SELECTING THE WASTEWATER TREATMENT ACCORDING TO SETTLEMENT SIZE

Marija Šperac[1*], Dino Obradović[1]

Faculty of Civil Engineering, Vladimira Preloga 3, Osijek 31000, Croatia

Abstract

The approach to the problem of wastewater treatment considering the size of the settlement is the following: settlements are grouped according to size - number of inhabitants, therefore it is a grouping according to the amount of water that settlements consume. The type of the wastewater treatment process is conceived in comparison to the size of the settlement. It will start from the large settlements (there are calculated settlements with over 20,000 inhabitants), followed by purification processes for smaller settlements (5,000 to 20,000 inhabitants), and at the end solutions for processes of wastewater treatment in small settlements (less than 5,000 inhabitants) will be considered. Wastewater from large settlements is usually processed in a centralized wastewater treatment plant. As for the treatment of wastewater from other settlements that we're not covering with an existing wastewater treatment plant, these settlements are using the following types: pre-treatment, primary treatment, secondary treatment, and tertiary treatment. For the group of the smallest settlements, up to 1,000 inhabitants, a solution for wastewater treatment in these settlements should be sought through the implementation of large septic tanks, combined with subsequent purification of effluents from such tanks, such as sand-gravel filters. Natural treatment systems are recommended for the treatment of wastewater from small settlements (less than 500 inhabitants).

Key words

alternative solutions; conventional approach; settlement size; wastewater treatment plant

To cite this paper: *Šperac, M., Obradović, D. (2016). Selecting the wastewater treatment according to settlement size, In conference proceedings of People, Buildings and Environment 2016, an international scientific conference, vol. 4, Luhačovice, Czech Republic, pp. 57-66, ISSN: 1805-6784.*

*Corresponding author: Tel.: +385-31-274-378, Fax: +385-31-274-444,
E-mail address: msperac@gfos.hr

1 INTRODUCTION

The principal objective of wastewater treatment is generally to allow human and industrial effluents to be disposed of without danger to human health or unacceptable damage to the natural environment. Irrigation with wastewater is both disposal and utilization and indeed is an effective form of wastewater disposal (as in slow-rate land treatment). [1]

Today, some developed and developing parts of the settlements/cities still have no built sewage system, and individual outlets into the road ditches resolve drainage, while some sewage is drained directly into watercourses. Such a solution does not meet today's needs and housing standards, or water protection.

Many cities and towns now have an incomplete drainage system (not covering the entire area of the city sewage system that would transport wastewater to water-processing plant); also, there is no water processing equipment for water treatment that would achieve necessary parameters for discharge of treated wastewater into the recipient (watercourse). The following table (Tab.1, Tab. 2.) shows the situation in the Republic of Croatia.

Tab. 1: Connection to sewage systems for the population of Croatia (2007) [2]

Settlement size	**The inhabitants**				
	Connected		**Not connected**		**Total**
Number of inhabitants	Number	%	Number	%	Number
< 2,000	111,717	6	1,640,828	94	1,752,545
2,000-10,000	267,602	37	455,883	63	723,485
10,000-50,000	501,527	74	172,036	26	673,563
>50,000	1,042,126	81	245,741	19	1,287,867
Total	1,922,972	43	2,514,488	57	4,437,460

Tab. 2: Number of settlements with sewage system with or without WWTP in Croatia (2007) [2]

Settlement size	**The settlements with sewage system**		
	With WWTP	**Without WWTP**	**Total**
Number of inhabitants	Number of settlements		
< 2,000	62	93	155
2,000-10,000	45	57	102
10,000-50,000	19	12	31
>50,000	5	2	7
Total	131	164	295

For these reasons, it is evident that for quality municipal drainage and wastewater treatment in towns and villages, as well as the achievement of higher standards for water protection, it is necessary to start construction of an integrated drainage system, and in particular devices for wastewater treatment.

Before discharge into the recipient, all the wastewater needs to be processed and purified. Selection of wastewater treatment type can depend on various criteria. One of the criteria is the size of the settlement or the amount of wastewater that needs purification. According to these criteria, settlements are classified into several groups and each group gets the best suitable type of processing device.

Selection of the wastewater treatment process is a complicated multi-criteria decision making process, which uncertainty, complexity and hierarchy are the most important in terms of its characteristics. In this paper, a practical approach is presented for selecting and weighing the wastewater treatment process problem based on the settlement size is population equivalent (p.e.).

Selection of an appropriate treatment process is an important issue before designing and implementing any wastewater treatment plant (WWTP). [3]

Technological progress allowed the realization of advanced wastewater treatment systems, which answer the very strict legislation imposed by EU (Directive no. 271 of 21st May 1991).

2 TYPE OF WASTEWATER TREATMENT PLANT

For the first group of settlements exceeding 20,000 population, we suggest conventional methods of water treatment and the Sequencing Batch Reactor.

Conventional Wastewater Treatment Process

Conventional wastewater treatment (shown in Fig. 1.) consists of a combination of physical, chemical, and biological processes and operations to remove solids, organic matter and, sometimes, nutrients from wastewater.

Although there are many variations of wastewater treatment plants, most will have the following steps: preliminary treatment, primary treatment, secondary treatment, tertiary treatment, disinfection, and solids handling. Each of these steps will be reviewed below.

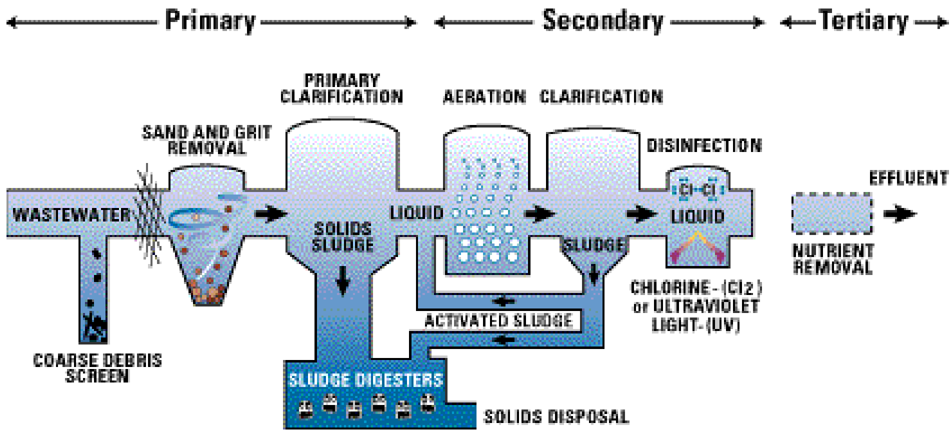

Fig. 1: Conventional Wastewater Treatment process

Preliminary treatment

Preliminary wastewater treatment ordinarily includes screening and grit removal. Wastewater screening removes coarse solids such as rags that would interfere with mechanical equipment. Grit removal separates heavy, inorganic, sandlike solids that would settle in channels and interfere with treatment processes [4].

Preliminary treatment serves to prepare wastewater for subsequent treatment, but it effects little change in wastewater quality. The residues from preliminary wastewater treatment, screenings and grit, are not ordinarily incorporated with sludges [4].

Primary

Primary wastewater treatment usually involves gravity sedimentation of screened, degritted wastewater to remove settleable solids; slightly more than one-half of the suspended solids ordinarily are removed. BOD in the form of solids removable by sedimentation (typically about one-third of total BOD) is also removed. At one time during the evolution of domestic wastewater treatment in the United States, facilities only practiced primary wastewater treatment and the primary effluent was commonly discharged to surface waters offering appreciable dilution. Now, primary treatment is used as an economical means for removing some contaminants prior to secondary treatment. The residue from primary treatment is a concentrated suspension of particles in water called "primary sludge".

Secondary

Secondary municipal wastewater treatment is almost always accomplished by using a biological treatment process. Microorganisms in suspension (in the "activated sludge" process), attached to media (in a "trickling filter" or one of its variations), or in ponds or other processes are used to remove biodegradable organic material. Part of the organic material is oxidized by the microorganisms to produce carbon dioxide and other end products, and the remainder provides the energy and materials needed to support the microorganism community. The microorganisms biologically flocculate to form settleable particles, and, following biological treatment, this excess biomass is separated in sedimentation tanks as a concentrated suspension called "secondary sludge" (also known as "biological sludge," "waste activated sludge," or "trickling filter humus").

Tertiary

Tertiary treatment is used at municipal wastewater treatment plants when receiving water conditions or other uses require higher quality effluent than that produced by secondary wastewater treatment. Disinfection for control of pathogenic microorganisms and viruses is the most common type of tertiary treatment. The concentrations of suspended solids and associated BOD in treated effluent can be reduced by filtration, sometimes with the aid of a coagulant. Adsorption, ordinarily on activated carbon, can be used to remove some persistent organic compounds and trace elements. The concentration of ammonia in secondary effluent can be reduced by nitrification. Tertiary treatment to remove nitrogen and phosphorus, so as to minimize nutrient enrichment of surface waters, is common; nitrogen is usually removed by nitrification followed by denitrification, and phosphorus is removed by microbial uptake or chemical precipitation. Not all tertiary treatment processes follow secondary treatment, nutrient removal, for example, can be achieved by design and operational variations to primary and secondary treatment processes. The residues from tertiary treatment typically become incorporated with sludges from primary and secondary treatment.

The example of conventional wastewater treatment plant in Zagreb, Croatia is shown in Fig. 2.

Fig. 2: Conventional wastewater treatment plant in Zagreb, Croatia

The Sequencing Batch Reactor (SBR)

The process involved in SBR is identical to the conventional activated sludge process. SBR is compact and time oriented system, and all the processes are carried out sequentially in the same tank. SBR is upgraded version of the conventional activated sludge process, and it is capable of removing nutrients from the wastewater.

The Sequencing Batch Reactor (SBR) is an activated sludge process designed to operate under non-steady state conditions. An SBR operates in a true batch mode with aeration and sludge settlement both occurring in the same tank. The major differences between SBR and conventional continuous-flow, activated sludge system is that the SBR tank carries out the functions of equalization aeration and sedimentation in a time sequence rather than in the conventional space sequence of continuous-flow systems. In addition, the SBR system can be designed with the ability to treat a wide range of influent volumes whereas the continuous system is based upon a fixed influent flowrate. Thus, there is a degree of flexibility associated with working in a time rather than in a space sequence [5].

Sequencing batch reactors operate by a cycle of periods consisting of fill, react, settle, decant, and idle. The duration, oxygen concentration, and mixing in these periods could be altered according to the needs of the particular treatment plant. Appropriate aeration and decanting is essential for the correct operations of these plants. The aerator should make the oxygen readily available to the microorganisms. The decanter should avoid the intake of floating matter from the tank. The many advantages offered by the SBR process justifies the recent increase in the implementation of this process in industrial and municipal wastewater treatment.

SBRs produce sludges with good settling properties providing the influent wastewater is admitted into the aeration in a controlled manner. Controls range from a simplified float and timer based system with a PLC to a PC based SCADA system with color graphics using either flow proportional aeration or dissolved oxygen controlled aeration to reduce aeration to reduce energy consumption and enhance the selective pressures for BOD, nutrient removal, and control of filaments [5]. An appropriately designed SBR process is a unique combination of equipment and software. Working with automated control reduces the number of operator skill and attention requirement.

The majority of the aeration equipment of sequencing batch reactors consist of jet, fine bubble, and coarse bubble aeration systems. The main focus of this report is a jet aerated sequencing batch reactor activated sludge system [6].

For towns of 5,000 to 20,000 populations, all types of WWTP (from conventional to natural depending on the settlement characteristics) are acceptable.

For towns of 5,000 to 1,000 populations, solutions should be sought in two directions: Sequencing Batch Reactor and procedures with immobilized micro flora, (i) bio-filtration or (ii) the so-called Rotating Biological Contactor.

For towns of 1,000 or less population, we recommend the use of large septic tanks and a natural wastewater treatment plant.

On-site septic tanks and leaching fields

In sparsely populated suburban or rural areas, it is usually not economical to build sewage collection systems and a centrally located treatment plant. Instead, a separate treatment and disposal system is provided for each home. On-site systems provide effective, low-cost, long-term solutions for wastewater disposal as long as they are properly designed, installed, and maintained. In the United States, about one-third of private homes make use of an on-site subsurface disposal system.

The most common type of on-site system includes a buried, watertight septic tank and a subsurface absorption field (also called a drain field or leaching field). The septic tank serves as a primary sedimentation and sludge storage chamber, removing most of the settleable and floating material from the influent wastewater. Although the sludge decomposes anaerobically, it eventually accumulates at the tank bottom and must be pumped out periodically (every 2 to 4 years). Floating solids and grease are trapped by a baffle at the tank outlet, and settled sewage flows out into the absorption field, through which it percolates downward into the ground. As it flows slowly through layers of soil, the settled wastewater is further treated and purified by both physical and biological processes before it reaches the water table.

An absorption field includes several perforated pipelines placed in long, shallow trenches filled with gravel. The pipes distribute the effluent over a sizable area as it seeps through the gravel and into the underlying layers of soil. If the disposal site is too small for a conventional leaching field, deeper seepage pits may be used instead of shallow trenches; seepage pits require less land area than leaching fields. Both leaching field trenches and seepage pits must be placed above seasonally high groundwater levels.

Imhoff tank

Imhoff tanks are used by small communities and due to the underground construction, land use is very limited. Investment costs are low and operation and maintenance simple. But the treatment efficiency is low and a secondary treatment of the effluent is required. Moreover, the tanks must be desludged regularly.

Natural wastewater treatment systems

Natural wastewater treatment systems are simple, cost-effective and efficient methods to purify the growing amount of wastewater produced by our society. They can be applied as secondary or tertiary purification treatment, allowing the removal of most of the bacteria, microorganism and the destruction of the organic matter. Among them phytodepuration, lagoon purification and storage in tanks gave good results in terms of yield and are quite diffused all over the world.

Their extreme simplicity in building, operation and maintenance make these systems competitive with the conventional (sewer) wastewater treatment methods [7].

Natural low-rate biological treatment systems are available for the treatment of organic wastewaters such as municipal sewage and tend to be lower in cost and less sophisticated in operation and maintenance. Although such processes tend to be land intensive by comparison with the conventional high-rate biological processes already described, they are often more effective in removing pathogens and do so reliably and continuously if properly designed and not overloaded. Among the natural biological treatment systems available, stabilization ponds and land treatment have been used widely around the world and a considerable record of experience and design practice has been documented. The nutrient film technique is a fairly recent development of the hydroponic plant growth system with application in the treatment and use of wastewater.

Constructed wetlands

Constructed wetlands (CWs) are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and the associated microbial assemblages to assist in treating wastewaters (see Fig. 3). They are designed to take advantage of many of the same processes that occur in natural wetlands, but do so within a more controlled environment. CWs for wastewater treatment may be classified according to the life form of the dominating macrophyte, into systems with free-floating, floating leaved, rooted emergent and submerged macrophytes [8]. Further division could be made according to the wetland hydrology (free water surface and subsurface systems) and subsurface flow CWs could be classified according to the flow direction (horizontal and vertical) [9].

Fig. 3: Horizontal CW in Vinogradci in Croatia

Constructed wetlands are artificial wastewater treatment systems consisting of shallow (usually less than 1 m deep) ponds or channels which have been planted with aquatic plants, and which rely upon natural microbial, biological, physical and chemical processes to treat wastewater.

Constructed wetlands have been used to treat a variety of wastewaters including urban runoff, municipal, industrial, agricultural and acid mine drainage. However, the scope of this manual is limited to constructed wetlands that are the major unit process in a system to treat municipal wastewater. While some degree of pre- or post-treatment will be required in conjunction with the wetland to treat wastewater to meet stream discharge or reuse requirements, the wetland will be the central treatment component [10].

The size of these systems ranges from small on-site units designed to treat the septic tank effluent from a single-family dwelling to 16,200 ha wetlands in South Florida for the treatment of phosphorus in agricultural stormwater drainage. These wetland systems are land intensive but offer a very effective biological treatment response in a passive manner so that mechanical equipment, energy, and skilled operator attention are minimized. Where suitable land is available at a reasonable cost, wetland systems can be a most cost-effective treatment alternative, while also providing enhanced habitat and recreational values [11].

Biolaguna

Biolaguna (see Fig. 4.) is the most modern method of treatment of municipal and industrial waste water, especially water supply lines and with varying concentrations. They can be used for secondary treatment or as a supplement to other processes. Lagoons remove biodegradable organic material and some of the nitrogen from wastewater [12].

They have the advantage of all the parameters by which they evaluate the efficiency of wastewater treatment water: low cost of construction, the highest level of treatment and the lowest operating costs. They are used for wastewater with mainly organic share of the load (e.g. for cities with a strong food industry – dairy, brewery, slaughterhouse) and the capacity 2,000-100,000 p.e. Process treatment lagoons are the low-loaded biological process with no refund or return of active sludge.

Fig. 4: Biolaguna in Ilok in Croatia

”I made aeration aeration chains” that provide good aeration mixing all parts of the lagoon. The lagoon sediment is deposited mineralized mud that draws only every 5 -10 years.

Biolaguna can be perfectly adapted to the specific requirements for the removal of nitrogen or phosphorus compounds.

Biolagunas are used mainly for sewage water treatment of individual households, groups of houses, municipalities, exceptionally up to 15,000 p.e., hotels, recreation facilities, restaurants, summer camps, small plants, agricultural and industrial wastewater treatment (especially the food industry), treatment of polluted surface water and treated wastewater.

3 CONCLUSION

Today there are many different types of wastewater treatment plants. There are many criteria that influence the selection of a wastewater treatment plant, such as: quality and quantity of wastewater, type of recipient, geographical characteristics, geological characteristics, socio-demographic structure, and economic possibilities. This paper is based on an analysis of just one criterion, and that is the size of a village. The grouping of settlements was largely done according to the situation in Croatia. There are no very large cities in Croatia, but there are a significant number of settlements with less than 500 inhabitants. Croatia has intensified the construction of wastewater treatment plants, especially because of legal obligations stating that in 2023 all settlements with 2,000 p.e. and more must have their wastewater treated prior to discharge into the recipient.

The predominant method of wastewater disposal in large cities and towns is discharging the wastewater into a body of surface water. Suburban and rural areas rely more on subsurface disposal. In either case, wastewater must be purified or treated to some degree in order to protect both public health and water quality. Wastewater treatment systems are generally capital-intensive and require expensive, specialised operators. The procedures of wastewater treatment are being developed around the world, and can be divided into conventional purification methods (which require significant financial investments) and economically acceptable unconventional methods of wastewater treatment [13].

REFERENCES

[1] Pescod, M. B. (1992). *Wastewater treatment and use of agriculture*. FAO. Rome, Italy. ISBN 92-5-103135-5

[2] Strategija upravljanja vodama. (2008). Narodne novine no. 91/08

[3] Karimi, A. R., Mehrdadi, N., Hashemian, S. J., Nabi Bidhendi, G. R., Tavakkoli-Moghaddam, R. (2011). Selection of wastewater treatment process based on the analytical hierarchy process and fuzzy analytical hierarchy process methods. *International Journal of Environmental Science and Technology*, **8**(2), pp. 267-280.

[4] Committee on the Use of Treated Municipal Wastewater Effluents and Sludge in the Production of Crops for Human Consumption, Commission on Geosciences, Environment and Resources, Division on Earth and Life Studies, National Research Council. (1996). Use of Reclaimed Water and Sludge in Food Crop Production. National academy press. Washington, D.C. ISBN 0-309-05479-6

[5] Norcross, K.L. (1992). Sequencing Batch Reactors-An Overview. *Water Science and Technology*. **26**(9-11), pp. 2523-2526.

[6] Chambers, B. (1993). Batch Operated Activated Sludge Plant for Production of High Effluent Quality at Small Works. *Water Science and Technology*. **28**(10), pp. 251-258.

[7] Fabrizi, L. (2016). Natural treatment of wastewater. Available at: http://www.lenntech.com/natural-wastewater-treatment.htm (accessed 20 May 2016).

[8] Vymazal, J. (2010). Constructed Wetlands for Wastewater Treatment. *Water*. 2, pp. 530-549.

[9] Borkar, R.P., Mahatme, P.S. (2015). Tidal Flow Constructed Wetland: An Overview. *International Journal of Engineering and Science*. **5**(10), pp. 31-34.

[10] U.S. EPA. (2010). Constructed Wetlands Treatment of Municipal Wastewaters. Manual. EPA/625/R-99/010. US Environmental Protection Agency: Cincinnati, Ohio, USA

[11] Crites, R.W., Middlebrooks, J., Reed, S.C. (2006). *Natural Wastewater Treatment Systems*, Taylor and Francis Group, Boca Raton. ISBN 0-8493-3804-2

[12] U.S. EPA. (2004). Primer for Municipal Wastewater Tretament Systems. EPA 832-R-04-001. US Environmental Protection Agency: Washington, D.C.

[13] Šperac, M., Kaluđer J., Šreng, Ž. (2013). Constructed wetlands for wastewater treatment. *e-gfos*. 7, pp. 76-86. http://dx.doi.org/10.13167/2013.7.8