


Flow characterization temporary streams

Using the model SIMGRO for the Evrotas basin, Greece

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Abstract

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Tools were developed to quantify space-time development of different flow phases at river basin scale. Such information is needed for the WFD. The spatial development of temporary streams was investigated in the Evrotas basin, Greece. We used the regional hydrological model SIMGRO, in a GIS framework to generate flow time series for all major streams. For a streams reach five flow phases are distinguished, being: floods, riffles, connected flow, pools and dry conditions. For each stream and flow phase, thresholds were identified based on local characteristics. The analysis shows the frequency of the flow phases per month. For all streams in the Evrotas basin the average frequency of the flow phase dry and pools are presented. The aim is that GIS helps to understand better the link between dry streams and spatially-distributed catchment characteristics. Local morphological conditions and roughness of the bed need to be considered in defining appropriate threshold levels for the flow phases.

Keywords: temporary stream, flow phases, pools, river basin. SIMGRO model, energy balance, SSEBI, Greece

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Contents

Preface

The work presented in this report was carried out in 2009 and 2010 within the framework of the Mirage project (**Mediterranean Intermittent River ManAGEment**). The goal of this study was to acquire data of river flow in temporary streams. This information is needed for the implementation of the Water Framework Directive.

We would like to thank everybody who has helped and supported us during this research. In particular we would like to thank the Technical University of Greece and the Prefecture of Laconia for supply of data. A special thanks goes to Vassillis Papadoulakis, Rania Tzoraki, Leonidas Vardakas, and to Nikolaos Nikolaidis for their help and support during the project. All the basic maps and their content were made available by the Technical University of Crete and the Prefecture of Laconia.

Summary

Many of the Mediterranean rivers are temporary. These intermittent streams have flowing water part of the year and become dry during the summer. Endemic species are adapted to these circumstances and survive in pools or moist areas that remain in the riverbed. These areas function as important habitats for re-populating the stream again when the dry period ends. Agricultural water use may have a major impact on flow variability of intermittent streams, and hence on the ecological functioning of these streams as well. River basin management plans have to be determined for temporary streams in the scope of the Water Framework Directive. Temporary streams ask for a different approach than perennial streams. Therefore, a new method must be used to spatially visualize water availability within the riverbed.

The objective of this study is to link the influence of agricultural water use to water availability during dry periods and to find a new way to visualize water availability within the river. The challenge is to visualize the availability of water in the river when there is no flow and to link changes in rainfall variability, climate and land use change to spatial and temporal characterization. This has been done for the Evrotas river basin in Greece, Peloponnese.

The SIMGRO model (SIMulation of GROundwater and surface water levels) has been used to predict the hydrological behavior of the Evrotas. SIMGRO simulates the flow of water in the saturated zone, the unsaturated zone and the surface water. The model is physically-based and therefore suitable to be used in situations witch changing hydrological conditions. The SIMGRO model was used to relate flow regime characteristics to spatially-distributed catchment characteristics or associated fluxes. Tools were developed to quantify space-time development of different flow phases at river basin scale. The Simplified Surface Energy Balance Index (SSEBI) algorithm has been used to determine the potential evapotranspiration and the actual evapotranspiration in the Evrotas basin. SSEBI is developed to solve surface energy balances on a pixel-by pixel basis using remote sensing techniques. The algorithm calculates the evaporative fraction using surface reflectance, temperature and the roughness of the surface area.

The results of the SIMGRO model correspond reasonably well with the measured water discharges, especially when intensive irrigation levels are included. Typical land-use change and increasing irrigation intensity in the Evrotas basin have been defined to approach scenarios corresponding with four periods within the last 100 years, being 1900, 1960, 1980 and the present situation.The historical scenarios show that the abstraction of groundwater and the increasing irrigation intensity in recent years changed low summer discharges in periods with no flow. This corresponds to the knowledge of local experts. The results indicate that the intermittent characteristics of the Evrotas river are manmade.

The flow status frequency graphs allow a rapid visual assessment of the stream regime, based on model results. From the analysis it appears that all the major streams are on average 34% of the time dry. Spatial differentiation in sub-basins can reveal regions with an excessive exploitation of the water resources. Such information can be used to give indications of the ecological status or to assess the effect of changes in e.g. land use or climate change. In this respect SIMGRO is a powerful tool for modelling the flow conditions and producing maps of the areal extent of temporary streams.

Evapotranspiration is a significant factor determining river discharge. Crop irrigation and deciduous forest are the most important land use types contributing to evapotranspiration. There is however a large discrepancy

between the SSEBI and the SIMGRO results. Further improvements of the evapotranspiration parameters are needed to increase the model reliability.

A scenario analysis using different levels of water use may reveal the conditions for sustainable use of the water resources. The proposed method can therefore help, not only to identify near-natural flow conditions in an ideal setting, but also to analyse measures to restore the hydrological system.

1 Introduction

Many of the Mediterranean rivers are temporary. These intermittent streams have flowing water part of the year and become dry during the summer (Gallart et al., 2008). Endemic species are adapted to these circumstances and survive in pools or moist areas that remain in the riverbed. These areas function as important habitats for re-populating the stream again when the dry period ends (Soulikidis et al., 2010a). The duration of the no-flow periods and the extend of the dry area within the riverbed has been increasing in recent years, because of more water use by agriculture, urban areas and industries. The dryer periods strongly influences the water quality as well, since domestic and agricultural pollutants accumulate inside the riverbed. Both the prolonged period of drought and the accumulation of pollutants endangers the survival chances of endemic species (Gallart, et al., 2008).
Agricultural water use may have a major impact on flow variability of intermittent streams, and hence on the ecological functioning of these streams as well. The presence of interstitial flow and the appearance of pools may not only be affected by the many direct withdrawals, but also by excessive use of groundwater from the shallow and the deep aquifer. It is however difficult to determine groundwater and surface water interactions. Until now there are plenty of model approaches available to describe flow, but there is limited information that describes the impact of agricultural groundwater use on expansion contraction dynamics of rivers and on the remaining pools in the riverbed.

River basin management plans have to be determined for temporary streams in the scope of the Water Framework Directive. It is however difficult to manage these stream types properly without having a better understanding of the true variability of river flow over space and time. The occurrence and duration of dry periods within temporary rivers can vary strongly per river due the natural and artificial local circumstances (Bonada, et al., 2007). Characterization of these river types is therefore important in order to determine reference conditions, the required ecological status and the right moment to sample the river. Species composition will be very different before - during - and after a dry period. The moment to sample will thus strongly influence the outcome of the analysis (Gallart, 2011).

Temporary streams ask for a different approach than perennial streams. Hydrological characterization at single points does not reflect the 'mentality' of the system. Measuring flow at the outlet is of less use since it won’t give any information about the existence of standing water within the river or local flow. Therefore, a new method must be used to spatially visualize water availability within the riverbed.

1.1 Goals and challenges

The objective of this study is to link the influence of agricultural water use to water availability during dry periods and to find a new way to visualize water availability within the river. The challenge is to visualize the availability of water in the river when there is no flow and to link changes in rainfall variability, climate and land use change to spatial and temporal characterization. This will be done for the Evrotas river basin in Greece, Peloponnese.

1.2 Outline of report

Chapter 2 gives a description of the Evrotas river and the most important aspects of the river basin. Chapter 3 gives a description of the research area in combination with a description of the input data used for the SIMGRO model. Chapter 4 describes land use change scenarios that were uses as input in the SIMGRO model and their results. Chapter 5 gives a description of the results of the visualization of the river flow. The results of the energy balance and the evapotranspiration in the river basin can be found in Chapter 6. The conclusions and recommendations are finally given in Chapter 7.

2 Description Evrotas basin

2.1 Geographic

The Evrotas is an intermittent river located in the south of Peloponnese, Greece. The river has a catchment size of 2410 km^2. It's basin includes a small part of the prefecture of Arkadia upstream, and covers almost the complete area of the prefecture of Laconia (Nikolaidis et al., 2009). Sparta is the largest city in the river basin. It is located at the middle reach of the Evrotas and has a population of approximately 15.500 inhabitants (www.geonames.org, *accessed on 15-06-2010*). The Evrotas river has a length of 90 km (Nikolaidis et al., 2009) and flows southwards into the Laconian Gulf of the Mediterranean sea. The river basin has a maximum width of 53 km and is bordered in the east and west by two mountain ridges. The Taygetos mountain range on the west side of the basin has the highest peaks in Peleponnese and reaches a maximum altitude of 2.407 meters, as shown in Figure 2.1. Parnonas mountain range is located on the east of the Evrotas basin with a highest peak of 1.935 meters. The main tributaries of the Evrotas are the streams of Oinoutas (temporary flow), Mariorema (episodic flow), Xerias, Magoulitsa, Gerakaris, Kakaris and Rasina (Valta et al., 2008). The pictures in Appendix 1-3 give a general impression of the Evrotas river and its surroundings.

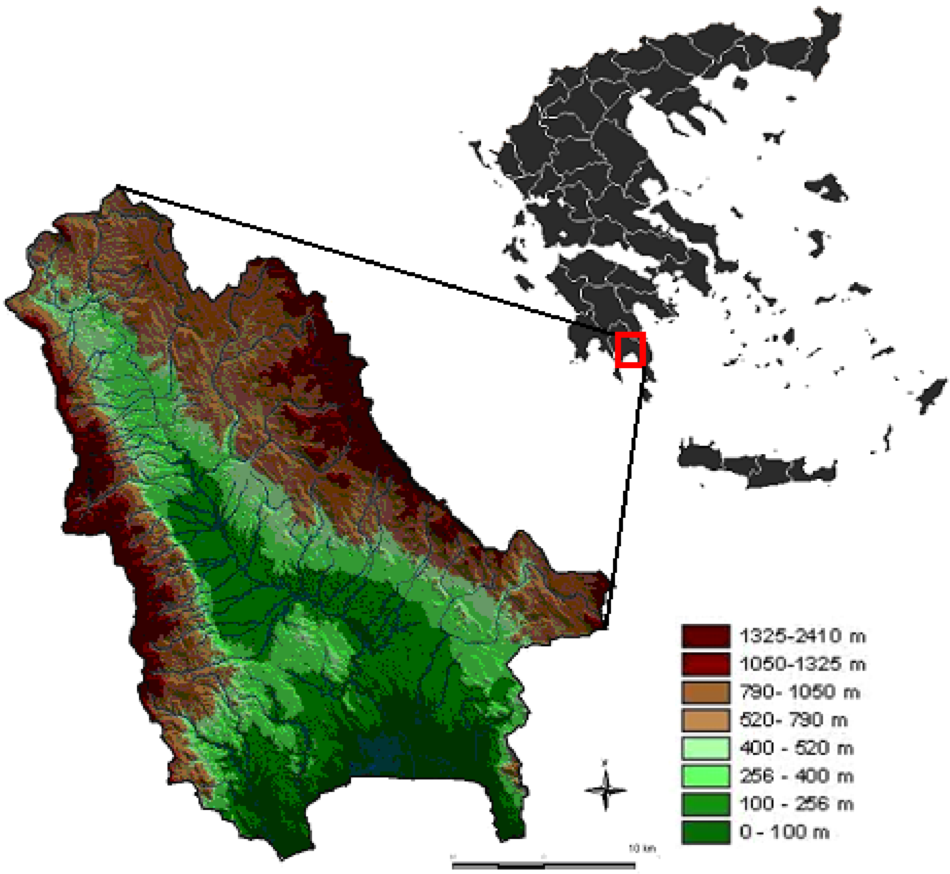


Figure 2.1
The Evrotas river basin and the elevation as located in the south of Peloponnese, Greece.

2.2 Geology

The geology of the Evrotas river basin is dominated by the presence of limestone and karst systems that underlie almost the complete catchment. Alluvial layers are found on top of the limestone near the riverbed and in the downstream part of the catchment (Nikolaidis et al., 2009). The slopes of Taygetos mountains are characterized by the presence of several alluvial fan systems. Individual fan systems vary in size and cover an area ranging between 15 and 350 ha (Appendix 4). In morphological terms fans can be defined as: 'conical, lobate or arcuate accumulations of predominantly coarse grained sediment which are characterized by variable surface morphologies' (Pope and Millington, 2000). The thickness of fan deposits is unknown. However, limited bore-hole data for the Sparta basin indicate that the gravel units range from about 28 to 60 m in thickness (Pope and Millington, 2000). There are two types of aquifers in the Evrotas basin, karstic aquifers and alluvial aquifers. The karstic aquifers are responsible for the many springs that characterize the Evrotas basin and that supply water to Evrotas tributaries and the municipalities and farms in the basin (Appendix 5). Alluvial aquifers are usually recharged by the karstic aquifers (Nikolaidis et al., 2009), the reverse is possible as well. There are five large karstic aquifers in the Evrotas basin and several smaller aquifers. The six larger aquifers are described by the Technical University of Crete (TUC) as follows:

Karstic system Zoros-Vivari. The system discharges though Zoros springs and though the Vivariou-Sellasia springs. The system also recharges the alluvial groundwater basins of the Evrotas. The water from this karstic system is used for irrigation by the local water administrative of Sallasia and Koniditsa. The Evrotas appears to flow permanently downstream of these springs.

Karstic system of north Taygetos. The system discharges into the many Kastori springs. These springs supply the drinking water for the municipalities of Pellana, Mistsra and Loggastra and are responsible for the supply of irrigation water as well.

Karstic system of central Parnonas. Supplies the stream Vasilopotamo and recharges the small groundwater basins near the Evrotas estuary.

Karstic system of Skala Krokeon. This karstic system discharges through the Skala springs. The system also supplies the stream Vasilopotamo and recharges the small groundwater basins near the Evrotas estuary together with the karstic system of central Parnonas.

Karstic system of south Parnonas an Zaraka. The system discharges mainly through coastal and undersea springs. It also recharges laterally the grained groundwater aquifers of Molaon and Apidias.

Small karstic systems. Small karstic systems are observed in the municipalities of Krokeon, Monembasia and Vion (Nikolaidis et al., 2009).

In depth research into the functioning of the karstic and sedimentary aquifers in the Evrotas basin is limited. There are however several observation wells in the area that are monitored by the prefecture of Laconia for the last 20 years. There are however some studies performed in the shallow alluvial aquifer of Sparta (Antonakos and Lambrakis, 2000; Lambrakis et al., 2004). The shallow aquifer of Sparta is unconfined in the west and north of the region and becomes semi-confined in the centre and in the south of the area due to an increase in clay content. The aquifer is mostly homogeneous and lacks strong variations in the hydraulic gradient that varies between 0.01 and 0.03. Groundwater drainage is observed in the east and north of this aquifer while groundwater recharge mainly occurs from the mountainous regions through the crystalline carbonate rocks and the surface water of the Evrotas. The Evrotas river itself drains the entire west bank of the riverbed while it recharges the aquifer on its east bank (Antonakos and Lambrakis, 2000).

2.3 Regions summary

The Evrotas river has been divided into zeven regions by the TUC based on the regions characteristics. The description of the TUC of each region, as shown in Figure 2.2,) will be described here, since it gives a clear overview of the different types of land use, geography and geology of the area.

Region 1 is the north of the river basin and covers a part of Parnonas mountain. The area has a high altitude and steep slopes of 10-30%. There are many calcareous formations in this region that are responsible for underground water flow in the karst. The main part of this region is covered with natural vegetation and a few small settlements and small scale farming. There is little pressure on the environment in this part of the Evrotas basin.

Region 2 is situated in the northwest part of the basin. The calcareous formations on the west side of the region recharge the Evrotas springs. Kastor, one of the tributaries has flowing water throughout the year as a result of this. However the upper part of the Evrotas river is dry during the summer. Region 2 has high altitudes in the west, medium altitudes in the rest of the area and medium to mild slopes. There are nine settlements and agriculture and animal husbandry are more important in this area as well. The environmental pressure is a little higher as a result of this.

Region 3 contains Inoundas, the largest tributary of the Evrotas. Some parts of the river have a continuing flow throughout the year, but a large segment of the tributary becomes dry during the summer. The area exists mainly out of karst formations. The main environmental pressures in the region come from livestock and a few settlements.

Region 4 holds the largest portion of Taygetos mountain, an area characterized by high altitudes and steep slopes. The region is strongly karstified and karst forms thus the most important aquifers of the area. The karst in region 4 is also responsible for the existence of the many springs that can be found in this region. There are several important springs such as Katagianni, Sotiros and Tripis that recharge Evrotas tributaries like Kakari and Magoulitsa stream.

Region 5 is an area with low altitudes and mild slopes. Alluvial deposits form the main formations. There are many streams in this area, several of them originate at springs higher in the mountains of region 4. Sparta is the biggest city in this region and the pressure on the environment is a lot higher due to agriculture, industry and large towns.

Region 6 is the area southeast of the Parnonas mountain range. Karst is also an most important formation in this region of the river basin and exists mainly in the higher part of the region. Other formations such as alluvial deposits can be found at lower altitudes. There are several small tributaries of the Evrotas in this area, but many of them do not carry water during a large part of the year. Mariorema is the largest stream that can be found in this region. There are no significant environmental pressures in this part of the Evrotas river basin.

Region 7 includes the towns of Skala, Ellos and Githio, also the Evrotas river estuary an important nature reserve can be found in this area. The region experiences high environmental pressures due the intensive and extensive orange cultivation and the pollution from olive mills is an issue (Nikolaidis et al., 2009).

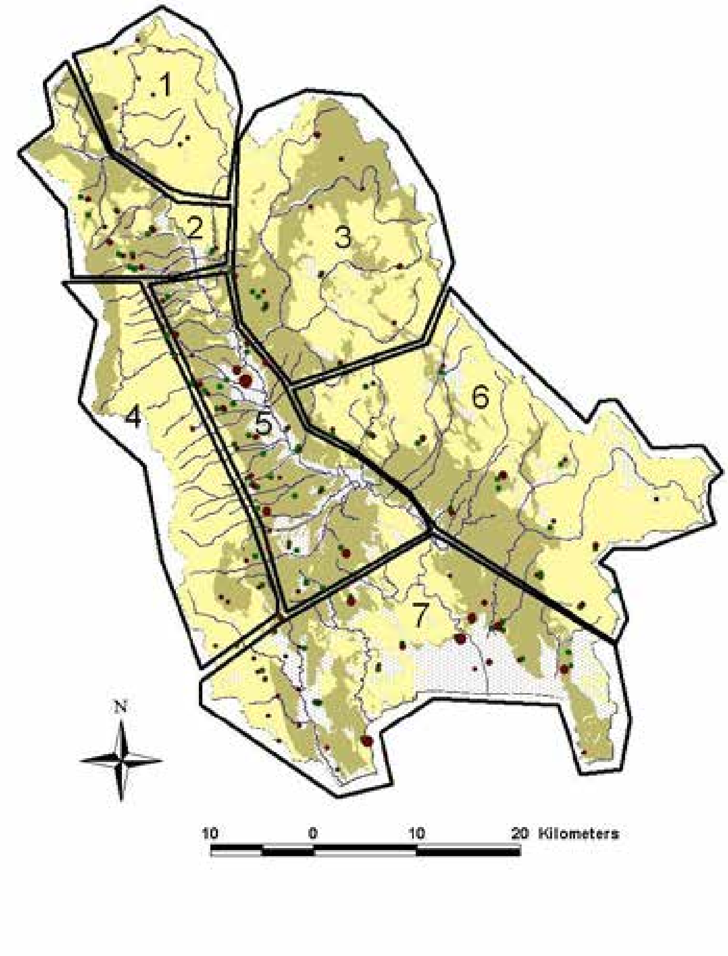


Figure 2.2
Regions in the Evrotas basin (source data: Technical University of Crete).

2.4 Water availability

The Evrotas river starts as a relatively small stream with a width of about five meters in the north of the basin. The width of the major part river fluctuates around the 10 and 20 meters. However, there are several braided areas where the river can reach a width of 200 meters. The riverbed reaches a width of about 30 meters in the south near the town of Skala. Floods are not unusual for the Evrotas. There is a floodplain visible on several locations along the river that can reach a width of about 400 m. There are several morphological alterations along the river as well that concern bank reinforcement and flood control. The mean annual discharge of the Evrotas is 3.3 m3/s (1974-2008). This value was measured at the Vrontamas site upstream of the Vrontamas-gorge (Skoulikidis et al., 2010b). The river flow downstream of Vrontamas is however much lower due to the water loss through the karst system in the gorge and the use of water for irrigation.

The Evrotas is a temporary or intermittent river. This means that the river has flowing water throughout most of the year, but falls (partly) dry during several months. The dry period in the Evrotas is seasonal and occurs during the summer (Angelidis et al., 1995). The dryness in the Evrotas and its tributaries is partly due to the karstic systems in the basin. A large quantity of the river water moves towards the groundwater through the intense faulted karst environment. Especially the karstic system of Vrontamas plays an important part in this. Most of the river water disappears when it reaches this area (Nikolaidis et al., 2009). Another important factor in the decrease in water availability during the summer is the intensive agricultural water use. In the Evrotas basin there are more than 3500 private wells and 150 public wells that are used to obtain a considerable amount of water (Nikolaidis et al., 2009). Water abstraction from groundwater and direct abstraction from surface water occurs uncontrolled. It is thus unknown how much water is used for irrigation and how this effects the river flow. The water table in some of the aquifers diminished dramatically due to groundwater over-pumping. A number of groundwater wells in the Skala and Ellos region have become unsuitable for the pumping of irrigation water due to sea water intrusion (Technical University of Crete and Prefecture of Laconia, 2006). The shallow unconfined aquifer in the Sparta area has become substantially enriched with nitrate (average 62.6 mg/l). The legislative threshold for nitrate in drinking water (50 mg/l) is exceeded in 65% of the measured samples (Antonakos and Lambrakis, 2000). The immense water abstraction in combination with unusual dry years, such as the summer of 2007, results in the complete desiccation of the majority of the river network (Vardakas et al., 2010). Vardakas et al. (2010) even names the Evrotas an 'artificially intermittent' river because of the effect of the intensive water abstractions in the river basin. Several wet river segments, pools and moist areas remain during the dry season in the Evrotas. These areas consist out of remaining river water, groundwater or the inflow of spring water. Wet areas and pools are important for the river ecology since they form refuge areas for endemic species of the river basin that can repopulate the river again when the water starts flowing.

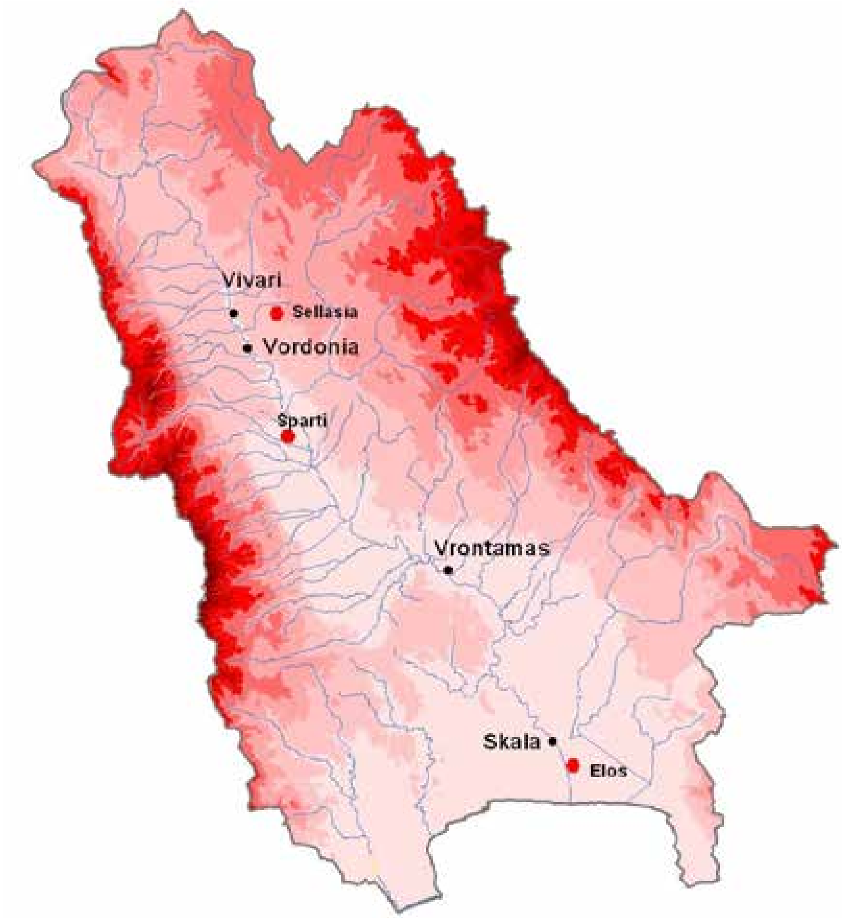


Figure 2.3
Evrotas river and its tributaries, shown as well are the gauge stations and the relevant cities.

2.5 Climate

The Evrotas has a Mediterranean climate with mild winters and long, hot and dry summers. The average annual temperature for the whole basin is 16 °C and the mean annual precipitation 803 mm (2000-2008) (Vardakas et al., 2010). The average annual temperatures of the main stations in the basin are 16.5 °C (Ribbiotissa), 15.7 °C (Sellasia) and 17.9 °C (Elos). Summers are usually very hot, maximum summer temperatures occasionally exceed 40 °C (sources data: Prefecture of Laconia). The temperature in the mountain ranges of Taygetos and Parnonas decreases below 0 °C during the winter resulting in the accumulation of snow. There are zeven meteorological stations in the Evrotas basin (Appendix 6): Perivolia (1202 m elevation), Sellasia (586 m), Vasaras (642 m), Ribbiotissa (163 m), Vrontamas (139 m), Petrina (240 m) and Ellos (4.5 m). Temperature, precipitation and evaporation are measured in Ellos, Sellasia and Ribbiotissa. Precipitation only is measured in the other meteo stations. There is a gradient of precipitation levels from west to east and from north to south in the Evrotas basin. The highest precipitation levels are found in the Taygetos mountain range where the highest recorded values are 1300-1600 mm. The highest recorded values in the eastern Parnonas mountain range are 1000-1200 mm. Downstream of the Evrotas precipitation values decrease towards 700-800 mm and the lowest precipitation values are found near the coast 500-550 mm. The majority of the precipitation (70%) occurs during the autumn and winter season, followed by the spring that accounts for about 20% of the precipitation. The summer is dry with up to 10% of the total precipitation of each year (Nikolaidis et al., 2009).

2.6 Land use

The majority of the Evrotas basin is covered with natural and semi-natural areas accounting for 61% of the area (Figure 2.4). Agricultural areas account for 38% (olives 26%, oranges 8% and remaining agricultural crops 4%) of the complete basin and only 1% of the basin is occupied by urban areas (Vardakas et al., 2010). Natural areas exist mainly out of dry and often grassed maquis vegetation, bare soil, pine forest and some deciduous forest higher in the mountains. Olives are by far the main crop grown in the basin followed by oranges. Some other crops that are grown as well are grapes, alfalfa, corn and wheat. The area in the valley on both sides of the river is used intensively for agriculture. The more hilly area is mainly planted with olive trees. Accessibility and the difficulty of cultivating crops in this area are the major reasons for this. The majority of the agriculture in the basin is irrigated. Only areas far from the river without access to groundwater or springs are rain fed. There are several diversions in the riverbed of the Evrotas and its tributaries to direct water towards cultivated fields. Other areas are irrigated with groundwater from the alluvial aquifer or with deep groundwater from the karst. Water is transported to relatively remote fields by hosepipe constructions that hang in the trees. Before 1950 only surface water was used for irrigation in Laconia. From 1950 also groundwater from shallow wells was used. In 1960 irrigation became a lot more intensive as a result of the installation of deep groundwater wells. Olive orchards used to be rain fed until 1990. This was changed however by the occurrence of three very dry growing seasons in a row after which irrigation became the standard practice[1]. Further details are given in Chapter 4.

[1] Communication with Vassilis Papadoulakis, Land Reclamation Service, Lakonia Prefecture, Sparta, Greece

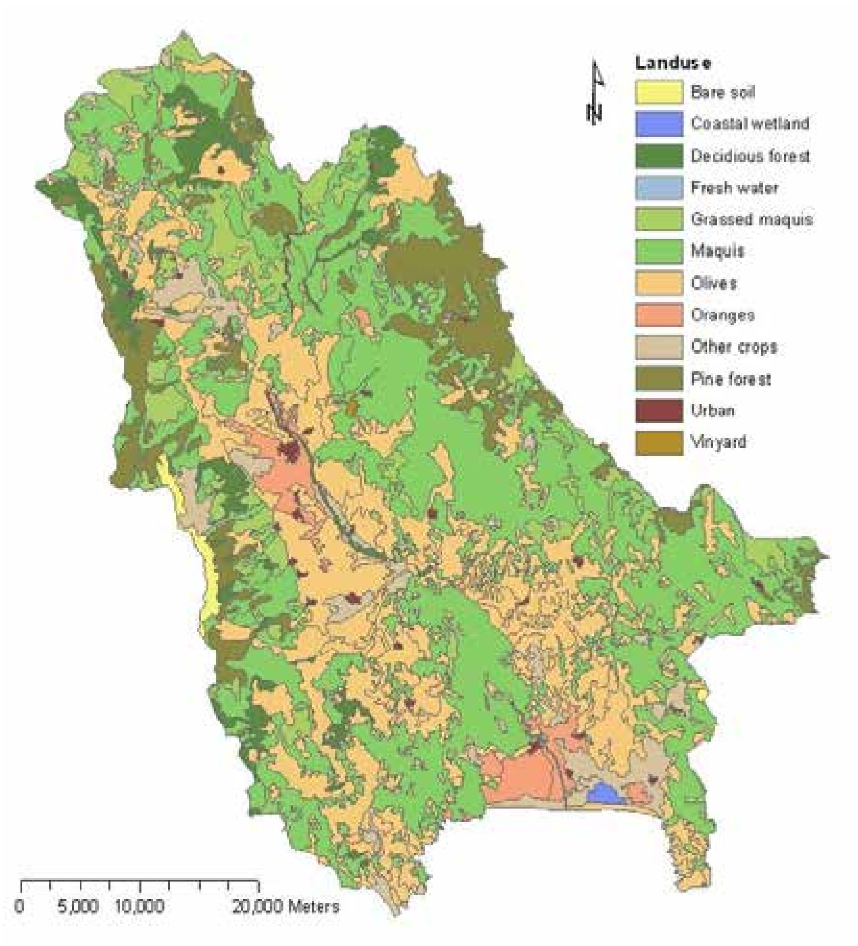


Figure 2.4
Land use for the Evrotas basin (source data: CORINE2000).

2.7 Biodiversity

The Evrotas basin is home to several important ecosystems which are listed in the Natura 2000-database (Appendix 5). The first area on this list is the Evrotas delta. The delta comprises a wide variety of wetlands and coastal ecosystems. The area has a high biodiversity with a large variety in flora and fauna. Several rare species such as the loggerhead sea turtle, the otter and the jackal can be found in this area. Furthermore the area is located on a bird migration route and is thus the most significant resting and feeding pace in southern Greece for a large number of migratory birds (Korakis and Gerasimidis, 2006). Other important areas in Laconia that are included in the Natura-2000 database are the vegetated sea cliffs along the Mediterranean coast, the Endemic oro-Mediterranean heaths with gorse (cushion-forming, often spiny shrubs), hard water springs in formations of sedimentary rock and calcareous rocky slopes with chasmophytic vegetation (Mediterranean vegetation growing in rock fissures or crevices).
The Evrotas river itself is an unique biodiversity hotspot as well. The river houses many local endemic plants and vertebrates. There are five native freshwater fish species in the Evrotas and two that have been introduced. Two of the native species can solely be found in the Evrotas river and one other species is restricted to a few rivers in southern Peloponnese only. The southern part of the Evrotas knows several marine species as well that can be found in the salt and brackish water near the river mouth. This high proportion of endemic species is the result of the geographic isolation of the area and the diverse ecosystems of the region.

The combination of these factors with the complex climatic and geological history of Laconia positively promotes speciation of species (Vardakas et al., 2010).

2.8 Environmental issues

There are several environmental problems in the Evrotas basin. The main issues according to Markantonatos et al., (1995) are listed below:

- Pollution of the river by the discharge of municipal sewage, agricultural runoff and industrial waste water;
- Overuse of surface water and groundwater.
- Degradation of maquis vegetation and forests as a result of the expansion of agricultural land, animal grazing and fire.
- Uncontrolled disposal of municipal waste.
- Uncontrolled use of pesticides and air spraying practices.
- Destruction of the riparian ecosystem of the river as a result of land claiming.
- Salinization of the groundwater and the soil in the lowlands near the Laconian gulf.
- Degradation of the marine water quality and sandy beaches by uncontrolled housing and tourist activities (Markantonatos et al., 1995).

Industrial waste water mainly exists out of the effluent from orange juice plants and mills that produce olive oil. Waste water from the orange juice plants is often orange of colour and has very high concentration of organic matter. These discharges usually occur during the winter months when the orange harvest is processed (Angelidis et al., 1995). Olive mills contribute significantly to the pollution of the water as well by disposing the waste and the wastewater without treatment in the Evrotas or its tributaries. The waste has a high COD content and some of its components are toxic as well. The volume of the liquid effluent from the olive mill can be double or even quadruple compared to the amount of olive oil that is produced. A large amount of solid waste is produced as well. There are 91 olive mills operating within the Evrotas river basin that contribute to the pollution and have a negative effect to the riparian zone and the groundwater as well (Nikolaidis et al., 2009; Tzoraki et al., 2008).

The self-purification capacity of the Evrotas decreases during the summer as a result of low flows. High concentrations of organic matter are not uncommon during these moths. However. However, the outflowing water in de Mediterranean sea has acceptable concentrations of pollutants during most of the year although occasional peaks do occur. The low concentrations of pollutants might be due to the large reed beds in the lower reach of the river that promote nutrient retention, denitrification, nutrient uptake and the trapping of sediments (Angelidis et al., 1995).

3 Methods and data

3.1 Description of the SIMGRO model

For such a complex system as the Evrotas River Basin it required the use of a combined groundwater and surface water model to predict the effect of measures. Therefore, the SIMGRO model was used. The model simulates the flow of water in the saturated zone, the unsaturated zone and the surface water (Figure 3.1). The model is physically-based and therefore suitable to be used in situations with changing hydrological conditions.

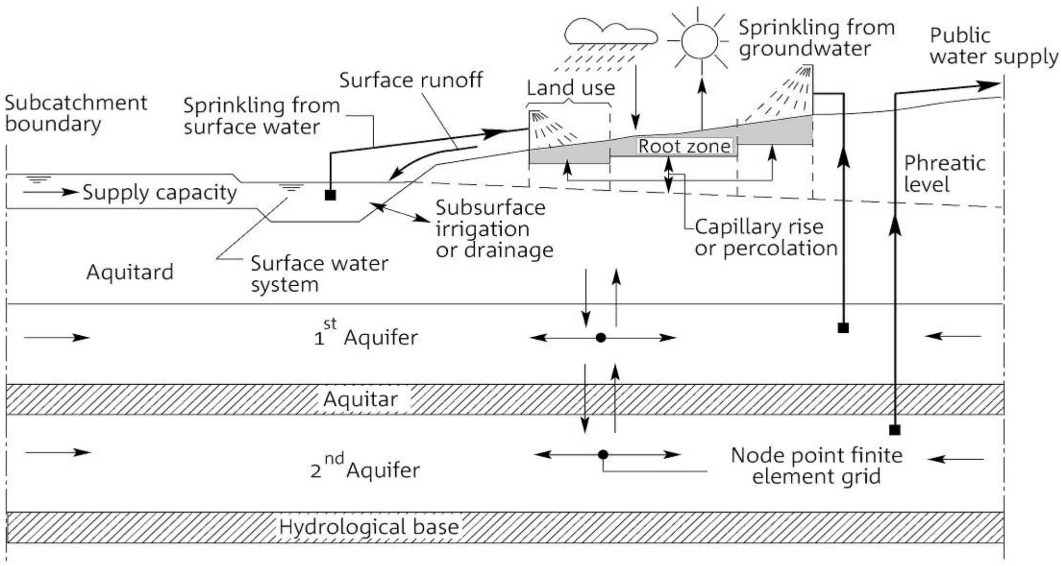


Figure 3.1
Schematization of water flow in the SIMGRO model (Querner, 1988).

SIMGRO (SIMulation of GROundwater and surface water levels) is a distributed parameter model that simulates regional transient saturated groundwater flow, unsaturated flow, actual evapotranspiration, sprinkler irrigation, stream flow, groundwater and surface water levels as a response to rainfall, reference evapotranspiration, and groundwater abstraction (Van Walsum et al., 2004; Querner, 1997; Povilaitis and Querner, 2006).

To model regional groundwater flow, as in SIMGRO, the system has to be schematised geographically, both horizontally and vertically. The horizontal schematisation allows input of different land uses and soils per sub region, in order to model spatial differences in evapotranspiration and moisture content in the unsaturated zone.

3.1.1 Groundwater flow

In SIMGRO the finite element procedure is applied to approach the flow equation which describes transient groundwater flow in the saturated zone. A transmissivity is allocated to each nodal point to account for the regional hydrogeology. A number of nodal points makes up a sub region. The unsaturated zone is represented by means of two reservoirs, one for the root zone and one for the underlying soil. Evapotranspiration is a function of the crop and moisture content in the root zone. The measured values for net precipitation, potential evapotranspiration for a reference crop (grass) and woodland are input data for the model. The potential evapotranspiration for other crops or vegetation types are derived in the model from the values for the reference crop by converting with known crop factors. The paved part of the urban area is assumed to have no evaporation, while the unpaved part is considered as grass.

3.1.2 Surface water flow

The surface water system is often a dense network of watercourses. It is not feasible to explicitly account for all these watercourses in a regional simulation model, yet the water levels in the smaller watercourses are important for estimating the amount of drainage or subsurface irrigation, and the water flow in the major watercourses is important for the flow routing. The solution is to model the surface water system as a network of reservoirs. The inflow of one reservoir may be the discharge of the various watercourses and ditches, runoff and water from a sewage treatment plant. The outflow from one reservoir is the inflow to the next reservoir. The water level depends on surface water storage and on reservoir inflow and discharge. For each reservoir, input data are required on a ‘stage versus storage’ relation and a ‘stage versus discharge’ relation.

3.1.3 Drainage

Watercourses are important for the interaction between surface water and groundwater. In the model, four drainage subsystems are used to simulate the drainage. It is assumed that three of the subsystems ditches, tertiary watercourses and secondary watercourses are distributed evenly over a finite element or sub region. These three systems are primarily involved in the interaction between surface water and groundwater. A primary system can also be included in specific nodes, to represent the larger channels in the area modelled. The interaction between surface and groundwater is calculated for each drainage subsystem using a drainage resistance and the difference in level between groundwater and surface water.

3.1.4 Snow accumulation and melting

In the SIMGRO model snow accumulation has been accounted for. The assumption is made that snow accumulation and melting is related to the daily average temperature. When the temperature is smaller than zero Celsius, snow accumulates. For temperature between zero and one degree Celsius, both precipitation and snow melting occurs: it is assumed that during day time precipitation occurs and during night time the snow accumulates (50/50%). When the temperature is higher than one degree Celsius, the snow melts with a rate of 3 mm/day per degree.

3.1.5 User interface AlterrAqua

AlterrAqua is a user interface in ArcView, developed around the SIMGRO model. The purpose of this application is to make the SIMGRO regional groundwater model more user-friendly and easy accessible. The application enables the use of SIMGRO within the GIS environment of ArcView. The power of the instrument is its link to existing digital geographical information (soil maps, land use maps, watercourses, etc.). SIMGRO inputs are generated in separate AlterrAqua modules. For more information and detailed description of SIMGRO input and output files, please refer to Dik (2005). For more information on the theory of SIMGRO, readers are referred to Van Walsum et al. (2004). For an example of the use of SIMGRO, readers are referred to Povilaitis and Querner (2006). In this last study a SIMGRO model is also used to analyse water management measures.

3.2 Input

3.2.1 Model area

The modelled area of the Evrotas river can be seen in Figure 2.3. The area has a surface of approximately 2410 km^2. The groundwater system of the Evrotas rivers is schematized by a network of more than 13400 nodes in which each node represents a part of the groundwater system. Nodes are spaced about 500 to 600 meters apart.

3.2.2 Ground level elevation

The surface level per node has been taken from the elevation map with pixels of fifteen by fifteen meters (Figure 2.1). This map was created by the Technical University of Crete (TUC) and the Prefecture of Laconia using a contour map based on data delivered by the Greek Military GIS Service and a map of the water bodies made by the Institute of Geology and Mineral Exploration (IGME). The elevation levels are the basis of the model calculations. Surface storage has been calculated by using the surface distribution in each influence area. The model area has a high variety in surface levels due to the mountains. The highest peak reaches a level of 2407 meters. The river discharges in the Laconian gulf at sea level.

3.2.3 Geohydrologic schematization

Geological maps provided by the Prefecture of Laconia and the TUC (Appendix 4) were used as the basis of the geological schematization of the river basin. A detailed geological map of the basin was simplified into four types of geological soils: alluvium, fan system, limestone and schist. The vertical geological profile has been divided into three layers. The first layer in the model holds the phreatic groundwater and consists out of the four types of soil. The second layers exists out of an aquitard and the third vertical layer is an aquifer existing out of limestone and schist. An important characteristic of the Evrotas basin is the underground water flow through the karst system. Locally fast flowing underground water has not been included in the model. However, the flow of this water has been taken into account using an average transmissivity (k-values * layer thickness) of the limestone formation. The hydraulic conductivity (k-values) and the layer thickness of the formations have been chosen based on the available geological maps and expert knowledge.

Hydraulic conductivity:

1st layer (aquifer)

Alluvium	1.000 m/d
Fan	5.000 m/d
Limestone	0.100 m/d
Schist	0.001 m/d

2nd layer (aquitard)

Schist	0.001 m/d
Rest	0.04 m/d

3rd layer (aquifer)

Limestone	0.1 m/d
Schist	0.001 m/d

Layer thickness:

1st layer

Alluvium1	20 m
Fan	25 m
Limestone	50 m
Schist	11 m
Alluvium2	50 m

2nd layer

All	2 m

3rd layer

All	50 m

3.2.4 Unsaturated zone

The necessary input data for the simulation of water in the unsaturated zone consists out of the elevation levels, soil characteristics and land cover in the area.
Soil characteristics were taken from the soil map provided by the TUC. Many of the standard AlterrAqua data files contain Dutch standard values because the program was developed according to Dutch environmental conditions. Therefore, the classification used for the soil map has been converted to the corresponding Dutch soil type in order to use the soil map in the AlterrAqua environment. The most common soil types in the river basin are loam with a homogeneous profile, loamy sand, and sandy loam on clay.

Data concerning land cover has been derived from the CORINE land cover 2000 map (Figure 2.4). Dutch land cover type characteristics in AlterrAqua were adapted to correspond with Greek circumstances (crop factors, depth of the root zone). The most common types of land cover we used for the basin are: dry maquis vegetation (52%), agriculture (38%), forest (10%), heavy grassed maquis vegetation(5%), urban areas (1%). SIMGRO uses per nodal (influence area) the main type of land cover for its calculations.

3.2.5 Surface water

The details of the Evrotas River, its tributaries and the small streams has been provided by the TUC who created their map based on data from the IGME (Figure 2.3). The dimensions of these watercourses have been simplified based on experience in the field and knowledge of the model itself. The main river has been given a bottom width of 30 meters, a total depth of three meters and a side slope of 1:1. The main tributaries have been given a bottom width of ten meters, a depth of three meters and a side slope of 1:1. Smaller tributaries and the head waters of the main tributaries received the same values as the main tributaries except that the depth of the riverbed was reduced to one meter. The dimension of all other small watercourses and ditches are a width of 50 cm, a depth of 80 cm and a side slope of one.

3.2.6 Meteorological, hydrological and groundwater data

Meteorological data has been taken from zeven stations in the area: Pervolia, Sellasia, Vasaras, Ribbiotissa, Petrina, Vrontamas and Ellos (for location see Appendix 6). The regions covered by these stations have been selected based on the elevation map. An extra meteorological region has been added in the Parnonas mountains. Precipitation in this mountain ridge is found to decrease by 20% compared to the western mountain ridge[2]. Meteorological data used in the extra region consist out of measurements from Pervolia station multiplied with 0.8.

River discharge measurements are available from three locations where discharges are measured monthly by hand since 1974 and on two locations with monthly measurements since 2000. There are five locations in the Evrotas basin with daily measurements of discharges by water loggers starting from 2006 and 2007. There are 22 groundwater observation wells in the area. The wells are monitored 2-4 times per year since 1990.

3.2.7 Compare model results with measurements

The SIMGRO model of the Evrotas basin could not be calibrated. The model consists out of a very large number of parameters that all need to be checked during calibration, but there is insufficient data available to make this possible. Instead a model analysis has been performed by visually comparing calculated and observed variables to fit the calculated discharges and groundwater levels to the available measurements.

The calculated discharges of the Evrotas river correspond reasonably well with the measurements of the river discharge. This is especially so for the upper reach and the middle reach of the river. Irrigation intensity is one of the major factors influencing the discharge. Adjusting the irrigation intensity towards higher levels improved the simulated results (Figure 3.2). Other factors that have been adjusted to fit the measured and calculated data were the storage capacity of the soil and the surface runoff. A lower storage capacity of the soil was used in order to decrease the discharge during dry periods and a slightly lower surface runoff in order to decrease the high peaks during heavy showers.

[2] Communication with Vassilis Papadoulakis, Land Reclamation Service, Lakonia Prefecture, Sparta, Greece

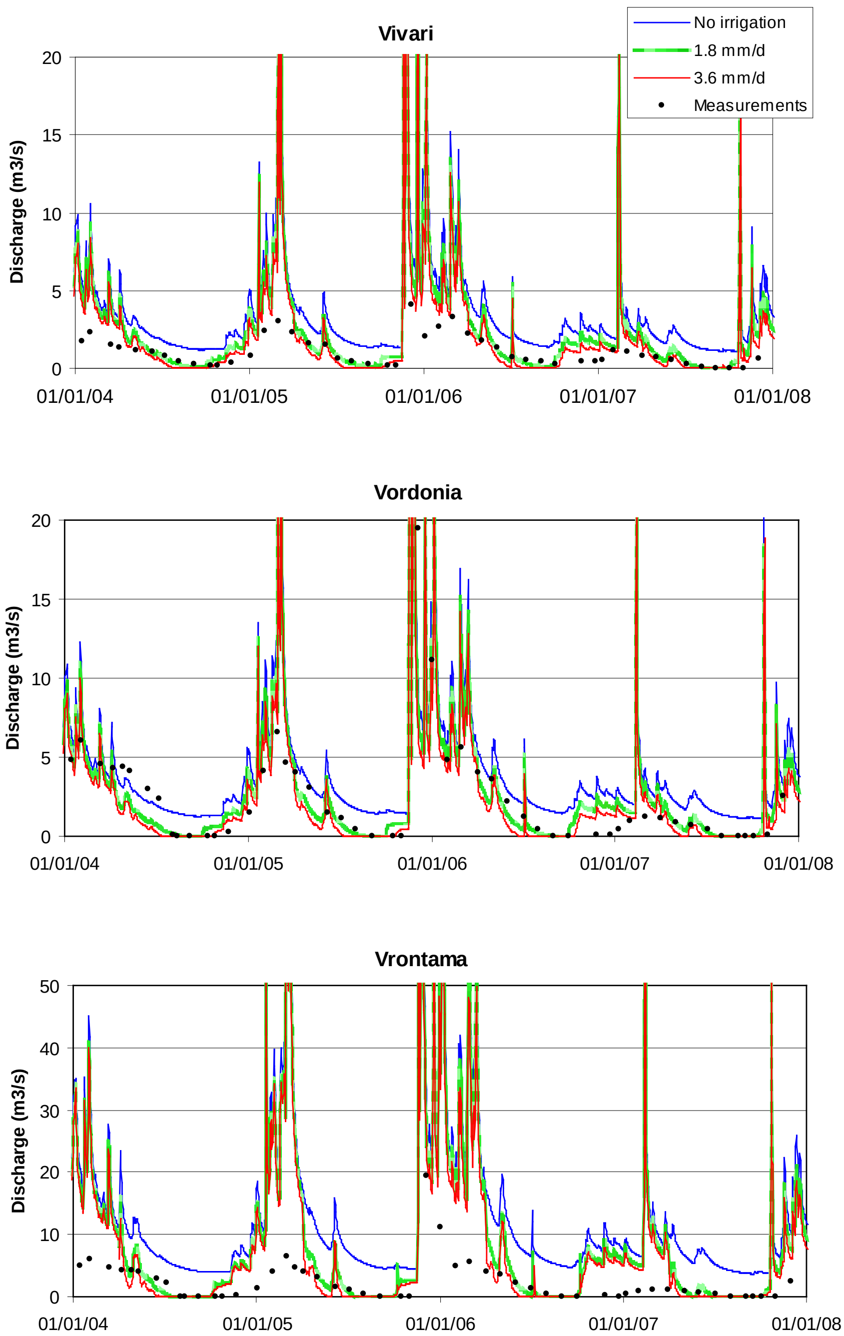


Figure 3.2

Simulated discharges (lines) and measured values (dots) in the upper middle reach (Vivari and Vordonia) and the lower middle reach (Vrontamas) of the Evrotas river

Groundwater levels are only measured 2-4 times per year in the Evrotas basin resulting in a limited number of data. Furthermore, groundwater levels are measured in relation to the top of the well, while SIMGRO calculates the groundwater level in relation to the reference level (Mean Sea Level). There has been no correction between the measured data and the DTM. Therefore, there is an inaccuracy between the DTM and the measured data that can add up to several meters. However, visual analysis of the measured and calculated groundwater levels shows that the model simulates the low summer levels and higher winter levels and follows the same pattern as the measured groundwater levels. The effect of the dry summers in 2007 and 2008 is visible in the changing groundwater level as well (Figure 3.3).

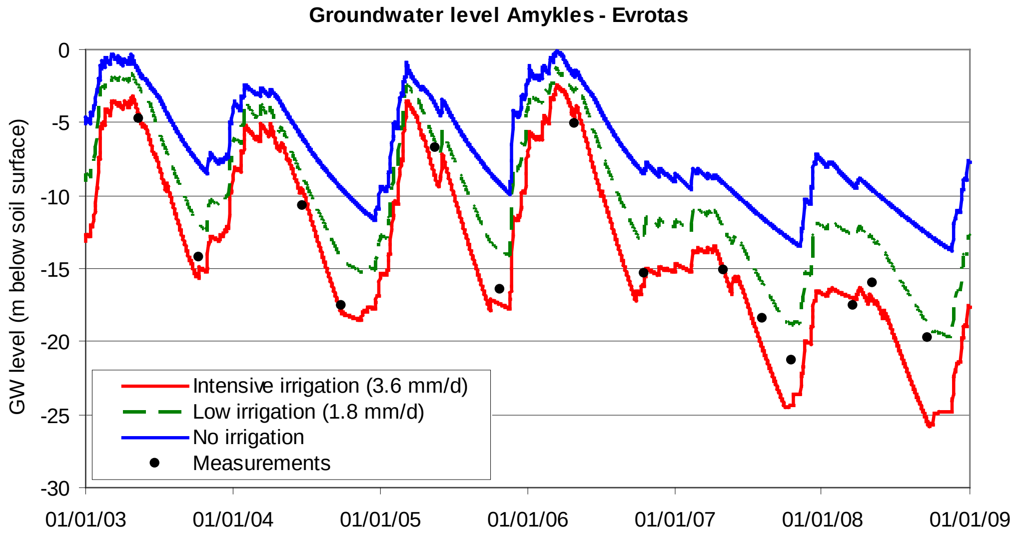


Figure 3.3
Ground water levels on the west side within the middle reach of the Evrotas basin.

4 Land use change scenarios

Land use and water use changed considerably in the Evrotas basin during the last 100 years. The effects of these changes have been analysed by SIMGRO using very general scenarios of different periods in time. The scenarios include a gradual increase of irrigation intensity (0% - 0 mm/d to 100% - 3.6 mm/d), an increase of the surface of arable land and include the major changes in water use for the Evrotas basin. Model input of these scenarios has been based on local expert knowledge[3] and agricultural statistics (http://faostat.fao.org, accessed in September 2010). The scenarios are meant to show the effect of agriculture development on river flows. It is not the intention to model the exact situation of each period in time. Meteorological data of the period 2000-2008 has been used to keep the effects of water use in the scenarios comparable to each other.

Early 1900
- Land use for agriculture is 30% less as compared to the present in the favor of deciduous forest.
- Only irrigation abstracted from surface water in a range of approximately 2 km on both sides of the Evrotas riverbed.
- Irrigation intensity is 20% as compared to the present situation.
- Olives are not irrigated.

1960
- Land use for agriculture is 30% less as compared to the present in the favor of deciduous forest.
- Groundwater abstraction from the shallow aquifer started since a few years.
- Irrigation in a range of approximately two km on both sides of the Evrotas riverbed is abstracted from the surface water.
- Irrigation intensity is 40% as compared to the present situation.
- Olives are not irrigated.

1980
- Land use for agriculture is 20% less as compared to the present in the favor of deciduous forest.
- Irrigation from the deep aquifer started since a few years.
- Irrigation in a range of approximately two km on both sides of the Evrotas riverbed is abstracted from the surface water.
- Irrigation intensity is 60% as compared to the present situation.
- Olives are not irrigated.

Present
- Land use for agriculture according to the CORINE-2000 land use map.
- Irrigation from both the deep aquifer, the shallow aquifer and from the surface water in the proximity of the river.
- Irrigation intensity is 100%.
- Olives are irrigated.

[3] Communication with Vassilis Papadoulakis, Land Reclamation Service, Lakonia Prefecture, Sparta, Greece

The results of the scenarios (Figure 4.1) show that the availability of river water strongly declined as a result of changes in water use. Discharges in the Evrotas changed from low-flow in summer periods (1900) to no-flow periods at present. This corresponds with the experience of local experts[1]. The impact of different water use changes varies per river segment. The strongest in the middle reach of the catchment (Vivari and Vordonia) occur after the use of water from the shallow aquifer for irrigation (1960) and the use of water from the deep aquifer (1980). The impact of irrigation of olive groves increases considerably in the lower part of the catchment (Vrontamas and Skala). The location of Vivari, Vordonia, Vrontamas and Skala is shown in Figure 2.3.

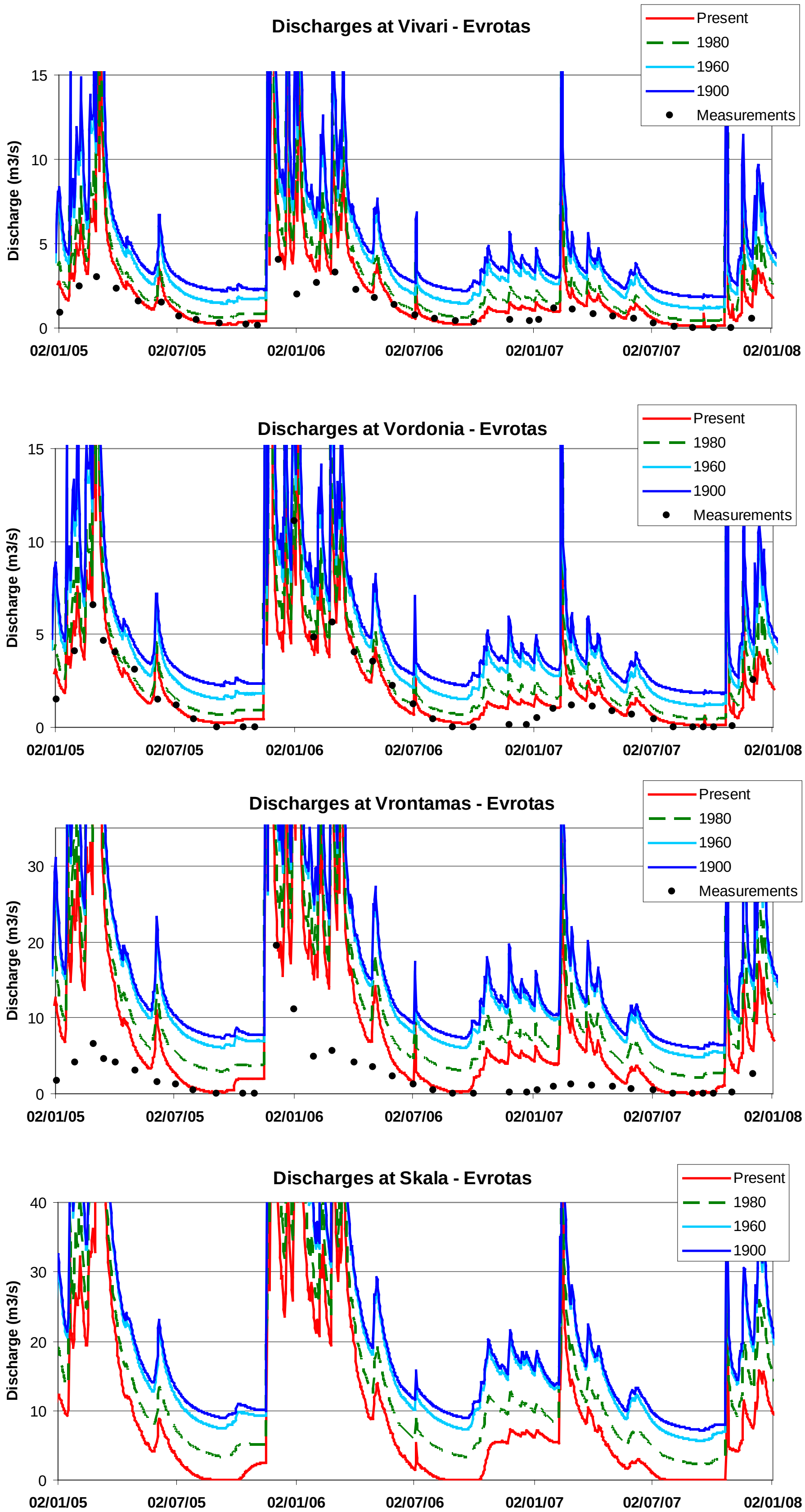


Figure 4.1

Discharges at Vivari, Vordonia, Vrontamas and Skala calculated for the land use changes scenarios of 1900, 1960, 1980 and for the present situation.

5 Visualization of river flow

To obtain the flow characterisation of all streams, model results of daily simulated flows were used from the SIMGRO model. The classification proposed by Gallart et al. (2011), based on field observations and discharge measurements, was adopted. The flow duration curve is derived from the time series of simulated stream flows. For a streams reach one can observe basically five situations, being: floods; riffles; connected flow; pools and dry conditions. The description of these flow statuses are given in Table 5.1. The adopted basic thresholds for the flow situations in the Evrotas basin are also given in Table 5.1. The thresholds vary between 10 and 75 l/s. For the threshold of floods the stream flow higher than the Q8 (flow exceeding in less than 8% of the time) has been considered. The assumptions presented in Table 5.1 are rigid and cannot be applied to all streams in a basin. The magnitude of the flow will differ for each stream reach depending on factors like stream width, bed slope, channel roughness and morphological conditions. Therefore the thresholds should also consider these local indicators, at present being the width and bed slope of the stream. A multiplication factor in the range of 0.8-3.0 considers the indicators and gives the actual thresholds per stream section.

For the gauge Vrontamas, as shown in Figure 3.2, the flow phases based on field observations were compared with the approach presented in this paper, and they compare reasonably well.

Table 5.1
Basic flow characterisation thresholds adopted for classification of model results for the Evrotas basin.

Flow phases	Description	Flow thresholds (l/s)
Floods	high flow condition, movement of bed sediments occurs	> Q8
Riffles	gradient and morphology give abundant riffles	< Q8 and > 75
Connected	abundant pools generally connected by slow flow	< 75 and > 15
Pools	abundant pools, flow connection between them is rare	< 15 and > 10
Dry stream	stream channel is dry and pools occur infrequent	< 10

The SIMGRO model was run for a period of nine years (2000-2008) to generate daily discharges for each stream. For a stream reach the flow duration curve is calculated and depending on local conditions the thresholds for the different flow phases are defined. The resulting flow characterisation is given in Figure 5.1 and shows the frequency of the flow phases per month. Particular between June and November the stream can be dry as much as 40% of the time. The phase pools occurs mainly in autumn. From November to July the reach has flowing conditions. The flood phase occurs about 20% of the time from December to April. For this reach the stream is dry for only five consecutive days in 2003 and 103 days in 2004.
Within the GIS user interface the above analysis is carried out for all streams, 544 in total. Figure 4.1 shows for all the streams in the Evrotas basin the average frequency of the flow phases dry and pools. Based on the average frequencies shown in Figure 5.2, it appears that the main stream does not become dry. For all streams the frequency of the flow phases is on average for floods 5%; for riffles 23%; for connected streams 31%; for pools 7% and a dry stream 34%. Such information can be used to derive the ecological status for the WFD.

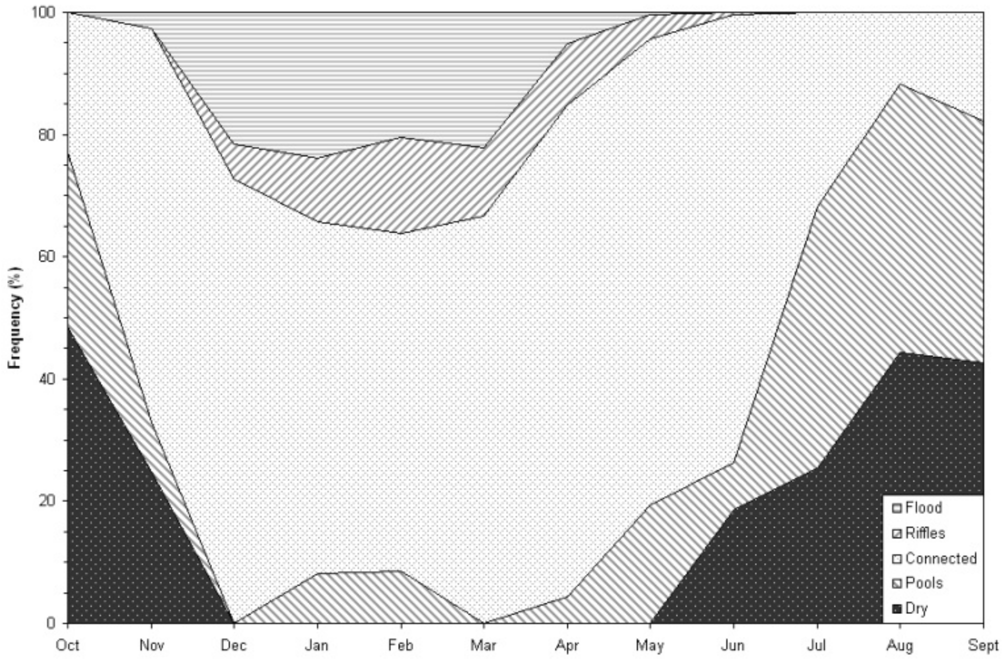


Figure 5.1
Frequency of the considered flow phases for stream reach A, Vrontamas (for location see Figure 2.3).

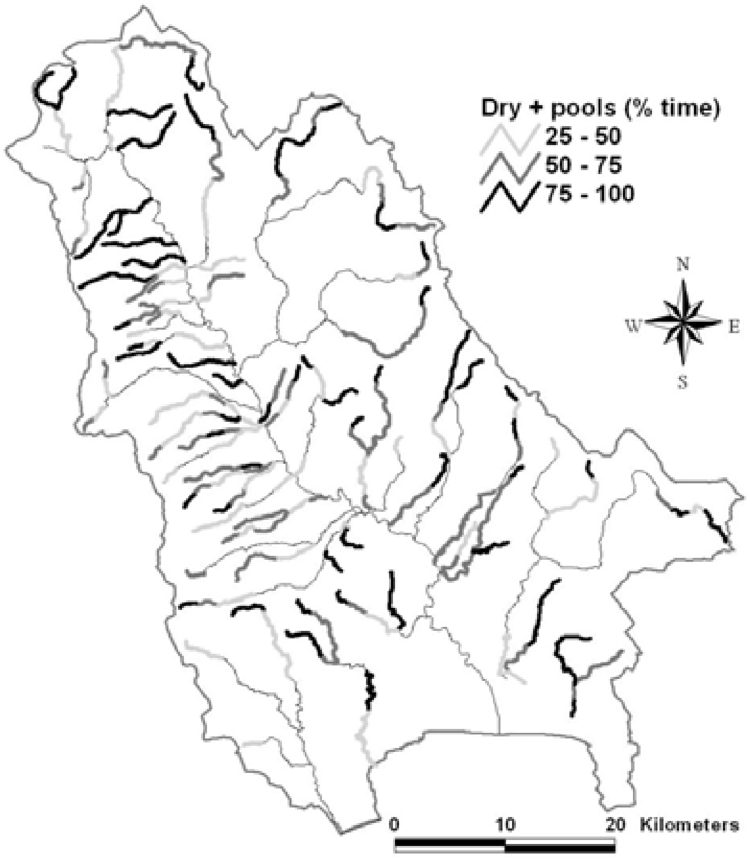


Figure 5.2
Average frequency of the flow phases dry and pools for all major streams in the Evrotas basin, based on results of the SIMGRO model (simulation period 2000-2008).

6 Evapotranspiration

6.1 Analysis by energy balance

The Simplified Surface Energy Balance Index (SSEBI) algorithm (Roerink et al., 2000), has been used to determine the potential evapotranspiration (ETp) and the actual evapotranspiration (ETa) in the Evrotas basin with the help of MODIS images. This can then be compared with calculated ETp and ETa values by the SIMGRO model. SSEBI is developed to solve surface energy balances on a pixel-by pixel basis using remote sensing techniques. The algorithm calculates the evaporative fraction using surface reflectance, temperature and the roughness of the surface area. The evaporative fraction is the part of the available energy at the surface that is used for the evaporation process. Assumptions done in order to perform the calculations are: constant atmospheric conditions over the whole image and both wet and dry spots available within the image.

SSEBI uses the principle that:
– On wet soil all energy is used for evaporation
– On dry soil all energy is used for heating up the surface
– The temperature rises with decreasing soil moisture

Evaporative fraction:

$$\Lambda = \frac{\lambda E}{H + \lambda E} = \frac{\lambda E}{R_n - G_0}$$

$$\Lambda_{SSEBI} = \frac{T_{dry} - T_0}{T_{dry} - T_{wet}}$$

Λ = Evaporative fraction
λE = Latent heat flux
H = Sensible heat flux
R_n = Net radiation
G_0 = Soil heat flux
T = Surface temperature

For further details the reader is directed to Roerink et al. (2000). For the Evrotas basin seventeen MODIS images in the period of April-September 2007 were used and fifteen images for the same period in 2009. Radiation data of this region is however only available for the period of 1981-1992. Since satellite images are taken from clear cloud free days we assumed that these days correspond with maximum values of incoming radiation. Therefore, the maximum value for each day measured within the period 1981-1992 was taken. From these values we derived an equation to compensate for minor fluctuations and to calculate the incoming radiation per image.

The potential evapotranspiration and the actual evapotranspiration were determined for each image. ETa and ETp values were calculated as well for three irrigated areas, a naturally vegetated area with low ET and a naturally vegetated area with high ET levels by calculating the average from a selection of ten random pixels within each area of interest (see for location Figure 6.1).

6.2 Results evaporation

The encircled areas in Figure 6.1 show the location for the ET analyses of the irrigated areas and the naturally vegetated areas. They contain from top to bottom the following areas and land uses:

- Parnonas: Deciduous forest on mountain slopes
- Sellasia: Mixed irrigated agriculture
- Sparta: Mixed irrigated agriculture
- Vrontamas: Natural area with little and dry vegetation
- Skala: Orange trees, intensive irrigation

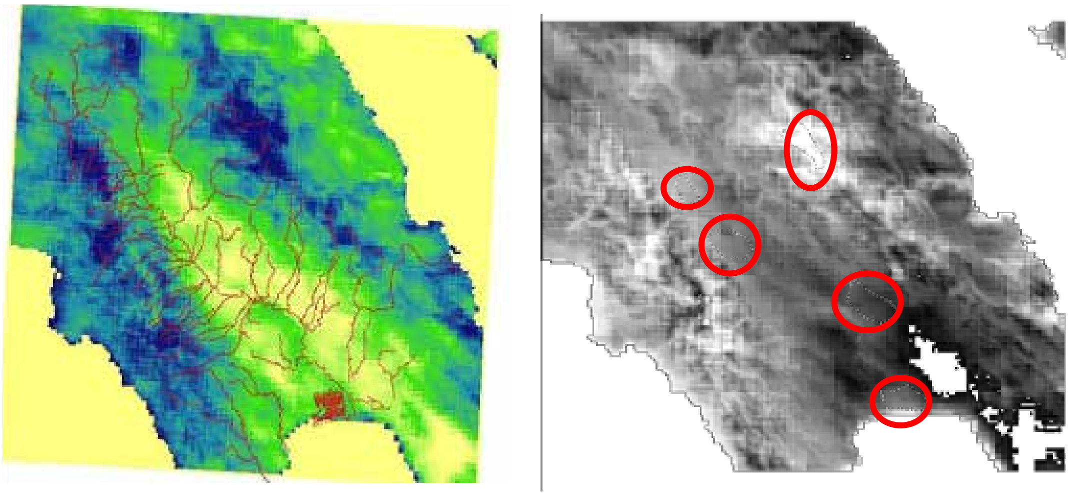


Figure 6.1

The location of the Evrotas river (left) and the location of the areas for ET analyses (right) from top to bottom: Parnonas, Sellasia, Sparta, Vrontamas, Skala.

The results of the SSEBI analysis give a general indication of the evapotranspiration in the area. The highest levels of ETa and ETp are found on the mountain slopes where deciduous forest is the main vegetation type and where mountain springs generate water. Irrigated areas have moderate evapotranspiration values and the lowest evapotranspiration values are found for the natural areas covered mainly by maquis vegetation. The general trend of ET as shown in the maps of the river basin (Figure 6.2) shows that ETa and ETp are high in the beginning of the summer when water is still available and when most of the vegetation is still green compared to the end of the summer when the landscape has become dry. There is little difference in the ETa and ETp results of 2007 and 2009 even though 2007 was a dry summer compared to 2009.
The average Eta and ETp calculated for the encircled areas (Figure 6.1) are shown in Figure 6.3. ETp levels for irrigated crops in the beginning of the summer are higher than the ETa levels. This suggests that the crops do not receive the maximum of irrigation water. However, there is little difference between ETa and ETp levels for mixed irrigated crops during the last part of the summer, especially in 2007. This can suggest that crops receive the maximum of necessary irrigation water, but it is also likely that crops like wheat have ripened and that evaporation levels thus have decreased. ETa levels of the intensively irrigated orange trees near Skala are higher than in the other irrigated areas. ETp levels of that same area are however still similar compared to Sellasia and Sparta.
The ETa and ETp levels calculated by SSEBI are very low compared to the levels calculated by SIMGRO, this difference reaches up to more than 6 mm/d, as shown in Figures 6.3 and 6.5. Evapotranspiration values calculated in SIMGRO show a gradual increase until July and a gradual decrease from July and onwards. The

evapotranspiration values calculated with SSEBI do not have such a gradual curve. Another important dissimilarity between the SIMGRO and the SSEBI results are the high levels of evapotranspiration from the irrigated areas in comparison to the deciduous forest. The highest levels of ETa are reached by the fields near Sellasia and Skala and the highest levels of ETp are reached by the irrigated area in Sparta and Skala. The deciduous forest near Parnonas has low ET values and during some periods reaches even below the ET levels of the dry vegetated area of Vrontamas.

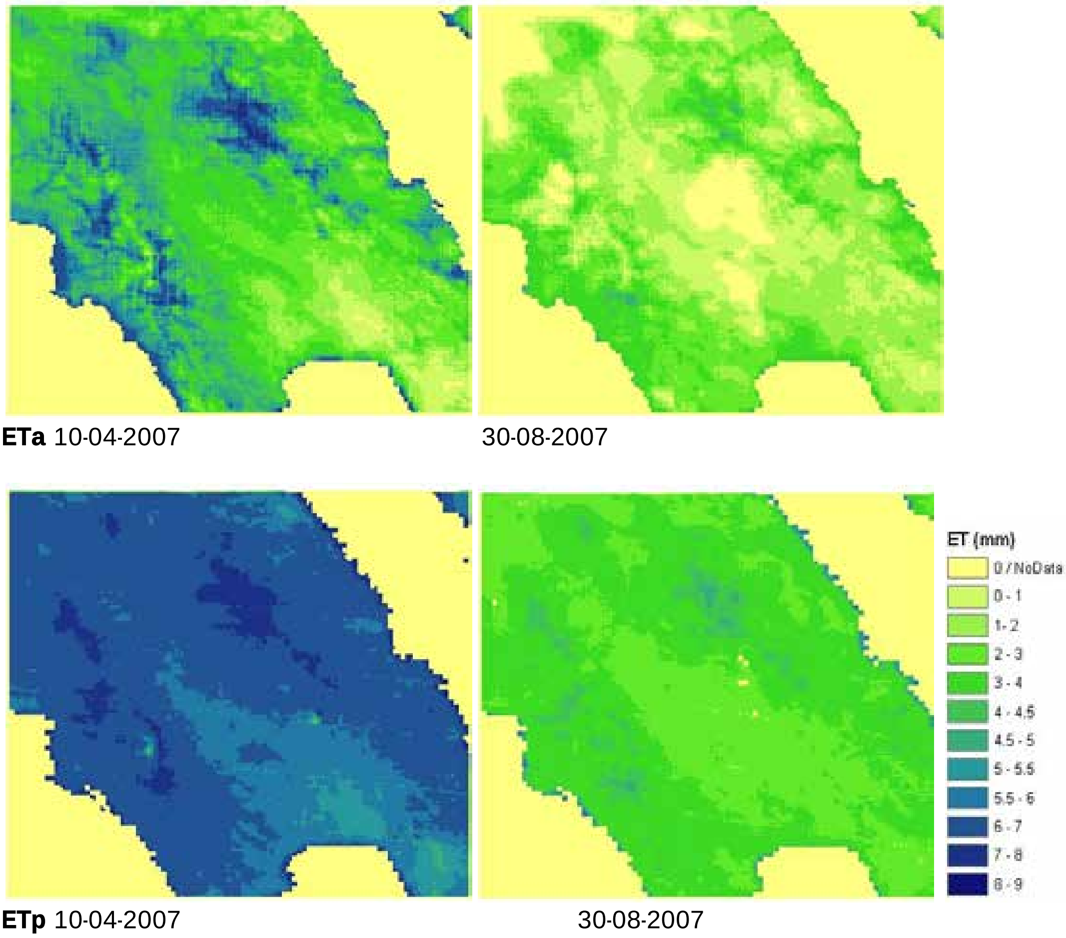
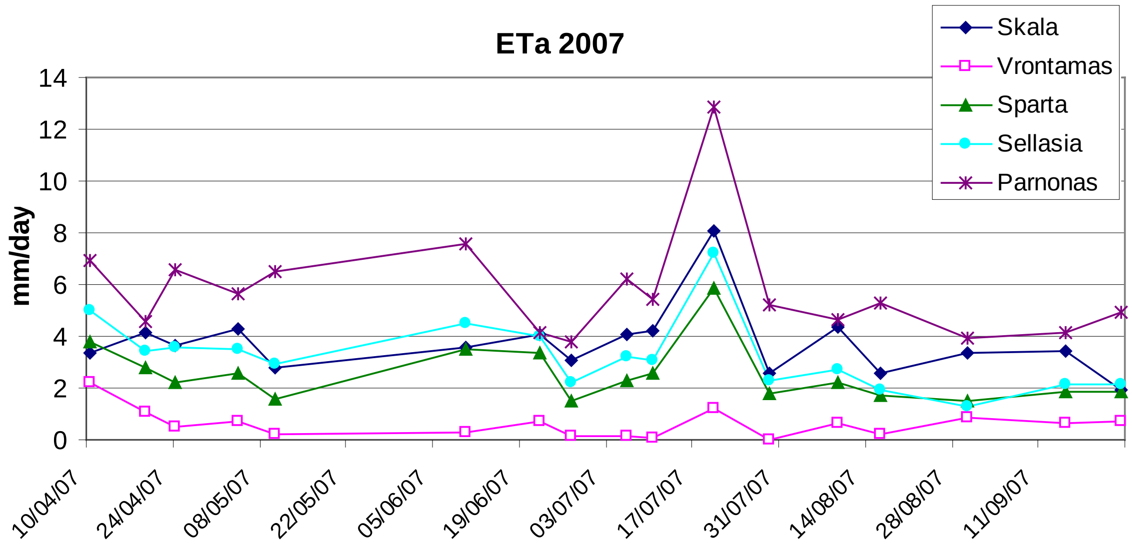


Figure 6.2
ETa and ETp levels during April and August in 2007 in the Evrotas basin. 0 and NoData are both represented by a yellow color. The sea and irregular shaped areas within green or blue regions can be seen as NoData; yellow within light green areas can be seen as 0 mm.



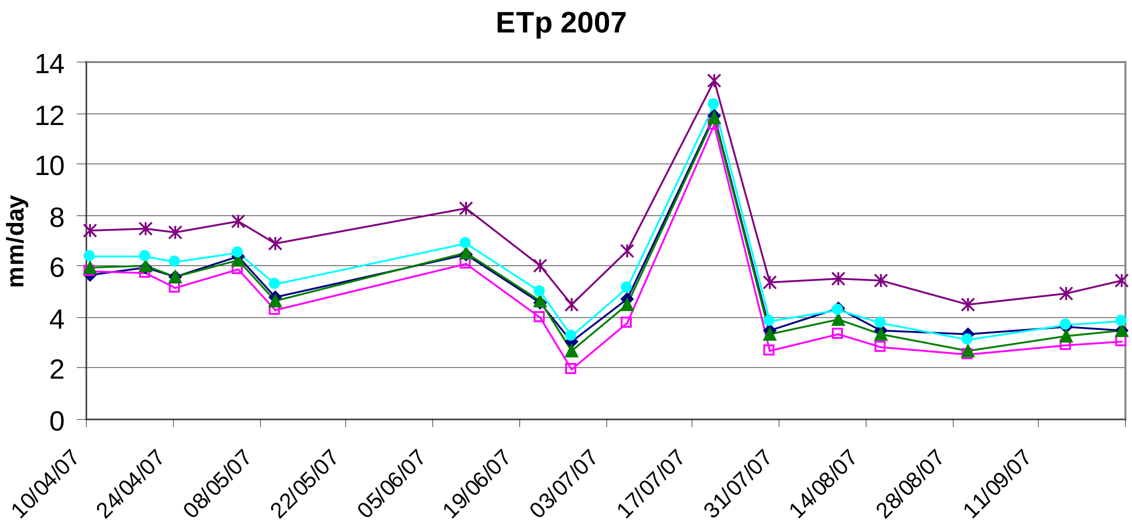
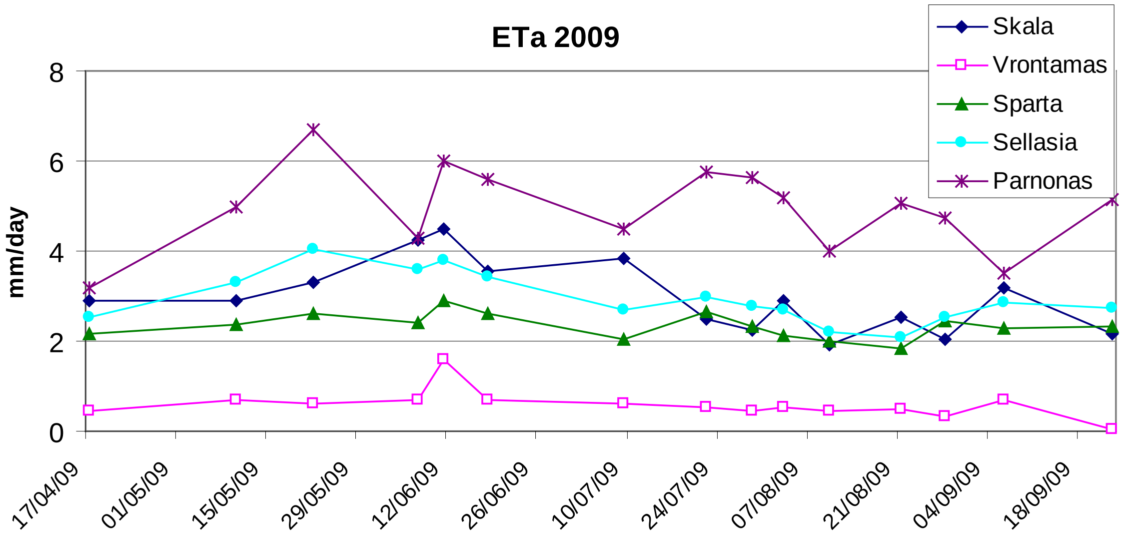


Figure 6.3
ETa and ETp levels calculated with SSEBI for the summer period of 2007 for irrigated and non-irrigated areas.



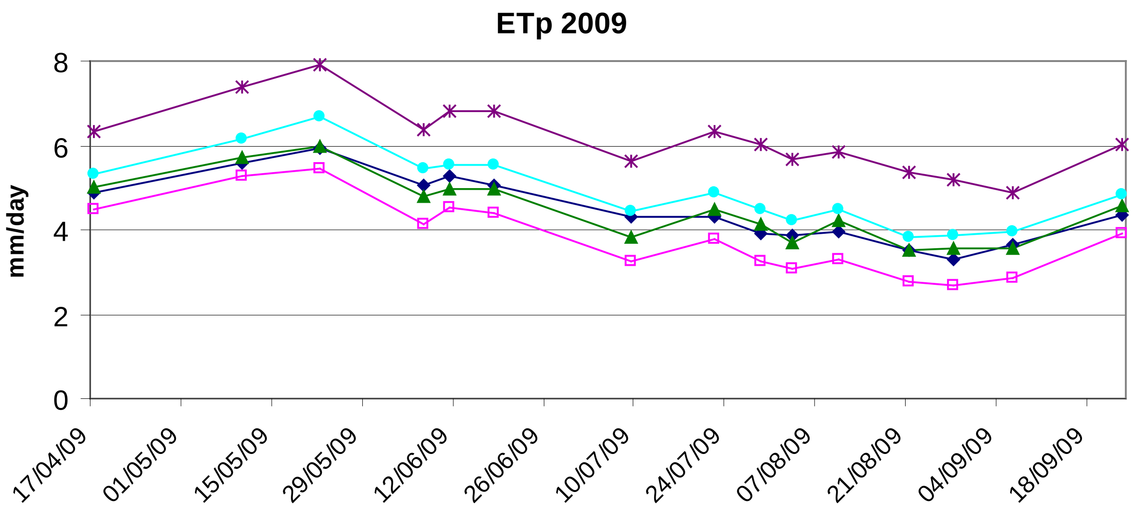
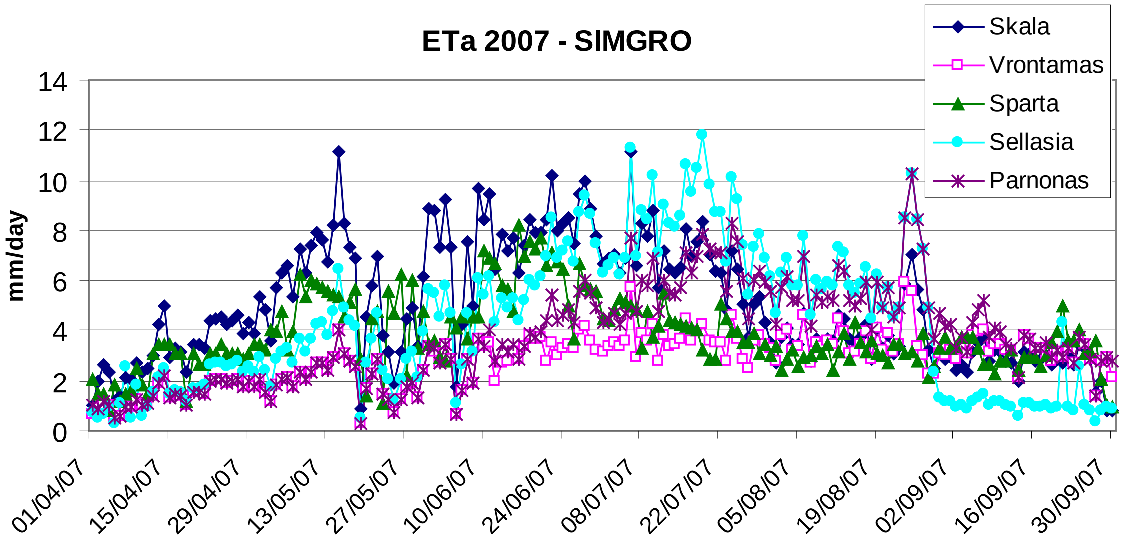


Figure 6.4
ETa and ETp levels calculated with SSEBI for the summer period of 2009 for irrigated and non-irrigated areas.



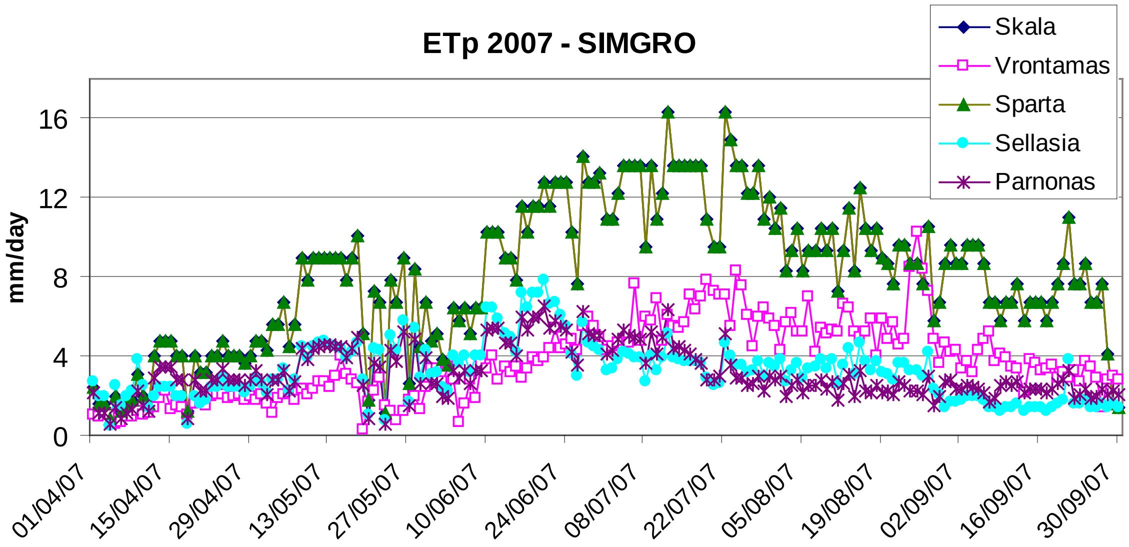


Figure 6.5

ETa and ETp levels calculated with SIMGRO for the summer period of 2007 for irrigated and non-irrigated areas.

7 Discussion, conclusion and recommendations

The results of the SIMGRO model correspond reasonably well with the measured water discharges, especially when intensive irrigation levels are included. The historical scenarios (Figure 4.1) show that the abstraction of groundwater for irrigation influenced river discharge. The low irrigation intensity in the beginning of last century still allowed flowing water during the summer. However, high irrigation pressure resulted in a dry riverbed in recent years. This corresponds to the knowledge of local experts. Especially the use of groundwater from the deep aquifer (1980) had a strong effect on river discharge. These results indicate that the intermittent characteristics of the Evrotas river are manmade.

The flow status frequency graphs allows a rapid visual assessment of the stream regime, based on model results. From the analysis it appears that all the major streams as shown in Figure 5.1 are on average 34% of the time dry. Spatial differentiation in sub-basins can reveal regions with an excessive exploitation of the water resources. Such information can be used to give indications of the ecological status or to assess the effect of changes in e.g. land use or climate change. We considered thresholds for each stream based on specific site characteristics. Further improvements are needed to quantify the thresholds for the flow phases to be used, based on a geomorphologic classification and roughness of the stream bed.

Evapotranspiration is a significant factor determining river discharge. Crop irrigation consumes an important part of the water within the basin. This goes as well for the water consumption by the deciduous forest on the mountain slopes. The amount of water used by these two types of land coverage and the importance of each land type differs however a lot when calculated through satellite imagery or by the SIMGRO model. This discrepancy either way can influence the calculated water availability in the river. Further improvements of the evapotranspiration parameters are needed to increase the model reliability.

A scenario analysis using different levels of water use may reveal the conditions for sustainable use of the water resources. The proposed method can therefore help, not only to identify near-natural flow conditions in an ideal setting, but also to analyse measures to restore the hydrological system. Such assessment is important for heavily modified water bodies (HWMB) in the framework of the development of RBMPs, to reach an increase in flow duration.

Prediction of the spatial-temporal characteristics of droughts is also an essential part of the assessment for current conditions, as part of integrated land and water management. It is important how a meteorological drought propagate through the hydrological cycle and develop into hydrological droughts, e.g. a spatial-temporal analysis of the groundwater drainage or recharge as reported by Querner and Van Lanen (2010). Such information forms also the bases for understanding the spatial-variability of temporary streams.

A physically-based model was used to simulate regional groundwater and surface water flow in basins with spatially-variable geo-hydrological conditions and land use. Such models have the potential to assess temporary stream conditions within a river basin. Hence they focus on the impact of e.g. agriculture or groundwater extractions, on the extent of temporary streams and thus the ecological status. In that respect the SIMGRO model is a powerful tool for modelling the flow conditions and producing maps of the areal extent of temporary streams. The study also shows that a hydrological model incorporated within a GIS makes it easier to relate flow regime characteristics to spatially-distributed catchment characteristics or associated fluxes.

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Appendix 1 Impression of the agriculture situation in the Evrotas basin





















Appendix 2 Evrotas river













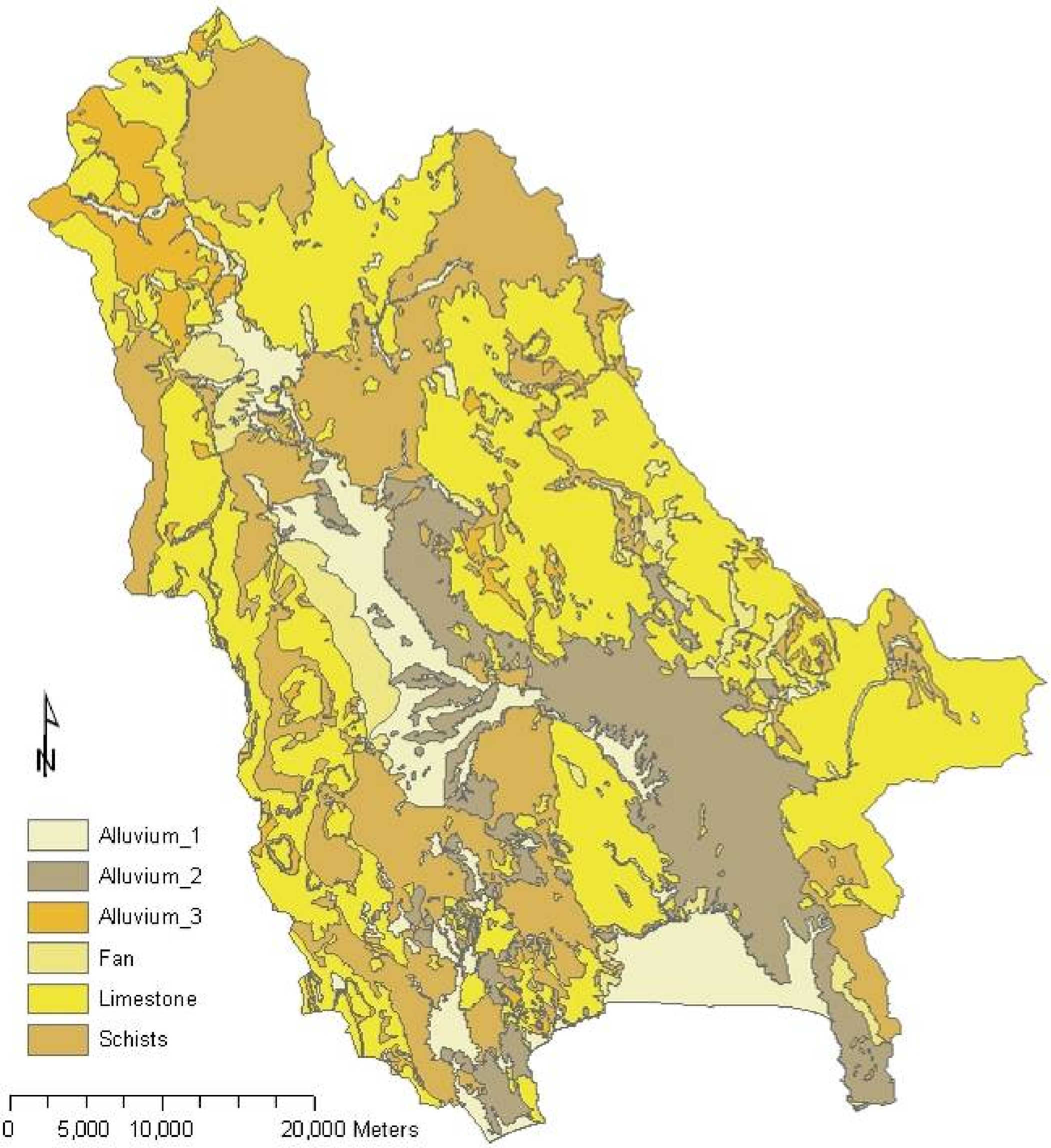




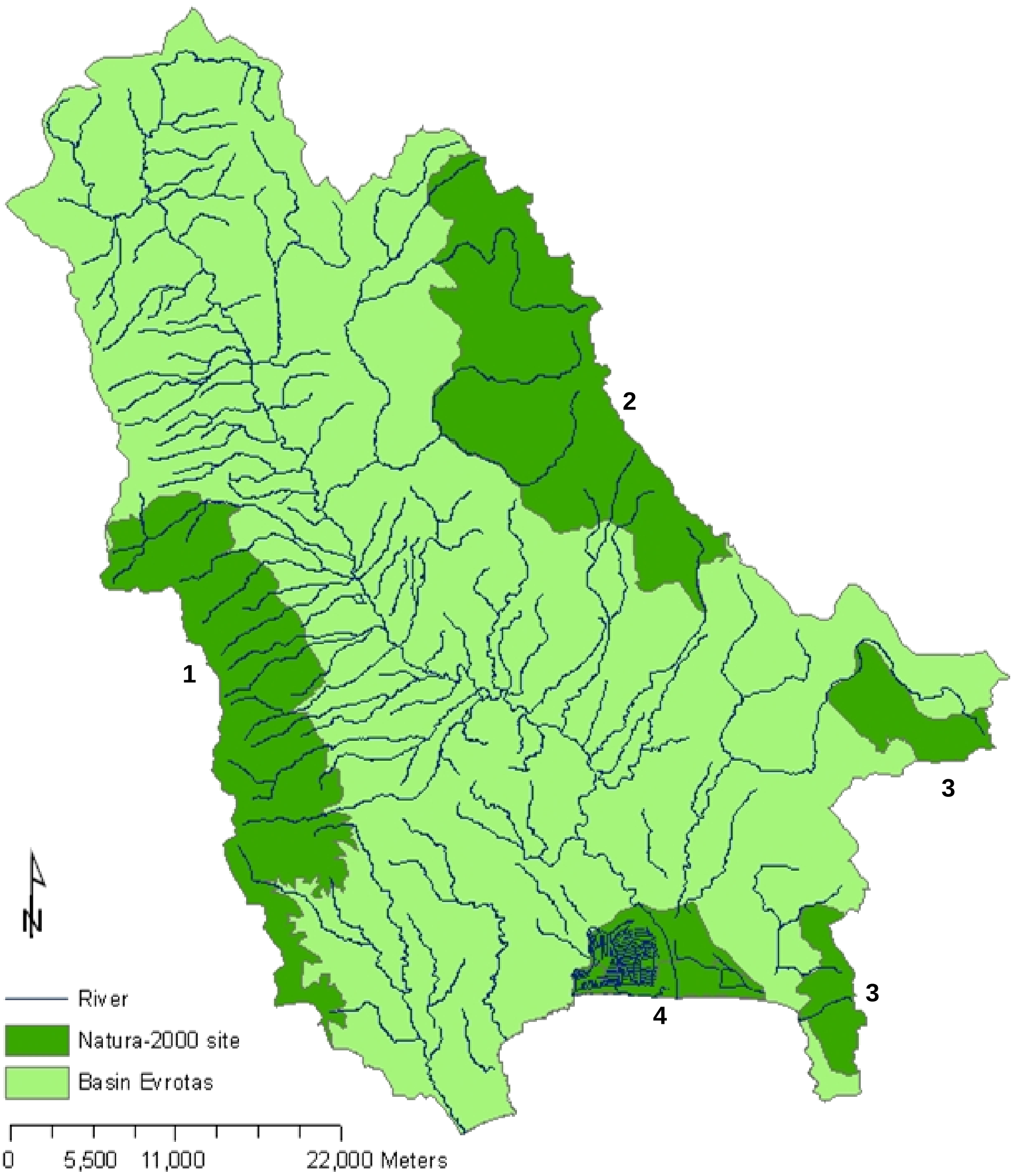

Appendix 3 Natural springs in the Evrotas basin

From left to right and from top till bottom: Kastori spring above the town, Dimaras spring, Vivari spring1, Vivari spring 2, lower Vivari spring, Kastori spring below the town

Appendix 4 Geology

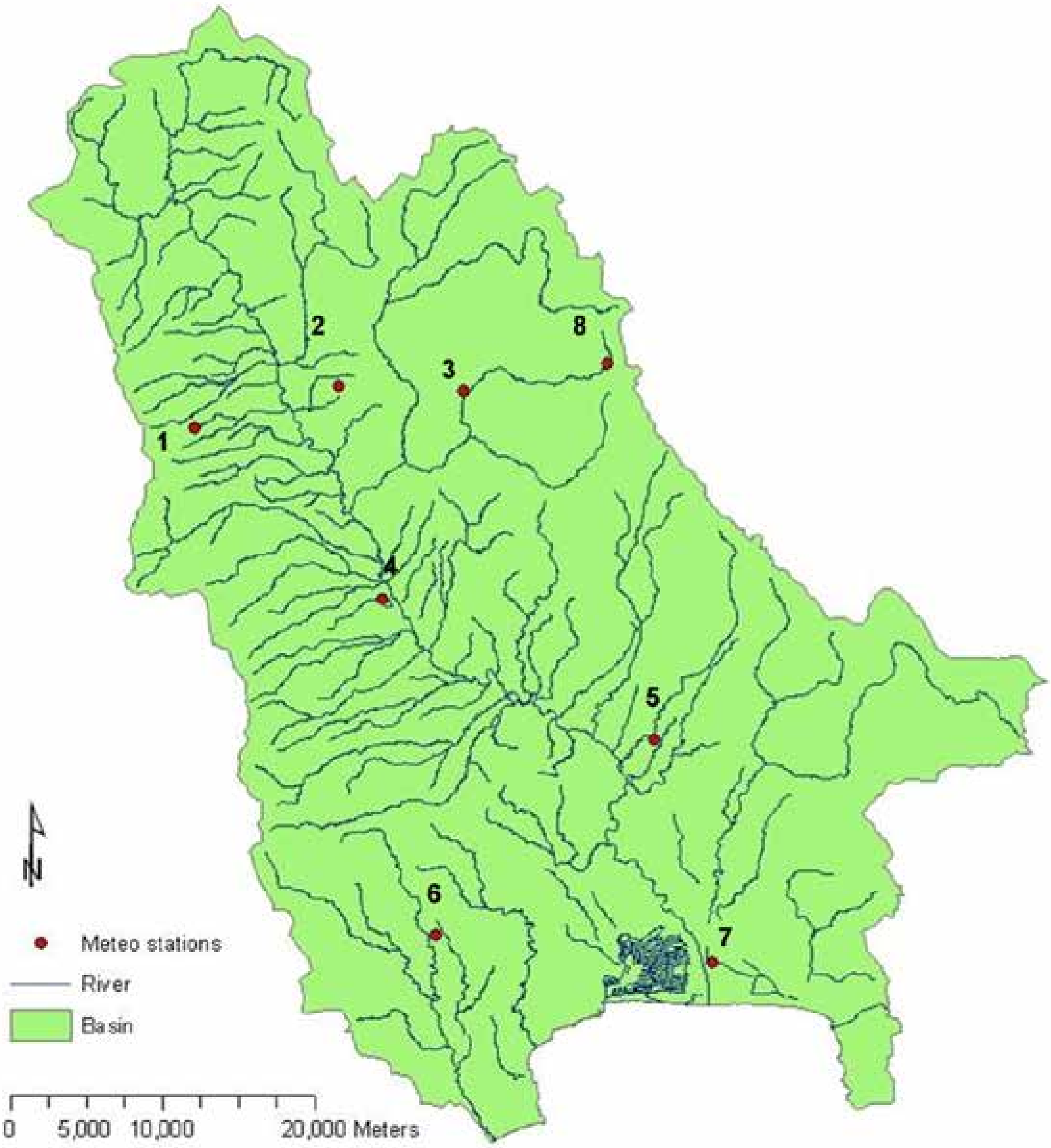


Appendix 5 Natura 2000 sites

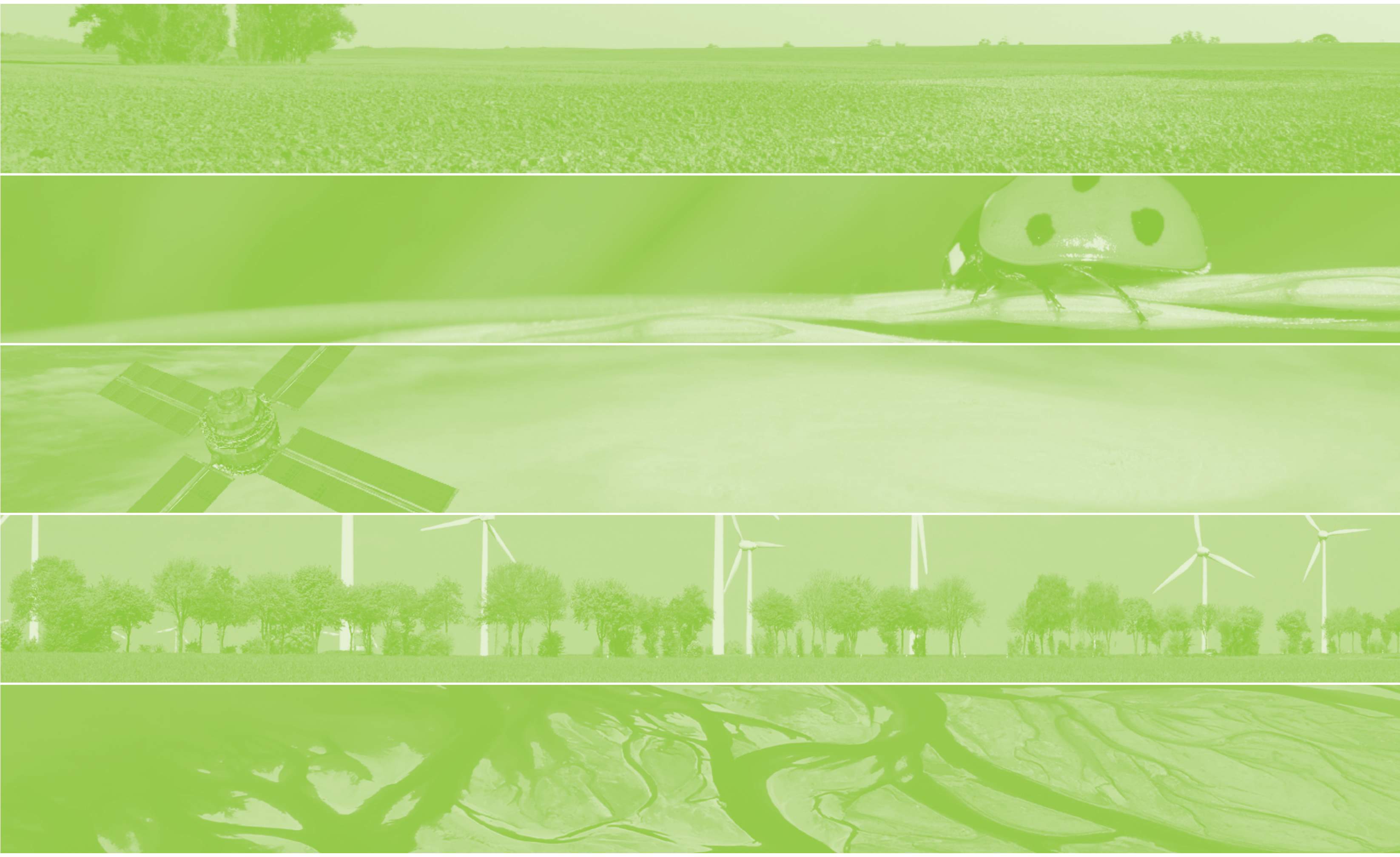


1. Hard water springs in formations of sedimentary rock and calcareous rocky slopes with chasmophytic vegetation
2. Endemic oro-Mediterranean heaths with gorse
3. Vegetated sea cliffs
4. Evrotas delta

Appendix 6 Meteorological stations



1. Perivolia
2. Sellasia
3. Vasaras
4. Ribbiotissa
5. Vrontamas
6. Petrina
7. Ellos
8. Calculated values (no station)



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