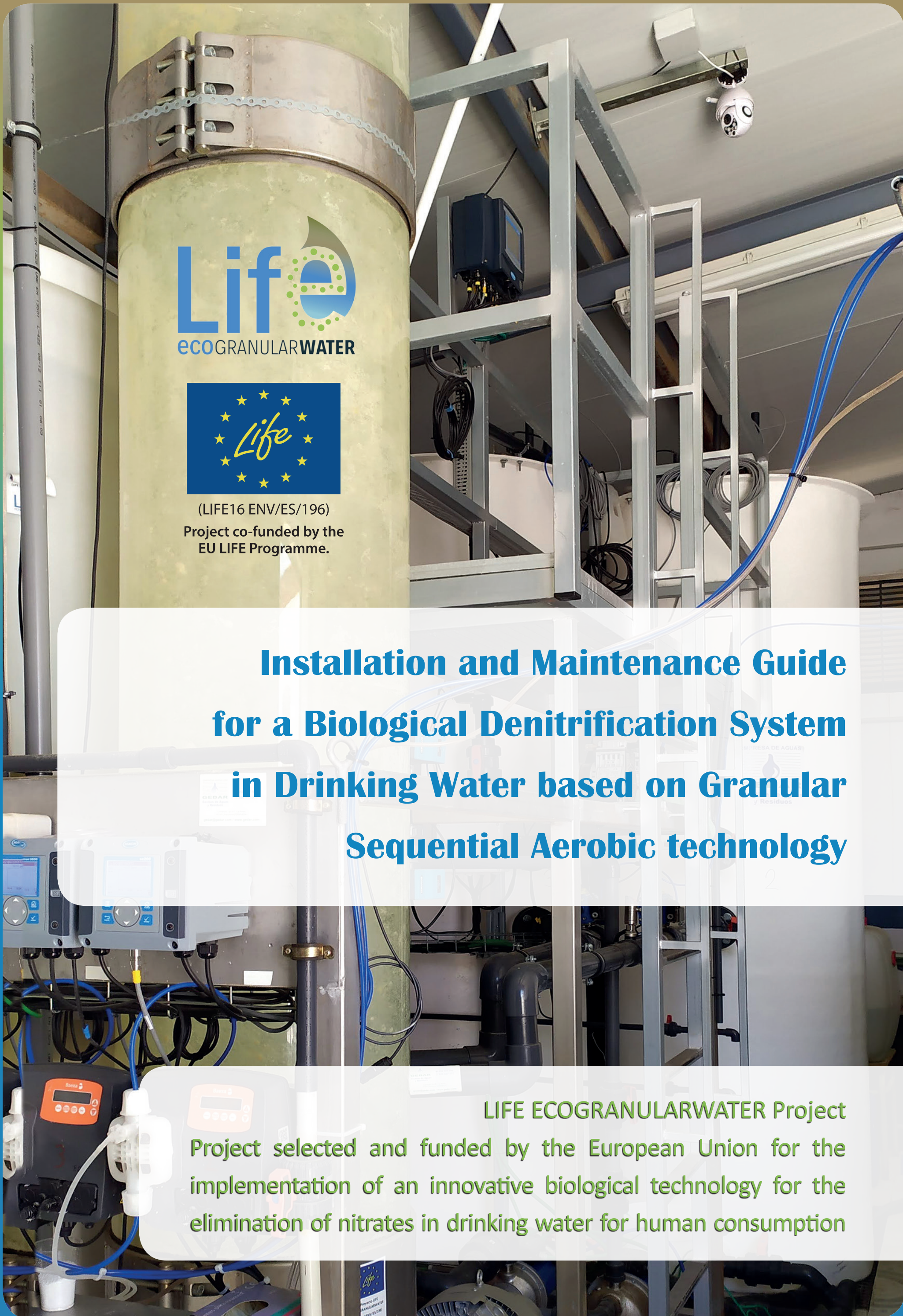

Life ecoGRANULARWATER

(LIFE16 ENV/ES/196)

Project co-funded by the EU LIFE Programme.

# Installation and Maintenance Guide for a Biological Denitrification System in Drinking Water based on Granular Sequential Aerobic technology

LIFE ECOGRANULARWATER Project

Project selected and funded by the European Union for the implementation of an innovative biological technology for the elimination of nitrates in drinking water for human consumption

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Provincial Council of Granada. Integral Water Cycle Service.

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## Abstract

The operation manual detailed below is part of the European project LIFE ECOGRANULARWATER (LIFE16 ENV/ES/196). This project is based on the implementation of a demonstrative system for nitrate removal in groundwater using a Sequential Granular Aerobic technology. This is a project of the LIFE program of the 2016 call. Its start date is set on the 1st of September, 2017, and it has been developed by the Provincial Council of Granada, the University of Granada, Aalto University in Finland and the Spanish companies Construcciones Otero and GEDAR.

The overall objective of this project has been the development and implementation of a novel biological denitrification technology for the treatment of groundwater polluted with nitrates. This system is based on Sequential Granular Aerobic technology, which consists of the use of microorganisms that under certain operating conditions form spherical aggregates called granules. These granules are formed exclusively by microorganisms, and consequently are not fixed to any surface or carrier, being confined in bioreactors and under certain operating conditions make possible the denitrification in an efficient and safe way.

The LIFE ECOGRANULARWATER project arose with the purpose of implementing Sequential Granular Aerobic technology for nitrogen removal compounds and other pollutants in small municipalities with nitrate pollution problems in their water supply. This project contemplates the implementation of a full-scale pilot plant in the municipality of Torre Cardela (Granada, Spain). Consequently, this technology is included in a line of projects focused on improving the quality of groundwater in small municipalities. It is a project based on the philosophy of sustainable and environmentally friendly treatments, generating very low environmental impact in nitrate removal processes. In this sense, it can be stated that this technology is based exclusively on biological methods to solve one of the main problems of groundwater, such as nitrate pollution. It is a low-cost technology, easy to implement in small municipalities with low municipal income.

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# 1.INTRODUCTION

# 1. INTRODUCTION.

Groundwater is an important resource for the world's population and provides supply to one third of the general population, hence the importance of conserving it in good characteristics and avoiding its contamination and degradation (Fillinger *et al*., 2021).

Groundwater resources supply 20% of the demand in cities with more than 20,000 inhabitants in Spain, however, this figure rises to 70% of urban supplies in cities with less than 20,000 inhabitants, in which their only sustenance is groundwater (De Stefano *et al*., 2015).

Up to 80% of the water pumped from the subsoil in Spain is used for crop irrigation, these data show us the great dependence of Spain on groundwater. This circumstance is frequently repeated in most Mediterranean countries that have a great scarcity of rainfall, which together with its uneven distribution throughout the year, generates important periods of drought in which groundwater supply becomes essential.

One of the main problems encountered in groundwater is the presence of pollutants that degrade its quality and make it unusable for certain uses such as human consumption, being the nitrogen compounds one of the main pollutants found.

Nitrate contamination of groundwater has various origins related to human activity in the vicinity of water bodies. This contamination can be localized at a certain point on the surface because of certain activities that cause discharges, such as wastewater effluents, certain industrial activities, etc. But in most water bodies, this pollution usually comes from diffuse pollution sources.

Punctual pollution is the result of an emitting source that generates a zone of pollution in its proximity. In this case we find discharges from different facilities that generate a pollution plume, which affects only areas in the immediate vicinity of the point of discharge at first. However, because of the natural movement of water through the aquifer, the contaminants are distributed throughout the aquifer, affecting larger areas (Figure 1).

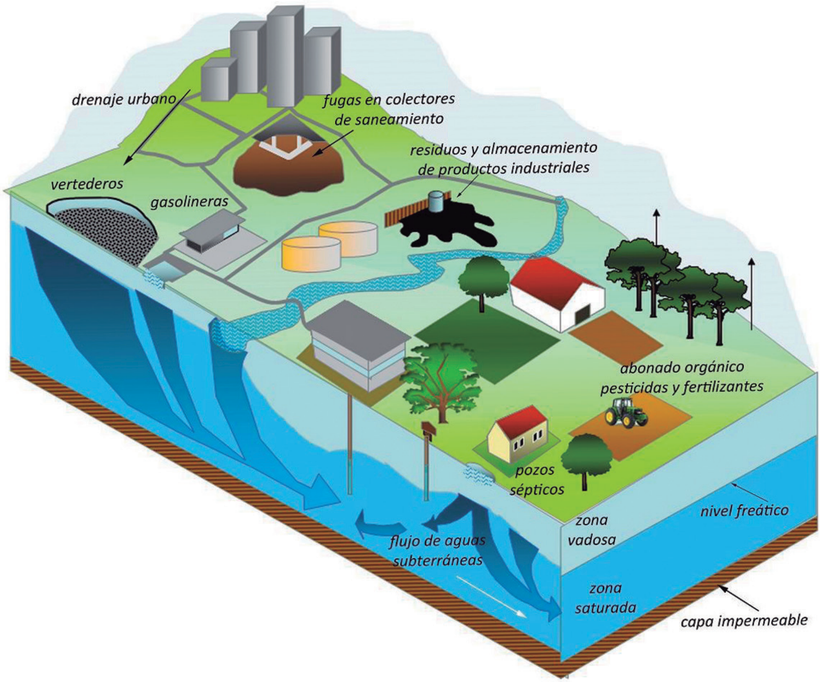



Figure 1: Sources of punctual and diffuse pollution in groundwater.
(Source: LIFE RURAL SUPPLIES project website).

Secondly, the diffuse groundwater nitrate pollution can occur due to sources of contamination that are not located at a specific point, with a specific extension, but affect large areas, as is the case of extensive crops. Consequently, if fertilizers and certain compounds supplied to crops are not properly managed, contamination can be caused by their excessive use, which ends up infiltrating groundwater and contaminating it. It should be noted that one of the main compounds added to crops is nitrogen, in the form of different formulations, which after passing through the soil is converted into nitrates that accumulate in groundwater bodies (Figure 1).

Nitrate pollution is a major problem in small municipalities, where aquifer recharge areas are occupied by agricultural and livestock activities which, if not carried out correctly, cause an excess of nitrogenous compounds that are washed away by precipitation and end up entering groundwater bodies. This causes a degradation of their quality and can even make them unfit for human consumption if the nitrate values required by drinking water legislation are exceeded.

The presence of high concentrations of nitrate in drinking water can generate significant health problems, having been described and related to various pathologies of the digestive tract, as well as in the development of methemoglobinemia in children (Vaishali et al., 2015). That is why the Water Framework Directive, which aims to achieve an improvement in water quality, together with Council Directive 91/676/EEC of 12 December 1991 on the protection of waters against pollution caused by nitrates of agricultural origin, establish that values above 50 mg/L of nitrate in water, strongly affect their quality, making them unfit for human consumption, and recommending not to exceed the level of 25 mg/L.

In Spain, and specifically in Andalusia, we can find numerous municipalities (many of them of small size) that have nitrate pollution problems in the groundwater used for water supply, with nitrate concentrations above 50 mg/L. One of these localities is the municipality of Torre Cardela, located in the province of Granada (Figure 3), and it is also noteworthy that the area where this municipality is located is catalogued as vulnerable zone due to nitrates.

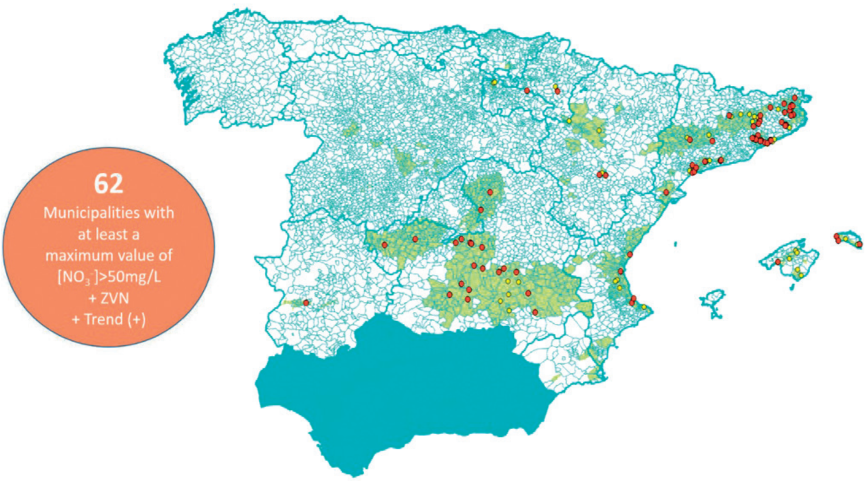



Figure 2: Map of areas affected by nitrate contamination in the rest of Spain.

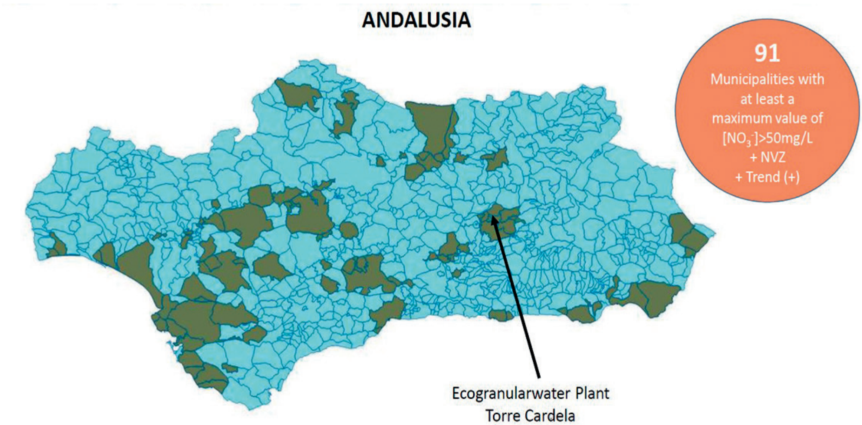



Figure 3: Map of areas affected by nitrate contamination in Andalusia.

The LIFE ECOGRANULARWATER project has been designed for the treatment of groundwater intended for human consumption in municipalities with nitrate pollution problems, with the clear objective of providing small municipalities with low availability of resources with a low cost and environmentally sustainable system. It is a modular technology that is easy and quick to implement and that allows solving nitrate removal problems in municipalities with low incomes that cannot afford the installation of more expensive technologies. In the same sense, it has been an objective to establish systems with low environmental impacts through the use of renewable energy sources.

# 2. PROPOSED TECHNOLOGY

# 2. PROPOSED TECHNOLOGY.

First, it seems necessary to explain the Sequential Granular Aerobic Technology and its specific application to the treatment of nitrate-polluted groundwater. In this sense, this technology bases its operation on the use of heterotrophic denitrifying microorganisms for nitrogen removal compounds, although unlike other denitrifying biological systems, such as biofilters, granular technology allows the formation of microbial aggregates (granules) formed under certain hydrodynamic conditions in sequential bioreactors (SBR). This granular structure determines a stratification of the microbial communities that makes them suitable for the biological denitrification process. This is due to the compact structure of the granule, which generates a decreasing oxygen gradient from the outside to the inside of the granule. Figure 4 shows a photograph of aerobic granules produced in SBR reactors during the treatment of nitrate-polluted groundwater. Figure 4 also shows the stratification of an aerobic granule, showing the different aerobic, anoxic and anaerobic zones and the location of different biological processes.

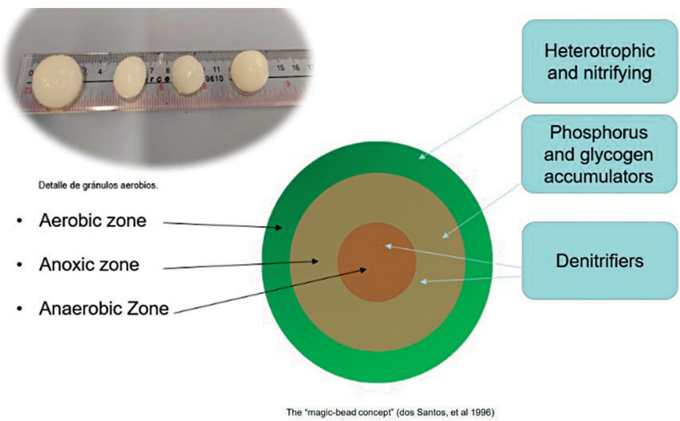



Figure 4: Detail of the different zones and biological processes occurring in an aerobic granule.

Aerobic granular technology has been fundamentally developed to be used in cylindrical reactors with a truncated cone base that allow a correct movement and development of the microorganisms confined inside the bioreactors (Figure 5). The reactors are aerated from their base, achieving a correct movement of the granules inside them, as shown in Figure 5. In the specific case of systems built for the treatment of water for subsequent human consumption, all the construction materials must comply with the regulations in force in relation to this aspect. Obviously, the system will be designed and built according to the needs of the population to be supplied and the flow of water to be treated.

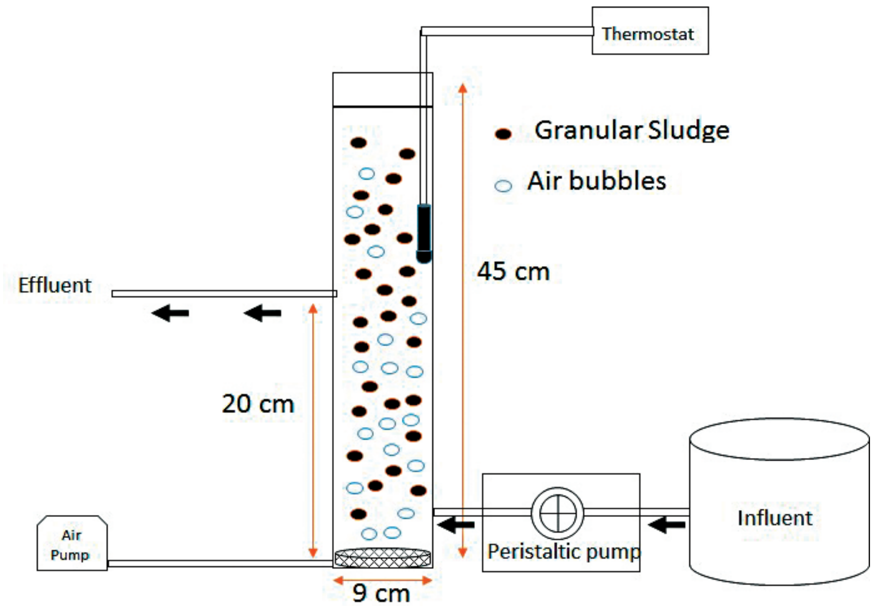



Figure 5: Diagram of an aerobic granular SBR plant showing the main elements that make up this technology (Muñoz-Palazon *et al*. 2018).

As mentioned above, denitrification that takes place in aerobic granular systems is heterotrophic. The microorganisms in charge of carrying out the biological denitrification process must have an adequate carbon-nitrogen ratio in the water. In the case of groundwater polluted with nitrates, this ratio is not in balance due to the excess of nitrogen. Therefore, for the process to occur in oligotrophic waters —such as groundwater—, the addition of an external carbon source is necessary to allow a correct carbon-nitrogen ratio and, consequently, an efficient denitrification process.

In general, the most used carbon sources in biological systems for nitrate removal are methanol and acetate. In the specific case of our proposal, after extensive experimentation, food-grade sodium acetate was selected, establishing a C/N ratio of 1/1 as appropriate.

**Nutrient solution composition.**

For the biological denitrification process to take place correctly in groundwater, it is necessary to add a source of organic carbon and a series of mineral salts in very low concentrations. In our case, after extensive research, we have established a compound composition that, when added to the groundwater, allow denitrification to take place very efficiently (Table 1).

| REACTIVE | QUANTITY (mg/L) |
|---|---|
| Anhydrous sodium acetate ($C_2H_3NaO_2$) | 100 |
| Magnesium sulfate heptahydrate ($MgSO_4*7H_2O$) | 7 |
| Dipotassium hydrogen phosphate ($K_2HPO_4$) | 7,2 |
| Monopotassium hydrogen phosphate ($KH_2PO_4$) | 2,1 |
| Potassium chloride (KCl) | 3,1 |

Table 1: Composition of the nutritional supplement added to groundwater to allow a properly heterotrophic denitrification process.

The amount of organic matter and salts to be added to the groundwater may be modified depending on the concentration of nitrate in the water and in general on the mineral composition of the water body to be treated. Therefore, the water to be treated must be previously characterized in relation to its possible concentration of nitrates, organic matter and mineral composition, so that the C/N ratio is maintained at 1/1 and the concentrations of trace elements are in suitable margins for microbial growth.

The C/N ratio must be considered of special importance in heterotrophic denitrification processes since denitrifying microorganisms simultaneously consume nitrate and organic matter. If this balance is broken, the system will fail, either by inhibiting the correct elimination of nitrate, if the amount of organic matter is insufficient, or by generating an excess of organic matter in the treated water, which is clearly undesirable.

As can be seen in Table 1, in our nutritional supplement, food grade sodium acetate was used as carbon source. The selection of this compound was the subject of extensive prior experimentation, establishing the suitability of this substance on the basis that its cost is very low and, more importantly, that its use does not pose any health risk. In addition, it should be noted that the organic matter used in the process is efficiently consumed by the microbial community present in the bioreactors, reaching consumption values of practically 100% once the system reaches stability (Figure 21). All the mineral components, which are added at very low concentrations, are of food quality.

| | **BIOREACTOR VOLUME (L)** |
|---|---|
| | |
| **REACTIVE** | **QUANTITY TO APPLY (mg)** |
| *Anhydrous sodium acetate* ($C_2H_3NaO_2$) | |
| *Magnesium sulfate heptahydrate* ($MgSO_4 * 7H_2O$) | |
| *Dipotassium hydrogen phosphate* ($K_2HPO_4$) | |
| *Monopotassium hydrogen phosphate* ($KH_2PO_4$) | |
| *Potassium chloride* ($KCl$) | |

Figure 6: Sample worksheet for the operator.

# 3. INFRASTRUCTURE AND OPERATION

# 3. DESCRIPTION OF THE INFRASTRUCTURE AND ITS OPERATION.

This section includes a description of the main elements that make up the aerobic granular plant located in the town of Torre Cardela for groundwater nitrate removal (Figure 7). A description of the design and operating parameters will also be given.

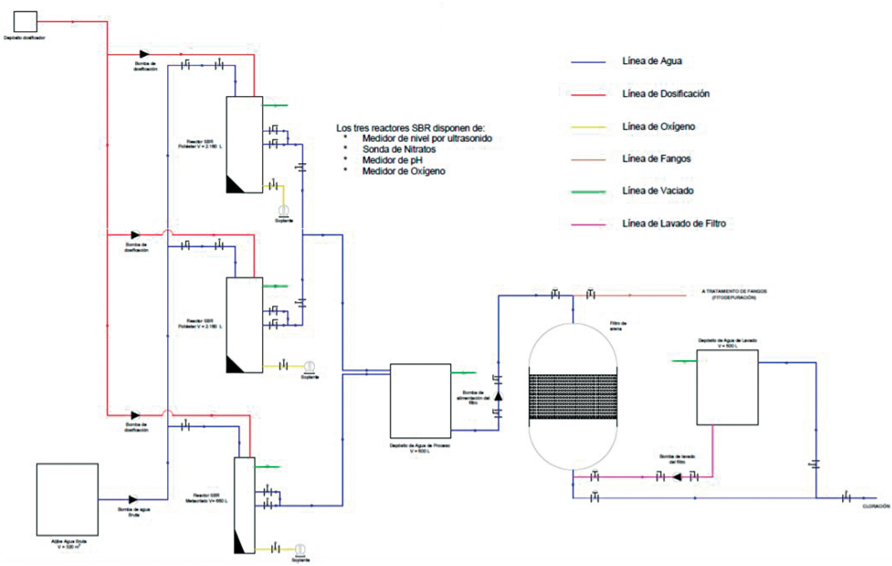



Figure 7. Diagram of the experimental aerobic granular SBR plant for the treatment of nitrate-polluted groundwater.

## 3.1. Description of the installation.

The system was designed and built based on the laboratory model shown in Figure 5 but adapting the dimensions according to the amount of water to be treated, respecting at all times the height-diameter ratio.

The Ecogranularwater plant (hereinafter the EGW plant) consists of 3 cylindrical reactors with a truncated cone base connected in parallel and operating sequentially in cycles. Specifically, the EGW plant was constructed with one reactor of 660 L capacity (4 m height and 0.5 m diameter) and two reactors of 2,163 L capacity (3 m height and 1 m diameter). The maintenance of this heigh-diameter ratio is very important, since we want to achieve reactors with cylindrical morphology for a correct operation and an optimal movement of the biomass inside them.

Another important parameter in the reactors was the bottom structure which was truncated cone-shaped with the air diffuser centered on one of the sides to achieve an adequate hydrodynamic movement of the granules inside it, as shown in Figure 8.

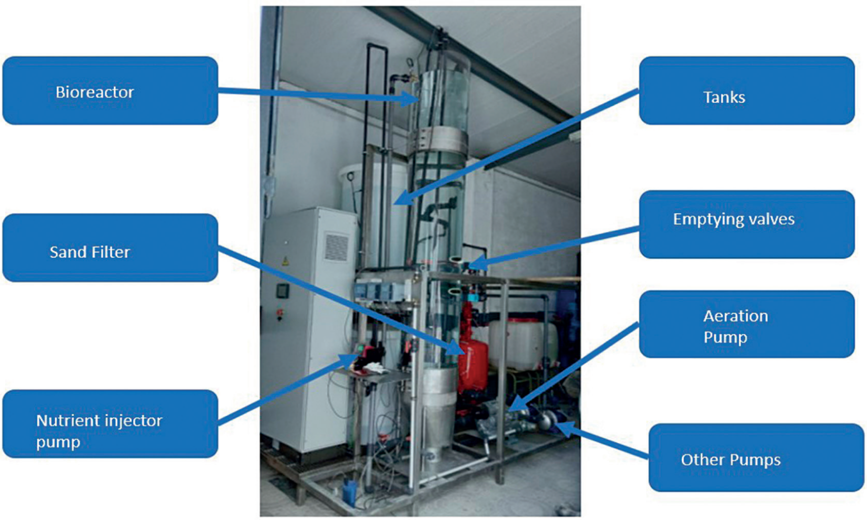



Figure 8. General view of the EGW water plant.

The design and correct construction of the nutritional supplement dosing system must also be considered as an essential part of the system. For this purpose, by means of an injector pump, the reactors were continuously supplemented from an external tank containing a concentrated solution, both the carbon source and mineral salts in sufficient quantity to reach the values described in Table 1.

The constructed installation has been designed in a modular way, which allows the addition of different reactors as necessary to supply the water needs. Therefore, it is a highly versatile system, the size of the reactors and the number of reactors can be modified according to the amount of water to be treated and the space available in the facility. Currently, as we have already mentioned, the EGW plant has three reactors of 660 L (1 reactor) and 2,163 L (2 reactors) of capacity, although it would be possible to build other units if necessary.

## 3.2. Ecogranularwater plant components.

The drinking water treatment plant consists of the following main elements:

- **Bioreactors**: These are cylindrical tanks with a truncated cone base with a volume of 660 L (one bioreactor) and 2,163 L (two bioreactors), in which aeration is carried out from the lower part through a fine bubble air diffuser. The reactors are filled from the upper part of the bioreactors with the groundwater water to be treated. The bioreactors have outlets that allow the evacuation of 50 or 60% of the total volume of the treated water according to operating conditions to be implemented in the system. At the same time, each bioreactor incorporated different control systems (dissolved oxygen, nitrates, ammonium, pH, temperature, and redox potential) located in the upper part as shown in Figure 9.

Figure 9: Detail of the control systems in one of the bioreactors.

- **Intermediate tanks:** The EGW plant also incorporates two intermediate tanks for carrying out the emptying and filtering operations of the bioreactors. Once the treated water has finished the stipulated time necessary for the physical separation of water and biomass by decantation inside the bioreactors, it goes to a tank where it accumulates to be filtered later. The second tank is similar to the first one and is where the filtered water accumulates, always maintaining the necessary quantity for the cleaning operations of the filtration system (Figure 10).

Figure 10: Intermediate tank where the treated groundwater was storage.

- **Nutrient reservoir**: The EGW plant must have a nutrient storage tank, with a hermetically closed top and equipped with a mechanical agitation system, to prepare the nutrient solution inside and feed the bioreactors at the beginning of each operating cycle (Figure 11).

Figure 11: Bioreactor feed tank.

- **Recycled glass filter**: After the settling process of the granular biomass in the bioreactors, the groundwater may contain small particles that have escaped from the previous decanting stage and must be removed by filtration. Therefore, a filtration system (recycled glass filter) was added to the system after the biological treatment (Figure 12).


Figure 12. Filtration system, using a recycled glass filter.

- **Aeration**: The system has an aeration system which was able to produce complete movement of the entire water column to keep the biomass in suspension during the aeration stage. The aerators are located at the bottom part of the reactors.

- **Pumps**: The plant has a set of pumps that together with the blowers make possible the different operations of the EGW plant.

- **Feed pumps**: The system has three injector pumps through which the nutrient supplement was supplied to each of the bioreactors from the nutrient solution storage tank (Figure 13).


Figure 13: Feed pump for reagent dosing.

- **Fill and drain valves**: The EGW plant incorporates a series of valves connected to the automatic control system that control the emptying and filling of the system, as well as the rest of the piping and conduits between the different elements of the installation.

- **Control system**: The entire plant is kept in operation thanks to an automated control system that regulates all the time and stages of the installation, allowing its autonomous operation, as well as remote control of the process (Figure 14). The control system also includes the necessary safety measures to prevent accidental emptying of the bioreactors.


Figure 14: Plant control system.

- **Phytoremediation system**: The EGW plant does not produce any type of reject stream, but the recycled glass filtration system must be cleaned periodically by performing the relevant backwashing operations. This process generates a small amount of sludge that must be treated by a small wetland system located on the outskirts of the treatment plant (Figure 15).

Figure 15: Phytoremediation system.

### 3.3. Ecogranularwater plant inoculation.

Once the EGW plant was designed and built, its start-up was carried out by inoculation with aerobic granular sludge. Specifically, each granular bioreactor was inoculated with 6 L of mature granules previously formed in lab scale bioreactors at the Water Research Institute of the University of Granada treating groundwater with high nitrate concentration.

After inoculation, a series of premises must be followed during the first 15 days to achieve optimal biomass growth until system stability was reached (Hurtado-Martinez *et al*., 2021).

1. **Settling time**: After inoculation and with the aim of not losing biomass and to achieve a rapid growth of granular sludge in the system, the settling speed should be 10 minutes during the first 3 days, 7 minutes during the next 7 days, 5 minutes during the next 5 days, and finally reduce it to 3 minutes, which was the value established for the system.

2. **Amount of organic matter**: During the first week of operation, it is convenient to increase the amount of organic matter up to a C/N ratio of 2, to achieve a strong growth of the newly inoculated biomass.

   Then, a 25% reduction of the organic matter will be made in the second week of operation and another 25% reduction in the third week, reaching the organic matter concentration of 100 mg/L of sodium acetate in the fourth week of operation.

Following the above strategy, the system can be commissioned in approximately one month of operation depending on system volume and site conditions. However, adequate organic matter and nitrate removal efficiencies must be established prior to bringing the system to a steady state. Once this is achieved, the system can be considered ready for operation.

### 3.4. Operation of the Ecogranularwater technology.

As previously described in this report, EGW system is based on a cyclical sequence of operation in which the system goes through a series of operating stages to achieve a correct nitrate removal process. This process could be called "system operating cycle".

It should be noted that the system operates in parallel. Thus, the system works in a modular way with different reactors in parallel, so that the different reactors can be operating in a different stage of the operating cycle, so that the production of treated water does not stop at any time. In other words, one reactor can be aerating while another is in the emptying stage, and so on with all possible combinations.

The system works sequentially in stages that are based on the hydraulic retention time of the system, the time it takes to renew all the water in the reactor. This time is must be determined according to the characteristics of the groundwater that will be treated and, fundamentally, the level of nitrates in the water.

The system works following a series of stages that are detailed below (operation cycles):

#### 1. Filling stage.

At this stage, the bioreactors were fed from the top with raw water from the groundwater supply tank. The bioreactors' filling process was controlled by the plant's computer system, which controls the filling electrovalves, as well as the water supply pump and the bioreactors' level sensors. All these elements were automatically synchronized to optimize the filling process (Figure 16).

The filling process was automatically controlled by the installation of ultrasonic sensors that automatically detect when the reactor is full to avoid a spill. During this stage, the reactor contains between 40% and 50% of the water volume from the previous cycle, together with the decanted granular biomass as shown in Figure 16.

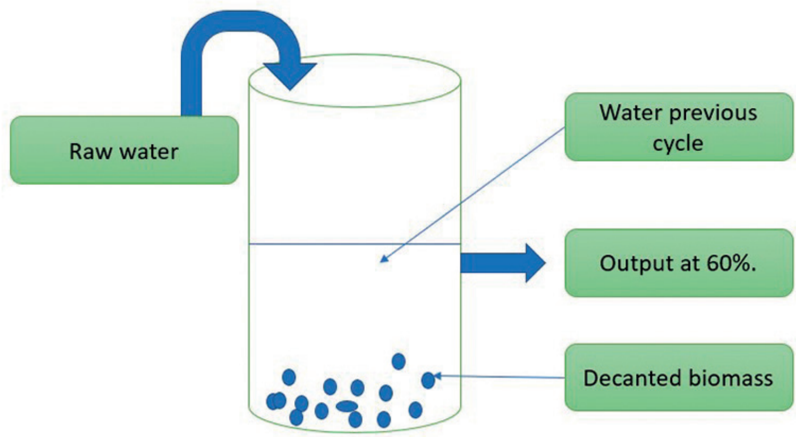



Figure 16: Filling stage.

## 2. Aeration stage.

After bioreactor filling process, the aeration stage begins automatically. In this stage, the bioreactors is aerated from the bottom by means of a fine bubble air diffuser connected to an aeration system by means of a blower. When the blower is activated, it produces the resuspension of the decanted biomass starting the automatic addition of nutrients (acetate and salts) to produce an effective mixing of nutrients inside the bioreactor (Figure 17).

The aeration stage may have longer or shorter depending on the characteristics of the groundwater to be treated, particularly of the nitrate concentration. For the case of the real plant located in Torre Cardela, this time was stipulated in 2 hours, time necessary for the total consumption of the added nutrients and nitrate removal in the groundwater. Thus, in the groundwater treated in Torre Cardela, nitrate concentration do not exceeds 60 mg/L, and consequently the operating conditions (2-hour cycles) were adjusted to the above-mentioned values. In the case of water with higher nitrate levels, this time must be modified, as well as the amount of nutrients added so that the system maintains a correct balance.

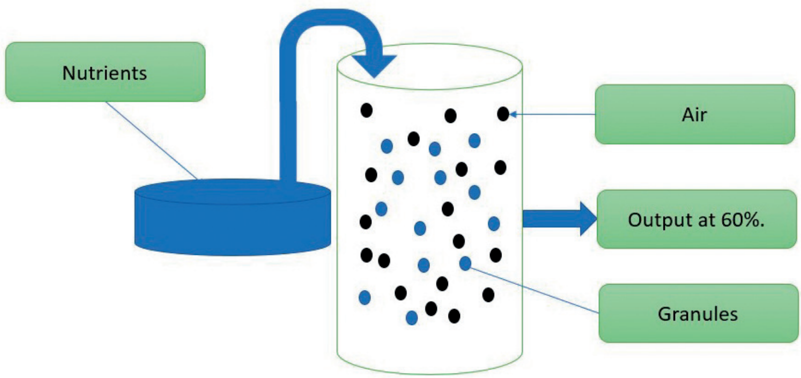



Figure 17: Diagram of the aeration stage.

## 3. Settling stage.

Once the aeration period is completed, the decantation of the granular biomass takes place in the bioreactor, producing a physical separation between water and biomass.

Decantation time in the EGW plant was set at 3 minutes, sufficient to produce a physical separation of water and granular biomass. This settling time depends on the density of the granular biomass and must be considered as a very important factor because if it is too short, we run the risk of losing part of the granular biomass in the emptying stage, and if it is too long, there may be a deficient elimination of filamentous microorganisms, which interfere in the granule formation process and cause a destabilization of the system.

Figure 18 shows a schematic of the physical separation that occurs between water and biomass.

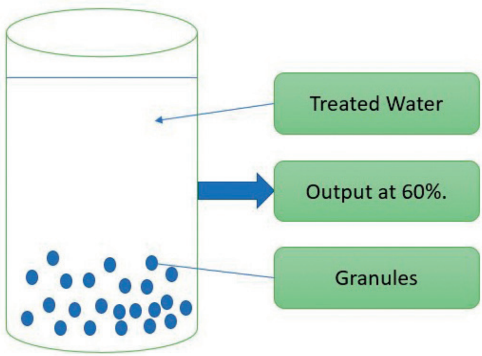



Figure 18: Schematic of the decanting stage.

## 4. Emptying stage.

Once the decanting time, necessary for the physical separation of water and biomass, has been completed, the control system opens the electrovalve to empty the bioreactor, discharging the treated water into the pre-filtration tank. The bioreactors are designed with two outputs, at 50% and 60 % of the total volume of the bioreactor, respectively. In the EGW plant has been tested that the extraction of 60% of the bioreactor volume produces good results and allows treating 10% more water in each operating cycle. It must be considered that in this system the operating volume per cycle is not 100% of the reactor volume, since part of the water is retained inside the reactor together with the biomass to continue treating the water in the next cycle. This is achieved by having the bioreactor output at a specific level, saving the water and biomass that remains below this level in each emptying cycle, as shown in Figure 19.

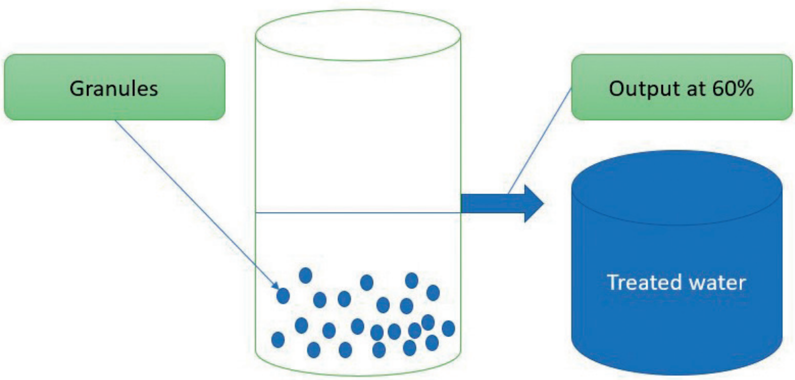



Figure 19: Schematic diagram of the emptying stage.

## 5. Filtration and disinfection stage.

In addition to the emptying stage, the output water is filtered through a recycled glass filter and disinfected with sodium hypochlorite before being discharged. Once the emptying stage is completed, a new operating cycle is started in the bioreactor and the filling stage is restarted.


Figure 20: Nutrient injector pumps and multiparameter meters.


# 4. RESULTS OBTAINED

# 4. RESULTS OBTAINED IN THE ECOGRANULARWATER PLANT.

The results achieved during the bioreactor monitoring phase are shown below.

## 4.1. Consumption of organic matter in bioreactors.

As previously mentioned, heterotrophic denitrification processes in oligotrophic environments require the addition of an external carbon source. Therefore, for the groundwater nitrate removal process, the addition of a carbon source and the maintenance of a correct C/N ratio was essential.

Different carbon sources such as methanol and acetate were tested in the system. The results showed that food grade sodium acetate has the best characteristics considering its marking value, easy transport and storage and high efficiency for denitrification.

Figure 21 shows the organic matter (acetate) removal in the bioreactors during the denitrification processes, being evident how the acetate is efficiently used by the granular biomass. Therefore, sodium acetate in the bioreactor is practically removed during the nitrate removal process. It can be seen how the performance increases from the inoculation of the system with denitrifying granules until it reaches stable conditions, at which point it is ready to treat water without any output of organic matter in the treated water.

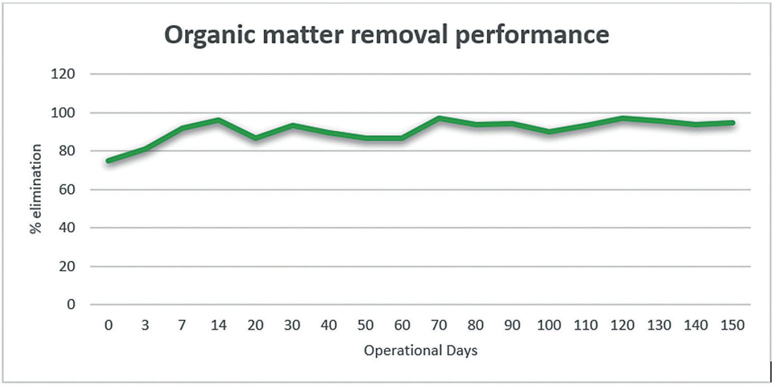



Figure 21: Organic matter removal performance of the system during 150 days of operation.

## 4.2. Analysis of the amount of biomass present in the system and granulation process.

The bioreactors were inoculated with denitrifying granules, observing an increase in biomass until stable conditions were reached with a concentration between 0.2 and 0.25 g/L, detecting that the system was susceptible to auto-regulation, so it is not necessary to add new granules or remove excess granules from inside the system, unless some type of accident occurs during its operation.

Granular size was also measured throughout the process to determine if they underwent any morphological change during the operation time, achieving an average granule size of around 7 mm once the stability of the system is reached.

Along with the size, the settling velocity of the granular biomass was also measured. This parameter is very important, since it informs us how dense the biomass is. The denser the biomass is, the faster it settles to the bottom of the bioreactors and the more effective is the separation between water and biomass, achieving a higher oxygen gradient inside the granule and making the nitrate removal process more effective.

### 4.3. Nitrate removal.

The main objective of EGW technology is the groundwater nitrate removal. Nitrate can be found in excess in many aquifers in Spain, Europe or anywhere in the world, hence the importance of achieving technologies that can be used for its treatment, generating a minimum environmental impact. In this context, EGW technology achieves good nitrate removal performance, producing output water with an average of 20 - 25 mg/L of nitrate as shown in Figure 21, which achieves removal performances of more than 60% (Figure 22).

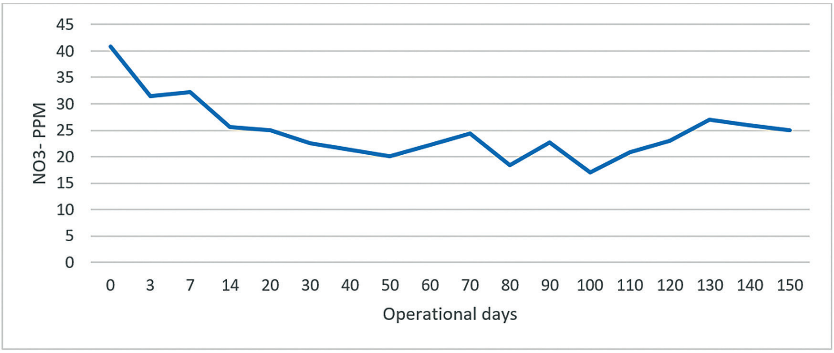



Figure 22: Nitrate concentration in treated water.

This reduction in nitrate values allows us to carry out mixing processes with untreated raw water, achieving the nitrate values recommended by legislation, without the need to treat all the water to be consumed by the population through the system, with the consequent savings in reagents and energy.

# 5. PLANT DIMENSION

# 5. GUIDELINES FOR DESIGNING A PLANT.

To achieve an optimal performance of a biological technology using Sequential Granular Aerobic Systems, the design of the bioreactors is very important, as well as the operational parameters of the system. Because of the modular nature of the installation, a multitude of parameters can be modified according to the needs of the site where the technology is to be located.

The different steps that must be followed are summarized in:

## 1. Groundwater and aquifer characterization.

First, it is necessary to know very carefully the characteristics of the groundwater, carrying out the relevant analyses over a long enough periods, in order to know chemical parameters such as nitrate and phosphate concentration. It is very important to know if these nitrate levels remain within certain limits, if they remain constant, or if these levels are modified with the annual precipitation cycles.

In order to know in a predictable way the nitrate concentrations in groundwater, the knowledge of the aquifer is especially important. That is why, prior to the use of a treatment system, it is of interest to know how the nitrate concentration evolves in the aquifer and evaluate possible changes in the pollution level over long periods of time. This will allow us to know the recharge cycles it has, as well as the nature of the materials that form it. For instance, some aquifers have a high porosity that produce pollution peaks after an intense precipitation that produces a very rapid washing of contaminants, while others have a lower porosity, and consequently a slower water movement speed that attenuates these contamination peaks. In this context, different groundwater samples directly taken from the aquifer must be periodically analyzed.

## 2. Volumen of treated groundwater.

As previous step to the construction of an EGW plant, it is essential **to know the quantity of water needed** to supply a determined population. Once the target flow rate is known, we can begin to calculate the necessary groundwater volume that must be treated per day.

Our EGW plant located in Torre Cardela (Granada), was built to supply drinking water to 500 inhabitants (132 L per inhabitant/day). According to these needs, the plant was operated with the capacity to generate a volume of treated water of 66,000 L/day.

We must also know **the nitrate concentration in the raw water** and establish the removal efficiency of the technology. In our case was possible mixed treated groundwater with raw water reaching a nitrate concentration lower less than 50 mg/L.

## 3. Amount of nutrients per operation cycle.

Once the level of nitrates in the water body is known, we can establish a nutrient administration strategy according to the amount of nitrates present in it, maintaining in any case the carbon-nitrogen ratio 1:1, which means that if the water has more nitrates than the amount detected in our case, the amount of carbon must be increased proportionally. Obviously, if the nitrate concentration found in the groundwater was lower the nutrient addition must be decreased.

Table 1 shows the different amounts of nutrients that must be added to the EGW plant to obtain good nitrate removal results. Obviously, the concentration of these nutrients will always be in relation to the level of groundwater pollution. All the nutrients were prepared as concentrated solutions in the feed tank and were added to the bioreactors until obtaining the desired concentrations (Table 1).

## 4. Nutrient solution preparation.

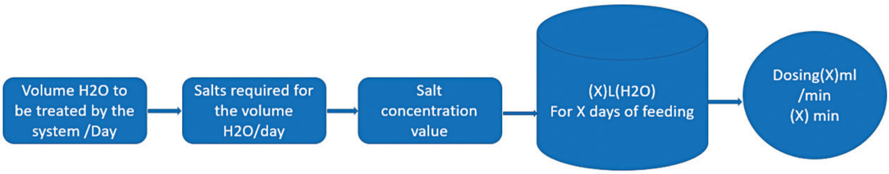
The preparation of the concentrated nutrient solution follows the steps indicated in the figure below:

Number of reactors X Operational volume of each reactor X Number of cycles per day = Daily production of water

First, we must know the volume of treated groundwater per day in the EGW system, number of bioreactors that our biological plant includes, as well as the treated groundwater volume per cycle and the number of cycles that these reactors perform per day. With all these data we will be able to establish the daily water production of our EGW plant.

Once this value is known and using the table shown in previous sections (Table 1), the amount of salts required for each period of operation can be easily calculated.

Specifically, one liter of concentrated nutrient solution allowed the treatment of 188.75 liters of raw water. Knowing this data and the operational volume for each cycle, we can adjust the dosing time by means of the injector pump, depending on the flow rate imposed on it.




## 5. Bioreactor design and other equipment of the EGW system.

Once the amount of water to be treated per day was known, the bioreactors must be dimensioned. In this sense, it is worth mentioning the high versatility of this type of systems, since the reactors can be dimensioned in different sizes depending on the characteristics of the installation. However, the relationship between height and diameter of the bioreactor will always have to be adequately maintained in order to achieve optimum performance and particularly an efficient granulation.

The EGW plant located in Torre Cardela was built with two different types of reactors.

One reactor was built in steel and methacrylate to observe the correct granulation process, as shown in Figure 23. However, the other two bioreactors that made up the system were built in polyester with fiberglass, due to its lower cost, easy transportation and handling (Figure 24).

The modular design of the EGW plant allows, if necessary, to easily increase the number of reactors and consequently to be able to comfortably increase the total volume of treated water. However, this is a possibility in the plant located in Torre Cardela, although another type of unit construction is possible.

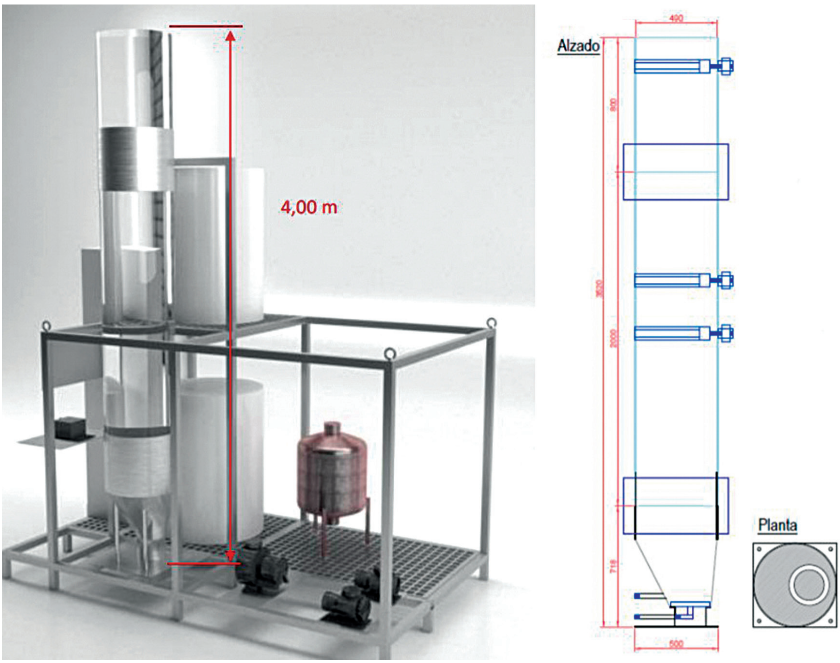



Figure 23: Bioreactor built in methacrylate.

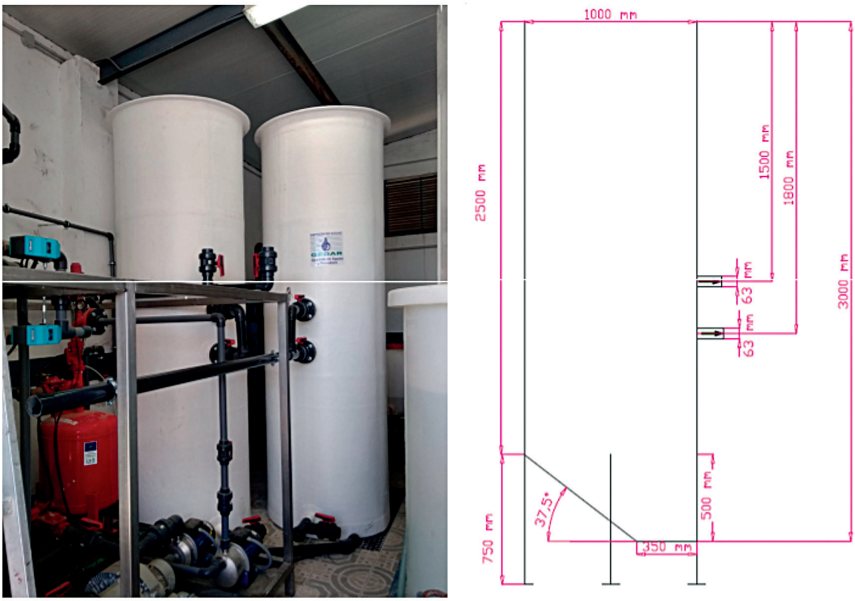



Figure 24: Bioreactors constructed in polyester-fiberglass.

Once the bioreactors have been designed, the **aeration system** must be built to allow the establishment of the hydrodynamic current that allows granulation. This is done with one or several blowers depending on the number of bioreactors to be installed. The air flow must be sufficiently high to ensure an optimal turbulent movement of the complete water column.

The **filtration system** also must be designed and scaled up, with a sufficient size to treat the bioreactors output flow. At this point, the installation of two storage tanks must be foreseen, one for the bioreactors' raw water output, and another one for the bioreactors' treated water. The raw water tank has the function of storing the water while it is being filtered, allowing the parallel operation of several pieces of equipment. Post-filtration tank has the purpose of storing water inside to proceed with the cleaning operations of the filtration system.

**Disinfection system** has the objective of making sure the total absence of viable microorganisms in the output water. For this process, a disinfection system has been foreseen at the bioreactors output, which will act together with the filtration system, to achieve an optimal water treatment.

To reduce greenhouse gas emissions, a **photovoltaic system** (Figure 25) was built with the aim of providing all the energy necessary for the plant operation. Therefore, the eco-granular plant can be considered as self-sufficient in terms of energy consumption, not requiring the use of external energy.

The installation of a small artificial **wetland** to treat the sludge from the cleaning of the filtration system was also included. This system for treating the generated sludge was of very small dimensions due to the small volume of sludge generated by the plant.

Figure 25: Photovoltaic system for supplying the installation.

Of particular note are the civil engineering works necessary for the construction of supply tanks in the facilities where the system is to be installed, both in case of new installations or the adaptation of existing ones.

# 6. MAINTENANCE WORK

# 6. MAINTENANCE OF THE ECOGRANULARWATER SYSTEM.

The biologic treatment system described in this guide requires very little maintenance, but certain operations must be performed on the equipment, which is detailed below.

## 1 Cleaning of sensors and measuring equipment.

The system has different equipment and sensors, already mentioned, located at the top of each reactor and in the municipal water tank for on-line nitrate determination. It also has flow sensors at the outlet of the different bioreactors and other safety elements that can allow to obtain information on different parameters such as real-time information on the amount of nitrates present in the municipal tank or in each bioreactor. Moreover, we can obtain complementary information such as pH and dissolved oxygen.

All equipment mentioned is in contact with water and granular biomass, in the case of those located inside the bioreactors. As a result, they can accumulate microbial biofilm and other incrustations that interfere with their optimal operation. For this reason, they must be cleaned and calibrated periodically following the indications established by the manufacturer for each one of them. Moreover, it is very important to periodically check the flow meters that measure the outlet water of each bioreactor, since they are not only informative elements, but are part of the safety system of the installation to avoid accidental emptying of the bioreactors. Therefore, they must be clean and calibrated according to manufacturer's instructions, so that in case of accidental water leakage they immediately stop the system to avoid biomass losses.

In conclusion, all the measurement and control equipment of the EGW system must undergo a strict surveillance and control system that allows the correct maintenance of the system. This will avoid costly repairs and undesirable downtime.

### 2 Maintenance of the filling and emptying electrovalves.

Correct maintenance of the electrovalve system is of vital importance in the EGW system. This equipment controls when the bioreactor was emptied or filled and must be properly maintained to avoid failures. The manufacturer's instructions for cleaning and maintenance must be followed, as well as their replacement when they are damaged.

### 3 Cleaning of storage tanks and intermediate tanks.

The EGW plant has two intermediate tanks of 500 L capacity, as well as another tank of 1,000 L for the storage of mineral salts and a storage tank of sodium hypochlorite for post-filtration disinfection.

The 500 L tank before the filtration system receives unfiltered water from the bioreactors, which can accumulate particles and incrustations, and should be cleaned every 15 days with a solution of hypochlorite and pressurized water.

The 500 L post-filtration tank receives the filtered and disinfected water ready for use, therefore, it does not usually present incrustations, even so, it has to be cleaned and disinfected every 15 days with a hypochlorite solution and pressurized water in the same way as in the pre-filtration tank.

The nutrient storage tank was responsible for storing the nutrient solution from which the system was supplied. It is a hermetic tank perfectly closed to avoid the growth of microorganisms inside. It should be cleaned once a week with a solution of sodium hypochlorite and pressurized water, making sure to remove all traces of hypochlorite before pouring the nutrient solution inside again.

The disinfectant storage tank was used for automatic disinfection and contains a sodium hypochlorite solution. It is recommended to clean it once a month as a precautionary measure.

### 4 Cleaning of the filtration system.

This system was built to remove particles that can be dragged from the bioreactor after the settling process. Although the filtration system has an automatic backwash system, it is advisable to perform an internal disinfection of the filter according to the manufacturer's instructions, to prevent the growth of microorganisms inside the recycled fiberglass filter. The recycled fiberglass filter should also be replaced periodically according to the manufacturer's instructions.

### 5 Revision and cleaning of the diffuser and aeration pumps.

The diffuser located at the bottom of the reactors must be replaced at the end of the useful life established by the manufacturer, or when a change in bubble emission is detected.

Along with the diffuser, the blowers that supply air must also be checked and replaced or repaired if a decrease in air flow is detected.

### 6 Revision of the dosing system.

The nutrient dosing system is essential for the correct operation of the plant, so it must be checked periodically to ensure that the dosage added to the reactor is correct and calibrated if anomalies are detected.

### 7 Periodic measurement of nitrates at the outlet of the bioreactors.

Although the system was equipped with on-line nitrate measurement system, which measure this parameter continuously both at the inlet and outlet of the bioreactors, it is advisable to take measurements of this parameter once a week to corroborate that the data provided by the sensors are correct. If these data are not correct, the nitrate sensor will be recalibrated or replaced if they are damaged.

### 8 Microbiological control.

Although the system has all the disinfection measures established by law, it is advisable to carry out a microbiological analysis periodically to ensure the correct functioning of the system, following the sanitary indications for drinking water.

Figure 26: Nutrient tank and view of the water treatment plant.

# 7. PROBLEMS AND SOLUTIONS

# 7. PROBLEMS ENCOUNTERED AND SOLUTIONS.

During the development of this experience, technical and operational problems have occurred, which have helped us to learn and improve the facilities and the biological process of nitrate removal.

One of the main challenges of this project was the physical dimensions of the facility where the technology was to be installed. This technology coexists with a reverse osmosis system, which is currently being used groundwater nitrate removal in the municipality. Both technologies, biological and physical, are located in the same place that has relatively small dimensions. This posed a major challenge when it came to building the reactors, since in addition to the limited physical space available we had the problem of the roof of the facility that limited us in height. Therefore, when it came to expanding the plant to supply the town for 500 inhabitants, we opted for a different reactor design to the one already installed in methacrylate. If replicas of this methacrylate reactor were installed, the space required would have been greater, having problems for its implementation inside the existing structure, so we opted for a reactor design of greater volume with a suitable aeration system and respecting the truncated cone base to achieve optimal movement of the granules inside them.

The second major challenge we faced was the failure of one of the outlets electrovalves that caused the loss of granular biomass in one of the bioreactors. This failure was caused by the opening of the outlet electrovalve during the aeration phase, without waiting for the necessary decanting time, with the consequent loss of the biomass that was in suspension. To prevent this problem in future, the computer system was equipped with a series of tools to prevent these accidents; firstly, a command was installed to ensure that the drain electrovalve cannot be opened until a minimum decanting time has elapsed, thus ensuring that there is always a delay between the order to open the electrovalve and the physical opening of the same. The second safety element was the installation of flowmeters at the outlet of the bioreactors, this element allows us to detect if water is coming out in a different stage than the emptying stage, or if the reactor outlet flow is anomalous, proceeding to the instantaneous shutdown of the reactor if any parameter is anomalous. This allows us to secure the biomass to avoid its accidental loss.

Another of the measures implemented in the system was the password identification of all personnel accessing the installation, both remotely and on the existing screen in the facilities. This allows personnel to be quickly identified and prevents any unauthorized person from modifying system parameters. All these remote-control measures provide the installation with the necessary safety to avoid accidents and loss of granular biomass from the bioreactors.

Although the safety measures mentioned above, physical failures can occur in the system, for example, the breakage of an outlet solenoid valve, which can cause the loss of biomass. For this reason, the system was designed to operate with different reactors in parallel, so that if one is rendered unusable due to a failure, the rest can continue to be used, and part of the biomass from these reactors can be used to re-inoculate the reactor that has lost it due to an accident. In this way, we always ensure that the installation does not come to a complete stop in the event of a possible failure in any of the reactors.

Finally, we will focus on the energy supply of the installation and the problems that may arise in this respect.

The current plant has a solar energy power supply system, which recharges a series of accumulators installed on the installation's premises, and which allow the bioreactors to be supplied. EGW system consumes a small amount of energy, but still needs it for its operation. To ensure that the facility does not stop production, it has a dual supply system, i.e., it is supplied with energy from the solar panels, but it is not disconnected from the local electricity grid, so that if the solar energy fails, the plant is automatically connected to the electricity grid until the failure is resolved. In this way, the installation always has energy for its operation.

The removal of excess biomass from the system is not usually necessary, since, due to the oligotrophic nature of groundwater, and the right proportioning of reagent, the system is always kept in equilibrium and excess biomass is not usually produced. Even so, the system is equipped with a purge system, if the amount of biomass is excessive.

# 8. BENEFITS AND CONCLUSIONS

# 8. BENEFITS AND CONCLUSIONS.

## 8.1. Benefits compared to other denitrification systems.

The municipality in which the biological technology was installed has had a physical nitrate removal system based on reverse osmosis for some years. This technology is used by many municipalities since it is a very effective system for nitrate removal and many other water components.

Reverse osmosis technology is based on a system of membranes, through which water is forced to pass to remove different compounds. This process requires large quantities of energy, since the water is forced to pass against the natural gradient, with high pressures, with the consequent energy cost that this generates.

The second problem with this technology is the rejection flow that it generates. This system concentrates the contaminants removed from the water in a rejection flow that must be treated. This means that to treat a certain amount of water, a part of the water that enters through this rejection stream must be discarded, this amount is called the rejection stream. This generates important problems in small municipalities that have few resources for the treatment of this polluted effluent, and that are also located in areas with a high deficit of precipitation and few available water resources.

As an alternative to these physical systems, biological technologies have emerged, particularly Granular Sequential Aerobic Systems.

The main advantage of these systems over the current reverse osmosis system installed in the area is the considerable energy savings. The EGW system consumes very little energy, so much so that it can be supplied using solar panels, further reducing operating costs.

The second advantage is the saving of water for the area, as it does not have a rejection stream, all the treated water can be used, without the need to discard any part of it. Therefore, it does not generate polluted effluents or any waste, being totally environmentally friendly. The only waste generated is the small amount of cleaning water from the filtration system, which is treated by means of an artificial wetland.

These characteristics mean that the system has zero greenhouse gas emissions if solar energy is used for its operation.

Figure 27: DWTP of Torre Cardela.

## 8.2. Conclusions.

The main conclusions that can be learned from this technology can be summarized as follows:

1) Through the implementation of the LIFE ECOGRANULARWATER technology, a solution is provided to various environmental problems related to the contamination of groundwater for human consumption.

2) A technology has been developed that is included in the line of LIFE projects, designed to solve environmental problems through the use of an economic method that is totally eco-friendly.

3) A biological technology has been developed that is easy to install in small communities with nitrate contamination problems.

4) The LIFE ECOGRANULARWATER technology permits the efficient nitrate removal from groundwater without significant waste production and can be powered by renewable energies, achieving the goal of zero greenhouse gas emissions.

5) The LIFE ECOGRANULARWATER technology provides considerable energy benefits, much greater than other physicochemical technologies such as reverse osmosis.

6) It is a highly versatile system, both in the case of the volume of water to be treated and in the case of the amount of nitrates in the water to be treated. In the first case, it allows us to install replicas of the bioreactors, depending on the volume of water to be treated. In the second case, by modifying the amount of organic matter and the duration of the operation cycles, we can treat influents with very different nitrate concentrations.


# 9. USEFUL INFORMATION

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## 9.2. Supplementary information.

- Provincial Council of Granada.
  **www.dipgra.es**
  Address: Periodista Barrios Talavera, 1, 18014 Granada.
  Telephone: 958 24 73 46.

- GEDAR. Gestión de Aguas y Residuos.
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- Instituto de investigación del Agua.
  **www.institutodelagua.es**
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- LIFE ECOGRANULARWATER Project website.
  **www.lifeecogranularwater.com**

This Guide is published as part of the Life ECOGRANULARWATER project, a demonstration project for the treatment of groundwater with an innovative system based on aerobic granular technology.

This project is based on the development of a novel biological technology for the elimination of nitrogen compounds in groundwater intended for human consumption.

*www.lifeecogranularwater.com*

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