Fundación Marcelino Botín
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Intensive groundwater development
A water cycle transformation
A social revolution
A management challenge

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Groundwater

Important component of the water cycle

Visible only through its { discharges / effects }

Poorly known by { people / water managers } → hydromyths

Difficult to be presented through images

Water resources { • quantity • quality } + { geological / geotechnical / ecological } aspects

Important for { Nature / as a freshwater resource } { resilient / slowly evoluting / free of pathogens }

Groundwater characteristics

Large ratio storage / flow

Long turnover times → 10s to 1000s of years

Recharge
Storage } distributed over the territory

Closely linked to surface water

Delayed response to {
- climatic variability
- exploitation
- chemical changes
- pollution

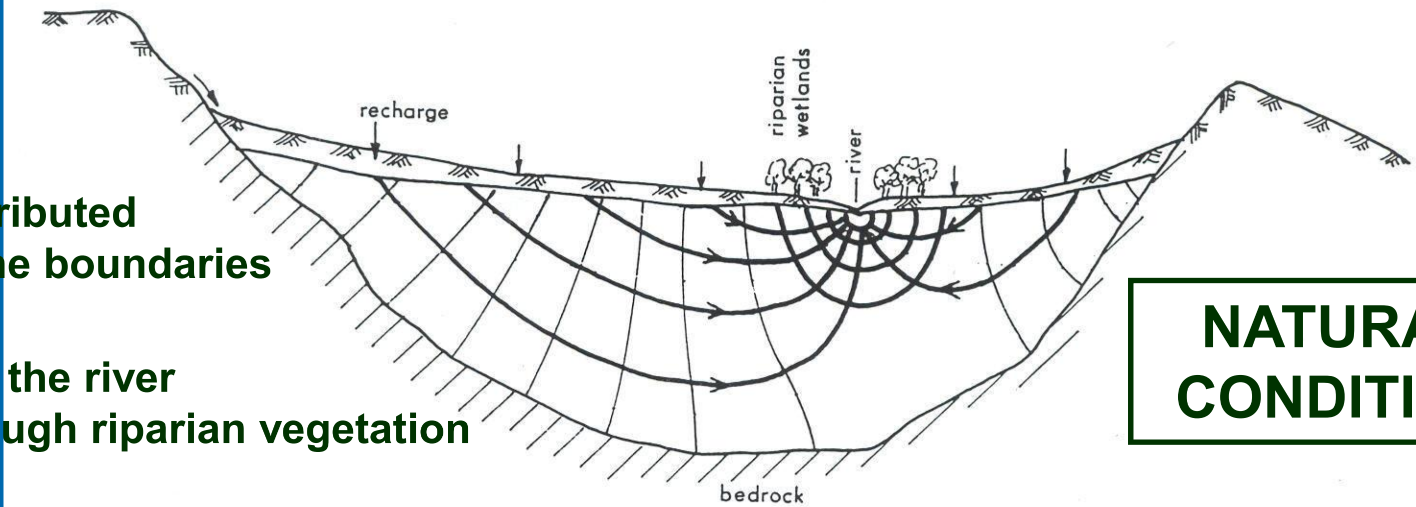
10s to 1000s of years

Groundwater systems → aquifers + aquitards

Basin aquifer I

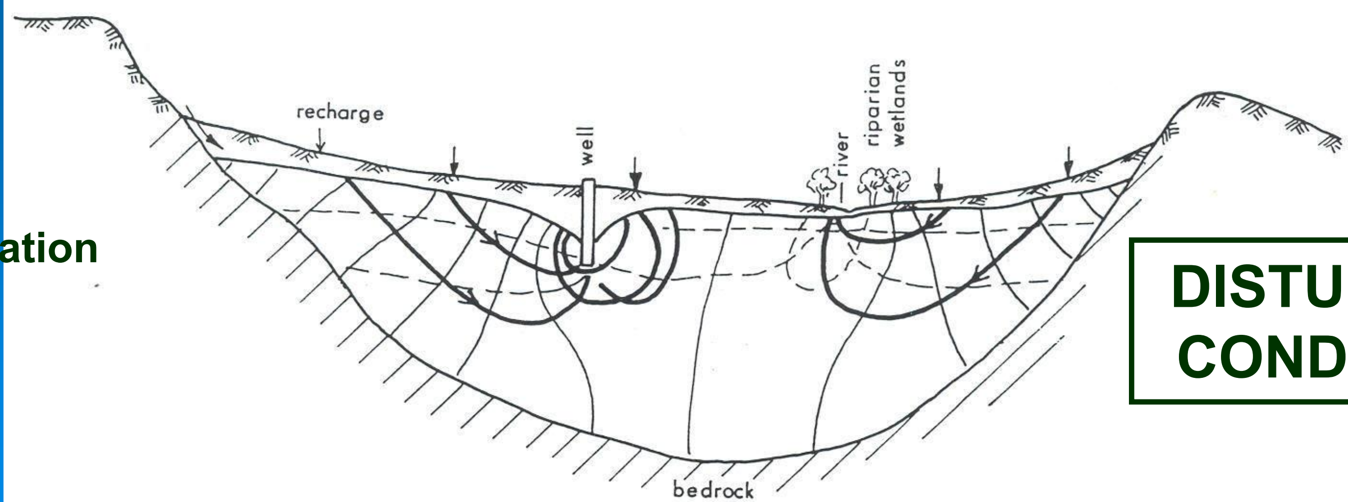
Recharge { distributed / at the boundaries

Discharge { into the river / through riparian vegetation



NATURAL CONDITION

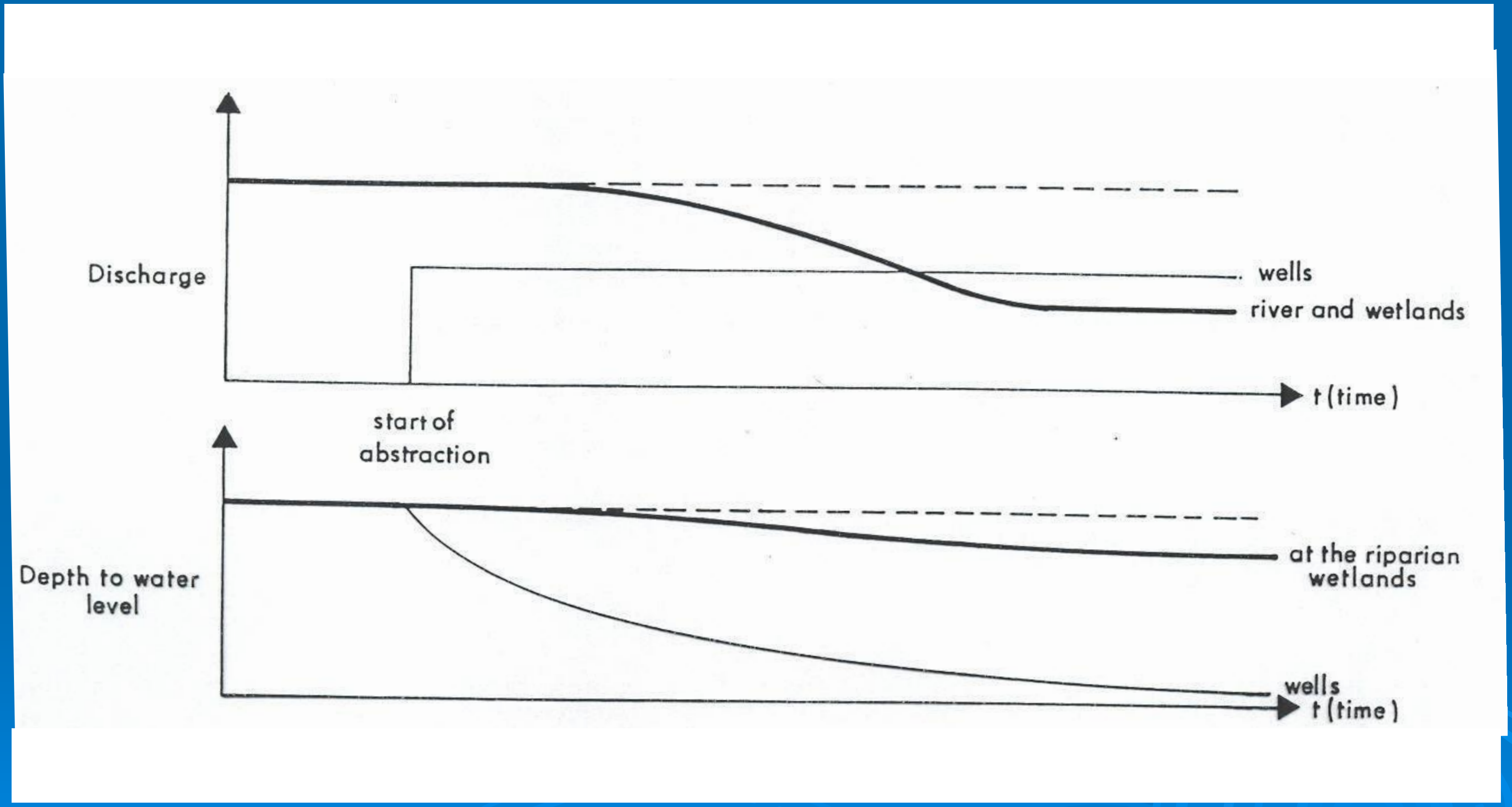
Effect of exploitation



DISTURBED CONDITION

Basin aquifer II

Effect of exploitation on discharge and depth to water level



Evolution I

Until 30–80 years ago

Difficult to { capture / pump } → used at natural outlets

small additional developments in { arid lands / shallow water tables / flowing aquifers }

by means of:
- water galleries (mines)
- shallow wells with { bucket–wheels / wind driven machinery }
- flowing wells → decreasing discharge
- wells with voluminous steam–driven pumps

Evolution II

Recently

High improved { drilling technology, electro–pumps, energy availability } → intensive development

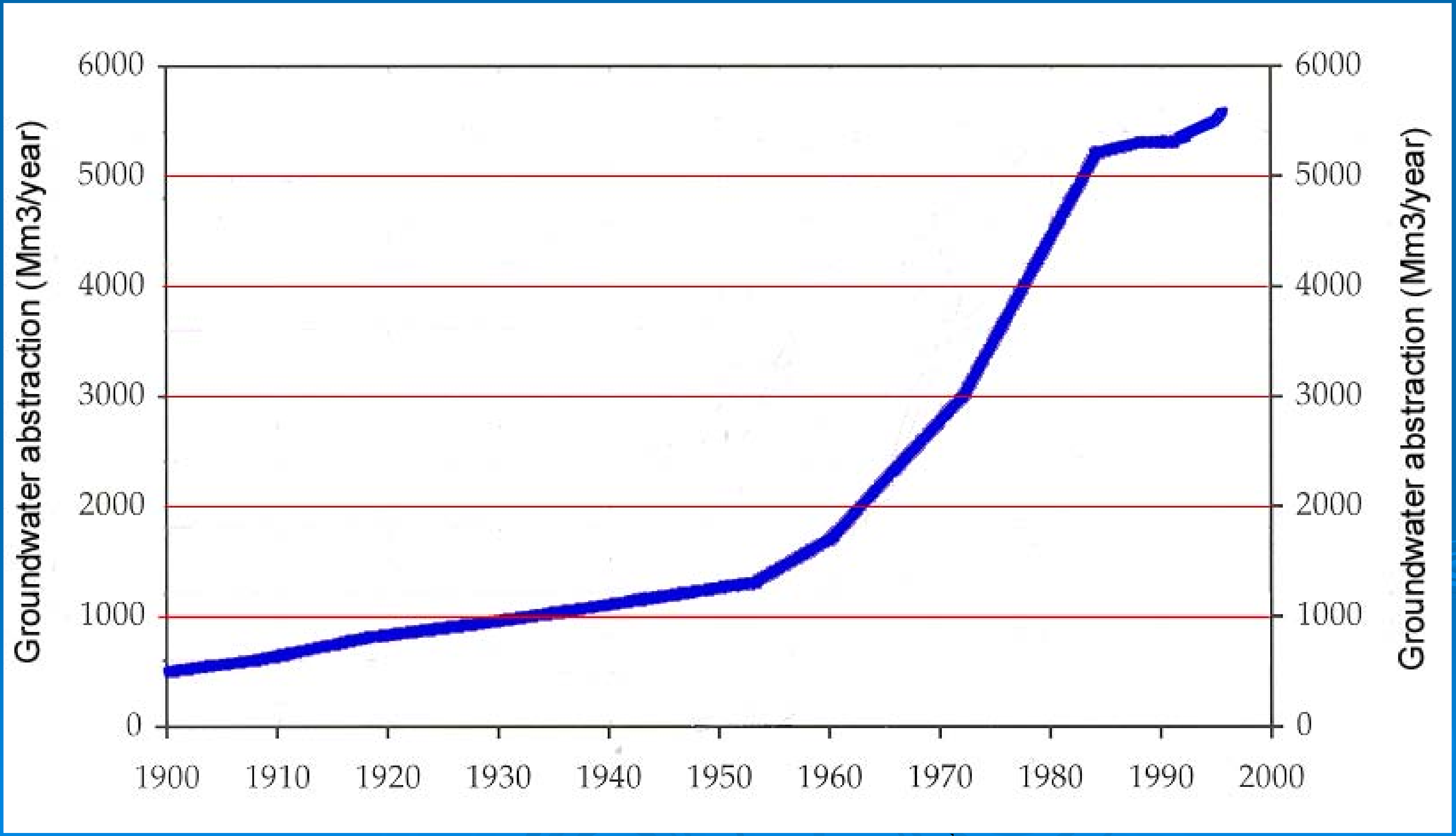
→ fast development, often exponential

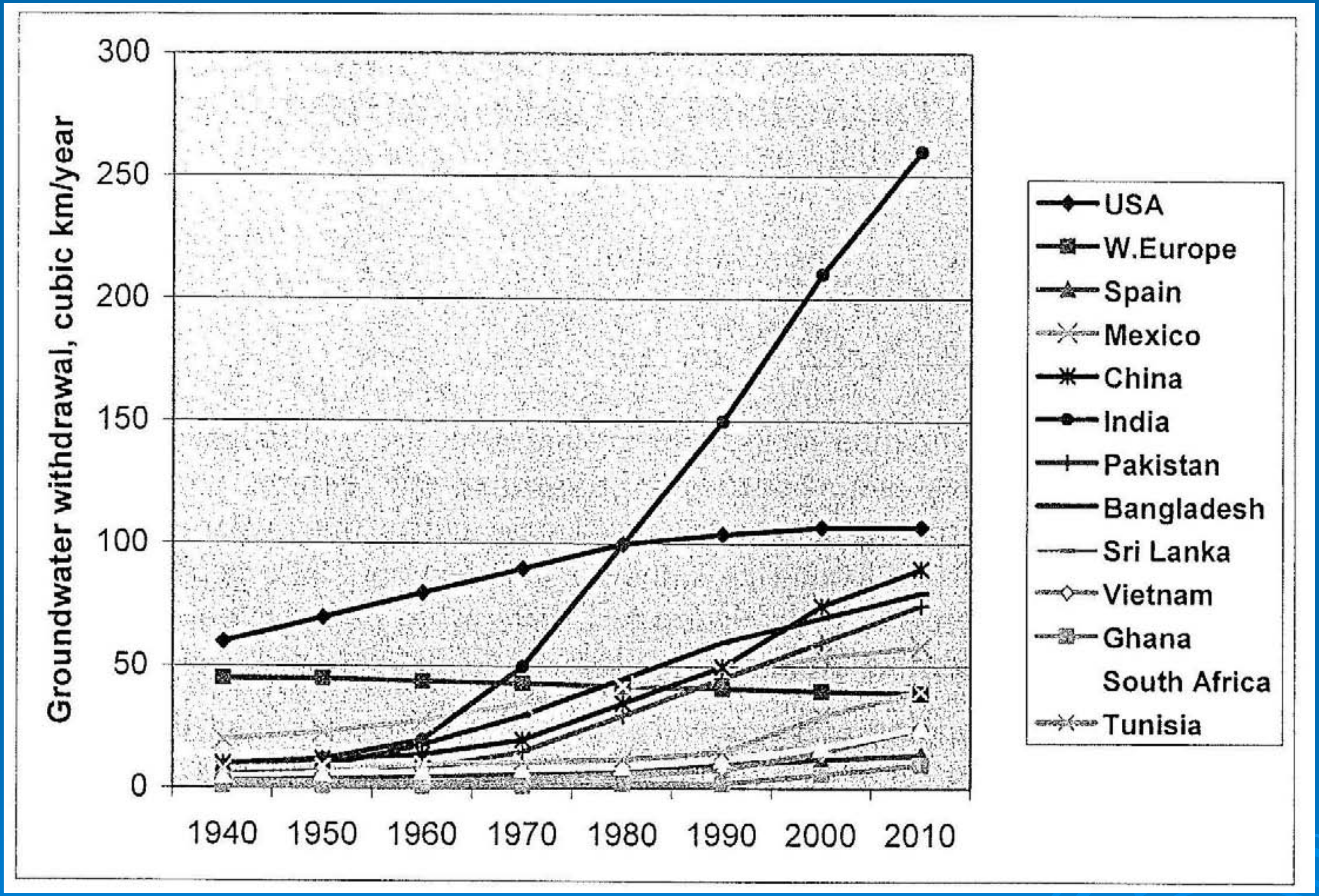
→ intensive development

→ {
- benefits to { developers, society }
- development of poor world areas
- drawbacks / interferences { inherent, often unrecognized }

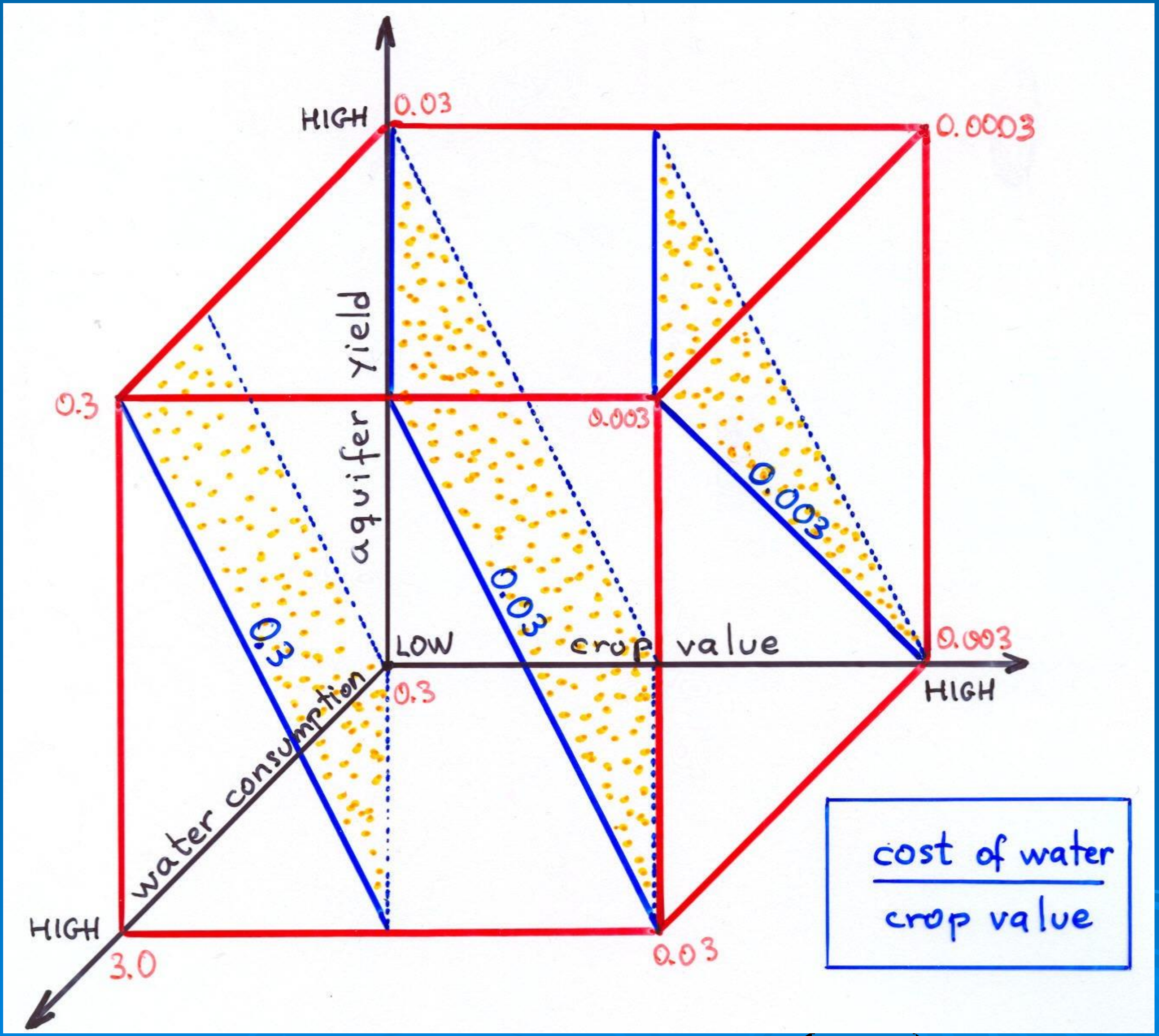
}

Spectacular development of groundwater in Spain

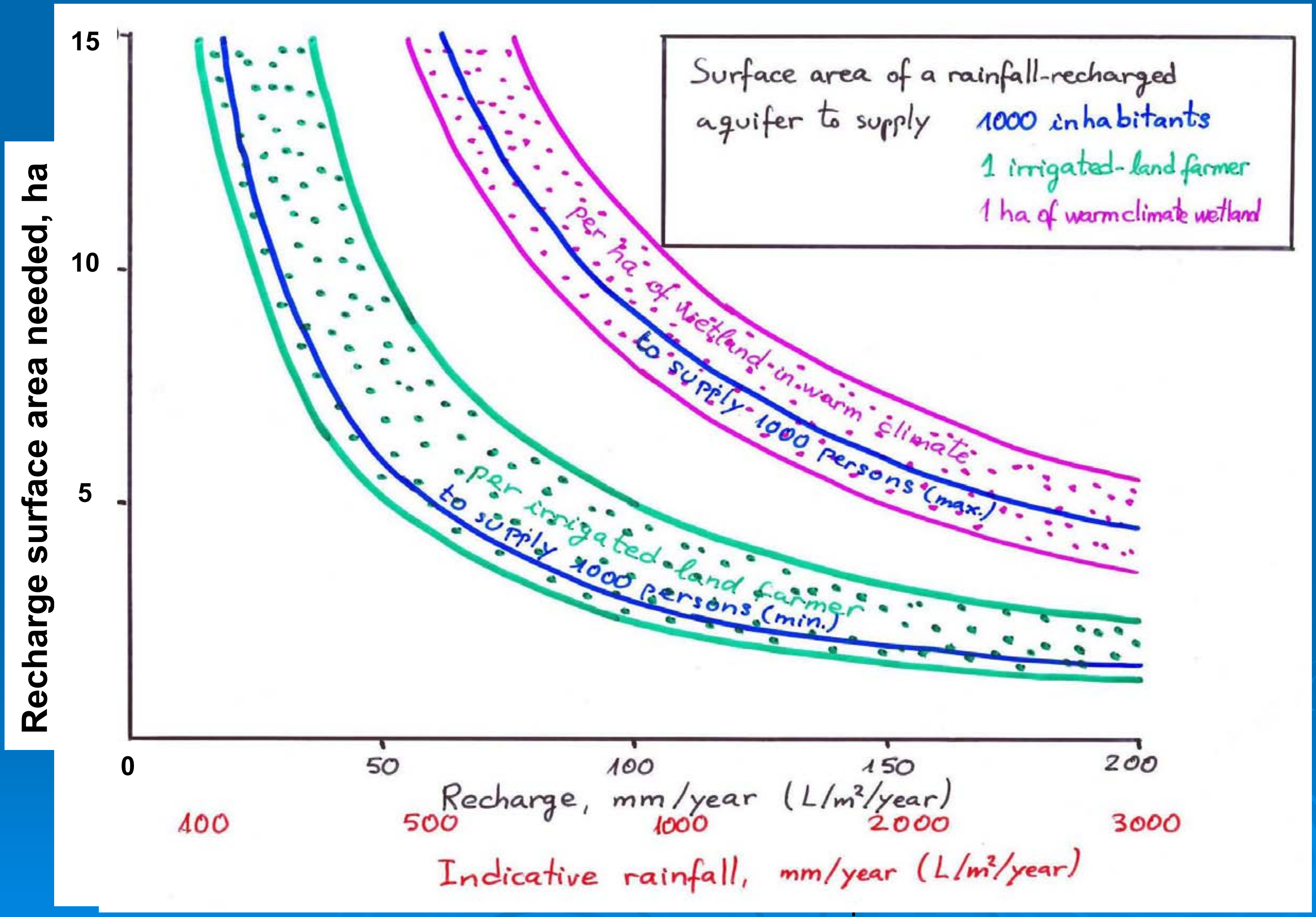




Development in groundwater use in selected countries (from Shah, 2004)



Direct cost of irrigation groundwater in relation to crop value [rough estimates]



Man activities may require uptake of recharge over a large area

Effects of groundwater [intensive] development

On water quantity
- groundwater level drawdown
- reduction of discharges
  - in springs
  - into rivers as base flow
  - into wetlands
  - in pheatophyte areas
- [storage decrease]

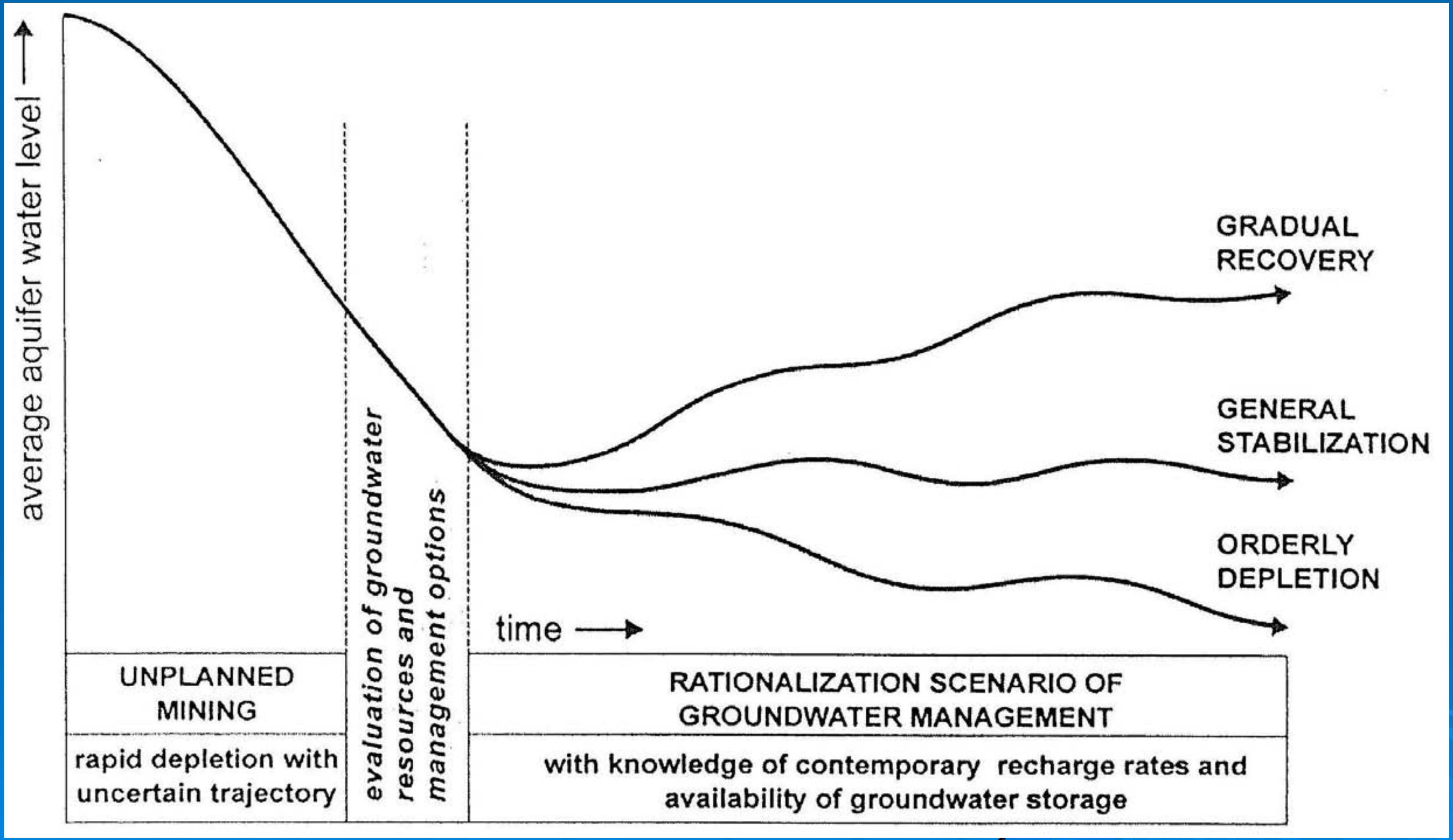
* <u>Slow hydrodynamic effects</u>

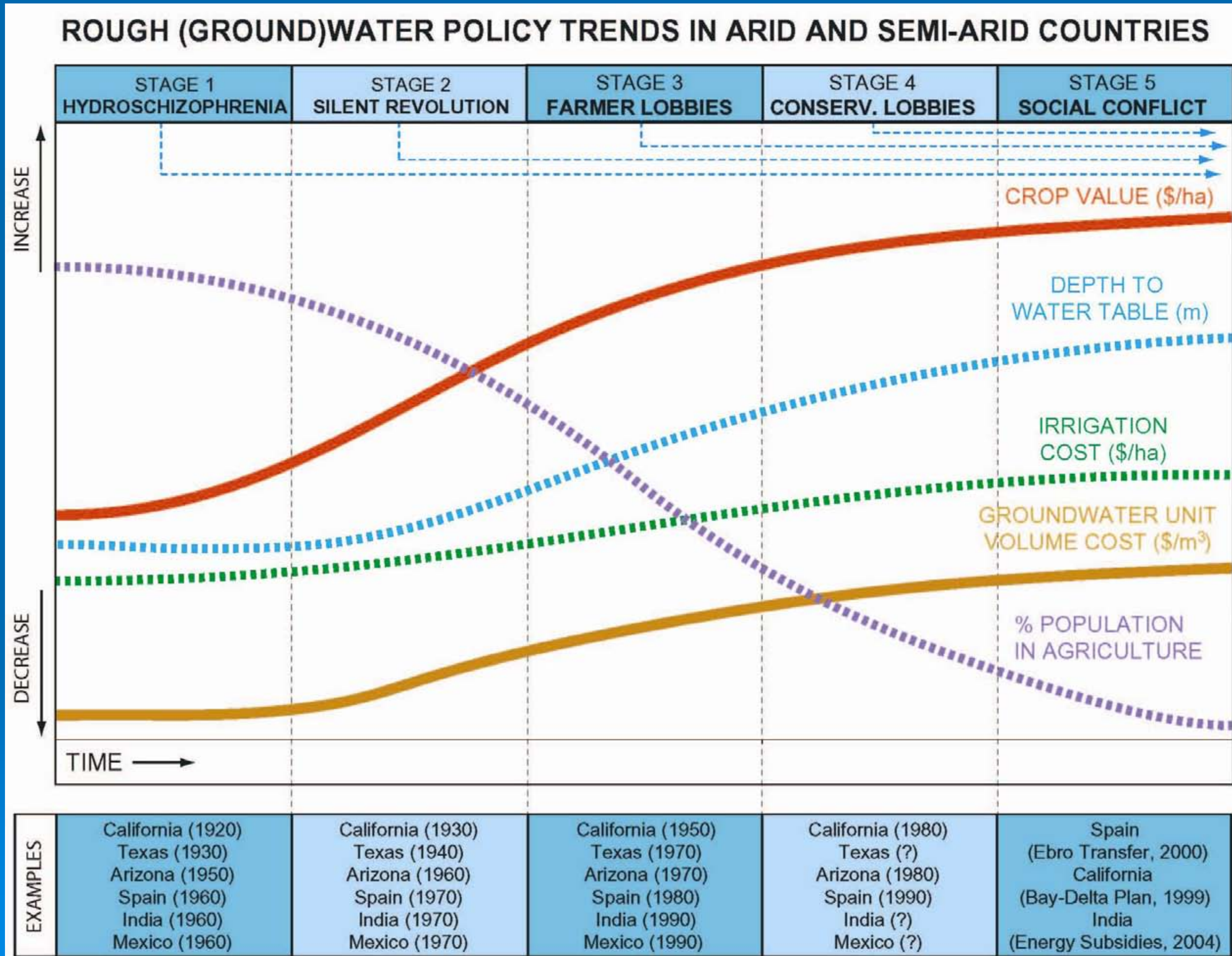
On water quality
- displacement of poor quality water
  - from other formations
  - from the surface
  - marine intrusion
- incorporation of solutes from the ground
  - dissolution
  - redox changes

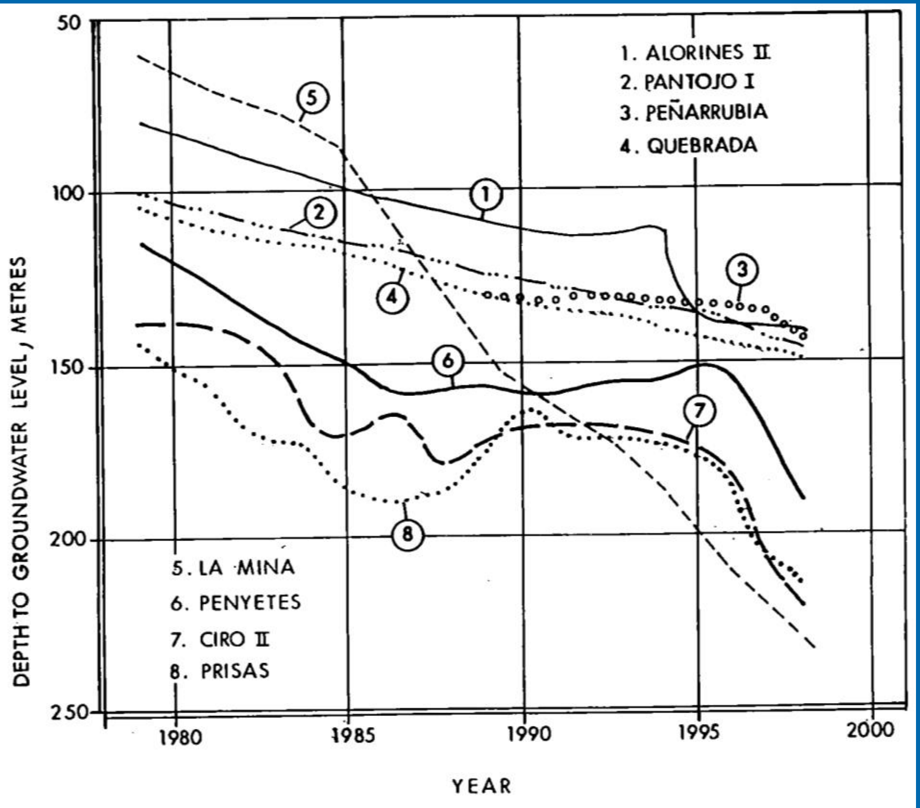
On land conditions
- subsidence
- collapses

On economical aspects → increasing cost

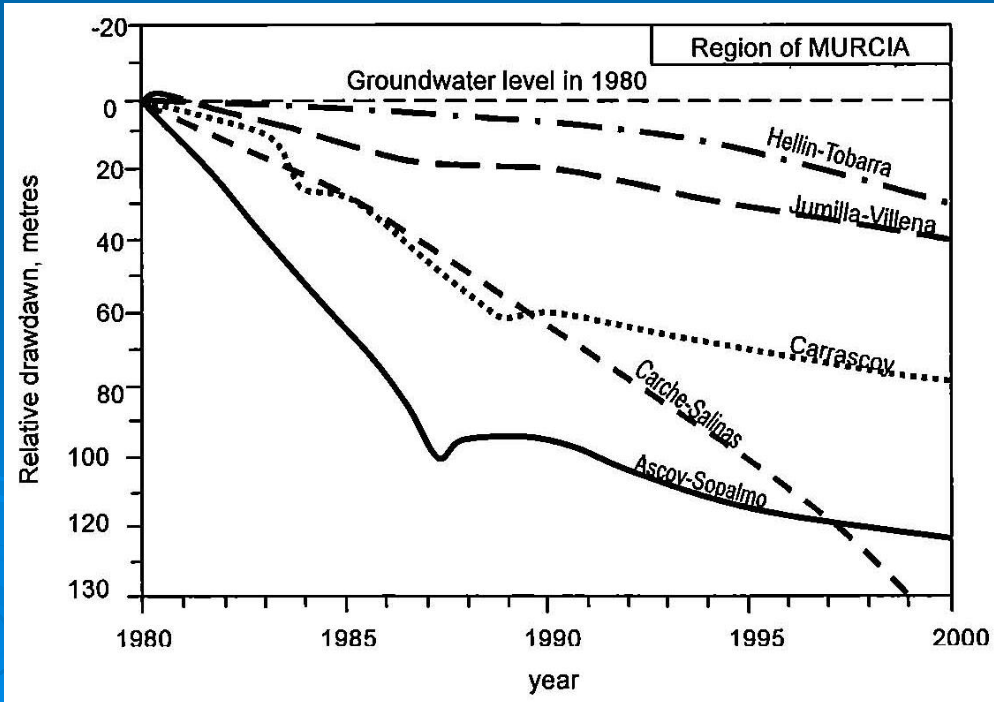
Groundwater level evolution according to management action



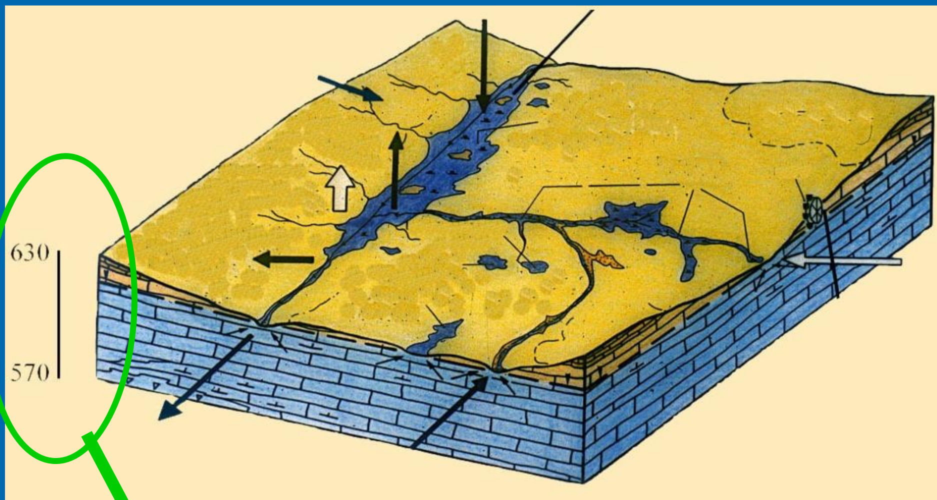

ROUGH (GROUND)WATER POLICY TRENDS IN ARID AND SEMI-ARID COUNTRIES
STAGE 1 HYDROSCHIZOPHRENIA
STAGE 2 SILENT REVOLUTION
STAGE 3 FARMER LOBBIES
STAGE 4 CONSERV. LOBBIES
STAGE 5 SOCIAL CONFLICT
INCREASE
DECREASE
CROP VALUE ($/ha)
DEPTH TO WATER TABLE (m)
IRRIGATION COST ($/ha)
GROUNDWATER UNIT VOLUME COST ($/m³)
% POPULATION IN AGRICULTURE
TIME
EXAMPLES
California (1920) Texas (1930) Arizona (1950) Spain (1960) India (1960) Mexico (1960)
California (1930) Texas (1940) Arizona (1960) Spain (1970) India (1970) Mexico (1970)
California (1950) Texas (1970) Arizona (1970) Spain (1980) India (1990) Mexico (1990)
California (1980) Texas (?) Arizona (1980) Spain (1990) India (?) Mexico (?)
Spain (Ebro Transfer, 2000) California (Bay-Delta Plan, 1999) India (Energy Subsidies, 2004)



Depth to groundwater level evolution in small, intensively exploited aquifers of south–eastern Spain (Murcia and Alacant)

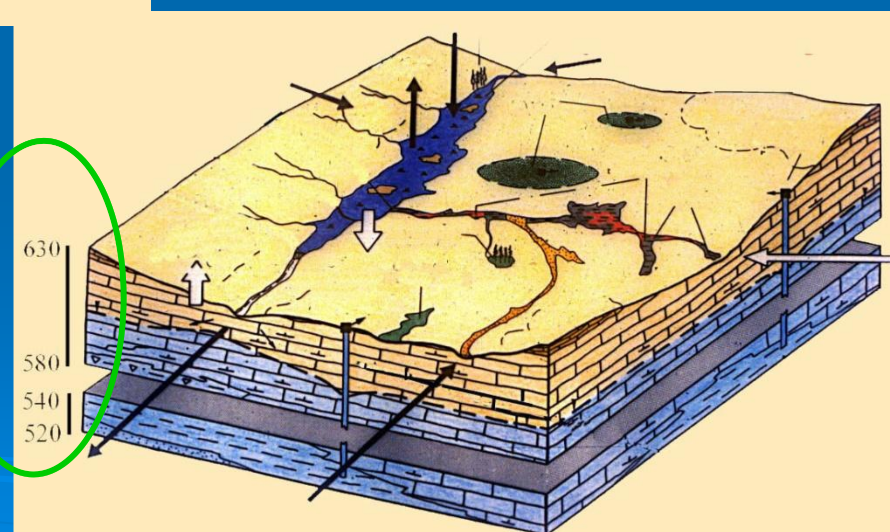


TABLAS DE DAIMIEL NATIONAL PARK



NATURAL STATE

DISTURBED STATE

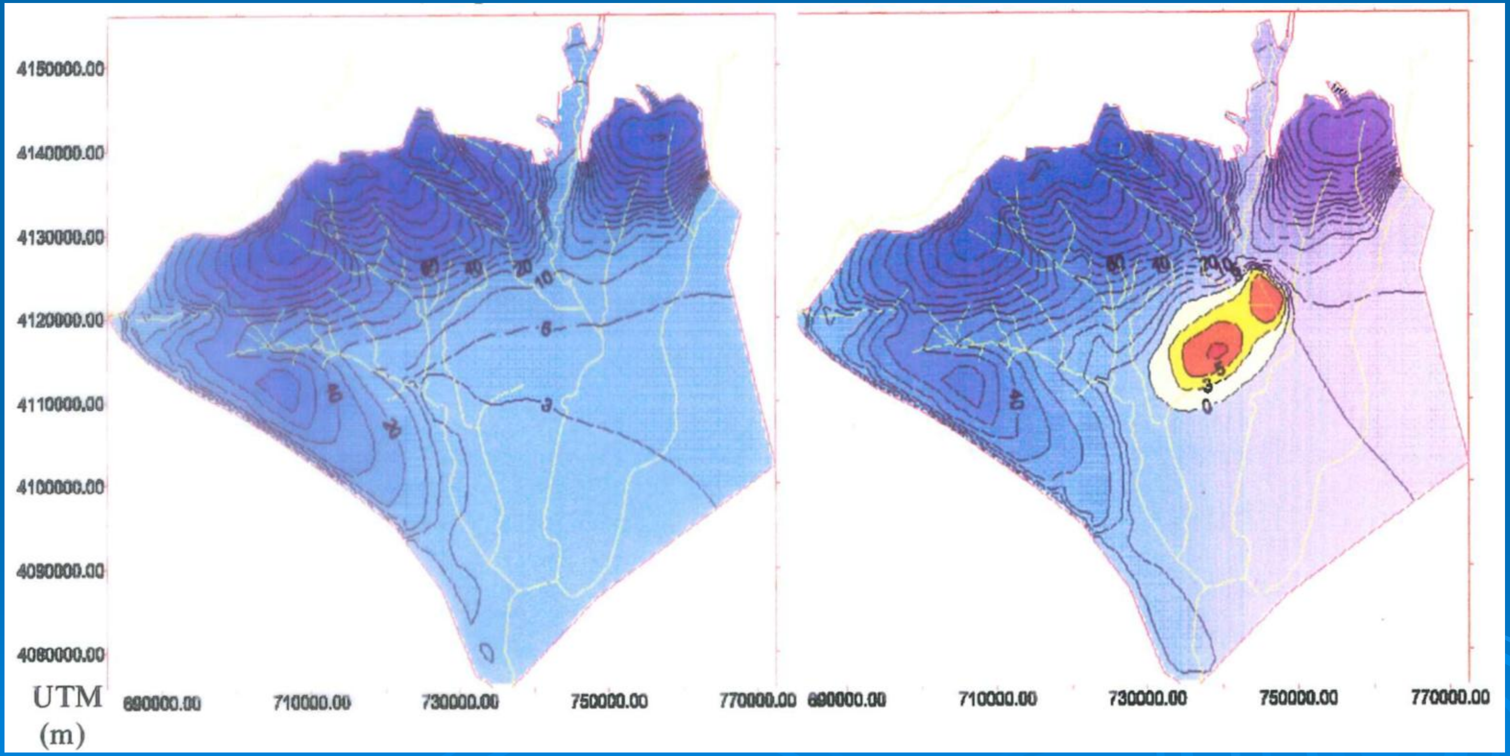


Significant decrease in piezometric levels; more than 30 m

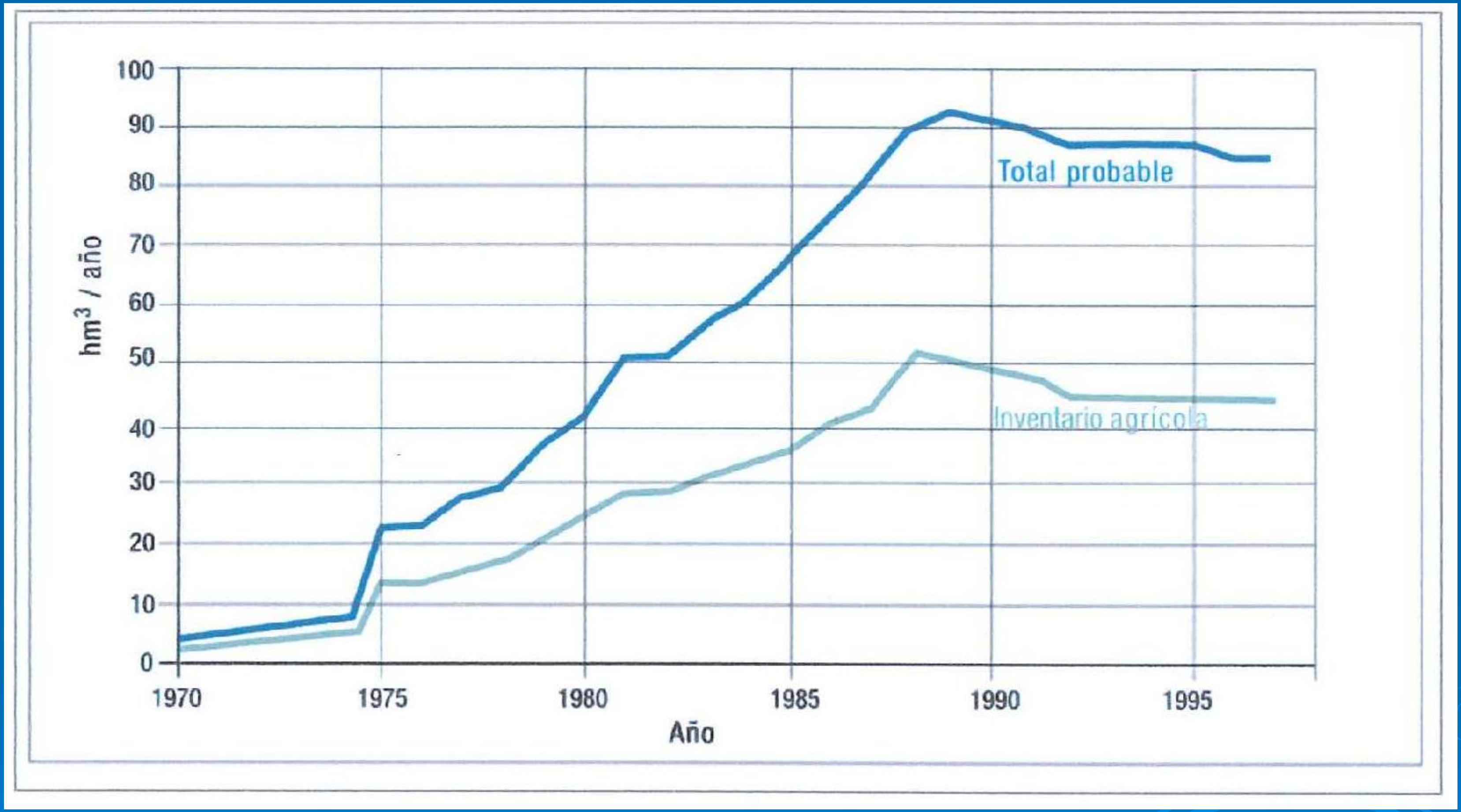
Doñana National Park. SW Spain

Groundwater flow pattern

Natural conditions / **October 1992** — **Disturbed conditons** / **October 1996**



Groundwater level above mean sea level (m)



Groundwater exploitation in the Doñana area, SW Spain, after irrigated agricultural development in formerly low productivity land. Main development between 1980 and 1990

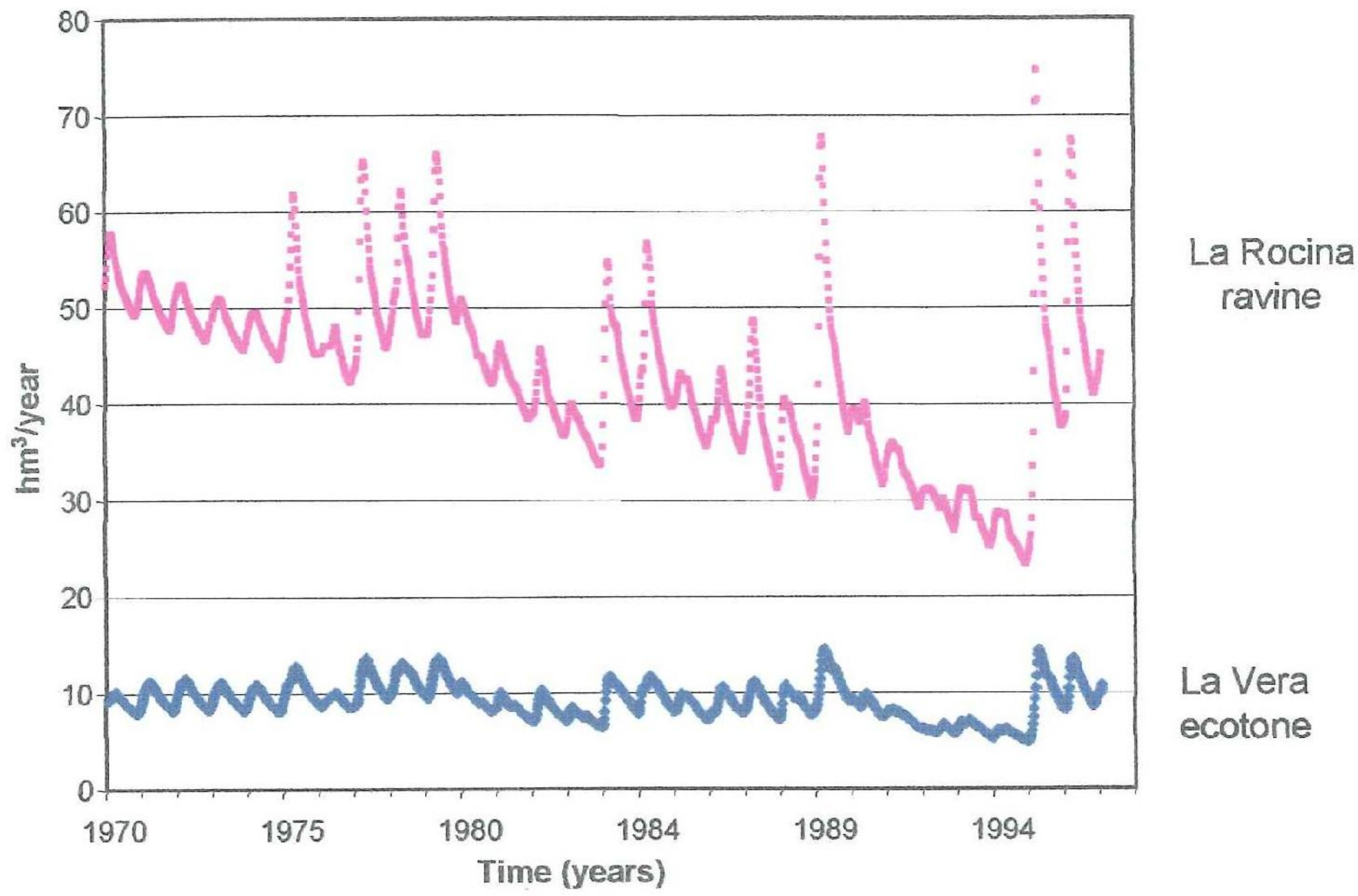
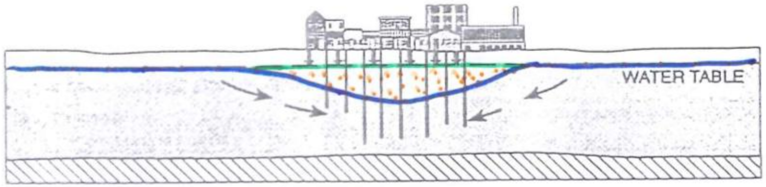
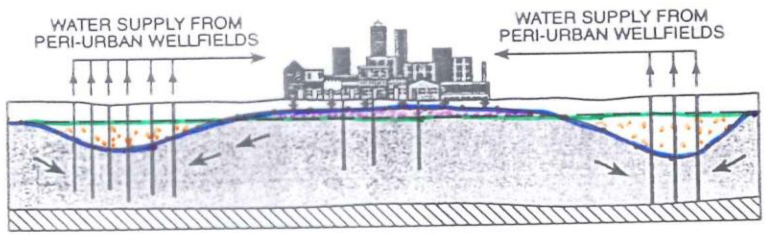


Figure 7.–Groundwater discharge flow evolution to La Rocina ravine and to La Vera ecotone (see location in Figure 1a) as calculated by groundwater flow numerical modelling. Note that the dramatic situation of 1994 is due to the combined effect of 1) accumulated interannual water level lowering due to pumping, and 2) a 4 years–long drought (modified from UPC, 1999)



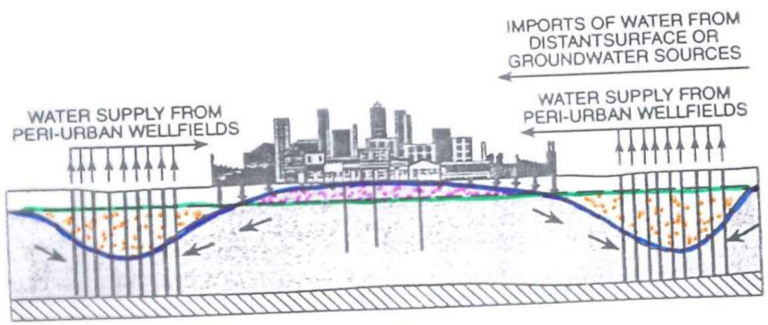
(a) town becomes city

- Water table lowered beneath city, wells deepened.
- Wastewater discharged to ground.
- Shallow groundwater in city centre becomes polluted.
- Subsidence can occur if aquifer is unconsolidated and interbedded.
- Expansion of pluvial drainage to ground and local watercourses.



(b) city expands

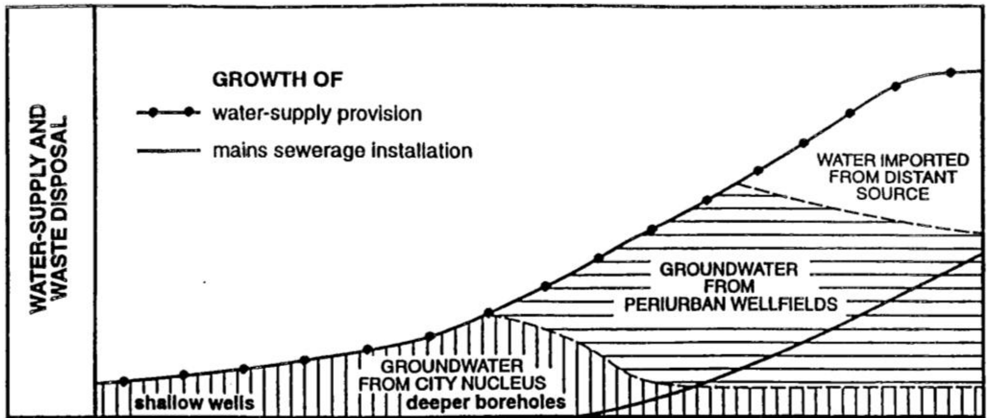
- Aquifer beneath city largely abandoned because of contamination.
- Water table begins to rise beneath city due to cessation of pumping and high urban recharge.
- Significant water table decline in city periphery due to heavy abstraction from wellfields.
- Incipient contamination of urban wellfields by groundwater recharged beneath city centre.



(c) city expands further

- Wellfields unable to cope with increased demand and threatened by outward growth of city.
- Expensive water imports from distant sources or conjunctive use schemes necessary.
- Water table rises beneath city nucleus - problems of flooding, wastewater disposal etc.
- Scope reduced for (low cost) pluvial drainage to ground.

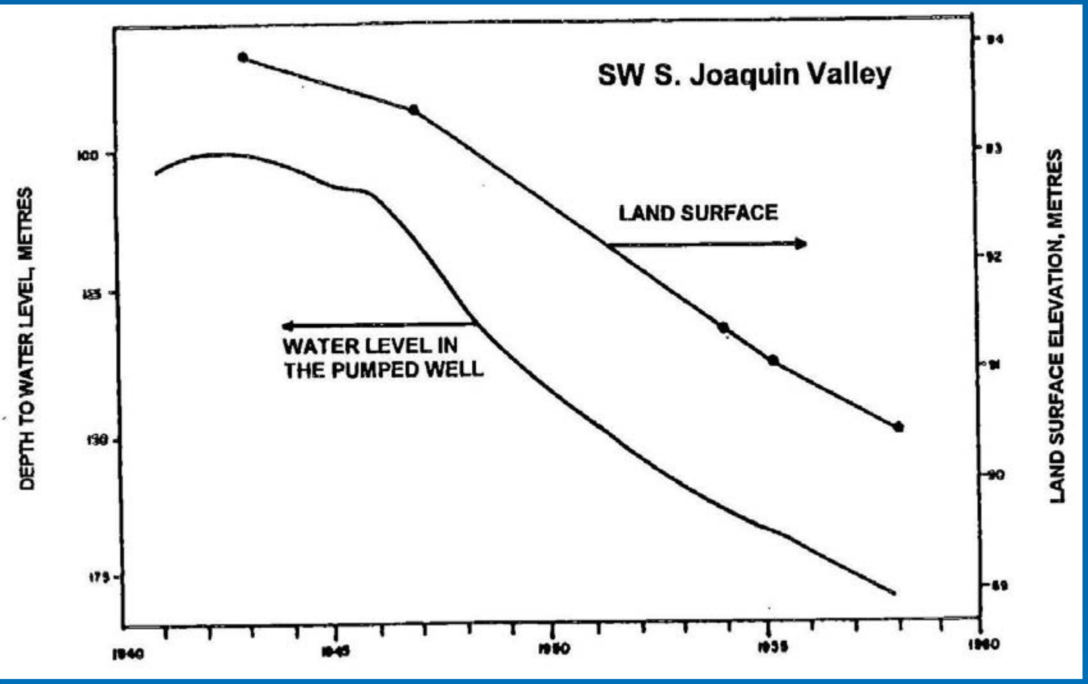
Evolution of water supply and waste disposal in a typical city underlain by a shallow aquifer

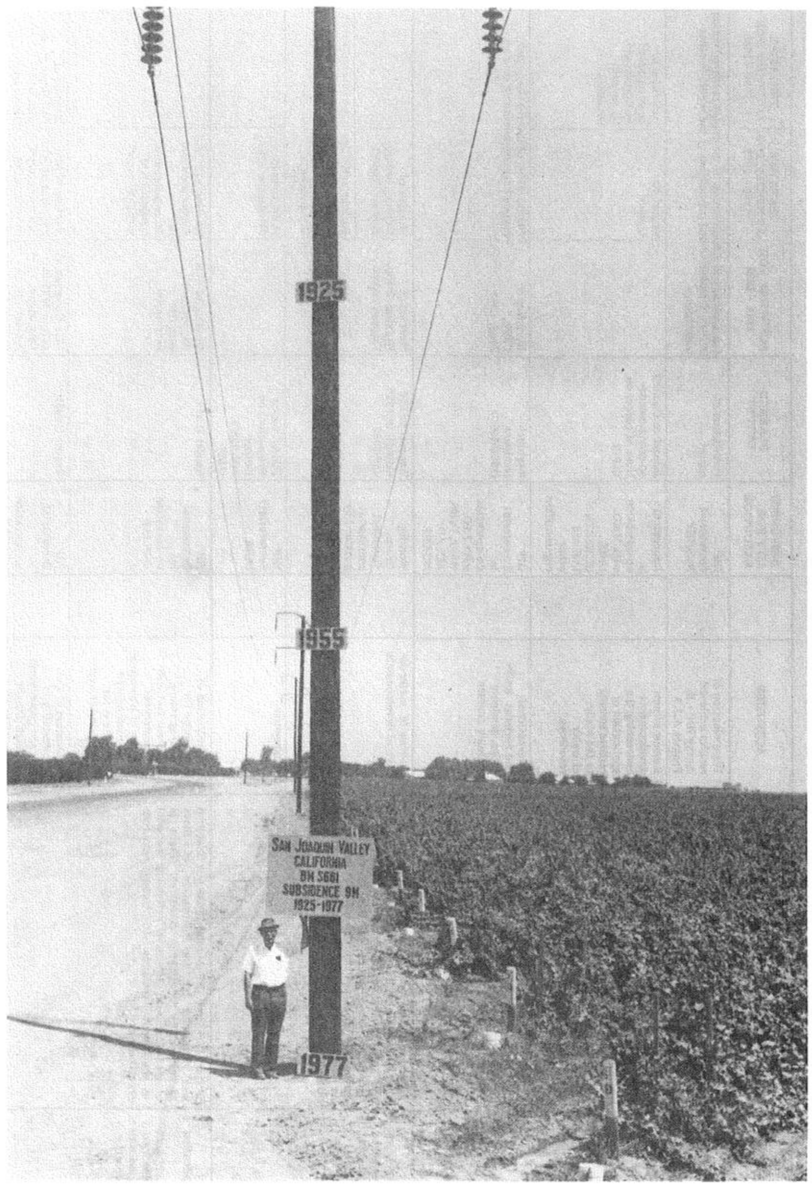


	INITIAL SETTLEMENT		URBAN EXPANSION	
WATER SUPPLY	Water obtained from shallow city wells.	Water obtained from city boreholes and wells.	Urban aquifer largely abandoned in favour of periurban wellfields.	Water obtained from:- (i) peri-urban wellfield (ii) Imported water
IMPACTS	None	- incipient contamination of urban aquifer - possible reduced urban well yields due to water table decline.	- urban aquifer contaminated - urban water table rises - decline of water table city periphery	- water table declines outside city (cannot meet increased water demand). - urban water table rises - incipient contamination of peri-urban wells.
HYDRO-GEOLOGICAL CAUSES	None	- over exploitation - excess pollution loading	- excess pollution loading	- over exploitation - excess recharge (local to city centre) - excess pollution loading
POTENTIAL CONFLICTS	None	Conflict between:- - urban groundwater users (private vs public) - water supply and wastewater disposal.	Conflict between:- - urban water users vs wastewater disposal - public supply (peri-urban) and irrigation	- water users (costs) urban and rural - water supply vs wastewater disposal.

Processes of urban evolution from the groundwater resources perspective

Land subsidence due to groundwater abstraction





U.S.A./U.S. Geological Survey

Land subsidence and collapse due to groundwater changes

Murcia, Spain

Unconsolidated aquifer exploitation in a dry year

Winter Park, Florida

Collapse in a karstic area

Threads to groundwater

- Quality degradation by pollution {
  - agricultural
  - from animal rising
  - urban
  - industrial

  very slow appearance
  large involved volumes
  costly, very difficult and long–lasting restauration

- Recharge reduction
  - by land use changes {
    - forest
    - agriculture
    - urbanization
    - river modification
  - by dewatering for { civil / mining } works

- Abstraction cost becoming to high

- Poor {
  - understanding
  - management
  - ethic behaviour

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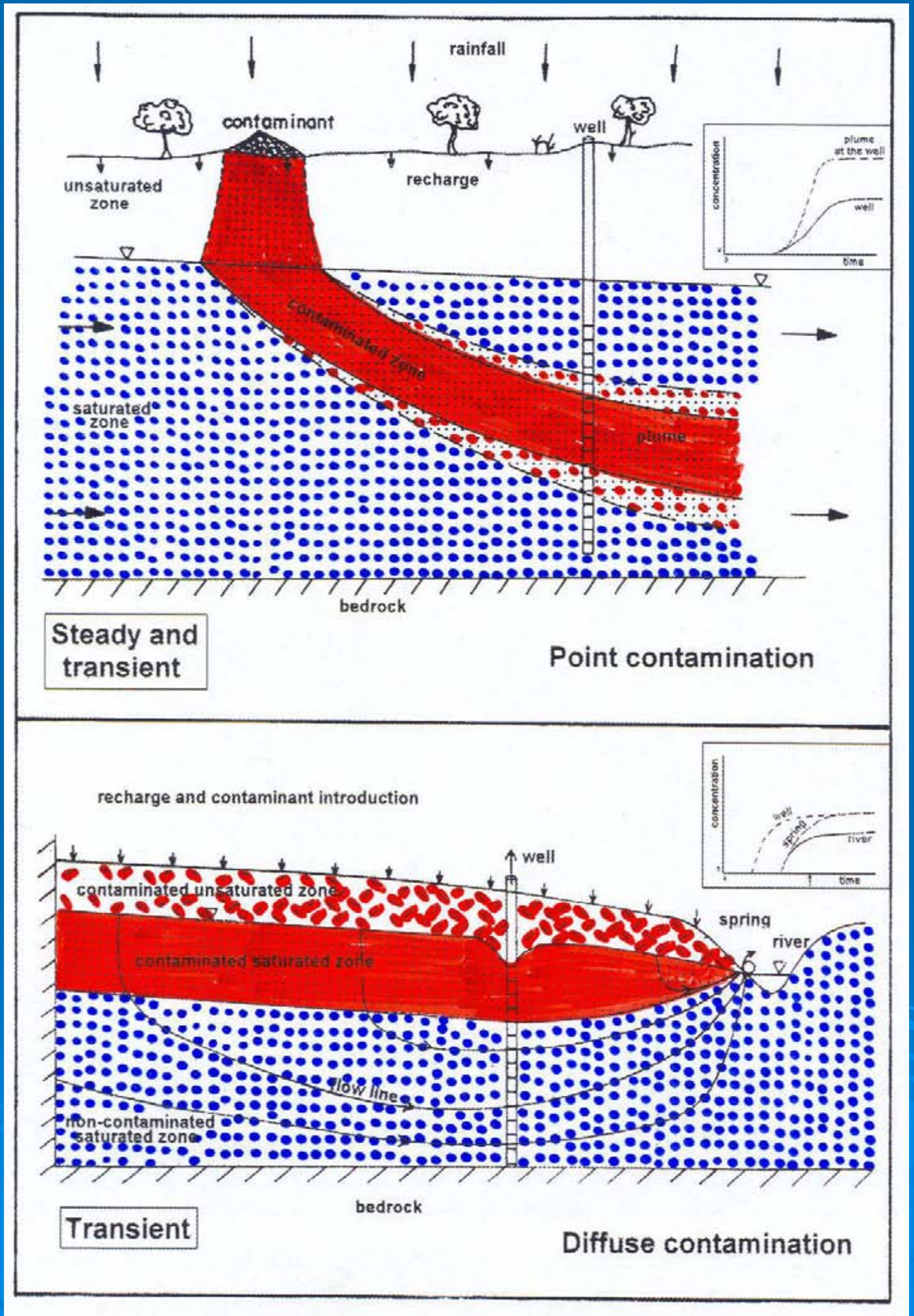

Point and diffuse groundwater contamination

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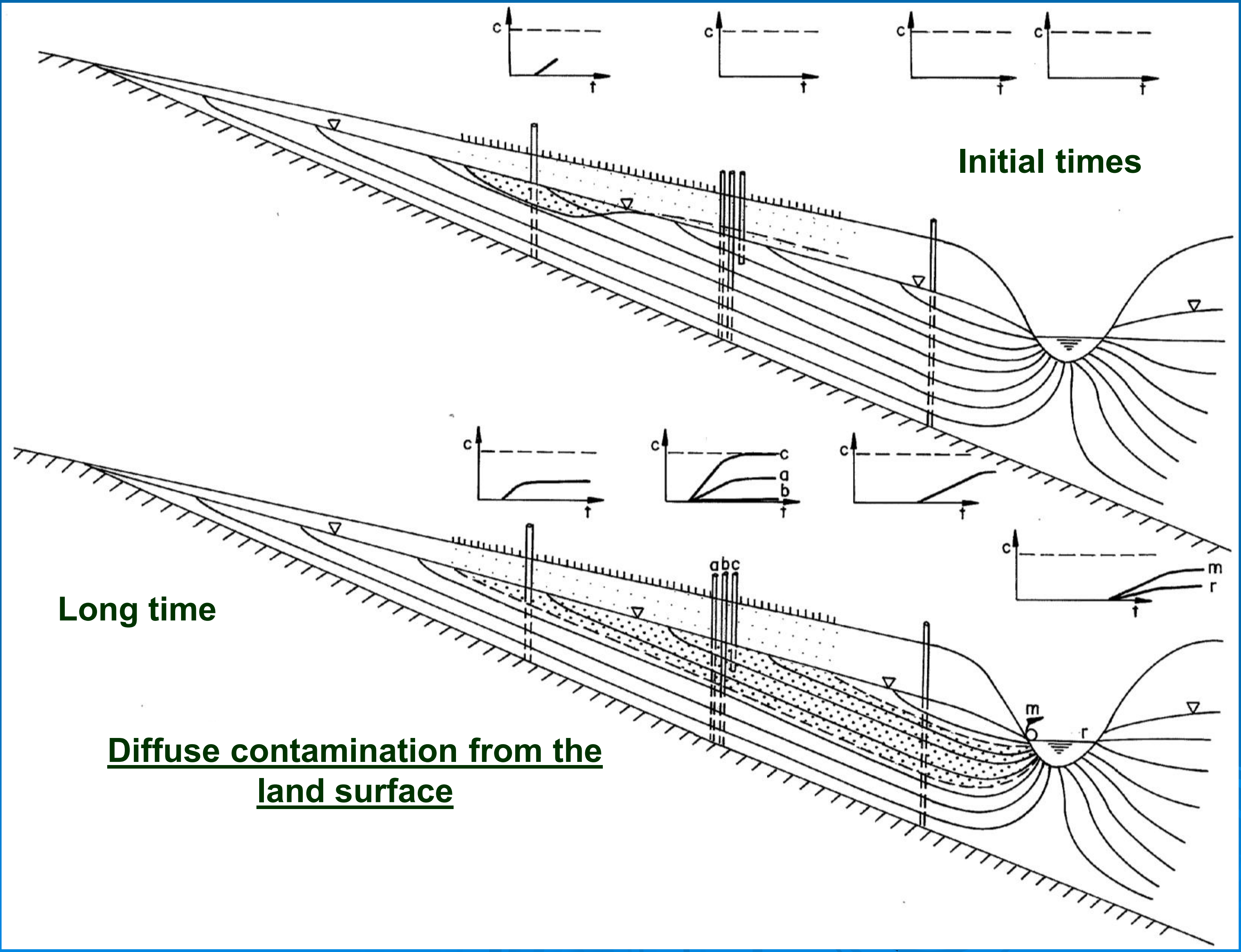
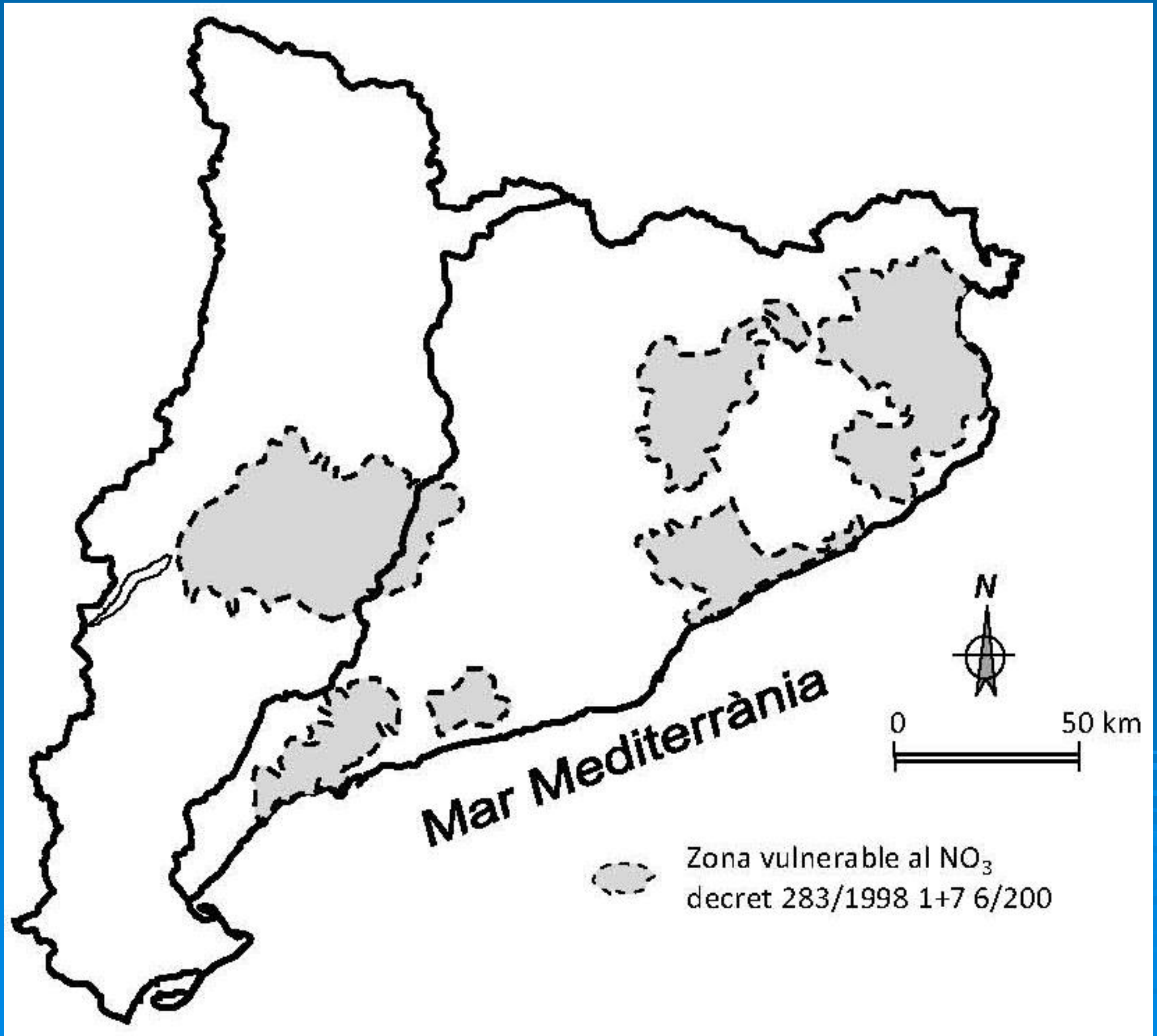


Diffuse contamination from the land surface

Areas of Catalonia, NE Spain, affected by excess nitrate in groundwater



Economic and social issues

- Groundwater development means { benefits / costs } { to the exploiter / to society } { direct / indirect / intangible }

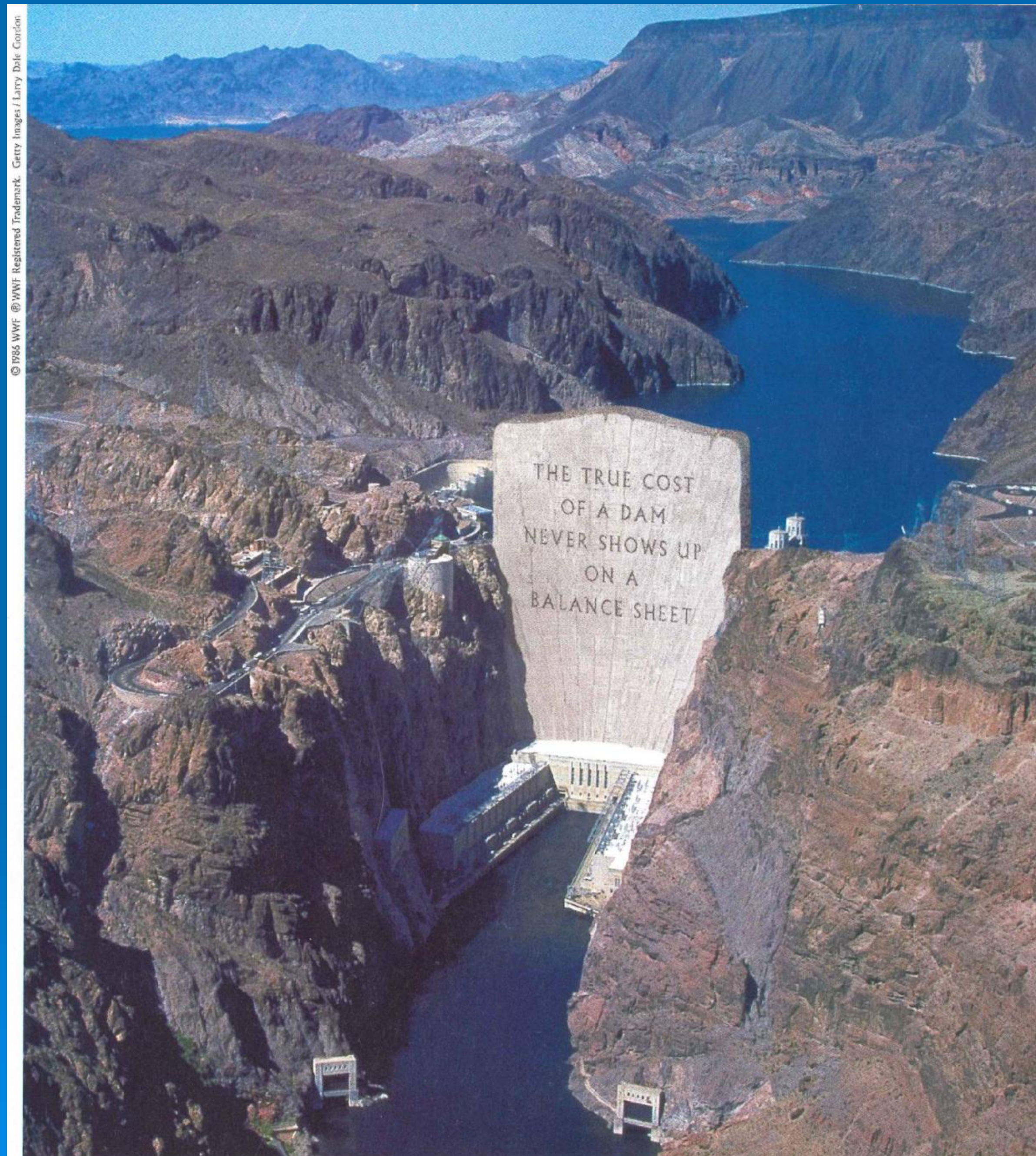
- Cost of groundwater in the terrain is not nil

- Consider long delayed effects → how to value the future
  → poor experience on evaluations

Consider social value of groundwater manifestations
{ aethetic / religious } { intergenerational / with neighbours }

apply ethical / moral principles

- Groundwater development → a social / → a silent { revolution from the floor


THE TRUE COST
OF A DAM
NEVER SHOWS UP
ON A
BALANCE SHEET
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Management issues and challenges

Groundwater is a kind of common pool good
- unrestricted use → tragedy of the commons
- rational use → sustainability

Management is needed

by { governmental authorities; groundwater { users, stakeholders }; civil society } acting { together, co–ordinately, responsively }

Management means {
- knowledge
- monitoring
- insitutions { from the top, from the bottom }
- legislation
- co–responsibility
- co–operation
}

Collective bodies → efficient tool for aquifer { management, governance }

Some challenges for safe groundwater use

Consideration of delayed { hydrodynamic / quality } **effects on** { resources / quality / economy / environment }

Land use effects on { quantity / quality (including pollutants) }

Integrated management of water resouces { surface / ground } relationships; reuse; desalinization and others }

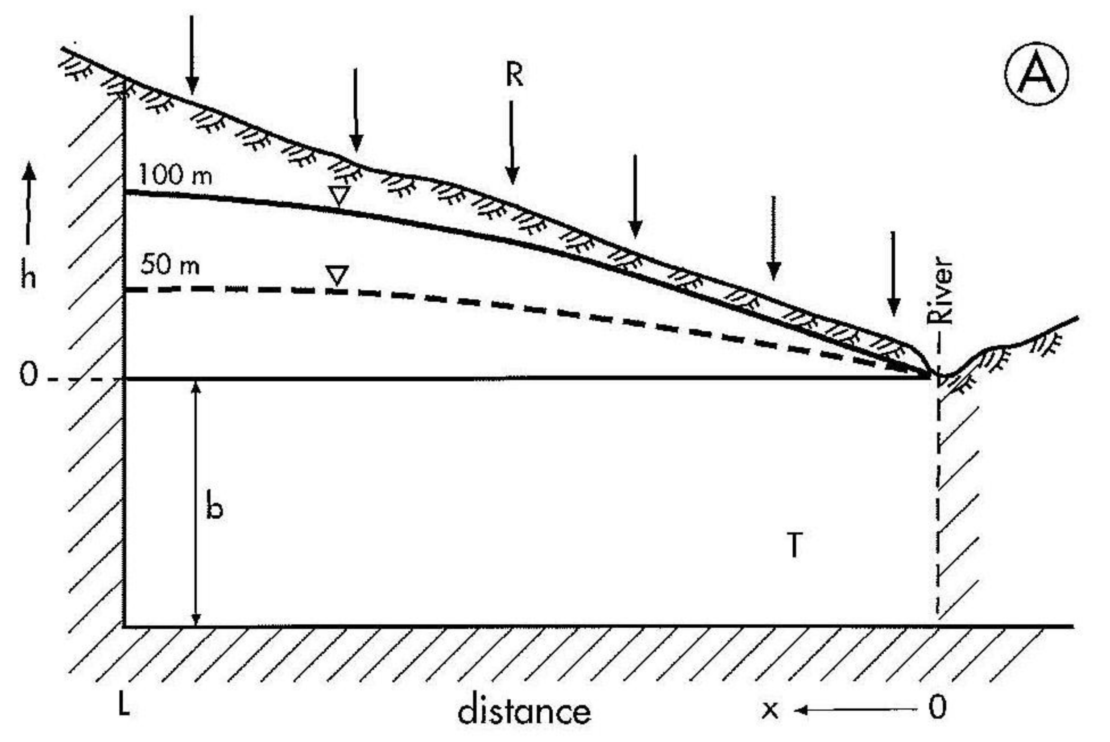
Understanding and management of natural { noxius water / dangerous } **components**

Management of large human collectives { numerous / over a wide territory }

Making aware the population on { groundwater basic principles / long–delayed effects }

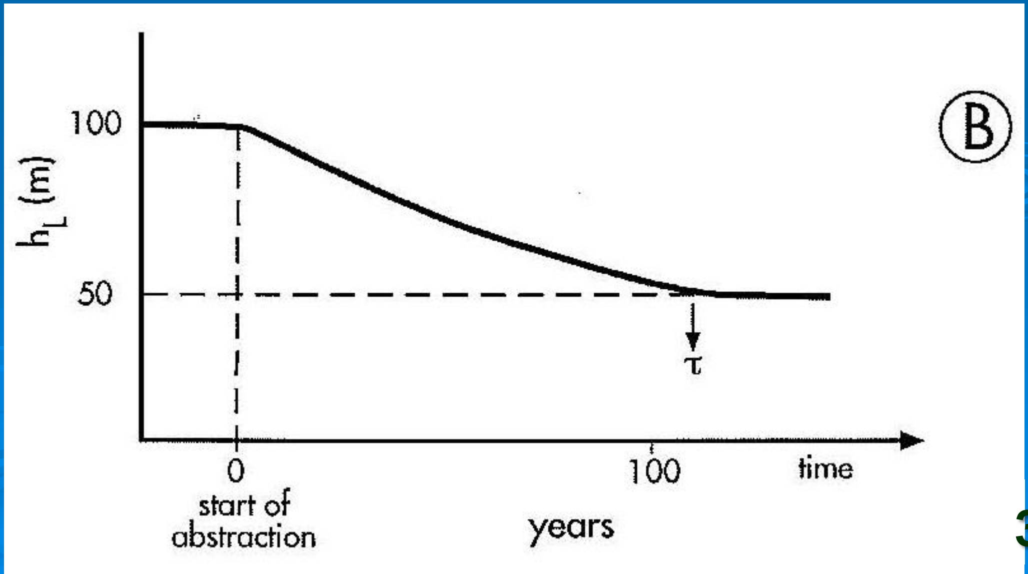
Introducing full social costs in groundwater economy

THANK–YOU FOR YOUR ATTENTION



Basin aquifer bounded by an impermeable boundary and a draining river

Rainfall distributed recharge.
Effect of distributed abstraction of half the recharge rate.
Delayed groundwater level evaluation



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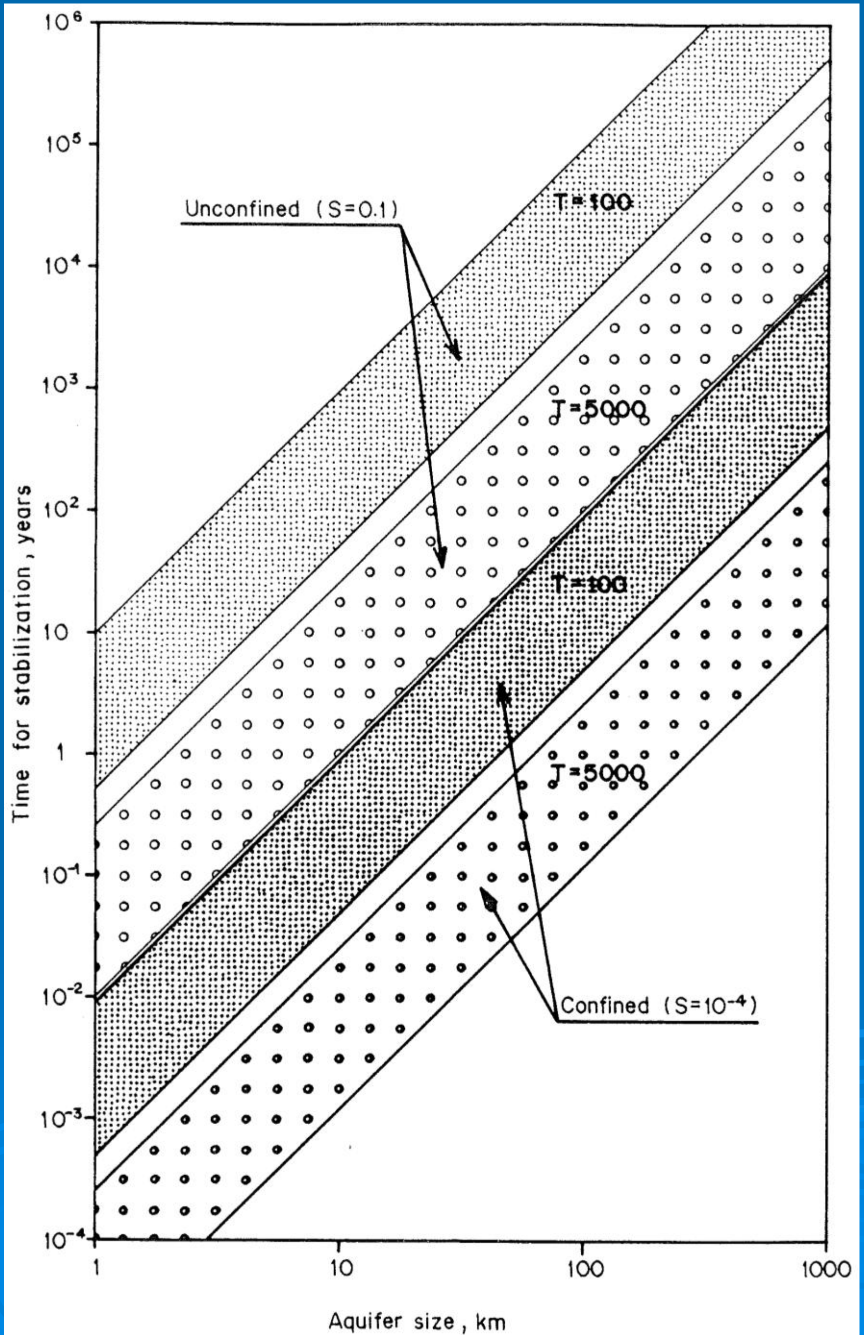
Time for groundwater level stabilization after starting a sustained development

This time depends on

- **aquifer size**
- **transmissivity**
- **storage coefficient**



Groundwater reserves and depletion rate: Eastern Spanish aquifers

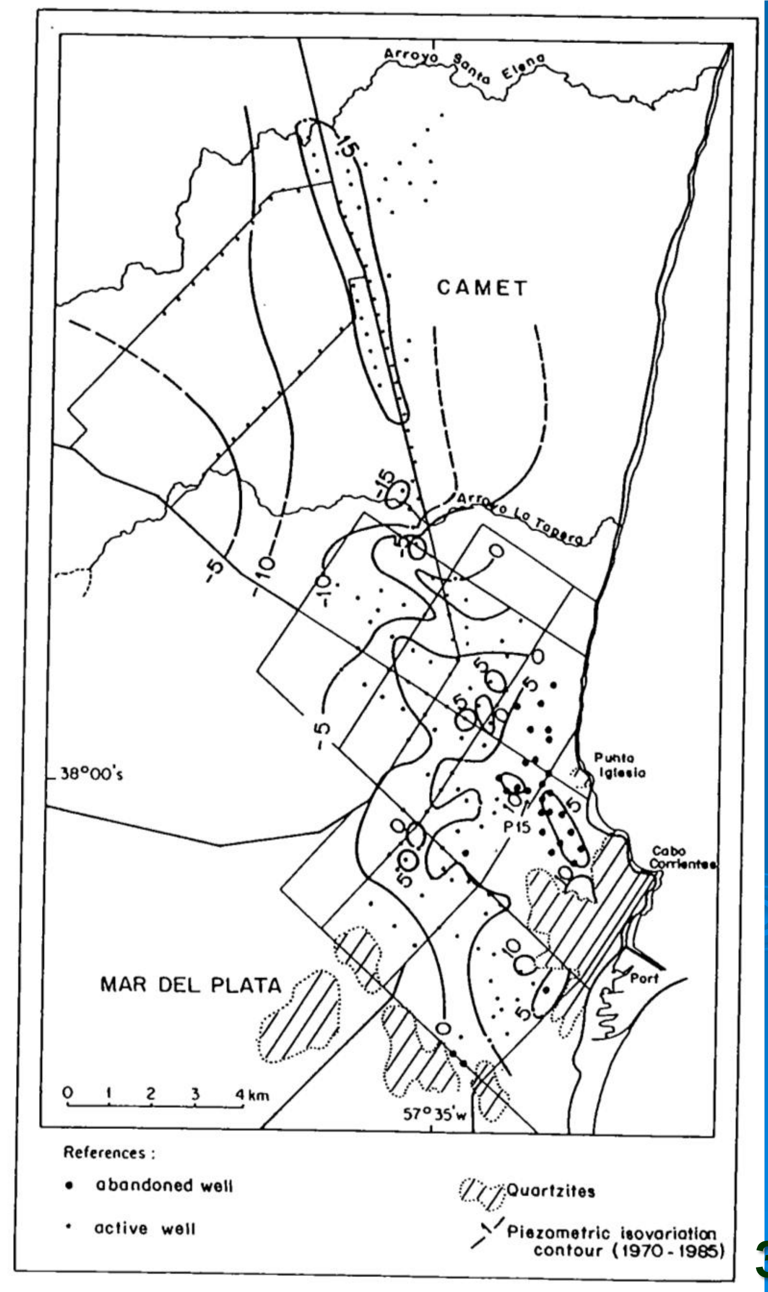
Figures are very uncertain

They are small, highly productive, well bounded (?) aquifers
Climate is semi–arid, with flash floods

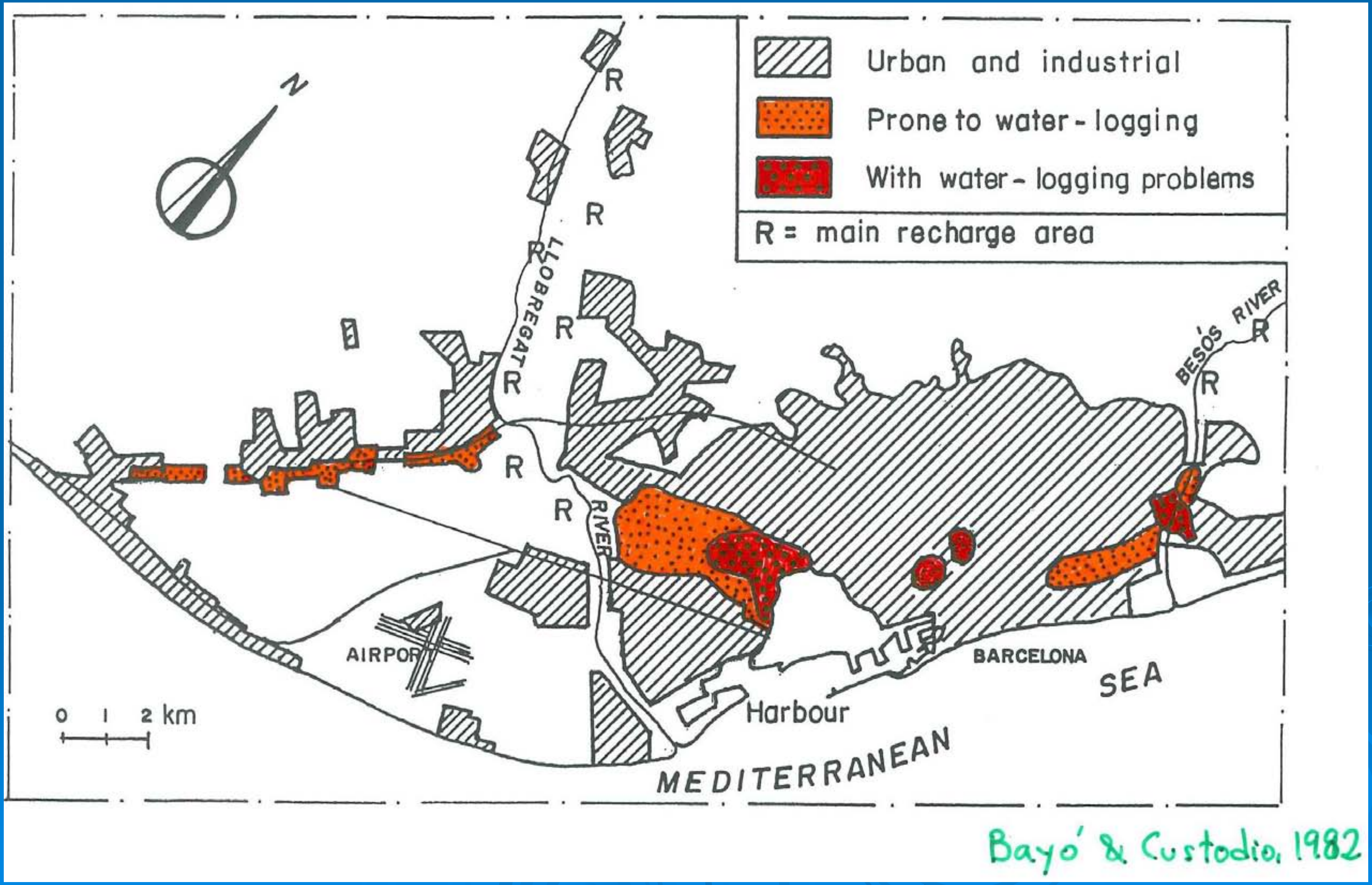
1995

Area	Reserves $10^6\ m^3$ Used (1980-1995)	Reserves $10^6\ m^3$ Remaining	Reserves $10^6\ m^3$ Usable	Depletion rate $10^6\ m^3/yr$	Time to depletion yr
Almería	800	1100	750	50	15 (10-75)
Murcia	2000	10000	7100	125	60 (10-800)
Alacant	1000	7000	6000	50	120 (10-400)
Valencia	100	2500	2000	15	130 (20-350)
Murcia (1985)			6000-11000	300	20-40

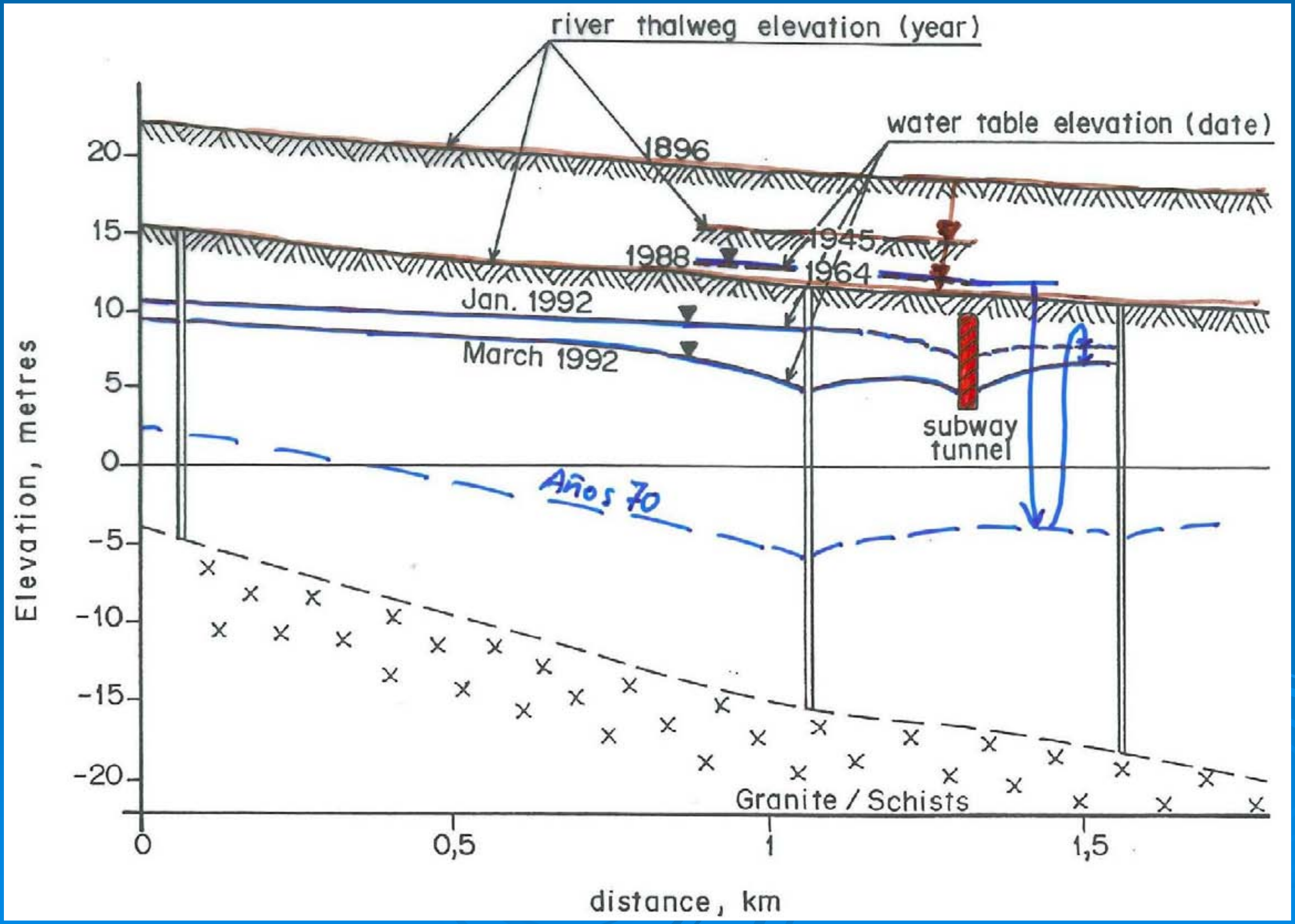
Results of groundwater development in urban and periurban Mar del Plata (Argentina) after wells in town has been closed down due to poor quality and saline contamination, and substituded by wells in the periphery. The isolines show the water table change (in metres) between 1970 and 1985 (after Bocanegra et al., 1992; Bocanegra and Custodio, 1995). Whilst there is a progressive water table drawdown in the periphery, in the city there is a recovery that affects the basements of high building due to underpressure and corrosive environment



Areas around Barcelona suffering water–table recovery effects

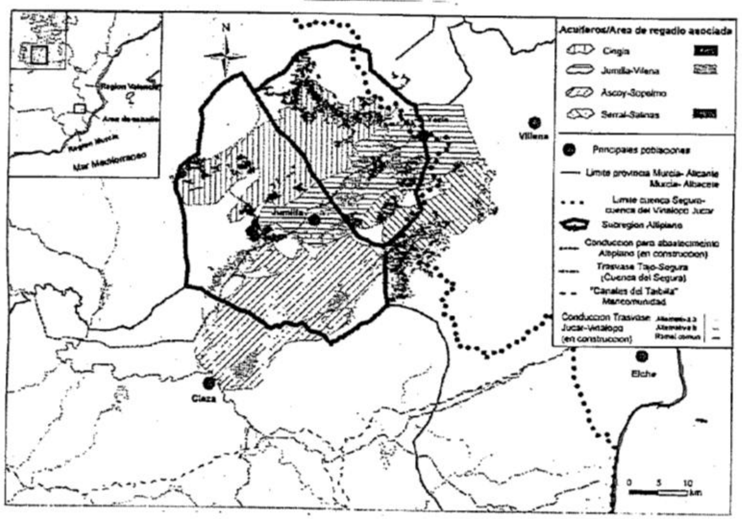


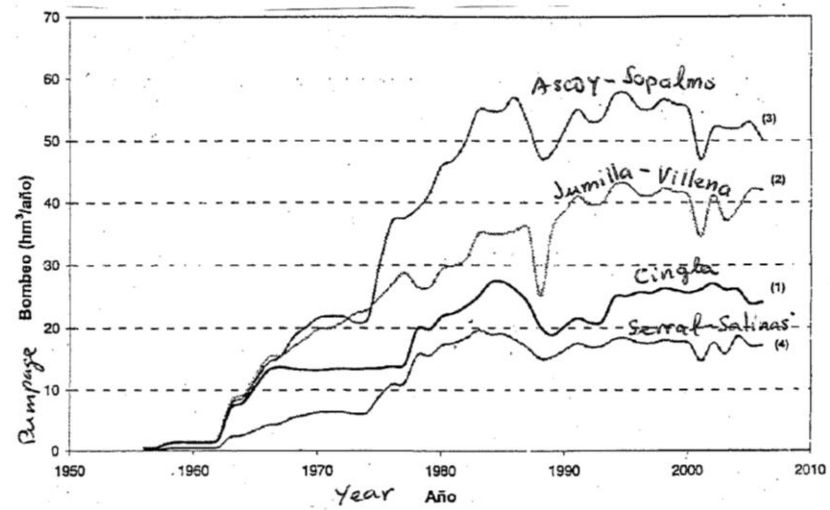
Water–table changes in the Low Besós area, near Barcelona due to intensive groundwater exploitation and later abandonment. Underground structures have been inondated



Altiplano Murciano. SE Spain. Alacant-Murcia.

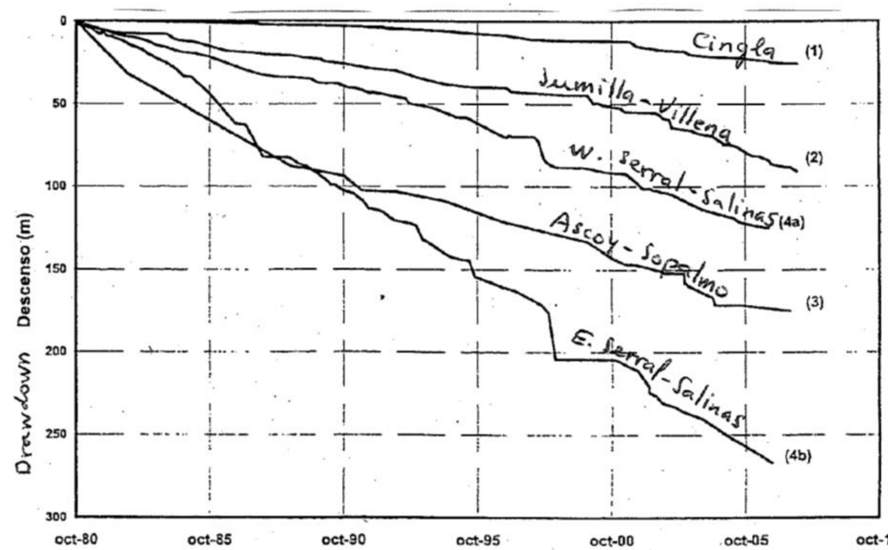
Molina et al. 2009. Planif y Gest. Aguas Subt. (ed. Vives et al.). Santa Rosa - IAH





Balance hídrico de los acuíferos estudiados y tasas de descenso piezométrico (Δ h)

Acuífero	Recarga (hm³/año)	Bombeo actual (hm³/año)	Variación del almacenamiento (hm³/año)	Δ h desde régimen natural (m)	Δ h medio últimos diez años (m/año)
Cingla	13	30	-17	25	1,3
Jumilla-Villena	15	46	-31	115	3,5
Ascoy-Sopalmo	2	52	-50	187	4,5
Serral-Salinas	5	18	-13	130 (sector W) 290 (sector E)	4,9 (sector W) 10,5 (sector E)
Total	35	146	-111		



Altiplano Murciano. SE Spain. Alacant-Murcia

Molina et al. 2009. Planif y Gest. Aguas Sub. (ed. Vives et al.) Santa Rosa. IAH

Análisis coste-efectividad de las intervenciones de gestión propuestas

Escenario	Descripción	Coste total (mill euros/año)	Efectividad (hm³/año) (cantidad de agua subterránea ahorrada)	Ratio (euros/m³)	Método de evaluación económica
S.1 Condiciones actuales	Condiciones actuales	0	0	0	----------------
S.2 Intervenciones individuales de gestión hídrica (aceptables por la población)	Reducción de la demanda hídrica	47	45	1.05	"Lucro Cesante"
	Entrada externa de agua para regadío (permuta utiliz. agua desaliniz. con comarcas riego costero con TT-Segura →)	14	43	0.32	Pérdida de Margen Neto agrícola (desde derechos de agua desalada)
	Entrada externa de agua para regadío (transv. Júcar-Vinalopó →)	1	20	0.05	Pérdida de Margen Neto agrícola (desde TJV Trasvase Júcar Vinalopó)
	Compra de derechos de agua	16	9	2.2	"Lucro Cesante"
S.3 Equilibrio en balances hídricos Como requerimiento de la DMA para el buen estado cuantitativo de las masas de agua	Entrada externa de agua para regadío	35	111	0.32	Pérdida de Margen Neto agrícola (desde derechos de agua desalada)
	Compra de derechos de agua	120	111	1.03	"Lucro Cesante"

Escenario S.1 Business as usual
Ref. 2007-08

Acuífero	Prob. recup. reg. natural %	Prob. rentab. agrícola % k€/ha	Empleos por ha.a
Ascoy-Sopalmo	0	1-5 80% 5-10 20%	>0.40
Serral-Salinas	3.3	1-5 100% 5-10 13%+	<0.1 (30%)
Jumilla-Villena	8.8 (100-200 a)	1-5 (100%)	
Cingla	0.74	1-5 (90%) 0-1 (10%)	
CONJUNTO		1-5 (82%) >10 (0.08%)	0.1 a 0.3 (94%)