Groundwater in the Southern Member States of the European Union:

an assessment of current knowledge and future prospects

Country report for France

Contents

GROUNDWATER ISSUES IN SOUTHERN EU MEMBER STATES FRANCE COUNTRY REPORT

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1. INTRODUCTION

France is one of the largest European member States (550,000 km²), and has high mountains (Alps, Pyrenees, Massif Central and Vosges), large plains, and four types of climate (oceanic, continental, Mediterranean and Alpine), with a predominance of oceanic. It has abundant and regular rainfall, and in the Mediterranean part, the Rhone is a large river by European standards. For Europe, it has a relatively low population density, with 107 inh/km^2 compared to over 400 in the Netherlands. The per capita potential annual water resource is 3,200 m^3, vs. 2,000 for Germany and 1,400 for England and Wales (2,200 for the United Kingdom). On average, continental and coastal water quality is good, and with its moderate development of irrigation, France has no severe water-stress problems and is almost entirely self-supplying. But some aquifers are overexploited and have been recognised as such even before the Second World War.

The exploitation of groundwater in France is indeed ancient, as in many “old” countries. The first wells drilled in confined aquifers date back to approximately the 10th century, and were made in the Chalk in Northern France, in Artois, where the name “artesian well” originated. The thin impermeable cover over the Chalk making the aquifer confined was the “Pissards sands”. The wells were most likely drilled by monks using cable percussion. One of the first recorded well in the Paris basin[1] (Puits de Grenelle) into the Cretaceous Albian sands was commissioned around 1840 by the City of Paris in accordance with a recommendation by Arago, who was a member of the Académie des Sciences and of the City council. Although Arago was a famous physicist, and not a geologist, he had observed that the Albian sand layer was outcropping in the southeast and northwest of the basin, and figured out that it probably existed underneath Paris. He estimated its depth to 400 m, but was wrong on that point (more than 600 m). The city of Paris was discouraged when the driller, after more than 3 years and 400 m of cable drilling (Fig. 1), did not discover the water, and stopped financing the operation. But the driller, Mr. Mullot, continued at his own expense and eventually reached the Albian sands at 600 m; the well was artesian, with an estimated pressure of 12 bars at the soil level. Mr. Mullot was made an honorary citizen of the City of Paris, and a statue of him was erected in Grenelle Square, but it is unfortunately lost today (melted down during a war). Plans were made to build a fountain (Fig. 2), and the water was later used for an industrial laundry, as its temperature was warm (>30°C).

The number of wells in the Albian aquifer increased rapidly, as they did in the city of Bordeaux, which tapped the Aquitaine basin Eocene sands to build many fountains whose water was wasted. But the level of the water was falling, and this was of great concern to

[1] The first deep artesian well in the Paris basin was made in Tours in the Cenomanian sands in 1830, and is discussed in details in Henry Darcy’s (1856) famous memoir.

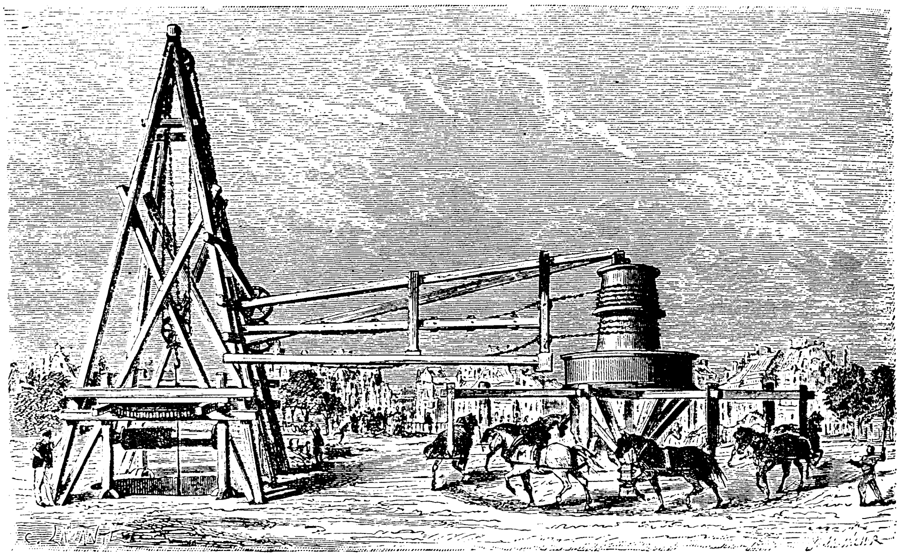

FIG. 4. — Forage du puits de Grenelle.
Extrait de *Les Grands Travaux du Siècle.*

Fig. 1 : Cable drilling of the Grenelle well in Paris, around 1840

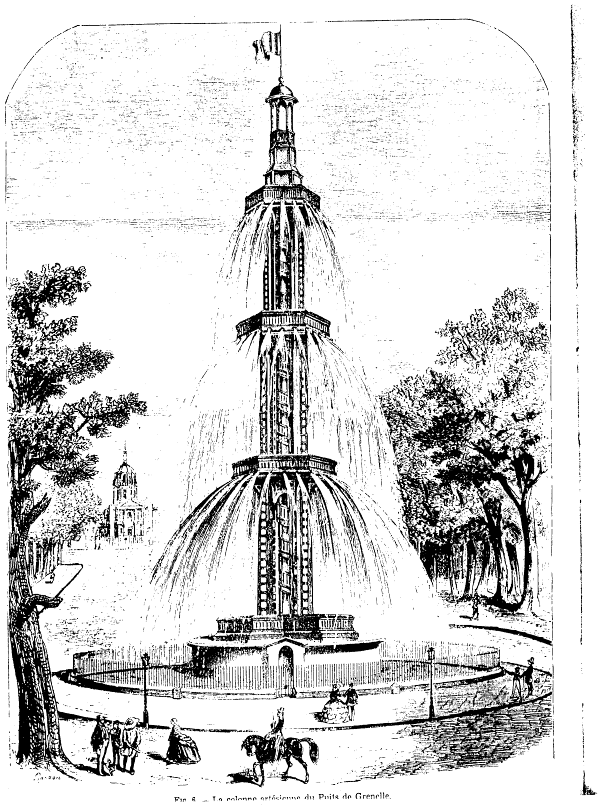

FIG. 6. — La colonne artésienne du Puits de Grenelle.

Fig. 2 : Planned fountain at the Grenelle well in Paris, around 1843

the French Administration. The great debate at the beginning of the 20th Century was whether or not the water was fossil, and therefore not renewable, or if it received recharge on its outcrop. Had the information that the water was more than 20,000 years old been available (this was estimated by radiocarbon dating in the 1950s), the concern would have been even greater.

Then in 1935, the first leftist Government came to power in France, with Léon Blum as Prime Minister and the "Front Populaire", and money started to leave the country and accumulate in Swiss or other foreign banks. The Parliament's only concern at the time was to "defend the franc" and stop the financial blood-letting of the country. The Administration in charge of Mining and the Underground then produced a decree "for the defence of the franc", the first decree in France concerning groundwater, where it was established that, to defend the franc, one method was to protect the French patrimony, and in particular the groundwater stored at depth in aquifers, which was under great danger of over-exploitation. This decree, still in existence today, stipulates that any drilling deeper than 80 m had to be authorised by the Mining Administration. The decree was made applicable immediately but only to "Ile de France" Départements (administrative districts around Paris), although it was extended later to major deep aquifers. Since that time, almost no authorisation to drill has been granted in the Paris basin, which has allowed the aquifer level to rise again, although all artesian wells have lost their artesian character.

During the same period, France produced numerous scientific works on groundwater flow, including Darcy's (1856) law, Dupuit's (1857) flow equations, Boussinesq's (1904) developments, and many others. But the most famous 19th century hydrogeologist in France was not Darcy, but Father Paramelle (1856) whose treaty on "the art of discovering springs" was determinative in making groundwater popular in France, and exploiting it for domestic water supply. Martel (1921), Imbeaux (1930), Schoeller (1962), Castany (1963), Avias (1968), among others, also made French hydrogeology develop and helped to find and exploit aquifers.

Today, about 59% of the domestic water supply comes from groundwater. Irrigation by groundwater has increased tremendously in the last 20 years, and surprisingly, the strongest negative effects of groundwater extraction have been felt, not in the Mediterranean part of France, but in the north, in the Paris basin. In the Beauce region, where maize is grown intensively and irrigated with water from the "Calcaires de Beauce" (Eocene-Oligocene lacustrine limestone) aquifer, the rivers, which were the natural outlets of this large aquifer, have dried up. In many regions of France, the aquifers are karstic, particularly in the south, and the study of karstic hydrogeology has been quite active in the country, see e.g. Avias (1992).

In this report, the current situation of French groundwater will be explored, in the context of the Southern EU Member States concerns for the protection of groundwater, but keeping in mind that in France, in the minds of the public, the major problem associated with groundwater is rather groundwater quality than quantity, given the current deterioration of groundwater quality by agricultural practices (mostly nitrates and pesticides).

2. SCOPE

This report is a compilation of various documents, including :

-B. Barraqué's chapter "groundwater management in France : from private to common property ?", published in 2004 and updated by its author;

-the new IAH-BRGM monograph of "Aquifers and groundwater in France", edited by J.C. Roux (2006), which provides a recent and exhaustive view of French aquifers;

-documents from the Water Directorate of the Ministry of Ecology and Sustainable Development, regarding the 2000 Water Framework Directive;

-reports from the French Institute of the Environment (IFEN, 2004, 2005) on the status of groundwater in France, quantitative and qualitative aspects;

-contributions by T. Rieu and J.P. Terreaux (CEMAGREF) Irrigation et gestion de nappes : quel retour d'expériences ? on the economics of irrigation, Journées Techniques de l'AFEID, Chartres (Eure et Loir), 5 October 2001;

-a report by the National Institute of Agronomic Research (INRA, 2006) on drought and agriculture : "Sécheresse et Agriculture, Réduire la vulnérabilité de l'agriculture à un risque accru de manque d'eau. Expertise scientifique collective.

The aim of this contribution is to present the current status of French groundwater resources, threats to them, trends and expected measures to improve the situation.

3. GROUNDWATER RESOURCES

3.1 Water Framework Directive data

Groundwater bodies

The French Ministry in charge of the environment has defined 553 groundwater bodies, among which 28 are in overseas territories (DOM) and Corsica, 13 are trans-hydrographic basins[2], and 15 are trans-boundaries (Fig. 3). Table 1 shows the distribution of these groundwater bodies over the 12 major hydrographic districts that have been defined for the WFD. The principles for defining the groundwater bodies were as follows :

-geologic and hydrogeologic criteria, a groundwater body is one (or part of) a hydrogeologic unit, decomposed into 6 types of aquifers (alluvial / bedrock / volcanic / mostly non alluvial sedimentary / mountain composite hydrogeological systems intensely folded / impervious systems but locally containing small disjoint aquifer units);

-the limits of groundwater bodies are stable and not variable in time (impervious geologic limits, stable piezometric tops; flow lines);

-all boreholes giving more than 10 m^3/j of drinking water or used for producing drinking water for more than 50 people must belong to a groundwater body, therefore in practice all aquifers are considered;

-deep groundwater, unconnected to rivers or surface ecosystems, in which there is no withdrawal and which cannot be used for drinking water supply because of its poor quality or for technical-economical reasons may be excluded from the list of groundwater bodies;

-groundwater bodies may exchange water as long as this can be understood/quantified;

-for large groundwater bodies, they may have spatially variable heterogeneity of their hydrogeological characteristics and quantitative or qualitative status;

-subdividing groundwater bodies for taking into account human pressure must be limited; it is acceptable only for particular problems (e.g. point pollution plumes from industrial sites, active or not, piezometric depressions linked to overexploitation; this subdividing can only be made if the zone of

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[2] Metropolitan France has been divided since 1964 into six major hydrographic basins, Adour-Garonne (AG), Artois-Picardie (AP), Loire-Bretagne (LB), Rhin-Meuse (RM), Rhône-Méditerranée-Corse (RMC), Seine-Normandie (SN), whose boundaries can be seen in Fig.3, long before the WFD, with six Water Authorities (Agences de l'Eau) and Water Parliaments (Comités de Bassin, see section 8).

interest needs that specific objectives be defined, different from the rest of the groundwater body, with a different management.

Hydrographic Districts	Number of groundwater bodies
Escaut et côtiers Manche Mer du Nord	16
Meuse	11
Sambre	2
Rhin	15
Seine et côtiers normands	53
Loire, côtiers bretons et vendéens	143
Rhône et côtiers méditerranéens	180
Garonne, Adour et côtiers de Charente	105
Corse	14
Guadeloupe	6
Martinique	6
Réunion	2
Total	**553**

Table 1 : Groundwater bodies in France per major hydrographic districts

Figures 5, 6, 7, 8 provide maps of the groundwater bodies in France.

Groundwater bodies at risk of not meeting the good status in 2015

Among the 553 groundwater bodies, the preliminary analysis for the WFD has identified 216 masses at risk of not reaching the good environmental status in 2015, and 100 doubtful ones (Table 2), for both qualitative and quantitative reasons. Figure 4 provides a map of the groundwater bodies at risk for quantitative reasons, per hydrographic unit.

Hydrographic Districts	Number of groundwater bodies			
	Good status in 2015 (except strongly modified water bodies)	**Doubts or lack of data** (except strongly modified water bodies)	**At risk** (except strongly modified water bodies)	**Total**
Escaut et côtiers Manche Mer du Nord	0	0	16	**16**
Meuse	5	1	5	**11**
Sambre	0	0	2	**2**
Rhin	5	1	9	**15**
Seine et côtiers normands	7	0	46	**53**
Loire, côtiers bretons et vendéens	57	13	73	**143**
Rhône et côtiers méditerranéens	109	50	21	**180**
Garonne, Adour et côtiers de Charente	41	30	34	**105**
Corse	8	0	6	**14**
Guadeloupe	4	1	1	**6**
Martinique	1	3	2	**6**
Réunion	0	1	1	**2**
Total	**237**	**100**	**216**	**553**

Table 2 : Groundwater bodies at risk of not meeting the good status in 2015

The principles for determining the good status were as follows :

-to consider only diffuses pollution sources, assuming that industrial pollution was under control (remedial action being on-going or planned);

-to consider that good status water meets all criteria for defining drinking water (except natural elements present in the rocks);

-that there was a risk of poor status if the pollutant concentrations reached 80 % of the drinking water thresholds (e.g. 40 mg/l for nitrates), except for pesticides for which a threshold level of 0.1 µg/l was used per pesticide (and 0.5 µg/l for the sum of pesticides), and also for ammonia, chlorinated solvents…

-average withdrawals must be below the available resources, also for the long-term;

-surface water and ecosystems in relation with groundwater must not be affected by the groundwater withdrawal;

-withdrawals must not create risks of seawater intrusion.

Strangely enough, the groundwater bodies quantitatively at risk are generally not in the Mediterranean part of France, but often in the north, which clearly indicates that groundwater problems are not necessarily specific to the southern EU states, but are a function of the ratio Resource/Demand.

3.2 New Monograph of French Groundwater

The new Monograph of French Groundwater (Roux, 2006), a 944-page book published in 2006 with many maps and tables, for its part, first classifies the French aquifers into seven different types, namely :

-continuous single-layer water-table aquifers :
detrital rocks, porous or fissured limestone, porous volcanic rocks

- continuous multilayer water-table aquifers : same lithology, but with a semi-pervious bedrock allowing leakage with underlying confined aquifers

- continuous single-layer or multilayer confined aquifers, not outcropping

-discontinuous water-table aquifers, karstic or volcanic

-discontinuous water-table aquifers in fractured crystalline rocks-semi-pervious cover above a water-table aquifer :

-clay sands, chert clay, superficial weathered formations (siderolithic), clayey limestone, conglomerates

-capacitive semi-pervious layers within multilayered systems or around local aquifers.

France is then described in the Monograph by 10 continental regions, plus Corsica and the DOM-TOM (overseas territories), altogether divided into 62 sub-regions[3]. The Monograph also describes the exploitation of groundwater (see section 4), thermal and mineral waters, geothermal energy, gas storage in aquifers.

It is outside the scope of this report to describe in any detail the 62 sub-regions of the Monograph, the WFD 553 groundwater bodies or the 3,500 aquifers systems estimated to exist in France (IFEN, 2004). The interested reader is referred to the Monograph (Roux, 2006) for details. First, a general summary description of the major aquifer systems is given for the six hydrographic basins defined since 1964 (see footnote 2 page 4), followed by total annual figures for the water balance in the year 2001, from IFEN (2004).

[3] Massif Armoricain (Bretagne); Bassin de Paris, with 21 sub-regions; Flandres-Artois-Ardennes (North), with 6 sub-regions; Alsace, Vosges (East); Pyrénées-Roussillon, with 4 sub-regions; Massif Central, with 9 sub-regions; Jura; Alpes, with 3 sub-regions; Couloir Rhodanien, Provence-Languedoc, with 8 sub-regions; Corse; DOM-TOM, with 7 sub-regions

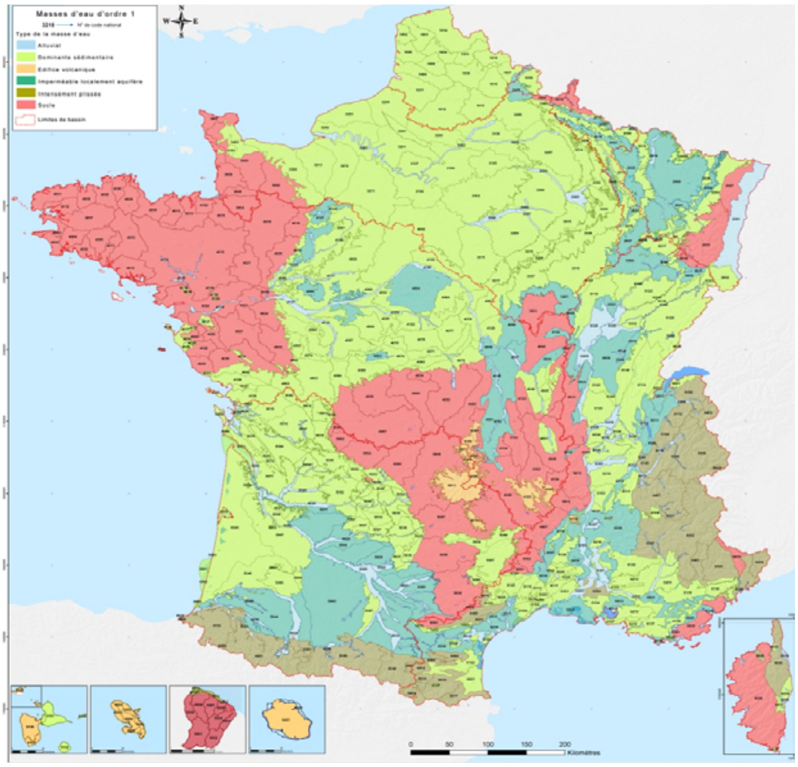


Figure 3 : Delineation of 553 groundwater bodies in France (MEDAD, 2004)

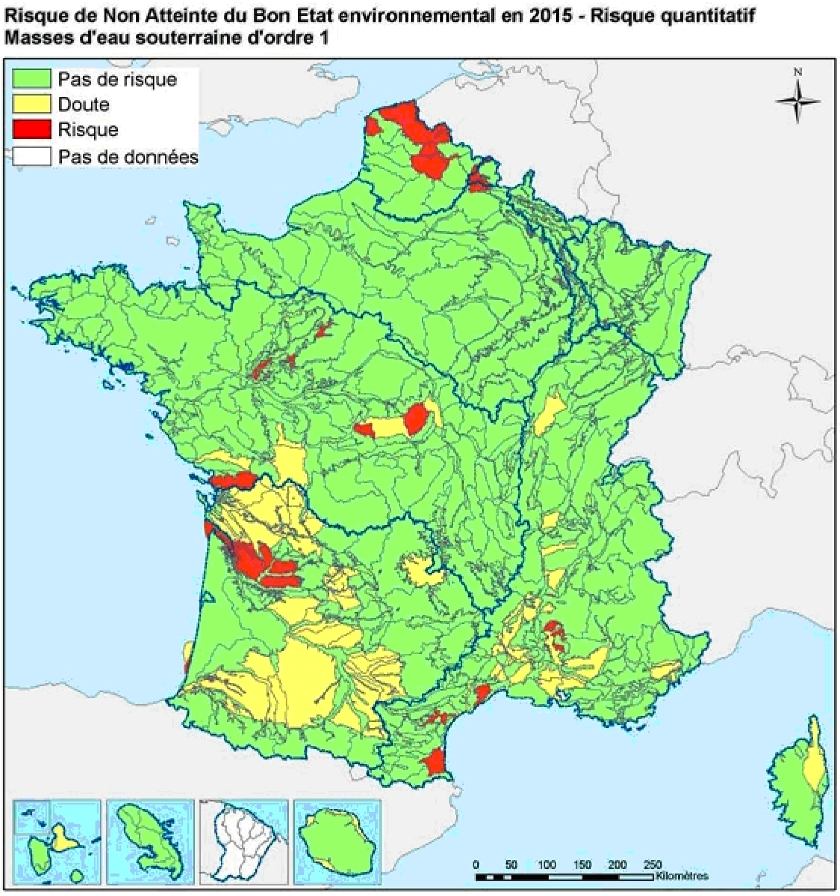
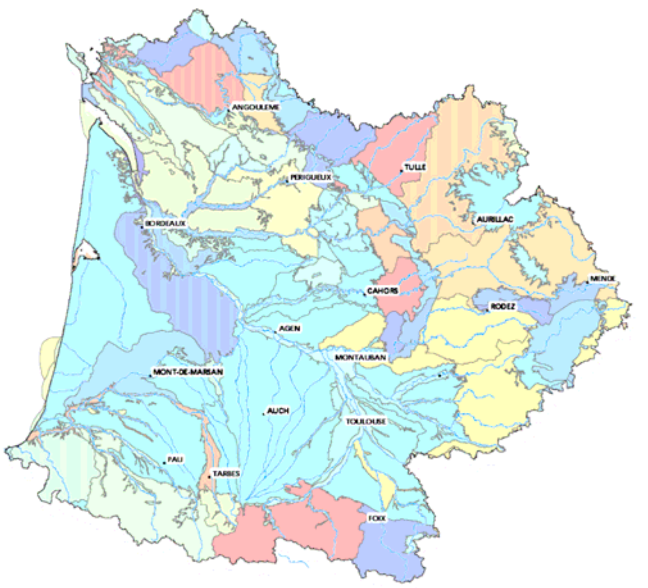


Figure 4 : Groundwater bodies at risk of not reaching good environmental status in 2015 or in doubt, for quantitative reasons, from MEDAD, 2004.

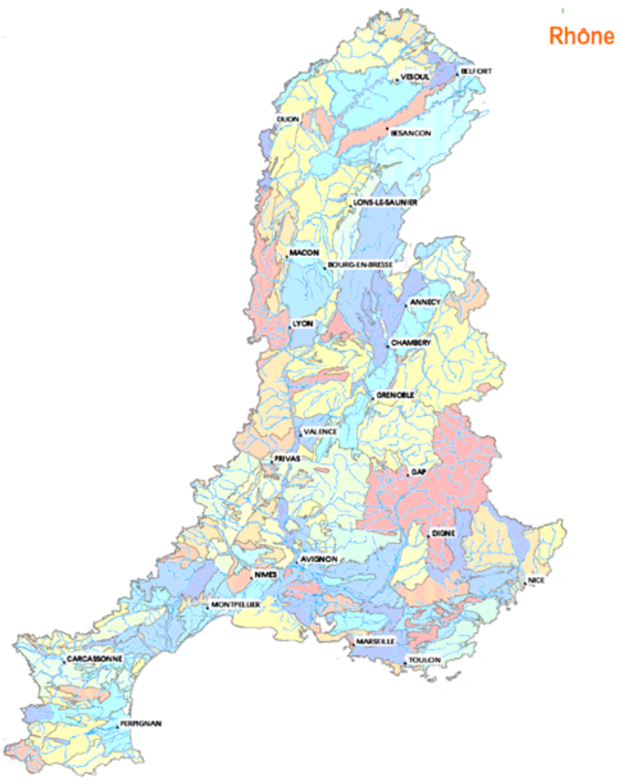
Seine et Côtiers Normands

Loire, Côtiers Bretons et Vendéens



Garonne, Adour et Côtiers de Charente

Figure 5 : Groundwater bodies in 3 hydrographic districts (Seine-Normandie, Loire-Bretagne, Adour-Garonne) Each colour represents a different water body. Scales can be seen on Figure 4

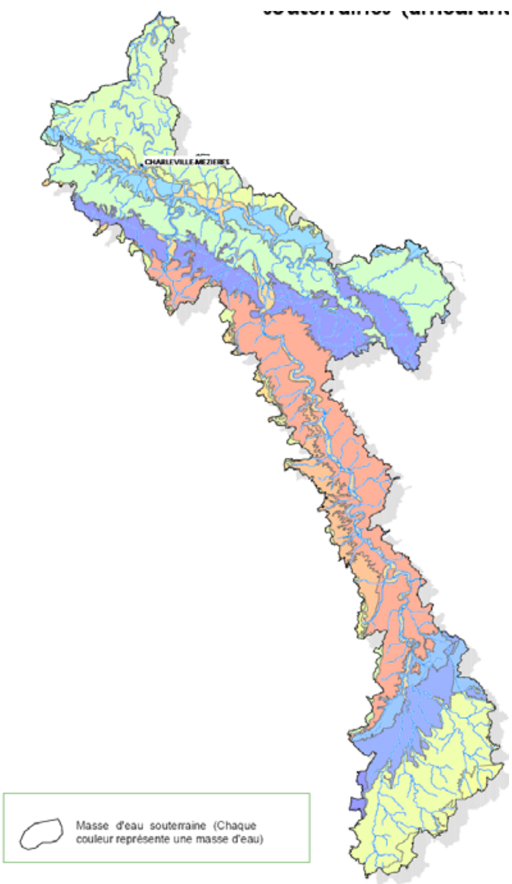


Rhône et Côtiers Méditerranéens

Rhin

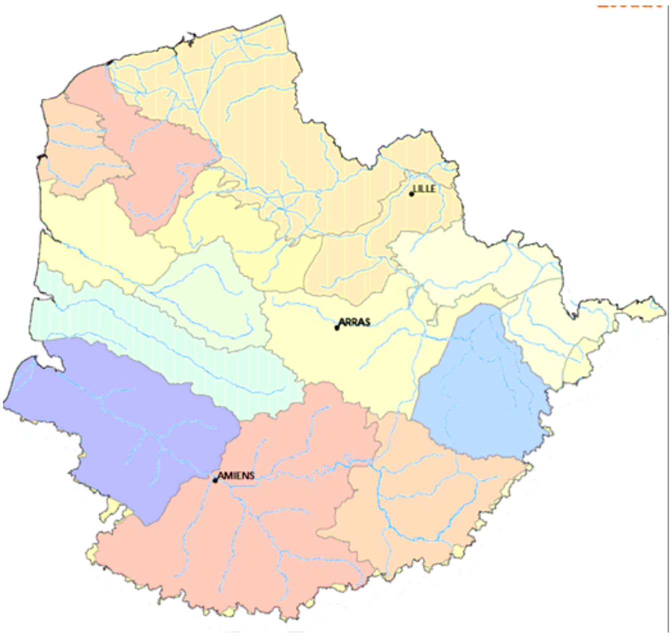
Figure 6 : Groundwater bodies in 2 hydrographic districts (Rhône-Méditerranée, Rhin)
Each colour represents a different water body. Scales can be seen on Figure 4

Sambre

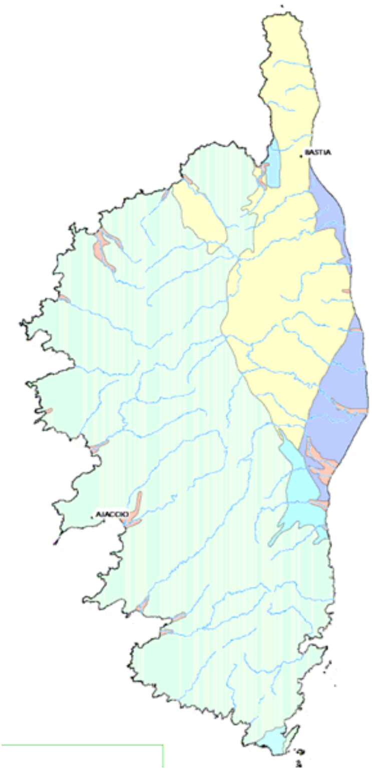


Meuse

Figure 7 : Groundwater bodies in 2 hydrographic districts (Sambre, Meuse) Each colour represents a different water body. Scales can be seen on Figure 4



Escaut et Côtiers Manche, Mer du Nord



Corse

Figure 8 : Groundwater bodies in 2 hydrographic districts (Escaut, Corse)
Each colour represents a different water body. Scales can be seen on Figure 4

Major hydrographic/hydrogeologic regions :

In very broad terms, France's hydrogeology can be described as belonging to the six major hydrographic basins (see Fig.3). Aquifers, of course, do not always follow the limits of river basins, which leads to problems and *inter-agency* working parties.

1. Northern France (Artois-Picardie, Escaut hydrographic districts) is well equipped with groundwater, at the surface the Chalk aquifer and at depth the Carboniferous Limestone aquifer, which is France's major cross-boundary aquifer, as its outcrops are in Belgium. Both aquifers are heavily exploited, because surface streams are few and heavily polluted due to past and present industrial activity (coal mines, metal works, wool and cotton, etc.). Concerning the Carboniferous Limestone, joint French-Belgian studies have shown that the majority of the water present at great depth in France actually comes from downward leakage from the overlying Chalk, and very little from the infiltration on the outcrops in Belgium. But a mixed French-Belgian committee organizes the management of this trans-boundary aquifer jointly.
2. The Paris Basin (mostly part of the "Seine-Normandie" hydrographic basin) is the largest sedimentary basin in France. It starts with Permian and Triassic and ends with Tertiary deposits. Vertically, at least seven aquifer layers can be found, the deeper of which are brackish. The most exploited ones (from bottom to top) are the Albian Sands (already mentioned in the introduction), the Chalk and several Tertiary layers, plus alluvia. The geological limits of the "Paris Basin" are very wide, at least for the Triassic layer: it includes the London basin, part of Germany, and goes all the way to Denmark. A large portion of this basin is included in the "Seine Normandie" hydrographic basin. To the east, in Bourgogne (Burgundy), there are karstified Jurassic limestone layers. In the Paris region, water demands have risen to the point where the low summer flow of rivers became insufficient. Large upstream reservoirs were built on the Seine and its tributaries, the Marne and Aube, and a smaller dam on the Yonne.
3. In Eastern France, the "Rhin-Meuse" hydrographic basin (Rhin, Sambre, Meuse), contains France's largest and most productive aquifer, the Rhine graben, which is filled with very permeable recent alluvia, with transmissivities of up to 10^{-1} m^2/s. It also includes a small portion of crystalline bedrock (Ardennes) and the edges of the Paris basin, in particular the Triassic "Grès Vosgiens" which is heavily exploited around Nancy.
4. In Central France, the "Loire-Bretagne" hydrographic basin, contains in its northern part the edges of the Paris basin, and in particular the Beauce limestone aquifer (Eocene-Oligocene), which is heavily exploited for irrigation. In the west lies Bretagne (Brittany), a region with an ancient crystalline bedrock. Groundwater resources are found in the weathered-fissured bedrock, and in local alluvial aquifers. For a long time, the resource was considered poor, but after the severe drought of 1976, and with the decrease of the cost of percussion drilling, a large number of wells were sunk and showed that the resource was very significant. For instance, the City of Rennes extracts, on a continuous basis, about 120 m^3/h from on single well field in Ploemeur. The major problem with groundwater in Bretagne is agricultural pollution, in particular by nitrates, both from fertilizers and from intensive pig farming and manure spreading. For this reason, groundwater protection has not been enforced in Brittany; surface water was intended to supply domestic needs with small dams constructed for storage. Unfortunately, the surface water is the outlet of the local aquifers, and it soon became heavily polluted with nitrates. France is under heavy pressure from the EU to improve the domestic water quality in Bretagne. To the south, the Massif Central is also a crystalline bedrock area with limited groundwater resources (weathered-fissured rocks and small alluvial deposits). Contrary to Bretagne, after the 1976

drought, no large groundwater resource was discovered in the bedrock, despite intensive drilling, perhaps due to different crystalline rocks or weathering and tectonic history. Tertiary and quaternary volcanic rocks can also be found in southern Massif Central with significant groundwater resources, often as alluvial palaeo-valleys covered with lava. In its southwestern part, the Paris basin extends over the “Seuil du Poitou” (which links crystalline Brittany with the crystalline “Massif Central”), at a depth of about 400 m, and is covered with Jurassic limestone extending to the Atlantic coast, forming large karstic aquifers, notably in the Charente area. They are heavily exploited. Finally, the Loire River flows from the crystalline south to the north, and then west to Nantes, with a broad alluvial plain along its course. On the Loire, large upstream reservoirs have been built to raise the summer flow and serve the nuclear power plant.

5. <u>South-Western France</u>, the “Adour-Garonne” hydrographic basin, contains France’s second largest sedimentary basin, the Aquitaine basin, heavily exploited in the Bordeaux area, especially the Eocene Sands. Again, up to five superposed aquifers exist, the deepest one being brackish. In the Dordogne region, east of Bordeaux, highly karstified systems exist, some of which have been used as shelters by man in pre-historic time (Lascaux, etc.). Along the coast, and in the south, the “Landes Sands” form a thick layer, whose groundwater is well exploited. In the east, the “Massif Central” is also present, with the same characteristics as in section on Central France above. Finally to the south, along the Pyrenees, groundwater resources are uncommon, the ground is clayey with low permeability, runoff is high, and surface water is the most common resource. Aquifers may exist at depth on, the southern edges of the Aquitaine basin, but they are not heavily exploited. There are alluvial aquifers along the Garonne and its tributaries. This is an area in Southern France of intensely irrigated maize crops, and groundwater would have been used extensively, if it had existed. But due to its absence, irrigation relies on surface water, with some large reservoirs also exploited for hydroelectric production, and very numerous small dams (“retenues collinaires”) built by farmers on their premises. However, locally exceptions exist, e.g., karstic systems in the Pyrenees.
6. <u>The south-east area</u>, the “Rhône-Méditerranée-Corse” hydrographic basin contains large karstic aquifers in the Jura Mountains, local and complex aquifer structures in the Alps, very productive alluvial aquifers along the Saône and Rhone Rivers, and France’s third sedimentary basin of the Southeast, which is not greatly exploited. Large limestone plateaus (Larzac, Cévennes, Montpellier and the Lez system, the famous Fontaine de Vaucluse, the Albion Plateau, etc.) have highly karstified aquifers. Along the Mediterranean coast, from east to west, the Côte d’Azur (Riviera) has poor groundwater resources, but ample surface water from the Alps; there are karstic limestone aquifers in the Marseille-Toulon area; the former Durance delta (Crau plain) is a rich alluvial aquifer, extending westward beneath the Camargue wetland, which is part of the present Rhone delta. Although the aquifers have large resources, they are not heavily exploited, given the availability of the Rhone surface water, whose flow is relatively high in summer, when fed by snowmelt in the Alps. Marine and alluvial aquifers exist along the Languedoc coast, including the over-exploited Astian sands, as well as local sandy systems. Finally, in the Roussillon area, towards Perpignan, significant groundwater resources are exploited in multi-layered alluvial plio-quaternary deposits. Karstic systems are also found. Corse (Corsica) is mostly crystalline, with low groundwater resources, except in the sedimentary Miocene plain in the east.
7. <u>DOM-TOM (overseas territories)</u> includes Guyane (Guyana), mostly crystalline, Nouvelle Calédonie (New Caledonia), sedimentary and volcanic, atolls in the Pacific (Tahiti…), and volcanic islands in the Atlantic Ocean (Guadeloupe, Martinique), and the Indian Ocean (La Réunion, Mayotte), which will not be discussed here.

<u>Hydrologic cycle per year in France</u> (from IFEN, 2004, including Corsica, but not overseas territories):

-479 000 million m^3: Total rainfall over France
-297 000 million m^3: Total actual evapotranspiration
-182 000 million m^3: Total internal flow
-18 000 million m^3: Total exportation of water towards France's neighbours, mostly to Germany, Luxembourg and Belgium
-11 000 million m^3: Total importation of water from France's neighbours (excluding the Rhine), mostly the Rhone from Switzerland and the Garonne from Spain.
-175 000 million m^3: Total water resources in France[4]
-100 000 million m^3: Total recharge of groundwater
98% flows into rivers, 2% flows directly to the sea
-75 000 million m^3: Total runoff water
-19 000 million m^3: Total withdrawal by man for energy needs
- 8 700 million m^3: Total withdrawal from surface water (except energy)
- 6 300 million m^3: Total groundwater withdrawal

<u>Aquifer recharge</u> :

In addition to the above figure of 100 000 million m^3/y (or 100 km^3/y), Margat (2006) provides a map of average "effective rain" in mm/y (equivalent to total internal flow) for 1970-1999. One interesting feature is that France can be divided approximately into two parts of similar surface areas, the north where rainfall is greater than the Potential Evapotranspiration, and the south where the opposite is true[5]. But southern France is not an "arid" country; even in the extreme south, there is direct recharge of the aquifers by effective rain, even in the driest parts, and not only indirect recharge from infiltration of runoff water in ephemeral streams, as happens e.g. in North Africa.

<u>Droughts</u>

Margat (2006) estimates that rainfall in dry years (average return time 10 years) is 330 billion m^3 (69% of normal).

Table 3 from INRA (2006) provides data for the major drought events, which have occurred in France since 1976 :

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[4] IFEN (2006) estimates the total water resource in France at 200 000 million m^3/y, without discounting exportation.

[5] When Rainfall exceeds Potential Evapotranspiration, on an annual average, this means that the overall need for water of the vegetation could be met without any additional input. Or that an open-surface reservoir will receive more rain than the water that evaporates. But if the storage capacity of the upper soil is poor, the vegetation may still need additional water in the summer months to transpire at or close to the potential rate. This is why irrigation is still required in northern France for crops like maize which need water during the generally dry summer months.

Type	1976	1979	1985	1986	1989	1990	1991	1992	1996	2003	2004	2005
Hydrologic								X				
Edaphic		X Mediterr.	X Centre & South	X Centre & South		X West & South	X North			X 2/3 of France		
Hydrologic & Edaphic	X North				X West				X North & West		X South	X 2/3 of France

Table 3 (INRA, 2006) Types of major drought events in France since 1976

Hydrologic drought: insufficient recharge in autumn and winter, leading to depleted reserves (rivers and aquifers) for the spring and summer
Edaphic (or agricultural) drought: insufficient rainfall in spring and summer leading to depleted soil reserves and insufficient water for the vegetation and agriculture

Volume of groundwater reserves :

Concerning the volume of groundwater stored in aquifers, the only available estimate was given by Margat (1986) at 2,000 km^3 for freshwater, plus 200 km^3 of variable reserves. This would translate into an average residence time of water in aquifers of 20 years, which is probably low, if deep aquifers are considered The World’s estimated groundwater reserves is 8,200,000 km^3, (Shiklomanov, 1999, Shiklomanov & Rodda, 2003), half of this reserve as freshwater and half as brackish water. Assuming a linear relation with the surface area of the country, France’s fresh groundwater reserves would be 17,000 km^3, equivalent to an average aquifer thickness everywhere of 310 m with a 10% porosity, which is certainly too large. This would translate into an average residence time of water in aquifers of 170 years. Having another half of the groundwater reserves brackish does not seem unreasonable, given that many deep sedimentary basins (Paris, Aquitaine and South-East basins) do indeed contain brackish water at depth, mostly due to the presence of evaporites. But these numbers are highly speculative.

Surface storage

Reservoirs have been built mainly for hydroelectric production and to sustain summer flows for nuclear power plant cooling, as well as for flood control and sustaining summer flow, in the Paris area. Their total capacity is 12 km^3 but they can yield 15 times more per year, as in other temperate climate areas. For comparison, Spain has a cumulated reservoir capacity of 54 km^3, but can yield only twice that amount, due to its Mediterranean climate. 75% of France’s reserves are operated by EDF, the public electric utility, but also used for other purposes downstream. For comparison, the total volume of freshwater lakes in France is estimated at 43 km^3, including the French part of the Lake of Geneva; the volume of mountain ice in France is estimated at 17 km^3.

Inundations

One problem worth mentioning here is the inundations that occurred in 2001 in the Somme region in Northern France, in the Chalk. The cause of the inundation was the rise of the groundwater table, due to several years of unusually high recharge. It took several months before the situation returned to normal.

4. GROUNDWATER USE IN FRANCE

4.1 Groundwater and surface water withdrawal

Table 4, from IFEN (2004, 2005) provides the total surface water and groundwater withdrawal for the year 2001-2002; the last line is an estimate made here of the amount of water that is actually consumed and not released to the hydrographic network, ready to be re-used farther downstream[6]. Table 5 from the BRGM provides slightly different figures, with a split between hydrographic basins.

Withdrawal	Municipal water supply	Industry (self supply)	Irrigation	Energy production [7]	Total
Surface water	2 600	2 300	3 800	19 000	8 700 + 19 000
Groundwater	3 700 (59%)	1 500 (24%)	1 100 (17%)	19 (~0%)	6 300 (100%)
Total	6 300	3 800	4 900	19 000	34 000
Estimated amount of water consumed	10% 630	15% 570	75% 3 675	2% 380	15% 5 255

Table 4 (IFEN, 2004, 2005) : Total withdrawal in France for the year 2001-2002, surface water and groundwater, in million m^3 and % per activity of the groundwater withdrawal

Water use Hydrographic basin	Municipal water supply	Industry (self supply)	Irrigation	Energy production[7]	Total
Adour-Garonne	700 (38%)	590 (22%)	780 (34%)	340 (0%)	2410
Artois-Picardie	360 (88%)	270 (41%)	26 (94%)	2 (17%)	658
Loire-Bretagne	1000 (55%)	210 (34%)	620 (71%)	2 450 (0%)	4280
Rhin-Meuse	380 (85%)	880 (49%)	64 (93%)	3 610 (1%)	4934
Rhône-Méditerranée-Corse	1 740 (73%)	1130 (52%)	990 (11%)	11 810 (0%)	15670
Seine-Normandie	1 690 (53%)	750 (32%)	74 (93%)	990 (0%)	3504
Total	5 870 (62%)	3 830	2 554	19 202	31456

Table 5 from BRGM-Agences de l'eau (2000) : Water withdrawal per Hydrographic basin, in million m^3/y and % of groundwater. These figures are from a different year than in Table 4, 2000 and 2001-2002, respectively

[6] One must also keep in mind that about 98 % of water used for energy is not consumed, but goes back to the hydrologic system, both for hydro-electricity (evaporation from dams goes back to the atmosphere and not to the hydrologic system, it is on the order of 2%) and thermal plant cooling. For domestic use, this figure is 90%, for industry, 85%, but for agriculture in France, around 25 % through losses during transportation in canals, and induced infiltration in the aquifers (the losses in the atmosphere do not go back to the hydrologic system). These figures come from Académie des Sciences, 2006, and from EU Water saving potential (Part 1 –Report for the European Commission) ENV.D.2/ETU/2007/0001r, 19 July 2007, Ecologic - Institute for International and European Environmental Policy, Berlin, Germany.

[7] These withdrawals for energy production do not include brackish water withdrawals for power-plant cooling (as in the Gironde estuary) nor seawater withdrawals along the coast.

Figs.9, 10, 11 (IFEN, 2004) provide a distribution of water withdrawals in France, of both surface water and groundwater, for municipal use, industry, and irrigation. It can be seen that the major groundwater extraction zones are located in the North, the East, Centre, Southwest and along the Rhone valley.

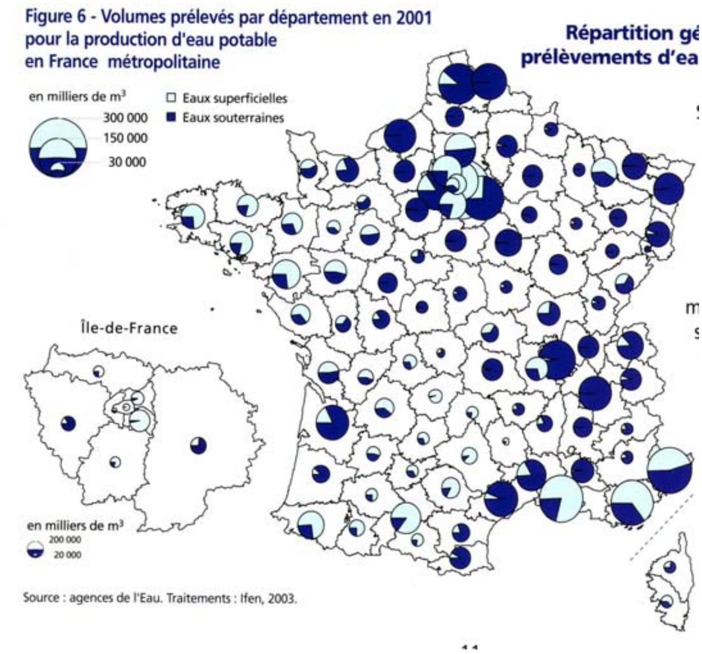

Figure 9 : Withdrawal Volumes in France per Département in 2001 (IFEN, 2004)
Drinking water: white = surface water, blue = groundwater

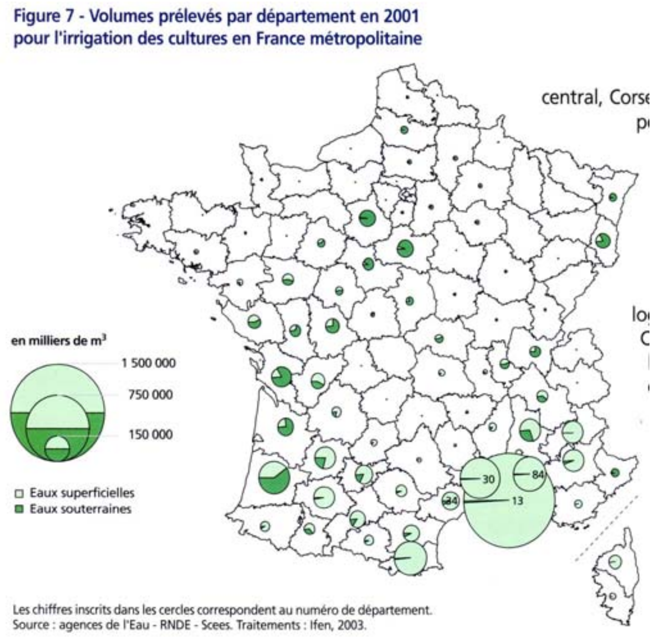

Figure 10 : Withdrawal Volumes in France per Département in 2001 (IFEN, 2004)
Irrigation water: white = surface water, green = groundwater

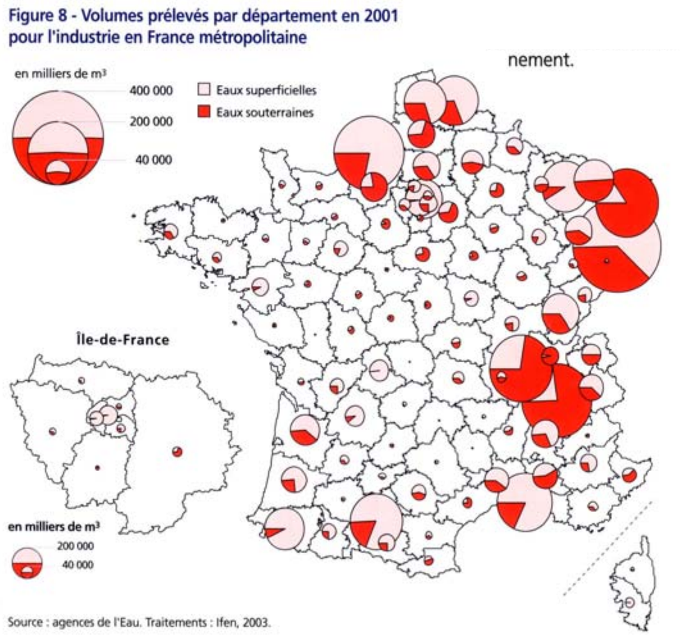

Figure 11 : Withdrawal Volumes in France per Département in 2001 (IFEN, 2004)
Industrial water: white = surface water, red = groundwater

Tables 4 and 5, by different authors, and for different years, agree relatively well for groundwater withdrawal (see Table 6), but not for surface water :

Estimates	Municipal	Industry	Irrigation	Energy	Total
GW, IFEN, 2004	3 700	1 500	1 100	19	6 300
GW, BRGM-AE, 2000	3 622	1 571	967	36	6 196
SW, IFEN 2004	2600	2300	3800	19 000	8 700 + 19 000
SW, BRGM-AE, 2000	2 641	2 259	1 587	19 164	6 487 + 19 164

Table 6 : Water withdrawal in France, in million m^3/y, comparison of data from IFEN, 2004-2005, and BRGM-Agences de l'Eau, 2000
GW : Groundwater – SW : Surface water

It is thus clear that these numbers are not well known, and vary significantly between authors. For instance, the total water use (SW+GW) for France from the EU (Ecologic, 2007) for 2002 is :

Estimates	Municipal	Industry	Irrigation	Energy	Total
IFEN, 2004-2005	6 300	3800	4 900	19 000	34 000
EU, 2007	5 812	3 583	3 120	18 488	29 820

Table 7 : Comparison of IFEN and EU total water withdrawal in France, million m^3/y

Finally, The Ministry of Health gives in 2006 (see section 7.2) slightly different figures for municipal water supply in France : 35,000 withdrawal points (4% for surface water, 96% for groundwater), with an annual production of 6 588 million m^3/y, 33% from surface water and 67% from groundwater.
However, Barraqué (2004) cautions that "*On the one hand there has been a reduction of water demand for all uses in the last decade. However, the statistics for water use in agriculture are usually grossly underestimated, since they are built on official estimates for the payment of water*

levies, and farmers underestimate their withdrawals, all the more so as they are only now in the process of installing meters. Note that the percentage of potable water originating from groundwater has been growing steadily since the early 1970s, because aquifers used to be less contaminated by agriculture. It is now about 50/50". Another word of caution must be said for withdrawals in alluvial aquifers: these are indeed groundwater withdrawals, but when they occur along major rivers like the Seine, the Rhone, the Rhine, the Loire or the Garonne, the water comes, in fact, indirectly from the river, by bank infiltration, and is not, for the most part, the result of direct aquifer recharge. It should therefore be considered as river water rather than recharge from groundwater.

Table 8 and Fig. 12 (From Margat, 2006) show the locations of major aquifer withdrawals in France, in decreasing order, at the end of the 1990s.

Rank	Aquifer	Hydrographic basin (see footnote 2 p. 4)	Withdrawal Million m^3/y
1	Alsace, Rhine alluvial aquifer	RM	500
2	West Aquitaine plio-quaternary water-table aquifer in the Landes[1]	AG	100
2'	West Aquitaine multilayer confined aquifers of the Oligocene, Miocene (100), Eocene (75), Cretaceous and Jurassic[2]	AG	250-350
3	Chalk aquifers in Northern France (Calais-Lille, Cambrai, Valencienne)[6]	AP	360
4	Lyon Plain, Rhone alluvial aquifer[6]	RMC	300
5	Moselle Uplands, Jurassic Limestone aquifer[3]	RM	225
6	Chalk aquifer in Seine Maritime depart., and lower Seine alluvia[4]	SN	200
7	Soissonnais sands, Tertiary "Calcaire Grossier", Eocene multilayer aquifer in the Paris Region and Northern Ile de France[7]	SN	180
8	Alluvial aquifer, Isère valley, Grenoble area	RMC	180
9	Confined lower Triassic Sandstone, Lorraine[5]	RM	160
10	Limestone water-table aquifer of Beauce[6]	LB+SN	160
11	Alluvial Rhone valley, Comtat, Aigues-Sorgues, Orange[6]	RMC	150
12	Alluvial Rhone valley, Vienne to St Rambert d'Albon[7]	RMC	100
13	Alluvial Aquifer + Chalk, Seine valley, Mantes to Vernon	SN	90-100
14	Chalk aquifer in Picardie, Somme valley	AP	90
15	Roussillon, multilayer alluvial Plio-quaternary aquifer[6]	RMC	80
16	Chalk aquifer, Pays d'Othe	SN	60
17	Chalk aquifer, Northern Champagne	SN	50
18	Alluvial aquifer, Provence, Crau plain[6]	RMC	50
19	Alluvial aquifer, lower Var valley	RMC	50
20	Volcanic aquifers, les Puys chain, Auvergne	LB	40
21	Champigny Limestone aquifer, Brie, Paris basin	SN	35
22	Karstic aquifers of Languedoc, lower Cretaceous and upper Jurrassic limestone, North of Montpellier (Lez system)	RMC	35
23	Alluvial aquifer, Rhone valley in the Gard, RB, lower Gardon valley	RMC	30
24	Alluvial aquifer, Saône-Doubs plain	RMC	30
Notes			
1	Total withdrawal in the Landes : 130, 100 form 2 and 30 from 2'		
2	Total withdrawal in Gironde : 150		
3	Decreasing trend due to the closing of the iron mines		
4	Strong decrease since the 1970s due to decrease of industry withdrawal		
5	Future trend of decrease due to the closing of coal mines : 50 towards 2010-2020 ?		
6	Increasing trend		
7	Decreasing trend		

Table 8 (Margat, 2006) Major groundwater withdrawal in France per aquifer, at the end of the 1990s, in million m^3/y, in decreasing order (see Fig. 12 for location)

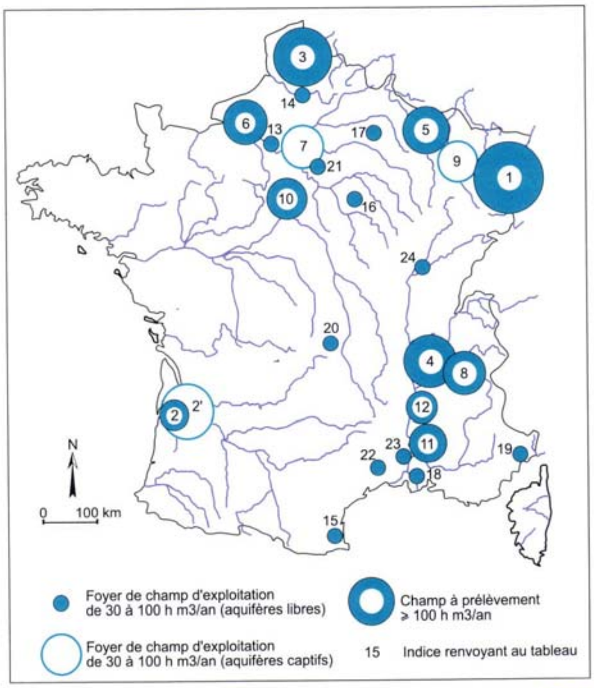

Fig. 2

Principaux champs d'exploitation d'eau souterraine en France.

1 - Foyer de champ d'exploitation de 30 à 100 hm3/an (aquifères libres)

2 - Foyer de champ d'exploitation de 30 à 100 hm3/an (aquifères captifs)

3 - Champ à prélèvement ≤ 100 hm3/an

4 - Indice renvoyant au tableau 1.

Figure 12 (Margat, 2006) Location of the major groundwater withdrawal zones in France, see Table 8 for numbers.

Table 9 (Margat, 2006) provides an estimate of the percentage of withdrawal per aquifer with respect to their average recharge, where the overdraft cases can be seen. Only a few aquifers are over drafted at present.

Aquifer system	Hydrographic basin (see footnote 2 p. 5)	Area km²	Average flux Million m^3/y	Withdrawal Million m^3/y	Withdrawal rate %
Multilayer Aquitaine system, Landes sands[a]	AG	13 000	1 400	~100	~7
Miocene sands and limestone		~15 000	210	~100	~50
Lower Eocene and “infra-molassic” sands		50 000	130	85	65
Chalk aquifer, Lys-Dunkerque	AP	630	100	~50	50
Chalk aquifer, Deule-Scarpe		1 105	100	95	95
Chalk aquifer, Somme basin		5 670	1 030	~90	9
Carboniferous Limestone, confined in France, Unconfined in Belgium		1 582	125[b]	25 (France) 110 (total)	88
Beauce Limestone, mostly unconfined	LB	6 000	465	160	34
Confined Cenomanian sands, Touraine sands	+	25 000		20	
Puys chain volcanic unconfined aquifer	SN	260	110	40	36
Rhine alluvial aquifer, Alsace	RM	2 600	~1 000	500	50
Unconfined Jurassic Limestone, Meuse uplands		1 500	300	~15	5
Unconfined Jurassic Limestone, Moselle uplands		3 300	600	225[c]	37
Confined lower Triassic sandstone, Lorraine		20 000	50	160[c]	320
Rhone alluvial aquifer, Lyon plain	RMC	480	140[d]	~300	215
Rhone alluvial aq., Comtat plain, Aigues-Sorgues		530	165	1 500	90
Crau alluvial aquifer		520	200[e]	50	25

Plio-quaternary multilayer Roussillon aquifer Karstic aquifer, Vaucluse plateau Karstic aquifer, Grand Causse (RMC+AG) Karstic aquifers, north of Montpellier, Lez syst.		950 1 230 4500 707	~60[f] 600 ~2 000[g] 160	80 ~0 ~0 41[h]	130 ~0 ~0 25
Confined Champigny Limestone, Brie Eocene multil. sands of Soissonnais, Calc. Gross. Confined Albian green sands, Paris basin centre	SN	3 500[i] 700 25-30 000	630 95 25	35 ~180 18	18 ~190 72
Notes a : this layer is recharging by leakage the underlying layers, more exploited in these lower layers than in the Landes sands themselves b : 35 induced by leakage c : including mine withdrawal d : plus 160 induced from the withdrawal (taken to the Rhone River) e : including 140 of recharge from irrigation f : including 18 from the confined Pliocene g : 1 365 in AG, 635 in RMC h : 2000 value					

Table 9 (Margat, 2006) Average natural recharge of aquifers, withdrawal and exploitation ratio in % of recharge

An important point is that nowhere is there a mention of the water (surface water or groundwater) used by natural ecosystems, and wetlands. The need of water for these ecosystems is understood, but apparently, no one has tried to quantify this need.

As a final remark, irrigation therefore appears as the major **consumer** of both surface and groundwater in France, which is the case in the majority of the World (Table 4, irrigation is 81% of all water consumed or 71% all of groundwater consumed in France). We will therefore provide more data on irrigation use.

4.2 Irrigation data

Irrigation water, which is of major importance in the Southern part of France, mostly comes from surface water, whereas in the North, irrigation is provided mainly by groundwater. This is in contrast to Spain, for instance, where irrigation water in the South is mostly taken from groundwater. Two reasons explain this difference:

-The major rivers in the South: e.g., the Rhone, the Durance, the Garonne and its tributaries receive melt water form the Alps and the Pyrenees or have very large dams upstream in the mountains that maintain their flow-rates in summer. The surface water resource is thus relatively abundant.

-In the 1950s, France invested heavily in the equipment of irrigation systems in the South. They were implemented by three major National Development Companies[8], and provide ample surface water to farmers for irrigation as well as municipal water to cities and supplies to industry. The water comes from big dams (Canal de Provence and Côteaux de Gascogne) or directly from the Rhone, whose flow is large in summer. Water shortages in southern France are therefore very rare or inexistent on the Côte d’Azur (Riviera,

[8] Compagnie du Canal de Provence, for south-east France, Compagnie Nationale d’Aménagement du Bas-Rhône-Languedoc, for southern France west of the Rhone, Compagnie d’Aménagement des Côteaux de Gascogne, for the south-eastern zone of the Pyrenees. The Compagnie Nationale du Rhône was also created along the Rhone River for hydro-electric development. Previously, XVII[th] century irrigation canals had already been built in the Rhone-Durance valley (Canal de Crapone) and extended in the XIX[th] century.

although new water transfers from dams are planned, as the resource is decreasing and the demand increasing), in the Rhone valley and the Languedoc, where the equipment is even used much below capacity. Only in the Pyrenees is the available irrigation water below demand, which has triggered plans to build a new dam in this area, the controversial Charlas site on the Garonne system, which is still under debate, as the economics of maize production can hardly justify the cost of building the equipment. Environmental objections to the dam are also significant.

Detailed irrigation data are given by INRA (2006), Table 10. They rigorously match the IFEN (2004) data for the totals.

Hydrographic Basin	Rhône-Méditerranée-Corse	Adour-Garonne	Loire-Bretagne	Seine-Normandie	Rhin-Meuse	Artois-Picardie	Total
Withdrawal:							
-surface	2 813(93%)	671(65%)	154(30%)	9 (8%)	9 (11%)	1 (4%)	3 657
-groundwater	196(7%)	361(35%)	351(70%)	107 (92%)	71(89%)	24 (96%)	1 110
-total	**3009**	**1032**	**505**	**116**	**80**	**25**	**4 867**

Table 10 : Withdrawal for irrigation in France per hydrographic basin, for 2001, in million m^3/y (INRA, 2006)

Figure 13, from INRA (2006) shows the types of crops on irrigated land for the year 2000 (for a total slightly above 1.5 million ha). It can be seen that one half of the surface area is taken up by maize. Figure 14 from INRA (2006) also gives the evolution from 1955 to 2000 of the irrigated surface area in France (1.5 million ha in 2005 out of about 2.7 million ha that are suited to irrigation), the number of irrigating farmers (90 000 in 2005) and the evolution of irrigated maize. It is also stated that 60% of the irrigated surfaces are private, 22% are operated by Authorized Syndicates of users, and 18% by regional Development Companies, see footnote 8 page 21.

Table 11 from INRA (2006) provides the regional distribution of irrigation in France, but unfortunately using administrative regions, and not the 6 hydrographic basins. For clarity only, we try to indicate within brackets the hydrographic basins (by their initial, see footnote 2 p. 4 and Figures 5-8 p.8-11) corresponding approximately to each administrative region in the table.

Regions (initials of corresponding hydrographic basins, see footnote 2 p. 4	Irrigation water consumed (not withdrawal)	Irrigated surface area (thousand ha)	Average input (mm)	% of maize in irrigated area	% of fruit & vegetables in irrigated area
Poitou-Charente (LB)	234.7	169	139	79	3
Aquitaine (AG)	409	278.7	147	74	17
Midi-Pyrénées (AG)	362	269.3	135	70	8
Provence-Alpes-Côte d'Azur (RMC)	616.9	115	537	6	33
Languedoc-Roussillon (RMC)	238.8	64.8	369	8	44

Table 11 (INRA, 2006) Irrigation diversity per region

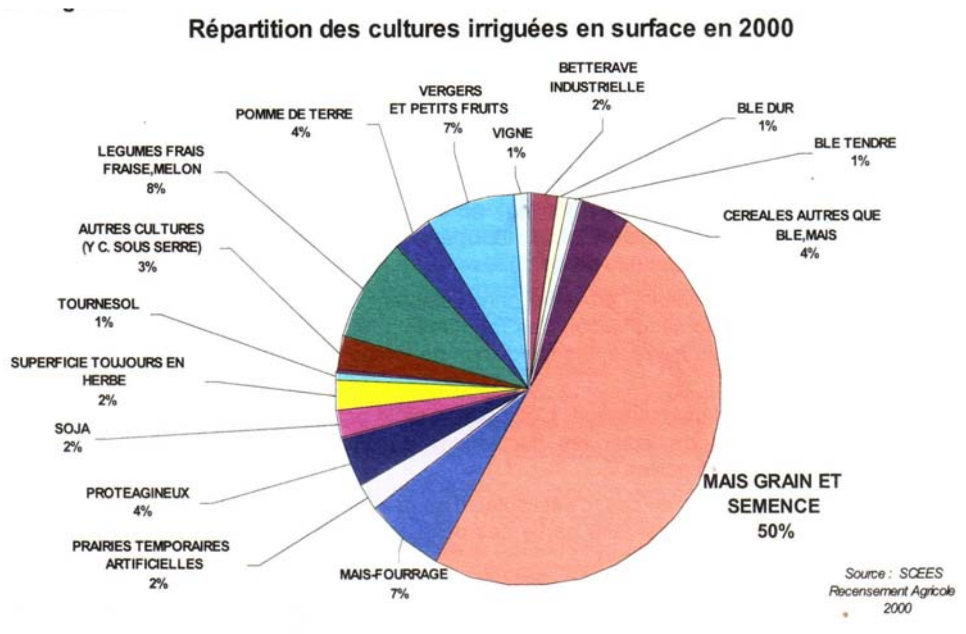

Figure 13 : Distribution of irrigated surfaces in France in 2000, per crop type, INRA (2006)

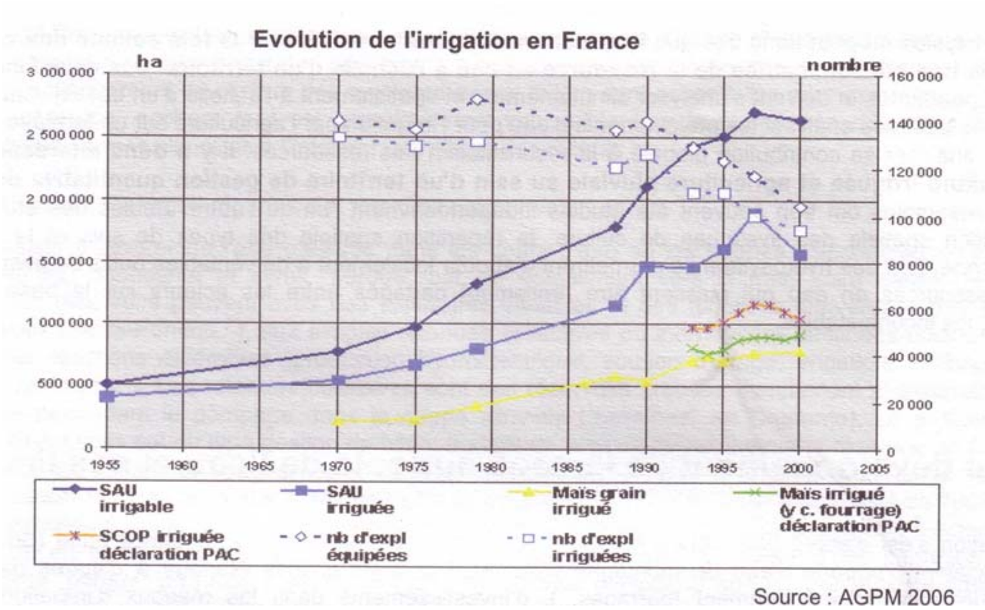

Figure 14 : Evolution of irrigation in France, 1955-2005, INRA (2006)

5. ECONOMIC VALUE OF THE VARIOUS GROUNDWATER USES

5.1 Urban water supply

Table 12 lists the income and expenses of the municipal water services, per hydrographic basin, together with a range of the water price paid by the consumer.

Basin	Popul. Million	Water bill	Grant	Total	Operat. costs	Capital used	Total	Mean water price, €/m^3
Escaut	4,5	518	121	639	364	235-484	599-858	2,99
Meuse Sambre	0,47 0,2	42	4,7	46,7	25,5	26,7-53	52,2-78,5	2,54 2,98
Rhin Moselle	1,724 1,981	374	33,7	407,7	270	221-442	491-712	2,52
Seine-Normandie	17,25	2812	727,6	3539,6	2230	841	3071	2,93
Loire-Bretagne	11,84	1510	50	1560	1164	943-1871	2107-3035	2,80
Rhône-Méditerra.	13,6	2579	85	2664	2029	885-1771	2914-3800	2,52
Adour-Garonne	6,66	1000	50	1050	779	550-1136	1329-1915	2,78
Corse	0,265	55	1	56	44	25-49	69-93	2,73
Total	58,49	8890	1073	9963	6905,5	3726,7 6647	10632,2 13552,5	2,75

Table 12 (From Ministère de l'Ecologie, 7/4/2005, WFD, Recouvrement des Coûts) Cost recovery, in Million € HT, for water and sanitation for municipal public services, around year 2000, paid by the consumer or grants by Water Agencies, operational costs (maintenance, personnel, financial costs), and a range of the annual fixed capital consumption (based on capital inventory and min/max lifetime of equipments).

5.2 Rural domestic water supply

No data found. The Direction Générale de la Santé (Ministry of Health, Health General Directorate) might have some data for individual domestic wells.

5.3 Bottled water and spas

France is a rich country in terms of bottled water and Spas, essentially coming from groundwater. The French legislation recognises three categories of bottled water :

-(i) mineral water, which is a label only given by the French Academy of Medicine to a small number of natural springs, whose water is recognized as having a positive effect on human health. The most famous brands are : Evian, Perrier, Vittel, Contrexeville, Badoit, Salvetat, Volvic, etc. They must also meet stringent conditions (e.g. constant quality throughout the year, constant temperature, excellent natural protection of the "impluvium" (the area where the aquifer is recharged), absence of any faecal contamination, etc. But these waters do not need to meet the drinking-water criteria imposed on domestic water supply, in particular, in terms of solute content. Some are excessively mineralised or have excessive contents of e.g., arsenic or fluorine. These waters cannot be treated, except for removal of “unstable” elements (in general iron and manganese, which are removed by simple treatment with air and precipitation plus filtration). However, very recently, and under the pressure of the EU, a new legislation authorises removal of “undesirable” elements, such as arsenic and fluorine, if their concentrations are excessive. The authorisation and the method to use are approved by the Ministries of Health and of Industry. These waters can contain CO_2, always produced by the same spring, separated from the water during the air treatment, and re-injected into the bottles. In 2005, France used 4,500 million litres of Natural Mineral water.

(ii) spring water, which is also a natural water with protected “impluvia”, constant quality throughout the year, no faecal contamination, but, contrary to mineral water, they must meet the drinking-water standards without treatment, except the removal of “unstable” elements and recently, “undesirable” elements. In 2005, France used 3,200 million litres of Spring Water.

(iii) bottled water made drinkable by treatment. Any water that meets the drinking-water standards can be bottled and sold. However, such waters, which are very popular in the US, UK and many other countries (e.g. water produced by double reverse osmosis and artificial addition of minerals), are very unpopular in France, as their taste is considered horrible ! On the contrary, many French people select their bottled water because of their taste rather than for their quality or beneficial effect on health.

Fig.15 from (Roux, 2006) presents a map of the major thermal and mineral establishments in France, and Fig. 16 the evolution of bottled-water production from 1972 to 2005.

In 2004, the total production of bottled water was 9.7 billion litres (6.61 mineral and 3.09 spring), with (for mineral) 4.41 domestic, and 2.2 exported, and (for spring water) 2.61 domestic and 0.48 exported. However, since 2007, the central management of mineral water has been discontinued, the authorisations are given at the local level, and the statistics may become unavailable.

5.4 Irrigation water

Rieu and Terreaux (2001) propose the following table for the cost of irrigation water

Case	Withdrawal Method	Total cost, €/m^3
Beauce aquifer	Individual	0.081
River with severe low flow (Drôme)	Individual	0.056
River with severe low flow (Drôme)	Collective	0.224
River with artificially increased low flow (Arros)	Collective	0.146
Small dam (Sologne Est)	Collective	0.366

Table 13 (from Rieu & Terreaux, 2001, adapted from Gleyses, 2000)
Total cost at the water supply point per m^3 depending on the withdrawal method (French Francs 2000 converted into €). Total cost includes capital cost, operation and maintenance costs, but not externalities due to the withdrawal.

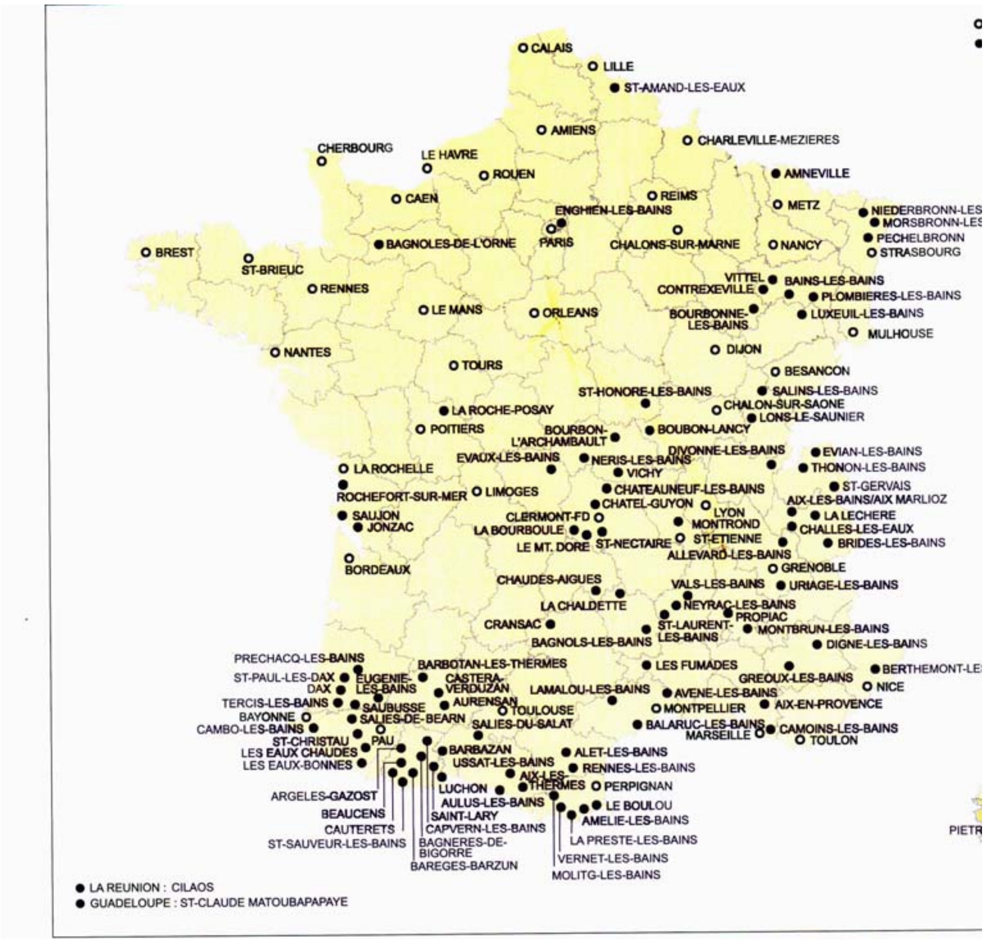

Figure 15 Locations of major mineral and thermal natural springs in France, from Roux, 2006, page 856

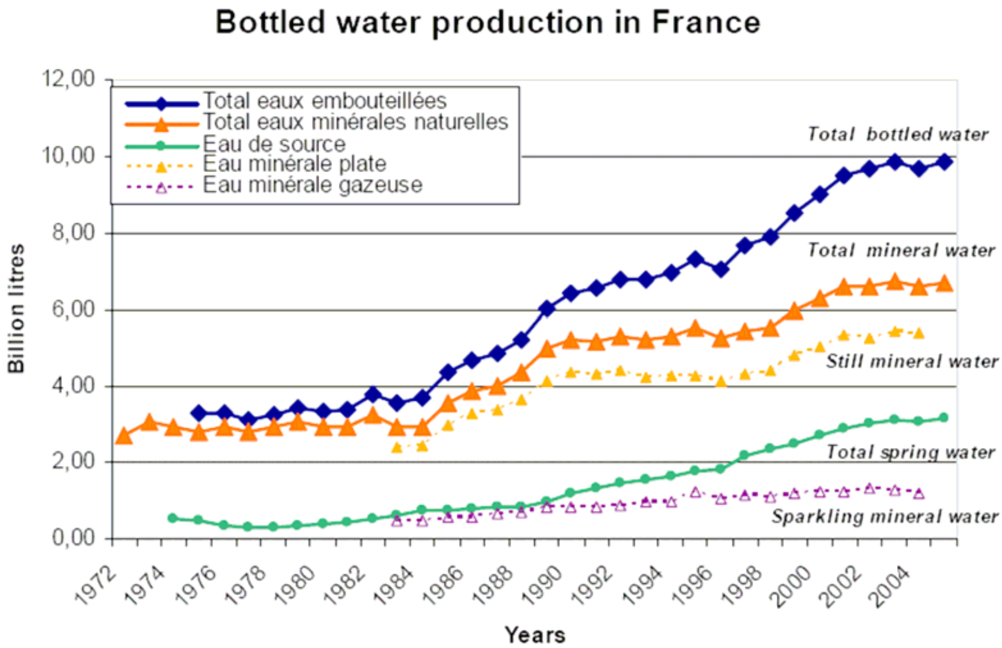

Figure 16 (From Chambre Syndicale des Eaux Minérales) Bottled water production in France, 1972 to 2005

An analysis has been made by the CEMAGREF of the relation between water cost and use, for the Beauce aquifer (Table 14).

	Reference Volume (m^3/ha)		
	1 650	1 285	918
Water cost in €/m^3	Consumed Volume (m^3/ha)	Consumed Volume (m^3/ha)	Consumed Volume (m^3/ha)
0.008	1 350	1 179	918
0.015	1 305	1 179	873
0.030	1 197	1 116	864
0.046	1 161	1 089	837

Table 14 : Water consumption (m^3/ha) as a function of water price (French Francs 2000, converted into €) and of the reference volume (m^3/ha), for maize and crops with contracts, for the Beauce aquifer. From Morardet et al., 2001. The reference volume is the amount of water allocated by the regulator to the farmers of a given region.

INRA (2006) also provides some numbers for the cost of irrigation, which is said to be extremely variable :

35-80 €/ha for sorgho
43-106 €/ha for soja
84-143 €/ha for maize

These costs represent about 12 to 20 % of total exploitation costs, estimated at 1 000 €/ha for the Midi-Pyrénées Region. The withdrawal tax imposed by the Water Authorities is only 2 to 8 % of the total cost. Irrigation costs also vary with the type of irrigation used (Table 15).

Type of irrigation system	Fixed costs (based on a rate of 4 m^3/h.ha used)	Idem	Volumetric cost	Total cost for 3000 m^3/y	Idem
	Mean	Variation		Per ha	Per m^3
By gravity	183 €/ha	+/- 76 €/ha	0	183 €/ha	0.061 €/m^3
Pressurized, collective	107 €/ha	+/- 46 €/ha	0.076 €/m^3	335 €/ha	0.111 €/m^3
Individual withdrawal	122 €/ha	+/- 21 €/ha	0.009 €/m^3	149 €/ha	0.05 €/m^3

Table 15 (INRA, 2006) Irrigation costs, Rhône-Méditerrannée-Corse basin

5.5 Industry

No data found

5.6 Ecosystem conservation

Barnaud and Fustec (2007) provide the following Table 16 on the surface areas of water meadow wetlands in metropolitan France (total of 440 000 ha). The total area of wetlands is not well known, the inventory is not yet completed, but is estimated at around 1.5 million ha.

Wetland type	**Zone**	**Surface area, 1000 ha**
Coastal marshes	**Manche** Marais d'Opale (4.8), Canche-Authie (4.1), bay and low valley of Somme (2), Lower Seine and Risle (12.2), Calvados coastal rivers (1.9), Carentan Marshes (34.1), Cotentin East Coast (1), Lessay land (1.1)	**61**
	Atlantic Vilaine marshes (3.1), Loire, Brière and Grandlieu estuary (17.8), Brittany marshes (29.1), Poitou Marshes (28.9), Charente marshes (18), Gironde estuary (6.2)	**103,2**
	Total	**164.4**
Major alluvial Plains	**Artois Picardie** Aa and Lys (2), Scarpe-Escaut (3.3), Avesnois (10.3),	**15.6**
	Rhin Meuse Downstream Meuse (3.3), Middle Meuse (1.2), Upstream Meuse (1.3), Bar (1.3) Seille (3), Nied (3.1)	**13.1**
	Seine-Normandie Béthune and Yères (1.1), Avelon (1.7), Middle Oise (3.8), Rognon (1.9), Upper Sarthe and Orne (3.2)	**11.7**
	Loire-Bretagne Lower Loire (6.1), Lower Anjou valleys (5.3), Loir (2.2), Huisne (2.3), Sarthe (1.1), Middle Loire (1), Indre (0.9), Arnon and Cher (1), Bourbon Loire (11.9), Allier (2.4)	**34.1**
	Rhône-Méditerranée-Corse Upper Saône (8.4), lower Saône (9.5), Doubs (1.5), Drugeon (3.3), Seille and tributaries (7.8), Dheune (1.6)	**32.1**
	Adour-Graonne Charente and Boutonne (1.4), Isle and Dronne (3.8), Adour (1.7), Nivelle and tributaries (2.1)	**9**
	Total	**115.5**
Mediterranean wetlands	Camargue (16.5) Languedoc-Roussillon (25) **Total**	**41.5**
Other marshes and alluvial sectors	Outside Nat. Observatory of wetlands Estimation : 20 x 6 hydrographic basins **Total**	**120**
	Total	**440**

Table 16 (From Barnaud and Fustec, 2007)
Estimates of water meadow wetland surface areas in France (1000 ha)

Furthermore, the same authors provide an estimate of the average economic value of wetlands, in US $ (2000) per ha and per year (Table 17), based on Schuyt and Brander (2004), estimated from 89 sites on several continents.

Function	Average economic value
Recreation	**492**
Flood control	**464**
Sport fishing	**374**
Water purification	**288**
Biodiversity	**214**
Habitat / nurseries	**201**
Leisure hunting	**123**
Water resources	**45**
Gravel extraction	**45**
Wood / energy	**14**

Table 17 (From Barnaud and Fustec, 2007, adapted from Schuyt and Brander, 2004) Average economic value of wetlands in US $ (2000) per ha and per year.

If we assume a surface area of 1.5 million ha of wetlands in France, and an average value of 226 $/ha.y, taking an exchange rate of approximately 1$=1€ for 2000, we obtain around 345 million € for the economic value of France's wetlands.

If we assume a water consumption of these wetlands of 1,000 mm/y, the amount of water required by the 1.5 million ha of wetlands is on the order of 15,000 million m^3/y.

6. PRESSURES, IMPACTS AND MEASURES TO ACHIEVE THE GOALS OF THE WATER FRAMEWORK DIRECTIVE

Not discussed here, see 7.

7- DESCRIPTION OF MAJOR NEGATIVE INFLUENCES OF GROUNDWATER EXTRACTION

7.1. Diffuse pollution from agriculture

The major problem for groundwater in France is diffuse pollution from agriculture. This phenomenon used to be partly overlooked, because the sampling points were usually abstraction points, and the most polluted ones were abandoned and replaced by cleaner ones. This led indirectly to an underestimate of the progression of contamination by diffuse pollution. Following the 1992 Water Law and instructions from the European Environmental Agency (in charge of harmonising environmental statistics in the EU), France set up a National Network of Water Data, RNDE, with a specific chapter on groundwater, RNES. When fully developed, this sub-network should have 1,400 sampling points covering the 750 different aquifers or sections of aquifers (IFEN, 2002). But today, there are still almost no sampling points in Adour-Garonne and not many in Loire-Bretagne and Rhône-Méditerranée-Corse. Concerning nitrates, there are 927 points with data for 2000, and a comparison with previous years shows a steady increase: between 1993 and 1998, the average concentration rose by 5 mg/l. The most worrying aspect is that the concentrations rose more at the sampling points that were above 40mg/l, while the European maximum drinking-water standard is 50 mg/l.

In 1999, 2000, 2001, 692 sampling points could deliver useful data on pesticide contamination, and 75% of them could trace one or more of 86 substances among the 259 that were searched for. 41% of the points had levels high enough to justify a treatment before drinking-water is distributed (IFEN, 2002). At less frequently sampled points, arsenic and nickel were found at levels above the threshold values. If agriculture is the major threat, bad surprises can be expected close to old or abandoned industrial sites. The survey of these sites is being carried out at an insufficient rate. Another problem is linked to the abandoned wells, which are no longer surveyed. They can become a source of groundwater contamination later.

7.2. Protection of potable water abstraction points

In France, it is well known that wellhead protection zones for drinking-water supply, clearly defined in the law, are not well enforced, in particular when extended perimeters are needed, since landowners obtain no compensation for the resulting loss of crops; rural mayors tend to protect their fellow-farmers through indefinite delays in the procedures. In France, as in other Member States of the E.U., the protection creates three zones: the immediate perimeter, which must be purchased by the local authority and closed off; the near perimeter, where most industrial and intensive farming activities are banned (list made up on a case by case basis after a survey by the official hydrogeologist); and the extended perimeter, where contractual measures can be adopted. The most difficult part is to obtain that the near perimeter constraints be made official in the “cadastre” (land-use map) so that any person purchasing land in the area is warned of the constraint. In 1995 for instance, there were 32 000 wellheads used by rural municipalities, out of which only 10% were fully protected according to the law and another 15% ready to be protected (covered by eminent domain rules). As a result, only 17.3% of the production capacity was fully protected. The increase in protection is significant compared to 1990, but much too slow compared to the deadline for protection completion (1997), which was not met.

In an official evaluation report on groundwater protection policy (Villey, 2002), more precise statistics from a 1999 survey by the Ministry for Public Health was produced: out of the 30,600 groundwater abstraction points, 11.4% were completely protected and recorded on the cadastre, and another 20.1% were already covered by eminent domain rules. 30.9% had not started the procedure at all. In the scientific committee responsible for this evaluation, however, it was pointed out that many abstraction points were, in fact, located in forests or woods owned by local authorities, so that their legal protection was not urgent. But this has still to be checked. A more recent survey estimated the number of domestic public water supply groundwater wells at 32,629.

In October 2006, for year 2005, according to Saout (2007), out of 35,000 abstraction points for public water supply (4% of surface water producing 33% of the municipal water, and 96% of groundwater, producing 67% of the municipal water[9]), 48% of the withdrawal points were protected, i.e. 56% of the production. Out of them, 49% of the wellheads are protected, with 67% of the groundwater production, and 30% of the surface withdrawal points, with 33% of surface-water production protected. The new deadline for total protection was fixed to 2010.

[9] This figure of 67% of groundwater is much larger than the 59% given by IFEN (2004, 2005) in Table 4. It may be over-estimated.

Anyway, legal regulations alone will not solve the degradation problem in the long run, since the real protection would be to revert to extensive or biological agriculture across the whole area or sub-basin above the abstraction point. This can only be done by contracts, as illustrated by what is now common in Germany, the Netherlands and Denmark, as well as in many places in France (this subject still has to be well documented). French agriculture has used fertilisers and pesticides later than their Dutch or German counterparts, which may explain the low protection perimeter enforcement rate. Now the proportion of wellheads contaminated by nitrates at a level above the 50mg/l limit has risen from 1% to 5% in 5 years (and 9% of volumes withdrawn); similarly, the contamination by micropollutants now concerns 2.4% of the wellheads and 7.6% of the capacity. This obviously is a time-bomb. A growing number of water suppliers either try to find cleaner water and to "blend" sources to stay within the EU health standards, or to install end-of-pipe technology to remove the pollutants. But the inevitable increases in costs prompt local community water authorities to try to negotiate new types of policies with farmers: *if we subsidise them anyway, let's make them work for the sake of environmental protection*. A 1991 EU Directive (CE 636/91) on Nitrates from Agriculture requests Member States to designate vulnerable zones where nitrate contamination is above 40 mg/l. France has zoned 12 million ha, out of a total of 29 million ha of Operational agricultural surfaces.

7.3. Overdrafting

As mentioned earlier, there are several cases of aquifer overexploitation. The best known examples are the Beauce aquifer, the Eocene aquifer in the Bordeaux area, the Astian sands aquifer close to Montpellier on the Mediterranean coast, and the Carboniferous Limestone aquifer near Lille in the North.

Overexploitation is unfortunately not precisely defined by different authors[10]. It can mean that withdrawals are on average larger than recharge, or that withdrawals have negative consequences on the aquifer or at its boundaries, as will be shown below on the Beauce aquifer example.

In 1996, the official evaluation report of sustainable groundwater management (Martin, 1996), recommended a systematic development of piezometric sampling points and the creation of a national data bank. This means that the situation was unsatisfactory. It remains difficult to estimate the abstracted volumes, for lack of cooperation of abstractors.
In the case of the Beauce aquifer, overexploitation was mentioned way back before the Second World War. But it was difficult to ascertain its cause because of climate variability (it is a low-rainfall and windy area with high natural evapotranspiration). However, the subsidy system developed by the Common Agricultural Policy (CAP) led farmers to turn increasingly to crops such as maize, which need irrigation. While drinking-water abstraction in the area remained approximately constant, around 80 to 90 million m^3/y, and industry stayed at 25 million m^3/y, irrigation rose from 40 to 200 million m^3/y in the last dry year. Besides, it is well known that irrigation water is under-metered. In normal years, aquifer recharge is 900 million m^3, but in dry years, it can go down to 100 million m^3, and then there is aquifer depletion. As a result, when there was a long drought period at the beginning of the 1990s, rivers fed by the Beauce aquifer dried up for the first time, with serious consequences for their banks and their ecology[11]. Previous purely regulatory

[10] See for instance the work of Margat in France (Bodelle and Margat, 1980) or Custodio in Spain.
[11] In Table 9, the withdrawal rate given by Margat (2006) for the Beauce aquifer is globally on average of 34%. Overexploitation is thus perceived through its negative consequences on the medium, not because of exceeding the recharge.

policies had failed and now, a series of more contractual procedures is developing. The same thing is happening in Montpellier with the Astian sands (see below, section 8.3.3). In Bordeaux, the situation is getting worse, since overdrafting has led to risks of saline intrusion. The most difficult case is probably that of the Carboniferous Limestone aquifer in the Lille area, since the overexploitation occurs in an international context. But none of these situations seems as bad as what is happening in southern Spain or the Algarve.

8. INSTITUTIONS FOR GROUNDWATER GOVERNANCE [12]

8.1. Introduction

In France, various policies have been attempted to control the overdraft and the more frequent diffuse contamination of aquifers by agriculture, some aiming at changing the legal status of groundwater, some trying to develop contractual arrangements and economic incentives.

As in the other Latin countries, recent policy trends in France are interesting since they do not seem to go towards the development of water markets such as those discussed at world level, but to consider groundwater as a common property. This evolution, which is even more visible concerning surface water, brings Latin countries, where water law derives from Roman law as reinterpreted by 19th century liberalism into the Civil code, closer to the other member states where water law derives more from Germanic community-customary law.

In a comparative study funded by the European Union, the Eurowater partnership has tried to build a typology of water rights and administration systems in five member States of the European Union[13], with a specific section on groundwater. The outcome of the analysis is the hypothesis that the formerly important debate on public *vs* private water appropriation is giving way to another debate between two competing and complementary trends : a generalization of consent and permits for all water uses in the hands of a centralized authority, with related top-down planning; and the rise of integrated water management at more appropriate and subsidiary levels, with contractual agreements between users themselves, possibly relying on economic incentives and compensation mechanisms, and with bottom-up planning.

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[12] Summarized and updated from the paper “Groundwater management in France: from private to common property ?” by B. Barraqué, published in Brentwood Mary & Robar Stephen, *Managing common pool groundwater resources, an international perspective*, Praeger, 2004, pp 85-96

[13] See chapter 8 in Correia Francisco Nunes (ed.), *Eurowater, selected issues in water resources management in Europe* (vol. 2), Balkema, Rotterdam, 1998. The initial countries were France, Germany, the Netherlands, Portugal and the U.K. The analysis is also extended to other member States, in a collective report edited in Sweden: Hilding-Rydevik Tuija & Johannson Irene (eds), *How to cope with degrading groundwater quality in Europe*, proceedings of the UNESCO-IHP, MAB, NFR, FRN Johannesberg conference of October 1997, FRN report 98:4, 1998. The very interesting case of Spain is covered by the recent synthesis by Ramon Llamas Madurga, Nuria Hernandez Mora, Luis Martinez Cortina : *Aguas subterraneas : retos y oportunidades*,, Fundacion Marcelino Botin, Ediciones Mundi-Prensa, 2001.

8.2. Six Hydrographic Basins

When the French decided to adopt the river basin as a water management unit in the 1960s, they finally split the country into six groups of basins (see footnote 2 page 4, Figures 5-8 p. 8-11, and brief descriptions p. 12-13). Each of these groups of basins has an *Agence de l'eau* (Water Authority), which levies pollution and abstraction charges on water users, and then brings subsidies and zero-interest loans to users/members who invest in pollution- or abstraction-control infrastructures, under the supervision of a "water parliament" where users are qualitatively represented. These original institutions are the loci of a considerable improvement in water knowledge, and data are often registered and synthesised at their level before the national level.

Apart from the Paris metropolis and a few cities with over 1 million inhabitants, France is a country of small towns and villages. This is the first explanation for the maintaining of a great number of water supply and sewage operations, and for the relatively low connection rate of industrial premises to public sewer systems. The number of water abstraction points is as high as 35,000, of which more than 33,000 from groundwater. One can imagine the difficulty in monitoring all these water systems for pollution problems. Of course, geography is not the sole explanation, and the number of small local authorities (36,000) is another one. It is due to a decision by Revolutionaries in the first constitution, in 1792, to transform the old parishes into *sociétés de citoyens*, i.e. elected municipalities with sovereign powers which have been reluctant to merge, and later this gave rise to a confrontation between central and local governments, analysed by Michel Crozier and his colleagues in terms of "cross-regulation": when central government wants to push a new policy, local government tends to beg for either financial support or subsidies (Grémion, 1976).

The *Agences de l'eau* are part of the institutions invented to try to develop different policy making, more inter-territorial, using economic incentives and increased private or corporate rationale. This is why initially, an equivalent amount of pollution levies were raised from cities (public sewers) and from unconnected industrial premises. Farmers were left out because the *Agences* were light-weight institutions and could not spend a lot of time on diffuse pollution. Clearly this is not the case anymore.

Irrigation developments have, on the whole, remained moderate, and there are very few cases where inter-basin water transfers have become necessary : in Provence and Languedoc, the situation is similar to that in Spain or Italy, and there are regional transfer systems with corresponding public companies to handle them[14]. However, the irrigated acreage is still growing, and has doubled over the last 20 years to reach 2 million ha[15] in 1997 (with a slight decrease since, see Fig. 14 p. 23). This induces new stresses : if unchecked, the development of maize crops may require similar investments in the Garonne and Adour basins North of the Pyrenees, and it is now recognised that the Beauce aquifer is overexploited in the rich agricultural area around Paris. Even though intensive farming developed later than in other European countries, contamination by nitrates and pesticides is a reality now, and is growing, leading to water stress in terms of quality.

[14] See footnote 8 page 21.
[15] In comparison, they cover 4.5 million ha in Spain, and demand 24 km^3/year.

The legal issue of appropriation

In most European countries, groundwater is traditionally considered as "closed" water, and as such is part of the landownership rights, together with rainwater, ponds dug by the landowners and springs generating minor flows maintained and used within the property. However, countries with stronger customary traditions have tended to limit the abstraction of groundwater to levels non-detrimental to their neighbours, while those who have increasingly relied on Roman law tradition have usually not placed any restrictions on the "use and abuse" of groundwater by each landowner, be it in the end detrimental to his neighbours. In all countries, however, when public water supplies rely on groundwater, public control of the water and of the land above has gradually developed.

In France for instance, until the 1992 law, a story like that told in Pagnol's novels *Jean de Florette* and *Manon des sources*, and in the subsequent movies, could still happen : indeed, in the 1980s, a Mediterranean coastal village drilled a well to increase its drinking- water supply. Having discovered the existence of the aquifer thanks to the public borewell, a private irrigator drilled his own well on his land and happened to dry out the public water well. The city was in no position to claim damages or a share of the aquifer. Because of this private appropriation tradition, there is usually no groundwater management administration, and even a real lack of knowledge of groundwater availability.

The legal issue of aquifer pollution control

One can illustrate legal problems in the field of pollution control, with the "only case" which the Agences de l'Eau lost in the administrative courts : it is a decision of the *Conseil d'Etat* dated October 20th 1976, "Villers-les-Pots", named after the village which won against *Agence de l'Eau Rhône-Méditerranée-Corse* : As soon as it was set up, in 1968, the board of the *Agence* proposed to levy pollution charges on the little village which had no sewer system. The mayor refused to pay for 1970 and 1971, arguing that his fellow citizens "did not pollute". In 1972, the Prefect of the *Département* forced the local authority to pay[16] and the local authority sued the Prefect. The lower administrative court ruled that the village had to pay (1974). On appeal, the *Conseil d'État* reversed the judgment : "water degradation charges can only be imposed by the *Agences* on public or private persons when these persons make the Agences' intervention useful or necessary. The contents of the 1964 law and subsequent decrees do not allow charges against local authorities where domestic pollution remains unrelated to discharges from communal or inter-communal sewage systems... Agence RMC's board has ignored the above-mentioned legal disposition..." (etc).

This court decision can be interpreted in three different ways : the simplest is to stay within the "formal approach" of the appeal court, and to say that since the 1966 application decree of the 1964 law fixed the pollution charge of the *Agences* in proportion to the sewerage charge levied by the local authority on city dwellers served by public sewers, it could not be levied on people not connected to centralized sewerage. The second is to focus on the initial resistance of rural mayors to the *Agences*, which they considered illegitimate. We know that it took several years for the *Agences* to gain the confidence of elected representatives. But the third is to consider the "technical culture" of water pollution at the time : most people thought that the *Agences* had been set up to improve water quality in rivers, via the control of effluent discharges from point sources. This

[16] The procedure is called "mandatement d'office", which means the prefect is allowed to impose the expense on the communal budget - centralization.

meant that the pollution charges would be used mainly to build sewage treatment plants, which was actually the case in the initial phase, and later to extend sewer networks. It may even be possible that the pollution-charge mechanism was viewed by the *Agence*'s administrators, as by most water engineers, as a general incentive to improve the connection rate of the population to the sewer systems. But this view is bound to consider the rural, unconnected population as simply polluting rivers (see Eurowater, vol. II, chapter 7) and to overlook decentralized sewerage in spite of its efficiency in low-density areas. Conversely, it ignores the water-table pollution problems resulting from unchecked decentralized sewerage, which should legitimise a charging mechanism allowing the *Agences de l'Eau* to become involved in its improvement. Hopefully this situation has changed with 1992 law.

8.3. Laws, politics and policy

8.3.1. Reforms of the groundwater law

In Germanic countries, customary communitarian law has always attached more importance to the rights to use the water than to the rights to own it (Caponera, 1992). Conversely, in Latin countries, traditionally, there are waters subject to ownership rights : public or "domanial" water comprising navigable rivers, and springs tapped for public use (aqueducts); and waters left to landowners appropriation, as being *res nullius*, i.e., groundwater, rainfall collected in closed ponds, etc. All non-domain flowing water was, however, considered *res communis omnium*, common property, i.e. subject to right of use only. Traditionally, aquifer exploitation was an unchecked right of landowners, who could dry up their neighbour's wells at will. However, in Latin countries today, there is a general trend to reduce or to suppress the freedom of groundwater use by landowners, and to question their private appropriation status as has always been done in countries with Germanic-based law. It is quite significant that Spain in 1985, France in 1992, Italy in 1994, and Portugal in a series of legal documents between 1984 and 1994, have reduced the freedom of private persons to use the water. Some have done it through a general domanialisation of ground- and surface-water (e.g. Spain), but others, like France, have chosen to develop the category of common property, which already included all flowing surface water, except large navigable bodies. The legal translation of common property is *Patrimoine commun de la Nation*, which also corresponds to what the Anglo-Saxon countries call Public trust.

Interestingly enough, the first action by the French government, already in the 1930s, was to try to domanialise all aquifers which were considered overexploited, as stated in the introduction : the French government and policy makers, then under the influence of governmental experiments in Italy, Spain and Portugal, favoured a "modernisation of the State" which would increase its economic role and lessen its dependence on the good will of local authorities or private property. Typically, the 1935 decree-law allowed the government to place groundwater beyond a certain depth below ground level in the public domain. This was done only in selected regions such as the Paris area, to protect the aquifer and the water supply. In these areas, all water extraction would require a permit from the Ministry of Industry. But this measure was poorly implemented for lack of personnel to control it, in particular after the return of the IVth Republic in 1944. There were interesting debates in the French Senate and Parliament at the time of the preparation of the 1964 law (see Barraqué, in Eurowater, vol. 1, section on France). In the end, the idea of changing the legal status of water was rejected, in favour of first developing an economic incentive system to ease the appropriation issue through financial give-and-take.

However, after 20 years of the *Agences* operation, a learning process has evolved, and a vision of surface water as a common heritage has slowly gained the upper hand among users. The *Agences* were initially created as marginal improvements on a still centralized economic water policy, with executive boards composed equally of representatives from the ministries involved and of water users. However, because of budget austerity and general decentralization developing in Europe, the central State has slowly withdrawn from water economics, and the boards have been reorganized accordingly with increased representation of various users. They now even have ecologists although the latter maintain that they are under-represented. Having failed to impose an initial top-down water planning via emission standards (the so-called quality targets approach), which was part of the 1964 law, the *Agences*, together with the Ministry for the Environment and intermediate tiers of government, became involved in contractual agreements called river charters, and later river contracts. Interestingly enough, the first two contracts were signed for the enhancement of Alsatian rivers. Alsace has kept many traits of a communitarian approach to territorial policy, which is part of Germanic culture. Contracts are now a familiar procedure, and they sometimes concern aquifers.

Experts in favour of a new law grew in number with the decentralization laws voted in 1983. Shouldn’t domain rivers entirely located in one Region be managed by this Region ? Anyway, local land-use planning could no longer be subjected to Central Government constraints except by a law passed by Parliament; therefore, an accommodation had to be found. Then severe droughts in 1989-1991 again stressed the limits of the complex system of water rights, both for surface and groundwater. The weak improvement of river water quality also called for cities to take increased responsibility for their discharges (Sironneau, 1994).

These reflections and debates resulted in the 1992 law : all categories of water are now declared to be part of the "common heritage of the Nation". Waters do not however become public, and beds and banks of non-domain rivers are left to riparian landowners. But, following legal expert advice, the rights to use water are transferred to the State, which could potentially rely on water communities to organize the new resource sharing. Two planning levels, the SDAGE (*Schémas directeurs d'aménagement et de gestion des eaux*) at the six *Agences*, and the SAGE (*Scéma d’aménagement et gestion des eaux)* at community or catchment level, are supposed to engineer the compromises between users and the State. Whereas river contracts are informal and not legally binding, the SAGE are much more formal procedures, beginning with the setting-up of a *Commission locale de l’eau* (CLE). It must be composed of 50% local elected representatives, 25% for the State and 25% of private users. The purpose of the CLE is to discuss and prepare a water plan, which will be implemented either by traditional water operators, or by a special joint board of local authorities in the concerned catchment. Enforcement powers are not transferred to the services of the Ministry for the Environment, but re-organized and co-ordinated at the level of each *Département*. The Prefect, head civil servant at this level, relies on a national set of standards laid down in a 1994 decree to deliver abstraction and discharge permits, unless he has an approved SAGE possibly with more stringent standards. Even though most SAGEs concern surface water catchments, the law explicitly considers the case of aquifers.

Ecologists in the last left-wing coalition government pushed the idea of a new water law where the economic version of the “polluter pays” principle would be more severely enforced, in particular on farmers who had been exempt from the beginning. However, they decided to fight this battle at national level to strengthen the powers of the Ministry for the Environment. Unfortunately, at this governmental level, the Ministry of Agriculture and farmers unions have very strong lobbies. Earlier, farmers had obtained that only pollution from large stock farms would be charged (above 500 units), and that they would first receive subsidies for 5 years and then they would pay charges on pollution. The *Agences* were supposed to implement this measure[17] even though it would breach their membership rules: no subsidy if you do not first participate in the charging system. A recent evaluation report by the Cour des Comptes (equivalent to the US GAO) criticised this policy for its inefficiency[18]. In the following law (discussed after the 2002 presidential and legislative elections), a levy on all nitrates, both artificial and manure, was to be created, but never materialised. This law was not passed until December 2006.

Groundwater improvements in the 2006 water law in France

The LEMA (*Loi sur l'eau et les milieux aquatiques*) of December 2006 does not explicitly mention groundwater, but it contains at least two important measures, which may have an impact on groundwater quantity and quality. Article 21 of the law (which is included in the Rural Code under article L211) gives the Prefect the liberty to create "zones of environmental constraints" where mandatory measures are imposed on water users, who will be compensated by the government; this is in conformity with art. 38 of the latest European RDR (Rural Development Regulation II), allowing member States to impose environmental measures with compensation, beyond the voluntary measures of art. 39, which extend but modify the classical agri-environmental measures of the CAP.

In terms of quantity, art. L221-3, 6°, allows the Prefect to delineate areas where water abstraction licenses for irrigation purposes will be granted to a single operator (implying the development of irrigation communities); in "zones of water allocation" (*zones de répartition des eaux*), i.e. areas subject to water stress, the Prefect can even designate the common monopoly operator.

In terms of quality, the Prefect can impose environmental constraints on farmers, including mandatory changes in crops and crop rotations, in three types of areas: catchments of drinking-water wells, erosion areas with impact on water turbidity and contamination and wetlands and other vulnerable aquatic environments. Constraints should then be compensated at better rates than what is usual in the traditional *Périmètres de Protection des Captages* (wellhead protection) where measures are mandatory only in areas exposed to accidental pollution risks (and not to diffuse pollution).

It is too early to know how these new measures will be implemented and enforced, and at what final cost. It remains to be seen how they will accord with the agri-environmental measures of art. 39 of the RDR. But a first case can be observed in Brittany, where the French Government adopted a series of measures to (at last) implement the first Water Directive (EC 75/440), before the end of 2009, and thus escape the very large fine granted the EU Commission by the European Court of Justice. The programme concerns five river basins, 2000 farms, and a total surface area of 60,000 ha. It includes significant reductions of manure spreading (by one third approx.), early retirement for ageing farmers, herd

[17] It is called PMPOA : *Programme de maîtrise des pollutions d'origine agricole*

[18] The most complete *a posteriori* evaluation was drafted by a mix of Treasury controllers and Rural engineers in July 1999. It is grey literature but can be obtained from the Ministry of Agriculture.

reductions and effluent treatment. The total cost of the various compensations is estimated at 69 million €.

8.3.2. Contractual policy

As also observed in Germany, the Netherlands and Denmark (Heinz, 2002), there is a general trend to establish contracts with farmers locally: they receive a subsidy per hectare when the nitrate levels remain very low at the end of the crop season, and/or pesticides are banned. In order to help implementing the Nitrates From Agriculture Directive, the European Commission has decided to subsidise national programmes of voluntary adoption of good practices. Various agri-environmental measures are proposed. Voluntary improved-fertilisation experiments (*Fertimieux* programmes) were conducted at 54 different locations in France, for a total of 1.2 million ha, among the 12 million mentioned above (these programmes were terminated in 2005 despite their good results). There are also Irrimieux and Phytomieux programmes, and recently the government has decided to generalise the environmental contractual agreements with volunteering farmers through the so-called CTEs (*Contrats territoriaux d'exploitation*). There is also a growing trend to make the transfer of Common Agricultural Policy subsidies conditional on the adoption of a code of environmental practice, in particular the installation of water meters.

In short, there is progress through contractual approaches and collective learning processes, albeit too slow. Most experts now agree on the need to supplement regulations and voluntary agreements with general economic incentives, i.e. abstraction and pollution charges, in particular on farmers, the former to be paid by volumes abstracted. However, through a direct application of Ronald Coase's theorem on solving the social cost problem, one can easily foresee an outcome more on the subsidy than on the taxing side: the value of potable water is so much higher than that of agricultural water or the added value of fertilisers, that water suppliers generally can buy the farmers losses from re-extensification. Water suppliers are increasingly concerned by the rising levels of fertilisers and pesticides in groundwater, and they have started making local contracts with farmers to "buy up their pollution".

Some water suppliers have had great experience bargaining with farmers over wide areas, or with rural councils : the city of Paris, in order to protect its groundwater supply in the Eure *Département* west of the capital, provides indirect land compensation by paying street maintenance in the concerned villages. This leads to a typically unclear situation. But some more formal and transparent compensation has to be established, since lawsuits have started, e.g., in Guingamp. In this Brittany town of 10 000 people, consumers and ecologists sued the Lyonnaise des Eaux utility for supplying water with an excess of nitrates, and they won. Now the Lyonnaise sues the government for not enforcing the regulations on discharges from poultry farms upstream (in the aquifer connected to the river). But the crucial question is : should Guingamp invest now in improvements of the drinking-water plant, which would cost an extra 0.3 Euro/m^3 and cause a 10% rise of water bills (the price is already among the highest in France), or else, for an equivalent or smaller amount of money, should they "buy" a re-extensification of stock farms from the farmers, ignoring the moral issue at stake (the polluter-pays principle) ? Or can the government enforce environmental regulations on a subsidised agriculture without subsidising it anyway, if through other schemes ? Anyway, drinking-water users just say that since they already pay 15% of their bills to the *Agence* to fight pollution, let the *Agence* take some of that money and give it to the farmers. Indeed, such contracts could be written if the *Agences* were involved. But the system under which they operate, implies that they are allowed to levy new charges on farmers' diffuse pollution, and simultaneously involve them more in the basin Councils. Finally, in Brittany, local authorities in charge of water supplies buy the farmland and convert it into woods to protect the aquifers below: see the Saint Ivy case. The end result is a story similar to the famous case of the Vittel mineral water: in France, as described above, mineral water does not have to follow the DWS that applies to tap water. Yet, when the company saw the nitrate content rise, they purchased vast tracts of land on the perimeter of their abstraction, and later they resettled farmers without charging them any rent. This is because in France, a landowner cannot impose any crop choice on his tenant farmer. If the land is lent and not leased, there are possibilities of imposing good environmental practices. What is discussed today is the fact that it is easy for a company to sell bottled water at prices 200 times higher than tap water, but it might be harder for PWS. Yet, as in Germany, similar contract procedures are developing. We just lack a comprehensive study of the subject.

8.3.3. Contracts on overdrafting

Although there is a growing number of local contracts concerning the quality of groundwater, the success stories are still scarce concerning aquifer overexploitation. Yet one good example is the "aquifer contract" that was signed by the Hérault *Département* (a very active one in terms of water policy), together with 14 municipalities, the chamber of commerce and the chamber of agriculture (Laurent, 1993). When aquifer overexploitation was identified in the Astien sands, most actors accepted to contractually diminish their abstractions (including water suppliers who partly turned to other sources). The government services brought initial support and knowledge, and now the contract is funded by the *Agence* (27% of the costs), the Ministry (12%) and the Conseil Général (23%). but it is essential to note that knowledge was built up simultaneously to identify and mobilise all concerned actors. Most of them have confidence in the existing contract formula, and they do not think it necessary to develop a more formal SAGE. Conversely, in the Bordeaux area, the Eocene aquifer has long been overexploited, and the consequence is a risk of irreversible saline intrusion. In this case, it was decided to constitute a *commission locale de l'eau*, to make a more formal SAGE, although this is a longer process (Chauveau, 1999).

This also seems to be the case for the Beauce aquifer: in 1997 a SAGE procedure was initiated, and it was supposed to be a pilot case of an aquifer SAGE. Yet, like in all SAGEs, setting up a CLE (local board), which both follows the official composition and manages to have all the concerned representatives is a long and time-consuming process. In the meantime, various local contracts have been signed to enhance a river flow, to develop an Irrimieux and a Fertimieux voluntary approach … In other cases, it has also been noted that formal planning has a better chances of being accepted if it has been prepared by informal arrangements and contracts. As mentioned above concerning Guingamp, a way to solve the problem is through the charges paid to the *Agences*. This has been advocated in an important report written by the Corps of Mines in the Ministry of Industry (Martin, 1996). As a matter of fact, in the 2002-2006 programme, the *Agence* in charge of Brittany is investing 120 million Euros in the PMPOA[19]: cleaning up the stock farms which are big enough to be subject to the French system of IPPC (*installations classées pour l'environnement* / listed premises). In the same programme, farmers will contribute only 10 million Euros. Some consumers and ecologists contend that farmers should not be subsidised just to follow the regulations, but the chosen solution is to first

[19] See footnote 17 p. 37.

facilitate their participation in the basin boards of the *Agences*, where they had no official seat until now, so that they can be charged tomorrow. Anyway, this programme deals, in fact, with point-source pollution (stock farms are regulated as industrial premises), and does not extend to non point-source pollution.

Decentralised sewerage

The Villers-les-Pots case first led the water policy community to abandon pollution control in very small communities where there are only septic tanks. But given the low population density in the country, there will always remain around 10 million people not connected to sewers. Several *Agences* have indeed reconsidered the matter, and give financial support for decentralized sewage treatment reconstruction or extension. However these experiments can only remain marginal, and at the edges of the law, because in France public money cannot be employed to subsidize the construction or the upgrading of private facilities. And a local septic tank is private. The 1992 law officially reconsiders the situation and requested local authorities to specify a zoning of sewered and non-sewered areas, and to control the operation of decentralized sewerage. Sludge disposal must be planned at the *Département* level. The law even legalizes public maintenance of septic tanks by a specific municipal service. However, since it does not propose a solution to overcome the issue of public service employees trespassing on private land, the result is the development of various experiments but on a contractual basis.

Legal and institutional reform of groundwater management in Mediterranean countries.

In most European countries, groundwater has traditionally been considered as "closed" water; the ignorance of its flowing character, and of the role it could play for water users if systematically used, has often led to it being considered a “no-thing”, and as such to leave it attached to the overlying land, and eventually to landownership rights.

In other Latin countries, both the Mediterranean climate and the contemporary history of authoritarian governments led to water being considered part of the public domain. This includes groundwater, which was formerly considered private and linked to landownership. In Spain, watertable overexploitation led to a significant change expressed in the 1985 law: groundwater is now considered common property of those who use it, but it is first placed in the public domain as is all water (Burchi, 1991). However, the law appeals to irrigators to abandon their rights, not to the State, but to the community and subsidiary institutions that they would set up together, following the famous Valencia water tribunal model[20]. In exchange, all irrigators accepting to participate would have their water rights maintained for the next 50 years, with priority over other farmers.

Yet this law is implemented very slowly, and it seems difficult to force farmers to join the communities. In Portugal and in Italy too, the trend is towards extended administrative control of private water rights, rather than toward a redefinition of groundwater as a common property, subject to user rights. But implementation will be difficult, and will often require building trust and cooperation of landowners. In the end, if Latin States voice their intention to place all water in the public domain, they are blocked by the existence of

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[20] In fact, the model of the law is a recent successful experiment which was developed to stop saline intrusion in the aquifer of the Llobregat delta close to Barcelona : without government support, but with the help of hydrogeology professors and students of Barcelona university, water users set up a community of water users which managed to reduce all water uses and to reverse the salinisation process (see Llamas, 2001).

well-established *droits acquis* (rights) and by a culture of private appropriation. In order to avoid that groundwater-use regulations be considered the “taking for a public purpose” or equivalent (*expropriation pour cause d’utilité publique*), Mediterranean countries should be encouraged to develop cooperative institutions and user participation. It is also necessary to make the new Common Agriculture Policy work in the same direction as the WFD. This means both enforcing mandatory instruments (in case of groundwater overexploitation or severe contamination) and encouraging voluntary agreements.

9. CONCLUSION AND RECOMMANDATIONS

In Europe, a step forward in water policy was made through the issuing of the Water Framework Directive in 2000. For the first time, the EU clearly adopted legislation with environmental improvement as its major goal. The Directive requests, among other things, that groundwater should reach a good chemical and quantitative status within 15 years, and before then, all sort of reporting and economic evaluations have to be made. No doubt this will have a strong influence on Member State policies. Yet, it remains to be seen how diffuse pollution from agriculture will be controlled. Indeed, the E.U. suffers from internal contradiction, since it supports a subsidies policy of intensive agriculture, which is responsible for more aquifer degradation.

Thus, there is good reason to believe that aquifers will be under continued threat, except in areas where other and richer water users will purchase from the farmers their losses linked to reductions in water abstraction or pollution. This might raise a moral issue. But in practice, along the lines of institutional economics and common pool policy analysis, such developments are in fact very important in terms of collective learning processes and lowering the transaction costs. Later, when water-use cultures and patterns have begun to change, it is possible to implement more severe laws and regulation. In France, in particular, we know that it is impossible to place a policeman behind each farmer. Even with the progress in satellites observation, participation by groundwater stakeholders in aquifer management communities has a good chance of remaining better than either government command-and-control or water markets. As we saw above, there is increasing recognition that water has an economic value, but within common property institutions. And a general but quiet evolution of the legal status of water, as a thing for reasonable and equitable use, is making headway.

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Acronyms

AE : Agence de l'Eau (Water Authorities)
AFEID : Association Française pour l'Etude de l'Irrigation et du Drainage
AG : Agence de l'Eau Adour-Garonne (River Basin Authority)
AP : Agence de l'Eau Artois-Picardie (River Basin Authority)
BRGM : Bureau de Recherches Géologiques et Minières
CAP : Common Agricultural Policy
CEMAGREF : Centre d'Etude du Machinisme Agricole, du Génie Rural, des Eaux et des Forets
CLE : Commission Locales de l'Eau (local water commision)
DOM : Départements d'Outre Mer

DWS : Drinking Water Standards
EDF : Electricité de France
EU : European Union
HT : Hors Taxes (without VAT taxes)
IAH : International Association of Hydrogeologists
IFEN : Institut Français de l’Environnement
INRA : Institut National de la Recherche Agronomique
LB : Agence de l’Eau Loire-Bretagne (River Basin Authority)
PWS : Public Water System
RDR : Rural Development Regulation
RM : Agence de l’Eau Rhin-Meuse (River Basin Authority)
RMC : Agence de l’Eau Rhône-Méditerranée-Corse (River Basin Authority)
SAGE : Schéma d’Aménagement et de Gestion des Eaux (local water management plan)
SDAGE : Schéma Directeur d’Aménagement et de Gestion des Eaux (general water management plan)
SN : Agence de l’Eau Seine-Normandie(River Basin Authority)
TOM : Territoires d’Outre Mer
WFD : Water Framework Directive