The importance of determining beforehand the geological properties of the land as a good practice in water regeneration schemes using extensive wastewater treatment processes

ENVIRONMENT

The technology of “green filters” (land filtration of wastewater combined with irrigation of plant species, called filtros verdes in Spanish) has been mooted as an efficient alternative for the treatment, management and reuse of liquid effluent from small built-up areas. A prerequisite in setting them up is an in-depth knowledge of the geological properties of the land to be used. This will enable us not only to protect the natural environment, especially bodies of groundwater, but also to ensure efficient implementation of the schemes as regeneration technology under current legislation. This article therefore proposes a methodology to follow in the early stages of setting up a green filter scheme as a wastewater regeneration technology. The demonstration case is the property-determination methodology proposed and applied in the experimental green filter plot to be set up in the experimental plant of Carrión de los Céspedes (Seville).

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Spain’s water utilisation rate (annual consumption/resources) of over 30% makes it, after Malta and Cyprus, the European country with the highest water deficit.

Water scarcity in Spain is a matter of great concern to many of its citizens, sparking off wide-ranging debates about possible solutions. Despite this concern water reuse has not been given the importance it deserves in this debate, which has focused instead on alternatives that are costly not only from the economic point of view but also in terms of their environmental impact. Nonetheless, water reuse is one of the water-resource conservation and management alternatives promising the greatest environmental advantages. It does not call for a large energy input and could be applied directly for environmental purposes. It might even turn out to be competitive economically with other alternatives, especially in small built-up areas, which represent 73% of Spain’s municipalities. In sum, it is a non-conventional resource that ensures sustainability, reduces environmental pollution and safeguards public health. Moreover,
this alternative water resource means that conventional water resources can be kept back for meeting the highest water-quality demand.

Urban wastewater, including domestic wastewater, rain runoff and some industrial wastewater, exerts a continual and heavy pressure on natural water systems. This impact can be reduced by appropriate treatment and especially if this wastewater is reused. According to figures of the National Statistics Institute (Instituto Nacional de Estadística), the amount of wastewater collected in 2007 was 5.204 billion m³, of which only 11% was reused (572 million m³). According to the model developed by Hochstrat, R. et al. [1] to determine wastewater reuse potential, Spain has a potential of 1.3 billion m³, way above the current situation. These low reuse figures are even more telling when we bear in mind that the Spanish government is duty bound to promote the reuse of purified water under Spain’s Water Act (Ley de Aguas) of 1985 (article 101), the amendment thereof by Act (Ley) 46/1999 (article 101) and the revised text of the Ley de Aguas (Royal Legislative Decree [Real Decreto Legislativo] 1/2001, of 20 July, article 109).

The reasons why water reuse has not been actively promoted in Spain are very diverse. One reason is the aforementioned lack of awareness of the importance of wastewater reuse but there are also technical or legal bugbears (Royal Decree [Real Decreto] 1620/2007, laying down the basic conditions for wastewater reuse, only saw the light of day on 8 December 2007).

**Green filters, an emerging technology for wastewater regeneration and reuse**

Small built-up areas have particular wastewater treatment needs. The systems used have to meet all technical effluent-purification specifications in a simple and affordable way while also ensuring a low environmental impact. The wastewater treatment processes meeting these characteristics were once lumped together under the umbrella term of non-conventional technologies; they are nowadays known as extensive wastewater treatment processes. The main difference between these extensive processes and conventional water treatment technology (sedimentation, filtration, adsorption, chemical precipitation, ion exchange, biological degradation, etc.) is that non-conventional extensive processes take place at natural speed (with no energy input) in a single reactor system. The energy saving is offset by the need for a much larger application area.

Spain has water utilisation rates of over 30%, making it the European country with the highest water deficit after Malta and Cyprus.

Both conventional and non-conventional systems are currently being used for the wastewater treatment of small built-up areas. Although both have proven to be effective for treating the discharges generated, there is also evidence showing that these smaller urban areas would do best to prioritise water treatment systems of robust technology and low running and maintenance costs, in view of the abovementioned environmental and economic advantages.

The so-called extensive processes include the treatment of wastewater by applying it to the land, where the soil itself is used as the purification agent. The so-called green filters (filtros verdes) are included in technologies of this type. They are processes of low hydraulic load (volume of water applied by unit land area in a given period of time) where the wastewater to be
treated is applied to land with vegetation, serving the twofold and joint purpose of treating the water and nurturing the growth of the planted vegetation. A fraction of the water applied to the soil is consumed by evapotranspiration and the rest filters down through the earth until reaching the aquifer. With this technology the wastewater is immediately reusable for the production of biomass and the system as a whole can be considered to be an earth-infiltration water treatment process with eventual arrival of the purified water at the aquifers. The low loads applied and also the presence of vegetation and the soil-associated ecosystem mean that low-load systems boast the best performance among all land application schemes.

In the legal context established by Royal Decree (RD) 1620/2007, which defines the concept of regenerated water as «treated wastewater that has been submitted, where applicable, to an additional or complementary treatment process to bring its quality into line with the purpose it is intended for», green filters also constitute a treated-water regenerating system, since the infiltrated water will undergo additional improvement during its percolation through the soil. This technology can therefore be considered not only a wastewater reuse method for the irrigation of plant species intended for purposes other than human consumption (chart 5, annex I, RD 1620/2007), but also an aquifer recharge system by localised percolation of the regenerated water through the soil (chart 5, annex I, RD 1620/2007). In short, green filters are a wastewater regeneration technology that enables reuse thereof for given environmental uses, as laid down in RD 1620/2007, namely: a) aquifer recharge by localised percolation through the soil and b) silviculture.

The idea of using green filters is to tap into a technology based on biogeochemical percolation-based aquifer-recharge processes, abiding by the fundamental axiom of maintaining water quality. It should be stressed here that a good part of current water supplies come from groundwater. About 70 % of Spanish municipalities and about one million hectares of cropland are supplied from resources of this type. The upshot is that many bodies of groundwater have now been declared to be overexploited, making it very difficult to achieve a good ecological state under the guidelines laid down by the Water Framework Directive.

**Water reuse is one of the most environmentally advantageous alternatives for the management and conservation of water resources, and might even become economically competitive with other alternatives**

Moreover, the growing demand in the biofuels sector means that the reuse of regenerated wastewater can be regarded as a good alternative for crop irrigation, since green filter systems of this type afford a series of additional advantages, to wit: a) the treated water represents a continuous and sure source of water even in times of drought, b) it represents a continuous input of nutrients (N, P, K and other microelements) for the plants, thereby cutting down fertilisation costs, c) it helps to reserve top-quality water resources for other uses, and d) it represents a possible reduction of irrigation costs.

**Justification and objectives of the determination of the geological properties of the land as a good practice in the implementation of green filters**
The aim in defining good practices in the application of the extensive technology of green filters is to draw up a set of guidelines to ensure proper protection of the natural environment, especially bodies of groundwater, while also achieving maximum efficiency in application thereof as a regeneration technology under current legislation.

This set of good practices includes several aspects that in turn define different work phases:

- Determination of the land’s geological properties
- Design of the green filter, including choice of the plant species.
- Setting up of the green filter.
- Control and monitoring of the irrigation effects and regeneration efficiency.
- Maintenance of the filter and control facilities.
- Evaluation of the technology (effects on the land and efficiency).
- Correction of the design and control tools, if any.

The need of identifying the land’s geological properties arises from the fact that a green filter is a system involving an interaction between the treated irrigation water and the soil-rock-organism system. It is precisely these interactions that define the system as an authentic natural water treatment system, serving as grounds for the use of this technology for water regeneration. It is hence necessary to find out which are the factors and processes that might intervene as well as the scope and effects (negative and positive) of these interactions. Only in this way will it be possible to design the system properly and achieve greater economic and environmental efficiency in applying the technology.

In green filter systems wastewater is applied to land planted up with trees to purify the water and nurture the growth of the planted vegetation

This paper proposes the methodology to follow in the initial stages of applying a green filter system as an urban wastewater regeneration process, in terms of determining the geological properties of the land involved (soils, lithological substratum and groundwater) and setting up the monitoring mechanisms. As a demonstration case this paper presents the preliminary results obtained with the property-determining methodology in the experimental green filter plot to be set up in the experimental plant of Carrión de los Céspedes (Seville).

The objectives set in terms of determining the properties of the geological medium, defined as a good practice in the application of the extensive green filter process, comprise the following:

- Definition of the original state of the land before irrigation with the treated wastewater, known as the «baseline» or benchmark state. This is a sine qua non of making a correct evaluation of the effects of this irrigation thereafter.
- Assessment of the possible effects on the land, once treated-wastewater irrigation has begun, ensuring a proper design of the green filter system.

Methodology proposed for determining the geological properties of the land
1. Caracterización de los suelos y las litologías (litoestratigrafía) del substrato

- Geophysical study of the surface by means of indirect methods (e.g., ground-penetrating radar, electrical tomography, etc.). 2-D profiles will then tell us the spatial distribution of the different types of material downwards in the soil and also the position of the water table.

- Field study (bore holes and soil pits) of the soil profile. On-the-spot study. Identification of the soil classification, structures and horizons. The aim is to find out the depth of the solum and the distribution of the layers making it up. This is crucial for making a first agronomical and taxonomical evaluation of the soil and for sampling the soil to gain a more thoroughgoing determination of its properties.

- Field study (bore holes and outcrops) of the lithostratigraphy. On-the-spot study. Identification of the types of rock, change of facies and sedimentary structures. As in the field study of the soil, this study determines the downward variation in the materials; this enables geophysical profiles to be brought into line with real depths and thicknesses. This study also helps to identify lateral changes in the nature of the material (lateral facies changes) and to sample the soil to find out the physical and compositional properties of the material.

- Mineralogical analysis on laboratory samples. These are carried out on rock and soil samples to ascertain the mineral makeup of the various materials recognised. The mineral phases are identified and their texture and chemical composition is determined to predict reaction with irrigation water as applied to the terrain. The techniques to be used are mutually complementary.
  - X-ray diffraction.
  - Optical microscopy.
  - Scanning electron microscopy.
  - Energy dispersive X-ray microanalysis.

- Chemical analysis on laboratory samples. Also carried out on rock and soil samples, thereby determining the chemical composition of the various materials.
  - Major and trace elements (e.g., X-ray fluorescence and instrumental neutron activation analysis).
  - Carbonate determination.
  - Organic carbon determination.

- Analysis of the physical properties of the material on laboratory samples. As in the case of the mineralogical and chemical analyses, these tests are also made on rock and soil samples to determine important physical properties for the interaction processes.
  - Texture (sieve testing).
  - Apparent and real density. Porosity.
  - Water retention capacity.

- Analysis of the physico-chemical properties on laboratory samples. Although these tests are considered to be essential in the case of soil samples, it might also be well worthwhile conducting them on rock samples, depending on the nature of the rock to be studied.
  - pH.
  - Conductivity.
  - Cation exchange capacity.
  - Determination of exchangeable-sodium and base-
2. Determination of hydrogeological and hydrochemical properties

- Study of piezometric levels and identification of main groundwater flows. This calls for an updating of the well inventory of the area where the green filter is to planted, including the mean well levels. Once updated, the piezometric map is then drawn up, identifying the main groundwater flows that might affect and be affected by the planned measure.

- Analysis of the chemical composition of the water. This includes determination of the main ionic species, trace elements and the main emerging contaminants and microcontaminants (pesticides, pharmaceutical products, toiletry and antiseptic products).

- Determination of physicochemical parameters. This includes determination of the parameters in the field and in the laboratory: pH, conductivity, dissolved oxygen, Eh, etc.

- Biological analysis of the subsurface water. Includes the laboratory determination of intestinal nematodes and Escherichia coli.

Results in the case studied: the experimental plot of the plant of Carrión de los Céspedes

A study has been made of a plot in the vicinity of Carrión de los Céspedes (Seville), beside the experimental plant of the New Water Technology Center (Fundación Centro de Nuevas Tecnologías del Agua) (PECC) (fig. 1). With an approximate area of 6000 m², the plot slopes down gently towards the south. To the NW it borders on the PECC, to the NE on the cereal fields and to the S on olive groves.

![Figure 1. Scheme of the plant of Carrión de los Céspedes and experimental plot.](image)

The study involved the drilling of 21 boreholes with retrieval of core samples. The boreholes were 145 mm wide (fig. 2). Two 2-
Metre soil pits were also dug (fig. 3). The drill holes were then used for fitting 7 piezometer nests to record groundwater levels and samples. Each nest was made up by three piezometers, 10, 6 and 2 m deep, made from stainless steel tube with a diameter of 65 mm, with a 1 m filtering zone set above the end of the borehole, except in the 2m piezometers, where the filtering zone was fitted between the first and second metre.

Figure 2. a) Drilling of the bore holes; b) blind tube for tubing the core samples; c) core samples of the bore holes; d) detail of one of the core samples

1. Determination of the properties of the soils and underlying rocks (lithostratigraphy)

The on-the-spot data obtained from the soil pits and core samples and correlation thereof, together with the information obtained from the electrical tomography profiles (fig. 4) identified a set of surface soil levels of various thickness (from 0.2 to 0.6 m) and three underlying lithological units.

Green filters are a wastewater regeneration technology allowing reuse of the water to recharge groundwater by localised land percolation and silviculture

The on-the-spot study of the two soil pits led to the determination and classification of two soil profiles (Oxyaquic Xerofluvents and Calcic Haploxeralf) (fig. 3), laid down on recent alluvial sediments with hardly any edaphic differentiation between horizons. The main transformation processes that have occurred are humification, brunification and gleification, as well as processes of dissolution and reprecipitation of carbonates as nodules, pseudomycelia, infillings, at various depths of the profiles.
The incremental processes are shown by an increase in the organic matter (table 1), deriving from the presence and activity of the vegetation, and also by small alluvial deposits. Large among the transformation processes looms the humification of vegetal remains (mainly of the root systems). Because of this humification the soil has a moderate to high content of organic matter, up to 32-37 cm (table 1), well above the habitual content of agricultural land, as a result of the land lying fallow for several years. One of the profiles (Oxyaquic Xerofluvents) showed signs of assayed ferriferous transformations with predominance of brunification (oxidising conditions) in the upper half of the profile and gleification (reducing conditions) in the lower part of the profile, the direct consequence of impeded soil drainage. The most noteworthy feature of the other profile studied (Calcic Haploxeralf) is a very strong clay build-up (argillic horizon), with a notably gross prismatic structure and abrupt break in its upper limit, representing a strong obstacle to root development. The hydraulic conductivity of this argillic horizon is fairly low, impeding drainage and provoking the formation of hanging water layers that occasionally spring to the surface. Despite this, the signs of gleification in this profile are not as marked as in the
other profile.

### Table 1. Physico-chemical properties of the soils of the experimental plot

<table>
<thead>
<tr>
<th>Profile</th>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Clay (%)</th>
<th>pH</th>
<th>CE (μS/cm)</th>
<th>CO (%)</th>
<th>CaCO₃ (%)</th>
<th>M.O. (%)</th>
<th>NO₃⁻ (mg/Kg)</th>
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<tbody>
<tr>
<td>Oxyaquic Xerofluvents</td>
<td>A1</td>
<td>0-23</td>
<td>59.77</td>
<td>8,29</td>
<td>2160</td>
<td>1.68</td>
<td>0.83</td>
<td>2.9</td>
<td>53</td>
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<td></td>
<td>AC</td>
<td>23-37</td>
<td>62.27</td>
<td>8,29</td>
<td>6460</td>
<td>1.15</td>
<td>0.71</td>
<td>1.98</td>
<td>23</td>
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<td></td>
<td>C1</td>
<td>37-90</td>
<td>64.05</td>
<td>8,63</td>
<td>2720</td>
<td>0.61</td>
<td>0.21</td>
<td>1.07</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>90-110</td>
<td>54.52</td>
<td>8,86</td>
<td>1570</td>
<td>0.59</td>
<td>0.62</td>
<td>1.02</td>
<td>4</td>
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<tr>
<td></td>
<td>C3g</td>
<td>&gt;110</td>
<td>52.05</td>
<td>8,79</td>
<td>1523</td>
<td>0.46</td>
<td>0.54</td>
<td>0.8</td>
<td>4</td>
</tr>
<tr>
<td>Calcic Haploxeralf</td>
<td>Ap1</td>
<td>0-14</td>
<td>54.42</td>
<td>7,75</td>
<td>738</td>
<td>1.21</td>
<td>0.21</td>
<td>2.09</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>14-32</td>
<td>57.01</td>
<td>8,17</td>
<td>740</td>
<td>0.96</td>
<td>3.32</td>
<td>1.65</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>A3</td>
<td>32-50</td>
<td>59.07</td>
<td>8,26</td>
<td>724</td>
<td>0.52</td>
<td>0.33</td>
<td>0.89</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Bt1</td>
<td>50-63</td>
<td>74.02</td>
<td>8,22</td>
<td>1082</td>
<td>0.70</td>
<td>0.12</td>
<td>1.21</td>
<td>1</td>
</tr>
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<td></td>
<td>Bt2</td>
<td>63-80</td>
<td>74.05</td>
<td>8,24</td>
<td>871</td>
<td>0.57</td>
<td>0.41</td>
<td>0.98</td>
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<td></td>
<td>Bt3</td>
<td>80-109</td>
<td>68.79</td>
<td>7,83</td>
<td>2880</td>
<td>0.54</td>
<td>0.12</td>
<td>0.92</td>
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<tr>
<td></td>
<td>Bt4k</td>
<td>109-140</td>
<td>55.77</td>
<td>7,85</td>
<td>4780</td>
<td>0.50</td>
<td>10.37</td>
<td>0.86</td>
<td>&lt;1</td>
</tr>
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</table>

The main limitation of the soil studied in terms of its cultivation is the deficient drainage and low content of useful water (field capacity – wilting point): this will call for small but frequent irrigation inputs.

Below the soil levels three lithostratigraphic units have been recognised (fig. 5):

- **Upper unit.** Fine to very fine sand, loose, reddish brown in colour and of variable thickness (petering out towards the SW), with low water content. Maximum depth 1.5 – 2 m. This appears in the eastern half and northern zone of the plot (figure 2). Material of higher resistivity.

- **Main unit.** Clayey silt of ochre to green colour with abundant nodules and some levels of carbonate precipitation, radicular aspect. Suggests a paleo-edaphic origin. In the SW end an agricultural soil has developed with abundant organic matter and some small carbonated nodules. Thickness over 10 m.


**Figure 5.** Observation point for determining the geological properties of the land. a) Castilleja de la Cuesta quarry, with clayey silt in the upper part (main unit) and marl in the lower part (underlying unit); b) Embankment of the industrial estate of Carrón de los Céspedes, with fine sand and red silt in the upper zone (upper unit).
As shown in table 2, all samples contained carbonates (calcite), quartz and clay minerals (smectite-montmorillonite, illite and kaolinite) (fig. 6). Other common minerals in the samples are albite (sodium plagioclase) and anorthite (calcium plagioclase). Also worthy of note is the presence of halite in two of the samples; this might explain the high values of conductivity and levels of Na\(^+\) and Cl\(^-\) found in the hydrochemical analyses. The mineralogical composition of the studied material is therefore coherent with the hydrochemical composition of the water, as will be explained later. Other soluble minerals also present, such as calcite, will also interact notably (dissolution) with the irrigation water after prolonged application, with maintenance of soil humidity conditions above the field capacity; this will lead to a progressive rinsing of the carbonate from the surface levels. The mineralogical analyses also show that the exchange complex is constituted mainly by montmorillonite (clay of the smectite group), built up in the subsurface horizons. (Bt horizon of Calcic Haploxeralf). In the study case, there is a certain build up of organic matter in the surface horizons, and the CEC determinations show that the CEC is indeed higher in said Bt horizons than in the A horizon. Nonetheless the purification role of the montmorillonite is reduced by its very behaviour as expansive clay, establishing a flow of percolating water (and thereby the mineral phase-water interaction) confined to the cracks in the prismatic aggregate.

Table 2. Summary of the mineralogy of the experimental plot, identified by X-ray diffraction and scanning electron microscopy of the environment.

<table>
<thead>
<tr>
<th></th>
<th>DRX</th>
<th>ESEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonates</td>
<td>Calcite</td>
<td>Calcite</td>
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<tr>
<td>Tectosilicates</td>
<td>Quartz</td>
<td>Quartz</td>
</tr>
<tr>
<td></td>
<td>Albite</td>
<td>Albite</td>
</tr>
<tr>
<td></td>
<td>Anorthite</td>
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<tr>
<td>Phyllosilicates</td>
<td>Illite</td>
<td>Illite</td>
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<tr>
<td></td>
<td>Montmorillonite</td>
<td>Montmorillonite</td>
</tr>
<tr>
<td></td>
<td>Kaolinite</td>
<td>Biotite</td>
</tr>
<tr>
<td>Haluros Halite</td>
<td>Halite</td>
<td></td>
</tr>
</tbody>
</table>
2. Determination of hydrogeological and hydrochemical properties

The study zone lies in the hydrogeological unit 05.51 Almonte-Marismas, formed by strong detrital deposits, whose impermeable base is made up by the blue marl. It is a very heterogeneous multi-layer aquifer. The zone where the plot lies is mainly constituted by low permeability material (sand, silt, clay and marl).

Figure 7 shows the isobars of the upper limit of the saturated zone (water table) obtained from compilation of level data. These isobars show the main directions of groundwater flow in the area and how this is concentrated in the southern limit of the plot. It is also important to note that the plot itself contains clayey layers that might impede percolation in one-off points and lead to a certain predominance of lateral flows.
A very high percentage of groundwater has been declared to be overexploited, making it very difficult to ensure a good ecological state under the Water Framework Directive.

The analysed groundwater is composed of sodium-chlorinated water (fig. 8), with very high conductivity, ranging from 8000 to 12,000 microS/cm, due mainly to the input of Na+ ions from the land's silty fraction. Prima facie there would not seem to be any type of man-made pollution and its composition derives from the nature of the material contained in the water.

As for emerging contaminants, an analysis was made of over 80 substances, finding remains of nicotine (and its derivatives), caffeine and salicylic acid. This suggests that these compounds are part of a regional scale contamination factor and, even if they are found after commencement of the irrigation, it will not be
possible to put this down directly to irrigation with treated wastewater. These compounds have been used for a long time now (over a century in the case of salicylic acid and several centuries in the case of nicotine and caffeine) and now form part of the natural system; hence their presence in this particular case.

**Conclusions**

The methodology proposed herein for determining the geological characteristics of the land include the implementation of a set of techniques geared towards:

- **Determining the properties of substratum rock and soils (lithostratigraphy)** (geophysical study of the surface by means of indirect methods, soil and rock studies in outcrops, soil pits and boreholes, mineralogical analyses, chemical analyses and study of the physical and physicochemical properties of the material).
- **Determination of the hydrogeological and hydrochemical properties of the groundwater** (study of the piezometric levels and identification of the main groundwater flows, analysis of the chemical composition of the water, determination of the physico-chemical parameters, biological analyses of subsurface water).

Determination of the land’s geological properties is fundamental as a good practice in designing the best possible green filter system and ensuring this extensive wastewater treatment process is implemented in the most economically and environmentally efficient way. It paves the way for the proper design of these land applications, ensuring not only the protection of the environment, especially bodies of groundwater, but also the most effective implementation of this regeneration technology under current legislation. This is borne out by the preliminary results obtained in this study.

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http://www2.uah.es/filtrosverdes/
http://www.consolider-tragua.com/1280.htm

BIBLIOGRAPHY


REFERENCE LEGISLATION

1. Real Decreto 1514/2009, de 2 de octubre, por el que se regula la protección de las aguas subterráneas contra la contaminación y el deterioro.

2. Real Decreto 1620/2007, de 7 de diciembre, por el que se establece el régimen jurídico de la reutilización de las aguas depuradas.

3. Real Decreto 907/2007 de 6 de julio, por el que se aprueba el Reglamento de la Planificación Hidrológica.

4. Directiva 2000/60/CE del Parlamento Europeo y del Consejo por la que se establece un marco comunitario de actuación en el ámbito de la política de aguas.

5. Real Decreto 2116/1998, de 2 de octubre, por el que se modifica el RD 509/1996, de 15 de marzo, de desarrollo del Real Decreto-Ley 11/1995, de 28 de diciembre, por el que se establecen las normas aplicables al tratamiento de las aguas residuales urbanas.


7. Real Decreto 261/1996, de 16 de febrero, sobre la protección de las aguas contra la contaminación producida por los nitratos procedentes de fuentes agrarias.


GLOSSARY

Aquifer. One or more layers of underground rock or other geological material with the sufficient porosity and permeability for allowing a significant flow of groundwater and extraction thereof in appreciable quantities.

Brunification. Process of iron enrichment giving rise to goethite or iron-rich minerals and tingeing the soil a brownish or reddish colour.

Cation exchange capacity. The capacity of a particle to retain cations and exchange them with those present in the soil solution.

Contamination. The direct or indirect introduction, by human action, of substances or heat into the air, water or soil, which may be harmful to human health or impair the quality of water
ecosystems, and which damage material goods or deteriorate or hinder the enjoyment or other legitimate uses of the environment.

**Edaphology.** The scientific discipline studying all soil-related aspects, including the soil's physical and chemical properties, the role of organisms in building up the soil, description of the soil and origin of the formation thereof.

**Emerging contaminants.** Contaminants hitherto unknown and without any regulation but likely to undergo regulation in the future, whose presence in the environment is not necessarily new but with a newly arising concern about their potential consequences. They mainly derive from toiletry products, drugs or cleaning products. Most of these contaminants are removed by conventional wastewater treatment plants.

**Exchange complex.** Set of particles with the capacity of absorbing polar molecules and ions from the soil solutions. These complexes are formed mainly by clays and organic matter.

**Expansive clay.** Phyllosilicates capable of storing water between their lamina and thereby increasing the volume or swelling the material.

**Extensive water treatment processes.** Wastewater regeneration techniques based on low-environmental impact systems and calling for large areas of land. These processes manage to cut down the contaminant load and achieve lower running costs than conventional solutions.

**Field capacity.** Amount of water held by the soil after draining off gravitational water (gravity-driven downward draining water).

**Geology.** The scientific study of the Earth and application of the resulting knowledge to the search for natural resources, reduction of the aftermath of natural disasters and preservation of the environment.

**Geophysics.** The study of the Earth by means of the quantitative analysis of its physical properties.

**Gleification.** Processes that occur in water saturated areas with dominance of reducing conditions favouring the formation of ferrous iron oxides.

**Green Filter (Filtro verde).** Non-conventional land-application wastewater treatment technique involving the periodic application of wastewater to the land for depuration thereof by the land's joint action, the microorganisms and plants, by means of physical, chemical and biological mechanisms. It is an appropriate wastewater treatment method for small built-up areas.

**Groundwater.** According to the Water Framework Directive (WFD), this term means all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil.

**Humification.** Set of processes responsible for the transformation of organic matter in the soil and the formation of humic substances.

**Hydraulic load.** Volume of wastewater applied per unit of land area in a given period of time.

**Piezometer.** A small diameter borehole custom-built to measure the groundwater level and for taking samples therefrom.
**Piezometric level.** Total energy by unit of weight of groundwater in a point of an aquifer. The total energy is equal to the sum of the potential energy plus the interstitial pressure. Kinetic energy can be disregarded due to the normal low flow rates in groundwater. It is measured in units of longitude and is equal to the level that water would have in a well dug on this spot.

**Regenerated water.** According to R.D. 1620/2007, this term refers to treated wastewater that has been submitted, where applicable, to an additional or complementary treatment process to bring its quality into line with the purpose it is intended for.

**Saturated zone.** Part of the subsoil lying below the water table where all the material pores, fissures and cavities are saturated with water.

**Soil.** This is the upper layer of the earth’s surface, formed by solid particles (rock and minerals mixed with transformed organic matter), liquids and gases. It characteristically has well-differentiated horizons or layers representing the original inputs by means of increments, losses, transfers and transformations of energy and matter.

**Soil pit.** Ditch or excavation dug into the land to study the soil and rock or nature of the subsoil. They are also used for mine prospecting purposes.

**Unsaturated zone.** In general, the part of the subsoil lying above the water table, partially saturated with water and with air in the pores.

**Urban wastewater.** According to Directive 91/271/EEC this term means domestic waste water or the mixture of domestic waste water with industrial wastewater and/or run-off rain water.

**Water contamination.** According to the Water Act (*Ley de Aguas*) (1985) this is the action and effect of introducing material or forms of energy or introducing conditions into the water, which directly or indirectly impair the quality thereof in terms of future uses or ecological function.

**Wilting point.** Amount of water or degree of humidity in the soil when the plants’ suction force is lower than the soil’s water retention force, so the plants are unable to extract water.