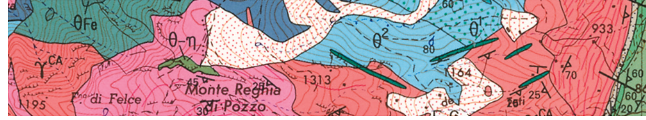

Groundwater in France

Geoscience Issues Collection

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Groundwater in France

March 2012

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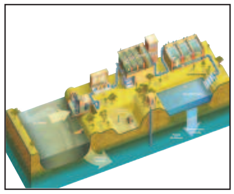
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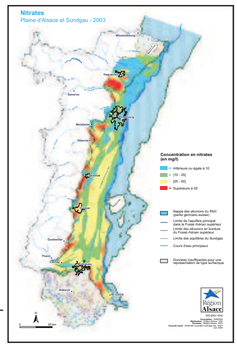
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Preface

Groundwaters have a vital role in the water cycle. They are the main source of the surface water that sustains aquatic ecosystems, from mountain springs to rivers and wetlands. They are vital to industry and irrigation, and cover two thirds of all water production in France.

But groundwater is often renewed very slowly, which makes it very vulnerable: the effects of chemical pollution or over-abstraction sometimes only become apparent after many years, leaving a legacy of sometimes irreversible ecological disruption to future generations. To use groundwaters sustainably, their management needs to be supported by better knowledge and monitoring, which help to understand the processes that govern their quality and flow patterns.

There has been considerable progress in this area in recent years, for example with the creation of a national database on groundwaters (ADES). It is also important to have the appropriate legal, technical, economic and spatial planning tools.

This was the purpose of the European Water Framework Directive (WFD) issued on 23 October 2000, which requires all water bodies to be restored to a "good status" by 2015, in particular through the introduction of management plans at catchment basin scale. In 2006, an additional "daughter" directive was issued on groundwaters. These directives introduce performance requirements and schedules for the gradual reduction of groundwater pollution and to reverse any tendency towards significant and lasting increases in pollutant concentrations.

The 30 December 2006 Act on Water and Aquatic Environments (LEMA) was passed in France to support these European measures, by providing for the necessary tools to restore water quality and to ensure sound management that matches water resources to needs. The Act provides for additional means for implementing SDAGEs and SAGEs (water management plans) and established the National Office for Water and Aquatic Environments (ONEMA), a public technical and forward planning institution responsible for coordinating the Water Information System. The Grenelle environment consultations further require the WFD target to be achieved for two thirds of French water bodies by 2015.*

Finally, preserving our water heritage and achieving the WFD quality standards depends on the active involvement of all the organisations concerned, to improve knowledge, collect all available information and effectively prevent pollution from point and diffuse sources, to guarantee lasting access to drinking water and to develop water management plans for the most vulnerable and over-exploited aquifers.

Odile Gauthier, Director for Water and Biodiversity, Ministry for Sustainable Development
Jean-Yves Grall, Director-General for Health, Ministry of Health
Patrick Lavarde, Director-General of ONEMA
Jean-François Rocchi, Chairman of the BRGM

Part I

Introducing groundwater

© Fotolia/J. Reitz

Water welling up from the Dionne Trench at Tonnerre (Yonne).

Groundwater is the foremost mineral resource used by humans, and thanks to the water cycle, the only one which is renewable. France has an abundance of groundwater and is the cradle of hydrogeology. For two centuries, knowledge on groundwater has steadily improved to bring a better understanding of our groundwater heritage, in terms of both quality and quantity.

Water beneath our feet

Chapter I.1

Groundwater is the foremost mineral resource used by humans, and thanks to the water cycle, the only one which is renewable. It is a living heritage that has to be protected and preserved for future generations.

A vital heritage for us all

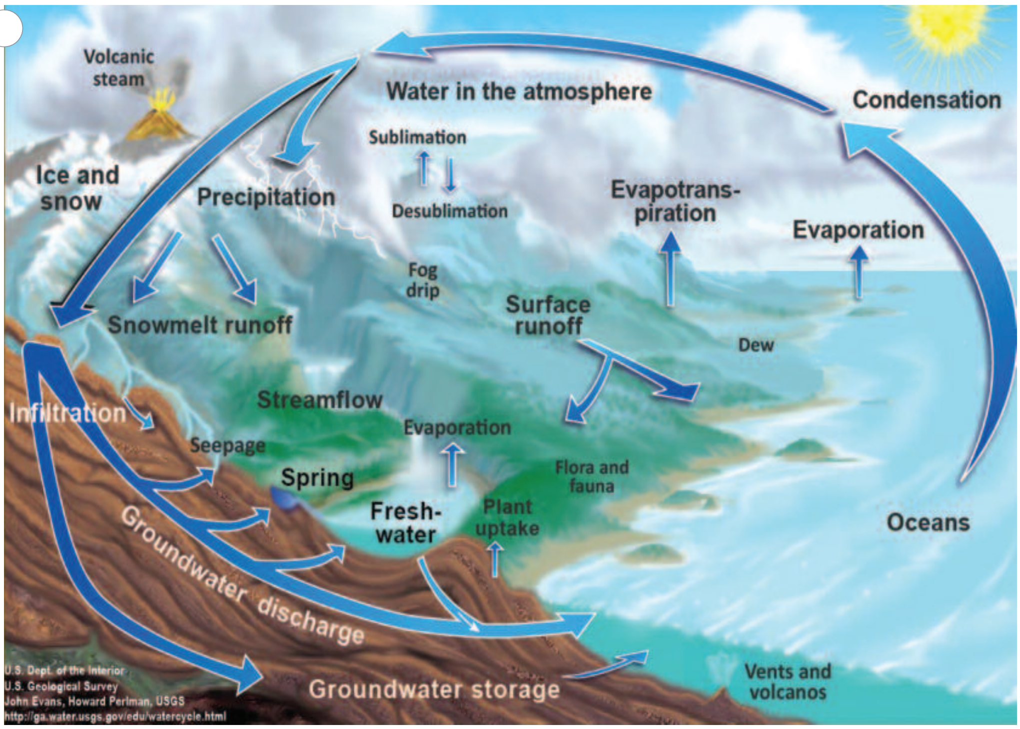
Inland waters can be fast-flowing, as in rivers and streams, or travel slowly through interconnected underground aquifers. Of the 43 000 billion m^3 of water in the planetary water cycle, which circulates continuously across every continent, about 12 000 billion m^3 first travel through aquifers*; 9/10 of this water eventually reaches rivers and streams, regulating their flow*, and only 1/10 goes directly into the sea.

Aquifers are underground reservoirs holding many million billion m^3 of fresh or salt-water. These vast stocks have useful regulating functions but are not resources as such. Unlike other mineral raw materials, water is an essentially renewable resource. The actual resource for human beings is the water flowing underground or on the surface that it is technically and economically possible to extract without harming the natural environment.

In France, total groundwater discharge is estimated at around 100 billion m^3 per year, of which only a fraction is a usable resource*. Water lying below ground can be relatively accessible and is less vulnerable to pollution than surface water. It has always been considered an essential raw material, especially

THE WATER CYCLE

The phases in the water cycle vary a great deal in duration: a few days from oceans to rain, a few hours to a few months from rain to groundwater (recharge), and several years or even millennia from groundwater to springs or wells.

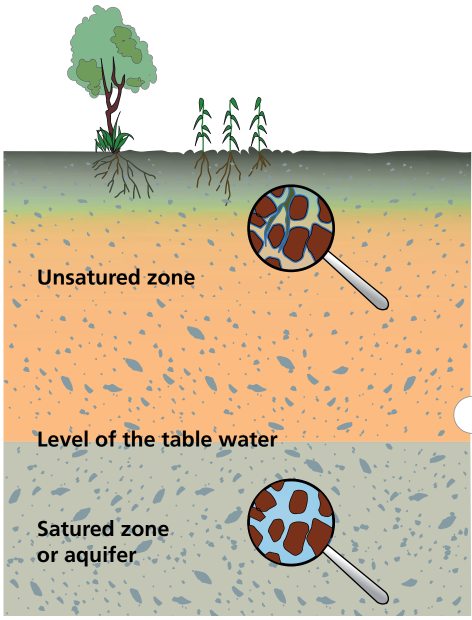


since the mid-20th century. Some 2 billion people and up to 40% of the world's agriculture depend at least in part on these hidden reservoirs. Groundwaters are also vital to our planet's ecological equilibrium. They feed springs, streams, rivers and the wetlands that are essential to the survival of rural and urban communities and wildlife.

From rainwater to groundwater

Groundwaters are mainly fed by precipitation, but not all of the rain or snow that falls is available to replenish water tables. Depending on the local environment, part of it returns to the atmosphere by evapotranspiration*, some of it runs off into lakes and rivers, and the rest, eventually, filters slowly down into the soil and substrate. Rainwater circulates in pores and microfissures in certain kinds of rock. These are known as "aquifer rocks", which literally means "rocks that contain water". These aquifers usually have two distinct zones: an unsaturated zone, which is the soil and the upper part of the aquifer rock: in this zone, the rock pores are not completely filled with water. Due to capillarity, which tends to draw water up towards the humus layer, like blotting paper, and gravity which draws it downwards, the water in the unsaturated zone is constantly in motion. Some of it eventually percolates downwards, soaking into deeper and deeper layers until it reaches a layer which is impermeable.

The saturated zone*, where water fills every available crack and space in the rock, lies above an impermeable layer. The groundwater body is contained in this saturated zone: water travels underground along the impermeable layer, usually following the topography, sometimes for hundreds of kilometres. This means the water is continually moving both vertically and laterally. Groundwater can emerge at the surface, forming a spring that usually feeds a stream, if the topography allows the water to run downwards.



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Groundwaters are not underground lakes

In unsaturated zones, water is only present in the form of moisture. In saturated zones*, water fills all available pores and fissures.

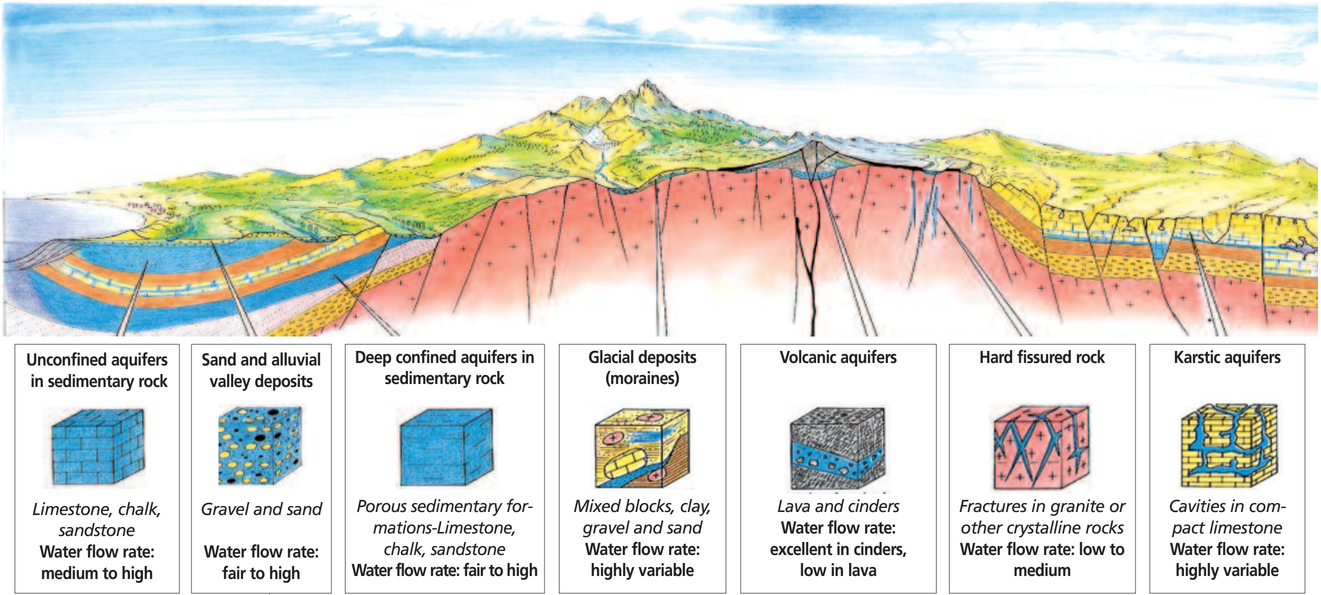
Unconfined and confined aquifers

Whether groundwater is phreatic (from the Greek *phreas*, meaning "well") or not, shallow or deep aquifers are neither lakes, nor underground rivers but simply porous layers saturated with water infiltrating from the surface. Unconfined aquifers lie beneath a permeable and unsaturated geological layer or sedimentary cover. The depth where these materials become saturated with water is the position of the water table. Depending on the quantity of water infiltrating from the surface (i.e. seasonal variations in precipitation), the water table moves up or down.

Unconfined groundwater is connected to the surface because the terrain above the water table is permeable: the rock pores are only partly filled with water, the soil is not saturated and can always absorb more rainwater. This means that the level of the water table can rise or fall depending on precipitation (seasonal and annual fluctuation*).

Aquifers are confined when they lie between two impermeable geological layers, usually

* See glossary, p. 52



© J.-J. Collin, Les eaux souterraines

several hundred metres below the surface or more. These water bodies are only in very slight contact with the surface from which water filters down, at the point where the permeable layer forms an outcrop. They are therefore recharged more slowly than unconfined water bodies. A confined aquifer can be under pressure, sometimes enough for the water to gush out naturally at the surface when a borehole is drilled, in which case it is called artesian water*.

Groundwaters are contained in the rock

Aquifer rocks vary with the geological nature of the terrain, but can be divided into three main groups:

- Sedimentary aquifers are contained in sedimentary rocks such as limestone, sand, sandstone or chalk. These groundwaters are characteristic of the main French

How old are groundwaters?

Surface waters	Age (orders of magnitude)
Oceans and seas	4 000 years
Lakes and reservoirs	10 years
Rivers and canals	2 weeks
Soil moisture	2 weeks to 1 year
Groundwaters	**2 weeks to 10 000 years**
Ice caps and glaciers	10 to 10 000 years
Water in the atmosphere	10 days
Water in the biosphere	1 week

Groundwaters have a certain age, which corresponds to the time spent below ground, from the moment they filter into the soil after rainfall until they return to the surface as spring water or through wells and boreholes. Depending on the type of terrain, water can take a few days, several months or several centuries to travel 1 km below ground. To calculate the age of groundwaters, scientists use natural “clocks”: radio-isotopes like tritium or carbon 14. These dating methods are used to estimate how long water has remained below ground, but also to identify the mechanisms governing the flow patterns and recharge times of groundwater bodies. Some groundwaters, like those in alluvial formations, are no more than 40 years old. These waters are renewed very quickly - within a few years, sometimes even a few days - which means that pollutants are washed out more quickly if the water becomes contaminated. Others are thousands of years old: the fountain in Lamartine Square in Paris, for example, is fed by 40 000 year-old water from an old well at Passy, so that we may be drinking the same water that soaked a Neanderthal family when it rained down in prehistoric times!

basins, such as the Paris or Aquitaine basins. They can be confined or unconfined.

- Alluvial aquifers are contained in sand and gravel, and are those most often in contact with waterways.

- Aquifer water in crystalline rock (granite, gneiss, etc.) and volcanic rock (lava) is contained in fissures and detritic zones. These form small groundwater bodies that are most commonly found in Brittany, the Massif Central, the Alps and the Pyrenees.

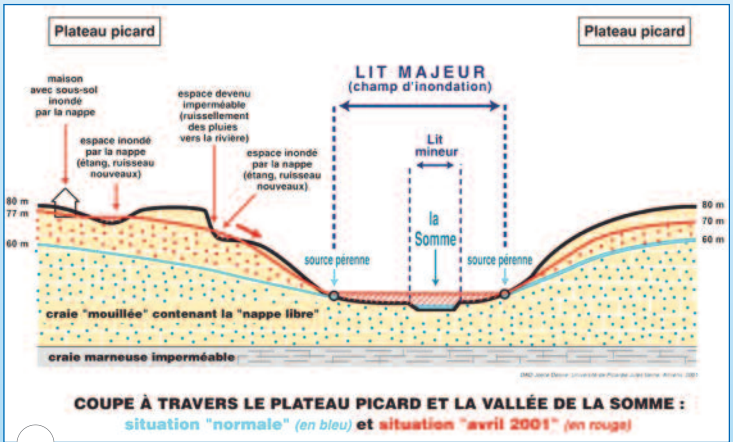
Groundwaters also differ in the percentage of spaces filled with water in the rock, i.e. rock porosity*. The degree of porosity can be inherent or the result of weathering that dissolves the rock. Recent sands (like dune sand) or sands deposited by the sea during the Secondary and Tertiary eras, sometimes over very large areas, are extremely porous. They can contain 100 to 200 litres of water per m^3, whereas sandstone, which is cemented sand, contains no water at all except in its cracks and fissures.

The limestone family includes very porous rocks, like chalk, as well as impermeable rocks like marble. Limestone rocks, because of their nature, tend to crack, sometimes forming underground rivers and even lakes, as in the karsts of the Causses plateaux in the southern Massif Central.

Crystalline rocks, like schists and most granites, are not very porous: water can only slip through cracks caused by the formation of mountain ranges. The porosity of volcanic rocks is variable: some can remain compact and sterile while others form fertile soils and excellent aquifers, like the pozzolans and cinders confined below the basalt layers in the Chaine des Puys in Auvergne.

The River Somme floods

When rivers burst their banks, this is not only due to runoff from heavy rainfall: groundwaters can also have a fundamental role in floods and their severity. This proved to be the case when the Somme River caused severe flooding in the spring of 2001. After several years with high rainfall, the water tables rose considerably: the subterranean reservoir feeding the tributaries of the Somme overflowed into the rivers, which in turn overflowed into the Somme valley. These observations formed the basis for the flood forecasting models developed for the Somme valley, to support an early warning system to alert populations and take protective measures.



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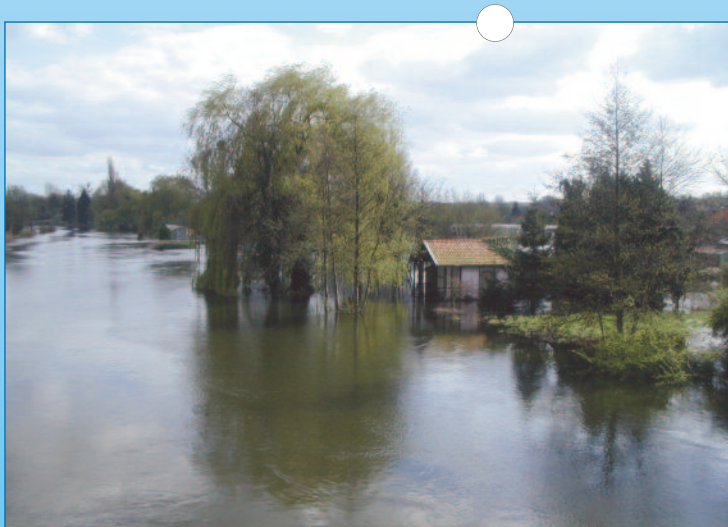
A case of water table rebound

The Somme catchment basin has a 200-metre thick chalk substrate. As the chalk is very porous, it can store large quantities of water, and because of its permeability*, water travels easily between different rocks, hence the fundamental role of groundwater in this particular flood.

The River Somme floods

Here at the Pont Vert in Amiens on 8 April 2001, the mechanism that caused the water table to overflow proceeded very slowly.



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From well-diggers to hydrogeologists

Knowledge on groundwaters is quite recent. It took off in the 19th century, thanks to researchers' discoveries and increasing demand for freshwater.

THE FIRST HYDROGEOLOGICAL MAP (1862)

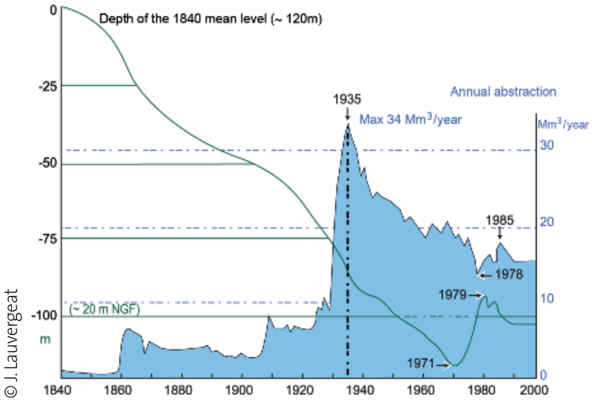
This hydrogeological map of the Seine *département*, commissioned from the engineer Delesse by Georges Haussmann, the Prefect of Paris, shows water tables and their contour lines, the Seine *département's* geology and its rivers.

Magical water

In the past, towns and villages were often established on sites close to groundwater springs. These places came to be seen as sacred, since freshwater is essential to life. Very soon, people also began to dig wells, which first appeared in the Neolithic with the spread of farming and the first sedentary communities. Dowsers would be called to show where wells should be dug. Dowsing, or "rhabdomancy" (from the Greek *rhabdos* for rod and *manteia* for divination) is a very ancient art: 8000 year-old rock engravings in the Tassili, in the heart of the Sahara, show water dowsers in action. But despite their skills and the devoted care of well diggers (who were responsible for maintaining both water wells and the channels feeding them), the real nature of groundwaters remained a mystery for a very long time. In the Middle Ages, for example, wells were used for water supplies but sometimes as rubbish tips for household waste and animal carcasses, with no thought given to the waters running below ground and how they were connected to the well-water, which was a major cause of epidemics until the end of the 19th century. Groundwater pollution is not a recent problem, any more than wells that dry out, but it was not until hydrogeologists came onto the scene with their discoveries on groundwaters that people began to understand the scientific reasons for these problems.

The birth of a discipline

The term hydrogeology* was first used by the French biologist and palaeontologist Jean-Baptiste Lamarck. In a collection of studies published in 1802, he used the term to mean "studies on the influence of water on the surface of the Earth". Although the term did not directly concern groundwater, Lamarck's insights laid the initial foundations for this scientific discipline. The first piezometric map* (the hydrological map for the Seine *département*) was plotted by Delesse in 1862. Knowledge at the time was based on the mechanics of water movement in porous environments. Hydrogeology thus branched out from the rapidly developing Earth sciences as it drew on advances in geological mapping,



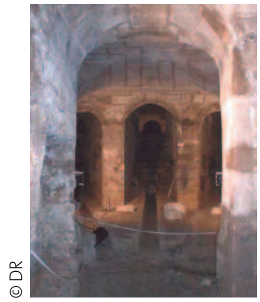
Changing levels of the Albien water table in Paris according to water quantities abstracted.

Abstraction levels dropped as soon as the 1935 decree came into force.

which was encouraged in particular by the corps of mining engineers. The first hydrogeology theoreticians and practitioners in France were therefore engineers and Ecole Polytechnique graduates who had practical aims for urban drinking water supplies. Héricart de Thury, Arago, Belgrand, Dupuit, Dausse and Darcy were some of these pioneers. The latter became famous for a law that bears his name, Darcy's Law, which became one of the cornerstones of hydrogeology. Thanks to Darcy's discovery, it took just one more century to understand the main outlines of hydrogeological conditions in France.

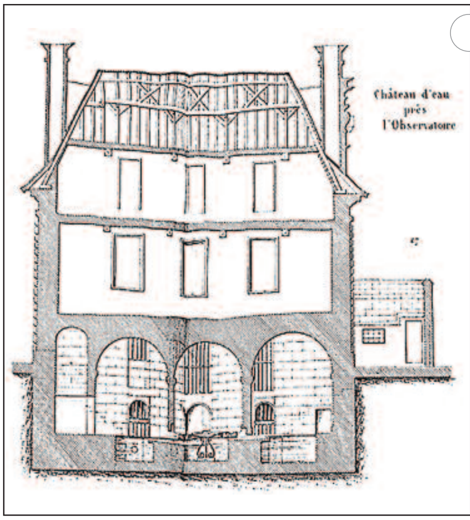
Early protective measures

In the 20th century, knowledge on hydrogeology further improved with new discoveries, for example in North Africa. The work of pioneering hydrogeologists in Africa greatly enriched the discipline. In the 1930s, Henri Schoeller laid the foundations for geochemistry through his studies of the thermal properties of groundwater in Aquitaine and the Maghreb. With economic development, demand for groundwater rapidly increased, drawing heavily on the artesian aquifers discovered earlier in the Paris and Aquitaine basins, northern France and, later on, in the Sahara. Drilling for groundwater expanded steadily. In France, abstraction from aquifers increased throughout the first half of the 20th century. The Albien green sands aquifer, in the centre of the Paris basin, was very heavily used, and an alarming drop in pressure was the reason for the first public groundwater conservation measure, when a decree issued in 1935 introduced a well-drilling licence. The idea of protecting the quality of water resources lying directly beneath drinking water abstraction points also emerged in the early 20th century. Protection areas around water abstraction points were first mentioned officially in the first Public Health Act of 1902, thanks to Edouard-Alfred Martel, the founding father of speleology.



The "Maison du fontainier"

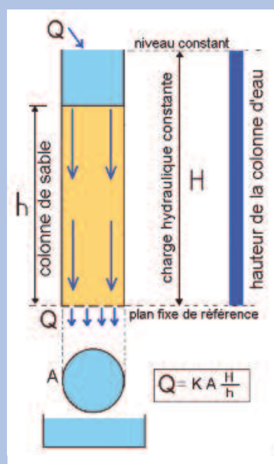
In the 17th century, water captured from the clay plateau around Rungis was channelled through the Médicis aqueduct to the "Maison du Fontainier" (the "well driller' s house", which became the water tower at the Observatoire in Paris). There, it was fed into three basins, one for the King (photo), for the water features at the Luxembourg Palace and the Palais-Royal, another for the city' s public fountains on the Left Bank and the third for the entrepreneur, which also supplied the Carmelite nunnery.



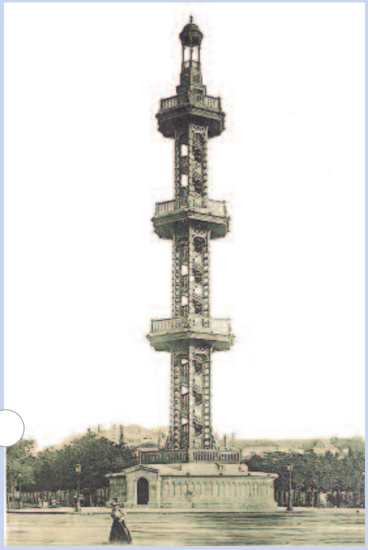
Darcy's Law

Henry Darcy, a public works engineer and graduate of the Ecole Polytechnique, was born in Dijon in 1803. In 1856, while in charge of modernizing water supplies to his native town, he discovered the law that governs water flow through a porous environment: "the volume of the flow is proportional to the charge and in inverse proportion to the thickness of the layer it travels through". In other words, the larger the layer of water, the faster it percolates downwards. The initial formulation of this law has evolved to apply to other environments and other fluids (oil and gases).

In the diagram, Q is the flow rate, K the permeability coefficient of the porous environment and A the water surface.



The Grenelle Well



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By the end of the 19th century, Paris was experiencing water problems: local spring waters could no longer cover demand and river waters were already badly polluted. Exploratory drilling began, deep into the substrate below Paris where a vast aquifer was discovered in Mesozoic limestone. The first well drilled at the Reuilly crossroads was a failure: instead of gushing out, the water stayed a few metres below the mouth of the well. The Mayor of Paris, a geologist named Arago, commissioned a new well from Louis-Georges Mulot (1792-1872), who was well known for his successful well-drilling operations around Paris, in Normandy and around Tours. Work began on the 24th of December 1833 in the chosen site, the courtyard of the Grenelle slaughterhouse. The horse-drawn equipment was rudimentary, tools kept breaking and it was eight years before water finally gushed out, on the 26th of February 1841. Louis-Georges Mulot reached a depth of 548 metres, a considerable achievement in those days.

The grandfather of large-scale well-drilling projects

In 1841, the Grenelle well was producing 4 000 m^{3}per day, which gushed 33 m up into the air at a temperature of 27 °C. As abstraction continued, production steadily declined, dropping to 775 m^3 per day in 1861, until the Grenelle well was finally sealed off in 1903.

A new profession

By the mid-20th century, the importance of water problems was well established. Academic courses on the subject were introduced: the first professional hydrogeologists were trained at the Higher National School of Applied Geology in Nancy, established in 1945, or through Ph.D. studies, with the first diplomas awarded in 1959. In 1963, groundwater resource inventories were officially entrusted to the Bureau of Geological and Mining Research (BRGM), which had only handled mining research until then. The profession began to change: hydrogeologists would not only locate water, they also became its guardians. They became specialists in prospecting, assessing and conserving resources, providing guidance and advice to ensure that projects for groundwater use and management would be sustainable. Hydrogeology became the study of groundwaters and how they are influenced by human activities.

The approach for improving knowledge on resources became multidisciplinary, bringing in hydrogeochemistry*, the ecology and socioeconomics of groundwaters, studies for drilling sites, active management and research on the links with associated surface waters and land ecosystems. Hydrogeologists usually specialize in a particular field: geophysics, drilling, geochemistry or hydraulics. They may work in different areas: water table modelling, geophysics, depollution, pumping systems or protecting underground workings in aquifers.

State-approved hydrogeologists

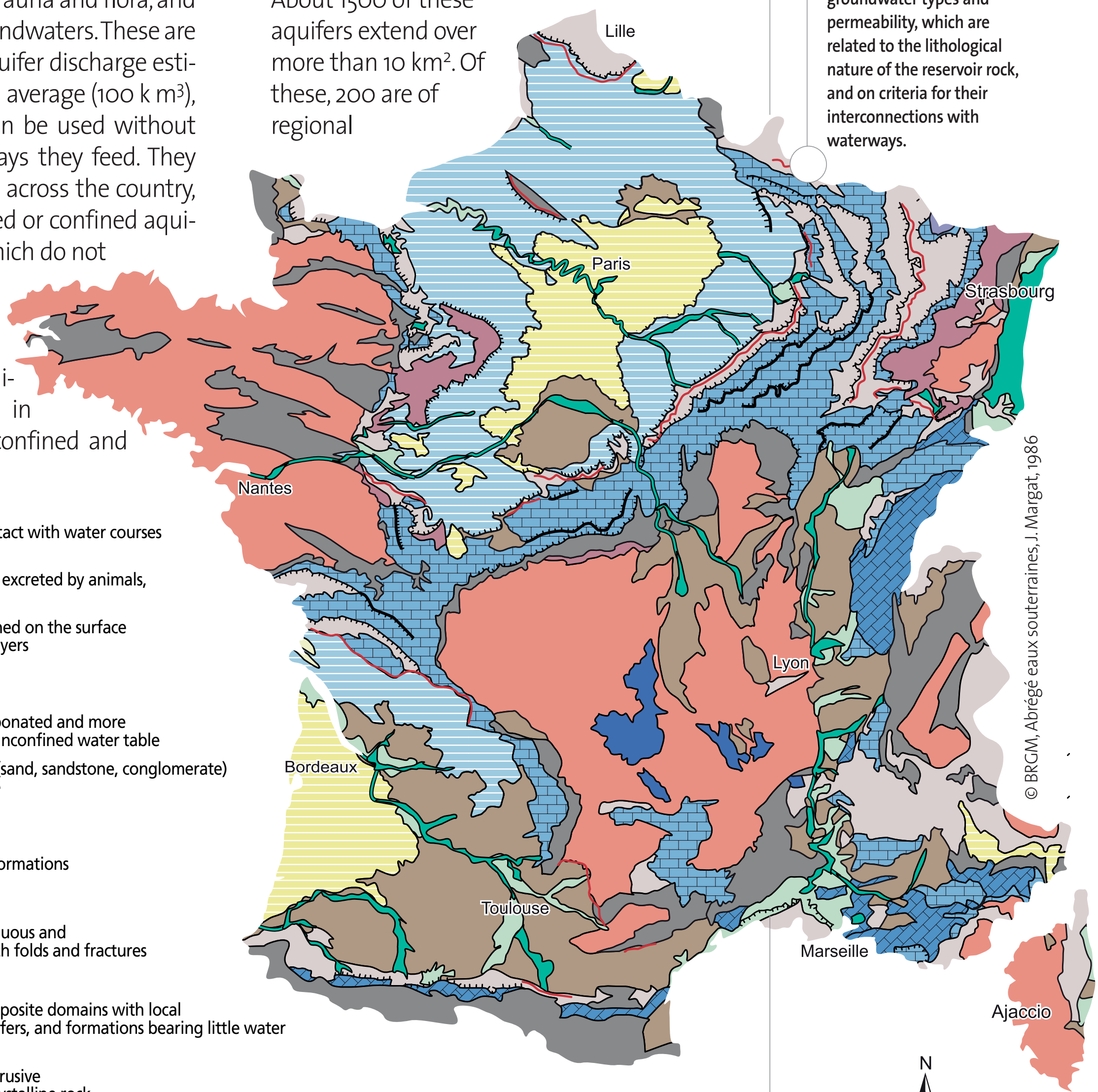
The Prefects appoint an approved hydrogeologist whenever there is a need for expert advice on the protection of water used for drinking water supplies. These experts are also involved in approval procedures for new public drinking water abstraction projects, for which they are required to advise on the amount of water available, the protection areas to be marked out around abstraction points, public easements and supporting activities. A hydrogeologist also has to be consulted in other cases, for example for wastewater releases into the soil, human burials outside cemeteries or burials of animal carcasses.

France's hidden wealth

France has an abundance of groundwaters but their quality and quantity have to be monitored.

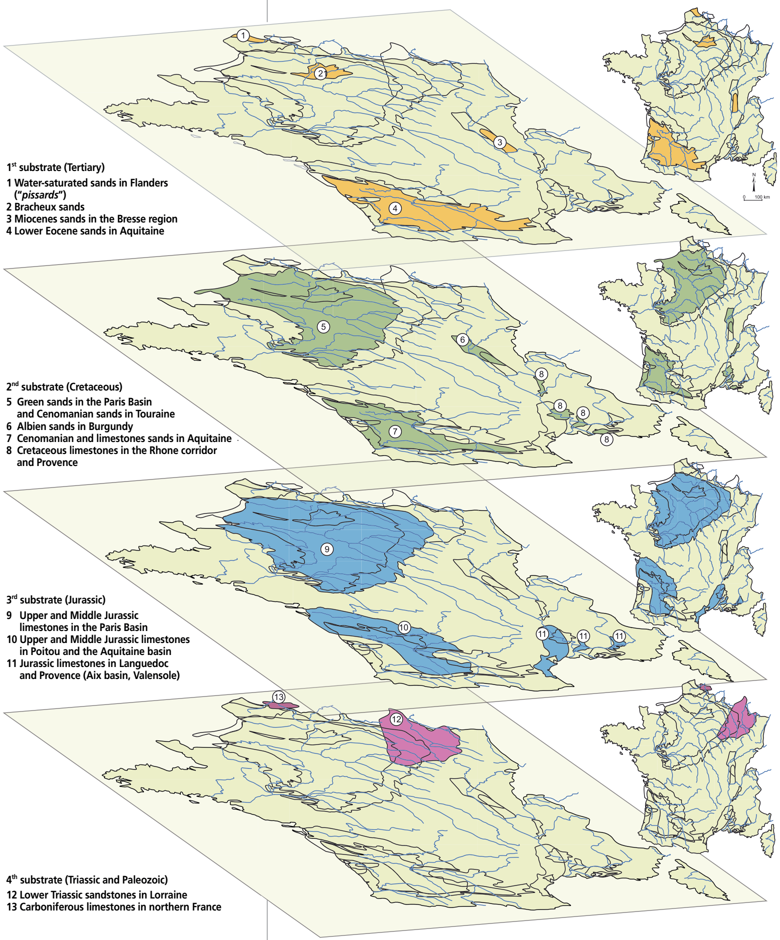
Waters with character

France is fortunate in its wide variety of climatic conditions, landscapes, fauna and flora, and the same is true of its groundwaters. These are abundant, with annual aquifer discharge estimated at 100 billion m³ on average (100 k m³), of which 20 billion m³ can be used without deteriorating the waterways they feed. They are also evenly distributed across the country, in a great many unconfined or confined aquifers. Even granite areas, which do not usually hold much water, contain groundwater in their cracks and fissures. About 6500 distinct aquifers have been identified in France. These include unconfined and confined aquifers, alluvial, karstic, fissured and multilayer aquifers, aquifers in bedrock and aquifers in wetlands. About 1500 of these aquifers extend over more than 10 km². Of these, 200 are of regional



STRUCTURAL HYDROGEOLOGICAL MAPS

Maps like these are based on structural criteria, groundwater types and permeability, which are related to the lithological nature of the reservoir rock, and on criteria for their interconnections with waterways.



© BRGM, Abrégé sur les eaux souterraines, Jean Margat, 1986

LARGE CONFINED AQUIFERS

Large sedimentary basins like the Paris and Aquitaine basins and, to a lesser extent, the Rhone corridor, contain layers of great hydrogeological importance and are all well protected against pollution.

importance, with an area of 100 km² to 100 000 km²; 25 of these are confined and 175 unconfined. The green sands aquifer in the Paris basin is one of the largest, extending over 75 000 km² and containing 400 billion m³ of water flowing from outcropping areas at a rate of only 2 metres per year, due to leakage through caprock and drainance.

The idea of aquifer systems* emerged when naturalist hydrogeologists combined their know-how with the laws of physics governing the behaviour of groundwaters, as formulated by hydraulic engineers. An aquifer system* is either confined between impermeable boundaries, through which no water can flow, or has open boundaries through which it can come into contact with surface waters. Within this system, everything is potentially interconnected, so that any water abstraction from a geographical zone can have repercussions on the entire system.

Aquifer systems are divided into five categories:

- Single-layer aquifers where the water is mainly unconfined (chalk aquifers and some extensive alluvial aquifers in Alsace and the Crau region).
- Single-layer aquifers where the water is mainly confined (green sands aquifer in the Paris basin, Triassic sandstone aquifer in Lorraine).
- Multilayer aquifers with or without unconfined water in the upper layer and significant internal drainance* (western Aquitaine, Beauce, Ile-de-France).
- Discontinuous karstic aquifers (perched aquifers in the Vercors, Vaucluse and Larzac, or continuing into confined waters as in the Quercy).
- Alluvial aquifers connecting with a river (Rhone valley aquifer).

The database for the French hydrogeology platform (BDRHF®) covers aquifer systems and hydrogeological domains as hydrogeological units, each of which is a functional unit in the subterranean environment.

To apply the EU Water Framework Directive (WFD), France has divided its groundwaters into eight districts and 503 water bodies*, based on their natural structure and on management criteria. 87% of these water bodies are unconfined and 13% confined.

Waters without borders

Within Europe, France is in a highly favourable position thanks to the abundance and diversity of its groundwaters. But groundwaters do not have borders: those along the Rhine and in northern France, for example, are managed collaboratively with the neighbouring countries. This can create difficulties: for example, the carboniferous limestone waters extending from the west of Belgium's Hainault region to the Lille-Roubaix-Tourcoing urban area in France are heavily used by both countries. Declining levels in France are directly linked to Belgium's water abstraction policy. This raises the problem of sustaining long-term supplies from confined transboundary groundwaters that recharge very slowly, as they are 15 000 years old in this case.

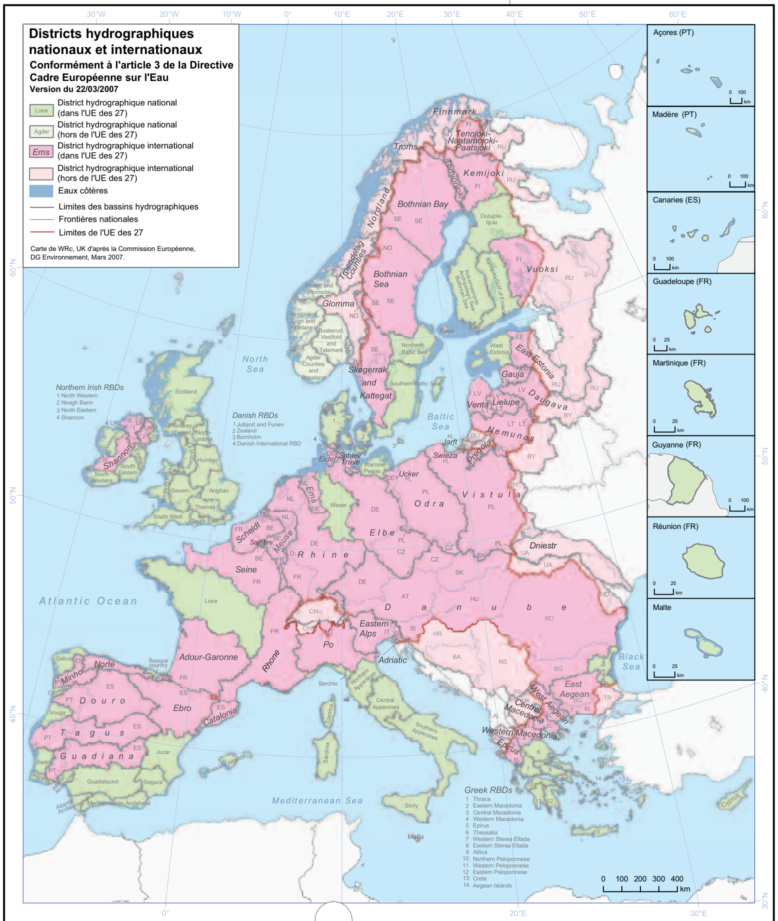
Annual groundwater discharge in some European countriese

France: 100 km³	Great Britain: 9,3 km³
Norway: 96 km³	Austria: 6 km³
Germany: 47,7 km³	Portugal: 5,9 km³
Italy: 43 km³	Netherlands: 4,5 km³
Spain: 30 km³	Denmark: 4,3 km³
Sweden: 20 km³	Switzerland: 2,5 km³
Ireland: 10,8 km³	Finland: 2,2 km³
Greece: 10,3 km³	1 km³ = 1 billion m³

Annual groundwater discharge in 10 countries with the largest resources

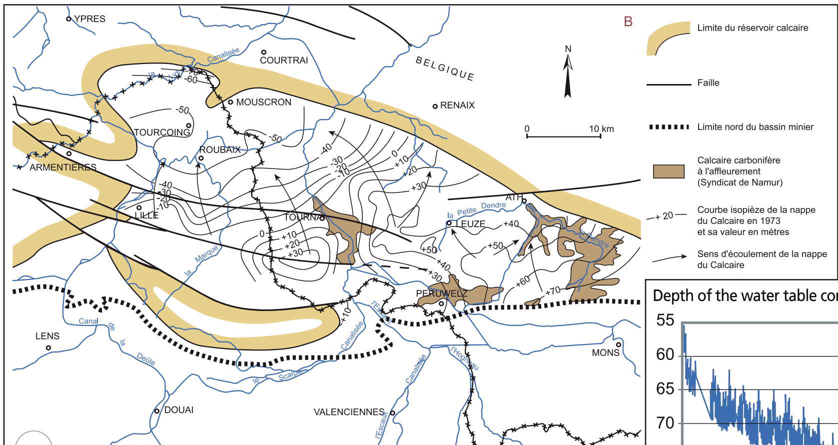
Brazil: 1 874 km³	Indonesia: 455 km³
United States: 1 300 km³	DR Congo: 421 km³
China: 829 km³	India: 418 km³
Russia: 728 km³	Canada: 370 km³
Colombia: 510 km³	Peru: 303 km³

Chiffres Aquastat FAO, 2007



Hydrographic districts in Europe

Under the EU Water Framework Directive, water resource management is organised by hydrographic districts: "a district is composed of one or more hydrographic basins and their associated groundwater and coastal waters, and is identified as the main unit for the management of river basins".

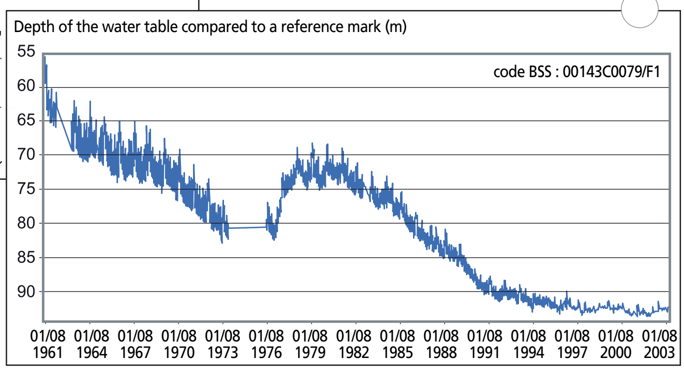


© J. Beckelynck et al, 1983

Franco-Belgian groundwaters

This carboniferous limestone aquifer extends from the west of Belgium's Hainault region to the Lille-Roubaix-Tourcoing urban area in France. It has been used by both countries since the late 19th century, which is now raising management problems for the longer term.

Piezometric variations in carbonated limestone at Bondues (near Tourcoing)



Chapter I.4

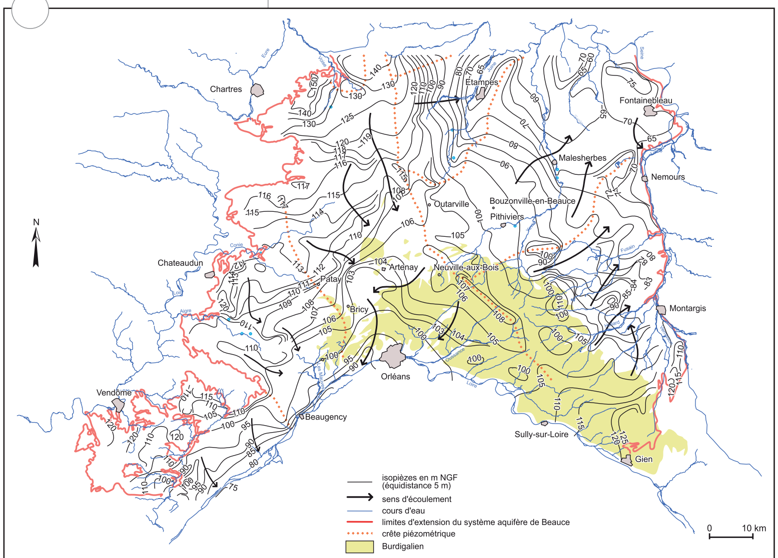
Collecting, measuring, modelling... to improve knowledge on water

There are different ways of observing groundwater quantity and quality, and management models have now been built up for many aquifers.

Using an aquifer demands sound hydrogeological knowledge of the terrain, supported by piezometric maps. These show the thickness and depth of groundwater bodies along with hydraulic and hydro-chemical parameters. These data are used to assess the resource against criteria for use, flow quality and available stocks. Depending on needs, a decision may be made to use the groundwater either by capturing it at a point where it wells up on the surface, or by drilling boreholes at different points in the aquifer zone.

PIEZOMETRIC MAP OF THE BEAUCE REGION

The Beauce aquifer system, which flows to the Seine and Loire catchment basins, has been closely monitored since the early 1970s through a network* of more than 50 measurement points.



MEASURING WATER DISCHARGE RATES

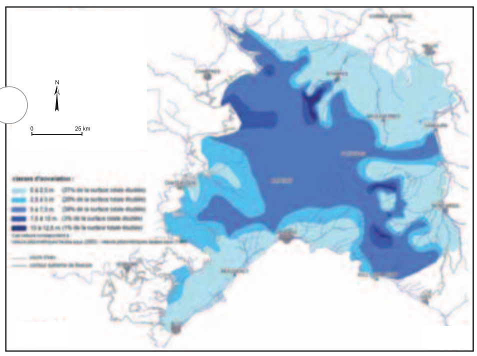
Micro-current-meters are used to measure flow rates from a spring.

Managing an aquifer demands the same data as for resource assessment, but managing it sustainably also requires other kinds of information, about the socio-economic context amongst others. Geological monitoring using drilling sections is essential, because the geology of the substrate can evolve and a porous environment may give way to an impermeable layer.

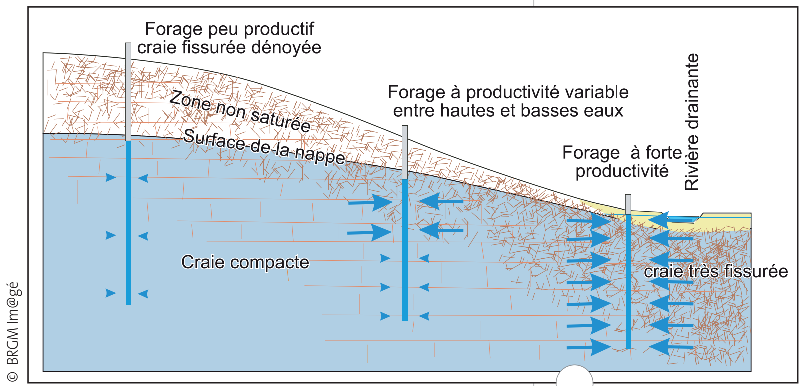
Trends in water levels and flows also have to be monitored. This information is obtained with piezometers, which show water levels, and flow-meters at gauging* stations. Groundwater monitoring is more demanding. Some measurements have to be taken

AQUIFERS CAN EVOLVE

Analyses of isovariations in the piezometric level of the Beauce water table, seen here between the low water period in 1994 and the high water period in 2002, are used to monitor trends and the effects of inertia.



on the spot because the substances concerned are fugitive and found in very low concentrations. Analysing the many different parameters set out in the regulations is also expensive. Health monitoring of water for human consumption is the responsibility of the State and requires water sampling and analyses by the devolved health authorities. The water agencies are responsible for developing specific monitoring networks to detect pollution at source.



A CHALK AQUIFER

The productivity of hydraulic installations depends on the topography: boreholes drilled into plateau areas can run dry, while those in river valleys can become saturated.

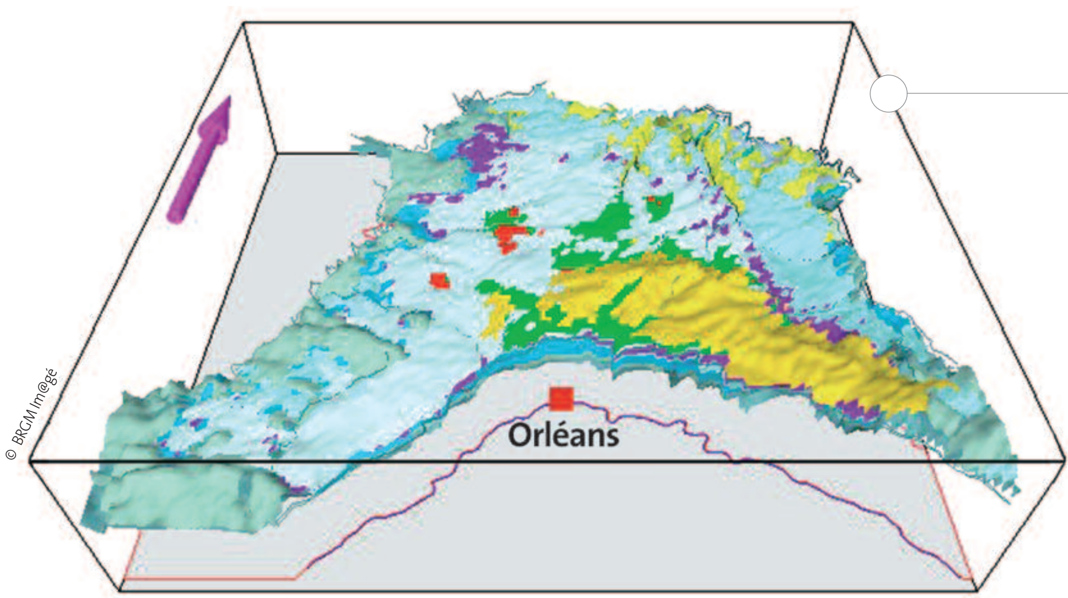
Quantitative resource monitoring

Piezometric monitoring over long periods shows trends in water table levels, which provide modelling input for forward scenarios.

The first piezometric measurements in France were made by industrialists, such as the Toury sugar company (Eure-et-Loir) in 1870 or the *Chemins de Fer du Nord* railway company in 1904. These piezometric networks have been greatly extended since then: there are now almost 2 500 piezometers operating in mainland France. Hydrogeologists have been contributing to piezometric map* surveys for many years.

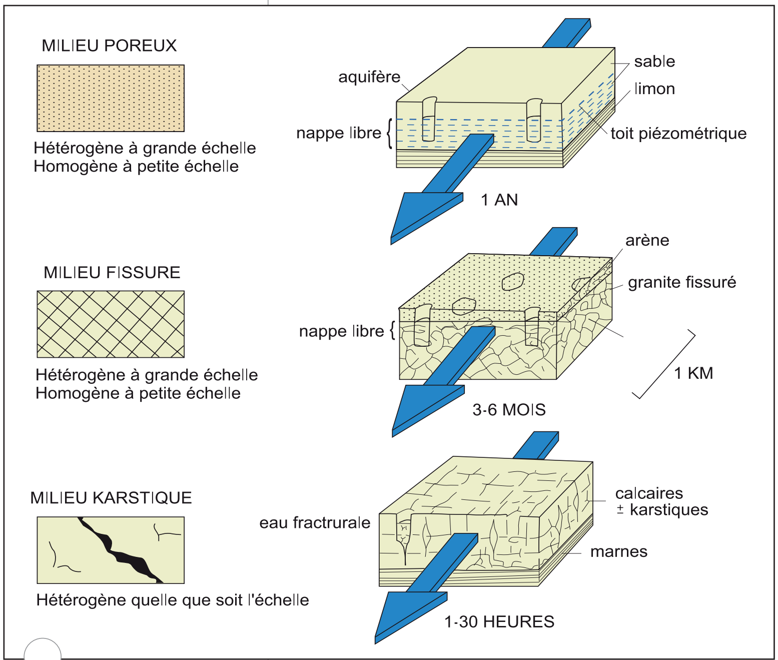
Modelling to support forward planning

When making decisions, a hydrogeologist has to anticipate the behaviour of the groundwater body. However, although long-term monitoring can reveal long-term resource degradation or overabstraction, there is no simple formula that can determine exactly what the condition of groundwater might be in the future, because of the complexity of aquifers and groundwater regimes. Mathematical models can be used to make predictions according to different parameters - for example, depending on the precipitation parameter, the level of a water table or its



3D MODEL OF THE BEAUCE AQUIFER SYSTEM

This is a complex system of superimposed and interconnected water bodies. 3D models are used to help optimize their use over the long term.



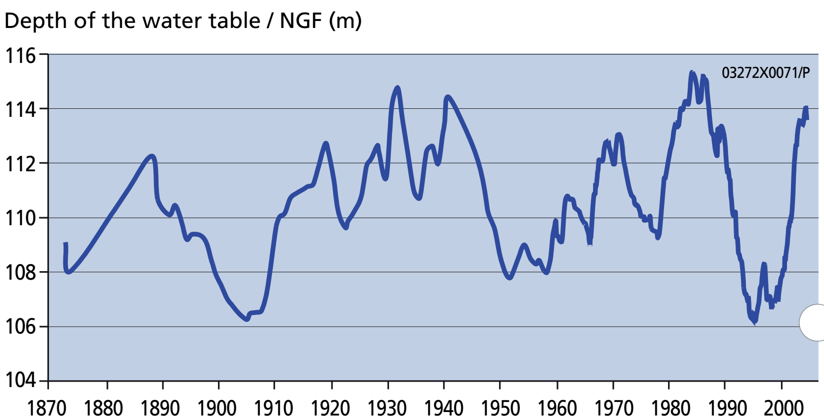
The discharge rate of an aquifer depends on its permeability*

The transfer of the same volume of water over the same distance (about 1 km) can take several years in alluvial and porous environments, a few months in fissured* environments and a few days, even a few hours, in karstic environments.

nitrate concentrations at a particular point can be predicted, assuming that the groundwater body will always react in the same way. Automatic recording devices may be used but the value of their measurements is limited: models simulating subterranean flows produce more reliable predictions. Initially, hydrogeologists worked with "physical" hydraulic models that reproduced the phenomena studied on a small scale. These models have now been replaced with simulation software (the simulations are either deterministic, when the percolation or flow patterns are known, or stochastic, i.e. probabilistic, when the phenomena are not really understood). The characteristics of the aquifer are computerized and processed through a fine-grid system. At present, modelling methods can predict the influence of abstraction or engineering work on the condition of a groundwater body, its salt content and the route and rate of propagation of a pollutant. This information can be combined with economic data to generate decision-support models. Management models, on the other hand, are fairly representative hydrodynamic simulation models* showing the constraints that will affect abstraction scenarios.

A piezometer

This apparatus is used to measure the piezometric level at a given point in an aquifer system. By recording the pressure at this point, it shows the level of unconfined water or the amount of pressure.



Piezometric variations in the Beauce water table at the Toury sugar mill (28)

The two biggest known drops in the level of the water table were recorded in 1906 and in 1993, following several consecutive years of low rainfall. The levels are about the same, although abstraction from the water table was virtually nil at the start of the 20th century.

Part II

The right quality and the right quantity for water's multiple uses

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France has an abundance of groundwater, which is usually of better quality than surface waters.
However, because the renewal process is slow, groundwaters are very vulnerable.

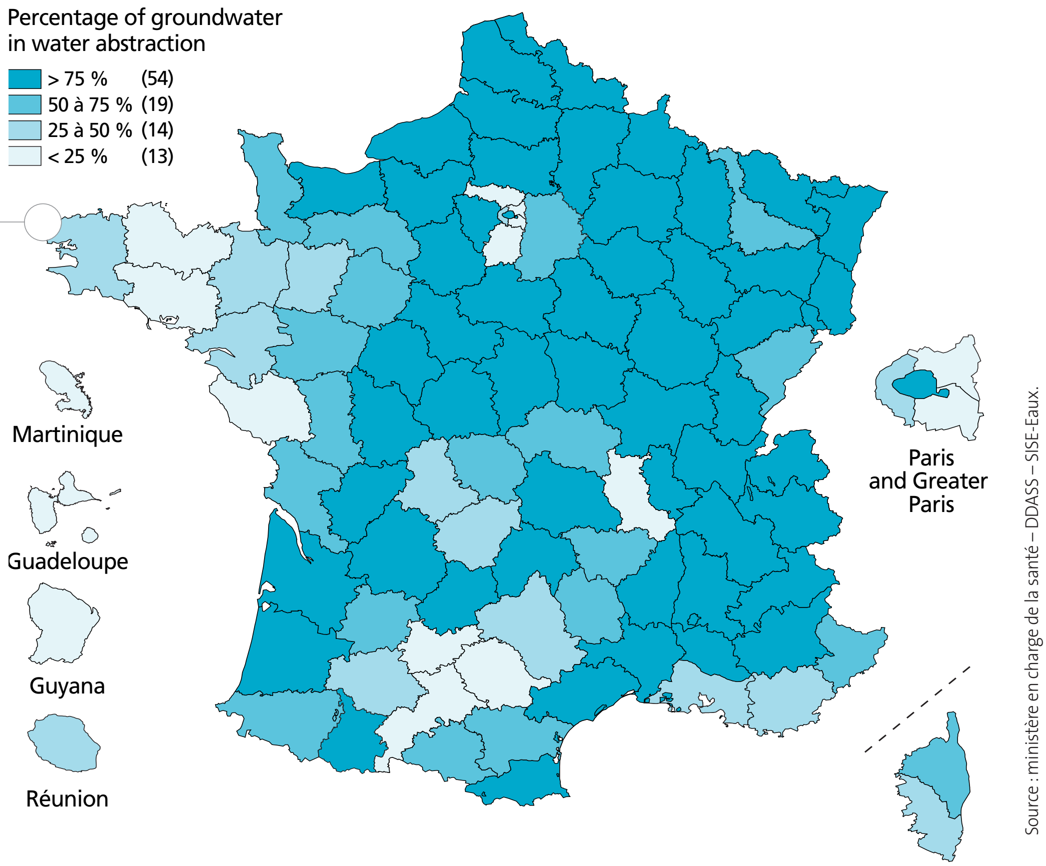
Water is precious

Groundwater is used for many purposes, from drinking water supplies to domestic heating.

What do we use groundwater for?

In an average year, France uses some 34 billion m^3 of water to supply the population's needs (for drinking water production, industry, irrigation, cooling for power plants, etc.). Groundwaters account for 19% of the total volume, or 6 billion m^3. Compared with the 100 billion m^3 feeding into aquifers in an average year, this may seem very little. However, the figure varies from one sector or region to another: some groundwaters (Eocene aquifers in the Bordeaux region, Carboniferous limestone aquifers in the north) are very heavily used and their levels are steadily dropping. Taking water from underground does not have the same consequences as taking it from a river. Wastewater is released into rivers, not into groundwaters, although leakage from sewerage networks and irrigation water eventually reach them.

More than half of the 6 billion m^3 abstracted each year is for drinking water production. This is because groundwater is often of more



SOURCES OF DRINKING WATER IN EACH *DÉPARTEMENT*

More than 95% of drinking water abstraction points take water from underground. Altogether, groundwaters account for 67% of the total volume used for drinking water, and for more than 50% in 73 *départements*.

Uses	Volumes abstracted	
	In million m³	% of total abstraction
Drinking water production	3 713	59
Industry	1 480	23
Irrigation	1 110	18
Energy production	19	< 0,5
Total	6 322	

Source : agences de l'Eau - SIE

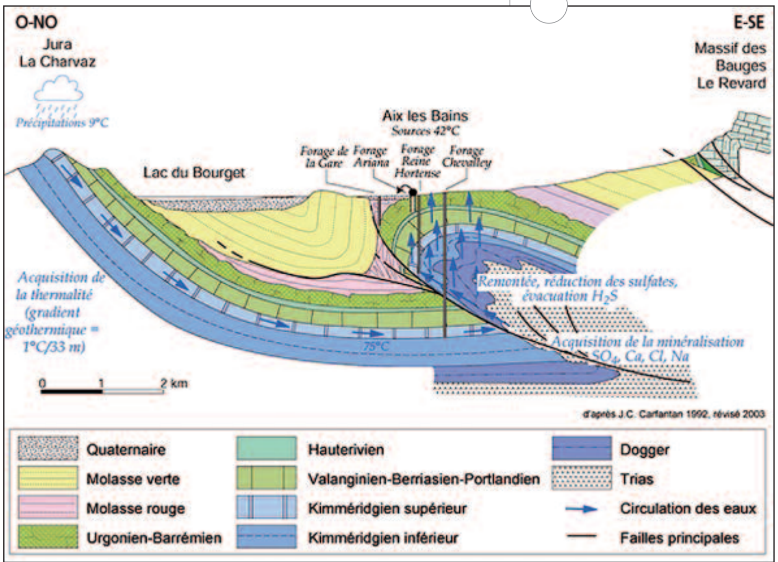
constant and better quality, since it is usually much less polluted than surface water. The rest is used for industry, irrigation and intermittently as cooling water for conventional or nuclear power plants. Sedimentary regions like Alsace and the Paris and Aquitaine basins or the Rhone valley, which have large reserves, use groundwaters heavily, while bedrock regions (Alps, Brittany, Corsica, Massif Central) tend to use more river water.

Natural mineral waters

Natural mineral waters* (as defined in Articles R. 1322-2 et 3 of the public health code) are a valuable resource for the 104 spa towns in France. Emerging from a spring or well, mineral waters gradually acquire their unique characteristics, mineral content and temperature through exchanges with the rock as they travel through the substrate. Some of the best-known mineral waters are very young, no more than a few months or a few decades old. In the Evian region, for example, the water completes its underground journey in only 15 to 40 years, while in the Contrexéville region in the Vosges range, the journey takes

Mineral water cycles

The mineral waters of Aix-les-Bains are fed by rain and snow falling on the mountains, and flow below the Bourget Lake.



© G. Nicoud, A. Paillet, laboratoire Edytem, d'après J.-C. Carfatan

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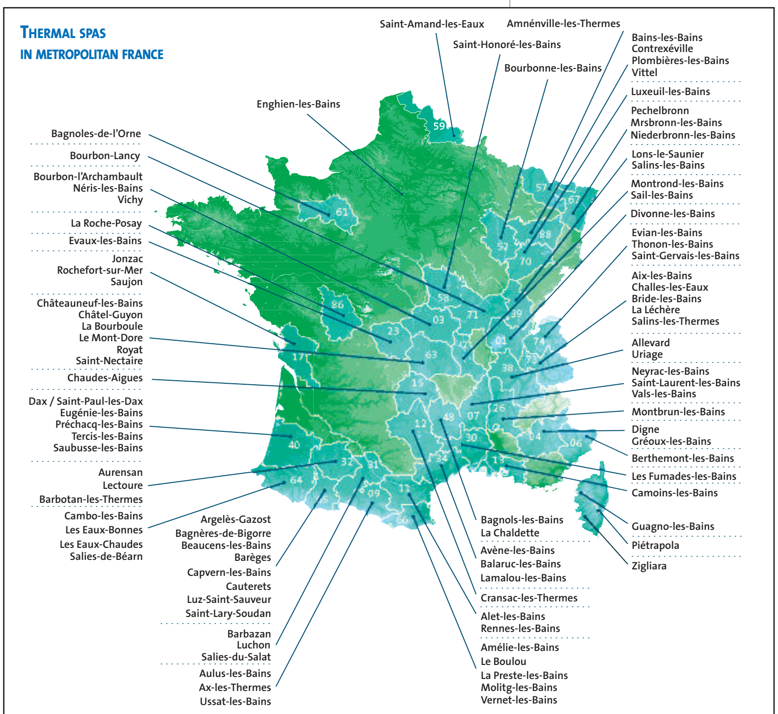
A spa in Auvergne

Every year, more than 500 000 people spend an average of 18 days taking the waters in spa towns. France has more than 700 known springs and 400 in operation, accounting for 20% of spa resources across Europe.

Thermal spas in metropolitan France



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For a long time, it was believed that ferruginous water could prevent alcoholism, as "a substitute for the iron content of alcohol".

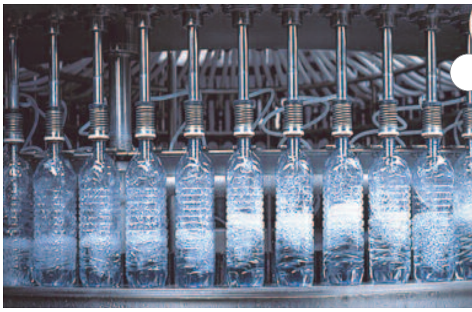
The Vic-sur-Cèr spring (Cantal)

In 2007, France was Europe' s 5th largest consumer of bottled water, with 122 litres per person per year, after Italy (198), Germany (156), Spain (136) and Belgium (129).

© DR

50 years or more. Some are very much older: those at Luchon (Haute-Garonne) or Amélie-les-Bains (Pyrénées-Orientales) are almost 20 000 years old and reach the surface at 75°C. Mineral waters sometimes lie as much as 5 km below the surface, which protects them from pollution, although problems can occur: the risks arise at the point where a spring emerges from the ground, as the ones in use are often in urban surroundings.

To avoid any risk of pollution, protection areas are marked out on the surface, and the water has to be captured by drilling to



© Volvic

A mineral water production line

France has 110 brands of still, sparkling or flavoured water. Still water accounts for about 84% of the market in terms of volume, and only 50% in value.

Groundwaters for heat pumps

Studies are currently under way on the possible impacts of drilling boreholes for heat pumps into aquifers, and on overabstraction from alluvial water tables in urban areas for heating purposes.

© EnBW Energie Baden-Württemberg AG

a sufficient depth to prevent the pressure drop that occurs near the surface from allowing polluted surface waters to enter the channels carrying the mineral water.
"Spring waters" make up another category. Despite their name, they are often captured from boreholes. They are recognized as "spring waters" not for any therapeutic value, but against potability criteria. Sales of bottled water increased rapidly until early this century, despite the fact that the quality of bottled spring water (Article R. 1321-84 of the public health code) is no better than most tap water in France, and some mineral waters do not meet the potability standards set out in the public health code.

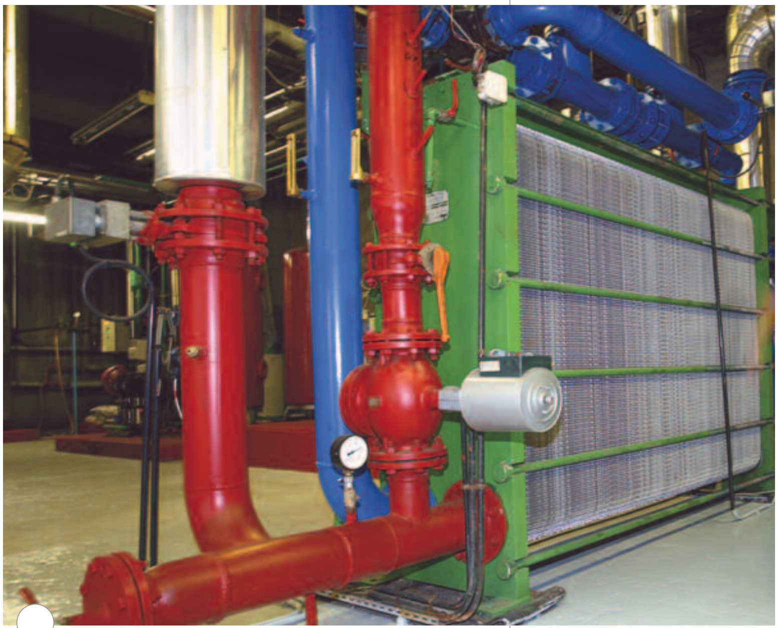
Geothermal waters

Groundwaters are also used to supply heat. The temperature of groundwater increases by 3.3°C on average with every hundred meters in depth as it is heated by the substrate. The hot water extracted is used for heating, and the steam to produce electricity. High-temperature geothermal resources that can be used to produce electricity are found in overseas France, in association with present or recent volcanic activity in these regions. A 15 MW geothermal power plant is operating in Guadeloupe, covering 7% of electricity demand on the island.

In mainland France, a new technique is being tested, which involves injecting water into deep, fractured, hot dry rock. A research programme began in 1987, in Soultz-sous-Forêts (Bas-Rhin), under a European collaborative project to trap steam for electricity production. An experimental 1.5 MW plant was brought into commission in 2008.

Meanwhile, nearer the surface, France has an abundance of diffuse heat which is now being extracted by 65 single, double or triple flow geothermal plants. Production is mainly for urban heating networks, which supply heat and domestic hot water for about 200 000 homes. These geothermal plants draw up hot water from the deeper layers of the water body. They are now required to reinject it into the substrate after extracting the necessary calories. This regulation was introduced to ensure that the groundwater is renewed.

Groundwaters up to 100 m in depth are increasingly used with geothermal heat pumps for heating and air-conditioning in buildings. These plants usually have two wells: the “production” well is used to extract the water; the second well, drilled more than 10 m away from the first, reinjects water into the aquifer to avoid releasing it at the surface. Geothermal heat pump installations are subject to an administrative declaration, to prevent badly installed systems from degrading groundwaters.



A geothermal plant

The geothermal fluid transfers its heat via a plate exchanger to a hot water circuit that supplies heat to users.

The Bouillante geothermal plant (Guadeloupe)

The 15 MW plant at Bouillante is now covering 7% of Guadeloupe’ s electricity demand. Production should increase in future thanks to the potential of the Bouillante geothermal reservoir.

Is groundwater being properly used?

Chapter II.2

The risk of water scarcity is virtually nil in France in terms of quantity, but demand varies depending on seasons and regions.

When rainfall is abundant

In France, and in Europe overall, water resources usually cover demand. The volumes abstracted from groundwaters each year to meet the needs of human activities are smaller than usable reserves. Groundwater recharge essentially depends on rainfall. Total rainfall has tended to increase since 1946, with dry and rainy years alternating. The increase is mainly observed in autumn and winter and in the western and northern parts of France, while the south and south-east are getting drier.

The figure for average annual precipitation in mainland France now stands at 479 billion m³. Two thirds of this quantity returns to the atmosphere as water vapour. Only the remaining third, called effective rainfall*, runs off to replenish water tables. Different factors determine what becomes of rainwater: the volume and duration of precipitation, the season (temperature and hours of sunshine), and the slope and nature of the terrain.

Surface runoff feeds into rivers and streams and can also trigger floods. Only the remaining water gradually filters further down into the substrate. The amount of infiltration* depends on rock fissures and permeability* and on the state of the vegetation on the surface. The latter has a very important role: in spring and summer, the powerful suction effect of plant rootlets draws up the water, which is then evaporated by the foliage. Except in karstic environments, by far the largest share of rainfall - some 297 billion m³ - returns to the atmosphere through evapotranspiration during spring and summer, when plant growth is most active.

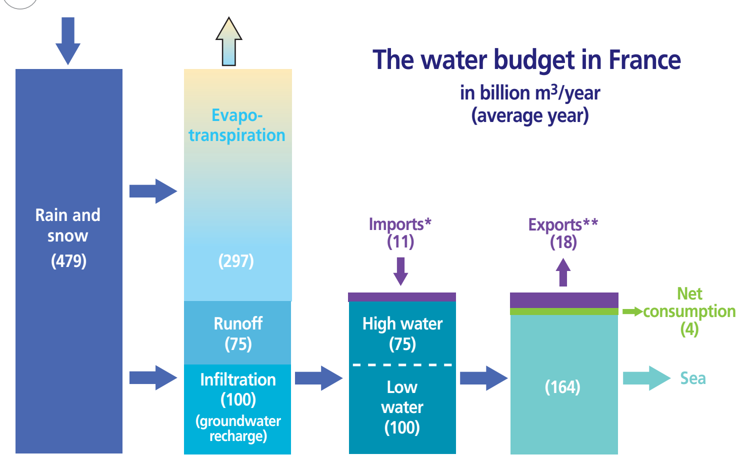
Water resources have to be considered in terms of flows, not stocks. As shown in the water cycle diagram on the left, the total annual volume of renewable water in France amounts to 182 billion m³, plus the inflow from neighbouring countries (11 billion m³) and minus the outflow via transboundary rivers (18 billion m³). Domestic resources therefore amount to 175 billion m³, of which 100 billion feed the country's aquifers. 164 billion m³ eventually reach the sea, and 4 billion are evaporated by human activity (net consumption).

When rainfall is too low

Groundwaters are mainly recharged between autumn and early spring. No infiltration occurs during the summer, even when rainfall is heavy.

THE WATER CYCLE IN MAINLAND FRANCE

100 billion m³ of water filter into the ground, recharging groundwaters, while surface runoff feeds into surface waters and springs, raises discharge levels in rivers and causes alluvial groundwaters to overflow.

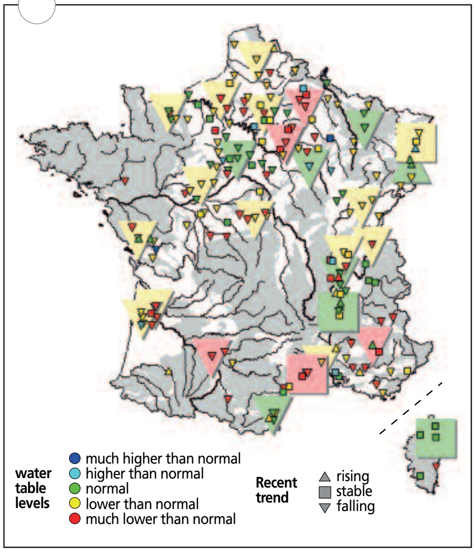


* Imports : water from the Rhone and Rhine **Exports : water from the Rhine, Lys, etc.

Source : MEEDDM - SIE - IFEN, 2006

Monitoring water table levels

Maps like this one are updated monthly (www.eaufrance.fr) to monitor change in water table levels.



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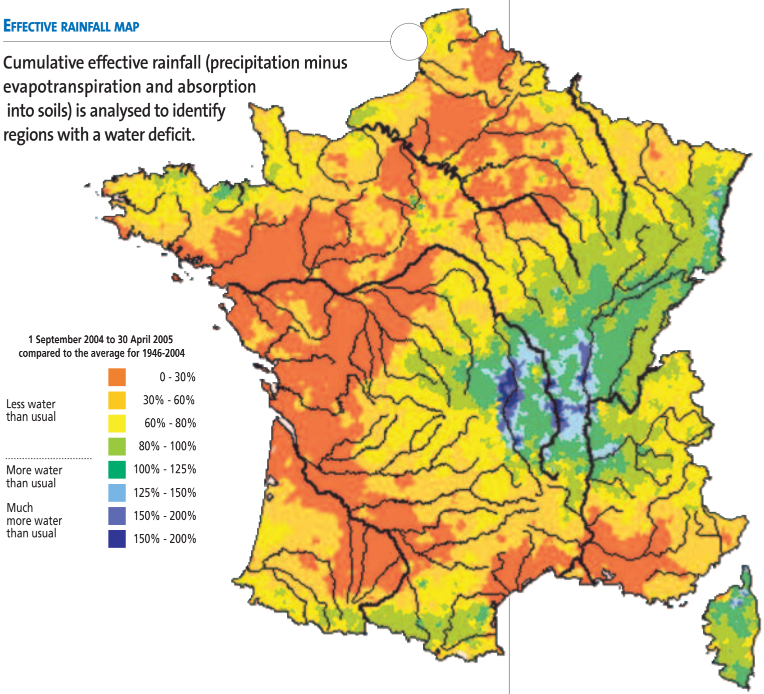
Effective rainfall map

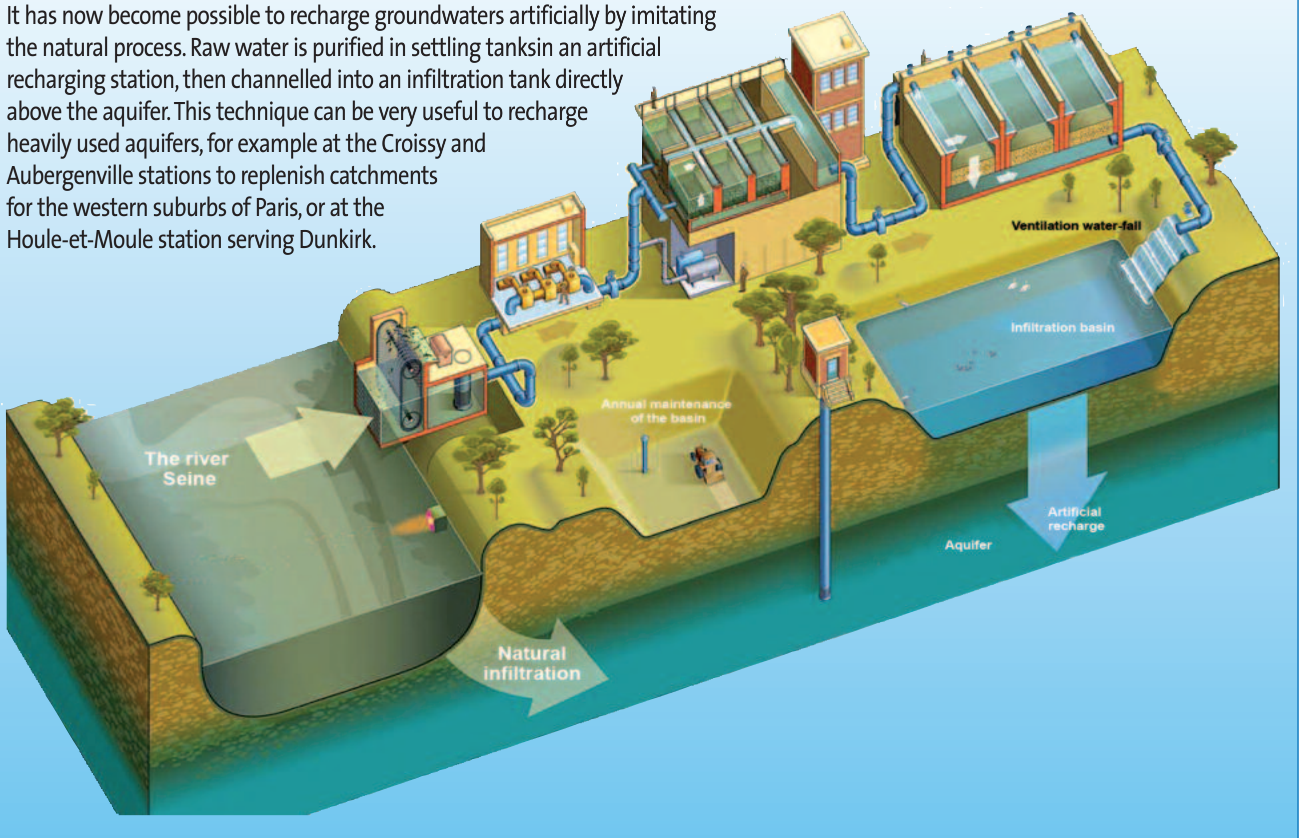
Cumulative effective rainfall (precipitation minus evapotranspiration and absorption into soils) is analysed to identify regions with a water deficit.



© Météo France

Recharging groundwaters artificially

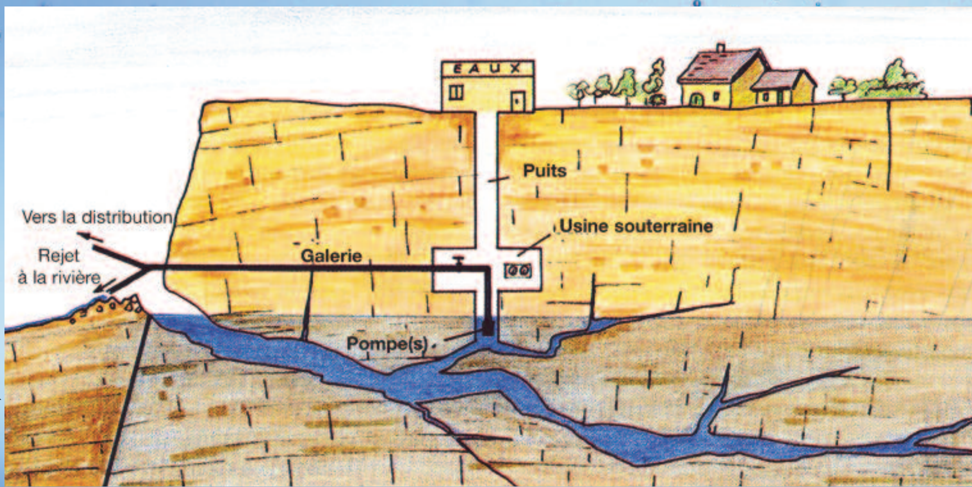
It has now become possible to recharge groundwaters artificially by imitating the natural process. Raw water is purified in settling tanksin an artificial recharging station, then channelled into an infiltration tank directly above the aquifer. This technique can be very useful to recharge heavily used aquifers, for example at the Croissy and Aubergenville stations to replenish catchments for the western suburbs of Paris, or at the Houle-et-Moule station serving Dunkirk.



© Lyonnaise des Eaux

Active management

Active groundwater management involves scaling up the regulating role of an aquifer by varying abstraction rates: increased abstraction during a dry year or season is compensated by reducing the flow at discharge points in winter and in wet years. The aquifer is thus handled rather like a dam reservoir. However, active management is the exception rather than the rule at present. One example in France is the karstic aquifer feeding the Lez River that supplies Montpellier's drinking water, which has been under active management for 20 years. Active management is also planned in the Drôme *département* and around Millau (Aveyron).



© J.-J. Collin, "Les eaux souterraines"

Deep borehole at the River Lez source supplying the city of Montpellier.

The severe droughts of 1976, 1989, 1992, 2003 and 2005 were essentially due to a succession of winters when not enough rain fell to recharge groundwaters, which dropped too low to feed into surface waters. When groundwaters are not sufficiently recharged, the entire surface water system is affected, since most aquifer systems connect with the surface water systems where exchanges and drainage take place.

During periods of drought, groundwater abstraction therefore has to be carefully managed as it affects the already low discharge of springs, rivers and coastal ponds. Rivers can become low and even dry up altogether, causing severe harm to the ecosystems that depend on them.

In years with a rainfall deficit, temporary water restrictions can be applied in some regions and resources may be unable to cover demand. Choices then have to be made. Essential needs will be covered, but some summertime uses (such as watering gardens, filling swimming pools, washing cars) will be restricted by order.

Groundwater quality in France

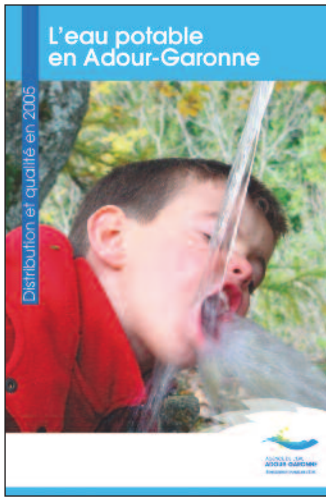
Almost all groundwater in France has to be treated to make sure it is fit for human consumption.

Water quality and health

Water quality is usually defined in terms of how it is used: the quality requirements for drinking water production and industrial uses are not the same. Water quality can also be assessed against its initial (heritage) state. This means there are several standards of water quality, depending on its uses and the relevant quality requirements. However, given that in France, 62% of all water volumes abstracted for human consumption are from groundwaters, the reference quality of the groundwater is usually calculated according to its suitability for drinking water production, while quality criteria are directly related to human health. Access to safe drinking water is a fundamental human right that over a billion people on Earth are still deprived of. Each year, almost 3.5 million deaths across the world are caused by a lack of clean, safe water and sanitation. In Western societies, the treatment of drinking water and protected areas around abstraction points, along with sewerage systems and wastewater treatment have gradually eradicated the major epidemic diseases such as cholera, dysentery and typhoid. However, this did not happen overnight. In France, a century elapsed (1850-1950) before Louis Pasteur's message was heard: "from the water, we drink 90% of our diseases". Furthermore, none of the advances in this area can be taken for granted. Epidemics of bacterial and viral gastroenteritis due to accidental pollution by faecal matter clearly show that any relaxation of surveillance can rapidly lead to health problems. However, as a general rule, groundwaters are safer than surface waters.

Natural quality problems

Even if it has not been polluted by human activity, groundwater is not necessarily fit for human consumption. Each body of

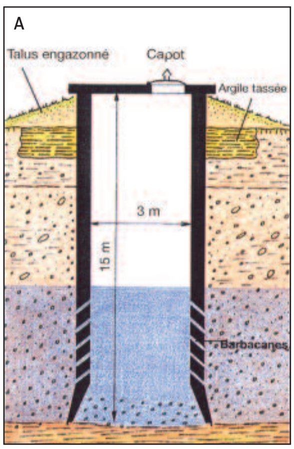


A brochure on drinking water quality

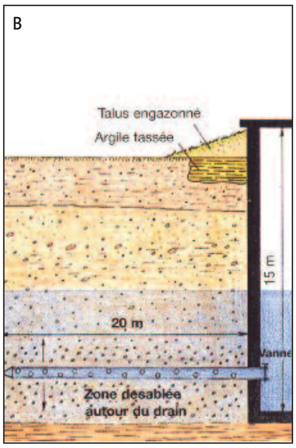
The EU Water Framework Directive emphasizes access to information, consultation, integrated approaches and effective public participation in the decision-making process.

The main groundwater collection systems

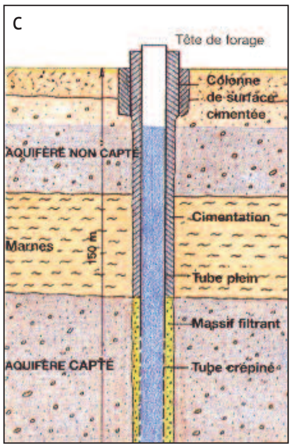
A: A conventional well tapping into alluvial groundwaters



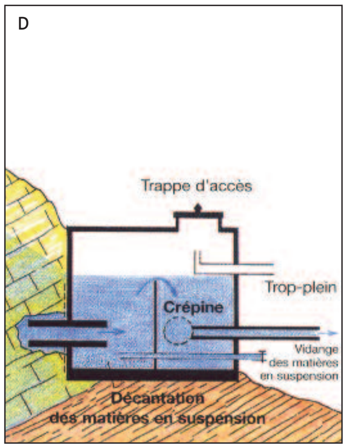
B: A radial well (half section)

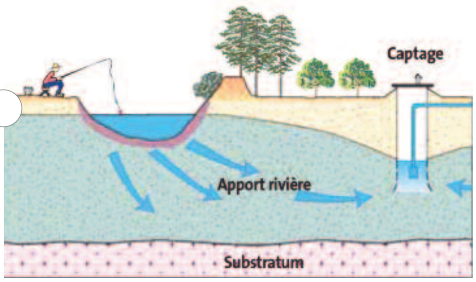


C: A standard borehole



D: Tapping a spring at the foot of a rocky bank





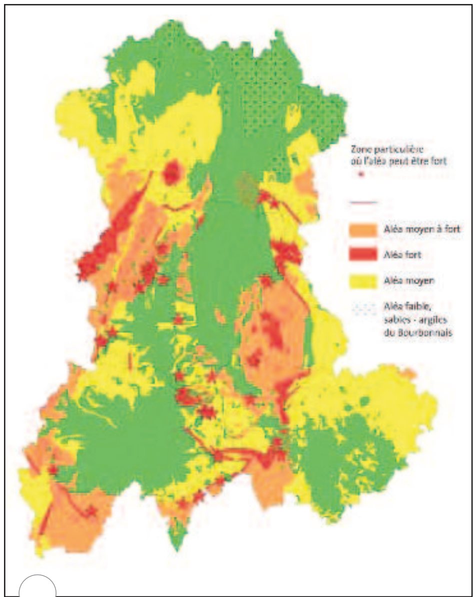
Filtering effect of river clay

The clay that tends to aggregate the first few centimetres of gravel in river beds helps to filter river water, thus helping to protect groundwaters.

groundwater is unique and its nature depends on the chemical composition of the rock it travels through.

Chemically pure water does not exist: even rainwater contains a few milligrams per litre of marine salts and atmospheric or natural pollutants carried in sea spray. However, it is mainly while it is filtering into the unsaturated zone that water becomes charged with dissolved salts and subsequently, during its underground journey, with mineral substances. Water gets its taste from common elements like calcium, magnesium, sodium and potassium, but it also contains many other chemical elements in small quantities, like fluorine, iodine, boron, iron, selenium or manganese. These are all essential to our health, but can become harmful in excessive amounts: since Paracelsus, it has been common knowledge that "the dose makes the poison".

Analyses made across France and Europe show that except for a few elements, concentrations of these substances in groundwaters are not in excess of standards for drinking water production. In some specific geological contexts, water can also become naturally charged with toxic elements such as arsenic, antimony or nickel. Natural arsenic has been detected in groundwater in some granite environments, for example, and antimony has been found in the Ardèche, Alps and the Cap Corse, as well as excessive nickel concentrations in some groundwater in the Artois-Picardy basin. Some coastal groundwaters also have an excessive salt content due to sea water intrusion, making them unfit for consumption. Other problems include water which is too hard (too much lime) or unsightly (high iron or manganese content).

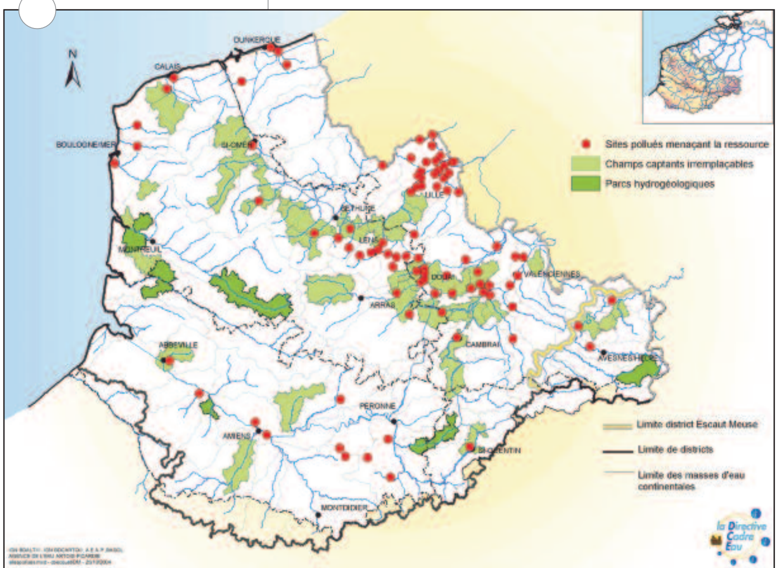


Map of arsenic hazards in groundwater in Auvergne

In this region, traces of natural arsenic have been found at some water supply points, sometimes at concentrations well above the 10 µg/litre potability standard. Maps like this one are used to support plans for new abstraction points.

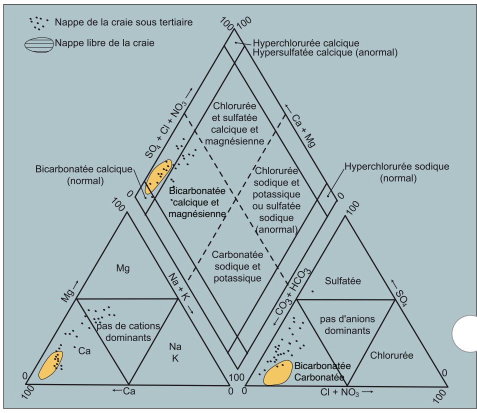
Polluted sites and soils in the Artois-Picardy region

Several polluted sites and soils in the Artois-Picardy basin have become a threat to the region' s water resources.

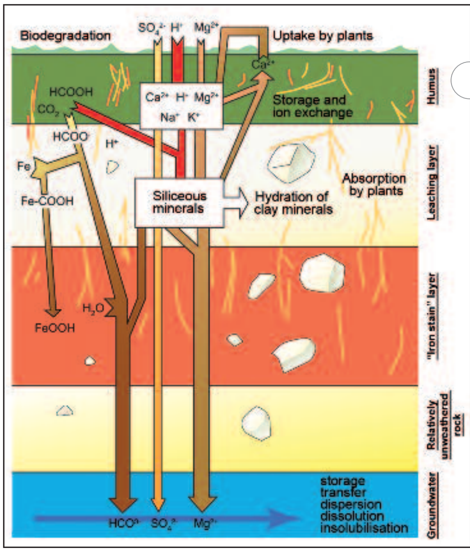


Diffuse pollution

Repeated and lasting diffuse pollution* is caused by sustained releases of pollutants that result from human activities. These substances are found over wide areas, and reach groundwaters when rainwater filtering into the ground draws them downwards. Diffuse pollution stems from defective sewage networks, acid rain, aerosols, industrial fumes and crop spraying residues. Heavy use of chemical fertilizers and pesticides is the main cause of water pollution. Excess nitrates in groundwaters contribute to eutrophication (by nitrate-fed green algae) in rivers and, as a result, in estuaries and along the coast. Nitrate quantities are kept down in household water supplies because of the



Source J.-Y.Caous, M. Caudron, 1983



© Atlas des eaux souterraines

Hydrochemistry of the chalk groundwaters in the Aisne *département*

These chalk waters have a high calcium bicarbonate content as well as a specifically local sulphate and magnesium content.

Mechanisms governing water/soil/plant and water/aquifer interactions

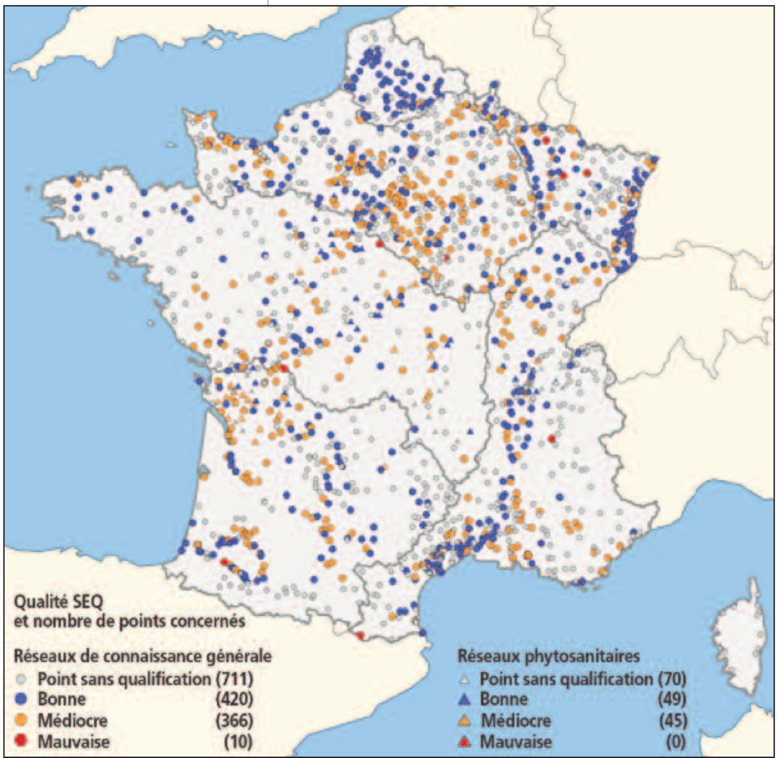
As rainwater percolates through the soil and subsoil, especially at the start of the process, it reacts with the solids it travels through in the porous environment and becomes charged with mineral salts. The composition of the water gradually reaches an equilibrium that endows it with its specific natural chemical qualities.

Fauna in groundwaters

Alluvial and karstic groundwaters harbour specific fauna, which are only beginning to be identified. In Europe, only one vertebrate is known to live in groundwaters, the olm, or cave salamander (*Proteus anguinus*), which is endemic to the subterranean rivers of Slovenia, Croatia, Bosnia-Herzegovina and the Trieste region in Italy. It has considerable heritage value, because as well as its adaptation to subterranean life (lack of pigmentation and eyes, slow development and sexual maturity at 15 years), it has a number of traits in common with primitive amphibians before they emerged onto land and into the air. Subterranean aquatic fauna also includes crustaceans, some of which are living fossils, as well as a wide variety of molluscs. They are thought to play a purifying role by assimilating organic matter or by bio-transforming or bio-accumulating certain pollutants. Most of these animals can serve as bio-indicators, as they are highly sensitive to the quality of the subterranean waters in which they live. Consequently, they are also highly vulnerable and some, like the cave salamander, are officially protected.

© Government Communication Office Slovenia

The olm, a protected amphibian living in subterraean rivers in Slovenia, Croatia and Bosnia-Herzegovina.

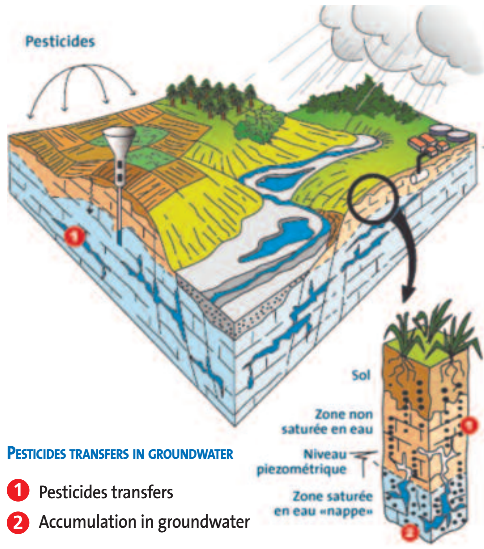


Groundwater quality in terms of pesticides

In 2006, in all of the groundwater analyses made in mainland France, 116 molecules out of the 443 being tested were quantified at least once. Glyphosate and diuron are the main pesticides (in number of occurrences analysed and number of different stations) responsible for the downgrading of measurement points to "poor quality" status (in general information networks and phytosanitary networks).

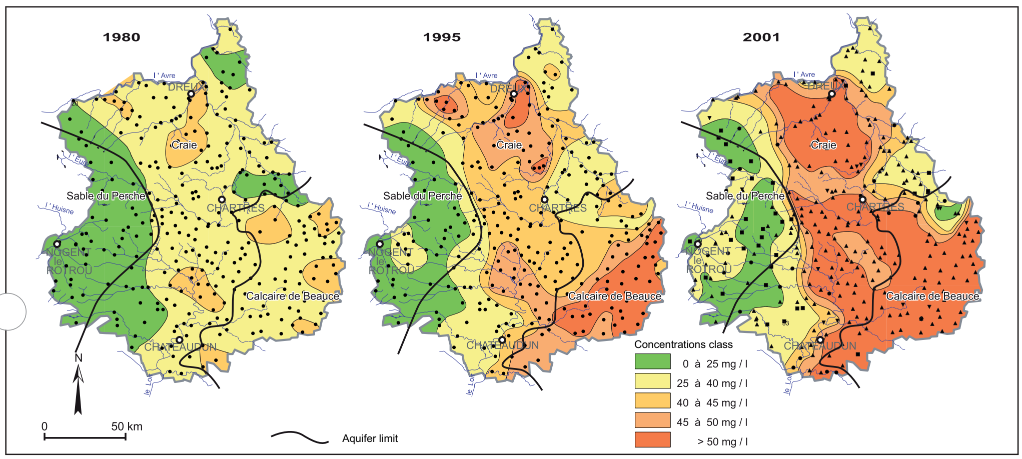
health risks of excessive concentrations, especially to babies. However, their presence in water reduces risks of biological infection. No serious health incidents linked to nitrates in water have been reported, as indicated in the national report on "Drinking water in France, 2005- 2006" published by the Directorate-General for Health. The French regions most seriously threatened by nitrate pollution are the North-west, the East (Alsace water table) and the Rhone Valley.

Most pesticide pollution is from agriculture, but green area and road maintenance also contribute, as well as gardening. In France, more than 500 phytosanitary molecules are authorized as ingredients in some 8000 products, and likely to be disseminated into the environment along with their degradation molecules. Improved analysis techniques show that these substances have already contaminated a great many aquifers. The regions most affected, as with nitrates, are intensive farming regions: the



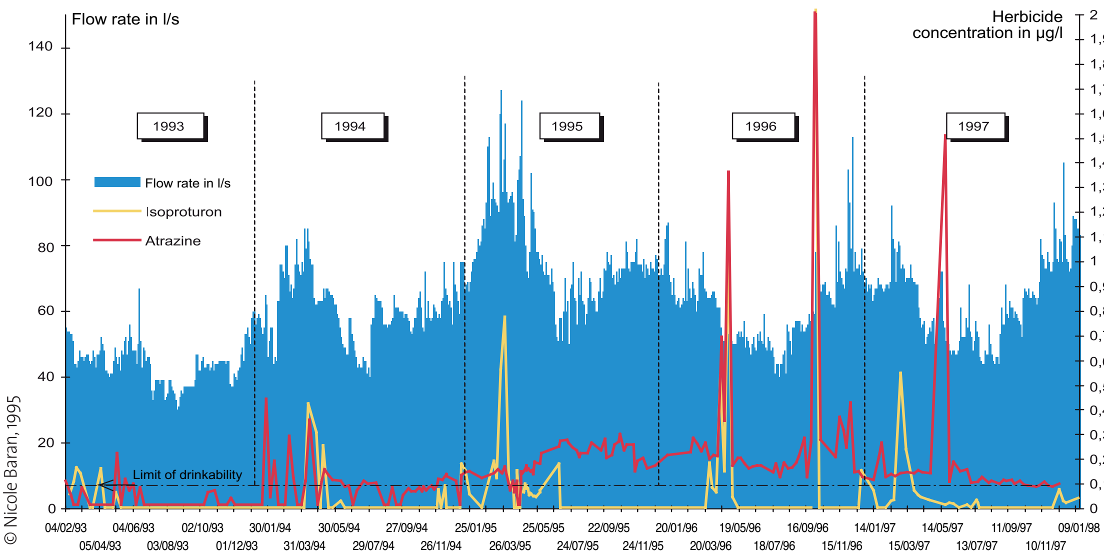
Pesticides transfers in groundwater

1 Pesticides transfers
2 Accumulation in groundwater



Trends in nitrate concentrations in the Eure-et-Loir *département*

These maps are based on average concentrations measured during statutory health inspections of water prior to treatment (raw water) in 1980, 1995 and 2001.



© Nicole Baran, 1995

VARIATIONS IN ATRAZINE AND ISOPROTURON CONCENTRATIONS AT THE JAURONNERIE SPRING (CHUELLES, 45) FED BY THE TROIS-FONTAINES KARST SYSTEM.

Atrazine, a maize herbicide which does not easily degrade and persists in the soil, is found during every high water episode, with short-duration peaks of concentration at close intervals. Isoproturon, an easily degradable herbicide used on wheat, only appears at the outflow when high water episodes occur soon after spraying.

Paris basin, the north-west quarter of France, agricultural lands in the south-west and the Rhone Valley. Chronic exposure, even at low doses, is the main risk factor for health (cancer).

Pollution from point sources

Groundwaters are also subject to pollution by overturned fuel trucks, accidental releases from

sed into a river, ruptured pipelines, illegal landfill, waste oil thrown into ditches, etc. Pollution by oil products is the most frequent. These make water unfit for consumption for decades, as a few drops are enough to contaminate one cubic meter of water. The protection areas provided for under Article L. 1321-2 of the public health code help to limit degradation by point source pollution, and depollution work has been undertaken in many places. As well as accidental pollution, effluent from former industrial sites is still present in the substrate because of the relative inertia of groundwaters, even though the sites may since have closed or adopted environmental standards. This "historical pollution" category includes toxic solvents from former industrial sites, sodium salts from potash mines and spoil

Groundwater monitoring networks	
Parameters measured	
In situ	T°, pH, conductivity, Eh
Major elements	HCO_3, CO_3, Cl, SO_4, Ca, Mg, Na, K
	Oxidizability, suspended matter, COD, F, Fe, Mn, SiO_2, NO_2, NO_3, NH_4
Mineral micro-pollutants	Sb, As, Al, B, Cd, Cr, Cu, CN, Hg, Ni, Pb, Se, Zn
Organic micro-pollutants/rural	Other pesticides (e.g. organochlorines)
	Pesticides (e.g. triazines, ureas)
Industrial/urban	COV, HAP, phenols

once or twice a year

once every 6 years

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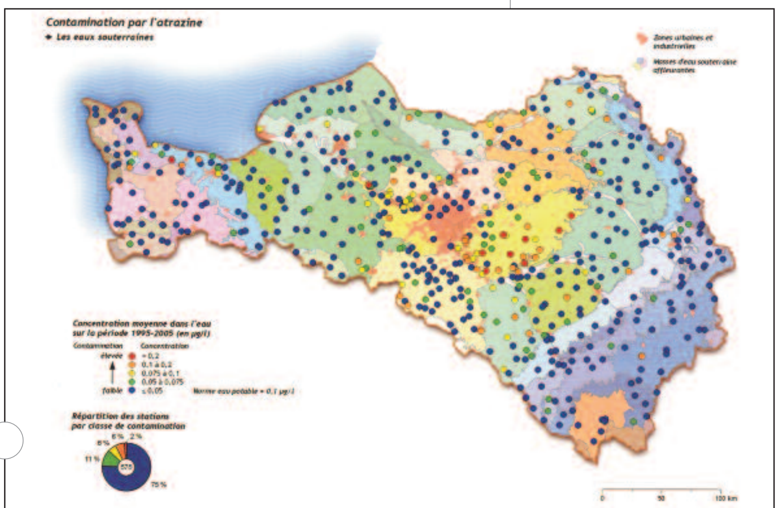
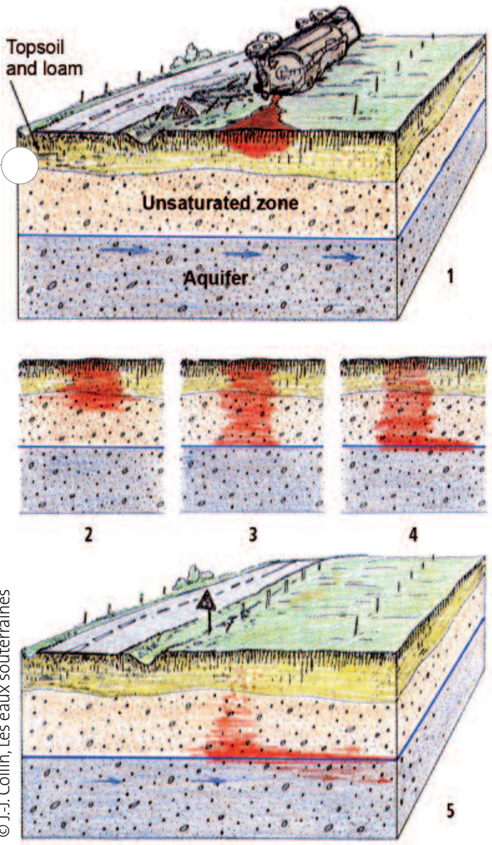


ATRAZINE IN GROUNDWATER IN THE SEINE-NORMANDY REGION

Concentrations of atrazine and its degradation products are still found in groundwaters in the Seine-Normandy basin although this substance was withdrawn from the market in 2003.

What happens when an oil truck sheds its load?

At the point where the spill occurs, the petroleum mixes with a quantity of water that may remain trapped in the unsaturated zone, but can also travel down to the water table.

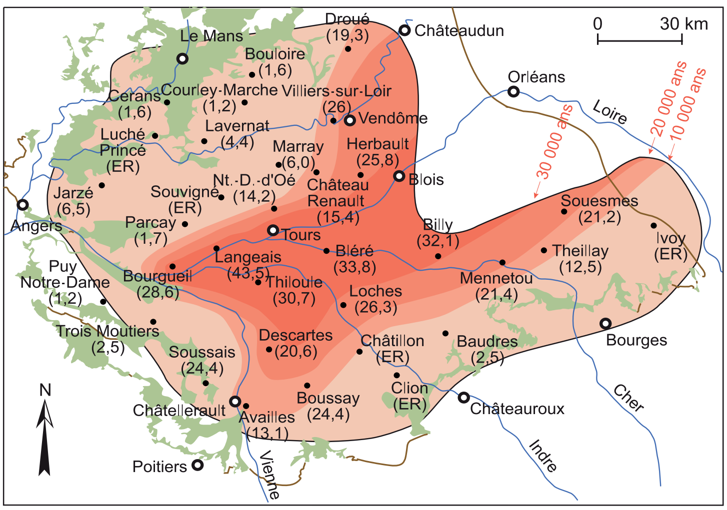


© J.-J. Collin, Les eaux souterraines

Aging the Cenomanian groundwater body in Touraine

Isotope studies of 34 boreholes in 1991-93, using carbon-14 dating, showed that the water increases in age during its journey, at about 2 m a year, from the outcropping zones containing unconfined water to the captive zone in the Tours region, which is at least 65 km away.

Aging Cenomanian groundwater in the Tours region



- Outcropping Cenomanian sands
- Water less than 10 000 years old
- Water 10 000 to 20 000 years old
- Water 20 000 to 30 000 years old
- Water more than 30 000 years old

(12.5) age of water in thousands of years
RW recent water
Cenomanian aquifer boundary

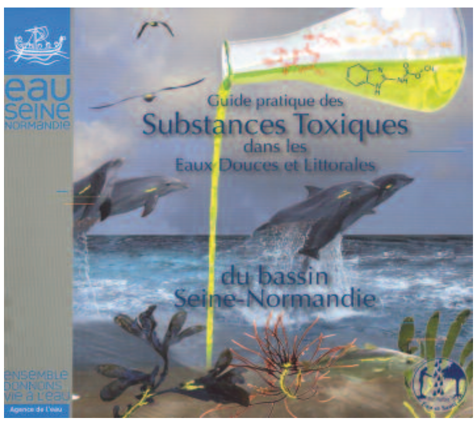
© Ph.Olive pour AELB, 2002

heaps and heavy metals from mining and iron and steel industries. Their toxicity makes their presence in groundwaters a matter of grave concern.

"New" pollutants

The list of pollutants requiring surveillance is getting longer all the time. New detection and measurement tools need to be developed to detect and analyse emerging pollutants in groundwater, such as nanoparticles, whose effects on health are as yet unknown, and pharmaceutical substances. After medicines are taken, they are eliminated in urine or faeces, sometimes in an active form. Several studies have demonstrated their presence in groundwaters in the form of residues.

Other pollutants, like pesticides, dioxins, phtalates, heavy metals and others have been under surveillance for some time and are now listed for priority attention. Because of their potential impacts on health, substances likely to affect the endocrine system have to be given particular attention. The need for surveillance of these new pollutants also requires the development of new detection and measurement tools.



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Guide to toxic substances in freshwater

Published by the Seine-Normandy Water Agency in 2009, this guide describes chemical substances both natural (mineral salts, hydrocarbons, heavy metals) and synthetic (solvents, plasticising agents, cosmetics, detergents, drugs, pesticides) that can be a threat to health and biodiversity.

Part III

Groundwater management in France

The source of the Touvre river (Charente).
The European Water Framework Directive, which states in its preamble that "Water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such", strengthens the principles of the French water management model.

Challenges for France, and for Europe

Who manages water?

Challenges for France, and for Europe

Chapter III.1

The Water Framework Directive strengthens the principles of the French water management model and establishes a Europe-wide sustainable development policy for water resources.

Groundwater monitoring

France operates a great many groundwater surveillance networks of varying sizes and with different objectives. There are three main types: general water information networks, networks for specific purposes and impact monitoring networks.

- The first type produces information on the status of groundwater quality and quantity. In accordance with the legislation, France operates a national system for overall groundwater surveillance. Other more local systems, like those operated in Alsace for instance, include a dense network of measurement points (1 every 4 km) to cover highly sensitive and heavily exploited groundwaters.

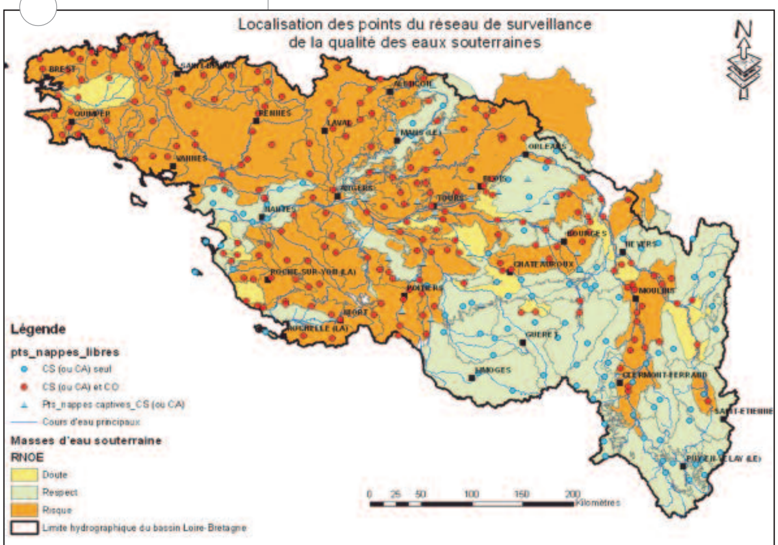
- These networks cater for specific needs such as policing, health monitoring, surveillance of specific parameters, pollution alerts and so on. Their coverage is variable (local, *département*, basin). The main networks of this type include the health and safety monitoring system for drinking water abstraction points. 34 000 measurement points are used to check that abstraction points for drinking water supplies comply with the quality standards set out in the public health code. All monitoring results are incorporated into a national database (SISE-Eaux water information system for environmental health) managed by the Ministry of Health. National reports on drinking water quality are also available from the ministry's web site.

- Impact monitoring networks are operated to assess the impacts of identified pollution on groundwater resources. Examples are the ICPE* network for facilities listed for environmental protection and the networks for nitrate or pesticide monitoring, which measure selected drinking water abstraction points.

In accordance with the EU Water Framework Directive, most of these networks are used to monitor the overall status of water, for operational inspections of water bodies where the "good status"* objective might not be achieved and to conduct surveys if the objective is not achieved.

Quality surveillance networks: the Loire-Brittany example

In January 2009, the national groundwater monitoring network comprised some 1800 sites including 70 in overseas France. The Loire-Brittany basin has 337 measurement points.



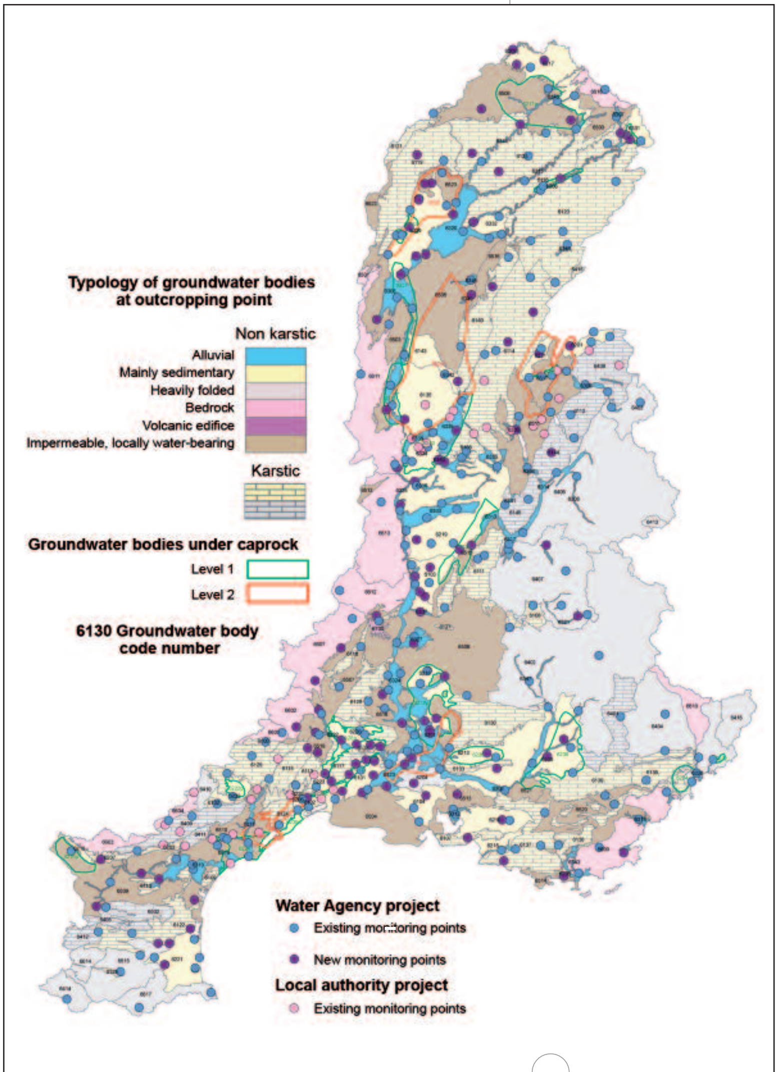
From measurements to databases

In 2002, a Water Information System (SIE) was set up to collect and organise all data on water from different sources into a database for dissemination to users. Besides the National Office for Water and Aquatic Environments (ONEMA), which is responsible for functional SIE aspects, government departments, water agencies and offices and several technical institutions (BRGM, Ifremer, Ineris, etc.) also contribute to the SIE, while local authorities may be involved in building up the data. Within the system, the national portal for access to groundwater data (ADES) collects data from all networks at their request or from those co-financed by the State.

National database ADES

This database provides information on the quantity and quality of groundwaters.

Several types of analysis are used to monitor the chemical status of groundwaters: in situ measurements (water temperature, pH, Eh, dissolved oxygen, conductivity), major physicochemical parameters, mineral micropollutants, and organic micropollutants.



Groundwater quality monitoring network in the Rhone-Mediterranean District

Groundwater quality is stabilizing in zones contaminated by nitrates and pesticides, but improving in many zones downstream from industrial sites, where contamination, by chlorinated solvents for example, has dropped.

ADES is a unique system in Europe and a valuable tool for addressing local groundwater management and WFD issues, such as monitoring of underground water bodies and the implementation and evaluation of management policies and plans. It allows users to locate measurement networks and stations and to find results from quantitative (piezometric) and quality measurements.

The information is regularly updated and available for each measurement point and network* covering any catchment basin, region, *département* or aquifer. In accordance with the recommendations of the National

ADES in figures (February 2012)	
	244 declared networks
	68 908 stations
	4 122 piezometers
	66 000 quality stations **8 666 818** water level measurements and **29 950 520** water analysis results are available online.

water data and data platforms service (SANDRE), data traceability from producer to user (origin of the data, validation level, etc.) guarantees high quality information to improve the use and interpretation of the data consulted.

Protection areas

Drinking water abstraction points in France are surrounded by one to three source protection areas (SPA, or PPC in France – *périmètre de protection de captage*), depending on hydrological or hydrogeological conditions. They protect the abstraction point, but also the area adjacent to the aquifer - which becomes more sensitive with abstraction - from the main causes of accidental pollution by humans. The idea was first brought into practice by the Act of 1902, adopted after numerous epidemics to protect drinking water springs from bacteriological contamination. The regulations were gradually strengthened during the 20th century, in particular when chemical, agricultural and industrial pollution were included in their scope. In the past, PPCs were decided on by "official geologists", but are now in place around all drinking water abstraction points. Their layout is determined by the public health hydrogeologists appointed in each *département* by the Regional Prefect. A PPC can extend across several parts of a water table. PPCs in France are defined in the Public Health Code (Articles L.1321-2 and R. 1321-13).

The well-head protection area is laid out around the abstraction point itself. This zone belongs to the local authority. It is fenced off and closed to any activity not related to water production. Its main functions are to prevent deterioration of the water abstraction facilities and pollutant releases in their immediate vicinity.

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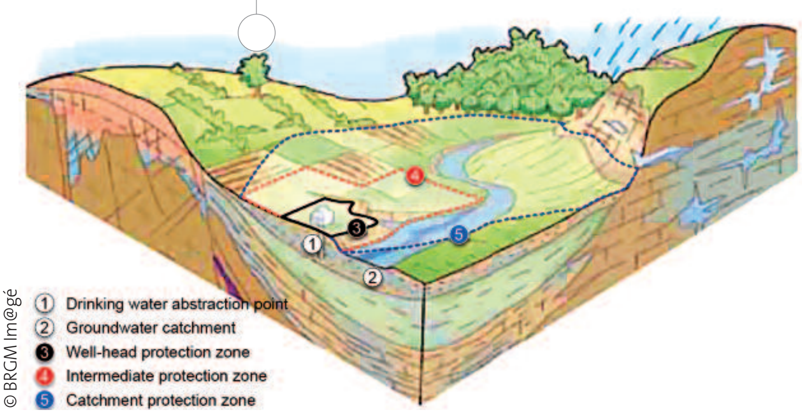
Intermediate protection area

To protect an abstraction point serving 3000 people, reducing nitrate inputs over a few dozen hectares can sometimes be enough for nitrate concentrations in water to drop below the 50 mg/l threshold.

An intermediate protection area is marked out around an area, usually a few hectares, which in theory covers the catchment area adjacent to the abstraction point. Any activities (construction, effluent, deposits, spraying, etc.) that are likely to cause pollution are banned within this area, or subject to specific regulations. The area covered by an intermediate protection zone is not always the same, as it will depend on the geometry of the water table; they may even be discontinuous in karstic zones.



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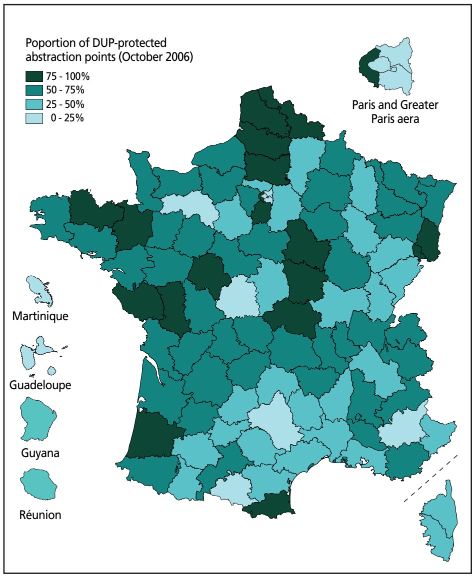
Principle of protection areas

Drinking water abstraction points (1) drawing on groundwater (2) are surrounded by three protection zones to provide well-head protection (3), intermediate protection (4) and source catchment protection (5).

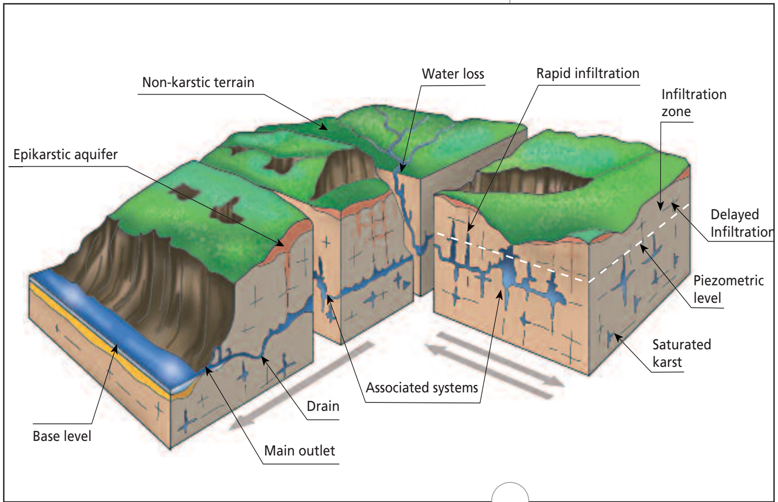
The source catchment protection area is marked out when certain activities are liable to cause significant pollution and when specific provisions could significantly reduce health risks. This zone covers the entire catchment area for the abstraction point and sometimes an entire catchment basin.

The target for PPCs in the national health and environment plan (PNSE) for 2004-2008 is protection for 80% of all abstraction points by 2008 and 100% by 2010. In January 2009, 54.9% of abstraction points were reported as protected by PPCs under a specific public interest procedure (source: SISE-Eaux database).



The water agencies - setting an example

The Water Act of 16 December 1964 set out the main principles of groundwater management in France. For this purpose, the Act divided the country into six major hydrographic basins. Different public institutions under State authority are responsible for dividing resources equitably between economic development and environmental protection needs. Six water agencies were established: Artois-Picardy, Rhine-Meuse, Seine-Normandy, Rhone-Mediterranean & Corsica, Loire-Brittany and Adour-Garonne.

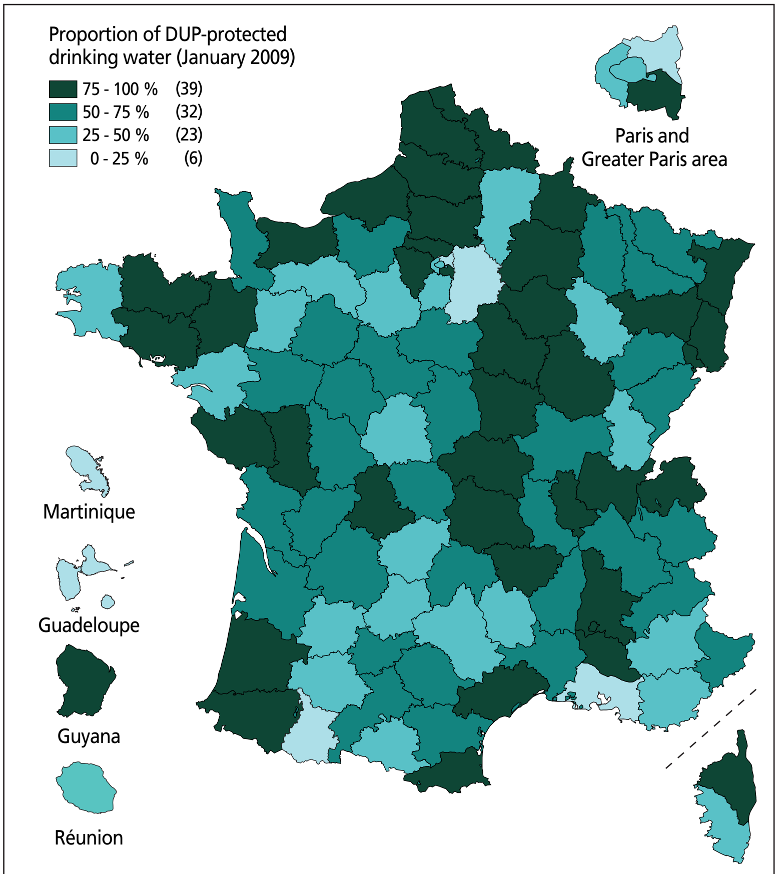


Protection under a Declaration of Public Utility

In January 2009, almost 55% of groundwater abstraction points, which produce some two thirds of all drinking water in France, were surrounded by protection zones defined in a Declaration of Public Utility (DUP).

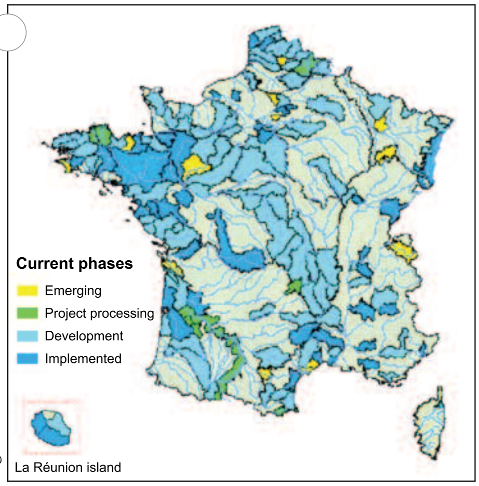
Protection in karstic zones

In a karstic zone, the "intermediate" protection area can be in several parts to match the patterns of aquifer recharge.



SAGE implementation to date

By early 2009, 148 water management plans (SAGE*) had been drawn up in France: 44 are under implementation (developed and approved), 84 at the development stage (delineation of protection zones completed and local water committee established), 7 are being processed and 13 are still in the preliminary stages.



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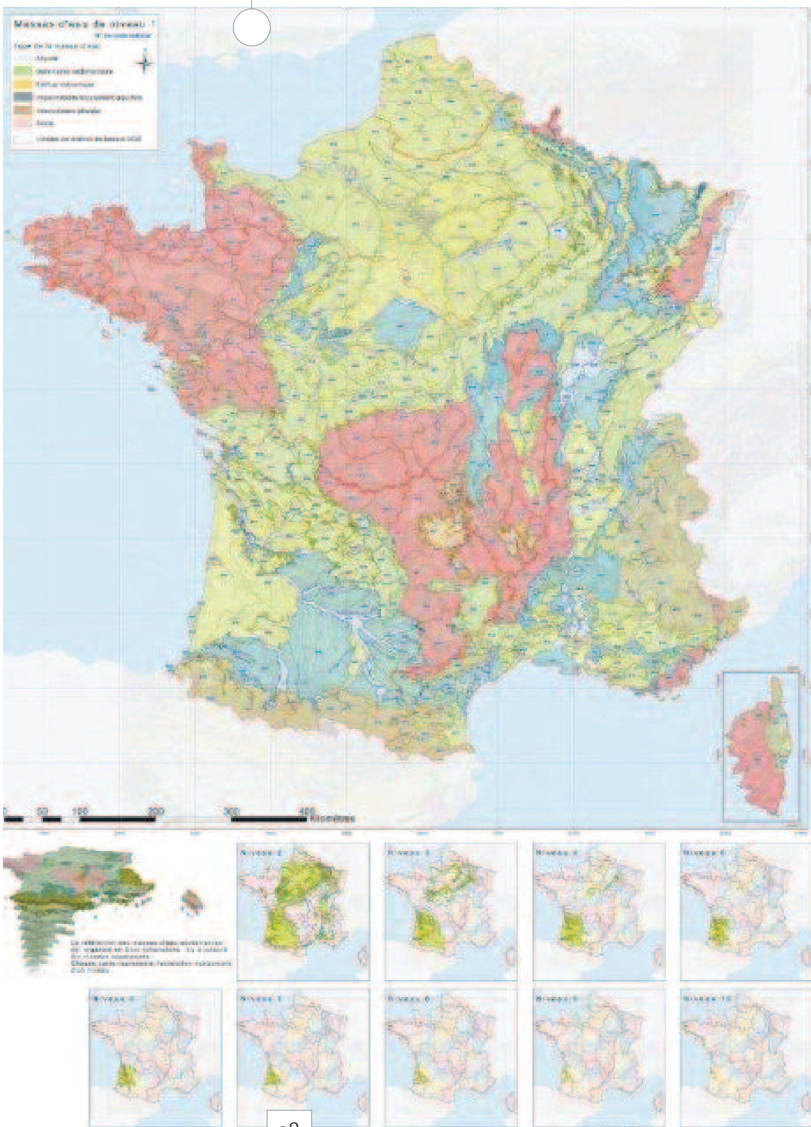
Map of groundwater bodies in France

A groundwater body is a unit used as a basis for assessments, target setting, quantity and quality monitoring and other management activities.

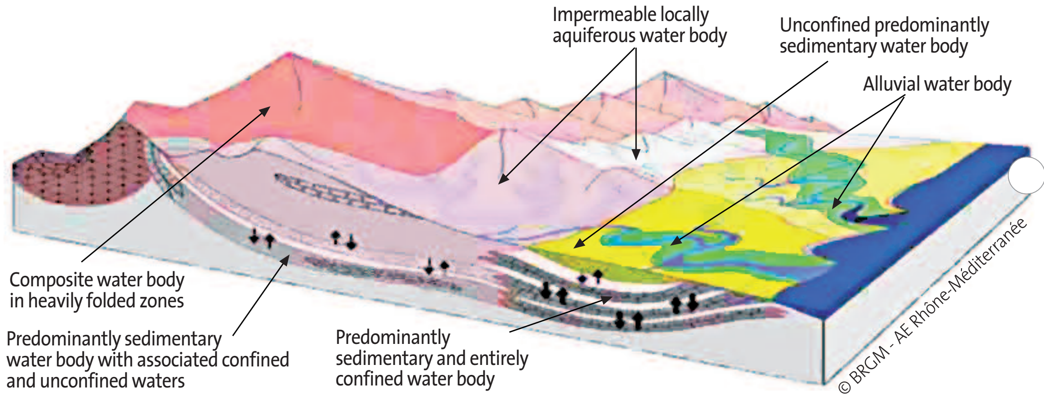


Source : données Agences de l'eau et DIREN de Bassins - synthèse BRGM

Each water agency is supported by a Basin Committee of elected officials, State representatives, users (industry and agriculture) and consumer and nature protection associations. The French model, with its division into large basins under integrated management, was strengthened by the 1992 Water Act, which introduces spatial planning principles through "water management masterplans" (SDAGE*) and "water management plans" (SAGE*), has set an example now adopted by the European Member states and 50 member countries of the International Network of Basin Organisations (INBO) created in 1994 by the French Ministry of the Environment. The Water and Aquatic Environments Act of 30 December 2006 (LEMA, n°2006-1772) further strengthens this policy. It has a twofold objective:

- to provide government administrations, local authorities and water stakeholders in general with the necessary tools to restore water quality and achieve the water quality objectives of the WFD of 23 October 2000 (transposed into French law by the act of 21 April 2004) by 2015, and to achieve a better match between water resources and needs with a view to the sustainability of economic activities using water, through consultations with all those concerned in practice,
- to provide local authorities with the means to adapt public drinking water and sanitation services to new demands for transparency towards users, solidarity with disadvantaged segments of the population and environmental efficiency.

The Act provides for additional means to implement SDAGEs and SAGEs, establishes the National Office for Water and Aquatic Environments (ONEMA), a public technical



Typology of groundwater bodies

Water bodies are determined according to the geological nature of formations and their flow regimes.

and forward planning institution responsible for coordinating the Water Information System (SIE).

It organizes the collection and processing of information for dissemination purposes, particularly for the Water Information System for Europe (WISE). As a national partnership-based organization, ONEMA guides knowledge-based water management and evaluates policies for each French basin and at European scale.

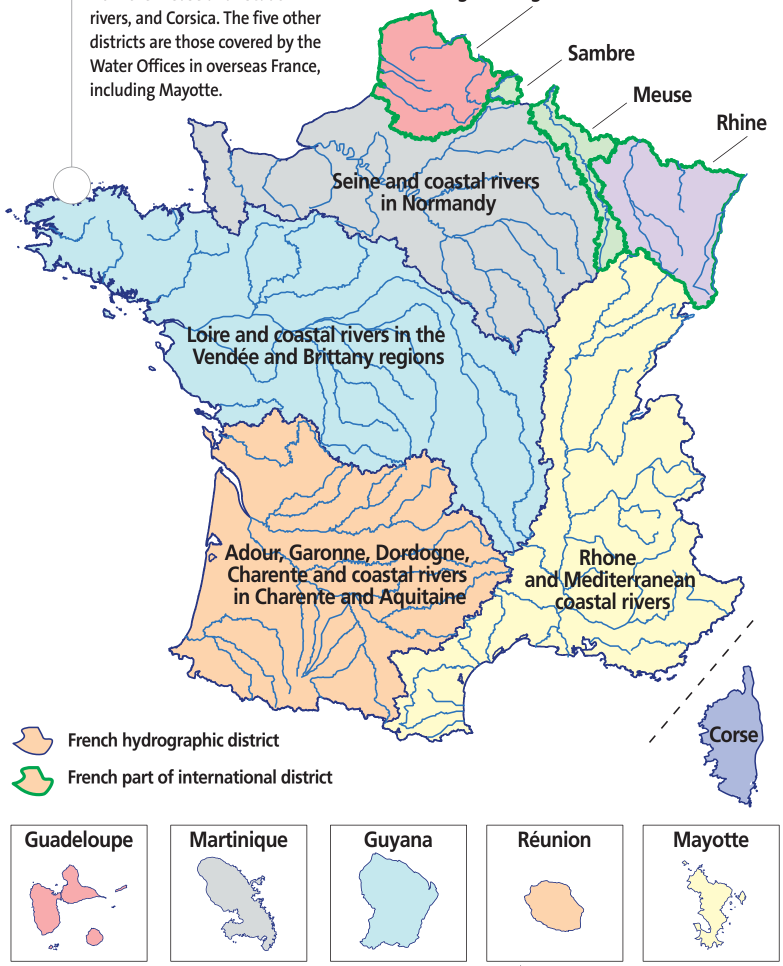
Management at European scale

Preventing water pollution is the most long-standing of Europe's environmental policies and has generated a great many items of legislation since 1976. Joint discussions on harmonising European and national legislation in order to improve the consistency and effectiveness of the policy resulted in the European Water Framework Directive (WFD) issued in October 2000, which was supplemented in 2006 by a “daughter” directive developed specifically for groundwaters. More than half of the European Union's groundwaters are polluted and action to prevent further pollution and deterioration is now urgent.

These items of legislation introduce Europe-wide management on the scale of large river basins, with planned objectives. They also introduce performance requirements and schedules for achieving a good overall status

Hydrographic districts under the EU Water Framework Directive

In mainland France, the six traditional water agency basins have been divided into nine districts, separating the Rhine from the Meuse and Escaut rivers, and Corsica. The five other districts are those covered by the Water Offices in overseas France, including Mayotte.

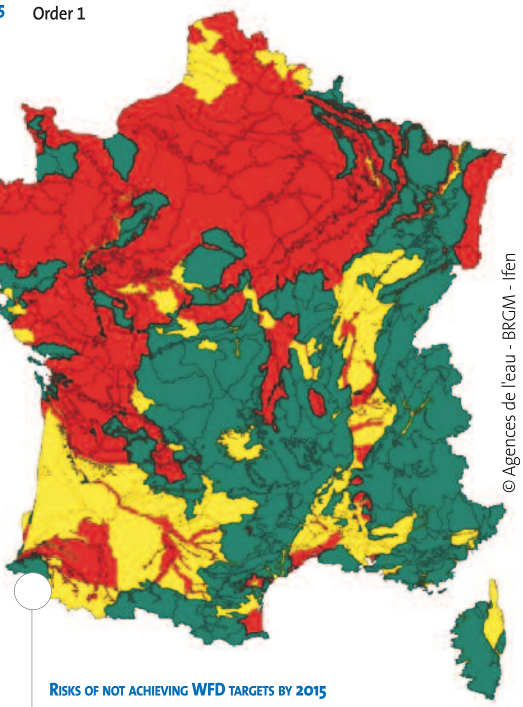


Risks of not achieving "good status" by 2015

- At risk
- Doubtful or insufficient data
- "Good status" likely

Orders 1 to 6 are the orders in which water bodies lie one above the other from the surface to deep underground (on a scale of 10 for France). A water body may contain several superimposed aquifers.

Order 1



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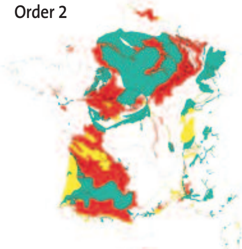
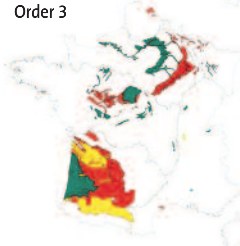
Order 2



Order 3



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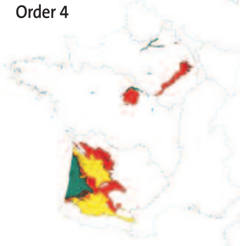
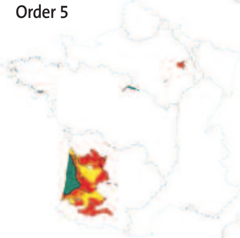


Order 5



Order 6

Risks of not achieving WFD targets by 2015

Map drawn up in 2004: since then, new risk assessments have been made for several of these water bodies.

for surface, coastal and groundwaters by 2015, as well as transparency requirements on pricing and the "polluter pays" principle. Except for a few parameters, laws passed in Parliament do not impose single Europe-wide standards; a new directive on quality assurance will be introduced to harmonize methods for measuring potential pollutants.

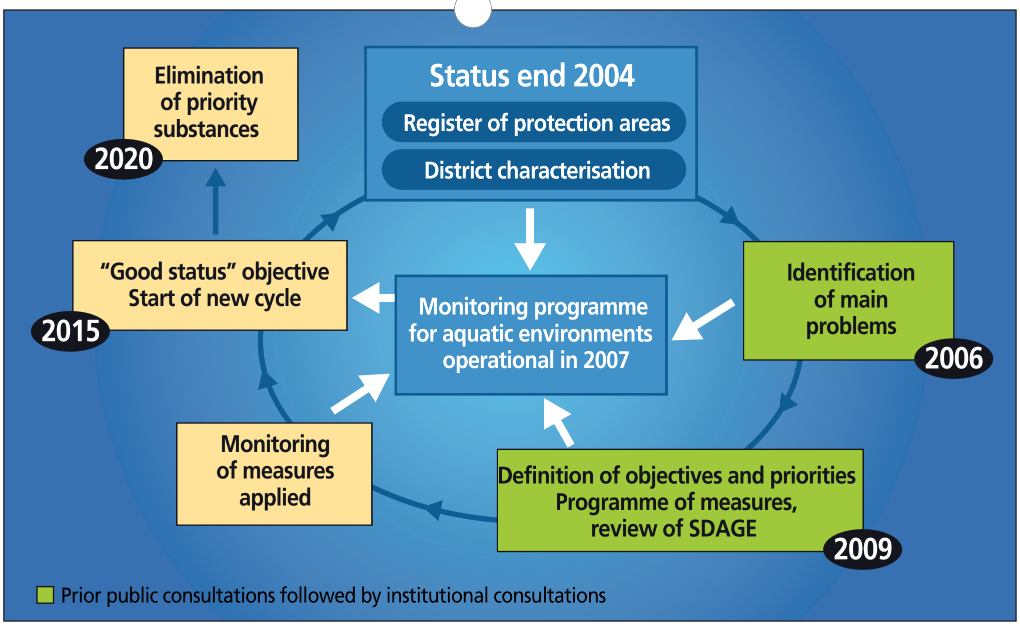
SDAGEs will be the French instrument for implementing EU policy in France, which is now divided into "water bodies", a new concept based on the structure of the natural environment and on management criteria. France is divided into 553 groundwater bodies, including 50 in the overseas areas. 28 of these straddle more than one district and 23, as in Alsace, are transboundary water bodies. In parallel, France has produced an exhaustive catalogue of aquifer systems, the BDRHF® database, and the future one BDLISA.

Restoring groundwaters to a "good status"

Achieving the WFD "good status" objective for groundwater bodies by 2015 demands substantial scientific and technical efforts. In 2005, the inventory required by the WFD

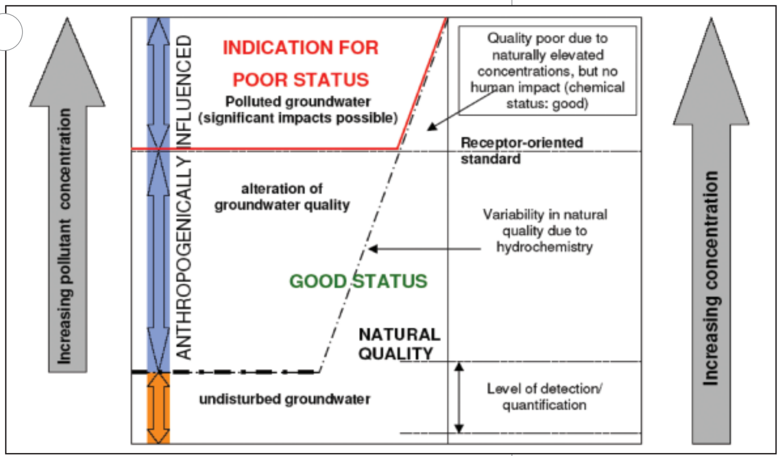
Main stages in WFD implementation

If a water body does not reach its "good status" objective by 2015, the next deadline set by the WFD is December 2020.



Guidelines for achieving WFD objectives for groundwater

The natural quality of groundwaters (geochemical background) is taken into account in assessments of human impacts on their quality.



produced an overall synopsis of the status of surface and groundwaters. For each of the 553 groundwater bodies, including those in overseas France, risks of not achieving the “good status” objective have been established: 208 of these water bodies are at risk if no additional measures are implemented, 108 are potentially at risk, and 237 are likely to reach a “good status”.

The risk of not achieving both quantity and quality objectives concerns surface aquifers, while the risk of not achieving quantity objectives mainly concerns deep aquifers, which are better protected from external risk factors. 52 groundwater bodies, or 10% of the total, are listed as being at risk because of excessive abstraction: this causes water table levels to drop sharply, which in turn lowers the discharge of rivers fed by them.

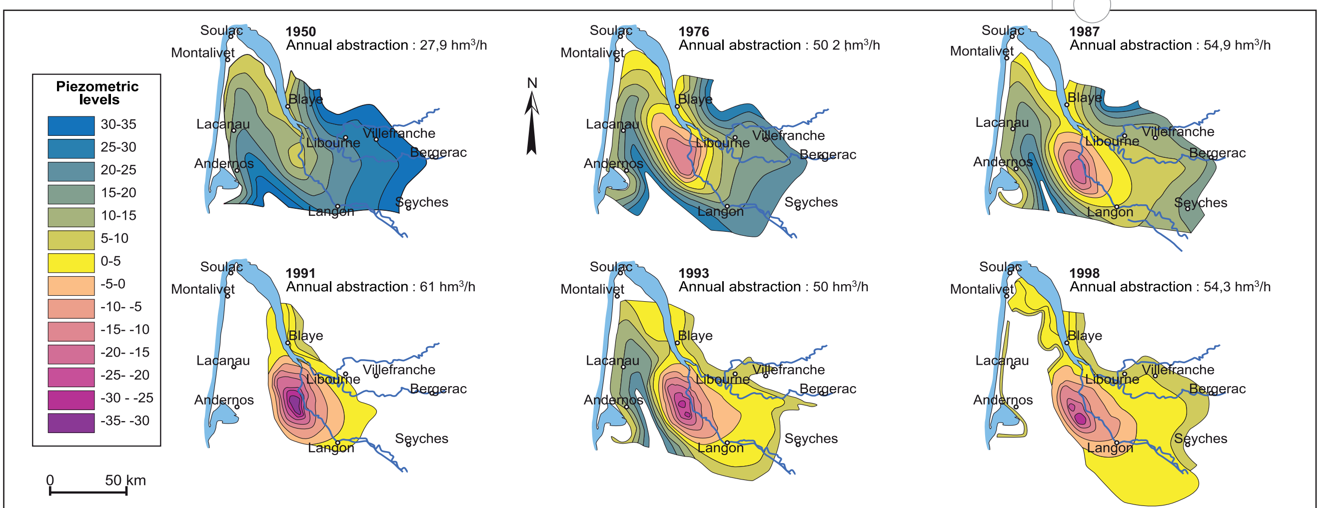
Concerning quality, the main parameters for downgrading groundwater bodies relate to agricultural nitrates and pesticides. The WFD “daughter” directive is designed to manage and protect groundwaters against pollution and deterioration, and commits Member states to take “all necessary steps to prevent the release of any hazardous substance into groundwater”, rather than merely to “make efforts to prevent” pollution of this type.

When groundwater abstraction becomes unsustainable

The state of the Eocene groundwaters around Bordeaux is a good illustration of the effects of over-abstraction for drinking water and industrial uses. The water deficit here has been calculated at 10.7 million m³ of water per year, and piezometric levels have dropped by 1 m every year in the last 30 years. A 50 m piezometric trough has been observed directly below Bordeaux and several wells are no lon-

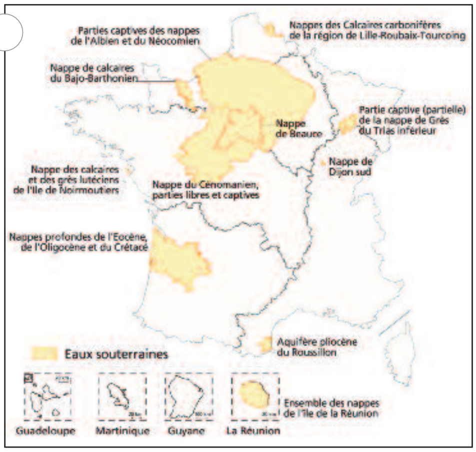
Changes in the piezometric depression of the Bordeaux region’s Middle Eocene groundwaters, 1950 to 1998

This series of measurements shows how the cone of depression has changed since 1950.
This cone of depression is linked to abstraction and has to be closely monitored: it could lead to a reversal of the direction of flow, making the aquifer vulnerable to practically irreversible salinisation.



Water division zones (ZRE)

Due to chronic overabstraction, 11 aquifer systems used for drinking water production and industry were listed as "water sharing zones" in 2001.



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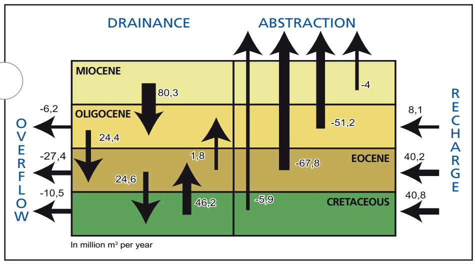
Flows and abstraction from Eocene groundwaters in the Bordeaux region, in orders of magnitude

Abstraction is causing a deficit of more than 10 million m³ a year and a steady drop in piezometric levels.



© BRGM-SAGE *nappes profondes de Gironde* (Deep aquifers in the Gironde, 2002)

ger artesian. In 1995, the water table dropped below sea level, raising fears of saltwater intrusion into the aquifer below the Gironde river. In 1999, a local water committee (CLE) representing the local authorities, the State and users was set up to develop a management plan (SAGE) for the Gironde *département*'s groundwaters. Its aims are ambitious: to reduce annual abstraction from the Eocene aquifer by 13 million m³, through water-saving measures and by switching to surface waters for industrial uses. As of today, abstraction has levelled off but groundwater stocks have not yet recovered.

In 2001, the Gironde's Eocene, Oligocene and Cretaceous groundwaters were classified as water division zones (ZRE), along with 11 other overexploited aquifer systems, 8 of which are essentially used for drinking water and industrial purposes, 2 for agriculture and 1 (in La Réunion) for all uses combined. Cases of chronic imbalance are mainly in the Paris and Aquitaine basins.

Assessing groundwater quality

Groundwater quality is usually defined in terms of the purposes for which it is used, so that different criteria apply to drinking water production and industrial uses. Water quality can also be assessed against its initial (heritage) state.

However, given that two thirds of groundwater abstraction is for drinking water production, its quality is generally assessed in terms of its suitability for this purpose, with any difference in quality compared to its heritage status also taken into consideration.

The system for groundwater quality assessments (SEQ), published in 2002, is based on 4 weathering categories (for drinking water production) and five other suitability categories (for other uses). These are all colour-coded to facilitate assessments of groundwater status. A new assessment tool, the SEEE (water status evaluation system), is now being developed to meet WFD requirements and will be applied for surface, marine and groundwaters.

Groundwater quality assessment system (SEQ)

Groundwater quality is assessed not in absolute terms, but relatively according to its suitability for a given use.

GROUNDWATER SUITABILITY CLASSES

	Uses	Heritage Status
4 CLASSES FOR "DRINKING WATER SUPPLIES"		
(light grey)	optimum drinking water quality	
(dark blue)	acceptable drinking water quality but potentially requiring disinfectant treatment	
(light grey)	non-potable water requiring treatment	
(light grey)	unfit for drinking water production	
5 CLASSES FOR OTHER USES AND CHARACTERIZATION OF "HERITAGE STATUS"		
	Uses : industry, energy, irrigation and livestock watering	**Heritage Status**
(blue)	Highly suitable	Water composition natural or subnatural
(green)	Suitable	Water composition close to natural or subnatural but contamination of human origin detected
(yellow)	Moderately suitable	Moderate contamination compared to natural status
(orange)	Not suitable	Severe contamination compared to natural status
(red)	Unfit	Very high contamination compared to natural status

Who manages groundwater?

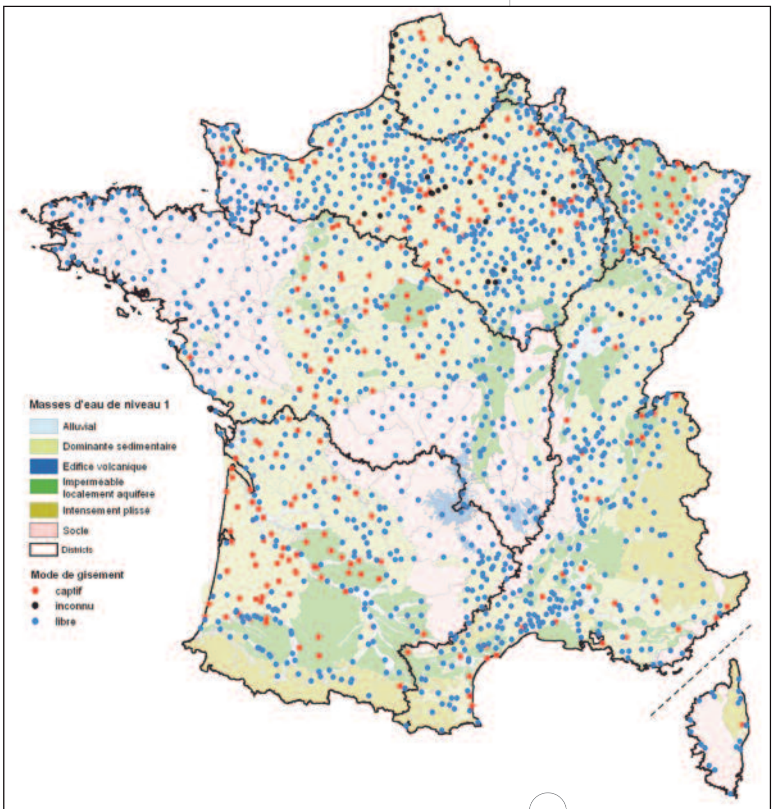
A great many agencies are involved in gathering knowledge on groundwaters in France and monitoring their quality and quantity in accordance with the WFD.

Planning needs sound knowledge

The water agencies are responsible for analysing groundwater samples, while devolved Ministry of Health departments are in charge of health inspections of raw water to be used for drinking water production - both tap water and bottled water - and for processing Declarations of Public Utility (DUP) for the protection of drinking water abstraction points. BRGM is responsible, under a contract with the State (ONEMA), for piezometric (quantitative) monitoring, in which continuously updated measurements from the field are combined with modelling in order to produce risk assessments. These data are essential for sound

Groundwater contracts: an example from the Hérault

Like SAGEs, groundwater contracts are management tools implemented at sub-basin scale. They set out quality and quantity objectives for each groundwater body: five-year action programme, project owners, financing methods, work schedules, etc. In the case of the Astian aquifer that extends over some 20 municipalities, two groundwater contracts were signed prior to developing the SAGE.



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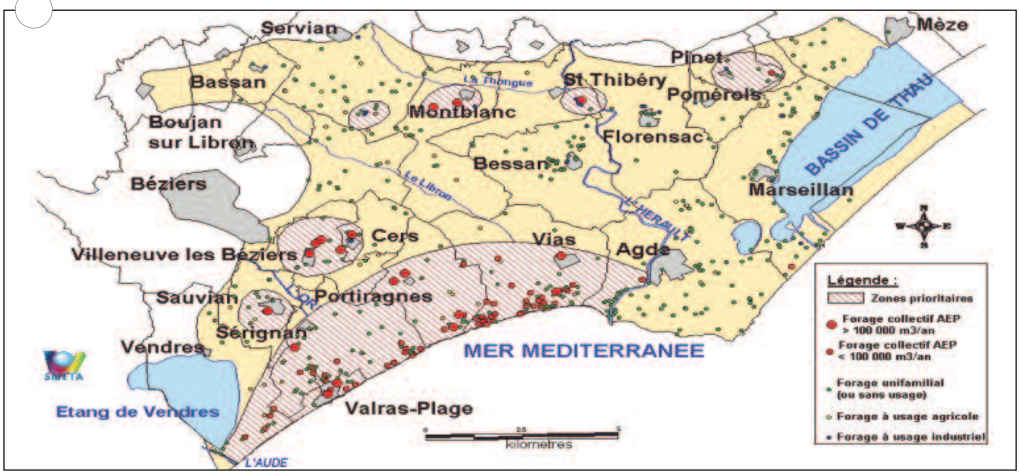
Quality monitoring network for groundwater bodies

This network analyzes groundwater quality monitoring results from more than 2000 measurements points, in compliance with WFD requirements. The data collected are updated continuously to ensure that trends in groundwater quality are closely monitored.



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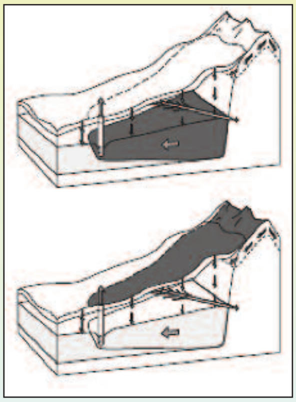
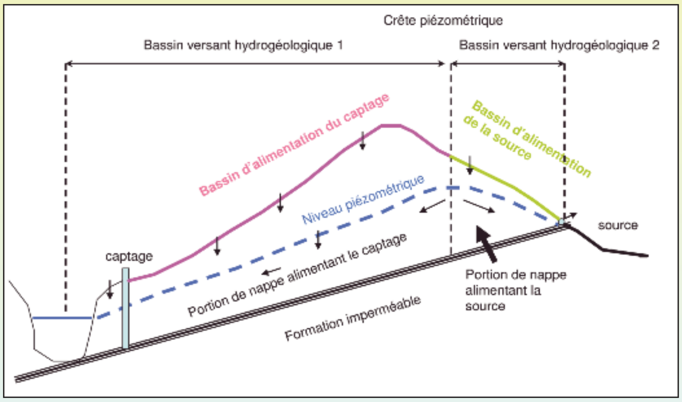
le Grenelle Environnement

The Grenelle environment process has specified that the WFD objectives for water must be achieved for two thirds of water bodies by 2015. These are mainly surface waters, since groundwaters take longer to regenerate due to their inertia. Given the context of climate change, groundwaters are considered as ultimate reserves that urgently need protection, in particular because they are liable to be adversely affected by climate change effects such as potential changes in atmospheric composition, groundwater regimes and sea levels. The situation therefore demands an inventory of techniques and new research to develop innovative solutions should problems arise. Finally, in addition to the necessary protection zones already in place, protection is now planned for 500 further abstraction points considered as priorities, in order to counteract diffuse pollution across catchment areas as defined by the Water and Aquatic Environments Act (see diagrams on the right).



© BRGM

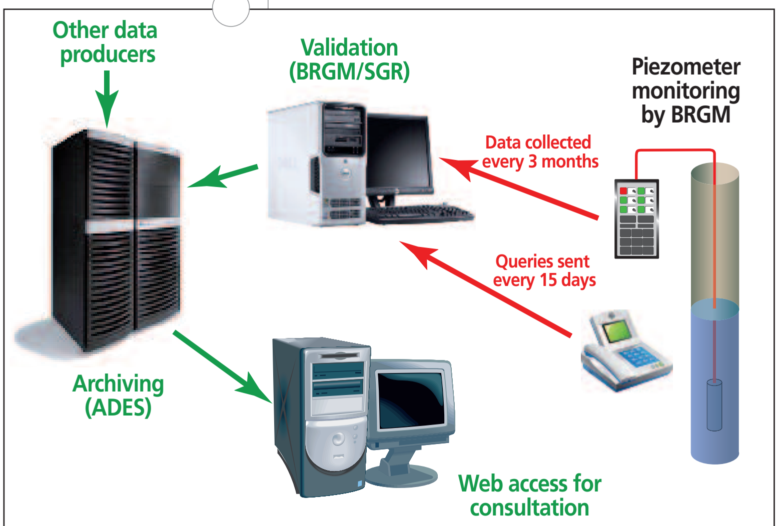
Top: portion of groundwater feeding the abstraction point.
Bottom: catchment area*



The catchment area includes all points on the surface from which water is drawn to the abstraction point. The catchment area (purple line) is defined here on the assumption that the surface between the topographical ridge and the piezometric ridge allows water to infiltrate.

Delivery of data from piezometric networks

The piezometers transmit their data at regular intervals. After validation, they are archived and downloaded to the Internet.



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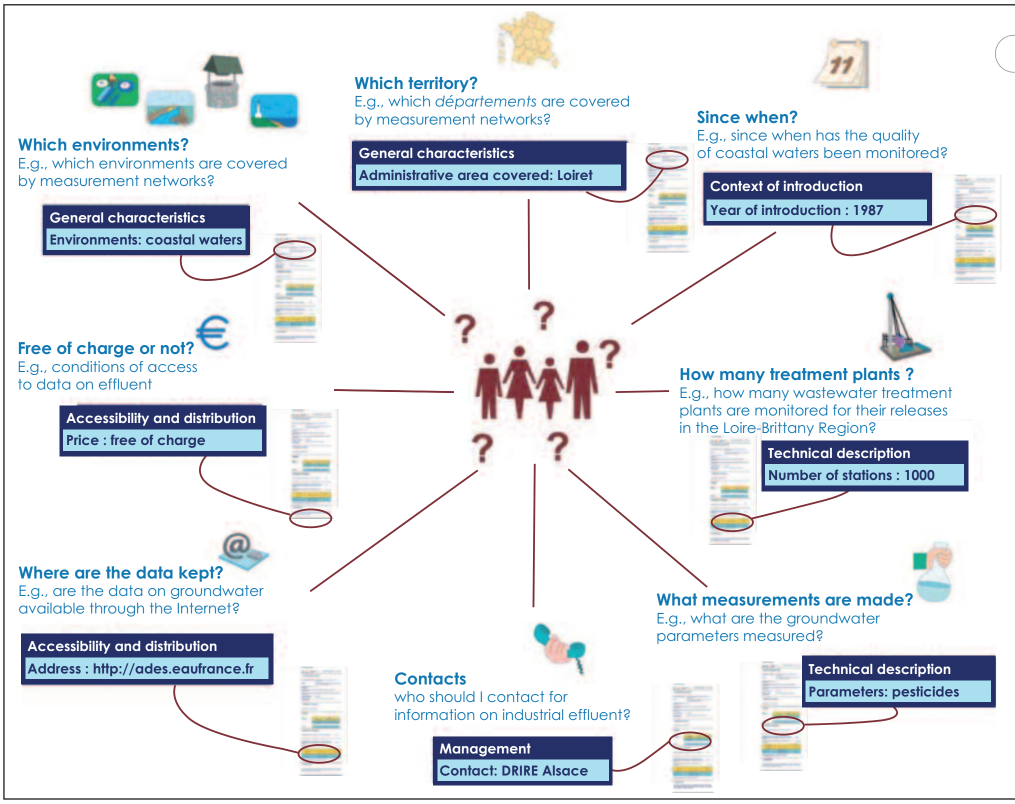
management at local level, but also to guide French policy in this area and bring early responses to the requirements of the EU Water Framework Directive.

Gathering this kind of information is also important at global level: water is a common global good, and under international agreements, France is under obligation to report on the waters within its territory. Gathering knowledge and data at these different levels involves a wide range of State agencies, including public research organisations, water agencies and field practitioners, all of whom now need to coordinate their work to meet WFD requirements.

A "nested doll" pattern of organisation

The first "dolls" are the hydrogeologists, who take measurements in the field. Measuring devices can now transmit data from nearly all groundwater observation points. However, there are a great many of them and they belong to different networks. In the area of quantitative resource measurements alone, piezometers are monitored by several different agencies, mainly government departments with responsibilities for the environment, the BRGM and local authorities, who all install and manage measuring networks.



For management and information purposes, these basic networks are grouped together into *département*, regional and basin networks. Several regions (e.g. Aquitaine, Limousin, Midi-Pyrénées and Poitou-Charentes) run information systems for groundwater management (SIGES); others (such as Brittany and the Limousin) have information systems for locating and using groundwater resources (SILURES). Both collect and summarise regional data, as does the Ile-de-France system (diren-idf-eaux-souterraines.brgm.fr). This information is collected from all agencies involved in water management and is available through the Internet (sigesaqi, sigespoc, sigesmpy.brgm.fr, etc.). In the Rhone-Alps region, the Starther.brgm.fr site (follow-up and active processing of data on thermal water resources) is used to monitor the quality of spa waters. *Départements* and river basin agencies also use geographic information systems, as in the Rhone-Mediterranean basin (rhone-mediterrannee.eaufrance.fr).

At the next level of aggregation, the national groundwater quantity monitoring network communicates information to the French government and the European Commission, under the responsibility of the Ministry of Ecology. In a move towards greater clarity, under the aegis of the recently established National office for water and aquatic environments (ONEMA), the national piezometric network managed by the BRGM is likely to be expanded by integrating other monitoring networks, thereby increasing the national network from 1100 to 1600 observation points. The information collected will be added to the national database on groundwaters (ADES).

Everything is interconnected

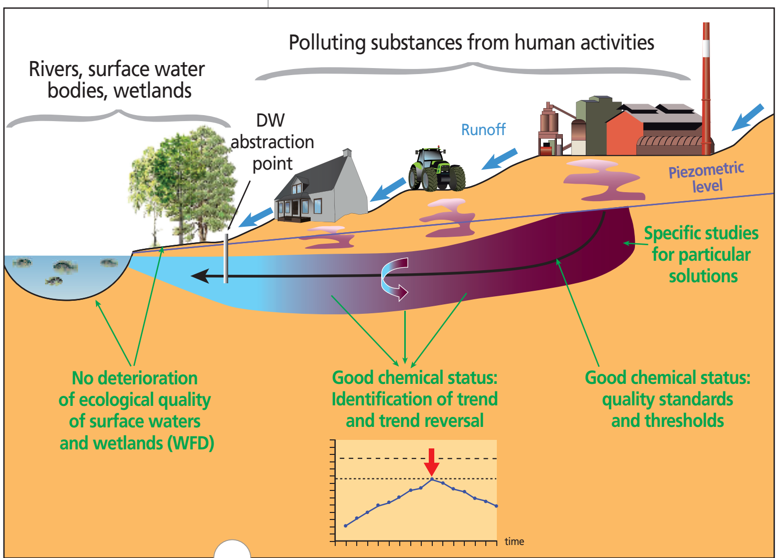
The WFD covers all of a country's surface waters (coastal waters, rivers and lakes) as well as its groundwaters. Its aim is to establish integrated water resource management in close interconnection with the sustainable development

THE DISC'EAU DATABASE: MONITORING DATA TO SUPPORT RESEARCH

The DISC' EAU national database offers Internet access to data from most measurement networks, surveys, declarations and self-monitoring systems, enabling all those concerned to use reliable, updated and relevant information at all times.
www.sandre.eaufrance.fr/disceau

concept. Achieving the WFD objective - a good chemical and ecological status in all water bodies by 2015 - requires links to be developed with other players involved in spatial planning, agriculture, transport, urban planning and so on.

Preserving the marine environment involves researchers at Ifremer, the French research institute for marine uses; protecting soils and reducing agricultural pollution involves researchers at INRA and Cemagref, while soil depollution involves engineers from Ineris, the National



Reversing downward trends in groundwater quality

A requirement under the WFD is to identify water bodies in poor chemical condition and to reverse any significant and lasting downward trend, including from point-source pollution.

Institute for the environment and risks. The CNRS and the Paris Ecole des Mines conduct studies under the Seine Interdisciplinary Environmental Research Programme (Piren Seine). In the area of health and safety, drinking water standards are a strategic priority for the French food safety agency (AFSSAPS), while the French agency for health and safety in the environment and the workplace (ANSESE) runs the Pesticide Residues Observatory (ORP) and a health and safety watch on new or unmanaged risks associated with the water cycle in general. Although it is spread across a great many agencies, reflecting the complexity of the issue, French experience in the water domain has been a success and an example for many other countries. It drives cooperation programmes with other EU Member states and countries in Central and Eastern Europe and the Mediterranean Rim, as well as supporting French involvement in the European Environment Agency and the Eurogeosurveys and UNESCO networks. France has been active from the start in global forums which, in the wake of the 1992 Rio Summit, have been raising awareness among the public and policy-makers on problems of access to water.

The future of groundwaters

Over the long term, it is becoming clear that most improvements in the state of the water cycle are the result of treating urban and industrial pollution from point sources. At present, water degradation is mainly from diffuse agricultural pollution, which is moving towards stabilisation. However, the presence of toxic chemical and biological micropollutants is a new and worrying problem. The degradation caused is less spectacular than before, but it is chronic - and improvements have reached an asymptotic stage which is not, unfortunately, conducive to the "good status" required by the WFD.

In terms of quantity, resources are being overexploited in all sectors. The persistent drop in the levels of several large deep and surface aquifer systems is acutely revealing of the effects of drought and overabstraction of surface waters for irrigation.

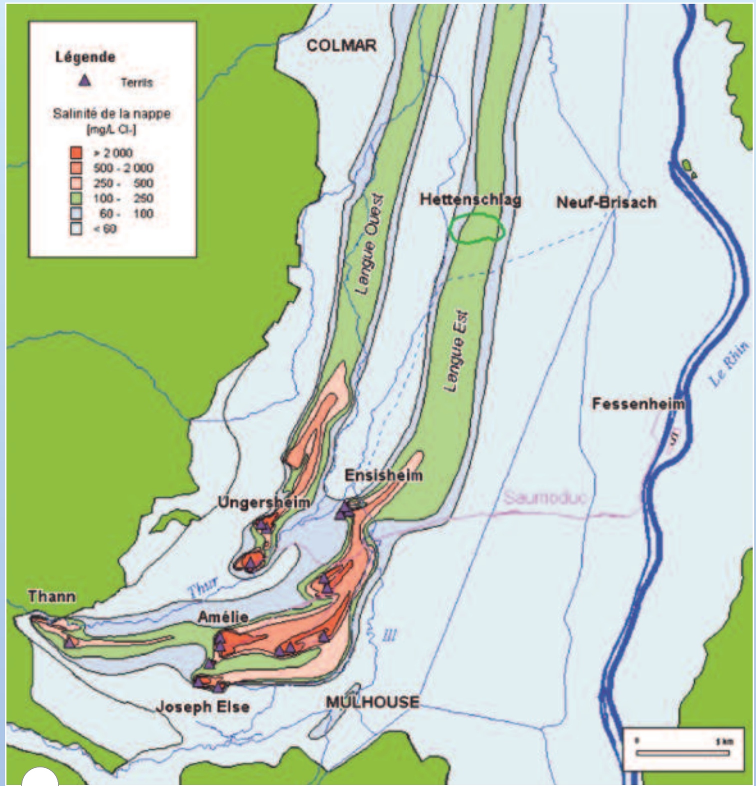
But the importance of groundwaters is now fully established. They are considered as a valuable heritage, to be managed with a concern for sustainability. In a time of uncertainty over climate change, groundwater protection measures are becoming increasingly urgent. This concern is reflected in many items of legislation: from the WFD to the December 2006 Water Act in France, actions been decided on – but now they need to be implemented.

Research also has a role to play. Managing water resources and aquatic environments sustainably raises important scientific challenges that

Restoring the quality of groundwater resources in Alsace

The Rhine water table, known as the Alsace water table in France, is contained within alluvial deposits from the Rhine and its tributaries in the Rhine trench. Given its considerable economic importance, it is the most frequently and intensively researched aquifer in France. In the late 1960's, the interministerial committee for studies of the Alsace water table (CIENPA) launched a series of modelling studies to determine patterns of flow into groundwaters and to calculate their water balance. In parallel, transboundary hydrogeological maps have been drawn up under the European INTERREG programme, and a great many Franco-German studies have been focusing on cartography, hydrodynamic flows and groundwater monitoring.

Concerning quantitative aspects, monitoring of piezometric levels is managed by APRONA, the Association for the protection of Alsace groundwaters, through a network of 200 measuring points. The results show the predominant influence of rivers in recharging groundwaters, since they account for 85% of inflows and 78% of outflows. The renewal rate is 2% a year.



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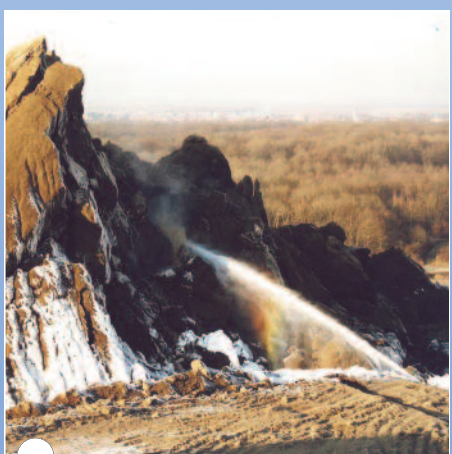
CHLORIDE CONCENTRATIONS IN MG/L AT DEPTHS OF 0 TO 40 M, OBSERVED IN 2005.

Concerning quality, the Alsace water table is shallow and easily accessible, and therefore vulnerable to human pollution as there is no impermeable layer protecting it on the surface. The quality of the water has deteriorated steadily over the years as a result of agricultural, industrial and urban activities and aggregate extraction (pollution by nitrates, pesticides and industry). In particular, potash mining around Mulhouse from 1913 to 2003 has caused severe saline pollution of the water table over dozens of kilometres, mainly from spoil-heaps leaching salts (potassium chlorate by-products) and to a lesser extent from saline effluent into the river from a salt "pipeline". In 1975, salt concentrations of more than 200 mg/l were found across more than 130 km² of the water table.

Major remedial measures have been taken in the last 30 years: the 1976 Bonn convention set out limitations on releases of salts into the Rhine, along with requirements to sink sump wells downstream from spoil heaps, dissolve salt-laden spoil more rapidly with water cannons and place depollution wells in zones with very high salt concentrations. Salt concentrations are now declining, but it is estimated that depollution will need to continue for another 20 years before the groundwater is restored to an acceptable standard of quality. Modelling work by the BRGM indicates that chlorides on the water table surface will be mostly flushed out by 2015, and by 2027 further down, thus meeting WFD deadlines.



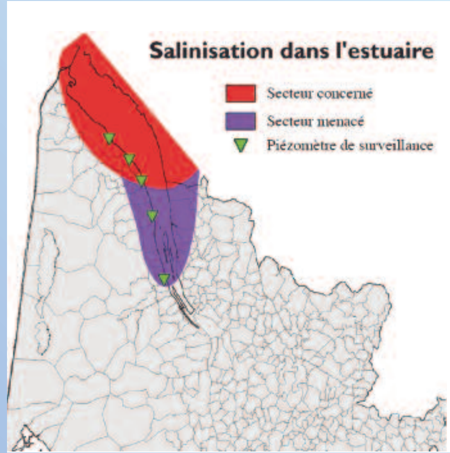
© MDPA

THE MARIE-LOUISE SPOIL HEAP
Speeding up the dissolving process with water cannons.

Groundwaters and climate change

Not all groundwaters in France are directly affected by the weather or climatic variations. Certain models suggest that deep, captive water bodies will retain their water for a long time despite global warming. The shallow unconfined waters in lowland and plateau areas, like those in the Paris basin and the Beauce and Brie regions, and small water bodies in old mountain ranges, are not expected to be severely affected as they are fed by infiltrating rainwater, mainly in winter.

Climate change is expected to bring more abundant rainfall in winter, but also to increase evapotranspiration as temperatures rise, so that an overall balance would be maintained. However, coastal groundwaters (Eocene, and Oligocene nearer the surface) are likely to be more severely affected. Because of sea level rise (15 to 30 cm by the end of this century), they could be contaminated by saltwater, especially in upper estuarine areas, for example between the Gironde river and the Bordeaux water table.



Reducing saline intrusions into Eocene groundwaters

In the Gironde estuary, there are potential risks of saline intrusion through three Eocene outcroppings. In 1965, these freshwaters had mineral concentrations of 0.3 mg/l. Today, the three northernmost monitoring stations are measuring concentrations of 4 to 6 g/l, which are due to saline intrusion into the water body as it loses pressure. To reverse these intrusions, which are likely to worsen with climate warming, water abstraction has to be reduced, especially during low water periods, to restore the pressure.

intersect with a wide range of disciplines that are working to improve knowledge on flow patterns and the circulation of pollutants in groundwaters, quantify their ecological status, anticipate the effects of climate change on water resources, assess the impacts of human activities, detect new pollutants found in very small doses, assess the long-term risks they carry, and much more.

But nothing can be done unless everyone, from citizens to official bodies, has the will to protect this precious resource as it should be. A major stumbling block is that protecting water brings in a great many conflicts of interest. For example, modern agriculture, which is the main source of water pollution today, is still the backbone of the future Common Agricultural Policy. For example, nearly half of all amateur gardeners use chemical pesticides...

Protecting groundwaters is an investment for the long term, because their relative inertia means that in some cases, their quality will not recover for several generations. Which is all the more reason to start protecting them now.

The source of the Lison river (Doubs)
Protecting groundwaters is an investment for the long term.

Contributing organisations:

Ministries

Ministry of Ecology, Sustainable Development, Transport and Housing

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Ministère de l'Écologie, du Développement durable, des Transports et du Logement

The Water and Biodiversity Directorate of the Ministry of Ecology, Sustainable Development, Transport and Housing is responsible for developing, facilitating and assessing policies concerning knowledge, protection, policing and management of inland, coastal and marine waters and aquatic environments and freshwater fishing, for ensuring balanced management of surface and groundwaters, estuaries and coastal waters, for protecting marine waters from pollution, including accidental pollution, and for wastewater treatment.

It develops technical guidelines and associated regulations to support water policy implementation. It also coordinates ministerial activities concerning water, runs the Secretariat for the Interministerial Mission on Water and the National Water Committee, and supervises several public institutions, including the Water Agencies and the National Office for Water and Aquatic Environments.

Ministry of Labour, Employement and Health - Directorate General for Health

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MINISTÈRE DU TRAVAIL, DE L'EMPLOI ET DE LA SANTÉ

The Directorate General for Health (DGS) is one of the three main Ministry of Health technical directorates. Its missions are concerned with public health and safety. It is responsible in particular for applying policy for the prevention and management of risks in the living environment and in food. Concerning water, the DGS is responsible for protecting the population against risks arising from water uses (drinking water, leisure, domestic hot water, bottled water, wastewater, etc.).
For this purpose, it develops laws and regulations in compliance with EU provisions, coordinates local water quality monitoring networks piloted by the regional and local authorities for social and health issues, defines water quality criteria with the support of national expert bodies, awards approval to analysis laboratories for health inspections of water, coordinates the procedure for appointing State-approved hydrogeologists, calculates national water budgets and draws up reports on water quality for the European Commission. Concerning groundwaters, the DGS and its local departments are responsible in particular for processing applications for protection zones around abstraction points and for health inspections of all water used for drinking water production. It communicates all its results to the ADES (national database on water).

Public institutions

The water agencies

Agences de l'Eau

The six water agencies (Adour-Garonne, Artois-Picardy, Loire-Brittany, Rhine-Meuse, Rhone-Mediterranean & Corsica and Seine-Normandy) are financially autonomous public administrative institutions. They work under the authority of the Ministry of Ecology, Sustainable Development, Transport and Housing and the Ministry of Economy, Finance and Industry.
Their mission is to facilitate action in the general interest in each hydrographic basin, including preservation and improvement of water resources, pollution prevention and furthering environmental knowledge.

The water agencies levy fees from water users for the pollution they cause and for the water they abstract. These funds are then redistributed in the form of loans or grants to local authorities, industrialists and farmers who carry out work to:

- prevent pollution: wastewater treatment plants and sewage networks, introduction of cleaner production processes, etc.
- develop and manage surface and groundwater resources and restore and maintain aquatic environments.

In each district, a basin committee representing the authorities, users (farmers, industrialists and associations) and the State set out the guiding principles of the water agency's programme and its fee structure. It develops the SDAGE and ensures consistency between SAGEs. In overseas France, water offices are established in Guade-

National office for water and aquatic environments (ONEMA)

ONEMA was established in April 2007 following the adoption of the 30 December 2006 Water Act, as a public institution working under the authority of the Ministry of Ecology. Its purpose is to promote overall sustainable management of water resources and aquatic ecosystems, in order to support the WFD objective of restoring water quality and achieving "good status" objectives by 2015. Its remit extends across all of mainland France, to Corsica under the basin solidarity principle, and to the overseas authorities. ONEMA's mission is to:

- mobilize public research, support research programmes and organize high-level expert input to accompany and assess the implementation of public policies concerning water;
- coordinate the Water Information System and contribute to the acquisition of data on water and aquatic environments and to associated activities and services;
- make this information available to the European and national authorities, water management bodies, the public, etc. ;
- support water use inspections and monitoring of aquatic environments, and efforts to prevent their degradation, restore their quality and preserve biodiversity;
- provide technical support and field knowledge to water management stakeholders.

To carry out these missions, ONEMA works closely and in a complementary manner with all water stakeholders.

BRGM

The BRGM is France's leading public institution in Earth Science applications for the management of surface and subsurface resources and risks.

Its missions are to conduct scientific research, support public policy development and run programmes for international cooperation and for mine safety and risk prevention. Its objectives are to:

- understand geological processes and associated risks, develop new methodologies and techniques, and produce and disseminate high-quality data.
- develop and deliver necessary tools to support surface, subsurface and resource management, the prevention of risks and pollution and climate change policy development.

Thanks to the scientific and technical competence it has acquired over several decades in identifying, characterising, monitoring and managing groundwater resources, BRGM works in a central position where different water related issues intersect.

BRGM provides its unique expertise in the management of groundwater quality and and quantity: support to the development of French regulations, monitoring of water bodies, acquiring and disseminating knowledge, developing methodologies and providing operational support to all those involved in the water sector, including the State, government departments, local authorities and water resource managers.

Private companies and associations

Lyonnaise des Eaux

As part of Suez Environnement, Lyonnaise des Eaux is a player in the water distribution and wastewater treatment markets. It offers services to local authorities and industries and supplies water to 19% of the French population, or about 12.3 million people. It collects and purifies wastewater for 18% of the population, or 9 million people. In the company's development strategy, innovation and customer satisfaction, including local authorities and consumers, are the top priorities. Its know-how in water resource management and protection guarantees the quality and availability of drinking water. Concerning wastewater treatment, it advises local authorities in their environmental protection efforts and in bringing their installations into compliance with European standards. Lyonnaise des Eaux invested more than 340 million € in 2007 in refurbishing, improving or building wastewater treatment plants and networks. Its research work in close liaison with Suez Environnement is aimed at improving the services offered and their quality, increasing productivity and offering fair value for services to local authorities. The company's 12-point commitment to sustainable development published in 2006 is central to its strategy for development and progress. Lyonnaise des Eaux intends to continue as the lead organization within Suez Environnement for water management and wastewater treatment.

French Hydrogeology Committee (CFH)

The French Hydrogeology Committee (CFH) is a member of the International Association of Hydrogeologists and was founded in 1973 by Gilbert Castany. Its aim is to support the advancement of theoretical and applied hydrogeology. It contributes to technical advances in research, water use and groundwater protection, and promotes national and international relations between hydrogeologists. The CFH has a membership of 350 hydrogeologists from public organizations (including the water agencies and BRGM), government administration, universities, local authorities and the private sector. Since 1993, it has organized an annual national symposium on different topics, as well as regional technical visits concerning groundwaters. A reference work on aquifers and groundwaters in France (*Aquifères et eaux souterraines en France*) was published under its aegis in 2006, written by 18 leading hydrogeologists and sponsored by the Academy of Science. The International Association of Hydrogeologists (IAH), founded in 1956 at the International Geological Congress in Mexico, has 4000 members from 130 countries and a national committee in 35 of these, including the CFH.

International Water Office

The International Water Office (OIEau) is a not-for-profit public utility association. Its purpose is to provide a platform for all public and private organizations involved in managing and protecting water resources in France, Europe and elsewhere in the world (cooperation agencies, ministries, water agencies, local authorities, universities, research centres, regional planners, water supply professionals, industrialists, etc.) in order to develop a network of partners. It runs activities in the general public interest concerning water, including vocational training, information, institutional support abroad for water management at basin scale and governance of water supply and sanitation services.

Glossary

Aquifer. A body (layer or mass) of permeable rock containing a saturated zone (and comprising both the solid matter and the water within it), which is sufficiently water-conductive to allow groundwater to flow and for an abstraction point to draw an appreciable amount of water from it. An aquifer can also comprise an unsaturated zone.

Aquifer system. The entire continuous area in which the effects of different more or less localised natural or artificial forces, exerted continuously or intermittently (natural or artificial water recharge or withdrawal, water level variations at aquifer boundaries) may propagate freely and therefore influence hydraulic functions, flows and the status of stocks, within a given time (system response).

Artesian well. A well or borehole in which water rises to a higher level than the top of the aquifer to gush out spontaneously at the surface. This type of well always draws on captive groundwater.

Catchment. This is the area on the surface from which runoff or water infiltrating into the ground is drawn to the abstraction point.

Diffuse pollution. Pollution which is not geographically localized, with multiple sources that cannot easily be identified, such as pollution from agricultural products leaching into the soil with rainwater.

Drainage. Part of the water from *effective precipitation* (see below) will percolate into the ground and part will run off to surface watercourses. It can take much longer for rainwater to filter into groundwater than into surface waters (several hours to several thousand years).

Drainance. Describes the passage of water through a semi-permeable formation and the exchanges between this formation and an adjacent, usually confined, aquifer.

Effective rainfall. Effective rainfall is expressed in mm and is equal to the difference between total precipitation and evapotranspiration, calculated directly from climatic parameters and usable soil moisture. Water from effective rainfall is absorbed into the ground either as surface runoff or by soaking down into groundwater.

Evapotranspiration. The amount of water vapour, expressed in mm, released as a combined result of evaporation, which is purely physical, and transpiration from plants. Groundwater recharge by rainwater is sometimes very slight during active vegetation periods, as most of the water is released into the air by evapotranspiration.

Fissured environment. A permeable, heterogeneous and discontinuous environment in which water flows through a network of open and variously interconnected fissures.

"Good status". The objective set by the European Water Framework Directive for the chemical and ecological quality of all waters by 2015. The level to be achieved is specified for different parameters, in comparison with reference levels defined on the basis of natural sites with little pollution.

Groundwater body. All of the water contained in the saturated zone of an aquifer of which all parts are hydraulically interconnected.

Groundwater resources. Not all groundwaters can be used as water resources, either because they are technically and economically inaccessible and cannot be exploited, or because they have to be kept intact to preserve their contribution to surface waters. A resource is exploitable up to the point where overexploitation begins.

Hydraulic gradient. In an aquifer, the rate of change of pressure head per unit of distance of flow at a given point and in a given direction. This is calculated by placing two piezometers within L metres of each other. The gradient is the ratio of the difference in the level h given by the piezometers and the distance L. It can also be calculated from piezometric maps by measuring the distance between 2 consecutive hydroisohypse curves.

Hydrodynamics. The field in hydrogeology and hydraulics relating to groundwater flows and the laws that govern them.

Hydrogeochemistry. The study of the chemical or physico-chemical characteristics of groundwaters, the processes whereby they are acquired and the laws governing exchanges between water, soils and subsoils.

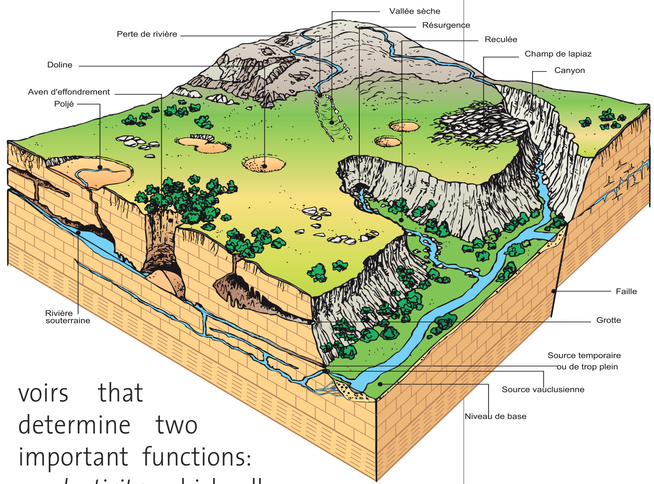
Hydrogeological basin. A simple or complex aquifer domain in which groundwaters all flow towards the same outlet or outlets. Like surface waters, aquifers are separated by an underground drainage divide or watershed.

Hydrogeology. The science of groundwaters, a field of the Earth sciences, and the application of that scientific knowledge to human activities involving groundwaters, particularly prospecting, abstraction and protection.

ICPE.(*Installations Classées pour l'Environnement*) Facilities listed for environmental monitoring.

Infiltration (recharge). Infiltration is the physical process whereby water filters down into soils and recharges aquifers.

Karst. Type of limestone terrain in which aquifer behaviour is determined by heterogeneous and compartmented reservoirs that determine two important functions: *conductivity*, which allows water to flow rapidly through interconnected karstic channels (underground rivers); this mechanism explains why these aquifers are highly vulnerable to pollution; and *storativity*, which determines how much water is stored in fissured zones and spaces (underground lakes). Because these waters flow more slowly, they are less vulnerable to pollution.



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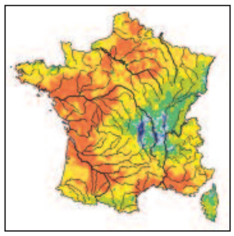
Measurement network. A system for collecting data from a series of measurement stations set up for at least one specific purpose. Each network operates according to a set of rules designed to ensure consistency between its observations, especially regarding the density and purpose of measurement stations, the selection of required parameters, the choice of measurement protocols and the determination of measurement intervals. These rules are set out in a protocol. Examples: national groundwater monitoring network, basin-scale quantitative monitoring network.

Natural mineral water. Microbiologically safe water drawn from an underground aquifer or reservoir at one or more wells or natural springs making up the water's source. Its essential characteristics are demonstrably stable, especially its composition (mineral content, oligoelements, etc.) and temperature at the source, which itself is not affected by the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quantities abstracted. It differs from other drinking waters in its nature (characterised by concentrations of minerals, oligoelements and other components) and its natural purity, both having been preserved in their original state by the water's subterranean origin, which keeps it away from any risk of pollution.

Overabstraction. Abstraction of groundwaters in quantities that exceed their average recharge rate, or liable to have an unacceptable impact on surface waters or ecosystems.

Permeability. The ability of a body or solid environment - especially soil or rock - to be penetrated and traversed by a fluid, such as water in particular, due to the effect of a potential gradient.

Piezometer. Tube sunk into the ground and substrate to record water levels.

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Piezometric map. A map showing groundwater levels. These are represented by the contour lines (hydroisohypse lines) that connect all points on a water table lying at the same elevation.

Porosity. Describes an environment, soil or rock comprising pores, or interstitial spaces that may be interconnected or not.

Porous environment. A permeable environment (soil or rock) comprising interconnected interstitial spaces and which, unlike a fissured environment, can be considered macroscopically as a continuous environment.

Saturated zone. An area in the substrate where water entirely fills interstitial spaces in the rock, thus forming an aquifer or underground water body.

SDAGE. Acronym for the "water management masterplans" (*schéma directeur d'aménagement et de gestion des eaux*) introduced in France by the 1992 Water Act and setting out guidelines for balanced management of each hydrographic basin in the general public interest and in accordance with the Water Act's principles. These guidelines must be observed in all decisions concerning water made by the State, local authorities and public institutions, in particular for administrative authorisation procedures (e.g. effluent releases); all urban planning documents must be consistent with the fundamental policy aims set out in the SDAGE. At a more local level, an SAGE (water management plan) for each coherent hydrographic district is drawn up by a Local Water Committee (CLE - *Commission locale de l'eau*) representing the various local stakeholders.

Stream gauging. All of the operations, measurements and calculations necessary for measuring the discharge of a river, stream, canal or spring at a given point along it, called a "gauging station".

Surface runoff. The fraction of rainwater that is not absorbed by the soil but runs in rivulets across the surface until it reaches the natural drainage level of the catchment basin. This occurs either when the amount of rainfall exceeds the soil's capacity for absorbing it, or when soil which is already saturated on the surface cannot absorb any more. Surface runoff contains quantities of dissolved and suspended matter.

Water body. A homogeneous aquatic environment, either on the surface (lake, reservoir, part of a stream or river) or underground. An underground water body is a distinct volume within one or more aquifers, in which the water is renewed over a shorter or longer period. It is the water management unit defined by the WFD to assess the quality and quantity of water bodies.

Water table fluctuation. The alternating rise and fall of water levels at the unconfined surface of an aquifer over a given time. Different fluctuation cycles may be governed by natural phenomena, such as rainfall, floods and low water levels in rivers during the dry season.

To find out more

Web sites

National portal for water issues: *http://www.eaufrance.fr*
Access to data on groundwater: *http://www.ades.eaufrance.fr*
SANDRE, portal for water standards and reference data: *http://sandre.eaufrance.fr*
Water status monitoring programme: *http://www.surveillance.eaufrance.fr*
GEST' EAU, tools for integrated water management (SAGE): *http://www.gesteau.eaufrance.fr*
Water table rise, spates and floods: *http://www.inondationsnappes.fr*
Ministry of Ecology, Sustainable Development, Transport and Housing: *http://www.developpement-durable.gouv.fr*
Ministry of Labour, Employment and Health: *http://www.sante.gouv.fr*
BRGM: *http://www.brgm.fr*
Lyonnaise des Eaux: *http://www.lyonnaise-des-eaux.fr*
International Water Office: *http://www.oieau.fr*
National office for water and aquatic environments (ONEMA): *http://www.onema.fr*
French Hydrogeology Committee (CFH): *http://www.cfh-aih.fr*
Portal for the European Water Information System: *www.water.europa.eu*
Water agencies: *http://www.eau-adour-garonne.fr* • *http://www.eau-artois-picardie.fr* • *http://www.eau-loire-bretagne.fr* • *http://www.eau-rhin-meuse.fr* • *http://www.eaurmc.fr* • *http://www.eau-seine-normandie.fr*
Water offices: *http://www.eauguadeloupe.com* • *http://www.eauguyane.fr* • *http://www.eaumartinique.eu* • *http://www.mayotte.pref.gouv.fr* • *http://www.eaureunion.fr*

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- *Aquifères et eaux souterraines de France* (Aquifers and groundwaters in France), collective publication edited by Jean-Claude Roux, Éditions BRGM-AIH, 2006, 956 p. in volumes, ISSN: 2-7159-0980-2.
- *Les eaux souterraines, connaissances et gestion* (Understanding and managing groundwaters) Jean-Jacques Collin, Éditions BRGM and Hermann, 2004, 184 p., ISBN: 2-7159-0910-1 Jean-Jacques Collin, Éditions BRGM et Hermann, 2004, 184 p., ISBN : 2-7159-0910-1
- *L'eau potable en France 2005-2006, du captage au robinet du consommateur* (Drinking water in France 2005-2006, from abstraction to domestic tap-water), Directorate-General for Health and DRASS, Ministry of Health, 2008, 64 p., ISBN: 2-7159-2440-6
- *Qualité naturelle des eaux souterraines* (The natural quality of groundwaters), Technical guide edited by Laurence Chéry, Éditions BRGM, 2006, 240 p., ISBN: 2-7159-0973-X.
- *Guide qualité pour la ressource en eau minérale et thermale* (Guide on quality for mineral and spa water resources), Philippe Vigouroux, Ed. BRGM, 2005, 82p. ISBN: 2-7159-0959-4
- *Code de la santé publique* (Public Health Code) available for consultation at http://www.legifrance.gouv.fr consultable sur : http://www.legifrance.gouv.fr.
- *Les eaux continentales* (Inland waters), report by the Academy of Sciences, editor Ghislain de Marsily, Editions EDP Sciences, 2006, 328 p., ISBN: 2-86883-863-4
- *Les eaux souterraines dans le monde* (Groundwaters across the world), ed. Jean Margat. BRGM-UNESCO, 2008, ISBN: 978-2-7159-2452-9
- *Groundwater Protection in Europe. The new groundwater directive, consolidating the EU regulatory framework, 2008, 35 p., ISBN: 978-92-79-09819-2*

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Cover photo: The source of the Loue river in the Jura (© A. Clerget)

Groundwater in France

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This book is aimed at a wide readership, including local authorities, government departments, professionals, teachers and members of the public.

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