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THE EFFECTS OF AGRICULTURE ON GROUNDWATER

Trabajo Fin de Grado

Grado en Ciencias Ambientales

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The effects of agriculture on groundwater

enric selfa martínez

ABSTRACT

Due to the problem of the uncontrolled use of groundwater in agriculture, as well as the introduction of agrochemicals into crops, it is necessary to study the weaknesses of the aquifers, the main hazards to which they are subjected, characteristics influence their contamination and the legislation that regulates the use of these products.

In this work the different topics previously mentioned will be treated with the maximum simplicity possible, making known the dangers to which the underground waters of the world are facing in the coming years.

Keywords: pollution, contaminants, groundwater, pesticides, agriculture, cultivation.

DEDICATION

I would like to express my gratitude to all the teachers of the UPV who have helped me to acquire the necessary knowledge for the realization of this work, also to the teachers of the Mendel University of Brno, especially to Petra Oppeltová, the tutor of this work. In addition, I also want to express my thanks to my family for supporting me.

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1. INTRODUCTION

Until very recently we wouldn't have thought about what agriculture and our methods could harm or affect our environment, but this is becoming a reality and the study of our agriculture and the consequences of our techniques and our feeding model is becoming more and more necessary because nowadays we already know that this can affect us directly or indirectly our environment and also ours health.

The increase of the world population makes necessary an improvement of the current agriculture as well as an increase of its production to be able to cope with this demand for food.

This results in an increase in fertilizers, herbicides, insecticides, etc. So far we had not imagined that this could become a problem for our environment and consequently for us.

Therefore, this study aims until very recently we wouldn't have thought about what agriculture and our methods could harm or affect our environment, but this is becoming a reality and the study of our agriculture to analyse one of the factors most affected by agriculture, water, more specifically groundwater. According to FAO, agriculture represents the main non-localized source of groundwater contaminants. In addition to the problems that this contamination can cause on the human supply waters, it also causes problems in the waters for irrigation of crops since the irrigation with contaminated water affects the soil and the crops and that is why if we don't stop this pollution we will probably have serious problems in the crops irrigation.

Drinking water, and drinking water of groundwater, are becoming scarce, which makes the protection and maintenance of this resource be essential for human life.

In addition, groundwater and aquifers have special characteristics that differentiate them from surface waters, and although they are more difficult to be polluted and are more protected, they are also much more difficult to detect and decontaminate, which in many cases pollution is an irreversible process at least in the short term.

This study will discuss the mechanisms of contamination of these waters, the factors that influence the vulnerability of the aquifer, the main potential contaminants of this type of water, the current state of the underground waters in Spain and Czech Republic, legislation etc.

2. DIFFERENCE BETWEEN SURFACE WATER AND UNDERGROUND WATER

At least initially, the pollutants involved in the contamination of groundwater are not different from those that cause the pollution in surface water: normal salts (Ca, Mg, Na, K ...), nitrates, organic matter (biodegradable or not), toxic organic or inorganic compounds, heavy metals, pathogenic microorganisms, radioactive elements... However, due to the peculiarities of groundwater, there are nuances that will be pointed out in the following sections.

General characteristics of groundwater and surface water	
Ground	**Surface**
Constant composition	Varying composition
High mineral content (e.g. Fe, Mn, Ca, Mg, etc.)	Low mineral content
Low turbidity	High turbidity
Low or no color	Color
May be bacteriologically safe	Microorganisms present
No dissolved oxygen	Dissolved oxygen
High hardness	Low hardness
Possible chemical toxicity	Possible chemical toxicity
Has natural filtering capacity that removes suspended solids, turbidity and pathogens	Easy to contaminate
Difficult to clean up if contaminated. Renewal times can be very long.	

***Table 1**: General characteristics of ground and surface water [G. Kassab (University of Jordan)]*

1. CONCEPTS AND CHARACTERISTICS OF UNDERGROUND WATERS

To understand the transport of pollutants in groundwater, first of all we should know the concepts of aquifer and porosity, as well as the characteristics of porosity and permeability. In the same way, it is possible to distinguish between saturated and unsaturated zones. I will define all of these terms below.

3.1 AQUIFERS

An aquifer is a geological formation that allows the circulation of water through its pores or cracks so that humans can take advantage of it. The main characteristics that determine the ability of a geological formation to become a good aquifer are porosity and permeability.

Also it was defined by the **Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy as "**a subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a signify cant flow of groundwater or the abstraction of significant quantities of groundwater."

3.1.1 Unconfined Aquifers

They are those where the underground water is in contact with the atmosphere through the open spaces of the soil or rock that covers it, which means that the aquifer is not confined (Isolated).

The upper surface of groundwater in an unconfined aquifer is called the water table. The depth of the water table varies according to various factors such as geology, topography, season, effects of tides, and the quantities of water pumped from the aquifer ... This type of aquifer is usually recharged with rainwater or current that infiltrates directly through the ground that covers them. It is therefore that they are easier to contaminate than confined aquifers.

3.1.2 Confined Aquifers

Confined aquifers are those whose rocks are impermeable and tend to be deeper than unconfined aquifers. Unlike the previous ones, the confined aquifers are totally covered by relatively impermeable rock or clay and are not in direct contact with the outside water. In addition, these layers of impermeable rocks limit the movement of groundwater inside or outside the confined aquifer.

Groundwater in a confined aquifer is under pressure and will rise into a well drilled in the aquifer. The level at which the water rises is called the potentiometric surface. Confined aquifers can be replenished or recharged by rain or water currents that infiltrate the rock at a considerable distance from the confined aquifer. The groundwater in these aquifers can sometimes be thousands of years old.

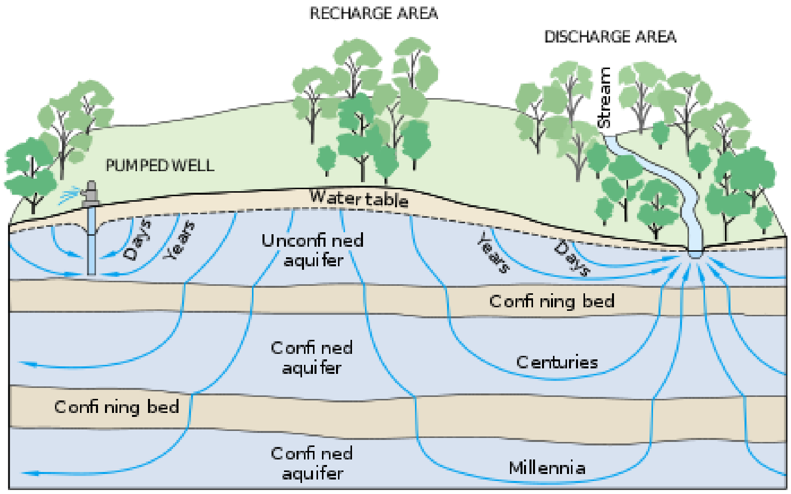

Figure 1: *Groundwater basics – Aquifer (U.S. Geological Survey)*

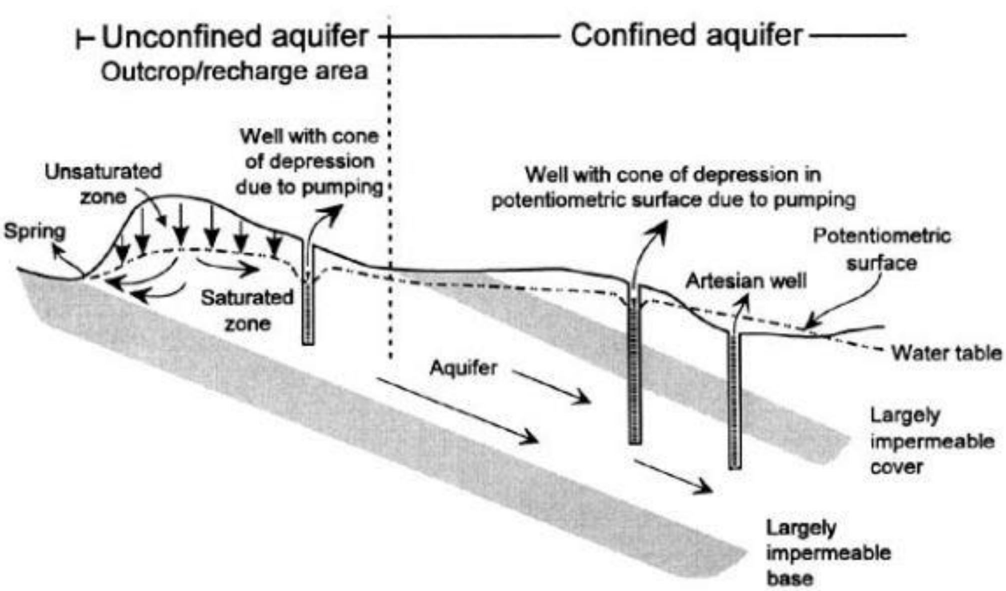

Figure 2: Schematic cross-section confined and unconfined aquifers (J.Chilton –Water Quality Assesstments UNESCO)

3.2 POROSITY

It is defined as the quotient between the empty volume or the pore volume and the total volume. There are also different pore sizes, pores where water circulates easily, closed pores and pores where water can circulate but very slowly.

That is why in hydrology, the parameter of interest is the effective porosity, that is, the relationship between the volume of pores through which water can circulate and the total volume.

In addition, in this section we have to talk about permeability, which is defined as the capacity of a material to allow the flow of some fluid through it without altering its internal structure. Thus the permeability depends on the size of the pores and the density and viscosity of the fluid.

3.3 DEFINITION OF SATURATED AND UNSATURATED ZONES

The saturated zone systems have two phases (solid and liquid). This is the space between the water table and the surface where the pores contain both water and air, but are not totally saturated with water.

Unsaturated zone has one more phase, gas; where only a part of the ground is filled with water. This is the area above the impermeable layer, where the water completely fills the pores of the rocks. The upper limit of this zone is separated by the unsaturated zone, is the phreatic level, which can vary according to weather conditions.

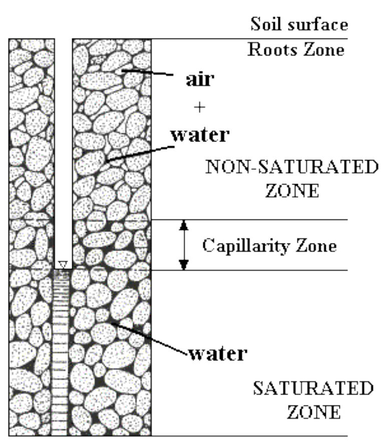

***Figure 3**: Saturated and unsaturated zone*

Water from soil representing water from the unsaturated zone, and which is the transit bond between matter and substances. These processes are part of a continuous cycle soil-plants-atmosphere while subsurface water level is influenced by rain percolation regime or irrigation water that crosses through the unsaturated zone.

In case of an unsaturated environment, hydraulic conductivity varies with soil humidity and water effective pressure, which is negative while in a saturated environment, effective water pressure in soil is positive and depends on the depth of submersion below the free water surface.

4. CHARACTERISTICS OF GROUNDWATER CONTAMINATION

Contamination of aquifers occurs when water leaches through the soil profile. This happens when the amount of water is higher than the storage capacity of the soil and because of that the water moves downwards under the force of gravity. The amount of water moving through the soil profile will depend on several factors, for example, soil water holding capacity, evapotranspiration rate, precipitation, type of soil (sandy soils have a higher leaching than clay soils), irrigation method, type of crop, method of cultivation, the gradient of soil. However, the most important factor is the temporal dynamics that combine the precipitation pattern with the water use pattern of the crop. In irrigated crops, the interaction of the amount of irrigation and time with the water use patterns of the crop should also be considered. Leaching through the soil profile occurs when the amount of precipitation exceeds the water use rate of the crop that leads to an excess in the soil profile. When leaching occurs, the soluble materials also move with the water through the soil profile, the most notable of the soluble materials is the nitrate. And it is at this moment when the contamination of the aquifers occurs.

2. MECHANISMS OF INTRODUCTION AND PROPAGATION OF POLLUTION IN UNDERGROUND WATER

The classification criteria can be diverse, in this case I will divide them depending on the point from where the contaminant spreads.

5.1 MECHANISMS OF PROPAGATION FROM THE SURFACE

In this group are the pollutants coming from the surface of the land by infiltration water, as for example the use of fertilizers on the ground or agricultural residues. It can also infiltrate previously contaminated surface waters such as rivers. This is the most common mechanism of contamination of aquifers due to agriculture.

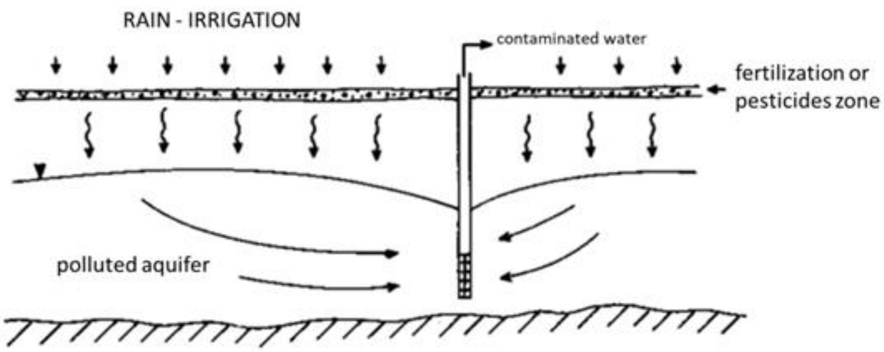

***Figure 4**: Movement of pollutants by rain and irrigation (IGME)*

5.2 MECHANISMS OF PROPAGATION FROM THE UNSATURATED ZONE

In this type of mechanism are the pollutants coming from the infiltration of domestic wastewater (septic tanks, leaks in the sewerage network, etc.) or through the subsurface embalming of contaminating liquid substances (evaporation ponds, infiltration ponds...) or in natural excavations. As we can see, this type of mechanism is not important to us because it is totally different from the causes of agriculture.

5.3 PROPAGATION MECHANISMS ORIGINATED IN THE SATURATED ZONE:

Excessive pumping in coastal aquifers hydraulically connected to the sea or the inadequate location of pumping catchments in this type of aquifer causes the advance of salt water, inland, by decreasing the flow of fresh water to the sea.

This is a real problem on the Valencia (Spain) coast due to excessive pumping over aquifers near the sea.

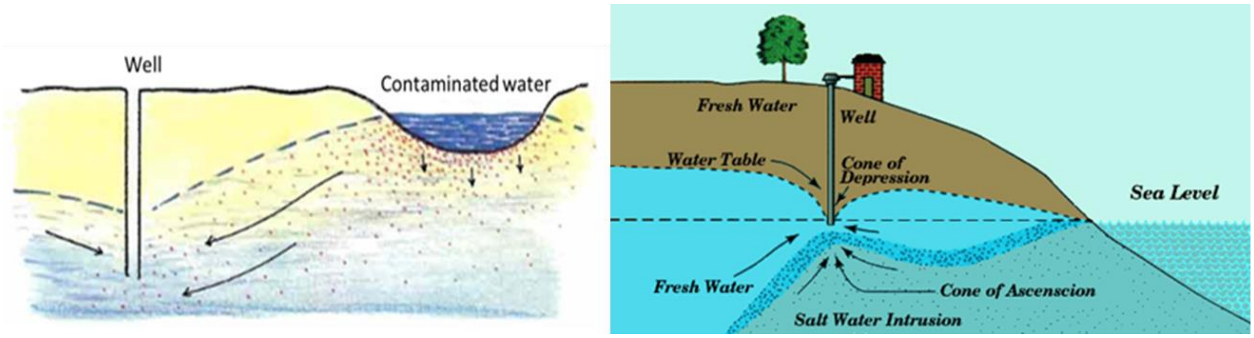

Figure 5: Groundwater pollution by excessive pumping (Lenntech)

6. TRANSPORTATION AND MOVEMENT OF WATER IN THE AQUIFERS AND TRANSFORMATION OF POLLUTANTS

The law that regulates the movement of groundwater under laminar flow conditions is Darcy's law. The expression of Darcy's law is:

$$u_D = -k\frac{dh}{ds}$$

U_D: Darcy's speed (m/s or m/day).

K: permeability (m/s or m/day).

H: piezometric level (m).

s: distance (m).

However, this is a fictitious speed because in its definition it is considered that water flows throughout the all section. But this is not true, the water does not occupy the entire section and moves at a variable speed according to the size and orientation of the pores. Thus, considering a sufficiently large average volume, an average velocity can be defined, called real speed (intergranular or filtering), whose relation with Darcy's velocity is given by:

$$u_D = \theta u$$

θ: effective porosity

u: real speed (m/s or m/day)

These equations are important to determine the speed at which the groundwater will move, which will influence the decontamination capacity of the aquifer.

6.1 TRANSFORMATION OF CONTAMINANTS:

Generally, in groundwater, chemical species of inorganic or organic nature are likely to experience interactions of a physical-chemical nature, and to a lesser extent biological nature, which is not frequent in saturated systems and in depth. Physical-chemical interactions include a whole series of reactions in solution (acid-base reactions, oxidation-reduction reactions and the formation of complexes in solution) as well as heterogeneous precipitation-dissolution and adsorption-desorption reactions. Therefore, a quality model that represents the behaviour of a natural system should incorporate all these interactions simultaneously.

3. PHYSICAL AND CLIMATIC CONDITIONS THAT MAKE GROUNDWATER VULNERABLE

7.1 CHEMICAL PROPERTIES

7.1.1 Solubility

Water has the ability to carry pollutants to the subsoil. That is due to the solvent power that water has. Therefore, depending on the solubility of the chemical compounds in the water, it is easier or more difficult for them to dissolve in the water and to leach to the underground water. The most soluble compounds are those that are more likely to contaminate aquifers.

7.1.2 Adsorption

Many chemicals do not leach because they are adsorbed, or tightly held, by soil particles. Adsorption depends not only on the chemical properties of the compounds, but also on the soil type and the amount of organic matter present that facilitates the chemical and biological decomposition of many contaminants before they reach groundwater.

7.1.3 Degradation

The degradation is produced by heat, sunlight, microorganisms, and a variety of physical and chemical properties. Most degradation takes place within the top few inches of soil.

Pesticides that take a relatively long time to degrade are said to be persistent and as longer the compound persists in the soil, the longer it is available to leach into groundwater.

7.1.4 Volatility

Volatile compounds are those that vaporize easily. However, highly volatile compounds and highly soluble in water can contaminate groundwater. On the other hand, compounds that are highly volatile but not very soluble usually volatilize and go into the atmosphere, so they do not usually contaminate groundwater.

7.2 SOIL PROPERTIES

7.2.1 Soil texture

The relative proportions of sand, silt, and clay determine the texture of a soil. Texture affects movement of water through soil, and thus movement of dissolved chemicals such as pesticides. The coarser the soil, the pores are bigger so the faster the movement of percolating water, and the less opportunity for adsorption or evaporation. Soils with higher clay or organic matter content tend to hold water and dissolved chemicals longer. These soils also have more surface area onto which pesticides can be adsorbed.

7.2.2 Content of organic matter

The amount of organic matter in a soil affects the adsorption capacity and the amount of water that the soil can contain. Soils with a high content of organic matter usually contain a large amount of water and dissolved chemicals around the root zone, where they are available for plants and can be degraded.

7.2.3 Soil permeability

The permeable soils are those in which water can circulate more easily and therefore, in this type of soil is more likely to contaminate groundwater as water can carry pollutants to the aquifer.

7.2.4 Depth to groundwater

The shallower the depth to groundwater, or the water table, the less soil there is to act as a filter, and the fewer opportunities there are for degradation and adsorption of chemicals. Areas with high water tables are thus more susceptible to contamination.

8.3 CLIMATIC CONDITIONS

8.3.1 Rainfall

If the precipitation is high, the pollutants dissolve and leach contaminating the groundwater more easily.

8.3.2 Sunlight hours and intensity:

In the places where the sunlight is higher the evaporation will be also higher so it's more probable that the pollutants volatilized. Also the activity of microorganism will be higher so this improves the disintegration of some pollutants.

8.4 DIFFERENCE BETWEEN LOCALIZED AND NON-LOCALIZED SOURCES OF CONTAMINATION

It is important to differentiate between localized and non-localized sources of contamination because this will allow us to more accurately assess the problem and determine how to deal with pollution problems and how to tackle or study them.

According to the United States Environmental Protection Agency (EPA), the non-localized sources of contamination would be all those that are not inside the definition of localized sources. The definition is as follows:

"The term localized source means any perceptible, delimited and discrete means of transport, for example, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feed activities, or vessel or another floating medium, from which pollutants are discharged or can discharge, this term does not include agricultural discharges of rainwater or the return flow of irrigated agriculture." (EPA, United States Water Pollution Act (Water Quality Act) of 1987)

Thus, agriculture would be a non-localized source and is one of the most important non-localized sources because it is not within the localized source definition given by the United States Water Pollution Act of 1987. This influences the way to deal with such contamination because it is not It is possible to detect a specific source, which makes detection and solution to such contamination more difficult.

8.5 POTENTIAL POLLUTANTS FROM AGRICULTURE IN GROUNDWATER

The agriculture is one of the most important sources of groundwater pollution and the type of pollutants that can affect the groundwater depends on the geological, climatological and social characteristics, also it depends on the type of crop. The main pollutants generated by agriculture are the following:

- Nutrients (Nitrogen and phosphorous)
- Pesticides
- Salinity

8.6 NUTRIENTS

This type of pollutant is probably the most important pollutant in groundwater because of agriculture. The nutrients are divided mainly in two compounds, Nitrogen and Phosphorous.

The use of ammonium sulphate fertilizers [$(NH_4)_2SO_4$], potassium chloride (KCI) or potassium carbonate (K_2CO_3) as well as phosphorus compounds these are generally not very mobile if the soil's fixing capacity is not exceeded and solubility changes are not produced although can lead to increases of concentration of sulfates, chlorides and phosphorus in groundwater. However, these compounds are almost always a problem of minor importance than nitrates.

8.6.1 Nitrogen

Nitrogen is the main fertilizer used in agriculture and is also the nutrient that produces the most pollution in groundwater. The use of fertilizers, of natural origin and, especially, artificial nitrogen-based has produced greater agricultural productivity. However, nowadays it is also an important cause of pollution of natural resources, in general, and specifically in groundwater.

It is estimated that every year in the European Community a surplus of between 50 and 100 kilos of nitrogen per hectare is applied in agricultural soils. Nitrogen is soluble in water and easily converted to nitrate, which frequently contaminates groundwater since plants are not able to absorb it completely. The main nitrogen components that leach into groundwater producing pollution are NO_3^-, NO_2^- and NH_4^+. The last two in a lesser proportion (less than 1%). The maximum limits allowed in drinking water of these compounds are: 50mg / l for NO_3^-, 0.1 mg / l for NO_2^- and 0.5 mg / l for NH_4^+.

The criteria followed to identify the groundwater that can be contaminated are based on whether they contain more than 50 mg / l of nitrates, or they can contain them if the action programs are not implemented (Annex I of Directive 91/676). The prevention of contamination of groundwater by nitrogen depends to a large extent on the ability to keep the NO_3 of the soil below a level that can be absorbed by the crops, and to reduce the amount of NO_3 retained in the soil after Harvest.

8.6.2 Measures to reduce nitrate pollution

a) <u>Rational application of nitrogen:</u> To avoid the excessive use of fertilizers, the rate of nitrogen fertilizer applied should be calculated according to the "nitrogen balance of the crops". It takes into account the needs of plants and the amount of N in the soil.

b) <u>Vegetable cover:</u> As far as possible, the soil should be covered with vegetation. Because the vegetation can absorb the nitrogen excess and prevents leaching during periods of rain.

c) <u>Control the period between harvests</u>: The organic waste produced by the harvest is easily mineralized in leachable N. Among the measures that can be adopted to reduce this N are the planting of "green manure" crops, and the postponement of plowing to incorporate straw, roots and leaves into the soil.

d) <u>Rational irrigation:</u> It is important to control the irrigation systems as they can cause a deterioration of the water quality if they are deficient. In addition to reducing the net cost of the water supplied.

e) <u>Try to improve the cultivation techniques:</u> To try to reduce the negative effects on the quality of the waters without reducing the production of the crops.

8.6.3 Nitrate pollution in Spain

"Around 170 of the 700 existing masses are affected by the diffuse contamination of nitrates, 25% of the total" explained Juan José Durán, director of the geoscientific research and foresight department of the Geological and Mining Institute of Spain (EFE). (IGME) in 2015.

GOUNDWATER BODIES CONTAMINATED BY NITRATES (2015)

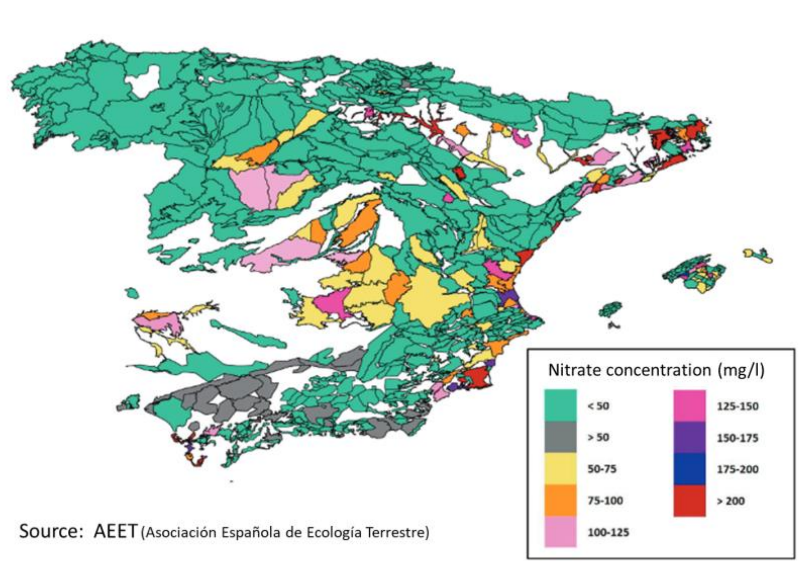

Figure 6: Groundwater bodies contaminated by Nitrates (2015)

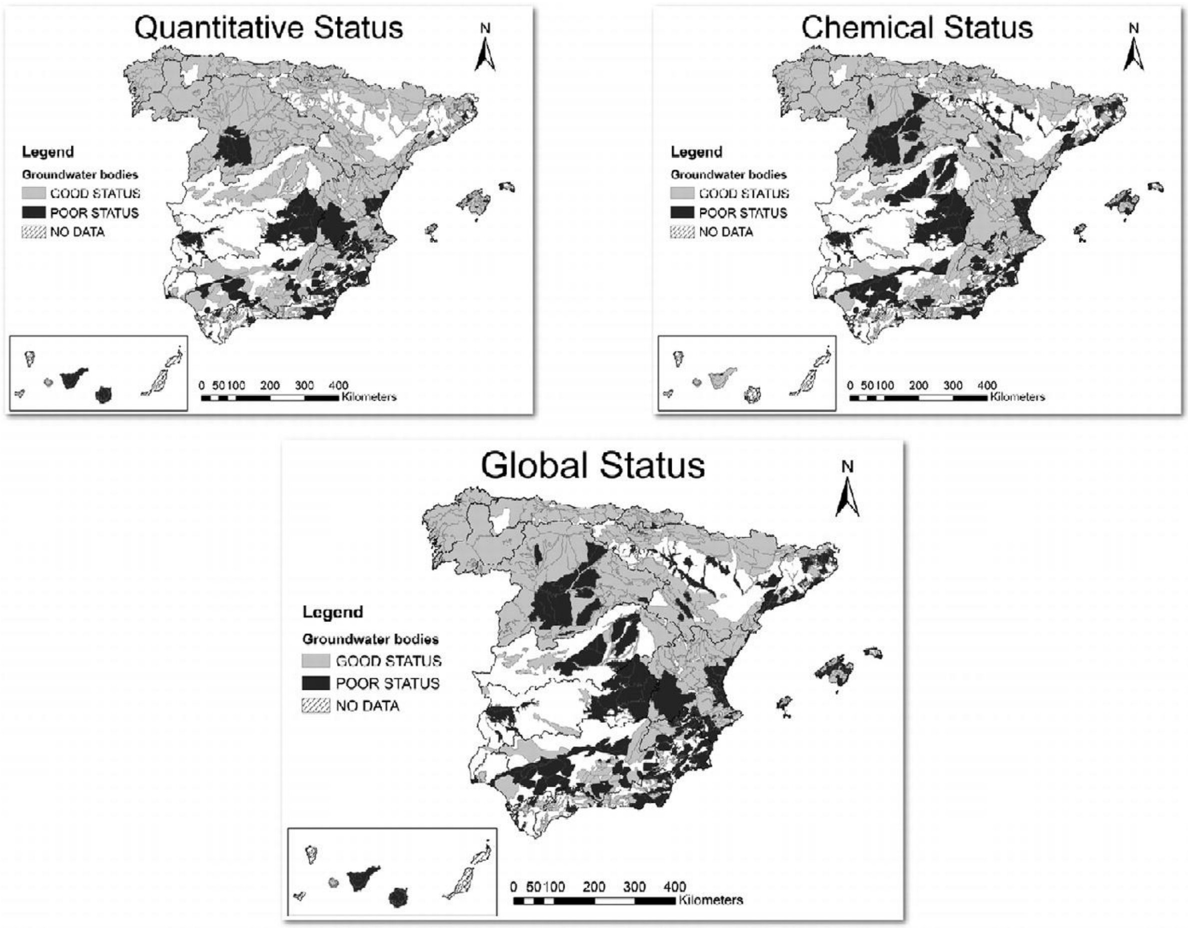

Figure 7: Status of groundwater bodies in Spain (2013) [Stefano, Martinez-Satos, Villarroya, Chico, Martinez Cortina]

8.6.4 Effect of nitrate on health

The main problem of nitrogen in public health are the effects derived from the ease of nitrates to transform into nitrites. The greatest biological effect of nitrogen is the oxidation of normal hemoglobin to methemoglobin, which is unable to transport oxygen, the blue child syndrome. The other effect is the carcinogenic potential in the digestive system, the tolerance of the human body and the intensity of its effects is variable and depends on several factors, being young children and people with Respiratory difficulties are the most sensitive. From a health point of view, children and other sensitive groups should not be given waters with a nitrate content higher than 25 mg/l.

8.6.5 Phosphorous

Phosphorus is not very soluble in water and rarely reaches groundwater, except in areas with sandy soil and free of clay and that is why traditionally has not been a great control over the pollution caused by phosphorus.

We usually can find it in the form of phosphate. The reference value for water in general is 0.2 mg/l of dissolved phosphorus although in some European countries the value of 0.1 mg/l is used for groundwater in particular.

Normally the fertilizer is applied to the soil in a soluble form or it can be leached from the manure when it is used for fertilization. However, mineralization and adsorption can retain the phosphorus and prevent it from leaching into the groundwater. In water, inorganic phosphorus is produced mainly as orthophosphate, which has a negative charge which facilitates its adsorption in soil particles. Those responsible for adsorbing orthophosphate are mainly clays and metal oxides (fine-grained iron oxides).

Also the presence of soils rich in calcium carbamates can slow down the movement of phosphorus since they form calcium phosphate minerals. Although the adsorption immobilizes the phosphors, the adsorption capacity of the soils is limited and can be saturated. When this occurs, the excess of orthophosphates will remain in solution and is likely to contaminate groundwater when infiltrated.

However, the ability of iron oxides to adsorb and immobilize orthophosphates depends on properties such as soil pH and dissolved oxygen, soils with a basic pH and with little dissolved oxygen are the ones that are fastest saturated. Measurements of environmentally available phosphorus are made which can be used by farmers to determine the specific phosphorus needs for each crop.

Possible measures to reduce phosphorus pollution:

- Calculate the dose of organic fertilizer based on phosphorus instead of nitrogen.
- Add to the manure salts of Fe, Al or Ca to decrease the solubility of phosphorus. Waste products containing these salts can be used for this purpose
- Keep the soil covered with vegetation.
- No tilling
- Do not apply manure when the probability of rain is high.
- Irrigation management

8.7 PESTICIDES

Pesticides are subject to control through the national registration system that is responsible for authorizing the sale and use of the pesticide. This is an official procedure in which pesticides are examined and then the decision is made to allow them or not.

There are many types of pesticides, which are usually divided into insecticides and herbicides. Some of the most frequent are: The **organochlorines** (DDT, aldrin, endrin, lindane, etc.), **organophosphates** (malathion, parathion, etc.), **carbamates** (Servin, Baygon, etc.) for insecticides and 2,4 **dichlorophenoxyacetic acid** (2,4-D) and **2,4,5-trichlorophenoxyacetic acid** (2,4,5-T) for herbicides.

8.7.1 Properties of pesticides

8.7.1.1 Solubility

Not all pesticides have the same solubility in water. Highly soluble pesticides are the most dangerous in groundwater since they are the most likely to reach groundwater.

8.7.1.2 Degradation

An important point to keep in mind for pesticides is the persistence of pesticides in the environment without being degraded. To determine the persistence of a pesticide, the term half-life is used, which is the period of time it takes for half of the total amount of chemical applied to decompose into non-toxic substances. In addition, the rate of degradation depends on the pH of the soil and water, the temperature and the activity of the micro-organisms. Therefore, climate and precipitation also influence the vulnerability of an aquifer to be contaminated.

8.7.1.3 Adsorption

Adsorption can also influence the contamination of groundwater since it is the capacity of the soil to retain chemical substances, which means that they do not reach groundwater. The adsorption capacity of a soil depends on the texture, the humidity and the amount of organic matter.

8.7.1.4 Volatility

The volatility of the pesticide is important since a very volatile pesticide is most likely to end up in the atmosphere and does not infiltrate into the groundwater.

8.7.2 Handling Practices

It is important that when using any pesticide, the instructions given by the manufacturer on the label should be followed since a greater benefit is obtained and a lesser impact on the environment is generated. It is also advisable to try to avoid spills and if they are going to make mixtures that are on impervious surfaces. It is also important to calibrate the spray equipment to avoid spraying with a greater amount of pesticide than recommended.
In general, the handling of the spray must be correct because it influences the amount of pesticides discharged that may end up in the groundwater.

8.8 SALINITY

The impact of agriculture on the salinization of groundwater can be divided into three processes. The first is when the salinity increases because the plant absorbs water but does not absorb most of the salts, which produces a higher concentration of salts. The second one is when the salts that are already in the soil go down into groundwater due the irrigation water or precipitations. And the third process is the saline intrusion. Especially in coastal areas the groundwater is being affected by the salinity caused by salt intrusion due to excessive pumping of groundwater to use it in irrigated agriculture.

This effect is produced by the decrease in the pressure of fresh water in the aquifer, which allows the entry of marine water into the aquifer. This causes a salinization of the wells which can’t be used both for drinking water for human consumption and for irrigation water.

The first process is unavoidable in that water leaving the root zone is always of higher salinity than rain or irrigation water received at the soil surface. Plants preferentially take up water and leave most of the salts behind in the remaining water.

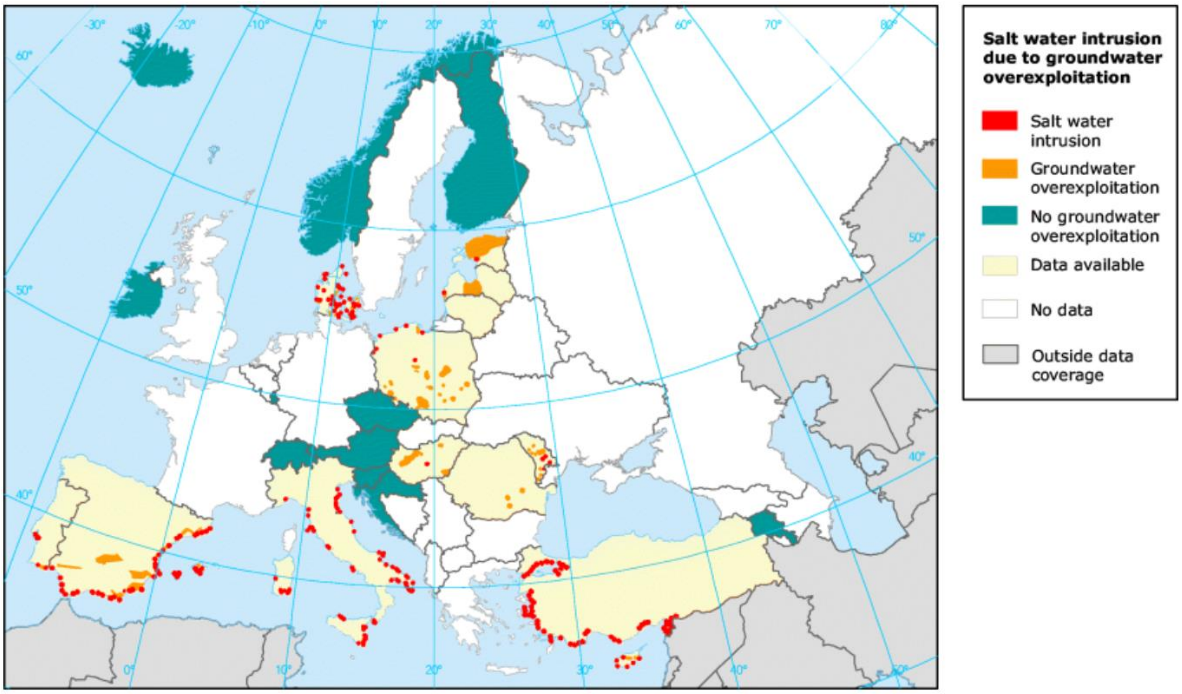

Figure 8: Groundwater overexploitation and saline intrusion [Source: EEA 2003/ EEA dataservice]

12.SPAIN

Many times the information that we can find about the underground waters of all Spain is scarce, this is due to the heterogeneity of the data. In the first place, the problem we have to obtain information on groundwater at a national level is that water management is divided into different levels.

Water management in Spain is based on the Hydrographic Basins. When a given hydrological basin is interregional, then water management depends on the Hydrographic Confederation, that is, the Ministry of Environment of the Government of Spain. On the other way, when the hydrological basin is located entirely in an Autonomous Community (regions of Spain with Autonomous Government), water management is the full responsibility of the Autonomous Community.

And finally, there are the local governments of the municipalities or the community of municipalities that are in charge of matters related to the public water supply. In addition, most official statistics on the use of irrigation water do not differentiate between surface and groundwater, making it difficult to collect data.

Spain is among the most arid countries in the European Union, but it has great hydrogeological potential. The annual recharge of aquifers in Spain was estimated around 10 years ago at some 30,000 Mm^3, equivalent to 30% of the total available water resources. The use of groundwater in Spain amounted to 6,500 Mm^3 / year, used mainly for irrigation of around 1 million hectares, which corresponded to around 30% of the total irrigated area of the country and we know that the percentage of irrigated area by underground water could be even greater.

In Spain, groundwater covers approximately one fifth of the total water demand and is used to irrigate about a third of the total irrigated land. In the last 50 years there has been an increase in the use of groundwater due to the ease of use of these, especially in arid and dry areas where surface water is scarce. The WFD requires EU countries to develop river basin management plans every 6 years based on baseline information on the state of water resources. The DMA's reference studies identified 777 bodies of groundwater, which cover around 360,000 km^2, 70% of the Spanish territory, and store more than 300,000 hm^3 [(López-Geta & Fernández Ruiz, 2013 López-Geta, JA, and Fernández Ruiz, ML (2013)].

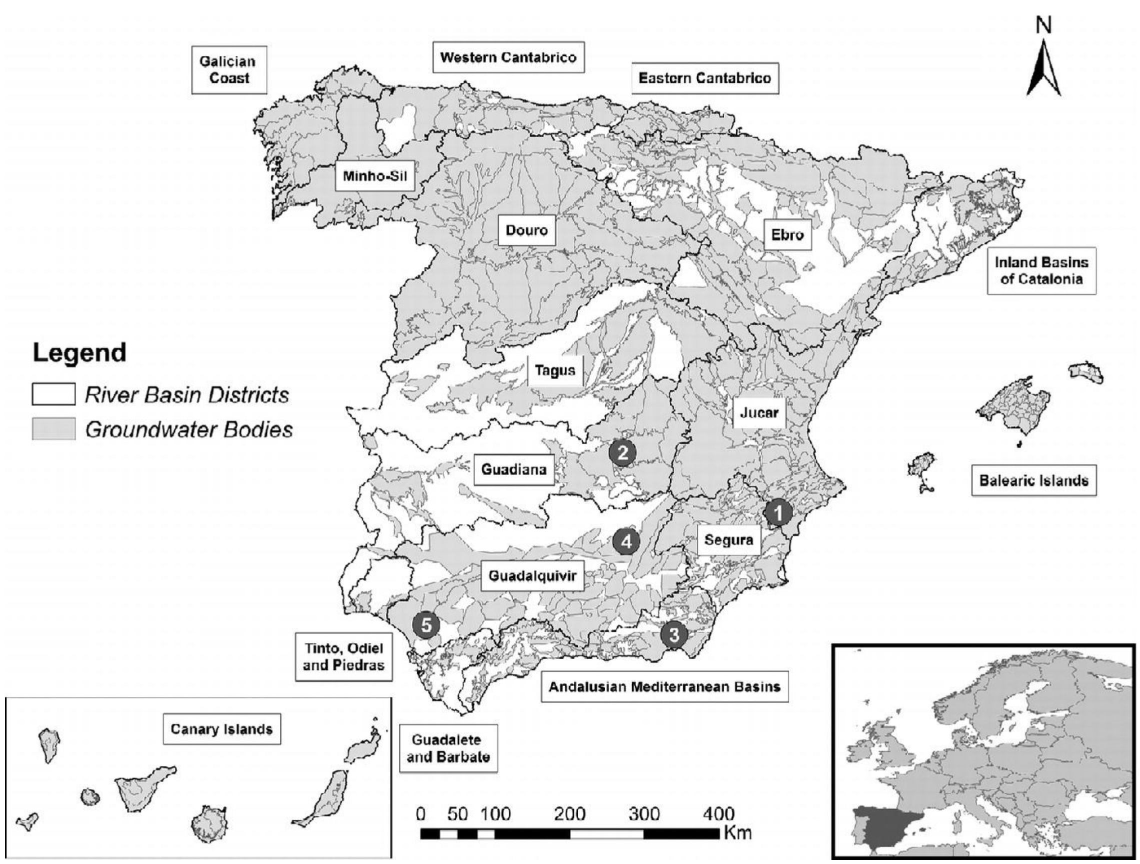

Figure 9: Groundwater bodies and river basin districts in Spain [López-Geta & Fernández Ruiz ML]

As in many countries of the world, agriculture is the main user of groundwater in Spain. In addition, according to some estimates the economic value of agricultural production of groundwater is approximately 4700 € million per year [average for 2005–2008; De Stefano, Martínez-Cortina, & Chico, 2013 De Stefano, L., Martínez-Cortina, L., & Chico, D. (2013). An overview of groundwater resources in Spain. In L. De Stefano & M.R. Llamas (Eds.), Water, agriculture and the environment in Spain: Can we square the circle? (pp. 87–104). Leiden: Taylor & Francis.]

In the following table we can see an approximation of the uses of groundwater depending on the sectors in Spain (2010):

Estimations of groundwater use in Spain.

Use	Total water (Mm^3/year) (1)	Groundwater (Mm^3/year)	Percentage of total use supplied by groundwater
Domestic supply	5,500 (≈ 15%)	1,000 – 1,500 (≈ 20%) (1)	≈ 20 %
Irrigation	24,500 (≈ 65%)	4,000 – 5,000 (≈ 75%)	≈ 20 %
Industry	1,500 (≈ 4%)	300 – 400 (≈ 5%)	≈ 20-25 %
Electrical energy production	6,000 (≈ 16%)	–	–
Total	37,500 (100%)	5,500 – 6,500 (100%)	15 –20 %

Source: OECD Economic Surveys: Spain 2010

Table 2: Estimations of groundwater use in Spain (2010)

Since 2010 the variations have not been very significant, which is why this table would be useful.

Another serious problem we have in the underground waters of Spain are the illegal wells. More than 10 years ago, there were more than 510,000 illegal wells throughout Spain and they could extract around 3,600 hm^3 /year according to official data from the Ministry of the Environment, which would be equivalent to approximately the average consumption of 58 million inhabitants.

However, instead reducing the number of illegal wells, it is estimated that although there are no official data, at present the number of illegal deposits could have been doubled according to a Greenpeace report.

One of the areas most affected by this problem is the Doñana Natural Park where the number of illegal wells for irrigated crops is affecting the ecosystem of a protected area drying out a large part of the wetlands of the place.

13.CZECH REPUBLIC

“The competence of the central water authorities to carry out state administration activities relating to the waters of the Czech Republic is regulated by the provisions of Section 108 of Act No. 254/2001 on Water and Amendments to certain Acts, as amended (hereinafter referred to as the “Water Act”). The Czech Republic has adopted a system of “shared powers” which in practice means that the jurisdiction of a central authority is shared by five ministries. The area of jurisdiction of the Ministry of Agriculture as a central water authority is defined by the Water Act as residual with respect to all acts of state administration for which no area of jurisdiction of any other central water authority has been stipulated by an exhaustive definition. “

“The activities of River Boards, state enterprises, in addition to Act No.305 / 2000 on River Basins, specified by the subject of business activity, recorded in the Commercial Register and in the Memorandum of Association. The basic role of the state enterprise is to carry out the duties of a river basin administrator, an administrator of the major and the specified minor watercourses; operating and maintaining state-owned hydraulic structures that the state-owned company is authorized to manage; and inexercising rights and carrying out other duties and activities entrusted to the state enterprise. All the activities of the River Boards, state enterprises, focus on the protection and inspection of the quantity and quality of surface waters and groundwater; conservation of the environment where water occurs; maintenance and operation of water management and hydropower facilities and waterways; economical and efficient use of waters, general protection against the detrimental effects of water; and establishing conditions for general water use and effective use of tangible and intangible assets. The state-owned company acts within the scope of its activities and in accordance with legal regulations, on its own behalf and upon its own responsibility. “

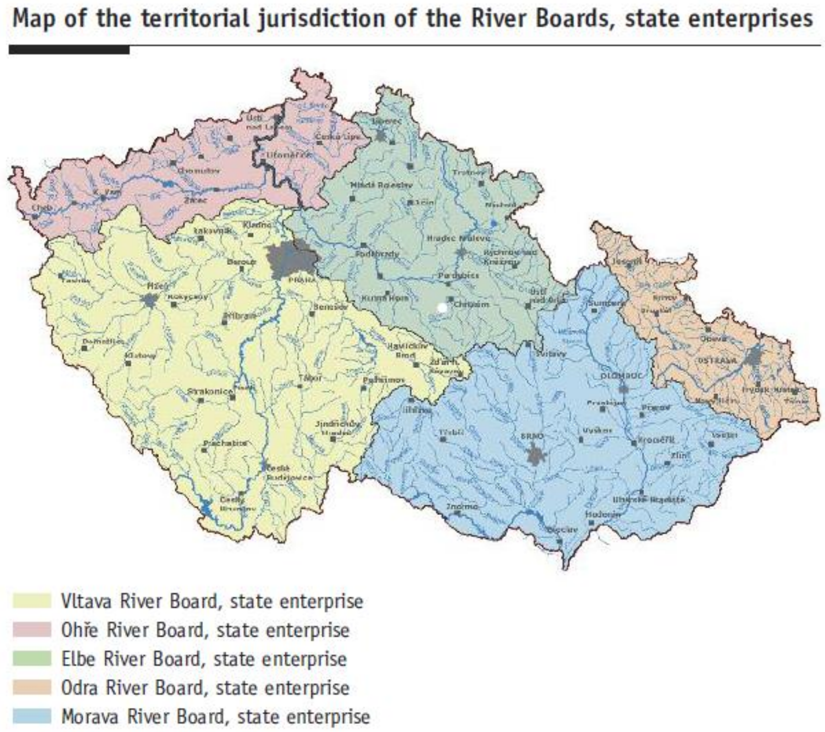

Figure 10: Map of territorial jurisdiction of the River Boards, state enterprises [Ministry of Agriculture of Czech Republic]

The quality of underground water in the Czech Republic has deteriorated in recent years. One of the reasons is the increase in rapeseed and maize crops that use pesticides that easily reach groundwater. About 2 years ago, the experts of the Czech Hydrometeorological Institute (CHMI) studied 675 wells, of which, 249 were contaminated. However one of the main problems and that are more worrying the Czechs in recent years is the drought and considerable decrease of groundwater due to decreased precipitation and snowfall that along with great extraction of groundwater is drying aquifers.

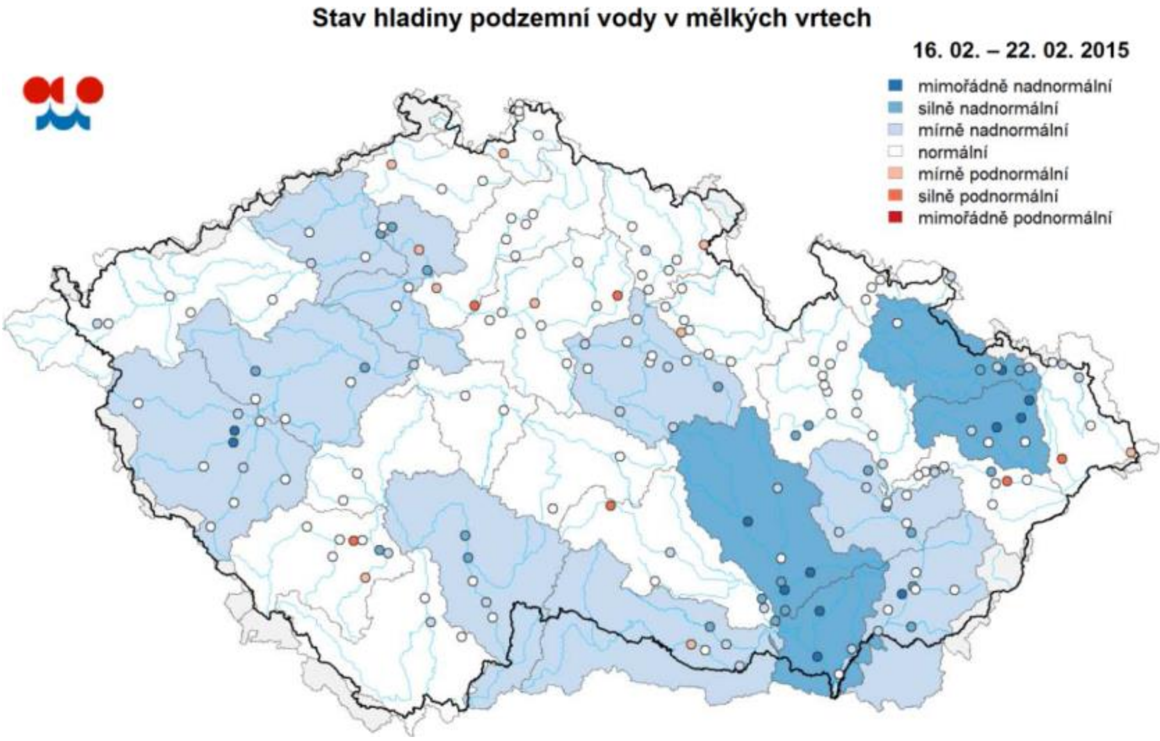

Figure 11: Levels of groundwater in shallow wells (2015)

11. HOW CULTIVATION METHODS CAN AFFECT THE GROUNDWATER

- The type of irrigation has different effects on the salinization of groundwater. The effects produced are:
  1) Concentration of salts as a result of plant water uptake.
  2) Movement of salts already in the unsaturated zone down to groundwater as a result of leaching or subsurface mixing of salt water with better quality groundwater.
  3) Intrusion of salt water in high quality groundwater as a result of groundwater pumping for irrigation

- **Watershed efforts**: collaboration between people and organizations in a watershed is vital to reduce nutrient pollution. State governments, agricultural organizations, conservation groups, educational institutions, non-profit organizations and community groups, all participate in successful efforts to improve the quality of water.This is one of the key points, the management of wells and agriculture through collaboration.

- **Nutrient management:** Applying fertilizers in the proper amount, at the right time of year and with the right method can significantly reduce the potential for pollution.

- **Cover crops:** Planting certain grasses, grains or clovers can help keep nutrients out of the water by recycling excess nitrogen and reducing soil erosion.

- **Conservation tillage:** Reducing how often fields are tilled reduces erosion and soil compaction, builds soil organic matter ·

- **Reduction of pesticides**: Reduce the use of pesticides and replace them to bioinsecticides and biological pest controllers. This techniques are already using in organic agriculture.

However, depending on the type of crop, the techniques are different and therefore the measures to reduce contamination are also different, which is why it is important to adapt our cultivation methods to the type of plant that we are going to cultivate.

12. WATER AND AGRICULTURE IN THE WORLD

Already in the 90s FAO warned of the possible problems that we will have if the contamination of the waters is not stopped and a different methodology in agriculture begins to be applied.

A decrease in growth of the use of nitrogen fertilizers by 2030 is foreseen since an improvement in the yield is expected. However, the current use of many developing countries is very inefficient. For example, in China, the world's largest consumer of nitrogen fertilizers, almost half of the nitrogen applied is lost through volatilization and 5 to 10 percent more through infiltration. In addition, the use of pesticides has also increased significantly in the last 40 years (4-5.4% in some regions).

However, in the 1990s there was a decrease in the use of insecticides, both in developed countries, such as France, Germany and the United Kingdom, and in a few developing countries, such as India. Although, on the other hand, the use of herbicides continued to increase in most countries. In spite of everything, in recent years it has been possible to observe an increasing demand for organic crops without the use of chemical products.

One of the most important problems that the world must and should face in the coming years, apart from access to drinking water, is access to food. As we all know, agriculture is an essential component in the world economy and at the same time that the population increases as does the demand for food. That is why this pressure has caused the increase in production necessary and as a consequence has led to the expansion of irrigation and an increasing use of fertilizers and pesticides in order to achieve and maintain higher yields.

For all these reasons, sustainable agriculture constitutes one of the greatest challenges in order to guarantee the supply of food without causing great environmental effects and human health.

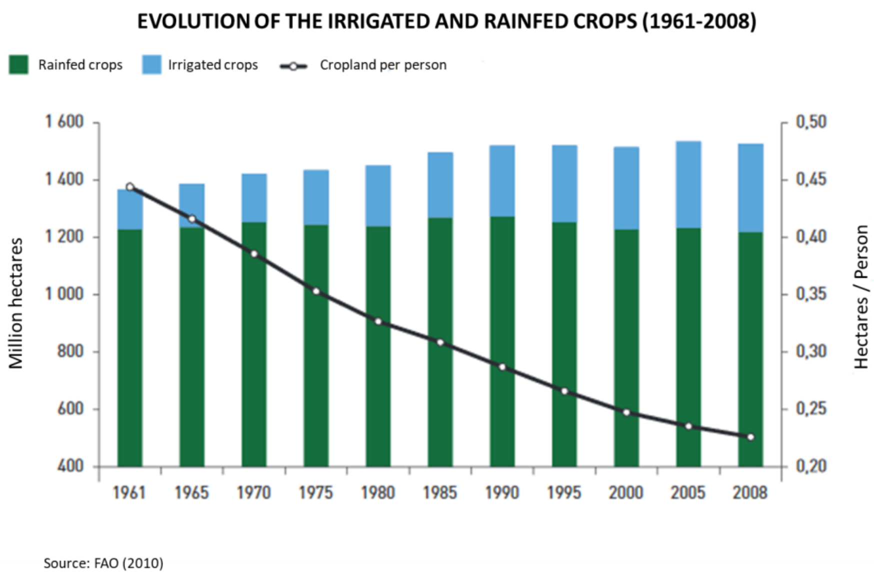

Figure 12: Evolution of the irrigated and rainfed crops in the world (1961-2008)

Experts predict that, as in many countries it is already impossible to solve the problem of contamination by dilution (in other words, the flow regime is fully used), the quality of fresh water will become the main limitation for the sustainable development of those countries.

Despite all this, there is enough water to meet the growing needs of the world but for this, a change in the use, management and sharing of water is necessary. The world water crisis is above all a crisis of governance (WWAP, 2006). Groundwater supplies drinking water to at least 50% of the world's population and represents 43% of all water used for irrigation (FAO, 2010). Worldwide, 2.5 billion people depend exclusively on groundwater resources to meet their daily basic water needs (UNESCO, 2012). It is estimated that 20% of the world's aquifers are being overexploited (Gleeson et al., 2012), which will have serious consequences, such as soil collapse and saltwater intrusion (USGS, 2013)

The concern of the water problem has led to more than half of countries with a human development index under whose governments they did not usually invest in the development and management of water resources to increase budgets and aid in the last 20 years (UN-Water, 2012)

Measures to improve the management of water resources have shown considerable economic gains. An investment of between 15,000 and 30,000 million US dollars in improving the management of water resources in developing countries can give direct annual benefits in the order of 60,000 million US dollars. Every dollar invested in watershed protection can save between $ 7.5 and $ 200 in costs for new water filtration and treatment facilities (SIWI, 2005).

World water demand is projected to increase by 55% in 2050, mainly due to demands related to increasing urbanization in developing countries (OECD, 2012a)

The agricultural sector accounts for approximately 70% of all freshwater withdrawals worldwide, and more than 90% in most of the least developed countries in the world (WWAP, 2014).

Further in 2050, agriculture will have to produce 60% more food globally, and 100% more in developing countries (Alexandratos and Bruinsma, 2012). So, according to some studies, the current growth rates of agricultural demand for freshwater resources are unsustainable.

On the other hand, the inefficient use of water for crop production depletes aquifers and has led to the salinization of 20% of the world surface of irrigated land (FAO, 2011a).

In most cases, increasing water productivity (that is, producing more crops or value per volume of water used) is the most important way to manage water demand in agriculture. This is possible thanks to the combination of better water control, better land management and better agricultural practices. However, investments only in water infrastructure are not enough to improve agricultural productivity, farmers need access to fertilizers and seeds, access to credit and better education and information about the use of materials and modern techniques.

With the increase of intensive agriculture, the contamination of water from point and non-point sources may worsen. The experience of the richest countries shows that a combination of incentives, including stricter regulations, compliance and correctly targeted subsidies can help reduce water pollution (FAO, 2012).

It is also necessary that those who live on agriculture receive enough benefits from it because only then can agricultural development become sustainable. For this, it is convenient to increase farmers' access to resources and assets, participation in markets and job opportunities.

12.1 EUROPE AND NORTH AMERICA

Diffuse agricultural pollution poses a significant pressure around 38% of the water masses in the region.

12.2 ASIA AND THE PACIFIC

It is estimated that irrigation with groundwater contributes to the Asian economy with between 10,000 and 12,000 million US dollars. If we also include the proceeds from the sale of groundwater for irrigation, this estimate increases to 25,000 - 30,000 million US dollars (Shah et al., 2003). Bangladesh, China, India, Nepal and Pakistan together account for almost half of the total use of groundwater worldwide (IGRAC, 2010).

In 2011 it was estimated that approximately 17% of the Arab population (60 million) did not have access to safe drinking water sources.

On average, the agricultural sector continues to consume the most water in the Arab region, although consumption levels vary significantly from one country to another. For example, in Djibouti it has represented only 16% of freshwater withdrawals during the last decade, and 99% in Somalia (FAO AQUASTAT).

12.3 LATIN AMERICA AMB THE CARIBBEAN

Due to the relative abundance of water in the region, the first priority is to improve and consolidate water governance, with a paradigm shift towards the sustainable integration of water resources management and its use in socio-economic development and reduction of poverty.

12.4 AFRICA

At present, only 5% of Africa's potential water resources are being developed, and the average storage per capita is 200 m^3, compared to 6,000 m^3 in North America.

The main source of income for many African economies is agriculture, which depends to a large extent on rainfalls that are highly variable and unpredictable since only 5% of the cultivated land in Africa is irrigated.

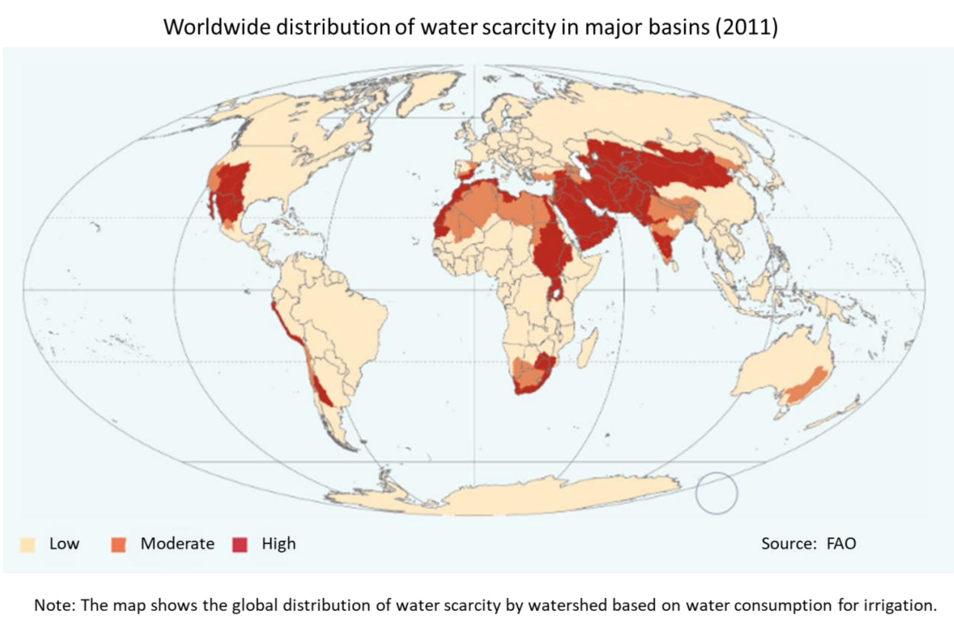

Figure 13: Worldwide distribution of water scarcity in major basins (2011)

13. LEGISLATION

13.1 EUROPEAN LEGISLATION

Coordination of administrative arrangements within river basin districts:

Member States shall identify the individual river basins lying within their national territory and, for the purposes of this Directive, shall assign them to individual river basin districts. Small river basins may be combined with larger river basins or joined with neighbouring small basins to form individual river basin districts where appropriate. Where groundwater do not fully follow a particular river basin, they shall be identified and assigned to the nearest or most appropriate river basin district. (Article 3, Directive 2000/60/EC)

Groundwater quantitative status:

2.1.2. Definition of quantitative status

Elements	Good status
Groundwater level	The level of groundwater in the groundwater body is such that the available groundwater resource is not exceeded by the long-term annual average rate of abstraction. Accordingly, the level of groundwater is not subject to anthropogenic alterations such as would result in: — failure to achieve the environmental objectives specified under Article 4 for associated surface waters, — any significant diminution in the status of such waters, — any significant damage to terrestrial ecosystems which depend directly on the groundwater body, and alterations to flow direction resulting from level changes may occur temporarily, or continuously in a spatially limited area, but such reversals do not cause saltwater or other intrusion, and do not indicate a sustained and clearly identified anthropogenically induced trend in flow direction likely to result in such intrusions.

Table 3: Definition of quantitative status

Member States shall provide a map of the resulting assessment of groundwater quantitative status, colour-coded in accordance with the following regime:

Good: green
Poor: red

Groundwater quality standards:

Parameters for the determination of groundwater chemical status

- Conductivity
- Concentrations of pollutants

For the purposes of assessing groundwater chemical status in accordance with Article 4 the following groundwater quality standards will be the quality standards referred to in Table 2.3.2 in Annex V to Directive 2000/60/EC and established in accordance with Article 17 of that Directive.

Pollutant	Quality standards
Nitrates	50 mg/l
Active substances in pesticides, including their relevant metabolites, degradation and reaction products (1)	0,1 μg/l 0,5 μg/l (total) (2)

(1) 'Pesticides' means plant protection products and biocidal products as defined in Article 2 of Directive 91/414/EEC and in Article 2 of Directive 98/8/EC, respectively.
(2) 'Total' means the sum of all individual pesticides detected and quantified in the monitoring procedure, including their relevant metabolites, degradation and reaction products.

Table 4: Quality standards of groundwater

Definition of good groundwater chemical status

Elements	Good status
General	The chemical composition of the groundwater body is such that the concentrations of pollutants: — as specified below, do not exhibit the effects of saline or other intrusions — do not exceed the quality standards applicable under other relevant Community legislation in accordance with Article 17 — are not such as would result in failure to achieve the environmental objectives specified under Article 4 for associated surface waters nor any significant diminution of the ecological or chemical quality of such bodies nor in any significant damage to terrestrial ecosystems which depend directly on the groundwater body
Conductivity	Changes in conductivity are not indicative of saline or other intrusion into the groundwater body

Table 5: Definition of good groundwater chemical status

A monitoring control will be established to detect problems that may arise in groundwater. The following set of essential parameters are controlled in all selected groundwater masses: oxygen content, pH value, conductivity, nitrate, ammonium.

Operational monitoring shall be carried out for all those groundwater bodies or groups of bodies which on the basis of both the impact assessment carried and surveillance monitoring are identified as being at risk. The selection of monitoring sites shall also reflect an assessment of how representative monitoring data from that site is of the quality of the relevant groundwater body or bodies. The controls in these areas at risk will be at least once a year.

Member States shall provide a map of groundwater chemical status, colour-coded as indicated below:

Good: green
Poor: red

Guidelines for the establishment of threshold values by member states:

When establishing threshold values, Member States will consider the following guidelines:

1) The determination of threshold values should be based on:

   (a) The extent of interactions between groundwater and associated aquatic and dependent terrestrial ecosystems.
   (b) The interference with actual or potential legitimate uses or functions of groundwater.
   (c) All pollutants which characterise bodies of groundwater as being at risk, taking into account the minimum list.
   (d) Hydro-geological characteristics including information on background levels and water balance.

2) The determination of threshold values should also take account of the origins of the pollutants, their possible natural occurrence, their toxicology and dispersion tendency, their persistence and their bioaccumulation potential.

3) Wherever elevated background levels of substances or ions or their indicators occur due to natural hydro-geological reasons, these background levels in the relevant body of groundwater shall be taken into account when establishing threshold values.

4) The determination of threshold values should be supported by a control mechanism for the data collected, based on an evaluation of data quality, analytical considerations, and

background levels for substances which may occur both naturally and as a result of human activities.

<u>Minimum list of pollutants and their indicators for which member states have to consider establishing threshold values:</u>

Arsenic, Cadmium, Lead, Mercury, Ammonium, Chloride, Sulphate, Man-made synthetic substances (Trichloroethylene and Tetrachloroethylene), Parameters indicative of saline or other intrusions (Conductivity)

<u>Information to be provided by member states with regard to the pollutants and their indicators for which threshold values have been established:</u>

Member States will summarise, in the river basin management plans , the way the procedure set out in in the previous section (*Guidelines for the establishment of threshold values by member states*).

In particular, Member States will provide, where feasible:

a) Information on the number of bodies or groups of bodies of groundwater characterised as being at risk and on the pollutants and indicators of pollution which contribute to this classification, including the observed concentrations/values.

b) Information on each of the bodies of groundwater characterised as being at risk, in particular the size of the bodies, the relationship between the bodies of groundwater and the associated surface waters and directly dependent terrestrial ecosystems, and, in the case of naturally-occurring substances, the natural background levels in the bodies of groundwater.

c) The threshold values, whether they apply at the national level, at the level of the river basin district or the part of the international river basin district falling within the territory of the Member State, or at the level of a body or a group of bodies of groundwater.

d) The relationship between the threshold values and:

i. In the case of naturally-occurring substances, the observed background levels,
ii. he environmental quality objectives and other standards for water protection that exist at national, Community or international level, and
iii. any relevant information concerning the toxicology, eco-toxicology, persistence, bioaccumulation potential, and dispersion tendency of the pollutants.

Starting points for trend reversals:

Member States will reverse identified significant and sustained upward trends, in accordance with Article 5, taking into account the following requirement:

The starting point for implementing measures to reverse significant and sustained upward trends will be when the concentration of the pollutant reaches 75 % of the parametric values of the groundwater quality standards set out in Annex I and of the threshold values established pursuant to Article 3.

River basin management plans:

Member States shall ensure that a river basin management plan is produced for each river basin district lying entirely within their territory.
River basin management plans are reviewed every six years.

13.2 SPANISH LEGISLATION

The decree that regulates the protection of groundwater against pollution and deterioration is RD 1514/2009, of October 2.

Quality standards of underground waters:

To assess the chemical status of a groundwater body or a group of groundwater bodies, the following quality standards shall be taken into account:

a) Nitrates: 50 mg / L.
b) Active substances of pesticides, including relevant metabolites and degradation and reaction products: 0.1 μg / L (for each substance) and 0.5 μg / L (for the sum of all pesticides) detected and quantified in the follow-up procedure.

This parameters are the same as we said before in the European Legislation (Directive 2000/60 / EC)

When it is considered that, given the situation of a certain body of groundwater respect to quality standards, the environmental objectives in associated surface waters may not be met, in accordance with Article 92 bis of the rewritten text of the Water Law or may to diminish in a sensible way the ecological or chemical quality of these masses or to occur a significant damage in the terrestrial ecosystems that depend directly on the groundwater mass, more stringent threshold values will be established.

The programs and measures required in relation to the threshold value will also apply to the activities contemplated in RD 261/1996, of 16 February, on the protection of waters against pollution caused by nitrates from agricultural sources.

Values threshold of pollutants of underground water and pollution indicators:

The threshold values shall be established in such a way that, in the event that the results of the monitoring in a representative control station exceed the threshold values, this circumstance indicates the risk that some of the conditions for the good chemical status of the control are not being met underground water.

For the establishment of the threshold values, the following guidelines shall be taken into account:

- The extent of contamination.
- Interference with existing or future uses or functions of groundwater.
- All the pollutants that characterize the masses of groundwater at risk.
- The hydrogeological characteristics.

The determination of the threshold values will also take into account the origins of the pollutants, their possible natural presence, their toxicology and dispersion tendency, their persistence and their bioaccumulation potential.

When there are high reference levels of substances or ions, or their indicators, due to natural hydrogeological reasons, when establishing the threshold values, these levels shall be taken into account.

Minimum list of pollutants and their indicators for the establishment of threshold values:

- Arsenic.
- Cadmium.
- Lead.
- Mercury.
- Ammonium.
- Chloride.
- Sulfate.
- Nitrites.
- Phosphates.
- Trichlorethylene.
- Tetrachlorethylene.
- Conductivity. (Salt contamination)

For the purpose of determining if the conditions of good groundwater chemical status are met when deemed appropriate and necessary, and on the basis of the relevant results of the monitoring activities and of an appropriate conceptual model of the groundwater body, the competent bodies will evaluate:

- The effects of pollutants on the groundwater body.
- The quantities and concentrations of the pollutants transferred, or that may be transferred, from the groundwater body to the associated surface waters or directly dependent terrestrial ecosystems.
- The possible incidence of the amounts and concentrations of pollutants transferred to the associated surface waters and directly dependent terrestrial ecosystems.
- The extent of the intrusion of saline waters or other intrusions into the groundwater body.
- The risk derived from pollutants in the groundwater body for the quality of the water extracted, or destined to be extracted, for human consumption of the groundwater body.

By the other hand, as well as, the European directive dictate, the starting point for applying measures aimed at reversing significant trends, as dictated by the European directive mentioned above, will be the moment in which the pollutant concentration reaches 75% of the parametric values and the threshold values. Unless a previous starting point is necessary for the cost of the measurements or a different starting point is justified if the limit of detection does not allow to establish the presence of an estimated trend in 75% of the parametric values.

13.3 CZECH LEGISLATION

The term water protection was first introduced in the Water Act No. 138/1973 Coll.

Nowadays, the most important current water management regulation in the Czech Republic is a special law - Act No. 254/2001 Coll.

The basic obligations in general water management are laid down in Section 5 of the Water Act. It states that everyone who deals with surface or underground water is obliged to take care of their protection and to ensure their economical and efficient use under the conditions stipulated by the Water Act and to ensure that their energy potential is not impaired and that other public interests are violated protected by special regulations (e.g. Act No. 17/1992 Coll., on the environment).

Diffuse pollution originating from agriculture is one of the biggest ecological challenges faced by European waters that do not achieve good ecological status. Nutrients (carbon, nitrogen, phosphorus and their compounds), heavy metals and agrochemicals (pesticides, industrial fertilizers)… are the main pollutants in agriculture that pollute surface and groundwater.

The protection of water, its use and rights are regulated in the abovementioned Water Act No. 254/2001 Coll. and its implementing regulations (Government Ordinance, Decree). The Ministry of the Environment together with the Ministry of Agriculture annually submits to the Government a Report on the state of water management in the Czech Republic, which describes and evaluates the quality and quantity of surface and groundwater as well as the related legislative, economic, research and integration activities. The Water Act, for example, requires that landowners are required to ensure, and that it should take care to improve the retention capacity of the landscape.

<u>Vulnerable áreas:</u>

Nitrogen is an essential nutrient to help grow plants and crops, but its high concentration is harmful to humans and nature. Therefore, in 1991, Council Directive 91/676 / EEC was adopted by the European Union with a view to protecting water quality throughout Europe by preventing nitrates from agricultural sources from being leaked to surface and groundwater

According to the Directive, the Czech Republic had to implement the directive into the national legal order (specifically Article 33 Act No. 254/2001 Coll., On Water, as amended) for EU accession.

On the basis of authorization in the Water Act, Government Decree No. 103/2003 Coll., On determination of vulnerable areas and on use, storage of fertilizers and manure, crop rotation and implementation of anti-erosion measures in these areas, as amended, was adopted by the Government. Part of the requirements of the Nitrate Directive is also applied by Act No. 156/1998 Coll., On Fertilizers, as amended.

At present, the issue of vulnerable areas is regulated by Government Decree 262/2012 Coll., As amended, on the definition of vulnerable areas and the action program (again, a four-year update of the Water Act is required here).

Vulnerable areas are those areas in river basins where nitrate contamination of underground and surface waters has already exceeded or could exceeded a limit of nitrate concentration of 50 mg/l.

Vulnerable areas are designated as individual cadastral areas, subject to revisions and reviews every four years from their publication. A list of territorial units belonging to vulnerable areas is included in the Annex to the Government Act No. 262/2012 Coll. Detailed information is available at www.nitrat.cz.

The first action program was announced for the period 2004-2007 by Government Regulation No. 103/2004 Coll. Lastly, vulnerable areas were revised in 2016. The new 4th action program for the period 2016-2020, containing the new conditions resulting from the Government Decree No. 262/2012 Coll., And its amendment, Act No. 235/2016 Coll. in force, was also drafted. Changes in the Action Program stemmed from the results of monitoring, new scientific knowledge and EU requirements.

The most important measures listed in the action program governing the management of vulnerable areas include:

- The period of the ban on fertilization.
- Limits for fertilizing crops.
- Fertilization in summer and autumn.
- Fertilization of permanent grassland.
- Prohibition of fertilization under unfavourable conditions.
- The requirement for uniform fertilization.
- Restrictions on the use of organic nitrogen.
- Storage of livestock manure.
- Crop rotation in vulnerable areas.

The Klír Methodology **[** *KLÍR J, KOZLOVSKÁ L (2016) Zásady hospodaření pro ochranu vod před znečištěním dusičnany* - *certifikovaná metodika pro praxi. Výzkumný ústav rostlinné* *výroby, v.v.i. 29 p***.]** includes principles of good agricultural practice for water protection against nitrate pollution from agricultural. The methodology clearly outlines management requirements that reduce nitrogen losses to water, such as the exclusion of nitrogen fertilization in an inappropriate period, on waterlogged, flooded, frozen or snow covered agricultural parcels, and describes the principles of farming on sloping land, near surface waters and principles of fertilizer use with regard to soil-climatic conditions, the need for stands and nutritional state of the soil.

In the context of the Nitrate Directive, Cross compliance has to be mentioned. This is a system of agricultural controls for paying direct payments and is related to the observance of good management. Part of the Cross-compliance Checker is the so-called GAEC (Good Agricultural Environmental Condition). GAEC is defined as a standard that ensures agricultural management in line with environmental protection. It contains seven main points. Farming in line with GAEC is a condition for providing direct payments (subsidies).

Applicants for subsidies must comply with the selected requirements for the protection of water against nitrate pollution from agricultural sources. The fulfilment of these subsidy conditions is also binding for applicants outside the vulnerable area.

If the applicant does not comply with the conditions set, the subsidy may be reduced or, in the most extreme case, not granted at all.

Farmers included in the Land Registry (LPIS) have the opportunity to obtain information on the methods of farming on individual soil blocks or their parts in the LPIS on the Farmer's Portal.

The current valid water legislation has changed the situation in that it allows the granting of compensation for proven restrictions on the use of land.

The operator of the water supply (or the water reservoir manager) is the person liable for payment of the compensation.

Priority will be given to optimizing the PZ (scope and protection measures), optimizing the use of fertilizers (N, P) and chemical plant protection products, ensuring soil fertility and reducing erosion. State support is very important, as well as monitoring compliance with proposed measures at the level of general, special and special water protection.

Among the largest and most important operating companies in the Czech Republic are VODÁRENSKÁ AKCIOVÁ SPOLEČNOST a.s. (hereinafter referred to as VAS), which provides the operation of water supply infrastructure in a substantial part of the Jihomoravský and Vysočina regions. Through water supply for public use it supplies more than 540 thousand drinking water inhabitants, drinking water produces both surface (about 54%) and underground (about 46%). The care of water sources of surface water the so called water reservoirs, belongs to the state enterprises of Povodí, in other cases all the operational care, maintenance and provision of preventive protection of these sources, to the operator of the water supply infrastructure VAS.

13. CONCLUSIONS

Agriculture is an essential sector for any economy and is responsible for supplying food to the entire population, hence its great importance. However, it also has negative effects on the environment, in this case, on groundwater. The methods used, as well as the products (fertilizers, pesticides ...) can affect the quality of groundwater, which is very important for the supply of human drinking water and for the irrigation of crops. This is why we must maintain control of aquifers and set limits and thresholds to protect groundwater.
In addition, the overexploitation of some aquifers and their salinization, especially in coastal areas, is beginning to cause problems.

For the protection of groundwater it is important, as we have seen before, to know the parameters and the peculiarities that each aquifer has since all this influences its contamination or possible scarcity.

Due to this, it is important to manage the water well, as well as to reduce the potential contamination of groundwater to avoid having serious problems in the future, since it is a vulnerable resource that could be in danger in the not too distant future.

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