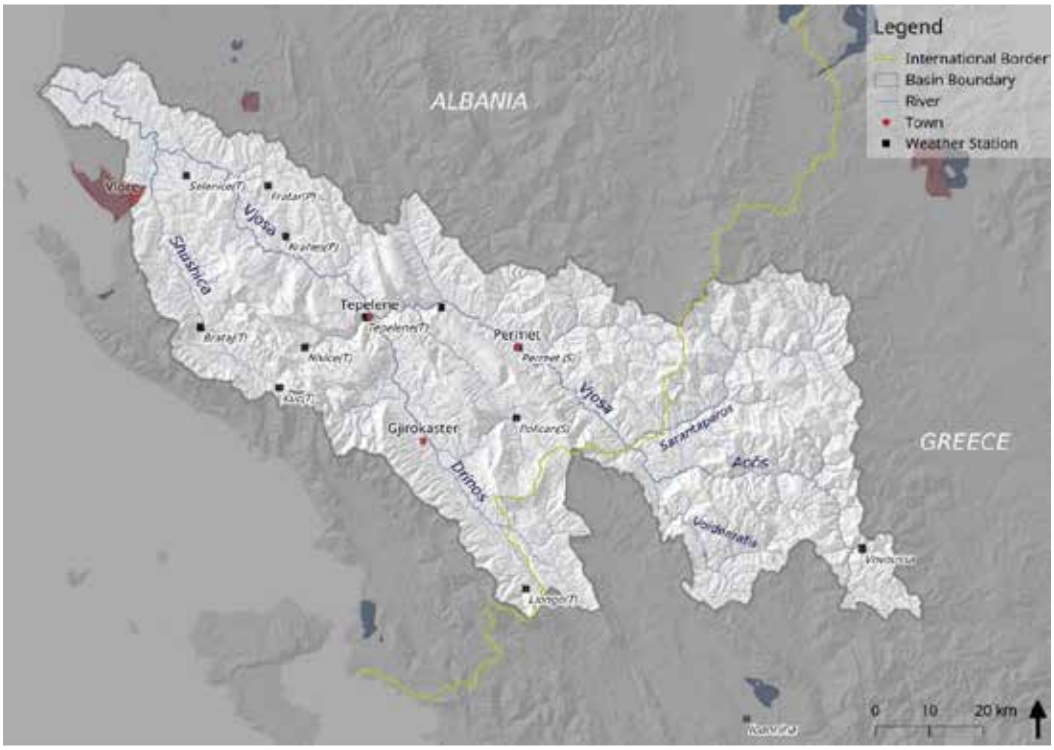


Figure 16. Locations of the selected meteorological stations for this project

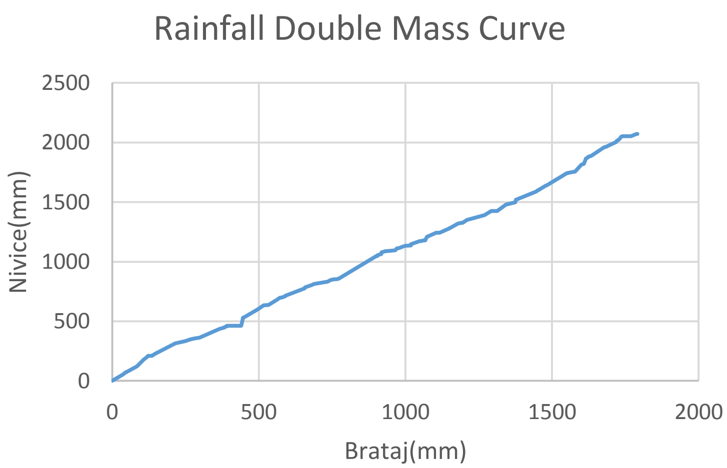


Figure 17. Example of a double mass curve for the Nivicë - Brataj stations

Although the data seems consistent, substantial gaps in the time series were identified and interpolated using a range of methods summarized in Appendix A.2.

4.4.1.2 Precipitation in the Vjosa Basin in Greece

Precipitation data for the Greek part of the basin proved difficult to obtain, though some sources that would require payment were identified. For the period 2002-2008, the data available was:

1) Daily precipitation records for Ioannina for 2002-2004 came from the European Climate Assessment & Dataset (www.ecad.eu). Of the 1096 daily records, ECAD labeled 899 records as "suspect" in terms of quality. In general, they showed more variation than then the average records. The daily data was summed into monthly data for the available data periods.
2) Average monthly precipitation data for Ioannina to fill in the years 2005-2006 was taken from http://www.ioannina.climatemps.com. Unfortunately this data set does not specify which years contribute to the average values.
3) Monthly precipitation records were available for Ioannina from http://penteli.meteo.gr/stations/ioannina for the years 2007-2008.

Vovoussa had less available data: monthly precipitation records were available for the climate station Vovoussa, located within the Greek portion of the Vjosa (Aoös in Greece) watershed, http://penteli.meteo.gr/stations/vovoussa from March - December 2008.

To complete the records for Vovoussa (2002-February 2008), was performed a regression of the existing data for March-December 2008 between Ioannina and Vovoussa (Figure 18), producing the equation

Vovoussa precipitation = 1.0378 (Ioannina precipitation) + 7.221 (R^2 = 0.61)

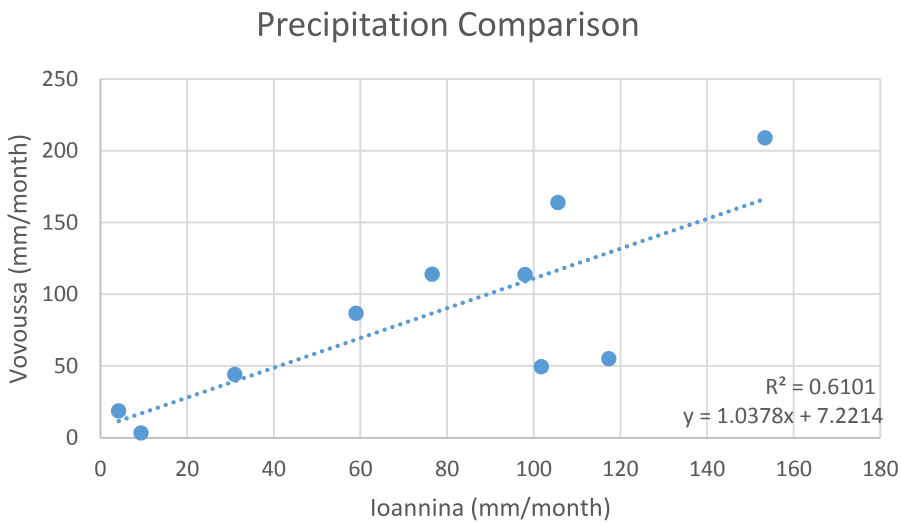


Figure 18. Correlation between precipitation values measured at the Ioannina and Vovoussa stations in Greece

This equation was used to extrapolate the Vovoussa data based on the Ioannina data for the period January 2002-February 2008 from the compilation of the Ioannina record described above. The opportunity for introducing error in this process was large due to the mixing of various data sources, each presumably with their own bias, and the extrapolation of the Vovoussa data based on an imperfect correlation.

4.4.2 Temperature

The stations used for the precipitation records were not necessarily also equipped with temperature measurements. The project gathered complete datasets for the years 2002-2008 for 10 temperature stations in Albania and Greece: Brataj, Këlcyrë, Kuç, Llongo, Nivicë, Përmet, Poliçan, Selenice, Tepelenë, Ioannina (Greece) and Vovoussa (Greece). However, Llongo and Nivicë were discarded because the records were deemed unreliable by IGEWE.

4.4.2.1 Temperature data for the Vjosa Basin in Albania

The data quality for temperature historical records for the Albanian side of the basin was assessed using annual graphs to identify missing data or data errors. Missing daily data was interpolated with the average of the previous and posterior date from the missing date before performing the monthly average (see Appendix A.3).

4.4.2.2 Temperature data for the Vjosa Basin in Greece

For the Greek data, the following available data were obtained:

1) Minimum and maximum daily temperature records for Ioannina for 2002-2004 came from http://www.ecad.eu/. All 1096 records were ranked as "valid" in terms of quality. The records were aggregated and averaged for each month for the available years.
2) Average monthly temperature records for Ioannina came from http://www.ioannina.climatemps.com/temperatures.php to fill in the years 2005-2006. The years that contributed to the average calculation are not specified, and we note that the average temperatures listed for Ioannina from http://en.climate-data.org/location/1375 (also with unknown years) are slightly lower.
3) Monthly mean temperature records were available for Ioannina from http://penteli.meteo.gr/stations/ioannina for the years 2007-2008.
4) Monthly mean temperature records for the climate station Vovoussa, located within the Greek portion of the Vjosa watershed, from http://penteli.meteo.gr/stations/vovoussa for March - December 2008.

To complete the records for Vovoussa, we performed a regression of the existing data for March-December 2008 between Ioannina and Vovoussa (Figure 19), producing the equation

$$\textit{Vovoussa temperature} = 0.942\ (\textit{Ioannina temperature}) + 3.2059$$

($R^2 = 0.9946$)

As one would expect, temperature exhibits a much greater correlation between stations than precipitation (Figure 18) due to the strong topographic dependence and smaller general variability of this parameter, facilitating more reliable extrapolation than for precipitation data examined in Section 3.4.1.

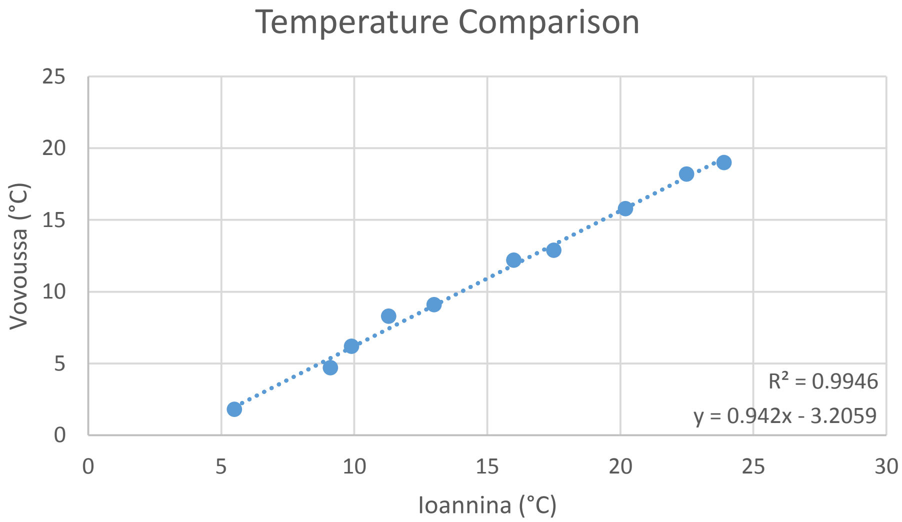


Figure 19. Correlation between temperature observations at the Ioannina and Vovoussa meteorological stations in Greece

This equation was then used to populate the Vovoussa data from the Ioannina data for the period January 2002-February 2008. The Ioannina record included the average data and the observed data (2007-February 2008), which introduced risk of error due to the different sources and their respective biases.

4.4.3 Relative Humidity

Relative humidity data allows for accurate estimation of evapotranspiration in the WEAP model. This parameter was not recorded or available for the Greek stations and is only recorded at two stations on the Albanian side, Përmet and Poliçan. As part of this project, the data record between 2002 and 2008 was compiled and evaluated.

Data quality for relative humidity observations was analyzed with yearly graphs and daily data missing was first completed with the average of the previous and posterior date from the missing date (see the methodology in Appendix A.4).

However, the Voronoi polygons interpolation process used for temperature and precipitation could not be used for only two geographical locations. Therefore, to obtain record for use within the WEAP model both in the historic calibration period and the future scenarios, the reconstructed monthly relatively humidity data for the years 2002-2011 was averaged to produce an annual record of relative humidity (Table 8) that could be repeated over the period of the model in all the catchments.

This methodology introduced error because the process of completing records prior to averaging them inevitably weighs some data points more than others since they may contribute to the records of multiple time steps. Additionally, the relative humidity of Poliçan and Përmet, both upstream of the center of the Vjosa basin, may differ from the relatively humidity in the headwaters or outlet of the basin. However, as this data was unavailable, the averaged Poliçan and Përmet data provided the only climate record, and thus was used throughout the model.

Table 8. Relative humidity data for all catchments

Month	Relative Humidity (%)
January	84.59
February	83.46
March	81.43
April	79.95
May	80.45
June	78.95
July	76.46
August	77.50
September	81.95
October	84.49
November	83.93
December	85.94

4.5 WATER USE/DEMAND DATA

Collected water demand data for the basin Vjosa is structured around three major subsets: Agricultural, Industrial and Urban demand. While some data may not be available, estimates can be made based on secondary parameters such as land cover, population census data and general knowledge in per capita water use.

The format of this data must fit the population subdivisions of the model divided according to catchments.

4.5.1 Agriculture

The land area of agricultural data is a major determinant the irrigation water demand in the catchment. Agricultural data in the Vjosa basin not always consistent. Figure 20 compares two data sets with land use data for agricultural areas, Zotaj 2016 and the CORINE dataset, using Heterogeneous agricultural areas and Permanent Crop areas to approximate agricultural areas.

CORINE 2006 Data Set

Zotaj 2016

Figure 20. Comparison of agricultural area data sets (Albanian section of watershed only)

The WEAP model used the land use data from the CORINE 2006 data set (see Section 4.2.2) to generally characterize the area under irrigation, recognizing that agricultural activity does not always imply irrigation.

WEAP's soil moisture model uses several parameters to calculate water needed for irrigation in the areas surrounding different catchments of the river. Observed irrigation demand data can be compared against the WEAP results to ensure the model is approximating the physical system.

No regular recordings of the water use data for agriculture for the study period (2002-2010) were available at the Albanian Ministry of Agriculture nor the Irrigation Board Agencies of Gjirokastër and Vlora. These are the most important prefectures within the Vjosa basin concerning irrigated agricultural land.

No political constraints have been used during the time period in study in the agriculture areas within the Vjosa basin, to limit water access for irrigation. Thus, WEAP has no upper bounds on the amount of water it can supply except for the volume of water in the river. Additionally, no clear information was available regarding any adaptation in the agriculture infrastructure that the local government could consider for the future development. Lastly, the financial data gathering regarding the projects that have been implemented in the study area was disaggregated and not clearly connected to benefits obtained, which prevented a cost-benefits analysis of agricultural development.

Because only unofficial information was available, estimating the agricultural demand required making assumptions. If, in the future, more data becomes available, it can be used to more accurately calibrate the agricultural demand of the model

Among the data gathered, the most reliable discharge data (with information about discharge and areas in hectares) was the data provided by the Irrigation Board Agency of Gjirokastër. For the year 2010, the irrigated agricultural areas in Gjirokastër, Përmet and Tepelenë districts had data for

- the total area that can be irrigated (ha);
- the actual irrigated area (ha); and
- primary channel discharges (total capacity and availability).

The primary channels, part of the irrigation system of each sub-basin, were:

- Drinos sub-basin: Nokova, Vrisera, Libohova, Kardhiq, and Shepeta primary channels;
- Përmet sub-basin Qilarishta, Iliar, Tremisht, Sternbec, Kaludh, and Zhepa primary channels;
- Lower basin sub-basin: Cerril primary channel;
- Memaliaj sub-basin: Memaliaj, Vinokash, Varibob, Kelcyre, Zuca, Pacomit, and Kosina primary channels.

This information were used in our model to calculate agricultural demand in the study period and create a future scenario of with increased irrigation demand (see Section 6.1.1).

Agriculture calculations and assumptions

The Vjosa sub-basins that were calibrated for the agriculture future scenario in the Vjosa WEAP model are: Drinos, Memaliaj, and Përmet. There was no information available about Lumi i Shushices, the sub-basins below Memaliaj, or Çarshova sub-basin, where much of the area is a national park in Greece.

The agricultural demand was estimated from actual discharges of the main channels (from the information of 2010, provided by the Irrigation Board Agency of Gjirokastër. These values were lower than the maximum discharge values, which will frame the characterization of the agricultural development scenario.

Using the data from 2010 as a source, the irrigation systems' water withdrawal from the Vjosa River were extracted. It was prepared in a 'klm' file with all the watersheds, prefectures, and the irrigation systems of the area, to determine their location according to the WEAP catchments.

After calculating the annual water withdrawal for irrigation for each catchment, the irrigation water usage for one year (in m^3/ha) was summarized. Table 9 shows the resulting irrigation demand for the Drinos, Memaliaj and Përmet catchments to be simulated in the Vjosa WEAP model.

Table 9. The actual agricultural water demands of the Vjosa catchments

	Km²	**Actual Discharge (m^3/s)**	**Annual rate (m^3/ha)**	**Annual Discharge (MCM)**
Drinos	36.10	0.56	4892	17.66012
Memaliaj	18.80	0.485	8136	15.29568
Permet	10.25	0.24	7384	7.5686

To use this information to estimate irrigation demand in WEAP, the land use type "Hetero Agriculture" from the CORINE data set in each catchment was divided into two categories, irrigated and unirrigated. Note that the land use type Permanent Crops tended to cover a much smaller area, and was deemed less likely by virtue of its permanence to include irrigated agriculture.

The land use values for irrigated areas within the Hetero Agriculture land use type were calculated to equal the hectares from the observed data (Table 10). For the basins without data, irrigation area was either assumed to be the same as a nearby catchment, or was estimated based on water availability in the river (more towards the river's outlet than its headflow). Table 10**Error! Reference source not ound.** shows the km² values for the irrigated areas of each catchment, and the percentages entered into WEAP to produce those numbers as well as the assumptions and justifications of those percentages.

Table 10. Irrigated Areas in the Vjosa Catchments

Catchment	Km² irrigated area of catchment	Percentage of Hetero Agriculture	Justification/Assumption
Drinos	36.12	22.1	Data
Memaliaj	18.80	13.07	Data
Permet	10.25	21.33	Data
Lumi i Shushices	11.63	13.07	Same as Memaliaj
Pocem	15.50	13.07	Same as Memaliaj
Lower Basin	55.74	25	Greater than Memaliaj
Carshova	4.48	10	Less than Permet

The results for the catchments below Memaliaj are highly uncertain because the agricultural data is based on assumptions, rather than data, and thus are not presented in this report.

Reproducing these values in WEAP required adjusting the land use parameters for the areas that require irrigation. WEAP calculates the water demand of these areas based on several specifications: Land use parameters in the Soil Moisture Model (such as monthly Kc values, runoff resistance factor, and soil water capacity, among others), the time of year when these areas were irrigated, and the lower and upper thresholds of soil moisture considered tolerable for the crop under examination.

Altering any of these parameters could produce higher or lower agricultural demand, and without detailed data, it is difficult to know which combination best represents the real world. To calibrate the agricultural demand in the model, irrigation was allowed only for the summer months and the parameters for upper and lower threshold were altered to match the irrigation data. If the precipitation and other climatic factors produce a soil moisture value in the catchment that is below the Lower Threshold, WEAP will irrigate the catchment. Similarly, if the precipitation and other climatic factors produce a soil moisture value in the catchment that is above the Upper Threshold, WEAP will cease irrigating. To calibrate to the irrigation values in the table, the thresholds of Hetero Agriculture and Permanent Crops were determined through the calibration process. Table 11 shows the results.

Table 11. Upper and lower thresholds of soil moisture in calibrated catchment

Catchment	Lower Threshold (% soil moisture)	Upper Threshold (% soil moisture)
Drinos	35	42
Memaliaj	35	57
Permet	35	65

In addition to changing the upper threshold for irrigation, the Kc values for the crops increased. This helped the land use areas demand more water (Table 12).

Note that the four uncalibrated catchments, Çarshovë, Poçem, Lower Basin and Lumi i Shushices assumed the same threshold and Kc values as Përmet (Çarshovë only) and Memaliaj (the remaining three catchments).

Table 12. Crop coefficient values for hetero agriculture in calibrated catchments

Catchment	Kc for Irrigated Area
Drinos	2
Memaliaj	1.62
Permet	1.25

Using these parameters allowed approximating the historical irrigation values, although the success varied by catchment due to different precipitation records. We note that the agricultural demand is highly variable throughout the years because WEAP is incorporating the changing precipitation and temperature measurements. Demand in upstream Përmet and Drinos are much more constant than Memaliaj, which was the least accurate of the three calibrations due to extreme sensitivity in the model, and extreme variations in the amount of agricultural water demanded (Figure 21).

Following these activities to help the model fit the data, Table 13 compares the actual values with the average values produced in WEAP for the corresponding catchment for the calibration period of the model, 2002-2008.

The irrigation data provided by the Irrigation Board Agency of Gjirokastër was for the year 2010, however in WEAP average annual irrigation over the calibration period (2002-2008) was matched to this data. The calibration period was used because it has the most reliable data, however to have switched the years may have introduced error, especially for a place like Memaliaj that displays broad annual variability in its demands in WEAP.

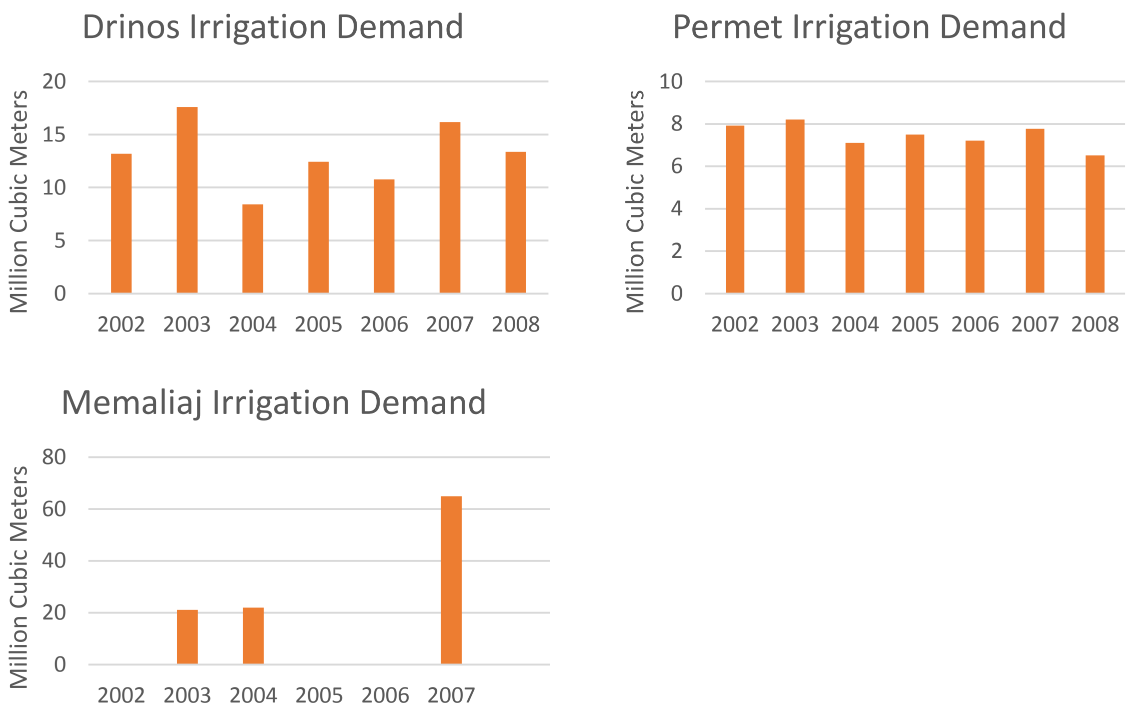


Figure 21. Comparing the intra-annual variability of the agricultural demands for the three calibrated catchments

Table 13. Comparison between actual and modeled agricultural demands

Catchment	Km^2	Actual Discharge (m^3/s)	ACTUAL Annual rate (m^3/ha)	Annual Discharge (MCM)	WEAP Calibration Mean Annual Discharge 2002-2008 (MCM)
Drinos	36.10	0.56	4892	17.66	17.59
Memaliaj	18.80	0.485	8136	15.29	15.43
Permet	10.25	0.24	7384	7.57	7.50

4.5.2 Industrial

Data was collected for industrial water use during the study period (2002-2008) in the five Albanian prefectures (Gjirokastër, Vlorë, Fier, Berat, and Korçë) that intersect the Vjosa catchment. The water demand data of all industrial activities in the study area was needed to calculate this demand for use in the WEAP model and to evaluate the water availability of Vjosa River according to this demand.

No regular recordings of the water use data for industry for the calibration period (2002-2008) was available in any of the responsible institutions, nor did any political constraints exist to limit water access for industry. No information was available regarding any adaptation in the industry infrastructure that the local government could consider for the future development. This included a lack of financial data that precluded any sort of financial analysis of industrial activity.

As a result, assumptions were made to estimate the industrial water demand.

The main document used was the "National Register of licensed water utilities" (provided by the Agency of Vjosa Basin) which allowed the identification of the main water users (companies/industries or people) licensed to withdraw from surface water, wells, and springs in Vjosa basin for different industrial activities. These activities include bottling activities, and other activities such as pools, washing of inerts (gravel, etc.), family/small businesses, etc.

All industrial demands in each respective catchment were aggregated into a single industrial demand site that withdrew water upstream of the flow gauge that delineated the catchment (see Section 3.2.1). For this, a 'klm' file was prepared to locate the local units (commune) of the water licenses, because the coordinates available did not specify the projection system and it was impossible to identify which system was used.

After summarizing all the water quantity used by different industrial users within each sub-basin, annual industrial water use (m^3/year) could be calculated for each catchment. Table 14 shows the results.

Table 14. The annual water withdrawal for the industry in the Vjosa sub-basin

Sub basin	Drinos	Lower Basin	Memaliaj	Lumi i Shushicës	Poçem	Përmet	Çarshovë
Water used (l/s)	27	17	10	20	0.5	13.2	Unknown
Annual Water withdrawal (m^3/year)	851,472	536,112	315,360	630,720	15,768	416,275	Unknown (0)

In the WEAP model, each catchment's respective industrial demand is withdrawn from the Vjosa River constantly throughout the year, without growth over the years. Wastewater return flow enters the river downstream, and is currently estimated to be only 10% of the industrial demand, due to the nature of the demands (especially water bottling).

4.5.3 Urban

The Albanian Regulatory Authority of the Water Supply and Waste Water Disposal and Treatment Sector (WRA) provided urban water demand. The provided data consisted on a total volume of water by Water Utility (WU) and the supplied population detailing cities and communes by WU per year. Based on the watershed delineation of Vjosa River, only the populated areas included in the given data and located within Vjosa Basin were used for further analyses.

Making use of Google Earth, all the cities and communes included in the given data were located so the population of any areas outside the Vjosa watershed could be discarded. Each population area was assigned to one of the seven Vjosa catchments in WEAP and aggregated within each catchment's respective demand site. Note that no data was available for Shushica catchment.

The Annual Water Use Rate was calculated for each demand site using available data for the water use rate in *l/capita/day*. The results of water use rate were very high in some areas and very low in others, brought the reliability of the data into question. Further analysis about population was conducted. The total population given by WRA by city or commune was crossed-checked with INSTAT data. Major inconsistencies in the population data indicated that the data was not appropriate for use in the model.

From the north to the south of Albania, there are problems in the exploitation of the water supply networks. Typically, the networks function only several hours a day, providing an intermittent water supply to the population. Rarely there is 24-hour water supply. One factor that heavily affects this result, is the percentage of water losses in the network. For example, in Novosela the designed water use rate was of 150 *l/capita/day* however the actual rate is 90 *l/capita/day*. (Management Plan Vjosa – Narta Landscape Protected Area, 2005). This difference might be associated to the water losses or mismanagement of the network.

Based on the results of the previous analysis of the data provided by WRA, the team were forced to use a water use rate estimate based on the general practice of the country. The standard design water value rate is 150 *l/capita/day* in Albania, in other countries domestic water use can range from 240 *l/capita/day* to 500 *l/capita/day*. Hence, it was chosen to be apply in the WEAP model an estimate of 150 *l/capita/day*. However, this value can be a bit high for some of the cities or communities. For input in WEAP, this value is equal to 54.75 m^3/person/year, which has been entered for all the Albanian population demands.

Additionally, the WEAP model requires relatively accurate estimates of seasonal variability of demands of each sector. The monthly variability of urban water demand was not available; instead the monthly percentages of annual demand were estimated as shown in Table 15.

These values are based on real municipal water demands of an area in Spain with similar temperature characteristics (see Table 16) to Vjosa River basin. The source of the data in the table is Segura -River Basin Management plan, published in 1998 (page 19).

Table 15. Summary of estimated variations of monthly Albania urban water demands as percentage of total annual water demand

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
% Annual Demand Albania	7.4	7.1	7.7	7.5	8.3	9.2	10.1	10.5	9.0	8.1	7.6	7.5

Source: Segura River Basin Management Plan, 1998.

Table 16. Average monthly temperatures comparison of Murcia (Spain) and Vlora (Vjosa River basin)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Murcia, Spain	10.6	12.2	14.3	16.5	20	24.2	27.2	27.6	24.2	19.8	14.6	11.5	**18.6**
Vlore, Albania (1961-1990)	8.9	9.6	11.3	14.3	18.2	21.8	24.1	24.1	21.5	17.9	13.8	10.5	**16.33**

Sources: AEMET, n.d. (Murcia) and IGEWE archives (Vlore).

The annual variation of Greek domestic demand estimates household use at 200 L/day/ per capita during cold season (275 days) and 330 L/day/per capita during warm season (90 days) (Seferlis et al 2008). This totals to 84.7 m^3/person/year.

Adjusted for the number of days in each month, Table 17 shows monthly percentages of annual demand according to these estimates.

Table 17. Estimates for monthly variation of annual water demand for Greek consumers

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
% Annual Demand Greece	7.3	6.6	7.3	7.1	7.3	11.7	12.1	12.1	7.1	7.3	7.1	7.3

Domestic demand withdraws water from the river, but also returns the wastewater, or return flow, which then can contribute to the river's total volume. In WEAP, the return flows are based on the rate of consumption of the demand. According to Gratziou et al (2006), detached houses in Greece consume roughly 12% of their total demand. Because data was not available for Albania, the same rate was used for Albanian communities.

4.5.3.1 Local Population

With the data in place for *per capita* water consumption, WEAP needed information about the populations in the respective catchments, including whether those populations are Greek, Albanian, or tourists, all of whom have different water demands.

Because population is not stagnant, the WEAP model needed to include the rates of population change to evaluate the total water demand for domestic water use. The assessment of the population in the Vjosa/Aoös watershed comes from the data provided by the Albanian Statistical Institute (INSTAT) and a report on the Aoös from the Hellenic International Development Cooperation Department (Seferlis et al 2008).

The population data in the Vjosa WEAP model had to be calculated for each of the seven catchment area. Demand in WEAP is modeled as demand nodes (red circles) and each catchment area received one demand node to represent all the domestic demand within that catchment. Figure 22 shows the WEAP model schematic with domestic demands (red circles labeled as being “Above” the gauge of their respective catchments). Other red circles are industrial demand (Section 4.5.2).

Figure 22. WEAP model schematic

For the purpose of the model, all the domestic demand within each respective catchment is withdrawn from the river in one point downstream of each respective catchment’s hydrological contributions, but upstream of the gauge that defines the catchment’s area. The unconsumed water from these demand sites in returned to the river immediately downstream of the withdrawal. In reality, none of these communities draw their water from the Vjosa itself, but rather from the mountain springs or small stream tributaries that would otherwise feed the Vjosa flow. In terms of the model, the simulated Vjosa flow should match the respective flow gauges, and as long as water is subtracted for domestic use upstream and wastewater is released into the river, the resulting reduction in flow is correctly incorporated in the model. In that sense, withdrawing water directly from the river in the model is equivalent to withdrawing water from the springs that feed the river.

The Albanian population calculations derived from population data (Source: INSTAT) and are calculated the density data of the five Albanian prefectures (Gjirokastër, Vlore, Fier, Berat, and Korçë), that intersect the Vjosa/Aoös catchment.

The population data preparation for the WEAP model began with the determination of the population of 2002 by catchment in WEAP. The population density for each prefecture was calculated using the annual population for the available years and the area of the prefecture calculated in QGIS. Subsequently, the prefectures were intersected with the seven sub-basins (Çarshovë, Përmet, Drinos, Memaliaj, Poçem, Lumi i Shushices and Lower Basin). Hence the area of intersection of each prefecture by sub-catchment was obtained (Figure 23). The catchment populations were the product of the prefecture density and the areas of each prefecture in each catchment (summed for all catchments overlapped by multiple prefectures).

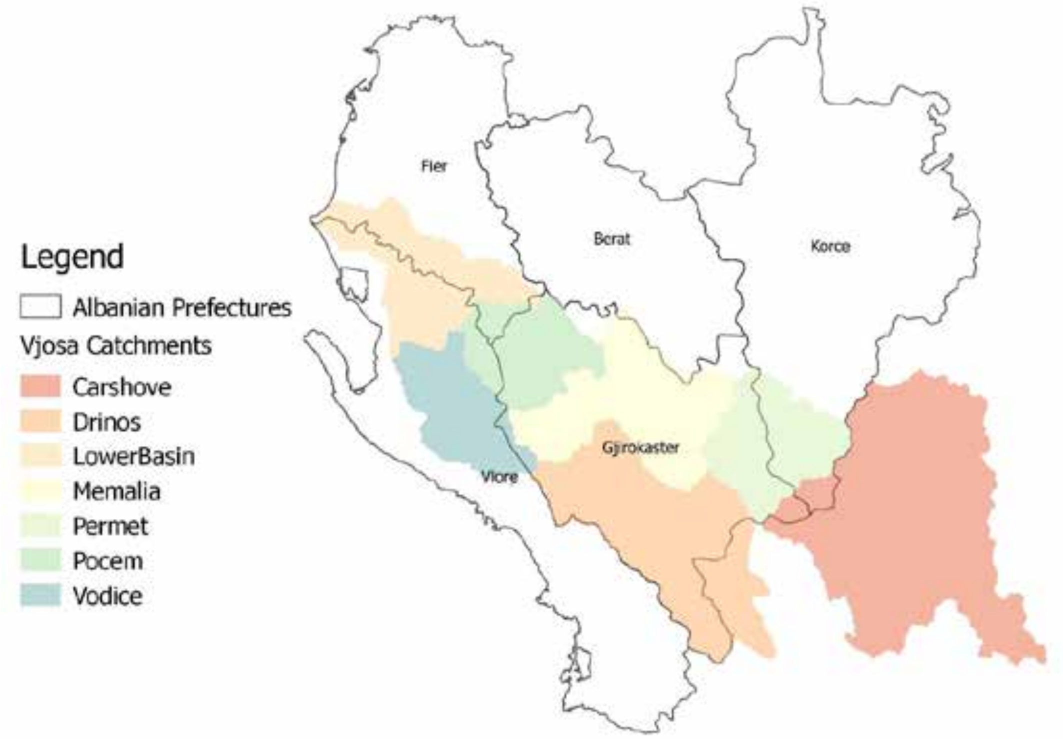


Figure 23. Intersections of Albanian prefectures with Vjosa catchments in QGIS

The population by catchment was calculated assuming that the population density was homogeneous throughout the whole prefecture. This hypothesis is not entirely true and can lead to less accurate results. However, this was the only way to calculate the population by sub-catchment within the study period (2002-2008) with the data available.

This allowed the calculation of the population in each WEAP catchment over time.

The rates of change for the Albanian population in each Vjosa catchment between 2002 and 2016 were calculated as an average for the years 2002-2016 based on the data in Table 19.

During the historic period of the WEAP model, the actual population data was entered for each catchment using Excel, and following the last year of data (2016), the rate of change within a “Growth” equation in WEAP’s Expression Builder. Figure 24 shows the total population over the course of the model in the Poçem catchment. The years 2002-2016 are taken from calculations based on existing prefecture records (INSTAT) as described above, after starting in 2017 the model uses the average population growth rate.

Table 18. Permanent Population of the Vjosa catchments between 2002 and 2016

Year	Albanian Population per WEAP Catchment							Total Vjosa Albanian Population
	Carshovë	**Drinos**	**Përmet**	**Lower Basin**	**Poçem**	**Vodicë**	**Memaliaj**	
2002	5,496	40,316	35,448	98,243	33,923	38,264	36,856	**288,544**
2003	5,413	39,292	34,864	97,385	33,397	38,312	35,915	**284,580**
2004	5,320	38,099	34,202	96,411	32,784	38,261	34,828	**279,905**
2005	5,227	36,931	33,543	95,232	32,143	38,175	33,761	**275,013**
2006	5,130	35,645	32,848	93,957	31,438	38,043	32,586	**269,648**
2007	5,022	34,332	32,086	92,641	30,711	37,817	31,383	**263,992**
2008	4,918	32,996	31,344	91,149	29,944	37,542	30,164	**258,057**
2009	4,812	31,739	30,603	89,783	29,227	37,271	29,012	**252,447**
2010	4,718	30,410	29,919	88,340	28,460	36,805	27,806	**246,457**
2011	4,613	29,013	29,172	86,944	27,673	36,277	26,553	**240,246**
2012	4,521	27,670	28,497	85,747	26,943	35,798	25,352	**234,527**
2013	4,490	27,271	28,277	85,360	26,729	35,826	24,986	**232,938**
2014	4,485	27,240	28,245	85,265	26,699	35,785	24,957	**232,677**
2015	4,439	26,752	27,927	84,773	26,435	35,823	24,503	**230,650**
2016	4,378	26,081	27,505	84,299	26,103	35,807	23,884	**228,056**

Table 19. The surface area and the Albanian population rate of change by catchment in the Vjosa catchment

Watershed	Surface (km^2)	Albanian Population Rate of Change
Carshovë	2160	-0.016
Drinos	1295	-0.030
Përmet	636	-0.018
Lower Basin	720	-0.011
Poçem	539	-0.018
Lumi i Shushices	544	-0.005
Memaliaj	922	-0.030
Total Area of Vjosa Watershed	**681**	

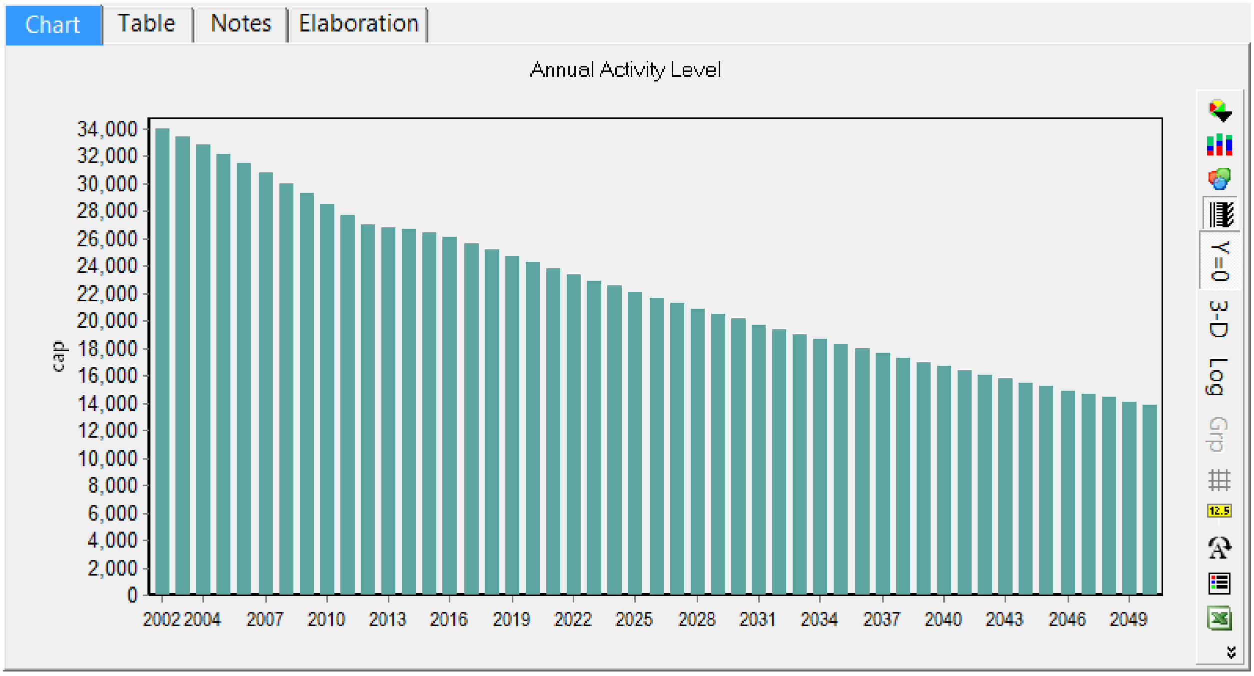


Figure 24. Population 2002-2050 in Poçem

In additional to the Albanian population, the Vjosa/Aoös basin contains two distinct sections in Greece with Greek residents. Figure 25 shows the intersection of three Greek prefectures (Kastoria, Grevana and Ioannina) with the Drinos and Çarshovë catchments.

Because the Greek population of the Aoös watershed had a density of roughly 14.4/km^2 people in 2001 (Seferlis, 2008), the total Greek population for 2001 in the Drinos and Çarshovë catchments could be calculated based on catchments' areas within Greece (calculated in QGIS with the shapefiles shown above, projected in WGS_1984_UTM_Zone_34N). See Figure 25.

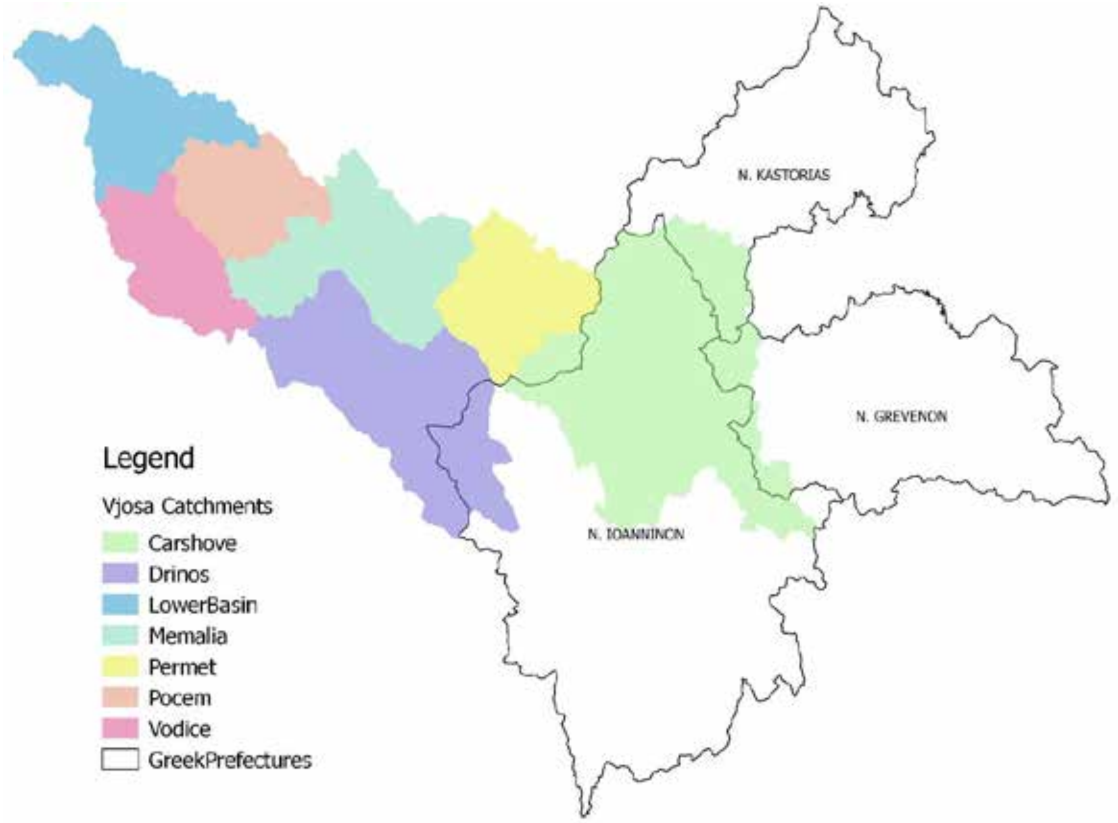


Figure 25. Intersection of Greek prefectures with the Çarshovë and Drinos catchments of the Vjosa/Aoös watershed

Table 20 shows the corresponding population numbers in 2001.

Table 20. Greek population in Aoös section of Vjosa watershed in 2001

Catchment	Greek Area in Catchment (km^2)	Greek Population in 2001
Carshove	2060.11	29,666
Drinos	256.67	3,696

Using data for Greece's rural population from 2000 to 2015 (World Bank, n.d.) and the equation

$$Percent\ Growth\ Rate = \frac{\frac{(2015\ Population - 2000\ Population)}{2000\ Population} * 100}{number\ of\ years}$$

The growth rate -1.3% was calculated for rural Greece, which best characterizes the areas in the Aoös catchment in Greece. This value may introduce some error into the model because the rural area around the Aoös River may have a greater or smaller rate of change in population than Greece as a whole.

To enter Greek population data for the model over time, the built-in WEAP expression GrowthFrom takes population data from a specific year (2001) and the rate of population change to generate the Greek population the Çarshovë and Drinos catchments forward through time. Figure 26 shows the results for each catchment, as well as the general population division between the Greek and Albanian populations in the Aoös headwaters (Çarshovë catchment) and the Drinos tributary of the Vjosa River.

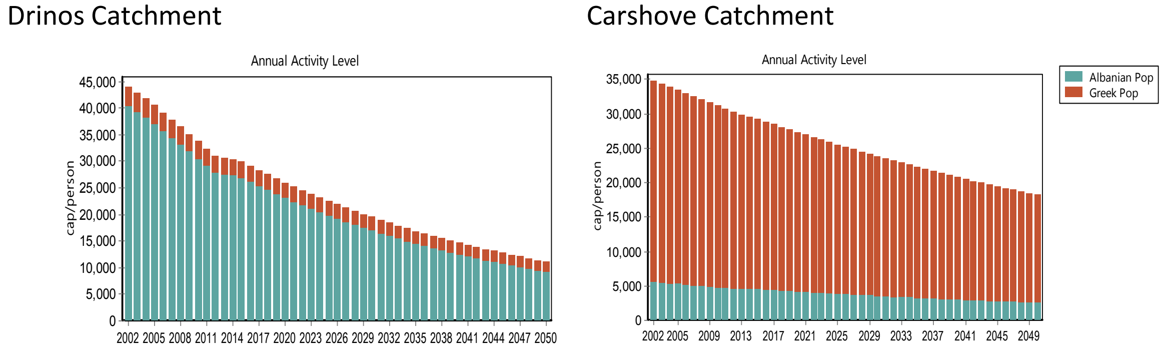


Figure 26. Population decline over time for the Greek and Albanian populations of the Drinos and Carshove catchments, 2002-2050

The rates of change in population for the Greek and Albanian populations also assumed to remain constant between the years 2002-2050 in the reference scenario. Government, economic or social changes may produce different trends in the future that are not currently represented in the model (with the exception of the Tourism scenario, described in Section 7.2).

4.5.3.2 Tourist Population

As detailed in Section 4.5.3.1, both the Albanian and Greek populations in the Vjosa/Aoös watershed are declining. However, Albania has seen a rapid growth in tourists over the past several years, following the end of communism in the 1990s and an increasing recognition of Albania's natural landscapes coupled with the country's affordable prices.

For the purposes of the model, the impact of tourism can be three-fold.

1) Increases the population and creates demand for water to hotels and restaurants that grow out of the tourist industry
2) Some of the population that would have left the area (contributing to the population decline), remains because of new job opportunities
3) Because the tourists may be coming from regions with higher water use, is assumed that tourists demand more water per capita than the Albanian inhabitants.

Because many of the specific characteristics of this data are not available for the delineated catchments in the Vjosa watershed, assumptions were made to characterize the numbers and impacts of tourists in the Vjosa watershed for the Reference (business as usual) scenario. These assumptions are detailed below, and will be compared to the Tourism Scenario (described in Section 6.1.2).

The Albanian Ministry of Urban Development and Tourism has tracked the number of tourists in Albania for the past several years (Figure 27).

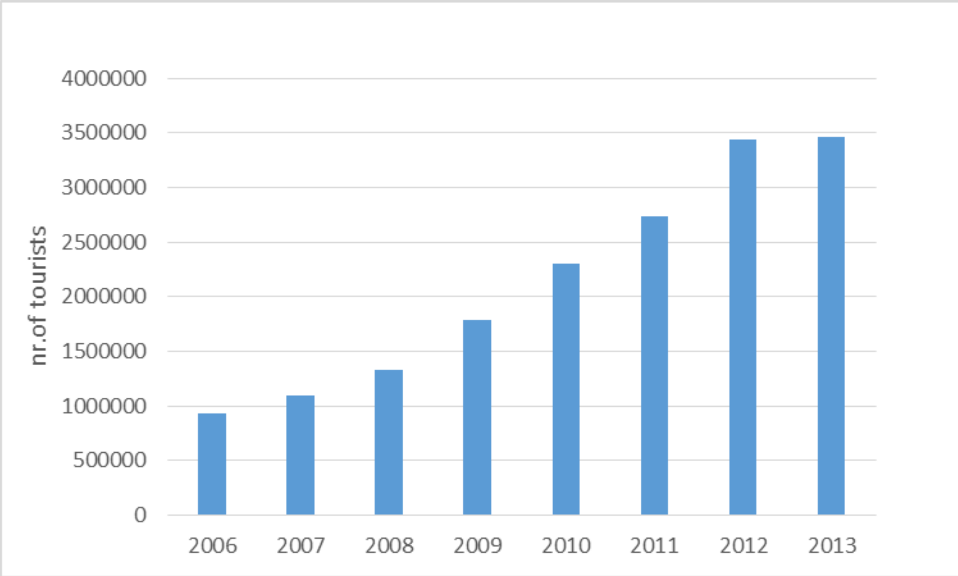


Figure 27. International visitors in Albania 2006-2013
Source: Ministry of Urban Development and Tourism (Albania), 2016.

This data has the potential for error due to the collection method. The General Directorate of the Police collects the border statistics through a survey asking the purpose of the visit, the country of residence, and the mode of transport. More training is needed. Several types of arrivals should not be considered visitor or tourist arrivals (Acorn Tourism Consulting Ltd, 2011).

Based on the available information, to calculate the number of tourists on the Albanian side of the Vjosa watershed, were assumed that tourists have a relatively equal distribution across Albania. Because the Vjosa occupies 15.6% of Albania's area, it could have 15.6% of Albania's total tourists, which would be 144,465 tourists in 2006.

There are two destinations in the Vjosa basin where tourists are likely to concentrate: Gjirokastër, in the Drinos watershed, and Përmet, on the border of the Përmet and Memaliaj watershed. Assuming that the catchments can each support a population of tourists as a percent of their local populations, the Drinos catchment population and the average of Përmet and Memaliaj catchments population were used to divide the 144,465 tourists between Drinos (56% of tourists) the Drinos catchment and Përmet city (42%, half in the Përmet catchment, and half in the Memaliaj catchment).

This calculates the total number of tourists in each catchment, but not the total number of tourists at a given time, or over the course of the year. According to the "Survey System of Tourism Statistics" from 2010, international tourists spend an average of 5 days in Albania, and Albanian citizens residing abroad but returning for tourism spend an average of 10 days (Acorn Tourism Consulting Ltd, 2011). The data about the division between foreign and Albanian heritage tourists is inconsistent, so it was assumed that they were equal in proportion. Then, using the number of days that each type of tourist stayed on average, it was possible to calculate the average population of tourists to be included in the Drinos, Memaliaj and Përmet domestic demand for the year 2006. However, after viewing this value, was decided to halve it to account for the fact that the Albanian coast (not included in the Vjosa model because it is outside of the Vjosa watershed) is much more popular for tourism than the Albanian interior, so half the tourists calculated through an equal distribution assumption would be expected in these mountainous areas.

The tourism data calculated thus far was specific to the year 2006. The tourism growth has been dramatic in the past few years, about a 17.9% increase per year from 2006-2014, based on calculations from the data. WEAP uses the built-in equation "GrowthFrom" to calculate the tourism population for 2002-2014, based on 2006 numbers and the 17.9% growth rate. Because this is a dramatic growth, in the WEAP Reference scenario, an assumption is made: growth will continue at a lower rate in the future. With no data available to estimate a new growth rate, the model assumes that the growth rate linearly decreases to 5% growth in 2015 and then 0% growth in 2020, which stays constant for the remainder of the model.

This growth rate, applied to the population calculate for 2006, enables the model to calculate population of tourists in the demand sites, on average during any time during the year for all the years of the model. Figure 28 shows the annual tourism population for Gjirokastër for the historic period of the model until the end of the scenarios in 2050.

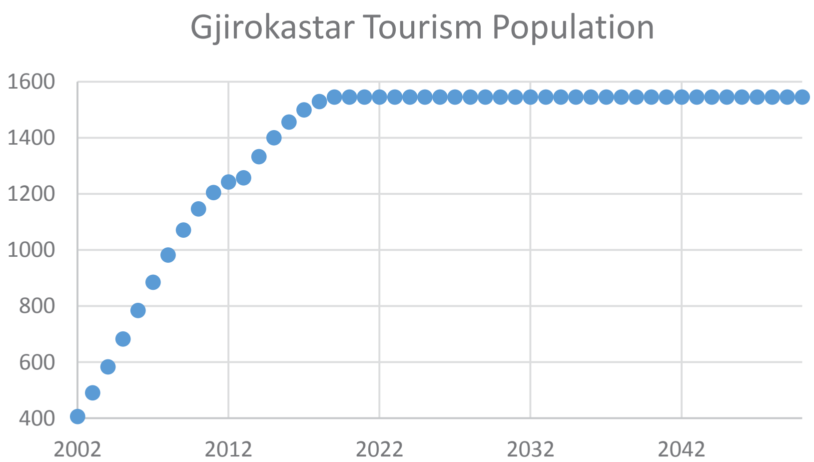


Figure 28. Tourist population per year, Drinos catchment

Figure 29 shows the tourism population (assumed to be in Gjirokastër city) graphed against the permanent population in the Drinos catchment in total.

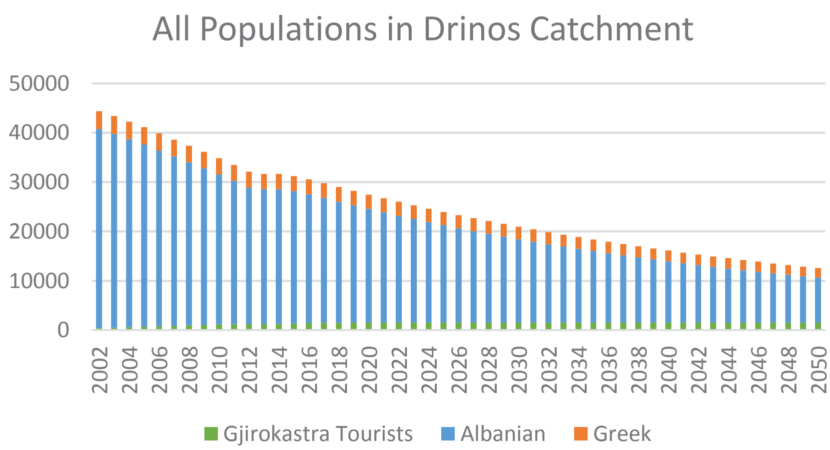


Figure 29. Greek, Albanian and tourist annual populations in Drinos catchment

These tourism assumptions define the Reference Scenario, in which the tourism growth is not assumed to impact the population rates of change as predicted through the records (see Section 4.5.3.1).

The Tourism Scenario (Section 6.1.2) will simulate more sustained tourism growth and subsequent changes in the rates of population decline of the tourist areas (Përmet, Memaliaj and Drinos catchments in WEAP).

No data was available to estimate per capita water use for Albanian tourists, so a value of 65 m^3/year was assumed as placeholder data until such a time when more data is available. This is noticeably higher than the permanent population per capita water demand of 54.75 m^3/year, but lower than the figure for domestic consumption in rural Greece.

Lastly, because the population of the tourists was included within the domestic demand nodes of each catchment, it was not possible to alter the values of Monthly Variation of water demand, data which does not differentiate between different types of disaggregated demand within a given demand node (for example, Greek demand, Albanian demand, and tourism demand). Therefore, the monthly variation of demand for tourists is the same as the variation calculated for the permanent residents, described in Section 4.5.3. In addition to the large number of assumptions made to generate the tourism data, this monthly variation may produce errors in the WEAP model, because in general, 50% of foreign tourists visit during the summer, and rest are divided over the remaining three seasons.

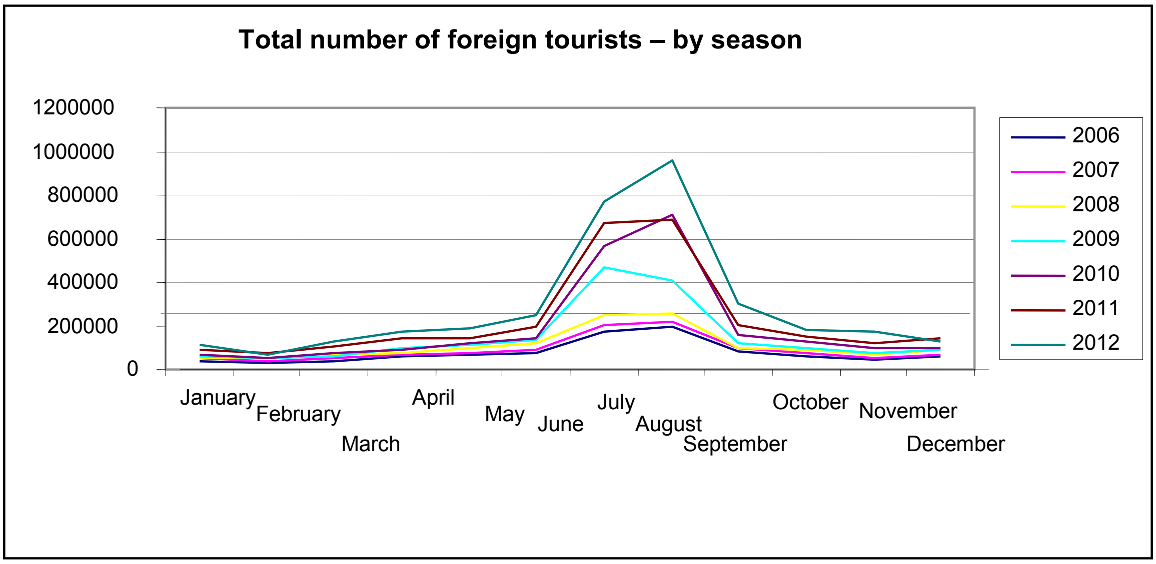


Figure 30. Annual monthly variation of tourists in Albania
Source: Ministry of Urban Development and Tourism, Albania

The current monthly variation data for water usage in the WEAP model is not so dramatic (see Figure 31) but is currently used to represent tourism water demand.

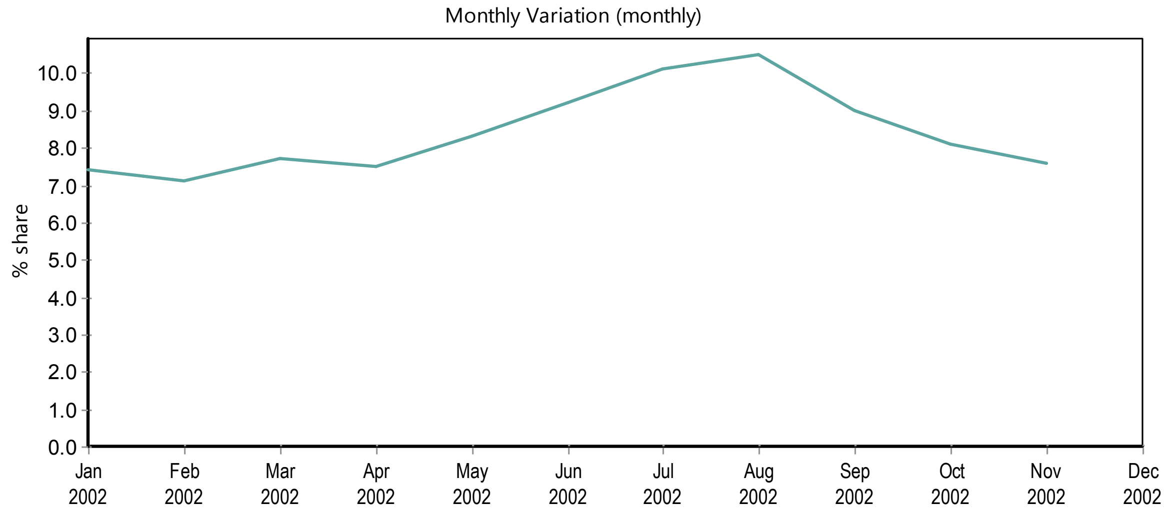


Figure 31. Domestic variation in Drinos, Memaliaj and Permet catchments

The model's simulation of tourism water demand could be improved in the future by restructuring the tourism demand in the model as a separate demand site with its own monthly variation. In general, the tourism data should be regarded as highly imprecise, and would benefit from improved detailed information about the tourist destinations in the Vjosa, the more information about the length of stay, their water demands and whether the monthly variation for water demand of Albanian heritage tourists could be approximated using the numbers in Figure 30.

4.6 Cost-Benefit Analysis

The planned Poçem hydropower project is currently the only large hydropower project (HPP) under consideration for construction in the Vjosa basin (Ministry of Energy, 2016). The site is located towards the middle of the Albanian section of the Vjosa River, downstream of Kalivac Reservoir. By gathering the financial data about the construction of the Poçem Reservoir, WEAP can conduct a cost benefit analysis that can calculate the changing value of a project's cost over time. This requires several data types:

<u>To Calculate the Value of Money over Time</u>

Discount Rate: the discount rate computes the net present value of an amount of money to accrue monetary quantities over time. As opposed to an interest rate, which depends on the terms of the loan that references it, a discount rate characterizes the general trend of an economy. It can be likened to the amount of money an investor would make investing in a "risk free" loan such as a government bond.

For the Vjosa model, the **discount rate** is 6% (Pandazi, 2016).

Inflation rate: The inflation rate calculates the change in the value of currency over time in the region under examination. It is used for converting future or past costs to the values in real dollars (2015 values for this analysis) that WEAP requires as inputs.

In Albania, the current **inflation rate** is 4%, although this has changed over time. For interval periods, we assume a linear increase in inflation rate from 2002 (2%) to 2016 (4%) (see Table 21) and use averages of the years within the interval under examination (Pandazi, 2016).

Table 21. Interpolation for annual Albanian inflation rate

Year	Interpolated Inflation Rate in Albania
2002	2.000
2003	2.143
2004	2.286
2005	2.426
2006	2.572
2007	2.715
2008	2.858
2009	3.000
2010	3.143
2011	3.286
2012	3.429
2013	3.571
2014	3.714
2015	3.857
2016	4.000

Loan periods: Assuming that the infrastructure costs require a loan to be taken out, WEAP needs to know the period over which the loan will be repaid.

In Albania, the **loan period** is seven years (Pandazi, 2016).

Interest rates: Interest changes depending on the terms of the specific loan under consideration.

In Albania, the interest rate in 2007 in local markets was 14% (Posch & Partners, 2007). It should not be less than 5% (Pandazi, 2016). The model uses the conservative value of 14%.

Cost Data

Capital Costs: the capital costs for a project quantifies the money needed to build or develop the project. This may be the amount of a loan, in which case additional cost is incurred for the interest payments.

For the Vjosa watershed, the Poçem Hydropower dam has an estimated **capital cost** of $141,154,084 in 2014 dollars (Cinar San. 2015). For the analysis, this value will need to be converted into the real value of 2015 dollars. In WEAP, the capital costs are entered as annual values, because it is usually the cost that must be paid off each year according to the agreements of the loan terms, for the agreed-upon number of years.

Fixed Operating Costs: Every year the infrastructure incurs fixed operating and maintenance costs, such as payments for the labor necessary to manage the infrastructure, rent for the land it is on, and other costs that need to be paid regardless of the volume of water that the infrastructure processes. The units of the operating costs are in $/year, in real dollars for the year 2015.

The **fixed operating costs** for Poçem may exist but are not available. Assumptions, detailed below, were used to calculate estimates for the operating costs.

Variable Operating Costs: These costs are part of operating and maintenance costs of the infrastructure, and accrue based on non-constant values, specifically the volume of water that the infrastructure processes. For example, if a desalination plant produces more water, it will need to spend more money to purchase the necessary energy.

The **variable operating costs** for Poçem may exist but are not available.

Fixed Benefits: If the reservoir produces known benefits each year that are constant, regardless of operation, these are considered fixed benefits.

The **fixed benefits** for Poçem may exist but are not available.

Variable Benefits: If the reservoir produces benefits dependent on the quantity of water processed, these are variable benefits. Variable benefits are usually applicable to infrastructure that purchases water in a block rate structure.

The **variable benefits** for Poçem may exist but are not available.

Electricity Revenue: The revenue from the energy production can be entered in WEAP as $/gigajoule.

The **electricity revenue** for Poçem is 0.0542 Euros/kWh in 2014 (Cinar San. 2015). A 2007 report for a hydropower plant provided a similar value (0.055 Euros/kWh), which even in 2007 was considered "on the low end of acceptable costings." (Posch & Partners, 2007, page 53), thus it is possible that the energy revenue will be higher.

Because not all this data was available, estimates had to be made based on other sources.

The Vjosa project was provided with a detailed feasibility report for the construction of two small hydropower plants, Bistrica 3 and Bistrica 4, near Saranda, Vlora prefecture, Albania (Posch & Partners, 2007). Annually, these reservoirs will produce 1.570 MW and 1.335 MW respectively, considerably less output than the Poçem plant (99.5 MW/year). However, the reservoirs have similar efficiency factors (82% for the Bistricas and 89% for Poçem). Converting between the listed KW and MWH for the Bistrica reservoirs reveals that they have operate 24 hours/day, every day, as opposed to Poçem, which would operate at 35%, or roughly 8 hours a day, 7 days a week.

The capital costs of Poçem, provided in 2014 dollars, are $141,154,084. The total investment costs for the Bistricas, broken down in the report, is €3,000,000 for Bistrica 3 and €3,250,000 for Bistrica 4 in 2007 (Posch & Partners, 2007), both much smaller investments than Poçem.

However, there are some useful breakdowns of costs in the Bistrica 3 and 4 report. "For the yearly maintenance costs, as a rule of thumb, 0.5% of investment costs on civil structures and for yearly reinvestments 3.0% on investments for E&M equipment are considered." (Posch & Partners, 2007, page 40). Though the breakdown of this cost information is not available for Poçem, it is available for Bistrica 3 and 4 (Table 22).

Table 22. Financial information about Bistrica 3 & 4 HPP

	Total Costs (2007 €)	Civil Works Cost (2007 €)	Electro-mechanical equipment (2007 €)	% Civil Works Cost of total Cost	% E&M Costs of total Costs
Bistrica 3	3,000,000	1,017,050	919,000	33.9%	30.6%
Bistrica 4	3,250,000	1,233,532	919,000	37.9%	28.3%
Average Percentage Values				35.9%	29.4%

Because Cinar San. (2015) compared Poçem the Bistrica plants, we apply the percentages to the Poçem hydropower cost. Table 23 shows the estimated costs for Poçem:

Table 23. Poçem estimated construction costs (2014 $)

Pocem Total Costs (2014 $)	Estimated Civil Works Costs (2014 $)	Estimated Electro-Mechanical Equipment Costs (2014 $)
141,154,084	50,674,316	41,499,301

Using the estimations annual operation and maintenance (0.5% of civil costs and 3% of E&M costs) from the Bistrica report, Table 24 estimates the fixed operating costs (O&M) for the Poçem reservoir.

Table 24. Poçem estimated annual O&M costs (2014 $)

Estimated Civil Works Costs (2014 $)	Estimated E&M Equipment Costs (2014 $)	0.5% of Civil Works (2014 $)	3.0% of E&M Costs (2014 $)	Total Estimated Annual Operation and Maintenance Cost (2014 $)
50,674,316	41,499,301	203,372	1,244,979	1,448,351

Therefore, we calculate the **fixed operating costs for Pocem Reservoir** at $1,448,351 (in 2014 dollars).

No data was available for calculating variable operating costs. It is also questionable whether the percentages for Poçem and the Bistrica 3 and 4 operating costs are comparable, since Poçem will operate considerably less time over the course of the year – though whether this reduces or increases costs is also unclear. Therefore, the calculated value for estimated annual operation and maintenance cost of $1,448,351 (in 2014 dollars) will be used within the model.

Using the Bistrica 3 and 4 feasibility report provides sufficient data to proceed with the financial analysis for Poçem reservoir. However, the data must first be correctly formatted to be entered into WEAP.

WEAP uses the real values of dollars in the Current Account year of the model, meaning the value of the currency in future or past years is converted to the value in 2015 by adjusting for inflation. The Vjosa model, though calibrated for the historic period 2002-2008, will run from 2015 as the Current Accounts year to 2050 as the last year of scenarios. The financial analysis will be conducted over this period, but all data must be entered in 2015 real dollar values.

The Poçem report assumes a profit of 0.0542 Euros per kWh (2014). Since 1 kWh = 0.0036 gigajoule, this value would be €15.05/gigajoule in 2014. Using the 2015 Euro-Dollar exchange rate from U.S. Foreign Exchange Services (USFOREX, n.d.), 1 Euro to 1.329 dollars in 2014. Therefore the cost in 2014 for electricity is 20.01 $/gigajoule.

The capital cost and fixed operational costs derived from it are assumed to be provided in 2014 dollars.

Using the equation:

$$CA = OV(1 + i)^n$$

Where

CA = Current Accounts (monetary base year) value (the “real” value of the money in the year 2015)

OV = original value (the value cited in 2014)
i = average inflation rate per period (3.71% in 2014 in Albania)
n = number of periods (1 year)

Table 25 provides the 2015 cost values for entry into the WEAP model.

Table 25. Converting Poçem HPP costs to 2015 $

	2014 $ Values	2015 $ Values
Capital Costs	141,154,084	146,390,901
Fixed Operating Costs	1,448,351	1,502,085
Price of electricity/gigajoule	20.01	20.76

Note that we are using the inflation rate in Albania, not the inflation rate for US dollars, because ultimately these costs must have equivalence to 2015 Albania Lek, despite appearing as dollars in WEAP.

To calculate the value of the capital costs over the course of the model, we assume that there is a loan for the full amount of the capital costs, starting in 2016, lasting for seven years, at 14%. This would be entered in WEAP using one of the built in expressions in the *Expression Builder*, the LoanPayment function. This function takes the syntax LoanPayment(Capital Cost, First Year, Loan Term, Interest Rate) and calculates the value of the money owed each year in the real value of dollars in the Current Accounts year of the model. The same amount is paid every year. For the case of Poçem, $34,137,242 (in 2015 value) are owed each year from 2016-2022 (see chart in Figure 32).

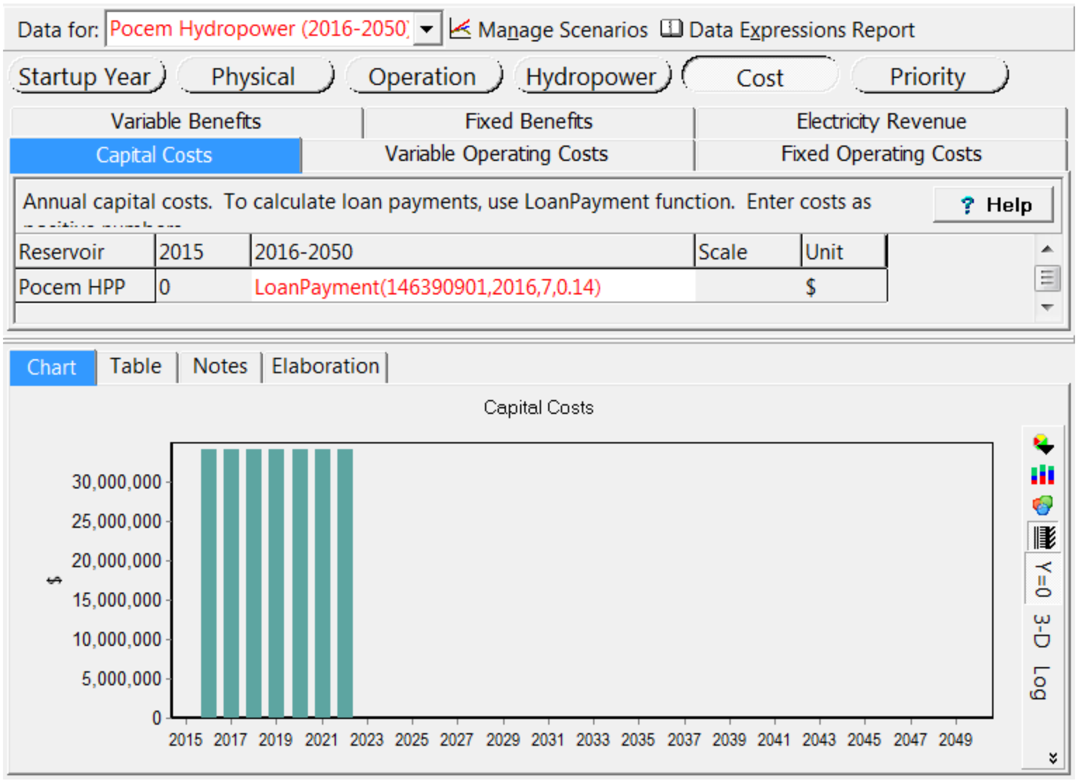


Figure 32. Data entry in WEAP for capital costs of Pocem HPP

The Fixed Operating Costs are entered according to the calculation above, and they are the same each year (in the value of 2015 dollars) (Figure 33). The hydropower plant is assumed to continue operation for the duration of the model.

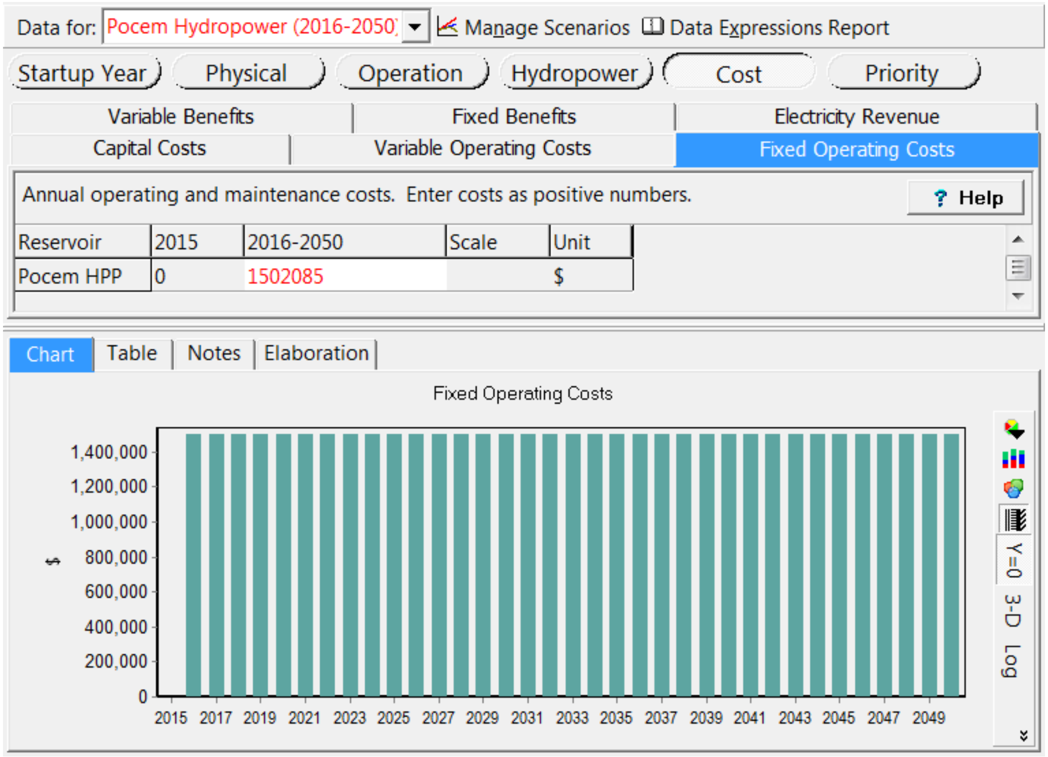


Figure 33. Data entry in WEAP for fixed operating costs of Pocem HPP

5. Model Calibration

With the data entered for the model in the historic period, model parameters can be calibrated for the period during which there are historic records for both meteorological data (temperature and precipitation) and streamflow gauge data. For the Vjosa, this period occurs from 2002-2008, which provides a short window for calibration exercises.

The calibration activities involved altering the land use characteristics for catchments upstream of the three monitoring stations used to calibrate the model. These were Përmet (upstream catchments: Përmet and Carshovë), Ura Leklit station on the Drinos tributary (upstream catchment: Drinos) and Poçem (upstream catchments: Poçem and Memaliaj – all others had already been edited for calibration). The two uncalibrated catchments (Lower Basin and Lumi i Shushices) assumed the same land use parameters as Poçem and Memaliaj, since those are the closest geographically (see Figure 10).

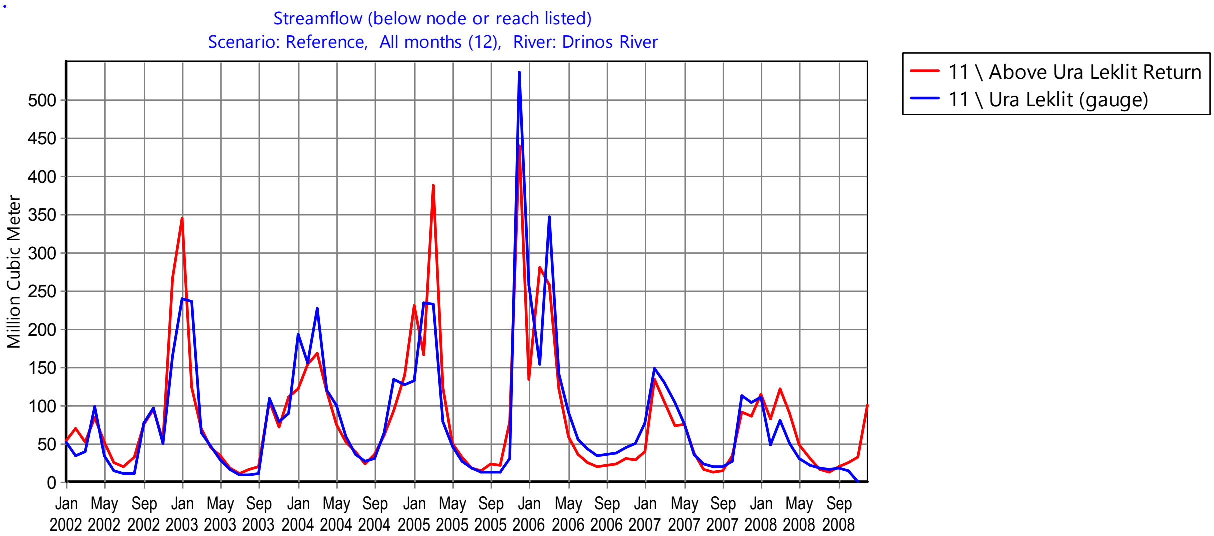
Figure 34 shows the observed and simulated streamflow for each of the stations following the calibration activities.

The calibration uses several indicators to evaluate and improve the initial calibration, using Nash-Sutcliffe Efficiency (NSE), percent bias (PBIAS), root mean squared error to the standard deviation (RSR) and standard deviation (SDR), as shown in appendix A.5.

Table 26 shows the values for theses statistical parameters according to the calibrations of the WEAP river flow at the location of the gauges for the Drinos, Përmet and Poçem catchments.

Table 26. Results of calibration activities for catchments with hydrological data

Catchment	NSE	%Bias	RSR	SDR
Drinos	0.747	-.283	.503	0.977
Permet	0.648	-0.075	0.593	0.822
Pocem	0.594	-3.659	0.637	0.940
(Ideal Value)	1	0	0	1
(Acceptable Value)	0.5-1	25% in either direction	Below 0.7	0.9-1.1



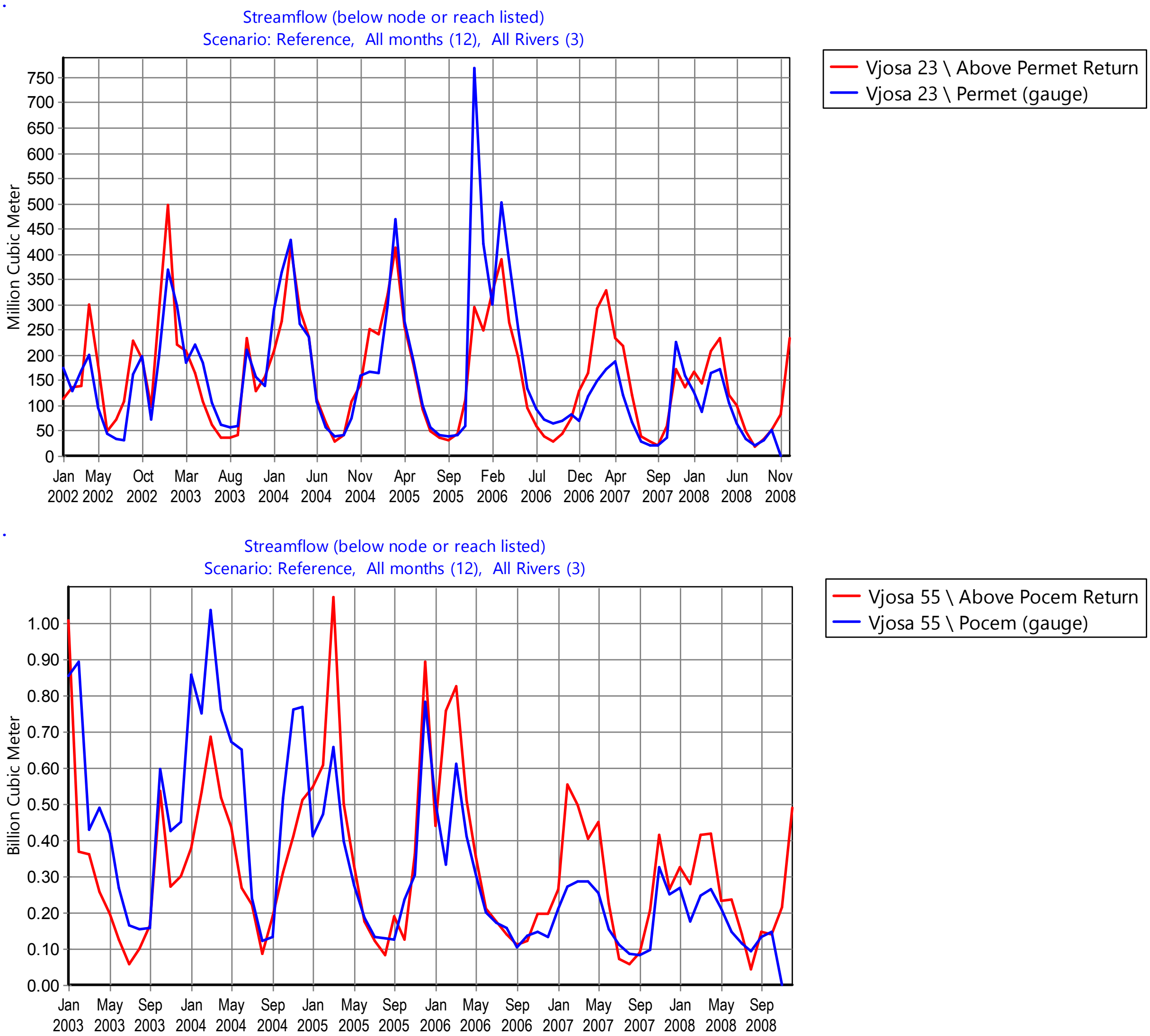


Figure 34. Streamflow comparison for Drinos, Përmet and Poçem hydrological stations

The upstream values both show a better match than the Poçem calibration downstream. Though overall Poçem shows a negative bias (not enough streamflow), viewing the annual total for the years of calibration reveals that this is true the first years of the calibration period, but not the later years (Figure 35). It is difficult to extrapolate how this might play out over the future scenarios of the model.

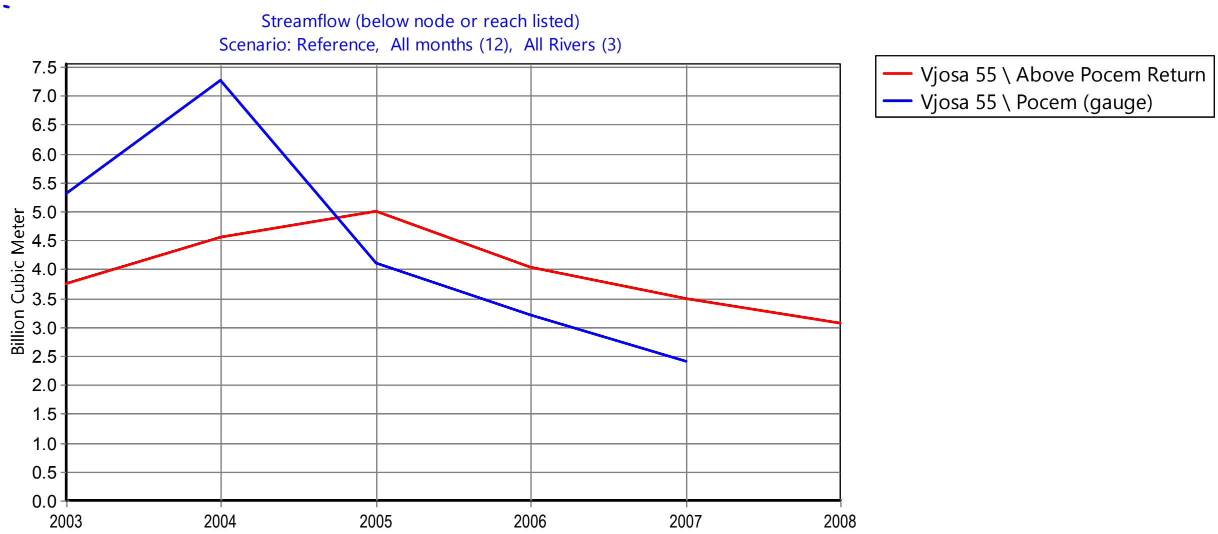


Figure 35. Annual streamflow observational data from the monitoring station and WEAP's simulated results, Poçem

The #Bias value in the Poçem model is particularly relevant for the cost-benefit analysis of Poçem HPP.

It is also important to note that because the streamflow gauges are located at Përmet, Poçem and Ura e Leklit (just before the Drinos meets the Vjosa), the Vjosa WEAP model does not have any calibrated streamflow below Poçem. The upstream catchments Memaliaj and Çarshovë can be calibrated as part of the calibration downstream, but the two basins in the lower watershed without accurate gauges (the Lumi-i-Shushices tributary, and the entirety of the lower basin, see Figure 10) cannot be calibrated. Though data for these catchments has been populated in the model based on calibrated data from upstream, this report will not present results for these catchments because they are unverified and highly uncertain.

6. Scenario Formulation

Having established the data for the WEAP model and calibrated the model to approximate the actual streamflows, the dates of the model can be changed from the historic past to evaluate water availability in the future, assuming the trends entered in the model will continue over time. The WEAP Aoös/Vjosa model will examine the years from 2015 (Current Accounts, when information is assumed to be known) to 2050, at which point all extrapolated trends should assumed to be increasing tenuous over time. Since the future is unknown, in additional to continuing the trends of the past, the WEAP model will examine potential climate change trends and development scenarios (Section 6.1 and Section 6.1 below, respectively). With these scenarios entered into WEAP, they can be combined to examine different development scenarios under different climate trends.

6.1 Scenarios – Climate Change

To evaluate climate scenarios, were incorporated a range of scenarios under various Representative Concentration Pathways (RCP)[4] that were developed in SimClim2013, using the package for Albania (see Mucaj 2016).

6.1.1 Temperature projections

The scenarios for Vjosa River basin predict that the area is likely to become warmer. Similarly, increasing trends in annual and seasonal temperatures, both minimum and maximum values, are expected, which can increase evaporation in the area and lead to less water availability.

The expected changes in annual maximum temperature for all RCPs, compared to the period 1986-2005, are presented in Table 27 and Figures 36, 37. Given the mitigation approach (warming at global scale is limited up to 2°C), RCP2.6 projects the lowest increase. The projections of average temperatures reach up to 1.1°C above the 1986-2005 record by 2050 and remain unchanged thereafter. The RCP 8.5 (4°C world) reveals the worst projections: increases in annual maximum temperatures up to 2.0°C and 4.1°C by 2050and 2100 respectively. The climate change scenarios project the lowest increase for temperature in winter and spring compared to other seasons. The distribution of expected summer changes in maximum temperatures is shown in Figure 36.

The same analytical process examined the expected minimum temperatures for the Vjosa basin and concluded that the average minimum temperatures and their variation limits are likely to increase (Figure 37, right). The expected changes in winter are of 0.9°C by 2100 for RCP2.6, and from 1.6°C and 3.8°C by 2050 and 2100 respectively for RCP8.5.

[4] RCP2.6, RCP4.5, RCP6.0 and RCP8.5 as per IPCC AR5

Table 27. Expected annual and seasonal changes in mean maximum temperature (°C) and their variation

	Scenarios	2050	2100
YEAR	RCP2.6	1.1 (0.7-1.7)	1.1 (0.7-1.7)
	RCP4.5	1.5 (0.9-2.0)	2.2 (1.4-2.8)
	RCP8.5	2.0 (1.2-2.9)	4.1 (2.8-6.9)
WINTER	RCP2.6	0.9 (0.5-1.4)	0.9 (0.5-1.4)
	RCP4.5	1.2 (0.9-1.4)	1.7 (1.2-2.0)
	RCP8.5	1.6 (0.9-2.5)	3.7 (2.2-5.9)
SPRING	RCP2.6	1.0 (0.5-1.4)	1.0 (0.5-1.4)
	RCP4.5	1.2 (0.7-1.9)	1.8 (1.2-2.6)
	RCP8.5	1.7 (0.9-2.5)	4.1 (2.1-6.0)
SUMMER	RCP2.6	1.5 (1.0-2.1)	1.5 (1.0-2.1)
	RCP4.5	1.9 (1.3-2.7)	2.7 (1.8-3.8)
	RCP8.5	2.6 (1.7-3.7)	6.4 (4.0-8.7)
AUTUMN	RCP2.6	1.2 (0.7-1.7)	1.2 (0.7-1.7)
	RCP4.5	1.5 (.09-2.3)	2.1 (1.3-3.2)
	RCP8.5	2.1 (1.2-3.0)	5.0 (2.8-7.2)

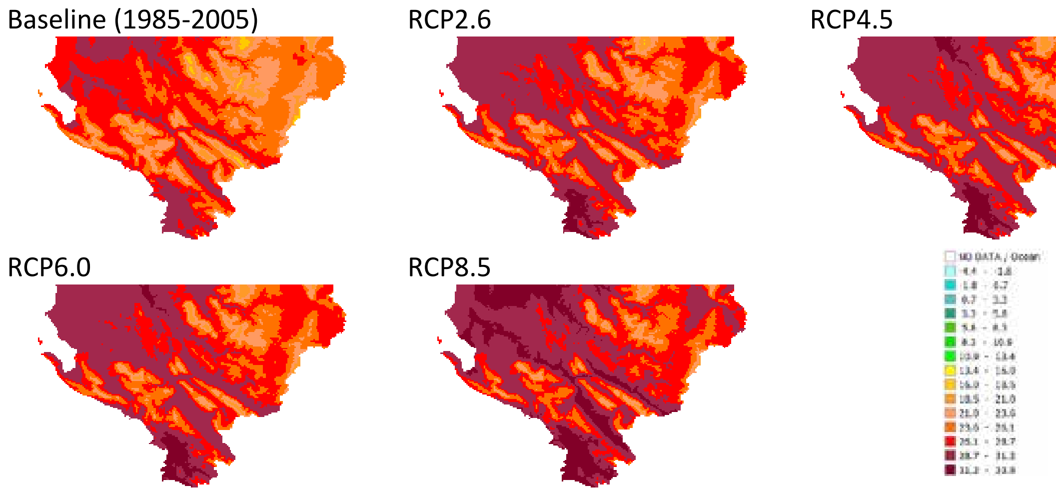


Figure 36. Summer distribution of Tmax, baseline and expected changes by 2050, different scenarios

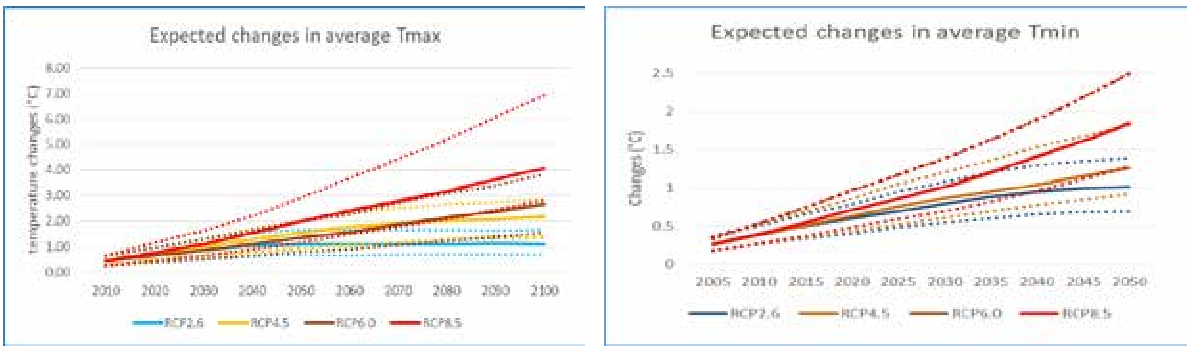


Figure 37. Expected changes in average Tmax and Tmin, Vjosa basin. Median estimates are given as full thick lines and the variation (lower 10% and upper bound 90%) given as dotted line.

Across all the RCP scenarios, the analysis reveals that temperature extremes are also expected to increase. In Përmet the absolute maximum temperature is expected to change from 42.5°C (current record) to 44.2°C (RCP2.6), 44.7°C (RCP4.5) and 45.5°C (RCP8.5) by 2050.

On the other hand, the return periods of maximum absolute temperatures are expected to drastically decrease over the Albanian coastal area. Projections for Tepelenë indicate that temperatures of 40°C that are currently reached once in 50 years, might occur more frequently, once in every 3 years

(RCP2.6) or 2 years (RCP8.5). A similar decreasing trend is expected for the occurrence of three or more consecutive days with daily maximum temperatures higher than 38°C.

An opposite trend is expected with regard to occurrence of absolute minimum temperatures between 2005-2100. All the RCPs predict that the return periods of absolute minimum temperatures are expected to increase. For example, the return period for absolute minimum temperatures of about -11°C are expected to increase from 1:20 years to 1:100 and 1:155 years respectively for 1 and 2 consecutive days according to RCP8.5 for the Përmet area.

6.1.2 Precipitation projections

All the RCPs reveal a likely decrease in annual and seasonal precipitation relative to 1995 (1986-2005). They show a slight positive trend of winter precipitation for all time horizons, likely to reach values of 1.5% (-21 to +24) and 3.7% (-52 to +57%) by 2050 and 2100 respectively. Expected higher winter temperatures can reduce the region's snowfall, which might lead to a reduction of river flows during spring. The RCP projections show that high-percentile precipitation (90% - Figure 38, Table 28) change/increase faster than average precipitation changes. This indicates a higher risk for intensification of heavy precipitation that causes flooding.

Table 28. Expected changes in precipitation (%), annual and seasonal (averages over the Vjosa basin)

		2050	**2100**
YEAR	RCP2.6	-4.0 (-19 to +13)	-4.0 (-19 to +13)
	RCP4.5	-5.3 (-25 to +17)	-7.7 (-36 to +25)
	RCP8.5	-7.3 (-34 to +23)	-17.6 (-73 to +55)
WINTER	RCP2.6	0.8 (-12 to +13)	0.8 (-12 to +13)
	RCP4.5	1.1 (-16 to +17)	1.3 (-23 to +26)
	RCP8.5	1.5 (-21 to +24)	3.7 (-52 to +57)
SPRING	RCP2.6	-3.3 (-17 to +13)	-3.3 (-17 to +13)
	RCP4.5	-4.3 (-22 to +17)	-6.0 (-33 to +26)
	RCP8.5	-5.9 (-31 to +23)	-14.2 (-74 to +56)
SUMMER	RCP2.6	-9.7 (-29 to +14)	-9.7 (-29 to +14)
	RCP4.5	-12.8 (-39 to +18)	-18.3 (-55 to +26)
	RCP8.5	-17.5 (-53 to +25)	-42.1 (-95 to +60)
AUTUMN	RCP2.6	-4.1 (-17 to +11)	-4.1 (-17 to +11)
	RCP4.5	-5.4 (-22 to +15)	-7.7 (-32 to +22)
	RCP8.5	-7.4 (-30 to +20)	-17.8 (-73 to +48)

On the other hand, the high reduction at the 10% percentile level of changes indicates a likely increase in drought frequency (Figure 38).

The return periods of maximum precipitation levels are expected to decrease over the Albanian coastal area. More frequent heavy rains with longer duration can cause flooding and economic damages.

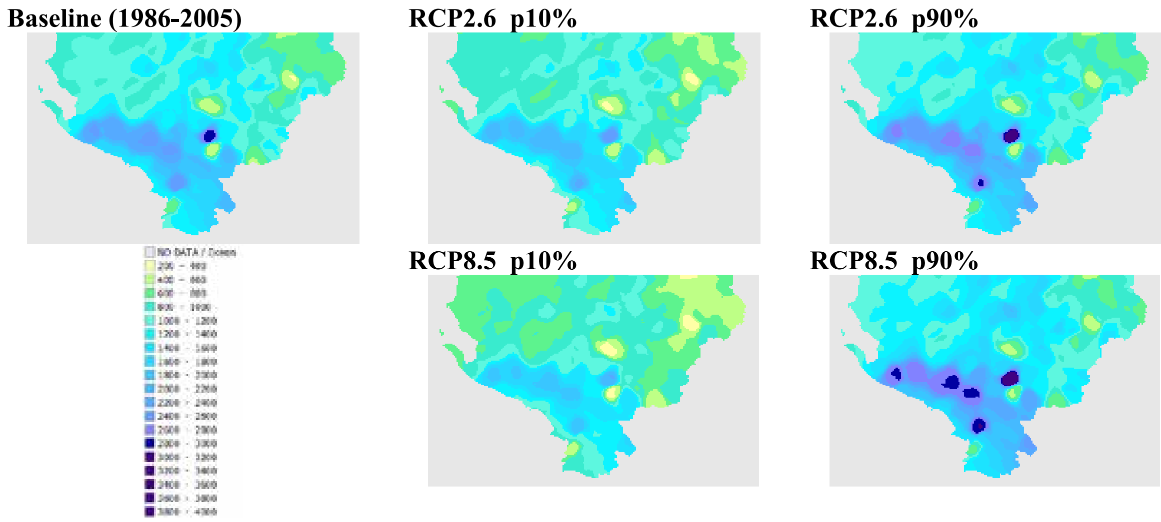


Figure 38. Annual distribution of precipitation, baseline and expected changes by 2050, RCP2.6 and RCP8.5 scenarios, percentiles 10% and 90%

Figure 39 illustrates the likely changes for Përmet area. A maximum precipitation of 190mm/d that historically occurred once in 50 years may now be expected to occur more frequently, every 44 years (RCP2.6), 42 years (RCP4.5&6.0) or 40 years (RCP8.5). Similar trends are projected for all the stations considered in the Vjosa area.

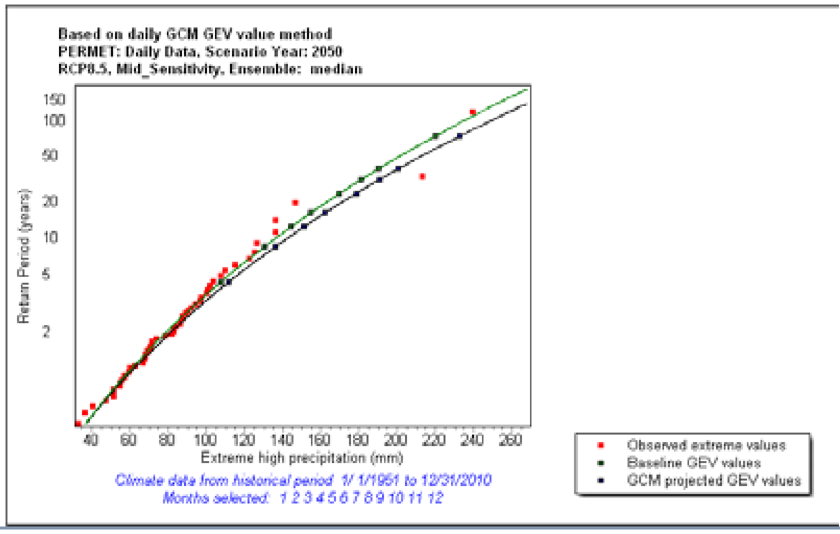


Figure 39. Change of return period, max 24h, Përmet

6.1.3 Climate scenarios used in WEAP

This project examines further the future climates RCP2.6, RCP4.5 and RCP8.5.

The projections consist in monthly values for precipitation and minimum and maximum temperatures. Each value is bounded by uncertainty limits of low (10%), median, and high (90%). The data is provided for twelve stations inside the Vjosa watershed: Brataj, Fratar, Këlcyrë, Krahës, Kuç, Llongo, Nivicë, Përmet, Poliçan, Selenice, Tepelenë and Vovoussa, as well as calculated for Ioannina for the purposes of interpolation.

Using these projection data, were constructed five climate scenarios to examine possible climatic futures in the WEAP model:

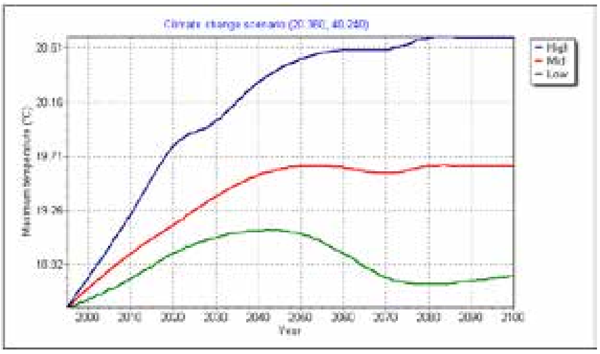
1. RCP2.6: Median precipitation, and average of median minimum and maximum monthly temperatures;
2. RCP4.5: Median precipitation, and average of median minimum and maximum monthly temperatures;
3. RCP8.5: Median precipitation, and average of median minimum and maximum monthly temperatures;
4. RCP8.5 Drought: Low (10%) precipitation, and average of median minimum and maximum monthly temperatures; and
5. RCP8.5 Hot Drought: Low (10%) precipitation, and average of high (90%) minimum and high (90%) maximum monthly temperatures.

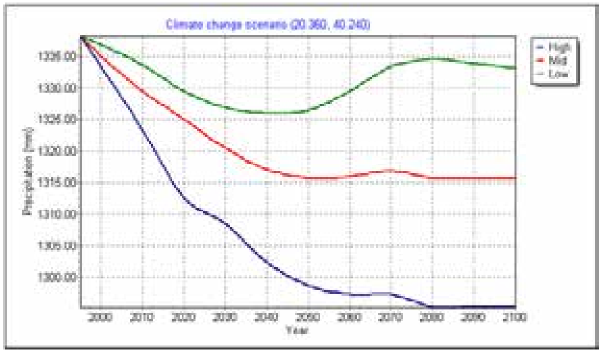
In addition to these climate scenarios, the model will also include a reference scenario with the contemporary meteorological data looped in the future periods, as if the climate were stationary. One year of climate record (2008) is looped to produce the record for the reference scenario (2015-2050), which avoids representing any inter-annual variability and thus is consistent with the climate scenarios.

Figure 40 shows the differences between the expected average annual maximum temperatures and precipitation for the three RCP climates examined in the Vjosa model, for the meteorological station in Përmet, Albania.

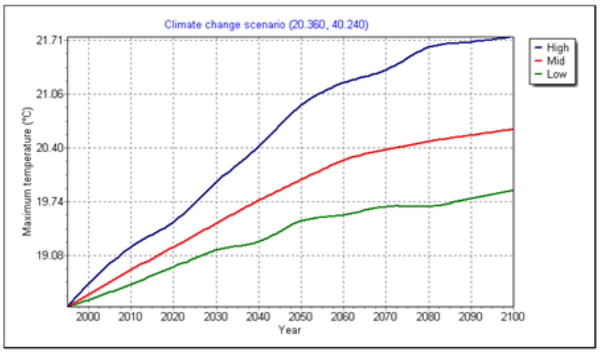
Tmax Precipitation

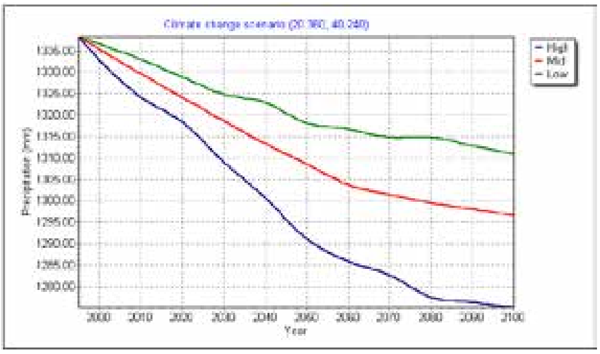
RCP2.6



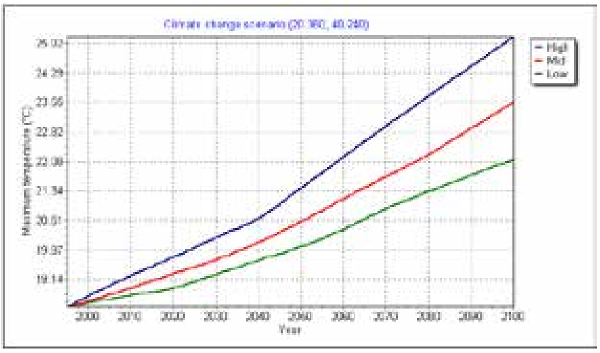


RCP4.5





RCP8.5



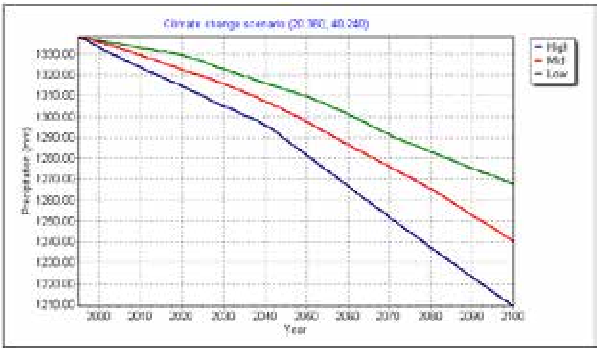


Figure 40. Expected annual average maximum temperatures and precipitation, different scenarios, Permet

6.1 Scenarios – Development

6.1.1 Agricultural Intensification

The WEAP model was previously calibrated to best approximate the estimated irrigation demands for the catchments Drinos, Memaliaj and Permet. The WEAP model land cover (Section 4.2.2) is based on CORINE data from 2006, and WEAP irrigates only a portion of the land use "Hetero Agriculture," based on available data about the hectares in each catchment that are irrigated (Section 4.5.1 describes the process of producing the irrigation demands in WEAP). The Agricultural Infrastructure scenario the multiplication factors to expand the irrigated areas within Hetero Agriculture, to areas that were previously farmed but not irrigated. This use of a ratio is based on the assumption that if the climate remains constant over time, the irrigation requirements will increase according to the expansion of irrigated land.

The scenario uses data for estimated potential irrigation capacity that could be supplied if the elements of the existing irrigation system were constructed or repaired. The irrigation estimates (Table 29) are provided for the three catchments with available data (Drinos, Memaliaj and Përmet).

Table 29. Actual and future irrigation discharge (Irrigation Board Agency of Gjirokastër)

		ACTUAL			FUTURE (Scenario)		
Catchment	**Ha**	**Actual Discharge (m^3/s)**	**Annual rate (m^3/ha)**	**Annual Discharge (MCM)**	**Maximum Discharge (m^3/s)**	**Annual rate (m^3/ha)**	**Annual Discharge (MCM)**
Drinos	3610	0.56	4892	17.66012	1.5	13104	47.30544
Memaliaj	1880	0.485	8136	15.29568	1.93	32375	60.865
Përmet	1025	0.24	7384	7.5686	0.43	13230	13.56075

Using the future irrigation demand estimates and the irrigation values calibrated in WEAP for the years 2002-2008 (Section 4.5.1), the estimated annual demand (discharge) for the respective catchments was divided by WEAP's irrigation provision in the Reference Scenario create a multiplication factor of hypothetical land expansion of irrigated areas (Table 30).

$$Irrigation\ Multiplication\ Factor = \frac{Estimated\ Annual\ Discharge\ for\ the\ Future_{catchment}}{WEAP's\ Irrigation\ Provision\ in\ Reference\ Scenario_{catchment}}$$

Note that the multiplication factor is calculated based on WEAP's actual irrigation provisions from 2002-2008, rather than the historical data values shown in earlier in Table 13, to best enable the model to produce accurate irrigation values for the future. The irrigation multiplication factors are shown in the last column of Table 30.

Table 30. Potential irrigation capacity for the future, and the multiplication factors for each catchment

		Scenario Data – Potential Irrigation Capacity			Original Annual Discharge Value (MCM)	Multiplication factor for irrigation expansion
	Ha	**Maximum Discharge (m^3/s)**	**Annual rate (m^3/ha)**	**Annual Discharge (MCM)**		
Drinos	3610	1.5	13104	47.30	17.59	2.69
Memaliaj	1880	1.93	32375	60.86	15.43	3.94
Permet	1025	0.43	13230	13.56	7.50	1.81

The multiplication factors are entered as Key Assumptions in WEAP and multiplied with the values for land use area percentages for the irrigated areas in Hetero Agriculture. We use the "Remainder(100)" function in WEAP to ensure that the land use areas still add up to 100% of the catchment area. Figure 41 shows how these changes were entered into the scenario in WEAP for the Përmet catchment.

The Key Assumptions for the irrigation expansion were also entered into the downstream basins. Poçem, Lumi-i-Shushices and the Lower Basin catchments all use the Memaliaj value (3.94), whereas Çarshova uses the Përmet multiplication factor. Only Çarshova, as an upstream basin, will contribute to the results reviewed as part of the scenario. Any results for the uncalibrated downstream basins using the Memaliaj irrigation multiplication factors are too uncertain to be considered accurate or appropriate for decision-making processes.

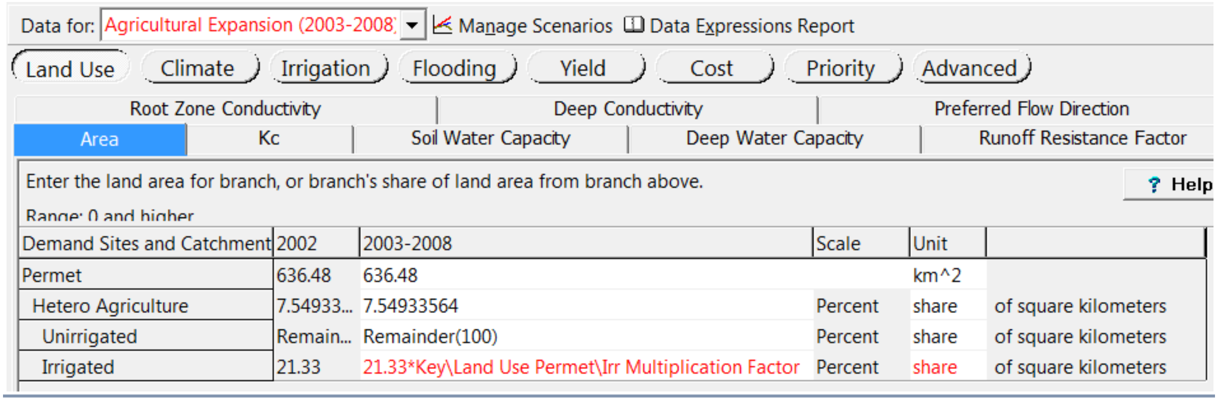


Figure 41. The changes made to the WEAP model for the Agricultural Expansion Scenario (Permet catchment)

6.1.2 Tourism Scenario

The model's Reference Scenario accounts for the historic documented growth in tourism from 2006-2014, with several assumptions made to imagine this growth manifests in the Drinos, Përmet and Memaliaj catchment demand sites in the WEAP model. One of these assumptions was that tourism growth would stabilize over time, dropping linearly from a 17.9% growth rate for the years 2002-2015 to a 5% growth rate from 2015-2020, and thereafter stabilizing so the tourist population remains steady over time.

The Tourism scenario models a more sustained growth rate of tourism, where the growth rate value of 17.9% in 2015 changes to 2% in 2025, where it stabilizes for the remainder of the model.

This produces a markedly larger tourism population than the Reference Scenario. To accommodate it, it is assumed that the tourism increase halves the Albanian rate of population decline among the local population due to new economic opportunities. Figure 42 shows the resultant population differences between the Reference Scenario and the Tourism Scenario for the three catchments with tourist populations: Drinos, Memaliaj and Përmet.

This Tourism scenario shows that the current annual growth rate of tourists is unlikely to remain sustained for much longer – even keeping the same rate until 2025 (less than ten years) will greatly affect the population of these basins, and subsequently their overall water demand.

This scenario answers the question of what would happen in the event of sustained tourism growth until 2025, but that does not mean that it is inevitable or even likely. When more accurate predictions for the future growth rate of tourism in Albania and their implications for slowing local population declines become available, they can plugged into the format of this scenario for further investigation.

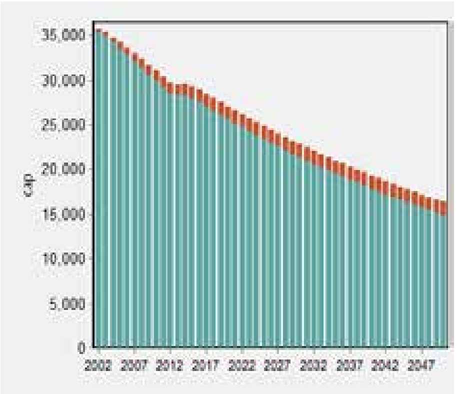
6.1.3 Hydropower Development Scenario

The Vjosa is treasured as one of the Europe's last wild rivers because development has been minimal in terms of damming or channelling the river. However, this may change in the near future as Albania tries to manage flooding risks and develop energy security.

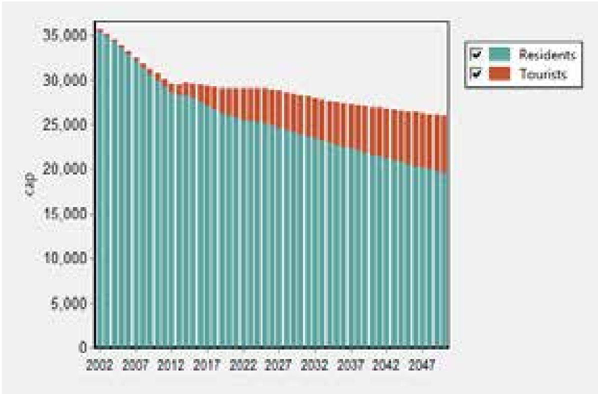
Plans already exist for many small scale hydropower plants on the tributary rivers feeding the Vjosa. This scenario will examine the construction of the Poçem Hydropower Plant on the main stem of the Vjosa River, about halfway between the Memaliaj and Poçem streamflow gauges.

Cinar - San Group is a Turkish company that is interested in renewable resources for energy production and has proposed investing and implementing the Poçem Hydropower Plant project (Cinar San. 2015). Cinar – San's project proposal is waiting for a determination in Albania's legislation.

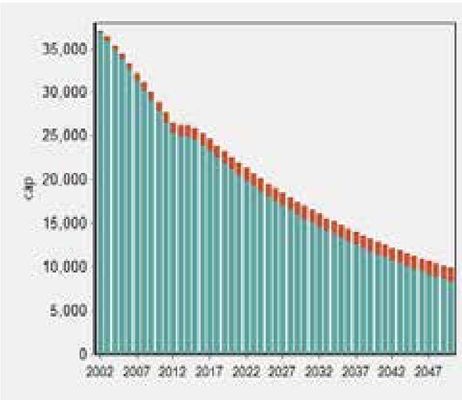
Permet Population Reference Scenario



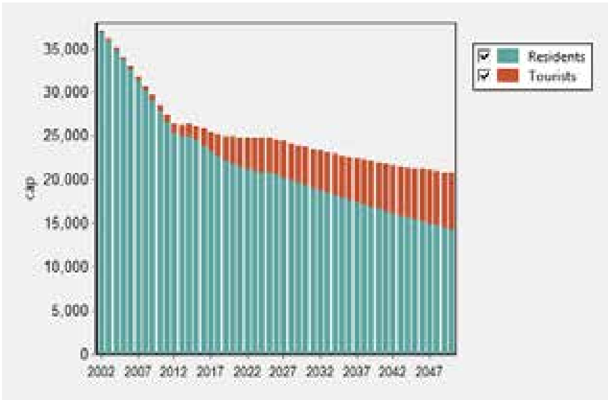
Permet Population Tourism Scenario



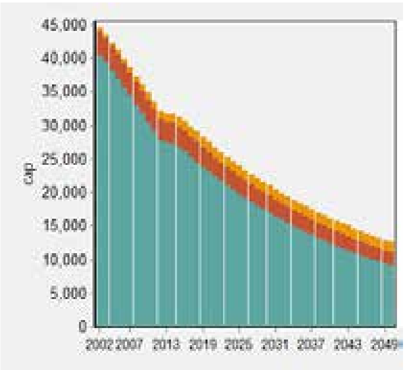
Memaliaj Population Reference Scenario



Memaliaj Population Tourism Scenario



Drinos Population Reference Scenario



Drinos Population Tourism Scenario

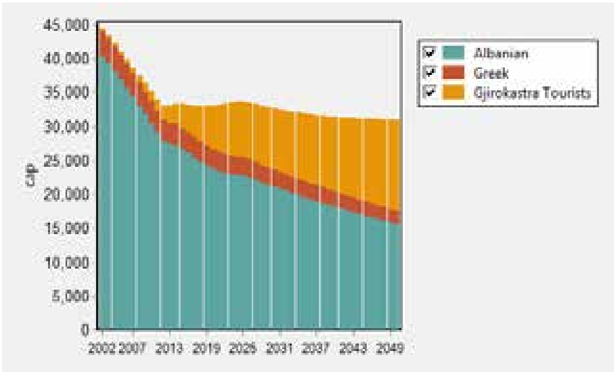


Figure 42. Comparison between populations between Reference and Tourism Scenarios

The project aims to better develop and manage a segment of the Vjosa cascade through:

- The development of the energy sector using a new and eco- friendly technology;
- Taking into account the social - economic impacts, through different mitigating measures;
- Flood risk management for the entire area below the Poçem dam axis that for several years has been several times under water (the latest flood event was observed in February of 2015).

The work for Poçem HPP construction was supposed to begin in 2016, but has not yet begun for various reasons. This scenario will assess this project for study purposes, to determine the impacts of the Poçem HPP in the Vjosa cascade.

In WEAP, data Poçem HPP has been entered based on the specifications available about the reservoir's characteristics.

Power generated: 99.5 MW. This is the maximum power that can be generated – but since the plant is not working all the time, and is not generating maximum amount of power, as will be described below, this is not assumed to be a constant power output).

Total Storage Capacity: 295 MCM

Volume of the Reservoir at the normal reservoir water level of 70 m is 250 MCM

Reservoir active storage: 112 MCM (70 m to 64 m)

Reservoir surface: 21.6 km2

Investment cost: ≈ 135 Million Euro (Source: Çinar – San. 2016) (141,145,084 UDS)

Figure 43 shows Poçem HPP on the Vjosa in a cascade with upstream Kalivaç HPP, which is currently not functioning.

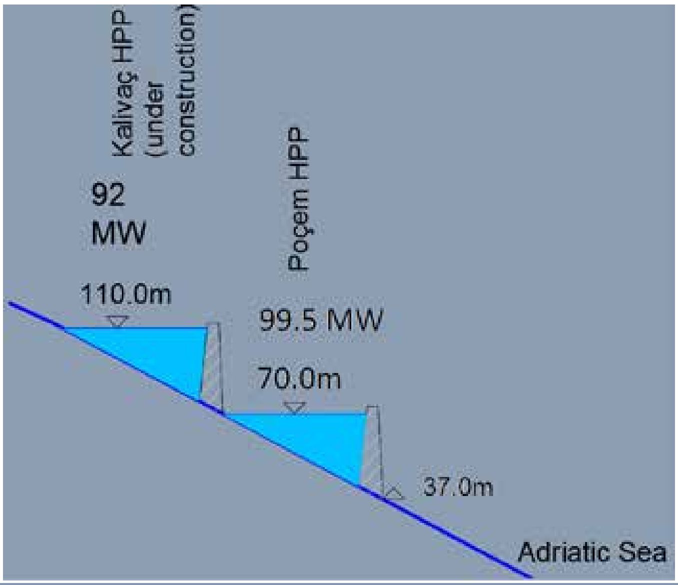


Figure 43. Partial longitudinal profile of the Vjosa River with Poçem HPP and non-functioning Kalivaç HPP
Source: Cinar San. 2015

The average annual flow in Vjosa River is evaluated to be around: 150m^3/s. For a dry year it can be 84.2 m^3/s (1990), and in a wet year it goes around 210.42 m^3/s (1979). So, some restrictions for the water use are as below:

For irrigation, 2m^3/s will be released from 15 of May to 15 of September that will not be used for energy production.

If the dam is constructed, a downstream ecological flow requirement will be added according to Albanian Law No.111, dt. 15.12.2012 about 'Integrated Management of the Water Recourses.' It is evaluated from the sustainability curve for the average year with 50% of security, in the value of 22.2 CMS (identified as a discharge for 355 days). This environmental flow will be discharged from the reservoir during the whole year. This data is entered into WEAP as a flow requirement node with a constant value of 22.2 CMS.

Normal water level of functioning (Top of Conservation) 70 m

Minimum water level of functioning (Top of Buffer) 64 m

The functioning vertical distance/high: 70 – 64 = 6 m

Figure 44 shows the volume elevation curve, which is entered into WEAP to help calculate the evaporation from the reservoir volume over time.

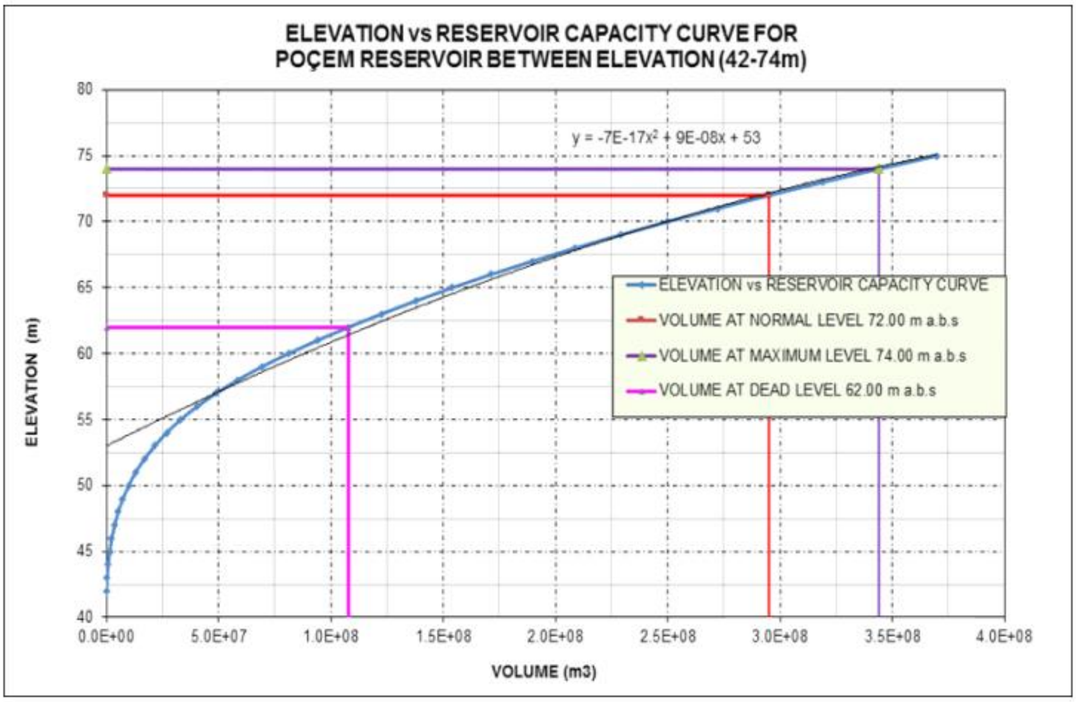


Figure 44. Volume elevation curve of Poçem HPP
Source: Cinar San 2015

There will be 4 Kaplan Adjustable Vertical Turbines, each with a capacity of 85 CMS. A fifth turbine will operate with a flow value of 22.2 CMS, explicitly to satisfy the downstream environmental flow requirements. Altogether, these turbines provide Poçem HPP with a total possible output of 362.2 CMS.

The plant will operate 3,070 hours in a year, or roughly 35.05% of the time (this value is entered in WEAP as the “Plant Factor”). The generating efficiency is 89%. Additionally, the model does not specify any priorities for hydropower production, therefore, hydropower is produced in such a way that prioritizes the reservoir being full, rather than producing energy during certain periods. With additional information, electricity generating priorities could be entered into WEAP to enable WEAP to prioritize producing a certain amount of hydropower, rather than only prioritizing meeting water demands downstream.

In additional to the data mentioned above, the value for evaporation from the reservoir was entered as the previous month’s evaporation calculated by WEAP for the Poçem catchment, where the reservoir is located. The Hydropower Development Scenario begins assumes construction in 2016 and the dam is full sometime during that year.

6.1.4 Land Use Change Scenario (Runoff Resistance)

Because the WEAP model uses the CORINE dataset, it is possible to use WEAP to study the impacts of changing land use. However, such an activity requires data to characterize the soil and plant parameters for each land use type, such as crop coefficient values, soil water capacity, runoff resistance and others. This data was largely unavailable for the land cover types specified in the model, and for the moment each catchment’s land cover types share the same quantifications, and thus cannot be differentiated, nor can land use change be studied within the current framework of the model.

However, it is possible to ask the question of what would happen to runoff in the Vjosa if land use were to change, specifically, if less runoff became available to flow into the river, and instead infiltrated into the ground were it became more likely to evapotranspire and be lost from the system. This could happen in the event of reforestation in the basin, or other land use change.

To answer this question, the Land Use Change scenario examines higher values across all land use types for the parameter “Runoff Resistance Factor” which determines how much precipitation is parsed into immediate runoff, and how much percolates into the soil. In a WEAP model, runoff resistance factor can be as low as zero (entirely runoff, no infiltration) and as high as 1000. The runoff resistance factor is relatively low in the Vjosa, especially in the upper catchments defined by steep mountain slopes and deep river canyons. In general, the model’s runoff resistance factors vary over the course of the year. Figure 45 shows the annual variability of the runoff resistance factor used to characterize all the land use types in Përmet and Çarshovë catchments (Reference Scenario).

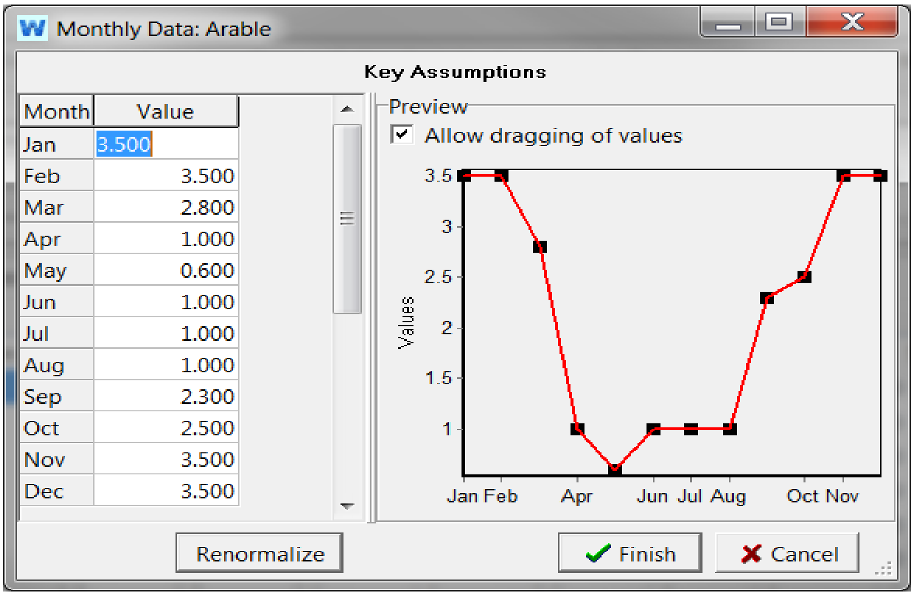


Figure 45. Values for runoff resistance factor used in Përmet and Çarshovë

To model more runoff resistance across the Vjosa/Aoös watershed as a whole, we will increase all the values of the runoff resistance factors by 0.7, entered as a Key Assumption in WEAP called RRF Change.

However, because the land use change is assumed to be happening in natural environments (not irrigated environments), the original monthly values for the Runoff Resistance Factor are kept for the area Hetero Agriculture, some of which is irrigated and the rest is cultivated.

Figure 46 shows how this data was entered into WEAP.

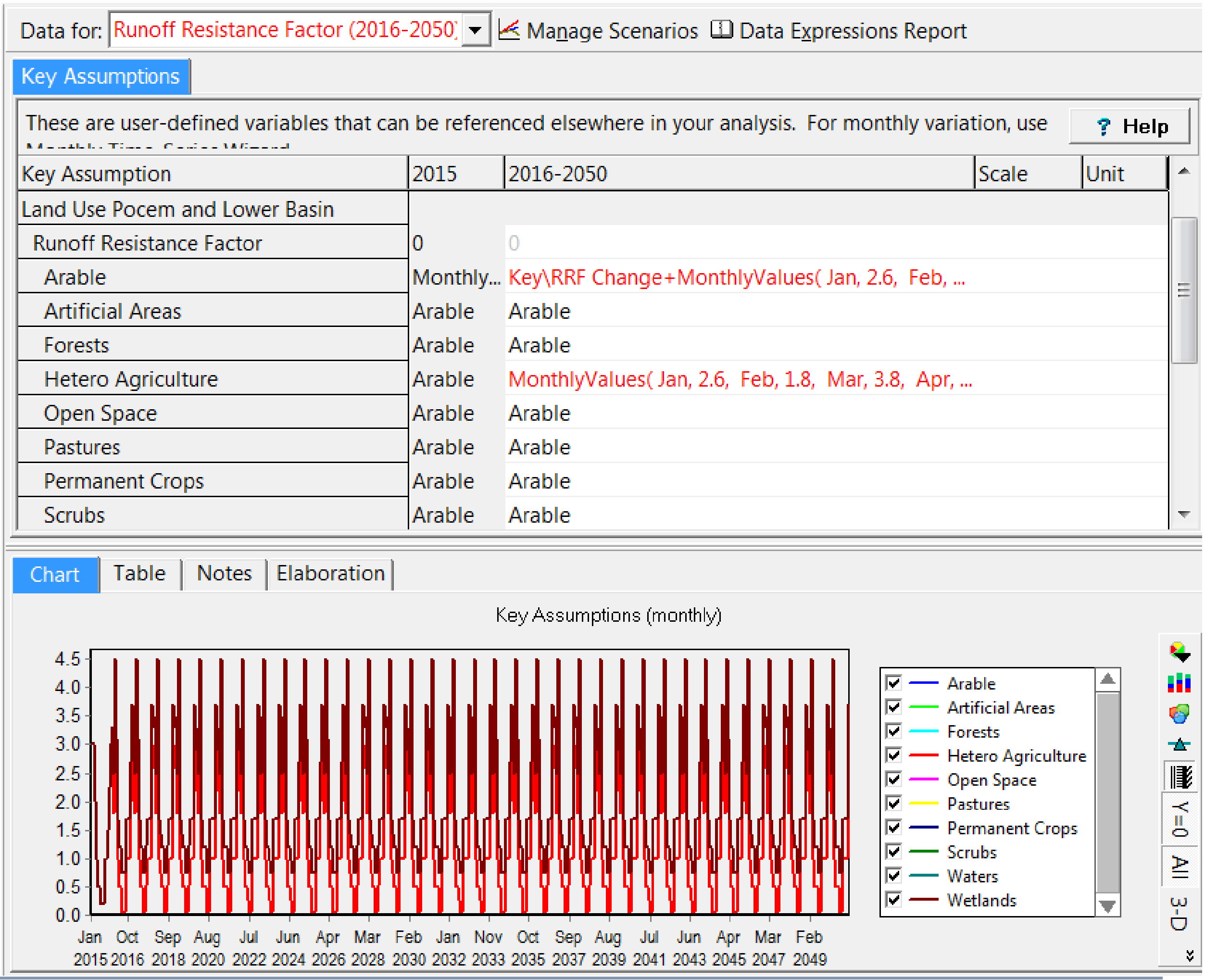


Figure 46. Runoff resistance factor scenario data entry

The chart shows the higher value of the runoff resistance factor for all the land use types except for Hetero Agriculture.

7. WEAP model results

After constructing the model, results for the climate and development scenarios were run for the years 2015-2050. Firstly we viewed the changes in water availability in the different climate scenarios, where the Reference Scenario represents a repetition of monthly climate averages from data available for previous (2002-2008) and the climate scenarios show possible climate trends for the future, as described in Section 6.1.

7.1 Climate Scenarios without Development

The differences in scenario temperature trends in the Drinos catchment can be best seen for the period at the end of the model (2049-2050) in Figure 47. The values for temperatures for the climate scenarios tend to be closer to each other than any of them are to the Reference scenario by the year 2050.

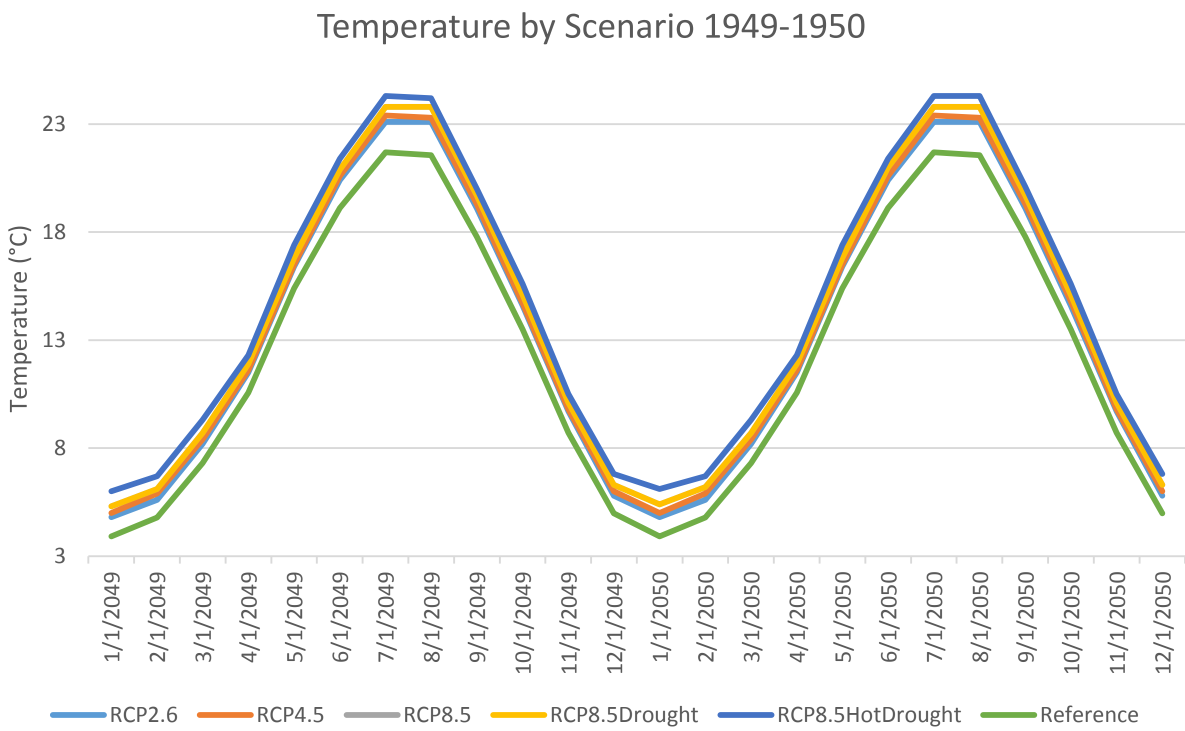


Figure 47. Future temperature by scenario (Drinos catchment) 1949-1950

Figure 48 compares the temperature changes over time in the Drinos catchment for the extreme scenario RCP8.5HotDrought and the Reference Scenario. The RCP8.5HotDrought Scenario produces increasingly higher temperatures in both the winter and summer.

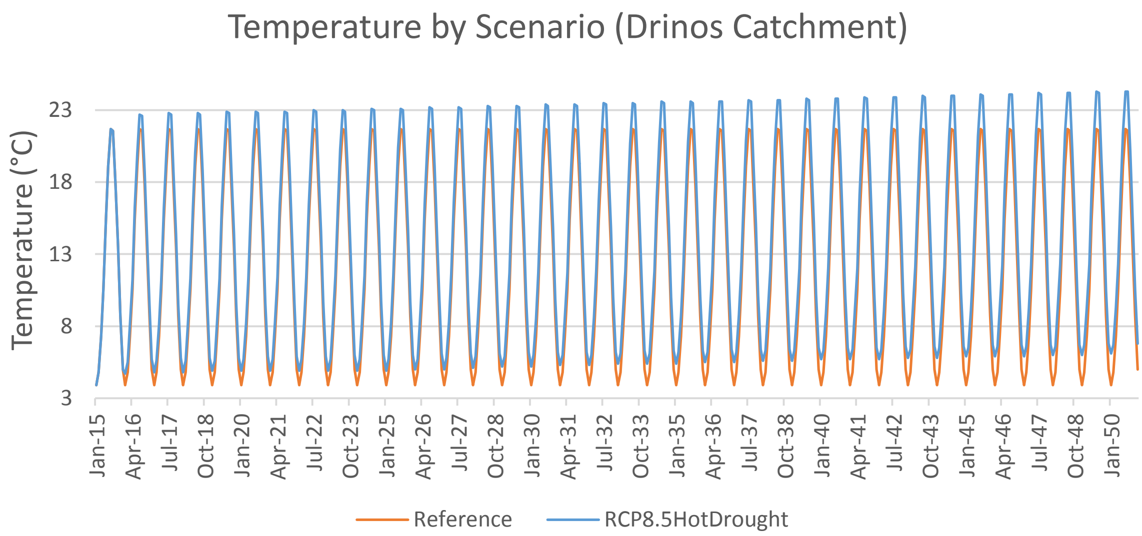


Figure 48. Future monthly temperatures by scenario (Drinos catchment)

Likewise, Figure 49 shows the difference in precipitation values for the final year of the model (2050). The scenarios Reference, RCP2.6, RCP4.5 and RCP8.5 overlap for the upper curve, and RCP8.5 Drought and HotDrought (both the same values of precipitation) constitute the lower curve. This serves to emphasize that the normal variations in climate trends (dry years, wet years, such as the 10% percentiles that generated the scenario records for RCP8.5 Drought and HotDrought) will likely have much more impact than the overall climate trends on average.

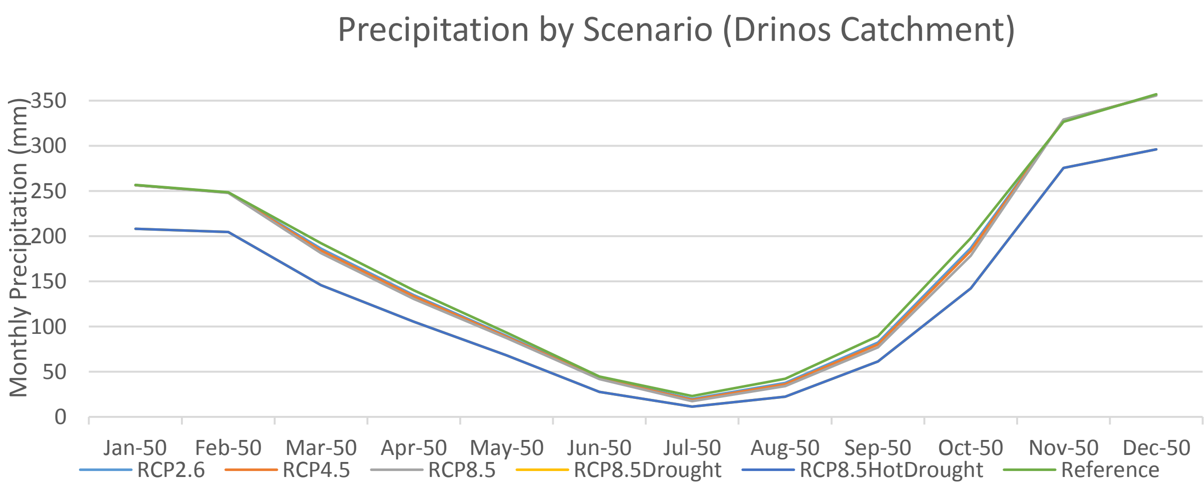


Figure 49. Future monthly precipitation by scenario (Drinos catchment), year 2050

The precipitation trends over time show the highest values for the reference scenario, and the lowest for RCP8.5HotDrought (Figure 49). While the Reference Scenario stays steady over time, the precipitation in the RCP8.5 drops for both winter and summer values, but more dramatically for winter values.

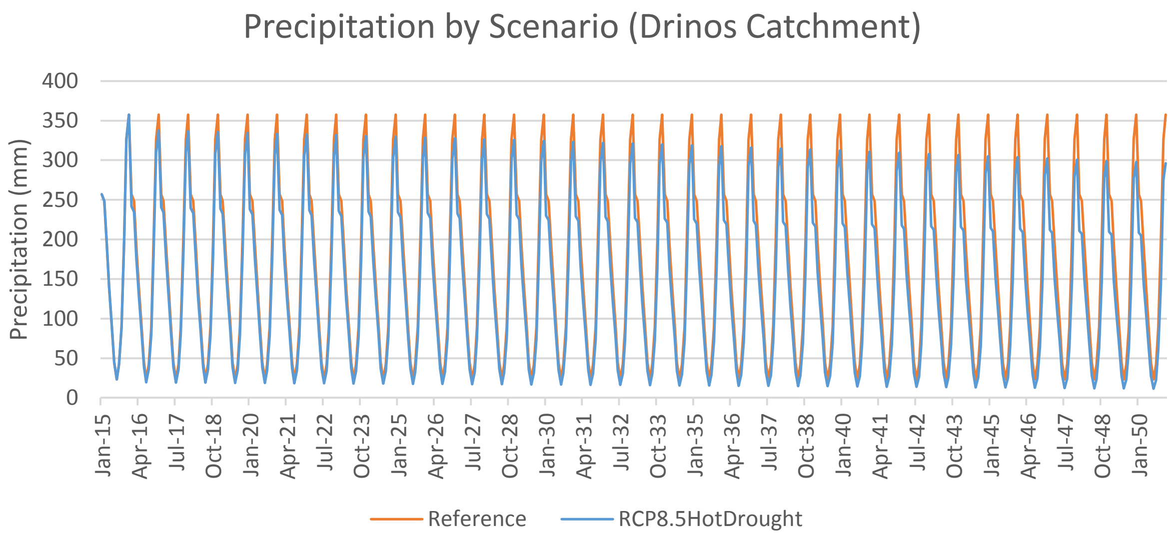


Figure 50. Future monthly precipitation by scenario (Drinos catchment)

The impacts of these various changes in the Vjosa hydrologic system can be viewed using these scenarios. Figure 51 shows the annual unmet demand for all demands in all climate scenarios, where *unmet demand exists for RCP8.5 Drought and RCP8.5HotDrought scenarios, starting in 2036 and 2035 respectively*. Note that RCP2.6, RCP4.5 and RCP8.5 are all zero, but do not show up in the chart because their zero values are underneath the zero values for the Reference Scenario.

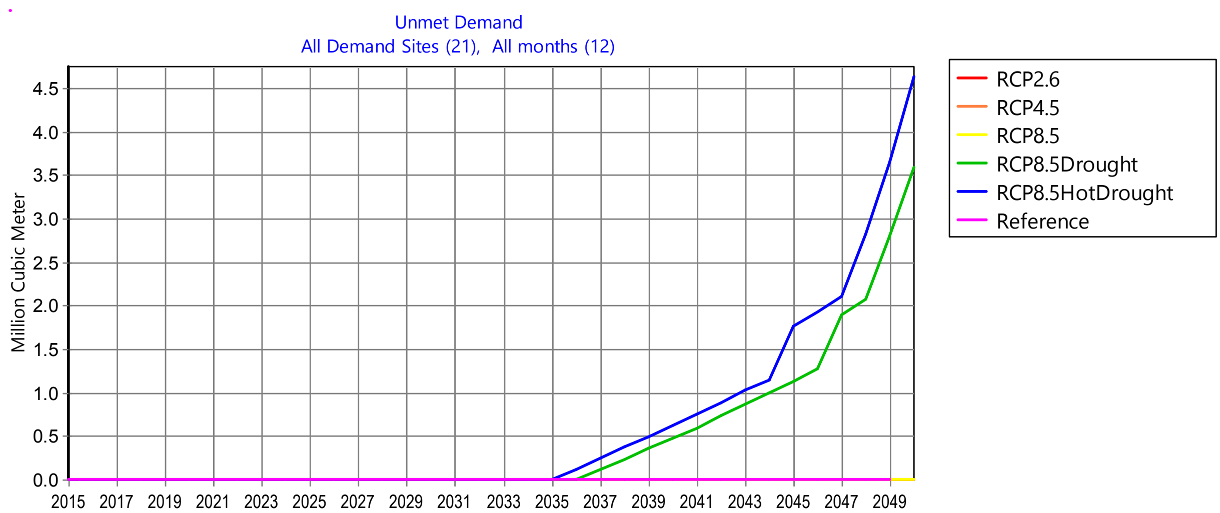


Figure 51. Annual unmet demand for all demand in Vjosa watershed for different climate scenarios (2015-2050)

The agricultural and domestic demands (see Table 15) are seasonal, and industrial demands are constant. Figure 52 shows the watershed's total the unmet demand, which demonstrates that *there is insufficient waters supply in July, August, and the highest unmet demand occurring each year in September, but only for the scenarios RCP8.5Drought and RCP8.5HotDrought*.

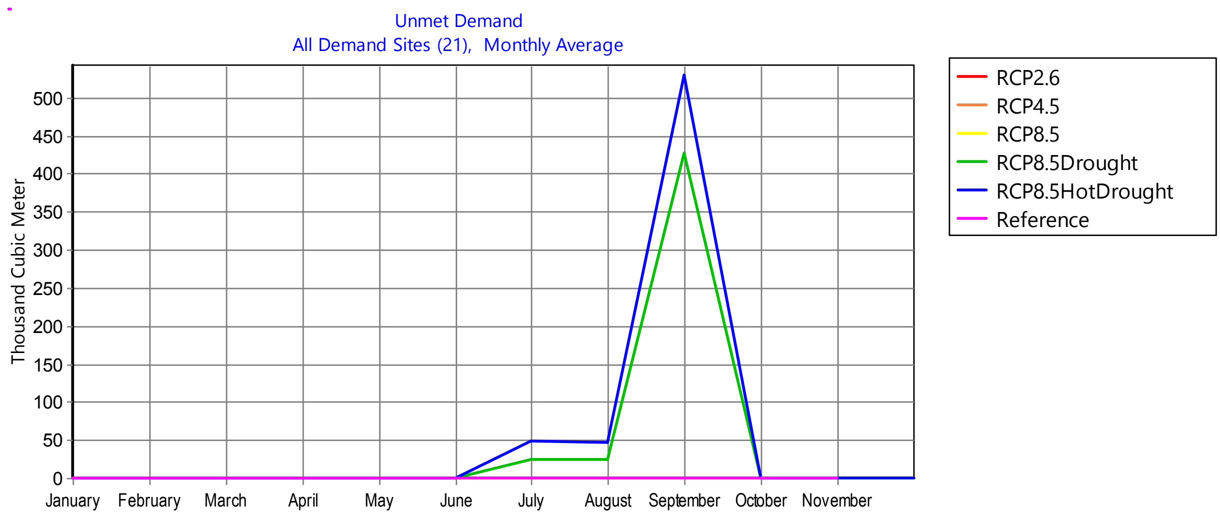


Figure 52. Monthly variation of unmet demand (averaged 2015-2050)

The domestic and industrial demand quantities do not change between the different scenario climate scenarios, only the irrigation demands are dynamic in WEAP to respond to changes temperature and precipitation. Though all sectors show unmet demand in RCP8.5Drought and RCP8.5HotDrought, it is only the irrigation demand that is exerting additional pressure on a changing system. Figure 53 shows how overall system demands grow over time from the first year of the Reference Scenario (2016) to the last year of the model (2050). The various scenarios show growing demand compared to the Reference Scenario in 2050. In the title of the charge, DSM stands for "Demand Side Management." Data for system water loss, reuse and DSM have not been entered into the Vjosa model.

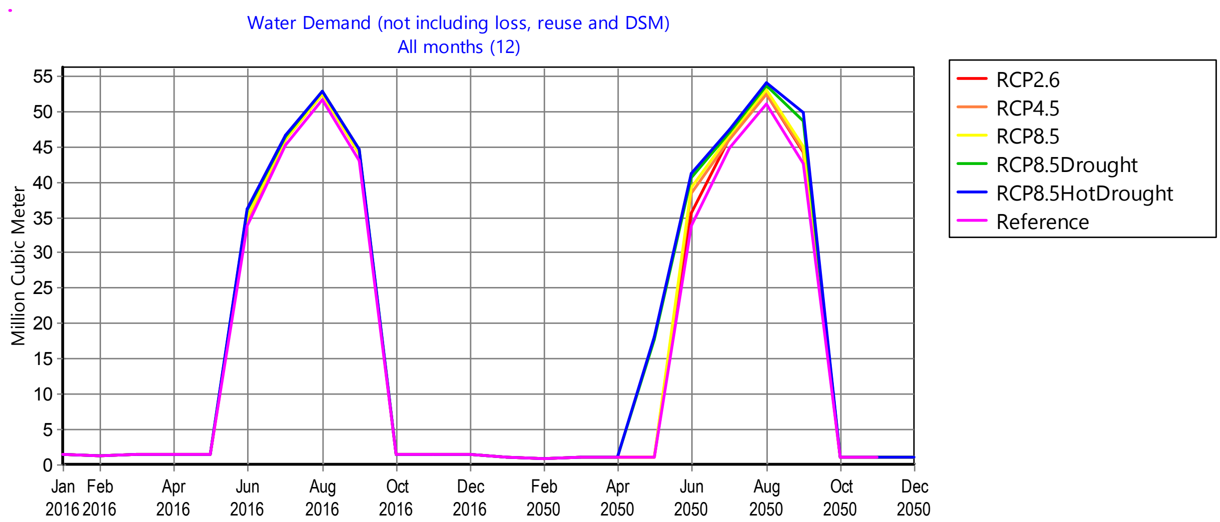


Figure 53. Vjosa watershed demand for all climate scenarios (all demand sites)

The differences in climate between the scenarios will produce different streamflow patterns in the Vjosa River. Figure 54 shows the monthly averages of streamflows (2015-2050) for the three calibrated catchments, Drinos, Përmet and Poçem. The *streamflows for the extreme scenarios, RCP8.5Drought and RCP8.5HotDrought are markedly lower than the others*. There Reference Scenario climate produces the highest streamflows for all three gauge areas, though often by a slim margin.

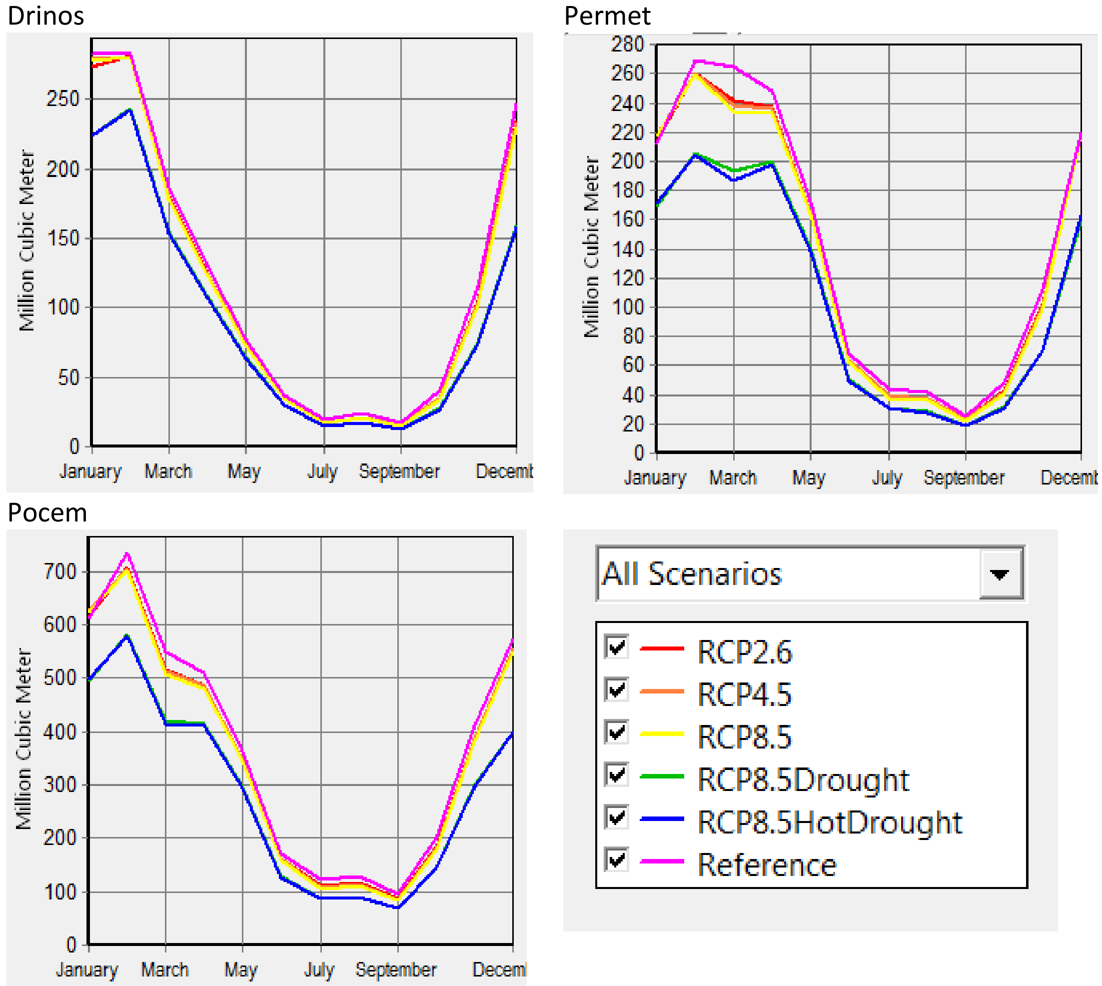


Figure 54. Monthly streamflow comparison for scenarios for the 3 calibrated gauges

The gap between the extreme scenarios with the ten percentile values and the remaining climate scenarios, including the RCP8.5 scenario shows the importance of intra-annual variation even more so than climate trends because it is this variability that is poised to produce unmet demands.

Next we can consider the impacts of climate change under specific development scenarios.

7.2 Increased Tourism in the Vjosa

The tourism scenario produced increased domestic demand, which already showed shortages in some catchments for the RCP8.5 Drought and HotDrought scenarios.

The only catchments with changes due to tourism are Drinos, Memaliaj and Përmet. Their changes in annual domestic water demands are shown in Figure 55,**Error! Reference source not found.** comparing the Reference Scenario (no tourism) and the Tourism Scenario (with domestic population change as described in Section 6.1.2). Even with the population increases in the Tourism scenario, the domestic demand in all three areas continues to decline overall after 2025.

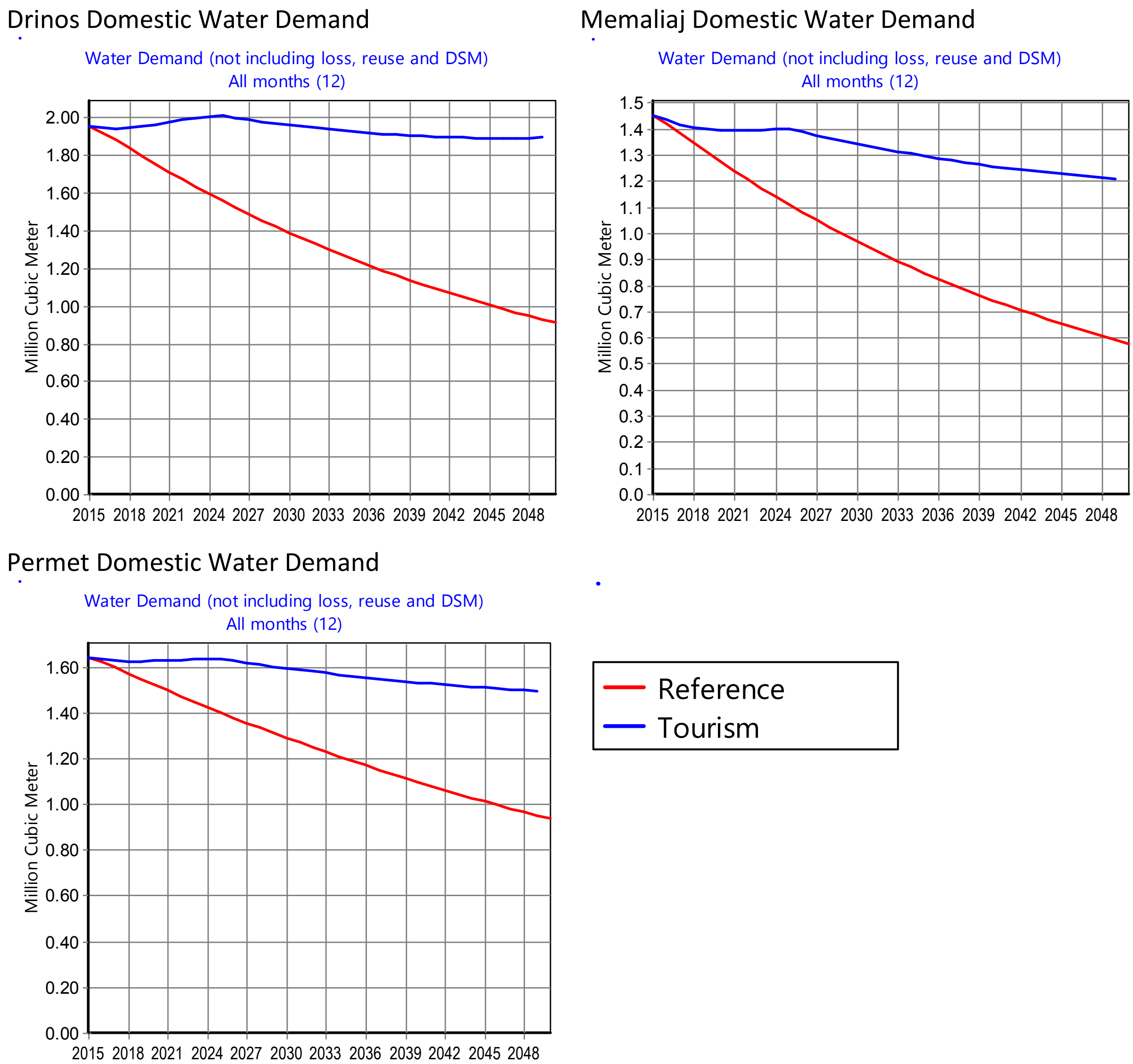


Figure 55. Annual water demand in catchments with tourism increases, Reference Scenario, Tourism Scenario

Figure 56 compares the annual demand total watershed demand between the Tourism Scenario and the Reference Scenario. The results for the whole system are very close together (despite not appearance of the graph, which is not grounded at zero, rather at 176 MCM), a difference of 1.2% (2.2 MCM out of 181.8 MCM demand in the Tourism Scenario) by the year 2050. This shows that the impact of tourism in these three regions is quite small for the Vjosa watershed as a whole.

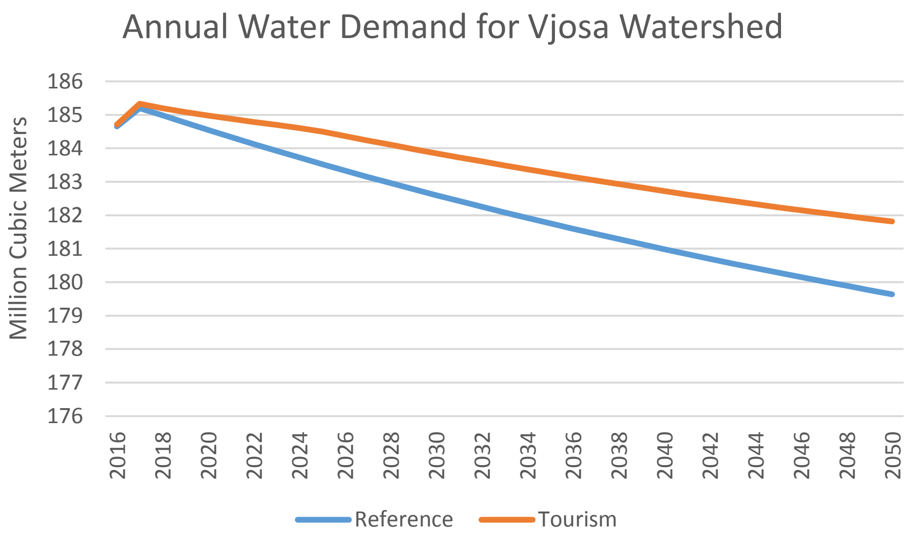


Figure 56. Demand for all demand nodes in Vjosa Watershed, Tourism and Reference Scenarios

Figure 57 compares overall watershed annual unmet demand for the different climate change scenarios if tourism increased (here the scenario "Tourism" represents tourism growth with the reference climate). Note that the climate scenarios of the same names, viewed above in Section 7.1, did not include data for tourism increase. However, WEAP allows scenarios to "inherit" the changes of other scenarios, before these results were run, the climate scenarios inheritance was changed to include the sustained tourism increase in the "Tourism Scenario."

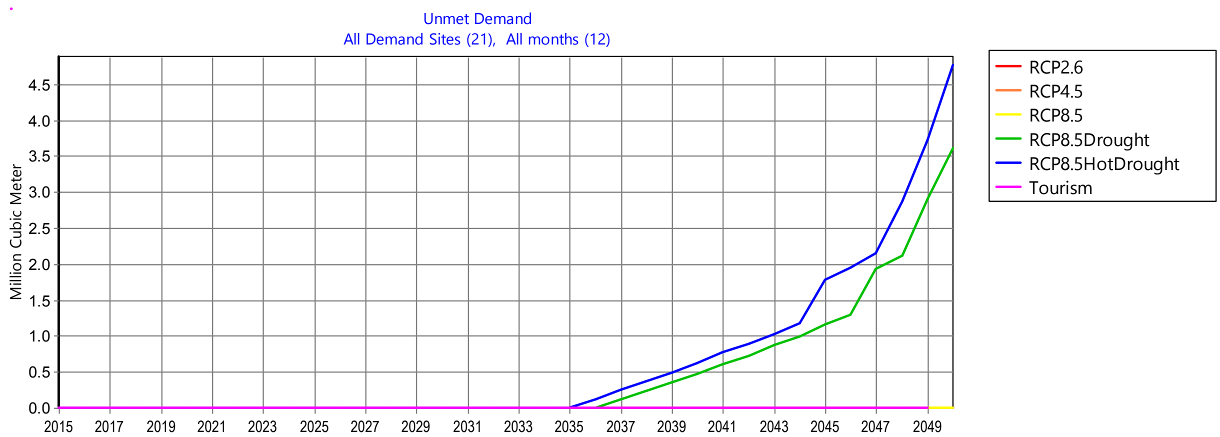


Figure 57. Annual unmet demand for all demand nodes in Vjosa Watershed

With the increase of tourists, instances of insufficient supply in the Vjosa watershed occur only in the extreme scenarios, RCP8.5Drought and RCP8.5HotDrought.

Nearly all the demand sites show no unmet demand (some agricultural demand can be wholly satisfied with only rainfall, thus the catchments exert no demand on the system, and thus register zero unmet demand). The domestic demand sites with unmet demand are: Carshova (same results as Reference Scenario without tourists, because it is upstream of any tourist impacts), Memaliaj, Permet, and Ura Leklit. The latter three are upstream, and impacted by tourism. The downstream demands are all met even in the extreme scenarios, though two of these three catchments (for the Lumi i Shushices tributary, and below Poçem) are not calibrated.

Agricultural demands are unmet in Çarshova (same as Reference Scenario), Memaliaj, Përmet, and Drinos (the same catchment as Ura Leklit), and downstream irrigation demands are met.

Industrial demand is not met in Drinos, Memaliaj and Përmet catchments for the extreme scenarios.

The unmet demand does not appear in the model until after the year 2035 with the Drinos agricultural demand. Finally, the unmet demand is again only for the most dire scenarios, RCP8.5Drougth and HotDrought. In viewing the same results as a monthly average for the years 2015-2050, deficits only appear in the summer months of July, August and September (Figure 58).

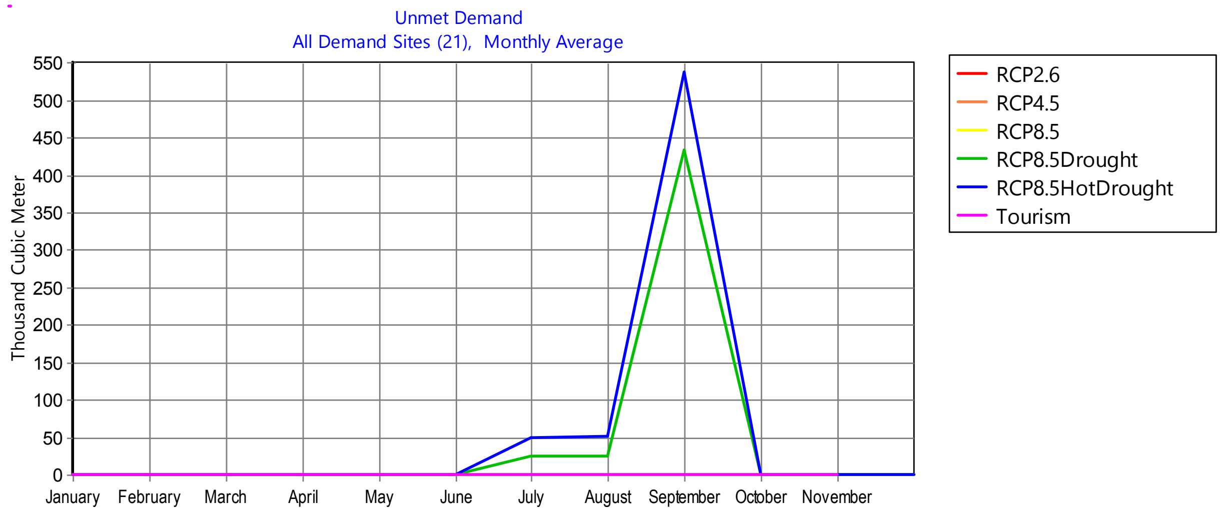


Figure 58. Annual variability of unmet demand for all Vjosa demands, Tourism Scenario

7.3 AGRICULTURAL INFRASTRUCTURE EXPANSION

Agricultural expansion in the three catchments calibrated for agricultural demand (Drinos, Memaliaj, and Përmet) produces large changes in the Vjosa watershed in annual total basin water demand. Figure 59 compares the Reference Scenario with the Agricultural Expansion Scenario (described in Section 4.5.1).

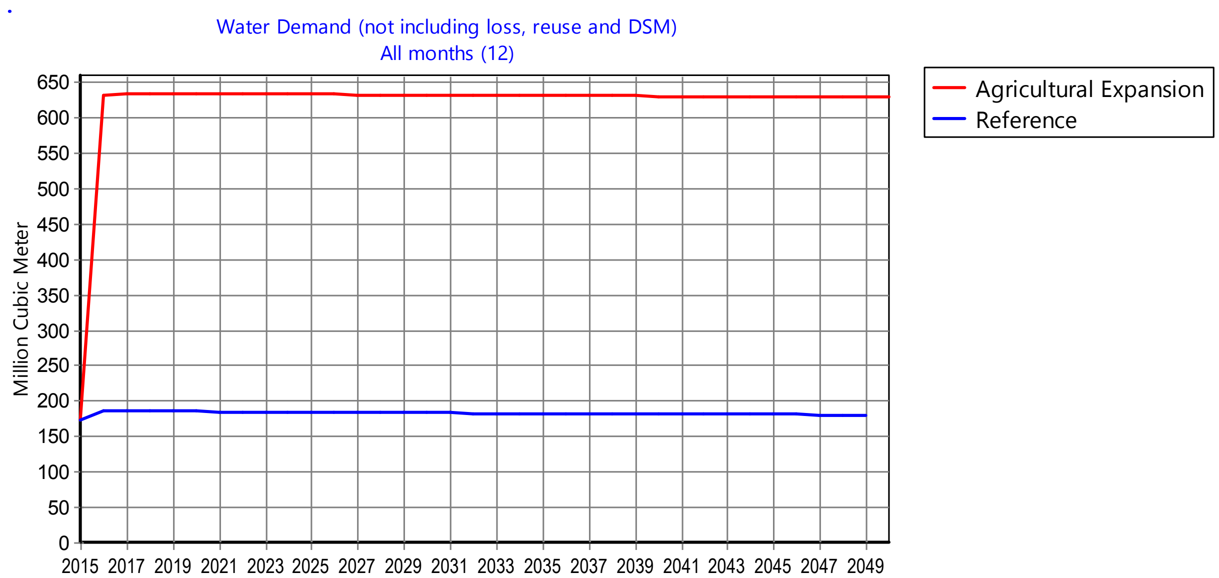


Figure 59. Annual water demand for all Vjosa demand sites, comparing Reference Scenario and Agricultural Expansion Scenario

The changes stem increases in agricultural land in the different catchments, based on data for the Drinos, Memaliaj and Përmet catchments. Catchments without increase estimates used the estimates of a nearby catchment. These increases were a 2.69-fold increase in irrigated land in the Drinos catchment, 3.94-fold increase in Memaliaj (and all downstream catchments as well as Lumi i Shushices), and 1.81-fold increase in Përmet (and Çarshova).

Figure 60 shows the increases in irrigation demand for the three catchments with data estimates, Drinos, Përmet and Memaliaj.

Despite these large changes in these catchments and others, both in the Reference Scenario (no expansion) and the Agricultural Expansion Scenario, there is no unmet demand in the Vjosa system.

However, unmet demands may emerge when the different climate scenarios are subject to agricultural expansion. In WEAP, the climate scenarios were changed to inherit the agricultural expansion. Below the scenario "Agricultural Expansion" represents the Reference Climate. These results show that all other climate scenarios experience unmet demand that grow continuously over the course of the model (Figure 61). The new agricultural demands are so large that they more than compensate for the declining demands of the decreasing populations.

The extreme RCP8.5 scenarios all show the fastest growing unmet demand over the course of the model, each quite separate from RCP8.5 which more closely approximates the record of the other RCP trends. This indicates that the Vjosa watershed is much more vulnerable to a low water year within any climate trend then to differences between the climate trends themselves.

The unmet demand is seen throughout the system in catchments (irrigation) as well as demand sites, since the water is shared.

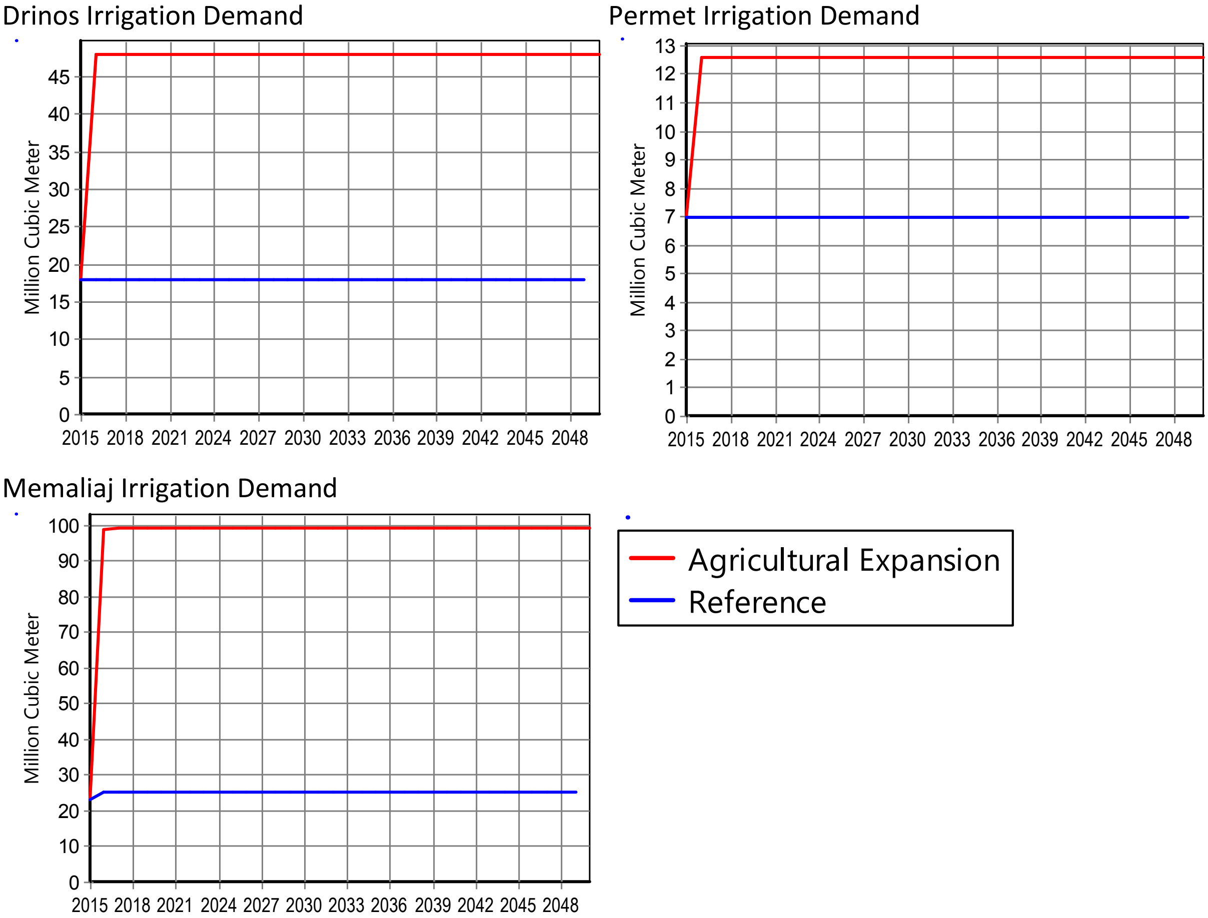


Figure 60. Annual total irrigation demand, comparing Reference Scenario and Agricultural Expansion Scenario

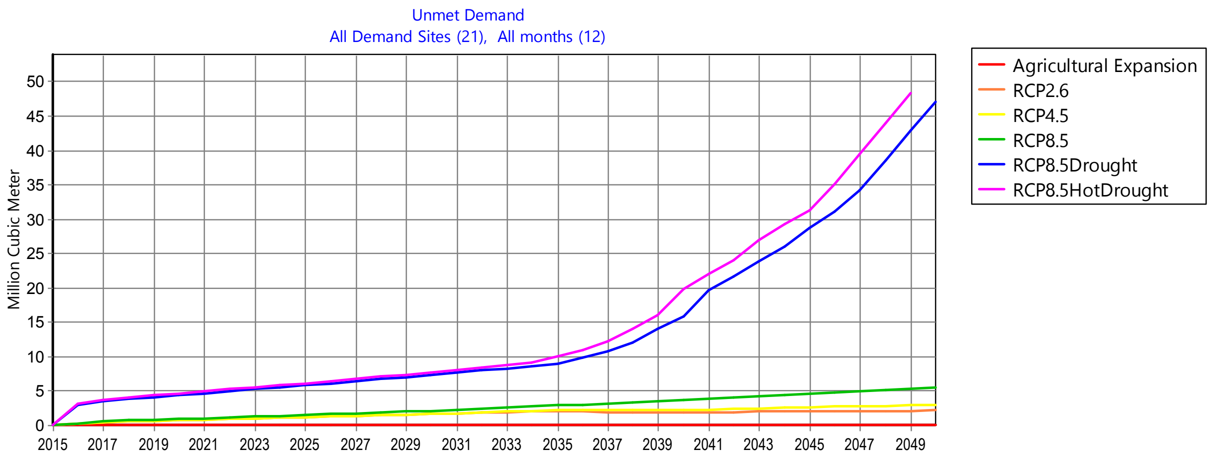


Figure 61. Annual unmet demand for RCP2.6 and RCP4.5, all demand sites. 2015-2020

7.4 Land Use Change (Runoff Resistance)

The 0.7 increase in the Runoff Resistance Factor value across all non-irrigated land use types, time steps, and demand sites approximates a basin-wide land use change agenda that lowers runoff to the river, increases evaporation, and reduces the overall amount of water in the Vjosa watershed. Increasing the runoff resistance factor also produces a small increase in overall demand in the Vjosa. Figure 62 shows this modest increase in demand.

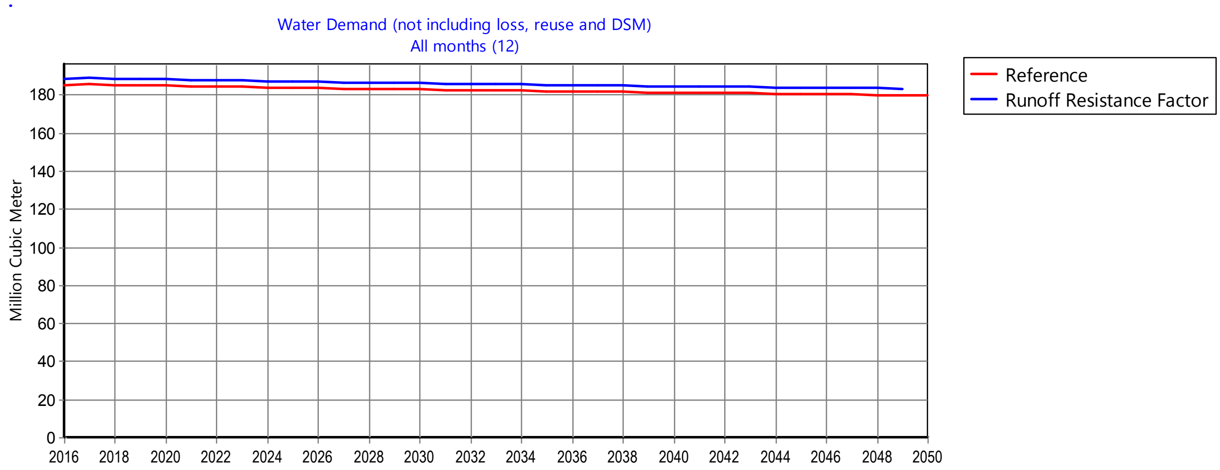


Figure 62. Changes in system-wide demand between Reference and Runoff Resistance Factor Scenarios

However, higher runoff resistance factor changes how water is parsed within a catchment according to the Soil Moisture method (see Section 3.2.2). This in turn affects all the other interacting elements of a catchment.

Table 31 compares how water is parsed, as an annual average for all the catchments in the Vjosa watershed, for the two different scenarios. Negative values, such as baseflow or surface runoff, indicate that the water is leaving the accounting system within the catchment, and positive values, such as precipitation, measure the water coming into the catchment.

Table 31. Average annual water balance for all catchments, 2015-2050, for Reference and RRF Scenarios

Inflows and Outflows	Reference Scenario (MCM)	RRF Scenario (MCM)	Difference (MCM)	% change from Reference
Base Flow	-320.47	-334.24	13.77	4.30
Decrease in Snow (Melt)	142.69	142.69	0	0
Decrease in Soil Moisture	2528.57	2482.84	45.74	-1.81
Evapotranspiration	-4198.87	-4348.40	149.52	3.56
Flow to Groundwater	0	0	0	0
Increase in Snow	-145.13	-145.13	0	0
Increase in Soil Moisture	-2540.14	-2509.08	-31.06	-1.22
Interflow	-1067.93	-1153.10	85.17	7.97
Irrigation	167.019	167.02	0	0
Precipitation	9969.20	9969.20	0	0
Surface Runoff	-4535.52	-4271.21	-264.31	-5.83

Comparing the two scenarios shows a nearly 6% decrease in surface runoff, roughly 264.3 MCM per year. Much of this water evaporates (there is an increase of 149.5 MCM evapotranspiration, or 3.5%). Because more water is going into the ground, there is an 8% increase in interflow (water released to the river from the model's top bucket) and a 4.3% increase in baseflow (water released to the river from the lower bucket) however this amounts to 85 MCM and 14 MCM respectively, not enough to compensate for the 264.3 MCM decrease in surface run off.

However, these changes are not large enough to impact unmet demand: demand is met in all climate scenarios except for the extreme RCP8.5s (in Figure 63 the scenario entitled "Runoff Resistance Factor" represents the Reference climate scenario with the changes to the runoff resistance factor). RCP8.5Drought and RCP8.5HotDrought show unmet demand starting earlier in the model in 2026.

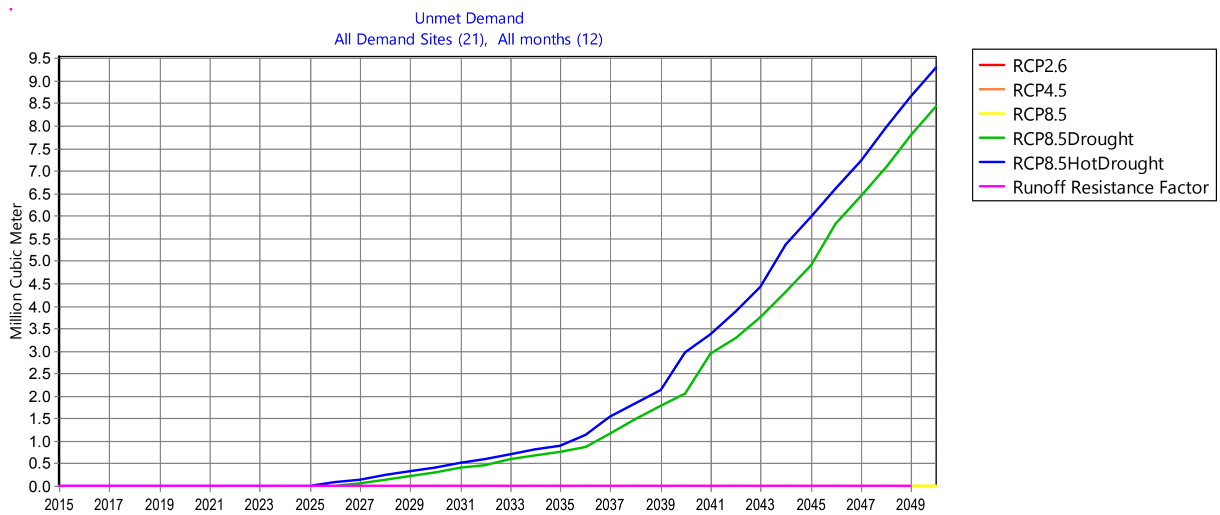


Figure 63. Unmet demands for all Vjosa watershed demand sites in the Land Use Change (RRF) Scenario

For the extreme RCP8.5s, the unmet demand appears significantly earlier than it would have without the change in Runoff Resistance Factor: in Figure 57 showing the climate scenario results without the Runoff Resistance change does not show unmet demands until 2035 and 2036. This demonstrates that under extreme climatic conditions, even small changes can have major impacts.

7.5 Poçem Hydropower Scenario

The Poçem Hydropower plant depends on sufficient streamflow to produce hydroelectricity. Within the different climate scenarios, the streamflow varies (Figure 64). Note that the y-axis starts at 2500 MCM, not zero and the Poçem Hydropower scenario represents the Reference climate scenario.

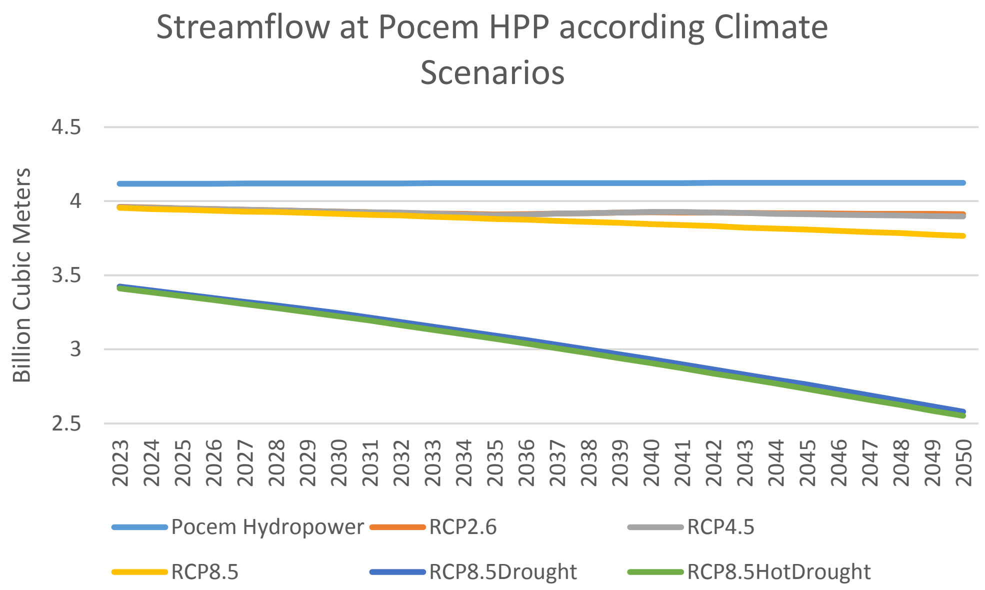


Figure 64. Annual total streamflow at Poçem HPP site by climate scenario (2017-2050)

In considering the streamflow volumes at Poçem, the average monthly streamflow varies between the different scenarios, the lowest at 70.01 MCM in August (RCP8.5HotDrought), and the highest at 700.5 MCM in February (Poçem Hydropower scenario/reference climate scenario). (Figure 65).

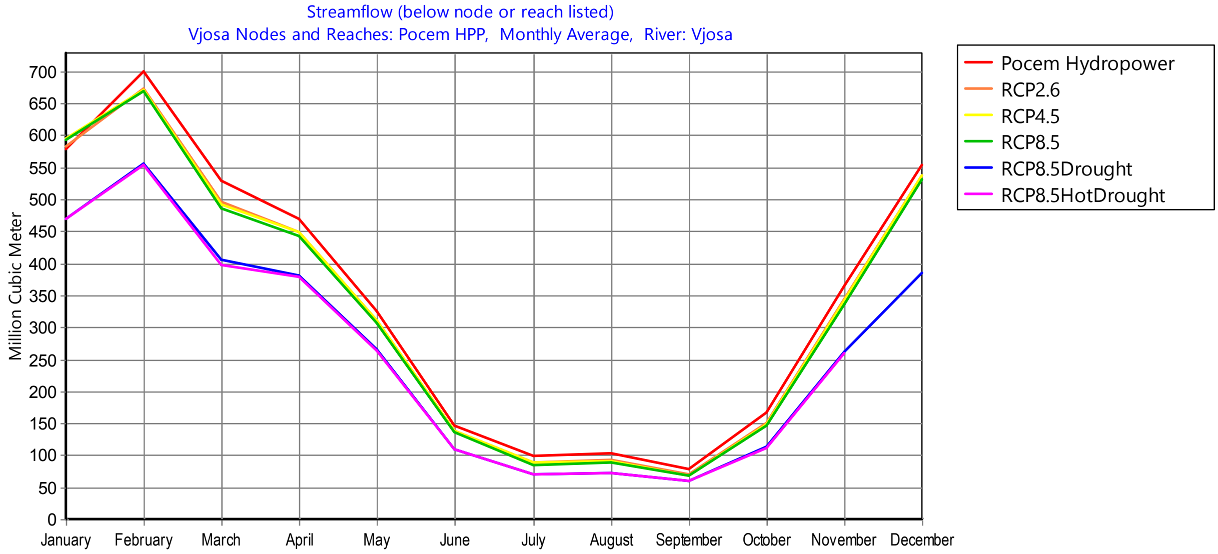


Figure 65. Average monthly streamflow at Poçem for the years 2015-2050

However, these streamflow differences are only sufficient to impact the storage of the reservoir in the RCP8.5Drought and RCP8.5HotDrought scenarios. For the Reference (called Poçem Hydropower), RCP 2.6, RCP 4.5 and RCP8.5 climate scenarios, the dam fills immediately upon completion (January 2016) and remains full through 2029. After 2029, the extreme RCP8.5s show increasingly larger drops in the reservoir's storage, in contrast, the storage volume of the reservoir "normal volume" of 250 MCM is not prohibitively large to keep full for the other climate scenarios (Figure 66). The other scenarios do not drop at all.

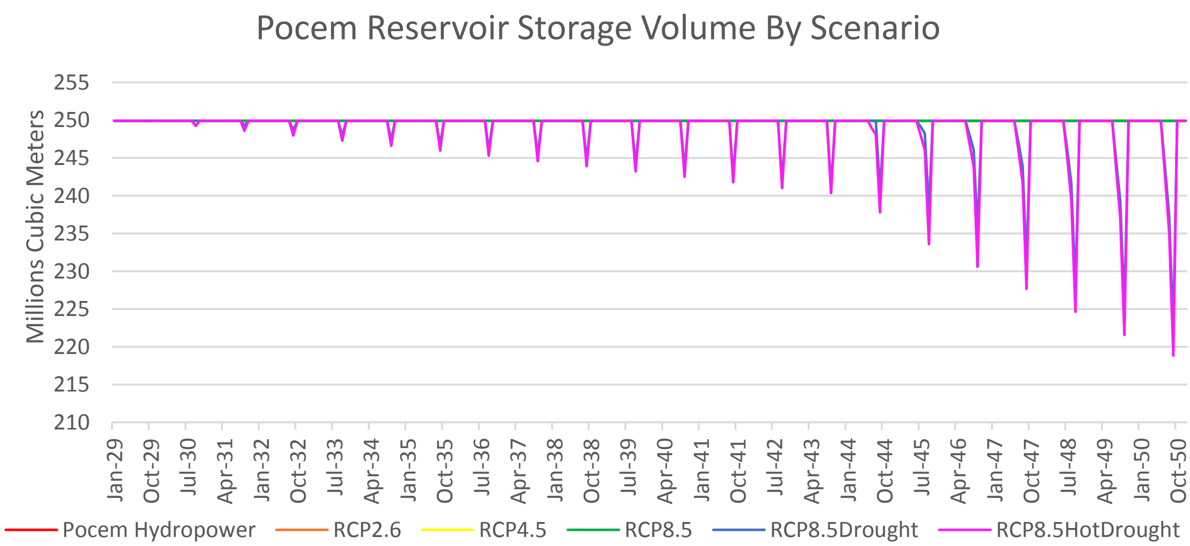


Figure 66. Storage volume in Poçem Reservoir, all scenarios, 2029-2050

It is predictably the summer when the storage volume drops below 100% (Figure 67 – note that the y-axis starts at 234 MCM).

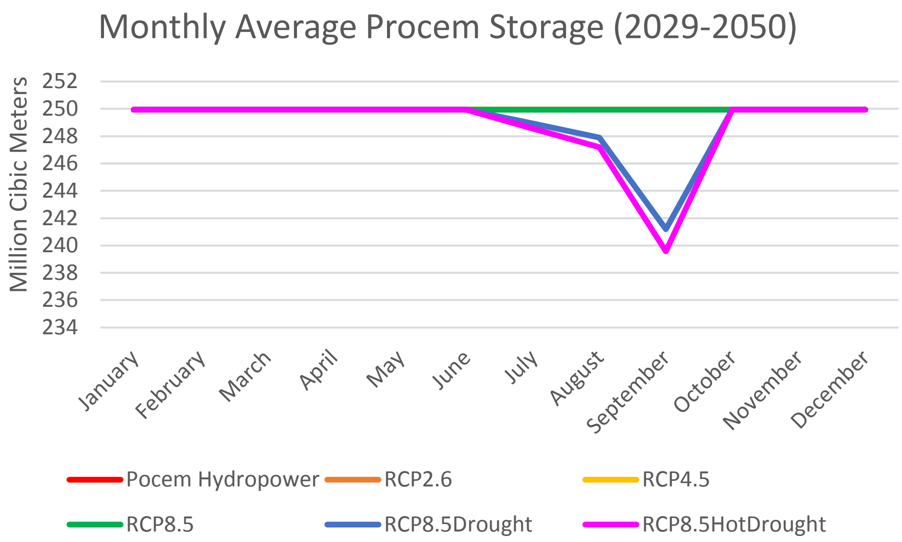


Figure 67. Monthly average storage volume of Pocem HPP for the years 2029-2050, by climate scenario

However, due to the differences in streamflow volume, the reservoir MW production varies according to scenario, for the years of full operation (after 2016, when the reservoir filled up) (Figure 68).

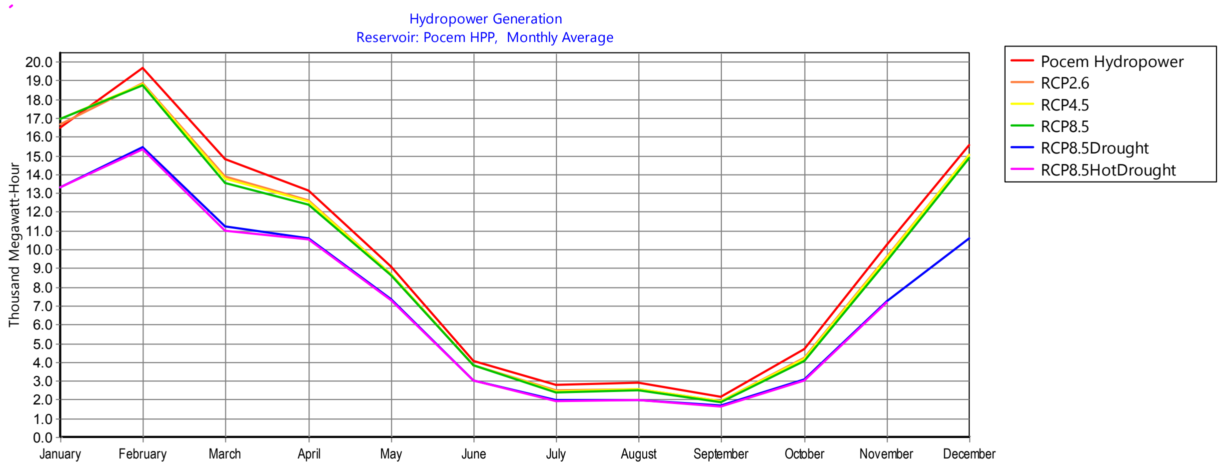


Figure 68. Average monthly hydropower generation (Thousand MWh) for Poçem HPP according to climate scenario, for the years 2017-2050

Table 32 shows the estimated average annual energy production per year at Poçem HPP under each climate scenario. Scenarios with a decrease over time (all scenarios except Reference) have lower averages.

Table 32. Pocem HPP average annual hydropower production (Thousand MWh) according to climate scenario (2017-2050)

Climate Scenario	Average Annual Production (Thousand MWh)
Pocem Hydropower (Reference)	115.51
RCP2.6	110.31
RCP4.5	110.25
RCP8.5	108.94
RCP8.5Drought	87.33
RCP8.5HotDrought	86.74

Over time decreasing demands from domestic demand sites (which in the absence of any development scenarios, are declining), creates higher streamflow and more power output. However, even these changes increasing the water in the river are not enough to compensate for the loss of streamflow resulting from climatic changes. For RCP8.5Drought and HotDrought, the streamflow at Poçem HPP and subsequent energy production is considerably lower. For these scenarios, representing low precipitation and temperature records that can occur as part of annual variability, the lower energy production will decrease the power plant profits (see Section 7.6).

7.6 Poçem Hydropower Cost Benefit Analysis

We can examine the net benefits of the hydropower plant over time in Million Real US Dollars. The Poçem Hydropower Plant produces different results under different climate scenarios, and here we present the results for the Reference Scenario (no climate change), RCP2.6 (mild climate change, 2°C world) and RCP8.5HotDrought scenario (4°C world), which takes the RCP8.5 scenario and uses the 10% percentile values for low precipitation as well as high temperature.

Based on the assumptions made about the loan terms, costs and energy prices for the Poçem hydropower plant, Figure 69 shows the costs over time in the Reference climate scenario. The negative values in the first seven years represent the sum of the loan payments and the O&M costs, offset slightly by the income from electricity generation. The positive values thereafter represent the income from electricity minus the O&M costs. Over the time, the overall benefits (profits) should be greater than the initial costs to construct the reservoir.

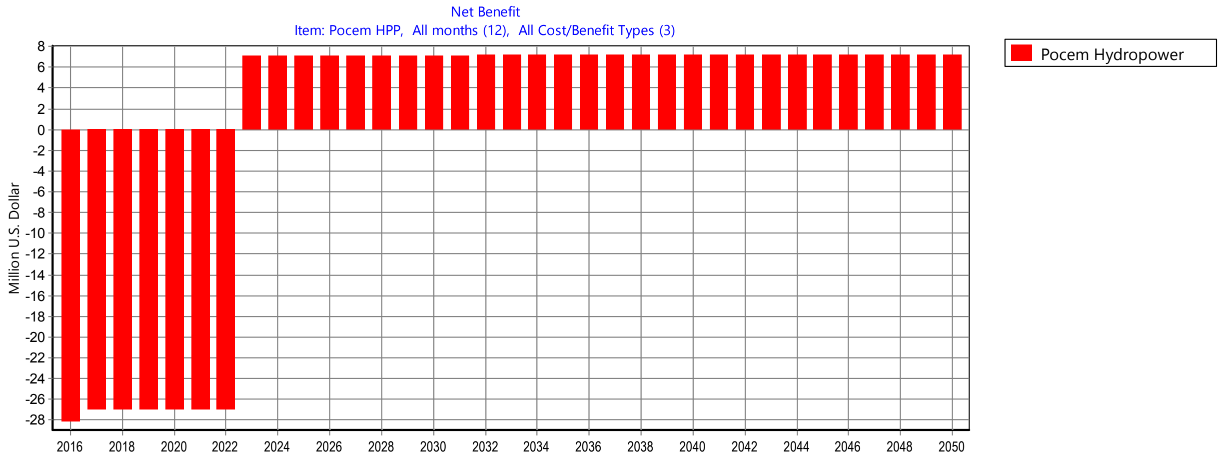


Figure 69. Costs and benefits of Poçem HPP construction in Reference climate scenario

Note that the costs are slightly higher in 2016 because the electricity revenue to offset them is not generated during the period that the reservoir is filling and less profits can be made. According to these prediction, the reservoir would be paid off by 2049, the first year positive payback.

The initial construction costs and the profits after 2022 vary based on the streamflow, which varies by climate scenario. Figure 70 shows that the Reference has the lowest costs and highest benefits, while RCP8.5 Drought and HotDrought have the highest costs and lowest benefits (the Poçem Hydropower scenario represent the plant's construction in the Reference climate conditions). Note that the different streamflow in these climate scenarios impact the amount of electricity that can be produced, and therefore the revenue.

Table 33. Debt and payback for Pocem HPP over time

Year	Costs Incurred (million USD)	Payback (million USD)	Year	Costs Incurred (Million USD)	Payback (Million USD)
2016	-28.12	-28.12	**2034**	7.13	-104.68
2017	-27.02	-55.14	**2035**	7.13	-97.55
2018	-27.02	-82.16	**2036**	7.13	-90.41
2019	-27.02	-109.18	**2037**	7.13	-83.28
2020	-27.02	-136.20	**2038**	7.14	-76.14
2021	-27.02	-163.22	**2039**	7.14	-69.01
2022	-27.01	-190.23	**2040**	7.14	-61.87
2023	7.12	-183.11	**2041**	7.14	-54.74
2024	7.13	-175.98	**2042**	7.14	-47.60
2025	7.13	-168.86	**2043**	7.14	-40.46
2026	7.13	-161.73	**2044**	7.14	-33.32
2027	7.13	-154.60	**2045**	7.14	-26.19
2028	7.13	-147.47	**2046**	7.14	-19.05
2029	7.13	-140.34	**2047**	7.14	-11.91
2030	7.13	-133.21	**2048**	7.14	-4.77
2031	7.13	-126.08	**2049**	7.14	2.37
2032	7.13	-118.95	**2050**	7.14	9.51
2033	7.13	-111.82			

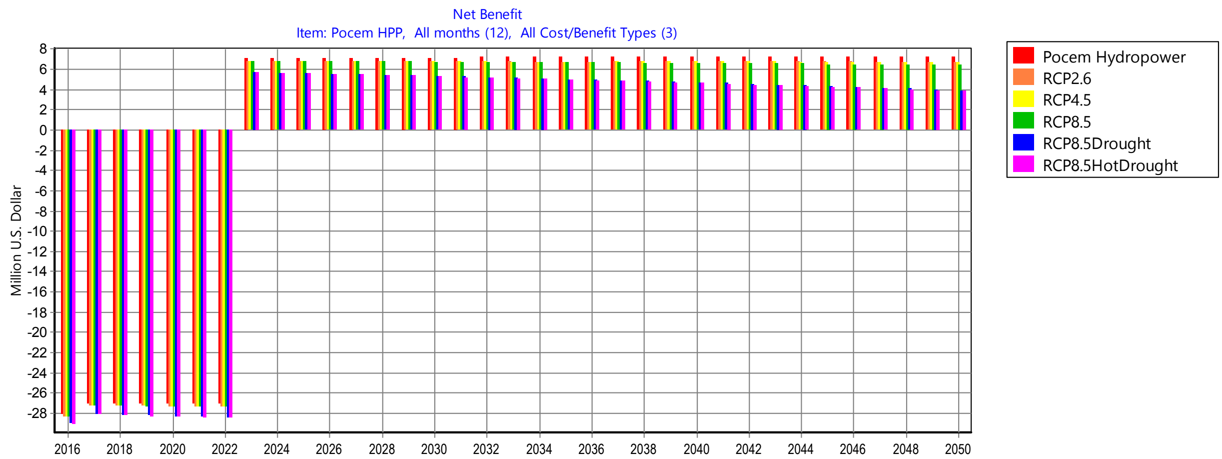
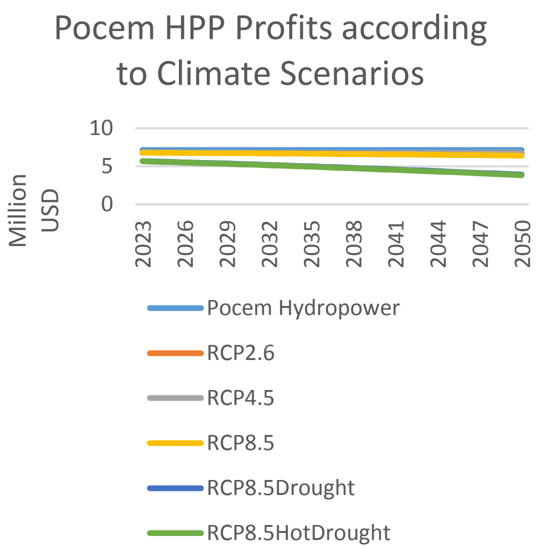


Figure 70. Costs and benefits of Poçem HPP by climate scenario

The profits diminish according to the respective climate scenarios. In Figure 71, the profits of the various climate change scenarios are noticeably lower than the Reference Scenario, with RCP2.6 and RCP4.5 very close until 2050, with a slight differentiation for RCP8.5 and major differentiations in profit for sustained low percentiles of precipitation and temperature in RCP8.5 Drought and RCP8.5 HotDrought. Not that while adding extreme temperatures to the drought scenario did worsen it, the difference was negligible compared to the differences made by using extreme precipitation values. Figure 71 compares the profits at the reservoir to the streamflow in the various scenarios for the years 2023 -2050.



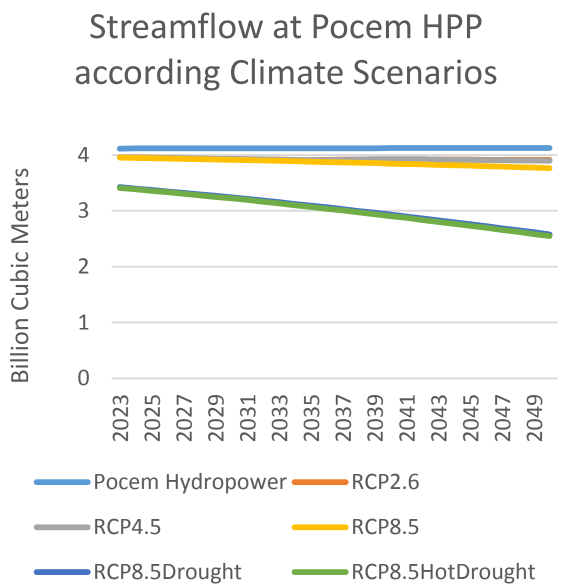


Figure 71. Annual profits at Pocem HPP by climate scenario compared to annual streamflow (2023-2050)

In considering these trends in costs and benefits, Table 34 shows the percent of cost incurred that has been recuperated by 2050 (27 years of reservoir operation).

Table 34. Comparison of percentages of loans still unpaid by 2050 according to climate scenarios

Climate Scenario	% of Debt Remaining in 2050
Pocem Hydropower (Reference)	None: Payback by 2049
RCP2.6	2.05
RCP4.5	2.13
RCP8.5	3.87
RCP8.5Drought	31.71
RCP8.5HotDrought	32.45

Table 34 shows that the all climate trends using 50th percentile values (RCP2.6, RCP4.5 and RCP8.5) have recuperated most of the construction debt by the year 2050, and the payback period will likely follow in the next few years. However, the extreme scenarios RCP8.5Drougth and RCP8.5HotDrought, which represent 10% values for temperature and temperature/precipitation, respectively, will take considerably longer to recuperate the construction's full costs.

Figure 72 shows the monthly average energy production (MWh) according to scenario. This shows minor differences between the 3 climate scenarios, but large differences between their respective values and the values for RCP8.5Drought and HotDrought.

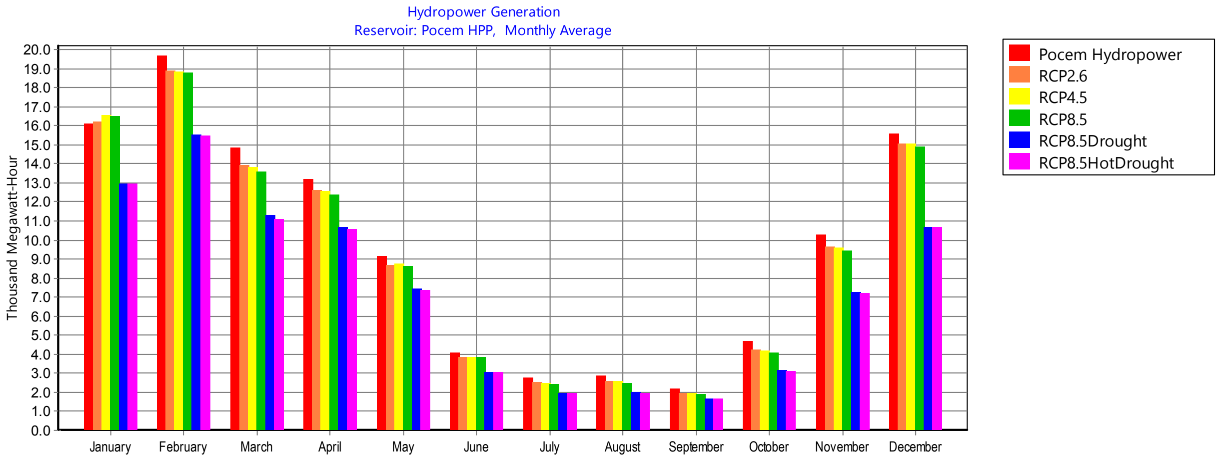


Figure 72. Projected monthly average MW energy production by climate scenario at Pocem HPP (2016-2050)

Table 35 shows the average annual energy production at Pocem HPP by climate scenario (2016-2050).

Table 35. Average annual Pocem HPP energy production (thousand MWh) by climate scenario (2016-2050)

Climate Scenario	Annual Energy Production 2016-2050 (Thousand MWh)
Pocem Hydropower (Reference)	115.09
RCP2.6	109.95
RCP4.5	109.89
RCP8.5	108.61
RCP8.5Drought	87.37
RCP8.5HotDrought	86.78

Much of the data gathered for this report is highly uncertain, and some of it could greatly impact the analysis for the model. Figure 73 shows the costs and benefits of different scenarios according to the loan period (either 7 or 15 years) and the interest rate (either 5% or 14%), all assuming the Reference climate scenario.

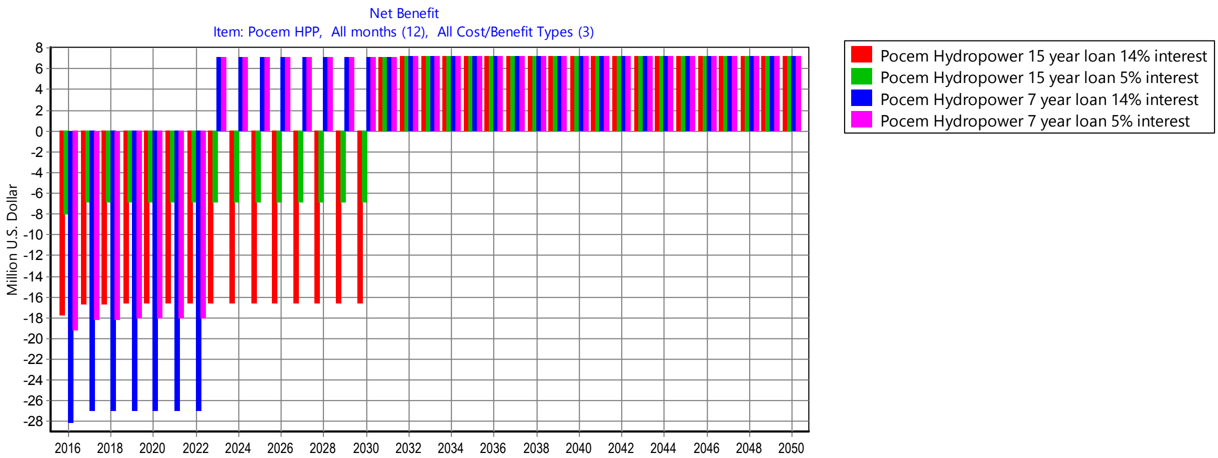


Figure 73. 7 year loan vs. 15 year loan for Pocem HPP (Reference Scenario)

Figure 73 shows that the benefits remain the same after the period of the loan, but the accrual of debt varies considerably based on the interest rate and loan period. Table 36 shows the differences in total debt incurred and subsequent profit by % of loan not yet recuperated by the end of the model in 2050.

Table 36. Comparison of percentages of loans still unpaid by 2050 in the Reference climate scenario according to loan terms

Loan Period	Interest Rate	Debt Incurred (million USD)	% of Debt Remaining in 2050
7-year	14%	212.9	49.6
7-year	5%	151.0	None: Payback by 2045
15-year	14%	251.76	None: Payback by 2049
15-year	5%	154.8	None: Payback by 2041

The breadth of differences in these estimations and profits indicate that accurate estimates for the loan terms will be very important for evaluating the cost benefit analysis of the Poçem HPP. A seven-loan with a 5% interest assures a much faster overall profit than that 15-year loan with 14% interest.

In additional to the sensitivity demonstrated by the construction's loan terms, the WEAP cost-benefit analysis may have some bias due its simulation of the streamflow at the Poçem HPP site. The Poçem site significantly downstream of the model's two upstream calibration points, Përmet and Drinos, and industrial and domestic demand for Memaliaj are removed from the river prior to reaching the Poçem HPP site. The closest calibrated gauge to the Poçem site is the model's Poçem gauge, which measures the river volume after industrial and domestic demands for the Poçem region have been removed from the river and their unconsumed demand (10% and 88% respectively) returned to the river (Figure 74).

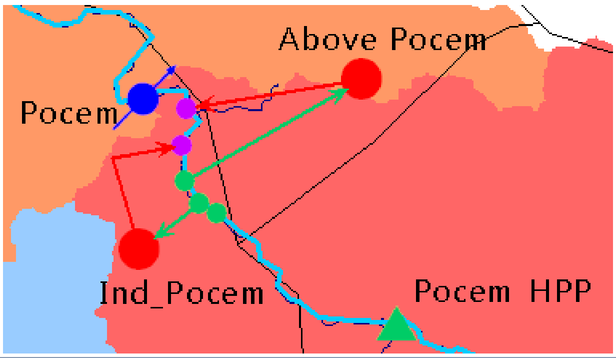


Figure 74. Pocem HPP site in upstream of the calibrated Pocem gauge

Viewing Figure 74 raises the question of how can accuracy of the streamflow at the Poçem HPP be judged. Fortunately, the overall water consumption of the two intervening demand sites are quite small: Poçem Industrial consumption is 0.014 MCM/year, and the average domestic consumption of water between the years 2002-2008 for Poçem domestic users was 0.213 MCM. The sum of these values (0.227 MCM) is small compared to the annual average streamflow at the Poçem gauge of 3,976 MCM/year (2002-2008, modeled streamflow). Therefore, despite these intervening demands, the accuracy of the streamflow at Poçem HPP can be inferred by the accuracy of the streamflow at the Poçem gauge.

The calibration for the Poçem streamflow gauge the years of record (2003-2008) had a bias of -3.659. This means that compared to the observed data for this period, the model simulated less streamflow in the river. For hydropower generation estimates, this could indicate that the results for hydropower generation and subsequent profit, are lower in the model than they would be in reality.

However, the streamflow bias varied by year (see Figure 35), and from 2005-2008, WEAP simulated too much streamflow. It is not possible to know how this trend of bias would have played out over time, but if the model is predicting too much or too little streamflow, that error can impact the Poçem's hydropower production, and with it the reservoir profitability and payback period. In Figure 74 the Poçem gauge is the gauge on the map (blue circle with line diagonal across it). It is the 55th

reach of the Vjosa River, which is why it is compared with the 55th reach of WEAP's simulated river (see legend in Figure 34, Poçem).

The Poçem Hydropower plant plans have been in development for several years. Beside strong concerns about environmental impacts, this analysis raises serious questions about viability and profitability of the reservoir as an investment. The relatively low cost of electricity and the uncertain future of streamflow in the Vjosa due to climate change, means that the large capital costs will not be recouped by 2050 in any climate or loan scenario, though some are closer to payback than others.

8. Priority Adaptations Measures

8.1 Introduction

The Fifth (and prior) Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC) project that, even with immediate implementation of climate mitigation policies, the global climate system will continue to shift and change for decades to come. Two centuries of industrial emissions of greenhouse gases have altered the radiative forcing of the planet, resulting in rapid changes in what humans often perceive as stationary climate conditions (IPCC, 2014; IPCC, 2013, IPCC, 2007a; IPCC, 2007b; Biggs et al., 2009). Besides taking urgent action on curbing emissions of greenhouse gasses, the need to adjust and adapt to climate change impacts is becoming increasingly critical for economic, social and environmental prosperity. As there is a growing body of evidence that we are already "locked in" to shifts in climate conditions, and major shifts in what we have perceived as 'normal' weather are increasingly likely, it is imperative that we prepare for and adjust to these impacts, even as they can be highly uncertain.

A major challenge in anticipating emerging future hydrological conditions is that past records are likely to have only limited value for looking towards climate impacts in the future (Milly 2008; Matthews and Wickel, 2009). While the past provides a historic reference, observational records are often limited in length and for most river basins only date back several decades. Even if these data exist, many legal and operational water management systems are often "locked in" based on these short term hydro-meteorological records, without the required flexibility to adjust to new conditions and significantly increasing uncertainty in decision making.

The trans-boundary Vjosa faces a set of water related challenges that are not unique to this basin, but that do require specific attention. This chapter discusses a priority areas for adaptation measures for the Vjosa basin.

8.2 A note on models and uncertainty

Given the current state of knowledge and limits to predictability of climate change impacts on water, effective decisions to adapt to climate change will need to be made in the absence of accurate and precise climate predictions (Dessai et al., 2009). Although is it becoming "standard" practice for climate change impact assessments for water to link the results of a climate change model for temperature and precipitation with a hydrological model for runoff, it is important to realize that these assessments have several limitations (Rodríguez-Iturbe and Valdés, 2011).

Model studies form a critical instrument in water resource planning and decision making. Tools such as WEAP can be designed to test and identify vulnerabilities to change, including climate and speculate about potential impacts and their costs. It is critical however to understand that as models only represent conditions to our best knowledge, and that all come with an inherent set of uncertainties. As model outputs serve as inputs for other models, a cascade of uncertainties may proceed for each potential socio-economic and demographic pathway, and the uncertainty in possible adaptation responses rapidly widens (Figure 75).

A useful approach for such planning is to turn the traditional top-down framework, which typically involves downscaling future climate scenarios, generating input data for impact models, evaluating the consequences relative to present climate, and finally considering adaptation responses, upside down (Yates, 2015). By doing so greater emphasis can be put on identifying and appraising adaptation choices from the outset (Wilby and Dessai, 2010). In this configuration, the scenario is used much later in the process to evaluate the performance or ''stress test'' adaptation decisions. As such, the scenario does not need to be explicitly tied to a given climate model or ensemble.

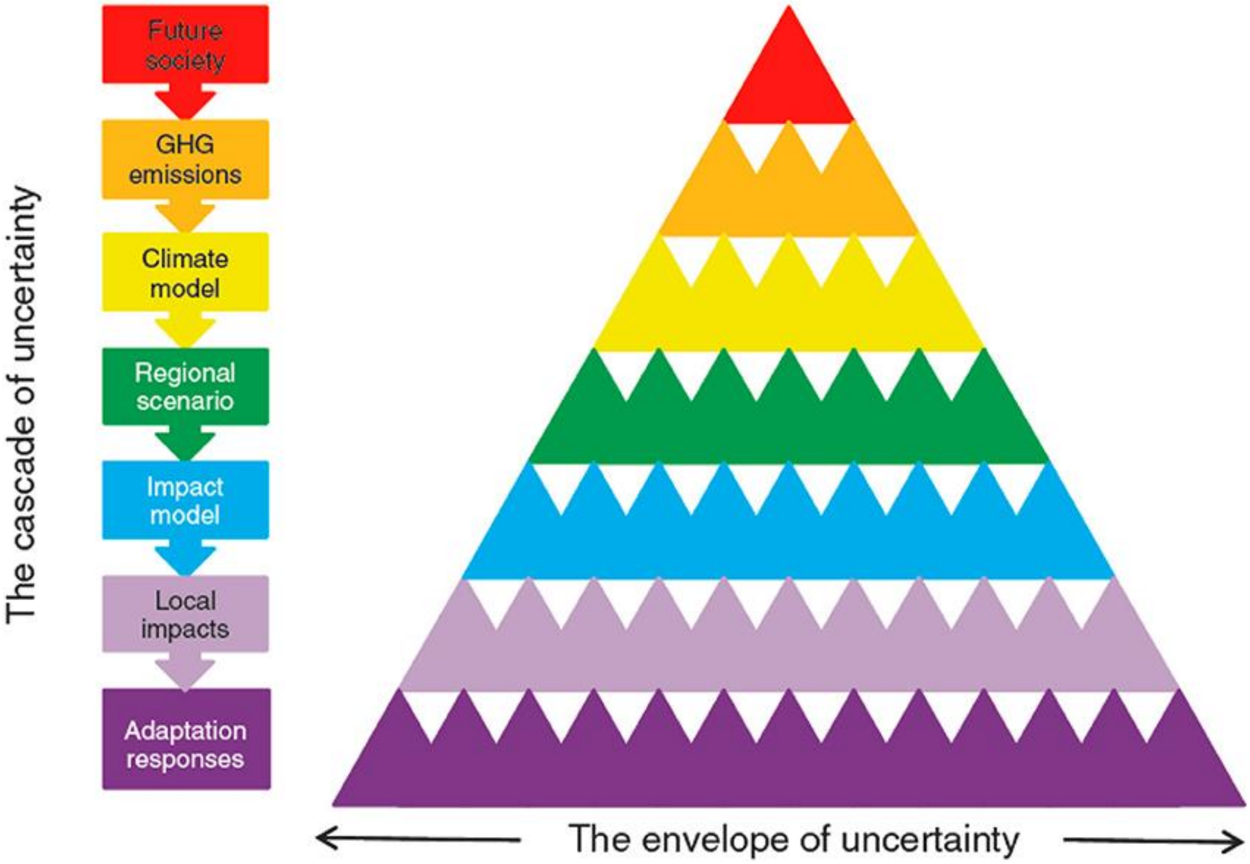


Figure 75. A cascade of uncertainty in the coupling of socio-economic, climate and hydrological models and potential adaptation responses (Adapted from Wilby and Dessai, 2010)

8.3 CLIMATE VULNERABILITIES AND IMPACTS

The Third National Communication to the UNFCCC for Albania, asserts that broader vulnerabilities and risks in Albania stem from:

- A non-existing or weak monitoring system for both surface and groundwater in quantity and quality, including calibration of measuring systems and evaluation and management of data;
- Non-existing or weak water infrastructure and poor maintenance, especially in water supply and wastewater management; this has to be seen in the context of the poor implementation of economic instruments, the dramatic increase in construction activity, which has been poorly planned and regulated, fast structural changes and absence of waste collection in rural areas;
- A poor regulatory and financial framework in the water sector together with the lack of a long term strategy which should act as a schedule for all activities and projects in the water sector.[5]

8.3.1 Vulnerabilities

The Vjosa basin experiences a great range of hydrological variability and conditions, but due to a general lack of data and a weak monitoring system little to none of the required information is

[5] Since the Third National Communication (launched on November 2016) the Water Sector Strategy has been drafted and is currently under review.

available to guide decision making. With increasing variability and uncertainty about future hydrologic conditions this lack of data poses a major vulnerability to the Vjosa basin and its inhabitants.

Based on our study for the Vjosa Basin we confirm some of these assertions and highlight some more specific ones that were exposed during model development. Some vulnerabilities were beyond the scope of the current study, but which could be simulated with WEAP when data become available relate to flooding and water quality. Depending on the application however it may make sense to evaluate those risks with models that are specifically designed to address those questions.

1. Lack of data in particular of consistent meteorological and discharge data, as well as water use information;
2. A weak monitoring system that lacks resources to maintain long term and consistent data collection and quality control;
3. Absence of a transparent system to access data;
4. High capacity for the development of climate change scenarios, but low capacity for the development and implementation of water resource and climate models;
5. Development of water management infrastructure that is particularly vulnerable to projected climate impacts/extreme events such as hydropower;
6. Lower forest cover due to deforestation in previous decades; and
7. Growth of tourism sector and its water demands.

8.4 Adaptation Priorities

Adaptation options identified in the Third National Communication for Albania (Ministry of Environment, 2016) are generally characterized as proactive measures and reactive measures. Proactive measures are taken in anticipation of certain impacts or could include the abstinence of pushing certain developments that could be mal-adaptive. Reactive measures are made once strong impacts are observed, but as an extensive body of literature on disaster risk reduction is illustrating, are several orders of magnitude more expensive than preventing them to happen in the first place.

The current project focusses entirely on proactive measures. The development of a systems model of water resource availability and demand of the basin, WEAP, in itself can be seen as part of an overarching adaptation priority. By creating a basin platform for the evaluation of water resources and climate impacts, adaptation priorities can be proposed and evaluated in terms of their importance. As these priorities are entirely driven by stakeholder inputs we can at this point only identify general areas of action while providing a set of examples of how adaptation actions may be prioritized.

The project aimed to start closing knowledge and data gaps through:

- the compilation of a consistent database of water and climate data for the Vjosa Basin;
- a first evaluation of climate change impacts and adaptation priorities under various climate scenarios; and
- building and strengthening capacity in the use of this climate informed water resource management platform.

It is important to note that this project provides just a first step towards the identification and implementation of priority adaptation actions. The continued improvement of the WEAP model, improved data collection and analysis and implementation of Robust Decision Support (RDS) approaches will strengthen the resilience of the economy and ecosystems of the Vjosa under climate change and directly supports the National Integrated Water Resource Management Plan (IWRM)

Strategy – which aims to provide adequate access to water of sufficient quality for human, animal, nature, secure food, energy production and protection against floods, especially while considering the expected impacts of climate change.

8.4.1 Closing data and knowledge gaps

The current project made significant progress in organizing and synthesizing available data related to water resources of the Vjosa, but also identified significant gaps in the availability and quality of data required for monitoring and evaluation of climate change impacts and preventing mal-adaptive decisions. Data gaps exist in both the availability of water resources as well as demand. The WEAP model provides an analytical foundation for evaluating water resources supply and demand under contrasting development and climate scenarios. Along with improved observational data of meteorological and hydrological conditions, it is critical to enhance the model with accurate information on water use and demands.

8.4.1.1 Hydro-meterological time series

WEAP facilitates the evaluation of available water resources based on rainfall-runoff models that are built on hydro-meteorological observation time series. The current WEAP model was built using monthly data, due to the availability of data for the Vjosa basin. While it is our understanding that daily data and longer term records are available, these data are either not digitized, scattered among users and poorly calibrated or documented. The existing monitoring network is facing a variety of challenges that include but are not limited to; poor condition and maintenance of the equipment, lack of financial resources for training, in monitoring practices and processing of data, lack of a systemic approach to organizing data, lack of transparency and access to the data. If historic and current, well calibrated, daily discharge data were made available, a more robust set of analyses that capture shorter term hydrological variability and impacts of climate change would be possible.

Priority actions

1. Expansion of a historic baseline of daily discharge and meteorological data by digitizing past data into computer accessible formats and making them available to users;
2. Invest in a robust and sustainable long term monitoring network operated by one agency;
3. Develop a consistent and accessible internet based system with near-real time telemetry for daily to hourly observations.

8.4.1.2 Water demand data

Water demand data for the basin Vjosa for this project was structured around three major subsets: Agricultural, Industrial and Urban demands. While we were able to secure some information about surface water uses and get estimates on demands, there is a large amount of uncertainty associated with the actual water use patterns.

The newly created Vjosa Basin Commission of the Ministry of Agriculture is making efforts to standardize and improve access to water use data through the ongoing project on development of the national water cadaster. Once in place the existing WEAP model can be enhanced with data from the cadaster and used to test and identify specific vulnerabilities in proposed water resource allocation schemes.

Priority actions

1. Link the information of the Vjosa Basin water cadaster to WEAP;
2. Improve knowledge on seasonal water demand; and

3. Integrate knowledge on current deficiencies in water distribution (e.g. irrigation networks and water urban supply).

8.4.2 Adaptation priority actions for specific sectors

Based on the current WEAP model various development scenarios were simulated, with and without climate change projections: increasing tourism and population change; general changes in land use; agricultural expansion; hydropower development; and reforestation.

8.4.2.1 Population change - Urban water use and tourism

As discussed Section 4.5.3, both the Albanian and Greek populations in the Vjosa/Aoös watershed are generally declining. However, Albania has seen a rapid growth in tourists over the past several years, following the end of communism in the 1990s, an increasing recognition of Albania's natural landscapes, and affordable prices. As a result water demand at tourist destinations in the basin is steadily increasing, but information on population numbers are inconsistent and difficult to gather.

Given the potentially growing importance of tourism in the basin and its potential vulnerability to climate impacts a review of water supply and potential distribution losses should be an adaptive priority for this sector. This analysis needs further improvement with a more accurate review of population, demographic changes and tourism numbers in particular.

Priority actions

1. Review population dynamics/census data to capture water demands of the tourism sector;
2. Develop strategies to minimize seasonal water supply vulnerabilities;
3. Review and reduce distribution losses where possible.

8.4.2.2 Agricultural expansion

A major challenge in assessing the impacts of climate change on agriculture in the Vjosa basin is the lack of reliable water use data for this sector. Our preliminary simulations reveal a potential failure to meet demand under dryer climate scenarios. An important aspect of agricultural water management, however, is the condition and efficiency of water distribution and delivery for irrigation. While good data on this aspect is lacking, qualitative estimates for the Gjirokastër irrigation district indicate that it is only operating at 30% of its capacity due to aging infrastructure, flood damage and lack of maintenance. The combination of these factors with increasing challenges due to climate change raise concerns about this sector.

Priority actions

1. Perform a comprehensive review of agricultural water use;
2. Review existing coping strategies for drought;
3. Explore possibilities for introduction of drought resistant varieties of crops; and
4. Rehabilitate storage capacity, with possible green infrastructure solutions.

8.4.2.3 Hydropower development

Water management infrastructure, in particular large dams for storage and power generation can bring great benefits, but can also be highly vulnerable to climate change, especially when assumptions on hydrological conditions are only based on (limited) historic observations. Under certain conditions infrastructure can exacerbate the impacts of climate change and result in a reduction of adaptive capacity or being "mal-adaptive".

While aiming to provide adaptation priorities, we think it is equally critical to evaluate mal-adaptive developments. The Poçem hydropower plant is in our opinion a good example of a project that has a high potential for mal-adaptation and that requires a full evaluation of climate risk.

Modeling results from this study indicate that, using the best available information, the hydropower project Poçem is unlikely to be cost effective even before factoring in climate change, given its long cost recovery period (See section 7.6)

As a high level of uncertainty is associated with the impacts of sediment – an aspect that was beyond the current scope of this project - on this project in one of Europe's most sediment loaded rivers, special efforts should be made in future evaluations to capture the linkages between increased peak flows which are likely under all future climate change scenarios and increased erosion and sediment transport by the river.

The Poçem hydropower project will significantly alter the flow regime. This will likely affect sediment transportation and stream temperatures in the Vjosa River and have significant impacts on the high biodiversity of the river and the Narta Lagoon in its delta. Simulations using climate projections show that the flows could be altered further, therewith severely limiting the ability to sustain environmental flows and significantly reducing the capacity of species and ecosystems to adapt to climate change.

It is important that the impacts of this project on stream temperatures due to reduced flows, but also increasing air temperatures as well as sediment transport implications are studied further. This can potentially be done by coupling WEAP with water quality models such as Qual2K and sediment transport models.

Priority actions

1. Incorporate climate projections in hydropower development planning processes;
2. Further evaluate mal-adaptive traits of hydropower development, in particular large scale impacts on adaptive capacity of natural systems; and
3. Evaluate impacts of potential changes in sediment budgets on hydropower operations due to climate change impacts.

8.4.2.4 Forestry/conservation

The Vjosa basin experienced significant loss of its forest cover in the early 1990's. Various national programs aim to reestablish forest cover and policy makers at the highest levels are aware of the importance of the role of forest cover in reducing erosion and improving soil conditions[6]. As reforestation brings climate mitigation benefits it also has the potential to improve infiltration, though the time frame over which these benefits manifest themselves are highly context specific (Bruijnzeel, 2000).

Simulations for the Drinos Basin (see Section 7.4) show that a general increase in runoff resistance reduces flows (as can be expected. Most importantly though it has moderate impacts on seasonality of flows and could buffer peaks, and increase dry season flows. This effect should be explored further with better data, ideally a longer term daily time series.

[6] https://www.theguardian.com/environment/2015/feb/05/albania-declares-state-of-emergency-over-historic-floods

Priority actions

1. Review the potential for synergies between climate mitigation and adaptation strategies through reforestation efforts in the Vjosa Basin;
2. Expand and conserve forested landscapes where possible.

8.4.3 Building capacity

Lastly, an important part of adaptation is preparedness and having the capacity to recognize and evaluate the impacts of change. Albanian institutions currently face gaps in capacity in monitoring, model development and implementation and operation of water management tools. Capacity building in the area of climate and water resource science and in the use of this knowledge in policy making is critical and an adaptation priority in itself.

Mainstreaming of climate science and adaptation from local to national levels through integration of:

Priority actions

1. Increasing community awareness of climate risks;
2. Strengthening the Vjosa Basin Agency in climate informed decision making;
3. Building of technical capacity in basin and water resource planning tools (WEAP) at the basin and national level; and
4. Facilitating multi-stakeholder basin (Robust Decision Support) workshops for comprehensive planning of water allocation and climate adaptation

8.5 Conclusions

The priority adaptation measures discussed in this report can be organized along three broad categories aimed at reducing uncertainty and integrating climate science in decision making:

- Closing data and knowledge gaps;
- Climate informed water resource decision making;
- Building capacity.

This report provides a general overview of general climate vulnerabilities and identified a set of specific development scenarios that are likely to be affected by climate impacts in terms of water supply. We provide a model that allows evaluation water resources that can inform planning and allocation decisions and make them more robust when facing climate change impacts.

While having a general abundance of water resources, this study indicates that particular practices or developments (e.g. dam development) may increase climate vulnerability, while others (e.g. reforestation) have a tendency to increase resilience. Since this project from the beginning was designed to look at water quantity, future efforts should attempt to address quality related issues as well. While reactive adaptation solutions can emerge out of necessity (e.g. implementation of levees for flood protection) it is important to evaluate possibilities for inclusion of green infrastructure and other proactive adaptation solutions.

This project provides a first step in addressing the three overarching priorities identified above, but this by no means is a one-time action. Adaptation and sustainable management of water resources is a continuous process that requires decision making with the best available knowledge, and closing gaps in this knowledge as we move forward.

9. Recommendations

The current project is the first of its kind for the Vjosa basin and the first attempt in Albania to develop a WEAP model for an entire river basin (a WEAP model exist for the Devoll River, in the Seman basin, Almestad 2015). The construction of this model, in strong collaboration with Albanian partners with the IGEWE, was highly productive and allowed for the development of an application of WEAP in a very short timeframe (less than 6 months) while providing the foundation for a series of much more complex analyses and applications in emerging decision making contexts in the future. An integral part of this project was capacity building (see the capacity building summary) which to some extent was more critical than the absolute calibration of the model. The model uses the best available data at the time of its development, but there are many opportunities for expansion and improvement, which would further improve the accuracy and utility of the model for decision making purposes.

9.1 Data Acquisition Recommendations

Sound water management and evaluation of future scenarios depend on reliable data. In particular, basic parameters such as stream discharge, precipitation and temperature need to be available for researchers and the broader community. The strongest data components of the current project are derived from large scale (non-national) spatial data sets. Despite recent investments, in particular by the World Bank, to produce data for the Vjosa basin, much of the relevant data are unavailable or poorly calibrated for a variety of reasons.

A major challenge (at a national level) seems to be the general lack of sustained financial support required to operate and maintain monitoring stations for streamflow and meteorological measurements, and to digitize the records. During a visit to the basin in June 2016 as part of this project, it was observed that only three stations are currently operational, though recent data (after 2008) were not available to the project. Various stations were in a state of disrepair due to the floods earlier in the year, while acts of vandalism complicate station maintenance as well. It was clear that the dynamic stream bed conditions in many locations impede maintenance of a permanent reference level. Historic data often lacks documentation of measurement conditions at the stream gauge stations. Reconstruction of streamflow data for this project was extremely time consuming, and significant uncertainties about the final data quality remains. While the literature references the existence of a more complete historic streamflow record between 1950 and 1990, this data was not accessible for the project because it is controlled by individuals, not in a central data repository. While these data may be less relevant for evaluation of current water use, they may be helpful for enhancing the calibration of the model.

Meteorological data are generally of higher quality, although they were also difficult to obtain. Various inconsistencies and missing data in the datasets resulted in the exclusion of several stations. Additionally, since many stations are located at lower elevations, and monitoring of important parameters (e.g. snow depth) were missing during the model's historic calibration period, it proved difficult to compile a comprehensive meteorological dataset. It is also possible that precipitation for the region is underestimated because there are more stations at lower elevation. These gaps in data were addressed through the various methodologies detailed in Section 4.4, such as interpolation within records and averaging with nearby stations, but these solutions potentially introduce errors into the record.

Together, these errors may be so egregious that they limit the overall accuracy of the model, and the model's subsequent predication powers for the future. We take as an example the calibration record of the Poçem station (Figure 35, chapter 5), in which the observed record (blue) shows very high streamflow in 2003-2004), and significantly lower streamflow from 2007-2008. The simulated streamflow, which is heavily dependent on the system's comparatively constant precipitation record during this time, inadequately captures the extremes of this variation, which might indicate errors in the streamflow measurements that either inflated the data values at the beginning of the record, or minimized them at the end.

Without knowing where the bias comes from, the model tries to split the difference between the extremes, possibly producing an over-prediction or under-prediction of streamflow that will affect the scenarios through the modeling period of 2050.

To improve the accuracy of the model, and the subsequent decision-making capabilities in the Vjosa system, we recommend implementing several steps in relation to monitoring:

- A thorough review of the operational practices and outputs of all gauging stations in the Vjosa Basin;
- Developing and implementing monitoring, data management, and maintenance plans;
- Devoting specific attention to the frequent revision of the stream conditions at the gauging stations;
- Investment in general maintenance of the equipment and telemetry;
- Increasing quality control of for all produced streamflow and meteorological data; and
- Publishing data publically accessible locations to increase transparency.

In relation to existing data we recommend obtaining the available historic records (1950-1990) and conducting a thorough data quality review so they can be incorporated in models like WEAP as well as other qualitative applications.

With the recently announced Vjosa Basin Commission under the Ministry of Agriculture and a World Bank supported project[7] to develop a water cadaster, we expect to see a great improvement in the quality and availability of information on water demand and use. The Director of Water Policies in the Ministry of Agriculture has announced they are working to install the servers and software in all institutions charged with provide the data. This may start as soon as late January 2017.

In addition to the hydrological data, the current model has many assumptions related to population of tourists and local populations, and how they change over time, as well as water demand and consumption rates, and the seasonality of these demands. For example, the tourism data for Albania is not disaggregated by region, nor are any predictions available for the future, making the tourist population data markedly tenuous even in the Reference Scenario. As another example, future estimates for irrigation data are only available for some catchments, and may be incomplete. This data was used throughout the watershed to study an irrigation expansion scenario, but the accuracy of this information is unknown.

As more information becomes available, the model can be improved to better represent the system and provide more useful and accurate answers about development scenarios in the future.

[7] The World Bank project will focus on the Drin-Buna and Seman River, however they will set a standard procedure to deliver a National Cadaster that could benefit the Vjosa watershed as well.

9.2 Model Development Recommendations

The model has several weaknesses that can be improved through informed assumptions or model restructuring. The following recommendations vary greatly in difficulty to implement, but would all improve the model:

1. The climate simulations for the future scenarios incorporate trends in the future, but not extremes, such as occurrences of dry years or wet years. These extremes are currently best represented in the 10 percentile RCP8.5 scenario records (Drought and HotDrought), which are often the only scenarios that predict water deficits. The Vjosa model will greatly benefit from incorporating annual variations. This could be done by repeating past records and with a delta value multiplier.
2. Better data for the downstream catchments (Lower Basin and the tributary Lumi-i-Shushices) would allow the results for these sections to be evaluated. In the current iteration of the model, the uncalibrated streamflow and assumptions about irrigation, tourism, etc. preclude any assurance of accuracy in the results, and thus they cannot be used for decision-making purposes.
3. To better represent the extreme seasonality of tourist water demand (50% of all tourists travel to Albania in the summer), tourism demand in the Memaliaj, Përmet and Drinos catchments could be moved to a separate demand site with separate monthly variation values.
4. If any information is available about electricity needs or goals for the Poçem reservoir, electricity production goals should be entered in WEAP, either as hydropower priority or energy demand.
5. During the calibration process for the historic irrigation demands, irrigation was restricted to the months June-Sep. Since WEAP calculates the irrigation demands based on the land use parameters, it might better represent seasonal irrigation demands if these restrictions were removed. Before doing so, we recommend obtaining data about the seasonal irrigation requirements in these areas. After removing the restrictions, the irrigation outputs in WEAP will need to be calibrated again to match the observed data, and then three calibrated catchments (Drinos, Përmet, and Poçem) should be recalibrated to accommodate any subsequential changes.
6. Figure 13 shows eight reservoirs on the Vjosa River, including the two in the WEAP model (Poçem and Kalivaç). The six mainstem reservoirs currently not included in the model should be included in the model, and data should be obtained for Kalivaç to allow WEAP to appropriate simulate its influences on the river's flow.
7. Other reservoirs exist on Vjosa tributaries that are not included in the model because gauge stations for these tributaries do not exist and therefore calibration and producing accurate streamflow records are not possible. Were gauge data for these tributaries to become available, it would be possible to model some of the larger reservoirs on the tributaries, where necessary.
8. The currently model simulates surface water runoff and groundwater runoff together as part of the same hydrological system. Not enough is known about the groundwater dynamics in the Vjosa region to model groundwater contributions separately, but perhaps in the future that will be possible. This, or the recommendation to model tributaries above, would also enable modeling springs, which in reality supply many of the demand sites, as opposed to them withdrawing water from the river itself, as the model is currently structured. This could enable representing the shortages that occur on much smaller spatial scales, though it would also require disaggregating the existing demand sites, which represent the domestic demands of entire catchment areas.
9. Many of the water distribution networks lose water from their distribution systems. This can be modeled within WEAP, preferably within disaggregated demand sites. Lost water could, if applicable, contribute to groundwater volumes.

10. A critical vulnerability of the Vjosa basin – flooding – is not currently well-captured in the WEAP model because the time step is too large. If more detailed temporal data were available, it might be possible to study the occurrences and impacts of flood in the Vjosa.
11. Water quality is not currently modeled for the Vjosa basin, although pollution is a problem close to urban areas. Further work could enable the WEAP model to simulate and explore water quality throughout the sections of the river, including the impacts of installing a waste water treatment plant.

Some of these suggestions may be unnecessary to answer the questions that decision makers are currently asking – for example, the aggregated catchment demand sites may be sufficient to estimate demand and examine the benefits of building the Poçem reservoir. All future improvements in structuring should be implemented only when they improve the model's ability to answer questions. This is one of many choices that modelers make as they construct and maintain models.

9.3 Model Dissemination Recommendations

Thus far, the WEAP Vjosa model has been used only within the context of this project to examine hypothetical development scenarios. Now that the model is calibrated and operational, even with the weaknesses described above, it may prove useful to planners throughout the Vjosa Basin. We recommend disseminating the model as broadly as possible, but limiting editing to people who are familiar with the WEAP program.

The staff at IGEME has received extensive training in the WEAP model, and we recommend that they lead any changes in the model. Licenses for WEAP are available to all non-profit, government, or academic users in Albania, and anyone with a license can edit the model, however, IGEWE's staff WEAP experience and understanding suggests that they will best manage any edits.

Therefore, to disseminate the model, we recommend presenting on the model itself, the data, and the results to other organizations within the Vjosa, but then IGEWE can engage with them as they use the model. As such, the WEAP model can be part of a long-term engagement across the Vjosa basin, led by IGEWE.

10. Appendix

A.1 The “zero graph level”

The zero of the staff gauge is meant to coincide with the measurement of zero discharge, however it could be different from the zero gauge (in which there is water in the river, but it is not moving). The zero graph is a benchmark to ensure that the measurements about it refer to the same point. Typically, this benchmark as well as the zero level on the staff gauge should remain in the same position in relation to the river bed over the years. The zero level of the staff gauge should be checked every year to be sure that the measurements are still well referenced to the benchmark.

If there is a change in the benchmark, the historical time series can be affected and should be recalibrated accordingly. The stream gauging measurements normally are conducted once every two months, or less frequently, depending on the year. Recording the gauging measurements each month would produce more accurate data. Daily water level measurements for each station are made manually by an observer employed by the IGEWE, at approximately 7:00 a.m. and 7:00 p.m. The written log is sent to the IGEWE at the end of each month to be processed and archived. During the processing procedure, a daily average water level referenced to the zero graph is recorded for each of the stations and stored in the archive. This benchmark referenced average water level will be used for the discharge conversion to flows.

If the measurements are made in locations with stable conditions in terms of stream bed profile and discharge measurements were made through a range of water level conditions, a relationship between water level and discharge or “rating” curve can be established. However, if the stream morphology changes, an entirely new rating curve needs to be established. Water levels at each station are related to a reference level, which is affected by changes in stream morphology. To account for these potential changes, rating curves would ideally be derived on an annual basis and frequent observations of the condition of the streambed at the gauging station recorded to capture potential changes in cross section over time. For the current dataset, these observations were not available, so the rating curves are based on average stream conditions, which could introduce a significant error in discharge values.

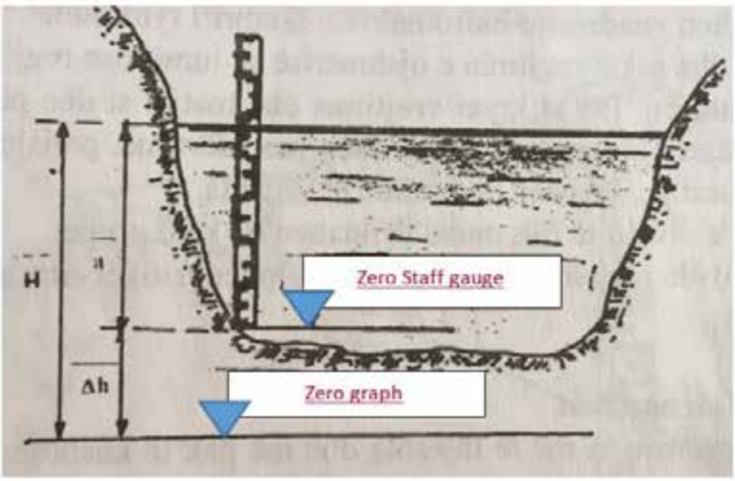


Figure 76. River cross section displaying zero graph and zero staff gauge (Shehu and Karanxha 2003)

A.2 Precipitation data

Although the data seems consistent, substantial gaps in the time series were identified (Table 37. Overview of available and missing periods of precipitation data for the Albanian stations and interpolated using a range of methods Table 38. Note that data outside the time period of 2002-2008 was not estimated because it does not overlap with the availability of the streamflow record, and therefore cannot be used to calibrate the historic WEAP model.

Table 37. Overview of available and missing periods of precipitation data for the Albanian stations

Station	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Brataj	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete
Nivice	Incomplete	Incomplete	Missing Until 12.07	Missing 26.10 -30.11	Missing 01.01-04.02	Complete	Complete	Complete	Complete	Complete
Fratar	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete
Selenice	Complete	Missing 31.11-31.12	Complete	Complete	Complete	Complete	Complete	Incomplete	Incomplete	Incomplete
Krahes	Complete	Complete	Missing 17.11-31.12	Complete	Complete	Complete	Complete	Complete	Complete	Complete
Kuc	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete
Tepelene	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete
Kelcyre	Complete	Complete	Missing 28.02-01.05	Missing 14.01-28.01	Missing 01.01-17.01	Missing 01.01-04.08	Complete	Complete	Missing 01.12-31.12	Complete
			Missing 04.06- 09.10	Missing 08.03-15.11	Missing 28.02-05.10					
			Incomplete	Incomplete	Incomplete	Incomplete				
Llongo	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Incomplete

To generate complete records in WEAP, the missing data was filled with a variety of methods, described in Table 38.

Table 38. Stations, periods of missing precipitation data and method used for data filling

Station	Period of Missing Data	Method for filling in data
Kuç	June 2002	Averages of the other Junes of Kuç record (2003-2011)
Krahës	December 2004	Average of other Decembers of Krahës record (2002-2011)
Selenicë	December 2003	Average of other Decembers of Selenicë record (2002-2008)
Nivicë	January 2006	Average of other Januarys of Nivicë record (2005-2011)
Nivicë	January 2002-December 2004 (3 years)	Average of other years of record for Nivicë (2005-2011), then averaged with the contemporary records of the nearest geographical stations, Kuç and Tepelenë.
Këlcyrë	January 2004-December 2007 (4 years)	Average of other years of record for Këlcyrë, averaged with the contemporary records from the nearest geographical station, Tepelenë. Missing data for Këlcyrë outside the period of interest (06/2009 and 10/2012) used contemporary Tepelenë data in order to be included in the initial averaging process.

A.3 Temperature data

The data quality for temperature historical records for the Albanian side of the basin was assessed using annual graphs to identify missing data or data errors. Missing daily data was interpolated with the average of the previous and posterior date from the missing date before performing the monthly average. If a large amount of data was missing within a month, the average temperature of the month was not performed and afterwards was completed using the following methods Table 39.

Table 39. Methods for filling missing temperature data records

Station	Period of Missing Data	Method for filling in data
Kelcyre	07/2003, 2004-2007	1) Average all other Kelcyre records for each missing month 2) Average that value with value of nearby Tepelene
Selenice	06/2003, 12/2003, 2/2004, 6/2005	Average value for respective months from the rest of the Selenice record
Brataj	06/2002, 07/2002	Average value for respective months from the rest of Brataj record
Kuc	6/2002, 7/2002	Average value for respective months from the rest of Kuc record
Permet	11/2005, 12/2005	Average of respective months in 2002, 2004, 2006, 2007, 2011 of record, averaged with Kelcyre and Polican
Permet	2008	Average of 2002, 2004-2007, 2011 (with gaps filled in previous step) and Kelcyre and Polican 2008
Permet	2003	Average of 2002,2004-2008 (with gaps filled), 2011, averaged with Kelcyre
Polican	2002	Average of Polican 2004-2008, 2010-2011, averaged with Permet (including filled values). This has a noted skew towards data further north in the basin.

A.4 Relative humidity data

Data quality for relative humidity observations was analyzed with yearly graphs and daily data missing was first completed with the average of the previous and posterior date from the missing date. The following exercises enabled the creation of a complete record from 2002-2008.

a) Relative humidity is highly variable based on ambient conditions at the monitoring site and because no reliable relationship could be established (or can even be expected) between the two stations ($r^2 = 0.0297$), we did not use one station to complete the record of another.
b) Instead, for any missing data areas, we took the average of the rest of the record.
   a. Poliçan 2002-2003 = average of the rest of the record (2004-2011)
   b. Përmet November-December 2005 = average of November and Decembers 2002, 2004, 2006-2011
   c. Përmet 2003 = Average of all other values of record (2002, 2004-2011)

A.5 Formulas for model calibration

The calibration uses several indicators to evaluate and improve the initial calibration, using Nash-Sutcliffe Efficiency (NSE), percent bias (PBIAS), root mean squared error to the standard deviation (RSR) and standard deviation (SDR), as shown below. For more information about these equations, see Moriasi et al, 2007.

The Nash-Sutcliffe Efficiency (NSE) coefficient is commonly used in hydrologic modeling to evaluate how well modeled stream flow matches observed:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs} - \overline{Y^{obs}}\right)^2}\right]$$

The percent bias (PBIAS) as a measure of the model's ability to match the total volume of flow

$$PBIAS = 100 * \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}\right]$$

The root mean squared error to the standard deviation (RSR) as a measure of how much the simulated flows deviated from the observed hydrographs

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - \overline{Y^{obs}}\right)^2}\right]}$$

The ratio of simulated versus observed flow standard deviation (SDR) as a measure of how well the simulated flows match the flow variability within the historical record.

$$SDR = \frac{STDEV_{sim}}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{sim} - \overline{Y^{sim}}\right)^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - \overline{Y^{obs}}\right)^2}\right]}$$

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