Groundwater Protection for Public Water-Supply in Portugal

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Abstract

Groundwater is a very important natural resource in Portugal, where it accounts for nearly 60% of the drinking water supplies, thus making it a priority its protection both in quality and quantity. One of the strategies used in groundwater protection, for public water-supply, is the definition of source protection zones (SPZs). These areas must be associated with other preventive practices in order to maintain the good quality of groundwater.

For the definition of the Source Protection Zones, it's necessary to know very thoroughly the aquifer systems: their lithology, hydrogeological characteristics and vulnerability. On the other hand, in order to stabilise the price of water supply a compromise between the economic activities and the areas to protect, is fundamental.

Since 1999, Portugal has specific legislation obliging groundwater-supply management authorities to define source protection zones for public wells. There are three protection zones (inner, intermediate and outer). The inner zone must always be defined but the other two, in some cases, may be absent. There are also special protection zones.

Introduction to Groundwater in Portugal

In Portugal, groundwater contributes with 60% to the bulk of drinking water supplied and is a very important resource, unequally distributed over the country, because of complex geological and precipitation occurrences.

The country is divided in four major hydrogeological units, each one containing aquifer systems. Figure 1 represents the hydrogeological units. Their characterisation is as follows:

- Ancient Massif - in this unit, only the main aquifer systems, which have regional representation and importance, were characterised. This is because the igneous and metamorphic rocks dominate. This way, only aquifers related with the most productive formations (paleozoic limestones and gabbros, terraces and gravel that filled depressions in the crystalline bedrock) were considered. They can be seen in figure 2.

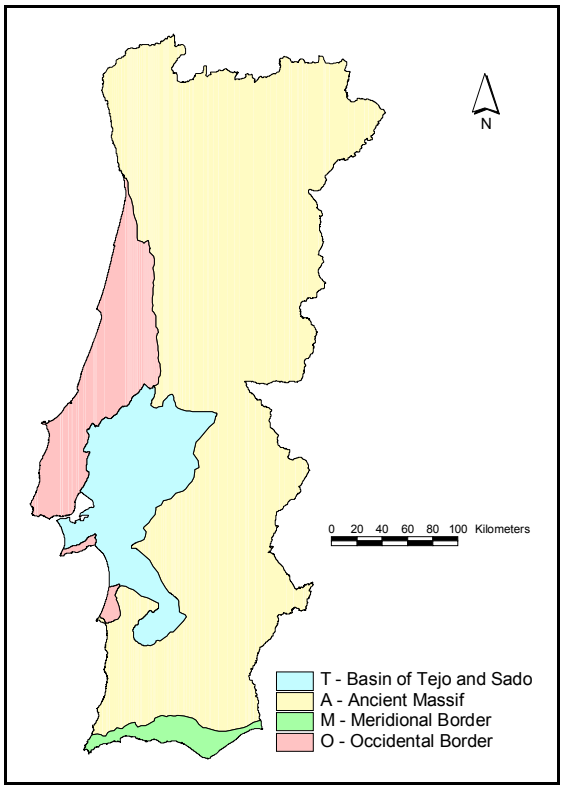


Figure 1 – Portuguese hydrogeological units

- Occidental Border - in this unit, the main aquifer formations are: sand, dune sands, terraces and alluvia from the Tertiary and Quaternary; sandstones and limestones from the Cretaceous and Jurassic limestones. In this unit 27 aquifer systems were defined (see figure 2).

- Meridional Border - the main lithologies that constitute the defined aquifer systems are: sands and dune sands from the Quaternary; Miocene formations; carbonate and detrital formations from the Cretaceous and Jurassic carbonate and dolomite formations. In this unit, there are 17 aquifer systems defined and they display themselves in the hydrogeological unit according to figure 2.

- Basin of Tejo-Sado: the most productive formations that provide support for the aquifer systems are alluvia and terraces from the Quaternary; Pliocene and Miocene formations. In this unit, four aquifer systems were defined (see figure 2).

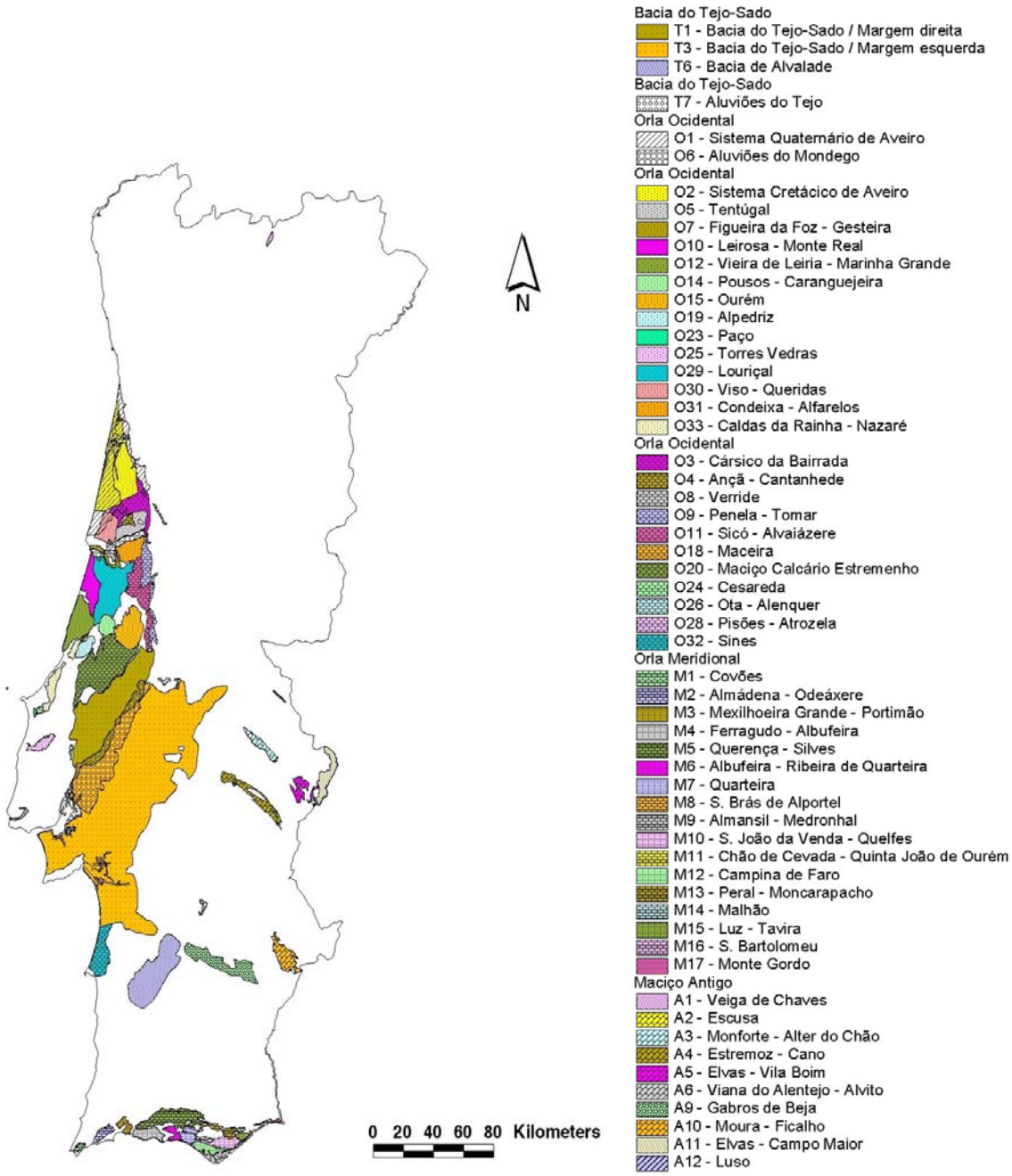


Figure 2 – Aquifer systems defined for Portugal

A total of 58 aquifer systems were defined and studied. The blank areas are formations with less hydrogeological productivity but they host small regions more productive that also supply domestic and public water.

In 1994, Portugal had 4960 public wells for water-supply and from these, 1010 supplied more than 500 inhabitants each. Only twelve of the 275 portuguese municipalities were supplied exclusively with

surface water. Figure 3 shows the distribution of public wells by municipalities (percentage), that supply more than 500 inhabitants.

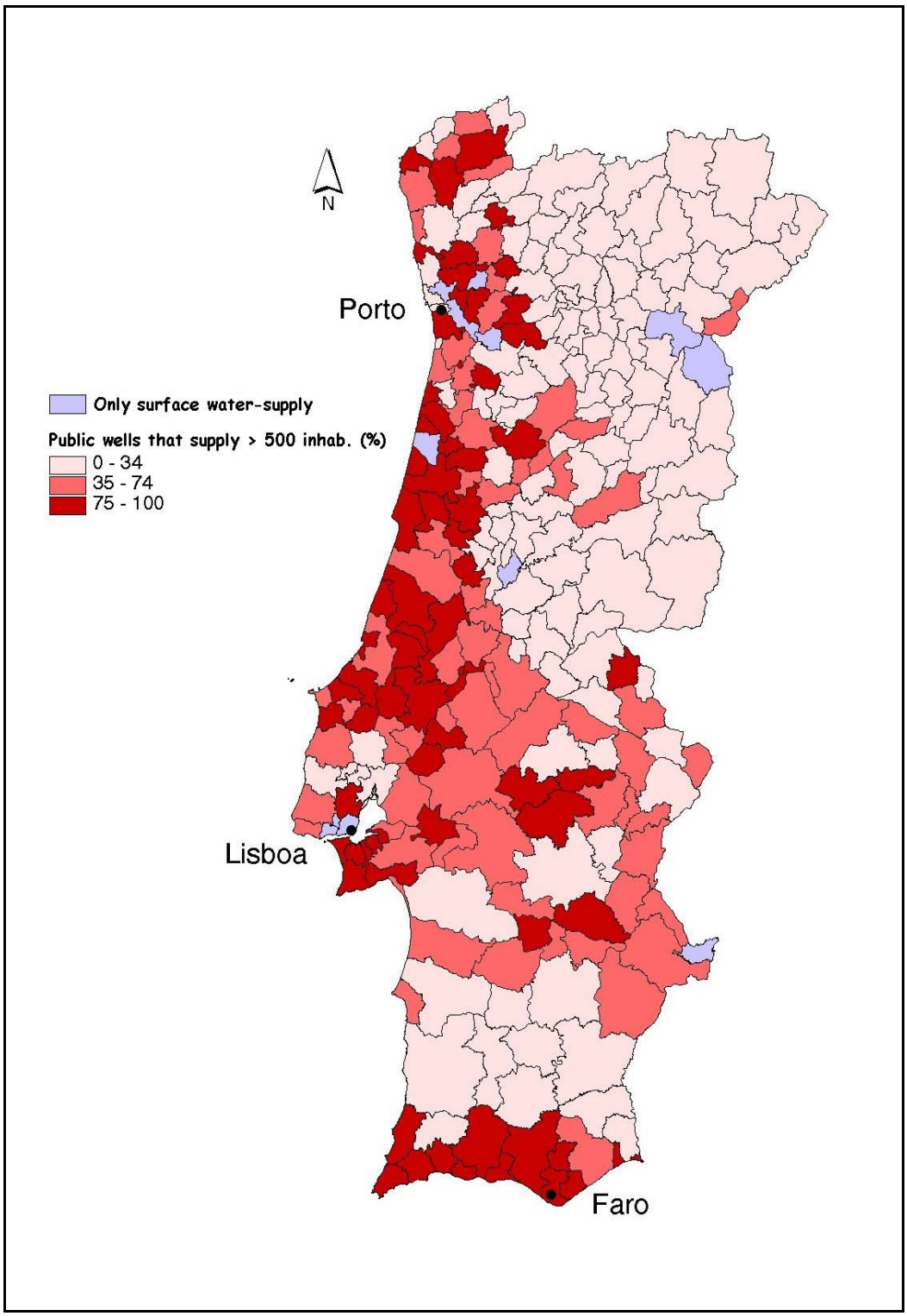


Figure 3 - Distribution (percentage) by municipalities of public wells that supply more than 500 inhabitants

Groundwater Protection

History

In 1971, there existed a Portuguese Norm (NP-836) that reported to Sanitary Protection and where two protection zones were defined: the inner and the outer well protection zones. But in practical terms, only some wells had a inner protection zone defined, yet deficiently, which didn't protect the source.

Also, the legislation that set the norms and criteria for water-supply quality standards (DL nº 236/98), did report, in its 18º article, about source protection zones to groundwater wells, but stated nothing about defining and calculating these areas.

Only in 1999 had Portugal specific legislation published (DL nº 382/99) that oblige groundwater supplies management authorities to define source protection zones.

Source protection zones

According to the law, a source protection zone is: all forbidden or conditioned activities and facilities which may pollute groundwater, in the area surrounding a well.

Three source protection zones were defined: the inner zone, the intermediate zone and the outer zone, as can be seen by figure 4.

The inner protection zone is the well's surrounding area, with size dependent on the aquifer type. The intermediate protection zone encloses the inner protection zone and is a function of the pumping rate and the aquifer type. The main goal here is to reduce or eliminate the pollutants before they reach the well.

The outer protection zone encloses the intermediate zone. With variable range depending on extend, its purpose is to protect the well from persistent pollutants.

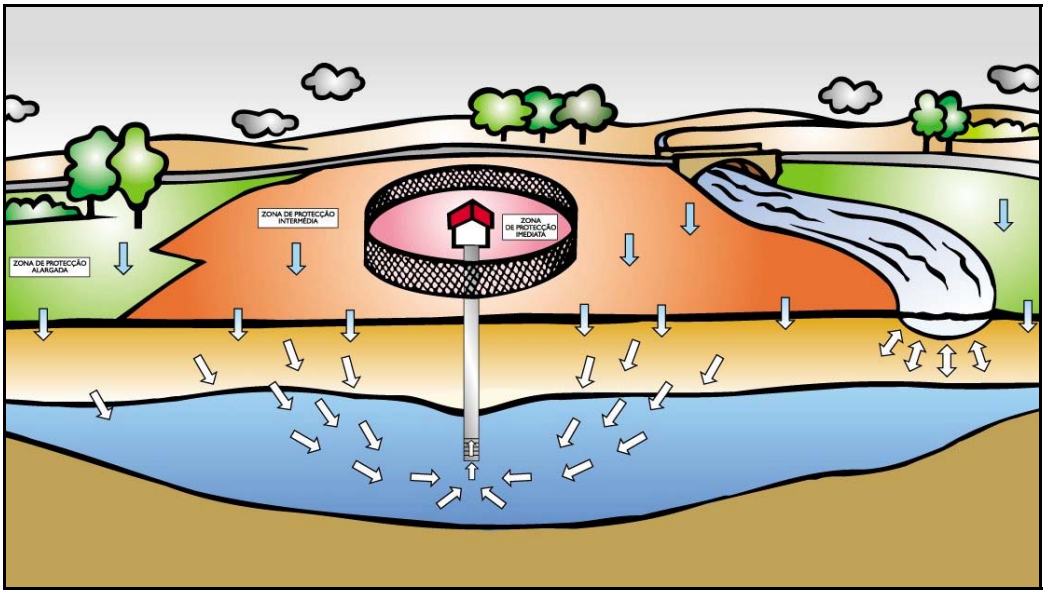


Figure 4 – The three source protection zones: inner zone (light pink), intermediate zone (orange), outer zone (green)

There are also special source protection zones in karstic areas or where direct hydraulic connection exists. In coastal zones, where seawater intrusion problems may arise, protection zones can be also defined.

The groundwater management authorities are required to define the inner protection zone for all the wells used for public water-supply. All three zones must be defined for every public well used to supply more than 500 inhabitants or where extractions over 100 m^3/day exists. In some cases, the intermediate and outer protection zones may remain undefined if it's proven that the aquifer system has a very low pollution risk.

How to calculate and define the source protection zones

Different aspects must be taken into account for the definition of the protection areas. These are mainly economic aspects, in addition to the hydrogeological knowledge of aquifer systems, vulnerability, pumping rate, hydraulic parameters and so on.

Economic aspects are very important because source protection zones may impose restrictions to land use and justify, in some cases, the payment of indemnities, which makes water supply too expensive. A compromise between the protection of the area and activities that may develop there is paramount. Protecting a wide area causes rise in groundwater distribution costs if done ineffectively.

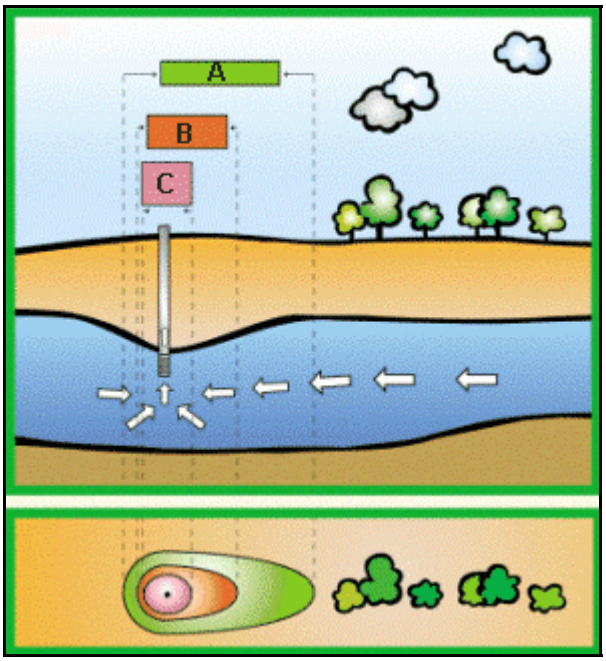
The portuguese legislation recommends the use of models and hydrogeological studies to define groundwater protection zones. This requires a good knowledge of the aquifer type (porous/fractured), lithology, transmissivity, vulnerability, flow direction, recharge rate, water level, well characteristics (depth, well screens depth, pumping rates) and drawdown data. With this data it becomes possible to use numerical models of groundwater flow and particle tracking in order to determine the extent of source protection zones.

If both hydrogeological studies or aquifer modelling are not feasible, the legislation proposes an alternative way to define protection zones using the simplified method of "fixed radius":

$$r = \sqrt{\frac{Q \times t}{3{,}1416 \times n \times H}}$$

r – "radius" of protection zone (m)
Q – pumping rate (m^3/day)
t – time needed for a pollutant to reach the well (days)
n – effective porosity (%)
H – well's saturated thickness (m)

The intermediate and outer zones resulting from this method must have a elliptic shape developed on the opposite direction to the groundwater flow, as can be seen from figure 5. Only the inner zone is circular.



A – Outer protection zone
B – Intermediate protection zone
C – Inner protection zone

Figure 5 – The resulting source protection zones obtained using the method of "fixed radius"

The legislation includes an annex where six different types of aquifer systems are defined: porous and confined; porous and unconfined; porous and semiconfined; calcareous; fissured, igneous and metamorphic; non fissured, igneous and metamorphic. For each aquifer type, the intermediate and outer zones must have a "radius" which is a function of the time a pollutant needs to reach the well (50 days to intermediate zone and 3500 days to the outer zone). The inner zone has a fixed value for each different aquifer type.

Restrictions to Land Use

After the different protection zones are defined, it's necessary to establish which activities or facilities, within the different protection zones, are to be restricted, in order to avoid pollution.

For each protection zone, the portuguese legislation states in its 6th article which activities or facilities are forbidden or restricted.

According to the law, in the inner zone all the activities or facilities are forbidden except those meant to preserve the well. A fence must be installed.

In the intermediate protection zone, some of the activities that may be forbidden or restricted are: roads; railways; wastewater treatment plants (WWTPs); cemeteries and so on. In addition: landfills; auto stations; waste disposal; transporting dangerous materials; etc. are forbidden.

Activities, such as: septic sewer; scraps waste; use of persistent and mobile pesticides; wastewater collectors; aeronautic installations and so on, may occur within the outer protection zone only if its proven that they consist of no threat in pollution to groundwater. In this zone: transportation of dangerous and radioactive materials and hydrocarbons; disposal of radioactive or dangerous materials and hydrocarbons; toxic piping; chemical industries and refineries; landfills and waste disposal, are forbidden.

The special protection zones also have restrictions to land use, since all activities or facilities are forbidden. In the coastal areas, where seawater intrusion problems may arise, there are limitations to pumping rate and restrictions to the construction of new wells.

Examples

With the simplified method of "fixed radius" good results can be achieved, mainly for porous aquifers. The first example presented consists of a public well which is in the porous and confined Ourém aquifer system. The well characteristics are as follows:

- well depth = 126 m;
- pumping rate (Q) = 720 m^3/day
- well saturated thickness (H) = 60 m
- transmissivity = 770 m^2/day
- effective porosity (n) = 10% (medium to coarse sandstones with gravel and pebbles)

The radius values for the three protection zones are:

- Inner zone: r = 20 m
- Intermediate zone (t = 50 days): r = 43 m
- Outer zone: (t = 3500 days): r = 365 m

The following figure shows the scheme for this source protection zones.

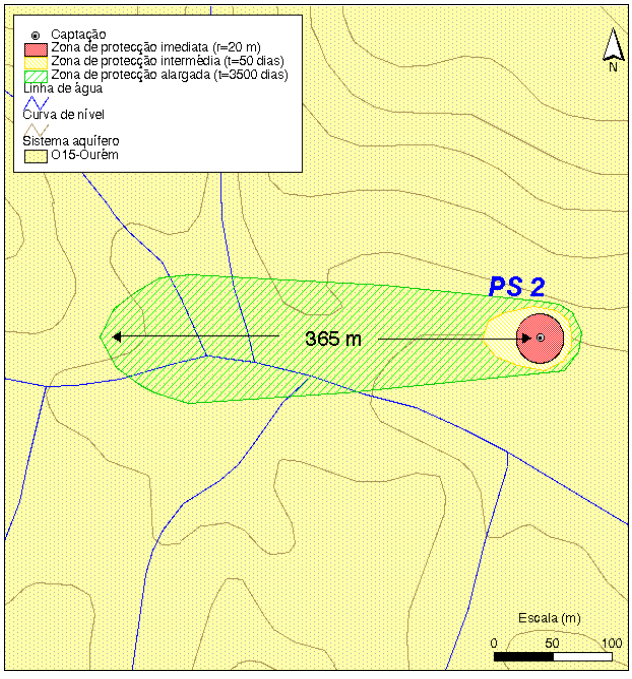


Figure 6 – Scheme of the SPZs for a public well in a porous and confined aquifer

Another example is a porous and unconfined aquifer called Vale Tifónico das Caldas da Rainha. The public well is extracting water from sands with pebbles and some clays. The wells characteristics are:

- well depth = 108 m;
- pumping rate (Q) = 1728 m^3/day
- well saturated thickness (H) = 81,4 m
- transmissivity = between 30 and 450 m^2/day
- effective porosity (n) = 10%

The radius values for each protection zone are the following:

- Inner zone: r = 40 m
- Intermediate zone (t = 50 days): r = 58 m
- Outer zone: (t = 3500 days): r = 490 m

Figure 7 shows the scheme for these three protection zones.

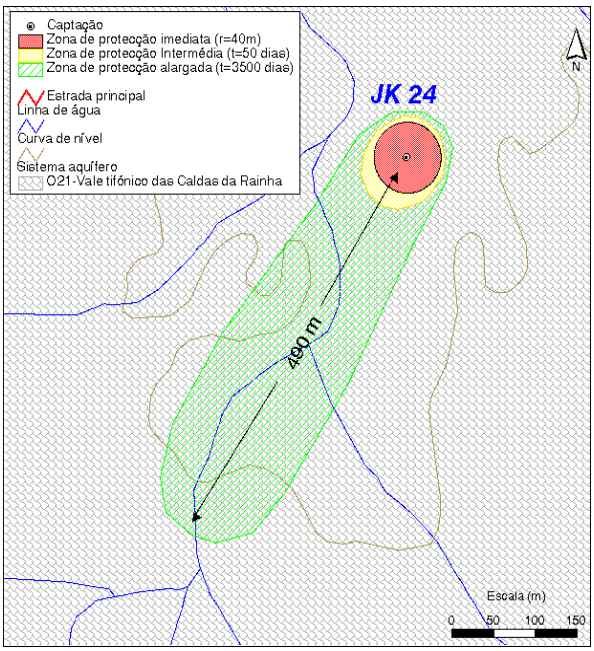


Figure 7 - Scheme of the SPZs for a public well in a porous and unconfined aquifer

The values for the intermediate and outer zones, obtained with this method and for this two examples, are very close to the radius values stated in the law.

Conclusions

The recent issue of the law about source protection zones created a good planning tool for groundwater protection and its very important that the groundwater-supply management authorities start to define the different protection zones. These authorities are responsible for the proposal of source protection areas and they should support hydrogeological studies by geologists or private companies. The proposals are next evaluated by the regional environmental authorities who then define restrictions to land use in each of the protection zones. The regional authorities may refuse the proposals allowing the groundwater-supply management authorities to make new studies and present new proposals.

The previous discussion, prior to the submission of this law for publication, involved several Ministries: Environmental, Management, Agriculture, and so on. Several meetings took place mainly to discuss the restrictions to land use and the implications that the implementation of these areas will have on planning.

Its full enforcement recommends the use of models and hydrogeological studies, instead of the "fixed radius" approach, although with this simplified method good results can be achieved. But it's very important that the application of this method is done by specialised technicians with appropriate graduation degree and knowledge. The obtained radius of the resulting zones must be properly analysed for the aquifer type or lithogies. Only some specialists have the knowledge required.

The source protection zones can be revised whenever necessary and new proposals presented by the groundwater-supply management authorities or the regional environmental authorities.

Although Portugal maintains this law since September 1999, there are just a few source protection zones already defined, which means we are at the very beginning. With the application of land restrictions problems with farmers are expected to rise.

Bibliography

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Portuguese Law D. L. N.º 382/99, of 22th of September that states the definition and implementation of source protection zones.