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Modelling of water allocation and availability in Devoll River Basin, Albania

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ABSTRACT

Albania is experiencing a significant increase in energy demands and insufficient generating capacities. Although Albania has a large potential for hydropower development, only 35% has been utilized so far. The current energy system is highly dependent on fossil fuels and approximately 40% of the energy consumed is imported. Development of renewable energy is one the priorities of the Albanian Government, with hydropower as the main contributor. In 2013, Statkraft AS acquired all shares of the currently developing Devoll Hydropower Project, which comprises two power plants with an expected annual production of 729 GWh. The power plants will be located along Devoll River in the southeastern part of Albania, and will increase the Albanian power production with 17%. Agriculture is the main source of income in the Devoll River Basin and irrigation is of vital importance to the farmers. The construction of the hydropower scheme may lead to conflicts in interests between the power plants and the irrigation schemes.

The purpose of this thesis is to analyze how climate change and irrigation will affect the runoff in the Devoll River, as well as the annual production at the power plants. A hydrologic model of the river basin was developed using the Water Evaluation and Planning (WEAP) software tool. The model includes nine sub-basins and 26 irrigation schemes. PBIAS, NSE and RSR was used to evaluate the calibration performance. The model performs very good with respect to PBIAS, and satisfactory with respect to NSE and RSR. Reservoir evaporation was calculated manually with the Penman-Monteith equation to further assess the water footprint of the power plants. Three scenarios of upstream irrigation was created with the IPCC RCP4.5 climate projection as foundation. This projection assumes an average increase in temperature of 2.4°C, and a reduction in precipitation of 10% from October to March, and 20% from April to September. The model has two major weaknesses: it does not consider groundwater and the hydropower function is too simple for any realistic simulations.

The main finding is that the Devoll River is not strongly affected by climate change. By 2100, the runoff at the outlet may be reduced with 14% compared to 1980-1985. The power production may be reduced with 43.9% due to this reduction in runoff. The upstream irrigation do not affect the global water balance significantly, as most of the demands are unserviceable. If the schemes are rehabilitated and all demands become serviceable, the irrigation demands alone may cause a reduction in the annual runoff of 17.5%. Based on net evaporation, the combined water footprint of the reservoirs is 1.7 m^3/MWh in 2100. Construction of the Banja HPP may provide great supply security for the irrigation schemes downstream of the dam.

SAMMENDRAG

Det er et raskt økende kraftbehov i Albania, men dagens kraftsystem klarer ikke å tilfredsstille behovene. Selv om Albania har et stort potensiale for vannkraft har bare 35 % blitt utviklet så langt. Per dags dato er Albania avhengige av fossile brensler og omtrent 40 % av kraften blir importert. Fornybar energi er et av satsningsområdene til den albanske regjeringen, der vannkraft er hovedsatsningsområdet. I 2013 kjøpte norske Statkraft AS alle andelene i Devoll Hydropower Project. Prosjektet består av to vannkraftverk med en samlet årlig produksjon på 729 GWh som skal bygges langs elven Devoll i den sørøstlige delen av Albania. Begge kraftverkene er for tiden under bygging, og det er forventet at de vil øke den albanske kraftproduksjonen med tilnærmet 17 % når de er ferdigstilt. Jordbruk er hovedinntektskilden til innbyggerne i nedbørsfeltet til Devoll, og følgelig har jordvanning stor betydning for bøndene. Byggingen av kraftverkene i nedbørsfeltet kan potensielt føre til en interessekonflikt mellom bøndene og Statkraft.

Hovedformålet med denne masteroppgaven er å analysere hvordan klimaendringer og jordvanning påvirker avrenningen og kraftproduksjonen i Devoll. Det har blitt etablert en hydrologisk modell av Devoll med modelleringsverktøyet Water Evaluation and Planning (WEAP). Modellen består av ni delfelt og 26 jordvanningsanlegg. Det ble brukt tre kriterier for å vurdere kalibreringen av modellen: PBIAS, NSE og RSR. Modellen presterer veldig bra for PBIAS og akseptabelt for de to andre kriteriene. Fordampning fra magasinene har blitt beregnet manuelt med Penman-Monteith-metoden. Fordamningsberegningene har videre blitt brukt til å vurdere vannforbruket (fotavtrykket) til magasinene. Tre scenarier for utvikling av jordbruksområdene i den øvre delen av nedbørsfeltet har blitt studert. Alle scenariene har fundament i klimascenariet RCP4.5 som er utviklet av FNs klimapanel (IPCC). Dette klimascenariet beskriver en gjennomsnittlig økning i temperatur på 2,4°C, samt en reduksjon i nedbør på 10 % mellom oktober og mars, og 20 % mellom april og september. Modellen har to betydelige svakheter: den mangler grunnvannsmodellering og vannkraftsfunksjonen er mangelfull.

De viktigste funnet i denne masteroppgaven er at Devoll er lite sensitiv for klimaendringer. Innen 2100 kan avrenningen i Devoll være redusert med 14 % sammenlignet med perioden 1980-1985. Produksjonen ved kraftverkene kan være redusert med 43.9 % sammenlignet med den forventede som følge denne reduksjonen i avrenning. Jordbruk i de øvre delene av nedbørsfeltet har ingen stor innvirkning på den årlige avrenningen ved utløpet av elven. Dette er hovedsakelig på grunn av den dårlige forfatningen av jordvanningsanleggene. Hvis jordvanningsanleggene rehabiliteres slik at de kan levere alle forsyningsbehovene vil jordvanning alene kunne redusere den årlige vannføringen i Devoll med 17 %. Basert på netto fordamping vil det samlede vannforbruket til kraftverkene kunne være 1,7 m^3/MWh i 2100. Etableringen av magasinene kan øke forsyningssikkerheten til de nedstrøms jordvanningsanleggende.

PREFACE

This thesis is submitted in partial fulfillment of the requirements set for a Master's Degree in Hydraulic and Environmental Engineering at the Norwegian University of Science and Technology. It contains work from August 2014 to June 2015, and is the work of the author under the supervision of Professor Knut Alfredsen and PhD candidate Tor Haakon Bakken.

The model established in this work is the author's first experience with developing a hydrological model from scratch. It has been a significant learning experience and immensely rewarding in terms of the knowledge gained about hydrological modeling. Climate change is one of the greatest challenges of this century. It is both interesting and meaningful to be able to work with topics related to water resource management and climate change. I hope the model developed in this work and the report will provide useful information about the Devoll River Basin and form a basis for further studies.

This work would not have been possible without help from many people. Firstly, I would like to thank Tor Haakon Bakken for his excellent guidance. You have been an inspiring and encouraging supervisor that have been available whenever needed. I would also like to thank Professor Knut Alfredsen for all his help with technical and formal matters, and for answering emails on late Sunday nights. Thanks to Siri Stokseth at Statkraft for allowing me to use the Devoll River Basin as a case study location and giving me a valuable and inspiring field trip to the Devoll River Basin. Thanks to Pål Høberg and Snorre M. Mossing at Statkraft for providing me with all the background information needed to build the model. Thanks to Erjon Kalaja and Agim Lazareni at Devoll Hydropower for invaluable information about irrigation practices and general conditions in the Devoll River Basin. I would also like to thank Marisa Escobar and Nilo Alberto Lima at the Stockholm Environmental Institute U.S. Center for helping me with the calibration of the model. Lastly, I would like to thank Chanatip Manomaiphan for helping me proofread the report.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

More than 70 % of the Earth is covered by water. The hydrosphere contains approximately 1.36 billion km^3 of water, of which 35 million km^3 is freshwater. Two thirds of the freshwater is stored in ice caps and glaciers, while the rest is available in liquid form for human use. Water is neither obtained nor lost from the hydrosphere, but continually recycled as it moves from one area to another via precipitation, condensation, evaporation, deposition, runoff, infiltration, sublimation, transpiration, and melting and groundwater flow.

Water is a necessity for human life, without water we will not survive. Over the past 50 years, human water use has more than doubled and affected streamflow over various regions of the world (Wada et al., 2013). Several countries and regions are experiencing water stress due to population growth and an increasing economic development. Climate change caused by anthropogenic green house gas emissions is one of the great challenges of the 21st century, which is expected to further increase water consumption and the pressure on existing freshwater resources (IPCC, 2012). Our future generations will suffer if this alarming trend is allowed to continue and actions are not taken.

Climate change may be mitigated by transforming fossil-fuel based energy systems into renewable systems. The IPCC Special Report on Renewable Energy (IPCC, 2012) presents the most important renewable technologies and their potential for replacing the energy systems based on combustion. Further, the report benchmarks each technology with respects to a set of criteria, including the amount of water consumed in the process of producing 1 MWh, often referred to as the water footprint. Most of the technologies considered in the report had water footprints of 1-5 m^3/MWh, while numbers on hydropower were sparse and appeared inconsistent with reported values up to a maximum of 209 m^3/MWh. These numbers were later criticized as they only take into account the water lost from reservoirs due to evaporation, and do not consider the benefits of the reservoirs (Bakken et al., 2013).

For centuries, reservoirs have played an important role in human development, and has been used to secure water for irrigation and drinking water supply, as well as providing flood protection and water for hydropower production. Integrated water resources management policies and supply systems will be necessary to maintain the health of aquatic ecosystems, and ensure a sustainable and efficient use of freshwater resources in the future. The purpose of this thesis is to analyze how reservoirs will affect water consumption and availability for hydropower production and irrigation. Devoll River Basin in Albania is used as a case for the thesis, where agriculture is the main source of income and irrigation is of vital importance during the summer months.

The Norwegian power company Statkraft AS, is developing and constructing two reservoirs and hydropower plants in this area with an expected combined annual production of approximately 729 GWh. The power plants are located along the Devoll River and are expected to be completed in 2016 and 2018.

One of the main tasks is to develop a hydrological model of the river that is adequately calibrated. The model was developed with the Water Evaluation and Planning (WEAP) tool, and has been used to study the effects of climate change, irrigation and construction of the reservoirs on the water balance within the catchment.

2 DESCRIPTION OF THE STUDY AREA

This chapter describes the area used for the case study and is essential for understanding the structure of the model and some of the assumptions and choices made in the next chapters. The first part is an introduction to Albania, and the second part is a description of the Devoll River Basin including its climate and hydrology, agriculture and irrigation schemes, the Devoll Hydropower Project, and hydrometric data received from Statkraft. Most of the work in this chapter is based Devoll Hydropower Project feasibility study reports and material received from Statkraft.

2.1 Albania

Albania is located in the southeastern part of Europe at the Balkan Peninsula, bordering to Montenegro in the north, Kosovo in the northeast, Macedonia in the east and Greece in the south and southeast. The west of Albania is a 362 km long coastline on the

Figure 2.1 *Albania (Shundi, 2006)*

Adriatic and Ionian Sea. Albania is a small country with an area of approximately 28,750 km^2. According to the Albanian Institute of Statistics (INSTAT), in 2011, its land area consisted of 43% forest, 24% arable land, 18% pastures and meadows, and 15% unproductive land, including urban areas, water bodies and unused rocky and mountain lands. Albania has a population of slightly more than three million people, 445,000 of which lives in the capitol Tirana. The topography of Albania is very diverse and has great spatial variability. Approximately 75% of the total land area is hilly and mountainous, and the mean altitude is 708 m above sea level (m.a.s.l.), which is double the European mean (Shundi, 2006). Lowlands and plains are found along the coast and in the south at altitudes between 0 to 200 m.a.s.l. and between 100 and 900 m.a.s.l. is the hilly zone stretching north to south with river valleys crossing east to west. Above 900 m.a.s.l. is the mountainous zone that extends from north to south with its peak at Korabi Mountain, 2,751 m.a.s.l..

2.1.1 Climate and Water Resources

Albania is located between two climatic areas: the Mediterranean coastal zone in the western lowlands and the Continental internal zone in the eastern mountains and hills. Combined with a diverse topography, this results in greatly varied climatic conditions when in one area to another. The climate is in general characterized by warm and dry summers, and cool and wet winters. Mean annual temperatures range from 16°C at the coastal lowlands to 8°C in the mountains. Albania is generally rich in water resources but there is great variability both in the spatial and temporal distribution of the annual precipitation. The driest areas are in the southeast and the wettest in the north with annual precipitation of 600 mm and 3,000 mm, respectively. Mean annual precipitation over Albania is about 1 485 mm, and more than 80 % of the annual total falls during the cold period from October to March (Porja, 2014).

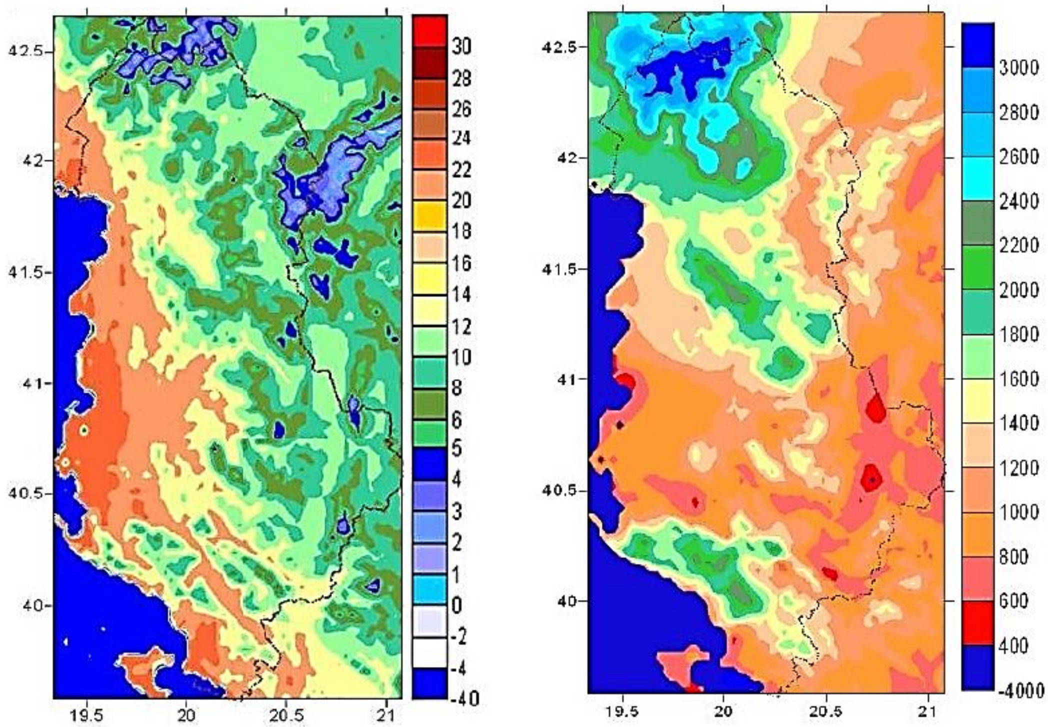

Figure 2.2 *Distribution of mean annual temperature and precipitation (Porja, 2014)*

The annual precipitation corresponds to a volume of 42.7 billion m^3 of water of which 30.2 billion m^3 are estimated as available renewable water resources. This is equal to more than 9,500 m^3 renewable water resources per capita per year. Snowfall is common during winter with low-lying areas receiving a few centimeters, whilst the mountainous regions experience considerable amounts.

2.1.2 Agriculture and Irrigation

Agriculture began in very ancient times in Albania and still provides the income base for most of the population (Shundi, 2006). It accounts for almost 30% of the GDP and more than 50% of the labor force works in agriculture and related fields (Norconsult, 2011a). Arable land accounts for 24% of the total land area of Albania, equating to an area of 690,000 hectares. During the socialist regime, the amount of arable land increased substantially mainly due to pasture and forest conversion and land reclamation. By 1990 there were 550 Government and collective farms with a total area of about 550,000 hectares of arable land. After the collapse of the socialist regime in 1991, the agricultural sector has changed radically. The 550,000 hectares of Government and collective farms were redistributed and broken up into small family farms. Today there are about 400,000 peasants owning pieces of land less than 1.2 hectares each, which are further fragmented into different plots of land. Approximately 25% of the arable land has gone out of production and only a small number of farms practice a more intensive agriculture aiming to produce for the market.

Irrigation is of great importance to the agricultural sector as less than 20 % of the annual precipitation falls between April and September. Between June and August, a crop water deficit of more than 400 mm builds up and makes irrigation necessary for the summer crops. During the socialist era, an extensive network of irrigation schemes was constructed. The coverage of the schemes peaked by the mid-1980s, servicing about 80% of Government farms and cooperatives. All of the irrigation schemes were based on utilization of surface water resources, including reservoirs, runoff river storage and pumping stations. In total, there were more than 600 pumping stations and about 640 dams constructed to supplement the irrigation demand. Most of the dams are of minor size placed on small rivers and streams, but some are off-river and water is transferred by either diversion, pumping, or both. Drainage was also provided, mostly within the perimeter of the irrigation schemes and often linked to flood protection embankments.

The irrigation and drainage schemes are designed in a grid pattern comprising primary, secondary and tertiary canals. Primary canals follow the contours of the area, secondary canals are aligned with the slope and are usually perpendicular to the primary, and tertiary canals are always perpendicular to the secondary and run across the slope. Minor schemes such as hill schemes were not constructed in such a rigid pattern and were usually based on the topography at site. Approximately 70% of the canals are unlined. The irrigation system controls are rudimentary, commonly without cross-regulators in the main channels and simple vertical slide gates on the secondary canal off-takes. The design of the irrigation system is based on a hydro module between 1.0 and 1.2 l/s per hectare, i.e. a command area of 100 hectares has a supply system with a capacity between 100 and 120 l/s. The canals are assumed to operate 24 hours a day, seven days a week delivering a minimum irrigation efficiency of 50%. This will meet the irrigation demands during the peak in summer (July and August) for a maximum irrigation intensity of 70%. In total, the irrigation and drainage schemes covered an area of about 424,000 and 278,000 hectares, respectively.

The irrigation practices today do not reflect the activities that once existed. Most of the irrigation infrastructure was vandalized shortly after the fall of the socialist regime in 1991. Through the 1990s, maintenance was almost totally neglected, and as a result a significant number of the irrigation and drainage systems have deteriorated and fallen into complete disrepair. Pump stations are either destroyed, removed or non-operational. The unlined irrigation canals need re-sectioning and cleaning, while lined canals suffer from disintegration of concrete and stolen lining slabs. Drainage canals are congested with silt, weeds and rubbish. Control structures are rusted, damaged and non-operational which has overall resulted in a seriously affected and reduced irrigation service. In addition, some drainage areas have problems with flooding due to inadequate drainage capacity. According to FAO, the total area equipped for irrigation was 337,600 hectares in 2013, of which 205,300 hectares were actually irrigated. This is less than half of the area that was irrigated in the 1980s.

2.1.3 Energy Sector

It may be suggested that Albania is heading towards a global energy crisis. There have already been incidents of local energy crises with some areas experiencing power cuts during the peak in demand during winter. The demand for electrical energy is increasing significantly in Albania and present generating capacities are insufficient. On average, the annual demand is about 7.0 TWh whilst production is almost 4.4 TWh (AEA, 2014). Albania is therefore highly dependent on importing electric energy to meet domestic demand. The Albanian energy system is completely based on hydropower. Although Albania has a large potential for hydropower, only 35% of this potential has been developed. The current system comprises seven large and 70 small hydropower plants with a combined capacity of 1466 MW (AEA, 2013). Only 38 of the small hydropower plants are in operation. A fully developed potential corresponds to a total installation of 4,500 MW and an annual production of approximately 16 TWh. Albania's dependence on energy imports is expected increase even further as the demand continues to grow. Consequently, the Albanian Government has recognized the current situation and has set development of the energy sector as a priority, focusing on development of renewable energy. Hydropower will be the main contributor and play an important part in the future development of Albania. In 2006, the Law on Concessions in the hydropower sector was approved and according to the Albanian Small Hydropower Association, by 2013, there were 83 concessions approved by the Ministry of Council, with a total capacity of 980.6 MW and annual production about 3.8 GWh.

2.2 Devoll River Basin

The Devoll River is the main tributary of the Seman River and is located about 70km southeast of Tirana. The river basin has an area of approximately 3,140 km^2 and stretches from the border of Greece to the east, to the confluence with the Seman and Osum Rivers in the west. At the confluence, the Devoll River changes its name to the Seman River. There are several tributaries joining Devoll along its course and the biggest is the Tomorrice River. The catchment lies within a mountainous region with a greatly diversified topography. In the first part of the basin, the river runs through the Korce plateau whilst downstream of Maliq, the river enters a wide valley with smooth flanks. West of Lozhan the valley narrows into a V-shaped gorge, where only a few places widen and form smooth slopes. This area is surrounded by an alpine landscape with mostly narrow valleys and high peaks up to an altitude of 2,100 m.a.s.l, which continues until Kokel. Between Kokel and Kozare, the river valley opens up and becomes increasingly smooth with a riverbed consisting of large sediment deposits. The mean elevation of the catchment is about 960 m.a.s.l. with altitudes ranging from 22 to 2386 meters.

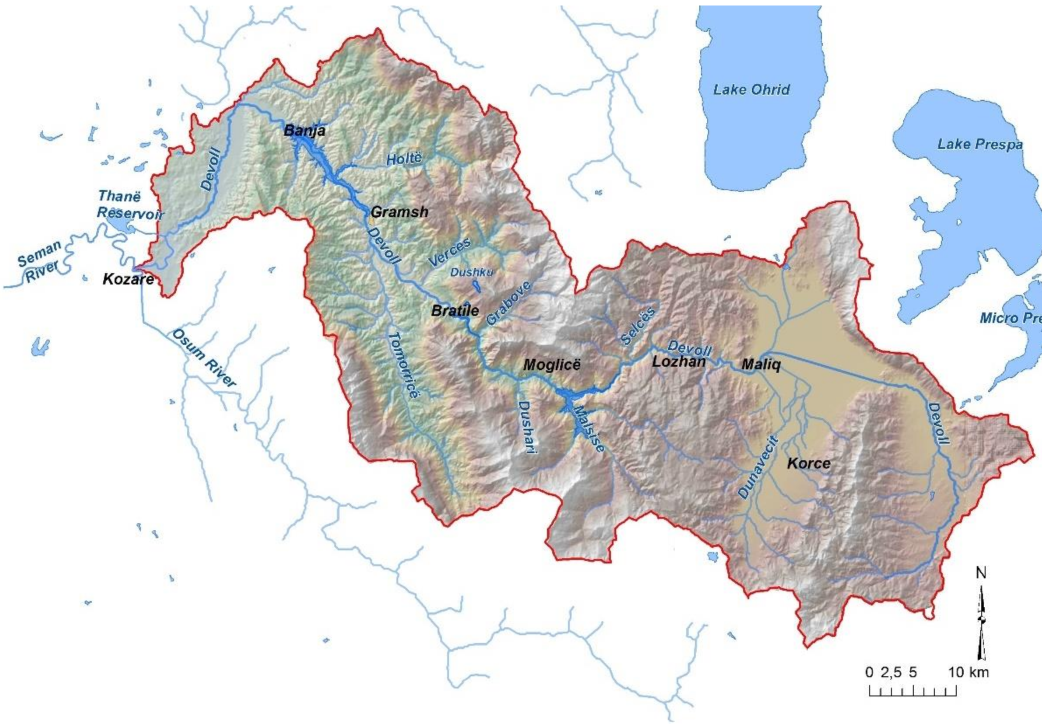

Figure 2.3 *Devoll River Basin (Norconsult, 2011a)*

2.2.1 Climate and Hydrology

The climate is greatly varied within the catchment and it is generally characterized by dry summers and wet winters. January is the coldest month and July is the hottest with the mean annual temperature varying from 7.5°C in the upper reaches to 14.7°C in the lower part. The topographic conditions and the distance from the coast heavily influences precipitation and precipitation consequently varies greatly from one area to another. The upstream part of Devoll has the lowest amount of precipitation in Albania with 600 mm a year in comparison to the upper parts of the basin, the mountainous part in the middle of the catchment, receiving considerably higher amounts. The precipitation regime is typically Mediterranean, which is characterized by an annual maximum in November and minimum in August, whilst a second maximum appears around May. Precipitation intensities are in general low. Snowfall is common during winter and may even occur in October and April. Snow cover days vary from about 90 days in the upper parts with a maximum depth of 100cm, to 30 days in the lower parts with a maximum depth of 20 cm. The observed maximum is 2 meters. The flow regime of the Devoll River and its tributaries is determined by precipitation and snowmelt. Abundant precipitation causes a flow maximum around November, while the second maximum around May is caused by snowmelt. The great variability in climatic conditions within the catchment is reflected by the specific runoff. Some sub-catchments have a specific runoff that is equal to more than four times the amount of another sub-catchment. Irrigation water withdrawals have had and still have an enormous impact on the natural flow in the Devoll and the tributaries.

2.2.2 Agriculture and Irrigation

The work in this section is primarily based on the Devoll Hydropower Project ESIA Report, Appendix K: *"Irrigation Benchmarking Report"*. Agriculture is the backbone of the economy and the main source of income for the majority of the population within the basin. Land is cultivated wherever possible by local farmers, and most of the produce is for either domestic purposes or sale at local markets. Typical crops are wheat, maize, vegetables, deciduous fruit, vines, alfalfa, tobacco and olives. Just as for the rest of Albania, irrigation is of significant importance for the agricultural activity within the basin. There is a complex network of irrigation and drainage infrastructure within the basin. Government farms and cooperatives systematically regulated agriculture prior to 1990. The irrigation and drainage infrastructure comprised Government pump schemes, village based gravity schemes, channels, barrages and reservoirs. Present activities do not reflect the practices that once were. A lot of infrastructure has fallen into various states of disrepair. This is due to vandalism and neglect, but also because the family farms lack capacity and funds to undertake the required maintenance. The irrigation can be divided into three areas within the basin, namely the area upstream of Maliq, the area between Maliq and Banja Dam, and the area downstream of Banja Dam. Figure 2.4 shows the some of the irrigation infrastructure within the catchment. The red triangles represent different control

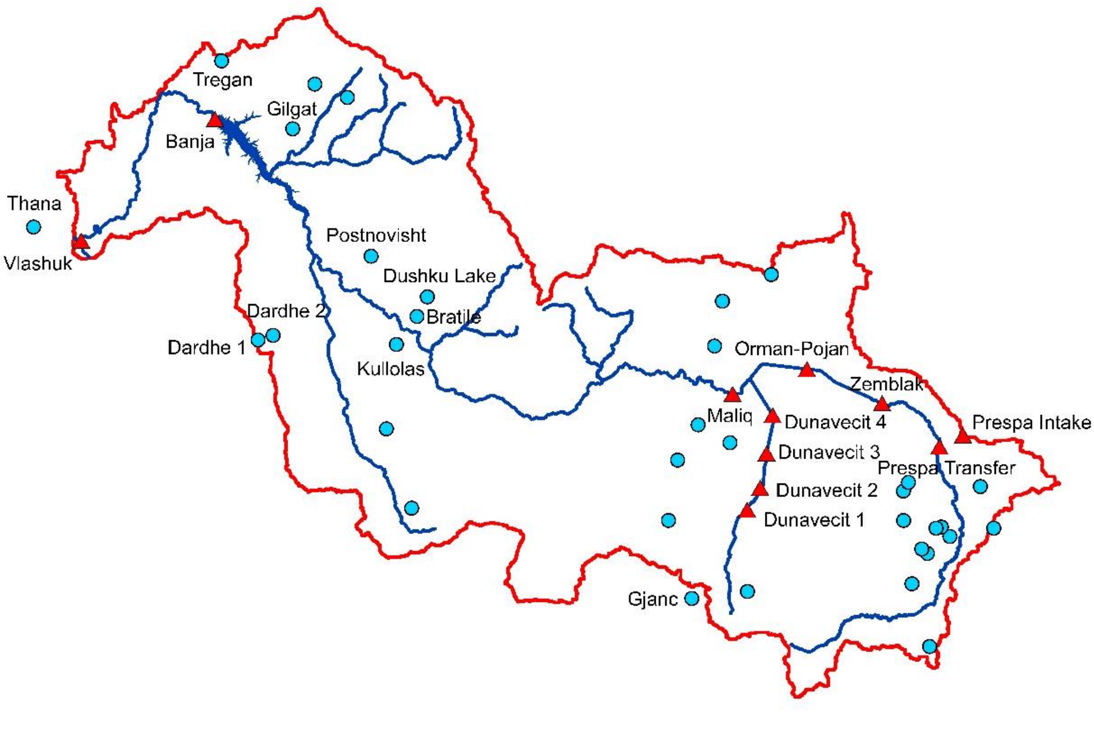

Figure 2.4 *Control structures and reservoirs in Devoll River Basin*

structures, while the blue circles are reservoirs. Some of the reservoirs are unnamed and thereby are unknown but found by visual inspection using Google Earth.

Irrigation Upstream Maliq

The Korce District and Korce Plateau was once an important agricultural area that was extensively cropped by Government farms and cooperatives. It lies at an altitude of 800 m.a.s.l. surrounded by hills and mountains, and has an arable land of 49,100 hectares. Originally, the area was set up for beans, sugar beet and sunflower cultivation. Today, typical crops are maize, alfalfa, vegetables, wheat and fruit trees, and the production is primarily for domestic consumption. There are several major irrigation structures and the most important are the Prespa Canal Scheme, Gjanc Reservoir, and seven control structures placed along the Devoll and the Dunavecit.

The five kilometers long Prespa Canal Scheme is a structure of special interest. It once connected Little Prespa Lake with the Devoll River. The canal utilized the little difference in elevation between the intake at Devoll (852.2m) and the outlet at Prespa (850.2 m), and transferred water from the river to the lake during periods of high flow levels. During periods of low flow in Devoll and high irrigation demands, the outlet at Prespa was opened and the flow in the canal was reversed. The canal crossed Devoll through a siphon and water was transported further to Zemblak and eventually to the hills to the southwest towards Korce city. Construction of the canal started in the 1980s and its design command area was 6,500 hectares. The initial capacity of the canal was 6 m^3/s but in 1990 the capacity was increased to 11 m^3/s. Operation of the canal stopped shortly after the capacity was increased due to objections from the Greek Government. The Prespa Scheme has not been operated since.

There are three barrages along Devoll River upstream of Maliq. Zemblak barrage is the largest and located northeast of Korce city. It has four main gates and two canal intakes, and a storage capacity of 800,000 m^3 servicing 3,500 hectares to the north and 3,300 hectares to the south. Orman-Pojan barrage lies about nine kilometers downstream of Zemblak and captures whatever water Zemblak does not hold. Maliq barrage supplies a low-lying area of 5,300 hectares in the immediate northeast of Maliq, where 45% of the area is currently irrigated, 45% only rainfed and the remaining10% constantly waterlogged. The bottom level of Devoll River at Maliq barrage has been dredged and deepened at three different stages to provide better drainage of the low-lying area. All three barrages were constructed in the late 1940s and early 1950s. During the irrigation season, the gates were closed for two to three months providing temporary storage for the irrigated areas nearby. Maliq and Orman-Pojan were also operating in conjunction to provide a gradient for better drainage of the lands.

Table 2.1 *Gravity schemes in the Upper Devoll River*

Scheme Name	Design Capacity (m^3/s)	Command Area (ha)	Operational Status
Miras	0.200	250	Rehabilitated 2008
Poncare	0.350	300	Rehabilitated 2008
Menkulas	0.250	250	Rehabilitated 2008
Dobranj	0.300	400	Yet to be completed
Proger	0.200	150	Not operational

The status of Zemblak and Orman-Pojan is not known but Maliq is reportedly out of function, as the gates are unserviceable. There exist five gravity irrigation schemes upstream of Zemblak. Table 2.1 shows their command area, capacity and status.

The Dunavecit River is highly regulated and has four control structures along its course before the confluence with Devoll. Three of them are barrages with a single gate, and the fourth and main structure is a set of control gates. The command areas they once serviced are unknown and all of them are currently in poor condition. Close to the Dunavecit spring, approximately 15km southwest of Korce city, lies Gjanc Reservoir. The reservoir provides off river storage and has a command area of 6,050 hectares. It was constructed in the 1970s and has suffered from neglected maintenance since 1990. By 2005, it was reported that it was unable to service more than 30% of its original command area (Norconsult, 2011a). There exist a number of private irrigation schemes in addition to the formal scheme on the Devoll and Dunavecit Rivers and their tributaries. Figure 2.4 shows many small and private reservoirs adjacent to the rivers. Some farmers have developed irrigation systems based on shallow lift pumps and groundwater.

According to INSTAT, the irrigated area within the Korce District was 22,250 hectares in 2011. There is still considerable agricultural activity in the area but the current situation does not reflect the levels of usage in the past. Most of the schemes that are operable have been rehabilitated with investment from projects by the World Bank. There are increasing investments and reforms in the area and it is reported that additional reservoirs are planned on the tributaries of the Devoll. In light of continued reforms, increasing investment and planned schemes, it is likely the assumption that the irrigation demand will increase in this area is well founded.

Irrigation between Maliq and Banja

Two drainage boards cover the area between Maliq village and Banje village. Elbasan Drainage Board covers the area from Banje to Grabove River and Korce Drainage Board covers the area from Grabove River to Maliq. The irrigation system consists primarily of past Governmental pump schemes and village based gravity schemes. In total, there are 50 pump schemes in the area and none of them currently in operation. 39 of the schemes have been removed or destroyed and 11 are not used due to high operational costs. A full list of the pump schemes, their locations and capacities is found in appendix D. The combined capacity of the pumps are 2.962 m^3/s. It is reported that the village based gravity schemes have a total command area of 4,500 hectares and intake capacities are typically 0.010 to 0.015 m^3/s. The water sources for these schemes are combination of springs, streams, reservoirs and rivers, including Devoll River and its tributaries. In total, Devoll River accounts for about two thirds of the sources. The largest gravity scheme is the Valamara Canal, also known as the Snosem Scheme. It diverts water from Grabove River and transfers it 11 km to the natural reservoir at Dushku Lake. Dushku Lake is also connected to Bratile Reservoir. The Valamara Canal has a capacity of 0.3 to 0.4 m^3/s and Dushku Lake delivers water to 150 hectares of irrigated land through the Snosem Scheme. Bratile Reservoir also delivered water to a siphon with a design flow of 0.6 m^3/s, which transferred water across Devoll River and 10 km away to the Tomorrice Valley. The siphon is severely damaged and has not worked since 1997. Figure 2.5 shows a picture of the siphon taken during a field trip to the area in February 2015. The picture is taken where the

Figure 2.5 *Former siphon pipeline from Bratile Reservoir. Photo: Christian Almestad*

siphon crosses Devoll River at Kokel. It is clear that the siphon is severely damaged. The Snosem Scheme was rehabilitated in 2006 through a World Bank project. It is not likely that the 50 Governmental pump schemes or the siphon will be rehabilitated and put back into operation, as it is a very demanding and costly task.

Irrigation Downstream Banja Dam

The Banja Dam lies about 14km west of Gramsh. Construction of the dam started in the 1980s and stopped in 1990 with collapse of the socialist regime. The intended purpose of the dam was for flood protection and irrigation. Since 1990, the dam has acted as a flood buffer with flow rates limited by the bottom outlet. It remains unfinished to this day. The area below Banja Dam is the central coastal plains, which represent the important agricultural districts of Lushnje and Fier. Crops in these areas are highly dependent on irrigation during the summer months and there a complex network of irrigation and drainage systems in these areas. In total, Lushnje and Fier have 108,100 hectares of arable land of which 76,000 hectares are irrigated (Norconsult, 2011a).

Thana reservoir is the most important source for irrigation in Lushnje and Fier, and it services Lushnje and Fier by 70 % and 30 %, respectively. It was constructed in 1959 and has a storage capacity of 66 million m^3 and as a surface area of $85km^2$ though a third of the storage capacity has been lost due to sedimentation. Vlashuk Barrage lies about 25km downstream of the Banja Dam. Some sources suggest it was constructed in 1959, while others other suggest 1976. It is the largest control structure on the Devoll River, downstream of Banja and its purpose is to divert water from Devoll River to Thana. The Vlashuk Canal and its intake is integrated into the barrage. It is about five km long and has a capacity of 60 m^3/s. The barrage and the canal have recently been rehabilitated under the World Bank Water Resources Management Project and is in good operational condition (Norconsult, 2011a). In addition to the Thana Reservoir and Vlashuk Barrage and Canal, which are the most important irrigation structures downstream Banja, there are a few canal and pump schemes immediately below Banja Dam. Their location, command areas and capacities are listed in Table 2.2.

Table 2.2 *Canals and pump schemes downstream Banja Dam*

Name	Design Capacity (m^3/s)	Command Area (ha)	Location	Comment
Banje-Shkumbin Canal (15.0 km)	20.00	-	Adjacent to Banja bridge	Transfers water to Shkumbin River
Soluva Canal (13.6 km)	1.00	1420	2 km down-stream Banja	Combined with 5 pumps, not operational
Cartalloz Canal (6.0 km)	0.60	560	5 km down-stream Banja	Not operational
Banja Pump (2.0 km)	0.15	150	Adjacent to Banja bridge	Not operational
Shitepanj Pump (4.0 km)	0.15	150	0.5 km down- stream Banja	Not operational
Floq 2 Pump (10.0 km)	0.05	50	0.5 km down- stream Banja	Not operational
Leproze Pump (2.0 km)	0.10	90	2 km down- stream Banja	Not operational
Devoll Pump (1.0 km)	0.26	200	3 km down- stream Banja	Not operational

The canals are generally in poor condition. Soluva is dependent on the five pumps that are not functioning, while Banje-Shkumbin and Cartalloz are in disrepair. Furthermore, all pump schemes are in poor condition and not operational.

2.2.3 Devoll Hydropower Project

In 2008, the Norwegian power company Statkraft AS formed a 50/50 percent joint venture – Devoll Hydropower Sh.A. (DHP), with the Austrian-based power company EVN AG. In December the same year, a Concession Agreement (CA) was signed with the Government of Albania, giving DHP the right to utilize the hydropower potential in the Devoll. In 2013, Statkraft acquired all the shares in DHP and is now the sole owner of the company and the construction project. The hydropower project consists of two hydropower plants (HPP), Banja and Moglicë, which utilize a head of 555 meters between 95 and 650 m.a.s.l.. Banja and Moglice are scheduled to be finished in 2016 and 2018, respectively, and is anticipated to increase the Albanian electricity production by almost 17 percent.

Banja HPP, with two Francis turbines, a total installation of approximately 70 MW and an estimated annual production of 254 GWh, is the first step in the development. The dam is based on the existing Banja Dam and will be an embankment dam with an impervious clay core, at a height of 80 meters and between 95 and 175 m.a.s.l.. Its highest regulated water level (HRWL) will be at 175 m.a.s.l. and the lowest regulated water level (LRWL) will be at 160 m.a.s.l.. The reservoir will have a storage capacity of about 400 million m^3 and a surface area of about 14 km^2. Moglicë HPP is the second step in the cascade and will be the biggest power plant of the project, located almost 50km upstream Banja HPP. The dam will be a 150m high asphalt core rockfilled dam with a surface area of approximately 7.2 km^3 and a storage capacity of approximately

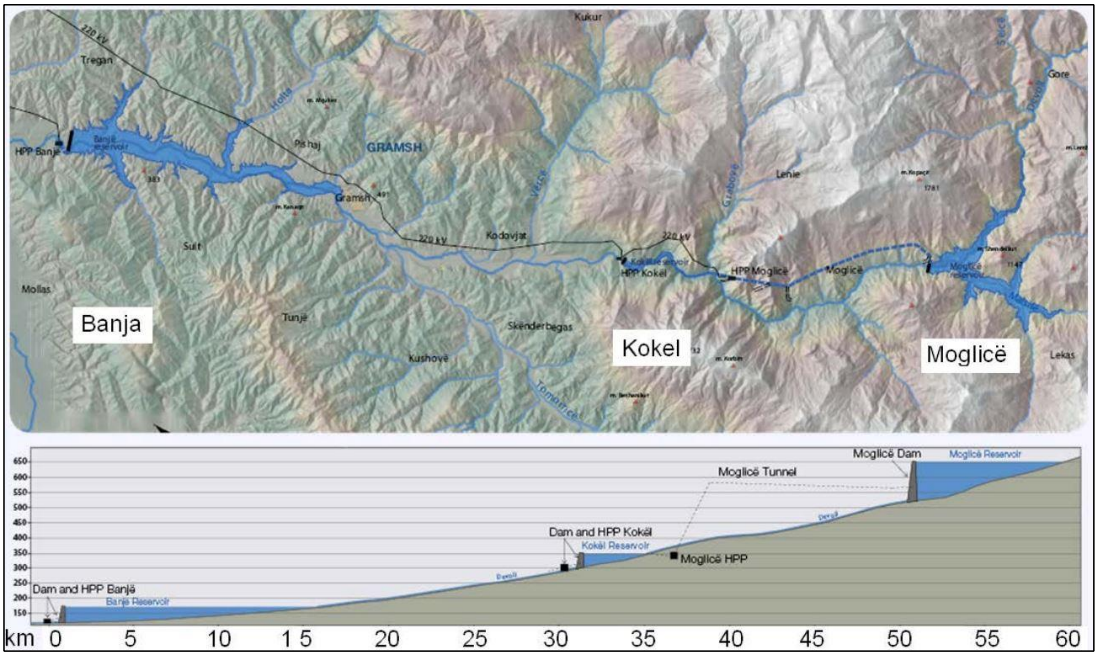

Figure 2.6 *Devoll Hydropower Project scheme (Norconsult, 2011b)*

360 million m^3. Moglice HPP will be constructed inside a cavern and receive water from the reservoir through long tunnel running almost 11 km long. This allows the power plant to utilize a head of 300 meters between 350 and 650 m.a.s.l. The power plant will have an installation of approximately 173 MW distributed on two Francis turbines, with a total and an annual production of about 475 GWh. Kokel is the third step in development sequence of DHP, and its investment decision will be considered after the completion of Banja and Moglice. Figure 2.6 shows the DHP scheme.

2.2.4 Hydrometric Stations

The data series presented in section was received from Statkraft. The series are of daily resolution, and include precipitation data from 20 meteorological stations, temperature data from one meteorological station and runoff data from 10 gauging stations. The earliest observations are from 1950 and the latest are from 1999. R Studio and Microsoft Excel have been used for calculations and graphical representation.

Precipitation

Figure 2.7 shows the location of the meteorological stations. The mean annual precipitation has been calculated for each station based on all the complete years in the observed data series. Table 2.3 lists the stations from east to west and their mean annual precipitation. It is evident that there are strong geographical variations and a significant east-west gradient in the precipitation. Figure 2.8 and Figure 2.9 show the annual precipitation for Sheqeras and Grabove, a dry and a wet area. The dotted lines represent the linear trends and the solid lines represent the 10-year moving averages. Both figures show great variation between years and that there is a decreasing trend in the annual precipitation. Studying the rest of the stations reveals this trend is similar for all stations, except Maliq and Pojan. This may be explained by the fact that Maliq and Pojan do not have observations after 1981. However, the length of the time series is too short to form any general conclusions about the long-term trend.

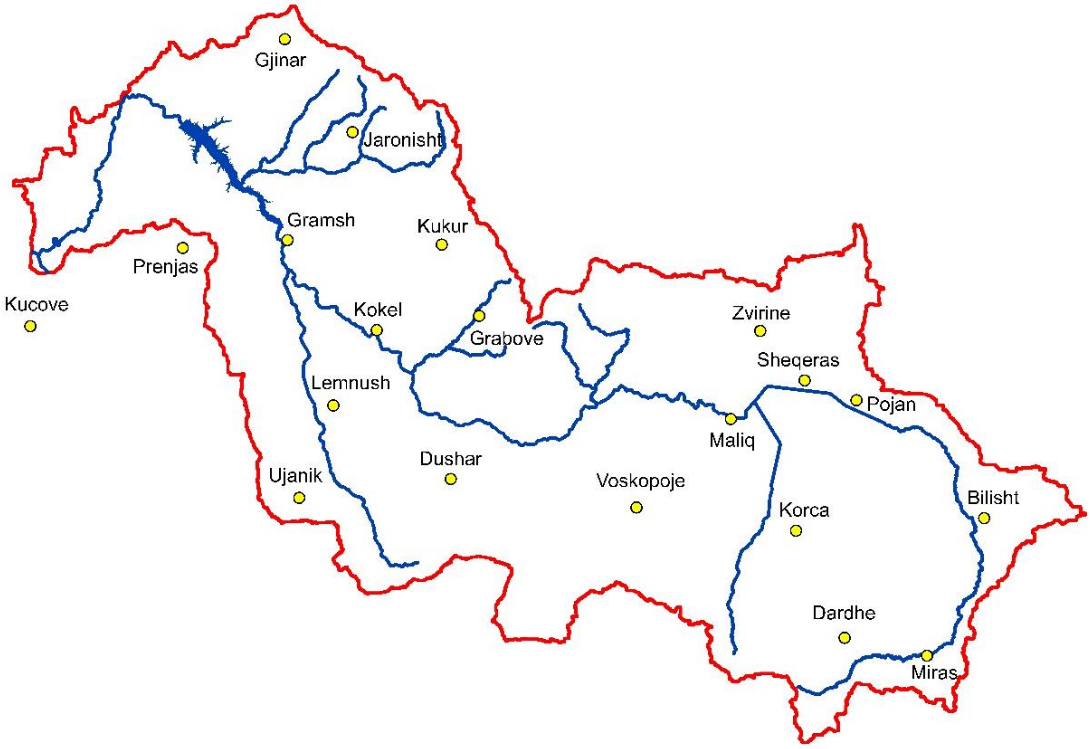

Figure 2.7 *Meteorological stations in Devoll River Basin*

Table 2.3 *Meteorological stations in Devoll River Basin*

Weather Station	Recorded Period	Complete Years	Location		Elevation (m.a.s.l.)	Annual Precipitation (mm)
			Latitude	Longitude		
Bilisht	1950-1994	40	40 37 26	20 59 20	896	660
Miras	1961-1992	29	40 30 14	20 55 25	1050	821
Pojan	1950-1961	9	40 43 36	20 50 33	823	919
Dardhe	1950-1998	42	40 31 10	20 49 46	1310	1001
Sheqeras	1953-1999	46	40 44 38	20 46 59	817	603
Korca	1950-1994	40	40 35 46	20 46 25	899	660
Zvirine	1950-1991	35	40 47 13	20 43 55	825	681
Maliq	1950-1981	30	40 42 36	20 41 59	830	732
Voskopoje	1950-1999	46	40 37 57	20 35 27	1180	945
Grabove	1950-1998	42	40 47 56	20 24 34	1250	1272
Dushar	1950-1992	34	40 39 23	20 22 41	830	1332
Kukur	1950-1994	38	40 51 39	20 21 57	800	1236
Kokel	1961-1992	30	40 47 09	20 17 31	300	1007
Jaronisht	1950-1995	39	40 57 30	20 15 44	834	1292
Lemnush	1950-1993	41	40 43 11	20 14 34	600	969
Ujanik	1957-1994	24	40 38 20	20 12 17	1228	1320
Gramsh	1950-1991	36	40 51 59	20 11 19	200	1095
Gjinar	1950-1992	37	40 02 20	20 11 00	815	1870
Prenjas	1950-1992	41	40 51 21	20 04 06	500	1175
Kucove	1950-1994	44	40 47 10	19 53 40	32	863

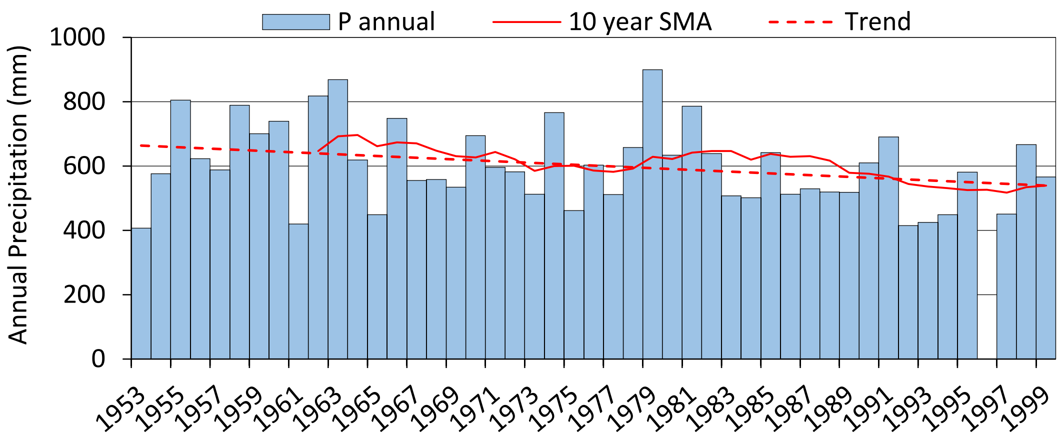

Figure 2.8 *Annual precipitation at Sheqeras*

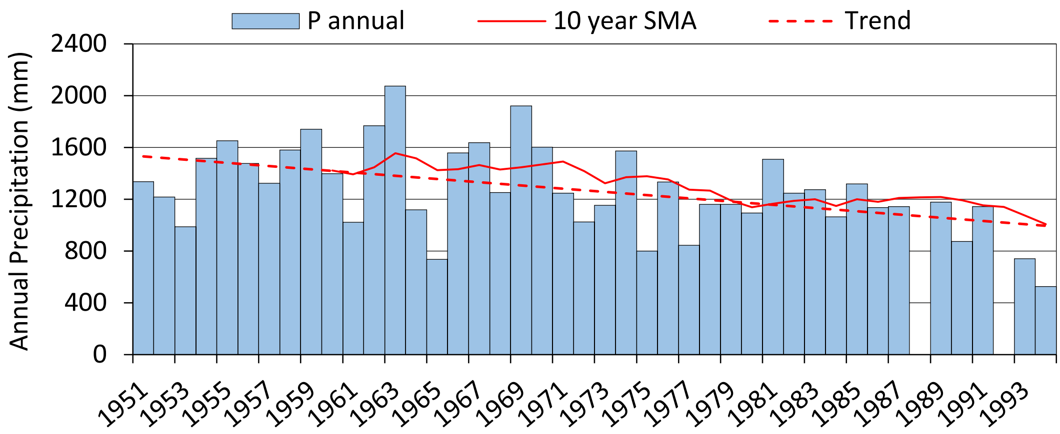

Figure 2.9 *Annual precipitation at Grabove*

Porja (2014) studied the climate in the Devoll River Basin between 1950 and 2012. The study included 14 of the stations. It was found that all locations show a decreasing trend in annual precipitation and number of precipitation days. The same trend was also observed for precipitation during the warm months. The cold months showed a decreasing trend in the eastern part, but an increasing trend in the western part. One important part of precipitation is snowfall. Porja (2014) found that both maximum depth of snow cover and number of snow cover days have decreased in the whole catchment.

Temperatures

The only time series available for temperatures are at Bilisht. Bilisht station has an elevation of 896 m.a.s.l. and lies in the very east of the catchment which does not necessarily make it representative of the temperature patterns in the catchment as a whole. The time series include both daily minimum and maximum temperatures recorded between 1951 and 2000. There are several days missing in the series but the period between 1957 and 1991 is more or less complete. Only complete years were used for calculating the annual means. Figure 2.10 show that the hottest month is August and the coldest is January. The lowest and highest temperature observed at

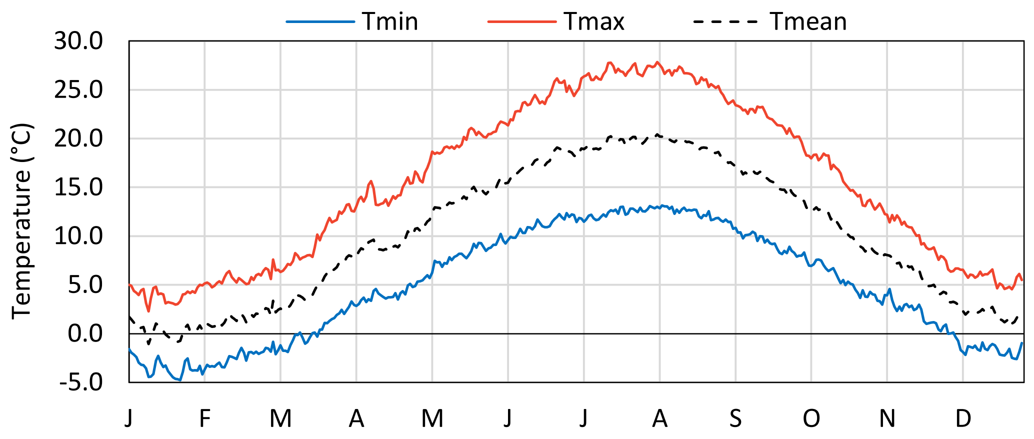

***Figure 2.10** Seasonal variation of daily temperatures at Bilisht*

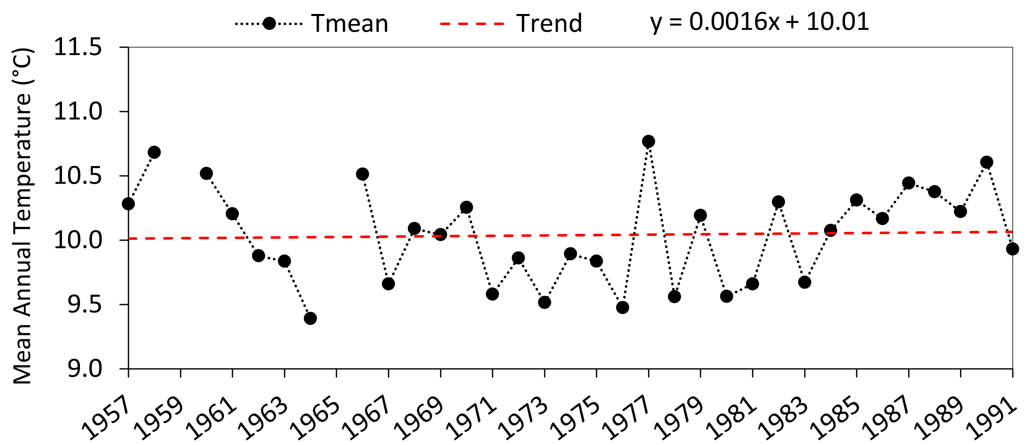

***Figure 2.11** Annual mean temperatures at Bilisht meteorological station*

Bilisht is minus 24.8°C and 40.8°C, and the mean annual temperature is 10.2°C. Figure 2.11 shows the mean annual temperature, where the dotted line is the trend. The figure shows an increase of 0.0016°C per year. Porja (2014)studied annual mean temperatures from 1950 to 2012 at 14 of the meteorological stations within the catchment. The study compared mean annual temperatures between two different periods, 1961 to 1990 and 1991 to 2012. It was found that the mean annual temperature had increased with an average of 0.5°C. Temperature fluctuations both in daily minimum and daily maximum are biggest in the eastern part of the catchment. The average amount of frost days vary between 96 to 162 days in the east, and from 19 to 61 days in the west.

Runoff

There are six runoff series available at the Devoll River and four series at the tributaries: Dunavecit, Selces, Grabove and Holta. The green circles in Figure 2.12 represent the location of the gauging stations, while the red triangles are control structures. The time series are of daily resolution and the series have been recorded between 1951 and 2005. Lozhan and Darzeze have unfortunately only one year of observed data each. Kokel has the longest time series and there are two versions

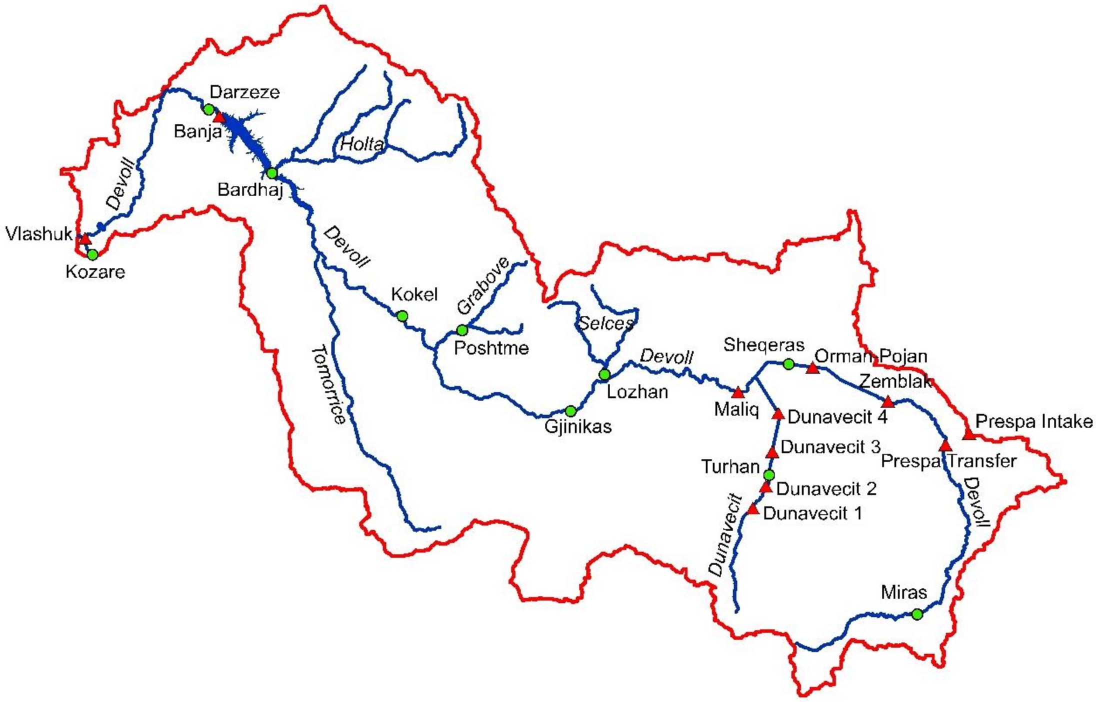

Figure 2.12 *Gauging stations and control structures in Devoll River Basin*

available for Kokel. One version has observations up to 1990 and the second extends to 2005. The first version was chosen for the work in this thesis as it is considered to have been better quality controlled (Lawrence and Haddeland, 2012). Kokel is also considered as the most reliable among the gauging stations. A field survey performed by Statkraft, NVE and Universiteti Politeknik Tiranes (UPT) concludes that the quality of the data at Kokel and Lozhan is “probably adequate”, while for the other gauging stations the quality is “probably questionable or even highly questionable” (Norconsult, 2010). Double mass plots do show in-homogeneities at almost all stations. The most obvious are Kozare, Gjinikas, Kokel and Sheqeras. For the work in this thesis, the quality of the data is assumed adequate for every gauging station.

Table 2.4 *Characteristics at gauging stations in Devoll River Basin*

Gauging Station	**Recorded Period**	**Complete Years**	**Drainage Area (km^2)**	**Mean Daily Runoff**			
				(m^3/s)	**($l/s \times km^2$)**	**(mill. m^3)**	**(mm)**
Miras	1958-1999	31	89.4	1.59	17.9	50.3	562
Sheqeras	1956-1985	23	430.3	5.22	12.4	168.1	391
Turhan	1951-1989	28	272.8	3.24	11.8	101.9	373
Lozhan	1951-1954	1	100.0	1.54	15.4	48.5	485
Gjinikas	1970-1995	24	1357.0	12.38	9.3	395.9	292
Poshtme	1976-1985	9	63.0	2.30	36.4	72.4	1149
Kokel	1953-1989	36	1879.3	28.28	14.5	857.0	456
Bardhaj	1980-1989	10	375.5	5.74	25.4	181.0	482
Darzeze	1983-1984	1	2900.0	35.25	12.2	1111.6	383
Kozare	1950-1985	34	3120.6	46.60	15.2	1492.0	478

Table 2.4 lists all the gauging stations and their characteristics. Hydrographs for all gauging stations are found in appendix Annual and monthly means were calculated using only complete years and months. The geogaphical variations in precipitation are clearly reflected by the specific runoff. Bardhaj and Poshtme have by far the highest amount of specific runoff and Gjinikas has the lowest. Irrigation has a strong influence on the runoff in the Devoll and is a significant problem when considering the runoff data. Increased areas of irrigated land and intensified irrigation between the 1950s and 1990s have altered the runoff properties. The development and construction of the irrigation and drainage schemes have disturbed the natural flow in the Devoll and the tributaries. However, the significance of the impacts from the different schemes are varying. In the upper reaches of the catchment, the previous Prespa Canal Scheme manipulated the flow in the Devoll River during the 1980s. The scheme may have had a strong influence on the flow at Sheqeras, Gjinikas and Kokel during this period, as their effective catchment areas varied with transfer of water back and forth between Little Prespa and Devoll. Between Maliq and Banja, the combined capacity of the

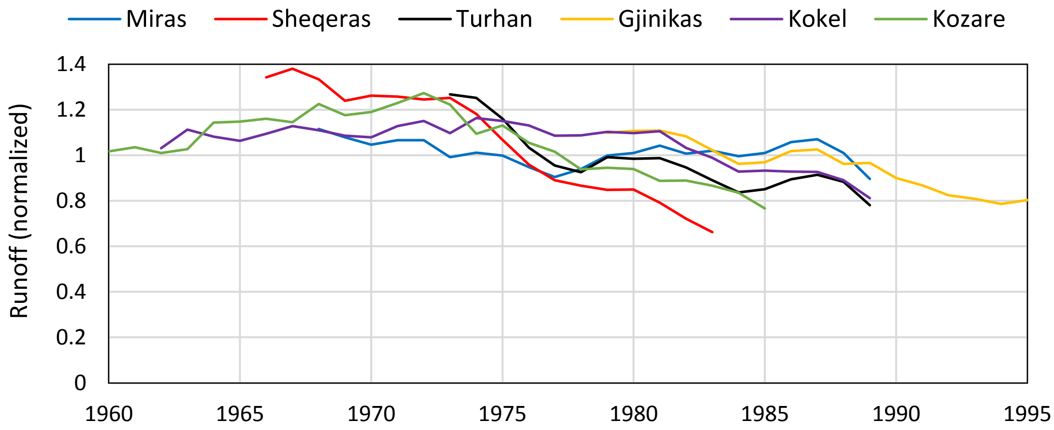

Figure 2.13 *Normalized 10 year moving averages*

pump schemes is equal to approximately half of the natural flow in Devoll River during the peak of the irrigation season. This may have had a considerable effect on the summer flows. An attempt to analyze the effects of the irrigation schemes was made by studying the normalized 10 year moving averages of Miras, Sheqeras, Turhan, Gjinikas, Kokel and Kozare. The flow was normalized for each station by dividing by the annual mean of the whole time series. Figure 2.13 shows changes at Sheqeras and Turhan around 1974. The reduction in runoff is suspected to be caused by changes in irrigation practices but there is not sufficient information to investigate the issue further. There are also indications of changes at Kozare around 1976. Between 1951 and 1975 the mean daily runoff is 51.9 m^3/s at Kozare, while it is 36.2 m^3/s after 1976. This may be explained by operations at Vlashuk Barrage and transfers to Thana Reservoir, and support the suggestion that the barrage was constructed in 1976 and not in 1959.

Darzeze gauging station is placed downstream of Banja Dam and upstream of Vlashuk Barrage and has only data recorded for one and a half years. Even though it is just a short period of time, the data gives important information about the water withdrawals downstream of Banja. Figure 2.14 shows a comparison of the runoff at Gjinikas, Kokel, Darzeze and Kozare from June 1983 to December 1984, and confirms significant withdrawals between Banja Dam and Kozare. As expected, the runoff increases with a growing drainage area as the flow moves downstream of the Devoll

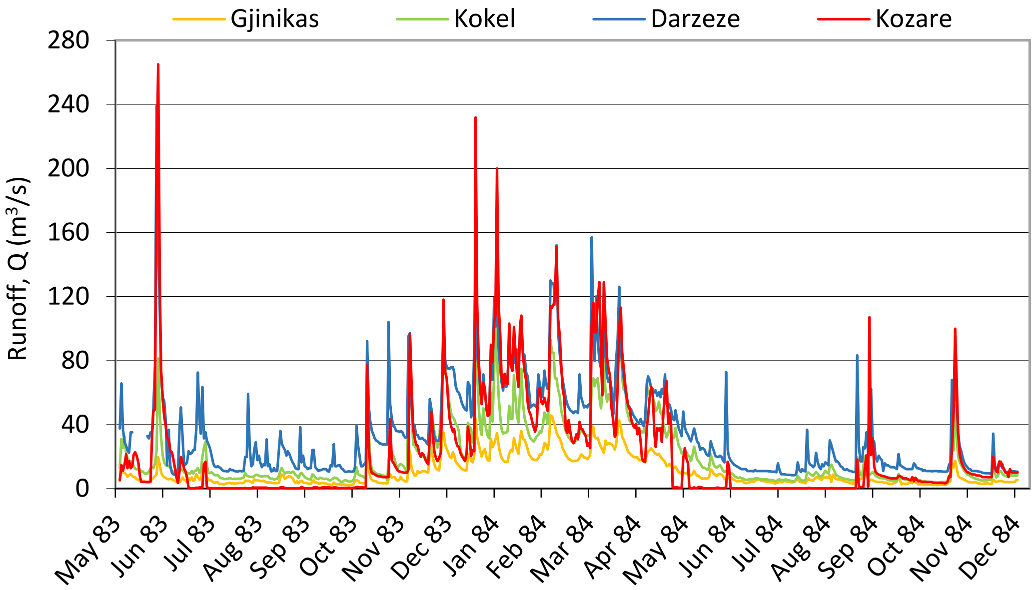

Figure 2.14 *Runoff at Gjinikas, Kokel, Darzeze and Kozare*

River. Between Darzeze and Kozare, the discharge decreases and the discharge at Kozare is in general less than Darzeze during the whole period except for some periods of flood peaks. Figure 2.14 shows that water is not only withdrawn during the irrigation season but also during the winter months. A possible explanation may be the filling of Thana Reservoir before the irrigation season starts in May. It is also worth noting the slow recession of the floods at Darzeze. One explanation may be that the flood water is delayed by Banja Dam, where the outflow is purely restricted by the capacity of the bottom outlet.

3 METHODOLOGY

This chapter is a description of the methods used for developing the hydrological model of Devoll River Basin. The first part describes the delineation of the catchment, estimations of catchment-averaged data, and estimation of irrigation withdrawals. Further is an introduction to the hydrological modelling software Water Evaluation and Planning (WEAP), and a description of some of the concepts and methods used in WEAP. The last part of the chapter explains the background of the scenarios.

3.1 Catchment Delineation and Basin-Averaged Data

Devoll River Basin has been divided into nine sub-basins. The delineation was conducted with a desire to include as many as the gauging stations as possible, and avoid large sub-basins. All gauging stations was used except Lozhan and Darzeze due to their short time series. Tomorrice River was delineated into a separate sub-basin even though it has no runoff data. This may make it possible to estimate the flow in Tomorrice. The catchment was delineated using ArcGIS software with the Arc Hydro Tools extension and a digital elevation model (DEM) with a three arc-second resolution. Three arc-second resolution is equal to a grid of 90 by 90 meters. The DEM was downloaded from the U.S. Geological Survey (USGS) Global Data Explorer (http://gdex.cr.usgs.gov/gdex/). Figure 3.1 shows the sub-basins and the characteristics for each sub-basin are found in Table 3.1. The total area of the delineated sub-basins is 3,120.6 km^2, which is slightly less than the total area of Devoll River Basin.

Second step of the delineation was to divide each sub-basin into different land cover classes. The land cover was studied using Google Earth and by visual inspection during the field trip in February 2015. Roughly, the land cover can be divided into four main classes: forests, meadows, hillsides and arable land. The forests consist of mainly conifers and underdeveloped broad-leaved species such as oak, beech and hazel. Natural meadows with small bushes and shrubs are found at higher altitudes. Hillsides are partly or fully eroded and covered in Mediterranean maquis. Arable land include both naturally and artificially irrigated areas. It is a considerable task to calculate the percentages of each of the four classes for all of the nine sub-basins in detail. For simplicity, the land cover was divided into two classes. Class “A” includes forests, meadows and hillsides, while class “B” represents all arable land. The percentages of each of the two classes within each sub-basin were estimated using a combination of visual inspection in Google Earth and hypsographic curves created in ArcGIS.

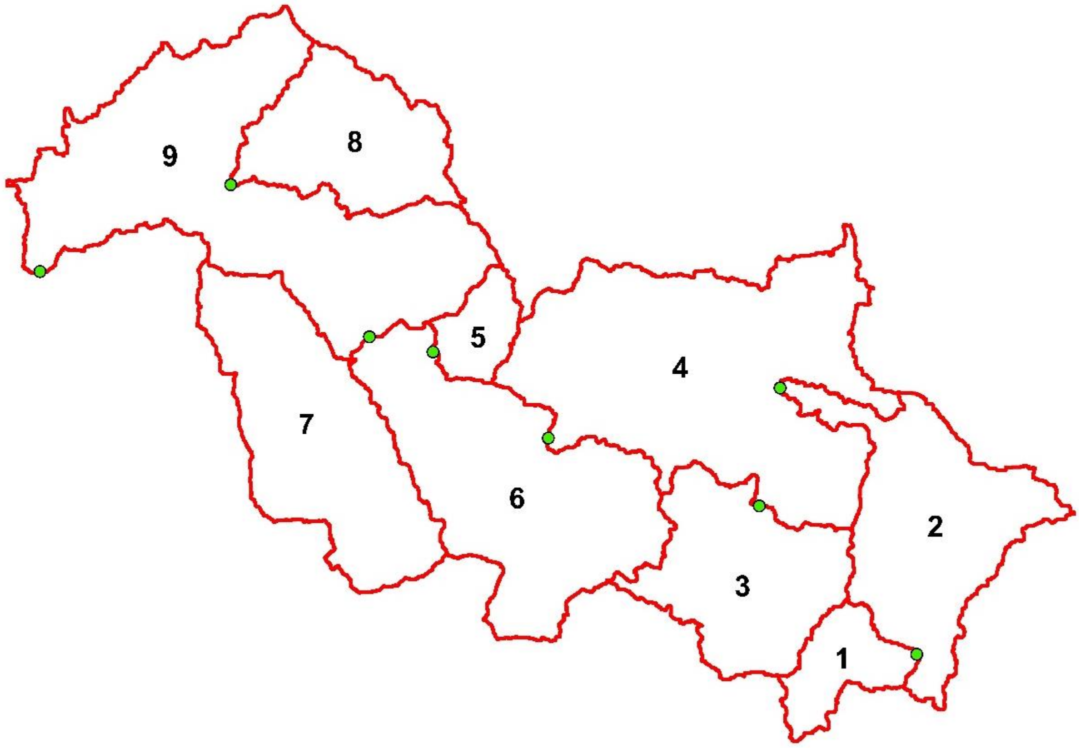

Figure 3.1 *Delineated sub-basins*

Table 3.1 *Characteristics of sub-basins*

Basin	Drainage Area (km²)	Land Cover (%)		Mean Elevation (m.a.s.l.)	Annual Precip. (mm)	Gauge	Annual Runoff	
		A	B				(m³/s)	(l/s×km²)
1	89.4	95	5	1371	966	Miras	1.594	17.8
2	430.3	50	50	1041	707	Sheqeras	5.331	12.4
3	272.8	60	40	1117	827	Turhan	3.230	11.8
4	1357.0	85	15	1093	574	Gjinikas	12.555	9.3
5	63.0	95	5	1578	1272	Poshtme	2.296	36.4
6	1879.3	98	2	1202	1114	Kokel	27.175	14.5
7	375.5	90	10	883	1157	-	-	-
8	226.3	80	20	903	1440	Bardhaj	5.738	25.4
9	3120.6	70	30	500	1276	Kozare	47.310	15.2

The climatic data needs to be transformed from point observations into basin-averaged data before they can be integrated and used in a hydrological model. There are several method for of calculating catchment-averaged data. One method is the arithmetic mean that gives each station within the catchment equal weight. Another is the method of Thiessen polygons, which calculates the area of influence for each of the stations as a percentage of the total area of the catchment. A third option is by isohyetal analysis. Isohyets are lines representing equal depths of precipitation over the catchment based on the measurements at each station. Both Thiessen polygons and isohyetal analysis are graphical methods. The arithmetic method is rather simplistic and isohyetal analysis is a considerable task. Therefore, the method of Thiessen polygons has been chosen. Creation of the polygon network was based on the meteorological stations with the best overlapping time series. Out of 20 stations, 17 was chosen. The excluded stations are Jaronisht, Maliq and Pojan. ArcGIS was used to create the polygon network and calculate the Thiessen weights for each sub-basin. Table 3.2 lists the weights of all meteorological station within each sub-basin. The Thiessen weights have been used to calculate basin-averaged precipitation, relative humidity, wind speed, and cloudiness fraction.

Table 3.2 *Thiessen weights for all sub-basins*

Meteorological Station	**Basin**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Bilisht	-	57.7	-	-	-	-	-	-	-
Dardhe	80.4	5.9	28.9	-	-	-	-	-	-
Dushar	-	-	-	-	-	42.6	18.6	-	-
Gjinar	-	-	-	-	-	-	-	38.0	19.9
Grabove	-	-	-	12.0	100.0	5.1	-	-	3.0
Gramsh	-	-	-	-	-	-	8.6	26.3	18.2
Kokel	-	-	-	-	-	8.4	2.9	-	10.0
Korca	-	5.7	47.1	15.3	-	-	-	-	-
Kucove	-	-	-	-	-	-	-	-	5.3
Kukur	-	-	-	-	-	-	-	35.7	13.2
Lemnush	-	-	-	-	-	2.1	36.3	-	-
Miras	19.6	20.5	-	-	-	-	-	-	-
Prenjas	-	-	-	-	-	-	6.3	-	30.4
Sheqeras	-	10.2	-	22.8	-	-	-	-	-
Voskopoje	-	-	24.0	14.6	-	41.8	-	-	-
Ujanik	-	-	-	-	-	-	27.3	-	-
Zvirine	-	-	-	35.2	-	-	-	-	-

Temperatures need to be calculated for each sub-basin. As mentioned in the previous chapter, the only time series for temperature received is recorded at Bilisht in the very east of Devoll River Basin, and is not necessarily representative for the basin as a whole. Two additional time series for temperatures were downloaded from The World Data Center for Meteorology (WDC) (http://gosic.org/wdcmet). The downloaded time series are monthly averages from 1961 to 1990, recorded at Korca 900 m.a.s.l. and at Kucove 33 m.a.s.l. The monthly averages at Bilisht between 1961 and 1990 was compared to the monthly averages for the downloaded time series. The difference in elevation between Bilisht and Korca is only 3 meters and the monthly averages were almost identical. Based on the difference in elevation between Kucove and Bilisht and their monthly values, a dry adiabatic lapse rate of 0.006 °C/m was estimated. Time series for each sub-basin was created by correcting the time series at Bilisht for altitude based on the estimated lapse rate and the mean elevation of the basins.

The FAO AQUASTAT Climate Information Tool was used to acquire data on wind speed, relative humidity and cloudiness fraction. This online tool uses the location and altitude of the point of interest as input, and returns data based on monthly averages from 1961 to 1990. Point data was downloaded for all of the 17 meteorological stations. The basin-average values are found in appendix C.

3.2 Estimation of Irrigation Withdrawals

The work in this section is solely based on the "Irrigation Benchmarking Report". To obtain an appropriate model calibration and realistic simulation results, it is important to identify all irrigation schemes that withdraw water from Devoll River and its tributaries. Except from Thana Reservoir, Banja-Shkumbin Canal and the areas downstream Vlashuk Barrage, there is no data on irrigation withdrawals given as annual volumes. There has been made many assumptions and simplifications regarding the crop mix, crop water requirements and irrigation practices in order to obtain an estimate of the withdrawals.

The type of crops grown have changed since the socialist area. They vary between locations due to climate and available irrigation. Prior 1990, the irrigation schemes were operable and set up for industrial production, thus crops with high water demands were grown. Today farmers tend to grow rainfed subsistence crops with low water demands, as many of the irrigation schemes are inoperable. There is no accurate data on the crop mix at different locations and their relative portions. The irrigation report describes crops with annual water demands ranging from 650 to 6,500 m^3 per hectare. For simplicity it is assumed that all irrigated areas regardless of location and types of crops, have an annual water requirement of 4,000 m^3 per hectare. The irrigation efficiency is optimistically assumed to be 50 %. This means that half of the water is lost in the distribution net during transportation, which gives a supply requirement twice as much as the crop water requirement. Further, it is assumed that the crops consume 90 % of the water delivered, which results in a return flow of 10 % of the water delivered to the irrigated areas.

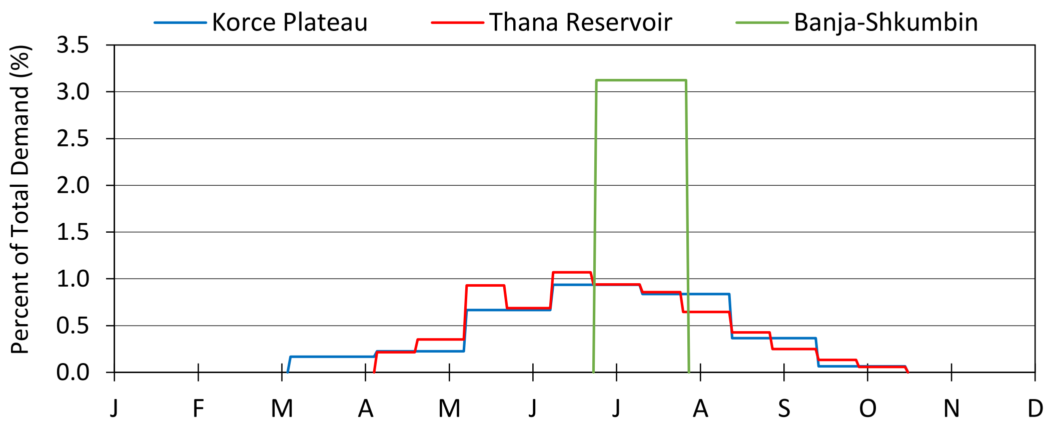

Figure 3.2 *Daily distribution of irrigation demands*

Different crops are grown at different times during the year. The irrigation season varies between locations and is dependent on the types of crops grown. Some areas grow winter crops as well, but these are not irrigated. In general, the irrigation season can be said to start around April and end in October. The irrigation report mentions three different distributions of the crop water demand for the Korce area, Thana Reservoir and the Banja-Shkumbin Canal. Figure 3.2 shows the daily distribution of the demands as a percentage of the annual total. These figures are assumed to be present practices. Studying the hydrographs of different gauging stations reveals that some stations have larger withdrawals in October and November than indicated by the figure. For the work in this thesis, it is assumed that the distribution at Korce represents all irrigated areas within the Devoll River Basin, except at Vlashuk Barrage and the Banja-Shkumbin Canal. The distribution in numbers are found in appendix E. Further, it is assumed that all winter crops are only rainfed. The demand sites are divided into three categories: gravity schemes, pump schemes and diversions. Diversions include all canals that divert and transports water at long distances, resulting in no return flow.

Gravity Schemes

Not of all the reported irrigated areas have reported capacities of their distribution network. Areas with missing capacities are assumed to have distribution systems with design capacities based on the hydro module of 0.001 m^3/s per hectare. Table 3.3 lists the irrigated areas identified. The first five have both reported command areas and design capacities, while the rest have only reported areas.

Table 3.3 *Reported irrigated areas*

Name	Command Area (ha)	Design Capacity (m^3/s)	River	Location
Miras	250	0.200	Devoll	Upstream Zemblak
Menkulas	250	0.250	Devoll	Upstream Zemblak
Poncare	300	0.350	Devoll	Upstream Zemblak
Dobranj	400	0.300	Devoll	Upstream Zemblak
Proger	150	0.200	Devoll	Upstream Zemblak
Zemblak N	3,500	3.500	Devoll	North of Zemblak
Zemblak S	3,300	3.300	Devoll	South of Zemblak
Maliq	5,300	5.300	Devoll	Between Zemblak and Maliq
Village irrigation	3,000	3.000	Devoll	Between Maliq and Banja
Sum	16,450	16.400		

Diversions

All of the schemes have reported command areas and design capacities, except the Banja-Shkumbin Canal. Estimation of the command area of Banja-Shkumbin Canal is pointless as it diverts water into a river. Gjanc Reservoir services a command area from sources that do not withdraw water from Devoll; hence, it is not included in WEAP.

Table 3.4 *Diversions*

Name	Command Area (ha)	Design Capacity (m^3/s)	River	Location
Banja-Shkumbin	-	20.000	Devoll	Immediately below Banja
Soluva Canal	1,420	1.000	Devoll	2.0 km downstream Banja
Cartalloz Canal	560	0.600	Devoll	5.0 km downstream Banja
Vlashuk Canal	39,000	60.000	Devoll	25.0 km downstream Banja
Valamara Canal	-	0.400	Grabove	Grabove River
Snosem Scheme	150	0.150	-	Dushku Reservoir
Sum	55,150	93.150		

Pump Schemes

Some of the pump schemes have both reported command areas and design capacities, while most do not have any reported command areas, only reported design capacities. It is assumed that the pump stations are designed on the same hydro module of 0.001 m^3/s per hectare. Table 3.5 shows a list of the pump stations identified, which is based on the figure and the list in appendix D. All pump stations located on the same tributary or in between the same confluences along Devoll River have been grouped into separate "pump zones". Pump schemes with unknown locations and the pump schemes removed due to construction of the Banja Dam are not included in WEAP.

Table 3.5 *Reported pump schemes*

Name	Command Area (ha)	Design Capacity (m^3/s)	River	Location
Pump zone 1	660	0.660	Devoll	Between Maliq and Gjinikas
Pump zone 2	190	0.190	Devoll	Between Gjinikas and Grabove confluence
Pump zone 3	210	0.210	Devoll	Between Kokel and Tomorrice confluence
Pump zone 4	422	0.422	Devoll	Between Tomorrice confluence and Holta confluence
Pump zone 5	400	0.400	Tomorrice	Tomorrice River
Pump zone 6	398	0.398	Holta	Holta River
Qerret pump	40	0.040	Devoll	Between Holta confluence and Banja
Banja pump	150	0.150	Devoll	Immediately below Banja
Shitepanj pump	150	0.150	Devoll	0.5 km downstream Banja
Floq 2 pump	50	0.050	Devoll	0.5 km downstream Banja
Leproze pump	90	0.100	Devoll	2.0 km downstream Banja
Banja pump	150	0.150	Devoll	Immediately below Banja
Removed due to Banja	512	0.512	Unknown	Banja Reservoir area
Unknown	130	0.130	Unknown	Unknown
Sum	3,552	3.552		

The Prespa Canal Scheme is a complex case with transfers both ways between Devoll River and Little Prespa Lake. To assess the relative withdrawals between Devoll and Prespa is a complex and time-consuming task; hence, the Prespa Canal Scheme is not included in WEAP. Valamara Canal has no specific command area as it transfers water to a reservoir.

Schemes Included in the Model

Table 3.6 lists the gravity, pump and diversion schemes that are included in the model for calibration. Irrigation schemes included in the scenarios are described in chapter 3.4.3. Only schemes with identified locations and that withdraw water directly from

Devoll River and the tributaries modeled as sub-basins have been included. The supply requirement for each site is estimated based the assumed command areas, crop water demand and irrigation efficiency. It is worth noting that the supply requirement results in flows that exceed the natural flow in Devoll River upstream of Maliq and downstream the Banja Dam during the summer months. The total annual supply requirement is 298.88 million m^3, which is equal to approximately 20 % of the annual flow volume passing Kozare gauging station.

Table 3.6 *Irrigation schemes included WEAP*

Scheme Name	Type	Supply Requirement (million m^3)	Peak Flow (Jul/Aug) (m^3/s)	Current Status
Miras	Gravity	2.00	0.217	Operational
Poncare	Gravity	2.40	0.260	Operational
Menkulas	Gravity	2.00	0.217	Operational
Dobranj	Gravity	3.20	0.346	Under rehabilitation
Proger	Gravity	1.20	0.130	Not operational
Zemblak N	Gravity	28.00	3.032	Partially operational
Zemblak S	Gravity	26.40	2.858	Partially operational
Maliq	Gravity	42.40	4.591	Partially operational
Pump zone 1	Pump	5.28	0.572	Not operational
Pump zone 2	Pump	1.52	0.165	Not operational
Pump zone 3	Pump	1.68	0.182	Not operational
Pump zone 4	Pump	3.38	0.366	Not operational
Pump zone 5	Pump	3.20	0.346	Not operational
Pump zone 6	Pump	3.18	0.345	Not operational
Valamara Canal	Gravity + pump	1.20	0.130	Not operational
Qerret pump	Pump	0.32	0.035	Not operational
Banja	Pump	1.20	0.130	Not operational
Shitepanj	Pump	1.20	0.130	Not operational
Floq	Pump	0.40	0.043	Not operational
Leproze	Pump	0.80	0.087	Not operational
Devoll	Pump	2.08	0.225	Not operational
Vlashuk Canal	Diversion	100.00	12.400	Operational
Banja-Shkumbin	Diversion	40.00	14.468	Operational
Kucove and Fier	Diversion	10.00	1.240	Operational
Soluva	Diversion	11.36	1.230	Not operational
Cartalloz	Diversion	4.48	0.485	Not operational
	Sum	298.88		

WEAP allocates water to different demand site based on their priority. There was not found any information about the priorities of the schemes. One way to determine the priority of the schemes is to rank them solely based on their supply requirements. On the other hand, a small scheme may be just as important as large scheme. As there is no further information about the allocation priorities of the schemes, it is assumed that all the schemes are of equal importance and have the same priority.

3.3 The WEAP Model

3.3.1 Introduction to WEAP

The Water Evaluation and Planning (WEAP) model is a software tool for Integrated Water Resources Management (IWRM) developed by the Stockholm Environmental Institute (SEI). WEAP has a long history of development and use in the water planning area (Yates et al., 2005). Over the years, several organizations (e.g. the World Bank, EU Global Water Initiative and U.S. Army Corps of Engineers) have supported and funded the development of WEAP. WEAP integrates physical hydrologic processes with the management of demands and infrastructure, as well as environmental and economic aspects of water planning. Simulations in WEAP are constructed as scenarios. Scenarios can be constructed and analyzed based on different trends in hydrology, water use and demands, demography, technology, operation rules and water management policies. WEAP is developed with the purpose of being a flexible and transparent tool for aiding IWRM, and is not a tool for modeling detailed water operations, such as optimization of hydropower production.

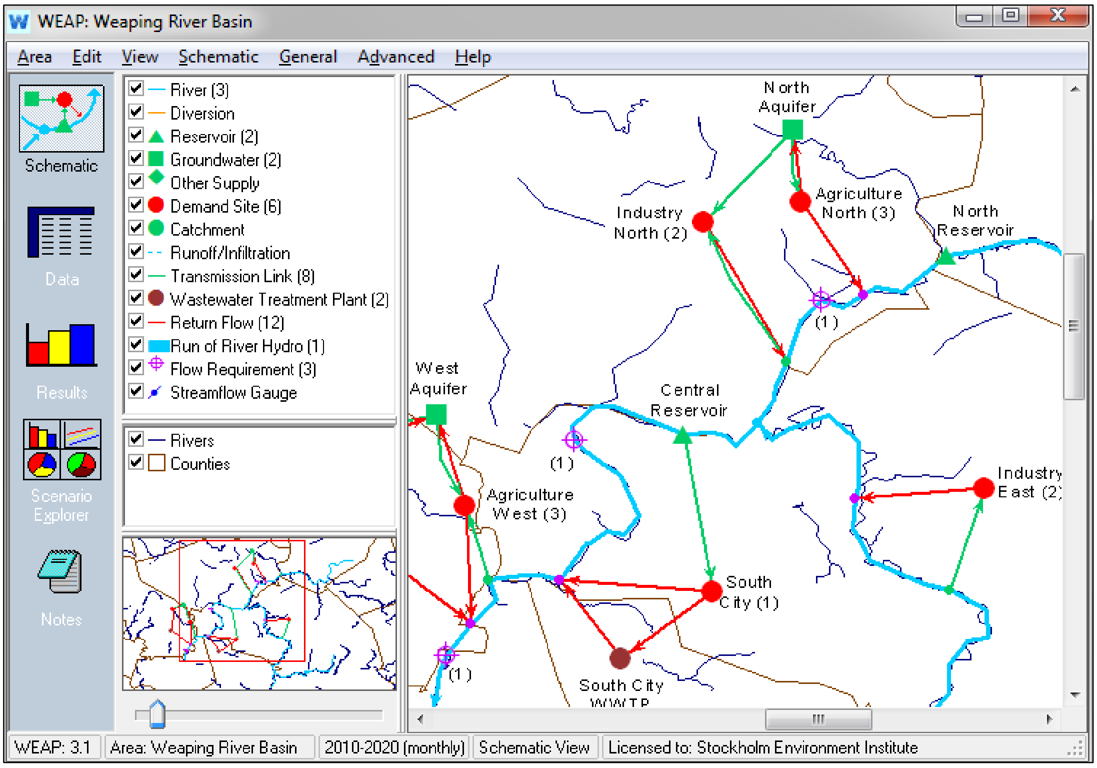

Figure 3.3 *WEAP interface and schematic view (Sieber, 2012)*

WEAP features an intuitive graphic interface that provides a user-friendly working environment and a straightforward understanding of the system studied. Figure 3.x is a screenshot of the WEAP interface. The main menu consists of seven sub-menus: an area, an edit, a view, a schematic, a general, an advanced and a help menu. There are five basic views in WEAP that can be chosen from the view bar seen on the left of the figure. Each view determines the layout of the rest of the screen:

1. **Schematic view:** This is the starting point for all activities in WEAP. It is a spatial layout of the area studied. The view features an easy “drag and drop” graphical interface for physical visualization and configuration of the system studied. Objects such as catchments, reservoirs, demand nodes, aquifers etc., can be created and edited in this view. Geographic Information System (GIS) files can be added as background layers to provide clarity. Any information or result linked any object is easily accessed by right clicking on the object.

2. **Data view:** This is where the system is defined and built. All assumptions, data and data structures, variables and relations, and documentation for “current accounts” and each scenario are entered here. Data view includes a hierarchical “tree” that organize the data structures under six categories: key assumptions, hydrology, demand sites, supply and resources, environment and other assumptions.

3. **Results view:** This view is the reporting tool of WEAP where the simulation results are reviewed. The results can be viewed as tables, charts or on the schematic, either in monthly or yearly values for any period of time within the time horizon. Reports of the results are available either as graphs, tables or maps and can be saved as text, graphic or spreadsheets. Each report can be customized as preferred and favorites saved for later retrieval. In addition, the result view is an important tool for validating all assumptions, data and models, and make sure they are consistent.

4. **Scenario explorer view:** This view groups together the tables and charts created in the results view into “overviews”. The overviews allows for simultaneous comparison of important aspects of the system. Effects of various assumptions across different scenarios can be studied by selecting what data to be displayed and which scenarios to compare. It is possible to change the inputs at the spot and WEAP will automatically recalculate to results.

5. **The notes view:** This is a simple notepad where assumptions, documentation and references are entered for each object in the tree. Note may include formatting or windows objects, e.g. Word files or Excel spreadsheets. Note are good way of documenting the scenarios as you model.

One of the strengths with WEAP is the flexibility. It is possible to run WEAP at many different temporal resolutions, ranging from daily to annual time steps with a time horizon from just one day to more than 100 years. WEAP lets the user choose from many different methods for defining and calculating water demands related to irrigated agriculture, industry and . The structure of demand data can be adapted based on the availability of data and the type analysis to be conducted. All supply and resource calculations are driven by a linear program allocation algorithm that determines the amounts of water delivered to each demand site, based on their priority defined by the user. The priority is given as number between 1 and 99, where 1 represents the highest priority and 99 the lowest. WEAP includes four methods for simulating hydrologic processes. These are the Irrigation Demands Only Method, Rainfall Runoff Method, Soil Moisture Method and the MABIA Method. It is also possible to link WEAP to other models such as MODFLOW, QUAL2K, LEAP:

- MODFLOW is a three-dimensional finite difference groundwater model developed by the USGS. Linking to MODFLOW is an alternative if the built-in WEAP groundwater model is not sufficiently complex. Data and results is transferred back and forth between WEAP and MODFLOW when they are properly linked.

- QUAL2K is a one-dimensional water quality model that can model chemical and biological constituents such as nitrate, pH, ammonia, algae, etc. The model can also calculate water temperatures based on the WEAP climate data. WEAP has a built-in water quality model but the QUAL2K is far more detailed and can model more types of constituents if necessary.

- The Long-range Energy Alternatives Planning System (LEAP) is a tool for analysis of energy policy and climate change mitigation. It is developed by SEI and can be linked to WEAP to track energy production, consumption, resource extraction and greenhouse gas emissions (GHG) from both energy and non-energy sectors.

In general, applications of WEAP can be divided into three main areas: As a database, WEAP provides a system for maintenance of water demand and supply information. As a forecasting tool, WEAP simulates water balance and allocation, or as a policy analysis tool that evaluates alternative policy and management options, and accounts for multiple and competing water users (Sieber and Purkey, 2011).

A WEAP analysis consists several of steps. The first step is to set up the time horizon, geographical boundaries, system components and configuration of the problem. Further is the baseline conditions of the area studied established in the "Current Accounts". Current Accounts represent the present situation, and include the actual climatic conditions, existing water users, and their demands, supply requirements and pollution loads. Factors that affect demands, policies and costs may be built into the Current Accounts as key assumptions. The model is calibrated based on the Current Accounts before the scenarios are created and simulated. Scenarios build on the Current Accounts, and represent alternative sets of assumptions about the future development of the area studied. These assumptions can be related to a wide range of factors, such as change in climatic and hydrologic conditions, changing water management policies and operations, improved irrigation technology, etc. At last, the scenarios are explored and evaluated. The scenarios can be compared with each other or relative to the reference scenario.

3.3.2 The WEAP Soil Moisture Method

The WEAP soil moisture method is the most complex of the four methods available for simulating catchment processes, and is chosen for the in this thesis. It is a one-dimensional, 2-compartment ("bucket") soil moisture model based on empirical functions that describe evapotranspiration, surface and sub-surface runoff, and deep percolation for a catchment unit (Yates et al., 2005). Figure 3.4 shows the components of the conceptual soil moisture model. The upper bucket represents the root zone layer and bottom bucket represents the deep soil layer. A river basin divided into N sub-basins, and each sub-basin into j fractional areas representing different land covers and/or land uses. Climatic conditions are assumed to be uniform over each fractional area. Soil water capacity and saturated hydraulic conductivity for both layers are the main parameters of the model. The model computes the water balance for each sub-basin based on the inflows, outflows and relative storage within the soil layers. For a

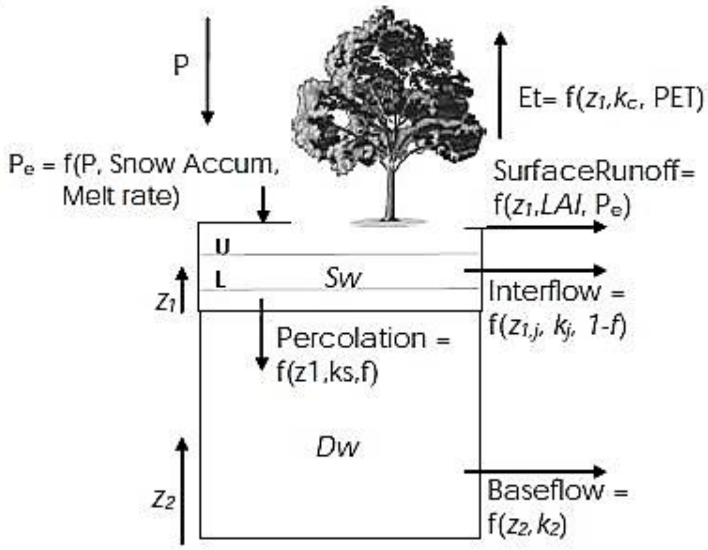

Figure 3.4 *Schematic of the WEAP soil moisture model (Yates et al., 2005)*

river basin divided into *N* sub-basins with *j* fractional areas of different land cover or land use, the soil water balance in the root zone layer can be formulated as:

$$Sw_j \frac{dz_{1,j}}{dt} = P_e(t) - PET(t)k_{c,j}(t)\left(\frac{5z_{1,j} - 2z_{1,j}^2}{3}\right) - P_e(t)z_{1,j}^{LAI_j} - f_j k_{s,j} z_{1,j}^2 - (1-f_j)k_{s,j} z_{1,j}^2 \quad (3\text{-}1)$$

where Sw_j is the soil water storage capacity of the fractional area j (mm); $z_{1,j} \in [0,1]$ is the relative soil water storage in the root zone layer, of a fractional area j; $k_{s,j}$ is the saturated hydraulic conductivity of the root zone layer (mm/time); $f_j \in [0,1]$ is a partition coefficient that divides the flow in the root zone into a horizontal and vertical flow; $P_e(t)$ is the effective precipitation including snowmelt and irrigation (mm/time); $PET(t)$ is the potential evapotranspiration (mm/day); $k_{c,j}$ is the crop coefficient for the area j; LAI_j is the leaf area index (runoff resistance factor) of the area j. The crop coefficient represents the relative magnitude of the evapotranspiration, and the runoff resistance factor describes the surface runoff response. The second term on the right hand side of equation 3-1 expresses the evapotranspiration, and the third term is the surface runoff. Percolation and interflow is expressed by the fourth and fifth term, respectively. For sub-basins without a separate groundwater flow model linked to the basin, the soil water mass balance of the bottom layer can be computed as:

$$Dw_j \frac{dz_{2,j}}{dt} = (1-f_j)k_{s,j} z_{1,j}^2 - k_{2,j} z_{2,j}^2 \quad (3\text{-}2)$$

where Dw_j is the deep water storage capacity (mm), and $k_{2,j}$ is the saturated hydraulic conductivity of the deep soil layer (mm/time) for a fractional area j. The second term on the right hand side of equation 3-2 represents the baseflow. WEAP has simple built-in snowmelt model based on a temperature index that computes the effective precipitation P_e. For each sub-basin, the snowmelt model estimates the snow water equivalent and snowmelt from an accumulated snowpack (A_c) for a time step i. The snow accumulation is a function of the observed precipitation P_i and a melt coefficient m_c. Equation 3-3 to 3-6 describes the computational scheme of the accumulated snowpack and the effective precipitation.

$$m_c = \begin{cases} 0 & \quad T_i < T_s \\ 1 & if \quad T_i > T_l \\ \dfrac{T_i - T_s}{T_l - T_s} & \quad T_s \leq T_i \leq T_l \end{cases} \tag{3-3}$$

$$Ac_i = Ac_{i-1} + (1 - m_c)P_i \tag{3-4}$$

$$m_r = Ac_i m_c \tag{3-5}$$

$$P_e = P_i m_c + m_r \tag{3-6}$$

T_i is the observed temperature for a time step i, and T_s and T_l are the freezing and melting temperature thresholds. The effective precipitation is a function of the observed precipitation, the melt coefficient and a snow melt rate m_r.

3.3.3 Evapotranspiration Estimations

Evapotranspiration data can be entered or uploaded directly into WEAP. If there are no observed data, WEAP calculates the evapotranspiration automatically for each sub-basin using the FAO Penman-Monteith combination method. There are no accurate evapotranspiration data available for Devoll River Basin; hence, the surface evapotranspiration for each sub-basin was calculated in WEAP. Open water body evaporation from the reservoirs was calculated manually with the Penman-Monteith equation, and uploaded into WEAP. The FAO combination method that was introduced in the *FAO Irrigation and Drainage Paper 56* in 1998 builds on the Penman-Monteith equation, and calculates evapotranspiration for a hypothetical reference crop. The reference surface and crop are defined as (Allen et al., 1998):

"The reference surface is a hypothetical grass reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sm^{-1} and an albedo of 0.23. The reference surface closely resembles an extensive surface of green, well-watered grass of uniform height, actively growing and completely shading the ground. The fixed surface resistance of 70 sm^{-1} implies a moderately dry soil surface resulting from about a weekly irrigation frequency."

The FAO Penman-Monteith combination equation for evapotranspiration consists of a radiation term, and an aerodynamic, and can be written as:

$$ET_{ref} = ET_{rad} + ET_{areo} \tag{3-7}$$

$$ET_{ref} = \frac{0.408\Delta(R_{net} - G) + \gamma \frac{900}{T_{mean} + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{3-8}$$

Surface resistance is assumed negligible for the case of open water body evaporation. The Penman-Monteith equation for open water body evaporation can be written as:

$$ET_0 = \frac{\Delta(R_n - G) + \gamma 6.43(1 + 0.535u_2)(e_s - e_a)}{\lambda(\Delta + \gamma)} \tag{3-9}$$

where,

$\boldsymbol{ET_{ref}}$:	reference evapotranspiration rate (mm/day)
$\boldsymbol{ET_0}$:	open water body evaporation (mm/day)
$\boldsymbol{R_{net}}$:	net solar radiation at the surface (MJ/m^2day)
$\boldsymbol{G}$:	Soil heat flux density (MJ/m^2day) (neglected G = 0)
$\boldsymbol{u_2}$:	wind speed measured 2 m above the surface (m/s)
$\boldsymbol{e_s}$:	saturation vapor pressure (kPa)
$\boldsymbol{e_a}$:	actual vapor pressure (kPa)
$\boldsymbol{e_s - e_a}$:	vapor pressure deficit (kPa)
Δ:	slope of saturation vapor pressure curve (kPa/°C)
$\boldsymbol{\gamma}$:	psychrometric constant (kPa/°C)
$\boldsymbol{T_{mean}}$:	mean air temperature (°C)

The net solar radiation is, R_{net}, is the available energy for evapotranspiration, and is defined as the difference between the incoming net shortwave radiation (R_{ns}) and the outgoing net longwave radiation (R_{nl}):

$$R_{net} = R_{ns} - R_{nl} \tag{3-10}$$

The net solar radiation is dependent on the extraterrestrial solar radiation, and the extraterrestrial solar radiation can be written as:

$$R_a = \frac{118.1}{\pi} d_r(\omega_s \, sin\varphi \, sin\delta + cos\varphi \, cos\delta \, sin\omega_s) \tag{3-11}$$

where,

$\boldsymbol{R_a}$:	extraterrestrial solar radiation (MJ/m^2day)
$\boldsymbol{d_r}$:	relative distance between the Earth and the Sun $d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right)$
$\boldsymbol{\omega_s}$:	sunset hour angle $\omega_s = \arccos(-tan\varphi \, tan\delta)$
$\boldsymbol{\delta}$:	solar declination

$$\delta = 0.4093 \sin\left(\frac{2\pi}{365} J - 1.405\right)$$

φ: latitude for the point or area studied

J: Julian day number (J =1 for January 1st)

The net shortwave incoming radiation and the net outgoing radiation are calculated by equation 3-10 and 3-11:

$$R_{ns} = (1-\alpha)\left(0.25 + 0.5\frac{n}{N}\right) R_a \tag{3-12}$$

$$R_{nl} = \sigma(T_{mean} + 273.2)^4 \left(0.34 - 0.14\sqrt{e_a}\right)\left(0.1 + 0.9\frac{n}{N}\right) \tag{3-13}$$

where,

N: maximum possible daylight hours (hours)
$N = \frac{24}{\pi}\omega_s$

n: Actual daylight hours (hours)

α: average albedo of the surface
α = 0.23 for the reference crop
α = 0.05-0.60 for liquid water (depends on the solar angle)

σ: Stefan Boltzmann constant
$\sigma = 4.9 \times 10^{-9}\ \ MJ/m^2K^4day$

e_a: actual vapor pressure (kPa)
$e_a = e_s \frac{RH}{100\,\%}$
RH: relative humidity (%)

The slope of the saturation pressure curve is a function of the mean air temperature, and describes the relationship between the saturation vapor pressure and temperature.

$$\Delta = \frac{4098 e_s}{(273.3 + T_{mean})^2} = \frac{4098\left(0.6108 e^{\left(\frac{17.27 T_{mean}}{237.3 + T_{mean}}\right)}\right)}{(273.3 + T_{mean})^2} \tag{3-14}$$

The psychrometric constant is the relationship between the partial pressure of water in air and the air temperature, and given as:

$$\gamma = \frac{c_p P}{\varepsilon\lambda} = 0.000665 P \tag{3-15}$$

where,

P: P: atmospheric pressure (kPa)

$$= 101.3\left(\frac{293-0.0065z}{293}\right)^{5.26}$$

z: elevation above sea level (m)

$\boldsymbol{c_p}$: Specific heat of dry air at constant pressure
c_p = 0.001013 (MJ/kg°C)

$\boldsymbol{\lambda}$: latent heat of vaporization
λ = 2.45 (MJ/kg)

$\boldsymbol{\varepsilon}$: ratio molecular weight of water vapor/dry air
ε = 0.622

WEAP calculates the reservoir evaporation based on predefined values of net evaporation (ET_{net}) and the volume-elevation curves. The net evaporation is the potential open water body evaporation (gross) minus the precipitation. Potential evaporation at each reservoir was calculated with equation 3-9. Temperature time series were created for both reservoirs by correcting the times series at Bilisht for altitude, with a dry adiabatic lapse rate of 0.006 m/°C. HRWL was chosen as the mean elevation for both reservoirs for radiation calculations. It is possible to download radiation data as maps from SolarGIS (www.solargis.info), but it was chosen to do the radiation calculations manually. Further, an albedo of 0.1 was assumed. Data on relative humidity, wind speed and sunshine hours was downloaded from the FAO AQUASTAT Climate Information Tool. These data are monthly averages but they are assumed equal for all days within each month. The net evaporation was computed using precipitation data for basin 6 and 9. Moglice reservoir lies in within basin 6 and Banja within basin 9. At last, the estimated values of net evaporation was uploaded into WEAP. The calculation scheme and an example of the estimations are found in appendix F.

3.3.4 Reservoirs and Hydropower

Reservoirs can be modeled either as online or offline, and it is possible for a reservoir to serve a single or multiple purposes in WEAP. Online reservoirs are instream and the river flows directly into the reservoirs. There are two categories of online reservoirs in WEAP: runoff-river and “river”. Contrary to “river” reservoirs, runoff-river reservoirs cannot provide storage and do not have a variable head for hydropower generation. Offline reservoirs or “local” reservoirs receive water from the river through a transmission link or diversion in WEAP. All demand sites linked to a local reservoir are assumed to be located downstream of the reservoir, and if the reservoir has hydropower plant, all releases are assumed to pass through the turbines. A “river” reservoir in WEAP delivers water to its demand sites through separate transmission links that are not connected to the turbines. Demand sites that are not directly linked to a reservoir withdraw water from rivers, and not from the reservoirs.

All reservoirs in WEAP, except runoff-river, are divided into four zone. Figure 3.5 shows the different zones. The buffer and conservation zone constitute the active storage of a reservoir, while the flood control zone will always to be vacant. No water that is below the inactive zone is available for use. It is possible for the water level to drop below the top of the inactive zone. This happens in extreme situations when all the water in the conservation pool is empty, and water evaporates from the reservoir surface. Reservoir operations in WEAP are regulated according to a buffer coefficient. Releases from the conservation pool are unrestricted in WEAP to meet demands and

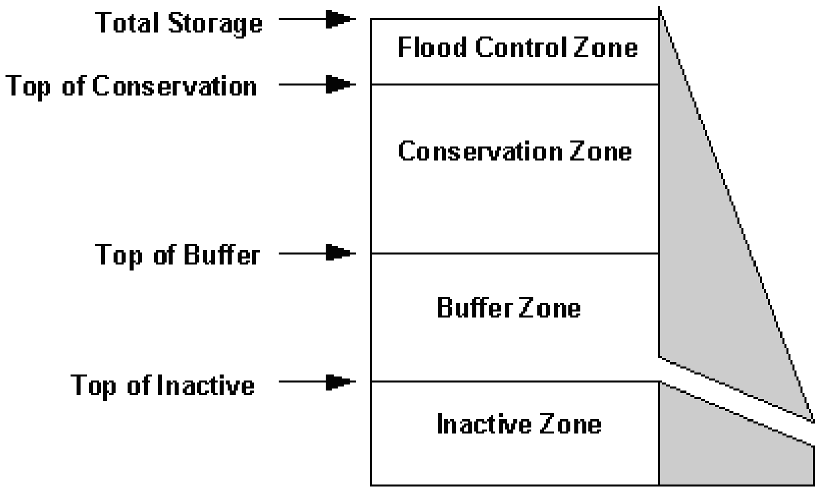

Figure 3.5 *Reservoir zones in WEAP(Sieber and Purkey, 2011)*

flow requirements. When the water level drops below the top of the buffer pool, releases are restricted according to a buffer coefficient. The buffer coefficient is a value from 0 to 1, where a value of 1 allows all water above the inactive zone to be released. WEAP is not developed for detailed hydropower production planning, which is reflected by its simple hydropower functions. Because of this, there has been made many assumptions and simplifications for some of the parameters related to the hydropower simulations. For a time step i, hydroelectric generation is computed with the following equation in WEAP:

$$E_i = \rho\ g\ \eta\ H_{e,i}\ Q_i\ f_{p,i}\ T_i \times 10^{-9} \qquad (3\text{-}16)$$

where E_i is the electricity generated (GWh); ρ is the density of water (1000 kg/m^3); g is the rate of acceleration of gravity on Earth (9.81 m/s^2); η is the total generating efficiency of the system (%); $H_{e,i}$ is the effective head working on the turbine (m); Q_i is the flow passing through the turbine (m^3/s); $f_{p,i}$ is the plant factor (%); T_i is the time step (hours). Several parameters needs to be defined for each reservoir for WEAP to compute the hydroelectric generation. The first step is to establish the volume-elevation curve, which is used to calculate the reservoir elevation for the each time step based on the inflows and outflows to the reservoir. The effective head on the turbine is calculated as the difference between the reservoir elevation and the tailwater elevation. Independent of what time step (T_i) the model is running on, the plant factor specifies the percentage of the time step the power plant is allowed to run. Two significant limitations related to simulation of hydroelectric generation in WEAP are the maximum turbine flow and the generating efficiency parameters. It is not possible to model individual turbines with different capacities. The maximum flow is the total combined capacity of all turbines at each reservoir. All flows passing through the turbines are restricted by this parameter, and excess water (floodwater) is assumed to pass through a spillway without any hydroelectric generation. The generating efficiency of a unit is a function of both the effective head and the flow passing through the turbine. In WEAP, the generating efficiency is a fixed value for all combinations of working heads and turbine flows. In reality, each individual unit has its own generating efficiency curve that states the relationship between the turbine flow and the efficiency. Since it is not possible to model this in WEAP, it is assumed that the generating efficiency is fixed at 85 % for both Banja and Moglice.

Banja and Moglice reservoirs and hydropower plants are modeled as "river" reservoirs in WEAP. All information about Banja and Moglice, including initial simulations of their potential hydroelectric production was received from Statkraft AS. Both reservoirs have three units: two units for the main production and one bypass unit for environmental flow requirements. The environmental flow requirement downstream Moglice is 1 m^3/s and 2 m^3/s downstream Banja. In addition, the concession agreement requires Banja to release water to Thana Reservoir and the Banja-Shkumbin Canal during the irrigation season. These numbers are presented in chapter 3.4. Volume-elevation curves for Banja and Moglice are found in appendix H. Table 3.7 shows some of the characteristics of Banja and Moglice power plants. For both reservoirs, the top and bottom of the buffer zone are set to HRWL and LRWL and the buffer coefficient is set to 1, allowing unrestricted releases from the conservation pool.

Table 3.7 *Banja and Moglice characteristics*

	LRWL (m.a.s.l.)	HRWL (m.a.s.l.)	Reservoir Capacity		Tailwater Elevation (m.a.s.l.)	H_{max} (m)	Q_{max} (m^3/s)
			Total (mill. m^3)	Active (mill. m^3)			
Banja	160	175	391	178.1	96	79	93
Moglice	625	650	362	151.7	349	301	65

In reality, a hydropower plant is not operated every hour, 365 days a year. The turbines are either running at their full capacities with high generating efficiencies or they are not running at all. Commonly, there are more than one turbine in a hydropower plant, which allows for more flexible operations and better utilization of the available water. The turbines have typically different maximum flow capacities, where the smaller ones are operated during periods of low water availability. It is a complex exercise to optimize the operation of a hydropower plant. The operation of the turbines is a function of several variables: the available storage, working head and their generating efficiency curves. In addition, power companies desire to run the power plants during periods of high profitability to maximize the income if possible. Because WEAP cannot model several turbines with different capacities, it is not possible model an environmental release and the river will dry up when the turbines are not running. To accommodate for this limitation, the plant factor is set to 100 % for both power plants. The environmental flow requirements are modeled as separate nodes downstream Moglice and Banja with a WEAP priority of 1, which ensures that the requirements always will be fulfilled. The production schedules at Banja and Moglice are not determined yet. Because of this, there does not exist any production goals for different days, weeks or months over the year. An initial assessment of the potential hydroelectric generation at Moglice and Banja has been conducted based on 40 years of runoff data (Snorre M. Mossing, Statkraft AS, pers. comm., 26.05.2015). These numbers represent average values for the 40 years and are based on optimal operation. The estimates are shown in Table 3.8 and assume an annual plant factor of 47.9 % at Banja HPP and 32.5 % at Moglice HPP.

Table 3.8 *Estimated monthly inflows and hydroelectric generation*

Month	Banja		Moglice	
	Inflow (m^3/s)	**Generation (GWh)**	**Inflow (m^3/s)**	**Generation (GWh)**
Jan	33.2	26.3	28.6	43.9
Feb	39.7	26.1	34.7	44.8
Mar	41.3	30.1	35.9	54.9
Apr	44.0	30.8	37.9	54.3
May	31.9	27.7	27.2	48.6
Jun	15.7	16.1	13.2	28.8
Jul	8.3	12.5	7.1	26.1
Aug	6.3	10.9	5.4	22.4
Sep	9.0	12.6	7.9	28.3
Oct	13.8	14.2	12.2	27.5
Nov	26.5	21.4	23.5	37.2
Dec	34.3	25.9	29.8	48.2
	Sum	254.6	Sum	465.0

The WEAP priority of the power plants are set to 2 during the irrigation season, and as 1 the rest of the year. Moglice reservoir is the most important for the annual generation and it is assumed that filling of Moglice has higher priority than Banja. To make WEAP run the power plants in the same pattern as in Table 3.8, the numbers were converted to daily values and uploaded into WEAP as demands. WEAP will then always try, as long as there is water available in the reservoirs, to run the power plants to meet the daily demand.

3.4 Devoll River Basin in the Future

The construction of the Devoll Hydropower Scheme will be finished in 2019. Operation of the Banja and Moglice reservoirs and power plants will have a significant impact on the future flow regime of Devoll River. Three different scenarios based on different assumptions have been defined to study the synergy between climate, irrigation and operation of the Devoll Hydropower Scheme. The aim of the scenarios is to be relevant and represent feasible future developments of the Devoll River Basin.

3.4.1 Projections of Climate Change

The foundation for all of the scenarios are the climate predictions in the *"Annex I: Atlas of Global and Regional Climate Projections*" (IPCC, 2013a). In this report, different projections of climate change is presented based on different Representative Concentration Pathway (RCP) scenarios. IPCC presents four different RCP scenarios: RCP2.6, RCP4.5, RCP6.0 and RCP8.5. Each scenario represents an increase in the radiative forcing due to anthropogenic greenhouse gas (GHG) emissions, i.e. a RCP6.0 scenario is equal to an increase in the global energy budget of 6.0 W/m^2. An increase in the global energy budget causes surface heating, and changes climatic variables such as temperature, precipitation, seal level, etc. The report focuses only on changes in temperature and precipitation, and these are given as spatial maps for 35 different regions. Figure 3.6 shows an example of a map of temperature changes from the report.

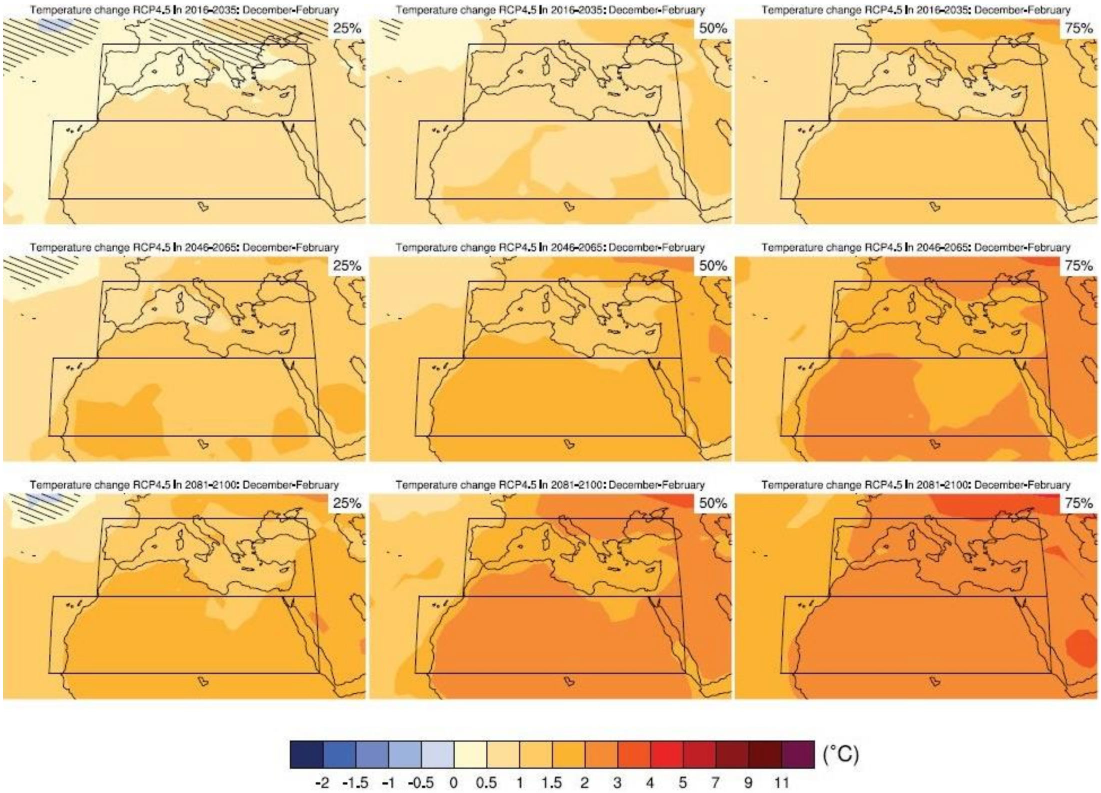

Figure 3.6 *Map of temperature changes (IPCC, 2013a)*

Temperature changes are presented for four seasons: December to February, March to May, June to August, and September to November, while relative precipitation changes are presented for two periods from October to March and April to September. The climate changes are relative to a reference period from 1986 to 2005, and given for three stages of twenty-year average changes: 2016-2035, 2046-2065 and 2081-2100. IPCC has used 42 global climate models to compute the temperature and precipitation changes (IPCC, 2013b). The maps show percentiles of the distribution of the results from the 42 models, with the 25th percentile to the left, the median in the middle and the 75th percentile to the right. For the work in this thesis, it is chosen to focus on the RCP4.5 scenario and the 50 percentile. Table 3.9 and Table 3.10 shows the changes in precipitation temperature found in the spatial maps in the report for RCP4.5.

Table 3.9 *Precipitation changes according to RCP4.5*

Months	2016-2035	2046-2065	2081-2100
(Oct – Mar)	- 10 %	- 10 %	- 10 %
(Apr - Sep)	- 10 %	- 15 %	- 20 %

Table 3.10 Seasonal temperature changes for RCP4.5

Months	2016-2035	2046-2065	2081-2100
(Dec - Feb)	+ 1.0°C	+ 1.5°C	+ 2.0°C
(Mar - May)	+ 1.0°C	+ 2.0°C	+ 2.5°C
(Jun - Aug)	+ 1.5°C	+ 2.5°C	+ 3.0°C
(Sep - Nov)	+ 1.0°C	+ 1.5°C	+ 2.0°C
Annual average	+ 1.1°C	+ 1.9°C	+ 2.4°C

The data set used as forcing data for the simulations is the same six-year period from 1980 to 1985 as used for calibration. This period is assumed to be representative for the climatic conditions for the 1986 to 2016 reference period for all scenarios. None of the data was initially adjusted as the temperature and precipitation trends result in insignificant changes from 1985 to 2016. Temperature and precipitation changes have been introduced with the delta change method, which is simply changing the input data series according to Table 3.9 and Table 3.10.

3.4.2 Agricultural Development

The concession agreement of the Devoll Hydropower Project requires Banja Reservoir to release water to important irrigation infrastructure downstream Banja Dam during the irrigation season between May and October. The total seasonal irrigation demand of the canals downstream of Banja is reported to be 150 million m^3 by the Albanian Ministry of Agriculture Food and Consumer Protection (MACFP) (Brevig and Knutsen, 2013). This demand comprises 100 million m^3 to Thana Reservoir, 40 million m^3 to the Banja-Shkumbin Canal and 10 million m^3 to irrigated land downstream of Vlashuk Barrage. The releases are specified to be sufficient to fill Thana Reservoir before the 1st of May, and provide sufficient water during the peak of the irrigation season between the 1st of July to the 15th of August. For the intermediate canals it is specified that the 40 million m^3 needs to be released from the 16th of July to the 15th of August. The sum of the MACFP requirements is equal to a maximum daily flow of 31.74 m^3/s in the second half of July.

Today, most of the irrigation infrastructure between Maliq and Banja is either removed or in a inoperable condition. Most of the existing irrigation schemes are small, gravity based schemes with very low intake capacities. Rehabilitation of the once existing Governmental pump schemes is not probable as the condition of the majority of the schemes is beyond repair, and the costs are much larger than the benefits. Development of irrigation schemes between Maliq and Banja is not likely because of lack of infrastructure and low amounts of irrigated land (Pål Høberg, Director Environmental And Social Management at Devoll Hydropower Project, Statkraft AS, pers. comm., 22.,01.2015). The Korce Plateau has still considerable agricultural activity. A major concern for the Devoll Hydropower Project is the irrigation in the upper reaches of the catchment. There are repeated statements from the Korce Drainage Board of no flow at Maliq during the summer months (Norconsult, 2011a). Korce Drainage Board is also planning additional reservoirs in the upper reaches of the Devoll River. Today, the reported irrigation command area and the drainage area at the Korce Plateau are about 23,000 and 20,000 hectares, respectively. The impression during a field trip to the Korce Plateau in February 2015 was that only a small portion of these areas is serviceable. Figure 3.7 shows a picture taken of a drainage canal at the Korce Plateau during the field trip. It is clogged by weeds and rubbish and clearly in a poor condition.

The condition of the barrages along Devoll River and the four control structures is

Figure 3.7 *Drainage canal at the Korce Plateau. Photo: Christian Almestad*

poor and not completely known. Even though a large portion of the irrigation and drainage infrastructure in this area is in poor condition, the Korce Plateau remains an important area in agricultural terms. Completion of several Word Bank Rehabilitation Projects in the area, in addition to continued reforms and investments in the area, indicate that the irrigation demand is likely to grow in future.

3.4.3 Scenario Definition

Three scenarios of development of the Korce Plateau has been created with the RCP4.5 climate scenarios as the foundation. The reference year for all scenarios is 2020, and the climatic conditions in 2020 are assumed to be equal to the period 1980 to 1985. Climate changes will take place from year 2021 and each scenario has three stages of climate changes according the RCP4.5 scenario. Stage 1 is 2035 to 2040, stage 2 is 2065 to 2070 and stage 3 is 2100 to 2105. For all scenarios it is assumed that Banja is obliged to fulfill MACFP's requirements during the irrigation season. Further, it is assumed that there will be no future development between Maliq and Banja and irrigation withdrawals in this area are negligible. The seasonal distribution of the irrigation withdrawals is assumed to be similar to the distribution defined for Korce Plateau in chapter 3.2. Irrigation efficiency is assumed to be 50 % and the consumption 80 % for all irrigation schemes upstream Maliq. Where no information about design capacities for irrigation schemes exists, it is assumed that the schemes are designed on a hydromodule of 0.001 m^3/s per hectare. Banja and Moglice reservoirs are assumed to be fully filled at the start of stage 1. For stage 2 and 3, it is assumed that the active storages are half full at the beginning of the simulations. At last, it is assumed that all irrigation schemes have equal WEAP priority of 1, and that irrigation is prioritized over hydropower generation during the irrigation season. The irrigation season is from April to October. Hydropower generation will have priority 2 in WEAP during these months and a priority of 1 the rest of the year.

Scenario 1

This scenario is called the “No Upstream Irrigation” scenario. It assumes continuing deterioration of the irrigation infrastructure upstream Maliq. By 2035, all of the schemes are assumed to be inoperable and crops are only rainfed.

Scenario 2

This scenario is supposed to describe the current situation upstream Maliq and is referred to as the “Present Upstream Irrigation” scenario. It does not reflect the true picture but is the best approximation obtained based on the available information. Most crops grown in the area have low seasonal water demands and are both rainfed and irrigated with water from Devoll River. The average seasonal irrigation demand for all schemes is assumed to be 3000 m^3 per hectare. Table 3.11 shows the model set up in WEAP. The command areas in the table are the ones assumed serviceable.

Table 3.11 *WEAP model set up scenario 2*

Name	Command Area (ha)	Design Capacity (m^3/s)	Seasonal Requirement (million m^3)	Peak Flow (m^3/s)
Miras	250	0.200	1.50	0.160
Menkulas	250	0.250	1.50	0.160
Poncare	300	0.350	1.80	0.190
Dobranj	400	0.300	2.40	0.260
Proger	150	0.200	0.90	0.100
Zemblak N	3,500	3.500	21.00	2.270
Zemblak S	3,300	3.300	19.80	2.240
Maliq	2,385	2.385	14.61	1.550
Total	10,535	13.400	63.21	6.840

Scenario 3

This scenario assumes continuing development, investment and rehabilitation of the irrigation schemes in the Korce area. It is referred to as the “Increasing Upstream Irrigation” scenario. For this scenario, the areas once serviced by the Prespa Canal and the unserviceable portion of the areas at Maliq are assumed rehabilitate. In addition, it is assumed development of 5000 hectares of irrigated areas that withdraw water from Dunaveci River. Further, it is assumed that crops with a higher demand is grown with an average seasonal demand of 4000 m^3 per hectare. The WEAP model set up for the scenario is listed and the schematic is seen in Figure 3.8. In this figure, green circles represent basin nodes and red circles irrigation command areas. The green and red lines are withdrawal and return flow links. Hatched blue lines mark catchment inflow links and purple circles are instream environmental flow requirement nodes. Demand nodes without return flow links are diversions.

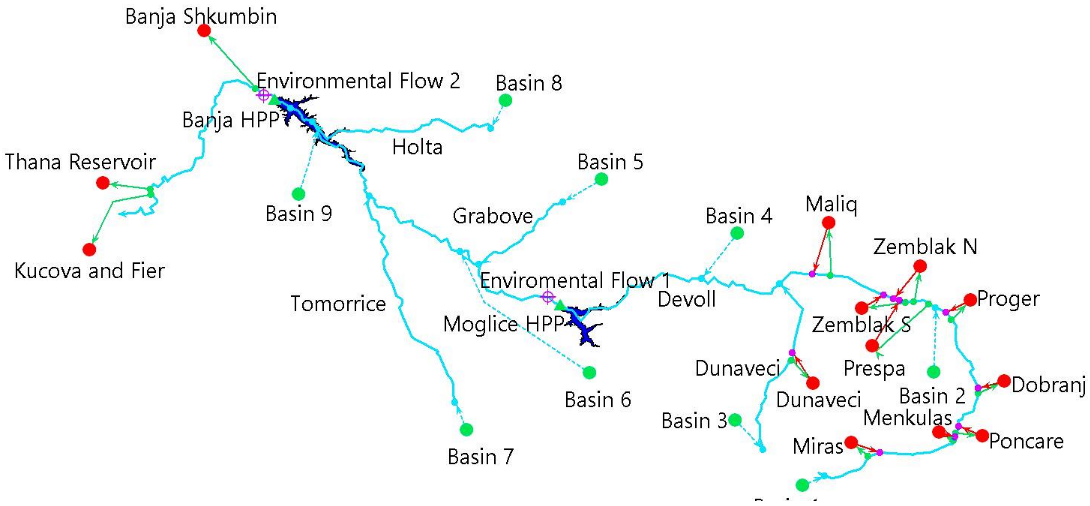

Figure 3.8 *WEAP schematic scenario 3*

Table 3.12 *WEAP model set up scenario 3*

Name	Command Area (ha)	Design Capacity (m^3/s)	Supply Requirement (million m^3)	Peak Flow (m^3/s)
Miras	250	0.200	2.00	0.220
Menkulas	250	0.250	2.00	0.220
Poncare	300	0.350	2.40	0.260
Dobranj	400	0.300	3.20	0.350
Proger	150	0.200	1.20	0.130
Zemblak N	3,500	3.500	28.00	3.030
Zemblak S	3,300	3.300	26.40	2.860
Maliq	5,300	2.385	42.40	4.590
Prespa	6,500	6.500	52.00	5.630
Dunaveci	5,000	5.000	40.00	4.300
Total	24,950	22.900	199.60	21.610

4 MODEL CALIBRATION

A satisfactory model calibration is important to reduce the uncertainties in the model simulations. Calibration has been a challenging and time-consuming task mainly due to the number of sub-basins but also because of the uncertainties related to irrigation withdrawals. The model was calibrated manually with daily time steps. This chapter describes all assumptions and choices made in the process of calibrating the model. The calibration results and a sensitivity analysis of some of the parameters is presented.

4.1 Period for Calibration and Validation

The data used for calibration should encompass a sufficient range of hydrologic events to activate all model constituent processes during calibration (Moriasi et al., 2007). Practically, this means utilizing at least three to five years of continuous data which includes average, dry and wet years. A calibration can be conducted with either data from the same period for all sub-basins, or data from different periods for different sub-basins. The limiting factor for the choice of period for calibration has been the runoff time series. Figure 4.1 shows the timeline for the runoff data. Studying the figure, two alternatives appear immediately and are considered as the most feasible:

- **Alternative 1**: Calibrate two for six years of data from 1980 to 1985, and the rest of the basins for ten years of data from 1970 to 1979. Kokel is missing runoff data for 1976.
- **Alternative 2:** Calibrate all sub-basins with data from the same six-year period from 1980 to 1985. Sheqeras is missing data for January 1985.

A general challenge regarding the calibration is the irrigation withdrawals. Both alternatives are periods with ongoing development and construction of irrigation schemes throughout the whole catchment. Consequantly, the quality of the streamflow records during the periods for both alternatives highly questionable. There is no systematic record of the quantities of water withdrawn, only information about capacities of the irrigation schemes. In addition, only a few of the irrigation schemes identified have known years of construction. The possibility for other unidentified schemes that may have affected the runoff properties is also high.

In general, it is desirable to calibrate the model for the longest period of continuous data. There are several reasons to choose both of the alternatives. Although alternative

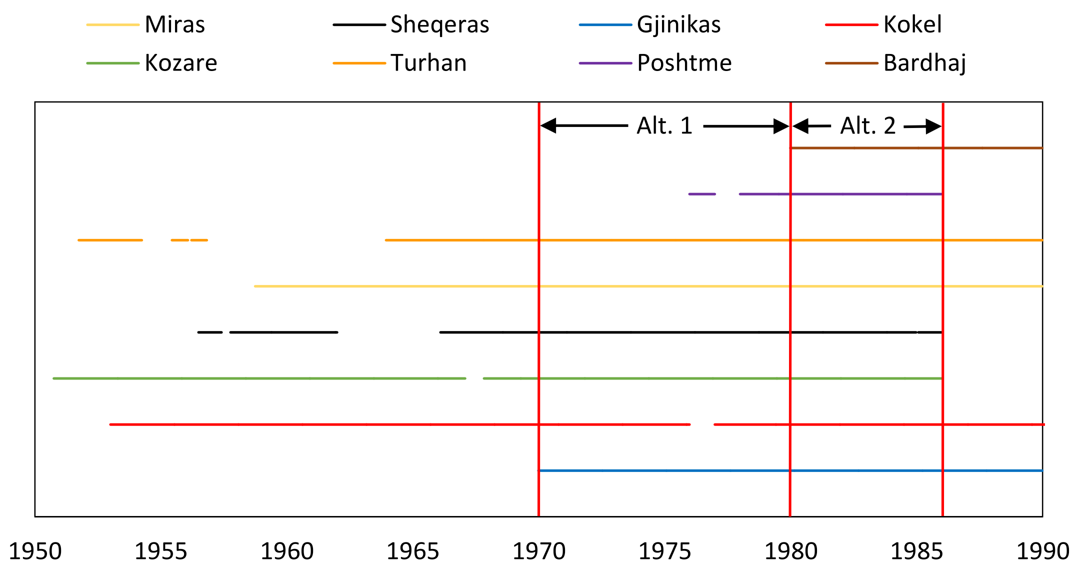

Figure 4.1 *Timeline for runoff time series*

1 has the advantage of a longer period of continuous data, there are some significant drawbacks related to this option. Firstly, figure 2.13 in chapter 2.2.4 shows significant changes in the runoff properties of the Sheqeras, Turhan and Kozare's gauging stations during the middle of this period. Calibrating the model for a period where the runoff properties of the catchment change is inappropriate. Furthermore, calibrating different basins for different periods may lead to an improper calibration as the climatic conditions and runoff properties are different during each period. It is also unpractical to calibrate separate basins for different periods in WEAP. Another drawback is the missing data at Kokel gauging station. Alternative 2 has a shorter period of data. Six years of continuous data is still sufficient to obtain an adequate model calibration. One factor weighing against this alternative is the Prespa Scheme that may have had a significant influence on the summer flows in the upper reaches of the Devoll River during the summer months. Runoff data during these months most likely does not represent the natural flow in the Devoll. On the other hand, it is believed that construction of most of the irrigation schemes was completed in the 1980s, and runoff data from this period are more stable than from the previous decade. Figure 2.13 shows similar trends for all gauging stations during this period with no abrupt changes in the runoff properties either.

Alternative 2 was chosen because the runoff properties are more consistent during this period. Another factor weighing for the second alternative is the desire to use data from more recent years. The climatic conditions during alternative 2 is believed to be more similar to the present than the first alternative. Irrigation schemes included during the calibration, and their command areas, design capacities and irrigation requirements are listed in Table 3.6 in chapter 3.2. Ideally, the model should be validated after the calibration to confirm that the model simulates sufficiently accurate. Validation was not conducted, as there was insufficient data available after 1985 for all weather and gauging stations.

4.2 Measurement of Calibration Performance

In order to evaluate the accuracy of the calibration and validation of the model there needs to be some measurement and rating of performance. The accuracy is simply measured by comparing the observed and simulated data. Common methods are based on either graphical or statistical techniques. For example, graphical evaluation is simply a visual comparison of hydrographs or percentage exceedance probability curves of the simulated and observed data. Statistical quantitative techniques measure the fit between simulated and observed data, and rate them according to a defined scoring system. There exist a great number of different statistical quantitative methods. For the purpose of the work in this report, three quantitative statistics have been chosen based on the recommendation in the work of Moriasi et al. (2007) to evaluate the calibration and accuracy of the model. The three statistics are percent bias (PBIAS), the Nash-Sutcliffe efficiency (NSE) and the ratio of root mean square error to the standard deviation of the measured data (RSR).

Percent bias (PBIAS) measures the deviation between simulated and observed data. A score of 0.0 is the optimal PBIAS value and values of low magnitudes express an accurate model estimation. Positive PBIAS values indicate model underestimation, while negative values indicate the contrary.

$$PBIAS = \frac{\sum_{i=1}^{n}\left(Q_i^{obs} - Q_i^{sim}\right) \times 100}{\sum_{i=1}^{n} Q_i^{obs}} \tag{4-1}$$

PBIAS is computed with equation 4-1 where PBIAS is expressed as percentage of deviation. Q_i^{obs} and Q_i^{sim} are the *i*th observed and simulated streamflow, and *n* is the total number of observations. The Nash-Sutcliffe efficiency (NSE) is commonly used and popular statistic that indicates how good the observed and simulated data fit. NSE is a normalized statistic that measures the relative magnitude of the variance of the simulated data compared to the variance of the observed data. NSE is calculated with equation 4-2, where Q_i^{obs} and Q_i^{sim} have the same meaning as for PBIAS. Q_{mean} is the mean value for the observed data.

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}\left(Q_i^{obs} - Q_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Q_i^{obs} - Q_{mean}\right)^2}\right] \tag{4-2}$$

The optimal value of the NSE is 1.0 and values can range between -∞ and 1.0. Values below 0.0 indicates unacceptable model performance, while values between 0.0 and 1.0 indicate an acceptable model performance. The root mean square error (RMSE) is a commonly used statistical error index. RMSE standard deviation ratio (RSR) standardizes the RMSE by dividing it by the standard deviation of the observed data. RSR is computed by equation 4-3. Q_i^{obs}, Q_i^{sim} and Q_{mean} are of same meaning is in PBIAS and NSE.

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\sqrt{\sum_{i=1}^{n}(Q_i^{obs} - Q_i^{sim})^2}}{\sqrt{\sum_{i=1}^{n}\left(Q_i^{obs} - Q_{mean}\right)^2}} \tag{4-3}$$

RSR values range from 0.0 to larger positive values. An RSR value 0.0 is the optimum and indicates no residual variation and perfect model behavior. The lower the RSR value is, the better the model performs. Based on an extensive literature review on methods of watershed model evaluation, Moriasi et al. (2007) defined model evaluation criteria for PBIAS, NSE and RSR. Table 4.1 lists the statistics and their recommended performance ratings.

Table 4.1 *Performance rating for PBIAS, NSE and RSR (Moriasi et al., 2007)*

Performance	PBIAS (%)	NSE	RSR
Very Good	PBIAS < ±10	0.75 < NSE ≤ 1.00	0.00 ≤ RSR ≤ 0.50
Good	±10 ≤ PBIAS < ±15	0.65 < NSE ≤ 0.75	0.50 < RSR ≤ 0.60
Satisfactory	±15 ≤ PBIAS < ±25	0.50 < NSE ≤ 0.65	0.60 < RSR ≤ 0.70
Unsatisfactory	PBIAS ≥ ±25	NSE ≤ 0.50	RSR > 0.70

The ratings in table 4.1 are recommended for data with a monthly time step and need to be modified appropriately for other time steps. According Moriasi et al. (2007), model simulations are in general less accurate for smaller time steps, and more relaxed performance ratings can be applied when using daily time steps.

4.3 Calibration Results

The conceptuality and parameters of the WEAP soil moisture method is described in detail in chapter 3.3.2. Most of the soil parameters were calibrated but parameters were predetermined before calibration. Values for the leaf area index (*LAI)* and crop coefficients (K_c) for both vegetation classes were found in the work of Ingol-Blanco and McKinney (2013). For vegetation class A that comprises forest, shrubs and bushes, the leaf area index was set to 6.0 and the crop coefficient to 0.5. Vegetation class B includes all irrigated areas, and the leaf area index was set to 2.5 and the crop coefficient to 1.0. The initial snowpack was set to 50 mm for basin 9 and 100 mm for all the others. For snow accumulation calculations, the freezing point was set to -0.1°C and the melting point to 2.0°C. Data on relative humidity, wind speed and cloudiness fraction used in the calibration is found in appendix C. The parameters that were chosen to calibrate are:

- S_w: Soil water capacity
- D_w: Deep capacity
- k_s: Root zone conductivity
- k_2: Deep conductivity
- f: Flow direction
- z_1, z_2: Initial moisture content of the root zone and deep layer

It is possible to define a daily variation for some of the soil parameters in WEAP. This function was not used because it was assumed that all parameters are constant with time. The calibrated parameter values and the hydrographs of the observed and simulated data for all basins are found in appendix G. Basin 7 was not calibrated as it has no runoff data. Parameter values for basin 7 were qualitatively chosen based on the calibrated parameter values of the neighboring basins. The estimated mean annual runoff for Tomorrice River is 3.88 m^3/s. Table 4.2 shows the calibration performance for each of the basins.

Table 4.2 *Performance of calibration*

Sub-basin	Q_{obs} (m^3/s)	Q_{sim} (m^3/s)	NSE	RSR	PBIAS
1	1.63	1.71	0.26 (Unsatisfactory)	0.86 (Unsatisfactory)	-4.72 (Very good)
2	3.83	3.86	0.29 (Unsatisfactory)	0.84 (Unsatisfactory)	-0.71 (Very good)
3	2.66	2.87	0.25 (Unsatisfactory)	0.87 (Unsatisfactory)	-7.92 (Very good)
4	13.77	12.93	0.42 (Unsatisfactory	0.76 (Unsatisfactory)	6.08 (Very good)
5	2.45	2.37	0.20 (Unsatisfactory)	0.90 (Unsatisfactory)	3.43 (Very good)
6	26.41	28.13	0.47 (Unsatisfactory)	0.73 (Unsatisfactory)	-6.49 (Very good)
7	-	3.88	-	-	-
8	5.94	5.86	0.30 (Unsatisfactory)	0.84 (Unsatisfactory)	1.38 (Very good)
9	35.23	36.32	0.47 (Unsatisfactory)	0.73 (Unsatisfactory)	-3.09 (Very good)

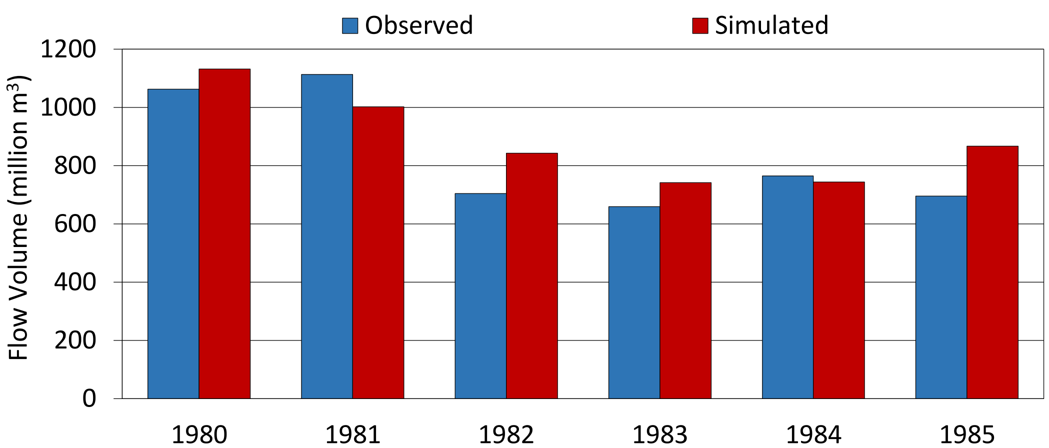

Figure 4.2 *Observed and simulated annual flow volume at Kokel*

Figure 4.2 shows that the model simulates the annual water balance adequately. The model scores well with respect to PBIAS. All basins have a PBIAS score corresponding to the best achievable rating. Basin 4, 6 and 9 have NSE and RSR scores close to satisfactory. Basin 1, 3, 5 and 8 are basins for tributaries that flow into the Devoll River. Their performance was inferior with respect to NSE and RSR scores. Figure 4.3 shows a comparison of the observed and simulated daily runoff at Kokel.

The figure shows that the model simulates the natural variability in runoff sufficiently accurate but is struggling with simulating the flood peaks accurately. Most of the flood peaks are not recreated by the model and if they were, they are mostly underestimated. In addition, the model has a tendency of underestimating the runoff during the spring months and overestimate the runoff during the autumn. On the other hand, the model simulates the periods of low flow sufficiently accurate. Similar trends are seen for all of the basins.

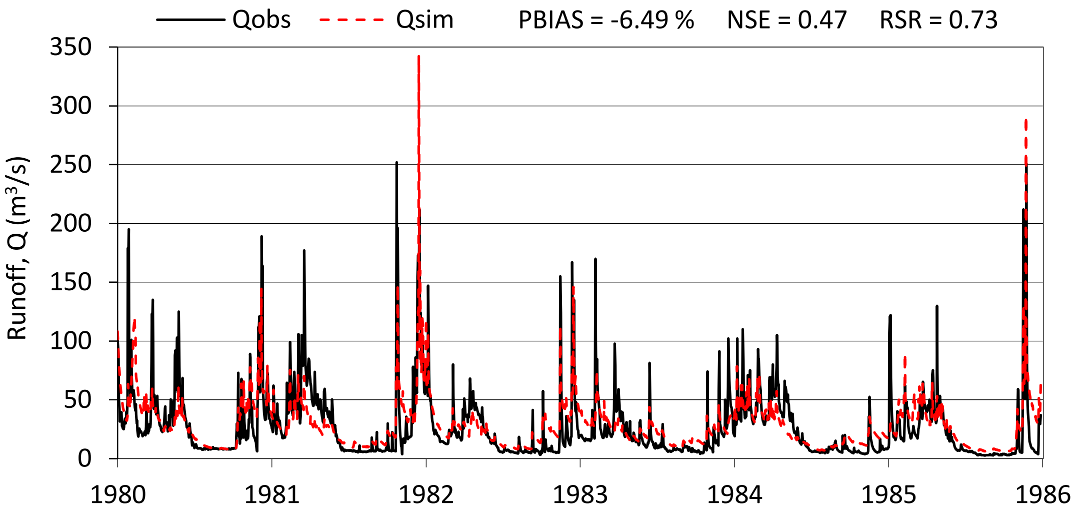

Figure 4.3 *Observed and simulated runoff at Kokel*

Although the model does not perform satisfactory with respect to NSE and RSR, it is still believed that the calibration is adequate. Firstly, the model performs surprisingly well considering that the model has been calibrated for a period of runoff data that is heavily influenced by irrigation. Studying the runoff data shows that water has been randomly withdrawn, and it is nearly an impossible task to systematically track the withdrawals. Secondly, the purpose of the work has to be taken into account when evaluating the model performance as well. Water balance is the main purpose of the work in this project and not simulation of flood events. NSE and RSR are sensitive to flood peaks. A small displacement of the simulated flood peaks relative to the observed will have a significant impact on these statistics. Therefore, the importance of these statistics is less emphasized than the PBIAS. Visual evaluation of the hydrographs confirms a sufficient level of agreement between the observed and simulated data. Finally, it has to be taken into account that the ratings in Table 4.1 are recommended for a monthly time step. It is assumed that a NSE above 0.40 can be considered as satisfactory for a daily time step. It can therefore be concluded that the calibration is adequate and that the model is sufficiently accurate for its purpose.

4.4 Sensitivity Analysis

Sensitivity analysis is the process of determining which model parameters have the largest impact on the model performance. Commonly, a model calibration starts with a sensitivity analysis to identify the parameter precision needed to obtain an adequate model calibration. An opposite approach was chosen for this project. The sensitivity analysis was conducted after the calibration and only for one basin. Because all basins are heavily influenced by irrigation, the choice of the basin to study becomes rather arbitrary. Basin 2 was chosen as it lies in the upper reaches of the Devoll and performs well with respect to PBIAS. The accumulated effect of irrigation may be less in the upper reaches of the Devoll than further downstream. Another reason for this choice is that the portion of each of the vegetation classes is equal in Basin 2. The sensitivity was assessed by adjusting the parameters with a value of ± 50 %.

Table 4.3 *Result of the sensitivity analysis*

Parameter	**Parameter value**			**Flow volume (million m^3)**			**Relative change**	
	Cal.	**+ 50 %**	**+ 50 %**	**Cal.**	**+ 50 %**	**- 50 %**	**+ 50 %**	**- 50 %**
Class A								
S_w	280	420	140	97.6	96.7	99.2	- 0.9 %	+ 1.6 %
k_s	3	4.5	1.5	97.6	100.3	94.4	+ 2.8 %	- 3.2 %
Class B								
S_w	200	300	100	97.6	97.2	99.0	- 0.4 %	+ 1.4 %
k_s	30	45	15	97.6	98.1	97.2	+ 0.5 %	- 0.4 %
Class A + B								
S_w		As above		97.6	96.3	100.6	- 1.3 %	+ 3.0 %
k_s				97.6	100.8	94.0	+3.3 %	- 3.7 %
D_w	3000	4500	1500	97.6	96.2	102.8	- 1.4 %	+ 5.3 %
k_2	0.1	0.15	-	97.6	100.4	-	+ 2.9 %	-

Only calibrated parameters were included in the analysis except the initial soil moisture content (z_1 and z_2) and flow direction because their maximum value is 1. The calibrated value of the deep conductivity (k_2) for Basin 2 corresponds to the minimum allowable value in WEAP; hence, the 50% reduction was not possible to assess. Both the individual effect of varying one parameter in just one vegetation class, and the joint effect of changing the same parameter in both vegetation classes were analyzed. Deep water capacity and deep conductivity are independent from the vegetation classes. Table 4.3 shows the results of the analysis. The most sensitive parameters are the deep water capacity and the root zone conductivity. However, it is believed that irrigation has the largest impact on the calibration result.

5 RESULTS

This chapter presents the results from the simulated scenarios. All results are presented as averages of the six years for all three stages of climate change. The reference period represents climatic conditions for the years 1980 to 1985, and not the present climate (2015). Changes in precipitation and evapotranspiration are independent from the scenarios and are presented collectively for all scenarios. Runoff, reservoir evaporation and hydropower generation are presented separately for all scenarios. The results presented in this chapter are further discussed in chapter 6.

5.1 Precipitation and Evapotranspiration

The precipitation changes for each stage of the RCP4.5 climate change scenario is depicted in Table 5.1. Table 5.2, while Figure 5.1 show the effects of the climate changes on the annual precipitation volumes. The numbers are averages for all six years for each stage. Changes in precipitation and evapotranspiration is equal for all scenarios. It is apparent that the large relative reductions in the spring and summer months do not have a significant impact on the total annual precipitation.

Table 5.1 *Precipitation changes according to RCP4.5 climate scenario*

Months	2016-2035	2046-2065	2081-2100
(Oct – Mar)	- 10 %	- 10 %	- 10 %
(Apr - Sep)	- 10 %	- 15 %	- 20 %

Table 5.2 *Annual precipitation for all scenarios*

		Annual Precipitation Volume (million m^3)					
Basin	**Reference**	**2035-2040**		**2065-2070**		**2100-2105**	
1	80.7	72.6	-10.0 %	71.0	-12.0 %	69.7	-13.6 %
2	233.7	210.4	-10.0 %	205.4	-12.1 %	201.2	-13.9 %
3	225.3	202.8	-10.0 %	198.1	-12.1 %	194.5	-13.7 %
4	377.7	339.9	-10.0 %	332.6	-11.9 %	325.7	-13.8 %
5	78.8	70.9	-10.0 %	69.0	-12.4 %	67.3	-14.6 %
6	473.3	426.0	-10.0 %	416.7	-12.0 %	409.8	-13.4 %
7	408.2	367.4	-10.0 %	359.4	-12.0 %	352.9	-13.6 %
8	286.7	258.1	-10.0 %	251.8	-12.2 %	246.4	-14.1 %
9	769.5	692.6	-10.0 %	675.6	-12.2 %	660.8	-14.1 %
Sum	2933.9	2640.6	-10.0 %	2579.5	-12.1 %	2528.2	-13.8 %

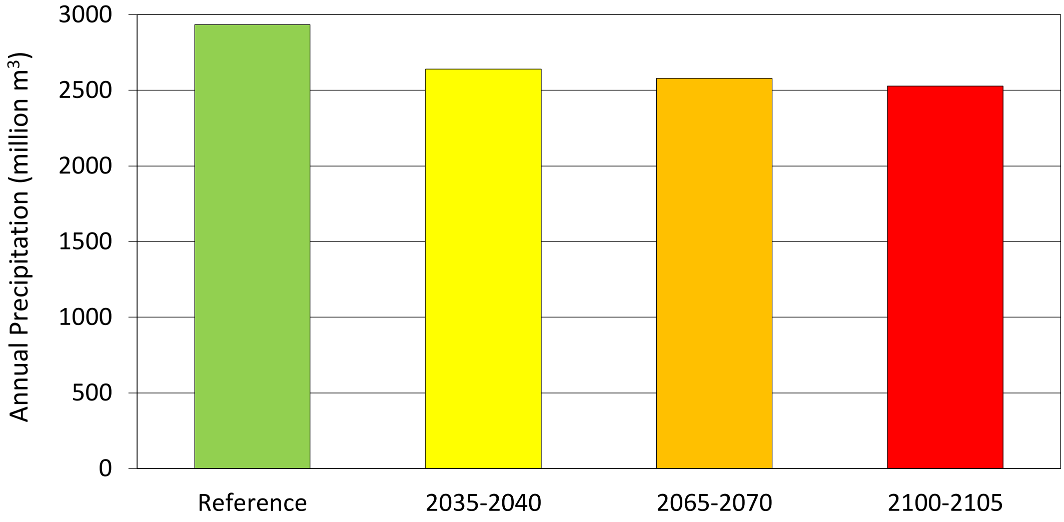

Figure 5.1 *Annual precipitation volumes for reference period and scenarios*

Table 5.3 and Figure 5.2 show the change in the potential and actual surface evapotranspiration from the catchment, and the change in the ratio between evapotranspiration and precipitation. These values were computed in WEAP with the FAO Penman-Monteith equation. All numbers represent the total evapotranspiration from the whole catchment.

Table 5.3 *Annual potential and actual evapotranspiration simulated in WEAP*

	Evapotranspiration (million m^3)						
	Reference	**2035-2040**		**2065-2070**		**2100-2105**	
Potential	1922.9	2000.7	+ 4.05 %	2051.2	+ 6.67 %	2083.0	+ 8.33 %
Actual	721.9	704.6	- 2.39 %	703.8	- 2.50 %	698.4	- 3.25 %
ET/P	0.246	0.267	+ 2.08 %	0.273	+ 2.68 %	0.276	+ 3.02 %

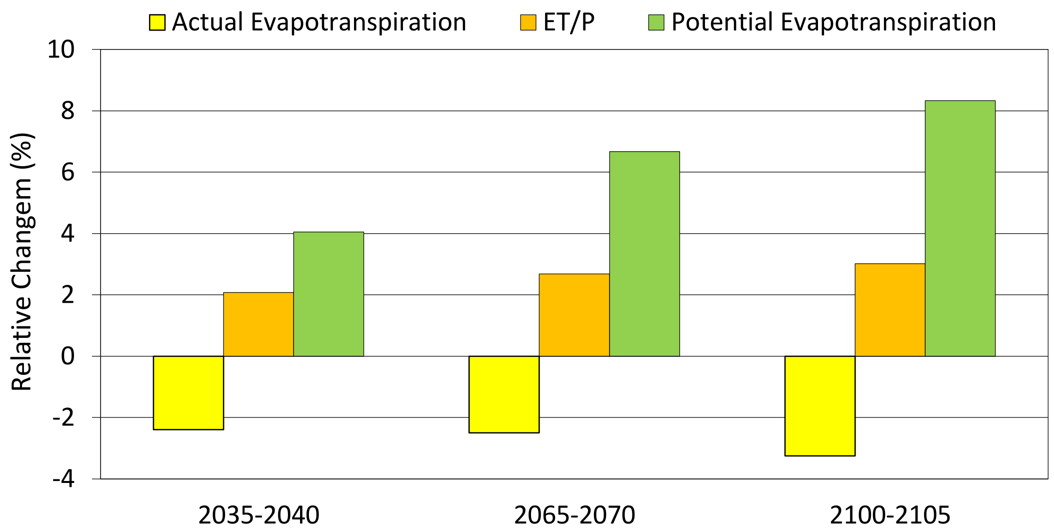

Figure 5.2 *Change in potential and actual evapotranspiration*

5.2 Runoff

Table 5.4 shows the mean annual runoff simulated for each sub-basin in WEAP. S1, S2 and S3 represent each stage of climate change. Figure 5.3 shows the simulated mean annual runoff at Sheqeras for all three scenarios. It is important to note that the reference period for the runoff data is not the observed data from 1980 to 1985, but the data simulated for the same period during the calibration of the model.

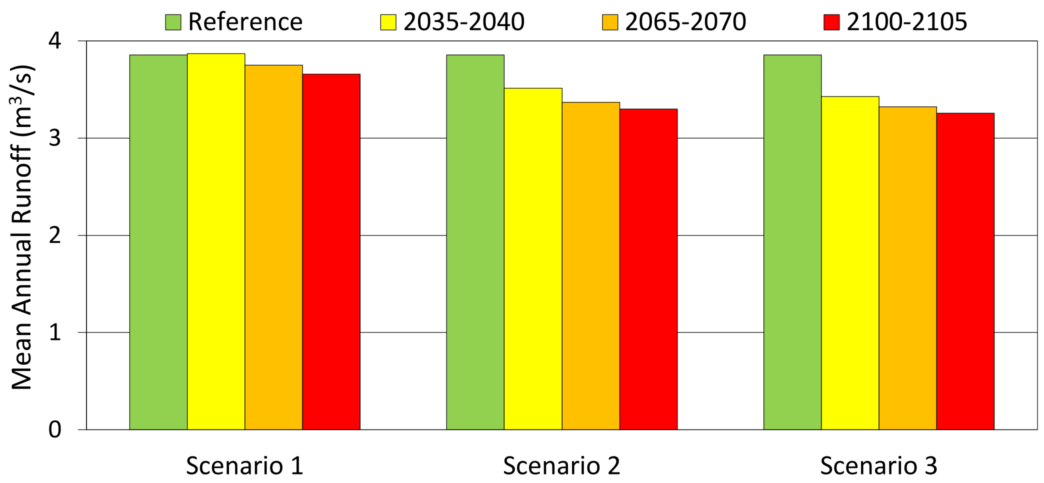

Figure 5.3 *Annual runoff at Sheqeras for reference period and all scenarios*

Table 5.4 *Simulated runoff in WEAP and reduction relative to reference period*

		Mean Annual Runoff (m^3/s)								
Gauging	**Reference**	**Scenario 1**			**Scenario 2**			**Scenario 3**		
Station	**Period**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
Miras	1.71	1.62	1.58	1.54	1.61	1.57	1.54	1.61	1.57	1.54
Sheqeras	3.86	3.87	3.75	3.66	3.51	3.37	3.30	3.43	3.32	3.26
Gjinikas	12.93	11.97	11.63	11.37	11.62	11.26	11.01	11.49	11.17	10.93
Kokel	28.13	26.20	25.17	24.67	25.84	24.78	24.30	25.71	24.70	24.22
Kozare	36.32	34.10	32.28	31.54	33.84	32.00	31.27	33.73	31.93	31.20
Turhan	2.87	2.39	2.32	2.28	2.39	2.32	2.28	2.35	2.28	2.24
Poshtme	2.37	2.14	2.09	2.04	2.14	2.09	2.04	2.14	2.09	2.04
Bardhaj	5.86	5.18	5.00	4.86	5.18	5.01	4.86	5.18	5.01	4.86
Tomorrice	3.88	3.22	3.13	3.07	3.22	3.14	3.07	3.23	3.14	3.07
Relative change (%)										
Miras		-5.4	-7.8	-9.7	-5.7	-8.1	-10.0	-5.7	-8.0	-10.0
Sheqeras		0.3	-2.8	-5.2	-8.9	-12.7	-14.5	-11.2	-13.9	-15.6
Gjinikas		-7.5	-10.0	-12.1	-10.1	-13.0	-14.8	-11.1	-13.6	-15.5
Kokel		-6.9	-10.5	-12.3	-8.1	-11.9	-13.6	-8.6	-12.2	-13.9
Kozare		-6.1	-11.1	-13.2	-6.8	-11.9	-13.9	-7.1	-12.1	-14.1
Turhan		-16.9	-19.1	-20.7	-16.9	-19.1	-20.7	-18.3	-20.5	-22.1
Poshtme		-9.7	-12.0	-14.0	-9.7	-11.9	-14.0	-9.6	-11.9	-14.0
Bardhaj		-11.7	-14.6	-17.0	-11.7	-14.6	-17.0	-11.6	-14.6	-17.0
Tomorrice		-16.9	-19.2	-21.0	-16.9	-19.2	-21.0	-16.8	-19.2	-21.0

Surprisingly, the numbers reveal that the reduction in the annual runoff is less than the reduction in the annual precipitation for all scenarios at Miras and Poshtme. The same trend is seen for Kokel and Kozare in scenario 2 and at Gjinikas during scenario 1. Turhan, Tomorrice and Bardhaj are the most affected by climate changes. Irrigation has the strongest impact on the runoff at Sheqeras. This is the only place that irrigation has a stronger impact than the climate changes. Comparing scenario 1 and scenario 3 show that the irrigation withdrawals reduce the runoff with more than 10 % at Sheqeras. Sheqeras also shows an increase in the annual runoff from 2035 to 2040 for scenario 1, compared to the reference period. Comparing all three scenarios shows that irrigation has in general less impact on the runoff of than the climate changes for most of the locations studied.

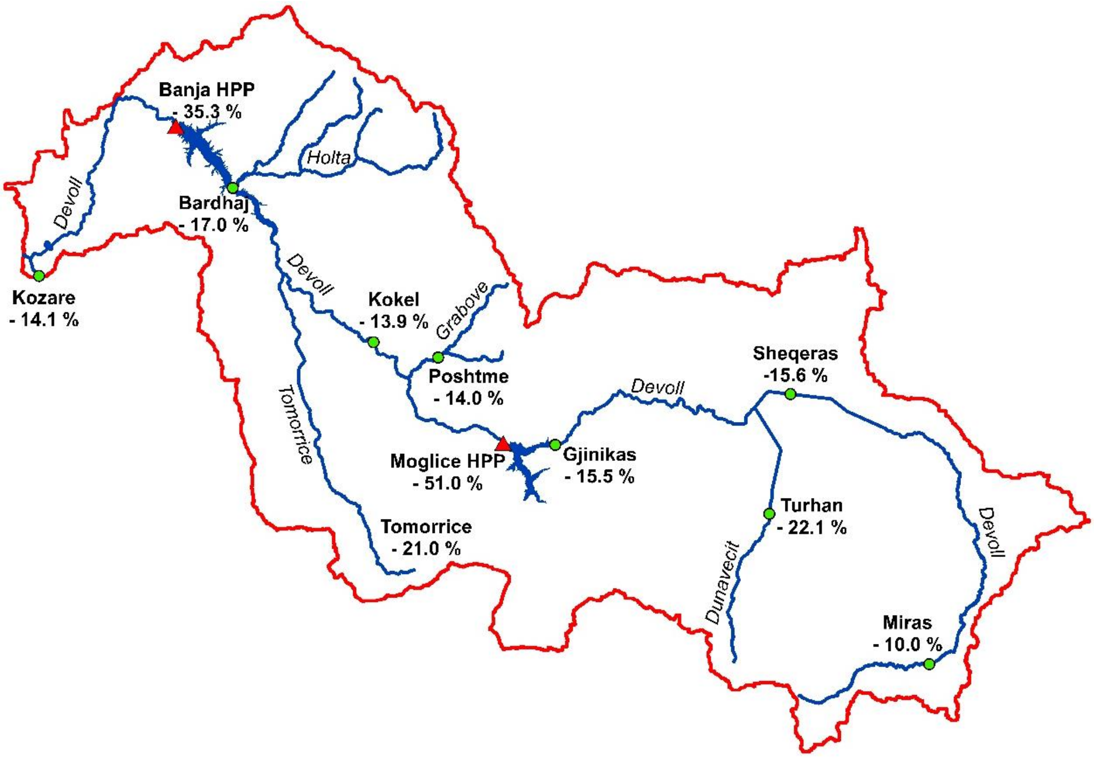

Figure 5.4 *Devoll River Basin from 2100 to 2105 according to scenario 3*

Figure 5.4 maps the "worst case scenario" for Devoll River Basin and the corresponding reduction in the annual runoff and hydropower generation at Banja and Moglice. The 14.1 % reduction at Kozare, which is close to the outlet of the river basin, corresponds to a lost volume of approximately 161.5 million m^3 every year.

5.3 Reservoir Evaporation

The evaporation from the reservoirs was calculated manually using the Penman-Monteith equation. It is important to differentiate between the gross (ET_0) and the net (ET_{net}) when considering evaporation from reservoirs. Table 5.5 shows the theoretical gross and net evaporation for Banja and Moglice. All numbers are the average values for each six-year period. The minimum and maximum values assume constant reservoir elevation at LRWL and HRWL. Banja Reservoir has a surface area of approximately 9.8 km^2 at LRWL and 14.1 km^2 at HRWL, while Moglice Reservoir has 5.0 km^2 at LRWL and 7.2 km^2 at HRWL. As expected, the evaporation increases as temperatures rise due to the climate changes. The numbers in Table 5.5 show a significant difference between the gross and net evaporation. During the hottest period from 2100 to 2105, the annual maximum gross and net evaporation equaled approximately 10.5% and 2.3% of the active storage at Banja. At Moglice, the maximum gross and net evaporation from the same period accounts for approximately 5.8% and 1.6% of the active storage. These numbers are, however, only theoretical values but give a useful indication of the future evaporation losses at Banja and Moglice. The actual evaporation is a function of the reservoir elevation, which depends on the operation of the reservoirs.

Table 5.5 *Theoretical gross and net reservoir evaporation*

	Annual Gross Evaporation			Annual Net Evaporation		
Period	**ET_0 (mm)**	**Min (million m^3)**	**Max (million m^3)**	**ET_{net} (mm)**	**Min (million m^3)**	**Max (million m^3)**
Banja						
Reference	1215.0	11.91	17.13	11.5	0.11	0.16
2035-2040	1264.9	12.40	17.84	181.8	1.78	2.56
2065-2070	1299.9	12.74	18.33	243.5	2.39	3.43
2100-2105	1321.0	12.95	18.63	288.0	2.82	4.06
Moglice						
Reference	1128.2	5.64	8.12	97.5	0.49	0.70
2035-2040	1176.4	5.88	8.47	249.2	1.25	1.79
2065-2070	1210.3	6.05	8.71	303.4	1.52	2.18
2100-2105	1230.8	6.15	8.86	338.9	1.69	2.44

Table 5.6 *Reservoir evaporation simulated in WEAP*

	Actual Annual Evaporation (million m^3)					
	Banja			Moglice		
Scenario	**2035-2040**	**2065-2070**	**2100-2105**	**2035-2040**	**2065-2070**	**2100-2105**
1	1.76	2.25	2.70	1.22	1.25	1.43
2	1.54	1.97	2.46	1.00	1.25	1.43
3	1.36	1.86	2.34	1.00	1.25	1.43

It was found during the simulations in WEAP that both reservoirs had an average elevation approximately at LRWL for all three scenarios. The actual evaporation calculated during the simulations in WEAP is found in Table 5.6. Banja evaporates more water than Moglice because it lies at a lower and warmer altitude, and has a surface area at the LRWL approximately twice as large Moglice. Figure 5.5 shows the actual reservoir evaporation at Banja calculated by WEAP during the simulations.

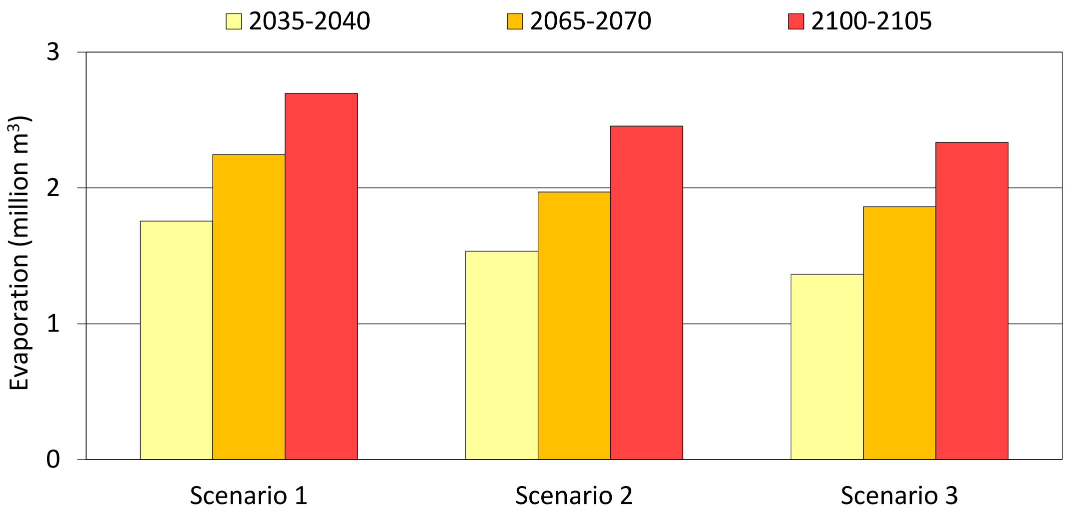

Figure 5.5 *Evaporation at Banja simulated in WEAP*

Irrigation clearly has a direct impact on reservoir evaporation, especially at Banja. Increased irrigation causes less inflow to the reservoirs and results in less water being available for evaporation. The same trend is seen at Moglice but there is no increase in evaporation from scenario 2 to scenario 3.

5.4 Hydropower Production

Because of the limitations of the hydropower function in WEAP, assumptions and some simplifications related to the generating efficiencies, plant factor and operating rules have been made. Consequently, the annual hydropower generation at Banja and Moglice hydropower plants are underestimated during the simulations in WEAP. Figure 5.6 shows the annual generation at Banja and Moglice for the first period from 2035 to 2040 in scenario 1. During the first year of operation, Banja and Moglice have a combined annual generation |of 648.4 GWh, which is 90 % of the expected amount.

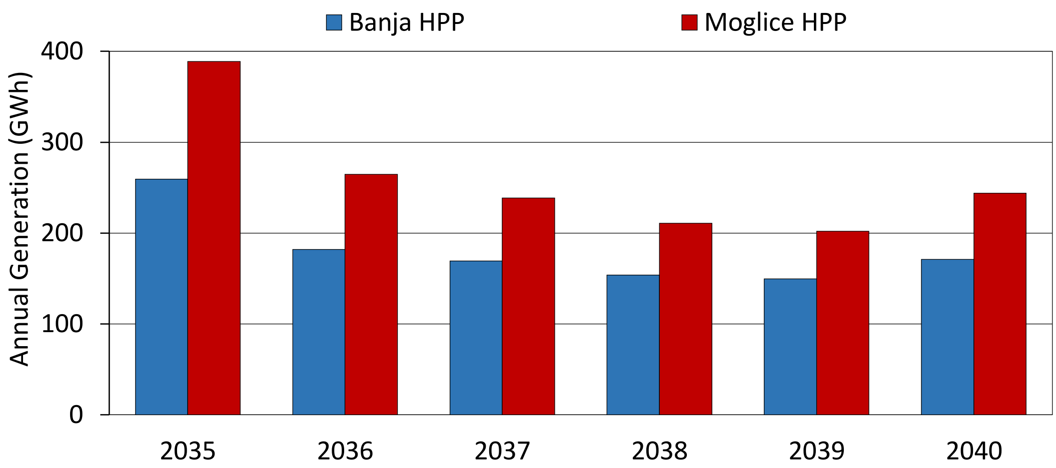

Figure 5.6 *Hydropower generation scenario 1*

During the following years, the annual generation is decreasing substantially, especially at Moglice. This trend is similar for each six-year period in all scenarios. Figure 5.7 that shows the storage of Banja Reservoir explains the decreasing trend in the annual generation. Blue lines represent the storage at LRWL and HRWL and the dotted red line is the actual storage during the simulation in WEAP.

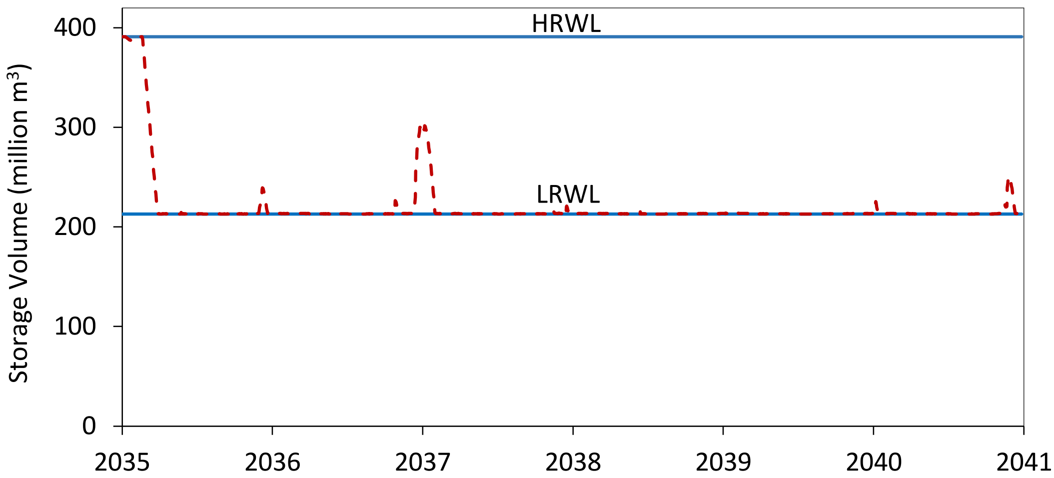

***Figure 5.7** Banja Reservoir 2035-2040 scenario 1*

Initially, the power plant ran at full capacity with a maximum working head and turbine flow. After a couple months, the active storage is empty and the power plant is running on a minimum working head. As WEAP forces the power plant to generate energy whenever possible, the reservoir never fills up and the turbines run constantly on a minimum working head causing low amounts of generated energy. The reservoir is operated more like a runoff-river plant and the elevation stays at LRWL except during a couple flood events. The same trend is also seen at Moglice. Because of the limitations, some assumptions about the future generation at Banja and Moglice have been made. Firstly, it is assumed that the power plants generate the expected amount in 2020, immediately after the completion of Moglice. Secondly, it is assumed that WEAP simulates the hydropower generation correctly and the numbers are used to calculate the reduction relative to the reference period.

Table 5.7 compares the hydropower generation simulated for all scenarios in WEAP with the expected generation. The numbers in the table show that climate change has a stronger impact on annual generation than irrigation. Irrigation withdrawals reduce hydropower generation by approximately 2% less than climate change. Climate changes also have a stronger impact on Moglice than Banja. Moglice will have an annual generation that is less than half of the expected amount at the end of the century.

Table 5.7 Simulated hydropower generation for all scenarios

	Annual Hydropower Generation (GWh)						
	Reference	2035-2040		2065-2070		2100-2105	
Scenario 1							
Banja	254.6	180.9	- 29.0 %	170.5	- 33.0 %	166.7	- 34.5 %
Moglice	465.0	258.1	- 44.5 %	242.2	- 47.9 %	236.7	- 49.1 %
Total	719.6	439.0	- 39.0 %	412.8	- 42.6 %	403.4	- 43.9 %
Scenario 2							
Banja	254.6	179.3	- 29.6 %	168.7	- 33.7 %	165.0	- 35.2 %
Moglice	465.0	251.0	- 46.0 %	234.4	- 49.6 %	229.3	- 50.7 %
Total	719.5	430.3	- 40.2 %	403.1	- 44.0 %	394.3	- 45.2 %
Scenario 3							
Banja	254.6	178.7	- 29.8 %	168.3	- 33.9 %	164.6	- 35.3 %
Moglice	465.0	248.4	- 46.6 %	232.8	- 49.9 %	227.7	- 51.0 %
Total	719.5	427.1	- 40.7 %	401.1	- 44.3 %	392.3	- 45.5 %

The sustainability of Banja and Moglice can be evaluated by their water consumption. Fresh water consumption from a hydropower plant, commonly referred to as the water footprint, is usually measured as the gross evaporation from the reservoir divided by the annual power production. Hoekstra and Hung (2002) introduced the concept of water footprinting, which is defined as the *volume of freshwater used to produce the product, measured over the full supply chain*. Hoekstra et al. (2011) standardized the concept and methodology in “The Water Footprint Assessment Manual”, which is available for public use. However, there is no commonly accepted method for computing the water footprint of hydropower plants, and scientist are divided on the matter (Bakken et al., 2013). IPCC presented estimates on water footprint from hydropower plants up to 209 m^3/MWh in the report on renewable energy (IPCC, 2012). These numbers were based on gross evaporation. A full assessment of the water footprint of Banja and Moglice is a time consuming task and is not within the scope of this thesis. Only evaporation and annual generation is considered in this work.

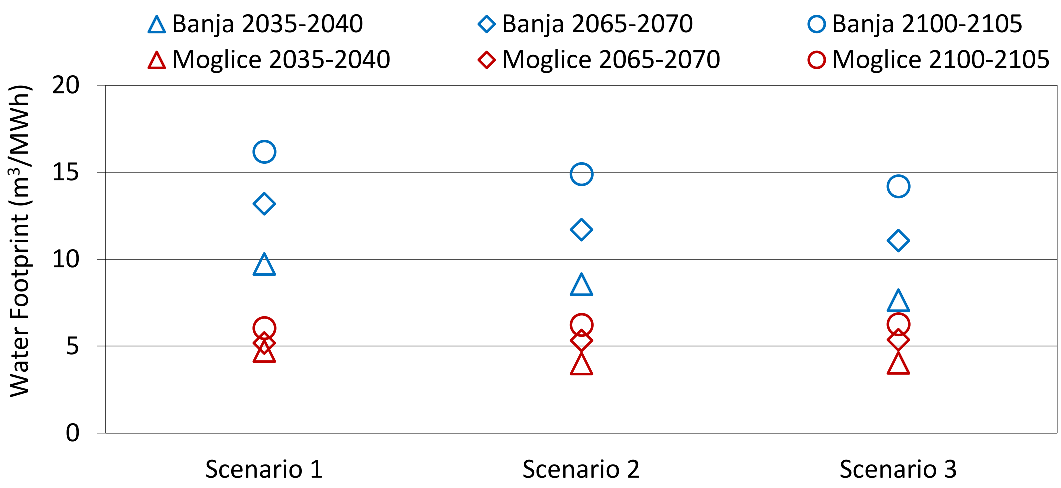

Figure 5.8 *Water footprints of Banja and Moglice HPP*

Figure 5.8 shows the estimated water footprints of Banja and Moglice for all three scenarios. The water footprints were computed as the annual evaporation minus the precipitation falling directly on the reservoir surface area divided by the annual hydropower production. Bakken et al. (2013) refer to this method as the “water balance” principle. Banja has a much greater footprint than Moglice due to a larger reservoir surface area and smaller annual generation. Banja and Moglice show opposite trends for the different scenarios. The decreasing water footprint at Banja is caused by the decreasing reservoir evaporation. At Moglice, the reservoir evaporation is identical during scenario 1 and 2, and the increasing water footprint is caused by the decreasing annual generation. It is believed that the real footprints will be smaller than indicated by this figure because WEAP underestimates the annual generation.

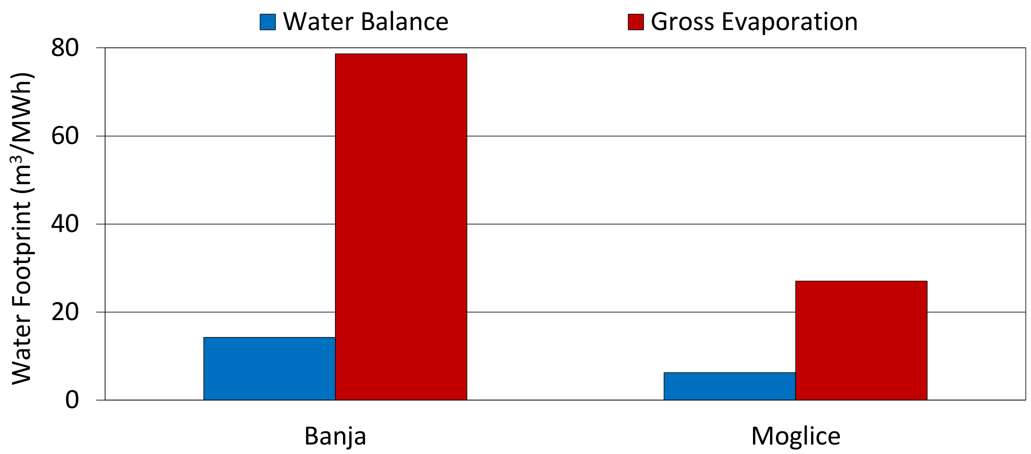

Figure 5.9 *Water footprint based on water balance and gross evaporation*

Figure 5.9 shows the average water footprint computed with both gross evaporation and the water balance principle at Banja and Moglice for the period 2100 to 2105 of scenario 3. It shows significant differences between the methods. The water footprints based on gross evaporation are more than four times larger than the footprints based on water balance.

6 DISCUSSION

The model developed is not perfect and shall not be considered as the true picture of the hydrologic processes in the Devoll River Basin. There has only been a limited amount of time for the work in this project. Consequently, many assumptions and simplifications have been made in the process of modeling that will directly affect the accuracy. The chapter summarizes and discusses all assumptions made during the modeling, and their likely impacts on the results in a qualitative manner. The last part discusses the results of the calibration and most importantly, the results of scenario simulations.

6.1 Quality of Input Data

Input data is the starting point of all uncertainties in this model. The very first assumption that introduces significant uncertainties and affects all of the results in this work is the assumption about the input data quality. This applies especially to the runoff data that is reported as highly questionable for all gauging stations used in this work except Kokel. Double mass analyses have shown in-homogeneities for several of the gauging stations that indicate changes in the runoff properties in the middle of the 1970s. Although the quality of most of the runoff data is reported as highly questionable, it was decided to assume that the time series at all gauging stations are of adequate quality. The runoff data forms the basis of the calibration and errors in the data set used for calibration will propagate through the whole model and bias the model outputs. However, the model is calibrated for a period that shows similar trends and no significant changes in the runoff properties at all gauging stations.

All climatic data has been averaged for each sub-basin. The weighting obtained with the Thiessen method of polygons may not represent the actual grade of influence of each of the stations within the catchment. Consequently, the basin-averaged values may not reflect the reality. In this work, this applies mostly to the precipitation data, especially for extreme events. Rainfall events that causes floods may be obscured, resulting in a model that underestimates the flood peaks. Similarly, the same effect can underestimate periods of drought. On the other hand, there is also a chance for the exact opposite effect: a model that overestimates floods and droughts. The eastern part of the catchment shows a strong correlation between the altitude and annual precipitation (Norconsult, 2010). Ideally, the precipitation data at each weather station should have been corrected for the mean elevation of the sub-basins before computing the basin-averaged precipitation.

The climate data downloaded with the FAO Climate Information Tool is based on the CRU2.0 (Climate Research Unit, University of East Anglia) high-resolution data set. This set comprises interpolated values at a resolution of 0.5° by 0.5°, which is equal to a grid of approximately 42 by 55 kilometers (X,Y) at 40 degrees north. Devoll River Basin stretches about 110 km from Greece in the east to the confluence with Osum River in the west. Although the grid is of a relatively high resolution, there is a chance that the interpolated values will not capture local climatic variations within the catchment. In addition, this data set comprises monthly averaged values for the period 1961 to 1990. The climatic conditions during these 30 years are probably different from the conditions between 1980 and 1985. However, it is assumed that the data is representative for the actual period studied. Data used in the model from the CRU2.0 set includes relative humidity, wind speed and cloudiness fraction.

Another assumption that affects the model output is the temperature data. The individual time series for each sub-basin and the reservoirs was created with the purpose of increased accuracy in simulations of snow accumulation, snowmelt, evapotranspiration, and reservoir evaporation. It is believed with great confidence that the time series created based on the temperature data recorded at Bilisht are of good quality due two reasons. Firstly, a comparison of the monthly mean temperatures at Bilisht and an individual time series at Korca downloaded from the WDC showed great agreement between the two time series. Secondly, the dry adiabatic lapse rate that was used for correcting the time series for altitude was estimated based on three individual data sets from three weather stations at different locations and altitudes within the catchment.

Any errors introduced by the processed climatic data will affect the catchment evapotranspiration and reservoir evaporation estimations. Incorrect evapotranspiration and reservoir evaporation estimations will affect the whole water balance of the model. Choices made in the work of preparing the climatic data for later inclusion in the WEAP model, have had the purpose of reducing the uncertainties to increase the accuracy of the model. The process has been a constant tradeoff between the available amount of time and the assumed relative improvement on the model accuracy. It is always possible to use more time on further analysis and quantification of uncertainties in the climatic data. However, the quality of the processed climatic data is with confidence believed to be more than adequate for the purpose of this study. The runoff data is the main source of uncertainty in this work, and endless hours of perfecting the climatic input data will not eliminate the uncertainties related to the runoff data.

6.2 Methodological Considerations

The main source of uncertainty and the most probable cause of any modeling errors is the estimation of the irrigation withdrawals. Past and present irrigation practices represent two different worlds. A lot of time has been spent on identifying all irrigation schemes that operated in the past and but also presently. Most important is the schemes that were operated during the period of calibration. Only the schemes that withdraw water directly from Devoll River or the tributaries modeled as individual sub-basins were included. There is a possibility of unidentified schemes that withdraw significant amounts of water. Most of the schemes had reported either a command area or a design capacity of the distribution network. A hydromodule of 0.001 m^3/s per hectare was used to estimate any missing information about command areas and design capacities. Not all schemes considered in this work may have been designed according to this hydromodule principle, and there is a possibility for both overestimation and underestimation of certain command areas and design capacities. In addition, the assumptions made about crop water requirements, irrigation efficiency and return flows, as well as the irrigation season and the percentage distribution of irrigation requirements, are assumed to be similar for all irrigation schemes. This may omit important local practices. The majority of the schemes considered do not have any known years of construction. Consequently, some of the schemes included during the calibration may not have been operated during this period. Although the accuracy of the irrigation estimates is highly uncertain, it is believed that the estimates are reasonable. The schemes with reported water requirements was Thana Reservoir, the Banja-Shkumbin Canal and the irrigated areas in Kucove and Fier downstream of Vlashuk Barrage.

All three scenarios studied in this work use the RCP4.5 climate projection as a foundation. This scenario of climate change is the second lowest emission scenario in the IPCC report and considers only changes in temperature and precipitation. Other climatic variables, e.g. wind speed, can be changed due to increased emissions of GHGs. Furthermore, future climatic conditions may be very different from the projections in the RCP4.5 scenario. All scenarios assume that irrigation is prioritized over hydropower production and do not take into account changing priorities and policies. Erosion and sediments are a significant challenge in the catchment, and is a major concern for the Devoll Hydropower Project. There is an ongoing research project on sediment transport in the Banja Reservoir area. However, none of the scenarios considers reduction in the active storage of the reservoirs due to sediment deposits.

The CRU2.0 data on relative humidity, wind speed and cloudiness fraction has been used both for evapotranspiration calculations in WEAP and for manual estimations of reservoir evaporation. It was not realized that the wind speed in this data set is measured at a height of 10 meters above the surface. The Penman-Monteith equation requires the wind speed measured at 2 meters above surface. A short analysis revealed that the wind speed at 10 meters is approximately 20 % larger than the wind speed at 2 meters above the surface. Consequently, there is a possibility for overestimated values of catchment evapotranspiration and reservoir evaporation. Other assumptions that affect the catchment evapotranspiration include the vegetation classes and their percentage distribution within each sub-basin, and the crop coefficients. Each sub-basin could also have been divided into more than two vegetation classes to get a more accurate description of the runoff and evapotranspiration properties.

The greatest weakness of the WEAP model is the hydropower function, which has turned out to be a limiting factor for some of the parts of this work. It is not possible to simulate the operations at Banja and Moglice properly because of the simplistic nature of the hydropower function. Firstly, it is not possible to define more than one unit for each power plant. Both Banja and Moglice have three units each, all with different maximum turbine flows and generating capacities. Secondly, WEAP does only allow a temporal variation of the generating efficiency, and not a generating efficiency based on the turbine flow and available working head. There was made an attempt to create a function in WEAP that reads the turbine flow and returns the generating capacity from a table of predefined values. This was not successful. The final decision was then to upload daily production goals for both power plants based on the estimates of the expected production received from Statkraft AS. In addition, the plant factor was set to 100 % and the generating efficiency set to a fixed value of 85 %. The result of this is clearly seen in Figure 5.6. During the first months of simulation, WEAP has emptied the conservation zones and for the remaining time of the scenarios, the turbines run constantly at a minimum working head causing low utilization of the water flowing into the reservoirs. As a result, all hydropower simulations have been underestimated and the values in Table 5.7 are not considered representative in any manner. In the very beginning of this work, it was originally intended the effects of the irrigation requirements downstream Banja. This idea was later discarded because the limitations in the hydropower functions in WEAP would make this work rather fruitless.

Another weakness in the model is that basin 7 has not been calibrated. There was no runoff data for Tomorrice River but it was still decided to model Tomorrice as an individual basin. The parameters were chosen based on the calibrated values of the neighboring basins. Because of this, there is a possibility that the flows from basin 7 are significantly incorrect, which primarily will have an impact on the inflow to Banja Reservoir. A quick assessment of the impacts of the flows from basin 7 was conducted by studying the flows at Kozare while altering the basin parameters. No significant impacts were found. It is also possible link the model to a ground flow node in WEAP but this was not considered before after the calibration.

The most important strength of the model are the good calibration results with respect to volumetric bias, despite of the uncertainties related to irrigation and the runoff data. There is a great consistency in the results of the calibration, especially between the gauging stations located along Devoll River. The fact that the soil parameter values did not vary significantly between the basins is reassuring. A lot of time has been used on collecting and processing tremendous amounts of climatic data, as well as identifying and systematizing the most important irrigation schemes and their capacities. The model can be seen as a database that can be used to analyze different policies of water allocation and their impacts on the runoff in Devoll River Basin. It has large potential for further development and additional extensions, depending on the purpose of the study.

6.3 Results

It is important for the reader to keep in mind that all results and relative changes in precipitation, evapotranspiration and runoff discussed in this chapter are relative to the reference period from 1980 to 1985. The precipitation and evapotranspiration changes are independent from three irrigation scenarios. During the first period of climate change, the annual precipitation volume is reduced with 10%. From 2065 to 2070, it is further reduced with 2.1%, and by 2105, the annual precipitation has been reduced a total of 13.8% compared to the period 1980 to 1985. The 20% reduction in precipitation from April to September does not have a significant impact on the annual total, which is explained by fact that the majority of the precipitation falls between October and March. A reduction of 13.8 % in the catchment average equals to a lost volume of approximately 405 million m^3 of water. Contrary to what is usually expected, Figure 5.2 shows that the rising temperatures have caused a decrease in the actual catchment evapotranspiration. While the potential evapotranspiration is only a theoretical number dependent on the atmospheric parameters, the actual evaporation is in addition dependent on the physical amount of water available for evaporation. The reduction in precipitation is what has caused less amounts water evaporated. Figures of total volumes evaporated is, however, deceiving. A more useful indicator is the ratio between the annual evapotranspiration and the annual precipitation. Comparing the annual precipitation volumes and the annual volumes of water evaporated from the catchment, reveals that the ratio between the evapotranspiration precipitation is increasing. For the reference period the annual evapotranspiration 721.9 million m^3 and the precipitation is 2933.9 million m^3, which gives an evapotranspiration percentage of 24.6%. Between 2100 and 2105 the annual precipitation is 2528.2 million m^3 and the evapotranspiration 698.4 million^3. This is equal to an evapotranspiration percentage of 27.6% and a relative increase of 3% compared to the conditions from 1980 to 1985.

The three scenarios were created mainly with the purpose of studying how irrigation in the upper reaches of Devoll River will affect the flow downstream of Maliq, and ultimately how this will further affect the annual hydropower production at Banja and Moglice HPP. Scenario 1 assumes no irrigation above in the upper reaches and is used to study the impacts solely from climate change. Scenario 2 and 3 describe upstream irrigation withdrawals of approximately 63 and 200 million m^3, respectively. The results of scenarios are rather surprising. Usually, it is expected that the relative change in the annual runoff equals at least to the relative change in the annual precipitation. This proves not to be the case for all of the basins and scenarios. Miras and Poshtme have both a reduction in the annual precipitation that is larger than the reduction in the annual runoff for during all three scenarios. The period from 2100 to 2105 during scenario 3 represents the worst conditions, but still the reduction in the annual runoff is 3.6% and 0.6% less than the reduction in precipitation at Miras and Poshtme. Table 5.4 and Figure 5.4 show that the tributaries are in general the most sensitive to climate change than Devoll River. Climate change causes a reduction in the flows at Dunavecit, Tomorrice and Holta River that are larger than the reduction in precipitation. Tomorrice River has the largest relative reduction in runoff in the basin with reduction of 21% for the period 2100 to 2105, which is 7.4% more than the reduction in precipitation. Devoll River itself is less sensitive to climate change than its tributaries. According to scenario 1, the annual runoff at Kozare is reduced with 13.2% at the end of the 21st century, which is equal to a lost volume of water of approximately 151 million m^3. The main channel (Devoll River) in the model is not sensitive to changes in precipitation, which can be a result of the period chosen for calibration. Irrigation withdrawals may have been underestimated during the calibration, causing the model to account for the lost water in soil moisture model instead. A short assessment of the demand coverage during calibration reveals that less than half of the supply requirement is delivered. Devoll River is most probably more sensitive to changes in precipitation than indicated by scenario 1.

Scenario 2 and 3 show that irrigation at the Korce Plateau has very little influence on the flow in the downstream reaches of Devoll. For the period 2100 to 2105 of scenario 2 and 3, upstream irrigation accounts for less than 1% of the total 13.9% and 14.1%

reduction in runoff. The local effects of irrigation in the upper reaches are on the other significant. Figure 5.3 shows the effects of irrigation at Sheqeras. The irrigation schemes drawing water from Devoll River upstream Sheqeras accounts for approximately two thirds of the total reduction of 15.6% in the annual runoff at Sheqeras from 2100 to 2105 during scenario 3. Dunavecit River joins Devoll about four kilometers downstream Sheqeras. Scenario 3 shows that irrigation on this tributary causes an additional reduction in the annual precipitation of approximately 1% on top of the reduction due to climate change. The real effects of irrigation, however, are not completely reflected by the model as it fails to deliver the water required. During scenario 2 and 3, the irrigation demand coverage is in average 25 % and 21.5% for all irrigation schemes at the Korce Plateau. It is in fact not possible to deliver the demands during the peak of the irrigation season as they far exceed the natural flow in Devoll and Dunavecit River. None of the barrages and control structures along Devoll and Dunavecit River was included in the model. Operation of these will increase the amount of water available for irrigation substantially and reduce the annual runoff way beyond the numbers indicated by the scenario 2 and 3. The barrages and control structures were not included in the model because of insufficient information about the design capacity of the gates and the storage capacities. It is believed with confidence that the effects of irrigation are much stronger than indicated by the results from the scenarios.

Table 5.7 shows that the variation in hydropower production between the scenarios has a trend similar to the runoff. Climate change is the main contributing factor to the reduction in the annual generation at Banja and Moglice. In scenario 1, the combined annual production is in average 403.3 GWh between 2100 and 2105, which is a reduction of 43.9% compared to the reference year 2020. The combined annual production for the same period in scenario 3 is 392.3 GWh, which is a further reduction of 1.6% compared to scenario 1 due to upstream irrigation. Moglice is more affected by the climate change than Banja. Between 2100 and 2105 in scenario 3, the annual production at Banja and Moglice is reduced with 35.3% and 51.0%, respectively. However, the production numbers in Table 5.7 are most probably not representative of the reality. WEAP is not able to simulate the hydropower production properly and underestimates the production at both hydropower plants. It is believed that the change in hydropower production would more reasonably have a trend similar to the reduction in runoff.

Table 5.6 shows that the evaporation from the reservoirs is increasing with each stage of climate, which is due to the rising temperatures. The reservoir evaporation is less during scenario 2 and 3 than for scenario 1, which is due to less inflow to the reservoirs. More water is evaporated at Banja than Moglice because Banja has a larger reservoir surface area. The combined average annual reservoir evaporation for the period 2100-2105 is approximately 4.1 million m^3, with 2.7 million m^3 at Banja and 1.4 million m^3 at Moglice. This equals to a reduction in the annual runoff of 0.13 m^3/s. Banja has the largest water footprint, with maximum footprint reaching a value of 16 m^3/MWh between 2100 and 2105 in scenario 1. The water footprints were calculated with the water balance principle. Figure 5.9 emphasizes the difference between methodologies for calculating the water footprint. The water footprint based on gross evaporation for the same period at Banja is 78.6 m^3/MWh. Another way of comparing the consumption from the reservoirs is the net evaporation. Net evaporation is in this relation defined as the difference between the evapotranspiration from the reservoir area before construction and inundation and the reservoir evaporation after construction and inundation of the area. During the reference period from 1980 to 1985, the average actual evapotranspiration from the catchment was 231 mm. The surface area of Banja Reservoir is 9.8 km^2 at LWRL, and 231 mm of water evaporated from this area equals to 2.26 million m^3. The net increase in evaporation between reference period and the period 2100-2105 is 0.44 million m^3, which is a relative increase of 16.3 %. The water footprint of Banja then becomes 2.6 m^3/MWh for the period 2100 to 2105. This significantly less than the number of 209 m^3/MWh described in the IPCC report on renewable energy.

7 CONCLUDING REMARKS

By the end of this century, the average runoff from Devoll River may be 13.9 % less than compared to the period 1980 to 1985. This prediction assumes an average increase in temperature of 2.4°C and an average reduction of 13.6 % in the annual precipitation relative to the same period. Furthermore, this prediction assumes that the irrigation at the Korce Plateau remains as present with an estimated seasonal supply requirement of 66 million m^3. The irrigation in the upper reaches of Devoll River accounts for only 0.7 % of the reduction in the annual runoff at the outlet of Devoll River. If the irrigation demand at the Korce Plateau increases to a total 200 million m^3, the annual runoff in Devoll River will be further reduced with 0.2 %. Climate change will have bigger impacts on the runoff in the tributaries than in the main channel. Tomorrice River is the largest tributary of Devoll River and the most affected by climate change with a 21.0 % reduction in the annual runoff. The model developed in this work is probably less sensitive to changes in precipitation than the real Devoll River Basin. Consequently, the impacts of the climate change are expected to be more significant than indicated by the model.

Banja and Moglice hydropower plant may have a total production of 403.3 GWh at the end of this century. This is a reduction of 43.9 % compared to the expected production in 2020. Climate change is the main cause of the reduction in the annual hydropower production. If the irrigation demand at the Korce Plateau increases to 200 million m^3, the annual production is reduced to 392.3 GWh. However, the model does not simulate the hydropower production properly and these figures are most probably unrealistic. The percentage reduction in the annual runoff in Devoll River is a more realistic indicator of the future development of the annual production at Banja and Moglice. The combined annual evaporation from the reservoirs may be 4.1 million m^3 at the end of the century, which is equal to a water footprint of 10.2 m^3/MWh. If the evapotranspiration from the reservoir areas prior to inundation is considered as well, the water footprint becomes 1.7 m^3/MWh. These footprints are much lower than indicated in the IPCC report on renewable energy.

The irrigation demand at the Korce Plateau has a strong impact on the flows in Devoll River in this area. At the end of the century, the annual runoff in this area may be reduced with 15.6 %, where irrigation accounts for more than two thirds of this reduction. The scenarios show that the irrigation demand in this area far exceeds the natural flow in Devoll River, and in average only 20 % of the demands are actually met without operational barrages. If the barrages are rehabilitated and put into operation, Devoll River will be significantly more affected than indicated by the results in scenario 2 and 3. The annual runoff at the outlet of Devoll River is 1145 million m^3 for the period 1980-1985. If the irrigation demand of 200 million m^3 in scenario 3 is delivered, the annual runoff in Devoll River will reduced be with approximately 17.5 %. This will have significant consequences for the production at Banja and Moglice in combination with climate change. Irrigation is of vital importance in the Korce area and becomes even more important in the light of climate change. Most of the irrigation schemes in the Korce area are presently in a poor condition and only a portion of the 23,000 hectares of irrigated land is serviceable. Increasing investments and rehabilitation of irrigation schemes in this area does indicate that the irrigation withdrawals in this area are likely to increase.

It is a popular misconception that dams are large water consumers. The opposite has been proved in this work. Banja and Moglice will result in a small net increase in evaporation but this becomes insignificant in light of their advantages. When completed, the power plants will increase the Albanian power production with approximately 17 %. In addition, Banja can provide valuable supply security for the irrigated areas downstream of the dam if operations at Thana Reservoir and Banja HPP are coordinated. In an economic perspective, the requirements made by the MAFCP may force Statkraft AS to release significant amounts of water downstream of Banja at unfavorable points in time.

The model developed in this work has many shortcomings and is not suitable for decision-making in its present state. On the other hand, the model contains detailed information about Devoll River Basin and has an enormous potential for becoming a valuable tool if further developed. If it is desired to use the model in decision-making, it is advised that more detailed land cover classes are developed, and the model is linked to a groundwater model to fully capture the hydrologic processes within the river basin. At last, the model should be calibrated and validated for a different period of runoff data than used in this work.

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APPENDICES

Appendix A: Description of master thesis

Appendix B: Hydrographs for gauging stations in Devoll River Basin

Appendix C: Basin-averaged FAO climate data

Appendix D: Map and list of pumping schemes in Devoll River Basin

Appendix E: Seasonal irrigation distribution at Thana Reservoir, Korce Plateau and Banja- Shkumbin Canal

Appendix F: Example of evaporation calculations

Appendix G: Calibration results

Appendix H: Volume-elevation and area-elevation curves

Appendix I: Digital appendix that includes:

- 10 WEAP models and corresponding data
- Spreadsheet of evapotranspiration calculations
- Hypsographic curves
- Raw temperature, precipitation and runoff data
- Altitude correction of temperature

APPENDIX A: DESCRIPTION OF MASTER THESIS

NTNU
Norwegian University of Science and Technology

Faculty of Engineering Science and Technology
Department of Hydraulic and Environmental Engineering

M.Sc. thesis in

Hydraulic and Environmental Engineering

Candidate: Christian Almestad

Title: Modelling of water allocation and availability in Devoll River Basin, Albania

1 BACKGROUND

A growing population with an increasing economic development and consumption leads to massive use of the Earth's resources (Rockström et al., 2009). Many countries and regions experience water stress and ecological degradation of aquatic ecosystems, which is expected to further increase and accelerate with climate change (Bates et al., 2008; IPCC, 2011; IPCC, 2014). Due to global warming caused by anthropogenic greenhouse gas emissions, an increased the share of renewable energy production is needed, and large-scale investments in solar, wind and hydropower are expected (IPCC, 2011). Reservoirs are also key-stones in the infrastructure and prerequisite in water-stressed areas to secure adequate water-services to a large range of sectors, and are used for the purpose of securing irrigation, drinking water supply, flood control, navigation and more, as well as hydropower production.

On one hand establishment of new reservoirs might affect the water availability positively, as they stores water from the wet to the dry season and secure adequate access to water all-year around. On the other hand, establishment of reservoirs might increase the total evaporation of water to the atmosphere hence reducing the annual total runoff from a basin. Finding the balance between the trade-offs of these two effects is a delicate management task. Acknowledging the fact that climate change, population growth, economic development, increased needs for food production (irrigation) will put additional pressure on the available water resources (Bates et al., 2008), a careful design, operation and management of the infrastructure to store and distribute water is challenging.

The thesis will analyze how the design and operation of the reservoirs will affect water consumption and the availability of water for various purposes, including irrigation and hydropower production. The study will be carried out using Devoll River Basin in Albania as a case, with an extensive on-going development with Norwegian ownership involved (Statkraft).

2 MAIN QUESTIONS FOR THE THESIS

1. Configure a hydrological/water allocation model (WEAP) for Devoll River Basin. This task will involve the following subtasks:
    a. Compile and process the needed climatic and hydrological data, as well as data on reservoirs, hydropower installations, water withdrawal, etc. in order to calibrate and carry out scenario simulations with WEAP.
    b. Calibrate the model with use of historical data in Devoll River Basin. Evaluate the model's 'goodness of fit' with use of selected statistical criteria.
    c. Analyze the model's sensitivity to a selected set of model parameters and/or input data.

2. Define a set of future scenarios ('what-if analyses), analyze the role of the reservoirs, and how the different water users in the river basin are affected, based on possible future changes in:

    a. Climate (precipitation and temperature) as projected by IPCC (2013)
    b. Water use in other sectors than the energy sector, e.g. increased developed of irrigated agriculture (based on specific information from Devoll, other basins in Albania or basins with similar characteristics elsewhere)
    c. Combination of the above factors, including occurrence of natural dry and wet years.

The final definition of scenarios could be made in communication with the supervisors during the work on the master thesis.

3 SUPERVISION, DATA AND INFORMATION INPUT

Professor Knut Alfredsen will be responsible for the thesis and PhD student Tor Haakon Bakken will be the main supervisor of the thesis work. Discussion with and input from colleagues and other research or engineering staff at NTNU, power companies or consultants are recommended, if considered relevant. Significant inputs from others shall, however, be referenced in a convenient manner.

The research and engineering work carried out by the candidate in connection with this thesis shall remain within an educational context. The candidate and the supervisors are therefore free to introduce assumptions and limitations, which may be considered unrealistic or inappropriate in a contract research or a professional engineering context.

4 REPORT FORMAT AND REFERENCE STATEMENT

The thesis report shall be in the format A4. It shall be typed by a word processor and figures, tables, photos etc. shall be of good report quality. The report shall include a summary, a table of content, lists of figures and tables, a list of literature and other relevant references and a signed statement where the candidate states that the presented work is his own and that significant outside input is identified.

The report shall have a professional structure, assuming professional senior engineers (not in teaching or research) and decision makers as the main target group. The thesis shall be submitted no later than 10th of June 2015.

Trondheim 15th of January 2015

Knut Alfredsen, Professor

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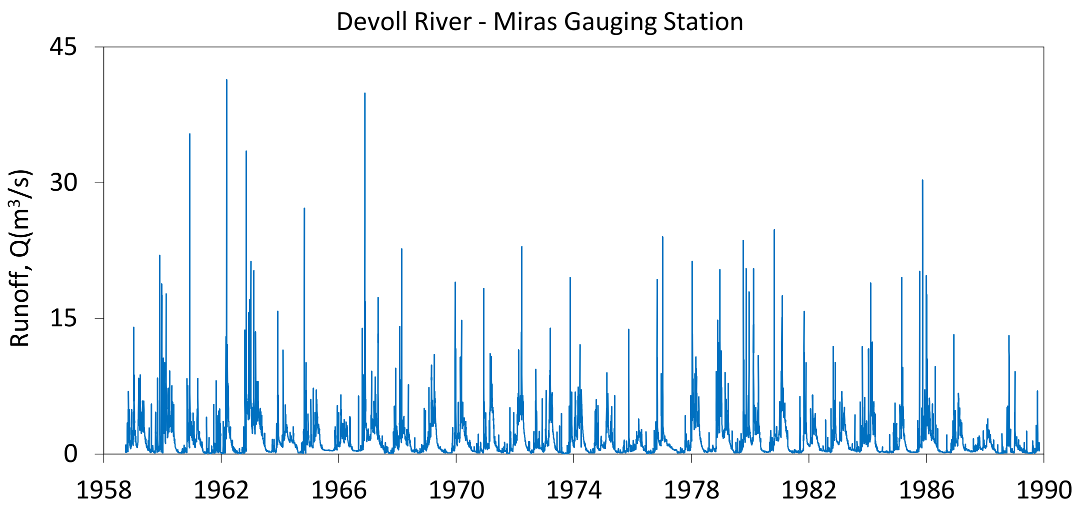
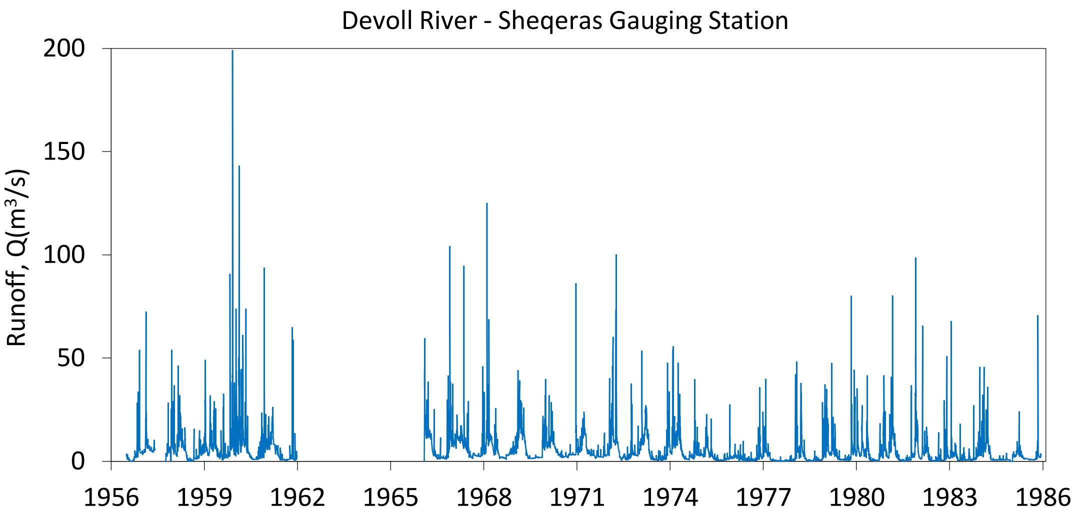
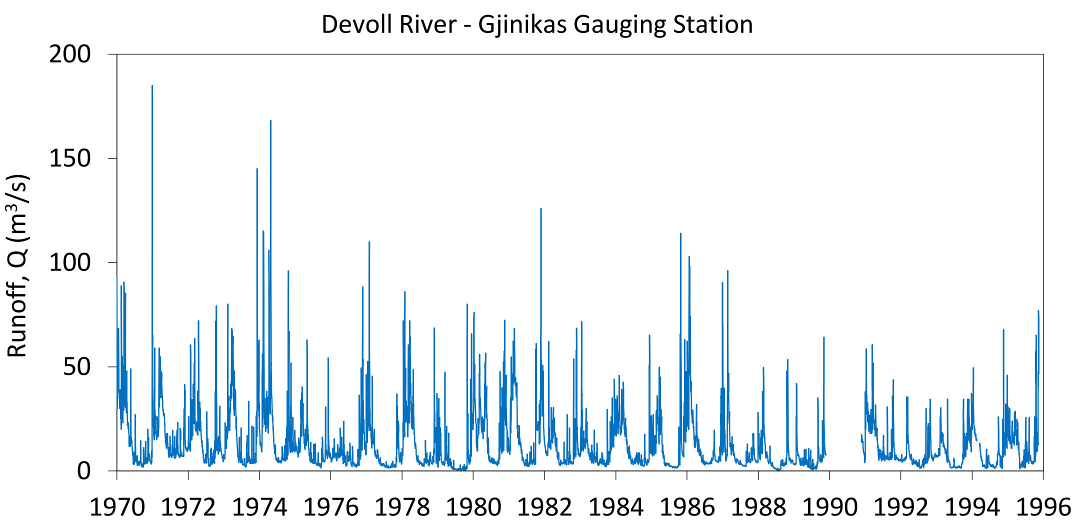
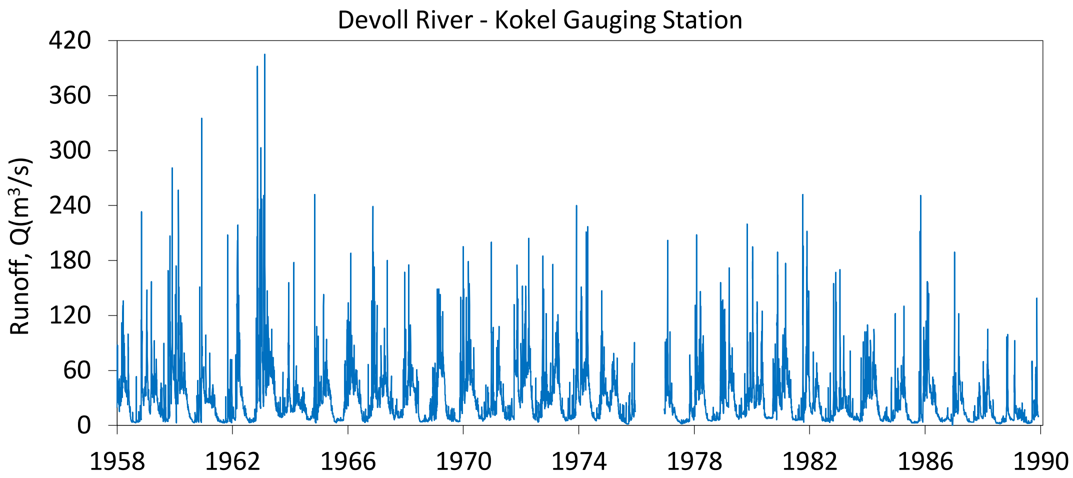
APPENDIX B: HYDROGRAPHS








Devoll River - Kokel Gauging Station
Runoff, Q(m3/s)
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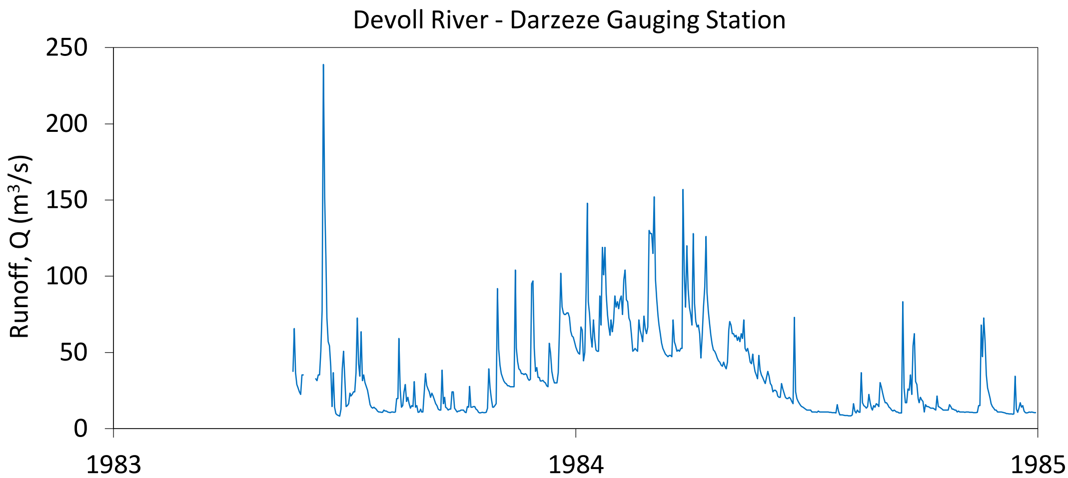
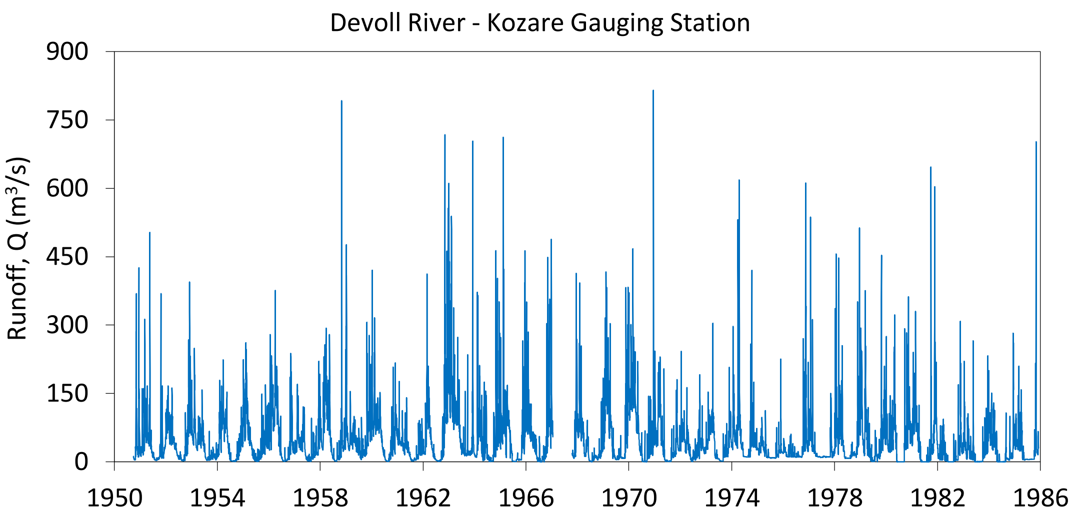
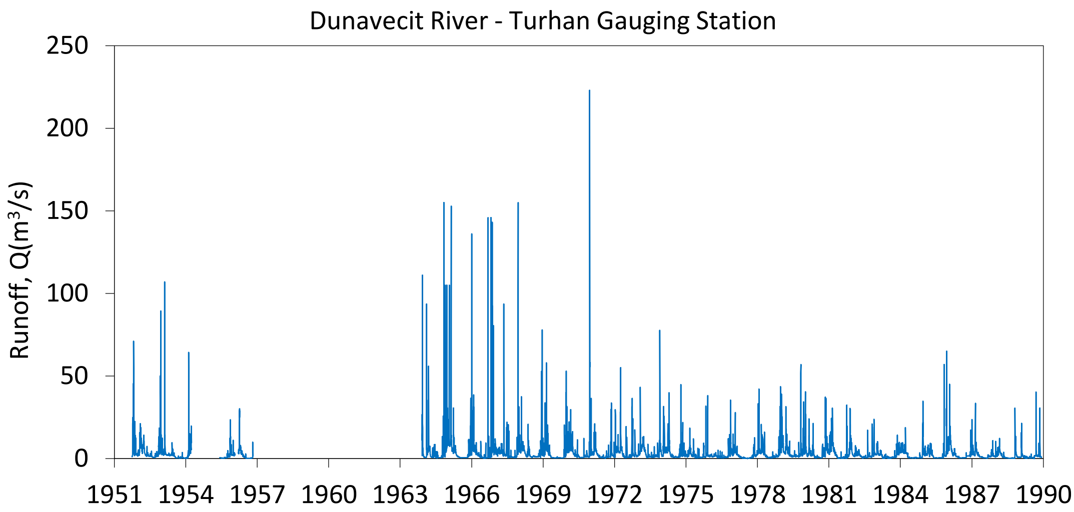
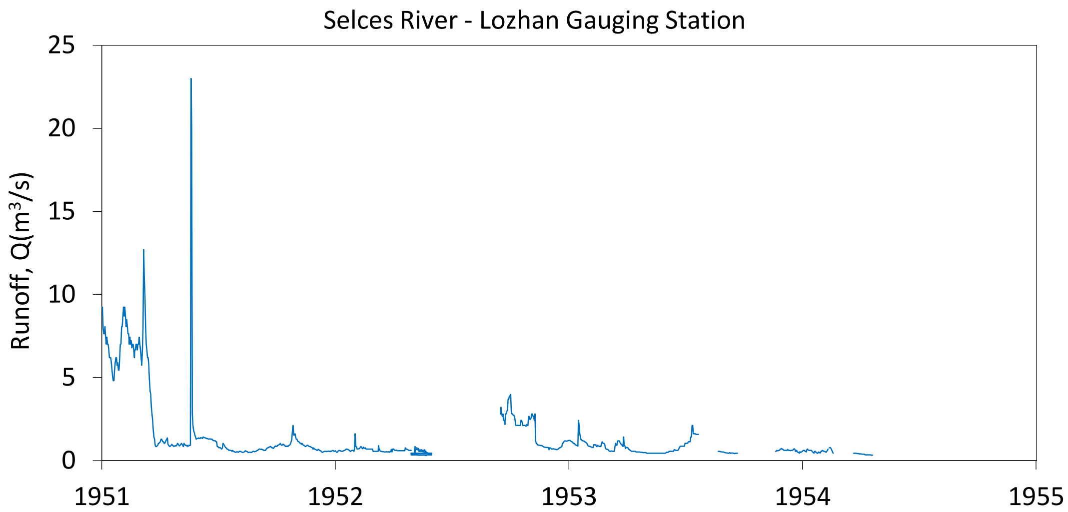
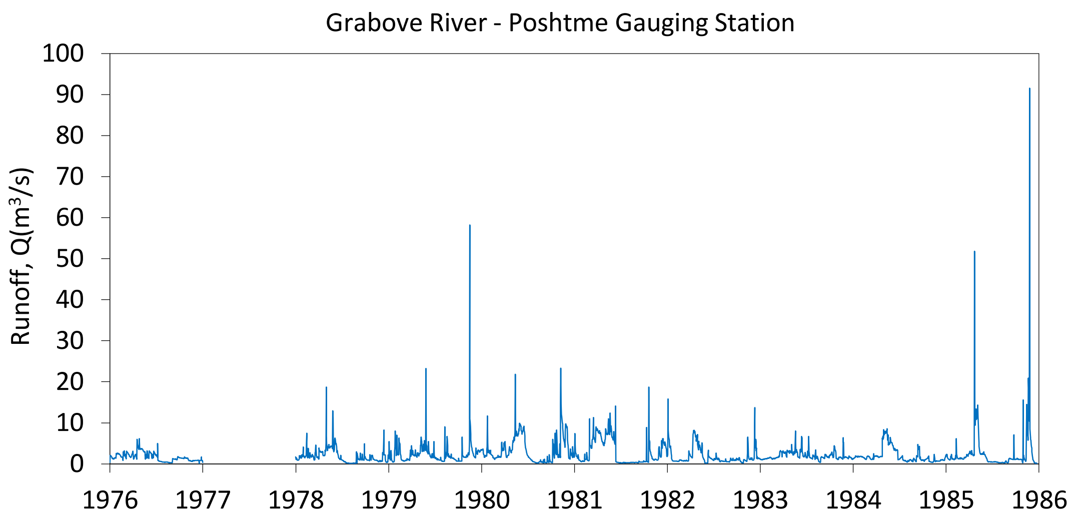
360
300
240
180
120
60
0
1958
1962
1966
1970
1974
1978
1982
1986
1990

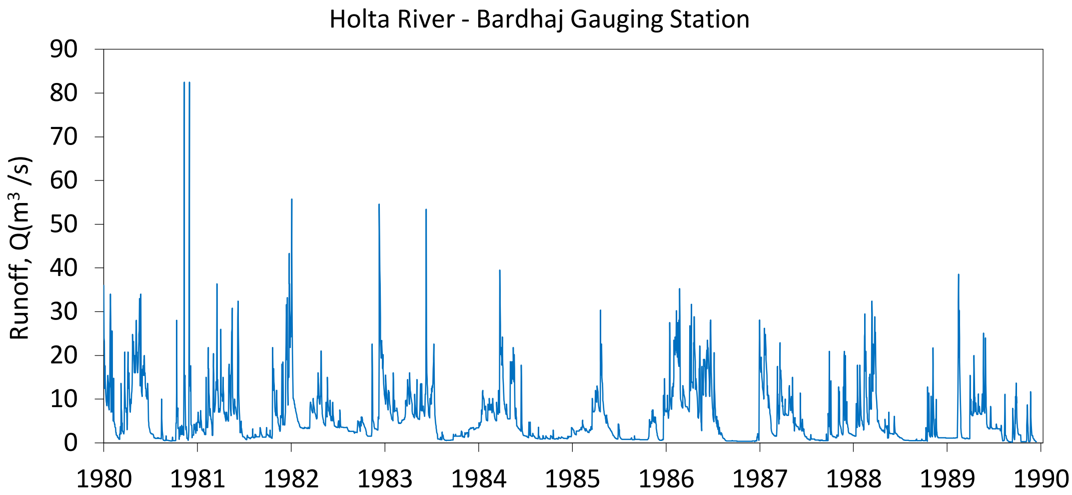

Devoll River - Darzeze Gauging Station
Runoff, Q (m3/s)
250
200
150
100
50
0
1983
1984
1985


Devoll River - Kozare Gauging Station
Runoff, Q (m3/s)
900
750
600
450
300
150
0
1950
1954
1958
1962
1966
1970
1974
1978
1982
1986


Dunavecit River - Turhan Gauging Station
Runoff, Q(m³/s)
250
200
150
100
50
0
1951
1954
1957
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990


Selces River - Lozhan Gauging Station
Runoff, Q(m³/s)
25
20
15
10
5
0
1951
1952
1953
1954
1955

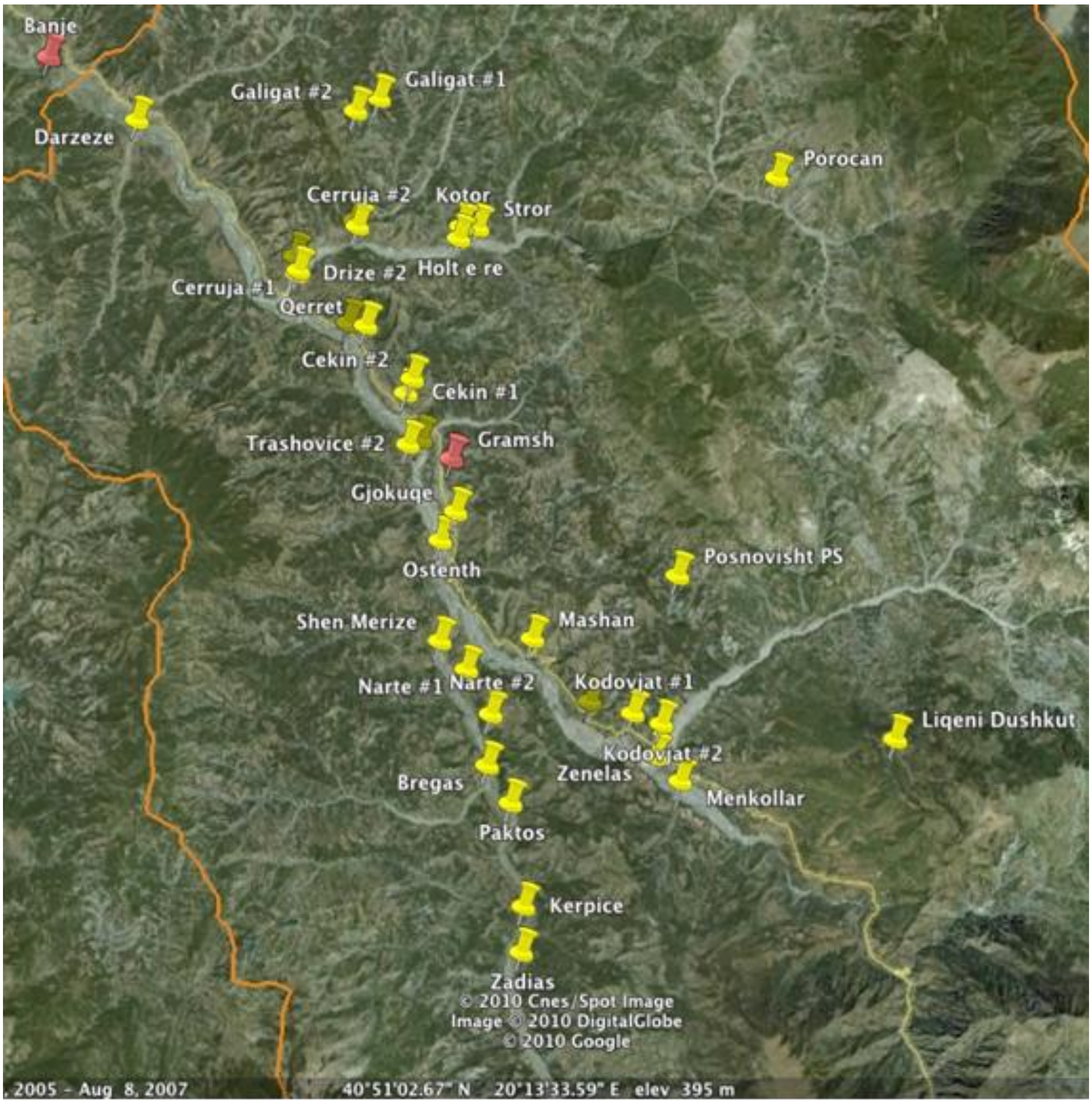

Grabove River - Poshtme Gauging Station
Runoff, Q(m³/s)
100
90
80
70
60
50
40
30
20
10
0
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986


Holta River - Bardhaj Gauging Station
Runoff, Q(m³ /s)
0
10
20
30
40
50
60
70
80
90
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990

Appendix C: Basin-averaged FAO Climate Data

Basin	1	2	3	4	5	6	7	8	9
Month	**Wind (m/s)**	**Wind (m/s)**	**Wind (m/s)**	**Wind (m/s)**	**Wind (m/s)**	**Wind (m/s)**	**Wind (m/s)**	**Wind (m/s)**	**Wind (m/s)**
Jan	1.6	1.4	1.6	1.6	2.1	2.1	1.9	1.8	1.8
Feb	1.8	1.6	1.8	1.8	2.2	2.2	2.1	2.0	1.9
Mar	1.8	1.6	1.8	1.9	2.2	2.2	2.1	2.0	1.9
Apr	1.8	1.6	1.8	1.8	2.2	2.2	2.0	1.9	1.9
May	1.5	1.4	1.5	1.5	1.8	1.8	1.7	1.6	1.6
Jun	1.4	1.3	1.3	1.3	1.6	1.6	1.6	1.5	1.6
Jul	1.3	1.2	1.3	1.3	1.6	1.6	1.6	1.5	1.6
Aug	1.2	1.2	1.2	1.3	1.6	1.6	1.5	1.5	1.5
Sep	1.2	1.1	1.2	1.3	1.6	1.6	1.5	1.4	1.4
Oct	1.5	1.3	1.5	1.6	1.9	1.9	1.7	1.6	1.6
Nov	1.5	1.3	1.5	1.5	1.9	1.9	1.8	1.7	1.6
Dec	1.6	1.3	1.6	1.6	2.0	2.0	1.9	1.7	1.7
Month	**RF (%)**	**RF (%)**	**RF (%)**	**RF (%)**	**RF (%)**	**RF (%)**	**RF (%)**	**RF (%)**	**RF (%)**
Jan	79.1	79.5	79.2	79.2	78.7	78.7	78.4	77.8	77.2
Feb	78.0	77.9	78.1	77.8	77.8	77.8	77.1	76.0	75.4
Mar	71.6	71.2	71.4	71.4	72.8	72.8	72.5	71.9	71.8
Apr	66.4	65.7	66.2	66.6	69.0	69.0	69.2	69.0	69.3
May	65.8	65.3	65.9	66.5	68.6	68.6	68.7	68.7	68.9
Jun	62.5	62.1	62.9	63.6	66.0	66.0	65.1	65.0	64.9
Jul	58.7	58.8	59.6	60.3	61.9	61.9	60.6	60.6	60.3
Aug	57.9	57.9	58.3	59.1	61.7	61.7	60.7	60.9	61.0
Sep	63.7	63.6	64.0	64.7	66.9	66.9	66.5	66.5	66.6
Oct	71.2	71.0	71.0	70.8	72.1	72.1	72.2	71.4	71.4
Nov	77.0	77.0	76.8	76.8	77.2	77.2	77.6	77.1	77.0
Dec	80.3	80.5	80.2	80.1	79.9	79.9	79.9	79.2	78.8
Month	**CF (%)**	**CF (%)**	**CF (%)**	**CF (%)**	**CF (%)**	**CF (%)**	**CF (%)**	**CF (%)**	**CF (%)**
Jan	43.3	42.2	40.3	37.4	37.7	37.7	37.7	35.7	36.0
Feb	45.8	45.8	43.2	40.6	39.1	39.1	39.2	37.8	38.0
Mar	46.7	47.0	45.0	43.3	41.6	41.6	41.9	41.4	41.5
Apr	49.3	50.3	48.3	47.3	44.7	44.7	45.7	45.6	46.0
May	54.2	55.5	53.6	53.0	50.2	50.2	52.1	52.5	53.4
Jun	62.5	63.5	61.8	61.0	57.8	57.8	60.2	60.2	61.1
Jul	73.4	73.8	72.4	71.5	69.6	69.6	71.9	71.6	72.6
Aug	72.4	72.7	71.3	70.2	68.2	68.2	69.4	69.0	69.4
Sep	66.6	66.7	65.1	63.7	62.4	62.4	62.9	62.4	62.6
Oct	56.0	55.8	54.6	53.4	52.9	52.9	53.4	52.8	53.2
Nov	46.9	46.3	45.1	43.3	42.8	42.8	42.7	41.3	41.4
Dec	40.2	39.3	37.4	34.8	34.8	34.8	34.8	32.9	33.2

APPENDIX D: Governmental Pump Schemes



	Name	River	Region	District	Design Flow (m^3/s)	Status
1	Porocan	Tributary	Elbasan	Gramsh	0.040	Removed
2	Stror	Holte	Elbasan	Gramsh	0.040	Removed
3	Kotorr	Holte	Elbasan	Gramsh	0.040	Removed
4	Gjergjovine	Devoll	Elbasan	Gramsh	0.040	Removed
5	Driza No. 1	Devoll	Elbasan	Gramsh	0.040	Removed
6	Driza No. 2	Devoll	Elbasan	Gramsh	0.040	Operable not used
7	Cerruja No. 1	Devoll	Elbasan	Gramsh	0.040	Removed
8	Cerruja No. 2	Devoll	Elbasan	Gramsh	0.012	Removed
9	Cerruja No. 3	Devoll	Elbasan	Gramsh	0.040	Operable not used
10	Bisht Talle	Tributary	Elbasan	Gramsh	0.040	Removed due to Banje
11	Darzeze	Tributary	Elbasan	Gramsh	0.070	Removed due to Banje
12	Dushk	Tributary	Elbasan	Gramsh	0.050	Removed due to Banje
13	Silare	Tributary	Elbasan	Gramsh	0.042	Removed due to Banje
14	Zgiupe	Devoll	Elbasan	Gramsh	0.050	Operable - not used
15	Cingar No. 1	Devoll	Elbasan	Gramsh	0.042	Removed due to Banje
16	Cingar No. 2	Tributary	Elbasan	Gramsh	0.014	Removed due to Banje
17	Cingar No. 3	Tributary	Elbasan	Gramsh	0.014	Removed due to Banje
18	Qerret	Devoll	Elbasan	Gramsh	0.040	Removed
19	Cekin No. 1	Devoll	Elbasan	Gramsh	0.145	Operable - not used
20	Cekin No. 2	Tributary	Elbasan	Gramsh	0.040	Operable - not used
21	Trashovice No. 1	Devoll	Elbasan	Gramsh	0.050	Operable - not used
22	Trashovice No. 2	Devoll	Elbasan	Gramsh	0.040	Removed
23	Shen Merize	Tomorrice	Elbasan	Gramsh	0.120	Removed
24	Ostenth	Devoll	Elbasan	Gramsh	0.043	Removed
25	Gjokuge	Tributary	Elbasan	Gramsh	0.040	Removed
26	Narta No. 1	Tomorrice	Elbasan	Gramsh	0.050	Removed
27	Narta No. 2	Tomorrice	Elbasan	Gramsh	0.070	Operable - not used
28	Paktos	Tomorrice	Elbasan	Gramsh	0.040	Removed
29	Kerpice	Tomorrice	Elbasan	Gramsh	0.040	Removed
30	Bregas	Tomorrice	Elbasan	Gramsh	0.040	Removed
31	Mashan	Devoll	Elbasan	Gramsh	0.050	Removed
32	Bersnik	Devoll	Elbasan	Gramsh	0.040	Removed
33	Posnovisht	Tributary	Elbasan	Gramsh	0.040	Removed
34	Godovjat No. 1	Devoll	Elbasan	Gramsh	0.040	Removed
35	Godovjat No. 2	Devoll	Elbasan	Gramsh	0.040	Removed
36	Liqeni Dushkut	Liqeni	Elbasan	Gramsh	0.040	Removed
37	Menkollar	Devoll	Elbasan	Gramsh	0.040	Removed
38	Prenjas	Rezerv	Elbasan	Gramsh	0.040	Removed
39	Zenelas	Devoll	Elbasan	Gramsh	0.040	Removed
40	Galigat No. 1	Rezerv	Elbasan	Gramsh	0.040	Operable - not used
41	Galigat No. 2	Rezerv	Elbasan	Gramsh	0.040	Operable - not used
42	Holta e re	Holte	Elbasan	Gramsh	0.210	Operable - not used
43	Zadias	Tomorric	Elbasan	Gramsh	0.040	Removed
44	Maliq	Devoll	Korce	Korce	0.300	Removed
45	Rotit	Devoll	Korce	Korce	0.120	Removed
46	Zboq	Devoll	Korce	Korce	0.100	Removed
47	Plovisht	Devoll	Korce	Korce	0.080	Removed
48	Tresove	Devoll	Korce	Korce	0.060	Removed
49	Rosover	Devoll	Korce	Korce	0.050	Removed
50	Moglice	Devoll	Korce	Korce	0.140	Removed
				Sum	2,962	

APPENDIX E: Irrigation Distribution

Period Commencing	Distribution of Total Seasonal Demand (%)		
	Korce Plateau	Thana Reservoir	Banja-Shkumbin
1 Apr	2.5	-	-
15 Apr	2.5	-	-
1 May	3.5	3.0	-
15 May	3.5	6.0	-
1 Jun	10.0	13.0	-
15 Jun	10.0	11.0	-
1 Jul	14.5	15.0	-
15 Jul	14.5	16.0	50.0
1 Aug	13.0	12.0	50.0
15 Aug	13.0	11.0	-
1 Sep	5.5	6.0	-
15 Sep	5.5	4.0	-
1 Oct	1.0	2.0	-
15 Oct	1.0	1.0	-

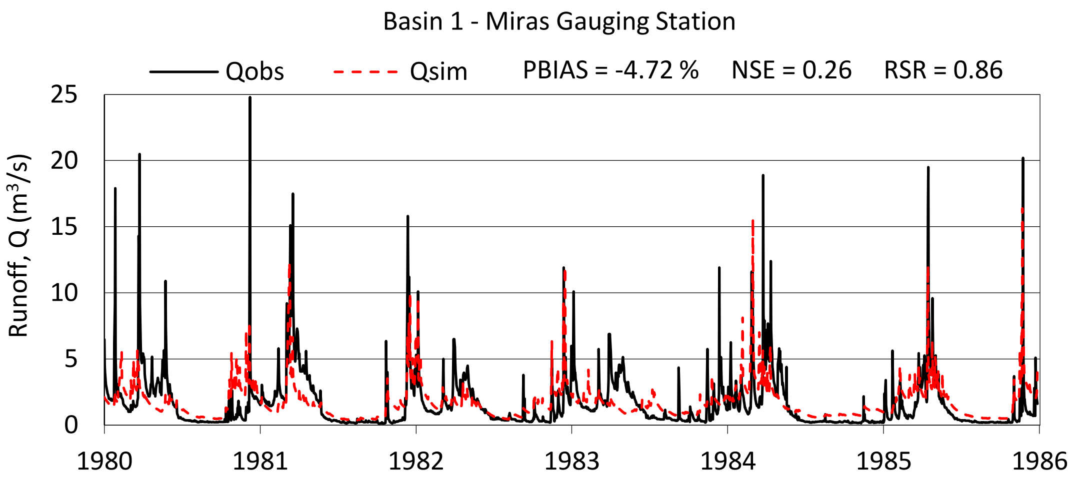
APPENDIX F: Example of Evaporation Calculations

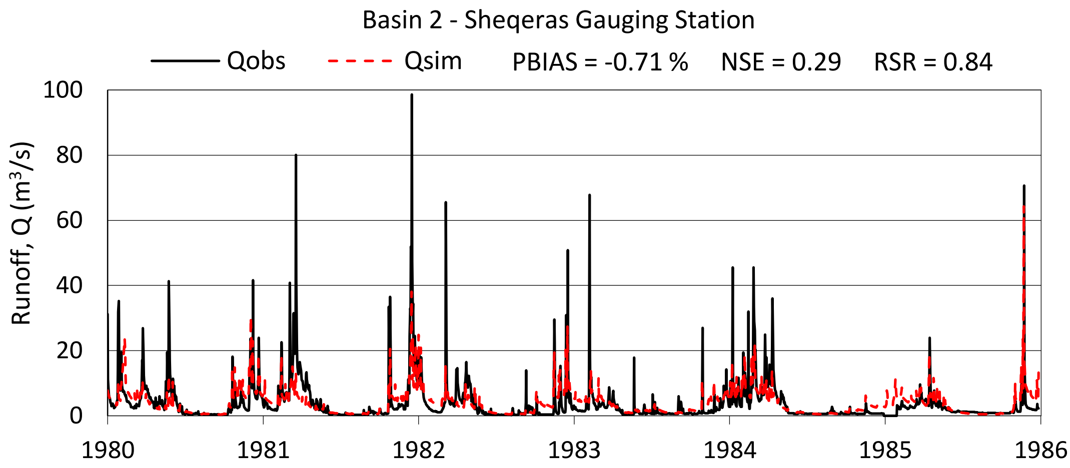
Moglice Reservoir	1980	**Elevation, z**	650 m	**Psychrometric constant, ϒ**	0.062 (kPa/°C)
Latitude, ϕ	40.686 °	**Pressure, P**	93.84 kPa		

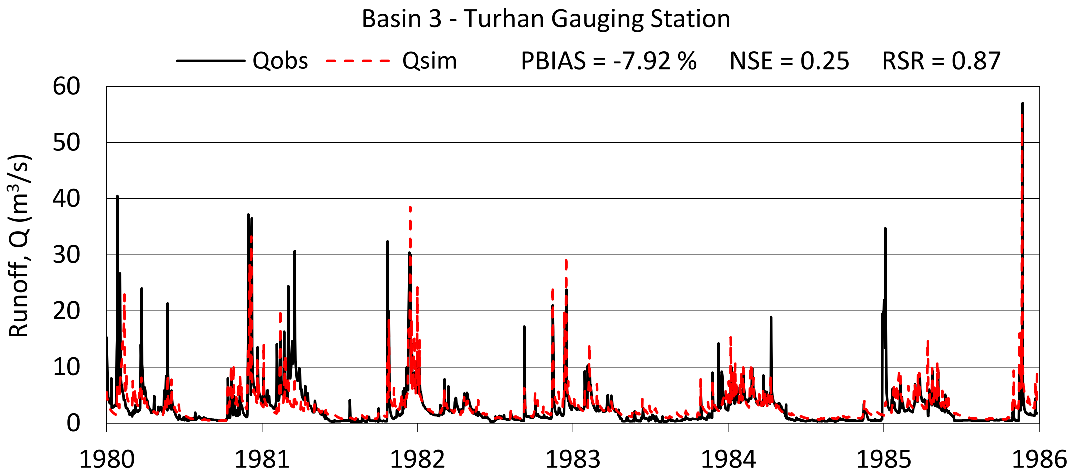
Statkraft Data			**FAO Data**			**Calculations**											
Date	**J**	**T_{mean} (°C)**	**RH (%)**	**U_2 (m/s)**	**n/N**	**dr**	**δ (rad)**	**ω_s (rad)**	**R_a (MJ/day)**	**R_{ns} (MJ/day)**	**e_s (kPa)**	**e_s (kPa)**	**R_{nl} (MJ/day)**	**R_{net} (MJ/day)**	**Δ (kPa/°C)**	**es – ea (kPa)**	**ET_0 (mm/day)**
01.01.1980	1	1.5	79.0	2.0	0.40	1.033	-0.402	1.196	13.35	5.38	0.68	0.54	3.03	2.36	0.03	0.14	0.83
02.01.1980	2	-0.2	79.0	2.0	0.40	1.033	-0.401	1.198	13.41	5.40	0.60	0.47	3.03	2.38	0.03	0.13	0.77
03.01.1980	3	-0.4	79.0	2.0	0.40	1.033	-0.400	1.199	13.46	5.43	0.59	0.47	3.03	2.40	0.03	0.12	0.76
04.01.1980	4	-5.6	79.0	2.0	0.40	1.033	-0.398	1.201	13.52	5.45	0.40	0.32	3.00	2.45	0.02	0.08	0.58
05.01.1980	5	-10.8	79.0	2.0	0.40	1.033	-0.396	1.203	13.59	5.48	0.27	0.21	2.93	2.55	0.01	0.06	0.43
06.01.1980	6	-7.4	79.0	2.0	0.40	1.033	-0.395	1.205	13.66	5.51	0.35	0.28	2.98	2.53	0.02	0.07	0.53
07.01.1980	7	-2.1	79.0	2.0	0.40	1.033	-0.393	1.207	13.73	5.54	0.52	0.41	3.02	2.51	0.02	0.11	0.71
24.12.1980	359	4.4	80.2	1.9	0.37	1.033	-0.409	1.189	13.1	5.11	0.84	0.67	2.82	2.29	0.04	0.17	0.90
25.12.1980	360	4.1	80.2	1.9	0.37	1.033	-0.408	1.190	13.1	5.12	0.82	0.66	2.82	2.30	0.03	0.16	0.88
26.12.1980	361	3.5	80.2	1.9	0.37	1.033	-0.407	1.191	13.2	5.13	0.79	0.63	2.83	2.30	0.03	0.16	0.86
27.12.1980	362	1.0	80.2	1.9	0.37	1.033	-0.407	1.192	13.2	5.14	0.66	0.53	2.84	2.30	0.03	0.13	0.77
28.12.1980	363	1.4	80.2	1.9	0.37	1.033	-0.406	1.192	13.2	5.15	0.68	0.54	2.84	2.32	0.03	0.13	0.78
29.12.1980	364	1.9	80.2	1.9	0.37	1.033	-0.405	1.194	13.3	5.17	0.70	0.56	2.84	2.33	0.03	0.14	0.80
30.12.1980	365	2.3	80.2	1.9	0.37	1.033	-0.404	1.195	13.3	5.19	0.72	0.58	2.84	2.35	0.03	0.14	0.82
																Sum	**1113 mm**

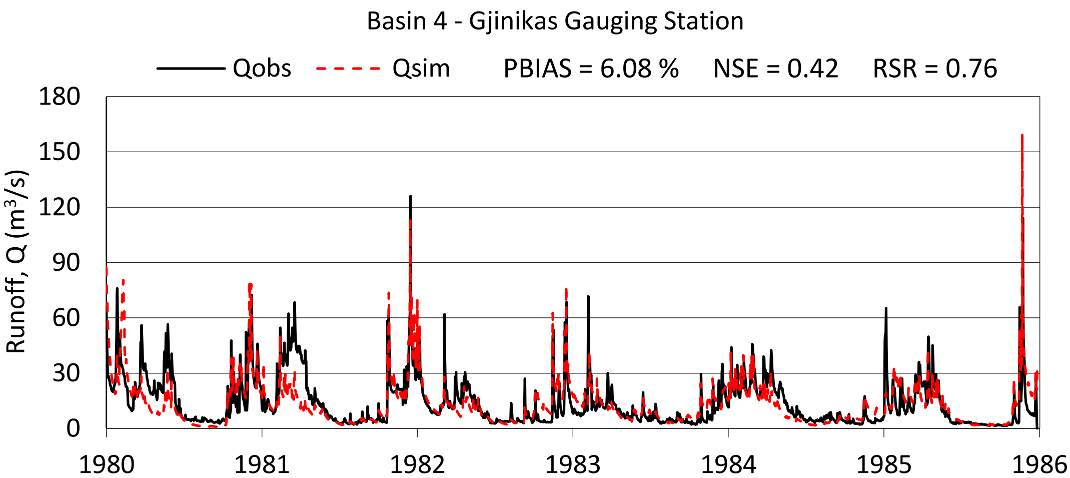
APPENDIX G: CALIBRATION RESULTS

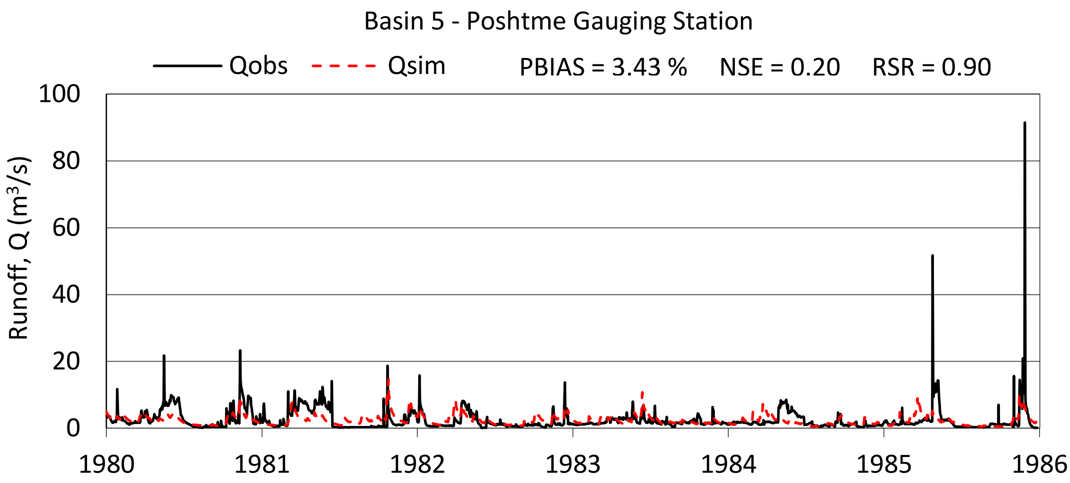
Basin	S_w (mm)	k_s (mm/day)	D_w (mm)	k_2 (mm/day)	*f*	z_1 (%)	z_2 (%)
1A 1B	280 150	6 10	3000	15.0	0.7 0.2	60 60	15
2A 2B	250 200	3 30	3000	0.1	0.8 0.2	60 60	50
3A 3B	280 150	5 30	3000	0.1	0.5 0.3	60 60	80
4A 4B	250 200	15 30	3000	0.1	0.8 0.2	100 100	50
5A 5B	350 100	30 5	3000	5.0	0.9 0.2	50 50	50
6A 6B	320 200	10 4	3000	5.0	0.7 0.2	50 50	50
7A 7B	300 200	5 30	3000	0.1	0.8 0.2	30 30	40
8A 8B	700 500	10 5	3000	0.1	0.9 0.5	60 60	60
9A 9B	350 300	25 25	5000	0.1	0.1 0.1	30 30	0



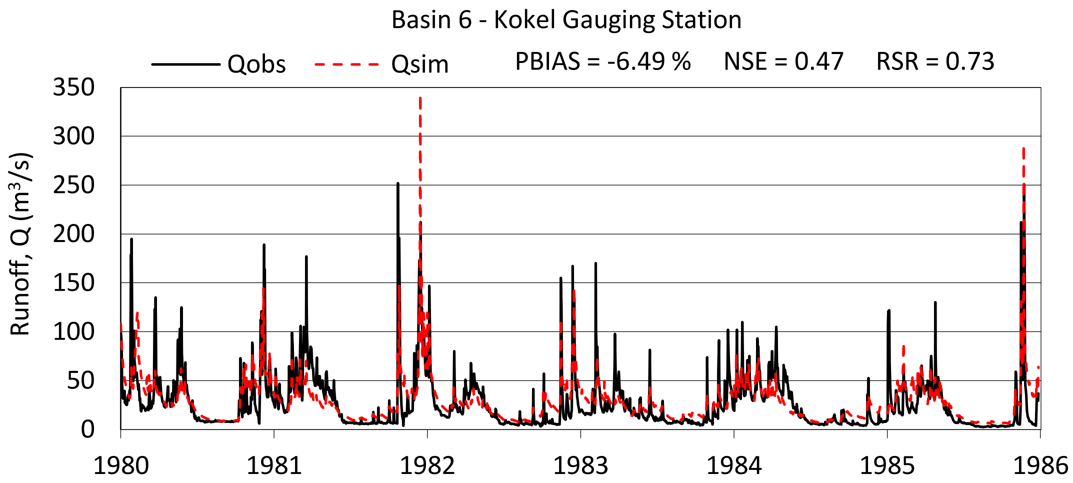

Basin 2 - Sheqeras Gauging Station
Qobs
Qsim
PBIAS = -0.71 %
NSE = 0.29
RSR = 0.84
Runoff, Q (m3/s)
100
80
60
40
20
0
1980
1981
1982
1983
1984
1985
1986


Basin 3 - Turhan Gauging Station
Qobs
Qsim
PBIAS = -7.92 %
NSE = 0.25
RSR = 0.87
Runoff, Q (m3/s)
60
50
40
30
20
10
0
1980
1981
1982
1983
1984
1985
1986

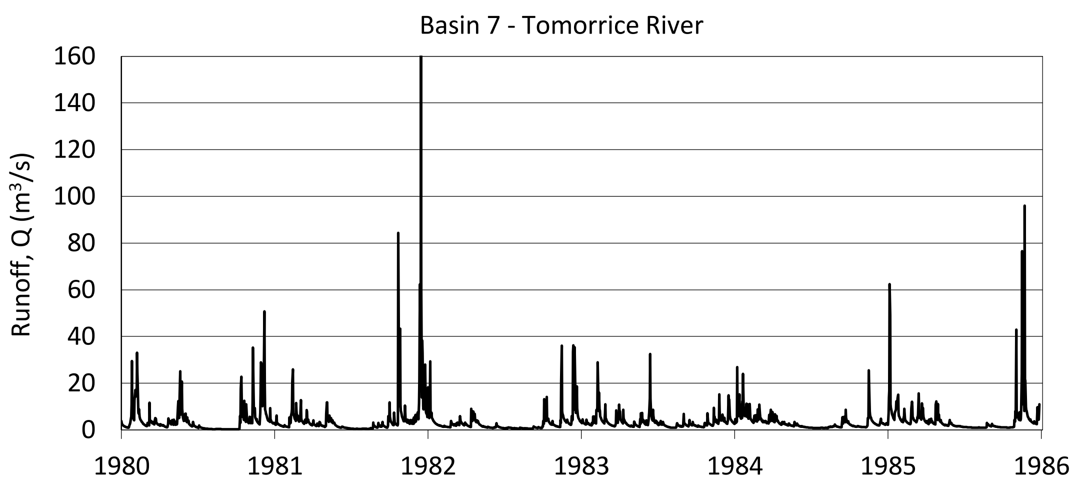

Basin 4 - Gjinikas Gauging Station
Qobs
Qsim
PBIAS = 6.08 %
NSE = 0.42
RSR = 0.76
Runoff, Q (m3/s)
180
150
120
90
60
30
0
1980
1981
1982
1983
1984
1985
1986



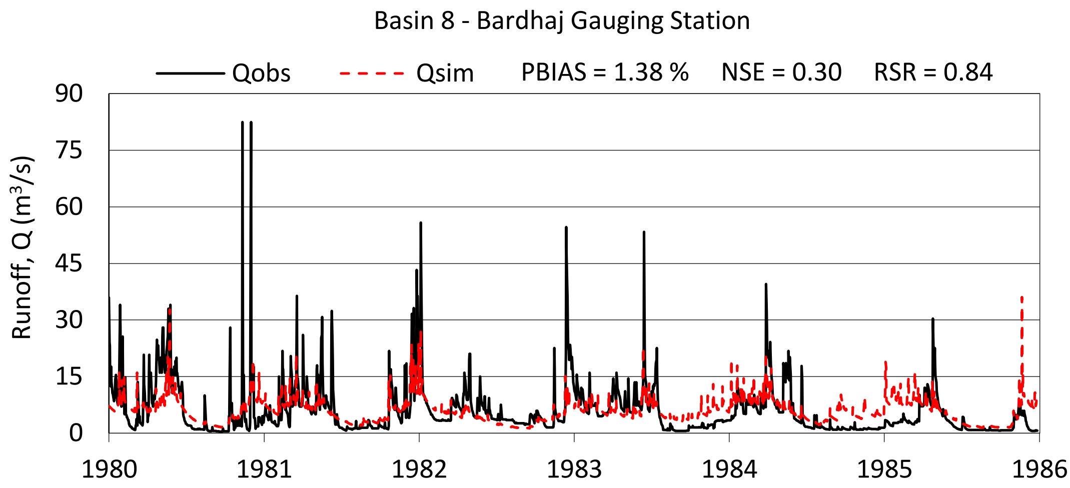
Basin 5 - Poshtme Gauging Station
Qobs
Qsim
PBIAS = 3.43 %
NSE = 0.20
RSR = 0.90
Runoff, Q (m³/s)
0
20
40
60
80
100
1980
1981
1982
1983
1984
1985
1986

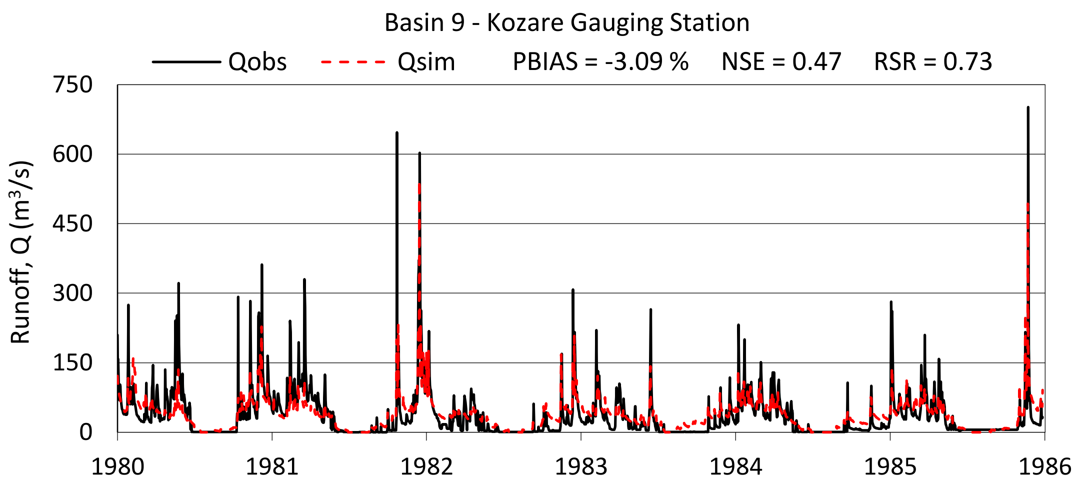


Basin 6 - Kokel Gauging Station
Qobs
Qsim
PBIAS = -6.49 %
NSE = 0.47
RSR = 0.73
Runoff, Q (m³/s)
0
50
100
150
200
250
300
350
1980
1981
1982
1983
1984
1985
1986



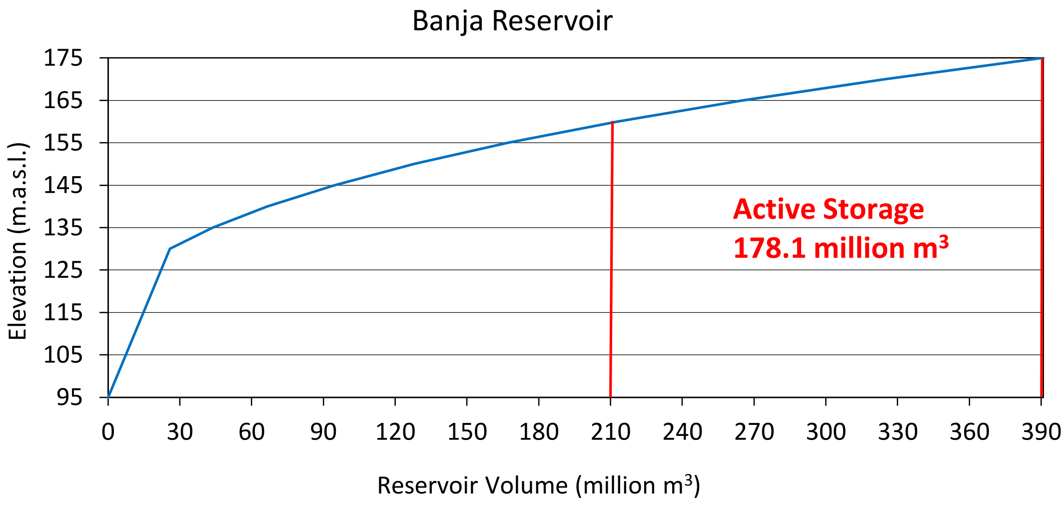
Basin 7 - Tomorrice River
Runoff, Q (m³/s)
0
20
40
60
80
100
120
140
160
1980
1981
1982
1983
1984
1985
1986

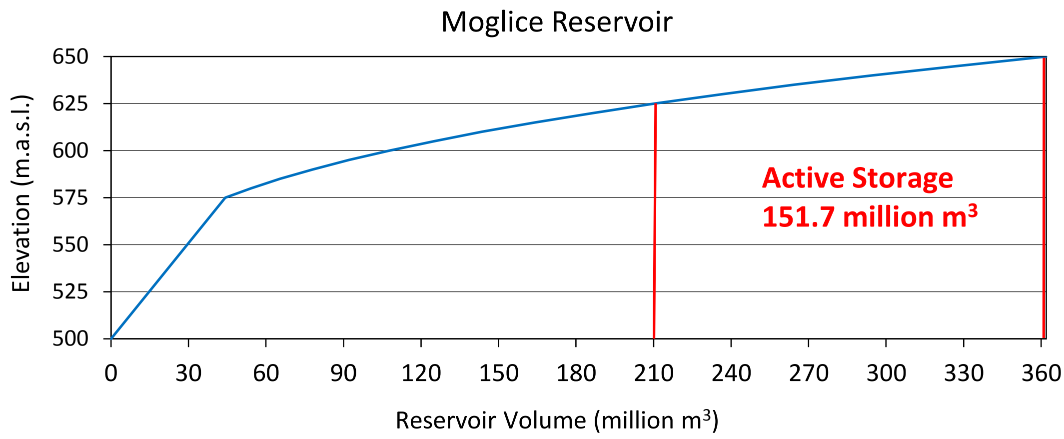

Basin 8 - Bardhaj Gauging Station
Qobs
Qsim
PBIAS = 1.38 %
NSE = 0.30
RSR = 0.84
Runoff, Q (m3/s)
90
75
60
45
30
15
0
1980
1981
1982
1983
1984
1985
1986

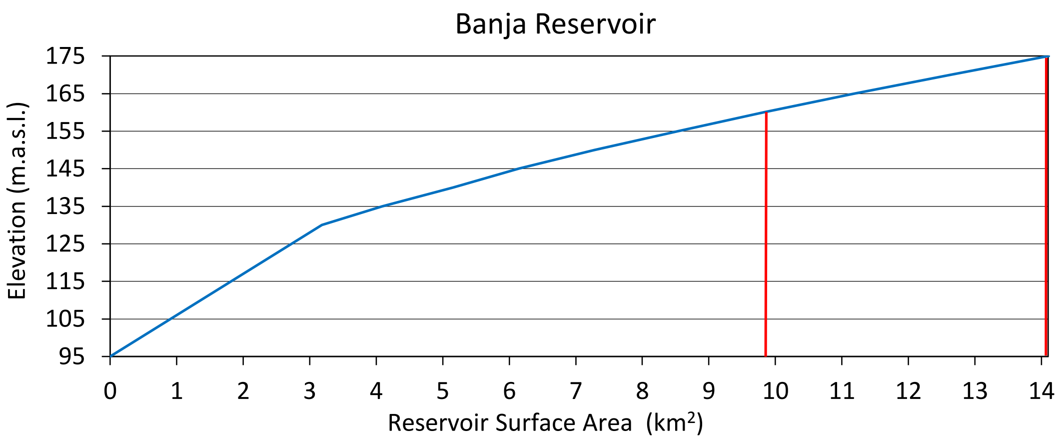

Basin 9 - Kozare Gauging Station
Qobs
Qsim
PBIAS = -3.09 %
NSE = 0.47
RSR = 0.73
Runoff, Q (m3/s)
750
600
450
300
150
0
1980
1981
1982
1983
1984
1985
1986

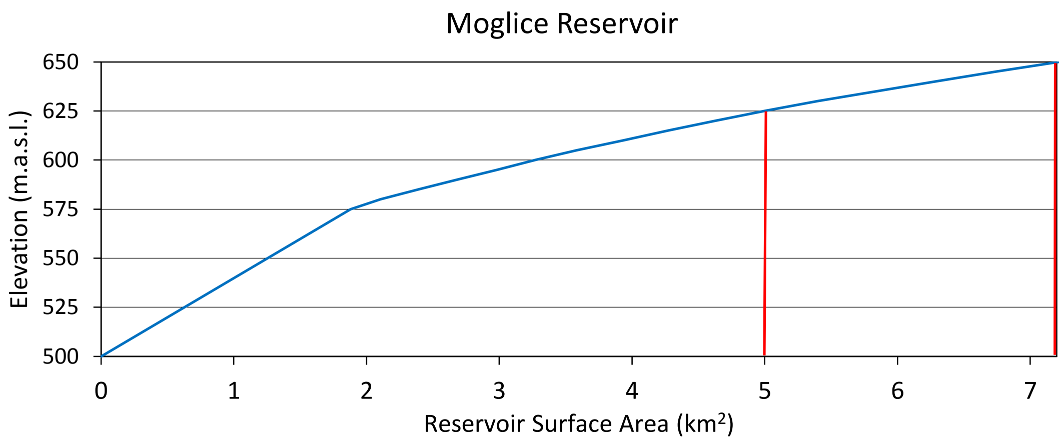
Appendix H: Volume-elevation and Area-elevation Curves

	Banja			Moglice	
Elevation (m.a.s.l.)	Area (km^2)	Volume (million m^3)	Elevation (m.a.s.l.)	Area (km^2)	Volume (million m^3)
95	0.0	0.0	500	0.0	0.0
130	3.2	25.9	575	1.9	44.2
135	4.1	43.8	580	2.1	54.2
140	5.2	66.6	585	2.4	65.4
145	6.1	94.6	590	2.7	78.0
150	7.3	128.0	595	3.0	92.1
155	8.5	167.2	600	3.3	107.7
160	9.8	212.9	605	3.6	124.8
165	11.2	265.2	610	3.9	143.6
170	12.6	324.5	615	4.3	164.1
175	14.1	391.0	620	4.6	186.3
			625	5.0	210.3
			630	5.4	236.3
			635	5.8	264.4
			640	6.3	294.6
			645	6.7	327.2
			650	7.2	362.0




Moglice Reservoir
Elevation (m.a.s.l.)
650
625
600
575
550
525
500
0
30
60
90
120
150
180
210
240
270
300
330
360
Reservoir Volume (million m³)
Active Storage
151.7 million m³


Banja Reservoir
Elevation (m.a.s.l.)
175
165
155
145
135
125
115
105
95
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Reservoir Surface Area (km²)


Moglice Reservoir
Elevation (m.a.s.l.)
650
625
600
575
550
525
500
0
1
2
3
4
5
6
7
Reservoir Surface Area (km²)