WASTE WATER TREATMENT IMPROVEMENT AND EFFICIENCY IN SMALL COMMUNITIES

LIFE ENVIRONMENT DG
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SHORT GUIDE TO IMPROVE SMALL WWTP EFFICIENCY

DELIVERABLE TASK 7

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1. Introduction

This document aims to support the Small Wastewater Treatment Managers in their decisions concerning the actions to take for technical improvement of their plants, taking in account the strategy adopted to WWTREAT project development and constraints. This Short Guide to Improve Small WWT Efficiency has several chapters of Handbook on Evaluation and Operation of WWTPs, where additional chapters were included describing in more detail, the existing knowledge related to this engineering science.

Urban waste water, commonly referred to as sewage, is generally a mixture of domestic wastewater from baths, sinks, washing machines and toilets, wastewater from industry and rainwater run-off from roads and other surfaced areas. Without suitable treatment, the waste water we produce every day would damage the water environment and create public health problems.

The main wastewater directive is the Urban Wastewater Treatment (UWWTD) – Council Directive 91/271/EEC. The Urban Wastewater Treatment Directive (91/271/EEC) is concerned with the collection, treatment and discharge of urban wastewater and the treatment and discharge of wastewater from certain industrial sectors.

“Due to their volume, discharges of urban waste water are the second most serious cause of the pollution of waters by eutrophication. The Urban Wastewater Treatment Directive seeks to harmonise measures relating to the treatment of such waters at Community level.”

Literature review, an assessment of existing technology being used in 4 EU countries and the audit of 5 small WWTPs across Europe identified several problems faced by WWTPs in small communities that are common for worldwide small level. The problems range from assets to operational or administrative issues.

Size: WWTPs in small communities by nature of their purpose and design have small footprint and small associated land. This makes redevelopment and expansion of the plant (if required) difficult.

Operational Capacity: The design capacity of several WWTPs in small communities is significantly less than 10,000 p.e. As the population in the area increase, the operation capacity of the plant is increased. The increase in operational capacity does not involve an increase in investment. The plant can therefore be easily stretched beyond its limit. In Northern Ireland, 20% of the WWTPs have a design capacity of less than 10,000 p.e., that is small community WWTP. 75% of the small WWTPs have an operational capacity that exceeds the design capacity. In some cases, the operational capacity is as much 3 times the design capacity.

The increase in the operational capacity with no change in the design or operational processes of the plant can result in a decrease in the effluent quality.

Technology: Most small wastewater treatment facilities apply no more than secondary treatment process to the wastewater. This usually involves relatively low technology or basic treatment processes. Where the plant is discharging to a sensitive are tertiary treatment may be applied. A survey of small WWTPs in some European countries showed that the most common processes are sedimentation (primary treatment) followed by a biological filter or Biodisk (Rotating Biological Contactor). Processes are adequate if all design parameters are the same. However, they are basic and can be affected by a change in operational parameters.

Lack of Automated / Online monitoring: Treatment processes in many small WWTPs do not usually possess automated instrumentation or telemetric system. These plants are manned by operators, who regulate and control the treatment process i.e. clean the pre-treatment screen, remove debris, monitor equipment, manually spread sludge to dry. The downside to this routine is that, should there be a problem like flooding or malfunctioning of equipment at the plant whilst the operator is off duty, the problem cannot be dealt with as immediately.

Discharge Requirement: In order to ensure and improve the quality of receiving waters, recent legislation requires increasingly more stringent effluent quality standards. Many small WWTPs are poorly maintained or maintenance is basic therefore are at risk of not complying with the required effluent quality standards.

Other generic problems that affect small WWTPs includes:

a) A greater **diurnal variation in sewage loading** and flow resulting over or under loading of the plant..
b) Lack of combined sewer overflows causing higher intensity storm flows.
c) Fluctuation in the influent quality such as sudden high ammonia, suspended solids and BOD levels
d) Excess grease and fibrous debris resulting in blockage in the plant.
e) Smaller plants are more susceptible to **short circuiting**.

In general terms the small plants are centralized units receiving the influent of communities until a **maximum of 5000 equivalent inhabitants**, in rural or suburban areas with reduced expression of industrial activities. In these cases the companies have their specific treatment plants instead of direct connections for the public municipal sewer network feeding the small wastewater treatment plants, e.g. of a pharmaceutical laboratory in Vila Verde.

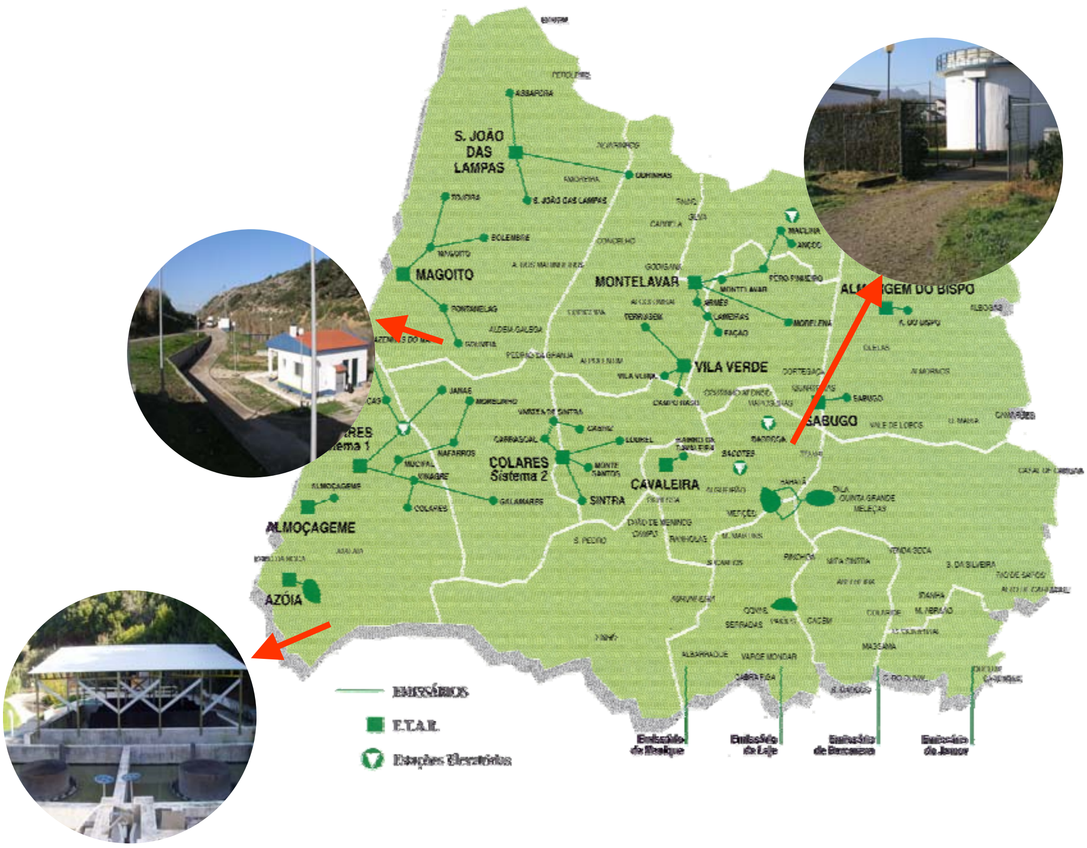
Once the urban growth in suburban areas was not due planed and many houses are a second residence for weekends and summertime, especially in Magoito close to sea cost, the construction of sewer network was urgency and considering the high costs of infrastructures in many points the rainfall and wastewater collectors are not separated. This situation induces a problematic management of plant inlet flows during rain periods since the plants have not storm tanks to assume the role of flow buffers.

Another problem detected and influencing the plant inlet flow is the connection of house rain drains to the municipal wastewater collection system. Recently the Sintra Water Utility (SMAS de Sintra) got a mobile unit equipped with a remote camera to inspect the network piping condition used also in the detection of incorrect connections.

In these cases the house owners are notified to correct the connections separating sewer and rain water.

Finally in few situations during night and rainfall periods were detected illegal deliveries of animal production farms wastewater in the public network. It is supposed that the delivery is made using the inspection covers of collector in zones out of villages. The Sintra small plants have operators keeping watch during the 8 hours normal working period, which means they remained without direct control during 16 hours per day.

Fig. 1 – Geographic location of Sintra WWT Plants



As consequence during night the plant failures, illegal wastewater pollution discharges, blackouts and storm high flows had originated a rupture or reduction of wastewater treatment. These treatment weaknesses were causes of green movements activists especially concerning the accidental cases of pollution in the Magoito Beach and interdiction of sea baths by health authorities, during a short period. Fortunately the sea baths pollution occurred out of season and did not put in risk the Blue Flag.

Fig. 2 – Magoito WWT Plant located in neighboring of Atlantic Coast

In beginning of project implementation the SMAS de Sintra promoted a workshop to press, elected authorities and general public, to present the project goals as a way to definitively solve the referred beach pollution problems.

Five 5 WWTP serving a population of 5,000 or less were selected for audit in Portugal (Vila Verde, Almoçageme and Magoito plants), Hungary (Révfülöp plant) and Northern Ireland (Moira plant). The upgrading was implemented only in the Portuguese plants, other partner's States plants were selected in order to get an overview of situation of small community's wastewater treatment plants, identifying technological solutions and performances. Additionally the project developed a bench size portable treatment plant to fit in parallel with each project plant in order to compare and set up them to the optimal operation.

The online monitoring was the priority and main reason for LIFE WWTREAT project implementation that can be replicated in identical small communities' wastewater treatment plants without continuous monitoring online system, anywhere they are located.

The project developed a methodology to achieve a balanced efficient monitoring solution at low cost that will be adopted in other small plants, integrating the water monitoring system centralized in SMAS de Sintra head office. The solution included an upgrading of sensing system, in each plant, related to the main wastewater physic-chemical treatment parameters, an acquisition and data processing system for on distance data transmission that provides the operation condition's access of authorized persons through a conventional PC. The public information data are available to any interested person.

2. Technologies applied in wastewater treatment

The next table resumes the correlation between wastewater stage of treatment and process as defined by EU.

Table 1. Stage and process of wastewater treatment

Sewage from domestic, commercial, municipal properties and certain industries is conveyed by sewer to sewage works/ wastewater treatment facilities		
Stage of Treatment	**Process**	**Discharge Area**
Preliminary	**Screening of large solids** **Grit removal by flow attenuation**	Appropriate treatment for discharge to: Fresh and estuarine waters <2,000pe; Coastal waters <10,000pe Applicable to any treatment stage - preliminary treatment to tertiary treatment, depending on water use and associated standards
Primary	**Settlement of suspended solids**	*Less Sensitive Areas* discharges: between 2,000 and 10,000pe to estuaries; >10,000pe to coastal waters
Secondary	**Biological treatment** (bacterial breakdown) (a) activated sludge process (aerated agitated liquor); (b) filter beds (sewage trickled over coarse aggregate coated with bacteria)	*Normal areas* discharges: >2,000pe to fresh and estuarine waters; >10,000pe to coastal waters
Tertiary	Various types of tertiary treatment exist and are applied, in combination if needed, to meet requirements for receiving waters phosphorus and/or nitrate reduction; disinfection by UV or filter membranes	*Sensitive Areas* discharges: >10,000pe (direct or indirect) contributing to the pollution of Sensitive Area
	Sewage sludge produced from various stages of treatment process	Agricultural Land (52%) Incineration (21%) Landfill (17%) Other (10%)

In the following paragraphs are detailed some of the most frequent WWT processes applied to treat the wastewater of small and medium populations, especially extensive techniques and also a brief overview over intensive techniques.

2.1. Traditional intensive techniques

The most developed techniques at the level of the urban treatment plants are intensive biological processes. The principle with these processes is to operate on a reduced surface area and to intensify the phenomena of the transformation and destruction of organic matter that can be observed naturally.

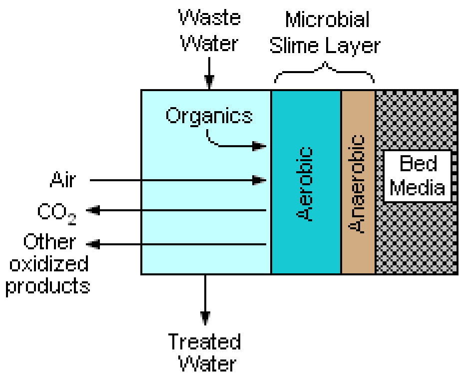
Three main types of processes are used:

- Biological filters and rotating biological contactors;
- Activated sludge;
- Enhanced biological filtering or biofiltering techniques.

2.1.1 Biological filters

The operating principle of a biological filter (also called biofilter, trickling filter or bacteria bed) consists in running waste water that has been previously settled through a bed of porous stone or open plastic material that serves as a support for purifying micro-organisms (bacteria).

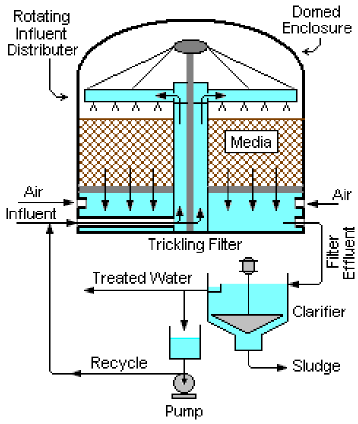
Fig. 4 – Trickling filter schematic diagram



Source: Wikimedia Commons - Milton Beychok

Aeration is carried out either by natural aspiration or by forced ventilation. It is a question of supplying the oxygen that is necessary for maintaining aerobic bacteria in proper working order.

Fig. 5 – Trickling filter – enclosed type



Source: Wikimedia Commons

The polluting matter contained in the water and the oxygen in the air are diffused, through the biological film, and assimilated by micro-organisms. The biological film has aerobic bacteria on the surface and anaerobic bacteria near the support media. By-products and carbon dioxide produced by purification are disposed of in gaseous and liquid fluids (Satin M., Belmi S, 1999).

2.1.2 Rotating biological contactors (biodisks)

Another technique that makes use of fixed cultures consists of rotating biological disks. This equipment is based in the biological contact between the aerobic bacteria film deposed in surface of blades, fitted in parallel and fixed in a rotating shaft, and the wastewater flow.

Fig. 6 – Biological film in the biodisk blades

Micro-organisms develop and form a purifying biological film on the surface of the disks. As the disks are partially immersed, their rotation allows the fixed biomass film to be oxygenated.

Fig. 7 – Biodisks in Vila Verde and Almoçageme Plants

With this type of installation, the following are necessary the mechanical reliability of the frame (gradual starting of the drive, support properly attached to the axis) and the sizing of the surface of the disks (this must be made with large safety margins).

Wastewater temperatures below 13°C will result in a reduction of biological activity and in a decrease in BOD removal. Temperature corrections shall be made using the appropriate manufacturer’s correction factors for installation where the wastewater temperature is expected to fall below13°C.

Effects of temperature should be examined in cases where the detention time of wastewater preceding the Rotating BC unit is excessive resulting in heat loss or in cases where pre-treatment tanks are susceptible to ambient temperatures. In such cases provisions to heat the wastewater may be necessary in order to obtain an efficient treatment.

Floats and alarms must be provided in the bucket feed well if preceded by a pump station. Any pumping to a bucket feed well shall be designed as to prevent the need for an overflow pipe.

The tank configuration shall be shaped to conform to the general shape of the media to eliminate dead spots where solids could settle and cause septic conditions and odors. Under drains or another means of removal of solids, which may settle out in the tank, must be provided.

All RBC units shall be enclosed in a building. If the RBC unit is proposed to be enclosed within a fiberglass cover located outside a building then sufficient heating and ventilation must be provided.

Fig. 8 – Biodisks enclosed and assembled in a building

Treatability of wastewater is dependent on the pH level and the alkalinity especially when dealing with nitrification. Provisions must be included for at the head of the RBC unit(s) for chemical addition for controlling pH and alkalinity.

RBC units shall be equipped with the necessary motor drive assembly and bearings or transmission chains to obtain a constant rotation of the shaft and media sufficient to maintain a peripheral speed of at least 18.3 m/minute.

Taking in account the high inertia and rotating mass the equipment must be provided with an adequate electric/electronic control, during the switch on or running when the biofilm thickness is excessive, or yet when the bearings or chain are broken.

2.2 Activated sludge – extended aeration

The activated sludge process and its various modifications have proven to be an effective treatment technology. It should be noted; however, that these processes require close attention and competent operating supervision, including routine laboratory control. These requirements should be considered when proposing these treatment processes.

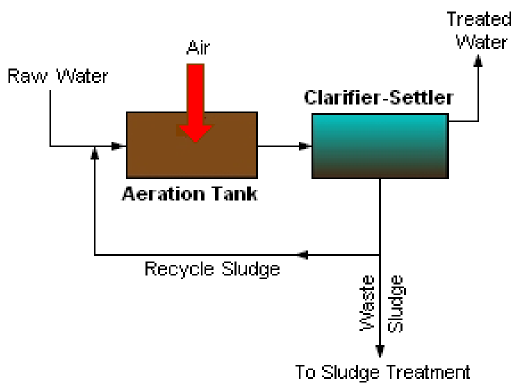
A number of modifications of the activated sludge process have been developed, some of which are referred to herein. To allow for proper responses to varying plant loading and process demands, aeration tanks should, wherever possible, have the capability to change mode of operation from plug flow, to step feed, to contact stabilization.

The "activated sludge" process consists of mixing and stirring raw sewage with recycled activated sludge, which is bacteriologically very active. Aerobic degradation of the pollution takes place by thoroughly mixing the purifying micro-organisms and the influent to be treated. Then, the "purified water" and "purifying sludge" phases are separated (Agences de l'Eau , 1999).

In the small plants the dimensions of each independent mixed liquor aeration tank or return sludge reaeration tank shall be such as to maintain effective mixing and utilization of air. Ordinarily, liquid depths should not be less than 1.82 m.

Tank geometry may affect aeration efficiency especially if diffused air is employed.

Fig. 9 – Activated sludge schematic diagram (Source: Wikimedia)



A treatment plant of this type includes the following steps:

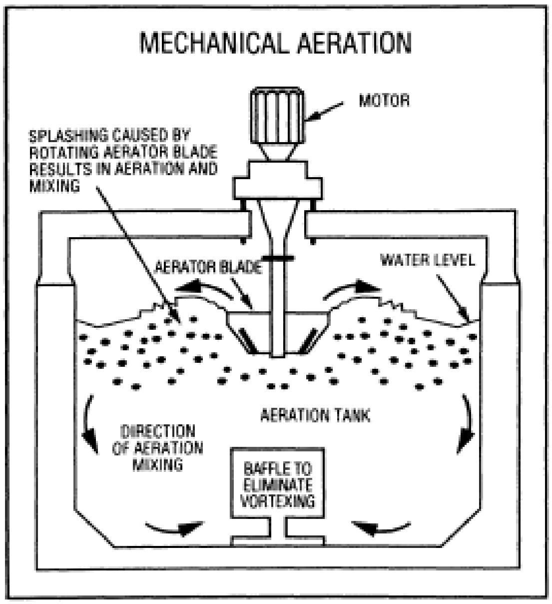
- Preliminary and, sometimes, primary treatment;
- Activation basin (or aeration basin);

- Secondary settlement tank where a part of the sludge is re-cycled;
- Disposal of treated water;
- Digestion of excess sludge coming from the settlement tanks

Fig. 10 – Activated sludge aerobic tank (in Magoito Plant)

Aeration equipment shall be capable of maintaining a minimum of 2.0 mg/l of dissolved oxygen in the mixed liquor at all times and providing thorough mixing of the mixed liquor.

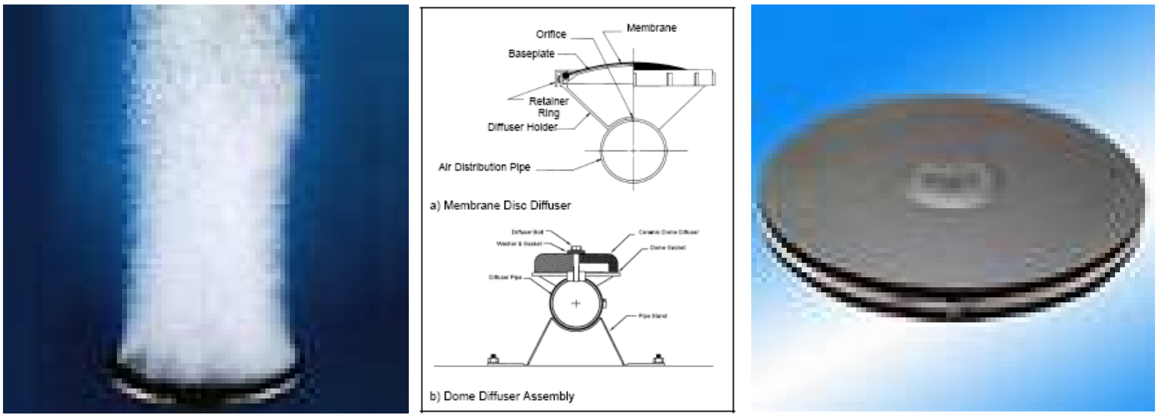
Fig. 11 – Mechanical aeration (Source: NY ERDA)



A separate means of mixing and aeration shall be employed utilizing any combination of mechanical aerators, coarse air or fine bubble diffusers, and anoxic mixers so that so that aeration can be adjusted independently without affecting mixing characteristics.

Fig. 12 – Air bubble in aerobic tank (Source: Aeration Solutions Inc.)

Fig. 13 - Fine bubble diffusers

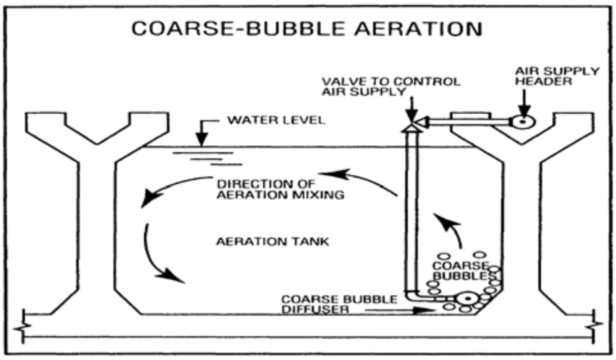


All aeration systems try to dissolve oxygen into the wastewater by creating bubbles that contain oxygen. As the bubbles move through the water, air and oxygen will diffuse into the bulk liquid by transferring across the bubbles surface.

Membrane media is the determining component of a diffuser. It controls the operating and long term performance capabilities of the diffuser, allowing operation at a reasonable head loss and release of fine, discrete gas bubbles. Proper membrane material selection is critical in achieving desired results. Polymeric compounds are selected and engineered to produce desired surface properties, material stability, as well as environmental and chemical resistance.

Course bubble static tubes create bubbles by pushing air through a series of baffles that break up the air flow into bubbles. The bubbles are then ejected into the water at the top of the tubes. From this point, they flow upward to the aerobic tank surface. Along this critical path, the air in the bubbles must diffuse into wastewater liquid. Once the bubbles reach the ponds surface, it will be too late to transfer oxygen and all of the remaining air will be lost to the atmosphere.

Fig. 14 - Coarse bubble tube diffusers



(Source: NYERDA)

(Source: Environmental Dynamics Inc.)

The importance of the return of activated sludge (RAS) is to maintain a sufficient concentration of activated sludge in the aeration tank so that the required degree of treatment can be obtained in the time interval desired.

The configuration of the piping from the secondary clarifier to the aeration basin is dependent upon the type of activated process: conventional plug-flow, step-feed aeration, or extended aeration. Ample return sludge pump capacity shall be provided. Return sludge pumping capacities of 50 to 150 percent of the wastewater flow rate are required.

The excess activated sludge produced each day must be wasted to maintain a given food-to-microorganism ratio or mean cell residence time. The waste sludge may be discharged to a dedicated sludge holding tank or to the primary settling tank.

Treatability of wastewater is dependent on the pH level and the alkalinity especially when dealing with nitrification. Provisions must be included for chemical addition for pH and alkalinity control throughout the aeration tank.

The aeration equipment should be sized to maintain minimum DO levels of 2 mg/l under maximum organic and nitrogen loadings or mixing requirements, whichever governs.

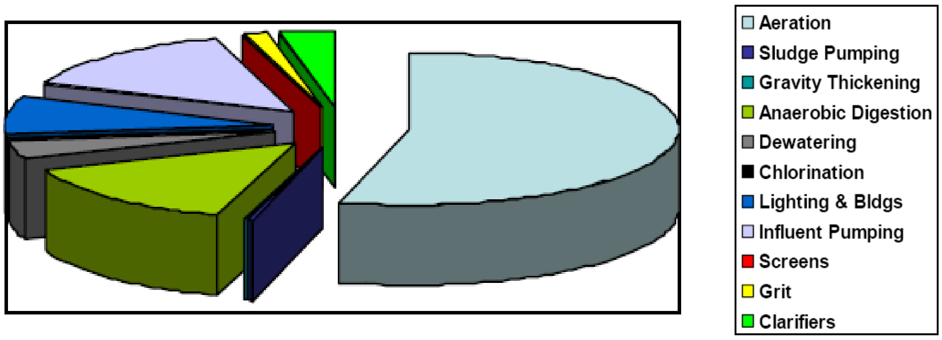
The air requirements assume equipment capable of transferring at least 1,0 kg of oxygen to the mixed liquor per kilogram of BOD5 aeration tank loading and, when nitrification is required, 4.2 kg of oxygen per kilogram of ammonia nitrogen oxidized. The specified capacity of blowers or air compressors should take into account that the air intake temperature may reach 40°C or higher and the pressure may be less than normal.

The air diffusion piping and diffuser system shall be capable of supplying peak diurnal oxygen demand or 200 percent of the normal air requirements, whichever is larger. The spacing of diffusers should be in accordance with the oxygenation requirements through the length of the channel or tank, and should be designed to facilitate adjustments of their spacing without major revision to air header piping.

The aeration technology used at the facility is paramount as aeration is the most energy intensive operation in the plant. The requirement for aeration increases even more when aerobic digestion is used, as shown in the next pie diagram.

Fig. 15 - Electricity Requirements for Activated Sludge

(Source: Environmental Dynamics Inc.)



The design and maintenance of aeration system in the wastewater treatment plants is a critical topic in the exploitation costs, this fact requires must take in account by the managers.

2.3 Conventional and non-conventional wastewater treatment technologies comparison

Table 2 – Types of Treatment Removal Efficiency (Source:USEPA)

Process	Oxygen Supply	Reactor Volume	Retention Time	Removal Efficiency
Activated sludge	Pressurized air	10 m^3	4-6 hr	90%-95% organic matter 90%-95% suspended solids
Biologic rotary discs	Air	1 m^3	1-3 hr	90%-95% organic matter
Ascendant flow	Anaerobic	2 m^3	24 hr	50%-60% organic matter 57% suspended solids
Anaerobic filtration	Anaerobic	2 m^3	36 hr	40%-50% organic matter 52% suspended solids
Septic tank	Anaerobic	2 m^3	36 hr	25% organic matter
Hydroponic cultivation	Aerobic/anaerobic	6 m^3	12 hr	65%-75% organic matter

Table 3 - Advantages and Disadvantages of Conventional and Non-conventional Wastewater Treatment Technologies (Source: USEPA)

Treatment Type	Advantages	Disadvantages
Aquatic Systems		
Stabilization lagoons	Low capital cost Low operation and maintenance costs Low technical manpower requirement	Requires a large area of land May produce undesirable odors
Aerated lagoons	Requires relatively little land area Produces few undesirable odors	Requires mechanical devices to aerate the basins Produces effluents with a high suspended solids concentration
Terrestrial Systems		
Septic tanks	Can be used by individual households Easy to operate and maintain Can be built in rural areas	Provides a low treatment efficiency Must be pumped occasionally Requires a landfill for periodic disposal of sludge and septage
Constructed wetlands	Removes up to 70% of solids and bacteria Minimal capital cost Low operation and maintenance requirements and costs	Remains largely experimental Requires periodic removal of excess plant material Best used in areas where suitable native plants are available
Mechanical Systems		
Filtration systems	Minimal land requirements; can be used for household-scale treatment Relatively low cost Easy to operate	Requires mechanical devices
Vertical biological reactors	Highly efficient treatment method Requires little land area Applicable to small communities for local-scale treatment and to big cities for regional-scale treatment	High cost Complex technology Requires technically skilled manpower for operation and maintenance Needs spare-parts-availability Has a high energy requirement

Activated sludge	**Highly efficient treatment method Requires little land area Applicable to small communities for local-scale treatment and to big cities for regional-scale treatment**	**High cost Requires sludge disposal area (sludge is usually land-spread) Requires technically skilled manpower for operation and maintenance**

Source: Ernesto Pérez, P.E., Technology Transfer Chief, Water Management Division, USEPA Region IV, Atlanta, Georgia.

2.4 Sludge and WWT Effluent Treatment, Disposal and Reuse

It is known that solid and semi-solid waste generated in human activities of today's societies cause severe environmental problems around the Globe. These wastes may come from waste water treatment plants (WWTPs), domestic activity, commercial, service or industries, originating the urban, agricultural and industrial solid wastes. The reduction in the production of these wastes may occur in several scenarios that vary from prevention to recovery of valuable products and final deposition.

The optimisation of the administration of these wastes depends on many factors: origin, quantity, composition, region of production, season of production, available technology for treatment and/or valorisation, treatment costs, deposition costs availability of human resources adequate to technological demands; environmental policy of the region; public acceptance of the proposed solution at a local and regional level.

The management of sludge originated from waste water treatment is an extremely complex activity, and many times also very expensive. If done in an inappropriate manner it can compromise the environmental and sanitary benefits that may be obtained by implementing treatment systems.

The final destiny of WWTP sludge constitutes a fundamental look for the success of a treatment system. The evaluation of alternatives for treatment and final destination of sludge is complex, since it involves technical, economical, environmental and legal aspects that go beyond the limits of the treatment plants.

Although the selection of sludge final destination is a complex process and, many times costly, it became neglected in the conception of the treatment systems. It is common to find WWTPs that were conceived and projected without particular concern about adequate sludge management, opting to concentrate their efforts in the treatment of the liquid stage. This situation leads to the fact that frequently, management of WWTP sludge by operator is carried out without planning, involving high costs, operational setbacks and, many times, generating environmental impacts that compromise the benefits of investment in treatment systems.

WWTP sludges have a complex composition, containing more or less high levels of organic matter and several nutrients that may become valuable if used in agriculture.

Furthermore, sludges contain several contaminants (heavy metals, pesticides, detergents, etc.), pathogenic organisms (virus, protozoa, bacteria and fungus) and organic compounds, that may potentially cause strong odours, attract animals (insects, rodents) and, depending on its concentration, may present greater or smaller risk of environmental pollution.

Sludges that come from urban waste water treatment, when properly treated and typified to form a set of quality waste, are named biosolids. In order to adopt this term, biosolid, it is mandatory that the sludges have certain chemical and biological characteristics compatible with a beneficial utilization, like for instance, in the agriculture.

Fig. 16 Wastewater treatment plant with a sludge system

The term biosolid is a way of enhancing its beneficial aspects as opposed to a mere unproductive final deposition, such as landfill deposition or incineration.

Sludge is an inevitable product of waste water treatment, coming essentially from the accumulation of the products in suspensions in residual affluent residual waters, generally transformed by the action of micro-organisms during the treatment.

Sludge is collected at different stages of the wastewater treatment process. In conventional treatment stations, sludges come from the primary decantation operation and from secondary and tertiary processes. In many cases sludges are obtained in a mixed form, (primary sludges combined with secondary sludges) in the primary decanter. In other situations, sludges are separated into different decanters and only afterwards processed in common. Normally, sludges generated in the tertiary treatment are in low quantity, except when chemical precipitation is involved for phosphorous removal.

The next pictures summarize the alternatives of biological process of sludge production until to obtain a stabilized byproduct for different uses, also are presented some chemical and thermal process in order to assure a sludge better stabilization and sterilization for specific applications.

Fig. 17 Biological processes of sludge production in WWT plants

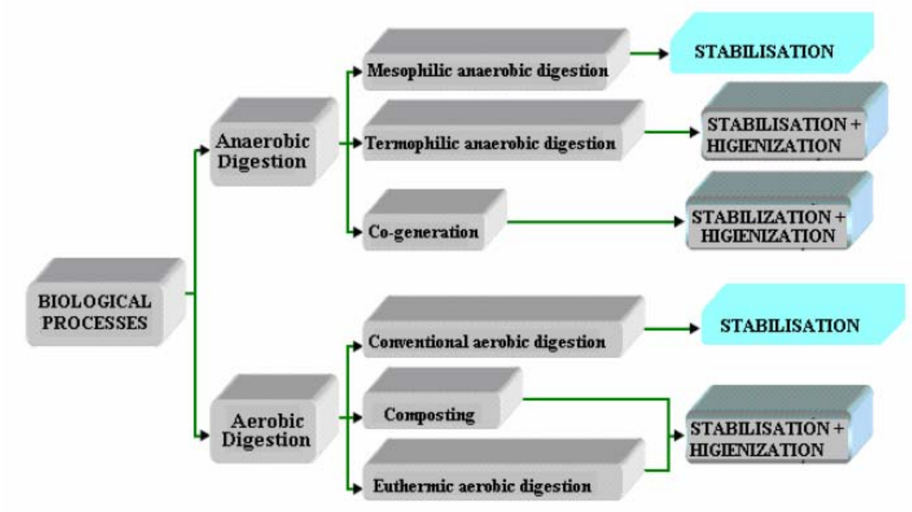
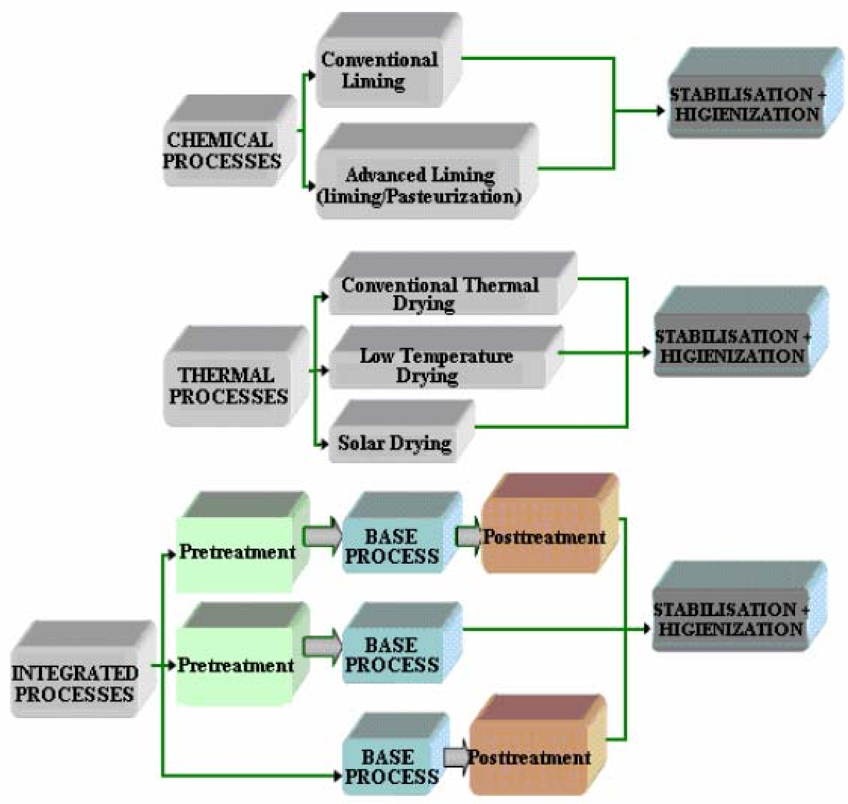


Fig. 18 Sludge treatment to improve the stabilization and higienisation

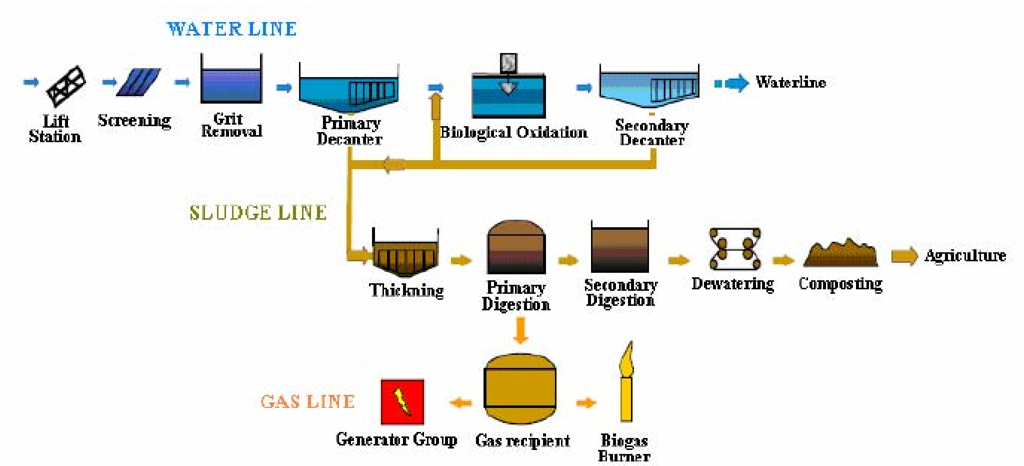


The first sludge composting plant working in Portugal is placed in Maia, in the north of the country, producing an average of 8 to 10 tons of compound per day. The Parada Sludge Composting Station is a complementary station of a whole of

WWTPs (Cambados – Vila Nova da Telha; Parada – Águas Santas; e Ponte de Moreira – Moreira). This station constitutes a pioneer project at a national level, and owns:

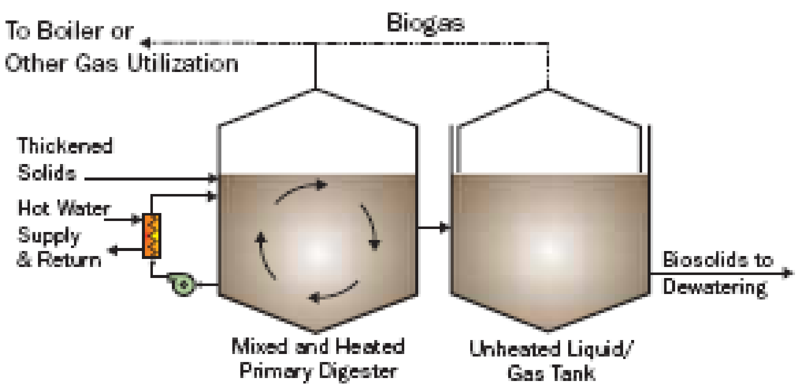
1 – Utilization of Biogas produced by sludge digestion, as burning fluid in the boilers of hot water production or in the anaerobic digestion of sludge for electricity production.
2 – Recovery of sludges produced in WWTPs in order to produce natural organic fertilizer, by the composting process, which assures the improvement of physical-chemical and biologic reactions in the soils where they are deposited. These sludges are easily directed to gardening and agriculture.

Fig. 19 Functional scheme of Parada plant



The waste waters affluent to the station are subjected to a secondary level type of treatment, through a biologic process of medium charge activated sludge.

Fig. 20-Aaerobic digestion system (Source: Water Environment Federation)



There are two types of anaerobic digestion: mesophilic and thermophilic. Mesophilic digestion uses bacteria that are active at body temperature (35-37°C). Thermophilic digestion uses bacteria that are active at considerably higher temperatures (50-57°C). Mesophilic is the more prevalent type of anaerobic digestion, used at many mid- to large-size wastewater treatment plants to produce Class B biosolids.
As a result, many operators are familiar with desired operating parameters and how to control them. Compared with the higher temperature process, mesophilic digestion rates are slower, more tank volume is required, and solids reduction may not be as good, but the process requires less energy and puts less stress on concrete tanks. Thermophilic digestion’s higher temperatures destroy pathogens more quickly, shortening retention time, increasing capacity, and making it possible to produce Class A biosolids. Although thermophilic digestion can produce highly volatile fatty acids, this problem can be avoided with subsequent mesophilic digestion.

a) Water flow – treatment process consists of the following stages:

- Preliminary treatment (harrowing and de-arenation)
- Primary treatment (decantation)
- Biologic treatment (activated sludge)

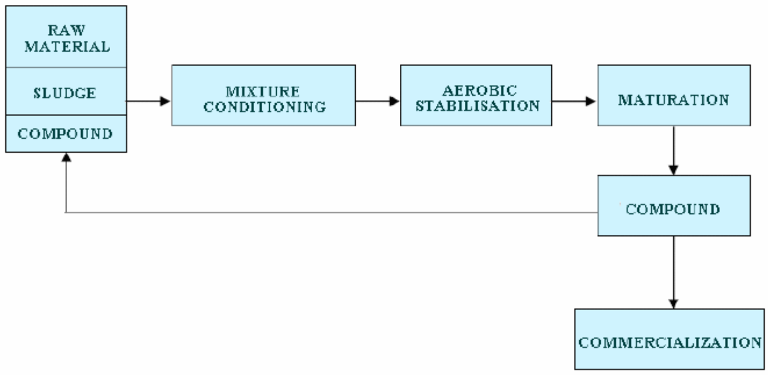
b) Sludge flow – the treatment process consists of the following stages:

- Thickening
- Anaerobic digestion (heated)
- Mechanical dewatering
- Composting

c) Gas Flow – storage, treatment e biogas reuse for electric energy production

The sludge composting process in Parada WWTP occurs in different stages that can be shown on the following scheme:

Fig. 21– Composting production scheme



3. EU Regulation and legislation in force for small WWTPs

The Council Directive 91/271/EEC concerning urban waste-water treatment was adopted on 21 May 1991. Its objective is to protect the environment from the adverse effects of urban wastewater discharges and discharges from certain industrial sectors and concerns the collection.

In case of urban or domestic small wastewater, it is defined by Directive as "urban waste water" means domestic waste water or the mixture of domestic waste water with industrial waste water and/or run-off rain water", in majority terms it corresponds to wastewater from residential settlements and services which originates predominantly from the human metabolism and from household activities.

In case of Sintra's plants that corresponding to a size of treatment lower than 5000 equivalent inhabitants, or person equivalent the concept of domestic wastewater means also that the organic biodegradable load has a maximum five-day biochemical oxygen demand (BOD5) of 60 g of oxygen per day, a requirement corresponding to the characterization of small treatment plants. The load expressed in p.e. shall be calculated on the basis of the maximum average weekly load entering the treatment plant during the year, excluding unusual situations such as those due to heavy rain.

In the specific case of Sintra since it is related to agglomerations between 2000 and 10000 p.e. which treated water is discharged to coastal waters might be subjected to treatment less stringent than that prescribed providing that:

- Such discharges receive at least primary treatment accomplishing the control procedures laid down in Annex I- D of Directive.
- Comprehensive studies indicating that such discharges will not adversely affect the environment.

Another important issue imposes to the Member States shall ensure that the urban waste water treatment plants built to comply with the requirements of Directive (Articles 4, 5, 6 and 7) are designed, constructed, operated and maintained to ensure sufficient performance under all normal local climatic conditions. When designing the plants, seasonal variations of the load shall be taken into account.

The treated waste water shall be reused whenever appropriate. Disposal routes shall minimize the adverse effects on the environment. Competent authorities or appropriate bodies shall ensure that the disposal of waste water from urban waste water treatment plants is subject to prior regulations and/or specific authorization.

In order to accomplish the Directive the Municipal Water Utilities must organize a self-monitoring done by the staff of the discharger or a laboratory or consultant which is contracted by the discharger and authorised by the authority.

The frequency of self-monitoring for analysing the parameters more adequate should be at least monthly for small for small plants. The utility should report the results of self-monitoring at least once a year to the authority, but in the case of non-compliance it must be immediately.

In order to identify polluters, in the case of sudden pollution of waters discharged, the samples should be stored for later cross-checking at least for 7 days. Internationally accepted standardized sampling, analyzing and quality assurance methods (e.g. CEN standards, ISO standards, OECD guidelines) should be used whenever available. For municipal waste water discharges COD or TOC, BOD5, NH4-N, total N (sum of Kjeldahl-N, NO2-N, NO3-N) and total P should be analysed on a regular basis. Considering the Directive definition for urban wastewater, if industrial plants exist which discharge into the municipal waste water treatment plant, it may turn necessary to analyse additional parameters.

The WWTREAT monitoring system provides and stores in data banks the operation qualitative and quantitative data, that can be online available to the public, e.g. by annual reports on monitoring of discharges.

The Directive transposition for internal law of Member States is mandatory in order ensuring that urban waste water entering collecting systems shall before discharge be subject to secondary treatment or an equivalent treatment in small plants from agglomerations of between 2000 and 10000 p.e. For the 10 new Member States in Central and Eastern Europe, which joined the European Union on 1 May 2004, staged transition periods were negotiated as part of the Accession Treaties, obliging the new Member States to comply with the Directive by 2010 to 2015, at the same time providing them considerable financial support by the European Union for planning considerations, design and construction of wastewater treatment systems.

The EU Dangerous Substances Directive (Council Directive 76/464/EEC on pollution caused by dangerous substances discharged into the aquatic environment of the Community) must be take in accounting to eliminate pollution
from detailed dangerous substances and to reduce pollution also detailed dangerous substances as contained in Annex to the same Directive. The implementation of this directive must be closely co-ordinated with that of the
Water Framework Directive, which is to eventually (by 2013) repeal it.

Concerning the discharges of listed substances, Member States must to apply:

• a system of zero-emission to discharges of List I substances, selected mainly on the basis of their toxicity, persistence and bioaccumulation.
• limit the discharge of List II substances which have a deleterious effect on the aquatic environment.

The Dangerous Substances Directive applies to inland surface water, territorial waters and internal coastal waters. The protection of groundwater from dangerous substances is regulated by a separate Directive (80/68/EEC). The regulations specified standards for pesticides and solvents, metals and other substances to be complied with by 31 December 2010.

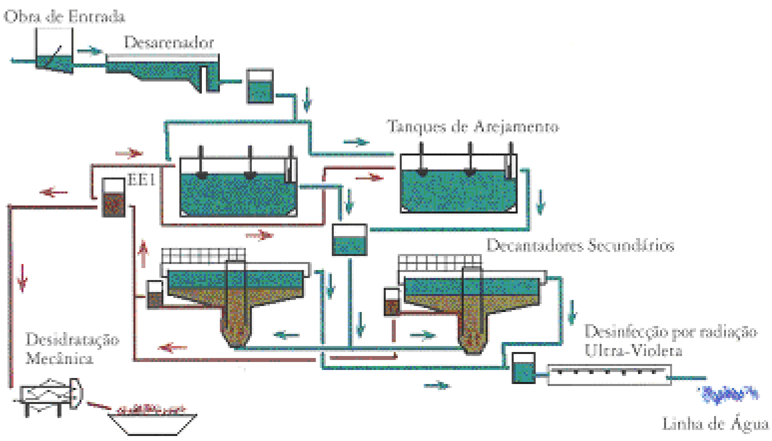
4. More common typologies applied in small communities WWTPs (Sintra)

The SMAS de Sintra plants correspond to more common typologies applied in small community wastewater treatment. Each plant has a specific design as following descriptions:

4.1 Magoito WWTP

Magoito WWTP initiated its activity in 2001, projected for a population of 5197 inhabitants. Presently, this WWTP treats only the wastewater from Magoito village, however, other connections are predicted to the villages of Bolembe, Tojeira, Fontanelas, Gouveias and additional small villages. Since Magoito is a seaside zone, a tertiary treatment process has been implemented with an ultraviolet water disinfection system.

Fig 22– Magoito WWTP process scheme



The following table presents some data regarding the number of inhabitants and affluent wastewater characteristics, reported to the project-year (1990) and horizon-year (2010).

Table 4 – Characteristics of Magoito WWTP

	1990	2010
Inhabitants (equiv)	3 336	5 197
Capitation (L/Inhabitant. d)	150	200
Medium Flow (m^3/h)	485	1 156
Punctuate Flow (m^3/h)	60.5	115,2
BOD (Kg/d)	182	281
TSS (Kg/d)	300,2	468

The treatment consists in aerobic biological degradation with activated sludge in aeration tanks followed by a tertiary treatment with ultraviolet disinfection. Magoito WWTP is composed by the following unitary processes and/or equipments: Screens, Sand Filters, Aeration tank (with turbines), Secondary Settler Tank, Ultraviolet Water Disinfection System and Sludge Dewatering (with filter bags). The plant is also equipped with flow and dissolved oxygen monitoring equipment.

The following table presents some operational data of year 2004, including consumption of resources such as electricity and fresh water, wastewater inflow and dry sludge production.

Table 5 – Magoito WWTP operational data (2004)

Month	Electric energy consumption (Kw)	Emergency generator functioning (h)	Wastewater inflow (m^3)	Dry sludge (m^3)	Fresh water consumption (m^3)
January	1066	-	10542	297.6	182
February	9897	10	12338	229	182
March	10575	2	10295	275	205
April	8582	56	8260	137	151
May	108	736	6586	343	218
June	10	708	5971	297	402
July	26	851	5782	366	454
August	10466	153	6765	480	1864
September	13194	19	5915	431	1591
October	12090	30	8215	389	706
November	10827	36	6953	686	212
December	13174	14	6000	335.8	99
Total	90015	2615	93622	4266.4	6266
Average	7501.25	217.92	7801.83	355.53	522.17

The concentrations of the main physical-chemical parameters in the WWTP influent and treated effluent are monitored once a month, through the collection of punctual samples (and 24 h compost samples each trimester). The following tables present the results obtained during year 2004.

Table 6 – Concentrations of main pollutants in Magoito WWTP influent (2004)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dez
Oxidability (mg O_2/L)	69.9	89	45.2	125	111.3	102	99.1	141.7	156	142	112.8	138.3
Conductivity (uS/cm)	1107	674	1148	1072	1257	1798	1266	1307	1066	1225	1230	1226
pH	7.86	7.86	7.62	7.83	7.74	7.51	7.69	7.8	7.5	7.82	7.93	7.67
BOD (mg O_2/L)	155	100	340	40	380	415	210	120	483	30	380	480
COD (mg O_2/L)	272	187	554	515	489	477	80	669	866	526	502	768
Ammonia (NH^{4+}/L)	59.0	20.1	57.3	78	88.5	65.5	87	144	77	91.4	88.5	56.5
Nitrites (NO^{2-}/L)	0.41	0.996	0.04	0.044	0.053	0.044	0.13	0.089	0.047	0.08	0.05	0.05
Nitrates (NO^{3-}/L)	1.57	17.1	0.86	< 1	0.43	< 1	< 1	< 0,95	7.6	2.78	6.19	16.15
Kjeldhal Nitrogen (mg N/L)	-	20.1	-	-	-	-	-	-	-	-	-	-
Tota phosp. (mg P/L)	3.89	2.15	5.07	6.24	8.09	7.54	5.73	8.03	8.56	6.55	8.40	7.03
Dissolv. oxygen (mg O_2/L)	0.42	5.59	0.08	0.08	0.13	0.16	0.97	0.08	0.13	0.05	0.15	0.08
TSS (mg/L)	170	462	280	224	310	220	222	308	398	275	228	280
Sulphates (mg/L)	109.7	64.3	120.5	91	92.9	173.8	112.7	95.1	108.7	122	127	79
Oils and Greases (mg/L)	19	3.6	31	28	53	74	33	28	70	27	< 0,7	13
Detergents (mg/L)	3.9	0.78	7	6	7	4.3	6	6	11	1.63	1.63	1.87

Table 7 – Concentrations of main pollutants in Magoito WWTP effluent (2004)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dez
Oxidability (mg O_2/L)	16	14.7	11.6	21	20.6	38.1	32.2	20.1	27	20	27.91	30.01
Conductivity (uS/cm)	924	623	978	1088	1163	1253	991	1068	1037	1065	1130	1100
pH	7.76	7.58	7.84	7.79	7.95	7.97	7.4	7.9	8.07	7.81	7.89	8.06
BOD (mg O_2/L)	< 0,9	4.66	1.14	2	0.21	5.64	3.88	< 2	0.6	0.4	0.14	0.91
COD (mg O_2/L)	42	62	30	85	45	124	48	65	86	71	37	97
Ammonia (NH^{4+}/L)	3.7	1.54	2.9	38.7	53.2	65.8	0.64	5.08	74.5	50.4	41.9	64.5
Nitrites	0.22	0.497	0.371	0.067	0.06	0.471	<	0.208	0.228	0.277	0.12	0.14

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dez
(NO^{2-}/L)					8		0,03					
Nitrates (NO^{3-}/L)	1.63	16.1	7.25	< 1	0.31	2.38	16.84	< 0,95	< 0,6	0.91	< 1,03	< 0,63
Kjeldhal Nitrogen (mg N/L)	5	6	5	34	50	66	< 3	54	60	44	40	11.2
Total nitrogen (mg N/L)	5.44	9.79	6.75	< 34,25	50.09	66.68	< 6,81	< 54,28	< 60,2	44.29	< 40,27	< 11,38
Tota phosp. (mg P/L)	3.75	2.10	4.44	1.18	1.62	2.88	8.00	0.68	1.97	< 0,34	5.27	5.22
Dissolv. oxygen (mg O_2/L)	8.47	8.72	10.05	8.80	8.73	8.88	10.06	7.83	9.02	8.46	8.39	10.01
TSS (mg/L)	18	26	24	19	10	44	28	20	20	28	28	46
Sulphates (mg/L)	115	73.9	113.6	99	109.4	122.6	123.7	91.7	107.05	109	104	75
Hydrocarbons (mg/L)	< 0,3	< 0,3	< 0,3	0.4	< 0,3	0.9	< 0,3	< 0,3	< 0,3	-	-	-
Oils and Greases (mg/L)	< 0,3	0.4	0.5	0.6	0.8	2.9	< 0,3	0.7	0.9	< 0,7	< 0,7	< 0,7
Detergents (mg/L)	< 0,2	< 0,2	< 0,2	0.23	< 0,2	0.4	< 0,2	0.33	0.35	0.15	< 0,05	0.11

Obs: Values in March, June, September and December are daily averages (24h compost samples).

The emission limit values (ELV) applied to this WWTP are those specified in the discharge permit, attributed by the local competent authority (Regional Development Coordination Commission - CCDR). These ELV, consonant with the values defined by Portuguese Law- Decrees 236/98 of 1st August and 152/97 of 19th June, are presented in table 6.

Table 8 – ELV specified in Magoito WWTP discharge permit

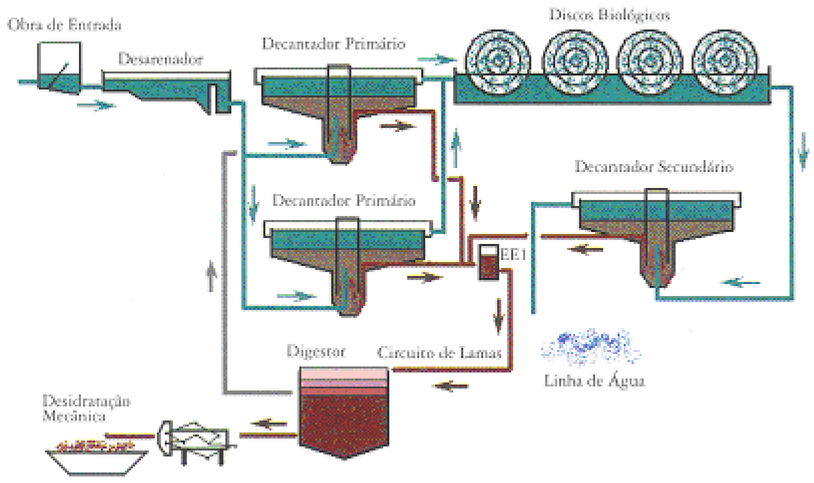
Parameter	ELV (permit)	Law Decree
pH	> 6 - 9 <	236/98
BOD (mg O_2/L)	25	152/97
COD (mg O_2/L)	125	152/97
Total phosporous (mg P/L)	10	236/98
Oils and Greases (mg/L)	15	236/98
Nitrates (mg/L)	50	236/98
Dissolved oxygen (mg O_2/L)	60	-

As observed in tables 5 and 6, all parameters are in conformity with the applied ELV.

4.2. Almoçageme WWTP

Almoçageme WWTP started its activity in 2000, designed for a population of 3500 inhabitants.

Fig. 23– Almoçageme WWTP process scheme



The following table presents some data regarding the number of inhabitants and affluent wastewater characteristics, reported to the project-year (1999) and horizon-year (2015).

Table 9 – Characteristics of Almoçageme WWTP

	1999	2015
Inhabitants (equiv.)	1 500	3 500
Capitation (L/Inhabitant. d)	150	200
Medium Flow (m^3/h)	150	420
Punctuate Flow (m^3/h)	21,6	61,2
BOD (Kg/d)	81	189
TSS (Kg/d)	135	315

The treatment consists mainly in Bio-Disks with anaerobic sludge degradation. Almoçageme WWTP is composed by the following unitary processes and/or equipments: Screens, Sand Filters, Primary decantation; Bio-disks; Secondary decantation; Anaerobic sludge digestion and Sludge drying by filter bags.

The following table presents some operational data of year 2004, including consumption of resources such as electricity and fresh water, wastewater inflow and dry sludge production.

Table 10 - Almoçageme WWTP operational data (2004)

Month	Electric energy consumption (Kw)	Wastewater inflow (m^3)	Dry sludge production (m^3)	Fresh water consumption (m^3)
January	3840	7024	23	323
February	3558	8509	23	161
march	3412	6436	-	236
April	3378	5481	-	276
May	3167	4248	42	203
June	2843	3904	23	302
July	3066	4104	23	493
August	3028	4201	23	434
September	3032	2965	23	766
October	3187	5537	19	705
November	3357	5021	23	443
December	3492	4911	23	378
Total	39360	62341	245	4720
Average	3280.00	5195.08	**20.42**	393.33

The concentrations of the main physical-chemical parameters in the WWTP affluent and the treated effluent are monitored once a month, through the collection of punctual samples (and 24 h compost samples each trimester). The following tables present the results obtained during year 2004.

Table 11 - Concentrations of main pollutants in Almoçageme WWTP influent (2004)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dez
Oxidability (mg O_2/L)	99.8	76.8	46.6	129	72.4	277.8	129.1	103.2	260	136	239.7	114.0
Conductivity (uS/cm)	1044	762	908	1028	906	1171	1169	918	1330	1201	1429	1308
pH	8.44	7.65	7.9	8.42	7.62	8.04	7.9	7.5	8.47	8.34	7.45	8.43
BOD (mg O_2/L)	20	310	185	360	< 40	960	580	200	380	405	680	425
COD (mg O_2/L)	545	450	375	637	386	1169	1101	691	906	647	550	581
Ammonia (NH^{4+}/L)	68	25.9	42.4	68	3.28	84	3.22	50.5	123.5	91.3	42.5	61
Nitrites (NO^{2-}/L)	1.6	1.075	0.672	0.07	0.045	0.061	0.146	0.055	0.072	0.069	0.11	0.04

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dez
Nitrates (NO^{3-}/L)	2.89	10.5	5.54	< 1	< 0,14	< 1,0	< 1,0	< 0,95	7.31	3.89	3.55	10.62
Kjeldhal Nitrogen (mg N/L)	-	-	-	-	-	-	-	-	-	-	-	-
Total nitrogen (mg N/L)	-	-	-	-	-	-	-	-	-	-	-	-
Tota phosporous (mg P/L)	6.42	3.46	4.76	6.85	3.76	8.73	7.57	6.11	10.13	8.74	5.87	8.04
Sulphates (mg/L)	97.7	80.3	103.3	89	83.4	138.5	101.8	78.3	121.6	116	109	76
Dissolved Oxygen (mg O_2/L)	0.37	0.2	0.08	0.09	0.13	0.16	0.16	0.06	0.05	0.09	0.56	0.06
TSS (mg/L)	310	200	132	242	122	500	424	196	480	332	682	260
Hydrocarbons (mg/L)	-	-	-	-	-	-	-	-	-	-	-	-
Oils and Greases (mg/L)	47	66	28	28	51	1,6[a]	48	42	85	< 0,7	15	< 0,7
Detergents (mg/L)	5	6	11	8	9	8.4	4.3	8	7	0.66	1.76	1.70

Table 12 - Concentrations of main pollutants in Almoçageme WWTP effluent (2004)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dez
Oxidability (mg O_2/L)	15.7	16.8	14.6	23	26.2	25.3	28.8	15.6	22	17	24.01	17.03
Conductivity (uS/cm)	902	685	829	783	887	830	899	776	971	822	1217	830
pH	7.6	7.59	7.45	7.73	7.51	7.3	7.63	7.60	7.52	7.63	7.51	7.36
BOD (mg O_2/L)	3.6	5.46	5	4.49	6.29	10.68	1	6	11	1.6	7.31	4.19
COD (mg O_2/L)	44	69	75	57	92	79	57	42	58	45	52	58
Ammonia (NH^{4+}/L)	1.48	4.31	1.90	1.8	2.72	4.1	97	1.70	2.28	3.88	3.54	2.96
Nitrites (NO^{2-}/L)	2.1	2.166	2.28	3.46	3.55	5.22	6.25	2.221	1.771	3.098	4.5	3.61
Nitrates (NO^{3-}/L)	161.5	76.4	135.9	146.7	164	15.94	149.2	133.4	143.6	80.1	169.8	159
Kjeldhal Nitrogen (mg N/L)	< 3	6	5	3	3	6	3	3	< 3	7.1	2.8	16.1
Total nitrogen (mg N/L)	< 40,11	23.91	36.38	37.18	41.11	11.19	38.59	33.80	< 35,96	26.13	42.51	53.10
Tota phosporous (mg P/L)	5.94	3.23	5.24	5.76	7.04	7.48	7.15	6.62	7.97	3.75	6.08	5.27
Sulphates (mg/L)	89.3	59.6	85.1	67	74.7	81	76.5	65.7	72.2	76.2	70	69
Dissolved Oxygen (mg O_2/L)	4.82	5.64	5.20	4.15	7.16	3.41	5.04	7.45	3.54	3.81	8.5	4.32
TSS (mg/L)	8	32	30	19	34	23	36.25	33	14	3	14	14
Hydrocarbons (mg/L)	<= 0,5	0.4	< 0,3	0.3	0.4	16	< 0,3	< 0,3	< 0,3	-	-	-
Oils and Greases (mg/L)	0.5	1.5	0.8	1	1.8	n/a	< 0,3	< 0,3	0.3	< 0,7	< 0,7	< 0,7
Detergents (mg/L)	0.22	0.39	0.34	< 0,2	< 0,2	0.2	< 0,04	< 0,2	< 0,2	0.26	0.26	< 0,05

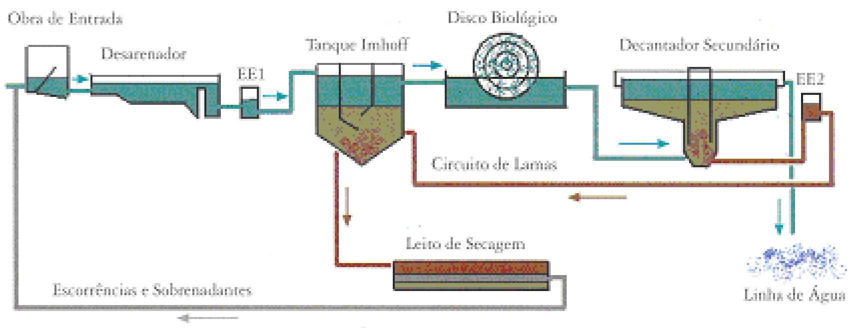
Obs: Values in February, May, August and November are daily averages (24h compost samples).

Almoçageme WWTP discharge permit defines ELV for pH, BOD, COD, total nitrogen, total phosphorous, TSS and oils and greases. For total nitrogen and TSS, the ELV's are, respectively, 15 mg N/l and 60 mg/l. For the remaining parameters, the ELV is the same applied to Magoito WWTP (see table 6). In 2004, concentrations of total nitrogen exceeded (with the exception of June) the ELV applied.

4.3. Vila-Verde WWTP

Vila-Verde WWTP initiated its activity in 1990, designed for a population of 3000 inhabitants and an average flow rate of 600m^3/day. This WWTP treats the wastewaters from Vila Verde, Ral and Terrugem villages.

Fig. 24– Vila-Verde WWTP process scheme



The following table presents some data regarding the number of inhabitants and affluent wastewater characteristics, reported to the project-year (1999) and horizon-year (2015).

Table 13 - Characteristics of Vila-Verde WWTP

	1990	2010
Inhabitants (equiv.)	2 000	3 000
Capitation (L/Inhabitant. d)	200	250
Medium Flow (m^3/h)	320	600
Punctuate Flow (m^3/h)	40	75
BOD (Kg/d)	108	162
TSS (Kg/d)	180	270

The treatment consists, mainly, in Bio-Disks with anaerobic sludge degradation in an Imhoff Tank. Vila Verde WWTP is composed by the following unitary processes and/or equipments: Screens, Sand Filters, Imhoff tank; Bio-disks; Secondary Decantation; and Sludge Drying by filter bags.

The following table presents some operational data of year 2004, including consumption of resources such as electricity and fresh water, wastewater inflow and dry sludge production.

Table 14 – Vila Verde WWTP operational data (2004)

Month	**Electric energy consumption (Kw)**	**Wastewater inflow (m^3)**	**Dry sludge production (m^3)**	**Fresh water consumption (m^3)**
January	3618	32839*	6	50
February	3190	28767.92	9	56
March	3329	32348.37	15	91
April	2911	25447.28	18	80
May	2631	11100.28	18	104
June	2107	4165.86	18	197
July	2173	3631.91	18	210
August	2337	2816.63	54	345
September	2253	3009.67	72	138
October	2822	9106.32	-	116
November	3101	13563.92	45	46
December	3061	11686.32	9	55
Total	33533	178483.1	282	1488
Average	2794.42	14873.59	23.50	124.00

The concentrations of the main physical-chemical parameters in the WWTP affluent and the treated effluent, discharged in *Ribeira de Fervença*, are monitored once a month, through the collection of punctual samples (and 24 h compost samples each trimester). The following tables present the results obtained during year 2004.

Table 15 - Concentrations of main pollutants in Vila Verde WWTP influent (2004)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dez
Oxidability (mg O_2/L)	44.35	49.5	29.2	53	90	66	130.4	85.03	189.4	73.25	61.43	108.3
Conductivity (uS/cm)	893	922	971	1087	993	1169	1139	783	1096	481	1015	990
pH	7.81	7.62	7.82	7.87	7.54	7.54	7.68	7.59	7.70	7.51	7.56	7.68
BOD (mg O_2/L)	200	180	60	380	360	405	310	145	320	125	365	290
COD (mg O_2/L)	254	296	269	713	2387	629	813	296	504	243	781	429
Ammonia (NH^{4+}/L)	34.7	26.4	43.0	57	36.4	73	73.5	21.4	97.5	12.56	47.9	64
Nitrites (NO^{2-}/L)	0.312	0.026	1.33	< 0,03	0.04	< 30	0.05	0.66	0.062	1.53	0.138	0.19
Nitrates (NO^{3-}/L)	4.64	0.45	3.83	< 1,0	< 0,53	< 1,0	< 1	< 1	4.75	9.21	2.32	3.87
Tota phosporous (mg P/L)	2.58	2.05	3.83	5.15	3.59	6.93	5.69	1.48	7.53	< 1,0	4.21	3.65
Dissolv. oxygen (mg O_2/L)	0.27	0.17	0.40	0.10	0.1	0.13	0.45	0.08	0.06	0.88	0.09	0.08
TSS (mg/L)	88	148	192	162	60	190	350	149	350	217	286	222
Sulphates (mg/L)	102.2	94.6	60.1	118	79.6	130.5	118.9	97.9	-	34.4	93	99
Oils and Greases (mg/L)	20.0	33	9.4	31	62	93	55	21	42	21	11	< 0,7
Detergents (mg/L)	1.8	3.8	1.3	3.9	9	7	7	3.4	6	0.09	1.11	0.38

Table 16 - Concentrations of main pollutants in Vila Verde WWTP effluent (2004)

Parameter	Vila Verde effluent – year 2004											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dez
Oxidability (mg O_2/L)	13.94	16.99	12.5	22.4	29	34	55.85	24.78	47.12	22.5	27.98	24.01
Conductivity (uS/cm)	859	928	827	981	947	1133	1202	697	1115	703	1056	934
pH	7.66	7.80	7.6	7.84	7.64	7.58	7.64	7.64	7.67	7.53	7.73	7.60
BOD (mg O_2/L)	4.0	5.87	3.87	3.9	-	41	110	2.41	10.02	25.7	6.878	4.233
COD (mg O_2/L)	48	42	48	112	133	402	199	83	185	93	116	93
Ammonia (NH^{4+}/L)	18.2	27.4	12.9	29.9	44.1	52.5	65	23.2	101.7	18.93	46.1	34.5
Nitrites (NO^{2-}/L)	0.413	0.384	1.07	< 0,03	0.02	< 30	0.04	0.242	0.034	2.04	0.044	0.07
Nitrates (NO^{3-}/L)	2.70	1.77	8.63	< 1,0	< 0,53	2.2	< 1	1	< 0,41	5.5	< 0,75	< 0,77
Kjeldhal Nitrogen (mg N/L)	18	26	13	32	43	69	72[a]	29	66	17.8	46	31
Total nitrogen (mg N/L)	18.74	26.52	15.27	< 32,23	< 43,13	< 78,63	< 72,24	29.30	< 66,1	19.66	< 46,18	< 31,20

Parameter	Vila Verde effluent – year 2004											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dez
Tota phosporous (mg P/L)	2.04	2.51	1.49	3.20	4.20	6.52	6.98	1.78	6.76	< 0,96	4.61	2.94
Dissolv. oxygen (mg O_2/L)	3.45	5.24	5.91	0.52	0.1	0.11	0.40	2.57	0.06	2.2	2.2	1.1
TSS (mg/L)	5	17	22	19	32	34	114	21	60	30	35	32
Sulphates (mg/L)	90.8	86.9	53.2	92	84.6	101.6	93.2	87.6	99.8	34.4	84	91
Hydrocarbons (mg/L)	0.4	0.5	< 0,3	0.5	0.6	1.5	1,6[a]	< 0,3	0.5	-	-	-
Oils and Greases (mg/L)	1.4	1.8	0.6	1	2.7	11	8,3[a]	0.6	1.9	< 0,7	< 0,7	< 0,7
Detergents (mg/L)	0.24	0.82	0.32	1.6	3.4	3.6	3,6[a]	0.31	2.10	0.102	1.08	< 0,05

Obs: Values in February, May, August and November are daily averages (24h compost samples).

Vila Verde WWTP discharge permit defines ELV for pH, BOD, COD, total nitrogen, total phosphorous, TSS and oils and greases. These ELV are the same than those applied for Almoçageme WWTP (see 2.1.2.). In 2004, all monitored concentrations of total nitrogen exceeded the ELV applied, as well as a few concentrations of BOD (June, July, October), COD (May, June, July, September) and TSS (July).

4.4 Advantages and Disadvantages of Conventional and Non-conventional Wastewater Treatment Technologies

The next table present the advantages and disadvantages related the conventional and non-conventional technologies considering the decision main constraints in design of new plants.

Table 17 – Advantages and disadvantages by treatment types

Treatment Type	Advantages	Disadvantages
Aquatic Systems		
Stabilization lagoons	Low capital cost Low operation and maintenance costs Low technical manpower requirement	Requires a large area of land May produce undesirable odors
Aerated lagoons	Requires relatively little land area Produces few undesirable odors	Requires mechanical devices to aerate the basins Produces effluents with a high suspended solids concentration
Terrestrial Systems		
Septic tanks	Can be used by individual households Easy to operate and maintain Can be built in rural areas	Provides a low treatment efficiency Must be pumped occasionally Requires a landfill for periodic disposal of sludge and septage
Constructed wetlands	Removes up to 70% of solids and bacteria Minimal capital cost Low operation and maintenance requirements and costs	Remains largely experimental Requires periodic removal of excess plant material Best used in areas where suitable native plants are available
Mechanical Systems		
Filtration systems	Minimal land requirements; can be used for household-scale treatment Relatively low cost Easy to operate	Requires mechanical devices
Vertical biological reactors	**Highly efficient treatment method** **Requires little land area** **Applicable to small communities for local-scale treatment** and to big cities for regional-scale treatment	High cost Complex technology Requires technically skilled manpower for operation and maintenance Needs spare-parts-availability **Has a high energy requirement**
Activated sludge	**Highly efficient treatment method** **Requires little land area** **Applicable to small communities for local-scale treatment** and to big cities for regional-scale treatment	High cost Requires sludge disposal area (sludge is usually land-spread) Requires technically skilled manpower for operation and maintenance

Source: Ernesto Pérez, P.E., Technology Transfer Chief, Water Management Division, USEPA Region IV, Atlanta, Georgia

5. Methodologies for identification of treatment efficiency improvement measures

Success or failure in operating an activated sludge plant depends on proper control of the mass of active organisms in the plant. For example, variation of the solids retention time (SRT) will modify the entire process performance, including denitrification rates, sludge production and stability, mixed liquor concentration, oxygen uptake rates, and possibly the extent of nitrification. Increasing the SRT generally will increase oxygen requirements, the stability of the process, the extent of sludge stabilization, the extent of nitrification, and mixed liquor in concentration. Longer SRTs will decrease sludge production and denitrification rates in the post-aeration anoxic tanks. For pre-aeration anoxic tanks, longer SRTs increase the mixed liquor suspended solids (MLSS) and result in a greater denitrification rate.

The treatment efficiency in wastewater is common to all size plants checking the following treated water parameters:

a) Biochemical Oxygen Demand (BOD)

The biochemical oxygen demand test has been used widely to gauge overall treatment plant efficiencies. The traditional BOD measurement of the plant influent, grit removal influent, and the final effluent gives the most common measure of treatment plant efficiency.

The BOD of wastewater is a common indicator of the fraction of organic matter that may be degraded by microbial action at a given time period at a temperature of 20º C. The test is related to the oxygen that would be required to stabilize the waste after discharging to a receiving body of water. The drop in BOD from grit removal effluent to final effluent is usually used in calculating the solids growth rate in the aeration tank.

Tests for BOD are to be made on composite samples daily. BOD tests run for at least 20 days are also to be made on the effluent periodically to determine the oxygen requirements of the nitrogen compounds present in the effluent.

b) Chemical Oxygen Demand (COD)

Chemical oxygen demand is another means of measuring the pollutional strength of wastewater. By using this method, most oxidizable organic compounds present in the wastewater sample may be measured. COD measurements are preferred when a mixed domestic-industrial waste is entering a plant or where a more rapid determination of the load is desired.

The chemical oxygen demand test has a major advantage over the biochemical oxygen demand analysis because of the short time required for performance - a few hours as opposed to five days for the standard BOD test. Since this test can be run in several hours, it gives the operator a more timely idea of what is entering the plant and how the plant is performing. This permits closer operational control of the treatment process.

Generally, COD values are higher than BOD values. The reason is that biochemical oxygen demand measures only the quantity of organic material capable of being oxidized, while the chemical oxygen demand represents a more complete oxidation. Typical COD values for domestic waste range from 200 - 500 mg/L.

c) Total Organic Carbon (TOC)

Total organic carbon measurements have been used as a method for determining pollutional levels of wastewater for many years. The organic carbon determination is free of many of the variables involved in the COD and BOD analyses, with somewhat more reliable and reproducible data being the result. The need for rapid determination of wastewater strength has led to the development of organic carbon analyzers and their introduction into some treatment plant laboratories. All of the available instruments measure the organic carbon content of aqueous samples, although there are several methods by which this is accomplished. The TOC values will generally be less than COD values, because a number of organic compounds may not be oxidized in the total organic carbon analysis. Typical values of TOC for domestic waste range from 100 - 300 mg/L.

d) Total Oxygen Demand (TOD)

Another method of measuring organic matter in wastewater involves the oxidation of the sample to stable end products in a platinum-catalyzed combustion chamber. Total oxygen demand is determined by measuring the oxygen content of the inert carrier gas, nitrogen. TOD measurements are becoming more popular because of their quickness in determining what is entering the plant and how the plant is responding. Analysis time is approximately 5 minutes. The results obtained generally will be equivalent to those obtained in the COD test.

d) Solids Determinations

Laboratory determinations of suspended solids (SS) in the influent, primary effluent, and final effluent are standard measurements used to indicate treatment plant efficiency. The SS measurements are used in calculating the sludge volume index (SVI) and sludge density index (SDI) - both important control tools. There is a distinction between total suspended solids (TSS) and total volatile suspended solids (TVSS). TSS measures both the active bacterial mass and the inert materials in the waste or mixed liquor. TVSS is a more accurate estimate of the mass of active microorganisms in the mixed liquor and is the parameter to be used in calculating the food-to-microorganism (F:M) ratio.

e) Sludge Density Index / Sludge Volume Index

To determine what the return sludge pumping rate should be and to get some idea of sludge settling characteristics, sludge indices have been proposed. One of the most common is the Donaldson Index, SDI:

$$\text{SDI} = \frac{\text{MLSS (\%)} \times 100}{\text{\% volume MLSS (after 30 min settling)}}$$

The other common index is the Mohlman Index, SVI:

$$\text{SVI} = \frac{\text{\% MLSS volume (after 30 min)}}{\text{\% MLSS mg/L MLSS}} \qquad = \text{ml settled sludge} \times 1000$$

These indices relate the weight of sludge to the volume the sludge occupies. They show how well the liquids-solids separation part of the activated sludge system is performing its function on the biological floc that has been produced and is to be settled out and returned to the aeration tanks or wasted. The better the liquid-solids separation is, the smaller will be the volume occupied by the settled sludge and the lower the pumping rate required keeping the solids in circulation.

f) Sixty-Minute Settling Test

The 60 minute settling test is a reasonable approximation of what is happening in the final settling tank. So that solids do not accumulate in the final settling tank, they must be removed at an average rate equal to that at which they are applied.

g) PH

PH is a method of expressing the acid condition of wastewater. The pH scale ranges from approximately 1 - 14, with a pH of 1 - 7 considered the acid range and 7 - 14 considered the base range. PH 7 is defined as neutral. PH is a vital tool of the wastewater treatment plant operator when determining unit operations.

h) Alkalinity

This is a measure of a wastewater's capacity to neutralize. The bicarbonate, carbonate, and hydroxide ions are the primary contributors to alkalinity. The determination of alkalinity levels at various points in a plant will be an aid to the proper understanding and interpretation of the treatment process. For example, if chemical addition is used to coagulate wastewater for solids removal, hydrogen ions may be released and cause the pH to decrease. Alkalinity will tend to neutralize the acids formed and permit coagulation to proceed in the proper pH range. Some other processes dependent on pH are disinfection, digestion, and sludge preparation and conditioning.

The bacteria and other biological entities which play an active role in wastewater treatment are most effective at a neutral to slightly alkaline pH of 7 to 8. In order to maintain these optimal pH conditions for biological activity there must be sufficient alkalinity present in the wastewater to neutralize acids generated by the active biomass during waste treatment. This ability to maintain the proper pH in the wastewater as it undergoes treatment is the reason why alkalinity is so important to the wastewater process.

During the nitrification process, hydrogen ions are released and alkalinity is consumed as the acid is neutralized. For every 1.0 mg of ammonia converted to nitrate, 8.14 milligrams (mg) $CaCO_3$ equivalent are consumed. The generation of acid during ammonia conversion, and the need to maintain the proper pH, is the reason why an alkali is added to the system. Nitrification of the wastewater is the single largest factor which leads to the consumption of alkalinity and the need to add alkali to the treatment system.

6. Best Available Technologies

Considerations to be taken into account when determining best available techniques should bear in mind the likely costs and benefits of a measure and the principles of precaution and prevention. For instance, consideration should be taken of:

a. the use of low-waste technology
b. the use of less hazardous substances;
c. furthering recovery and recycling of substances and waste (where appropriate) generated and used in the process;
d. comparable processes, facilities or methods of operation which have been tried with success on an industrial scale;
e. technological advances and changes in scientific knowledge and understanding;
f. the nature, effects and volume of the emissions concerned;
g. the commissioning dates for new or existing installations;
h. the length of time needed to introduce the best available technique;
i. the consumption and nature of raw materials (including water) used in the process and their energy efficiency;
j. the need to prevent or reduce to a minimum the overall impact of the emissions on the environment and
k. the risks to it;
l. the need to prevent accidents and to minimise the consequences for the environment.

The next tables summarize compare available treatment techniques:

Table 19 - Treatment Techniques Associated with BAT for Biological Treatment

	Anaerobic biology	Aerobic Biology			
		Activated sludge (mix) / Membrane bioreactor	Trickling / percolating filter	Expanded-bed	Biofilter fixed-bed
Purpose	Conversion of organic content by micro-organisms and exclusion of air (oxygen)	Conversion of organic content by micro-organisms in the presence of dissolved oxygen, injected as air or pure oxygen			
Application	Pretreatment of high organic load and streams of constant quality	Pretreatment of high organic load; Final treatment in tributary streams; Used as central WWTP	As part of a central WWTP (first or pretreatment stage) to reduce the most easily degradable contaminants and improve the sludge quality	Pretreatment of high organic loads; Final treatment of smaller streams	Direct pretreatment step or polisher after activated sludge process in central WWTP; Good conditions for slow growing microorganisms
Application limits	Prevention of toxic substances because process is very sensitive	High concentrations, even of non-toxic substances, to be avoided; Inhibitor needs to be avoided, though well-adapted micro-organisms can cope with inhibitor concentrations not too high; Maximum temperature 30-35 ℃; Salt concentrations should be <30 g/L			
Consumables	Neutralisation chemicals; Energy	Air or oxygen; Neutralisation chemicals; Flocculants: 300-550 kg per tonne COD; Nutrients: 23-42 kg/tonne COD; Energy: 9.5 kWh/m3	Air; Neutralisation chemicals; Energy	Air; Neutralisation chemicals; Energy	Air; Neutralisation chemicals (when used as pretreatment); Energy
Cross-media effects	Biogas with 70 % CH_4 can be used as combustible gas; Only 10 % of excess sludge compared with aerobic biology	Excess sludge about 10 times the amount from anaerobic biology, needs treatment; High energy input because of aeration Emission of odour and noise	Excess sludge	Excess sludge	Excess sludge; No emission of odour
Space requirements	Less than aerobic treatment	Large for central WWTP	Comparatively small	Comparatively small	Comparatively small
Achievable performance (% pollutant removal)	COD: 75-90 in combination with aerobic; COD: 95-97; BOD: 99-99.8	BOD: 97-99.5; COD: 76-96; 90-96 (membrane); Phenol index: >99 total inorg. N: 82 (membrane); NH4-N: 96 (membrane)	BOD: 40-90 (1-stage); 85-95 (2-stage)	BOD: >98; COD: 90	refractory COD: 26-68; Phenol index: 75-98; AOX: 55-98; total inorg. N: 4-50
Achievable emission levels [mg/l]		TSS: 10 (central WWTP)			
Retrofittability	Need of gas vessels or flare to cope with methane	dependent on size	easy	easy	easy

Table 20 – MBR and Activated sludge comparison

	Membrane bioreactor	Activated sludge plant
MLSS (mg/L)	15119	3241
Hydraulic retention time (h)	3.61	29.8
Sludge age (d)	3.61	12.4
Influent		
BOD (mg/L)	189	189
NH_4-N (mg/L)	27.6	27.6
SS (mg/L)	203	203
Effluent		
BOD (mg/L)	0.55	1.32
NH_4-N (mg/L)	3.08	0.24
SS (mg/L)	0.6	-

Table 21- BAT-associated Emission Levels for Final Waste Water Discharge into a Receiving Water

Parameter [a]	Emission levels [mg/l] [b]
TSS	10-20 [c]
COD	30-250
Total inorganic N [d]	5-25
Total P	0.5-1.5 [e]
AOX	

[a] for BOD see preceding section on central biological treatment
[b] daily average, exception TSS
[c] monthly average
[d] sum of NH_4-N, NO_2-N and NO_3-N (a more recommendable parameter would be total N. Because of the lack of information on total N, total inorganic N is used here)
[e] lower range from nutrient feed in biological WWTP, upper range from production processes

Future Developments

Looking towards the sewage treatment works of the 21st Century, there are two factors that may be of major significance – the standards required for discharge, and the future for biosolids.

Concerning the future for discharge standards – the industry has moved from specifying standards for BOD and SS to standards that also require limits on COD, total nitrogen and total phosphorus. Thus treatment systems which were designed to optimally remove BOD and SS are now required to achieve much more than that for which they were originally designed.

Other problem compounds for the future might include trace organics, such as endocrine disrupting chemicals.

There is also increasing concern about discharges containing chemicals which, either alone or in combination with other compounds, could have adverse effects on elements of the food chain in surface waters. In addition, there is the school of thought that toxicity-based consents should be introduced. This is leading to the development of direct toxicity assessment (DTA), which would measure the overall effect on the receiving watercourse.

It is likely that more stringent standards will be introduced for the processing and disposal of sewage sludge.

Most potential processes currently under investigation seek to recover energy or some other useful by-product from the sludge. Vermiculture (the use of worms to convert sludge into an odourless, useable product) and thermal treatments (making use of the high calorific value associated with sewage sludge by burning it with fossil fuels) are some of the concepts currently being piloted in parts of Europe.

7. Cost-benefit analysis and other tools to evaluate the improvement measures of WWTPs

All projects whether part of a company's environmental programme or not, require some form of appraisal to assess their relative merit as recipients of resources. Given that companies must now consider the concerns of all stakeholders, in addition to shareholders, traditional financial project appraisal is no longer sufficient in scope. Cost benefit analysis provides a "broader" appraisal framework, capable of assessing all the effects of a project on all the affected stakeholders, including environmental costs and benefits.

Cost Benefit Analysis (CBA) contains specialist techniques, which can be used to assess the "broader" implications of a project on the stakeholder community as a whole, including environmental effects. In this sense, CBA provides an appropriate framework for appraising projects in an environmental management content.

To an economist, CBA refers to a framework for assessing all the impacts of a project, measured in accordance with economic principles, on the welfare of society as a whole. Strictly speaking, this is what is meant when one refers to CBA. The appraisal of a project, however, may be much narrower in scope looking only at those effects that are captured in the balance sheet of the investor: this is typical of current practice in business. In the latter case, the desirability of the project is assessed solely on financial grounds, and is therefore referred to as financial project appraisal.

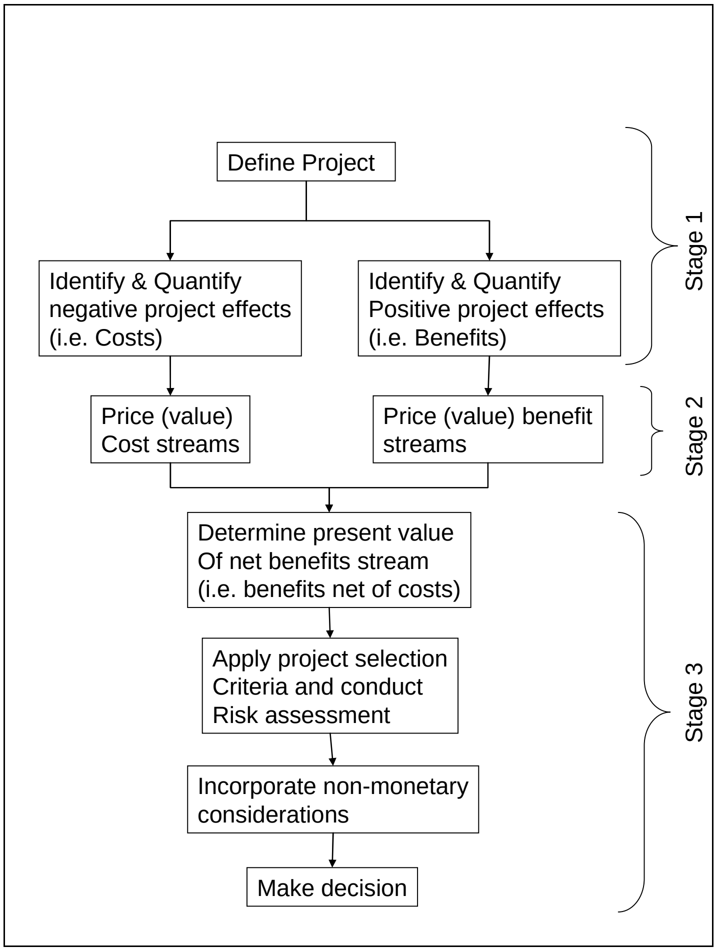
It is important to note that project appraisal can range anywhere between the two extremes from simple financial appraisal to full scale social cost benefit analysis. Moreover, depending on the investor's objective, both approaches provide equally valid frameworks for project appraisal. If as an investor, your objective is to address the concerns of all relevant stakeholders (including environmental concerns), you will need to use a broader appraisal framework, capable of incorporating the wider interests of stakeholders into the analysis. This is the domain of the CBA, and it is in this sense that CBA provides a more appropriate project appraisal framework in the context of environmental management.

The basic approach to CBA (and project appraisal) may be divided into three main activities or stages:

1. The process of identifying all parties affected by the project and quantifying the impact of the project on these parties.
2. The process of attaining an appropriate "price tag" to all economically relevant impacts. (Strictly speaking, one should attempt to value the impacts of the project on the affected party, as it would be valued in monetary terms by them.

3. The process of discounting (at an appropriate discount rate) all costs and benefits that occur in different time periods so that the net benefit of the project can be determined and a decision made on the relative economic merit of the project. Prior to making a decision, the accuracy of the analysis should be subjected to some form of risk assessment and non-monetary impacts should also be considered.

Fig. 25 Flow chart of Cost Benefit Analysis



Identify and Quantify Project Effects

Stage 1

All the tangible negative effects (costs) and tangible positive effects (benefits) experienced by the providers and consumers of the project's output. In addition the intangible effects borne by third parties (may be either provider or consumers) must be considered. The most important group of intangible effects is the externalities.

Example of negative externality:

A paper mill operates on the banks of a river, while a salmon farm is situated further downstream. Both use the river in different ways:

- The paper mill uses it as a receptacle for its wastes; and
- The salmon farm uses it to support its fish.

The wastes that the paper mill discharges into the river impose a cost on the salmon farm in terms of reduced out put. However, in deciding on the level of its own production, and subsequently the quantity of waste discharged, the paper mill does not consider the loss of productivity experienced by the salmon farm. While the paper mill might be aware of the effects its wastes have on the salmon farm, it does nothing about them because they do not register in its financial accounts. I such circumstances an externality is said to exist and is defined as an external effect on the point or welfare of one agent arising as an incidental by-product of some other agent's activity. While the above example illustrated a negative externality the incidental by-product of one agent's activity would improve the profit or welfare of all other affect agents.

Stage 2 - Project Costs

The total cost of a project is given by the costs of all resources used by the provider(s) of the project over some pre-defined time horizon (usually the useful life of the project), plus any costs imposed on third parties. Tangible costs are usually split between investment expenditures and recurring costs. Investment expenditures are incurred towards the start of a project, and do not tend to recur throughout the project's life; hence they are also known as non-recurring costs. This category of costs typically includes land and property costs, infrastructure expenditures, plant and equipment, plus associated installation costs.

The operation and maintenance of a project usually incurs expenses. As these expenses tend to be incurred annually throughout the life of the project, they are termed recurring costs. Tangible recurring costs tend to be grouped into three categories:

1. energy costs
2. labour costs; and
3. material costs.

External costs take into consideration effects on third parties, and may take many forms, e.g. water pollution and air pollution from industrial activities may adversely affect human health and impair ecological functions. The output of Environmental Impact Assessments (EIAs), and in particular, Life Cycle Assessments (LCAs) is often useful in helping to identify and quantify possible external costs.

NB: in CBA (project appraisal), all expenditures should be recorded in full when the cost is incurred (e.g. when the payment is actually made for the pollution control equipment).

Stage 3 – Project Benefits

The tangible benefits of a project may take two forms: direct revenue and/or cost savings. The direct revenue accruing from a project may be broadly defined as the amount earned from the project's output over its useful life, i.e. the income generated by the project. Projects may also produce savings in resource costs. In fact, tangible cost savings (and reductions in external costs) are one of the main objectives of many projects undertaken in an environmental management context. (Clearly foregone or avoided costs are positive effects, and should therefore be included in a project's benefits stream.)

A positive Net present Value (NPV) indicates that a project's total benefits exceed total costs. By the undertaking a project with a positive NPV, the wealth of the investor will increase by the magnitude of the estimated NPV. If the NPV of a project is negative, the funds would otherwise have been used for this investment should be left in the bank or used to implement a project whose NPV is positive. Undertaking a project with a negative NPV will make you worse off than you were to begin with.

Benefit-cost Ratio

The benefit-cost ratio (B/C) is simply the ratio of the sum of the project's discounted net benefits (i.e. benefits minus costs) to the discounted investment costs. IN terms of the B/C ratio, a project should be accepted "if its B/C ratio is greater than 1", this implies that its NPV is positive.

Internal rate of return

The Internal rate of return (IRR) is that rate of discount, which equates the discounted net benefits to be discounted investment costs. The IRR may alternatively be seen as the rate of discount that set NP equal to zero.

A project is acceptable if its IRR is greater than the selected rate of discount (the NPV of the project will be positive). The IRR is widely used in business, where decision-makers are used to rate of return concepts. However, one needs to be careful when using the IRR criterion to rank projects relative to one another. IN some cases, the IRR criterion will produce different ranking to the NPV criterion.

Project selection criteria

The Net Present Value of a project is given by:

$$NPV \Rightarrow \sum_{n=0}^{N} \frac{(b_n - c_n)}{(1+r)^n}$$

Where *b* and *c* are benefits and costs in each period n equal to 0,1,…..*N*, and *r* is the chosen rate of discount. E.g. a project with an investment cost of £1 million in year zero yields net benefits of £0.6 million in years one and two. If the selected rate of discount is 10%, then the *NPV* is £41,000 ,i.e.

$$NPV = \frac{-£1{,}000{,}000}{(1.10)^n} + \frac{£600{,}00}{(1.10)^1} + \frac{£600{,}000}{(1.10)^2} = £41{,}000$$

The benefit-cost ratio *(B/C)* is generally defined as:

$$B/C \frac{\sum_{n=0}^{N} \frac{(b_n - c_n)}{(1+r)^n}}{\sum_{n=0}^{N} \frac{I_n}{(1+r)^n}}$$

Where *I* is the investment cost in year *n*. Using the same figures in the above example, the *B/C* ratio is 1.04.

The internal rate of return *(IRR)* is the discount rate that satisfies the following relationship:

$$\sum_{n=0}^{N} \frac{I_n}{(1+r)^n} = \sum_{n=0}^{N} \frac{(b_n - c_n)}{(1+r)^n}$$

Where all the symbols are as before. The *IRR* for the above example is 13%.

The choice of discount rate

Clearly, both the NPV and the B/C criteria require you to specify a rate of discount. The choice of a discount rate is a complex and with respect to the valuation of environmental impacts, controversial topic.

Risk and Uncertainty

The formulae given above assume that the net benefits of a project are known with certainty. However, in the real world this is rarely true, even when restricting the analysis to financial costs and benefits. Clearly, the inclusion of environmental costs and benefits only serves to further decrease confidence in the final results. When management appraises a project, it will seek to assess it not only in terms of the net benefits generated, but also with respect to the level of risk/uncertainty associated with the anticipated net benefits. Thus an important element of project appraisal is how to account for risk and uncertainty.

Even after risk and uncertainty have been accounted for, it is still important for the project analyst to come to grips with all the key factors that can determine the success or otherwise of the project. Several techniques exist which allow one to evaluate projects more thoroughly.

Non-monetary considerations

It will rarely be possible to quantify and value all project effects, as recommended above. This degree of completeness will not be feasible, for example, due to methodological gaps, data limitations and/or resource constraints. Once you have applied the project selection criteria and conducted and accounted for risk and uncertainty, any unquantified effects should be itemised and qualified as much as time and resources permit. One approach, typically adopted, is to determine the magnitude that the “unvalued” effects would have to take in order to make:

- an “unfavourable” net present value “favourable” or;
- a “favourable” net present value “unfavourable”.

8. Planning and implementation phases for WWTP efficiency improvement measures

The planning to improve the WWTP efficiency requires a **Master Plan for WWPT improvement measures** including several steps detailing and evaluating the processes as following:

- A plant system condition (status) assessment, including budget development and risk analysis;
- Field investigations/rehabilitation of specific problems; and
- Medium-long range planning and execution of projects.

The **1st step** of planning of efficiency improvement measures needs that plant managers take in account the plant exploration data, namely the flow monitoring records, at least, during the last 2 years period, disaggregated day by day, storm tanks in order to achieve following minimum data for improvement measures decision:

1) wastewater influent daily, weekly, monthly average and peak flow
2) maximum and minimum percentage of treatment capacity
3) additional treatment capacity required to satisfy the existing population and economic activities in the plant sewage network
4) growth of equivalent-person for short, medium and long term
5) physical and chemical characterization of influent flow weekly, monthly
6) dry weather and wet flow loads
7) rainfall event statistical analysis
8) storm peak analysis
9) estimation of storm overflows
10) storm tanks required capacity
11) average operational availability of plant equipment to accomplish the current influent peak flows without failures

12) critical equipment failure percentage in the treatment process
13) failures in redundant process equipment
14) age and accumulated running time of critical equipments
15) percentage of equipments aged more than 10 year and technologically obsolete
16) required time for reestablish the operation in critical process equipments
17) energy consumption daily, weekly, monthly, yearly in the plant and in each equipment.
18) local availability of wind energy, biogas, solar PV, hydraulic energy potential
19) costs of treated water per cubic meter (management, labour, energy, chemicals, maintenance, investment pay-back, insurance, etc.).

The **2nd step** consists in design and estimation issues:

i. **Review of WWTP existing plant**

ii. The **Population and Environmental Needs** (Dwelling analysis and Urbanisation Master Plan study) in order to establish the quantitative and qualitative goals, taking the last few years' influent capacity in the wastewater collection system, as well as the collapsed operations have led to the contamination of beaches, rivers, and other natural resources that caused a rapid deterioration of the system.

iii. **Environmental Assessment.** As part of the planning process, an environmental assessment (EA) is submitted to the public authorities in charge to deliver the permit or licensing the exploitation and modification measures in accordance with the EU and National legislation.

iv. **Compliance with Ecology and Local Regulations**

v. **Technical Feasibility** consisting in following:

a) **Appropriate Technology** identifying the following priority projects: 1) rehabilitation and expansion of the wastewater treatment system; 2) selection, site construction and assembly of equipment for new treatment alternatives; 3) assembly of wastewater changed equipment

b) **Project Management**. The project will be managed by an entity to be defined (Water Utility, Municipality, etc.). As part of the program, several institutional development strategies will be implemented, the project investment and feasibility study. The wastewater system is expected to operate in a self-sufficient manner, supporting itself through user fees.

c) **Rate Model.** The proposed fee increase per cubic meter of water consumed. This rate increase is a service tax applied in water consumption invoice must be approved by local legal entity (if applicable).

The **3rd step** is the implementation of measures in the field, since it was confirmed their feasibility, in order to achieve the expected improvement of plant efficiency. During this period the plant owner designates an independent surveyor to check and validate the fine accomplishment of planed intervention in terms of equipments, construction, assemblage of parts, integrity of materials, perfect connections of piping and electrical wiring, safety of work, scheduled time for works, etc. During this phase must be planned periodic meetings, inspections and works progress reports. Any failure or non accomplishment of work program and specifications will be discussed in terms of corrections and signed the meeting minutes.

Finally the **4th step** is the period correspond to the commissioning, including wastewater collection of samples for laboratory analysis, checking of operation condition of equipments and overload, verification of energy, chemical consumption, data collection signals, alarms generated by instrumentation (probes, SCADA, etc.), software and hardware. Any gap, failure will be discussed and corrected, with parts change if do not assure the planned goals of project aims.

The **Master Plan** provides, during the all implementation period, for:

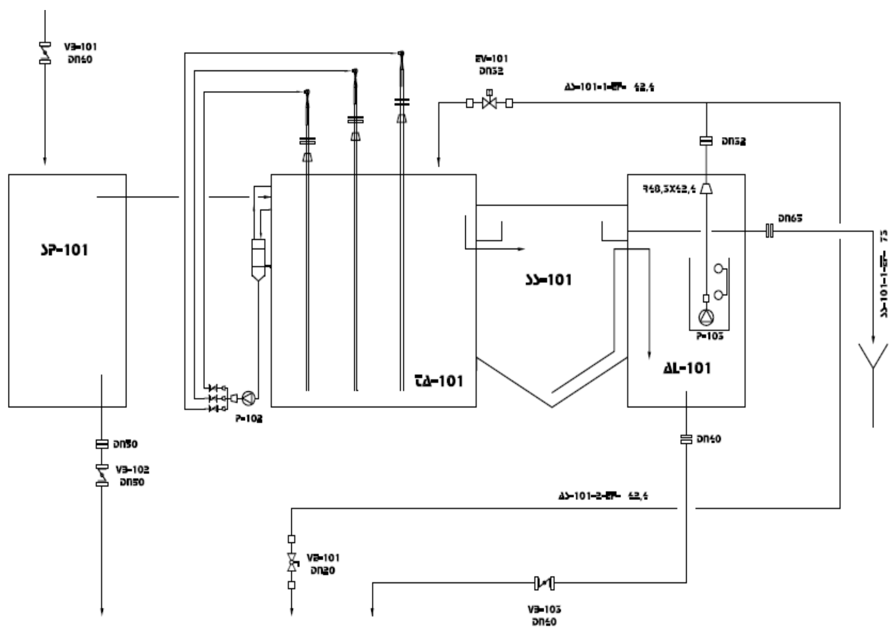
- Review of current procedures, practices, and standards;
- Interviews with key maintenance/operations, sewer system, engineering, and design personnel;
- Best practices comparisons of similar water facility organizations;
- Development and use of modeling tools; and
- Communications with water customers and local environment organizations at public meetings to ensure their understanding of the issues surrounding the rehabilitation, in terms of community satisfaction and environmental improvement.

As part of the process, the WWTP management staff has identified the following opportunities for improvement:

- Utilization of an Asset Management (AM) Program approach for better integration of data gathering and program implementation, cost tracking and scheduling;
- Identification of potential approaches to reduce the time involved for procurement of goods and services;
- Focusing resources by contracting out non-specialized items and using internal staff for more specialized mainline and service installation;
- Enhancing training to keep engineering, inspection and construction staff current with the latest rehabilitation practices and technologies;

- Utilization of practices and technologies to achieve on-time cleaning and implementation of additional programs to enhance productivity; and
- Standardization of closed-circuit television camera data collection and identification procedures.

Fig. 26 - Portable aerobic treatment plant for field testing



For wastewater plant testing the WWTREAT plants it was developed a portable plant to assemble in parallel, comparing 4 influent and effluent physical-chemical parameters.

9. Conclusions and recommendations.

Each plant is a very specific detailed case and these guidelines are a minimal requirement for to get a successful project implementation in the upgrading of small existing centralized wastewater treatment plants, in spite of the tendency to consider that a small community wastewater treatment plants are less important than a plant treating effluents of a big city.

Any small pollution accident can be a big disaster, since the environment in rural areas generally is richer and sensible in terms wild life. A human error many times irreversibly destroys an ecosystem in a clean water line, the correct wastewater treatment is more than a mandatory procedure of water engineering, it is part of our survival on face of Blue Planet.

The main conclusions taken in project implementation period are listed as following:

1) The small communities' wastewater plants easily can be upgraded to accomplish the EU regulations.
2) The improvement costs are lower than environmental costs.
3) The main difficulties are the collection of exploitation data once the plants have operators more dedicated to solve failures and to maintain routines.
4) The small size plants are similar than big size plants in terms of technology and management solutions.
5) After rehabilitation or improvement of plant efficiency the monitoring and management are easily accepted by all intervenient persons (operators, managers and water facility responsibles).
6) The improvement planning is accepted by progressively by all operation actors until a full adhesion as improvement results are visible.
7) The training on job is the best way for a successful operation.
8) The efficiency improvement is a non stop process, since there are many alternatives and new technology innovations available enlarging the cycle life of plants.