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International Symposium on Groundwater Sustainability (ISGWAS)

Technical Field Trip - January 27

"Water Management in Alicante: Hydrogeology, Economics, Environment, and Main Institutions in the Vinalopó Basin and Campo de Alicante"

Organized by

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1. INTRODUCTION

Within the context of the **International Symposium on Groundwater Sustainability** (ISGWAS) of the Interacademy Panel (IAP), we believe that the international experts of different scientific fields attending the said Symposium would benefit from learning about and analysing in person a practical case of groundwater use and management development. With that purpose in mind, the organisers have selected the Vinalopó River basin and exploitation system. The exploitation of the water resources found in this region has yielded countless social and economic benefits. To a large extent, the exploitation efforts have been done on the initiative of farmers, private institutions and town councils, who have searched for water resources based on public support.

Nevertheless, the harsh climatic and hydrogeological conditions of this region, coupled with intense and reckless urban development, can have a negative impact on the environment, the economy, and the community. Groundwater is an essential element of the Vinalopó River water management system. This system has supplied water to other neighbouring areas, such as the city of Alicante and several stretches of the Costa Blanca littoral. These groundwater is indispensable for human consumption, irrigation, and industrial purposes. Also, groundwater provides multiple ecological services in lacustrine and lagoon-like areas comprised in and influenced by this basin and meet several social and recreational needs in the region. Groundwater become particularly important in the Vinalopó basin, a semi-arid region with a long tradition in the use and management of its scarce surface and underground resources. To meet its needs, the population of this region has historically depended on these resources, which today remain virtually the only available resources for human consumption.

The negative effects of the current level of overexploitation have alerted stakeholders to the unsustainability of these exploitation levels in the short term. The organisers have included this technical field trip in the Symposium to analyse this paradigmatic case, discuss the challenges arising from it, and come up with solutions that will contribute to a sustainable use of groundwaters.

1.1. Objectives and Overview of the Technical Field Trip

The technical field trip, following the theoretical sessions of the Symposium, aims to 1) provide participants with an in-depth knowledge of the harsh climatic and hydrogeological conditions of the Vinalopó River basin; and 2) analyse the topics of technology, management, and efficacy in the use of water resources.

In order to gain a global understanding of the exploitation system at hand, one first needs to analyse the acute water scarcity conditions of the city of Alicante (which is not located in the Vinalopó hydrogeological system). This city, since the late 19th century, has obtained water resources from several external systems - including the Vinalopó system.

Three main phases can be distinguished in the complex development process of Alicante's drinking water supply system: planning, technological development, and exploitation/ management of hydraulic infrastructures. In line with that general development process, the authorities have invested funds in hiring, training, and empowering the specialist personnel and human resources of the Aguas de Alicante Company. In this field trip, the participants will analyse the origins of the water resources that are available to AMAEM (Aguas Municipalizadas de Alicante-"Alicante Municipal Water Company"). Those resources come from the waters that are managed and produced by the state-run Mancomunidad de Canales del Taibilla ("Taibilla Basin Water Association"), which is dependant upon the Spanish Ministry of the Environment, and also from underground resources (aquifers located in the Higher and Middle Vinalopó counties) extracted by AMAEM. To conclude, participants will analyse the resource management and control systems in place.

Firstly, participants will visit the Canal de Alicante Desalination Plant and become familiar with the importance of this site, which is included in a larger programme promoted by the Ministry of the Environment. Its goal is to guarantee the current and future water supply needs of the population of this coastal region. Traditionally, such needs were met by exploiting the meagre groundwater resources (needed for multiple uses) and surface water resources (some are local and some are transfers from other basins, namely the Tajo, Segura, and Júcar basins).

Our next stop will be the Crevillente reservoir. Multiple reasons explain its relevance for the purposes of the Symposium. To begin with, participants will become familiar with another system of water regulation and supply found in the region. Secondly, this reservoir is part of an inter-basin water transfer system (i.e. Tajo-Segura). Finally, participants will see the seaside and lower basin of the Vinalopo River valley (Fig. 1), thus getting a full picture of the hydrological complexity of this region and of the local environmental/socioeconomic units that compete for the water resources.

We might add that this reservoir is one of several sites and facilities controlled by the Ministry of the Environment through the Automatic Hydrological Information System (SAIH, abbreviation in Spanish) of the Segura River basin, which will be briefly analysed during the visit.

The third stop will be the Galería de los Suizos, which is a paradigm of the groundwater catchment systems of the Vinalopó basin. It is the major site in the exploitation of the Crevillente Mountain Range aquifer and an important reservoir of carbonated formations from the Prebetic period. It has undergone an intense extraction activity which has led to a dramatic drop in its resources. It has been declared overexploited and terminal. As a result, the basin authorities have implemented withdrawal monitoring and control processes.

The fourth stop will be the Tolomó wells, another key site in the exploitation of the Crevillente aquifer. The main impact of the intensive exploitation activity in this part of the aquifer will be analysed briefly. Reference will be

Fig. 1. Town and salt marsh of Santa Pola – Lower Vinalopó.

made to the Federal regulatory reservoir, an example of a groundwater storage and management mechanism and a key component of the integrated administration of the resources of this exploitation system.

The final stop will be the city of Villena (Upper Vinalopó). A round table will analyse "Water Management in the Vinalopó Basin" from a cross-sectorial and multidisciplinary perspective.

To sum up, the main goal of this technical field trip is to contribute to the sustainable use of water resources in general and groundwaters in particular by offering specific proposals on the basis of an analysis of the Vinalopó basin, in harmony with the general spirit of this Symposium.

1.2. Location, hydrological and socioeconomic characteristics of the area under study

The Vinalopó River is in the east of Spain and flows into the Mediterranean (Fig. 2). Its hydrographic basin is one of the southernmost ones in the province of Alicante. It is located southeast of the Júcar basin and towards the south of the Autonomous Community of Valencia. The Vinalopó River basin drains a territory of 1,979km^2. The regional population, farmers, and industries compete intensively for the use of the scarce water resources.

The river runs through three counties (Upper, Middle, and Lower Vinalopó), including twenty-one municipalities that represent 31% of the total population of the Alicante province, whose landmark physiographic basis is precisely this river basin. This fluvial system belongs to the hydraulic divisory and hydrological management control of the Júcar River basin.

To better understand the complexity of the territory under study during this technical field trip, one should know that this area is also integrated in the Vinalopó-Alacantí Exploitation System. This system, located in the south of the Alicante province, covers the basins of the Vinalopó River, the Monnegre River, the Rambla del Rambuchar, and the littoral subbasins that are comprised between the northern border of El Campello municipality and the divide line with another basin located south, managed by the Segura River Water Authority, whose administrative territorial division intersects with the Vinalopó River. One further feature that shows the complexity of this region and its water resource exploitation system is the frequent and numerous water transfers between the different basins.

Today, this territory, with a population of 441,956 inhabitants, covers 30% of its needs with resources from the Upper and Middle Vinalopó, at the expense of the water reserves found in its aquifers, which are exploited for the benefit of the Lower Vinalopó and the adjacent basin (which includes the city of Alicante and neighbouring towns, adding another 341,000 inhabitants).

The acute scarcity of surface hydric resources has triggered a long history of water resources exploitation, under the pressure of the considerable number of urban settlements and a high population density, and favoured by the local conditions as regards communications and ecological and topographical accessibility. These factors have brought about a solid agricultural and urban-industrial development, which can be seen particularly well in some sites of the Vinalopó River. The need for regulations, resulting from the lack of surface water and the uneven distribution of groundwater resources, goes back to the times of Roman and Arabic domination of Spain. Initially, such regulations had the mark of customs and traditions and were later turned into formal, comprehensive, and detailed codes and regulations. There is proof of such exploitation activity through records of constant disputes and litigation among water users. However, such litigation failed to prevent the abusive extraction of groundwaters and the overexploitation of aquifer systems.

Such overexploitation went on until the late 20th century under the legal protection of the Water Act ("Ley de Aguas"), enacted on 13th June 1879, and binding for over a century. A remarkable feature of that act was the unnatural distinction between groundwaters and surface waters, which remained over a time of intense construction and industrial revolution in the area under study. It should be stated that, other than that flaw, the old Water Act had countless positive features in terms of formalising and legally

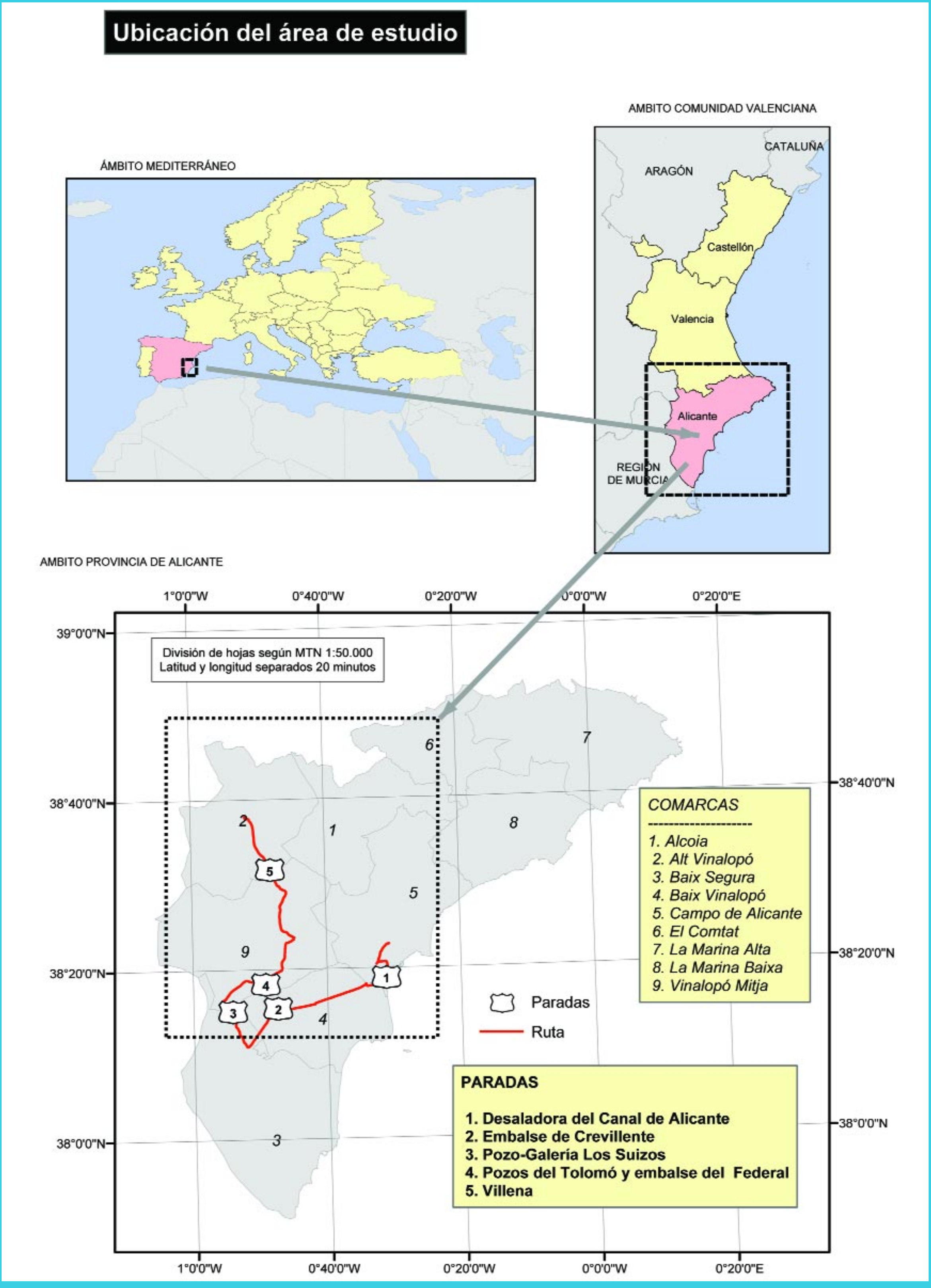

Fig. 2. Location of the area under study.

Fig. 3. The Vinalopó River as it flows through the city of Elche.

regulating water uses. Nonetheless, it stayed in force with the said flaw until the new Water Act was passed in 1995.

The Vinalopó River, in spite of being the most developed water artery in the province (with 89.5km in length and a basin of 1,979km^2) is an intermittent stream, a rainfed watercourse, with no relevant tributaries and whose original sources are just a few meagre springs. The river runs dry in the Benejama area (Fig. 3). As a matter of fact, the river flows do not reach the sea – they dry up in the alluvial cone which the river forms in the Lower Vinalopó. In other words, other than in the higher stretch of the basin, the water sources that feed the Vinalopó River are sporadic. The permanent flows found in the river bed are waste waters and industrial spills from the towns it goes through, thus being highly polluted.

The basin inflows are estimated at 48Mm^3, of which about 50% flow epigeally, particularly in its higher stretch. However, according to a long hydrological gauging series performed in the late 1980s (before the overexploitation of the basin), the mean value at that time was 12Mm^3. Nevertheless, at that time, and today even more so, the Elda reservoir (17th century) and the Elche reservoir (17th-19th century) were and are silted up. The current balance of regulated surface resources for this basin is zero. For those reasons, groundwaters constitute the main and virtually only source of water resources in the Vinalopó basin and other adjacent areas.

1.3. Groundwaters in the Alicante province

The Alicante province has numerous geological formations with aquiferous characteristics, most of them of a carbonated nature (Table 1). Nevertheless, its great tectonic complexity has generated a strong hydrogeological compartmentalization, the result of which is the existence of a high number of aquifers, usually of a small size.

The biggest systems are located in the northern part of the province. Their larger dimensions, along with their high degree of karstification and a much wetter climatic pattern than that of the south, allow these northern systems to own a higher level of resources. It is therefore in this northern part of the province where we find the largest number of springs and the biggest and most spectacular ones in terms of hydrodynamic functioning. From a hydrogeochemical point of view, the aquifers located in this part of the province tend to have waters with a weak mineralisation and calcic bicarbonated facies, suitable for human consumption.

The aquifers located in the southern part of the province are usually smaller and have a lower level of resources, because they are located in a drier area. A large part of them, particularly those with good-quality waters located in the Vinalopó Valley, have undergone intensive exploitation. This intensive use of groundwaters is due to several factors. On the one hand, the good climate that characterises this area makes it attractive for intensive farming (tomato, vines, fruit trees, etc.). This made the expanses of farmed land grow a lot since the 1960s, which in turn meant a demand for large volumes of water for their irrigation. On the other hand, we must also highlight the absence of surface watercourses and

Table 1. Water balance and characterisation of the aquifer systems in the Vinalopó basin. Source: Hydrological Planning Office for the Júcar Basin.

HYDROGEOLOGICAL UNIT	WATER BALANCE (Mm^3/year)					
	Resources	Minimal exploitation	Typical exploitation	Surplus	Deficit	DIAGNOSIS
SIERRA OLIVA	3.00	3.70	4.61	0.00-	1.61	Under study
JUMILLA - V ILLENA	17. 00	33.70	34.29	0.00	17.29	Overexploited (1987)
YECLA –VILLENA - BENEJAMA	26.00	40.26	48.02	0.00	22.02	Reserves exploitation
SIERRA DE MARIOLA	16.30	11.90	13.13	3.17	0.00	In balance
PEÑARRUBIA	4.00	5.43	5.72	0.00	1.72	Reserves exploitation
CARCHE –SALINAS	4.00	11.79	15.26	0.19	11.46	Reserves exploitation
ARGUEÑA- MAIGMO	6.50	5.48	6.78	1.73	2.01	Reserves exploitation
AGOST-MONNEGRE	1.75	3.96	5.54	0.06	3.85	Reserves exploitation
SIERRA DEL CID	1.90	2.49	3.14	0.86	2.10	Reserves exploitation
QUIBAS	5.50	6.79	8.33	0.39	3.22	Reserves exploitation
SIERRA CREVILLENTE	2.00	15.06	16.00	0.00	14.00	Overexploited (DP 1987)
LOCAL AQUIFERS & RETURNS IRRIGATION	6.90	9.63	11.50	3.25	5.50	Reserves exploitation
TOTALS	94.85	150.19	172.32	9.65	84.78	Unsustainable by itself

the very poor rainfall levels, with average values below 400mm/year.

The intensive exploitation of aquifers has had a number of technical, environmental, social, economic, administrative and legal consequences. Among these are the decrease of piezometric levels, with the subsequent increase of the total head and the growth of exploitation costs; the impact on free-water areas like brooks, rivers, lagoons or wetlands; the salinisation of aquifers, both inland ones (as a result of pollution processes due to the dissolution of evaporitic salts) and coastal ones (as a result of marine intrusion); as well as the legal problems related to water affections and properties. However, a large part of the agricultural and economic development of the Alicante province has taken place thanks to the water from the aquifers. In this respect, many pieces of land have been exploited with intensive farming using exclusively groundwaters and, similarly, we have only been able to meet the ever increasing demand for water derived from population growth during the summer months through more groundwater extractions.

Groundwater quality is one further problem, as it varies greatly from reservoir to reservoir. Although dolomitic calcareous outcrops tend to have higher qualities, the presence of triassic formations, the high overexploitation levels of the aquifer, farming pollution, and industrial/urban spills occasionally cause quality alterations.

The water balance for the basin (see Table 1) is as follows: the mean groundwater exploitation is 150m^3, of which a high percentage (between 40% and 63%) are extractions from the reserves, since the rainfall water recharge is minimal (54.2-94.8Mm^3) if compared to the pumped amounts. There are imbalances in the Yecla-Villena-Benejama, Carche-Salinas, and Argueña-Maigmó aquifers. A partial recovery of their reserves would be possible by limiting the extraction rate and by implementing recharge systems and other systems to stop the hydric deficit. The aquifers of the Crevillente Range, Quibas, and Cid Range are in a state of overexploitation and depletion (the water authorities have declared them terminal). According to technical reports from 1989 from the Júcar River Water Authority, the water resources of those aquifers have been under exploitation for mining purposes since the late 1980s.

Considering the depths at which water is extracted in some sites of the basin (e.g. 650 m in the Crevillente Range) and water salinity, one can see there is an added cost involved in the use of these groundwaters. The energetic cost that is involved and the low water quality have repercussions in the economy of farmers and the quality of produce. There is an astonishing paradox in that the Vinalopó basin, particularly its upper and middle reaches, not only supply water to its region, (which covers about 30,000 irrigated hectares, a population of 209,430 inhabitants, and large number of industries) they also, satisfy 30% of the water demand in the lower Vinalopó (239,335 inhabitants and 21,746 irrigated hectares) and the Greater Alicante area (341,000 inhabitants and 18,892 irrigated hectares).

1.4. The complex control against overexploitation and current status

The overexploitation of the Vinalopó aquifers (see Table 2), with a deficit of 84.78Mm^3/year, is a clear handicap that hinders the sustainability of intensive farming, which is the main agricultural activity in the area. This makes it necessary to use water with a salinity that is higher than 2,000mg/l in some fields. That, in turn, has a negative impact in crop quality and productivity. Twenty percent of the pumping is carried out at depths of more than 475m. As a result, water withdrawal is not cost-efficient, given the energetic cost involved.

The scarcity of resources and the water deficit are longstanding realities in the Vinalopó, as are the demands for water transfers from other basins,

Table 2. Basic characteristics of the hydrogeological units related to the Vinalopó exploitation system. Year: 1989. Source: Inventory of hydraulic resources of the Vinalopó exploitation system. Júcar River Water Authority. 1993. Note: The data for the overexploited Crevillente Range and Jumilla-Villena aquifers were taken from their Extraction Control Plans and were current as of 1987.

Hydrogeological Unit	Area (km^2)	Water sites with exploitation	Water sites with no exploitation	Mean exploitation (Mm^3)	Irrigated area (1989) (hectares)	Height (metres above sea level)
AGOST-MONNEGRE	50	9	10	5.5	2,703	110-340
ARGUEÑA-MAIGMO	130	18	25	-	6,930	350-670
CARCHE SALINAS	–270	22	43	14	11,511	340-500
Peña Rubia	34	15	8	6.9	963	370-410
QUIBAS	317	18	98	8.5	-	330-570
SIERRA DEL CID	112	10	33	3.2	7,405	75-530
Sierra Mariola	287	29	36	-	5,784	402-730
SIERRA OLIVA	310	10	11	3.9	2,670	657-720
Yecla-Villena-Benejama	440	96	128	49	17,137	380-530
SIERRA CREVILLENTE	90	19	22	15.06	8,676	20
Jumilla-Villena	340	41	-	34.25	12,700	400-425
Aquifers of local interest	181	35	20	8.6	6,102	23-664

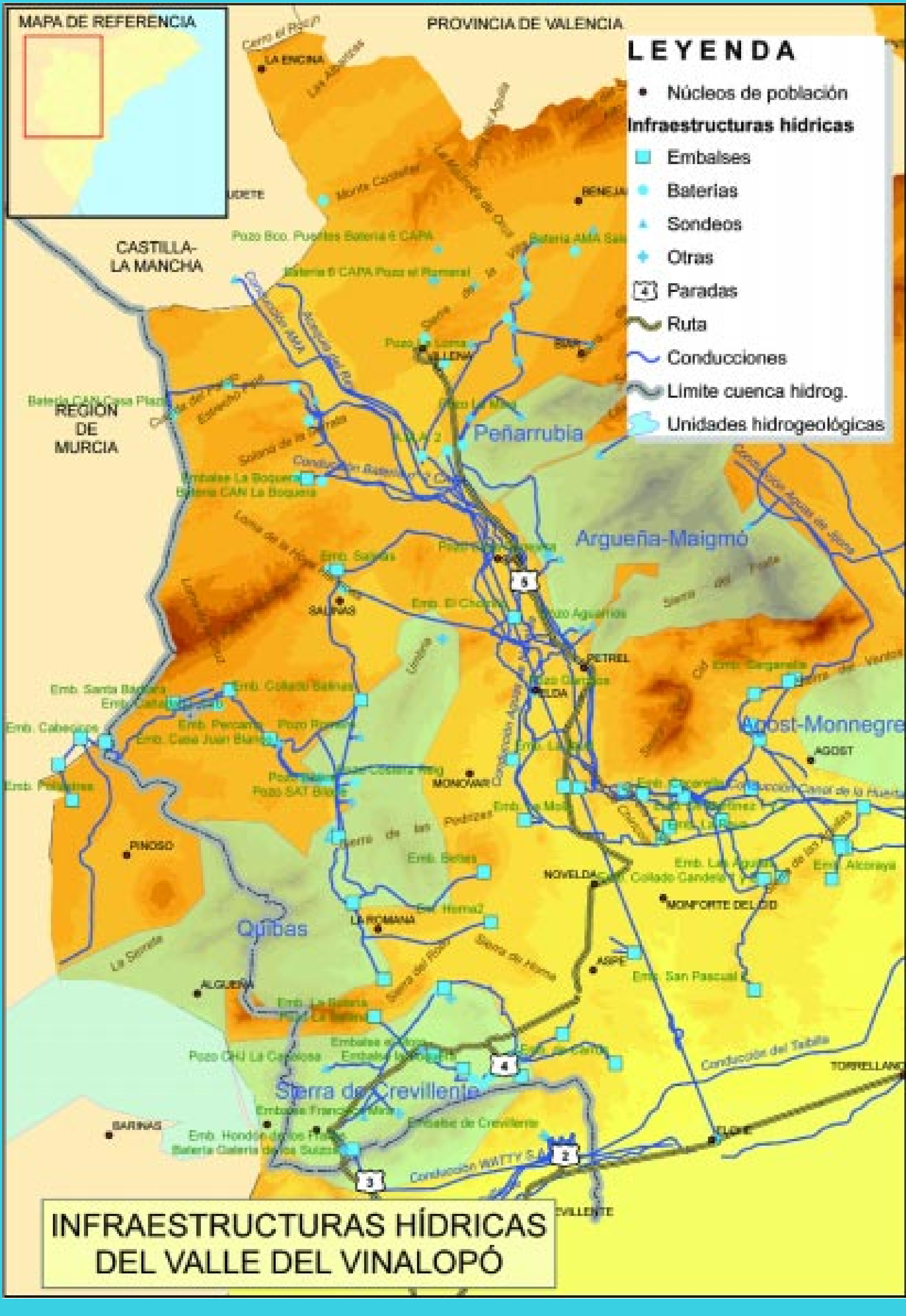

Fig. 4. Water infrastructures in the Vinalopó Valley.

which date back to the 14th century (there is documented proof of it). However, the issues of water scarcity and groundwater overexploitation became more acute since the early 1980s, in connection with frequent droughts and a number of structural problems arising from the prevailing economic system and the inexistent land use regulation and planning. This has strongly revived projects of water transfer from other basins, included in the Hydrological Plan for the Júcar Basin (1997) and the National Hydrological Plan, passed in 2002.

The agricultural tradition of the Vinalopó area is a positive factor for this basin, which, far from wasting water resources, has managed to economise its resources through multiple solutions. Its authorities have spared no efforts to face the water costs well over and above the standards and tariffs applied in other basins (particularly in the Júcar basin, considered as source basin in the National Hydrological Plan). Undoubtedly, however, a rigorous management of the urban, industrial, and environmental demands is absolutely required, particularly in view of European-level regulations that have established specific goals and deadlines.

The shortage in water supply has severely hit the irrigated intensive crops in the Vinalopó basin. Arable land has been abandoned as a result of the water shortage and several structural factors related to costlier production processes, new market conditions and increased competition in the aftermath of the Common Agricultural Policy.

The Vinalopó farmers have made considerable efforts to meet the need for a highly efficient management of both current and future resources. They created Water User Associations (*Juntas de Usuarios*), whose role was to take the necessary steps to finance and build infrastructures (catchment, regulation, transfers, implementation of new irrigation techniques). The associations' general objective was to adapt to new technologies and to conform to both national hydrological planning regulations and the European Framework Directive, which involve and require a strict control of the uses, management, and efficient administration of conventional and non-conventional resources.

In the Region of Valencia, the Vinalopó exploitation system is currently right in the centre of heated political debate around the management of water resources. The area under study has been caught up in a social and political controversy that involves particular and conflicting interests. Unfortunately, the debate is far from carrying out a rational, technical-scientific analysis guided by a principle of consistency with the hydric and environmental reality that defines this territory in the 21st century, nor does it approach the matter from the long-term hydrological planning perspective that is required.

While some present the transfer policy as the right solution that will guarantee the sustainability of the regional economy, others conceive of water transfers as a solution for the overexploitation of the aquifers in this system that should meet farmers' needs. In the meantime, the water demands for urban and residential uses, which are soaring in the whole area but particularly in the littoral (to which the water resources have traditionally been channelled since the late 19th century) are inevitably met with waters from desalination plants.

Recent developments include the passing of the new Water Act and derived regulations, the approval of the Plan for the Júcar Basin, the amendment to the Water Act, the recent amendment to the National Hydrological Plan, and the EU Framework Directive requirements. In spite of all that, the solutions needed in this territory are taking long to come. The very implementation of such solutions is only beginning, as a consequence of the lack of consensus between the conflicting stakeholders. Overall, this remains a major handicap for the future sustainability of the basin.

The policy of the Ministry of the Environment, on the basis of a land use planning and regulation policy, offers comprehensive solutions that rest on the following ideas: modernisation and enhancement of water catchment systems, regulation, supply and irrigation, desalination, wastewater use, control and reduction of environmental impacts, resource sparing, and also recouping the investment and environmental costs. All these proposals are in conflict with the solutions that are advocated by specific groups of stakeholders who are after quick solutions, guaranteeing water flows (primarily for urban supply and development), and who are less environmentally committed to this territory and to the future generations.

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2. WATER SUPPLY IN THE CITY OF ALICANTE: AMAEM (ALICANTE MUNICIPAL WATER COMPANY)

2.1. Introduction and brief history of water supply

The city of Alicante is located towards the Southeast of the Iberian peninsula, where rainfall is scant and irregular; moreover, its effectiveness is reduced by the considerable intensity when rainfall does occur and by high levels of potential evapotranspiration. Furthermore, there are no allochthonous rivers with a regular, permanent water flow, as the watercourses that do exist, comprising streams and *ramblas* (dry courses), only channel water intermittently. Finally, there are few permeable formations, and their storage capacity is adversely affected by their geological structure.

In short, the fact is that our city suffers a chronic water shortage, which makes it necessary to obtain resources from beyond our boundaries and to make the best use possible of what is available from various systems. In all cases, it is necessary to perform a fairly complex exercise of planning, development, exploitation and management of water infrastructures.

In this latter respect, the basic development of Alicante's system for the supply of potable water can be considered to consist of three stages, which evolved in parallel to the continuous growth in the human population of the area:

– Hypogene water, based on the first public supply system established for the city, and the only one existent until the first half of the 20th century. The original system, which dates back at least to the times of the Muslim domination of Spain, seems to have consisted of elementary procedures for lifting water from relatively shallow depths. During the 17th and 18th centuries, technological advances made it possible to dig mines, wells and galleries, and thus watermills constituted an essential element of the water economy, and some of these remained in use until the early years of the 20th century.
– The growing demand for resources, together with the recurrent periods of drought, meant that from

the late 19th and early 20th century, important water-management projects were undertaken. The first of these was to bring water in from La Alcoraya, a project that was inaugurated in 1881. Household distribution was performed by means of water delivery-men, who went around the city bearing pitchers of water filled at the five fountains installed within the city boundaries.

This first installation was followed by another project that was even more ambitious and innovative, the Alicante Canal, which was 48Km long and brought water from the artesian wells at Sax, in the Alto Vinalopó area in 1898. The volume of water channelled through the canal amounted to 10 l/s, which according to census records of the time corresponded to a supply of 21.6 l/inhabitant/day, a much higher supply than was then available in other major cities.

In the mid-1930s, the Barcelona General Water Company, which had been responsible for supplying the city since 1911, undertook large-scale investments that led to an increase in its water-channelling capacity, an extension of the urban supply network, the further deepening of the wells and the tapping of new groundwater supplies, although this latter development actually took place in the 1970s. Thus, urban water supply was consolidated and expanded, and the service was taken into municipal ownership via the Alicante Municipal Water Company (AMAEM).

– The new sources of water were soon found to be insufficient for the growing demand, particularly in coastal regions, and so the City Council of Alicante was obliged to enter the *Mancomunidad* (inter-municipal partnership) de Canales del Taibilla ("Taibilla Basin Water Association"), which obtained water from the Taibilla River, located in the neighbouring Segura River basin. Nevertheless, before long (by the 1960s), this latter *Mancomunidad* found itself unable to meet the water demands of its members, whose numbers had grown from 2 to 26 in a single decade.

In this context, the Tajo-Segura water transfer scheme was proposed in 1967; its conclusion coincided with that of new infrastructures provided by AMAEM, based upon two main areas of activity: on the one hand, improving the transportation of the water obtained from Higher Vinalopó, by twin-channelling and completely renovating the old El Cid Canal along its whole constructed, lined length (parts of these works are still in use and bear volumes exceeding 2000 l/s); and, on the other, diversifying and directing extractions of groundwater to aquifers of better water quality and with larger reserves.

However, these measures have proved to be insufficient, and water necessities will continue to increase, according to present forecasts, and so the current approach is to consider new sources of water supply in the form of desalination plants, such as that of the Canal de Alicante which has a nominal output of 50,000 m^3/day of water for human consumption.

2.2. Description of the supply system

As noted above, the water made available by the Alicante Municipal Water Company (AMAEM) for the supply of potable water to the towns it services is derived from two well-differentiated sources: the water received from the Taibilla Basin Water Association, and that extracted from the aquifers located in the areas of Higher Vinalopó and Middle Vinalopó.

The first of these water supplies is distributed to the municipalities of Alicante and San Vicente del Raspeig, while the second is transported, as well as to these towns, to Petrer, Monforte del Cid, part of Novelda, San Juan and El Campello.

The water available to the Taibilla Water Association is obtained from the following sources:

– Taibilla River.
– Tajo-Segura water transfer.
– Sea-water desalination plants.

AMAEM's rights to exploit the aquifers located in Higher Vinalopó and Middle Vinalopó amount to an annual volume of 31,044,300 m^3. This water is extracted by means of 20 boreholes drilled into the following hydrogeological units:

– U.H.G. 08.41 Peñarrubia.
– U.H.G. 08.36 Villena-Benejama.
– U.H.G. 08.43 Argueña-Maigmo.
– U.H.G. 08.50 Sierra del Cid.
– U.H.G. 08.99 Aquifer of local interest.

2.3. Water Management

The management of water resources in arid and semi-arid regions of the Mediterranean, as is

Fig. 5. Origin of the water supplied by AMAEM.

the case of Alicante, is a complex task involving many hydrological, environmental and management factors that must be taken into consideration in order to maintain a supply of water sufficient to ensure basic standards of living and environmental protection. Periods of drought, which are so frequent in the Mediterranean area, make the above task yet more demanding. As these phenomena are unpredictable, both in occurrence and in duration, forward thinking and preparation are key elements in reducing their impact.

In this respect, the supply model currently used by AMAEM efficiently combines two types of resources (Fig. 6):

– *Surface water:* this is obtained from the Taibilla Water Association and therefore AMAEM has no control over its exploitation. The role of AMAEM is limited to that of distribution. A basic characteristic of this type of resource is the predominance of current extraction volumes over reserves.
– *Groundwater:* this is managed by administrative concessions for the exploitation of groundwater located in AMAEM's operating area, extracted from wells owned by AMAEM or otherwise. Thus, the company is able to control the whole management cycle, including water extraction, transportation and distribution. For this type of water resource, contrary to the previous case, reserves are more abundant than current extraction levels.

This system of combining the use of surface and groundwater has made it possible to establish a means of reliably supplying water. Such reliability is essential for the present situation, in which demand is constantly increasing in Alicante and nearby towns and villages. Uninterrupted supplies of potable water can be guaranteed, even in particularly difficult periods such as the present, by the use of both surface water and reserves of groundwater, built up during periods of lower demand.

This guaranteed supply is based upon appropriate, effective management for the simultaneous use of the two types of water resource and on their integration with other water-management techniques such as the use of alternative sources of water for non-potable applications, the implementation of water markets, demand management, recycling technologies, etc. Also crucial is correct planning for the effects of changes that may occur in the future concerning water demand and availability.

2.3.1. Management of groundwater resources

The high degree of effectiveness achieved by AMAEM in the management of underground resources is based on its extensive understanding of the medium in which it operates. The following aspects, therefore, are fundamental in the assessment of groundwater resources:

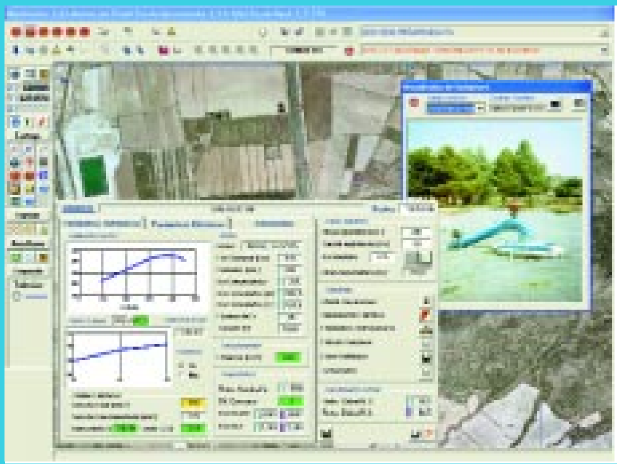


Fig. 6. Hydrogeological Control System.

Exhaustive knowledge of the aquifers that are tapped, obtained by:

– developing accurate methods and techniques for calculating recharge and its variability in time and space, under the varying conditions encountered in the aquifers exploited. Precipitation levels are recorded at the company's own meteorological stations, in addition to those run by other public bodies.
– using newly-developed geophysical techniques for surface and depth exploration, to characterise the water-bearing properties of the soil, the boundaries of the aquifer and the arrangement of the different aquifer horizons; thus, it is possible to extend our knowledge of the reality of the aquifers, their area, volume, available reserves and potential for exploitation.

Optimising the exploitation and distribution of groundwater, by the following means:

– using the latest technology for the design, drilling, construction, development and disinfection of wells, together with the installation of machinery and other infrastructures. Using specialist techniques for the renovation of wells under various foreseeable circumstances, in order to maximise the useful life of the wells exploited for potable water supply. Moreover, sophisticated techniques are used to protect the drilling installations, with real-time remote control of the main operational parameters, such as phase consumption, F cosine, temperature and amperage, thus providing all possible guarantees of production continuity, limiting as far as possible the consequences of possible technical problems with regard to the availability of the water supplied.

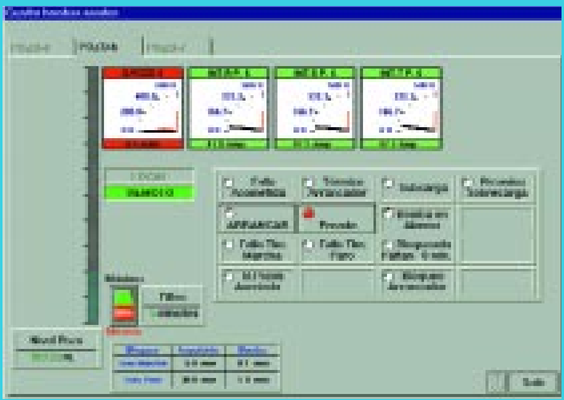


Fig. 7. Remote Control System.

– using an "Integral Extraction Control System", consisting of automated software that makes use of exploitation data – static and dynamic levels, extraction rates, volumes, electricity consumption, etc. – obtained by the corresponding sensors and transmitted via the remote control system (Fig. 7), to evaluate the state of the impeller pumps. Different states of alarm have been established to reflect corresponding operating deficiencies. This whole system is integrated into a hydrogeological GIS system, which includes, in addition to data concerning exploitation systems, hydrochemical data, pumping tests, lithological columns and construction schemes, characteristics of the pipelines and their control mechanisms (troughs, vents, discharge, etc.).
– using a battery of tests, both to obtain the real characteristic curves of the hydraulic component of the impeller pumps (which are subsequently employed by the Integral Extraction Control System) and to check that repairs have been carried out correctly by the workshops contracted for this purpose, thus ensuring optimum effectiveness of the machinery that is repaired and the selection of the most efficient workshops to perform such repairs.
– using the most up-to-date techniques and methodologies to detect leaks and to repair and renovate distribution conduits, by these means obtaining the maximum possible output and minimising the exploitation volumes required to satisfy the demand for potable water by the population to be supplied. Loss rates are minimised by means of exhaustive controls both of inputs to and outputs from water conduits, backed up by differential capacity techniques.

Appropriate management of the various aquifer systems involved in the production of potable water is ensured by the following:

– the use of aquifer management systems, controlling both the evolution of current supplies and reserves, for normal use and for emergency situations, taking into account possible consequences of the exploitation on the quantity and quality of water resources.
– the evaluation of the consequences of intensive exploitation of aquifers, including severe falls in piezometric levels, changes in water quality arising both naturally and as a result of human action, the preparation of emergency plans for periods of drought, and other extreme situations. The development of modelling techniques for the sustainable exploitation of these aquifers, with special emphasis on the measures required to protect them, such as protection of the immediate surroundings of the installation, the creation of inventories of potentially dangerous activities in the vicinity, proposals for a protection perimeter , etc.
– the use of automation models for production selection criteria. By examination of the many variables that may influence the choice of the origin of the water to be exploited, among the various boreholes that are available, the selection process is automatised, taking into consideration the demand requirements and the particular conditions affecting each borehole, such as the piezometric level, the chemical

quality of the water, the maximum extraction volume, the interaction with other boreholes being exploited, etc. Thus, at all times, the production system adopted is the most rational one and, at the same time, the one enabling greatest energy savings.

– the use of alternative sources for the supply of potable water, including shallow groundwater derived from small local aquifers beneath urban areas and surface water proceeding from local water-treatment plants, to satisfy water demands for secondary applications such as the irrigation of green spaces, street cleaning and other uses that do not require adherence to such high levels of chemical quality as is the case with water intended for human consumption.

2.3.2. Management of water resources in extreme situations

Special attention should be paid to the water-supply measures that are utilised in managing available resources under extraordinary circumstances of drought, of severe over-exploitation of aquifers or similar situations of special need, urgency or the coincidence of anomalous or exceptional situations. Such measures should make it possible to minimise the effects of any water shortage, particularly the negative consequences on the population receiving the supply. The above extreme parameters are listed in the Emergency Plan for Drought Situations drawn up by AMAEM in compliance with the 10/2001 Act, which regulates the National Hydrological Plan. Article 27 of this law sets out the fundamental aspects of the management plan for droughts, comprising two basic pillars:

– DEMAND MANAGEMENT: aimed at saving water by the application of voluntary measures, fundamentally consisting of public information and education and awareness campaigns, together with client management, rationalisation of uses, information campaigns and school campaigns. Also considered are obligatory measures, involving prohibitions and sanctions, including the possible modification of tariffs.

– SUPPLY-ORIENTED ACTIVITIES: under Article 56 of the consolidated text of the 2001 Water Act, and mainly intended to improve guarantees of supply, by means of the following:

– increasing available volumes of water in existing wells, by applying techniques for the renovation and stimulation of boreholes. In this respect, stimulation programmes will be intensified and boreholes will be developed in order to obtain a constant supply of water with the lowest possible fall in levels, thus enabling an appropriate equilibrium between electricity consumption and production. Moreover, and what is more important, the rate of descent of piezometric levels should be moderated, tin order to enable the best possible guarantees of supply.

– the incorporation of alternative water flows, by the bringing onto stream of reserve boreholes, by increasing the use of recycled water and by extracting non-potable water for secondary uses. Additionally, the negotiation of temporary rights of water use, the utilisation of a centre for the exchange of such rights, and the start up of the Júcar-Vinalopó transfer scheme, when it becomes available.

– the temporary increase in exploitation volumes established in the assignments determined by the corresponding Water Catchment Area body. Using new sources of groundwater to be incorporated into the supply system and used, on specific occasions, to increase the volume of water supplied and the total water availability assigned to the concession, to be applied only in extraordinary circumstances of drought. Such measures would not, in practice, constitute a permanent increase in the water resources intended for supplying the population.

– the increase in the efficiency of water distribution, intensifying measures to control leaks, which is a factor of vital importance in improving the performance of the potable water distribution network .

2.4. Bibliography and sources

1- Aguas de Alicante Empresa Mixta - 2005

3. THE CANAL DE ALICANTE DESALINATION PLANT

3.1. Location

The facility is located at a place called Aguamarga, within the town limits of Alicante, close to the N-332 road and is part of the Vinalopó-Alacantí Exploitation System.

3.2. Objective of the visit

The Canal de Alicante Desalination Plant forms part of a joint execution programme for the construction of four Desalination Plants which will provide ca. 80Mm^3 of desalinated water to the hydraulic system of the Taibilla Water Association, an autonomous body within the Spanish Ministry of the Environment that is responsible for delivering the essential public service of drinking water supply to a population of about 2 million inhabitants (nearly 3 million during the summer) of 77 municipalities, 32 of which are located in the Alicante province (over 50% of the population), while another 43 belong to the Region of Murcia (all except Yecla and Jumilla) and 2 (Férez and Socovos) to the Castilla-La Mancha Autonomous Community.

The objective sought by the Ministry of the Environment with this programme is to guarantee, complementarily with the potential resources coming from other transfers between basins (Júcar-Vinalopó transfer), the present and future supply for the corresponding population nuclei.

3.3. Description of the facility

The Canal de Alicante Desalination Plant (Fig. 8) produces 18Mm^3 of desalinated water every year and has worked on a concession contract basis during a 15-year period, just the same as the Nuevo Canal de Cartagena Desalination Plant (24Mm^3 per year), located in the coast of Murcia. The programme is completed with two new desalination actions identified as 'Enlargements of the Desalination Plants of the Taibilla Water Association in Alicante and Murcia' in the Investment Annex of the Spanish National Water Plan.

The Ministry of the Environment's Waters and Coasts Department gave the concession of the Canal de Alicante seawater desalination plant to the Temporary Enterprise Consortium formed by FERROVIAL-AGROMAN S.A., NECSO ENTRECANALES CUBIERTAS S.A., INFILCO S.A. and CADAGUA S.A. Technical assistance for work management was provided by PROINTEC S.A.

The Canal de Alicante seawater desalination plant produces 50,000 m^3 of drinking water daily (Table 3) which are incorporated into the Canal de Alicante of the Taibilla Basin Water Association upstream from the Elche supply intake point. The facility is located at a place called Aguamarga, within the town limits of Alicante, close to the N-332 road. The water discharges are consumed directly in the Elche, Santa Pola, Alicante and San Vicente del Raspeig municipalities.

The Desalination Plant consists of the following units:

- Seawater intake point
- Desalination Plant
- Desalinated water impulsion unit
- Regulatory deposit and connection to the Canal de Alicante
- Reject water spill unit

3.3.1. Seawater intake point

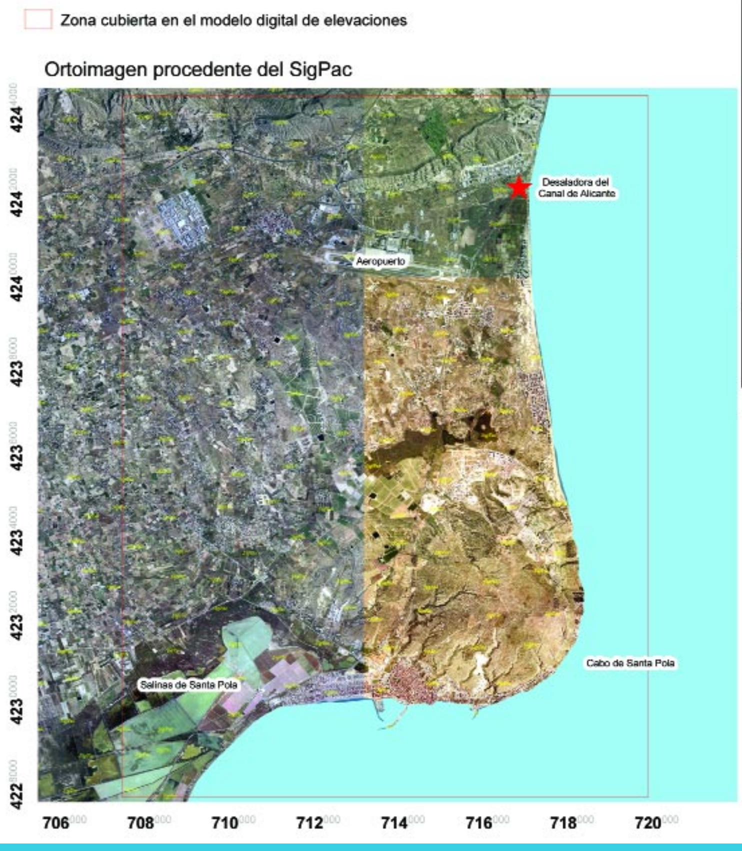
The seawater intake point is located near the desalination facility, in the maritime-terrestrial public domain protection area. Water catchment is carried out through a battery of 18 wells, in each one of which a waterproof pump with an up to 360m^3/h at 28 mwc pumping capacity has been installed. The water is sent to the plant through a 1,100-mm in diameter, 677-meter long GFRP duct.

The 2,500-kVA power installed is supplied from a transformation centre (20,000/380 volt) located near the battery of wells, where the intake point local control systems are placed.

3.3.2. Desalination plant

Pre-treatment:

- Seawater pre-treatment guarantees the optimum (physical and chemical) condition of



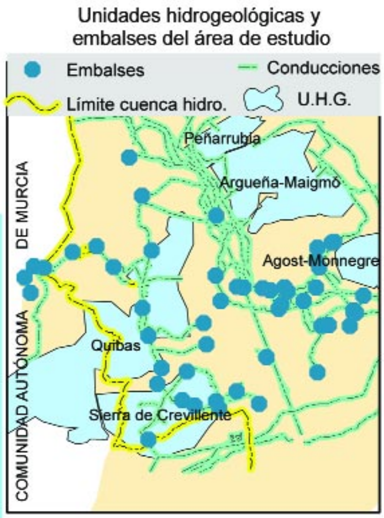


Fig. 8. Stop 1: Canal de Alicante Desalination Plant. Location.

Fig. 9. Panoramic view of the plant

the water fed to the desalination process. At the Canal de Alicante Desalination Plant (Figs. 9 and 10), the high quality of the intake water requires minimum pre-treatment. Nevertheless, the following stages are fulfilled in order to guarantee the good functioning of the process:

- Dosification of a disinfectant (sodium hypochlorite).
- Dosification of a coagulant (ferric chloride).
- Filtration on a stone-free-layer siliceous sand bed.
  10 6.60 by 10.95-m filters on a plant with a 1.00-m filtrating bed and a $6m^3/h/m^2$ surface filtration speed.
- Filtrated seawater intermediate pumping.
  6 split chamber centrifugal pumps with a $1,150m^3/h$ at 30 mwc speed variator.
- Dosification of an acidificant (sulphuric acid).
- Dosification of a dispersant (sodium hexa-metaphosphate).
- Security filtration.
  6 pressure filters with 5 um. passage section polypropilene cartridges
- Free residual chlorine reduction prior to the membrane (sodium bisulphite).

Desalination:

Desalination was carried out using the reverse osmosis process. Seven membrane frames with the following characteristics were installed to that end:

Fig. 10. Processing facilities.

- Frame unitary production: 7,200m^3/day.
- No. of modules: 100
- No. of membranes per module: 7
- Conversion: 42%
- Permeate salinity < 400mg/l

The basic characteristics of the membranes used are:

- Type of membrane: spiral rolling-up
- Material: crossed tissue aromatic polyamide
- Standard productivity: 19m^3/day
- Salts reject: 99.75%
- Maximum operation pressure: 700 mwc.

Associated to each frame are arranged 7 high-pressure trains for system energy supply and recovery. They include the following components:

- Centrifugal split chamber high pressure pump (760 m^3/h at 700 mwc, 1,709 kW)
- Electric engine (engine power 1,120 kW, 6,000 volt)
- Pelton-type recovery turbine (440m^3/h at 640 mwc, 732 kW)

The total power installed for the supply to high-pressure trains amounts to 13,500 kVa.

Post-treatment:

Seawater post-treatment makes it possible to guarantee compliance with the criteria established for human consumption waters by the regulations in force. In the Canal de Alicante Desalination Plant, post-treatment consists of a remineralisation to increase the pH through the dosification of calcium hydroxide, and the dosification of sodium hypochlorite to ensure adequate residual disinfectant levels.

The said post-treatment is carried out in a small reinforced concrete deposit with a 2,200m^3 capacity located in the plot of land occupied by the Desalination Plant.

3.3.3. Desalinated water impulsion

The desalinated water produced is pumped by four 680m^3/h at 195 mwc groups toward the Elche regulatory deposit (Fig. 11). Transport is carried out through a two-stretch duct with the following characteristics:

- Stretch I. From the Desalination Plant to the Canal de Alicante, near the Santa Pola branch line intake point. Executed with a 1,100mm in diameter and 8,300m-long helico-welded steel pipe.
- Stretch II. Attached to the Canal de Alicante up to the Elche regulatory deposit. Executed with a 700mm in diameter and 13,625m ductile cast iron pipe.

Fig. 11. Filtrated water pumping.

3.3.4. Regulatory deposit

Located in the vicinity of Elche and close to the Canal de Alicante, it is executed in reinforced concrete and has two chambers with a total capacity of 50,000m^3. It takes up an area of 10,000m^2 and the maximum layer height is 5.50m.

3.3.5. Reject water discharge

Seeking to reduce the environmental impact of reject water as much as possible, various studies have been carried out by the *Centro de Estudios y Experimentación de Obras Públicas (CEDEX)*, with the participation of the University of Alicante. Those studies materialised in the direct spill, through a 1,800mm in diameter GFRP pipe at a coastal spot located 1 km away from the Desalination Plant -direction Alicante- (Cala de las Borrachos). This has no environmental impact due to the characteristics of the sea bottom and the distance to the beginning of the Posidonia Oceanica prairie (over 1,600m.). The great respect for the environment which prevails in the actions of the public administrations will lead to the strict compliance with all the preventive and corrective measures imposed by the competent environmental bodies.

Table 3. Basic facility characteristics. Canal de Alicante Desalination Plant.

BASIC CHARACTERISTICS	
Production:	50,000m^3/day
Desalination process:	Reverse osmosis
No. of Reverse Osmosis frames:	7 units
No. of high-pressure trains:	7 units
Catchment type:	Battery of 18 coastal wells
Desalinated water pumping:	4 units
Impulsion duct:	8,300m. in ∅ 1,100 13,625m. in ∅ 700
Spill duct:	1,070m. in ∅ 1,800
Regulatory deposit:	50,000m^3
Total power installed:	14 MW
Works start date:	November 2000
Concession period:	15 years
Investment made:	52,618,644.86€
Cohesion Fund financing:	85%

3.4. Bibliography and sources

1- Spanish Ministry of the Environment. Secretaría de Estado de Aguas y Costas ("National Secretariat for Water and Coastline Administration"). Dirección General de Obras Hidráulicas y Calidad de las Aguas ("General Directorate for Hydraulic Works and Water Quality"), 2005.

4. THE CREVILLENTE RESERVOIR

4.1. Location

The Crevillente Reservoir is located in the Garganta gully, at a place called Castell Vell. It lies about 2km away from the town of Crevillente, on route N-330 (left-hand side), which connects the towns of Crevillente and Aspe (Fig. 12).

4.2. Objective of the visit

Visiting this reservoir is interesting for a number of reasons: Firstly, participants will become familiar with another water regulation and supply system of the region under study. Secondly, this reservoir is part of the inter-basin Tajo-Segura water transfer system (Fig. 13). Finally, participants will see the seaside and lower Vinalopó valley, thus gaining a full picture of the hydrological complexity of this region and of the local environmental/socioeconomic units that compete for the water resources.

4.3. The Tajo-Segura water transfer and the Crevillente reservoir

The Crevillente reservoir is comprised within the Segura River basin, an "artery" that drains an area of 19,000km^2. That basin includes other minor basins, all of which flow into the Mediterranean Sea.

Given the mild climate of this basin, located by the Mediterranean coast, and its high population density from ancient times, the need to stop the hydrological deficit of South-East Spain became clear already in the first half of the 20th century. That called for the construction of infrastructures that regulate water uses and bring water supplies from other regions.

The project of building a water transfer duct from the Tajo River basin to the Segura basin began to take shape in 1966. The project was approved on August 2, 1968. The government then granted authorisation for all the required construction work, which effectively started in 1978 based on the 52/1980 Act, which set the financial and exploitation conditions for the Tajo-Segura aqueduct.

In the first phase of the Tajo-Segura transfer scheme, a number of infrastructures were constructed in order to channel an estimated volume of 600hm^3 per year. The infrastructures are divided in four parts.

The first part involves the impulsion of water from the Bolarque reservoir to the La Bujeda regulatory deposit (overcoming a land unevenness of 270m.) In part 2, a 92km canal carries the water from the La Bujeda deposit to the Alarcón reservoir.

The waters flow until the Alarcón afterbay reservoir, where the waters are channelled to El Picazo waterfall. Part three of the aqueduct begins in the loading chamber of the said waterfall, namely yet another canal 97km in length. This is an uncovered canal which links directly to the Talave tunnel (part 4), which crosses the divide line between the Júcar and Segura basins.

Once in the Segura basin, the waters flow along the Mundo River (Talave and Camarillas reservoirs) and the Segura River, on to the Ojós weir. This is the key site in the Segura basin for the distribution of water coming from the Tajo River. The Ojós weir forks into two canals (one in each bank). The canal on the right-hand side distributes the water to the southern part of Murcia and Andalusia. The left canal has a capacity of 30m^3 per second. It carries the water for 27km until it reaches a distributor that forks into two canals. One of them continues on to La Pedrera reservoir. The other one, called the Crevillente Canal (Fig. 14), connects with the Crevillente regulatory deposit. That deposit is the "tail" reservoir of the said canal and also the source for Riegos de Levante ("Mediterranean Irrigation Service") on the left bank.

This is a high-capacity canal, as it begins in the left-hand side of the distributor accepting 17m^3/second. After several tributes, it feeds the Crevillente reservoir with 10m^3 of water per second. This means that, at full capacity, the canal can supply the Crevillente reservoir with approximately 300Mm^3 per year. Its unused transport capacity is no less than 200hm^3/year.

The Crevillente reservoir constitutes one of the main regulatory components of the entire infrastructure connecting with the Tajo-Segura

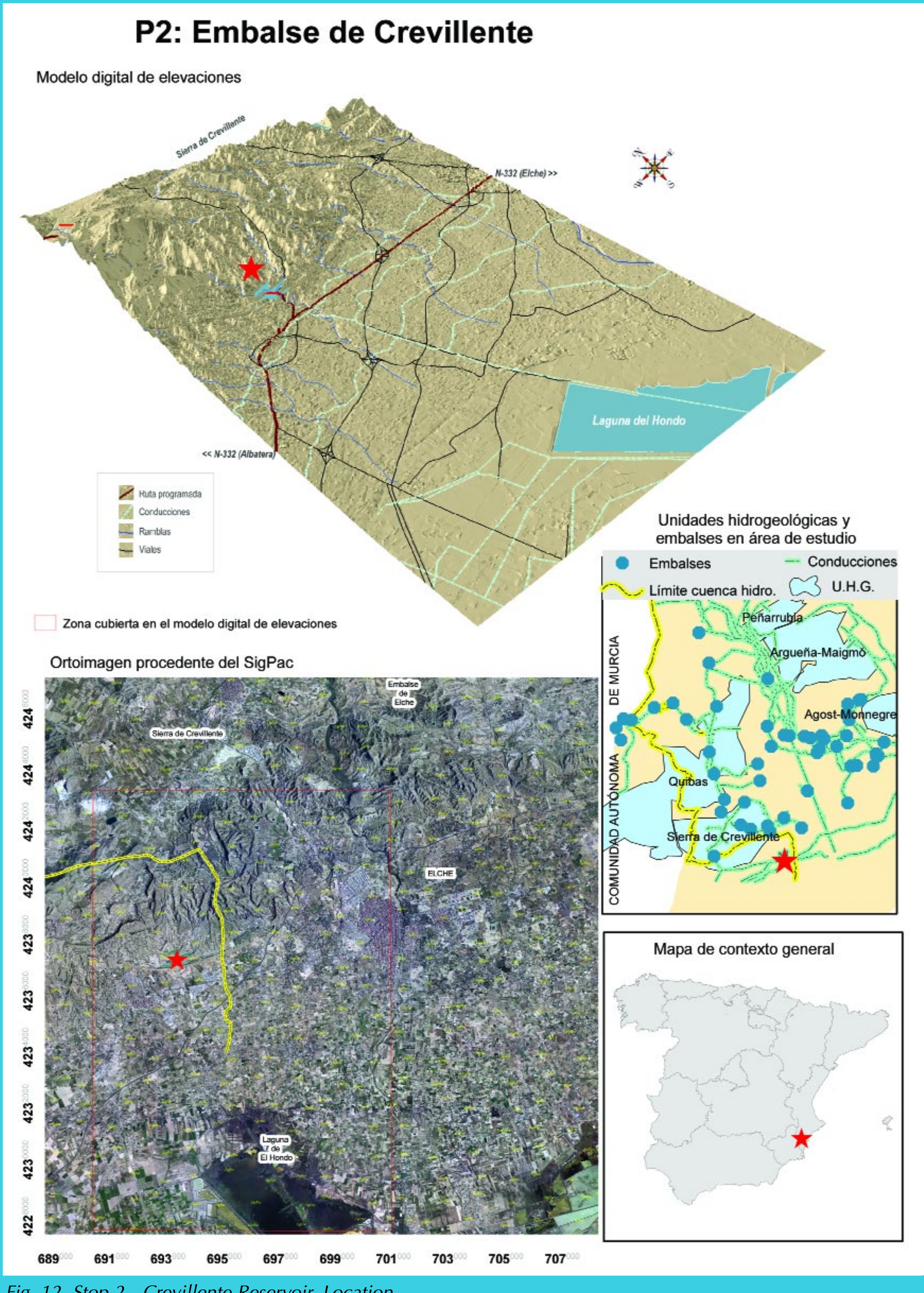


Fig. 12. Stop 2 - Crevillente Reservoir. Location.

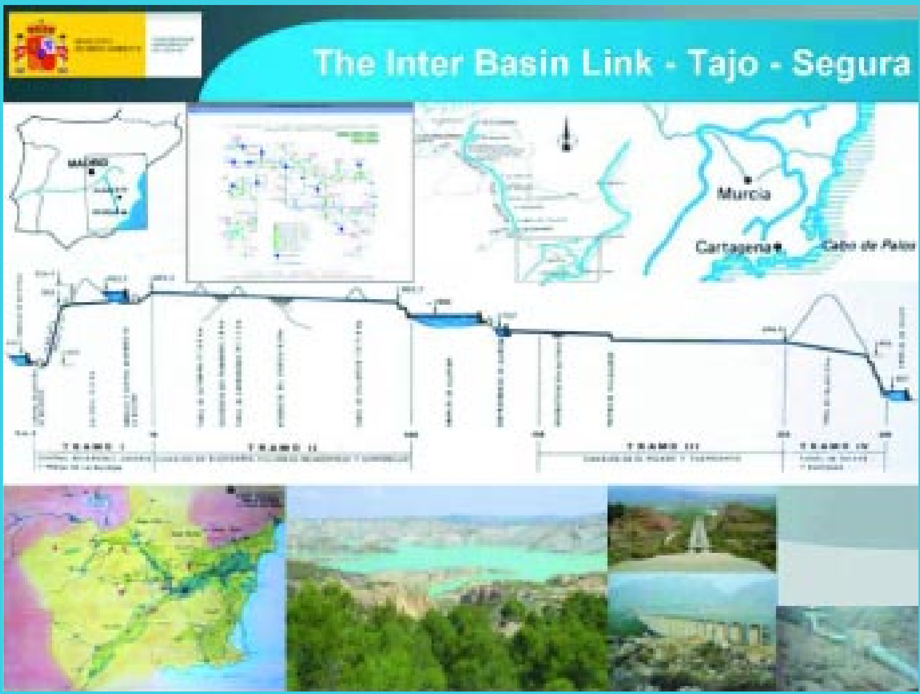


Fig. 13. The Inter Basin Link - Tajo - Segura.

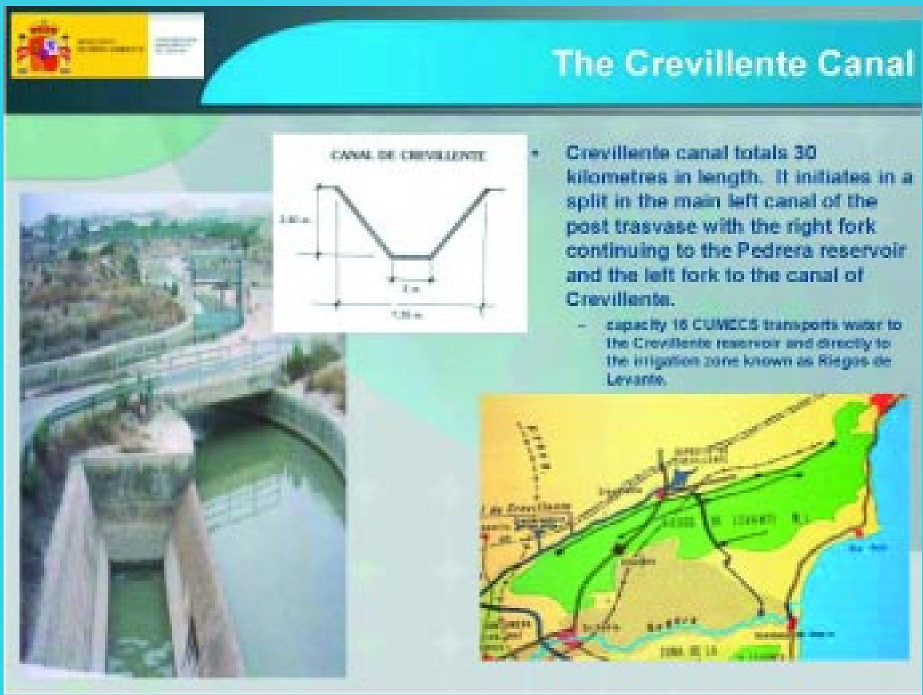


Fig. 14. The Crevillente Canal

Fig. 15. Panoramic view of the Crevillente Reservoir.

aqueduct. It has a capacity of 13.5Mm3. Its dam is 55m high. The wall is 360m wide at the top. It was built as a rubblemound breakwater. It floods a vast area of orthoclinal passages, rockfaces and backslopes located in the foothills of the Crevillente range. Ever since it started to operate (in 1985) and to accept water through the Tajo-Segura transfer, the semi-arid surroundings have gained in value as a recreational area. Second residential areas have been built.

According to the original project, the reservoir was meant to administer an estimated 125Mm^3 of water received from the large Tajo-Segura transfer so as to meet the water needs of the Lower Vinalopó and Greater Alicante areas.

The Crevillente Canal has been repaired in the past few years. Emergency repair works ordered by the Segura River Water Authority will presumably be completed by the end of 2005. The objectives of such repairs were: 1) to put an end to the water losses caused by the presence of cracks due to recent canal filling and emptying activities given the unsteady water supply for irrigation purposes; and 2) to fix the sections that risked collapsing. In addition, the access of water to the reservoir has been improved with four pumps in order to provide the supply network that serves the population nuclei with the highest possible volume of water. Recent works by Riegos de Levante have enhanced the accesses to the dam and also the pressure irrigation intakes and systems.

4.4. The Automatic Hydrological Information System (SAIH) of the Segura River basin

The General Directorate for Hydraulic Works of the Ministry of Public Works and Transportation is carrying out, through the Segura (Fig. 16), the construction and bringing on line of an Automatic Hydrological Information System (S.A.I.H) in the 18,900km^2 region served by the Segura Water Authority.

The system permits:

- data collection, by sensors installed at various control points located throughout the basin.
- the transmission of these data from the control points to data concentration points, by way of a radio based communication network.
- the storage, processing and computer monitoring of these local data at the concentration points.
- the transmission of these data from the concentration points to the final reception centre.
- the storage, processing and numeric and graphic monitoring of all the data from the river basin at the Murcia data processing centre, where the headquarters are located.
- the complete process of data collection, transmission, reception and storage in the computer at the Murcia headquarters is automatically updated every five minutes, and the central operator can change this period for every point.

A system of these characteristics will be of great aid for the decision making both in day-to-day operation and under flood conditions, when the availability of real-time hydrological data can be critical (Tables 4 and 5).

Moreover, it will permit an efficient way for the storage of hydrological databases in the basin, and the maintenance of hydrological records.

Table 4. Checkpoints

CHECKPOINTS	Number
Reservoirs	15
Isolated rain gauges and rain and snow gauges	25
River flow gauges	23
Canal flow gauges	17
Gully flow gauges	6
Pump gauges	6
	92

Table 5. SENSOR TYPES

SENSOR TYPES	Number
Rain Gauges	64
Rain and Snow Gauges	3
Reservoir Water Level	15
Pipe Floor Meters	14
Fixed Floor Meters at Gates	38
Level Alarms	48
Pressure Gauge Level Meters	35
Ultrasonic Level Meters	55
Open flow level and velocity meters	4
Open gate detectors	16
Pumping circulation detectors	4
	296

REPEATER STATIONS

Murcia – Hurchillo – Serratilla – Atalaya
Ricote – Selva – Puentes – Carrascoy
Taibilla – Santiago de la Espada
Elche de la Sierra – La Losa
Santa Ana – Cenajo
Collado del Carril – Caravaca – El Ardal

DATA CONCENTRATION POINTS

01 Murcia
02 Ojós
03 Camarillas
04 Cenajo
05 Puentes
06 Cartagena
07 La Pedrera

At present, this SAIH is being implemented by means of configuring a comprehensive hydrological information system that will cover both conventional and unconventional resources and allow real-time information retrieval. The goal is not only to improve the planning and management tasks that are carried out by the water authorities, but also such tasks performed by water users, in line with the objectives set by the Water Framework Directive.

4.5. Power supply

The network's electronic systems are powered by batteries capable of functioning autonomously and without recharging for 10 days.

These batteries are recharged by photovoltaic panels where commercial power line is not available. In other zones, they are hooked up to the electrical power supply network.

4.6. Civil works

Besides the installation of electronic and computer equipment, many civil works have been carried out throughout the basin both to house/support equipment and to create structures where hydraulic flow measurements can be taken.

The electromechanic equipment as well as data receivers and transmitters have been housed in prefabricated sheds designed especially for the project.

Fig. 16. SAIH in the Crevillente Canal & Reservoir.

These sheds are equipped with a security door with intruder alarm, and the entire installation is surrounded by a metal fence. Where necessary, the sheds have been elevated above potential extraordinary flood levels.

Concrete frames, adapted to the topography and characteristics of the area, have been built along certain sections of rivers, gullies and canals. These, along with periodical updating of rating curves with flowmeters, permit the obtention of sufficiently accurate, reliable flow and water level data.

Already existing hydraulic installations, modified to meet the system's objectives, have been used in some cases.

Likewise, service roads have been built or already-existing roads improved to permit access to outlying, isolated areas.

4.7 Bibliography and sources

1 Confederación Hidrográfica del Segura (Segura River Water Authority). Dirección General de Obras Hidráulicas ("General Directorate for Hydraulic Works"). Ministry of the Environment. 2005.

5. GALERÍA DE LOS SUIZOS

5.1. Location

The Galería de los Suizos (Fig. 17) is located in the Algueda ravine, at the Southwest extremity of the Crevillente Mountain Range (UTM Coordinates: X=683.500; Y=4235.700). Access is via a path towards the east starting shortly before Km. 9 of the CV-873 local road that links the villages of Albatera and Hondón de los Frailes .

5.2. Objective of the visit

We will take advantage of this stop to visit the outer part of Galería de los Suizos. This is a unique installation for the extraction of groundwater, and one of the main extraction points from the Crevillente aquifer.

5.3. Description of the visit

5.3.1. The Crevillente aquifer and the Galería de los Suizos

The Crevillente aquifer, in the Southwest of the province of Alicante, occupies a surface area of almost 140km^2. The main areas of high land in this region are the mountain ranges of Crevillente, Algayat-Rollo and Reclot (Fig. 18). It is a carbonate aquifer constituted of a sequence of over 500m of limestones, dolomitic limestones and Jurassic dolomites belonging to the sub-Betic Domain, arranged tectonically in the Prebetic domain of the Betic Mountain Range. In the intra-mountain basins left by the carbonate rocks there outcrop sub-Betic Cretaceous marls that form an impermeable top. The impermeable layer at the base is made up of the clays associated with Triassic evaporitic rocks (Pulido-Bosch and Fernández Rubio, 1981; Murcia and Mira, 1981) or by a non-transmissive strip of silt-clay matter of a limestone-dolomitic type that resulted from the crushing of aquiferous rock in the area of sub-Betic overthrusting (Andreu, 1997).

The intensive exploitation of this aquifer began in the 1960s, when water was extracted from both ends of the Crevillente Range. One of the main extraction sectors was in the vicinity of Hondón de los Frailes; the most noteworthy aspect of this was the fact that most of the water pumped out was done so via a gallery branching out from the southern face of Crevillente Range within the town limits of Albatera (Fig. 18). This gallery is called Riesgos de la Salud, though it is better known as Galería de los Suizos, due to the intervention of Swiss nationals in its design and construction (Fig. 19).

The realisation of this project resulted from a modification of the initial project proposed by the Riesgos de la Salud company to extract 5 m^3/s from the aquifer, through a vertical well drilled near the village of Hondón de los Frailes, as large volumes of water were believed to lie in this region (Andreu et al., 2005). This belief was founded on the hypothesis that the Jurassic carbonate materials of this aquifer were hydraulically connected to other carbonate structures further north, extending as far as the region of La Mancha. Thus, one of the main exit flows of the aquifer in the latter zone would be through the Hondón basin towards the impermeable Triassic formation of the Albatera Range and Crevillente Range (Fig. 19).

The most singular aspect of this gallery is that it does not drain water in the normal way; on the contrary, it contains vertical shafts through which water flows and is released to the soil, thus flowing freely by gravity towards the mouth (Fig. 20).

5.3.2. Main features of the Galería

The gallery entrance is at an altitude of about 250m a.s.l. and it extends some 2,360m within the rock formations, such that it completely penetrates the Crevillente Mountain Range and reaches the valley of Hondón de los Frailes. The first 700m of the tunnel are lined with concrete, after which there is just bare rock except for a cement floor. The tunnel is 2.5-3m wide and about 3.5m high, and its average gradient is 1 per thousand.

From a hydrogeological standpoint, the shaft begins in Tertiary white marls, of an impermeable type (Fig. 20). After this stage, it passes through a section made up basically of calcarenites and conglomerates that also belong to the Tertiary era. When it was drilled, the water-filled sections were emptied of liquid. After these detritic

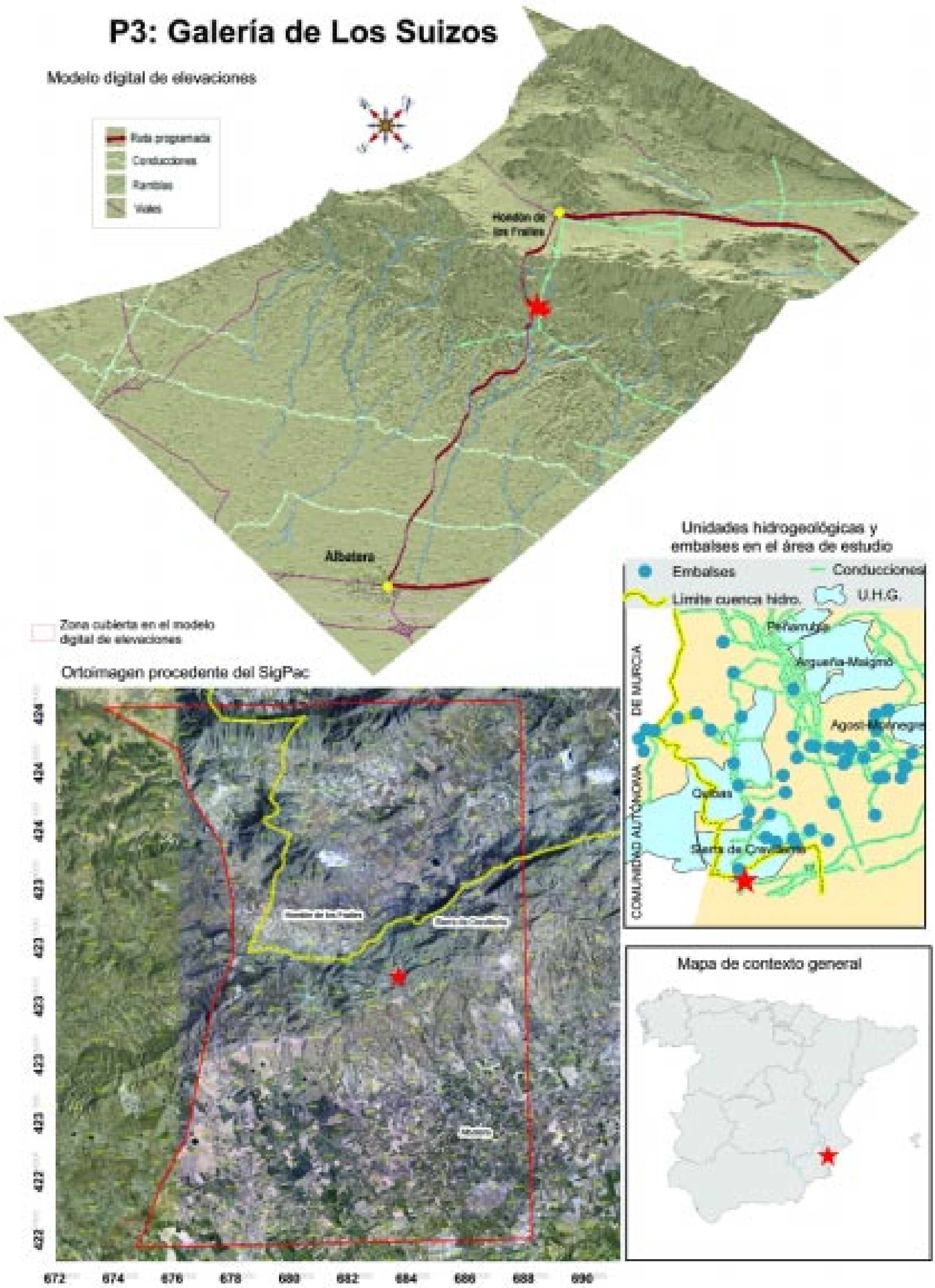


Fig. 17. Stop 3: Galería de los Suizos. Location.

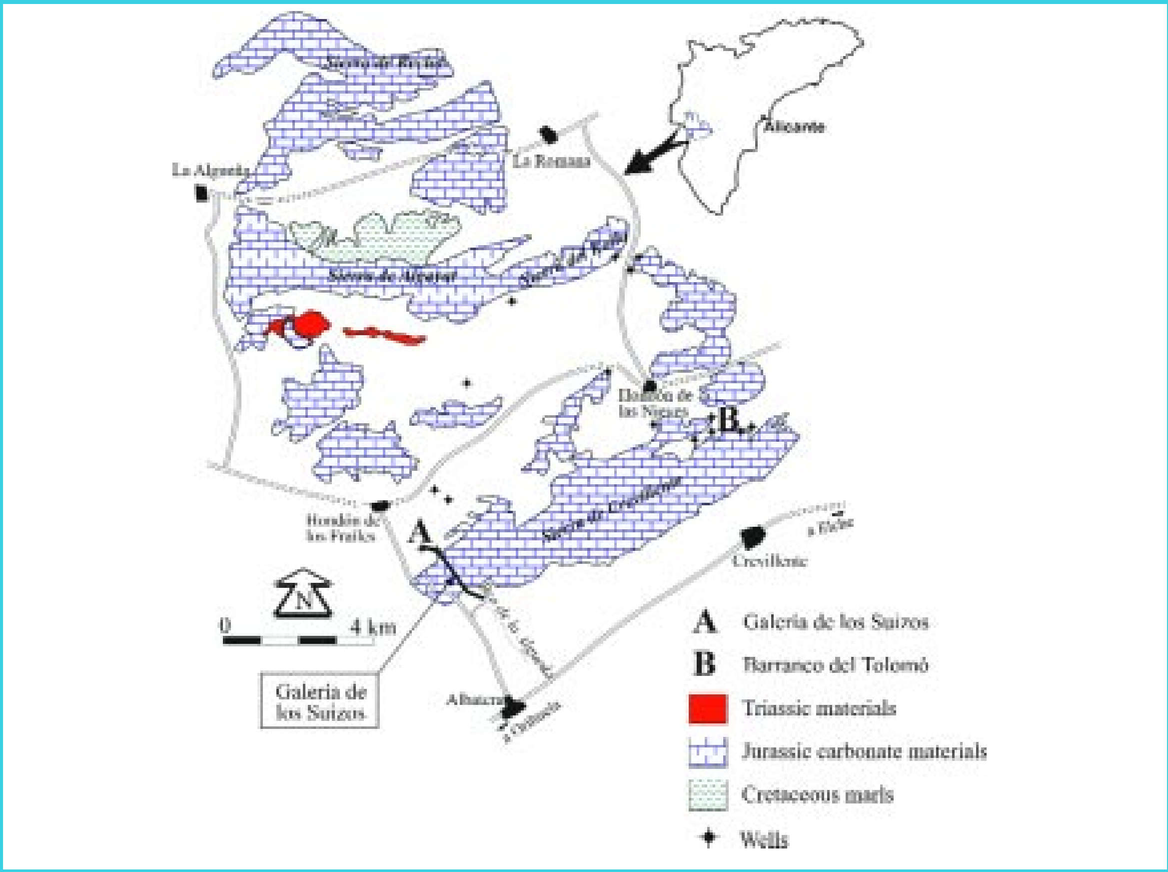


Fig.18. Location of the Crevillente aquifer, the pumping sectors and Galería de los Suizos.

Fig. 19. Entrance to Galería de los Suizos.

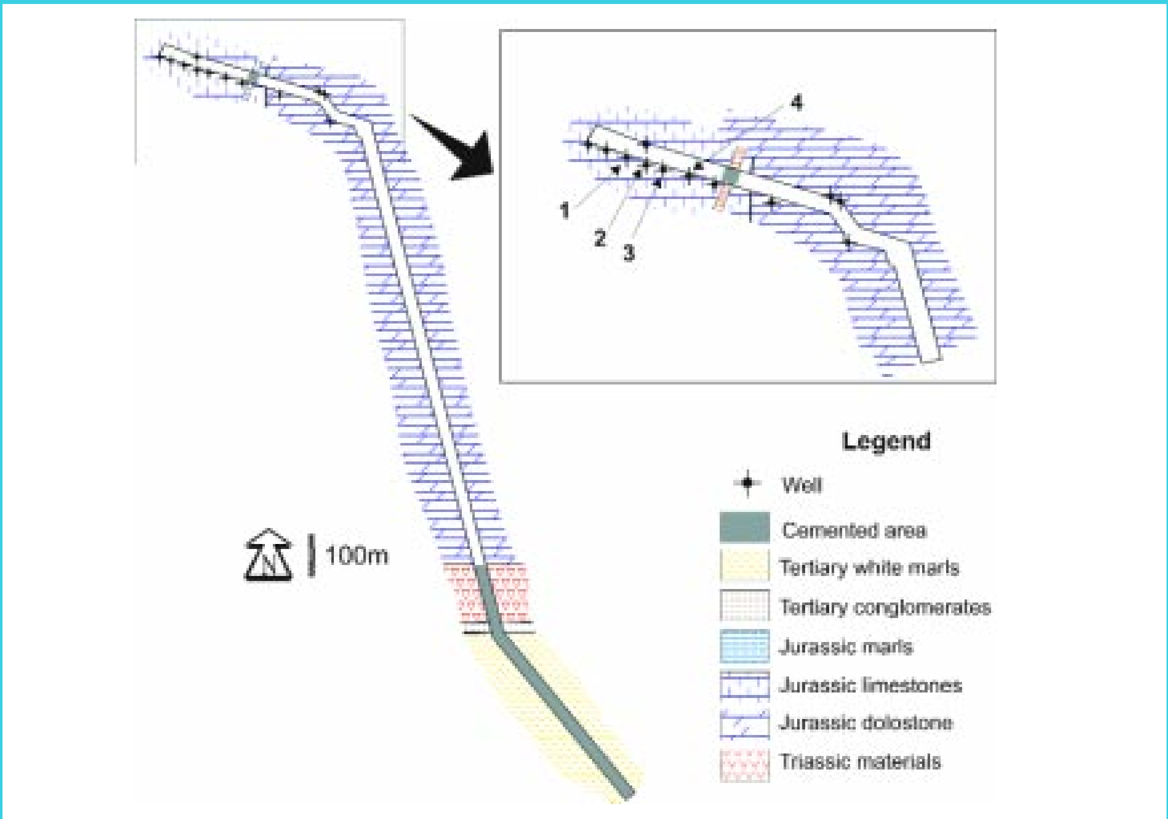


Fig. 20. Hydrogeological scheme of the Galería. The numbered boreholes correspond to the present-day extraction points.

materials, the tunnel passes through an area of Triassic gypsum (Keuper), on the southern slopes of the Crevillente Range, which comprises the southern boundary of the Crevillente aquifer. None of these materials can be observed within the gallery, because they lie within the sector of coffer outcropping).

Beyond the zone that is covered over, we can see the cutting of the grey Liassic dolomites (Andreu et al., 2002) that make up the Crevillente aquifer *s. str*. The main characteristic of these rocks is their high degree of tectonisation and formation of breccia. Fractures and diaclases can be observed throughout the gallery, some of these being open and karstified. According to available historical records, during the drilling of this sector various points of water springs were seen (Andreu et al., 2005).

At the end of the gallery, the dolomites come into contact with limestones, via a fault that lowers the northernmost block. The limestones, too, are strongly tectonised and brecciated, giving rise to a significant amount of secondary porosity. Also notable are the very many fractures filled with calcite precipitates, as well as the greater proportion of open fractures (in comparison with the dolomite sector), some of which exceed 50cm in width. Some of these open fractures are filled with rock fragments that constitute genuine conglomerates. The different rock faces bear a calcite film that joins them and provides evidence of the passage of carbonate-saturated water.

5.3.3. Exploitation of water from the Galería

When the construction of the gallery ended in 1964, water ceased to emerge naturally and it was necessary to create vertical passages to pump out water to the surface. This means of exploiting the water remains in use today.

In total, 12 extraction points were drilled. These were initially quite shallow and produced a considerable volume of water. However, the

Fig. 21. Water extraction via boreholes within the Galería.

lowering of water levels that has occurred over the years has given rise to the loss of output from some of the drillings within the gallery. Although they were further deepened, in some cases to more than 300m, not all of them have regained the initial flow volumes, which is why today only four pumps remain in use, the others having been abandoned. The current pumping capacity is 350l/s (Fig. 21). The water extracted is mainly used to irrigate various areas within the boundaries of Albatera, Crevillente, Elche, Hondón de los Frailes and Orihuela.

For several decades, this was the only point where the aquifer was exploited at its western end. The volume of water extracted varied over time, with the greatest amount being produced between 1970 and 1985, when pumping rates exceeded 10Mm^3/year, with 18.1Mm^3 being extracted in 1980 (Pulido-Bosch, 1985); in recent years, however, rates have not exceeded 4hm^3/year.

The large volumes of water extracted from the gallery, together with those from the rest of the aquifer, produced a fall in water levels of over 200m in this part of the aquifer.

5.3.4. Characteristics of the water in the Galería

With respect to the physico-chemical characteristics that are currently present in the water pumped from the gallery, it is notable that the electrical conductivity ranges from 2600 to 2900sμS/cm, and that the facies is sodium chloride (Table 6). This latter feature, which is characteristic of the water throughout the Crevillente aquifer, has been interpreted as resulting from the dissolution of the Keuper evaporites (Pulido-Bosch et al., 1995; Andreu, 1997). However, the water in the gallery is different from that in other sectors of the aquifer,

Table 6. Physico-chemical characteristics of the water. Summary of the hydrogeochemical characteristics of the water from Galería de los Suizos (October 2005). M: mean; SD: standard deviation; E.C.: electric conductivity µS/cm; T: temperature in ºC; ions in mg/L.

	M	SD
E.C.	2805	112
pH	7.42	0.02
T	27.4	0.2
Ca^{2+}	176	9
Mg^{2+}	58	2
Na^{+}	421	19
K^{+}	6	0.2
Cl^{-}	622	32
HCO_3^{-}	209	10
SO_4^{2-}	509	21
NO_3^{-}	7	0.1

in that its sulphate content exceeds 450mg/l, while in the other sectors the corresponding value is usually below 350mg/l. These differences could be due to lithological variations of the various Keuper facies, these being more gypsum-rich in the vicinity of the gallery.

Finally, note that the high degree of mineralisation of the water seems to have existed since the start of its exploitation, as the water that was drained during the drilling of the gallery presented chloride values of 410mg/l (Andreu et al., 2002). On the basis of this initial value, and as a result of the desaturation of the aquifer in this sector, there would have occurred an increase in the mineralisation to values of over 600 mg/L, as currently recorded. However, this increase in the saline concentration would have taken place before the 1990s, because there have been no significant variations in the chemical characteristics of the water since then.

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6. VISIT TO BARRANCO AND POZOS DEL TOLOMÓ AND THE FEDERAL RESERVOIR

6.1. Location

The Barranco del Tolomó is a small ravine that starts from the northeast sector of the Crevillente Mountain Range, continues as far as the basin of Vega de Aspe and then, its water flows into the River Tarafa (a tributary of the River Vinalopó). Access to the site (coordinates UTM: X=690.800; Y=4241.900) is by means of the track providing access to the quarries situated at Puntal de Ors, which leads southwards and starts at approximately the 4Km point on the CV-845 local road that links the villages of Aspe and Hondón de las Nieves.

6.2. Objective of the visit

One of the main aims of this stop is to visit the other historical sector of importance in the explotation of the Crevillente aquifer. Thus, we hope to carry out a brief review of the main consequences of the intensive water exploitation that has taken place in this part of the aquifer. In addition, we shall visit the Federal reservoir, which is an example of the storage and regulation of groundwater practiced by the users of this aquifer.

6.3. Description of the visit

6.3.1. The exploitation of Barranco del Tolomó

The Barranco del Tolomó and its surroundings have been one of the main areas in which the Crevillente aquifer has been exploited (Fig. 23). The extraction of groundwater in this area goes back to the late 1950s (Asencio, 1982). Initially, the installations for this purpose were located at the foot of the mountain range, on Quaternary rocks in the Vega, and were therefore beyond the Crevillente aquifer. However, from the 1960s and 1970s, and as a consequence of the high rates of flow volume obtained from the boreholes over Jurassic carbonate materials, the activity spread up the valley to reach the vicinity of Hondón de las Nieves. The water pumped from this part of the aquifer was used to irrigate land that had previously been uncultivated, in the municipalities of Aspe, Hondón de las Nieves, Elche and Crevillente. To a lesser extent, the water was also extracted for human consumption.

It has been estimated that, in all, this sector of the aquifer there came to be more than 30 extraction points, reaching pumping rates of over 600l/s. The maximum level of pumping from the Tolomó sector was reached in 1979 when a total of 13.5Mm^3 was pumped out. However, this intensive exploitation has led to the abandonment of most of the pumps, and so today only 7 are still functioning with a reasonable degree of reliability. Mean extraction rates in recent years have been less than 2Mm^3/year, and the most common use for the water from this sector has been for agriculture.

6.3.2. The consequences of intensive exploitation in Barranco del Tolomó

The intensive exploitation of the groundwater in this part of the aquifer has provoked a series of consequences. From the hydrogeological point of view, the following are the most significant: severe falls in the piezometric level, a deterioration in water quality and a loss of output from the pumps.

Since the outset of this exploitation, decreases in the piezometric level began to occur. The decreases became more and more severe as extraction volumes increased (Fig. 24). The most important decreases took place between 1979 and 1983, with falls exceeding 30m. Until then, the piezometric evolution of the aquifer had been totally comparable between the two main sectors of exploitation. But after 1983 the behaviour patterns of the two zones began to differ; this has been interpreted as the result of a possible disconnection or, at least, a reduction in the hydraulic communication between the two ends of the Crevillente Range (Corchón et al., 1989; Andreu, 1997). Thus, the piezometric evolution of the Tolomó sector began to register more severe falls between 1983 and 1988, with relative decreases of 18m/year. The effect of the rainy

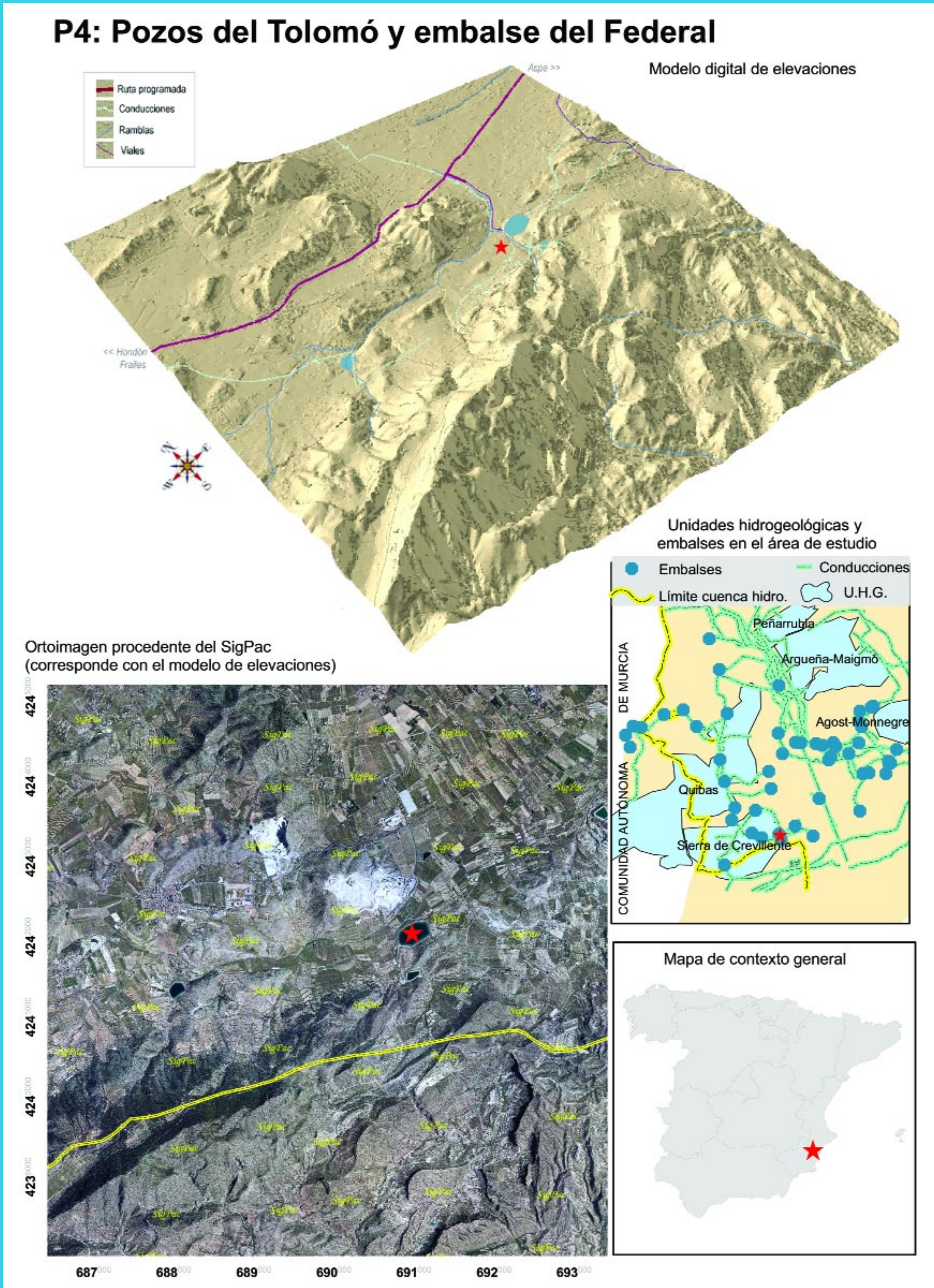

Fig. 22. Stop 4: Barranco & Pozos del Tolomó (Tolomó gully & wells). Location.

Fig. 23. Panoramic view of Barranco del Tolomó. Each of the towers corresponds to the location of the former electrical transformers and, thus, to the location of one or more pumping installations.

period of 1989-1991 was similarly marked, with a recovery in piezometric levels of over 40m. However, after the early 1990s there began another period of falling water levels, to depths that are currently around 60m b.s.l. As a result,

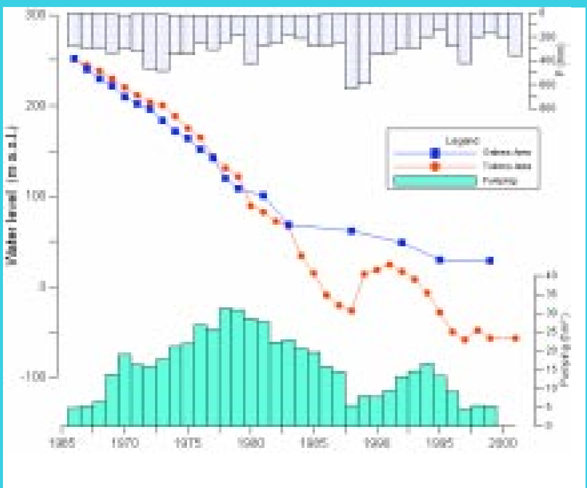

Fig. 24. Piezometric evolution of the main pumping sectors in the aquifer.

the total desaturation that has been undergone by this part of the aquifer since the beginning of its exploitation has been of approximately 350m.

As regards the chemical characteristics of the water, it is noteworthy that this area of the aquifer is one of the most severely affected by processes of water quality deterioration, and the one where most pumps have had to be abandoned for this reason. The original physico-chemical characteristics of the water in this sector have not been accurately determined. The first analytical data available date from 1978. It is from then on that reasonably regular information has been recorded and, therefore, from when we can establish how intensive exploitation has affected the chemical quality of the water. Figure 25 shows the evolution of some physico-chemical parameters at one of the pumps located in Barranco del Tolomó. There seems to be a high degree of correlation between the pattern of electrical conductivity (a parameter that is indicative of the level of mineralisation) and the piezometry. As the piezometric level falls, the

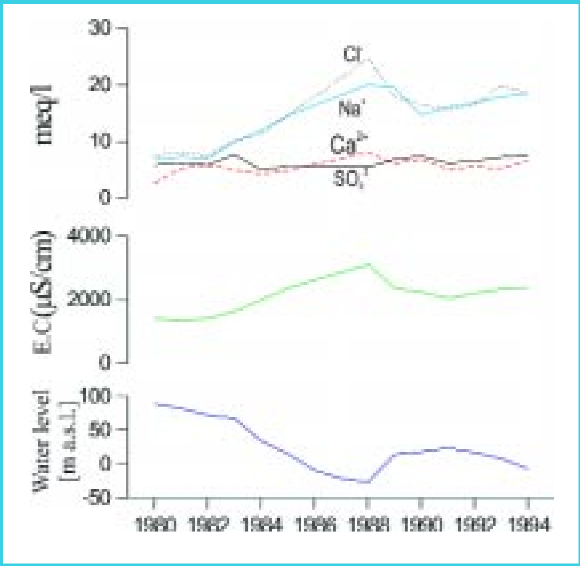

Fig. 25. Evolution of some parameters related to water quality at one of the pumps located in Barranco del Tolomó.

electrical conductivity of the water rises. This increase in water mineralisation is favoured mainly by its enrichment in chlorides and sodium. Similarly, the effect of the rainy period at the end of the 1980s was apparent on the chemical characteristics, with a fall in electrical conductivity and in the content of chlorides and sodium.

This pattern of change in the chemical nature of the water seems to be related to geological characteristics and to the presence of evaporite rocks (Pulido et al., 1995). Thus, in those areas where the presence of deep-lying saline rocks is known, as is the case of this sector of Barranco del Tolomó, more saline water tends to be found at the deepest levels (Andreu, 1977).

Finally, another of the consequences affecting the pumps in this sector has been the loss of pumping output as water levels fall. The considerable expansion in the number of extraction points was encouraged by their high productivity levels. During the 1970s, many of

Fig. 26. Panoramic view of the Federal reservoir.

the pumps produced water flow volumes exceeding 100l/s. The continual fall in water levels has brought about progressive reductions in the volumes of water extracted. Attempts have been made to overcome this by constant re-deepening of the boreholes, but not all the pumps have recovered their initial output rates and some of them became unproductive and had to be abandoned. At present, 4 of the 5 pumps that SAT No. 3819 retains in activity in Barranco del Tolomó achieve output volumes of less than 30l/s.

6.3.3. Management initiatives

Given the situation experienced in the 1980s, the Crevillente aquifer was declared "provisionally over-exploited" on July 31, 1987, as set out in the Public Water Domain Law. This administrative situation requires the establishing of a Users' Association and the presentation of a Management Plan to attempt to alleviate the effects of the overexploitation as much as possible (Aragonés et al., 1989).

Several activities have been implemented in the Crevillente aquifer since the presentation of the Management Plan, although the most significant of these, and the ones that have most affected the Barranco del Tolomó sector, have been the redistribution of pump sites, the release of water flows and the activities of regulatory projects.

The redistribution of pump sites consists in siting pumps further from the classical areas of exploitation, in an attempt to reduce the depression cone that is caused by a concentration of pumping points in the same zone and which, thus, aggravates the loss of output and lowers water quality. The setting in operation of two boreholes located in the central sector of the aquifer has enabled exploitation in Barranco del Tolomó to be reduced.

Although the water from the Crevillente aquifer meant for human consumption was much less than that for agricultural use, the replacement of this water with supplies obtained from the Taibilla Basin Water Association, provided to the villages of Aspe and Hondón de las Nieves, involved certain small savings in the water extracted from the Barranco del Tolomó sector.

Finally, another activity carried out has been the construction of facilities for the storage and regulation of groundwater, in order to better exploit the aquifer's resources. One such facility is the Federal reservoir, which was created between March 1991 and July 1992 (Fig. 26 Photo). This is a reservoir constructed with loose materials and an asphalt sheet. It has a capacity of 1Mm^3, and the dam height is 18m. This reservoir has a distribution coverage of approximately 3,500ha, mostly dedicated to the cultivation of table grapes. At present, the Tolomó reservoir is mainly filled from the boreholes in Baranco del Tolomó, which function uninterruptedly from March to September. Thus, SAT No. 3819 has sufficient capacity to respond to the demand for irrigation water during the summer.

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7. LIST OF COLLABORATORS AND ACKNOWLEDGEMENTS

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Fig. 27. The Vinalopó River as it flows through the town of Novelda. The main activities of the town are marble processing and table grape growing.

Fig. 28. Municipality and dry lagoon of Salinas. Higher Vinalopó.

Fig. 29. Villena. Higher Vinalopó basin. Site of the final round-table and final stop in the programme.