RESERVOIR

Sustainable groundwater RESources managEment by integrating eaRth observation deriVed monitoring and flOw modelIng Results

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GROUNDWATER REGULATION IN THE PILOT SITES

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UNIPD	Università di Padova	Italy
IGME	Instituto Geológico y Minero de España	Spain
UA	Universidad de Alicante	Spain
DEU	Dokuz Eylul University	Turkey
UJ	The University of Jordan	Jordan
CER	Consorzio di Bonifica di secondo grado per il Canale Emiliano Romagnolo	Italy
RSCN-AWR	Royal Society for the Conservation of Nature - Azraq Wetland Reserve	Jordan

GLOSSARY

Acronym	Description
Art.	Article
D.Lgs.	Legislative decree
D.P.R.	Decree of the president of the Italian Republic
DLS	Department of Land and survey, Jordan
DPCM	Prime Minister's Decree
DSI	General Directorate of State Hydraulic Works under the Ministry of Agriculture and Forestry, Republic of Turkey
GRB	Gediz River Basin
GRBMP	Gediz River Basin Management Plan
GWD	EU Groundwater Directive
HD	Hydrographic Demarcations
HP	Hydrological Plans
IWMI	International water management institute
Kushan	Official land deed, authorized by the DLS
L.R.	Regional law
MoA	Ministry of Agriculture
MWI	Ministry of Water and Irrigation, Jordan
P.T.A.	P.T.A., - Water Protection Plan (In Italian: Piano Tutela Acque)
PdG	Management plan of the river basin district of F. Po (in italian: Piano di Gestione del distretto idrografico del fiume Po)
Qc	Marine and continental sediments accumulated in the Middle Pleistocene–Holocene age
Qm	Marine and continental sediments accumulated in the Early to Middle Pleistocene age

R.D.	Royal decree
RSCN	Royal Society for the Conservation of Nature, Jordan
SHD	Segura Hydrological Demarcation
SHP	Segura Hydrological Plan
SYGM	General Directorate of Water Management under the Ministry of Agriculture and Forestry, Republic of Turkey
Tafwid	Delegation; a process were people, private or public companies can rent state land for a period of time from the government in order to build, cultivate or make a project on it
WAJ	Water Authority of Jordan
WFD	EU Water Framework Directive

SUMMARY

LIST OF FIGURES AND TABLE

1. INTRODUCTION, GOAL AND PURPOSE OF THIS DOCUMENT

The objective of the work package 2 (WP2) of RESERVOIR project is the identification of the stakeholder requirements and the setup of the groundwater conceptual model for each pilot site. WP2 activities are aimed to assess the preliminary scope statement and data collection for the RESERVOIR implementation. Therefore, the starting point of the RESERVOIR activities is the review of the background of the groundwater governance to identify the groundwater policies and regulation for each pilot site (Task T2.1 - Review of the groundwater regulation in the pilot sites - Task Leader: UNIPV)

The four pilot sites are:

1. The coastal aquifer of Comacchio in Italy;
2. The Alto Guadalentín aquifer in Spain;
3. The alluvial aquifer of the Gediz River basin in Turkey;
4. The Azraq Wetland reserve in Jordan.

The selected pilot sites are representative of different aquifer systems in the Mediterranean area and they have been selected on the basis of one or more of the following criteria:
1) located in coastal areas suffering of land subsidence and salinization due to seawater intrusion;
2) vulnerable to drought during dry periods;
3) highly exploited for agriculture and touristic purposes;
4) providing key strategic water resources to ensure water supply to population during dry periods.

Each pilot site has been selected in order to answer to specific scientific questions:

(i) How can we manage groundwater resources to avoid seawater intrusion?

The coastal aquifer of Comacchio (Italy): it is an intensively farmed area where the primary land use is horticultural crops and during summer, tourism increases water demand along the coastline. This pilot site is affected by seawater intrusion. In low-lying coastal areas, the shallow groundwater system is affected by water levels in ditches, managed by local water authorities, and it supplies an important resource of fresh groundwater for crops and to control salt groundwater intrusion.

(ii) How can we manage groundwater resources to avoid groundwater over-exploitation and subsequent land subsidence risk?

The Alto Guadalentín aquifer (Spain): hundreds of wells were drilled in the 60’s to improve agriculture´s productivity, but led to the declaration of overexploitation in 1987. Thepiezometric levels have been continuously descending over the last 60 years, resulting also in the highest subsidence rates measured in Europe (> 10 cm/yr).

(iii) How can we manage groundwater resources to ensure sustainable use of groundwater?

The Gediz River Basin (Turkey): it is one of the most important, largest and most stressed river basins in Turkey. This basin is agriculture-dominated; however, significant competition for water exists among various stakeholders and sectors. Sustainability of available groundwater is a key issue as there are more than 40,000 registered wells mostly in alluvial aquifers on the basin. In addition, there are thousands of unregistered wells for which the total groundwater withdrawal rate is unknown. Land subsidence linked to overexploitation of groundwater is observed in some parts of the basin, however it does not cause any major problems yet.

(iv) How can we manage groundwater resources to preserve groundwater-dependent ecosystem?

The Azraq Wetland Reserve (Jordan): it is a reserve of international importance and constitutes one of the most peculiar ecosystems in the world, i.e. a wetland rich of biodiversity in a desert. During the last two decades, experienced an environmental disaster due to overexploitation and abuse of water. The Azraq Wetland Reserve has an important social and economic role for the local community.

Each partner involved in this activity has reviewed the groundwater policies and regulation for the pilot site for which was responsible.

In particular, this document aims to describe for the four pilot sites:

- the geographical, geological and hydrogeological setting;
- the groundwater policies and regulation.

As far as concerning the last point (groundwater policies and regulation), the following information has been collected:

- Groundwater use.
- Groundwater laws and regulations.
- Groundwater management tools:
  - Technical instruments (e.g. surveying, groundwater quantity and quality monitoring and modelling, other diagnostic analyses);
  - Managerial and planning instruments (e.g. land use and spatial planning, environmental impact assessment, groundwater protection zoning, definition of responsibilities and roles of various groundwater resources management entities);
  - Regulatory instruments (e.g. groundwater property and rights, well licensing and registering, drilling accreditation, water legislation);
  - Economic instruments (e.g. groundwater pricing, environmental taxes, tradable rights and groundwater markets).

2. THE COASTAL AQUIFER OF COMACCHIO, ITALY

2.1. DESCRIPTION OF THE PILOT SITE

2.1.1. Geographical setting

The Comacchio aquifer pilot site is located in the coastal floodplain of the Po River in northern Italy, Emilia Romagna region, within the coastal area of Ferrara province (Figure 2-1). The pilot site extends for 1,055 km^2, approximately 15 km north of Ravenna city. The area represents the eastern part of the Po River plain, including a Site of Community Importance (Habitats Directive) designed in 1995 by the European Union and named Comacchio Lagoons (https://econservation.jrc.ec.europa.eu/site/3661). The Comacchio area is a reclaimed land with flat topography below the mean sea level, and with an altitude ranging from 5 to 11 m above sea level (a.s.l.); the only topographic heights consist of dune systems, paleodunes and riverbanks. The surface hydrographic system includes the course of the Po River from where the water is derived by gravity, its tributaries and an extended hydrological network consisting of west-eastern-oriented channels and drainage ditches. The main water courses within the study Comacchio pilot site are Po di Goro, Po di Volano and Reno River plus a dense man-made network of ditches and channels more than 1,850 km long used to keep dry the land and managed by specific Reclamation Authorities.

Among the artificial channels, the Emiliano Romagnolo Channel is one of the most important Italian hydraulic works. It ensures, by means of derivation from the river Po, the water supply of an area covering over 3,000 km^2, characterized by intense agricultural activity and widespread urban and industrial settlements and, on the other hand, poor in surface waters.

This area is characterized by intensive agriculture inland and intensive tourism along the coast during summer periods (June–September).

Several natural and anthropogenic features threaten this area: saltwater intrusion in the phreatic aquifer and seawater encroachment inland along the rivers (Giambastiani et al., 2007); natural (Carbognin and Tosi, 1995, Carminati et al., 2005) and anthropogenic land subsidence (Teatini et al., 2006); land reclamation drainage systems; soil salinization; high demand of water during the peak tourist season; insufficient aquifer recharge and sea level rise (Antonellini et al., 2008). Natural and anthropogenic land subsidence has dropped most of the territory below mean sea level, modifying river and groundwater flow regimes. A drainage system is necessary to lower the phreatic level, guarantee water discharge toward the sea and maintain this lowland dry (Giambastiani et al., 2013).

2.1.2. Geological setting

The geological setting of the Comacchio pilot site is characterized by a 700–800 m thick sedimentary sequence accumulated during the Pliocene-Pleistocene (Pieri and Groppi 1981; Castellarin et al. 1985). These sediments derived from two major depositional cycles of Quaternary age, Qm and Qc. They are marine and continental sediments accumulated in the Early to Middle Pleistocene age (Qm) and in the Middle Pleistocene–Holocene age (Qc) (Ricci Lucchi et al. 1982; Ori 1993; Regione Emilia-Romagna and ENI-AGIP 1998). In particular, these deposits are characterized by alternations and interdigitation of continental and marine facies accounting for the complex evolution history (Figure 2-1). In proximity of the coastline, fine sands and silty-sands are largely distributed, whereas silty-clay soils and soils rich in organic matter (peat) are present in the hinterland areas (Bondesan et al., 1995). The stratigraphic architecture of the Po Delta plain was controlled by eustatic and climatic fluctuations. Tectonic and compaction subsidence provided a significant contribution to the relative sea level and the spatial pattern of subsidence probably influenced the maximum transgression coastline configuration and the continental drainage network (Stefani & Vincenzi, 2005).

According to Regione Emilia-Romagna and ENI-AGIP (1998), these deposits are named Subsynthem Emiliano-Romagnolo and subdivided in the Sintema Emiliano-Romagnolo Inferiore (AEI) and the Sintema Emiliano-Romagnolo Superiore. The AEI is the oldest part of Supersynthem; the AES represents the upper portion of the Supersynthem.

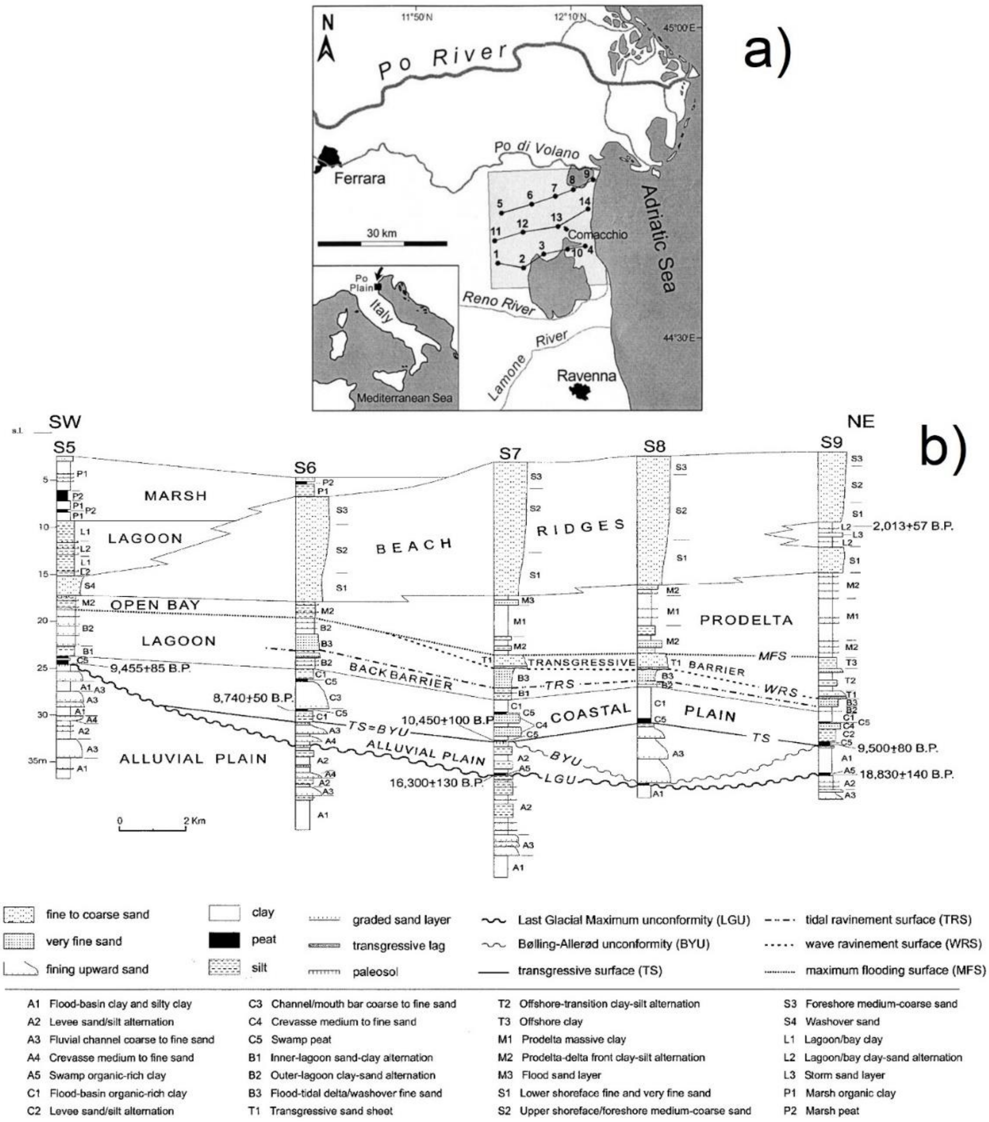

Figure 2-1 (a) Sheet 205 "Comacchio" of the Geological Map of Italy to scale 1:50,000 and localization of the section traces. (b) Stratigraphic correlation and architectural interpretation of the Late Quaternary deposits along the section trace 5-9 (from Amorosi et al. 2003).

2.1.3. Hydrogeological setting

The complex sediment deposition history of the Comacchio coastal area led to a complex hydrogeological setting. Three Plio-Pleistocene aquifer systems are found in Po aquifer systems: Aquifer Group A (from 0 to 150-200m), Aquifer Group B (from 150-200m up to 300-350m) and Aquifer Group C (more than 300-350m deep; Regione Emilia-Romagna and ENI-AGIP, 1998). These deposits correspond to fluvial and marine deposits, both with coarse and fine textures. The Aquifer Groups host different main aquifer complexes: e.g. Group A is made of A1, A2, A3, and A4 aquifers. The hydrogeology of the coastland is characterized by a multi-layered aquifer system confined between aquitards, where the sediments are related to the transgressive and regressive sea phases (Figure 2-2). A shallow unconfined aquifer is located above the multiaquifer system. Locally thin confining lenses of silt and clay sediments can be found within the shallow unconfined aquifer that is characterized by a thickness ranging between 2 and 24 m (Bonzi et al. 2010).

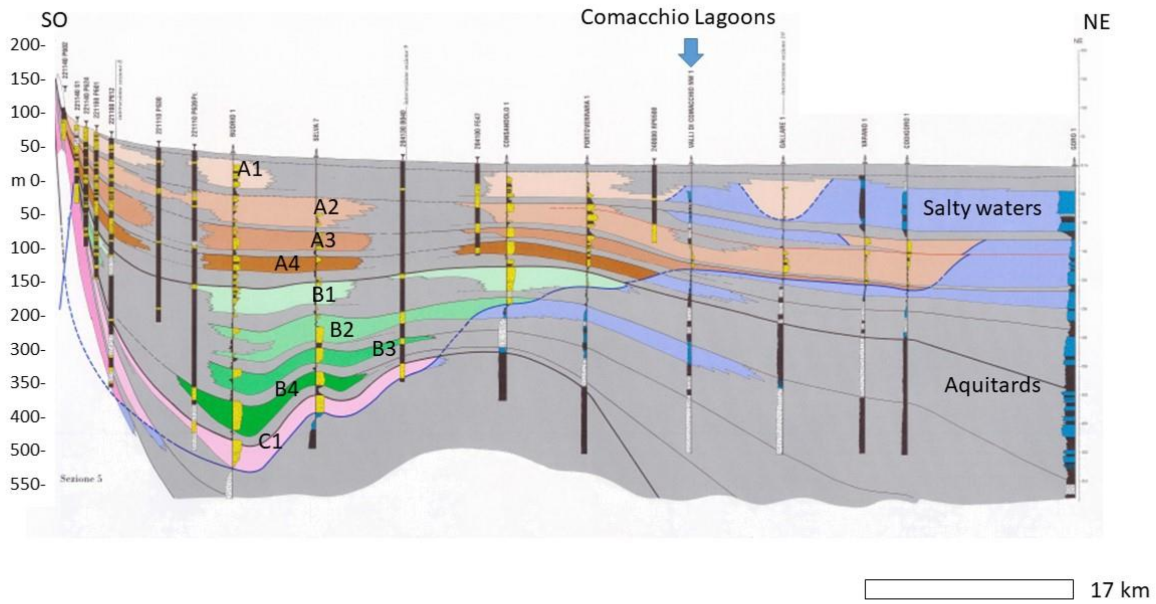

Figure 2-2 Cross-section showing the multi-layer aquifer system of the Comacchio coastal aquifer (modified from Regione Emilia-Romagna and ENI-AGIP, 1998).

2.2. GROUNDWATER POLICIES AND REGULATION

Several Authorities are involved in the groundwater governance of the Comacchio pilot site depending on the different uses of water, such as supply to the population, wastewater treatment, farmland irrigation and drainage, wildlife management and biodiversity protection. A Regional Plan of Protection Water was developed and implemented to monitor surface and subsurface water bodies, with the identification of required interventions and measures.

2.2.1. Groundwater use

The pilot site of Comacchio is an intensively farmed area where the primary land use is horticultural crops. Beach tourism during the summer season (June–September) has significantly increased water demand along the coastline, favoring a severe seawater intrusion. In low-lying coastal areas, the shallow groundwater system is significantly affected by the water levels in ditches, which are managed by local reclamation authorities through a large number of pumping stations. Ditches and channels supply an important volume of fresh water for crop production and to control salt groundwater intrusion. The whole coastal area has been affected by land subsidence since the last World War with values that changed significantly over time and in space. The total land subsidence is caused by the superposition of various processes such as natural consolidation, peat oxidation, surface loading due to new structures and infrastructures, groundwater withdrawals, hydrocarbon production from deep reservoirs (Simeoni et al., 2017). Disentangling the contribution to land subsidence due to aquifer exploitation from the other factors is a difficult effort.

2.2.2. Groundwater laws and regulations

The Water Framework Directive 2000/60/EC (WFD) establishes a European frame for the protection and management of water resources. Its main aim is the prevention of water resources deterioration, both in terms of quality and quantity, using as 'precautionary' principle the reduction of the pollution.
In the Italian context and especially in the Po River Basin, which is the largest plain in Italy and representing also the most important economic area for the country, the WFD was first transposed in 2006 with the legislative decree n° 152. The most recent modifications (DLgs 4/08) provide a complete treatment of the whole subject related to the legislation on environmental issues. This legislative decree unified previous regulations concerning the environment and water use in order to reduce the fragmentation of competencies, which is still the major problem of the country. The fundamental modification of this law is the definition of 14 water districts, in which all minor basins are merged. District Authorities replace the previous Basin Authorities and are responsible for the application of the principles of the WFD within each district. This reorganization is aimed to establish for each district a governing Institution of equal relevance, characterized by similar organs, applying similar procedures to approve and adopt planning actions. These District Authorities are supervised at the national level by the Minister for the Environment (Civita et al., 2017). Furthermore, institutional cooperation is established among Regions belonging to each district and the State, through a central body, the Committee of Ministers. Two Sectorial Plans for each basin belonging to the district are carried on:

1. Hydrogeological Plan, concerning soil protection and hydrogeological risk;
2. Management Plan, concerning environmental protection of water bodies and rational exploitation of water resources.

Regional Authorities are involved in the quality of the water bodies by implementing a set of measures adopted through Environmental Plans to be issued every 6 years. These plans must conform to the general directives of the District Authority contained in a Master Plan and must be approved by the District Authority (Civita et al. 2017).

Table 2-1 Groundwater laws and regulations implemented by the institutional entities of the groundwater governance in the Padano Hydrographic District

INSTITUTIONAL ENTITIES	PLAN	REGULATION	MANAGEMENT BODY		WEB SITE
			Service	Local authority	
ADBPO - Po river basin Authority	PdG Po Water Plan - Management plan of the river basin district of F. Po (in italian: Piano di Gestione del distretto idrografico del fiume Po)	Decree n° 1/2016 of 03/03/2016 (included in the DPCM 27/10/2016)	• Management of water withdrawn for irrigation • Study of the groundwater use for irrigation, industrial and civil purposes • Well licensing for irrigation	CONSORZIO DI BONIFICA C.E.R. – Canale Emiliano-Romagnolo Irrigation Consortia For the management of the groundwater for farmers	http://pianoacque.adbpo.it/il-piano/ cer@consorziocer.it
Emilia-Romagna Region (RER)	P.T.A., 2015 - Water Protection Plan (In Italian: Piano Tutela Acque)	Resolution n° 40 of 21/12/2005 Regional legislative assembly			Ambpiani@regione.emilia-romagna.it ambiente.regione.emilia-romagna.it › acque › temi › piano-di-tutela-delle-acque segrgeol@regione.emilia-romagna.it informaticageol@regione.emilia-romagna.it

Agenzia Territoriale Emilia-Romagna Servizi Idrici e Rifiuti (AT.ER.SIR) – A.T.O. unico	• PdGPo, 2015 • PTA, 2015	L.R. 23/2011	• Water Integrated Service (S.I.I.) • Urban waste Integrated Service (S.G.R.U.)	CADF spa Romagna Acque-Società delle Fonti S.p.A HERA spa	www.atersir.it/servizio-idrico
ARPA ER - Regional Prevention and Environment Agency of Emilia Romagna	• Analysis and monitoring of the air and water quality • Report • Environmental certificate • Licenses for the water well	L.R. 32/1988 L.R. 9/1999 R.D. 1443/1927 D.P.R. 128/1959 L.R. 13/2015.			www.arpae.it/elenco_minisiti.asp?tipo=Temi

2.2.3. Groundwater management tools

2.2.3.1. Technical instruments

The Comacchio aquifer is monitored by different monitoring networks for piezometry and water quality. The water level of the shallow phreatic aquifer is monitored by “Consorzio di Bonifica di secondo grado per il Canale Emiliano Romagnolo” (CER) through 14 monitoring wells. The piezometric level of the deep aquifer system is monitored by “ARPAE Emilia Romagna” through 16 piezometers. In particular, six piezometers are collecting measurements for the phreatic aquifer localized in the shallow 20 m from ground level, whereas 10 piezometers are collecting data for the confined aquifer system from 20 up to 180 m from ground level.

Furthermore, 13 monitoring wells are managed by Emilia Romagna Region (RER) to monitor the water level of the shallow phreatic coastal aquifer.

2.2.3.2. Managerial and planning instruments

The framework described in section 2.2.2. gives insight about the fragmentation of the groundwater governance in Italy that includes a number of institutional actors at ministerial, district and regional levels. Therefore, the cooperation for the data collection and monitoring is crucial for the whole system.

Different local institutions such as Regions, District Authorities, Regional Environmental Protection agencies, ATO‟s agencies, Reclamation and Irrigation Authorities are involved in the groundwater management (Table 2-2).

Table 2-2 Boards in charge of water management in Emilia Romagna region.

WATER TYPE / DESIGNATED USE	BOARDS	TECHNICAL BASIN SERVICES
Natural rivers and streams	ADBPO - Po river basin Authority	• PdG Po Water Plan - Management plan of the river basin district of F. Po, Protection of groundwater and surface water • PGRA - Flood risk management plan • PAI - Piano Assetto Idrogeologico • PBI - Water Balance Plan • SIGRIAN – Data-hub for management of water in agriculture
	AIPO - Interregional agency for the Po River (ex- Magistrato per il Po)	Hydraulic safety, water domain and river navigation
Water drainage and irrigation	ADBPO - Po river basin Authority	Management plan of the river basin district of F. Po
	REGIONAL GOVERNMENT - Emilia Romagna	P.T.A., 2015 - Surface and ground waters Transitional waters
	RECLAMATION SYNDICATES	Land reclamation consortia for management drainage areas (of first and second degree)
Waters for human use (incl. waste waters)	REGIONAL GOVERNMENT - Emilia Romagna	Water Protection Plan (P.T.A., 2015)
	LAND AGENCY OF EMILIA-ROMAGNA (A.TER.SIR)	Water Integrated Service (S.I.I.) Public companies (Romagna Acque-Società delle Fonti spa, HERA spa, …)
	ARPA ER - Regional Prevention and Environment Agency of Emilia Romagna	Authorizations and concessions for the use of water resources (springs and wells) and State water property

Po river Basin Authority developed various management plan such as Drought Management Plan (DMP) for managing different extreme weather condition through adaptation and mitigation strategies in climate changing environment.

Real-time monitoring system of irrigation water diversion of 1 cubic meter per second or higher from surface water bodies are managed by Irrigation and Land Reclamation Authorities. Basin authority copes data gathering from water users to manage water in case of shortage.

2.2.3.3. Regulatory instruments

In the case of River Po Basin, difficulties were found and still are present to carry out a complete economic analysis and to define the mechanism of water cost recovery with particular reference to the most exposed areas, such as the Comacchio coastal area.

Errore. L'origine riferimento non è stata trovata. summarizes the institutional entities in charge of the g roundwater management in the Italian test site and their regulatory instruments.

Table 2-3 Institutional entities in charge of the groundwater management

INSTITUTIONAL ENTITIES	WATER LEGISLATION		ISSUE
	Regulation	Type of Directive	
THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION	98/83/CE of 03/11/1998	Council Directive	Quality of water intended for human consumption
	2000/60/CE of 23/10/2000	Water Framework Directive (WFD)	Establishing a framework for Community action in the field of water policy
	2006/118/CE del 12/12/2006	Water Framework Directive (WFD)	Establishing a framework for Community action in the field of water policy
ITALIAN GOVERNMENT	Constitution of the Italian Republic	Italian Republic	Restrictions of the land use and resources
	D.Lgs. 31/2001 of 02/02/2001	Legislative decree	Implementation of the Directive 98/83/CE about the water for civil use
	D.Lgs. 152/2006 of 03/04/2006	Legislative decree	Implementation of the WFD 2000/60/CE “Code of environment” – art.1 and 144
	D.Lgs. 30/2009 of 16/03/2009	Legislative decree	Implementation of the WFD 2006/118/CE
	D.Lgs. 219/2010 of 10/12/2010	Legislative decree	Implementation of the Directive 2008/105/CE
	D.M. 131/2008 of 16/06/2008	Ministerial Decree	Technical criteria for the water body characterisation
	D.M. 56/2009 of 14/04/2009	Ministerial Decree	Technical criteria for the water body monitoring
	D.M. 260/2010 of 08/11/2010	Ministerial Decree	Technical criteria for the shallow water body classification

	D. M. 31/07/2015	Ministerial Decree MiPaaF	Technical review for measuring of water use in agriculture
PO RIVER BASIN AUTHORITY (ADPO)	Delibera 1/2016 of 03/03/2016 D.P.C.M. 27/10/16	DPCM	Water Plan of Po basin
LAND RECLAMATION AUTHORITIES	R.D. 13/02/1933 n.215		Management of the water for the irrigation and drainage Land reclamation authorities for management drainage areas (of first and second degree) (C.E.R.)
REGIONAL GOVERNEMENT - Emilia Romagna	Resolution N. 40 of 21/12/2005 - Regional Legislative Assembly		Tool for the sustainable water supply
AGENZIA TERRITORIALE EMILIA-ROMAGNA (A.TER.SIR)	L. R. n. 23/2011		Water Integrated Service (S.I.I.) Urban waste Integrated Service (S.G.R.U.)
ARPA ER - Regional Prevention and Environment Agency of Emilia Romagna			Well licensing and registering

2.2.3.4. Economic instruments

Water concession fees are charges and tariffs paid by water right holders and were established in R.D. 1775/1933 (Santato, 2016). The following environmental laws L.D. 26/1994 and 152/2006 (Env. Cod.) confirmed the 'public nature' of the source and that the water fees are mainly a cost recovery for water services. The principle of cost recovery for water service was establish in art. 9 of Water Framework Directive 2000/60/CE. So, in the last years strong efforts were focused by water authorities on calculating and charging a binomial fee (Molle, 2007) on water users: fixed cost for service management and variable cost based on water withdrawal. In the **Errore. L'origine riferimento non è stata trovata.**Table 2-4 we report a water withdrawal fees as in 2014 in Po River basin district.

Table 2-4 Water concession fees (mod. from Santato, 2016)

Use	Unit	Lombardy	Piedmont	Emilia-Romagna	Veneto
Potable	€/L/s	22.51	22.22	20.43	43.06
Irrigation	€/L/s	0.53; 0.26	0.53	0.48	1.01; 0.51
Industrial	€/L/s	165.30; 333.22	166.74	142.41	300.42
Hydropower	€/kW	15.35; 30.91	28.24	13.93	29.38

Civil	€/L/s	11.25	11.11	10.33	21.53
Fish Farming	€/L/s	3.75	3.74	3.41	3.76; 7.18
Sanitary	€/L/s	11.25	11.11	10.33	21.53
Zootecnic	€/L/s	11.25	56.72	10.33	21.53

In pressurized networks the water services have carried out investments for installing water meter whereas in open channel system the technical constraints are still persistent as well as in private point source of water abstraction (i.e. private well and spring).

Land Reclamation and Irrigation Boards in all Italy achieved, at the end of 2019, an important result on irrigation water fees charging: a clear method for cost recovery distribution among irrigation water user is applied based on binomial fee. The fixed and variable cost are calculated and applied to water fees based on the benefit of real estate. The variable part of the fees is charged based on withdrawal water amount when available otherwise it is standardized on crop irrigation water needs.

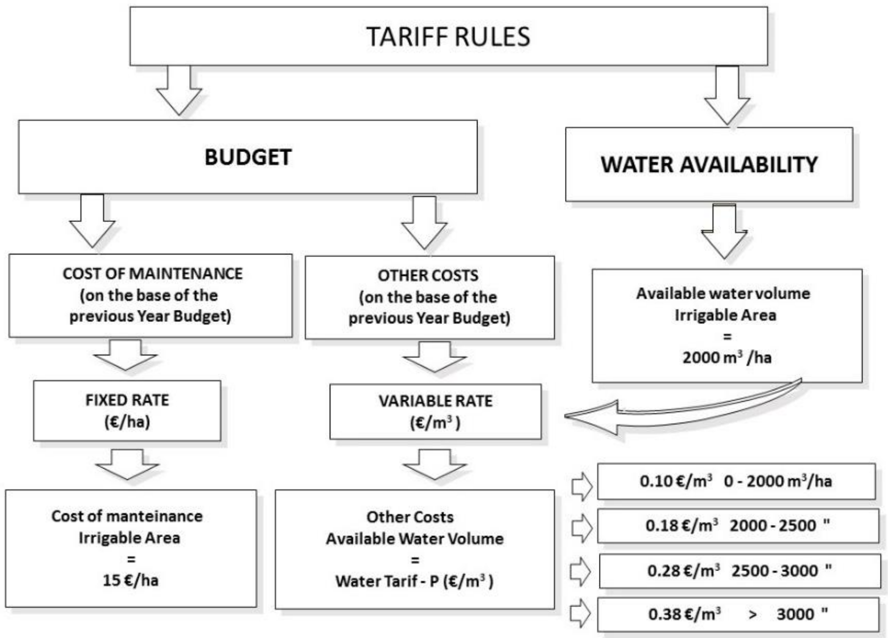

Figure 2-3 example of calculation method for variable and fixed terms of water fees in irrigation in case of lack of water meter (CER 2014).

The water fees are related to the benefit of land reclamation and irrigation on real estates. The benefits are divided into: hydraulic, water availability and hydrogeological. About the water availability, the Irrigation Boards can classify the water right owner based on location of water source respect to the plots, on type of network (open canal or pipeline) and other parameters to define the part fixed of charge. While for variable cost the fees is related to the irrigation water abstraction when measured or to irrigation water need for crops. An example of calculation method is reported in Figure 2-3.

3. THE ALTO GUADALENTÍN AQUIFER, SPAIN

3.1. DESCRIPTION OF THE PILOT SITE

3.1.1. Geographical setting

The Alto Guadalentín aquifer is located in Murcia Region, Southeast Spain (Figure 3-1 and Figure 3-2). The Segura Hydrographic Demarcation (SHD) is the organism that manages both surface and ground water bodies in the area.

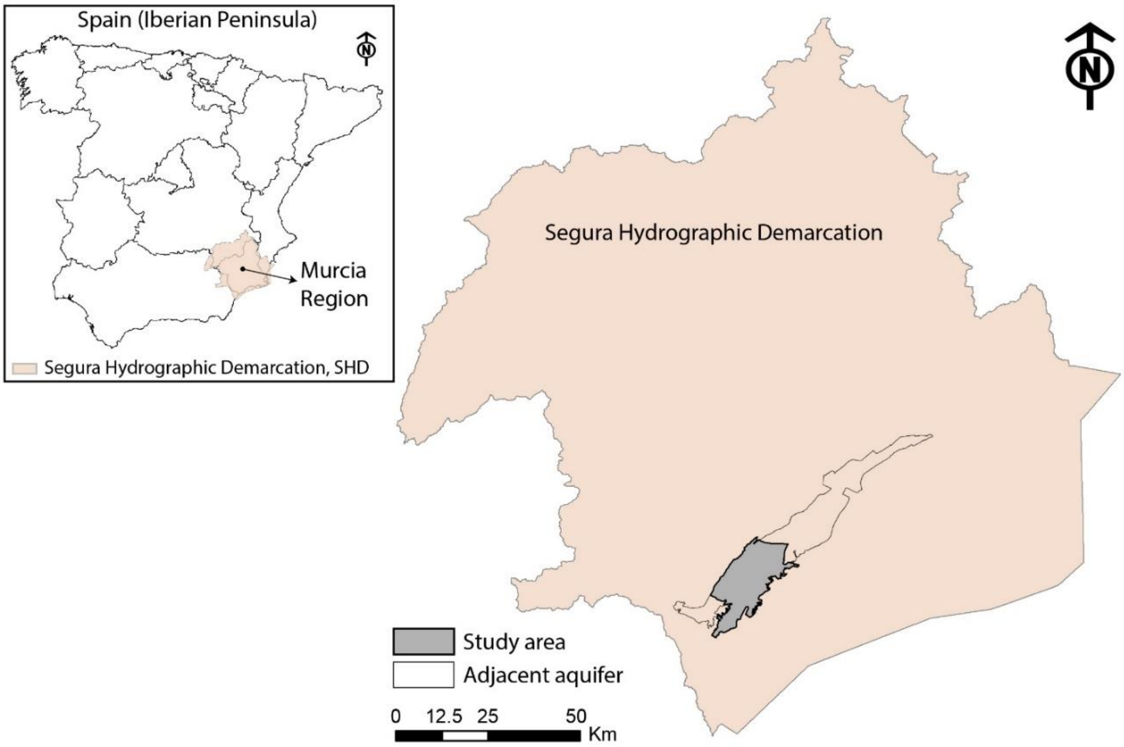

Figure 3-1 Segura Hydrographic Demarcation.

Within the boundaries of the SHD, the Alto Guadalentín aquifer is placed in a large basin developed by tectonic shifts. The aquifer has an extension of 273 km^2 with altitudes varying from 251 m a.s.l. to 551 m a.s.l. (Figure 3-2). The main watercourse in the area is the Guadalentín River with very low flow non-permanent rates that only increase due to extreme flood events (Ezquerro et al. 2017), reaching up to 3000 m^3/s (Cerón 1995). There are other non-permanent watercourses (e.g. Viznaga, Nogalte, Galian), which also become active after these extreme flash floods events (Ezquerro et al. 2020). These water courses do not reach the Guadalentín River since they directly infiltrate to the aquifer or reach endorheic depressed areas (Cerón 1995). Mediterranean areas such as the Southeast of Spain are affected by convective storms (commonly developed in autumn) with very quick development, short duration and very high intensity constituting a permanent potential threat (Jodar-Abellan et al. 2018). Particularly, for Guadalentín basin, these events resulted in numerous catastrophic floods with episodes registered from XIII century until the present (Ezquerro et al. 2017).

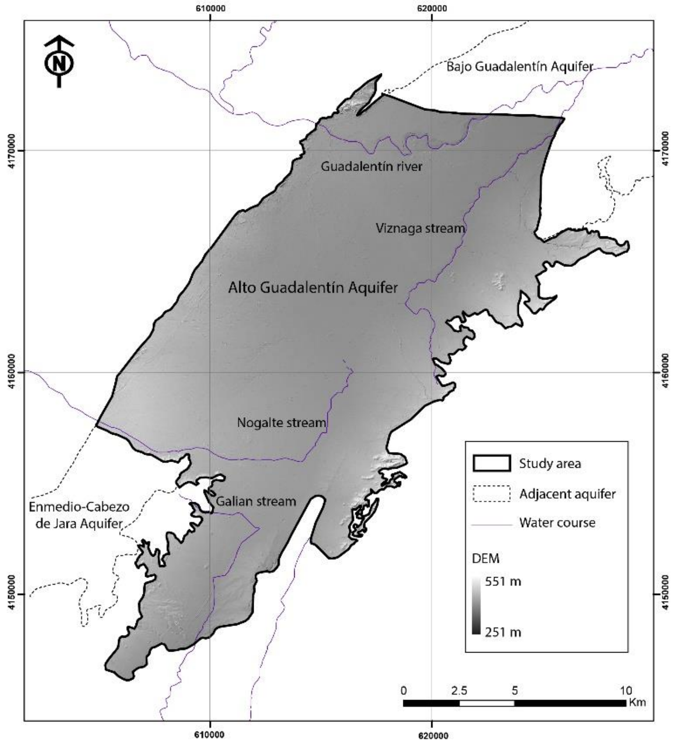

Figure 3-2 Alto Guadalentín aquifer.

The area presents a dry climate following the Koppen-Geiger Classification modified (AEMET-IM 2011). This matches with severe drought periods and the absence of vegetation in the closer mountains that stablish the aquifer borders. Precipitation presents an average annual value of 283 mm (calculated for the period 1957-2017) and a non-regular temporal behaviour with interannual drought periods and nearly inexistent precipitation during summer. Several drought periods have been declared from 1980 (1980-1983; 1993-1995; 2005-2008; 2015-2018 (Figure 3-3).

Consequently, water stress in the area has historically appeared with temporal effect causing water shortages. The potential and real evapotranspiration are 993 mm/year y 341 mm/year, respectively. Average values of calculated water infiltration for the study area are very low, not higher than 5 mm/year.

Land uses in the study area comprise artificial (4.5%), agricultural (91.0%) and forest areas (4.5%). Among the agricultural areas (248 km^2), 85% corresponds to irrigated surfaces. Related to the artificial land use, Lorca and Puerto Lumbreras constitute the two principal urban areas (Figure 3-4). The population in the basin area reached 107,000 inhabitants in 2012, with a slow decreasing trend since then (data from annual census, Spanish Statistical Office; Ezquerro et al. 2020). The main population centre is Lorca city (nearly 94,500 inhabitants in 2019), which constitutes the third most populated urban area in the Murcia Region. The economy is based mainly on irrigated agriculture, although farming and industrial activities are also weakly developed (Cerón 1995). Agricultural development has led to the overexploitation of the aquifer system (CHS 2007).

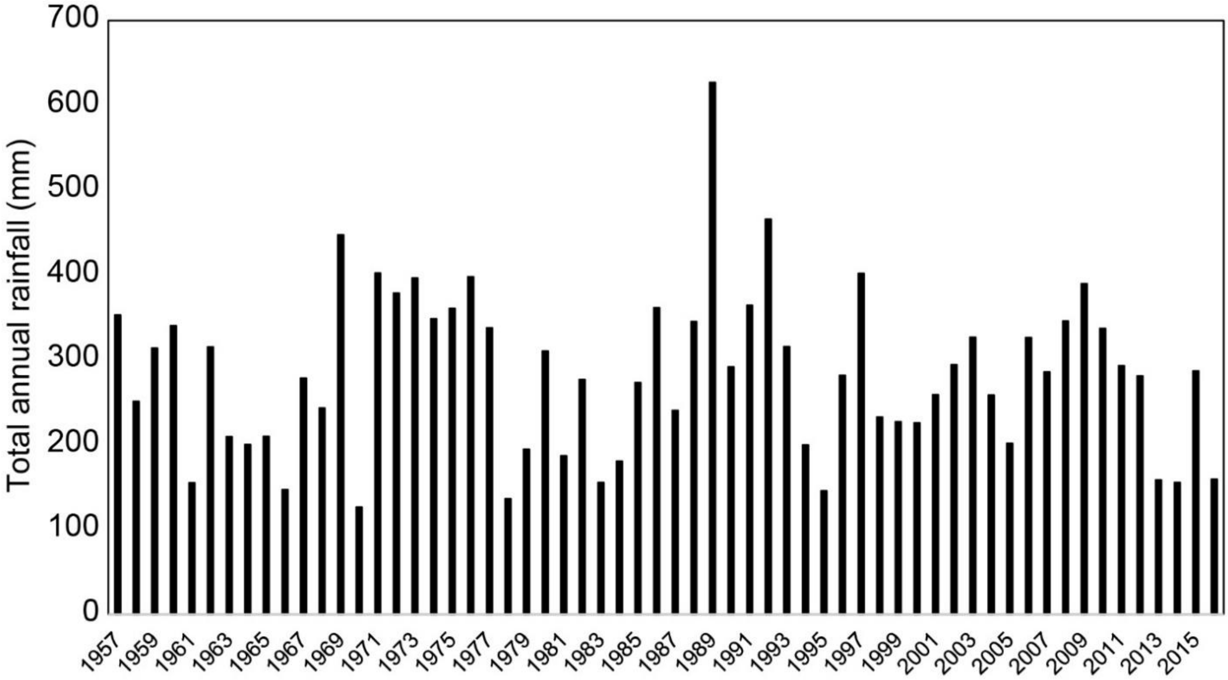

Figure 3-3 Average annual precipitation in the study area (AEMET).

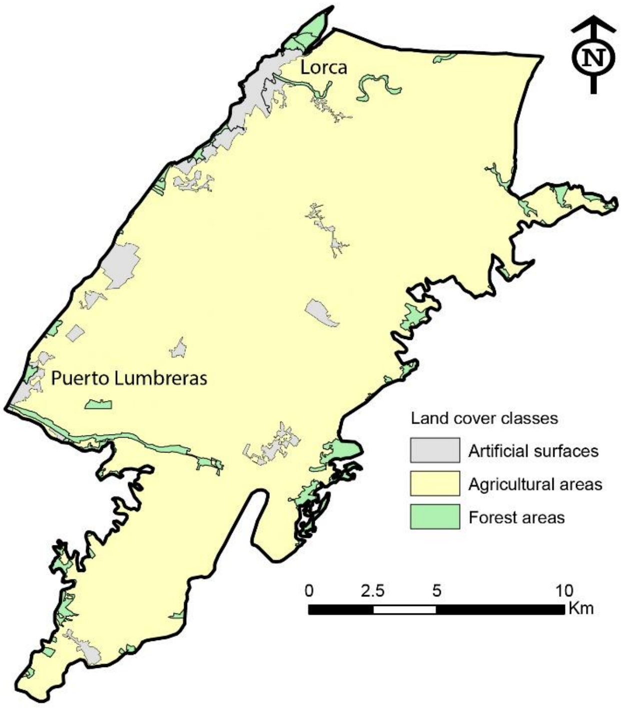

Figure 3-4 Land uses in the Alto Guadalentín aquifer (Corine Land Cover 2018).

3.1.2. Geological setting

The Guadalentín basin is a tectonic depression located in the eastern part of the Betic Cordillera, an alpine orogenic belt resulting from the collision between the African and Iberian Plates (Béjar-Pizarro et al. 2016; Bonì et al. 2015). The ongoing convergence between both plates is responsible for the existence of large and numerous NE-SW faults that appear defining the borders of the valley. These borders are mostly occupied by outcropping MioceneMiocene materials (conglomerates, marls, sandstones) with pronounced dip. Mainly in the left margin of the basin, many normal faults become clearly identified due to the alignment between the filling materials of the basin and the existing materials of the borders. The Alhama de Murcia fault (NW), is the largest fault in the study area. In addition, the fault system Palomares-Almenara also contributes to define the SE aquifer boundary. These fault systems define regions of instabilityinstability and subsidence (Cerón 1995). The basin is a depression with SW-NE direction whichwhich develops from Enmedio mountain to Vega Media Segura basin, the adjacent basin in the NE boundary.

The overlying P-QPlio-Quaternary layers of the basin filling are alluvial materials composed by sand and gravels embedded in a clayed and sandy matrix (Cerón and Pulido-Bosch 1996; Bonì et al. 2015). These filling materials overlap with MioceneMiocene deposits mainly composed (from bottom to top) of marls with conglomerates and sandstones (Figure 3-6). The bottom of the basin consists of PermianPermian-Triassic metamorphic materials exhibiting a horst and graben structure (Cerón and Pulido-Bosch 1996). The average thickness of the filling layers reaches more than 300 m. However, as a consequence of the horst and graben pattern of the bedrock this thickness increases locally up to 900 m.

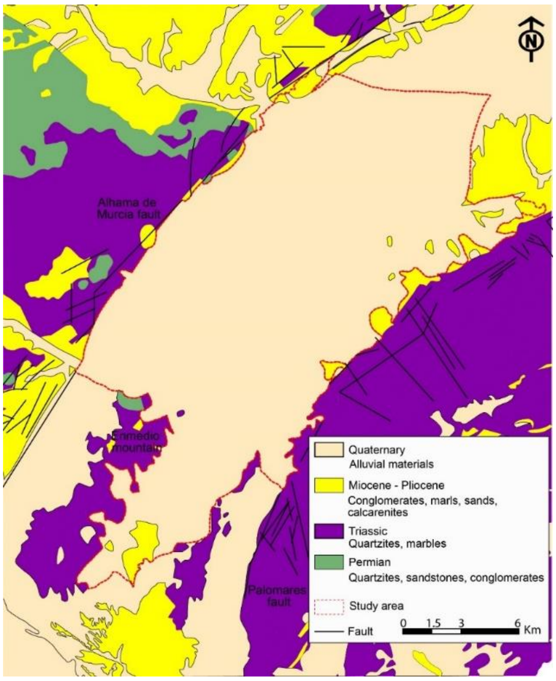

Figure 3-5 Geological settings of the Alto Guadalentín aquifer (modified from Mapa Geológico de España 1:50000).

Geometry of Plio-Quaternary sediments was studied by Cerón (1995) through vertical electric soundings (VESs) resulting in the Figure 3-6 a) thickness map. Recent studies developed by Bonì et al. (2015) have demonstrated that Plio-Quaternary materials can be divided into two sublayers. The shallower layer is comprised of soft soils, clays, and silts, while the deeper one is the coarse fraction of Plio-Quaternary materials, sands or gravels, which constitute the main productive layer. Soft soils geometry was estimated by Bonì et al. (2015) using geological information from 23 boreholes in the basin (Figure 3-6(b)).

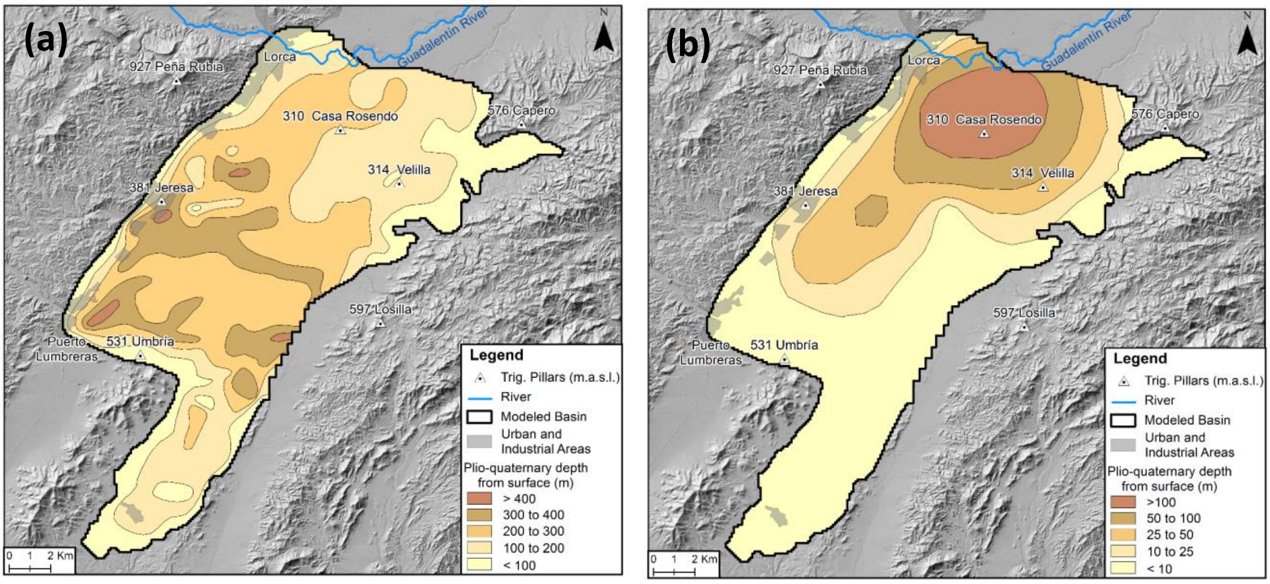

Figure 3-6 Plio-Quaternary materials depth, derived from Cerón (1995). (b) Compressible soils thickness distribution from Bonì et al. (2015).

The Guadalentín hydrographic system responds to a structural control: the main watercourses fit in the geological fracture system, partially controlled by the faults activity in the Guadalentín area. The hydrographic system provokes multiple deposits and geological features (gullies, badlands, alluvial fans, debris cones, glacis, alluvial terraces, ravines, etc.; Cerón 1995).

3.1.3. Hydrogeological setting

The geometry of the aquifer is defined by limits in NW (Permian-Triassic materials), SE (Triassic-Miocene materials) and N. The northern limit is defined by the contact with the multilayer aquifer system of Bajo Guadalentín. The transition zone between the two aquifers is characterized by thick clay layers that lose lateral continuity towards the Alto Guadalentín. The southern border (open) is defined by the contact with the Sierra de Enmedio triassic loamy materials (CHS 2015). The Plio-Quaternary sediments (gravels and sands) define the upper unconfined aquifer layer followed by a layer composed of Miocene detrital materials with conglomerate and sand deposits. This layer constitutes a low permeable semiconfined level. The Triassic materials represent the deepest impermeable limit.

Aquifer-system recharge strongly depends on rainfall (8.80 hm^3/year, CHS 2005). There is an area in the northern part of the basin of 30 km^2 with low permeability materials outcropping at the surface which can be considered impervious and not susceptible to surface recharge. There are also inflows to the aquifer system infiltration and stream infiltration through Guadalentín River, Nogalte Rambla and other minor water courses along the eastern and western margins. Another important source of recharge is infiltration from the irrigation return flow (2.70 hm^3/year, CHS 2005). **Errore. L'origine riferimento non è stata trovata.** resumes yearly water inflows estimated for the period 1960-2012 by Ezquerro et al. (2017).

Table 3-1 Yearly water inflows to the Alto Guadalentín River, estimated for the period 1960-2012 by Ezquerro et al. (2017).

Inflows	Average (hm^3)	Max (hm^3)	Min (hm^3)
Guadalentín River	1.04	2.60	0.20
Nogalte Rambla	1.04	2.60	0.20
W rambla	0.70	1.73	0.13
E rambla	1.39	3.47	0.27
Rainfall infiltration	7.0	26.74	2.23
Irrigation returns Lorca Irrigators Association	2.09	2.83	1.65
Irrigation returns Puerto Lumbreras Irrigators Association	1.55	3.09	0.12

Discharge from the Alto Guadalentín aquifer occurs through the connection with the Bajo Guadalentín aquifer system and the numerous wells pumping its resources. At present, the semiconfined layer is the most productive layer since the upper unconfined layer is mostly depleted. Therefore, the pumping wells that take water from the unconfined layer are, in occasions, nearly 400 m depth. However, in the past, the piezometric level was close to the surface and artesian wells were exploited. The intensive use of groundwater for agricultural purposes since 1960, led to a decline in the aquifer-system levels near 200 m in 50 years (Bonì et al. 2015). Groundwater drawdown became apparent in 1972 (Cerón and Pulido-Bosch 1996). In 1988, the amount of extraction reached maximum historical value of 77.6 hm^3/year (Bonì et al. 2015; IGME 1994). After 1988, a general reduction of pumping and/or abandonment of wells were recorded due to CO_2 pollution of groundwater resources and to new sources of water transferred from the Tajo River to the Segura River (Cerón and Pulido-Bosch 1996). The evolution of the piezometric levels from 1988 to present shows a continuous decrease trend with an average accumulate value of 30 m (Figure 3-7). Nowadays, average value of pumping rates is quantified in around 34 hm^3/year.

Hydrogeochemistry analyses of the aquifer reveal problems of high concentration of chloride and sulphate in some control points. Moreover, there are isolated areas where nitrates exceed 134 mg/l (CHS 2015).

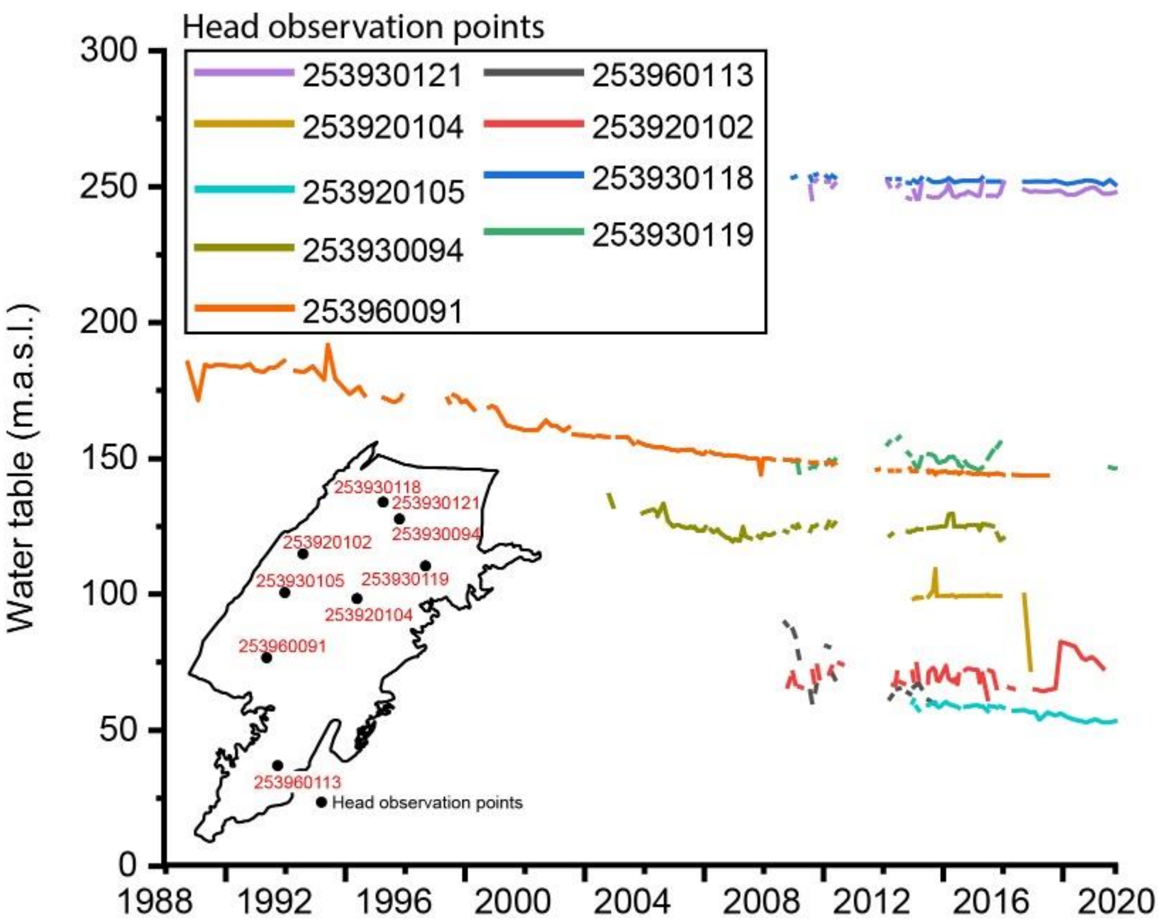

Figure 3-7 Head observation points and piezometric evolution in the Alto Guadalentín aquifer (CHS 2020, http://www.chsegura.es/chs/cuenca/redesdecontrol/estadisticashidrologicas/visorpiezo/visorjs.html).

3.2. GROUNDWATER POLICIES AND REGULATION

3.2.1. Groundwater use

In the area of the Alto Guadalentín aquifer, urban, industrial and agricultural activities accomplish all water demands in the area.

Urban water demands are gathered into two so-called urban units of water demand, codified as USU6 and USU12. USU6 is composed of the municipalities of Lorca, Puerto Lumbreras and Águilas and USU12 of the municipalities of Chirivel, Maria, Vélez-Blanco y Vélez-Rubio. USU6 includes more than 140,000 inhabitants considered as permanent population and more than 6,000 additional temporal inhabitants associated to touristic activities. USU12 is much smaller, with more than 12,000 permanent inhabitants and more than 3,000 seasonal inhabitants. According to the SHP 2015-2021, urban water demands from USU6 arise to 11 hm^3/year (i.e. 146 l/inhabitant·day), which comes from the superficial water resources in the SHD and the Tajo-Segura transfer; no groundwater resources are used in the present, neither is expected to be used in the future to satisfy the USU6 water demands. In the future, desalinated water from Águilas-ACUAMED desalination plant is expected to complement the water resources for the USU6 urban unit. USU12 demands a rise to 1.4 hm^3/year which are completely obtained from the Alto Guadalentín aquifer.

The industrial water demands can be satisfied directly or jointly with urban water networks. Industrial water demands directly satisfied arise to 8.9 hm^3/year in the whole SHD. Additionally, and according to the Lorca City Council, the most important industrial center in the aquifer, 17.8 % of the urban water demands correspond actually to industrial uses.

Regarding agricultural uses, water demands are gathered into two agricultural water demands units, codified as UDA61 and UDA63. Actual irrigated surfaces of each agricultural water demand unit and each type of crop is shown in **Errore. L'origine riferimento non è stata trovata.**. However, the maximum area able to be irrigated is 13,353 ha for UDA61, and 22,829 ha for UDA63.

Table 3-2 Extension of the agricultural water demand units in the area, total and classified by plant types. Units in ha.

	UDA61	UDA63
Total net irrigated area	7319	11484
Winter cereal	761	804
Spring cereal	29	0
Potatoes	73	0
Cotton	29	0
Vegetables	5797	6362
Citrus trees	0	2297
Almond	0	815
Olive	263	861
Other fruit trees	366	345

The irrigation systems used are gravity (36.7% in UDA61 and 2.7% in UDA63), sprinkler (5.4% in UDA61 and 7% in UDA63) and drip irrigation respectively (57.8% for UDA61 and 90.3% for UDA63). The prevalence of the drip irrigation comes from the long-term effort of water authorities and farmer associations to increase the efficiency of irrigation water.

Unit UDA61 includes 8 main users (concession of more than 0.5 hm^3/year) and some other less important users. UDA63 includes 13 farmer associations. Total water demands are 34.18 hm^3/year for UDA61 and 44.16 hm^3/year for UDA63, which are expected to keep constant in the future. In UDA61 water demands are satisfied mainly by superficial water from external demarcations through the Tajo-Segura transfer. Additionally, treated wastewater, desalinated and ground water can be used. In UDA63 water demands are satisfied mainly by groundwater, and to a lesser extent with treated wastewater, desalinated and other superficial water resources. **Errore. L'origine riferimento non è stata trovata.** includes the percentage of each water resource for both UDA61 and UDA63, considering all kind of administrative concession obtained by the different farmer associations in the past. These volumes include the farming industry demands, with an estimation of 3.28 hm^3/year for all farming industries in the Guadalentín Valley, which accounts to 4.19 % of the water resources assigned to these two agricultural water demand units.

Table 3-3 Percentage of the origin of water resources in the UDA61 and UDA63.

	UDA61	UDA63
Superficial	6.4 %	5.0 %
Groundwater	27.2 %	54.0 %
Wastewater treatment plants	4.7 %	4.0 %
Desalination plants	17.5 %	37.0 %
Tajo-Segura transfer	44.1 %	0 %

The SHP 2015-2021 quantifies renewal resources in the Alto Guadalentín River in 11.50 hm^3/year. Among them, 8.8 hm^3/year come from rainfall infiltration and 2.70 hm^3/year from irrigation returns. Additionally, additional inputs corresponding to lateral inflows (1.30 hm^3/year) should be considered in the renewal resources assessment.

In the Alto Guadalentín aquifer water demand for environment preservation does not exist.

3.2.2. Groundwater laws and regulations

3.2.2.1. General description of the legal structure for water management in Spain

Water resources in Spain are considered public. Water management in Spain is based on River Basin Agencies. When a given hydrological basin is interregional, the autonomous organism receives the name of Hydrographic Demarcations (HD), and the water management depends on the Central Government (i.e. Ministry to the Ecological Transition and the Demographic Challenge). On the contrary, when the hydrological basin is entirely located in an Autonomous Community (regions of Spain with Autonomous Government), the water management is a full responsibility of the Regional Autonomous Government.

The Water Law, approved in 2001 as the Royal Decree (RD) 1/2001, constitutes the main legal document related to water resources in Spain. Among others, it defines the structure, functions as well as the economic and patrimonial regime of each HD. The Water Law was later modified by the Law 62/03 in order to incorporate into the Spanish legal system the European Water Framework Directive (2000/60/EC), aiming a common European framework in water management

Water resources management into a HD is defined by hydrological plans (HP), which are reviewed every 6 years (RD 907/2007, and the hydrological planning instruction ARM/2656/2008). Nowadays the HP 2015-2021 is applicable, and it is under development the HP 2022-2027. The Water Law (RD 1/2001, articles 40-42) defines the extension and content of the HP, which must include:

- A general description of the HD, including groundwater and superficial water, the extension of each water body and its water quality and hydrological regimes.
- An inventory of all pressures and water-related human activities and their impact on water resources.
- A general description of all water uses, the priority guidelines and the compatibility of different uses.
- An inventory, description and maps of natural protected areas.
- The monitoring network for the water quality and quantity of all water bodies into the HD.
- The environmental objectives for all water bodies, and a list of activities and programs adopted to reach those objectives.
- An economic analysis of water uses, including the description of the exceptions for this plan.

3.2.2.2. Groundwater regulations for the Segura Hydrographic Demarcation and the Alto Guadalentín

The Alto Guadalentín aquifer belongs to the Segura Hydrographic Demarcation, SHD (Figure 3-1). The territory of the SHD extends over four autonomous regions, so the water management competences for this SHD belongs to the Central Government, assigned, for administrative effects, to the Ministry for the Ecological Transition and the Demographic Challenge. In case of the SHD, the HP 2015-2021 is completely accessible in the Segura DH webpage (http://www.chsegura.es/chs/planificacionydma/planificacion15-21/). The Alto Guadalentín aquifer is identified in the SHD by the code 070.057.

The DHS Hydrological Plan 2015-2021 stablishes the following priority for the different water uses:

1. Urban water supply.
2. Agricultural, farming and industrial uses other than hydroelectrical generation.
3. Industrial hydroelectrical generation.
4. Aquaculture.
5. Others uses not included in the previous ones.

The assigned water volume for the farmer associations working in the Alto Guadalentín aquifer are as follows:

- 4.2 hm^3/year to the irrigated lands already existing in 1953 from the superficial water resources in the SHD.
- 23 hm^3/year from the desalination plant of Águilas-ACUAMED to the Lorca farmer association.
- 5 hm^3/year from the desalination plant of Águilas-ACUAMED to the Puerto Lumbreras farmer association.
- 29 hm^3/year to the Lorca farmer association from the Tajo River transfer.

3.2.3. Groundwater management tools

3.2.3.1. Technical instruments

First surveys in the Alto Guadalentín aquifer were performed at the beginning of 1970's by IGME. From them, several studies have performed piezometric and hydrochemical measurements, as well as pumping well campaigns and first estimations of the aquifer water balance (CHS 1991; IGME 1994; Cerón 1995; CHS 2005).

Nowadays, the SHD maintains two different monitoring networks for piezometry and water quality. The piezometric net consists of 9 piezometers, called 253930121, 253930118, 253920102, 253960091, 253960113, 253930119, 253930094, 253920105, 253920104 in the Hydrologic Plan documents. Measurements are registered several times during the year, but rarely the measurement frequency is monthly. The beginning of measurements varies from 1989 to 2013, depending on the point. Historical piezometric measurements can be consulted in the SHD web page (where these piezometers are the same that the ones mentioned before, but named PA12231, PA12212, PA12203, PA4035, PA12202, PA12213, PA3887, PA12272, PA12267). The aquifer presents a global descendent groundwater level trend until 2009 (Figure 3-7). In 2009 groundwater levels stabilized.

Groundwater quality monitoring networks extend within the whole Segura Catchment. One of them is the Surveillance Program, which measures every three months at two locations of the Alto Guadalentín aquifer. This network assesses the impact of human activities in the groundwater quality and estimates the long-term trends. The other network is the Operative Control Programme. It is focused on the groundwater bodies that are at risk to not achieve a good water quality and detects the presence of contaminants introduced anthropogenically, which is the case of the Alto Guadalentín aquifer. There are two measurement stations from this network in the Alto Guadalentín aquifer. In this second network analysis are performed with annual time interval. The last report about the quality state was published in 2018, detecting high values of nitrates (up to 134 mg/l), conductivity (up to 4933 µS/cm), chlorides (up to 1230 mg/l) and sulphates (up to 1896.7 mg/l). Reference values for these hydrochemical parameters are defined according to results from a statistical study performed on hydrochemical analysis available until 2007 (SHP 2015-21, Anejo II). The origin of this bad quality is attributed to the mobilization of old saline water due to overexploitation and the irrigation with fertilizers. There is also punctual contamination from tanning industries at Lorca whose spill arrives to the Guadalentín River, however, its affection to groundwater is not yet quantified.

There are several old versions of groundwater numerical models performed with MODFLOW (CHS 1991; IGME 1994; CHS 2005) and a new one which has been recently published (Ezquerro et al. 2017, 2020).

To measure sustainable aquifer yield the hydrological planning instruction ARM/2656/2008 defines several indexes:

- Good quantitative state: when the long-term annual groundwater extraction does not overheads the available groundwater resources and when there are not anthropogenic alterations preventing to reach the environmental objectives.
- Good qualitative state: when the groundwater chemical state does not overheads the quality references, there is not saline intrusion and the environmental objectives are reach.
- Renewable groundwater resources: annual value of recharge rate minus the flux to superficial water bodies required to maintain the ecological quality of associated surface bodies or ecosystems.
- Groundwater exploitation index is the rate between the extraction and the renewable groundwater resources. In 2020 this index for the Alto Guadalentín aquifer is of 2.97. In other words, there is no sustainable exploitation of the aquifer.
- Volumetric guarantee: fraction of the demand that is satisfied.

At present the Alto Guadalentín aquifer does not reach neither good quantitative nor qualitative state

3.2.3.2. Managerial and planning instruments

In the Alto Guadalentín area, the responsibility for land use and spatial planning corresponds to the Autonomous Region of Murcia, but the Central Government developed a framework legislation guiding regional laws. This includes, for example, the definition of the requirements of municipal master plans and the definition and content of the different planning instruments. In 2015 the Autonomous Region of Murcia developed its regional spatial plan in the Law 13/2015.

The consolidation and expansion of irrigation in Spain were strongly supported by the authorities responsible for land-use policies (i.e. regional authorities and the central Ministry for Agriculture). From the beginning of groundwater development in the 1970s until today, these public land-use policies have maintained their firm support to irrigation, first through direct subsidies to thirsty crops and then by subsidizing infrastructure to consolidate existing irrigation. Water authorities reacted using the legal instruments established in the 1985 Water Law to counteract the expansion of irrigated areas, but their effectiveness was hindered by limited resources and the lack of political support to curb unauthorized groundwater use (de Stefano et al. 2015). As it was mentioned before, this Water Law was modified in 2001 in order to incorporate the European Water Framework Directive.

It has been already said that responsibilities related to groundwater resources management and their sustainable exploitation correspond to the Segura River Basin authority (SHD), to the Autonomous Region of Murcia and to the Municipalities. As the aquifer was officially declared overexploited, restrictions must apply to users in both the public and private property regimes and no new pumping are allowed. All users in the aquifer are required to organize themselves into Groundwater User Associations. These associations can represent the interests of the users and cooperate with the SHD in the design and implementation of water management plans. However, the practical implementation of these measures is not completed now. Groundwater User Associations are included in the participatory board of the SHD called Public Work Boards and Aquifer Management Boards, which aim to coordinate, respecting the concessions already given, the exploitation and new superficial and groundwater concessions. The proposals from these boards are translated to the SHD. In the Alto Guadalentín aquifer there are three boards related to groundwater uses: "Titulares de aprovechamientos del Alto Guadalentín", "Junta central de usuarios del Alto Guadalentín" and "Junta central de acuífero sobreexplotado del Alto Guadalentín".

The Water Framework Directive (WFD, approved in 2000) constitutes an environmentally oriented legal umbrella requiring EU countries to achieve good status in all their waters – including groundwater – by 2015, or 2027 at the very latest. Consequently, the SHP defines the environmental objectives in the Alto Guadalentín aquifer. However, the WFD allows the definition of different deadlines other that 2027 and to relax sustainable objectives when there is a good justification. Alto Guadalentín is one of these cases, as it is considered that it will not be able to reach a good quantitative and qualitative state in 2027. This has been decided also because environmental impacts of intensive exploitation have been relatively low and, and at the same time, there has been a huge economic and social benefit. Regarding nitrates, the objective is a concentration of 105 mg/l in 2027. In 2015 overexploitation was estimated in 22.2 hm^3/year. The objective proposed by the SHD is an overexploitation of 8.6 hm^3/year in 2027.

The SHP stablishes integrated zones to protected areas in order to facilitate their management. In the Alto Guadalentín aquifer there is one area that integrates the protected spaces from the Red Natura 2000: 6 Special conservation areas and one Special bird protection areas.

3.2.3.3. Regulatory instruments

The Spanish Water Law, from 1985, declared all groundwaters as public domain resources for the first time. The new law left two possibilities to existing groundwater owners: (a) to remain in a transient private regime until 2038 and after that becoming a public concession, or (b) to remain permanently in a private regime. Owners had a 3-years deadline to register themselves in a Catalogue of Private Waters. According to the Water Law, new groundwater exploitations requested after 1986 must be approved by the corresponding Basin Agency (SHD in the case of the Alto Guadalentín aquifer) and registered in a Registry of Public Waters. Drilling works must be first approved by the Municipality and next must be accredited by the Mining Administration of the corresponding Autonomous Community (Autonomous Region of Murcia in present pilot site). There is not any national or regional normative stablishing minimal requirements for the construction and closure of the water wells and boreholes.

As a result of the Water Law, the overwhelming majority of groundwater rights are still private, creating situations of high legal complexity because public and private ownership entails different rights and obligations for users and different legal options and constraints for water authorities. Moreover, now both the Registry of Public Waters and the Catalogue of Private Waters are still incomplete after more than 30 years after its creation. Hundreds of new wells and boreholes have been constructed since the Water Law of 1985 in the Murcia Region, most of them without submitting any application for approval to the SHD, so actually being out of any control. There are not updated and reliable records of existing groundwater uses and total extraction volumes, which makes difficult their effective management (Molinero et al. 2011).

The WFD provides a framework for the protection, improvement and sustainable use of all water bodies in the environment across Europe. These water bodies include surface, underground and coastal waters. The main aims of the Directive are to protect and improve the water environment. This includes preventing the deterioration of aquatic ecosystems and, where possible, restoring ground and surface waters to achieve a "good status" by 2015. Afterwards, on 12 December 2006, the European Parliament approved a new directive (2006/118/EC), known as the "Groundwater Directive on the protection of groundwater against pollution and deterioration". This second directive explicitly reinforces those key aspects of the WFD dealing with groundwater. SHD officially declared that Alto Guadalentín aquifer was at risk of not reaching the "good status" by 2015, and now by 2027. As mentioned above, human activities responsible of this overexploitation and groundwater contamination in this aquifer are mainly irrigation crops. Furthermore, restrictions to users and no new pumping permits must be applied.

3.2.3.4. Economic instruments

Water has a cost associated with the operating, maintenance, correction of the quality, replenishment of facilities and amortization of the economic investment made. There are also environmental costs, though they are not assessed in the Alto Guadalentín aquifer. In the Alto Guadalentín aquifer groundwater has clear economic advantages over other remote water sources, which adds the transport, pumping, and, where appropriate, the temporary storage site. Additionally, the current costs are overloaded by a high price of electricity and the corresponding taxes (VAT).

The average costs of agricultural water in the SHD are 0.05 €/m^3 for surface waters, and 0.2 to 0.3 €/m^3 (800 €/ha) for groundwater (Aldaya et al. 2017). If environmental costs were added, unitary prices would be increased by 0.05 and 0.3 €/m^3 (Garrido and Calatrava 2009). Water costs for horticulture range from 0.15 to 0.75 €/m^3 (Calatrava and Martínez-Granados 2012). In the SHD water payments for irrigation range between 0.3 €/m^3 and 1.2 €/m^3. The cost of regenerated water is in the order of 0.15 €/m^3. Desalinated seawater has a total cost of around 0.8-1.0 €/m^3, depending on the plant efficiency. The final price for the farmer must include the transportation expenses. One example of the water cost variability in the irrigation area of Lorca, within the Alto Guadalentín aquifer, is presented in **Errore. L'origine riferimento non è stata trovata.** (Rey et al. 2015).

Table 3-4 Examples of different costs, paid by the farmers in the Lorca irrigation area depending on their origin (Rey et al. 2015).

Origin of water	Puentes Reservoir	Tajo-Segura transfer	SHD Regulation System	Own wells	Buy rights Tajo basin
€/m^3	0.10	0.13	0.10	0.14	0.20
Origin of water	Third party wells	Treated waste water	Águilas desalinization	Drought wells	
€/m^3	0.25	0.10	0.45	0.27	

Aldaya et al. (2017) quantified the economic productivity of water throughout the whole SHD obtaining values between 0.07 and 6.97 €.

Thanks to the reform of the Water Law in 1999 (Law 46/1999), HD may acquire rights from water holders (Calatrava and Gómez-Ramos 2009), similarly to the water banks operating in the United States (Garrido et al. 2013). The acquisition of water rights allows the reduction of extractions, as well as being less controversial than restrictions policies or consumption quota. However, it has a high cost to the Administration and, by reducing water use, it can be a significant impact on rural employment and economy (Martínez-Granados and Calatrava 2016). In any case, no rights have been acquired in the Alto Guadalentín aquifer. Moreover, the recent development of desalinated resources is an opportunity to tackle this problem at a lower social cost, albeit at a high economic cost that perhaps the agricultural sector could not assume.

The irrigated areas in the SHD represent probably the most productive agriculture in Spain and one of the most productive in the world. The value of agricultural production is approximately 202 million €/year, the net margin is 64.6 million €/year and the agricultural employment generated constitutes 1,263 million of working days per year (**Errore. L'origine riferimento non è stata trovata.**, Martínez-Granados y Calatrava 2016).

Table 3-5 Economic impact assessment of the overexploitation elimination in the Alto Guadalentín aquifer by restricting pumps and buying public rights (Martínez-Granados and Calatrava 2016).

<table>
<tr><th></th><th>Actual situation</th><th>Prohibition of non-renewable extractions</th><th>Acquisition of rights (€/m³/year)</th></tr>
<tr><td>Total water use (hm³/year)</td><td>81.88</td><td colspan="2">74.44
(-9.1%)</td></tr>
<tr><td>Groundwater use (hm³/year)</td><td>36.32</td><td colspan="2">8.72
(-76%)</td></tr>
<tr><td>Extraction reduction (hm³/year)</td><td>0.00</td><td colspan="2">27.60</td></tr>
<tr><td>Desalinated water use (hm³/year)</td><td>7.44</td><td colspan="2">27.60
(+271.0%)</td></tr>
<tr><td>Agricultural production (millions of €/year)</td><td>201.97</td><td colspan="2">189.51
(-6.2%)</td></tr>
<tr><td>Agricultural net margin (millions of €/year)</td><td>64.59</td><td>58.62
(-9.2%)</td><td>69.11
(+6.9%)</td></tr>
<tr><td>Employment (10⁴ working days/year)</td><td>126.26</td><td colspan="2">114.87
(-9.0%)</td></tr>
<tr><td>Cost for the Administration (millions of €/year)</td><td>0.00</td><td>0.00</td><td>10.47</td></tr>
</table>

These authors assessed the economic impact of eliminating overexploitation in the Alto Guadalentín aquifer by publicly purchasing groundwater rights. They also evaluated the option of restricting the extractions of groundwater resources to their renewable fraction by setting quotas (**Errore. L'origine riferimento non è stata trovata.**). This last option has been considered by the Administration, but due to its complexity, high economic costs and reduction of employment, it has been neglected. Considering the imminent availability of resources from desalination in the area, the negative impact of the ban would be reduced.

4. THE GEDIZ RIVER BASIN, TURKEY

4.1. DESCRIPTION OF THE PILOT SITE

4.1.1. Geographical setting

The Gediz River Basin (GRB) is one of the most important and most water-stressed river basins in Turkey. It is located in the Aegean region between 26° 42' - 29° 45' eastern longitudes and 38° 04' - 39° 13' northern latitudes. The GRB has a drainage area of 17034 km^2 and it covers about 2.2% of Turkey's total land area. The GRB is named after its main river reach, the Gediz River, which has a length of about 400 km. The river flows through various morphological settings and fertile agricultural lands, eventually discharging to the Aegean Sea. A topographical map of the GRB is shown in Figure 4-1.

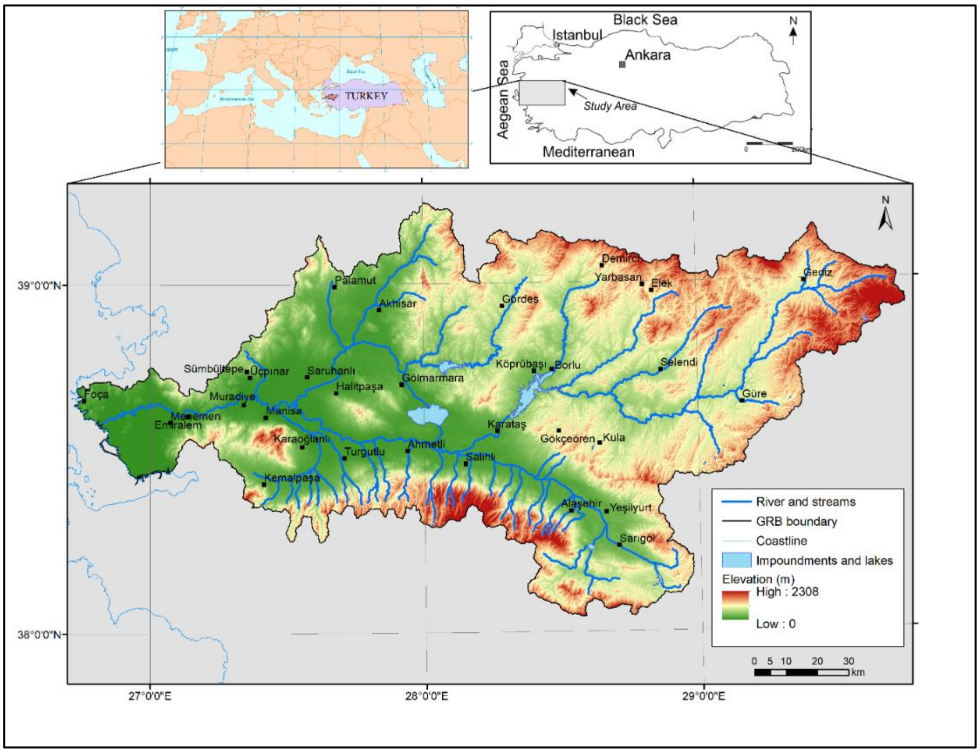

Figure 4-1 Map of the Gediz River Basin.

The basin exhibits a typical Mediterranean climate with hot, dry summers and cool, rainy winters. Long-term mean annual temperature and precipitation are 15.0 °C and 524 mm, respectively (SYGM, 2017). Most precipitation is typically observed in January and February, whereas July and August are the driest months. As of 2016, 1.34 million people live in towns and cities; 483 thousand people live in rural areas within the boundaries of the GRB. The main socio-economical activities are agriculture, animal husbandry, food industry, textile industry, geothermal energy production, and mining. All of these activities are the source of environmental problems that combine with natural factors to exert pressures on both quantity and quality of groundwater resources in the basin.

The land use distribution based on the CORINE2018 database is shown in Figure 4-2. The breakdown for the entire basin is as follows: Agricultural areas 52% (894,546 ha); artificial surfaces 2% (34,093 ha); forests and semi-natural areas 45% (761,972 ha); wetlands 0.3% (381 ha) and water bodies 0.8% (12,965 ha). Within the boundaries of the alluvial aquifer, the land is predominantly used for agricultural purposes.

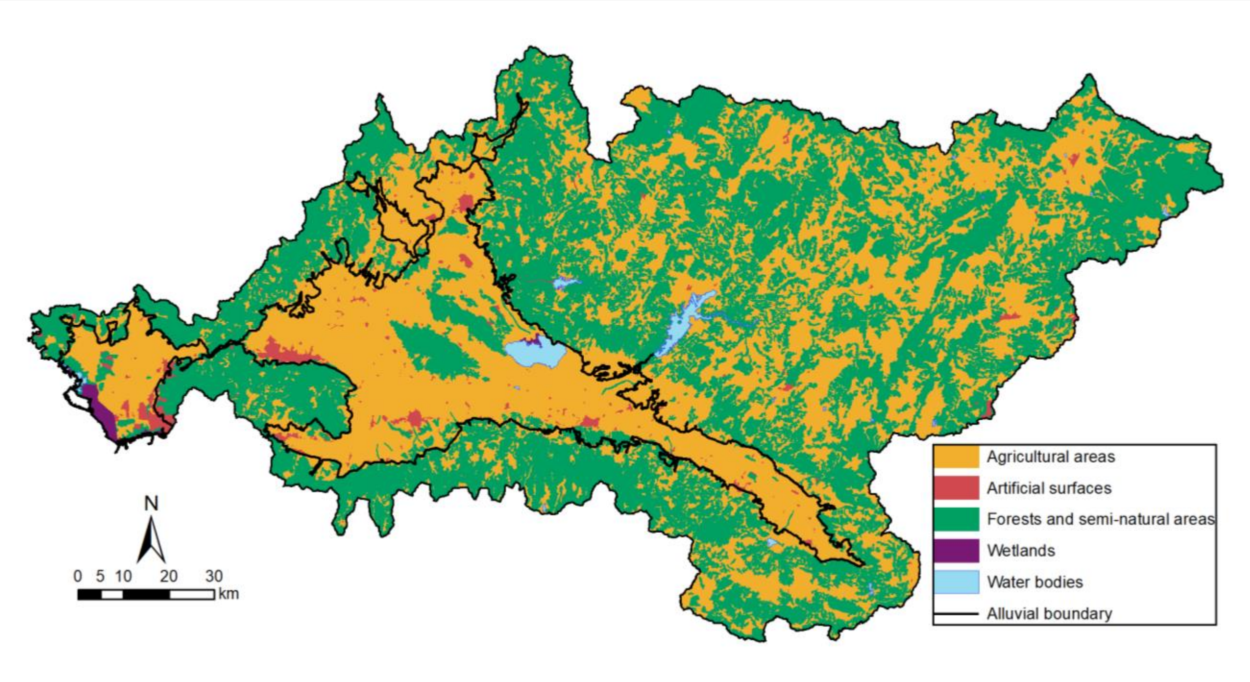

Figure 4-2 Land use map of the GRB and the boundaries of the alluvial aquifer.

4.1.2. Geological setting

The geology of the GRB was recently described comprehensively in a hydrogeological study report (DSI, 2015), and later in a separate study by Bulut et al. (2020) who cite that report. The study describes the basement rocks of the basin made up of metamorphic rocks of the Menderes Massive. "Paleozoic units are unconformably overlain by Mesozoic schists intercalated with meta-conglomerates. These units then overlap with carbonates, while the transition zone is identified by alternating dolomite, quartzite, and calcschists. Massive dolomites overlying these alternating units are located beneath very thick (reaching to 1500 m) massive marbles. The Izmir-Ankara zone, made up of ophiolite and flysch units, is located on top of the Menderes metamorphics by thrust faults. These units are unconformably overlain by terrestrial and lacustrine sequences of Neogene sedimentary units, volcanic and igneous units. Quaternary basalts and alluvium units cover all the above-mentioned base units of the GRB. Basalts in the eastern part of the GRB, specifically in the Kula region, are well-known formations. They comprise approximately 80 volcanic cones of lava and tephra. Other Quaternary units of the basin are the uncemented alluvium, talus, fan, and terrace deposits (Bulut et al., 2020)"

4.1.3. Hydrogeological setting

Hydrogeology of the GRB is classified as 76 groundwater bodies consisting of different lithological units which are mainly sedimentary units such as clay, sand, and gravel; karstic rocks such as limestones and marbles; fractured volcanic rocks and other types of rocks such as sandstone, shale, schist, and gneiss (Figure 4-3). Sedimentary units with extensive and abundant groundwater are mainly formed by alluvial deposits. These units are referred to as the alluvial aquifer of the GRB or the Gediz Plain Aquifer, which is developed mostly in the WNW-ESE directional Gediz graben area. The GRB alluvial aquifer constitutes a significant share of the total groundwater potential in the basin (DSI, 2014).

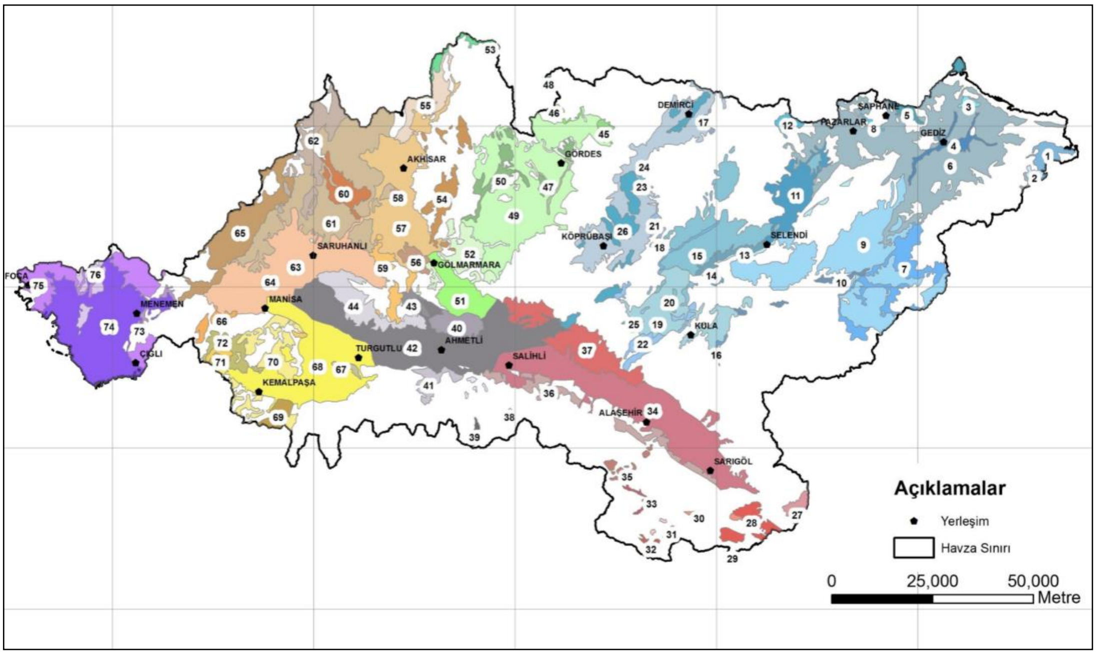

Figure 4-3 Defined groundwater bodies (aquifers) of the GRB (TUBITAK-MAM, 2018).

"The karstic rock groundwater bodies made up of marble, limestone, dolomite, and travertine are described as aquifers providing significant amounts of groundwater. In addition to these karstic units, granular units, which are commonly observed in the basin and are deposited as alluvial sediments, alluvial fans, cones, and slope debris; also have significant groundwater potential. In the basin, groundwater can be obtained with high rates from Neogene aged clastic rock mass, depending on the sandstone and conglomerate levels it contains. Similarly, Neogene aged volcanic rocks in the basin can provide groundwater at the regional and local scale where they have secondary porosity. In addition to these units, clayey limestone units of Neogene limestones in the basin are also used to supply groundwater locally. However, in the regions where the clay content is high, specific capacities of wells drilled in this unit are reduced. On the other hand, Paleozoic metamorphic rocks and Mesozoic flysch units display very low specific capacities and are defined as the units not having the potential to be classified as aquifers. According to the hydrogeological study by DSI (2014), all the aquifers in the GRB are grouped according to their groundwater-abstraction potentials, as follows: Neogene clastic rocks, volcanic rocks, and clayey limestones are classified as lower-yield aquifers of limited groundwater potential; while Paleozoic marbles, Mesozoic and Neogene limestones and uncemented units (alluvium, alluvial fans, talus) were classified as higher-yield aquifers of significant groundwater potential. (Bulut et al., 2020)".

The dominant mechanism of groundwater recharge in the GRB alluvial aquifer is precipitation. Mountain-front recharge and irrigation return flow are secondary mechanisms of recharge. The spatial distribution of recharge is heterogeneous with higher rates observed in the plain. The mean annual groundwater recharge is estimated at 165 mm (DSI, 2014).

Specific capacities of groundwater pumping wells are important indicators of the groundwater productivity of a groundwater body. Based on the analysis of data obtained from 994 well logs, the spatial distribution of specific capacity was obtained for the alluvial aquifer (Figure 4-4). Specific capacity values range from 0.01 to 45.8 l/s per m of drawdown. Higher values can be observed at alluvial fans around the branches of the Gediz River.

Hydraulic conductivities (K) display a wide range of values depending on whether the well is drilled in Neogene sedimentary rocks (flysch, sandstone, and claystone), alluvial sediments (gravel, sand, and silt) or karstic formations (limestones). The observed range of K values for selected wells is reported as 0.05 to 8 m/d. The distribution of K measurements is shown in Figure 4-6.

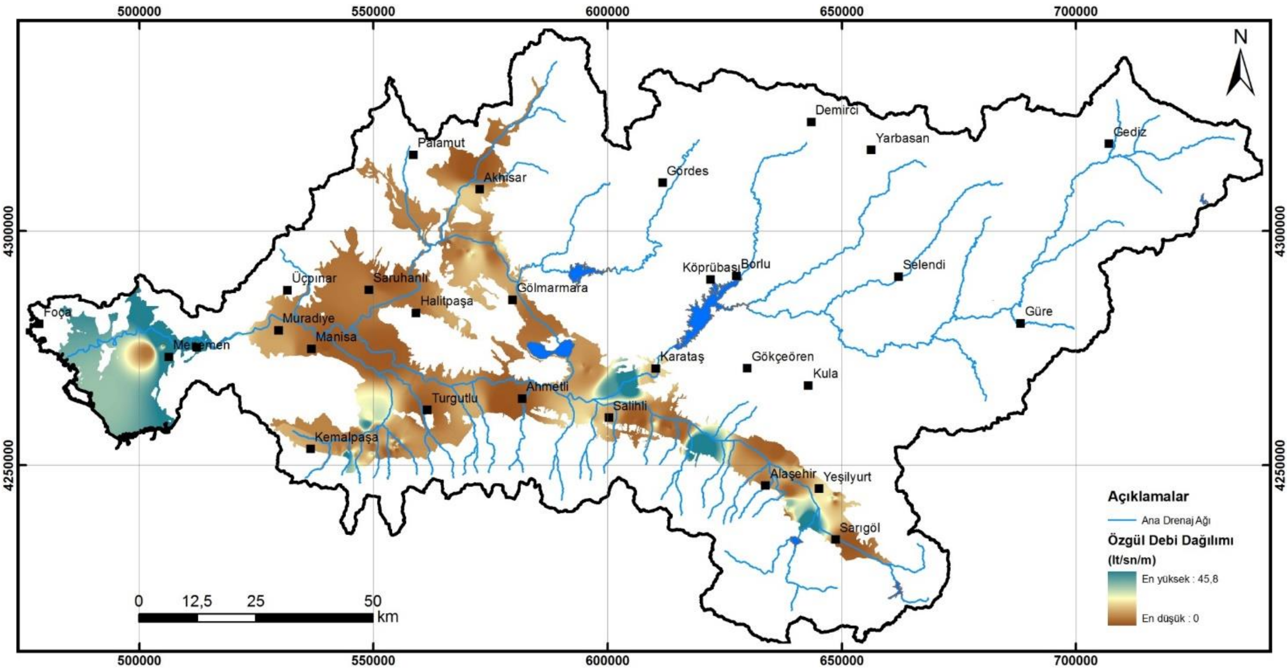

Figure 4-4 Specific capacity distribution of the GRB alluvial aquifer (DSI, 2014) (Translation of figure legend: Ana Drenaj Ağı → Main Drainage Network; Özgül Debi Dağılımı → Specific Capacity Distribution; lt/sn/m → L/s/m; En yüksek → Maximum; En düşük → Minimum).

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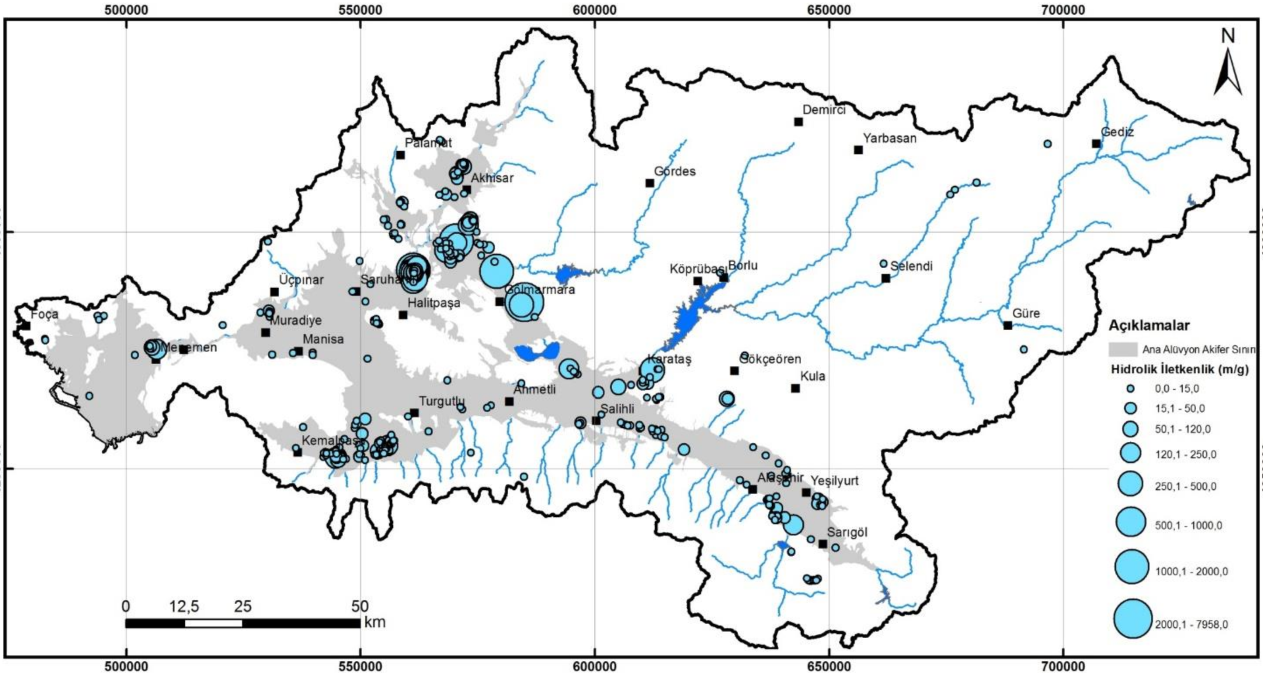


Figure 4-6 Hydraulic conductivity measurements taken from well logs in the GRB (DSI, 2014)).

Over-abstraction of groundwater from thousands of pumping wells caused steady declines of groundwater reserves in the GRB. An analysis of measurements from wells with long time series of monitoring data reveals that there is a decreasing trend in piezometric heads for the vast majority of wells. The average rate of the decrease in head varies between 9.9 and 152.2 cm per year. Figure 4-17 illustrates the decreasing trends in the piezometric head at two selected monitoring well in the GRB alluvial aquifer.

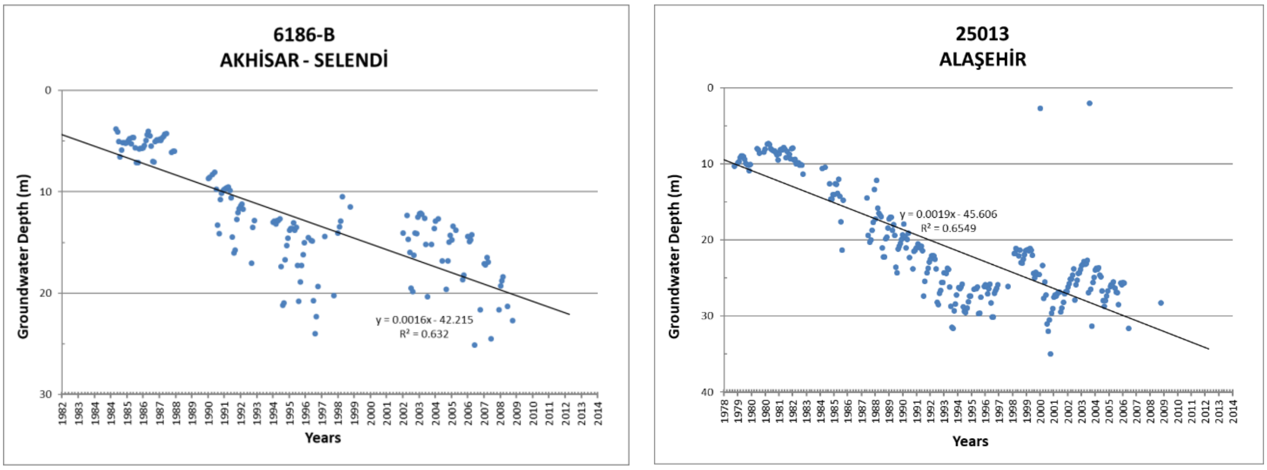


Figure 4-17 Temporal change in piezometric heads in two selected wells in the GRB alluvial aquifer.

4.2. GROUNDWATER POLICIES AND REGULATION

4.2.1. Groundwater use

The agriculture sector is the largest groundwater user since the basin is agriculture-dominant; however, significant competition for water exists among various stakeholders and other sectors. The main socio-economical activities are agriculture, animal husbandry, food industry, textile industry, and mining. According to DSI (2014), an area of approximately 615,102 hectares is irrigated. Most of the agricultural land is irrigated using surface water from reservoirs and smaller impoundments. The main crops cultivated are cotton, grapes, maize, and olives.

The total groundwater withdrawal from all aquifers in the GRB is estimated as 684 million m^3 per year. The fraction of the total withdrawn groundwater used as municipal water, irrigation water, and industrial process water is 18.2%, 71.7%, and 10.1%, respectively. Most of the groundwater (663 million m^3) is pumped out of the alluvial aquifer. The recharge is estimated at 610 million m^3 per year. The breakdown of estimated groundwater use for various purposes is summarized in **Errore. L'origine riferimento non è stata trovata.Errore. L'origine riferimento non è stata trovata.**.

Table 4-1 Estimation of groundwater use in the GRB (DSI, 2014).

Groundwater user	Annual groundwater pumping ($\times 10^6$ m^3)
Municipalities	124.36
Irrigation associations	57.47
Private irrigation well owners	224.45
Unlicensed irrigation wells	206.06
Husbandry farmers	2.53
Industrial facilities	69.12

4.2.2. Groundwater laws and regulations

The first water-related institution in the Republic of Turkey is the General Directorate of State Hydraulic Works (DSI), which was established in 1953. As part of the process to meet EU criteria for accession to full membership, Turkey started negotiations with the EU on the environment and water. During this process, two other main water institutions have been established; the General Directorate of Water Management (SYGM) and the Turkish Water Institute. One of the main responsibilities of the SYGM is the implementations of the EU-Water Framework Directive (WFD) and its relevant guidance documents such as the Groundwater Directive (GWD). Since the establishment of SYGM, new legal structure of environmental protection and water management has emerged that is aligned with European policies. The foundation of some regulations on water management in Turkey is the WFD and its relevant guidance documents.

Contrary to scientific facts, surface water and groundwater resources are traditionally regulated as independent entities. Therefore, a “groundwater basin” is not explicitly defined in regulations, and groundwater bodies are delineated within surface water basin boundaries. In recent years, however, an integrated perspective on water resources is being adopted and holistic approaches in water management are reflected in studies and management plans.

Groundwater in the GRB and for all other river basins in Turkey are administered at the scale of the watershed rather than the scale of the aquifer. The primary laws (acts), by-laws, and legal notices that are currently in force for groundwater governance in Turkey are:

- Groundwater Law (No.167) (16.12.1960); revised and supplemented several times
- By-law on the Protection of Groundwater against Pollution and Deterioration, Official Gazette No.28257 (7.4.2012); revised on 22.5.2015 (Official Gazette No.29363)
- Legal Notice on the Determination of Protection Zones for Aquifers and Springs Providing Drinking Water, Official Gazette No.28437 (10.12.2012)
- By-law on Groundwater Measurement Systems, Official Gazette No.28793 (12.10.2013)
- By-law on Monitoring of Surface and Groundwater, Official Gazette No.28910 (11.2.2014)
- By-law on Protection of Waters Against Nitrate Pollution Originating from Agriculture, Official Gazette No.29779 (23.7.2016)

The Groundwater Law (No.167), which overarches all related by-laws and decrees, was first enacted in 1960 and defines the ownership of groundwater resources and rights of inhabitants sharing these resources. The law imposes that groundwater resources in Turkey are managed by the General Directorate of State Hydraulic Works (DSI, the Turkish acronym). Therefore, the responsibility and granting permission for any kind of action on groundwater resources, including research, exploration, development, use, and licensing are given to DSI. The DSI is along with SYGM one of the general directorates established under the Ministry of Agriculture and Forestry.

Regional Directorates of the DSI are partly responsible for groundwater governance in Turkish river basins. The GRB is located within the jurisdiction boundaries of the 2nd Regional Directorate of DSI, which is based in Izmir. The boundaries of the GRB coincide with surface water catchment boundaries and are not necessarily aligned with aquifer boundaries.

DSI is not the sole authority on groundwater governance in the GRB. The SYGM is also responsible for protecting and sustaining water resources and coordinating the preparation of river basin management plans together with relevant stakeholders (Harmancioglu & Altinbilek, 2020). Furthermore, in each metropolitan municipality a separate public legal entity names water and sewerage administration (WSA), which is affiliated to the related municipality is established. The Municipalities Law (no.5393, 2005) assigns several duties to municipalities, which are for example the supply of drinking water and construction sewerage systems and wastewater treatment plants. WSAs have their own budgets, accounts, and human resources. In this regard, at the regional and city scale, Izmir Water and Sewerage Administration (IZSU) and Manisa Water and Sewerage Administration (MASKI) are the local authorities responsible for wells supplying municipal water for the Izmir and Manisa provinces, respectively. In rural areas where the towns are considered as non-metropolitan municipalities, water and sewerage departments are established that operate as ordinary municipal departments.

Since the Groundwater Law itself does not include provisions specifically for the prevention of groundwater pollution, the Turkish by-law on the Protection of Groundwater against Pollution and Deterioration (YASKBKKY, 2012) was implemented in 2012, which takes the GWD as the basis. This by-law obligates the delineation of groundwater bodies as management units of groundwater resources. Groundwater bodies, as it is defined in the by-law, are distinct volumes of groundwater within aquifers.

4.2.3. Groundwater management tools

4.2.3.1. Technical instruments

Groundwater monitoring in the GRB dates back to the early 1970s in just a few irrigation and water supply wells. The monitoring network has not been consistent over the years, which caused incomplete time series of piezometric head measurements. Currently, groundwater monitoring in the basin is performed using a selected set of wells that are a combination of different types. Most of the wells are large-diameter wells that may be screened over multiple hydrogeological layers. These wells were initially drilled for a different purpose such as for logging of layers or for pumping tests to obtain aquifer parameters. Another subset of monitoring wells is selected among irrigation or water supply wells. Recently, new wells with small diameters were drilled that are specifically intended for groundwater monitoring and are screened only in the phreatic aquifer or the layer below. Some of these wells have automatic water level loggers installed.

Piezometric head in the GRB is measured manually by personnel of the 2^{nd} Regional Directorate of DSI using two different measurement intervals. As of the year 2014, 65 wells are measured monthly and 147 wells are monitored every 6 months. Since 2014, 50 additional wells have been monitored with automatic level loggers using pressure transducers.

As part of a comprehensive hydrogeological study by the State Hydraulic Works (DSI, 2014) a groundwater flow modeling study was conducted. The model was set up as a two-dimensional regional model and for steady-state conditions. Groundwater flow dynamics and the water budget for the alluvial aquifers of the GRB were determined (Elçi et al., 2015). An update of the current flow model or further development to a transient version was never undertaken.

4.2.3.2. Managerial and planning instruments

Groundwater governance in the GRB is fragmented due to the regulations enacted by different institutions at the governmental (ministerial), regional and provincial levels. The GRB is one of the nine river basins that have priority in the 'Action Plan on Groundwater Management'. This action plan was developed in 2013. The river basin management plan for the GRB was prepared between 2016-2018 following the inception of the River Basin Action Plan. The GRB Management Plan (GRBMP) was put in force in November 2018 and is being implemented since then. The GRBMP covers all aspects concerning the management of water in the GRB, including measures to achieve good status of groundwater in terms of quantity and quality. According to the GRBMP, 33 out of 76 groundwater bodies are quantitatively and qualitatively in poor status. Therefore, several measures have been developed and outlined in the GRBMP.

Several managerial instruments are implemented to coordinate, monitor, and assess actions on water resources and to protect groundwater in the GRB:

- Wellhead protection: Water supply wells for municipal water pumping in the GRB are protected by the 'Legal Notice on the Determination of Protection Zones for Aquifers and Springs Providing Drinking Water'. An absolute protection zone with a diameter of 50 m around any drinking water supply well is defined.
- Basin Management Board: Basin management boards are established for all 25 river basins in Turkey. The governor of the province Manisa presides the board and is responsible for coordinating its actions. Members of the board are representatives of various public institutions at the national and regional levels, and representatives of organized industrial districts, universities, non-governmental organizations, and irrigation associations. The board convenes at least once in a year.
- Provincial Water Management Coordination Board: This board monitors and assesses practices of the RBMP in the province. It is presided by the governor of the province. Representatives of various public institutions are assigned as members of the board.

In recent years, the SYGM has developed with the cooperation of private consulting companies a series of plans:

- GRB Sectoral Water Allocation Plan: Provides a comprehensive assessment of the current status of water resources in the basin and presents solutions for fair sharing of water resources among water users while maintaining sustainability and considering potential impacts of climate change.
- GRB Drought Management Plan: Provides feasible measures before, during, and after drought events in the GRB.
- GRB Flood Management Plan: Defines flood risk areas, delineates flood hazard zones, and provides feasible measures to prevent realizations of risk.

4.2.3.3. Regulatory instruments

According to the Groundwater Law No.167, groundwater resources are public waters under the command and possession of the state. Therefore, being an owner of the land does not imply ownership of groundwater under that land. The water user is allocated a share of groundwater after the request for licensing has been approved by DSI. This groundwater allocation serves at the same time as a groundwater cap, which theoretically should not be exceeded. Based on this scheme, the estimated safe yield is divided into groundwater allocations. Consequently, licenses for new wells are almost always granted unless the total allocation of previously licensed wells does not exceed the groundwater reserve (safe yield) of the basin.

Water users in the GRB are required to apply for a well license if the well meets certain criteria in terms of withdrawal depth and pumping rate. Usually the depth to groundwater criteria is more than 10 meters below the ground surface. Groundwater licenses cover only the right to use and they can neither b transferred nor sold.

Furthermore, one of the provisions of the revised Groundwater Law No.167 is the establishment of water meters at pumping wells. However, due to strong opposition from farmers, the enforcement of the meter requirement is continuously postponed. Therefore, this instrument can only be used to a very limited extent on just a minority of the wells.

4.2.3.4. Economic instruments

Volumetric based pricing of water is not implemented for irrigation, whereas it is used for domestic and industrial water consumers. The price for the irrigation water is based on operation and maintenance costs in all irrigation schemes and the pricing practice is per hectare. The user organizations determine the overall water charges considering also the expected investment costs for the year. Irrigation organizations calculate the price by simply dividing the expected costs to the total area irrigated by the farmer. The farmers can invest in sprinkler and drip irrigation systems at their own expense, however, they can apply for government incentives and/or low-interest financing with delayed payment of loans.

As of 2006, the average price charged by irrigation organization was 209 $/ha for pumped irrigation water (Cakmak, 2010).

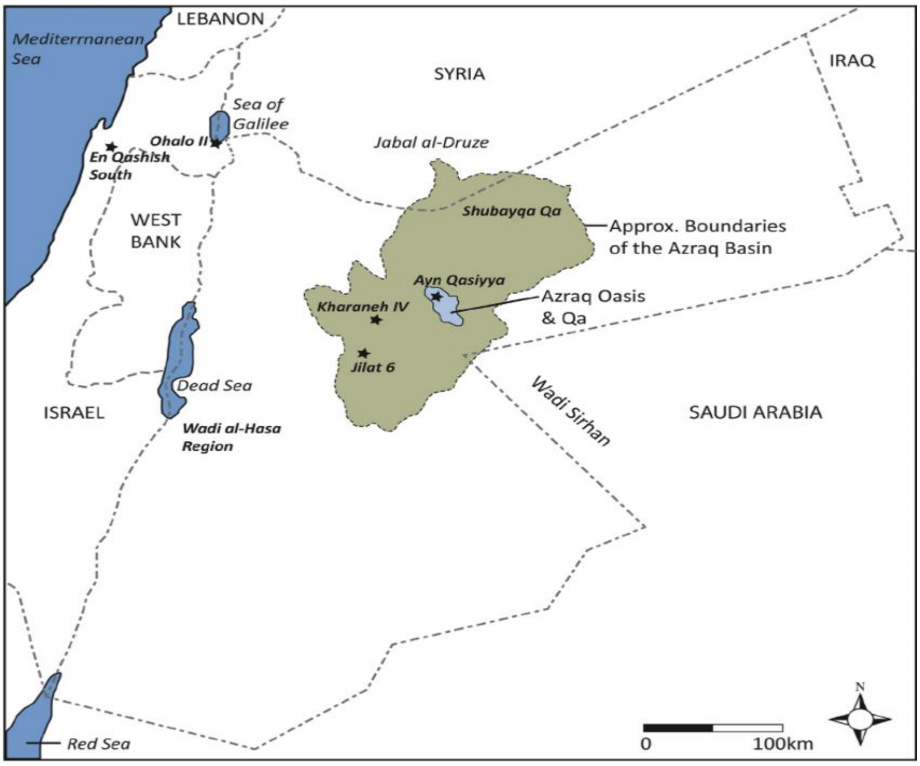
According to the Municipalities Law (No.5393), municipalities in the GRB have the responsibilities for the provision of water and sewerage services, and also setting tariffs and service charges for water services. All registered domestic, industrial customers in metropolitan municipalities are obliged to install water meters, and the water consumption is measured and billed on a volumetric basis regardless of the source of water (User Pays Principle).

5. THE AZRAQ WETLAND RESERVE, JORDAN

5.1. DESCRIPTION OF THE PILOT SITE

Jordan is one of the driest countries in the world and faces a critical water issue. It is heavily dependent on groundwater resources, which constitute 57% of the supply. Groundwater is the main source of drinking water for the Kingdom and the main source of water for irrigation in the Highlands, while surface water is the main source for irrigation in the Jordan Valley. Renewable groundwater resources represent the major source of water supply. Water scarcity has led to significant competition between different sectors, mainly agriculture and drinking water. In 2010, 10 of the 12-groundwater basins in Jordan faced severe over-abstraction, sometimes at about twice their annual recharge rates (or safe-yield).

Azraq is a small village of approximately 15 000 inhabitants located at the very heart of an extensive trans-boundary, renewable groundwater basin in the northern part of the Eastern Desert of Jordan (Figure 5.1). The Azraq Basin forms the largest resources of good quality groundwater in the northeast of Jordan. Intensive pumping through the last 20 years has caused lowering of the basin water table and consequently increasing the salinity of the basin water. Azraq Basin supplies Amman and Zarqa governorates with about 20 MCM/Y. The rest amount of abstracted water is extracted by the farmers and used for domestic uses in the basin area. The Azraq Oasis (called locally Sabkhah or Qa'a Azraq) is located in the heart of the basin and considered as part of RAMSAR site in Jordan according to the Convention on Wetlands (Ramsar Convention, 1971) (Figure 5.1). The oasis is important for the migratory birds; more than millions of birds utilize the area during spring migration every year. However, the oasis is under severe pressure and ecosystem is in far stage of degradation. The main cause of the oasis deterioration over the past 20 years is the overexploitation of the basin. Therefore In 1994, an agreement between the government and the Royal Scientific Society for Nature Conservation was signed to reverse the pumping of water from the Ministry of Water and Irrigation wells into the Shishan pond, which re-created 10-15 % of the Shishan marches.



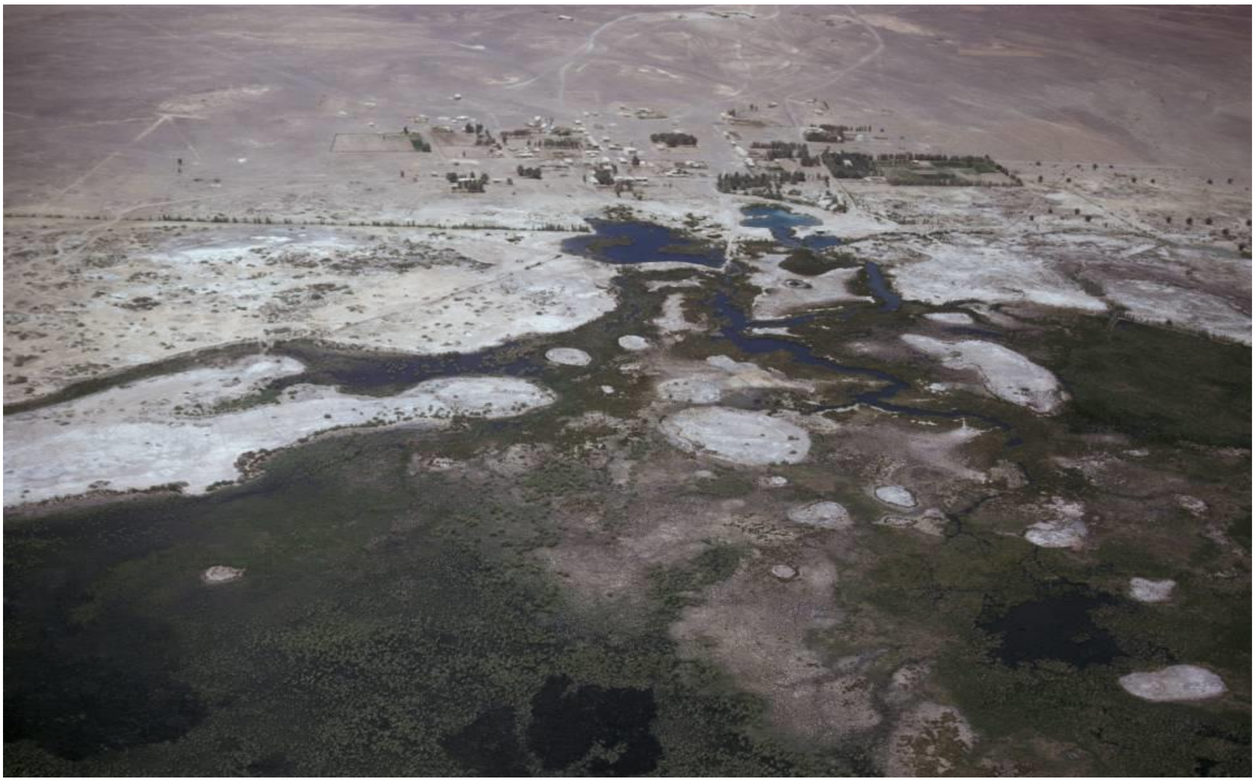


Figure 5-1 Azraq Basin, Azraq Oasis

5.1.1. Geographical setting

The Azraq Basin is located in the North-eastern part of the Jordan with an area of 12,710 km^2. The largest part of the catchment (94%) is in Jordan with smaller parts in Syria (5%) and Saudi Arabia (1%). The basin covers three Jordanian governorates: Zarqa governorate represented by Azraq district; Mafraq governorate represented mainly by a part of North Badia district; and Amman Capital governorate represented mainly by a part of Al Jiza district.

The climate of Azraq Basin is characterized by hot and dry summers, leading to very high evapotranspiration rates (80-90%). The winters are wet and mostly cold. The mean annual rainfall within Azraq Basin ranges from 100-150 mm in the west and north sectors, 50-100 mm in the middle of the Basin to less than 50 mm in the South. Only 5% of the Jordanian territory receives enough rainfall to support cultivation; therefore, most lands require complimentary irrigation.

Agriculture is currently the largest consumer of water, while farmers irrigate less than 10% of the total agricultural land. Agricultural demand of water represented 56% of the total water demand in 2016. The predominant landscape is bare soil or rock. Plant-covered land (natural vegetation and irrigated areas) are limited to the oasis and to the foothills of Jabal Al-Arab in the South of Syria. The Azraq Oasis is located in the center of the basin. The Oasis area is a depression with a central mudflat (Qa'a or Sabkha), that is occasionally inundated. It stands at a distance of about 120 km northeast of Amman. Azraq Oasis was an example of a wetland in an arid region, but it dried out in the early 1990s.

5.1.2. Geological setting

The Azraq area seems to have developed as a basin during the Paleozoic, testified by the total thickness of both Ram and Khreim Groups in the Azraq subsurface being slightly less than twice those in the southern outcrops did. In this case, the Azraq Basin is similar to the Wadi Sirhan Basin. From the Carboniferous, Late Paleozoic, to the top Ajlun Group, Mid Cretaceous, no basinal development took place in the Azraq area. Dramatic changes seem to have taken place in the Azraq Basin during the deposition of the Belqa Group. Northwest-trending faults became active since the Coniacian, such as the Fuluk Fault and Rajil Fault. A subsiding graben, called Hamza Graben, was the scene for a thick, fast sedimentation of more than 2000 m during the Coniacian-Campanian represented by the Rajil. Hamza and Hazim Formations that are dominated by carbonates. This is explained by synsedimentary deposition in a subsiding basin. The basin continued up till the Eocene albeit being at a slower rate during the rest of the Belqa Group. By the end of the Eocene, the Neo-Tethys Ocean had migrated from the eastern Mediterranean and the Azraq area, as well as almost all Jordan, and the area became terrestrial, and subjected to erosion. The Azraq Basin continued as a depression where lake deposits formed from the Miocene onwards. The large recharging area of the Azraq depression seems to have ensured enough water for the marches and springs of the Azraq oasis even in the driest climates in the past, which made the oasis a refugia for hominins and animals throughout the Pleistocene time. Azraq Basin in general is a part of the limestone plateau in east Jordan. As shown in Figure 5-2 the northern part of this plateau is covered by six basalt flows, tuff and volcanic eruption originated mainly in Jabel Arab in Syria and many other relatively small volcanoes in the area occurred during the Miocene-Quaternary. These flows overlie Tertiary rocks in the northern part of the catchment area. The youngest sediments in the Qaa' consists of gravels and sands of fluviatile origin (NRA, 1992). The outcropping formations are, the Rijam and wadi Shallala in the central and eastern part of the basin, both of Eocene age.

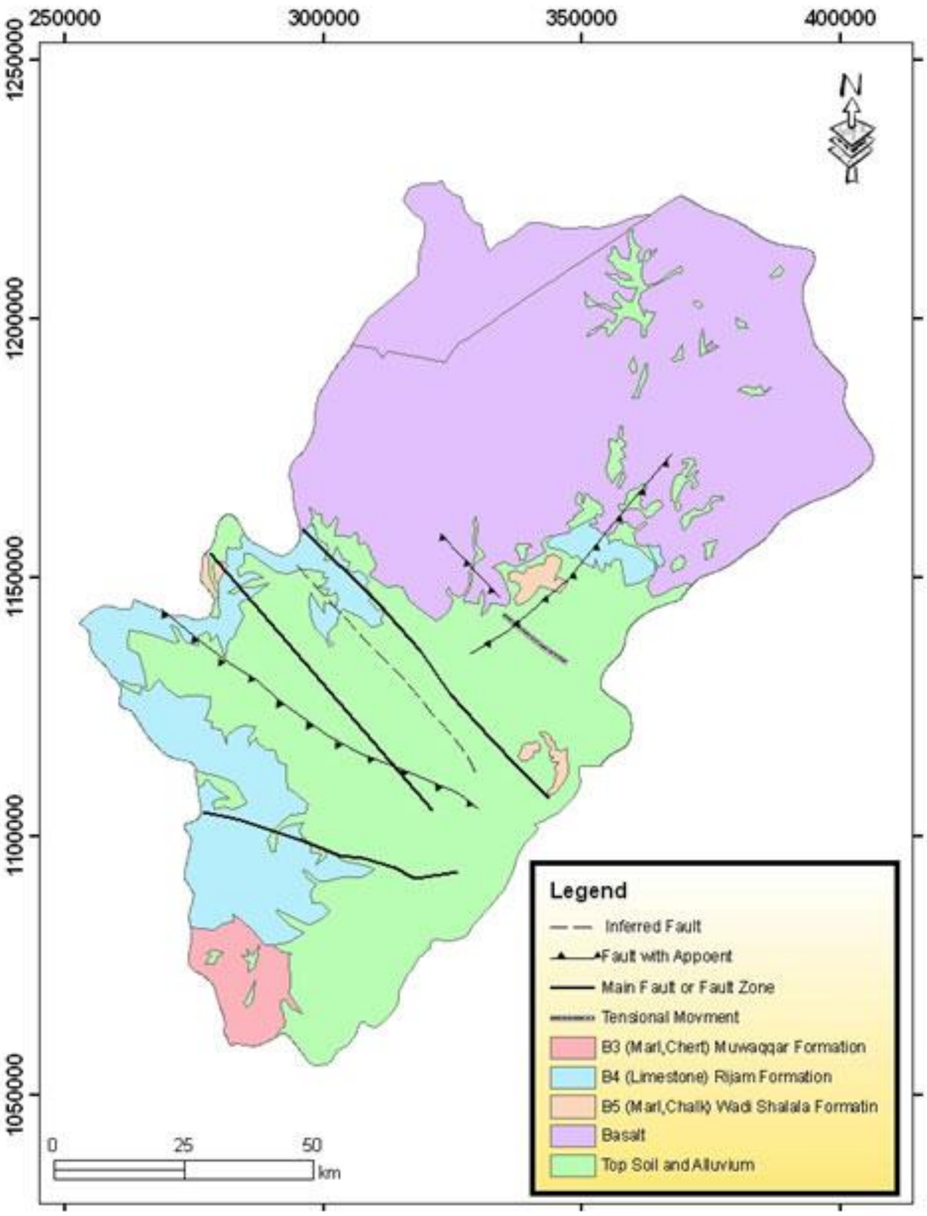


Figure 5-2 Geology of Azraq Basin

The northern part of the Azraq basin is dominated by Miocene to Pleistocene basalt whereas to the west and south by Rijam and Muwaqqar formations of late cretaceous- Early Tertiary age. Regional distribution of the outcropping geological formations is shown in Figure 5-2. The area as the whole of Jordan was affected by the transgressions and regressions that occurred during the time from Cenomanian until upper Eocene (NRA, 1992). These transgressions and regressions are represented in the Azraq Basin by the changes of facies in the Ajlun Group (limestone, dolomite, marl, shale and dolomitic limestone) and Belqa Group (marl, limestone ,chert, silicified, limestone, dolomite and chalk),that crop out in the central, western and southern part of the basin. During the period from upper Oligocene and into the lower Miocene, the Azraq Basin has gone under erosion and tectonic activity (Bender, 1974). In the Azraq playa (wetland reserve), the basalt is missing. Upper Tertiary sediments (B5) (Wadi Shallala) are located in the structural depression zones. The (B5) Formation consists of Marly Clayey layers in the area of AWSA well field and acts here as an aquitard between the B4 (Rijam) and the Basalt aquifer. Towards the southeast, the B5 Formation contains more sandy layers and it is classified as an aquifer in this area. South of the basalt areas Paleocene and Eocene,marly limestone, chalks, and chalky limestone with chert layers of the B4 formation, dominate the landscape. The B4 formation is underlain by the Maastrichtian B3 (Muwaqqar) formation. B3 formation reaches a thickness of about 300 m and consists of marl and marly limestone with some gypsum and evaporite. The underlying Campanian to Turonian B2/A7 formations (Amman/Wadi Sir) is mainly formed by chert and limestone, (El Naqa, 2010).

5.1.3. Hydrogeological setting

The groundwater in the Azraq Basin is found in different aquifer systems ranging from recent deposits to deep sandstone aquifer complexes:

1.The upper aquifer complex (Shallow Aquifer Complex), which is composed of the Quaternary sediments, basalts, Shallala and Rijam formations. The B4 layer and the basalt are part of this aquifer complex. The thickness of the basalt increases towards Jabal Al-Arab in Syria, where it may reach approximately 1500 m. The Quaternary sediments are of great importance in the farming areas northeast of Azraq Druze and east of the Azraq Qa'a. Most of the hand-dug wells are in the top 10 m of this formation and are used for irrigation. Comparing the transmissivity of the basalt with that of the B4, a significant difference can be detected. The recharge rate in the basalt part is higher than in the B4 part. This upper aquifer is a very important aquifer because the groundwater quality is relatively good (however, the salinity of the water from the basalt aquifer is usually low). Drilling costs are relatively low compared to the rest of the areas in the Kingdom, and the aquifer is renewable.

2. The middle aquifer complex (Upper Cretaceous Aquifer Complex) is divided into several layers from A1/2 to B3. It is relatively old, dating back to hundreds to thousands of years. The layer A7/B2 is part of this aquifer complex. The A7/B2 unit is by far the most important aquifer in Jordan because of its vast extent and its favorable auriferous properties. In the central part of the Azraq Basin (the Amman-Wadi Sir system A7/B2), water is mineralized and sulfurous and is of generally poor quality, with total dissolved solids concentrations ranging between 800 and 2,500 mg/l. In the western and northwestern rims of the basin, the quality is good with total dissolved solid concentrations ranging between 200 and 500 mg/l. The depth of the aquifer is more than 600 m.

3. The lower aquifer complex (Deep Sandstone Aquifer Complex) is represented by the Disi group aquifer. The water is also old (the aquifer was recharged during the last humid period, probably about 5000 years ago). The depth of the aquifer lies at more than 800 to 900 m from the ground surface. The water extraction costs are very high because of the depth and the bad quality of the water.

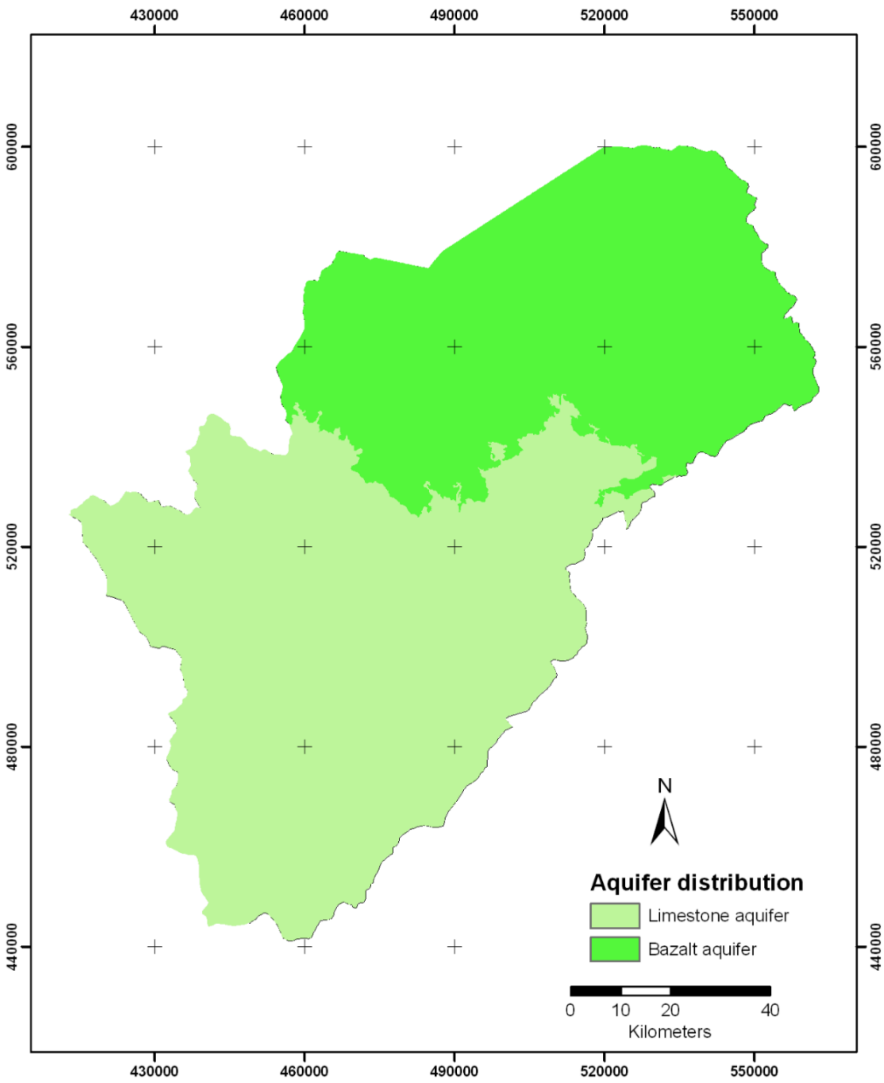


Figure 5-3 Hydrogeological Formations in Azraq Basin.

Data available about Azraq Basin groundwater was limited to the upper and middle aquifers. Therefore, modeling is focused on the first two aquifers. Accordingly, the domain representing the simulated area was divided into three overlain layers for groundwater flow: upper layer representing the B4/B5 formation (upper aquifer), middle layer representing the B3 formation (aquitard) and lower layer representing the B2/A7 formation (middle aquifer). These layers, in addition to the surrounding boundaries (e.g. no-flow), are distinguished from each other by the hydraulic conductivity for each cell in its field. Hydraulic conductivity values for the layers are presented in **Errore. L'origine riferimento non è stata trovata.**. Water flow in the model starts from the domain boundaries and ends at the center of the domain, where springs and extraction wells are located.

Table 5-1 Ranges of calibrated hydraulic conductivity.

Formation	Hydraulic conductivity (m/day)
B4/B5	1.5-3.5

B3	0.008
B2/A7	0.09-2.0

The Azraq Basin's safe yield has been established at 20 Mm^3 in 1987 and later modified to 24 Mm^3 per year. The main recharge of the upper aquifer system originates from infiltration through the basalt layers from high rainfall areas at Jabal Al Arab in southern Syria. Intensive thunderstorms and flash floods in the Azraq basin are also minor contributors to groundwater recharge. The estimated total recharge is about 34 Mm^3/year. Water consumption in Jordan already exceeds renewable freshwater resources by more than 20% and, after the year 2005, freshwater resources are likely to be fully utilized. Over 50% of supply derives from groundwater and this focuses on a small part of the northern Badia region of Jordan that is underlain by the Azraq groundwater basin where it has been estimated that annual abstraction stands at over 100% of the projected safe yield. While water supply is a crucial issue, there is also evidence to suggest that the quality of groundwater supplies is also under threat as a result of salinization and an increase in the use of agrochemicals.

5.2. GROUNDWATER POLICIES AND REGULATION

5.2.1. Groundwater use

Groundwater in Azraq has been used since the early 1960s by several sectors for different purposes: domestic, industrial, agriculture and environmental use. Groundwater in the Azraq Basin is a major source for drinking water for the cities of Amman, Irbid and Zarqa as well as the Azraq area itself. Via a series of well-fields, the government abstracts about 23 Mm^3 of groundwater from the Azraq Basin every year for drinking purposes. Irrigated agriculture is the major consumer of water in the basin with an estimated abstraction volume of 28 Mm^3 of water per year, nearly the equivalent of the basin's safe yield (24 Mm^3 per year) (Figure 5-4, Table 5-2). Modern groundwater-fed agriculture was developed in the 1970s with the introduction of the diesel engine and the availability of modern irrigation techniques such as drip and sprinkler irrigation systems. Before that, users depended on traditional surface irrigation techniques and traditional shallow wells with low abstraction rates for subsistence agriculture. Modern irrigation techniques first spread in the Jordan Valley when agriculture was still incipient in the Highlands (especially Azraq). When modern irrigation techniques extended to the Highlands, well-drilling techniques had also improved and energy costs had been lowered, while land was cheap and easy to access and water quality was still good. All these factors helped make agriculture the first investment option in Azraq. Such expansion was also fueled by the government who freely awarded licenses for wells in the 1980s and early 1990s causing agriculture to dramatically expand in the Highlands.

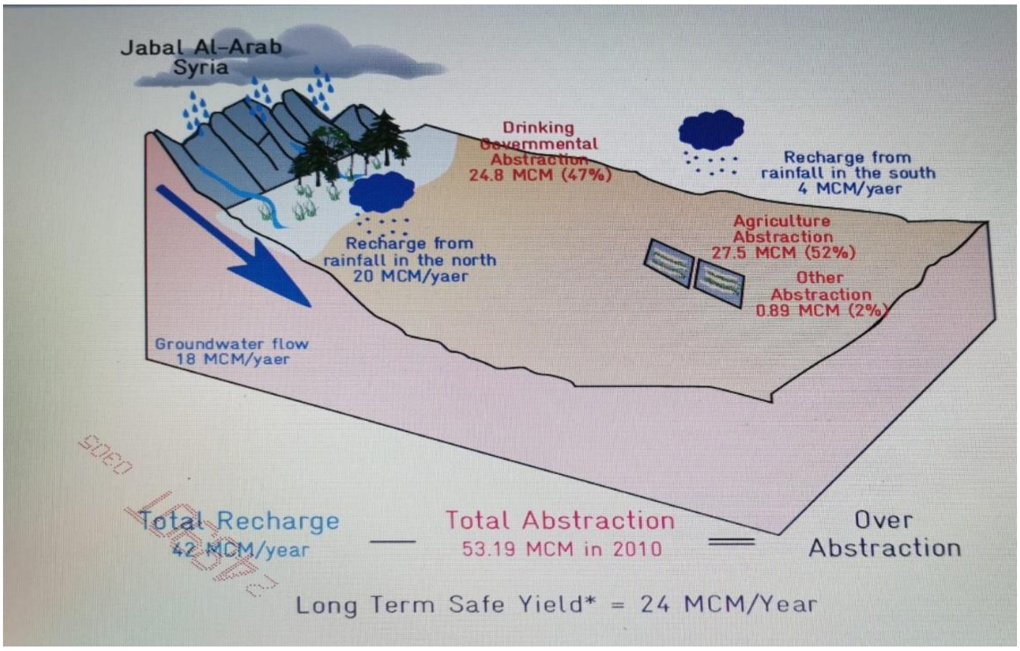


Figure 5-4 Recharge and water uses

Table 5-2 Groundwater usage in Azraq Basin from the registered legal and illegal wells in 2009 (MWI, 2009).

	Abstraction rate (MCM 2009)	Safe yield MCM	Abstraction rate %
Private drinking wells	0.32	N/A	N/A
Governmental drinking wells	22.9		
Industrial purpose	0.35		
Agricultural purpose	28		
Rural area	0.09		
Total	51.66	24	215%

5.2.2. Groundwater laws and regulations

The Ministry of Water and Irrigation (MWI) is the official body responsible for the overall monitoring of the water sector, water supply and wastewater system and the related projects, planning and management, the formulation of national water strategies and policies, research and development, information systems and procurement of financial resources. Its role also includes the provision of centralized water related data, standardization and consolidation of data. The MWI will be described in section 5.2.3.2.

Three main types of land ownership are to be found in Azraq. First, owned by the state (miri). State lands are officially under the custody of the state but are traditionally known to be 'owned' and claimed by tribes, but without a legal deed from the Department of Land and Survey. Second, the land settlement procedure largely follows the land settlement rules carried out by the British between 1930 and 1950, and later enshrined in the 1952 Land and Water Settlement Law. A group of persons can request the opening of a land settlement process, if they together claim an area of no less than 6 km^2. The request is first reviewed by the Governorate and then by the Department of Land Survey (DLS), which checks the status of the claimed land and the conformity of the request, and forwards it to the prime minister for approval. The settlement must be announced in the newspapers and in public places and starts by a survey of the area and the attribution of numbers to all plots and hawds ('basins'), and by listing present persons using/claiming the land in a 'field book'. Third, the 'delegation' of land (tafwid) is ruled by Law No. 17 of 1974 and Law No. 53 of 1977. Individuals, private or public companies can rent state land from the government in order to build, cultivate or make a project on it. Would-be renters should present their project through an application directly to the DLS director. If the land is 'delegated' for agricultural purpose it should be rented for a minimum of five years before it may be registered legally under the beneficiary's name, although the latter cannot buy or sell it during the following ten years after its registration The maximum area that can be delegated varies according to the location of the land and can be up to 500 dunum in desert lands in the east. Tribes and settlers take advantage of this law to occupy land, reclaim and cultivate it, and then claim it officially.

5.2.3. Groundwater management tools

Well control can be achieved using different tools such as introducing a well registry and/or permit system, defining a minimum spacing between wells, or delineating prohibition areas were aquifers should be conserved. New technologies are adopted to assist in groundwater management, like GIS and remote sensing which help control illegal well drilling and cultivated area expansion. All Arab countries have introduced a registry system for wells whereby licenses or permits are required. Different licenses are sometimes granted for the act of drilling/constructing the well first, and then for exploiting the well (e.g. Lebanon, Jordan). The procedure for obtaining well licenses may vary from country to country: in Yemen for example, wells should have licenses permitting a specific amount of abstraction under the Manage supply, Deepening/cleaning wells, Water harvesting, Artificial recharge (injection), Water harvesting structures, Bring substitute surface water or treated/desal water, Licensing wells, Prohibition zones, Well spacing ,Backfill illegal wells, Control drillers, Buy out wells, Ban new wells, Sanctioning, Do not allow deepening/rep., Community rules, Revert to rainfed, Subsidize micro irrigation (& control expansion), Awareness raising ,Water pricing, Control electricity grid, Restrict crop type, Impose quotas (per ha, per well), Input or output subsidies Policy objectives, Micro irrigation, Change crops, Collective rules, Control the number and expansion of wells, Control abstraction by existing wells.

In Jordan, drilling first requires a permit and all working wells should then have licenses or permit and a metering system. Each well has its own specificity in allowable water abstraction and fees for water use (Molle et al., 2017). Oftentimes, when registration systems are established or tightened up, the question of the legalization of existing wells comes up. As documented by Molle and Closas (2017) for countries like Morocco, Jordan, Lebanon, but also Mexico or South Africa, this is a tedious and never fully achieved process. In Jordan, a driller permit is issued for a period of one year and it is subject to yearly renewal, with penalties in case of illegal practice Yet, such regulations have been insufficient to wipe out illegal well drilling.

5.2.3.1. Technical instruments

Azraq Basin, being one of the largest basins in Jordan and a viable drinking water resource, witnessed a dramatic increase in water demand over the past four decades. This led to an over-abstraction from this aquifer, which in turn resulted in deterioration of its water quality.

Numerous methods of assessing groundwater vulnerability have been developed over the past 20 years (Morris et al. 2003). All of them based on selected parameters describing climatic, soil and hydrogeological properties that affect the leaching of contaminants. These methods are used to create zones of equal hydrogeologic properties based on scores or qualitative ratings that assigned to each relevant hydrogeologic parameters affecting vulnerability.

The three-dimensional groundwater flow model MODFLOW was applied to simulate water level change in the complex multi-aquifer systems (the Upper and Middle Aquifers) of the Azraq basin. The model was calibrated by matching observed and simulated drawdown for steady and transient states over the period 1970–1992. Drawdown data for the period 1993–1997 were used to test the model's ability to predict the response of the aquifers. The model performed well in representing the water level contours of the Upper and Middle Aquifers for steady state calibration. Agreement between the observed and simulated drawdowns was obtained for transient state calibration. To predict the aquifer system responses for the period of 1997–2025, four different pumping schemes (scenarios) have been investigated. The first scenario (present pumping rate) reveals that there will be approximately a 25 m drop in the water level at the well-field area in 2025. However, the worst scenario (pumping rate at 1.5 times the present rate) reveals an approximate 39 m drop in the water level at the well-field area in 2025. The safe yield for the Upper Aquifer System was found to be about 25 million cubic meters (MCM) yearly (Abdulla et al., 2000).

5.2.3.2. Managerial and planning instruments

Groundwater is the main source for water supply in Jordan. Surface water is limited due to low precipitation rates.

The Ministry of Water and Irrigation (MWI) is the official body responsible for the overall monitoring of the water sector, water supply and wastewater system and the related projects, planning and management, the formulation of national water strategies and policies, research and development, information systems and procurement of financial resources. Its role also includes the provision of centralized water related data, standardization and consolidation of data. Since its establishment in 1992, MWI has been supported by several donor organization projects that have assisted in the development of water policy and water master planning as well as restructuring the water sector. The Ministry of Water and Irrigation MWI embraces the two most important entities dealing with water in Jordan: The Water Authority of Jordan (WAJ): WAJ is a financially and administratively autonomous body, established in 1988 under the Water Authority Law No.18, with the full responsibility of carrying out water and wastewater projects in Jordan. The Jordan Valley Authority (JVA); responsible for the socio-economic development of the Jordan Rift Valley (north and south of the Dead Sea), including water resources development, management, distribution of irrigation water, land reclamation and development, tourism development and environmental improvement and protection. JVA is mandated to plan, design, construct, operate and maintain irrigation projects, dams and hydroelectric power stations in the Valley.

5.2.3.3. Regulatory instruments

Since its establishment in 1992, MWI has been supported by several donor organization projects that have assisted in the development of water policy and water master planning as well as restructuring the water sector. The law states that water is public property and under control of the government. In the early 1990s, the MWI established a law prohibiting the drilling of new wells in most parts of the country, where aquifers were afflicted by depletion and quality degradation. The MWI was carried out all over the country to register wells, measure coordinates and obtain information on depth, water level, year of drilling, water use, etc. As a result, the Ministry has established a databank to register nearly all wells in the country whether they are licensed or illegal. The total number of wells in 2000 was 2,449; of which 1,830 were used for irrigation, 450 for municipal supply and 169 for mainly industrial uses. The MWI also took an important step to install meters on all wells including those used for irrigation. The first objective was to measure the abstracted volume of water from all wells. The second objective was to remind farmers that they are allowed to abstract only the amounts of water stated on their drilling licenses. Farmers resisted the installation of meters and some of them even destroyed meters at the beginning. To address the issue, the Ministry announced it would close any wells in which the owner hindered or destroyed the installation of the meter. Now, the Ministry is proud of the fact that the enforcement rate is about 95%. Farmers were also asked to pay for the amount of water exceeding the limits in the licenses. As a result, farmers gradually stopped selling water to others. Prior to this, they would frequently abstract water not included in the licenses for trade (MWI 2001).

5.2.3.4. Economic instruments

In 1998, a new regulation was issued, charging a price for all extracted groundwater for municipal, industrial, and commercial uses, excluding irrigation. The charge was a flat rate of US$ 0.15/m^3. All wells were metered on a regular basis by the MWI, which collected fees based on the abstraction volume. In 1999, the charge was raised to $ 0.37/m^3 (MWI 2001).

6. SUMMARY

The report describes the geographical, geological and hydrogeological setting, the primary water usage and the main issues of the four pilot sites (Table 6-1).

Table 6-1 Details of pilot sites.

Pilot site name	Area (km^2)	Aquifer geology and type classification	Primary water usage	Main issues
COASTAL ACQUIFER OF EMILIA-ROMAGNA REGION (Italy)	1,055	Sedimentary Multi-layered aquifer system	Irrigation/drinking water	• saltwater intrusion in the phreatic aquifer; • natural and anthropogenic land subsidence; • land reclamation drainage systems; • soil salinization; • high demand of water during the peak tourist season; • insufficient aquifer recharge and sea level rise.
ALTO GUADALENTÍN BASIN (Spain)	273	Detrital, Sedimentary Multi-layered aquifer system	Irrigation / Drinking water	• over-exploitation; • high groundwater demand to sustain the most important economical wealth in the area; • groundwater pollution due to agriculture; • semiarid climate (insufficient recharge); subsidence due to groundwater extraction.
GEDIZ RIVER BASIN (Turkey)	17,034	Alluvial aquifer	Irrigation / Drinking water	• over-exploitation of groundwater • unbalanced reliance on groundwater use • groundwater pollution and deterioration due to agriculture, interaction with

				polluted river water and geothermal water influence
AZRAQ WETLAND RESERVE (Jordan)	12,700	Complex aquifer systems ranging from quaternary deposits to deep sandstone aquifer complexes	Irrigation / Drinking water	Over-abstraction of water and groundwater abstraction

The deliverable is the starting point for the next steps in the project represented by:

D2.2 – Proceedings of the first stakeholder/end-user workshop at each pilot site: including the workshop presentations and Stakeholder requirements list [M4] (T2.2 - Development of a Stakeholder and end-user group and establishment user requirements for each pilot site);

D2.3 – GIS platform v1 including data for the pilot sites [M12] (T2.3 - Collection of geological, hydrogeological and geomechanical at the pilot sites)

D2.4 – Conceptual model for the pilot sites [M12] (T2.4 - Development of conceptual model at the pilot sites).

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