L'Europe en Méditerranée
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STATE OF THE ART OF WATER RESOURCES IN MEDITERRANEAN ISLANDS
D.3.1.1

C3.1.1 – State of art in the participating islands

Responsible partner: MRA

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Sustainable management of environmental issues related to water stress in Mediterranean islands

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1. Introduction

This report identies the state of the art of water resources in the main Mediterranean islands and thus sets the scene for the main actions of the MEDIWAT project, which actions are aimed at providing best practices for improving the management of water resources in the Mediterranean region.

The main chapters of this report thus characterize in detail the state of water resources in the Balearic islands, Crete, Malta, Cyprus, Sicily and Corsica.

An analysis of these island reports yield the not so unexpected result that these Mediterranean islands show a number of similiarities, possibly quite different from the prevailing contintental scenario. This is truly an encouraging result, since management actions tested in a particular island can find application in other islands with similar characteristics, thus strengthening the role of the MEDIWAT project in increasing and facilitiating an improved water management scenario in our region.

In fact, if one considers the background scenario in each of the island one finds that typically for the Mediterranean region all the islands present (to varying degrees) strong inter- and intra- annual climatological variabilities. To cite an example, considering rainfall characteristics one finds that:

Mallorca

Average: 650 mm/yr
Range: 300 – 1200 mm

Cyprus

Average: 500 mm/yr
Range: 300 – 1100 mm

Malta

Average: 550 mm/yr
Range: 250 – 950 mm

Sicily

Average: 750 mm/yr
Range: 450 – 1000+ mm

Crete

Average: 900-1076mm
Range: 400 – 2000mm

The same can be said for the islands' phisiographic and demographic characteristics. Thus, the reports highlight that:

(i) the Island economies are increasingly becoming service oriented, but
(ii) agriculture whilst having a low contribution to the GDP is still the major land-user.

Thus, to cite some examples:

Balearics

Economic characteristics
Agriculture – 1.5% of GDP
Services – 81.3% of GDP

Land-use characteristics
41% Agricultural
12% Urban

Malta

Economic characteristics
Agriculture – 1.6% of GDP
Services - 48% of GDP
Manufacture – 35% of GDP

Land-use characteristics
45% Agricultural
31% Urban

Crete

Economic characteristics
Tourism – 77% of GDP
Industry – 11% of GDP
Agriculture – 12% of GDP

Land-use characteristics
39% Agricultural
5% Urban

Considering the availability of natural water resources, groundwater comes out as the single most important water resource; and this since island size constrains the possibility of major surface water resources. This with the exception of Sicily. Moreover, due to the high demand for water, groundwater is generally overexploited.

The reports thus highlight the following facts as pertains to groundwater:

Balearic Islands

Main water resource of the Balearic Archipelago
78% of total water supply

Cyprus

Overexploited by around 40% of sustainable extraction.
44% of total water supply.

Malta

Main source of naturally renewable freshwater.
Overexploited.
56% of total water supply.

Crete

Main source of naturally renewable water
94% of exploitable water supplies

A consideration of the availability of surface waters further corrobrates the importance of the groundwater in the island context. Thus:

Mallorca

No permanent surface water features
Two reservoirs – combined volume 13Mm3.

Cyprus

No permanent surface water features.
330Mm3 of surface water storage capacity behind dams.

Malta

Malta has no surface waters of economical importance.

Sicily

Surface water resources exceed groundwater resources.

Crete

No perennial streams (only from karstic spring flow)

Another important fact which the reports highlight relates to the increasing dependence of all islands on alteranative water resources such as desalination. Moreover, all the islands view treated effluents as a potential new resource of water; particularly for uses such as irrigation and in certain types of industry. This is highlighted in the following exrepts from the reports:

Desalination

Mallorca

Three desalination plants producing 42.2Mm3/yr
17% of available water supplies

Cyprus

Production at 32Mm3/yr
15% of available water supplies

Malta

Three plants, potential production 33Mm3/yr (current production at 19Mm3/yr)

34% of current water production
60% of municipal water supply

Sicily

Current production at 31Mm3/yr
To increase by a further 9Mm3/yr

Treated Effluent

Mallorca

Wastewater reuse estimated at 24Mm3/year.
Amounts to 25% of agricultural sector demand.

Cyprus

Production of treated effluent to reach 52Mm3 by 2012.
Potentially, this amounts to 28% of agricutural sector demand.

Malta

Three new wastewater treatment plants which produce approx. 14Mm3/year
Qualitative concerns (high salinity of effluent, emerging pollutants).
Potentially, can cater for 80% of agricultural sector demand.

Crete

All major towns have wastewater treatment plants
Use envisaged for irrigation (agriculture and landscaping) and artificial recharge.
Annual volume of secondary treated wastewater effluent >36.5Mm^3.

Such results highlight the importance of increasing the inter-island cooperation in the field of water management and the need of establishing the necessary structures to enable and facilitate such cooperation. Undoubtedly, this could prove to be one of the major results of the MEDIWAT project.

2. State of the Art of Water Resources in the Balearic Islands

2.1 Background

The Balearic Islands form an archipelago located in the western Mediterranean between the meridians 1º09’37” W – 4º23’46” E and the parallels 38º38’25” S – 40º05’39” N. The total surface of the Balearic Islands is 5,014 km^2, divided into three major islands, Mallorca, Menorca and Ibiza, and western wards two smaller ones, Formentera and Cabrera, apart from minor small islands. Mallorca is by far the largest of the islands (3,640 km^2). Its shape is roughly rectangular, with a maximum N-S distance of 80 km and E-W distance of 100 km and total coastline length of 555 km. The territory ranges from the steep and rugged terrain of the Serra de Tramuntana, with several peaks exceeding 1,000 m (its higher peak, Puig Major, reaches 1,443 m) to the plains of the “Central Depression”: the plain of Palma and Inca-Sa Pobla with heights of only a few meters. On the northwest coast cliffs are even several hundreds of meters high, punctuated by small bays. The long beaches are located in the bay of Palma, in the south and in Pollença and Alcúdia bays. In much of the Serra de Llevant there is a flat coastal strip of about 4 or 5 km wide, formed by limestone and molasses and its dissection by streams originated a number of coves and beaches characterized by considerable tourism development.

The climate of the Balearic Islands is variable and there are notable differences between the islands and even at very small scale within each island. In very general terms, the weather can be considered as arid-temperate Mediterranean climate with average annual temperatures of 17 ºC. In this climate, there are significant variations throughout the year, with hot summers, especially during August with an average temperature of 24 ºC and annual rainfall rather moderate, or even low, characterized by an irregularity in both its temporal and spatial distribution. Average annual rainfall is characterized by a peak in autumn, usually during the month of October, which can be maintained throughout the winter, but records fall in spring and during the summer season are practically nonexistent, especially in July. In Mallorca, the annual average rainfall is around 650 mm, although with a spatial variation due to its diverse landscape. The maximum rainfall is usually in the month of October, with the exception of the central part of the Serra (Tramuntana Range) where it is reached in December. Values above the 1.200 mm per year are achieved in the higher peaks of the Serra de Tramuntana, while on the southern coast they are not exceeding 300 mm.

The Balearic Islands must be regarded as the emerging part of the Balearic promontory, which geologically is the eastern end of the Betic ensemble (Betic range in Andalusia), part of which is currently submerged under sea water. The whole archipelago is aligned in ENE-WSW sense, in accordance with the Betic characteristics and main direction and is bordered on the northwest side by a deep groove called the Valley of Valencia, while on the south side there is the northern edge of the deep Algerian-Balearic basin.

The island of Mallorca has three geological units with its own characteristics both structural and geomorphologic (Figure 2.1):

- Northern mountains (Serra de Tramuntana): a steep mountain chain which extend from Dragonera Island to Cape Formentor. It has a width of 15 to 20 kilometres and it runs parallel to the coastline, oriented southwest to northeast, forming a steep area characterised by overlapping folds consisting of dolomite, marl and limestone from the Jurassic and Cretaceous, which slide on Triassic materials, along with levels of conglomerates, limestone and detrital Miocene marls and clays. Its geological structure is very complex, with various longitudinal and transverse thrusts. There are many peaks above 1.000 m, with a maximum of 1.441 m of the Puig Major d'en Torrelles. In calcareous materials, karst have developed in many and varied forms.
- Central depression (Central Mountains and Plains): occupies most of the island between the North and the Serra de Llevant (Llevant Range). It is fairly flat with some hills in the central part; central plains are formed by materials from Miocene and Quaternary, in which Mesozoic outcrops can be found (Serres centrals: Central ranges). Great formations of marl, conglomerate, limestone, sandstone, sandy loams and molasses conglomerates from Miocene and loose Quaternary sands and silts can be observed. There are also coastal lagoon sedimentary facies formed by blue and yellow marls, lacustrine and continental deposits and marine terraces and dune deposits more or less consolidated. The Plains occupy the centre of the island, forming wide valleys and small hills that do not exceed altitudes of 300 m. In the NW and SW ends, reaching the coast, as two areas of subsidence, the Muro - Sa Pobla Basin- and the Palma Basin, occupied by wetlands such as the Albufera in Alcúdia or the Pla de Sant Jordi in Palma. The "river catchments" of Inca and Sa Pobla are separated by the threshold of the Puig de Santa Magdalena. Inca basin has experienced a remarkable and continuous subsidence during the Quaternary, as evidenced by the significant thickness of sediments of this age found during soil surveys. Sa Pobla basin has experienced a movement as a "piano keys" during the Quaternary, sinking into the bay of Alcúdia. The south eastern part of the unit is occupied by post-orogenic sediments that rest on the structured Burdigalian-Langhian.
- North-eastern mountains (Serra de Llevant: Llevant Range): it occupies the southern portion of the island with a length of 45 km, and 8-15 km width. It aligns from the capes Ferrutx and Capdepera, south east of Alcúdia Bay, in parallel to the Serra Nord (North Range), to be introduced under the Campos Plains, south of the island. The Serra de Llevant presents a similar geological formation as the Serra de Tramuntana but with a less violent geology and a smoother topography. It extends discontinuously along the coast line and reaches a maximum altitude of 561 m (Talaia). The northern coast, which runs parallel to the Serra de

Tramuntana, is formed by cliffs that can reach heights of 300 m with small coves and a major interruption which is the Port of Sóller. In the far NE, large bays such as Pollença and Alcúdia are characterized by long sandy beaches.

- The eastern and southern coasts end with less high cliffs, which can reach 100 m in the south. There are numerous streams that origin sandy coves and beaches. Campos's depression to the south ends with a low coast with white sandy beaches.

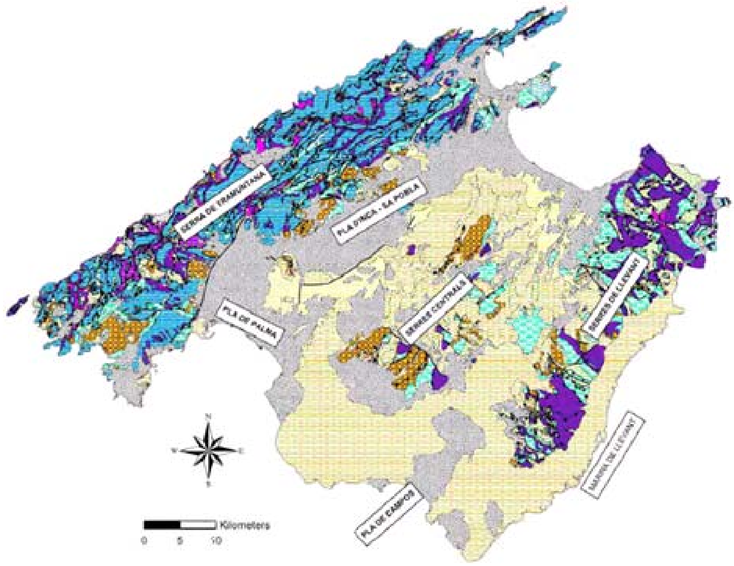

Figure 2.1: Geological characteristics of Mallorca.

The evolution of the Balearic Islands population has undergone profound changes in recent years due to tourist development that started at the end of the decade of the 50's. The analysis of average population growth rates between 1950 and 2007 showed for the period between 1950 and 1975, a cumulative annual growth of 1.69%, registering peaks in the periods between 1966-70 and 1971-75, corresponding to the growth and consolidation of mass tourism on the islands. Later (between 1975 and 1981), these rates experienced a decline, where the cumulative average annual increase was 0.94%, a figure that, between 1981 and 1986, fell further to stand at 0.76%. The evolution of the Balearic population between 1986 and 2008 is characterized by a strong growth in absolute population, mainly due to high immigration rates. The data for the period 2004-2005, show that the Balearic Islands is the Spanish region with one of the fastest demographic growth, with 2.9%, only surpassed by Valencia and Murcia, and above the national average (2.1%). However despite this positive trend described, nowadays population growth is slowing down. Mallorca experienced from the 1950's, a progressive population growth and it is now the island with the largest number of inhabitants, 846,210 (79% of the total population of the whole archipelago). The main characteristic of the distribution of the population in Mallorca is the concentration along the coast and in the cities. Almost 50% of the population of the island is concentrated in Palma, which shows the great importance of this city because of the centralization of many services for the entire Balearic Community. The urban network is complemented by the medium-sized towns of Manacor and Inca, of 34,000 and 24,000 inhabitants, respectively, and other cities over 10,000 inhabitants. Only the municipalities of Palma Bay are hosting 60.9 % of the population of the island. The current trend is the exodus of people from the city and the consequent growth of the neighbouring towns of Palma, as Marratxí, Llucmajor and Calvià. In this context, Calvià, with 1,785 new residents, and Marratxí and Llucmajor, with 1,505 and 1,490, respectively, are among the five municipalities of the Balearic Islands that have grown the most in absolute terms. At the second level are the municipalities of Inca and Manacor, which maintain their population number Thus, while Manacor is the fourth center in the Balearic Islands, with 37,165 inhabitants and an annual growth of 3.5% in 2006, Inca, with 27,301 inhabitants, is in eighth place, with a growth 3% (2006). In the remaining municipalities of Mallorca, the increases in population experienced in the period 2005-2006 (Capdepera (8.1%), Puigpunyent (7.8%), Consell (5.8%), Porreres (5.5%), Andratx (5.1%) or Santa Margalida (5%)) explained by tourism and agricultural development, which create new jobs, together with more accessible prices of housing, new roads or by the facility to get residence permits that draws foreign population groups. The non resident population may represent 65% of the resident population (reaching 75% in August).

Most of the Balearic territory correspond to agricultural areas, which represent 41% of the total area, while forests correspond to 34 %, areas with other vegetation (grassland, wetland vegetation, etc.) comprise 4 % and areas without vegetation (bare soil rocks, reservoirs, etc.) occupy 9 % of the territory. Finally, urban premises and infrastructure (roads, highways, etc.) represent 12% of the island surface (Figure 2.2). Of the total agricultural area, 15.6 % belongs to mountainous areas.

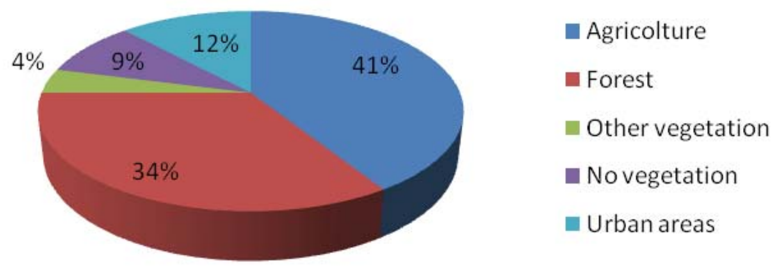

Figure 2.2: Land uses (2005).

The Balearic Islands currently have a high percentage (approximately 38%) of protected area in their territory. Taking into account all the Parks and Nature Reserves in the Balearic Islands the protected area is 36,722.66 Ha, of which 24,428.04 terrestrial and 12,294.62 marine. The only National Park in the Balearic Islands is the Cabrera Archipelago National Park. Moreover, there are 7 Natural Parks in the Balearic Islands, 5 of which in Mallorca:

- Mondragó,
- Sa Dragonera,
- S'Albufera,

- S’Albufereta,
- S’Albufera des Grau, Illa den Colom and Cap de Favàritx.

To the mentioned parks it must be added the Serra de Tramuntana Natural Park with an area of 62,403.6 Ha, implemented by the Balearic Government on March, 16th 2007. Furthermore, a European ecological network (Red Natura 2000) for conservation of biodiversity started to act on the islands with the purpose of ensuring long-term survival of threatened species and their habitats. The work of Red Natura initiated in 2000; and by 2006 the sites catalogued as Sites of Importance for the Community in Mallorca were 84 and the Special Protection Areas for Birds were 27.

Similarly, Law 1/1991 of January 30th, 1991, defined as areas of special interest for protection, those areas that have ecological, geological and landscape exceptional characteristics, and the necessity to establish management and urban planning measures for their conservation and protection. The land areas of special interest for protection are categorized as follows:

- Natural areas of special interest,
- Scenic rural areas,
- Settlements within areas of special interest.

In the Balearic Islands there is a total of 169,910.82 Ha classified as Natural areas of special interest of which 115.675,74 Ha are in Mallorca. Recently, the Law of Emergency Actions for sustainable territorial development in the Balearic Islands extended the special protection areas for the island of Mallorca and the island of Ibiza, changing the rating territory 1414.54 Ha, till covering approximately 38% of the Balearic Islands.

Marine reserves are protected areas where the use and exploitation of the marine environment is regulated with the goal of increasing natural resources regeneration and conservation of representative ecosystems. In addition to being measures of protection of ecosystems and species, marine reserves are tools that allow a sustainable exploitation of resources and fisheries management. The existing marine reserves in the Balearic Islands are: the Bay of Palma (between s'Arenal Yacht Club and Regana Cape) in Mallorca island; the Migjorn, the Toro and the Malgrat Islands and, finally, the Llevant; in Menorca; the Northern Marine Reserve; and in Eivissa and Formentera, the Freus. In total, in the Balearic Islands approximately 60,000 Ha of marine area are protected.

The economic structure of the Balearic Islands is characterized by the dominance of tertiary activities (mainly tourism related), which determine the existence of a high *per capita* income. The urbanization of the coast and the countryside, the degradation of indigenous culture, the congestion of infrastructure and facilities, high population density and rising land prices are also a consequence of the current economic structure. The prevalence of the service sector in the Balearic economy can be observed in the following chart, which shows the sectorial distribution in terms of GDP (Gross Domestic Product), of the economy of the Balearic Islands:

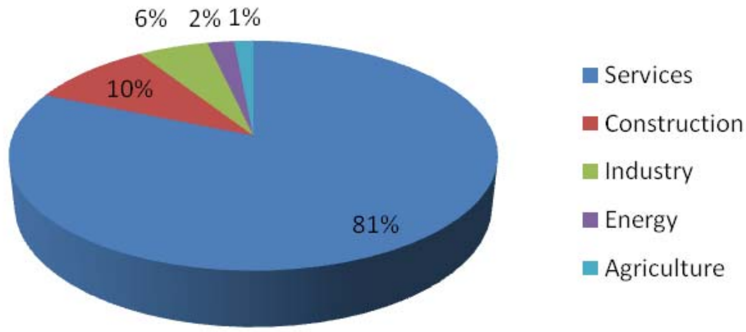

Figure 2.3: sectorial distribution in terms of GDP (2005).

The Balearic economy is characterized, as indicated, by a heavy reliance on services sector, contributing to 81.3% of the GDP of the Balearic Islands, followed, to a lesser degree of importance, by the construction sector with 9.6%, the industry with 5.5% and the energy sector with 2.1%. Finally, despite the lower contribution to GDP, only 1.5 %, the agriculture, livestock and fishing, is a major source of diffuse pollution of aquifers.

As it can be seen, services and construction sectors contribute to over 90% of GDP of the Balearic Islands. The evolution of the agriculture sector on the overall production shows that since 2000 it has lost 15% of its weight and the industry had a reduction of nearly 5%. By contrast, energy and construction show an increase in Balearic production, of 15 and 8.5 % respectively. On the other hand, given the importance of the services sector in the Balearic economy, the total GDP growth is closely linked to the growth in this sector. Summarizing, the Balearic economy experienced during the 1990's one of the fastest growth phases of its history. It went from a GDP of 6,809 million Euros in 1989, to 16,173 million Euros in 1999, which meant that the average income in 1998 was 54.5 %, higher than the national average of 25.82 % and the *per capita* income of the European Union. From November 2000 until November 2007, the Balearic GDP increased 25.4 %, only surpassed by the regions of Catalonia (27.8 %), Murcia (27.7 %) and Rioja and Melilla (27.2 %), to obtain in 2006 a GDP of 24,391 million Euros, equivalent to a GDP *per capita* of 24,456 Euros, 2,304 Euros higher than the state average. Mallorca provides 80.6 % of the Balearic Islands GDP. It is to note nevertheless, that these figures should have changes with the construction sector crisis which started during the year 2009.

2.2 Water Resources

Groundwater is the main water resource of the Balearic Archipelago. Because of marked hydro-geological differences of the lithologic materials that constitute aquifers, the island of Mallorca is divided into three aquifer systems, which correspond to the mountain ranges of Serra Nord and Serra de Llevant and the island's central depression.

The aquifer of the Serra Nord is located in the north western sector of the island, with an area of 900 km^2, bordering the north-western shores and limited internally by the towns of Palmanova, Binissalem and Alcúdia. It is a very “contracted” zone, folded by tangential forces of the Alpine orogeny, which makes it formed of three major tectonic series on each other in the direction NE-SW. 90 % of the outcrops are secondary and only 90 to 100 km^2 correspond to tertiary materials, from Miocene and Oligocene. About 650 km^2 are limestone and dolomite, mostly porous, and some 250 km^2 are impermeable marl and gypsum outcrops. The Serra Nord is potentially the main aquifer system of the island due to high rainfall in the area and high permeability of the outcropping materials, but because of the extraordinary geological complexity, which has originated many independent aquifers, presents major difficulties in the use of groundwater resources.

The central depression comprises the central part of the island, with an area of about 2.200 km^2, flanked by the Serra de Llevant. It is a very flat area where elevations normally do not exceed 150 m and punctually, in the central highlands, reach the altitude of 500 m. Due to the topographical characteristics in this system, agriculture has experienced its highest development and, together with the greatest concentrations of resident population, it results in the greatest water demand for human needs and agriculture, and higher pumping aimed to meet these demands. Due to bad farming practices that have been carried out for many years and the high livestock farming density in some parts of this system, problems of nonpoint pollution from agricultural sources have been detected. For this reason, the evaluation of the possibility of reduction of agricultural and livestock waste generation is necessary; as well as its reuse and sustainable management., The reduction and sustainable use of agricultural fertilizers and pesticides to help reduce nonpoint pollution of groundwater is also deemed necessary.

In the last mentioned area, about 350 km^2 correspond to waterproof outcrops mostly Burdigalian marls. 1,850 km^2 are permeable materials of the Vindobonian and Quaternary age sand consists of limestones and calcarenites in almost its entirety. Given the differences in land quality, demand and use; this great system can be divided into 5 water-related areas, which are: Llano de Palma, Llano Inca-Sa Pobla, Marineta, Llucmajor-Campos and Central Mountains.

The aquifer of the Serra de Llevant is located east of the island. It occupies about 500 km^2 and it consists of a series of limestone-dolomite infraliasic units and coast materials formed by limestone and calcarenite from the Miocene. Outcrops from Miocene, Oligocene and Cretaceous separate these units and origin a number of unconnected aquifers. Permeable materials occupy an area of 350 km^2. In general, the surface of the system is quite shallow and elevations do not exceed 500 m.

Groundwater resources are calculated from the values of water inputs into each of the groundwater bodies. Nevertheless, not all inputs are usable as environmental flows, understood as natural recharge of aquatic ecosystems, and the minimum flow to the sea to counteract seawater intrusion should be maintained. The rain infiltration rate in Mallorca is 20.5 % and, in addition to infiltration, deferred to the rivers, irrigation and loss and leaks in urban pipe networks are considered major components of recharge, as shown in the Table 2.1.

Table 2.1: aquifer recharge sources.

Aquifer recharge	hm^3/year
Rain infiltration	308.8
Temporary water courses	17.45
Irrigation	8.73
Losses and leaks in urban supply network	10.14
Other losses	39.21
Wastewater	5.96
Reserves consumption	1.06
Sea water	19.95
Total	**410.58**

Potentially usable resources are approximately 220 hm^3/year if overexploitation and salinisation are to be avoided. The uses of extracted groundwater are shown is Table 2.2: urban supply, irrigation, domestic use, livestock and agricultural industries and water sales in the free water market. Based on the water balance of groundwater bodies, natural resources are 308.1 hm^3 from which 179.8 are usable resources.

Table 2.2: uses of extracted groundwater.

Aquifer extraction	hm^3/year*
Urban supply	79.27
Irrigation	81.01
Domestic use (not by network)	19.18
Livestock and agricultural industries	0.21
Water sale	0.13
Total	**179.8**

** hm^3 = 1,000,000 m^3*

Many factors are affecting global water resources in the Balearic Islands: first, the location of the islands in an area considered as arid, where annual rainfall is less than 600 mm/year and unevenly distributed throughout the year; secondly, for the simple fact of being an island, the renewal rates of natural resources are lower than the continental ones; thirdly, it is important to bear in mind the massive limestone substrate (which favours a strong infiltration of water into the phreatic zone) and the very small length of the surface water network. These factors explain the lack of permanent surface water courses. Thus, in the Balearic Islands, the surface water network consists of temporary streams and wetlands; complemented by natural polls and ponds, and artificial ponds and reservoirs. Regarding permanent surface water in Mallorca, two reservoirs, the Cuber and Gorg Blau ones, are remarkable, with maximum capacities of 6.9 and 5.9 million m^3 respectively. These two comparatively large reservoirs were implemented as part of a hydroelectric project in the Serra Nord, dated 1959 and completed in 1971 and became one of the key elements of Palma Bay supply. Finally, regarding water resources of the Serra de Tramuntana, Sa Costera water canal, which connects the town of Sóller with the transverse artery of the island of Mallorca, deserves to be mentioned. This project was committed in early 2009, channelling the water from Sa Costera aquifer (that previously was pouring into the sea) through a section of underwater pipeline until a reservoir in Sóller port. From here, the water is pumped into another reservoir located in Sóller town, which can supply water to Sóller, Fornalutx and Deià. Part of the water is pumped to EMAYA's treatment plant, located in Son Pax, at the entrance of Palma de Mallorca; the estimated average flow is 40,000 m^3/day. EMAYA is the acronym for Palma's municipal company for water and sanitation.

Seawater desalination is a non-conventional technique obtaining water of good quality from the sea. 3 desalination plants are currently in operation in Mallorca Island and for the year 2010, was scheduled to start the operation of another 2 desalination plants, located in Camp de Mar and Alcúdia, out of Palma. Table 2.3 reflects the current and future desalination facilities and their average production.

Table 2.3: desalination plants.

Desalination plants	m^3/d	hm^3/year
Palma	64,800	23.65
Calvià	5,500	2.00
Andratx*	14,000	5.11
Alcúdia*	14,000	5.11
Total	115,800	42.25

*not in operation

Another non-conventional technique for increasing the availability of water is wastewater reuse. The reuse is directly related to the available volume of treated effluent, which depend on the number and capacity of existing wastewater treatment plants (WWTPs). According to data from 2006, the use of treated wastewater for irrigation was of 24 hm^3/year in the entire Balearic Islands, which represents approximately 25% of total tap water. According to the Balearic Water and Environmental Quality Agency, in Mallorca reclaimed wastewater from 11 treatment plants is partially reused with a total of 19 hm^3/year. Moreover, about 7 hm^3/year are used to irrigate golf courses (19 courses in Mallorca, 1 in Menorca and 1 in Ibiza) and 3 hm^3/year to irrigate parks and gardens. Moreover, the Ministry of Agriculture, Fisheries and Food in collaboration with the Department of Agriculture and Fisheries of the Balearic Government, is planning a series of actions to irrigate several areas with reclaimed water, replacing groundwater use, which will increase the volume of reclaimed water used to 9.03 hm^3/year. Some municipalities (Calvià and Alcúdia) are planning reclaimed water use for green areas irrigation.

Artificial aquifer recharge is a set of techniques that allow, through programmed intervention and direct introduction of water in an aquifer, increasing the degree of security and availability of water resources and act on its quality. The artificial aquifer recharge has been used in Spain for many years to store surface water runoff or surplus. However, in the Balearic Islands has been used only in very specific periods: s'Estremera aquifer has been recharged with water proceeding from the reservoirs Cuber and Gorg Blau in order to recover the groundwater levels in the aquifer. In the period 1996-2003 a total of 7.84 hm^3 of water has been recharged. Since 2009, some wells have been built to recharge s'Estremera aquifer during the wet season with the water surplus from Cuber and Gorg Blau reservoirs and Sa Costera.

3. State of the Art of Water Resources in the island of Crete, Greece

3.1 Background

Greece covers an area of 130000 km^2 and is located in the Mediterranean region at the south of Europe and facing northern Africa. Greece is divided in 13 political Regions and 51 political counties (prefectures). Recently with the new law L.3852/10 instead of the 51 prefectures 74 regional unions were created (Figure 3.1). The island of Crete together with some small islands surrounding Crete is the 13th out of 13 southernmost river basin districts (RBD) of Greece and one of the southernmost RBD of the European Union. The boundaries of the four old prefectures in Crete coincide with the four new Regional Unions of the Kallikratis Law.

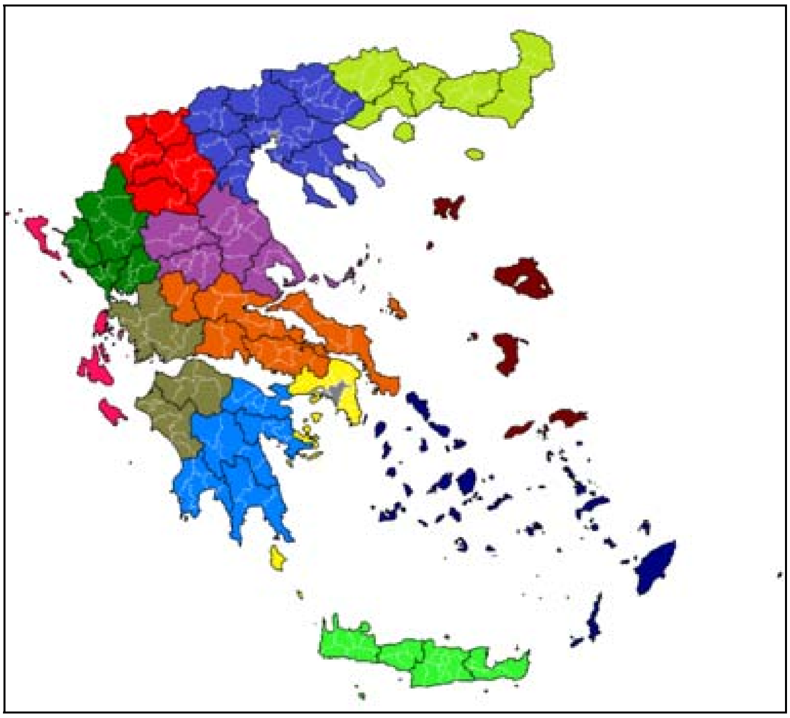

Figure 3.1: The boundaries (black color) of the 74 Regional unions in Greece.

The island of Crete occupies the southern part of Greece (N34^o 54' to N35^o 41' latitude, E23^o 30' to E26^o 20' longitude) and is the biggest island of Greece and the 5th of Mediterranean Sea. The island covers an area of 8336 km^2, which is 6.4% of the area of Greece and is divided into four counties (prefectures, and recently regional unions) Lassithi, Heraklion, Rethymno and Chania (from east to west), as shown in Figure 3.1. The maximum length of the island is 269 km and the maximum width 60 km, while the smallest width 12 km in the eastern part of the island close to Ierapetra city.

The climate of the island of Crete is characterized as dry sumi-humid Mediterranean with dry and warm summers and humid and relatively cold winters where mean annual rainfall decreases from west to east and from north to south, but increases with altitude. There is also a slight increase in mean annual temperature from northwest to southeast and a decrease with altitude. The mountainous areas especially of the west part present also mountainous climate. Crete contains sub-regions with different hydrological features. The lower altitudes have a climate characterized by xerothermic conditions and considerable water deficiency. Such great climatologically differences are due to the complex vertical and horizontal distribution of Crete.

The mean annual precipitation has been recorded to be 900 mm to 1086 mm. At the western part (White Mountains), the precipitation height is much higher (1700 mm) as compared with the eastern part of the island (Figure 3.2a and Figure 3.3). The annual rainfall ranges from 400 mm to 700 mm in the low areas and along the coast and from 700 to 1000 mm in the plains of the mainland, while in the mountainous areas reaches up to 2000 mm. Dry conditions are usually taken place from March to September. About 45 % of total precipitation occurs in the months of December and January.

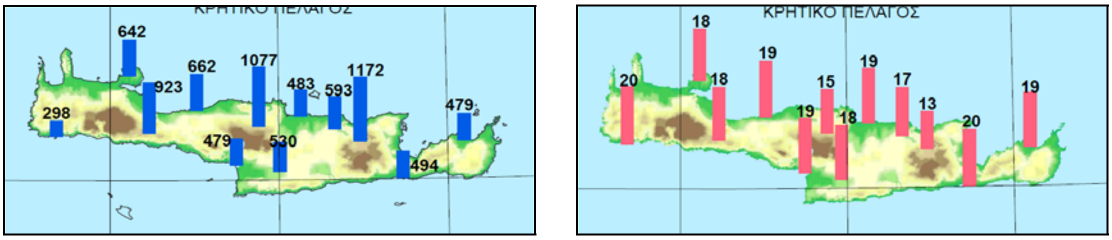

Figure 3.2: (a) precipitation regime in Crete and (b) temperature regime in Crete

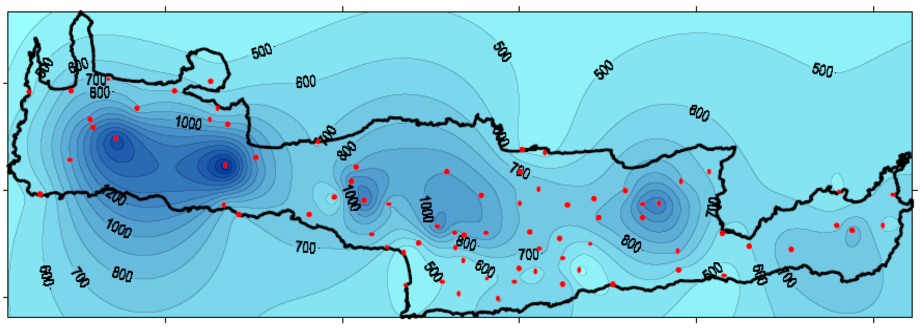

Figure 3.3: Contours of mean annual precipitation for the period 1977-1997, ordinary kriging regression, No of precipitation gauges: 80.

The mean annual air temperature in the island ranges from 18.5 ^{o}C in the west part to 20 ^{o}C in the south part (Figure 3.2b). The annual temperature range is 14 ^{o}C to 15 ^{o}C. The southern and south-eastern coastal areas of Crete are warmer than the northern parts and of the warmest areas of the Country. During the cold period, temperature increases with decreasing latitude. In winter, the lowest temperatures scarcely fall below 0°C in the plains. Spring is short because of the cold fronts often affecting the region in March, whereas May is rather warm especially due to the appearance of the first south winds and the disappearance of the action of low pressures. In the warm period and especially in the period from May to August, temperature increases from the coast to the mainland and particularly in the plains, while temperatures greater than 40°C may occur in the lowlands of Crete.

The mean annual cloud ranges between 3.5 to 4.5 degrees. The mean annual relative humidity is low and ranges among 65% to 68%. The dominant winds are north and north-west and follow the south and south-west. In summer winds create very dry conditions, which are enhanced by the diminishing of low pressures in eastern Mediterranean and are only interrupted by some local rainfalls of tropical origin. Heat waves in the plains during summer may be rather lasting, affected by south winds blowing from Africa. The drier is the hydrologic year, the total precipitation tends to be distributed into less months and the relative difference of the percentage distribution among the month's increases. In other words, the more wet months of the year tend to present increased contribution in the annual precipitation as compared with the less wet months (Figure 3.3). In dry hydrological years river runoff decreased by 31 to 84%, compared to its mean annual rate.

Table 3.1: Frequency of appearance or exceedance of the mean annual aerial precipitation in the island of Crete.

Probability, %	Crete	Upper 95%	Lower 95 %	Western Crete	Eastern Crete
P99 (T=1.01 years)	353	390	315	426	287
P90 (T=1.11 years)	611	658	564	707	525
P50 (T=2 years)	927	989	865	1051	816
P10 (T=10 years)	1244	1322	1165	1395	1108
P5 (T=20 years)	1333	1250	1416	1493	1191

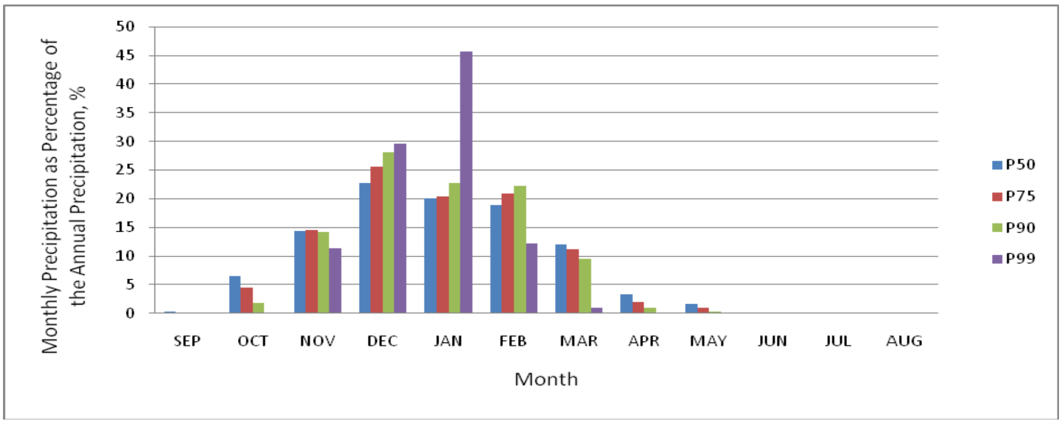

Figure 3.4: Monthly distribution of aerial precipitation of hydrologic years for certain return period for the island of Crete P50: normal year, P90: dry year, and P99: very dry year (data taken from Region of Crete).

Crete presents an extremely mountainous terrain of several massifs, with the highest summits of similar altitude to the majority of those in the Greek mainland. These massifs are separated by lowlands, which are sometimes extended flat areas close to the sea level. Crete presents high variation in altitude within relatively short distance (Figure 3.5). Due to its predominantly steep terrain and adverse climatic and bio-climatic conditions, the island is facing significant soil erosion problems. Lowlands (<200 m) cover 40% of total area and the highest mountains are: Idi (2456 m), Lefka (2453 m) and Dikti (2148 m). Actually, 79.5% of the surface area has slopes greater than 12% and only 6.9% of it comprises lowlands with slope less than 6%.

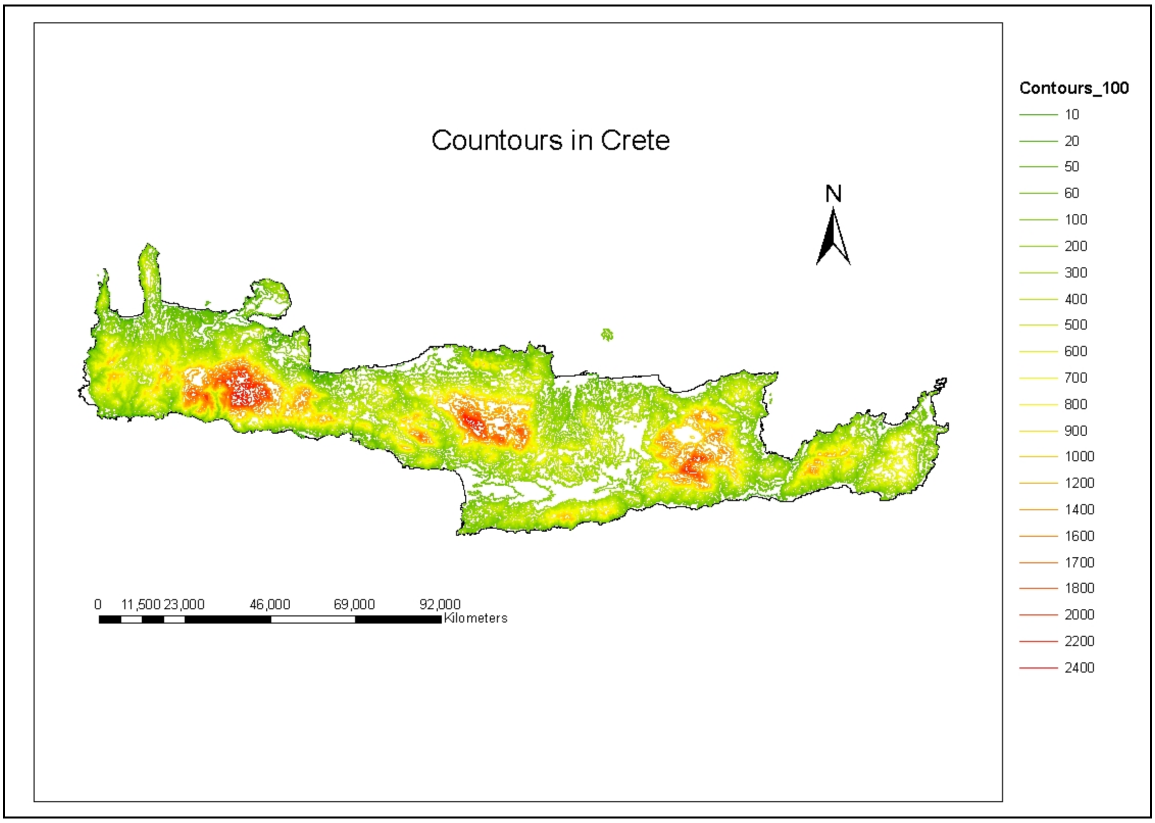

Figure 3.5: Contour map of Crete.

The island of Crete is characterized by a complex geological structure and the presence of successive tectonic zones. Various calcareous rocks (limestone and dolomites) dominate the mountain terrain, whereas Neogene sediments including limestones, sandstones and marls, cover large areas of the lowlands. In the island there are also ortho-quartzites, phyllites, flyschs, Quaternary rocks and alluvian deposites. Throughout the geologic history of Crete the following deposits and tectonic units appeared in a more or less successive, overlapping sequence: The basement is consisted of the limestones of Crete-Mani geo-tectonic unit (semi-metamorphic platy-limestones or Plattenkalk units), the Crystalline carbonate unit of Trypalion, the Phylite-Quartzitic basement and its carbonate alpine cover of Tripolitza-geotectonic zone and the overlapping nappes of Pindus (limestones and flysch) and of the more internal Hellenides geotectonic zones. All pre-alpine formations are intensively folded, thrusted and faulted. The morphologic lower parts and basins of the island are covered by thick clastic sediment of Neogene (marls, calcaric marls and limestones) and Quaternary.

The terrain profile of the island is characterized by the high degree of land-use mixture existing all over its extent. Land parcels are narrowly separated. The rough anaglyph of the island promotes the parallel development of micro-environments favoring different degrees of evolution of the natural and agricultural vegetation species. The landuse according to CORINE2000 database (http://www.eea.europa.eu) is presented in figure 3.6.

Crete has about 255000 hectares of agricultural land or 8% of the country's agricultural land. Most of the agricultural land is cultivated with permanent crops. Annual crop cultivation in 1991 constituted 6% of the cultivated land in Crete compared to 57% in Greece. About half of the agricultural land is concentrated in the prefecture of Heraklion and the rest is evenly distributed among the other three prefectures (regional unions). Special climatic conditions, particularly in Lassithi, make possible the production of products off-season, thereby improving the competitive position of the whole island for such products. Heraklion is favored with respect to the size of land, flatness of cultivated land and climate. Chania is favored with respect to size and flatness of cultivated land.

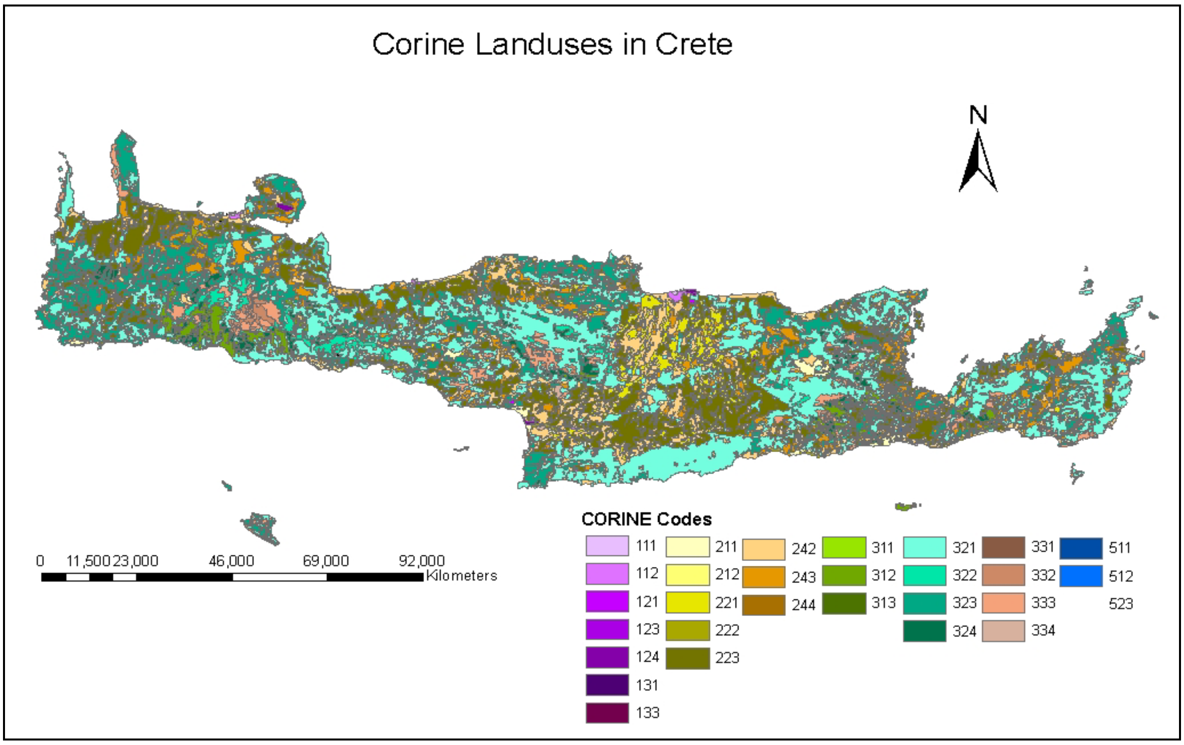

Figure 3.6: Landuse CORINE 2000 map: Artificial surfaces (111-133), Agricultural areas: arable land and permanent crops (211-223) and pastures and heterogenous agricultural areas (242-244), Forests (311-313), Scrub and/or herbaceous vegetation associations (321-324), Open spaces with little or no vegetation (331-334), island waters (511-512),and Marine waters (523).

Crete has a natural comparative advantage in olive cultivation both in terms of climate and soil. The climatic and soil conditions of the island are also conductive to viticulture for all three products, grapes, raisins, and wine. Despite the problem of phylloxera in the 1980s and the CAP policy to reduce the area of vineyards, viticulture remains one of the most important production activities in Crete. Citrus and fruit trees production is also very important for the Cretan economy, albeit 80% of production is concentrated in Chania. Orange trees are the main citrus crop. Greenhouse products also play a very important role. Although they occupy only 1% of cultivated area, they account for a quarter of agricultural GVA. Cucumbers and tomatoes are the main greenhouse products covering 70% of the area. Both of these products are exported.

The aerial coverage and the population for its prefecture (regional union) as it was measured in 1991 and 2001 are presented in Table 3.2. The population of the island increased by 11.3% from 1991 to 2001. The average population density is relatively low, 67.5 people/km², for the whole island, except for the large cities (Chania, Heraklion) in which population density is high (>4200 people/km^2). Population density increase by 4 to 5 times during summer period due to large number of tourists arriving in the island. The population can be divided in urban (41.5%), semi-urban (12.3%) and rural (46.2%), while 50.6% of the population comprised of males and 49.4% females. Other statistical data provided by the Social and Economic Conditions description of the MEDIS project and deriving by the National Statistical Service of Greece are following: The age distribution is almost the same for the ages >65 and <15 years, 16.3% and 17.0%, respectively. The other two classes of ages 15-35, and 35-65 years represent 31.2% and 35.5% of the total population. The statistical data of Greece (year 2001) indicated the following distribution of education level in Crete: (a) without any education 3.3%, primary school level 47.5%, secondary school level 38.4%, and university level 10.8% of total population of Crete. People in rural areas mainly work in the primary sector. This population consists of elder people and therefore there are various advantages or disadvantages such as lack of knowledge of new practices, old fashioned way of cultivating the land, lack of information on recent developments. Even though the population density is not high in Crete, over-exploitation of the natural resources has been recorded in the last four decades by expanding agricultural land in natural areas by deforestation, increasing irrigated area in the olive groves, over-exploitation of water resources, and overgrazing rangeland.

Table 3.2: The aerial coverage and the population of the four prefectures (regional union) in the island of Crete.

Prefecture (regional union)	Area, Km^2	Population (1991)	Population (2001)
Heraklion	2,671	264,906	292,489
Chania	2,376	133,774	150,387
Rethymno	1,496	70,095	81,936
Lassithi	1,823	71,279	76,319
Total	8,336	540,054	601,131

The local economy of Crete is based on agriculture, tourism and industry (Table 3.3). Based on the Greek Statistical Service, 32.4% of the Cretan population is working in the primary sector (agriculture and fishery). The rest of population is working on industry, local administration, service, tourism, etc. The distribution of tourist-overnight stays to native and foreigners is presented in Table 3.4. In rural areas close to the seashore, parallel employment in agriculture and tourism business is very common. On the other hand the income of people leaving in the upper hilly or mountainous areas usually comes totally from agriculture or livestock-farming.

Table 3.3: The population distribution (1991) to the economical sectors.

Sector	Population	Population, %
Primary	64,600	32.4
Secondary (Industry)	35,088 (17,737)	17.6 (8.9)
Tertiary (Tourism)	99,787 (8,982)	50 (4.5)

Table 3.4: The distribution of tourists to native and foreigners.

	Overnight stays	Percentage, %
Foreigners	9,106,763	93.8
Native	603,174	6.2
Total	9,709,937	

The main agricultural products are: olive oil, early growing vegetables, oranges, avocado, wives, grapes, milk, and meat. Other products include bananas, and fruits crops, various fish and shellfish. Crete is the 1st largest olive oil producer providing about 37% of total national production in Greece. Milk production and livestock corresponds to about 13% and 25% of the total national production. Additionally, early growing vegetables in greenhouses or in open areas are estimated to 300000-400000 t/y. The area of greenhouses covers about 50% of the total area in Greece.

Since 1960, it was clear the need of breaking dependence on the cultivation of olive trees because unstable production has led to unstable income. However, the focus to tourism and the immediate need to develop infrastructure (hotels, roads and transport), especially, since Greece's accession to the EU made the tertiary sector the prominent. The growth of the primary sector was suppressed due to small size land ownership, restricted natural resources, ageing population and low competitiveness of agricultural products (because of high production and market competition). Farmers' income is declining and depends increasingly on state subsidies and community funds which, following revision of the CAP and the enlargement of the EU, are eventually be reduced. The decline in farmers' income is the most important factor affecting land use decision making. The prices of the main products (olive oil, meat, and milk) do not follow the general trends of the market, thus reducing the income. In many cases the prices of products such as olive oil decreased, while the cost of living increased. Labour, fertilizers, pesticides and fuel costs have increased significantly without any parallel increase in the prices of products.

The great increase in tourist numbers in the last few decades has greatly affected the economy of the island and land use especially in the lowlands such as Messara valley, Ierapetra plain, and Chania lower area along the coast. Furthermore tourism development has also largely influenced land value in some parts of the island, affecting a significant part of rural land. The main land use changes that occurred due to these processes were expansion of annual agricultural crops (vegetables) and extension of urban areas into agricultural or natural areas.

Productivity (GNP) per occupied in Crete is relatively high in all sectors and particularly in the tertiary sector (services, tourism), where the modernization of some enterprises it is of the highest in the country (Table 3.5). However, the illegal economy in tourism is also high, which can reach the 60% of the total activity. This justifies the relatively low index of the head GNP in Crete.

Table 3.5: Socio-economic profile of the island (MEDIS project).

Sector	Population
GDP of the country (€)	130 436 10^6 (2001) (market prices)
On the island (€)	6930 10^3 (2001)
Per capita (island) (€)	11 533.38 (2001)
Declared income per inhabitant a year (€)	3 844.5 (2001)
Average household income (€)	11 539.6 (reported)
Employed/1000inh	893
Contribution of agriculture to the island GDP	12
Employment agriculture	32.9%
Contribution of industry (incl. construction) to the island GDP	11%
Employment-industry	10.3%
Contribution of services-tourism to the island GDP	77%
Employment-tourism	9%

3.2 WATER RESOURCES

An average water balance in the island of Crete as it was estimated by the Hellenic Ministry for the Environment, Physical Planning and Public Works in the Masterplan of 2006 is presented in Table 3.6.

Table 3.6: An average water balance in the island of Crete.

Parameter	Crete Region
Area (km^2)	**8336**
Precipitation (mm)	**900**
Volume of precipitation (Km^3)	**7500**
Evapotranspiration (Km^3)	**4874**
Percolation (Km^3)	**1068**
Surface runoff (Km^3)	**1558**
Theoretical surface and underground water potential (Km^3)	**2626**

The three types of hydrogeologic systems found in the island and the summarized water balances are presented in table 3.7. The carbonate rocks cover 40% of the total area of the island. The major aquifers occur within the carbonate rocks (karstic aquifers) of Crete-Mani and Tripolis zone. The carbonate mountains White Mountains (Lefka Ori), Idi and Dikti are the most important karstic aquifer systems in Crete for management purposes. The total aerial coverage of these systems is about 2730 km^2 and the average annual precipitation is 1300 mm. The average water volume from precipitation is 3.5 10^9 m^3/y and the water contributing to the karstic aquifers has been estimated to be 1.8 10^9 m^3/y, which discharge in many karstic springs. However, in many parts of the island, especially in eastern Crete, the limestones are in contact with the sea, and the karst aquifer systems often discharge groundwater through large brackish springs. The main brackish springs, the discharge of which is systematically monitored, transfer 450 million m^3 of water, annually. It has been estimated that the total brackish water together with submarine discharges is 800-1000 million m^3/year.

A large number of anisotropic and heterogeneous confined aquifers occur in the plio-pleistocene deposits, as well as in the Quaternary deposits along the torrents. The Neogene-sedimentary systems of 2597 km^2 get 693 mm annual precipitation and contribute to groundwater with 365 million m^3 (average percolation 20%). Finally, other mixed systems (Viannou, Achentria, Antiskari, Palaiochora) with 976 km^2 aerial coverage and precipitation 780 mm/y contribute to groundwater with 81 million m^3 (average percolation 10%). Totally, these systems occupy 6303 km^2 and contribute groundwater with 2234 million m^3/year.

The remaining 2000 km^2 (the total area of Crete minus the area of the aforementioned systems) mainly refers to phyllites-quarzites and flysch as well to limestones and sediments (Neogene- Quaternary) which do not relate with the previous mentioned basins.

Table 3.7: Hydrogeologic system and water balance.

	Area	Precipitation	Volume of Precipitation	Percolation	Groundwater potential
	million Km^2	Mm/y	million m^3/y	(%)	million m^3/y
A. Karstic	2730	1300	3549	50	1788
B. Neogene-sedimentary	2597	693	1799	20	365
C. Other	9758	780	7607	10	81
TOTAL:	**6303**	**969**	**6109**	**37**	**2234**

Sedimentary aquifers: The last 10 years the majority of these aquifers has been overexploited and the last dry years accepted even higher pressures, because the increased requirements by the agriculture and their small enrichment.

Karstic aquifers (coastal zone): Depletion and pollution of coastal aquifers of the central and Eastern Crete from sea water intrusion occurred during the last decades due to the over-pumping of aquifers, especially during long-lasting dry periods. Their water is used mainly for the water supply of big cities and for tourist use and circumstantially for irrigation. The last dry years and the lack of snow make the situation even worse. As a consequent high drawdown of ground water level resulted due to imbalance between recharge and abstractions from the aquifer systems. Water levels at depths of several meters below m.s.l. were recorded. The overexploitation of coastal aquifers has gradually led to a significant deterioration in groundwater quality. The adverse effects are depicted by the high concentrations of chlorides, due to seawater intrusion.

Karstic aquifers (mainland): It has been observed a decrease of the water depth in deep karst wells. However, while for the karstic systems of Asterousion and Diktis (Mithon and Nipiditou Basins) the substitution is not satisfactory, in the case of west and central Crete (Lefka Ori and Psiloritis) it is presented good substitution.

Springs: The spring discharges are monitoring on monthly basis for about 30 years. Most of the presented averaged values are of 15-20 years monitoring data, while very few are the cases with data less than 10 years. Most of the springs are karstic and refer to the same hydrogeologic system (Lefka Ori, Psiloritis-Dikti-Selena, Elountas-Fourni, Zakrou). Big brackish springs are the following: Almiros-Georgioupolis, Almiros-Heraklion, Almiros-Agios Nikolaos and brackish springs of lower discharge are the following: Platanos-Kissamos, Almiros-Mallia, Grammatikaki-disharges of the southern part of Lefka Ori. Submarine discharges, which have not been measured, can be found in the southern part of Lefka Ori, Souda bay, Bali bay, Mallia bay, Elounta, Skinia, Malavra, and the eastern part of the limestones of Zakros.

By analyzing the hydrographs of karst springs it is possible to identify aquifer characteristics and, accordingly, the main features of a karst rock-fissure massif. Consequently, relevant data can be obtained by analyzing hydrograph recession curves. Maillet (1905) introduced an analytical expression into hydrotechnical theory and practice for defining a hydrograph recession curve in a long-lasting dry period (with no precipitation):

$Q_t = Q_o e^{-at}$

where Q, is the discharge at time t, Q_o is the discharge at the start of the recession, and a is a recession coefficient which depends upon the geological and morphological structure of the catchment analyzed.

Although Maillet (1905) developed this equation from catchments with aquifers consisting of granulated media, it has been very widely used for karst media, i.e. non-homogeneous and anisotropic media with fissures. Numerous authors have used this equation to describe the discharge hydrograph of a karst aquifer and identify its transportation and storage characteristics.

For the characteristic hydrologic year it was selected the period of no precipitation and the recession coefficient 'a' was estimated. Moreover, the water volume remaining for discharge without any other input was estimated for the months June and September. The value estimated for the month September shows the potential of the spring if a dry period follows. These calculations are presented in table 10.

The springs are grouped into three categories.

Category A: $a<0.0005$

Category B: $0.0005<a<0.06$

Category C: $a>0.06$

The Qmax/Qmin ratio is about 3 for Stilos and Meskla springs and about 166 for Vrisses spring. This indicates direct discharge. The rest of the big springs present lower ratio (<3) indicating homogenization of the water flow.

The springs which have been affected by pumping and present decrease in their discharge are: koleni, Argiroupolis, Migkilisi, Simi, Zaros, Episkopi-Mousela, Almiro nero-Panormou.

The springs can be separated into three categories according to their annual discharge.

1. $>20 * 10^6$ m^3
2. $10\text{-}20 * 10^6$ m^3
3. $5\text{-}10 * 10^6$ m^3
4. $3\text{-}5 * 10^6$ m^3
5. $1\text{-}3 * 10^6$ m^3
6. $<1 * 10^6$ m^3

The six groups are presented in Table 3.8.

Table 3.8: Springs according to their annual discharge (data taken from Region of Crete, 2008).

		Mean annual discharge, million m^3
Almiros-Heraklion	SP1	241.3
Karavas/Platanos/Kavousi/Vrisi-Stilos	SP41	82.1
Almiros-Ag. Nikolaos	SP9	81.6
Platanos/kalamionas-Agia	SP43	69.5
Kourtalioti	SP32	36.8
Zourbos	SP40	31
Nikoliana/Panagia/kefalovrisi-Meskla	SP42	30.7
Vrisses	SP38	26.2
Panagia/Platanos/Piggadaki-Armenoi	SP39	24
Boloniana/Drapania/Ag. Pantes-Koleni	SP46	10.3
Elliniki-Pelekanioti	SP44	8.6
Therisos	SP48	8.3
Ktima Kegia-Geropotamos	SP28	7.9
Argiroupoli	SP52	5.5
Zakros-Sitia	SP2	5.4
Chochlakies-Sitia	SP3	5.1
Almiro nero-Panormos	SP27	4.7
Konto kinigi-Palaiochora	SP45	4.6
Panagia/Skotini/Kefalovrisi Fodele	SP22	3.7
Pirgos-Kalo Chorio	SP8	3.4
Kefalovrisi/Kalamoukas-Ierapetra	SP49	3.3
Archon Stavrochoriou-Sitia	SP6	3.2
Spili	SP30	3.1
Votomos-Zaros	SP20	2.7
Almiros-Mallia	SP12	2.3
Sinikoismos Simis-Viannou	SP19	2
Ag.Fotia-Spili	SP31	1.9
Ag. Paraskevi-Sfinari	SP47	1.8
Emparos	SP25	1.7
Zou-Sitia	SP11	1.5
Gergeri	SP21	1.5
Seises	SP26	1.5
Ligkres-Kerame	SP35	1.5
Lithines-Sitia	SP5	1.4
Kefalovrisi-Viannou	SP7	1.4
Ag. Georgios-Sitia	SP4	1.3
Kria Vrisi-Viannou	SP18	1.3
Loutraki-Anw Viannos	SP51	1.1
Migkilisi-Avlis	SP14	1.1
Retikou-malles Ierapetras	SP10	1
Mega Vrisi-Ag. Vasileioi Viannou	SP16	0.7
Chalazia-Loutraki Ano Viannou	SP15	0.6
Grammatikaki-mallia	SP13	0.5
Sikia-Sitia	SP50	0.2
Tertsa-Viannou	SP24	0.2
Keratokampos	SP23	0.2
Ag. Georgios-Viannou	SP53	0.1

The steep relief of the island, the big amount of atmospheric deposition, the extent of the island and its complicated geological structure create a complicated distribution of groundwater as well as surface water. As a result, many small hydrologic basins which do not exceed the 600 km^2 have been formed. The main river basins of the island are presented in Figure 3.7. The dense river network presents ephemeral character and big fluctuation of its discharges. The streams that present permanent flow during the whole year (Geropotamos, Platanias-Chania, and Kourtaliotis-Rethimno) are very few and are mainly supplied by karst spring water. The average water balance for some of main hydrologic basins is presented in Table 3.9. The total surface flow emanating from karst spring water or surface runoff from the main rivers of the island it has been estimated to be 500 million m^3/y. The two bigger hydrologic basins of the island, Geropotamos and Anapodiaris of extent 525 and 600 km^2 respectively, are found in the southern part of the island in the region of Messara-Heraklion.

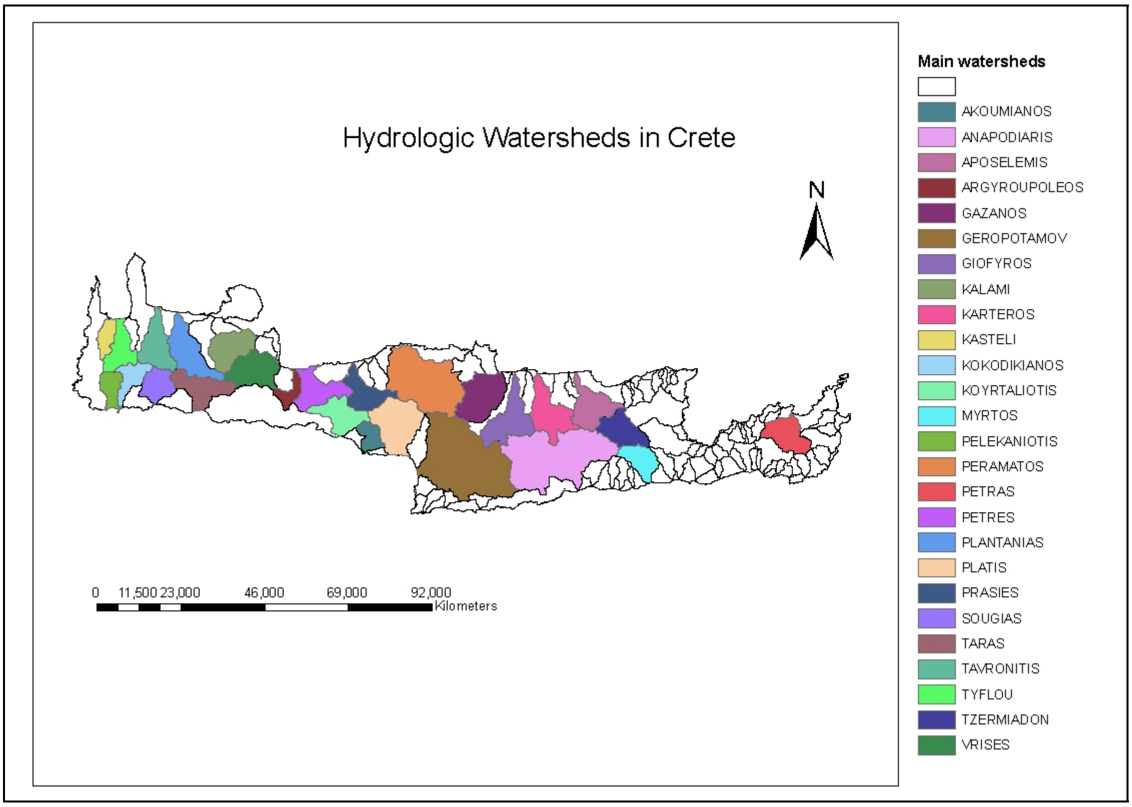

Figure 3.7. The most important hydrologic basins of the island of Crete.

Table 3.9: Average water balance for hydrologic basins (1977-1997) in Mcm

Hydrologic Basin	Precipitation	Potential Evapo-transpiration	Actual Evapo-transpiration	Runoff	Runoff from base flow	Groundwater storage	Percolation coefficient, %	Total runoff coefficient, %	Surface runoff coefficient, %
Seberniotis	41.7	38.7	23.6	12.2	1.4	4.5	10.8	32.6	29.3
Roumatianos	30.6	30.9	21.1	5.8	1.2	2.5	8.2	22.8	19
Kakodikianos	82.2	117.7	53.5	15	0.6	13.1	16	18.9	18.2
Agiou Vasiliou	26.1	36.8	17	3.2	0	5.9	22.7	12.4	12.3
Prassanos	111.6	135.3	64	18.8	0.6	28.2	25.3	17.4	16.9
Akoumianos	54.8	83.5	33.6	9.9	0.1	11.2	20.5	18.2	18.1
Platus	219.3	306.3	101.4	48.6	6.9	62.3	28.4	25.3	22.2
Geropotamos	254.5	573.6	182	26.1	4.4	42	16.5	12	10.3
Koutsoulidis	159.7	175	86.8	13.4	2.9	56.7	35.5	10.2	8.4
Lithaios	39.6	62.3	23.1	7.4	0.9	8.2	20.8	20.9	18.7
Gazanos	167.3	262.9	111.7	6.5	0	49	29.3	3.9	3.9
Giofuros	124.1	228.4	80.3	22.6	4.3	16.9	13.6	21.7	18.2
Anapodaris	58.3	105.4	36.1	13.5	0.7	7.9	13.6	24.5	23.2
Anapodaris	369	686.9	263.7	35.5	1.9	67.9	18.4	10.1	9.6
Mparitis	96.7	136.1	68.7	3.2	0	24.9	25.7	3.3	3.3
Iniotis	77.1	145.7	57.2	1.9	0.4	17.7	22.9	3	2.5
Aposelemis	70	97.4	34.7	11.7	2.7	20.9	29.8	20.7	16.7
Xavgas	169.8	174.8	95.5	17.3	0.9	56.2	33.1	10.7	10.2
Katovianos	32.4	53.8	26.8	0.8	0	4.8	14.8	2.5	2.4
Arvi	20	30.2	11.3	3.5	0.5	4.7	23.6	19.6	17.3
Mirtos	96.2	148.6	53.5	12.9	1.2	28.7	29.8	14.6	13.4
Kalamankianos	28.8	54.8	17.2	4.2	0.3	7	24.4	15.8	14.6
Mpramianos	24.6	55.9	17.9	1.9	0	4.9	19.9	7.6	7.5
Patelis	49.3	81.9	28.8	7	0.6	12.9	26.2	15.4	14.2

The non-conventional water sources mainly comprise of desalinated seawater, reclaimed water from wastewater, brackish water and excess rainwater catchment. The cases of waste water reuse in Crete are minimal:

- At Palecastro (Heraklion), 280 m^3/d are used to irrigate olive trees after loading on a 20 m3 reservoir. The irrigation method is closed pipe network.
- At Zakros (Heraklion), 210 m^3/d are used to irrigate olive trees without any storage. The irrigation method is trickle irrigation. During the un-irrigated period, effluent is diverted to the adjoining ephemeral stream.
- At Chersonissos (Heraklion), treated effluent is stored in two reservoirs of total volume 1000 m3. The system provides water for irrigation of olive trees on an area of 2200 ha. The irrigation method is trickle irrigation. In addition, water for fire protection is provided through the storage tanks used for agricultural irrigation. In these tanks water should always be above 200 m3 as this quantity is regarded as the minimum needed in case of fire at the area.
- At Hersonissos (Heraklion), two types of landscape irrigation are applied: a) irrigation of ornamental plants at the side of the new national road Heraklion-Ag. Nikolaos (6-7 km), and b) irrigation of a land of 5 ha planted with ornamental trees and shrubs in the surrounding areas of two hotels sewerage network.
- Creta farm which is a meat producing, processing and packaging industry located in Rethymnon, uses 300 m3/day, from the produced wastewater, for the irrigation of more than 2000 eucalyptus, 1500 tamarix trees, and a large number of olive trees.

In the next paragraphs it is described the potential for the use of non-conventional water sources in Crete.

Desalination: In Greece, the local water and wastewater enterprises (municipality-owned companies) are currently operating approximately 48 relatively small desalination plants, with total capacity of 24,000 m^3/d. A significant number of desalination plants are currently under construction or under design. Most of the desalination plants have been installed on islands, using the reverse osmosis processes. There is also in operation a number of private plants, most of which are owned by big hotels. The cost of desalinated water in Greece is between ⁄0.5 and ⁄3.5 per m^3; and in most above ⁄1.2 per m3. This is relatively higher compared with large desalinations plants operating in Israel, Malta and Cyprus, where it is usually below ⁄0.7 per m^3. Due to the critical importance of desalinated water, it is expected that the Greek government will subsidize the electric energy consumed for this purpose.

Water reclamation from wastewater: Almost all the major towns in Crete have wastewater treatment plants, thus water reclamation, after appropriate extra treatment is feasible. Reclaimed water may be used for agricultural and landscape irrigation.

- The use of reclaimed water can provide an economic alternative water source for irrigation. It is well known that the agricultural products produced in Crete are of high quality and thus of high demand. Moreover, the relatively higher temperatures in this region are ideal for offseason fruit and vegetable production. The potential nutrient content (N and P) of the reclaimed water can also eliminate the use of artificial fertilizers. However, the decision to remove nitrogen and phosphorous when the reclaimed water is used for irrigation depends on the local legislation and on the potential risk for contamination of the surface and underground water.

- Reclaimed water can provide also water for landscape irrigation to the numerous holiday houses and hotels in Crete. As domestic water tariffs (cost of water per cubic meter) in Greece usually rise with the increase of monthly consumption (step-like charge), the use of reclaimed water will decrease this cost.
- An additional application of reclaimed water is to be introduced in aquifers which suffer from sea intrusion to push back the sea-born slats. Alternatively, the aquifers may be used for water storage, which then can be used for a variety of applications.

The cost of reclaimed water for small- and medium-size wastewater treatment plants (100–5000m^3/d) has been calculated between ⁄0.15 and ⁄0.35 per m^3, which is below onefifth of the cost of desalinated water. The cost-reclaimed water is still considerably lower than the cost of desalinated water, if the cost of separate storage and distribution system is taken in to account. The energy required for the reclamation of water from wastewater has been estimated to be below one-thirtieth of the energy required for the desalination of equal volume of seawater. An additional advantage is the pattern that follows the wastewater production, which reaches the maximum during the hot months, when the demand for reclaimed water maximizes. As a result, there is no need for the construction of extended reclaimed water storage facilities, which account for a large fraction of the total cost of the reclaimed water production and distribution system.

Brackish water: The total brackish water potential for Crete has been estimated to be over 1000 million m^3/yr. Just from the Almiros spring, at Heraklion, approximately 250 million m^3 of brackish water are produced per year; this is sufficient quantity to cover over 50% of the total water demands on the whole island of Crete. The Cl^- concentration in the water of Almiros spring varies from 100 mg/L (during winter) to 600 mg/L (during summer). For about 25–50 days per year (during winter), the above spring yields good quality freshwater, which may be used as potable water. The last one itself has been estimated that can save more than 4 million m^3 of water per year. The exploitation of brackish water involves a considerably lower cost, compared to the desalination of seawater. The cost reduction may be over than 50% compared to seawater desalination because of the lower cost for the removal of dissolved salts.

Rainwater: A number of artificial lagoons has been constructed or is under design or construction in Crete. Alternatively, rainwater may be collected by a series of well-placed small dams and reservoirs.

4. State of Art of Water Resources in the island of Malta

4.1 Background

The Maltese archipelago consists of three inhabited islands, Malta, Gozo and Comino and a number of uninhabited islets scattered around the shoreline of the major islands. Its location is approximately 96km south of Sicily and 290km north of Tunisia and located at latitudes 35º 48' and 36º 05' North and longitudes 14º 11' to 14º 35' east. The total surface area is approximately 316 km^2 and the perimeter of the shoreline in Malta is 136km whilst that of Gozo is 43km.

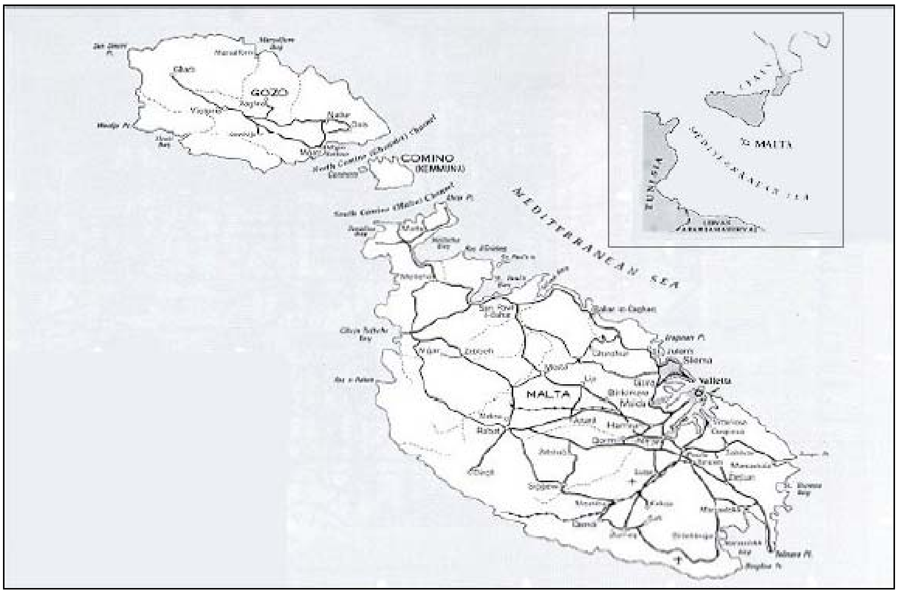

Figure 4.1: The Maltese Islands

The climate of the Maltese islands is typically semi-arid Mediterranean, characterized by hot, dry summers and mild, wet winters. During the summer season, the islands are dominated by high pressure conditions. The mean annual rainfall is approximately 550mm (mean for the period 1900-2000) but with high seasonal and interannual variability (variation coefficient 27%); with some years being excessively wet and other years being extremely dry. The highest precipitation rates generally occur during the period from October to February. During the past century, the wettest month was December with an average rainfall of 93 mm and the driest month was July with only 0.3 mm of rainfall. Rainfall is characterized by storms of high intensity but of relatively short duration.

Month	Rainfall (mm)	Max. Temp. (°C)	Min. Temp. (°C)
January	86.4	14.9	10.0
February	57.7	15.2	10.0
March	41.8	16.6	10.7
April	23.2	18.5	12.5
May	10.4	22.7	15.6

June	2.0	27.0	19.2
July	1.8	29.9	21.9
August	4.8	30.1	22.5
September	29.5	27.7	20.9
October	87.8	23.9	17.7
November	91.4	20.0	14.4
December	104.3	16.7	11.4

Table 4.1: Mean monthly values of main climate parameters (island-wide average)

Figure 4.2 presents the annual rainfall for the Luqa meteorological station for the period 1947-2004. The average rainfall for this site for this period was 569 mm. So as to give a better impression of inter-annual variability. This figure shows clearly that annual rainfall 300 mm greater or 250 mm less than the average is common. Although there is no indication of systematic variability, consecutive years of above or below average annual rainfall are common.

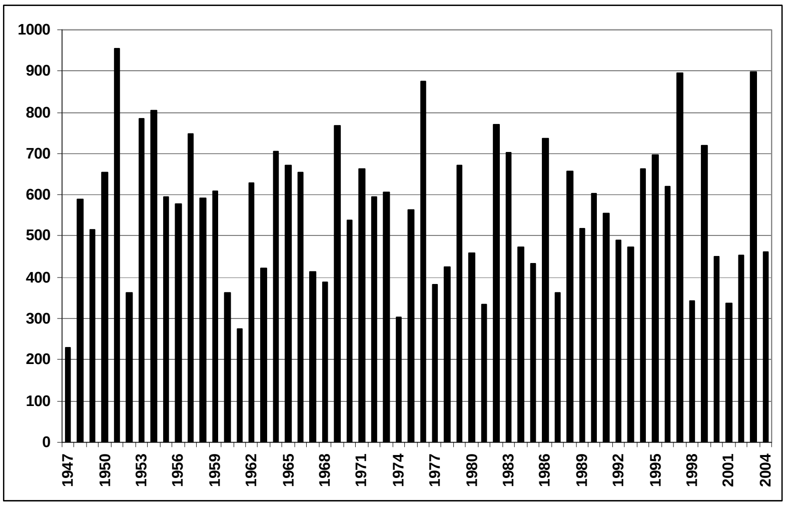

Figure 4.2: Annual rainfall for Luqa meteorological station (1947-2004)

Consequences of the semi-arid Mediterranean climate that are of particular relevance to water management include the:

- Variability in inter and intra-annual rainfall
- High intensity short-duration rainfall events
- Seasonal scarcity of precipitation when the water requirements of the agricultural and tourism sectors are highest (normally from June to August)
- Frequent occurrence of low rainfall years when groundwater recharge is likely to be low
- Frequent occurrence of high rainfall years when run-off is likely to be high

The Geological formations exposed in the Maltese Islands are of Tertiary and Quaternary age, having been deposited during the last 35 million years. The Lower Coralline Limestone is of Oligocene Age (23-35 million years old); with the other overlying formations being of Miocene age (5-23 million years old). The very top of the Upper

Coralline Limestone could be of Upper Messinian age possibly extending into the early Pliocene age (1.6-5 million years old).

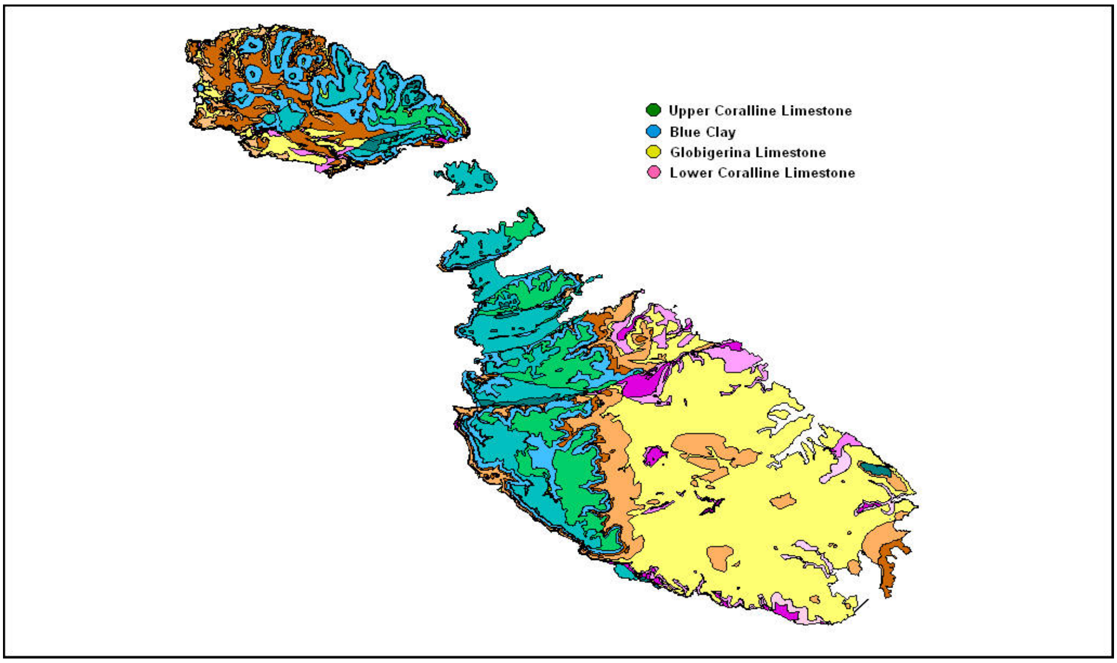

Figure 4.3: Simplified Geological Map of the Maltese Islands.

The Maltese Islands are thus mainly composed of two porous and fissured limestones: the Upper Coralline Limestone and the Globigerina-Lower Coralline Limestone, separated by a relatively thin layer of clayey and marly material, the Blue Clay formation, sometimes overlain by the Greensand. The lithological different natures of these formations together with their geologic position give occurrence to two broad aquifer types: the Upper (Perched) Aquifers in the Upper Coralline Limestones and the Lower (Mean Sea Level and coastal) Aquifers in the lower limestone units (porous and fissured Globigerina and/or Lower Coralline Limestone) and due to the general structure of the islands in the Upper Coralline Limestone in the Northern region of Malta.

The Upper and Lower Coralline Limestone formations are considered to function as aquifer rocks. The Globigerina Limestone functions locally as an aquifer, only where fractured and/or located at sea level, and normally is expected to transmit water from the surface into the main groundwater bodies along fractures. The Blue Clay and the Greensand are normally impermeable and underlie the perched aquifer. Faulting, sinkholes and patch reefs however partially penetrate these impermeable layers. The soils have a high water storage capacity; but however are generally present as thin layers.

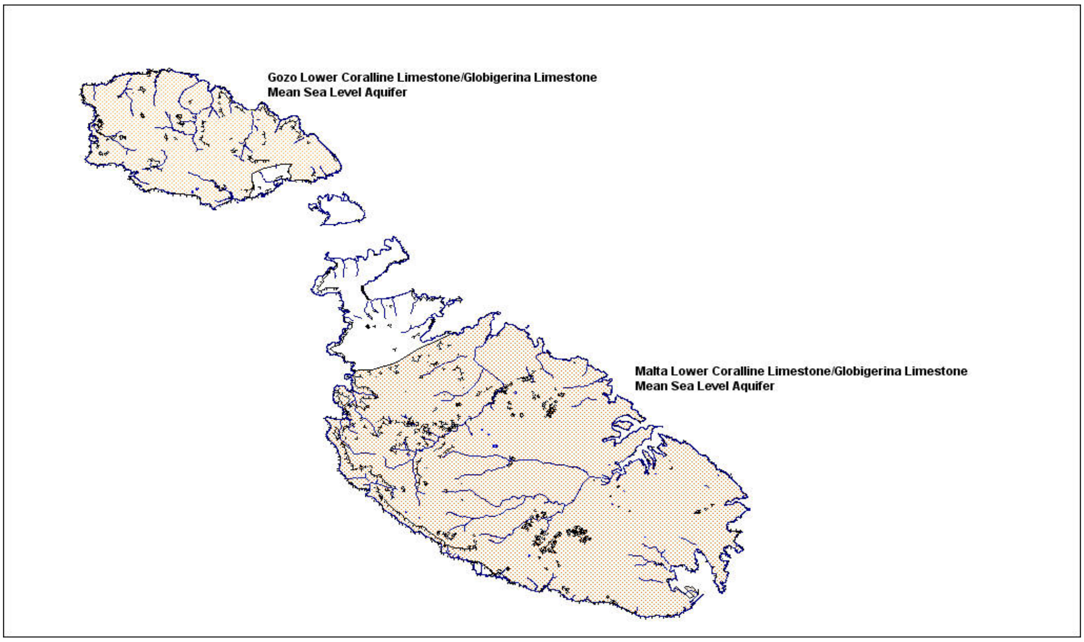

Figure 4.4: Extent of the Globigerina/Lower Coralline Limestone Aquifers in the Maltese Islands.

From a structural point of view, the island of Malta can be subdivided into two parts: the north-western part and the central south-eastern part; the limit being marked by the major fault line usually called the Victoria Fault. Fault systems in the island are not consistent in their hydraulic function. There are fault seals, especially where the aquifer is displaced against an impermeable formation. The Ghar Lapsi fault appears to work as a seal due to a dragged clay and marl fill along the fault plane. Other faults encourage communication, especially vertically. The Victoria Line fault allows communication along and across the fault due to intense fracturing.

In a significant part of the island, south of the Victoria fault, the Upper Coralline Limestone and the Globigerina/Lower Coralline Limestone aquifers are stacked vertically. The Lower Coralline Limestone (LCL) aquifer is in lateral and vertical contact with sea-water. Due to the density contrast of freshwater and saltwater a Ghyben-Herzberg system is developed: a freshwater lens floating on saltwater with a thickness approximately 36 times more below sea level than the height of the freshwater surface above sea level. In the central regions of the island, hydraulic heads of around 4-5m were recorded in the 1940's when the aquifer was still relatively unexploited. Today the potentiometric surface in these regions has receded to levels around 1m amsl mainly due to unsustainable groundwater over-abstraction. The effect of the pumping station gallery network must also be taken consideration since basically the galleries skim the surface of the groundwater lens thereby fixing the piezometric head at the skimming level.

Porosity and permeability of the rock depend to a large extent on fissures and microfractures. Infiltration into the sea level aquifer is predominantly through fissures in the overlying Globigerina Limestone. From this aquifer extraction takes place through a gallery system near the centre axis of the island and by boreholes further away from the centre. Due to brackish water upconing, the water pumped from the LCL exceeds

1000mg/l chlorides in a number of major sources, with peaks exceeding 2000mg/l chlorides being registered.

The Upper Coralline Limestone aquifer in this zone is perched above a Blue Clay seal (aquiclude) on the Rabat-Dingli Plateau. The aquifer outcrops, partly below a thin soil cover, and infiltration of surface water is direct. No saltwater intrusion is possible. Large scale private extraction from shafts and springs takes place.

The northern part of the island is divided by a NE-SW fault system into a succession of horst and graben like structures; the graben being occupied by rather flat valleys separated by ridges. This structure with parallel compartments separated by faults leads to the point that the resulting aquifer blocks should be considered as independent from one another from a hydrogeological point of view. The fault bounding the south of the Pwales Valley between Ghajn Tuffieha Bay and St Paul's Bay separates the main aquifer of the island from the northern smaller graben and horst units. Perched aquifers are thus developed in the Upper Coralline Limestone of Mellieha Ridge, Mgarr/Wardija Plateau and Mizieb Valley whilst coastal aquifers are present at Mellieha Bay, Pwales Valley and Marfa Ridge. The aquifers in the northern part of Malta have only a small potential for water abstraction. The aquifers at Mgarr and Mizieb have a limited vertical contact with saltwater thus further limiting their potential groundwater yield. The groundwater is largely used for public water supply and irrigation. The small broken up blocks allow little room for economical, large scale water production development.

In Gozo, the Lower Coralline Limestone sustains a mean sea level aquifer displaced over the whole of the island except for a small region around the harbour of Mgarr where the Blue Clay formation occurs at sea level due to faulting. The Upper Coralline Limestone outcrops in the island, namely at Ghajnsielem, Nadur, Xaghra, Zebbug and Victora/Kercem sustain small perched aquifers which are exclusively used for irrigation. A number of minor perched aquifers are sustained by small outcrops of the Upper Coralline Limestone such as those at Ghar Ilma and il-Gordan.

The Maltese Islands have a population of approximately 400,000, increasing at a rate of around 2,400inh/year. Official statistics show that the Maltese population is expected to continue growing for the next fifteen year period when it is estimated to reach 425,000 inhabitants. This increase will superimpose further pressures on the socio-economic and socio-cultural structures of the country with significant added strains on the water resources. With a population density of 1,250 inhabitants/km^2, the Maltese islands are amongst the most densely populated countries of the world. Consequently, Malta is highly urbanised and over 23% of the surface area is built-up.

It is expected that the total number of households in the Maltese islands will increase, a change which will be accompanied with a decrease in household size - mainly due to changing family perceptions. The steady decrease in household size has been evident over the last years and from the average household size of 3.1 registered during the 1995 Census it is projected to continue decreasing reaching 2.7 by 2020. As a consequence, the total number of households is expected to increase from the 119,479 households recorded in the 1995 Census to around 160,000 households by 2020. Population statistics also indicate an internal migratory flow from the Southern Harbour to the Northern Harbour and other districts which will also be reflected in a re-distribution of the housing stock in the country.

The Maltese economy is increasingly becoming service oriented. In fact during 2002, the manufacturing sector contributed to approximately 35% of GDP, while the market/services sector accounted for slightly over 48% of GDP. Sectorally, the percentage employment share in 2004 was 1.6%, 24.2%, 37.4% and 36.8% for the agricultural, industrial, services and public sectors respectively.

Tourism plays an important role in the country's development and through the multiplier effect contributes towards an employment complement of around 40,000. Approximately 1.1 million tourists visit the islands where they spend an average of 10.5 million days. This contributes to an added average daily population of 32,000 tourists. Tourist arrivals peak in the months of July and August, obviously posing additional strains on the country's water resources.

Urban development in Malta has increased dramatically in the last 50 years and development has drastically altered the physical characteristics of the landscape, increasing the quantity of impermeable surfaces and thereby reducing infiltration processes resulting in a decrease in natural groundwater recharge.

4.2 Water Resources

Traditionally, groundwater has been the main source of water for human consumption in the Maltese islands. In fact, until the early 1980's, when desalination was introduced on a major scale, groundwater abstracted from both the Upper Coralline and the Lower Coralline aquifers was almost the exclusive source of potable water. Today, groundwater accounts for around 45% of the municipal water supply. The sea-level (or Lower Coralline) aquifers provide around 93% of this groundwater production. Approximately 7.1hm^3 per annum is abstracted from a system of 36km of galleries situated at sea level in the central regions of the islands (11 pumping stations) and a further 8.0hm^3 per annum are pumped out of 136 boreholes. The remaining 7% are abstracted from the perched (or Upper Coralline) aquifers, which are essentially small distinct aquifer blocks in the North and North-west regions of the islands. Figure 5 shows the location of the public groundwater sources. These include boreholes and pumping stations.

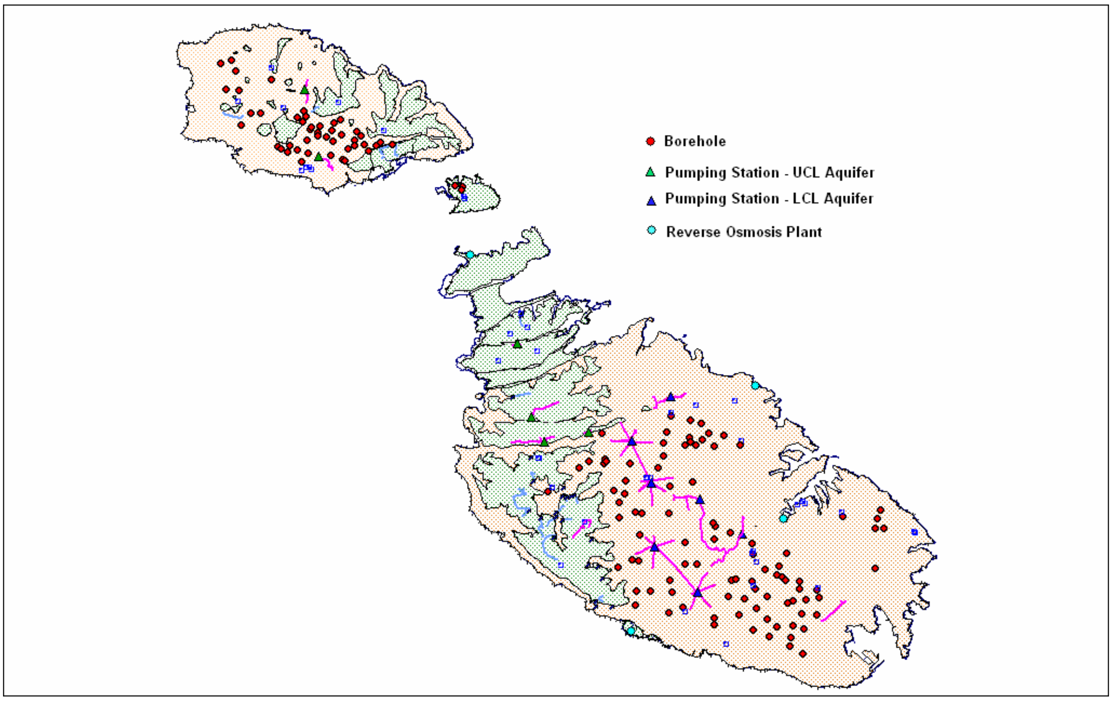

Figure 4.5: Public Groundwater Production Sources in the Maltese Islands

Replenishment of the aquifers is by rainfall and leaks from the water supply system. Surface run-off into the sea is comparatively small, due to the morphology, good water absorption by the soil and infiltration into the rock, and run-off interception by numerous dams, walls and terraces built over centuries. The major surface water loss is by evapotranspiration. Aquifer recharge varies according to the rainfall. The amount of water in storage in the Ghyben-Herzberg lens of the main aquifer is of the order of 1500 hm^3. Before the impacts of groundwater over-extraction, this could be considered to be quite large compared to yearly recharge whereas in the perched and coastal aquifers, the recharge forms a very large percentage of the water in storage. In the sea level aquifers the yearly recharge replaces abstraction and storage water after dry years. Relatively, a considerable amount of water flows into the sea from coastal and submarine springs or is lost by diffusion into the sea. For a long-term average, the total recharged water which is not abstracted flows into the sea. Since the existence of the freshwater lens also implies an outflow gradient, even in years of subnormal rainfall freshwater is lost in this way and adds to the water deficiency in the sea level aquifers. It should be noted that the occurrence of this outflow is a pre-requisite for the existence of the freshwater lens.

Table 2 represents a holistic groundwater balance for the aquifers in the Maltese Islands. It is important however to stress that all conclusions drawn from the water balances presented here must be used in full view of the fact that the figures are no more than estimates. A major assumption in this water balance is that groundwater outflow was in the same region as the inflow during the base-year in consideration, based on the fact that the piezometric levels in gauging boreholes in the sea-level aquifers during the last-five year period indicate only mild decreases. This fact led to the choice of the ATIGA coefficient of 0.5 for natural groundwater outflow to the sea as opposed to the 0.6 BRGM coefficient; which would significantly increase the deficit in the sea-level aquifers.

The groundwater balance is based on an average hydrological year with a precipitation of 550mm. The evapotranspiration coefficient is taken as 63% whilst the runoff coefficient varies from 2 to 5% according to the geomorphological conditions of each aquifer catchment area. The Water Services Corporation official abstraction figures for the period 2002/03 are used; whilst the private extraction is based on estimates of the irrigation demand of the agricultural sector activities and of the various industrial and commercial concerns.

INFLOW		hm^3/year	Comments
A	Precipitation	174	based on an average annual rainfall of 550mm (Met. Office)
B	Surface runoff to the sea	24	Estimate based on a variable catchment area runoff coefficient *(excluding coastal built up areas)
C	Actual evapotranspiration	105	assumed as 68% of the total surface water
D	Natural Aquifer recharge	45	B and C deducted from A
E	Artificial recharge from leaks	12	Estimated inflow from potable water and sewage network leakages
F	Total Groundwater Inflow	57	sum of variables D and E

OUTFLOW		m^3/year	Comments
G	WSC Groundwater abstraction	16	official WSC extraction for hydrological year 2002/03

H	Private Groundwater abstraction	15	estimate based on water demand of various sectors (industry and agriculture)
I	Subsurface discharge to the sea	23	estimate based on groundwater modelling
J	Total Groundwater Outflow	54	sum of variables G, H and I

BALANCE		m^3/year	Comments
K	Total Groundwater Inflow	57	equal to variable F
L	Total Groundwater Outflow	54	equal to variable J
M	Balance	3	inflow (K) less outflow (L)

Table 4.2: Holistic groundwater balance for the aquifers in the Maltese Islands for the base-year 2002 (MRA Annual Report, 2003)

This holistic groundwater balance however masks the fact that individual important aquifers are in imbalance and therefore a breakdown of the calculations on an aquifer by aquifer basis is presented below. The table clearly shows the sea-level aquifers to be in gross imbalance when compared to the perched aquifers and the overall positive balance in the holistic representation is being achieved through the combined contribution of the smaller perched aquifers.

Large increases in unconventional water resources are planned. In particular, the WSC is planning to treat all sewage effluent by 2010. If this is achieved and if the effluent is desalinated to the level that it can be used for artificial recharge and a wide range of industrial and agricultural purposes, total annual production of treated sewage effluent (TSE) be around $14hm^3$. It is too early to estimate the impacts on the groundwater balance, however, TSE may be used to reduce groundwater abstraction or could be utilized to increase artificial recharge to some aquifers.

Groundwater Body Code	Groundwater Body Name	Size (km^2)	Inflow (hm^3)	Outflow (hm^3)	Balance (hm^3)	Major Extraction
MT001	Malta Main Mean Sea Level	216.6	34.27	36.65	-2.38	Abstraction for potable and agricultural purposes
MT002	Rabat-Dingli Perched	22.6	4.64	4.62	0.02	Abstraction for agricultural purposes
MT003	Mgarr-Wardija Perched	13.7	2.86	3.46	-0.59	Abstraction for potable and agricultural purposes
MT005	Pwales Coastal	2.8	0.69	0.69	0.00	Abstraction for agricultural purposes;
MT006	Mizieb Mean Sea Level	5.2	1.11	0.96	0.15	Abstraction for potable and agricultural purposes
MT008	Mellieha Perched	4.5	0.75	0.53	0.22	Abstraction for agricultural

						purposes
MT009	Mellieha Coastal	2.9	0.69	0.38	0.31	Abstraction for agricultural purposes
MT010	Marfa Coastal	5.5	0.89	0.62	0.27	Abstraction for agricultural purposes
MT011	Mqabba-Zurrieq Perched	3.4	0.50	n/a	n/a	Abstraction for agricultural purposes
MT012	Comino Mean Sea Level	2.7	0.52	0.30	0.22	Abstraction for agricultural purposes
MT013	Gozo Mean Sea Level	65.8	8.66	9.78	-1.12	Abstraction for potable and agricultural purposes
MT014	Ghajnsielem Perched	2.7	0.73	0.34	0.39	Abstraction for agricultural purposes
MT015	Nadur Perched	5.0	1.15	0.58	0.57	Abstraction for agricultural purposes
MT016	Xaghra Perched	3.0	0.71	0.33	0.38	Abstraction for agricultural purposes;
MT017	Zebbug Perched	0.4	0.10	0.03	0.07	Abstraction for domestic purposes
MT018	Victoria-Kercem Perched	1.5	0.39	0.14	0.25	Abstraction for domestic purposes

Table 4.3 Water balances of the individual groundwater bodies in the Maltese Islands (base-year 2003)

During the late 1970s and early 1980's the country was suffering from extreme shortages of water because demand greatly outstripped supply. In 1982, the first desalination plant was constructed in Malta at Ghar Lapsi with a maximum capacity of 20,000m^3/day. Desalination has been crucial towards the country's economic development. The investment in desalination increased water availability and satisfied the demand for potable water. In fact, in 2003/04 desalination contributed approximately 55% (18.9hm^3) of the water supplied into the public distribution system. Currently the Water Services Corporation (WSC) operates three seawater reverse osmosis plants at Lapsi, Cirkewwa and Pembroke. Malta, today has one of the longest and best track records of reverse osmosis plant operation in the Mediterranean region with high output levels and reliability.

There has been a significant decrease in RO-water production since 1994/95 as shown in Table 4.4. RO production reached a minimum during 2001/02 largely as a result of water demand management actions adopted by the WSC. These actions included intensive leakage control, improved management practices and water conservation programmes. This downward trend in production has currently been reversed with slight increases in reverse osmosis production being registered in the last three hydrological years. However, this figure must be quoted in full view of the reduction registered in groundwater abstraction by the same WSC and the stabilisation of the total annual production at around an approximate value of 33 to 34hm^3 during the last four years.

	Lapsi	Cirkewwa	Pembroke	Tigne	Marsa	Total
1994/95	7,474,547	5,330,357	14,313,367	4,471,061	1,135,732	**32,725,064**
1995/96	7,230,901	5,025,538	12,545,201	2,767,145	1,198,332	**28,767,117**
1996/97	6,184,113	3,744,213	13,348,596	29,431	1,196,526	**24,502,879**
1997/98	5,717,995	3,777,559	11,753,338	-	1,201,697	**22,450,589**
1998/99	3,933,032	3,787,597	10,566,473	-	1,113,979	**19,401,081**
1999/00	3,511,275	3,669,047	10,079,919	-	81,533	**17,341,774**
2000/01	3,085,585	3,702,376	9,786,928	-	35,185	**16,610,074**
2001/02	3,482,973	5,981,059	10,360,825	-	-	**17,924,857**
2002/03	3,829,721	4,046,030	10,352,358	-	-	**18,228,109**
2003/04	4,250,263	3,706,696	10,945,033	-	-	**18,901,992**

Table 4.4: Desalination Production Trends

The total potential surface runoff generated in an average year has been estimated at around 30 hm^3 in Malta alone, of which over 80% occurs in the built-up areas. The main drawback facing the harnessing of this resource is the fact that it occurs as large volumes over a comparatively short period of time.

Responsibility of stormwater management has been historically divided amongst a number of government departments/agencies. This arrangement has traditionally led to a fragmentary approach to stormwater management. A Stormwater Master Plan is being prepared by the WSC which aims to transform existing threats into opportunities by optimizing stormwater use. Most runoff occurs after heavy torrential rain. This is the only time when surface water flows for a few days at most along the beds of the major valleys. To retain this storm discharge, a large number (31) of small dams have been constructed across the drainage lines. They also serve the purpose of reducing the rate of soil erosion. During the late 1970's open reservoirs were also been constructed alongside roads to catch runoff from road surfaces. Total dam capacity is estimated at 154,000m^3 and the water collected is mainly used for agriculture and recharging the sea level aquifers.

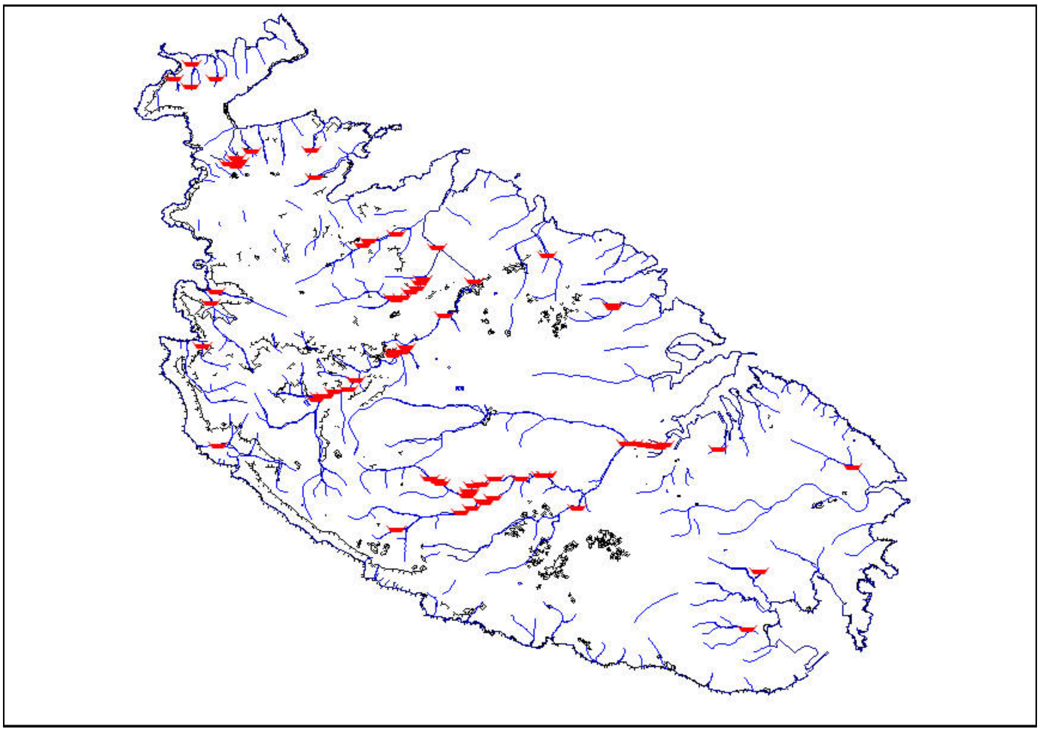

Figure 4.6: Location of Dams in the main watercourses in Malta

With the consutrction of the Ta Barkat Wastewater Treatment Plant in the sourth of Malta all wastewater in Malta is being treated to secondary/teritiary level prior to discharge to the sea. This was achieved with the construction of three new treatment plants during the last decade at the locations of the sewage outflows. The fourth, inland lying, Sant' Antnin wastewater plant treats water for re-use by the agricultural and industrial sectors. Eventually, this plant will be decommissioned with highly polished treated water for re-use being produced at the Ta Barkat plant.

The quality of the treated effluent from the SASTP is as follows: $BOD_5 \approx 10$mg/L, COD≤70mg/L, $NH_3^+ \leq 30$mg/L, P-PO_4^{2-} <30mg/L, FC≤5counts/100mL and EC ranges from 7.00 to 15.00 dS/m. The major problems encountered for re-using the effluent produced in Sant' Antnin is its high Electrical Conductivity. Measurements carried out by Cowiconsult (1992) indicated that these high values are due to a number of reasons the most important of which is sea water infiltration through confined parts of the sewerage system, occurrence of which was identified for the Malta-north, Marsa sea and the Zejtun-Zabbar sewers. In addition the same study concluded that the dumping of brine reject from inland private RO plants into the sewers and the use of sea water for flushing purposes in hotels also contributes significantly to the high salinity of the sewage in the Malta-north sewerage system.

v) suggests a projected average rise in sea-water levels of 0.45 ± 0.15cm/yr.

Based on this local climate change scenario, the report goes on to identify the following potential impacts on water resources:

i) any lowering in annual rainfall volumes will mean a decreased contribution to volumes of freshwater resources thus consolidating Malta's dependence on desalinated water;

ii) variability in inter-annual and intra-annual rainfall will have corresponding effects on demand as well as on the amount of water potentially available for recharge;

iii) seasonal scarcity of precipitation when the water requirements of the agriculture and tourism sectors are highest (normally from June to August) could contribute to increased pressures on freshwater resources;

(iv) high rainfall intensity events, with shorter durations, will have a lower contributing effect to recharging groundwater resources;

(v) increased demand for water resources to combat the effects of higher temperatures;

(vi) higher evapotranspiration rates that will demand increased water volumes for cultivated areas; and

(vii) a potential increase in the salinity of groundwater resources if sea water levels rise with salty water replacing freshwater sources.

5. State of Art of Water Resources in the island of Cyprus

5.1 Background

Cyprus is situated at the northeastern part of the Mediterranean basin, 33° east of Greenwich and 35° north of the Equator. Cyprus is the third largest island in the Mediterranean with an area of 9.251 square kilometres out of which 47% is arable land, 19% is forest land and the remaining 34% is uncultivated land.

In 2004 the population of Cyprus was 837.300 of whom 76,8% were Greek Cypriots, 10,5% Turkish Cypriots, 1,0% Armenians, Maronites and Latins and 11,7% foreigners residing in Cyprus.

Cyprus is dominated in its topography by two mountain ranges, the Troodos range in the central part of the island, rising to a height of 1.982 metres and the Pentadaktylos range in the north of the island, rising to a height of 1.085 metres.

Between the two ranges lie the Morphou and Messaoria plains, which together with the narrow alluvial plains along the coast make up the bulk of the agricultural land of the island.

Most of the rivers, which flow only in winter, have their sources in the Troodos mountains and only one substantial river has its source in Pentadaktylos.

Cyprus has a typical Mediterranean climate with mild winters, long hot, dry summers and short autumn and spring seasons.

The average annual rainfall is about 500 millimeters and ranges from 300 millimeters in the central plain and the south-eastern parts of the island up to 1 100 millimeters at the top of the Troodos range and 550 millimeters at the top of Pentadaktylos. The variation in rainfall is not only regional but annual and often two and even three-year consecutive droughts are observed.

Sunshine is abundant during the whole year, with an average duration of sunshine of 11,5 hours per day in summer and 5,5 hours in winter.

The average maximum temperature in July and August ranges between 36 °C on the central plain and 27 °C on the Troodos mountains while in January the average minimum temperature is 5 °C and 0 °C respectively. Due to the aridity of the climate evapotranspiration is high, which, on an annual basis, corresponds to 80% of the rainfall.

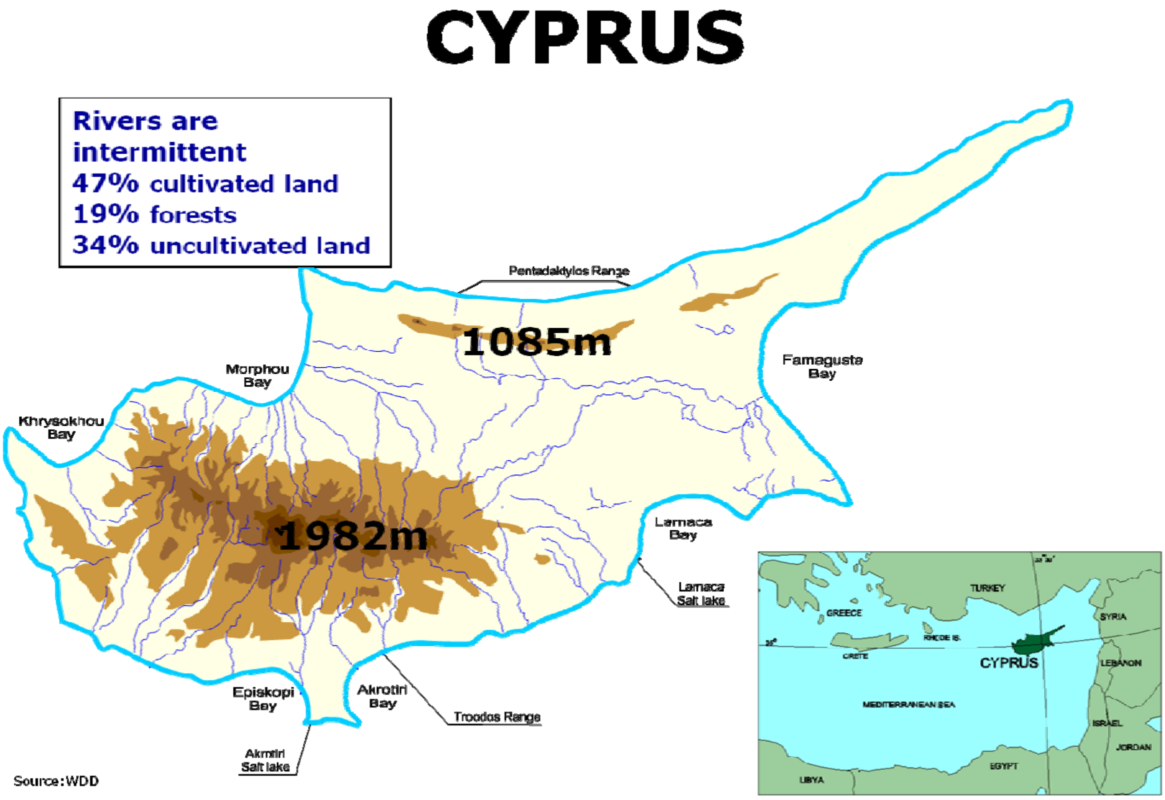

Figure 5.1: Cyprus

5.2 Water Resources

Cyprus water resources consist of Groundwater, Surface Water and non-conventional resources such as Desalination Water and Recycled Water. According to the Water Development Department's statistical figures, for the year 2008, 78 million m^3 was surface water, 95 million m^3 was ground water, 32 million was desalinated water and 11 million was recycled water.

Surface runoff in Cyprus is available for only a few months. Groundwater, available round the year, traditionally provided the resource needed for domestic use and irrigation.

Groundwater resources in Cyprus are overexploited by about 40% of sustainable extraction. During the last decade, aquifers exhibited depleting trends. Repeated and persistent drought episodes reduced direct and indirect groundwater recharge, while the construction of dams further reduced recharge of downstream aquifers. Besides its growing scarcity, groundwater is also being abandoned for domestic supply because of quality problems. Intensive agriculture and excessive use of fertilizers have resulted in nitrate pollution of many aquifers. Similar nitrate pollution problems appear in aquifers developed in inhabited areas because of direct sewage disposal in adsorption pits. According to European Union directives, aquifers in a country should be managed in ways that guaranty adequate quantities of good quality water. Intense pressure on the island's water resources, and the current state of quantitative and qualitative degradation of groundwater in the most important aquifers in Cyprus, point to the need for the establishment of an island-wide groundwater monitoring system.

To satisfy the increasing demand and to minimize the losses of surface water to the sea the Government of Cyprus embarked to an ambitious program of water development works with the construction of many dams and conveyors and irrigation networks. The storage capacity of the reservoirs increased from 6 million m^3 in 1960 to 330 million m^3 today. The inflow to the dams is directly related to the inter-annual variations of precipitation therefore the reliability of the yield of the dams is very low for long term planning and management of the water resources. In spite the extensive investments for the construction of all these dams, the shortage of water in the island was not solved.

The considerable decline of the conventional water sources, the recent years' droughts and the increase in water demand in the island were the reasons that non conventional water such as desalination and recycle water became additional sources to reduce the imbalance of the supply and demand. Desalination of seawater was first produced in Cyprus in April 1997 with the operation of a 20.000 m^3/day plant at Dekelia east of Larnaka. The government then proceeded with the operation of 3 additional desalination plants with a minimum production of 54.250.00 m^3/year and has another unit with a minimum production of 13.120.000 m^3/year under construction. All the desalination plants are of reverse osmosis type. The measure was successful in providing to the domestic sector, including the economically important tourist industry, a steady supply. However, considering that close to 70% of all water resources on Cyprus are used by agriculture, a sector that contributes only a minor part to national wealth and struggles with labor scarcity problems, a close scrutiny of water allocation policy appears to be in order.

An additional source of water is becoming the recycled water. The first large sewage treatment plant started operating in Limassol in 1995 produced 4 million m^3 of tertiary treated water which is used for irrigation in agriculture, the urban environment and for artificial recharge of the Akrotiri aquifer. Recycled water is a fast growing resource because new sewage treatment plants are under construction and design in all major cities and rural areas with provisions for tertiary treatment in order to use the treated effluent. It is estimated that recycled water will increase from 14,5 million m^3 in 2010 to 52 million by the year 2012 which will be the 28,5% of agricultural water demand.
In the next three charts, the total supply of water, the domestic supply and the irrigation supply separately, from the government water works for the years 1991 to 2009, are indicated. It can be seen also that about 70% of the water produced is consumed today for irrigation purposes, while most of the water supplied for domestic use comes from desalination plants and most of the water supplied for irrigation comes from the dams.

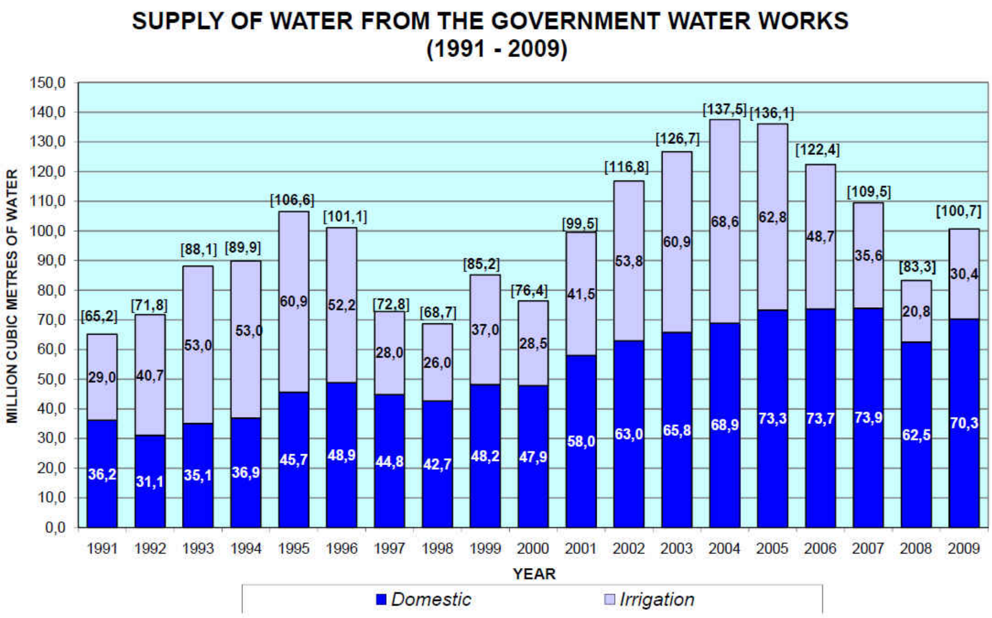

Figure 5.2: Supply of water from the government water works

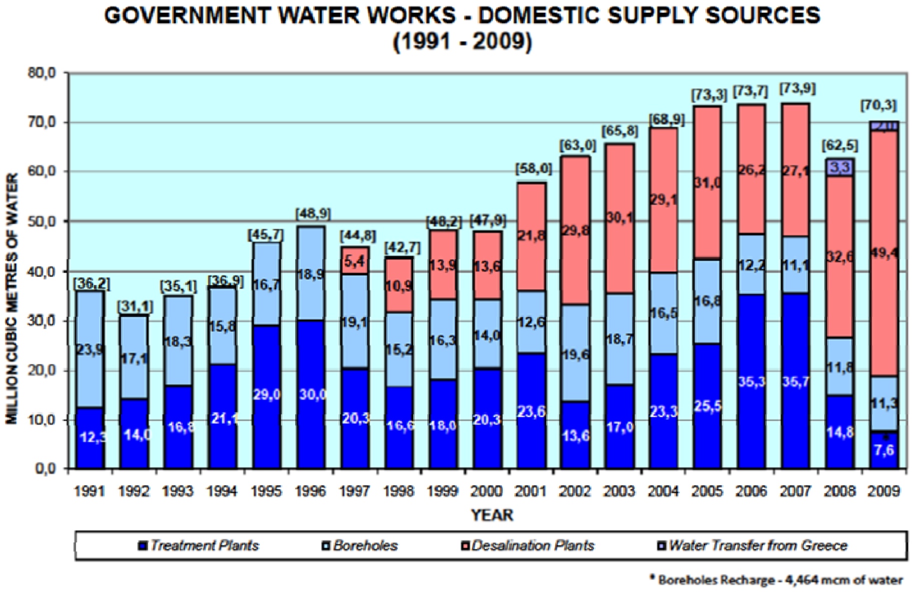

Figure 5.3: Domestic supply sources

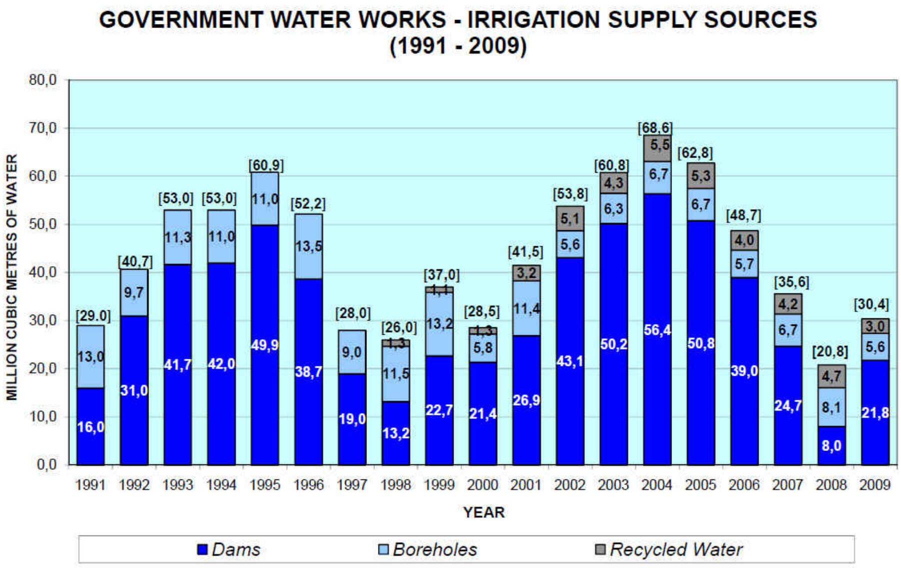

Figure 5.4: Irrigation supply sources

6. State of Art of Water Resources in Sicily

6.1 Background

Sicily covers an area of 25,707 km^2 (including smaller islands) and it is the largest Italian region. Its triangular shape and the mountain system determine its division into three distinct fronts:

- the northern side or the Tyrrhenian side from Cape Peloro to Cape Boeo, with area of 6,630 km^2;
- the southern Mediterranean area from Cape Boeo to Cape Passero, with an area of around 10,754 km^2;
- the eastern side from Cape Passero to Cape Peloro, with an area of about 8,072 km^2.

The geography of Sicily shows strong contrasts between the northern part, mostly mountainous, represented by Peloritani, Monti Nebrodi, Madonie, and the Trabia Mountains, the Mountains of Palermo and Trapani Mountains, and the Central-Southern and Southeast- West areas where the landscape looks very different, generally characterized by a typical low relief hilly, with the exception of the mountain Sicani. The South-Eastern area morphology of plateau and east, dominated by the Etna volcano, presents different characteristics.

In Sicily, the hilly affects 62% of the surface morphology, mountains take up to 24% of total area while the percentage of flat areas is equal to 14%.

Sicily is divided administratively into nine provinces, whose capitals are: Agrigento, Caltanissetta, Catania, Enna, Messina, Palermo, Ragusa, Siracusa and Trapani.

In agreement with the World Meteorological Organization, which states that "*the climate is the set of meteorological observations on a three-decade*", the climatological analysis has been made starting from the data base of the thirty years 1965-1994 of 127 rain gauges and 55 temperature gauges of the Regional Hydrographic Service (*Ufficio Idrografico Regionale* - UIR).

The main climatic information, in terms of rainfall and temperature, were obtained by superimposing, using the GIS, the catchment map respectively with the chart of the annual values of rainfall occurred in Sicily processed according to the 50th percentile (mm), with the map of the maximum temperature °C (fig. 6.4), of the minimum °C (fig. 6.3) and of the average °C (fig. 6.2) derived from Climatological Atlas of Sicily (SIAS - *Servizio Agrometorologico dellaRegione Sicilia*).

Looking at the different thermometric and pluviometric regimes considered in this study, one can see that the average annual temperature varies from 12°C to 21°C from Floresta to Isola delle Femmine, while the total annual precipitation ranges from an average annual of 419 mm in the Caltanissetta province up to 1029 mm in the Catania province.

The climatic classification was made by using the map on climate indices provided by SIAS of the Sicilian Region, prepared according to the indices of classification proposed by Lang (Pluviofactor), De Martonne (Index of aridity), Emberger (IQ rainfall) and Thornthwaite (global index of humidity).

Furthermore, a characterization based on the index of aridity (I_a) was also obtained. The index of aridity is equal to the ratio P/ETP, where P is the median annual rainfall and ETP indicates the annual average potential evapotranspiration. The final elaborate of a such kind of analysis is the regional map of drought index (fig. 6.5, scale 1:250.000), with a division into the following three classes:

1. $I_a < 0.5$, semi-arid climate-arid;
2. $0.5 < I_a < 0.65$, dry climate-subhumid;
3. $I_a > 0.65$, humid climate.

The areas of the region with humid climate are those relative to the northern mountains, the highest part of the Iblei mountains and the north slopes of Etna. In these areas, the combined effect of high values of rainfall and low values of ETP leads to humid climate. Intermediate conditions, where the weather is dry and sub-humid can be found in the remaining areas of northern hills, in the central mountainous areas and hilly areas of Iblei. The areas with a semiarid climate are finally in arid plains and low hills of the western, central-southern part of the island. The low quantities of total annual precipitation, together with the high radiative forcings and high temperatures, which leads to high values of ETP, give to these zones an evident state of aridity or dryness.

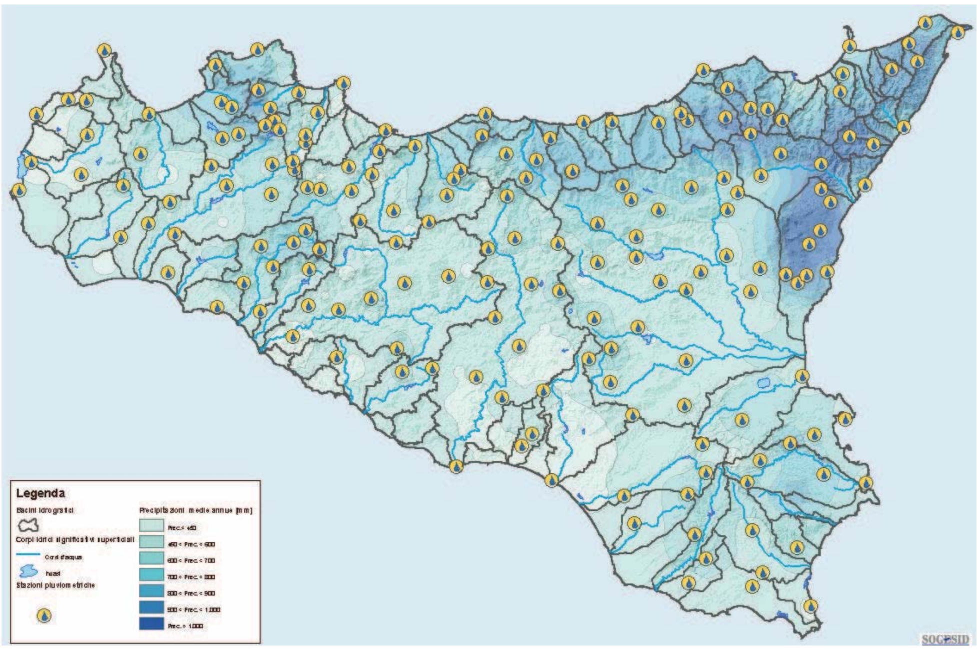

Figure 6.1-Average annual rainfall

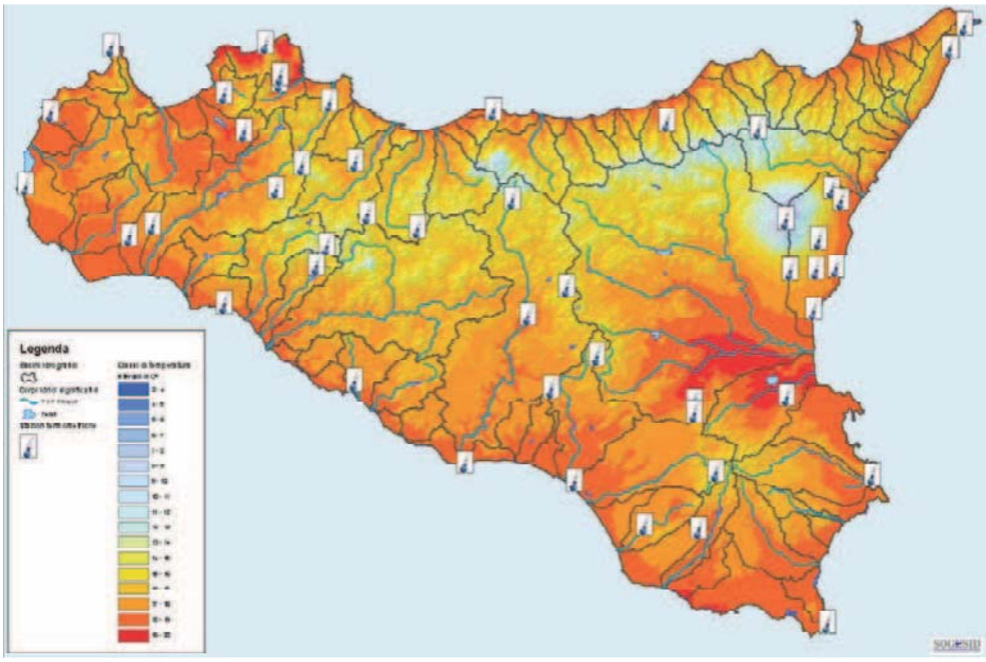

Figure 6.2-Average annual temperatures

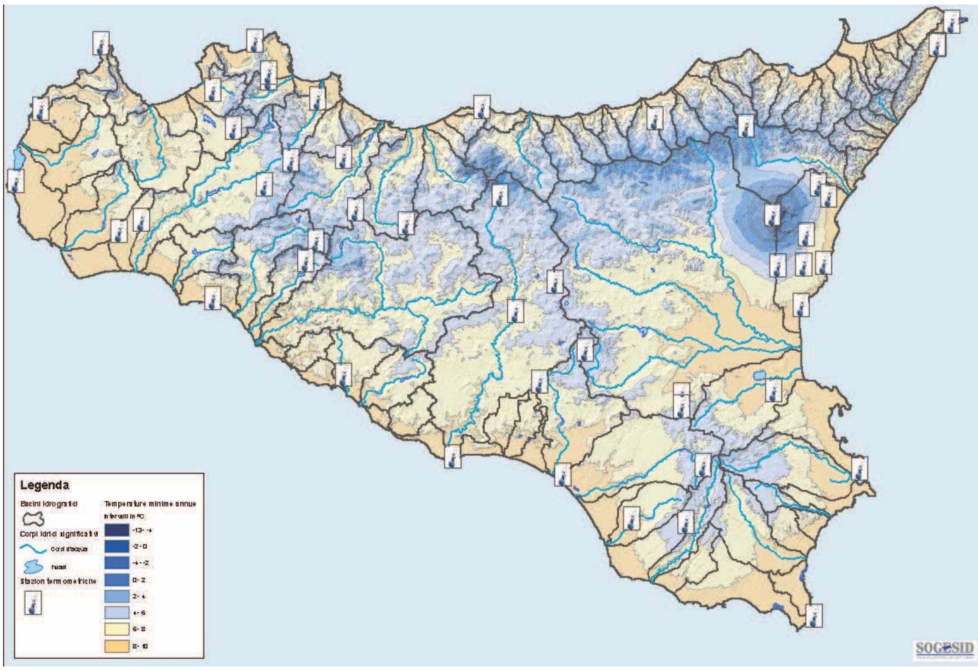

Figure 6.3-Annual minimum temperatures

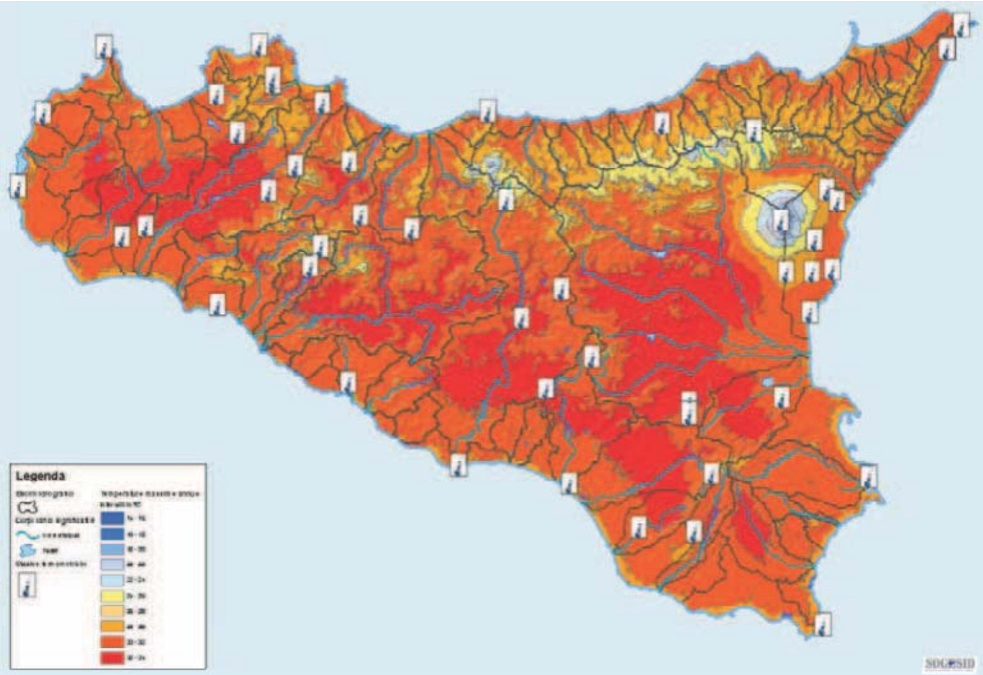

Figure 6.4-Annual maxima temperatures

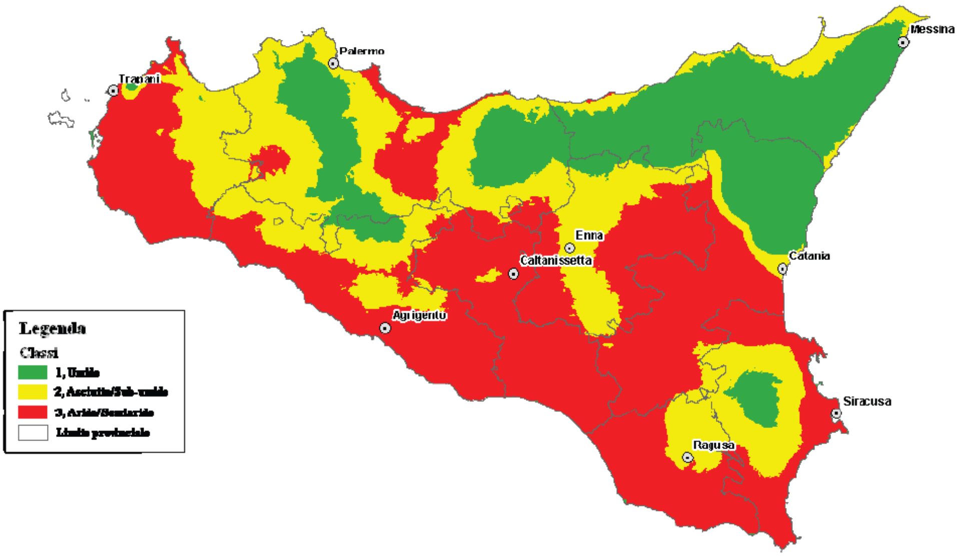

Figure 6.5-Regional map of the index of aridity

In order to characterize Sicily from a hydrological point of view, the recorded data of the hydrometric stations of the UIR were used. In particular, the following information are available: the basin areas, the altitude of hydrometric stations, the hydrological balance made by considering the historical rainfall and runoff data (mm), the historical minimum and maximum flow and the average monthly flow expressed in m^3/s (or in l/s).

The current state of geological knowledge about Sicily allows to make a schematic model, where are mainly recognized:

- a mountain chain, consisting of a series of rocky bodies more or less "powerful", "released" from their original substrate and superimposed on each other;
- a foredeep, located on the front of the mountain chain and constitutes a large depression in which flock to the products resulting from the dismantling of the progressive lifting chain;
- a "stable" region, not affected by any deformation and final destination of the rocky chain.

This scheme is conveniently applicable to the territory of the region for its geological and geodynamic features, which can be divided into three main areas, from South to North:

South- Eastern sector: it coincides with Iblei Mountains. From a structural point of view there are no signs of movements or deformation in the basement buried or in the overlying sedimentary cover. The base buried is probably of African crustal affinity. Its roof is formed by a thick sequence of platform carbonate rocks, unstable in the Triassic, of basin active in the Jura-Eocene and finally of open platform in the Oligo-Miocene.

Intermediate area: oriented from west to east and divided into two basins: Castelvetrano-Sciacca emerging and Caltanissetta-Gela partially buried by geologically recent deposits. This sector consists of carbonate sequences (Trias - Miocene), weakly deformed and stratigraphically covered by sediments of a foredeep basins residual Plio-Pleistocene.

Northern sector: ranging from Trapani to Messina, it is represented by geological bodies with different characteristics and lithology, which form a complex stack of tectonic slices crossed, thick to more than 15 km.

Fig. 6.6 shows the geological map of Sicily.

The Sicilian groundwater can be schematically grouped into four main classes:

a) groundwater in carbonate rocks;
b) groundwater in volcanic rocks;
c) groundwater in clastic rocks;
d) groundwater in metamorphic rocks.

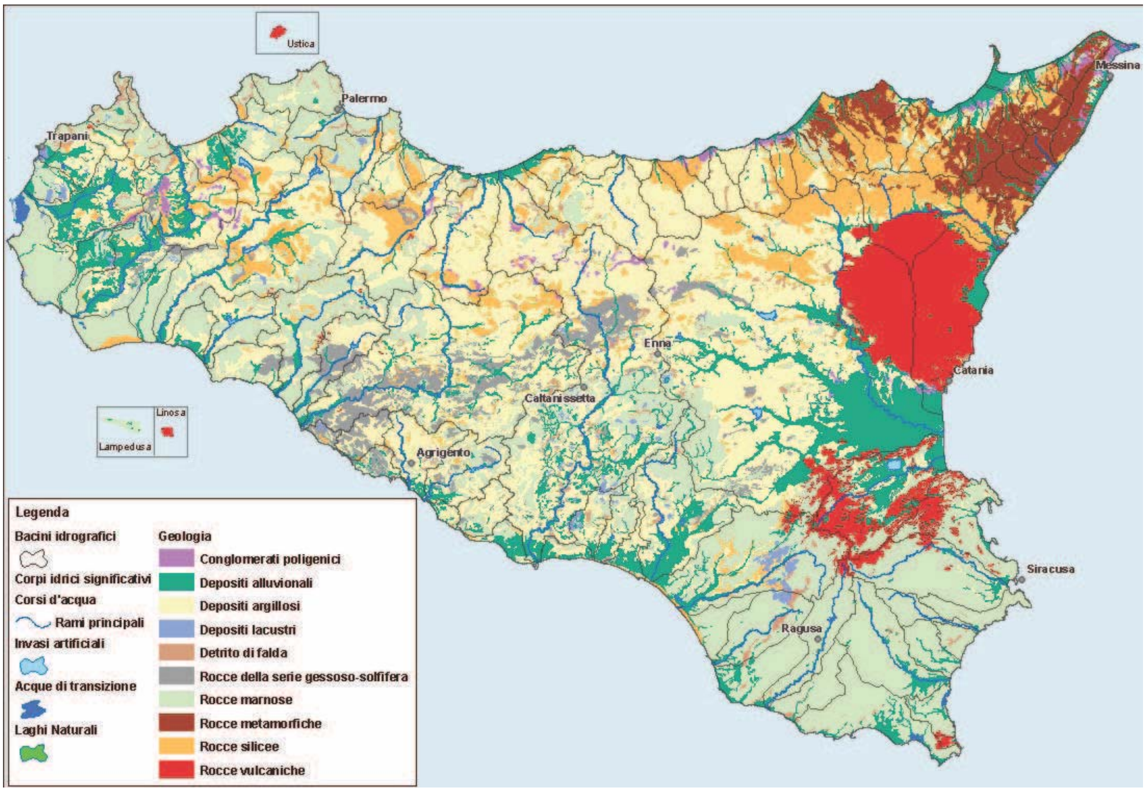

Figure 6.6 – Geological map of Sicily.

The study of land use characterization was carried out to provide a summary of the human pressure resulting from economic activities and the presence of settlement in the territory. The study includes also the analysis of floating population and the study of significant impacts by industrial, agricultural and livestock on the status of surface waters.

Urban Settlement

Demographic analysis in the region has been derived from the study carried out as part of updating and revision of the general plan of the aqueducts (SOGESID SpA). The total population in the region equal to 6,226,204 inhabitants. The resident population includes the residents surveyed by ISTAT (8^{th} census of industry and services, 2001), together to the present stable but non-residents and daily attendance.

The floating population consists of two components: the fluctuating and seasonal tourists. In particular, the term fluctuating seasonal means the population that uses the second houses and holiday houses, while tourists are hosted in the public accommodation.

Industrial activity

Starting from the classification made by ISTAT, different industrial activities have been identified. Industrial activities, tertiary activities, water demanding industries and industries discharging hazardous substances were highlighted. Among these different types of factory, the greatest impact on water resources is exercised by the water demanding industries, which are characterized by high levels of water withdrawals and release of pollution.

In Sicily the presence of tertiary activities is much more important than industrial activities. Among the industrial activities a percentage ranging from 49% to 64% is water demanding, while a smaller percentage, which ranges from 3% to 20%, releases hazardous substances.

Agricultural use of land and livestock

A brief analysis shows that the products of Sicilian agriculture and horticulture can be found in lowland areas, mostly coastal, with a coverage of 7.5% of the total region area, while the arable land (with no irrigation) stands on about 32% of the regional area and are commonly located on hills. There are other activities significant for the Sicilian economy: olive growing and viticulture, affecting respectively about 10%, (of which less than 1% are irrigated orchards) and 6% (3% are irrigated vineyards) of the total area of the region. The figure 6.7 shows the agro-forestry land use map. The forests cover 120,290 ha: leaved forest area is equal to the 60% (72,127 ha) of total regional area, while coppice cover 26% (30,748 ha)of the total area. The remaining area is covered by Mediterranean scrub (14% with 17,353 ha) and a small part of a woody crop (2% with 2,530 ha).

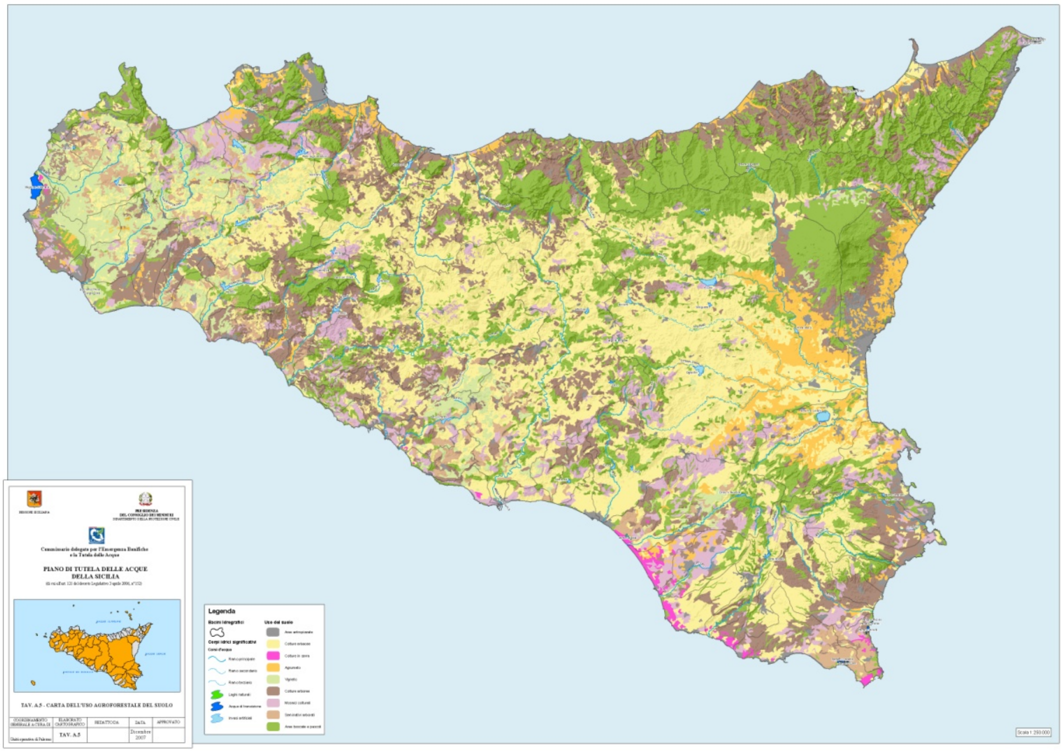

Figure 6.7-Agro-forestry land use map.

6.2 Water Resources

The term "groundwater" denotes an hydrogeological structure, consisting of one or more aquifers, sometimes with autonomous behavior, or in hydraulic communication with other hydrogeological contiguous structures with which they can exchange water. The choice of significant groundwater has been carried out considering the volume of water taken from the same groundwater for drinking purposes and/or irrigation and also taking into account the quality of the groundwater.

In the final analysis, a significant groundwater denotes a structure that allows the accumulation of relatively large quantity of subsurface water resources of good quality. In Table 1 and Figure 8 the significant hydrological basins identified in Sicily are shown.

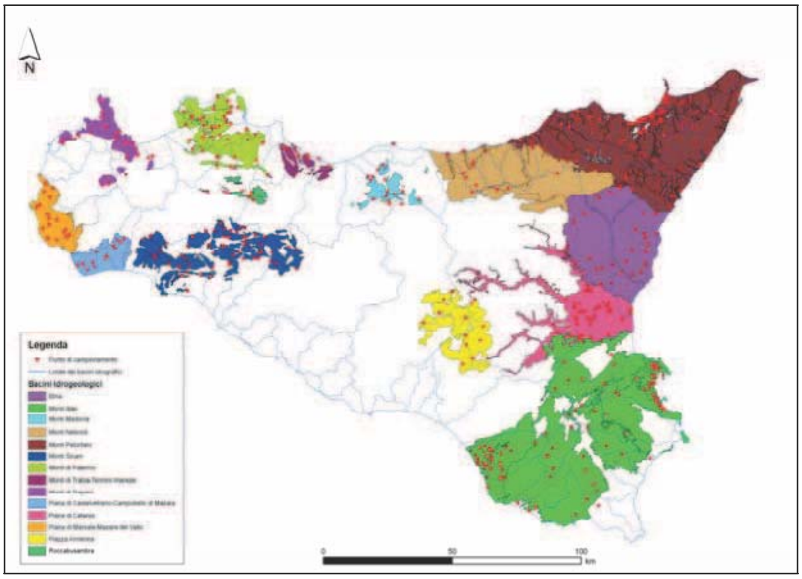

Figure 6.8-Significant hydrogeological basins

For each groundwater potential infiltration was estimated through water balance on a monthly basis. For the balance assessment, precipitation data *P*, surface water runoff *Q* and monthly temperature were used. Data were collected for the period 1996- 2003 by UIR. Evapotranspiration *ET* was estimated using the Turc formula which reads:

$$ET = \frac{P}{\sqrt{0.9 + \left(\frac{P}{L}\right)^2}}$$

where *L* is the potential evapotranspiration. The latter has been calculated as a function of monthly average temperature. Infiltration has been obtained with the following equation:

$$I = P - ET - Q$$

The following table gives the total potentially available water from each groundwater (table 1).

Table 6.1: Groundwater resources estimation

Index	*Name*	*Groundwater resources [Mm3/y]*
R 19 006	Bacini minori tra Muto e Mela	12.0
R 19 011	Bacini minori tra Mazzarrà e Timeto	26.2
R 19 026	Pollina	41.2
R 19 030	Imera Settentrionale	50.6
R 19 031	Torto e bacini minori tra Imera Settentrionale e Torto	10.4
R 19 033	San Leonardo	29.4
R 19 037	Eleuterio	52.3
R 19 039	Oreto	17.3
R 19 042	Nocella	15.8
R 19 043	Jato	17.1
R 19 045	San Bartolomeo	89.2
R 19 049	Lenzi	2.5
R 19 051	Birgi	49.7
R 19 052	Bacini Minori tra Birgi e Mazaro	19.2
R 19 054	Arena	12.5
R 19 055	Bacini minori tra Arena e Modione	17.1
R 19 057	Belice	39.5
R 19 059	Carboj	16.2
R 19 061	Verdura e bacini minori tra Verdura e Magazzolo	27.3
R 19 062	Magazzolo e bacini minori tra Magazzolo e Platani	12.6
R 19 063	Platani	68.7
R 19 067	San Leone e bacini minori tra S.Leone e Naro	4.2
R 19 068	Naro	14.2
R 19 072	Imera Meridionale	204.0
R 19 075	Comunelli	13.1
R 19 077	Gela	65.0
R 19 078	Acate e bacini minori tra Gela e Acate	150.9
R 19 080	Ippari	43.6
R 19 082	Irminio	29.5
R 19 084	Bacini minori tra Scicli e Capo Passero	29.2
R 19 085	Bacini minori tra Capo Passero e Tellaro	10.8
R 19 086	Tellaro	82.5
R 19 089	Cassibile	5.0
R 19 091	Anapo	99.4
R 19 092	Bacini minori tra Anapo e Lentini	58.7
R 19 093	Lentini e bacini minori tra Lentini e Simeto	120.8
R 19 094	Simeto	443.4
R 19 096	Alcantara	73.6
R 19 101	Fiumedinisi	6.5
R 19 102	Bacini minori tra Fiumedinisi e Capo Peloro	28.4
	Total	**2109.5**

In the characterization phase, 559 points were sampled; on the basis of investigations and the results of tests made during the first year of monitoring, the monitoring network has been optimized for the second monitor step which is currently using of 493 sampling sites (springs, wells).

On all the samples the analysis of the basic parameters (Temperature (° C), Potassium (mg / L) Total hardness (mg / L $CaCO_3$), Sodium (mg / L), Electrical conductivity (µS/cm (20 ° C)) Sulphates (mg / L) as SO_4, Bicarbonates (mg / L), Ammonium ion (mg / L) as NH_4, Calcium (mg / L), Iron (mg / L), Chlorides (mg / L) , Manganese (mg / L), Magnesium (mg / L), Nitrate (mg / L) as NO_3) and trace metal was carried out. Furthermore, on 313 points the analysis of additional parameters (Aluminium, Total halogenated aliphatic compounds, Antimony, Silver 1,2-dichloroethane, Arsenic, Total pesticides, Barium, Beryllium, Boron, dieldrin, Cadmium, heptachlor, Cyanides, heptachlor epoxide, Chrome tot., Chromium VI, Acrylamide, Fluoride Benzene, Mercury, Vinyl chloride, Nickel, Neighing, Benzopyrene, Lead, Copper, Selenium, Zinc) was performed. Sampling and analysis of organic compounds and pesticides were performed in groundwater located in areas characterized by great vulnerability and/or a high degree of human settlement.

The wells used by the monitoring network are mostly privately owned, so the access depends on the presence of the owner and his desire to keep active any lifting equipment. The environmental state of groundwater is determined, according to D.L. 152/1999. The detection of the quality of the groundwater is generally based on the determination of basic parameters shown in Table 19 of D.L. 285/2000. This classification provides the basis for the definition and planning of measures to protect subsurface water bodies from pollution and overexploitation. The results of investigations carried out in the second year of monitoring show that:

- most of the groundwater, 55% of the total, has a "*good*" environmental status;
- 27% of the groundwater has been classified with as "*bad*";
- 12% of the groundwater has been classified with as "*particular* ";
- 3% of groundwater has been classified with as "*sufficient*";
- no groundwater has been classified with "*high*" environmental status;

The results of this analysis are depicted in fig. 6.9.

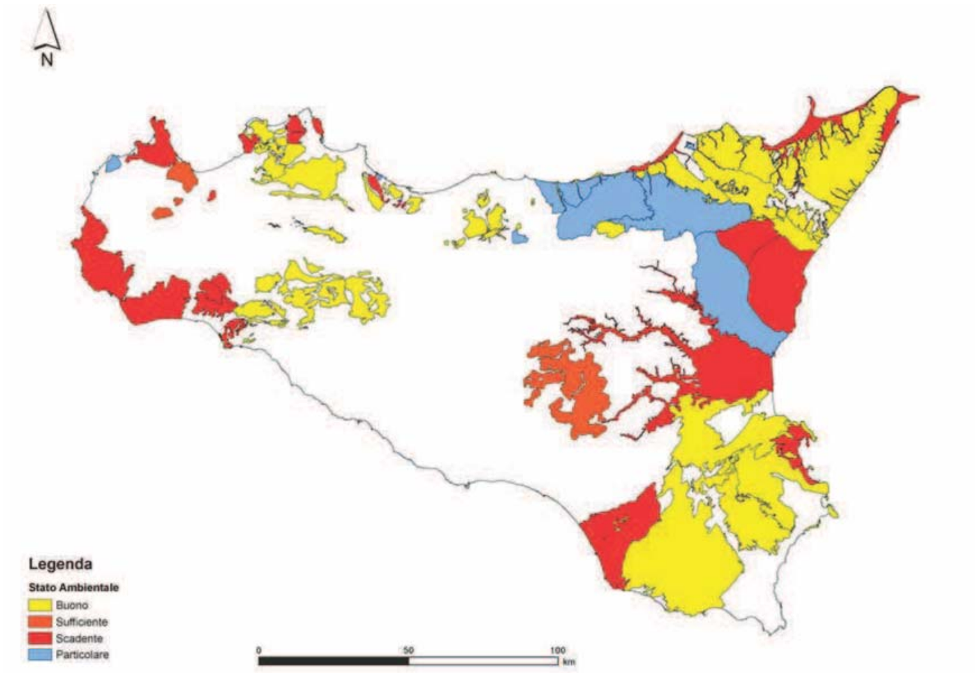

Figure 6.9 - Environmental status of groundwater bodies in Sicily

D.L. 152/06, Annex 1, "*Monitoring and classification of waters in relation to environmental quality objectives*" provides, for the different categories of water bodies, the criteria that must be met for inclusion in the same category of significant superficial water bodies. These criteria can be grouped into three broad categories:

- dimensional criteria;
- criteria of environmental significance;
- criteria related to downstream pollution risk.
-

In this way a total of 102 river basins in Sicily have been identified, (excluding the 14 smaller islands), 41 major river basins (Table 6.2) containing the significant surface water bodies mentioned above. The minor basins between Muto and Mela rivers are special case since, despite having no dimensional significance, were taken into account for the strong human impact on the coast. Fig. 6.10 shows the map of watersheds and significant surface water bodies.

Table 6.2 Significant catchments in Sicily

INDEX	NAME
R 19	Bacini minori fra MUTO e MELA
R 19	Bacini minori fra MAZZARRA' e TIMETO
R 19	POLLINA
R 19	IMERA SETTENTRIONALE
R 19	TORTO e bacini minori fra IMERA SETTENTRIONALE
R 19	S. LEONARDO
R 19	ELEUTERIO
R 19	ORETO
R 19	NOCELLA e bacini minori fra NOCELLA e JATO
R 19	JATO

R 19	S. BARTOLOMEO
R 19	LENZI BAJATA
R 19	BIRGI
R 19	Bacini minori fra BIRGI e MAZZARO
R 19	ARENA
R 19	Bacini minori fra ARENA e MODIONE
R 19	BELICE
R 19	CARBOJ
R 19	VERDURA e bacini minori fra VERDURA e
R 19	MAGAZZOLO e bacini minori fra MAGAZZOLO e
R 19	PLATANI

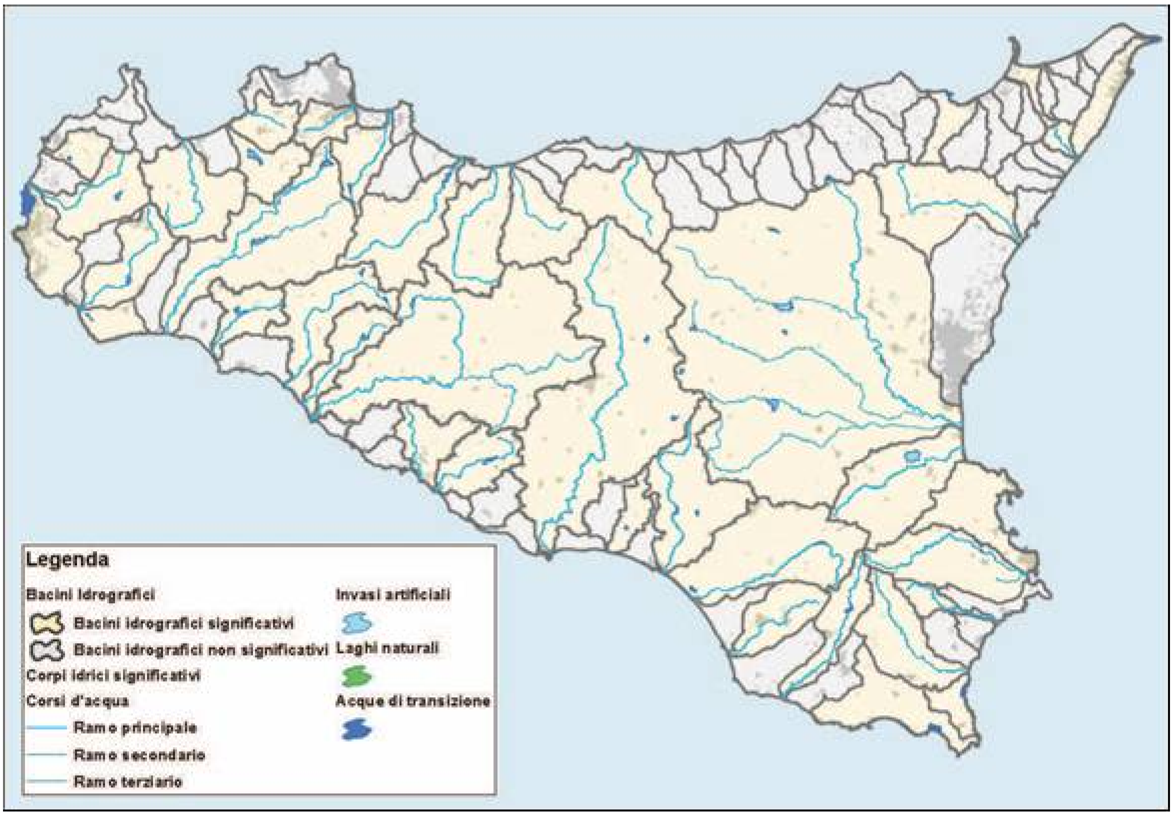

Figure 6.10-River basins and significant surface water bodies

The estimation of the natural surface water resources was carried out with reference to the 41 significant river basins in some outlet sections considered here indicative, because of the presence of hydrometric gauging stations. The time series (precipitation and runoff) used in most cases, regard the last two decades (1981 - 2000), provided by the Regional Agency for Waste and Water - Water Sector Monitoring (former UIR). If available, also more recent years data (until 2003) were used. On the basis of monthly rainfall data for the period 1980-2000 the average runoff values have been calculated using a simple rainfall-runoff model. In order to do this a simple statistical-based model which correlates the runoff to the rainfall through the study of the data series available at the hydrometric station has been implemented.

Surface runoff at the sea outlet and in sections of interest was determined once calibrated rainfall-runoff model; in particular the value of the runoff at the sea outlet is considered as the total value of natural surface water resources for the entire river basin. Table 6.3 shows the value of natural surface water resources. In the last row the total value of water resources, with reference only to significant basin, is reported (it is approximately equal to 2637 Mm^3/year).

Table 6.3: Natural surface water resources of the 41 major river basins

Index	Name	Surface water resources
R 19	Bacini Minori tra Muto e Mela	18,0
R 19	Bacini Minori tra Mazzarrà e Timeto	35,0
R 19	Pollina	77,9
R 19	Imera Settentrionale	56,2
R 19	Torto e Bacini Minori tra Imera Settentrionale e	41,1
R 19	San Leonardo	56,1
R 19	Eleuterio	34,0
R 19	Oreto	26,8
R 19	Nocella e Bacini Minori tra Nocella e Jato	18,6
R 19	Jato	18,7
R 19	San Bartolomeo	59,2
R 19	Lenzi	5,6
R 19	Birgi	38,7
R 19	Arena	11,8
R 19	Bacini Minori tra Arena e Modione	3,6
R 19	Belice	111,2
R 19	Carboj	9,2
R 19	Verdura e Bacini Minori tra Verdura e	52,2
R 19	Magazzolo e Bacini Minori tra Magazzolo e	29,3
R 19	Platani	70,4
R 19	San Leone e Bacini Minori tra S.Leone e Naro	17,2
R 19	Naro	14,2
R 19	Imera Meridionale	187,9
R 19	Comunelli	4,7
R 19	Gela	24,6
R 19	Acate e Bacini Minori tra Gela e Acate	35,5
R 19	Ippari	23,7
R 19	Irminio	27,9
R 19	Bacini minori tra Scicli e Capo Passero	0,0
R 19	Bacini minori tra Capo Passero e Tellaro	0,0
R 19	Tellaro	41,3
R 19	Cassibile	33,8
R 19	Anapo	112,7
R 19	Bacini minori tra Anapo e Lentini	0,0
R 19	Lentini e bacini minori tra Lentini e Simeto	77,1
R 19	Simeto e Lago di Pergusa	985,0
R 19	Alcantara	190,8
R 19	Fiumedinisi	16,1
R 19	Bacini minori tra Fiumedinisi e Capo Peloro	48,8
	TOTAL	**2.637,4**

The water quality assessment has been carried out in accordance with D.L. 152/99 and successive modifications and integrations. The above mentioned D.L. provides the classification of the environmental quality, SACA, carried out on the basis of ecological status (SECA) and chemical status of the water body.The classification of ecological status is determined by crossing the data resulting from macro-descriptors (LIM), with the index IBE, according to Table 8, Annex 1 of D.L. 152/06.

For each of the 63 monitoring stations a classification of the ecological and chemical status has been carried out. Six stations are in Class 5 (very bad), namely the n.17 on Nocella river, the n.45 on Magazzolo river, the n.54 on San Leone river, and two stations, n.95 and n.97 on the San Leonardo (Lentini) river (fig. 6.11). Summarizing the results it is possible to say that: 12% of the monitored rivers are in very bad ecological conditions, 30% are in bad ecological conditions, 46 % are in a sufficient conditions, while only the 10 % of rivers are in a good environmental status.

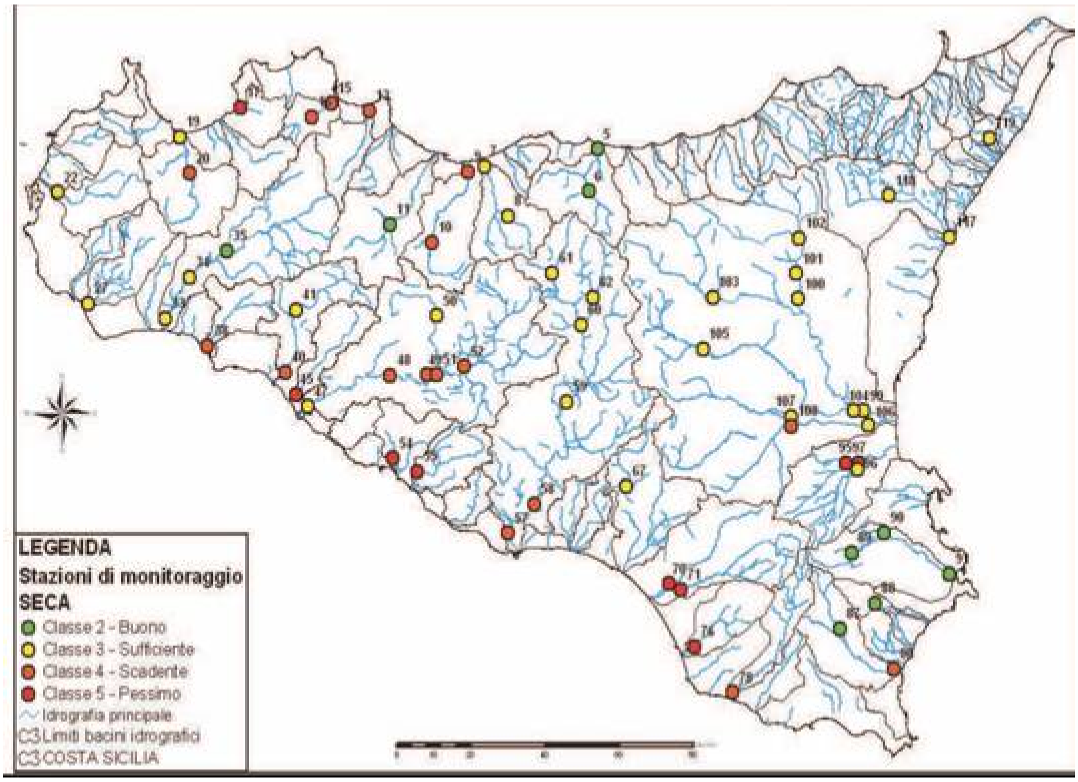

Figure 6.11-Class SECA in the monitored rivers

For a first classification of lakes and artificial reservoirs status of Sicily, the instructions of the D.M. 29 December 2003 have been used. In order to qualify the environmental state (SAL), the D.L. 152/99 states that this must be done crossing the ecological status with the chemical status.

From the analysis of water quality it was found that 60% of lakes and reservoirs belongs to Class 3, which corresponds to a fair environmental state, 27% were classified as Class 4, which corresponds to a poor environmental state and only 10% can be attributed to the ecological status of Class 2 which is a good environmental status (fig. 6.12). In addition, it should be noted that, for 4 of the 34 monitored reservoirs, attributing a quality status has not been possible because of technical problems.

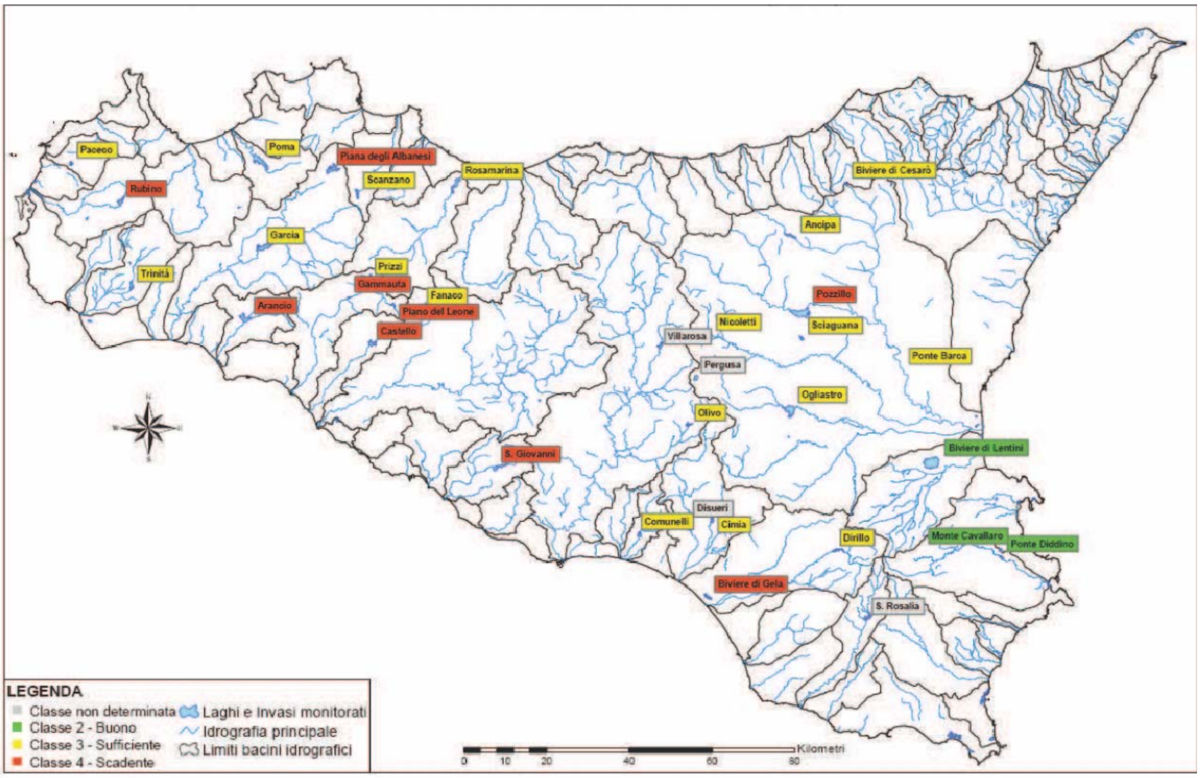

Figure 6.12 - Environmental status of natural lakes and reservoirs monitored.

In table 6.4 some relevant information relative to the main desalination plants operating in Sicily and in some small island are reported. The greatest plant is located in Gela and supplies more than 10 Mm^3/year. The total contribution of desalination plants for drinkable water supply in Sicily was estimated in about 31 Mm^3/year. Although it is a relatively small amount, it is crucial in small islands, where it is the only source of potable water.

Table 6.4: Desalination plants in Sicily.

Desalination plant	***Year built***	***Age [years]***	***Annual volume [Mm^3] 2006 - 2008***
Gela	1971 (MSF)-1991 (OI)	38 (MSF) - 28 (OI)	10,8
Gela V modulo	2002	7	4,65
Trapani	1994	15	9,26
Porto Empedocle	1995	14	0,75
Nuovo dissalatore Città di Agrigento	2006	3	3,00
Pantelleria C.da Mangiuluveddi*	1975	34	0,24
Pantelleria C.da Sataria*	1975	34	0,58
Lampedusa*	1988	21	0,24
Linosa c.da Mannarazza*	1990	19	0,11
Lipari	1995	14	1,04
Ustica	1995	14	0,26
Total			30,9

In Sicily, like in the most Mediterranean regions, because of the shortage of water due to an almost dry climate subject to drought, wastewater reclamation and reuse can play an important role in water resource management as a supplementary water source, mainly for irrigation. In Sicily there are 523 urban wastewater treatment plants (WWTPs), but only 259 are working. The other plants are abandoned (32), under construction (47), not working (89) or planned (96) (fig.6.13).

The most WWTPs serve small and medium communities with less than 10,000 inhabitants. In particular, 49% of working plants treat wastewater from urban area with person equivalent (PE) between 2,000 to 10,000 and more than half of planned plants will serve communities of less than 2,000 inhabitants (Table 6.5).

Table 6.5. Number of WWTPs

PE	**Number of WWTPs**				
	abandoned	working	under construction	not working	planned
< 2,000	-	69*	13	29	63
2,000 – 10,000	-	128	16	42	25
10,000 – 100,000	-	60	15	18	6
> 100,000	-	2	3	0	2

*PE are missing for 4 WWTPs

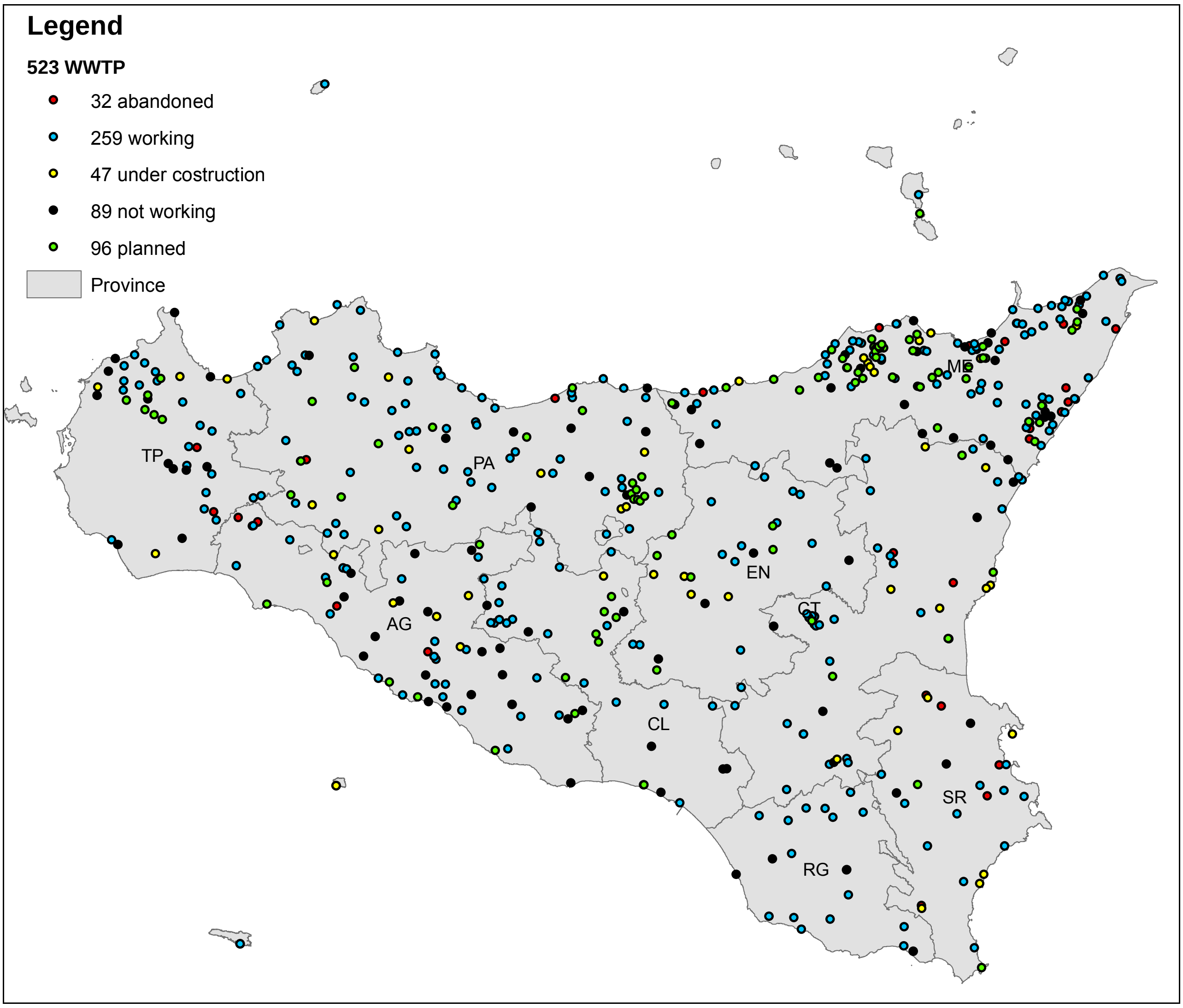

Figure 6.13. Urban wastewater treatment plants in Sicily

The potential of wastewater reuse for irrigation purposes in Sicily, has been evaluated taking into account only the effluent from working and under construction WWTPs. In particular, each one has been attributed to the nearest sub-irrigation district operating within the 11 irrigation districts managed by *Consorzi di Bonifica* (CB), for a total amount of about 184,475 irrigable hectares (fig.16.4).

In particular, the 11 Sicilian irrigation districts include 37 sub-districts for each of which have been evaluated:

- the irrigable area;
- the mean altitude;
- the irrigation requirement, assessed on the basis of irrigated area and seasonal water needs for each crop;
- the available water resources, evaluated on the basis of volumes actually derived from reservoirs or wells;
- the water deficit, evaluated as the difference between irrigation requirements and available water volumes;
- the available wastewater volumes from working and under construction WWTPs.

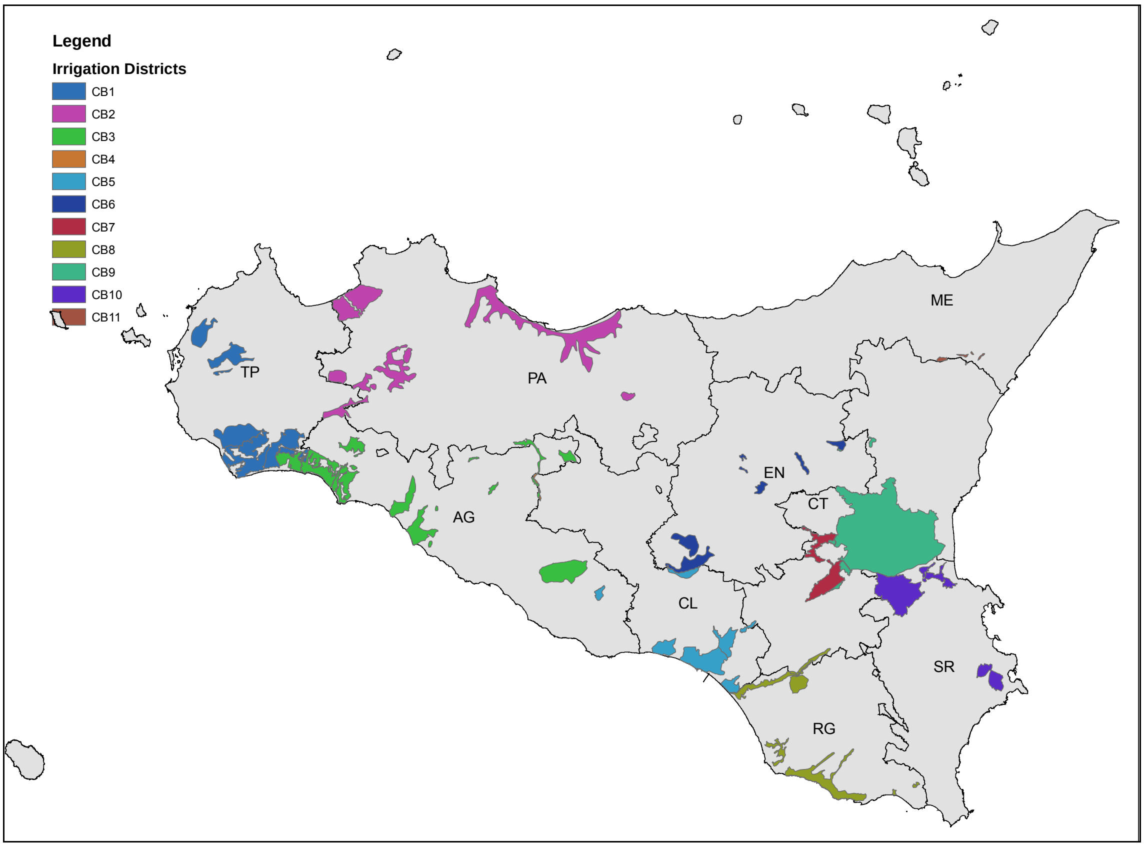

Figure 6.14. Sicilian irrigation sub-districts

The latter data were assessed considering the WWTPs that respect the following selection criteria:

- working or under construction;
- PE > 2,000;
- altitude of WWTP > of altitude of the nearest irrigation sub-district;
- if the distance from the WWTP to the nearest irrigation sub-district is > 5 km, then the effluent wastewater volume must be > 300,000 m^3/year (considering 150 L/PE/day).

The results of this assessment highlight the fact that the delivered volume of freshwater resources is not always enough to satisfy the seasonal water needs of each crop in the irrigation sub-district, with a total deficit of about 68 Mm^3. The treated wastewater can represent a fundamental additional source of water supply. In particular, in the sub-districts with a water deficit, reclaimed wastewater can contribute to satisfy irrigation demand. In the other sub-districts, wastewater reuse can leave better quality water for other purposes or increase the irrigated areas. However, the quality of wastewater that can be reclaimed must comply with the law limits for agricultural reuse. It is to note that in the present report there are no data about the quality of wastewater. Considering that almost all wastewater treatment plants have been designed to meet limits for wastewater discharge into surface waters, probably further treatments are needed to achieve the more restrictive Italian limits (D.M. 185/2003) required for irrigation.

Globally, the amount of treated wastewater available for agricultural reuse in Sicily, in the short (60 Mm^3, working WWTPs) and medium (46 Mm^3, WWTPs under construction) term, would be more than enough to satisfy the actual water deficit (68 Mm^3) of the irrigable areas within the Sicilian irrigation districts.

7. State of Art of Water Resources in the island of Corsica

7.1 Background

Corsica is a mountainous island with contrasted terrain geographically as well as morphologically speaking. Its length is approximately 180km and width 80km. Its average altitude in 568m with 9 summits above 2000m. A North-South crest divides the area no two stops the clouds and allows a regular rainfall distribution along the year, except during the summer period. Violent rainfall episode are often observed.

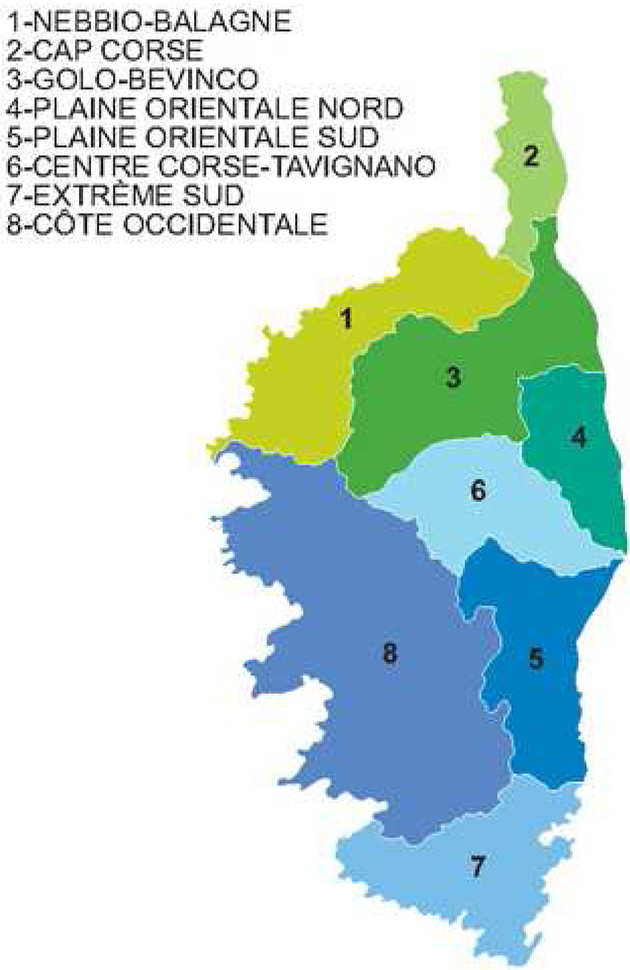

Figure 7.1 – Corsica

The yearly cumulated sun shining time is 2600h which allows good potentialities in terms of agricultural productions.

Numerous rivers and stream are crossing the island but with unsteady flows, e.g. on oriental side the annual variation of rivers is 1 to 450. Numerous lakes are existing in the mountain and large swamps on the oriental coast.

All these characteristics allow dividing the territory in 8 homogeneous subterritories.

The permanent population is estimated 300 000 inhabitants (1.6% of French territory, 0.5% of the French population). The contrasted relief separates sharply the different river basins. The Island is structured around two urban area: Ajaccio and Bastia grouping half of the population, the second half is distributed in 360 cities and villages. 60% of the population is living in urban areas.

Economic activity is located similarly with 70% of the enterprises located in urban areas. The primary sector is represented by 3600 farms and food processing units employing directly 3.6% of the population, and another 3.0% as indirect employment. Agricultural policy is quality oriented with numerous labels (AOC) supporting the development of agro-tourism. Regarding water the agricultural sector as a diffuse but important impact on the resource in terms of water uptake and wastes discharge.

The secondary sector is mainly constituted of approximately 6500 SMEs, generating 15% of the GDP and 17% of the employment. The main problem remains the small size of the local market and distance from the continent. The productions are mostly of high value to support the cost of exportation out of Corsica, its impact on water resources remains low. The tertiary economic sector occupies 79% of the workers and generates 83% of the GDP. This sector is constituted of public administration, tourism and ICT enterprises. Regarding the tourism, Corsica welcomes yearly more than 2 millions tourists representing 300M€ turnover a year. This sector is still expanding by enlarging the touristic season before and after the summer period. Obviously this variability in frequentation induces a variation in hydraulic pressure that makes it complicated to dimension water supply and waste water treatment infrastructures. Consequently despite a rather low economic growth rate at national level, Corsica's one varies from 4 to 5% since 2002.

Regarding the touristic sector, with some 25 millions nights and one billion turnovers, it represents the main activity of the island. The tourism relies on preserved natural areas unique among the Mediterranean, most of them involving water, whether it is sea or

river water. The activity is distributed as follows: 30% from January to June ; 50% from July to August ; 20% from September to December. All these parameters impact and make it more complicated to operate a participative water management system:
- Secure potable water supply;
- Select, dimension and operate waste water infrastructure;
- Adapt public support policy to touristic population fluctuation;
- Keep natural sites quality to keep attracting people.

7.2 Water Resources

Corsica undergoes as the other Mediterranean islands the effects of the climate change. Two phenomena are observed: a constant decline of cumulated yearly precipitation, a higher heterogeneity of cumulated precipitation between years, as well as a global increase of the intensity of the precipitations.

The global water requirement of the island was estimated in 2003 86 Mm3 distributed in 47 Mm3 for the agriculture and 39 Mm3 for cities and few industries. The resource is as follows: 65 Mm3 of water from the rainfall runoff, 10Mm3 from alluvial water tables and 5 Mm3 from inland aquifers.

A river is supposed to be permanent flowing over the year, and not limited to the collection of artificial flows coming from treated waste or direct rainfall. This induces that a biological continuity of the flow is on-going along with a diversity of natural habitats allowing a sustainable development of aquatic species. The river constitutes as well a support for other activities such as: potable watersupply, recreation, self treatment capacity of residual pollutions. The territory in divided in 22 hydr-eco-region, more or less corresponding to 22 identified river basins draining water to the sea (see Figure 7.2).

The specificity of Mediterranean rivers results from 4 factors:
- Climate: high seasonal variability from low water to floods resulting in a permanent crisispopulation river dynamics. This is increased by the pressure of the population, major during the low water level periods;
- Topography and geology: mountainous partly karstic and christallin;
- Biogeography: animal and plants species distribution;
- Proximity with the sea with high level of salt.

The number of reservoirs of more than 50ha is 9, all are artificial. The mountainous relief makes it complicated to find sites of construction for reservoirs and their costs of construction as well as that of infrastructures are very high. The existing dams representing 104 Mm3, are all used to produce some electricity what supplies 30% of the total needs.

The proximity with the sea and alluvial accumulations has created areas more or less permanently submerged by sweet or salted water constituting a high biodiversity area

very sensitive to hydraulic and pollution perturbations. They are important for several purpose:
- hydrologic : acting as buffer zones to mitigate water level variations in the rivers ;
- biologic : constituting a shelter for numerous animal and vegetal species;
- landscape and recreation.

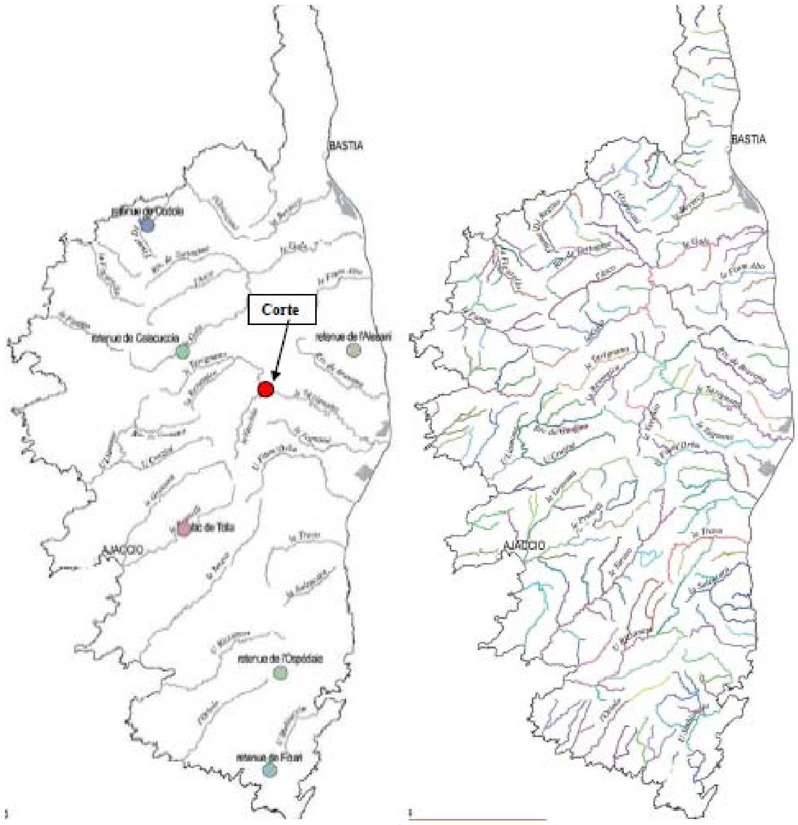

Figure 1 : Main rivers and reservoirs in Corsica **Rivers in Corsica (SDAGE Corse)**

Figure 7.2: Main Rivers in Corsica

Humid areas and lagunas are distributed over the entire island representing 20 000 ha subjected to high pressure:
- Draining for agricultural or touristic purpose (production, struggle against mosquitos);
- Hydraulic works for maintaining river banks, calibration of streams, small dams for irrigation… modifying hydrology and progressively reducing their area.

The sea shore humid areas are the only to be easy to keep out of entropic pressure, in Corsica theonly one concerned by water management issues is Bibugglia, close to Bastia, supplied by the river Golo.

A number of concerns are coming regarding the effects of climate change on water resource recharge capacity. Rainfall intensity is increasing, lowering rainfall storage efficiency by the environment. 9 water bodies are recorded on the territory, on the average the level of quality can be considered satisfactory, but some bodies remain exposed to pollution risk, in particular regarding the pollution with arsenic and antimony related to former mining activity in the centre of the island.

In Corsica the resource is abundant but irregularly distributed spatially as well as timely. The total withdrawal in 2010 has reached 100 Mm3 annually, half used for potable water. 80% of the water is supplied by surface water and 20% by water tables. Consequently the pressure on natural aquatic bodies is high.

The second pressure is due to hydropower plants and attached storage development. The island shows a high deficit renewable energy production that resulted in the adoption of an energy action plan in 2005. Provided the hydropower capacity is exploited the remaining solutions are oriented toward other types of sources that hydraulics.

About one fourth of the rivers are affected by an excess uptake resulting in quantitative as well as qualitative concerns. Efforts are anticipated in terms of water supply security and water savings while continuing the investigation to understand better the hydrology of the different water bodies.

In 2010, despite rainfall above the average, the water tables are still under their normal level in Marsh. From 2005 a network of observation points has been set, displayed on the map given hereafter fro the region of Corte. One solution is to find substitutive resources like treated waste water that Mediwat could contribute to explore.