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An integrated approach to the design and operation of low capacity sewage treatment works

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ABSTRACT

Low capacity sewage treatment works (STWs) serving small-scale urban areas make up approximately 80% of the total number of water works in Europe. There are many limitations to the attention and economic resources that management offices can allocate to these treatment facilities generally serving a population equivalent of less than 5,000. The adequate coordination and management of these works is often compromised due to the large quantity of plants and their distances from the head office. Consumers currently pay an average of €0.4/m³ according to what is measured in their water meter, which is bigger than the amount of waste water drained. This amount has to cover the cost of power, maintenance and operations, as well as other expenses for conservation and upgrading. In addition, STWs give rise to sludge that must be disposed of in compliance with a very specific legislation. Spreading sludge around the fields adjacent to the STWs has become a thing of the past; the general public no longer tolerates the use of sludge as a fertilizer due to the strong odour that is produced. Furthermore, there is an increasing concern about potential contamination from pathogens in the sludge. From a technical point of view, small STWs should involve an individual design approach based on a specific catchment assessment and its response to storm events. Due to the major differences between peak and low flow rates, there is a high risk of untreated effluent reaching public watercourses. This risk is greater during rainy seasons, even though, theoretically, these networks are independent. The aim of this article is to provide an integrated overview as a guide in the design of small STWs. The information and findings (both operational and economic) have been compiled from existing treatment works in the Spanish region of Navarra.

Keywords: Trickling filters; MBBR; IFAS; Sand filters; ATAD; SUDS; CSOs

1. Introduction

When we refer to small-scale sewage treatment works (STWs) we are thinking normally of those plants which serve less than 2,000 equivalent populations or with a daily influent that does not exceed 200 m³. The concept of a small-scale works could possibly disappear if it were feasible to employ the same treatment technology and technical, economic and human resources in small urban agglomerations even with fewer than 2,000 inhabitants, as is applied in large-scale facilities. However, in reality, small-scale works require a design and a specific operation that can maintain the cost of each m³ of treated water within the scope of the economical resources of the user and on a par with the quality levels achieved in larger works in urban populations. If we consider the population that benefits from the environmental improvements that stem from the works, it is simply unfair to expect that the inhabitants of a small township should pay in excess for something that is not exclusively profited by them. Generally, with few exceptions, it is reasonable to assume that the same cubic meter rate should

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apply to all the users that affect the same watercourse or geographical area, independently of the size of the residual water treatment plant. With the rates per m³ of residual water, current averages established by the various government authorities most of the works that serve fewer than 500 inhabitants have shortfall budgets. The cost of treating one m³ of water in a plant serving 250 inhabitants can be up to 5 times greater than that of a larger plant for the same degree of service.

The small water treatment plants referred to in this paper should be designed and operated to meet all the requirements set forth for general wastewater treatment works independently of their size:

1. The specifications of the treated water must meet all limitations set forth in the current legislation.
2. The works must be designed to incorporate emergency systems that prevent direct spillage to the watercourse and minimize the environmental impact in the event of accidents.
3. The treatment given to and the final disposal of sludge should be of the same quality standards as those of large-scale installations.

2. Specific characteristics of small wastewater treatment works

A basic parameter to consider when planning the design of a small-scale water treatment works is the high variation of the influent flow rate and the pollutants concentration of the incoming waste water. These peaking loadings are likely to occur when the community source is small and where the pattern of activity of individuals is similar.

With regard to rainwater, even in towns with separate sewer system, flow rates can increase sharply due to uncontrolled connections. This is easy to understand bearing in mind the low flow rate of waste water in such installations. For a town of 500 inhabitants, the average flow rate would be around 0.87 l/s, with a peak of 2 l/s and a minimum night rate of 0.3 l/s.

Another factor to underline is the distance between these small plants and the control and administration centres. Typically, when a small urban centre finds itself situated not very far from a reasonably-sized water treatment plant, the first alternative to be studied is the connection with the pipeline linked to the larger installation. Hence, it might be economically viable to build a new sewer or pumping station as opposed to the construction and operation of a new installation. In the case of Navarra it is not difficult to find sewer rising mains of over 10 km and even longer if the vulnerability of the watercourse and the environmental requirements so justify.

3. Economic aspects

Fig. 1 shows the variation in investment required per equivalent inhabitant for small plants generally with trickling filter. This graph covers waterworks for areas with a population equivalent between 180 and 77,000 inhabitants with comparable performance and characteristics.

Not taking into account amortization of the capital investment for the construction of the works, the highest expense in the Operation and Maintenance of a small water treatment works is personnel. Considering that a plant for 1,000 inhabitant equivalent, with a set rate of €0.4/m³ invoiced, generates a daily income of around €60 we get a clear idea of the serious limitation facing us.

Fig. 2 represents in the income and expenditure for the case of a STW with two persons (16 man-hours per day at €23/h) to attend the plant. The reason for having two persons instead of one is based exclusively on crite-

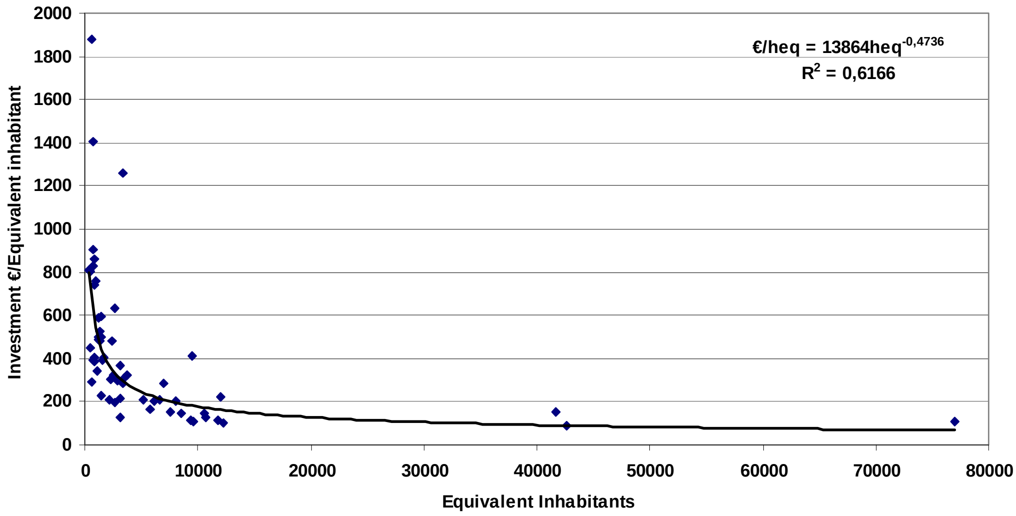

Fig. 1. Necessary investment to build a wastewater treatment plant (without interceptor cost).

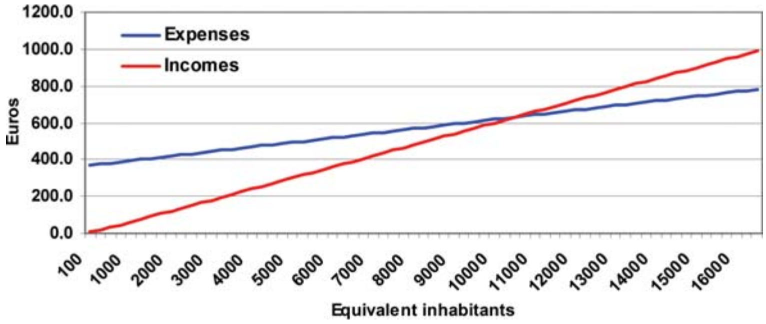

Fig. 2. Break-even point with 16 man-hours per day of operation and maintenance.

rion of safety at work. The economic balance is obtained with a plant size for a population equivalent of 8,500 inhabitants. Other expenses contemplated to obtain the graph are: 0.7 kWh/m^3 of influent, as well as the treatment and disposal of sludge (€147/ton of DM with a production of 40 g DM/inhabitant equivalent per day). Also contemplated is that once the sludge has been fully treated at the plant, it is then transported to an external compost station which entails an additional cost per ton of dry sludge in addition to the cost of transport. Indirect management costs are not taken into consideration here. The resulting breakdown of basic expenses is as follows: electricity 15%, sludge treatment almost 10% and human resources 75%.

If the calculation is inverted, the maximum personnel that can be afforded in a treatment plant for a population equivalent of 500 inhabitants is 4 man-h per week, which comes down to one 2-h visit per week. In this case, the total breakdown is as follows: electricity 21%, sludge treatment 38% and human resources 41%.

The energy cost, as can be seen, is especially important as the use of low energy systems would help towards a better break-even point and more diligent personnel in smaller plants.

4. Design criteria

In order to overcome the abovementioned limitations, the project should be conceived from the outset from a global perspective in the design of the plant. If all the small-scale plants were designed using the same parameters as large-scale plants, we would have a good plant but one which would call for excessive economic inputs which might lead to its partial neglect and underperformance.

Some of the points mentioned below could be of great interest in the case of undertaking a new design:

1. With a view to the “Water Framework Directive”, the first factor to consider is the required level of quality in the watercourse downstream and the assessment of the impact on said watercourse in the event of a breakdown.

   In view of the outline given above, thought must be given both to the elements required by the plant and the complementary safety systems to be adopted. In accordance with the overall design and the risk of non-compliance, it will be necessary to decide on what staffing and remote control devices will be required. The permissible flow rates in the biological system will depend on the existing pipe network characteristics and on the effects of the untreated effluent that is released into the river by combined sewer overflows (CSOs). The use of a drain pipe as an on-line storage tank that is equipped with suitable sections, gradient and control devices (vortex valves, throttles, orifice plates, etc) can help to laminate the increased flow of water during short severe storms. Fig. 3 shows the water lamination obtained in a storm drainage system with a diameter of 300 mm, a length of 1,000 m and a gradient of 0.5%, without any control measures and for a rainfall of 30 l/s Ha (EN 752-4) during a period of 1 hour and a contributing area of 1.5 ha. The flow rate is reduced from 11 l/s at the inlet to 5 l/s at the STW. With the aid of control systems, which allow for greater pipe filling, it would be possible to obtain enhanced lamination.

2. Another very important issue is the capacity of the biological system to absorb peak flow without causing damage. In this sense, biofilm-based systems fulfil these requirements with greater safety, unlike those based on suspended cultures which undergo intensive washing of solids and require a certain period for regeneration. For small plants in which it is only necessary to eliminate organic matter, and even a portion of nitrogen, the use of trickling filters is recommended. These systems absorb peak flows of over 8/1 without suffering any damage. The only requirement for these systems is a filter inflow pump that is regulated by a variable speed driver and controlled by an ultrasound system that adjusts the rate depending on the water level in the wet well. A further benefit that is derived from the trickling filter system is its lower power consumption, if you only wish to re-

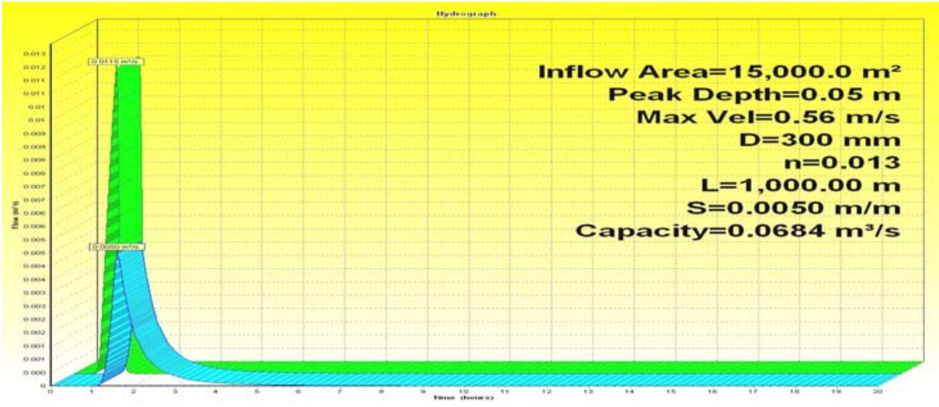

Fig. 3. Lamination in a 1,000 m storm draining system with a gradient of 0.5%.

move BOD. Fig. 4 shows the total cost per m^3 of trickling filter works, depending on their size. It is important to note that some of the works considered in the graph have a double stage system that can eliminate up to 70% of the total nitrogen content thanks to a high degree of internal recirculation.

The IFAS system is a very successful method to adopt if the regulations for the effluents into the river specify the removal of nutrients. This is a hybrid system that uses biofilms within plastic carriers (MBBR) that are shaken along with the sludge in suspension. Although the admissible flow rate range is not as broad as in systems based purely on biofilms, the sludge settling capacity and ability to operate with a broad range of mixed liquor suspended solids concentrations (MLSS) make this system a promising option for relatively small plants and which, given their sturdiness, require minimal human supervision. NILSA have experienced good operation with concentrations of MLSS between 600 and 8,000 g/m^3.

3. One important factor in reducing human resource requirements is the installation of inflow sieves that wash the retained residues. Without this feature, the residues would have to be collected practically every day to avoid the presence of odours and flies. With this washing feature in the sieve, one weekly collection is enough. For plants serving less than 500 inhabitants it is preferable to avoid the use of sieves and use instead an Imhoff tank at the inlet. This tank could receive both the primary and biological sludge. The inconvenience is that subsequently it is necessary to sieve the sludge at the destination treatment plant.

4. If the objectives involve the effective maintenance of a minimum level of quality of the effluent, then a double system with two biological reactors should be mandatory. The dual system arrangement may be varied, but with two complete mix reactors, higher efficiency is achieved if they are arranged in series rather than in parallel. If arranged in series, the first reactor can be dedicated to eliminating BOD and the second for nitrification. Should there be a breakdown in one of the reactors, then the other could partially treat all the influent.

A complementary design uses a series of pools at the end of the treatment line. Depending on the length of hydraulic residence, this design may be considered as a tertiary treatment or safety tank. Based on our experience, in the event of a weekend breakdown in a biological reactor, this arrangement (with a retention capacity of 2 or 3 days and a depth of 2 m) was capable of withholding the effluent in conformance with applicable standards. In practice, it has been demonstrated that the pools at the end of the line act not only as a dilution tank, but also as a biological reactor, eliminating a part of the organic pollution.

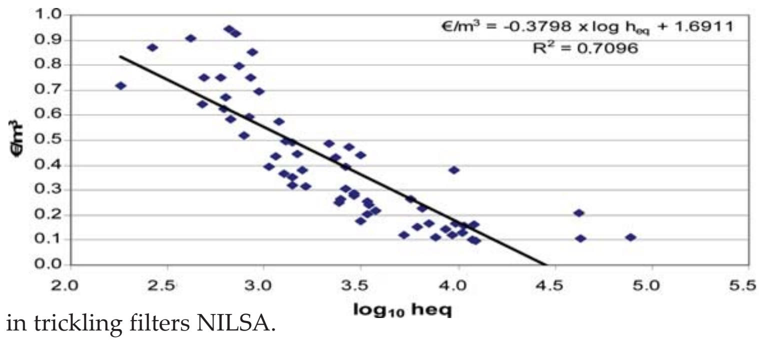

Fig. 4. Treatment expenses in trickling filters NILSA.

5. Installations for towns of less than 100 inhabitants, without special requirements, resorting to low technological level systems, is inevitable as with very little attention they ensure acceptable performance levels of organic load removal. Within this group of technologies we have successfully experimented with artificial wetlands, sand filters and trickling filters with single or double twin-tipping container distribution systems (Fig. 5). These lines include: primary Imhoff tank, and a trickling filter with or without a final Imhoff tank. In systems consisting of an Imhoff tank followed by this type of trickling system 80% efficiency is obtained in eliminating BOD_5. Efficiency can reach as high as 90% if at the outlet of the trickling system another Imhoff tank is included to retain any bio-solids. In the sand filters the greatest inconvenience is the uniform distribution of water over a large surface although this aspect can be compensated by a greater filter area per inhabitant equivalent. In the case of constructed wetlands the recommendation is that the width of the first wetland is sufficiently generous to avoid frequent obstructions of the aggregate front of the entry zone.
6. In cases which require not only BOD_5 elimination but also maximum concentration of coliforms downstream from the treatment plant's outlet because of bathing areas, an alternative that has given good results is the arrangement at the end of sufficiently large pools or, space not permitting, a sand filter with effective grain size of between 0.2 and 0.4 mm which eliminates approximately one unit of log10 in the concentration of faecal coliforms, for each 0.3 m thickness. This sand filter may be designed as a safety storage tank in case of breakdown in the plant or excess effluent flow which needs to be deviated (Fig. 6).
7. With regard to the management of sludge generated at small plants, one option which allows for an adequate level of treatment is its transfer to the nearest STW plant that has a sludge treatment system. In Navarra we opted for transporting the liquid sludge (between 4 and 8% DS) as fresh as possible, to avoid greenhouse gas emissions, in loads of 10 or 20 m^3 to plants offering thermophilic aerobic digestion (ATAD) treatment. The digested and sanitized sludge, once dewatered, is transferred to an external plant where, together with other animal origin waste, is composted packed and distributed. The average real cost of transporting the liquid sludge to the STW plants with sludge treatment is €0.071/ m^3 of wastewater.

Fig. 5. Double twin-tipping container distribution in a trickling system.

Fig. 6. Final sand filter with complementary safety volume in Roncal (Navarra).

5. Conclusions

To obtain an economic breakeven point in small size plants, a holistic view of the problem is inevitable. Apart from the overall administration of the water treatment plants of a region or of one single watercourse, which allows for a fair distribution of costs, it is necessary to add a meticulous design which facilitates reaching an adequate level of treatment, at a moderate price and independently of the distance to the management and control centres of the companies. The specific excesses in flow which are usual in these small plants must be combated with complementary installations in the plant, through the use of storage tanks or preferably going to the origin of the problem to eliminate the uncontrolled connections. Separating rainwater using sustainable draining systems (SUDS) which avoid the contribution of contaminating waters that runoff directly to the rivers, could be the most economic and efficient option.

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