FREEWAT
Free and Open Source Software Tools for Water Resource Management
EU HORIZON 2020 Project

European Commission

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Open Workshop
ICT tools for innovating Groundwater Management in a changing world

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PROBLEMS, BENEFITS and RESULTS OF GROUNDWATER RESERVE CONSUMPTION
The MASE and SASMIE Projects:
Groundwater mining and seawater intrusion in Spain

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EIP Water Online Market Place
Matchmaking for water Innovation
MAR Solutions - Managed Aquifer Recharge Strategies and Actions (AG128)

50 anys
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CID CELEBRAR INNOVAR DEBATRE
CENTRE D'INVESTIGACIÓ I DESENVOLUPAMENT 1967-2017

Taken from: http://travessa-pirineus.blogspot.com.es/2014/08/dia-15-de-lospitalet-al-refugi-de-juclar.html

Project FREEWAT

Tools for monitoring groundwater in a changing world

PROBLEMS, BENEFITS and RESULTS OF GROUNDWATER RESERVE CONSUMPTION

The MASE and SASMIE Projects:

Groundwater mining and seawater intrusion in Spain

Serra de Crevillent, Alacant

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Effects of groundwater exploitation

Simplified aquifer with diffuse recharge without surface water recharge

Exploitation modifies the flow pattern

→ **Primary effects** { groundwater level drawdown; discharge reduction

When abstraction < recharge:

→ **new equilibrium in time τ**

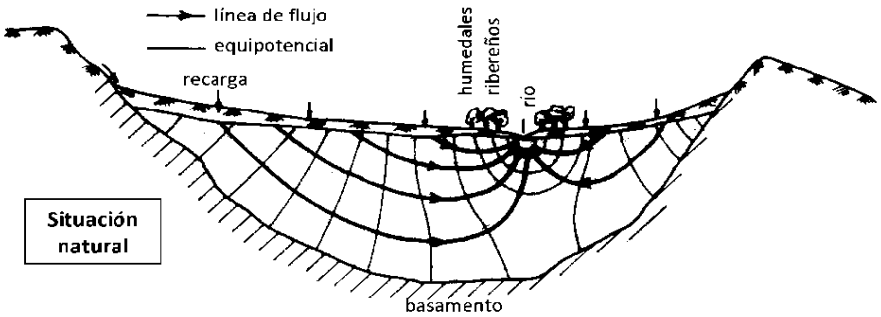
$$\tau \approx \frac{L^2 S}{T}$$

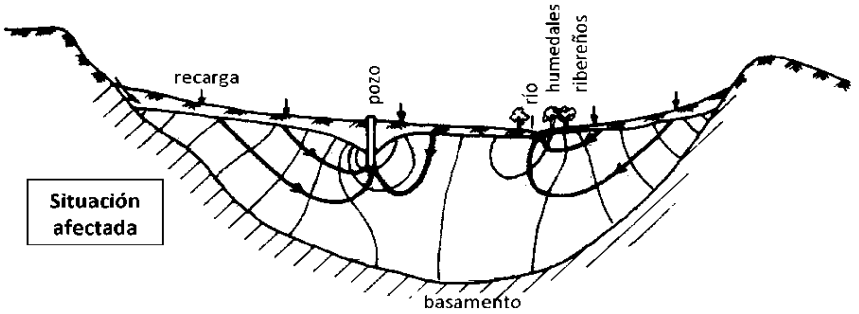
L = system size
T = hydraulic transmissivity
S = storage coefficient

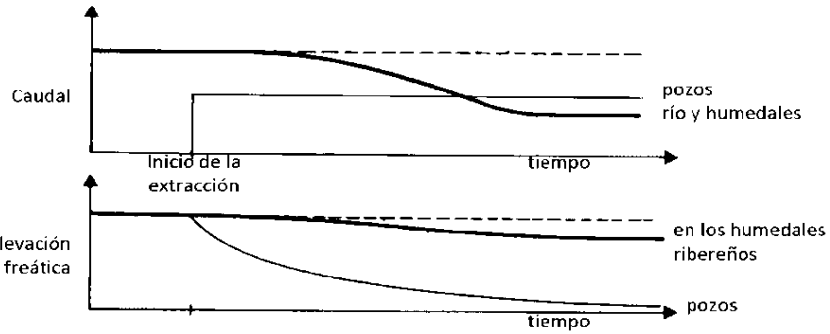
τ { months in small aquifers, nearby recharge; years in mid-sized aquifers; decades to millennia in large aquifers

The new equilibrium involves drawdown

→ **dynamic drawdown**







Definitions

- **Intensive exploitación**

  →**hydrogeological conditions are greatly modified:**

  - **groundwater flow**
  - **chemical composition**
  - **relationships with other water cycle components**
  - **reduction of dynamic groundwater reserves**

- **Groundwater mining**
  - **abstraction rate greater than possible recharge**
  - **continuous consumption of groundwater reserves**
  - **substitution of freshwater reserves for saline / brackish water**
  - **no recovery in less than two human generations (about 50 years)**

Groundwater intensive exploitation and groundwater mining → similar initial evolution

Effects of intensive and mining groundwater exploitación

- Decrease / cessation of spring flow
- Decrease / cessation of river baseflow
- Reduction / dessication of wetlands
- Discharge areas become recharge areas
- Water level drawdown in wells

- Groundwater becomes progressively more expensive

- Possible groundwater mining → non-sustainable
  → but reserves may last many years
  Social benefits from development

- Environmental damage and social stress
- Possible changes in water quality → seawater intrusion

- It is a path toward a new form of using water and other resources
- It needs complex water governance and planning

Groundwater mining in the world

Selected countries, around year 2000

Foster y Loucks, 2010

Country	Groundwater / total water	Groundwater use, hm³/a		
		Total, T	Non-renewable, NR	NR/T
Argelia	0,54	2600	1680	0,65
Saudi Arabia	0,85	21000	17800	0,85
Bahrain	0,63	258	90	0,35
Egypt	0,07	4850	900	0,19
UA Emirates	0,70	1900	1570	0,82
Libya	0,95	4280	3014	0,70
Oman	0,89	1644	240	0,15
Qatar	0,53	185	150	0,81
Tunis	0,59	1670	460	0,28
Yemen	0,62	2800	700	0,25
Spain	0,35	7000	300	0,04

Projects MASE and SASMIE

Carried out by: Dpt. Civil & Environ. Eng., Technical University of Catalonia (UPC)
Economic support: AQUALOGY / SUEZ
Overview : CETAQUA

Objetive: Analyzing the hydrological, hydrogeological, economic, managerial, social, environmental and ethic aspects of groundwater intensive exploitation

MASE: 2013–2015.- Groundwater mining in Spain
→ when recovery needs at least a few human generations

South-eastern Spain: South of Alicante, Murcia and Almería
The Canary Islands: Gran Canaria and Tenerife

SASMIE: 2015-2017.- Groundwater salinization in Spanish Mediterranean and island coastal aquifers

Mediterranean coast of the Iberian Peninsula
Balearic and Canarian Archipelagos

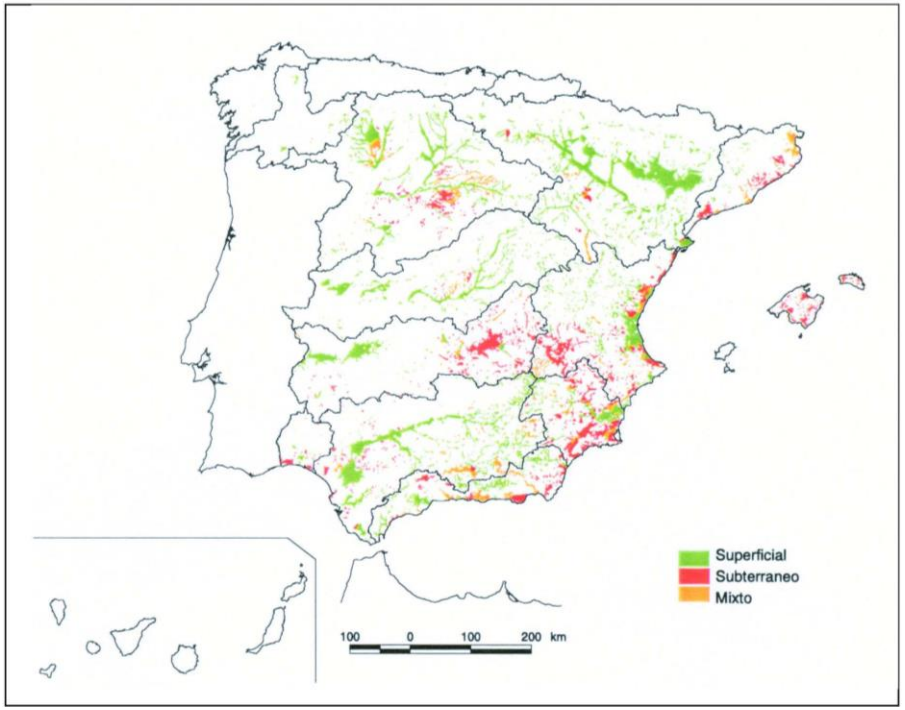
METHODOLOGY → gathering of información { available (non-exhaustive) from experts

CONDITIONS No new studies

Integrated vision of water resources and their implications
Without { looking for solutions
proposing actions

Publication as an e-book by the UPC

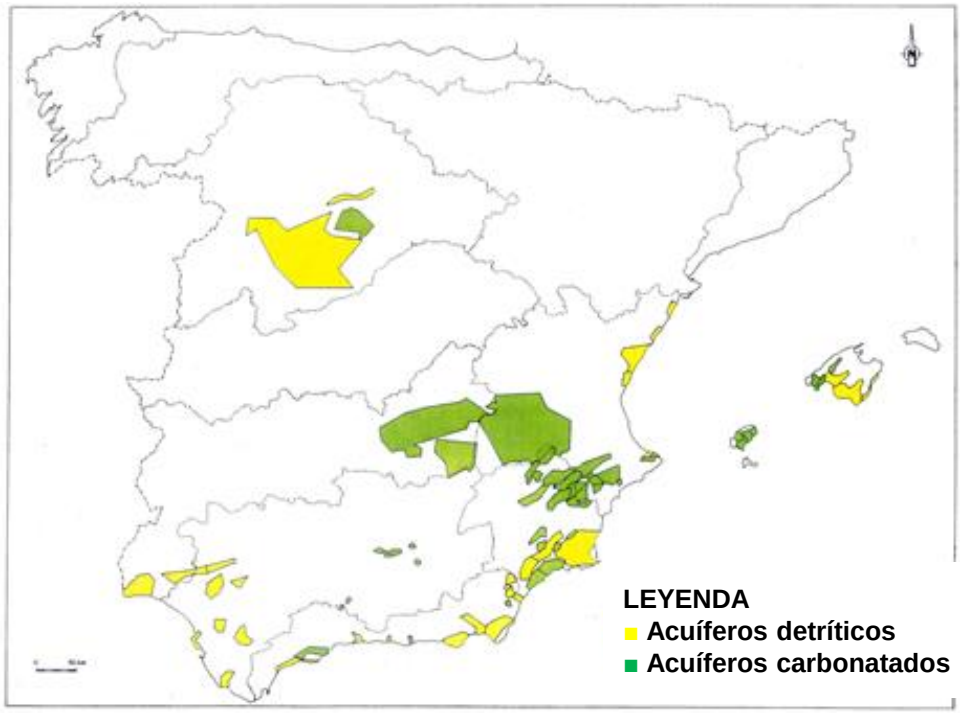
Intensive groundwater exploitation in Spain



Irrigation areas after water origin

Red: groundwater
Green: surface water
Orange: mixed origin

LBA, 2000

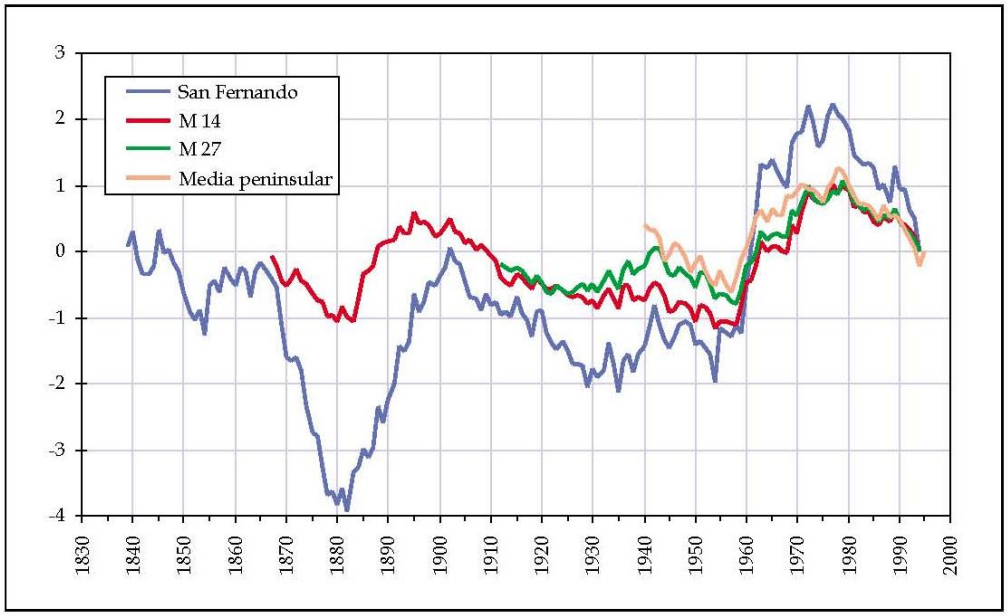


Spanish aquífers in which "overexploitation" problems were detected in 1996

DGOH–ITGE, 1987

Percentage of groundwater used in agriculture
80% in the Peninsula
50–60% in the archipelagos

Water resources irregularity in Spain



Cumulated deviation relative to the mean in the time period, in metres

High irregularity
Cyclic behaviour: 20 and 40 years
→ long dry periods

Annual precipitación
Longest period : 1840–1995

LBA, 2000

Groundwater is much less variable → high reserve / recharge ratio
Delayed and damped reaction
Enviromental effects
Water may become progressively more expensive
Risk of groundwater mining and seawater intrusion
Groundwater is a reserve → to overcome transient situations
→ to mitigate climate and global change effects

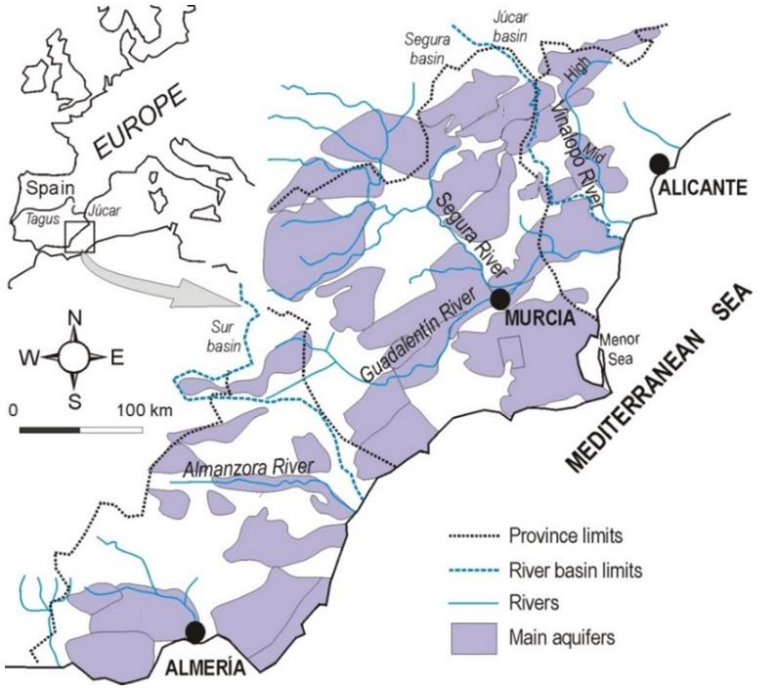
Groundwater reserve consumption
Preliminary estimation in 1995 in south-eastern Spain

Area	Groundwater reserves, hm³			Consumption rate hm³/a	Time for exhaustion, years
	Consumed 1980–1995	Existing 1995	Usable 1995		
Almería	800	1100	750	50	15 (10–75)
Murcia	2000	10000	7100	125	60 (10–80)
Alacant–Vinalopó	1000	7000	6000	50	120 (10–400)

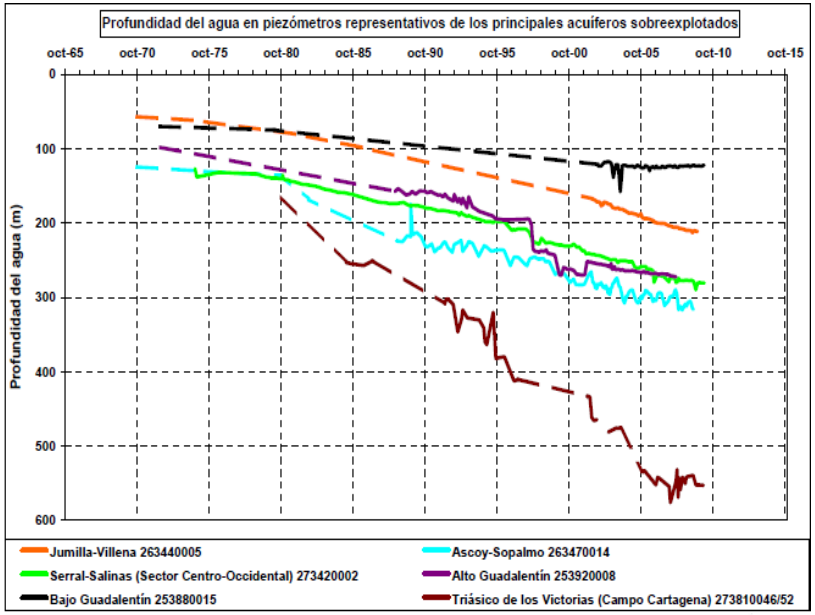
DOGH–ITGE, 1997

Very uncertain values
Reserves still non-exhausted in 2015
Decreasing abstraction rate
Slow recovery due to natural recharge

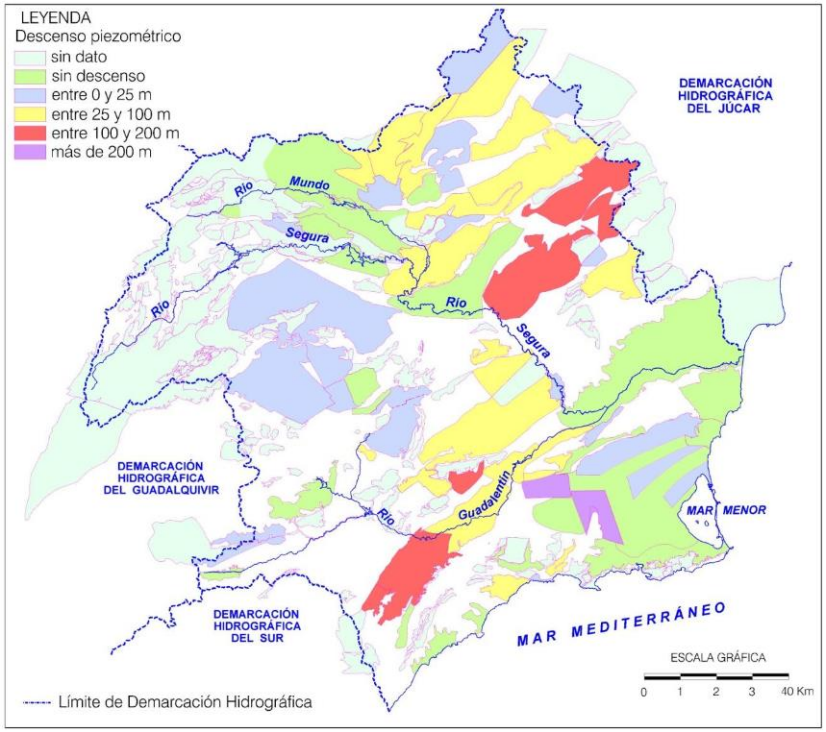
Total groundwater mined until 2014: 15 km³

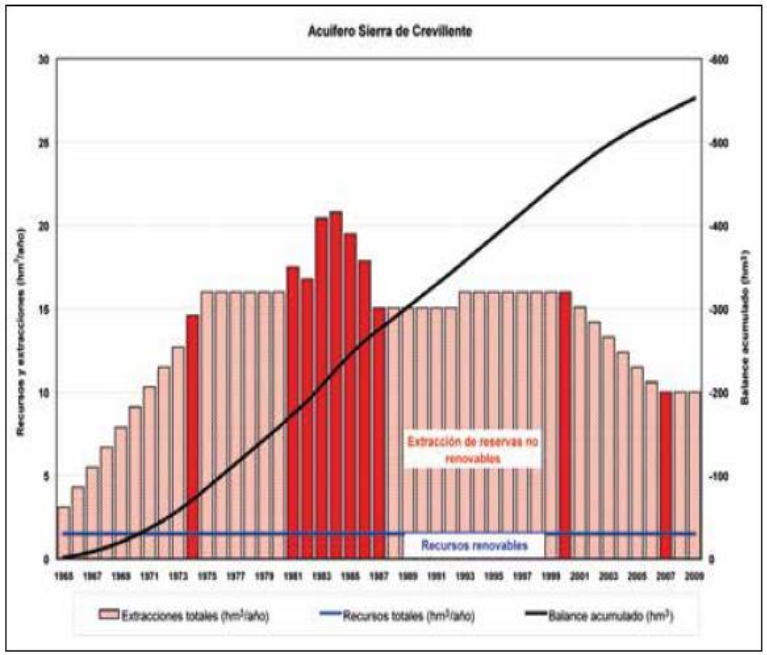


Piezometric level deawdown in the Segura River basin



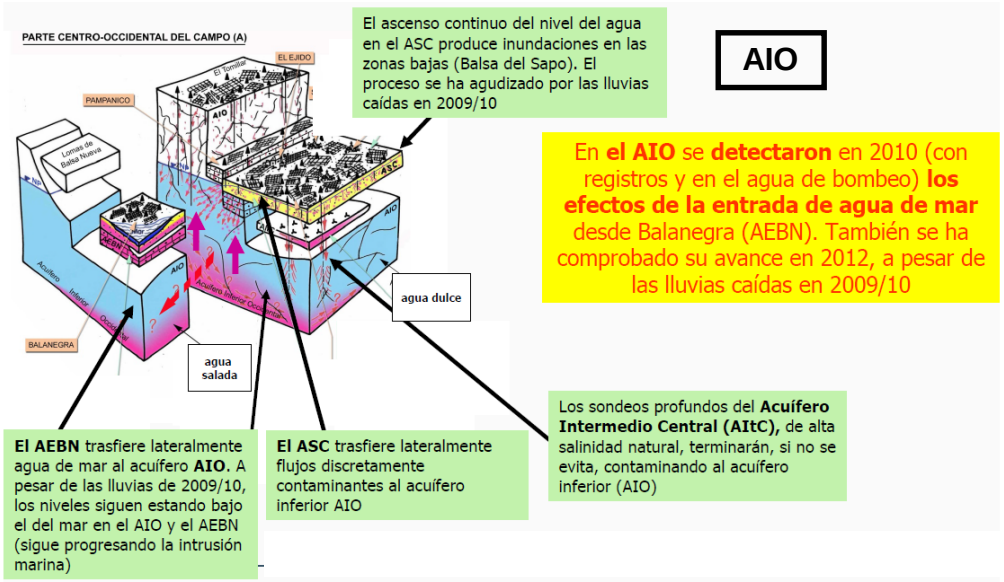
Piezometric level evolution → up to 20 m/yr
(Cabezas, 2001, García–Aróstegui, 2013)





Cumulative average piezometric drawdown in the main intensively exploited aquifers
(PHS, 2013)

Campo de Dalías, Almería



El ascenso continuo del nivel del agua en el ASC produce inundaciones en las zonas bajas (Balsa del Sapo). El proceso se ha agudizado por las lluvias caídas en 2009/10

AIO

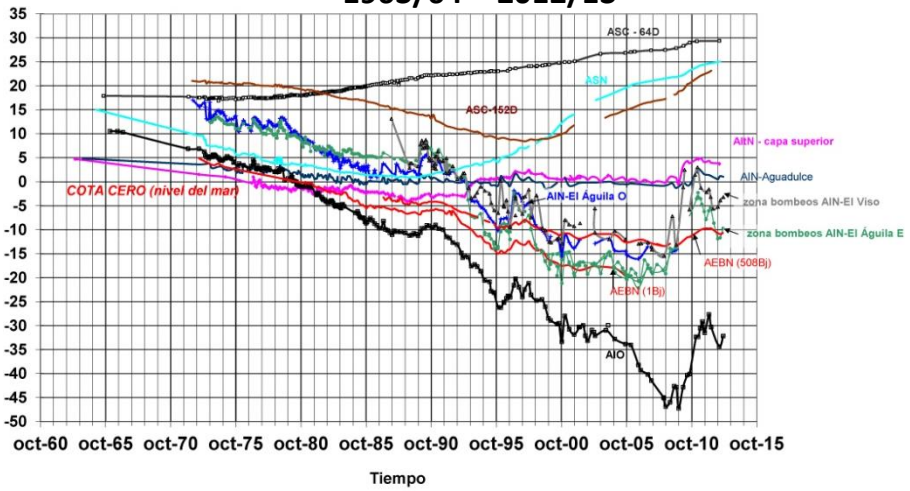
En **el AIO** se **detectaron** en 2010 (con registros y en el agua de bombeo) **los efectos de la entrada de agua de mar** desde Balanegra (AEBN). También se ha comprobado su avance en 2012, a pesar de las lluvias caídas en 2009/10

El AEBN trasfiere lateralmente agua de mar al acuífero **AIO**. A pesar de las lluvias de 2009/10, los niveles siguen estando bajo el del mar en el AIO y el AEBN (sigue progresando la intrusión marina)

El ASC trasfiere lateralmente flujos discretamente contaminantes al acuífero inferior AIO

Los sondeos profundos del **Acuífero Intermedio Central (AItC),** de alta salinidad natural, terminarán, si no se evita, contaminando al acuífero inferior (AIO)

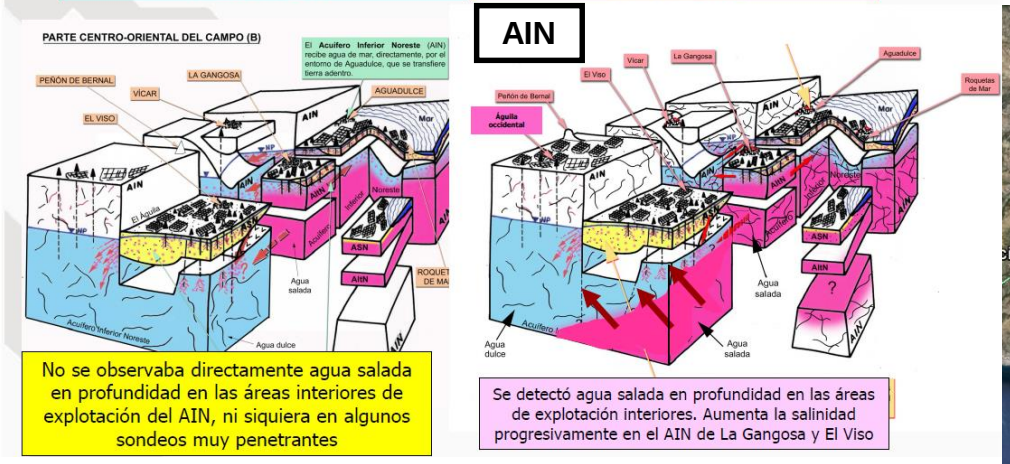
Piezometric level evolution (elevation in m asl): 1963/64 – 2012/13



The biennium 2009–2011 → very humid

Situación a 2006 | Situación 2012

AIN



No se observaba directamente agua salada en profundidad en las áreas interiores de explotación del AIN, ni siquiera en algunos sondeos muy penetrantes

Se detectó agua salada en profundidad en las áreas de explotación interiores. Aumenta la salinidad progresivamente en el AIN de La Gangosa y El Viso

Salinization processes

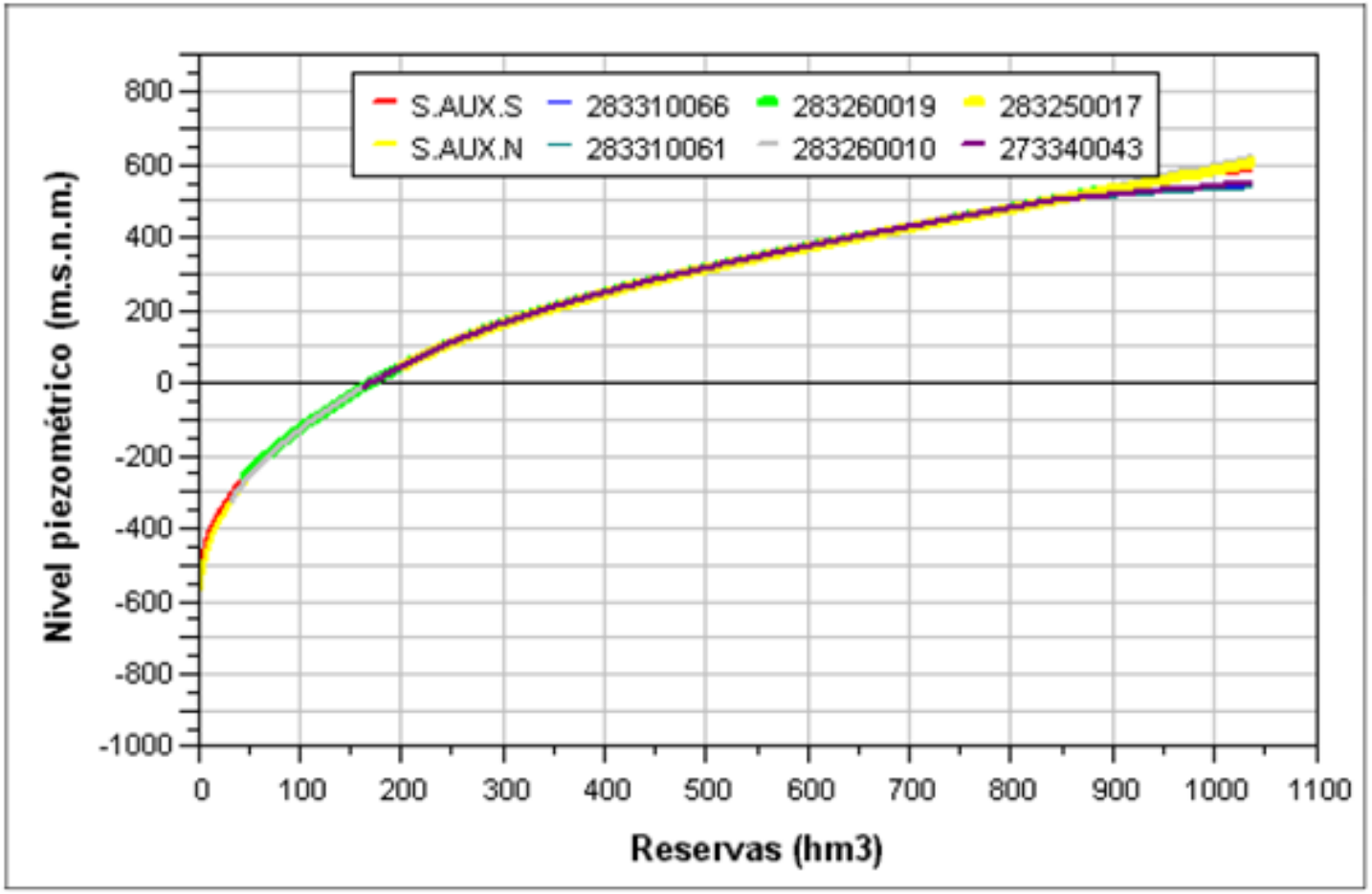
AIO = Acuífero Inferior Occidental (West Lower Aquifer)

AIN = Acuífero Inferior Noreste (North-East Lower Aquifer)

Domínguez Prats et al. (2013)

Planned groundwater depletion

Aquifer in Alicante (Alacant)

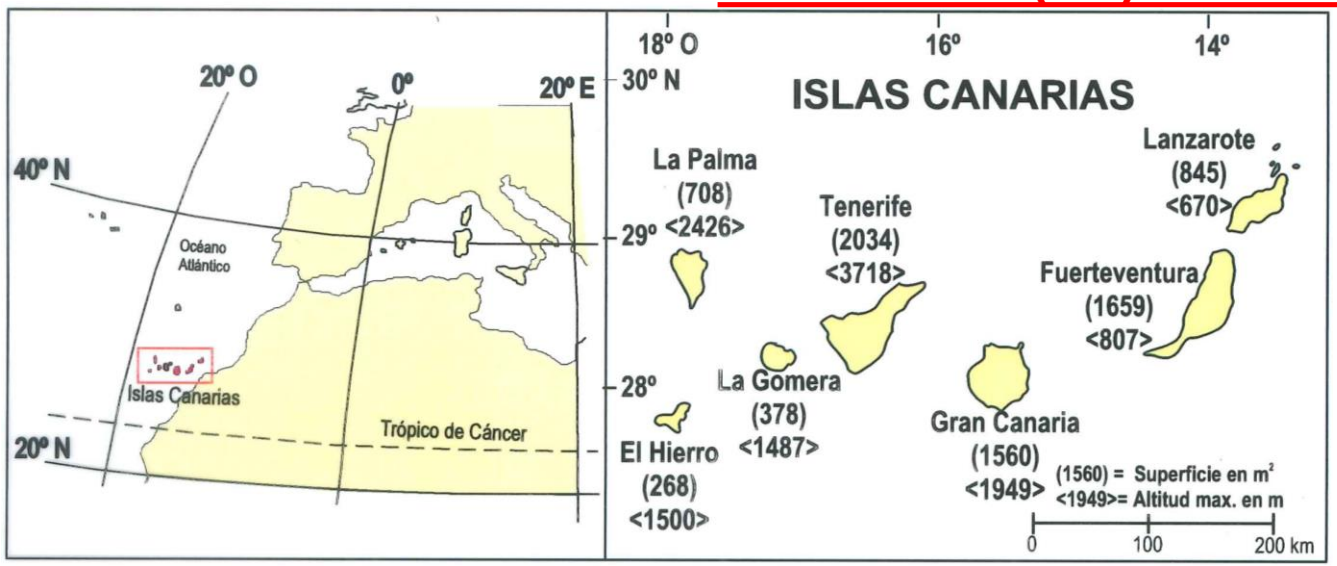


Piezometric level and groundwater reserves. Solana aquifer (Villena–Beneixama)

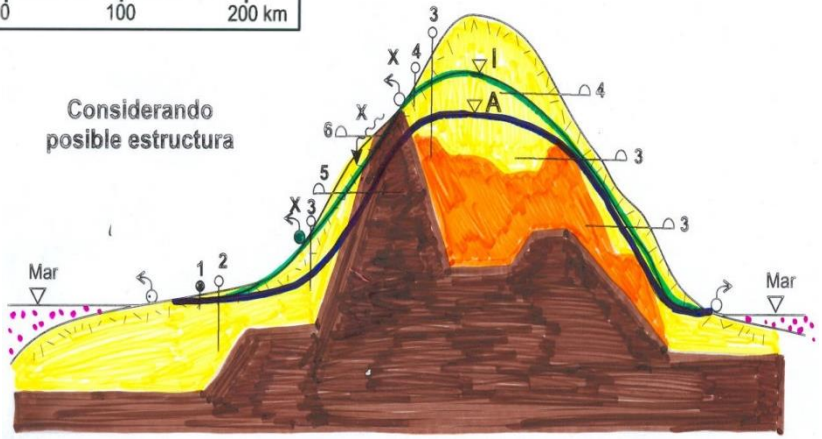
Diputación de Alicante 2014 – MASE

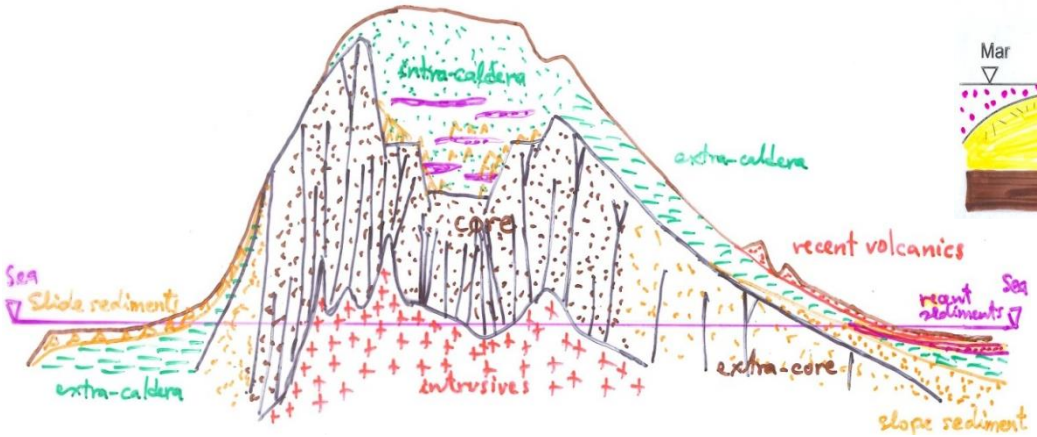
Groundwater mining in the Canary Islands

Gran Canaria (GC) and Tenerife (TF)



Hydrogeological conditions in a simple volcanic island. The case of Gran Canaria





General hydrogeological data on GC and TF

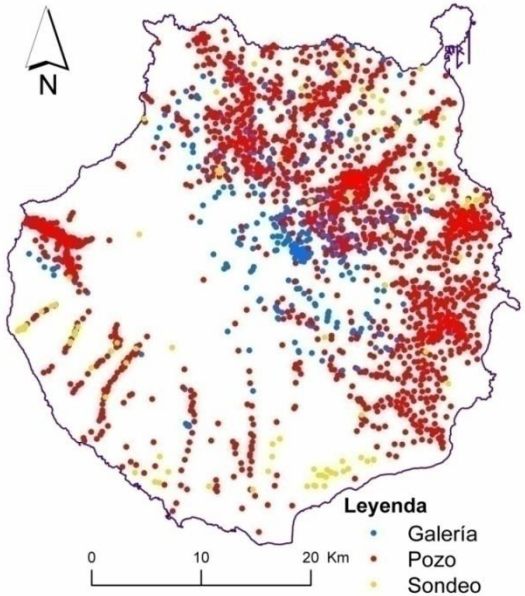
Number of significative groundwater capture works

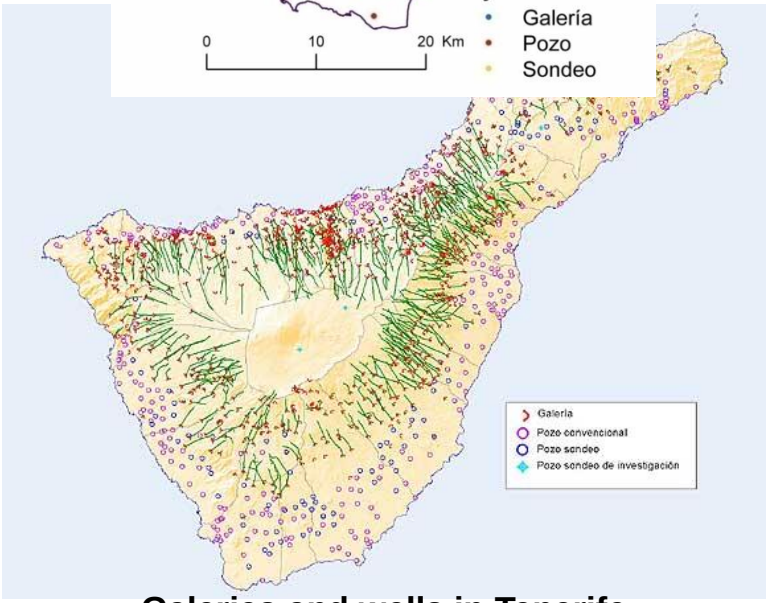
		GC	TF
Large-springs		—	—
Water galeríes:	total	410	1670
	in exploitation	—	1050
Wells, boreholes:	total	2130	380
	in exploitation	1330	172

Water average resources, decade 2000–2010, hm^3/yr

	GC	TF
Precipitation	465	865
Surface run-of	75	20
Recharge + return irrig. flows	90	240
Discharge to the sea	40	140
Groundwater mining	50	80
Groundwater-caption	100	180
Desalinization + debrackishing	80	20
Reuse	10	10
Total available water	190	210

Large diameter wells and boreholes in Gran Canaria
(Consejo Insular de Aguas de Gran Canaria)





Galeries and wells in Tenerife
(Consejo Insular de Aguas de Tenerife)

Results for Gran Canaria and Tenerife

Groundwater discharge to the sea { moderate in Gran Canaria / high in Tenerife

Cumulated reserve depletion (coarse approach) { 0,3 – 0,5 km³ Gran Canaria / 2 km³ Tenerife

→ Important reserves still remain

→ Actual abstraction < Total recharge (precipitation + irrigation return flows)

Time to groundwater level recovery → decades

→ not possible in mid and high areas in Tenerife

→ permanent drainage produced by the galeries

For capturing discharge to the sea • excessive drawdown { large investment / high abstraction cost

- possible great water productivity loss
- serious risk of water quality deterioration

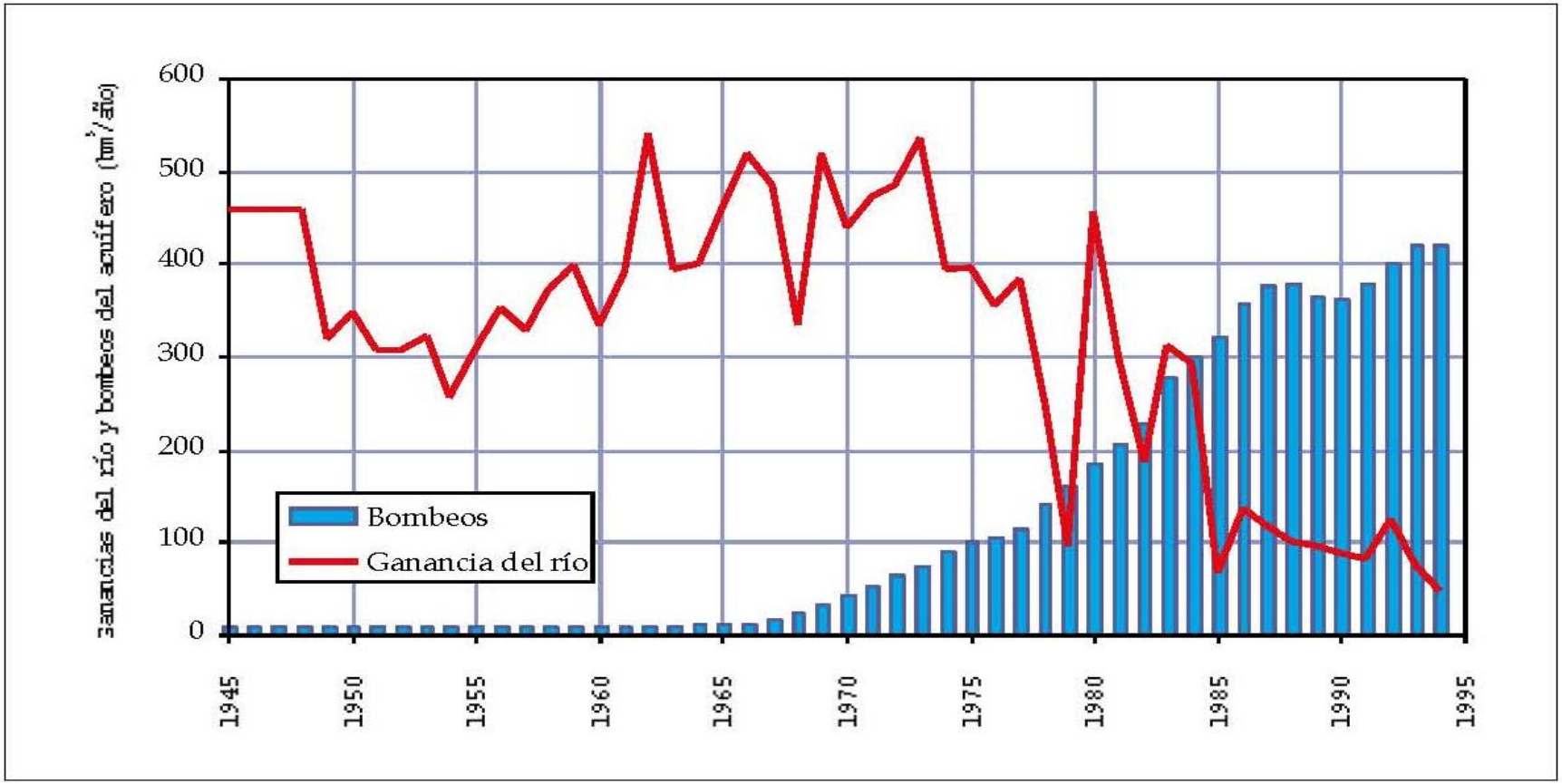
Groundwater use (GW) and agricultural productivity in South-eastern Spain and the Canaries

Use	hm³/year Spain	Júcar	Segura	CMA	Canaries
Urban	1500	320	——	140	125
Irrigation	5000	1180	450	377	210
Industry	300	100	——	3	8
Recreation	65	10	——	20	12
Total groundwater (GW)	7000	1610	485	540	355
Total water use (TW)	31500	3156	1850	1225	510
GW / TW	0,22	0,51	0,26	0,44	0,70
GW irrigation / GW	0,71	0,73	0,93	0,70	0,59

M€/year	Total	15300	2260	1450	2460	340
	GW	4730	410	585	1385	340
€/ha/year	Total	4600	4600	7200	11700	13600
	GW	5000	2800	8400	16300	13600

Modified from De Stephano et al., 2013

Effects of intensive groundwater exploitation
Decrease of downstream river flow

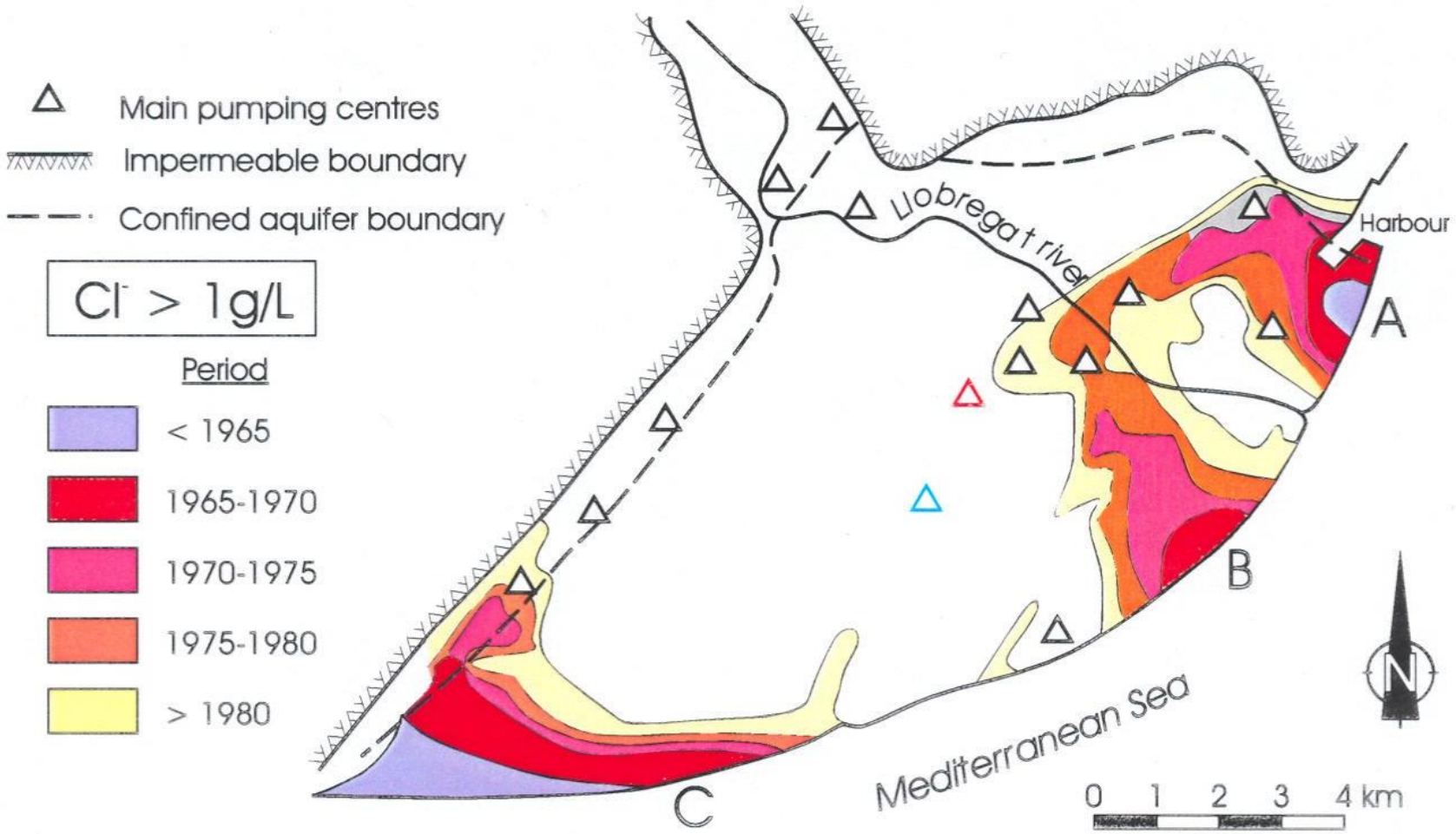


La Mancha Oriental plains

Flow decrease in the Júcar River at the lower end

→ due to irrigation with groundwater since the late 1960 decade in the headwaters

Effects of intensive groundwater exploitation
Seawater intrusion

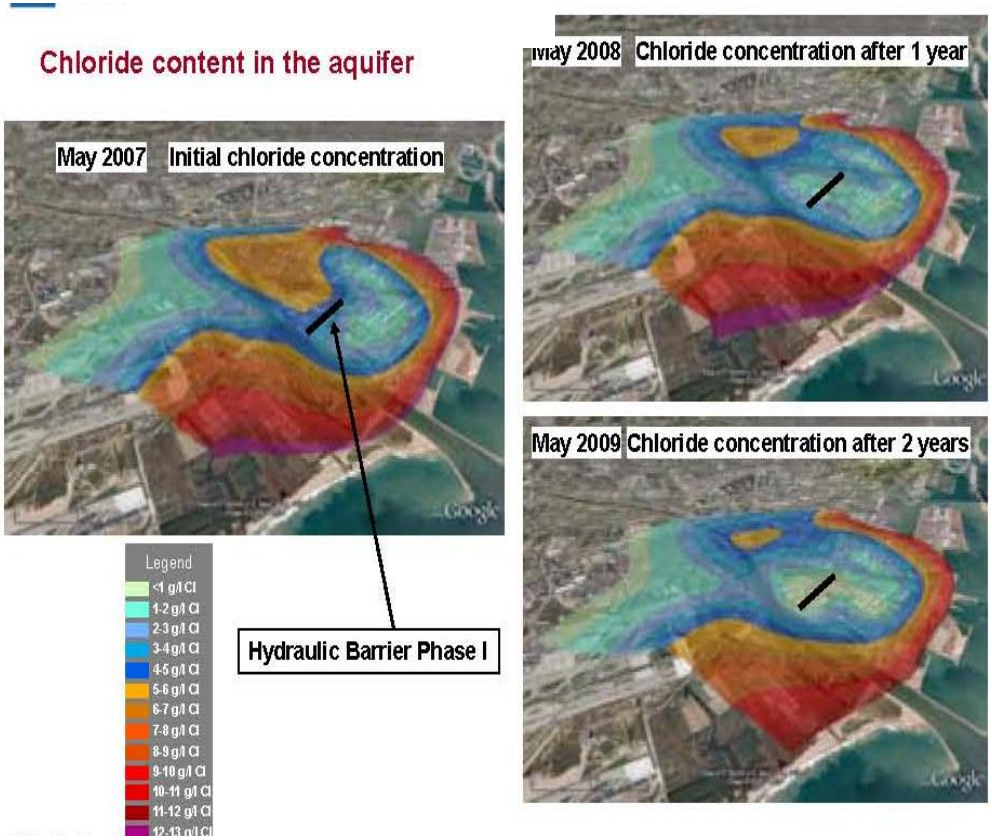


Llobregat delta deep aquifer, Barcelona

Freshwater barrier to control seawater intrusion

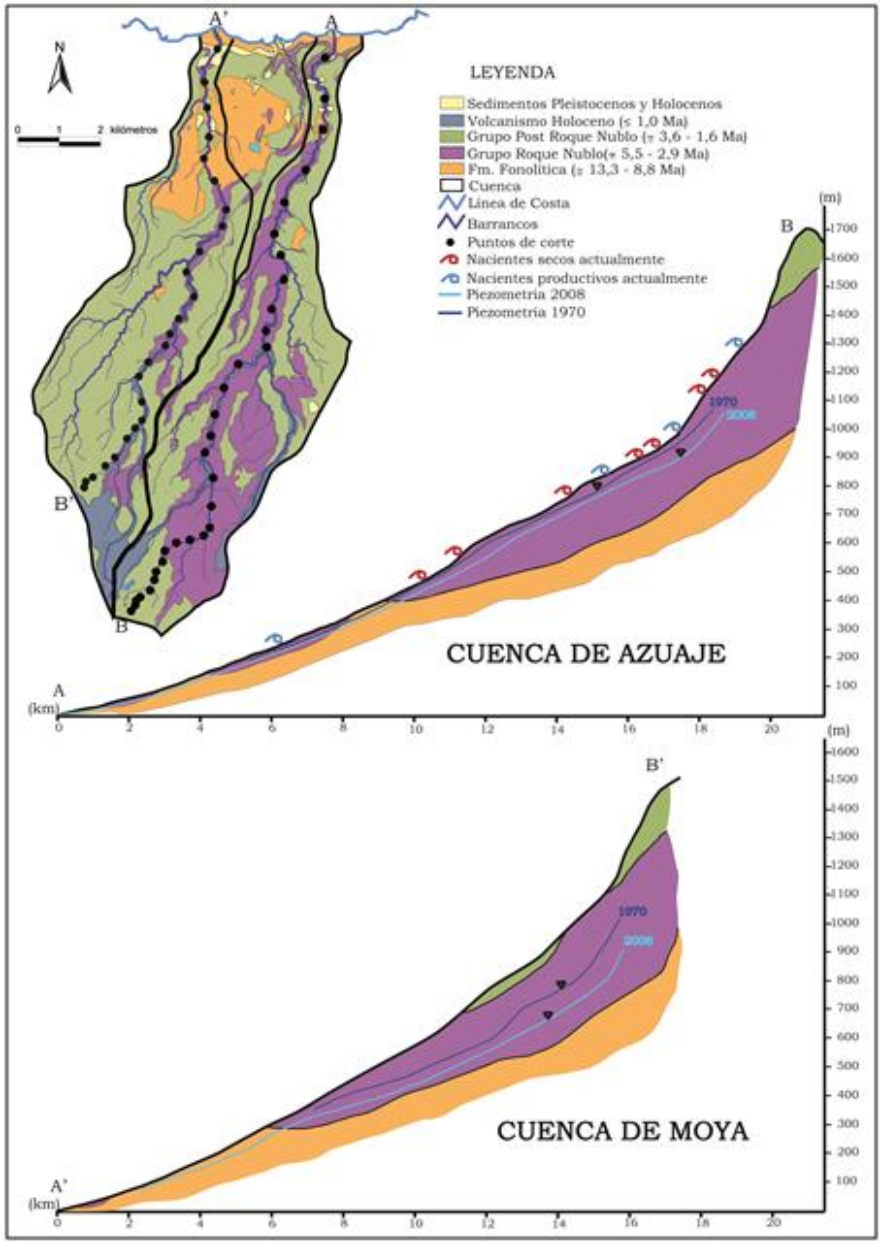
Injection by means of wells of highly-treated reclaimed urban waste water

Llobregat delta deep aquifer, Barcelona



ACA, 2010

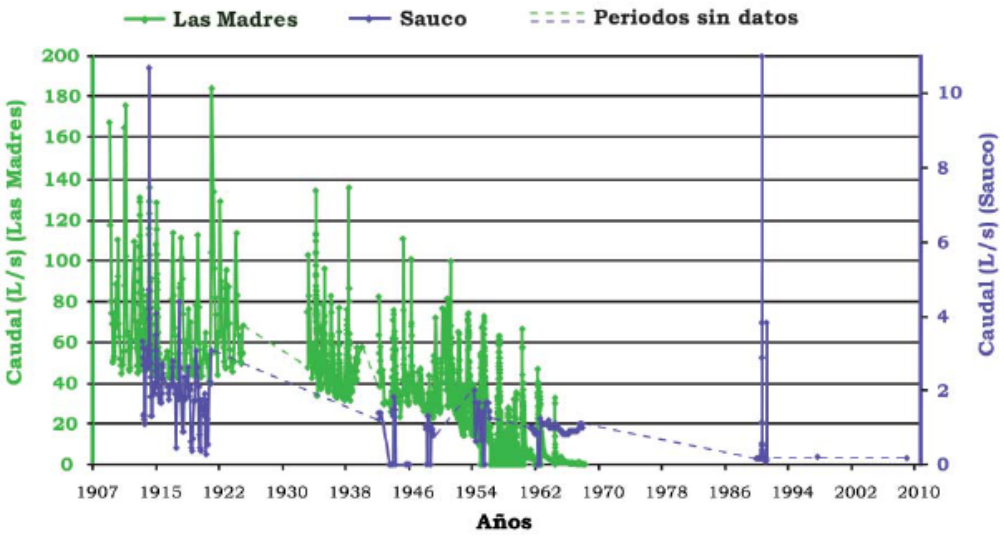
Intensive groundwater exploitation effects



Evolution between 1970 y 2008

Large effects in { springs, environment, other GW exploiters

Barrancos de Moya y Azuaje
N Gran Canaria
←



Spring flow depletion
Bco. Azuaje, N Gran Canaria

Hernández–Quesada et al., 2011
Cabrera et al., 2014

Real facts on intensive use and mining of groundwater in Spain

High abstraction cost: 0,3 a 0,5 €/m³ → up to >1 €/m³ in the Canaries

→ still cheaper than other water sources at the place of use

Water suppliers and farmers will continue using and mining groundwater { **regularly** / **in droughts** / **as an insurance**

→ except if the cost of other water sources is subsidized → economic distortion

Tendency to water transactions

- **of public rights→ under the administration control**
- **of private rights (even if groundwater is a public domain) → since long time ago**

Water markets exist since one century ago in Gran Canaria, Tenerife and La Palma Islands

Groundwater mining → is a fact

→ it will continue if cheaper water is not made available

→ who pays for the damage?

→ actions that introduce some control →

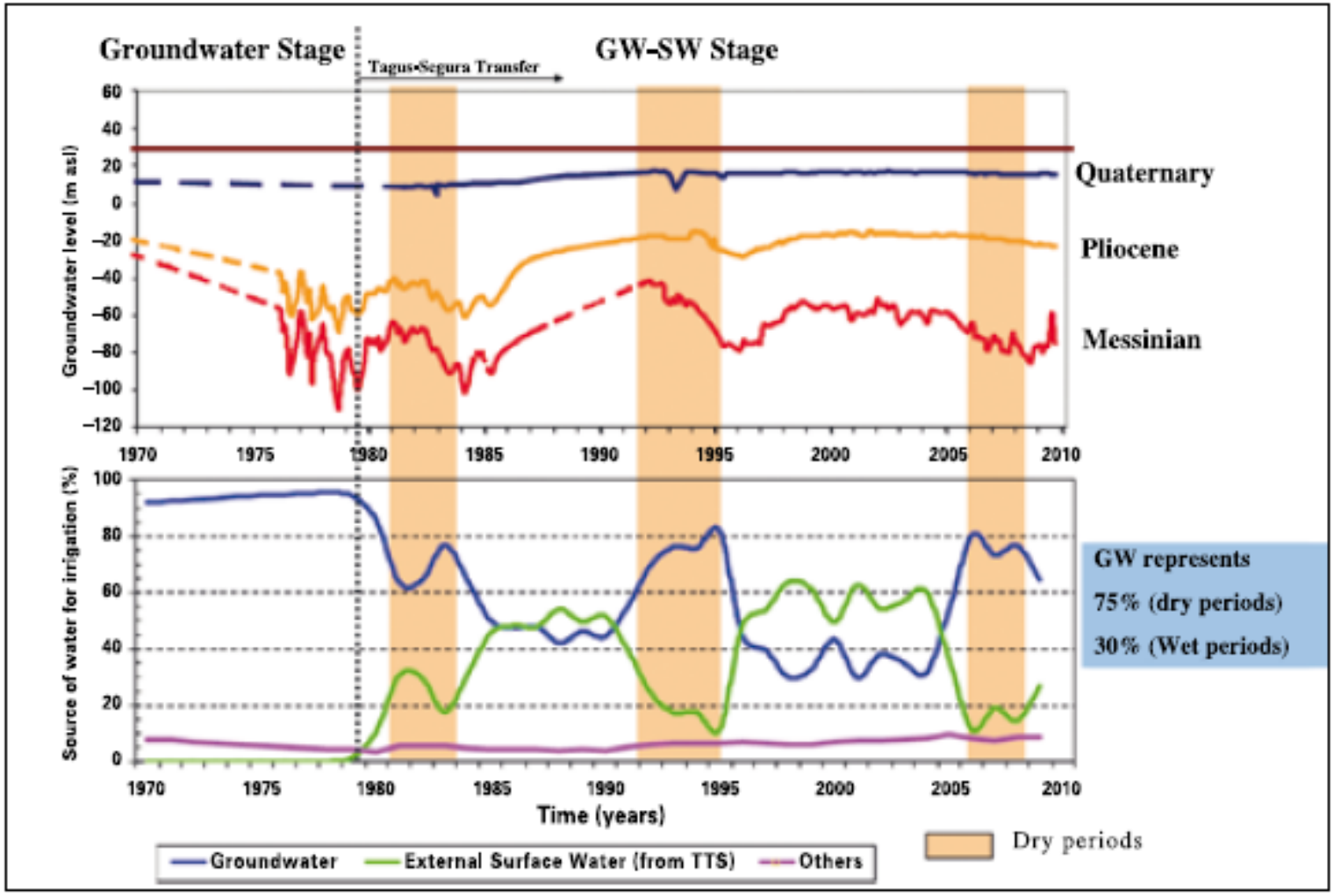
increasing cost of energy for water abstraction: effective and external

salinity and progressive deterioration of water quality: partly effective

regulatory administrative-legal action : generally poorly effective

→it is nor known whether long-term social benefits > social costs

Groundwater use in droughts in the Campo de Cartagena



Extracción intensiva en sequías cuando fallan otras fuentes

«Drought wells» → in use in the Mediterranean area

Prospective of groundwater use

A new **Water Act** is needed → it should consider:

- groundwater rights realistically, not only un an administrative point of view
- flexibility to adapt to the changing reality
- guaranteed participation and involvement of all stakeholders
- improved and regulated decision, ejecution and corrective capacity
- a flexible equilibrium between use and ecological values
- economic-social aspects, explicitely
- regulated adequate knowledge, monitoring and control
- groundwater mining
  - is not intrinsically bad
  - may contribute economic and social benefits
  - must be under control
  - benefits have to compensate for damage in the present / in the future
  - is a transient situation
    - with a dead end
    - recovery may be required
- how to compensate the costs transferred to others
- disproportionated costs
- ethics in evaluation and decision making

Groundwater mining ≠ common mining → it is essential to life and to ecological processes and services
A political "pact" may be be needed for water management

Intensive groundwater exploitation, seawater intrusion and GW mining in the European Water Framework Directive

The following considerations define the WFD position:

- **Intensive groundwater exploitation have to agree with environmental objectives**
- **Unfairly economic concurrence among state members have to be avoided**
- **Costs / problems have to be not transferred to the future**
- **Exceptions can be introduced if adequately argued and demonstrated**
- **Disproportionated costs may justify some exceptions → well-documented**
- **Groundwater mining /seawater intrusion is not allowed**
- **Recovery has to be carried out, if feasible**

Intensive groundwater and mining environmental damage is:
Often poorly known and non-evaluated
Many effects happened decades ago → people do not remember them
Some effects are partly recoverable

Recovery
- **difficult**
- **possible disproportionate cost**
- **possible damage in some areas**
- **possible groundwater use improvement → decreased pumping**

Final considerations

Groundwater mining

Happens in many arid and semiarid countries → it is a fact in Spain

Not necessarily bad → may provide important benefits

Unsustainable in the long-term, but it may be a path to the future

Needs adequate legal-administrative planning

Needs a dedicated treatment → do not generalize → each case is unique

Groundwater mining & seawater intrusion have to be placed in the context of

- **total water resources,**
- **other natural and human resources,**
- **social objectives,**
- **economic and social evaluation in the mid- and long-term,**
- **existing legal framework,**
- **ethical and moral principles,**
- **transient groundwater resources development → change of paradigm**

The way forward

Make a sound use of the large fresh groundwater reserves to

- **Improve integrated water resources management efficiency**
- **Secure the reasonable estate and preservation of the environment**
- **Regulate groundwater mining as a transient evolution to a**

  new water use paradigm

  under the social and economic circumstances of the moment